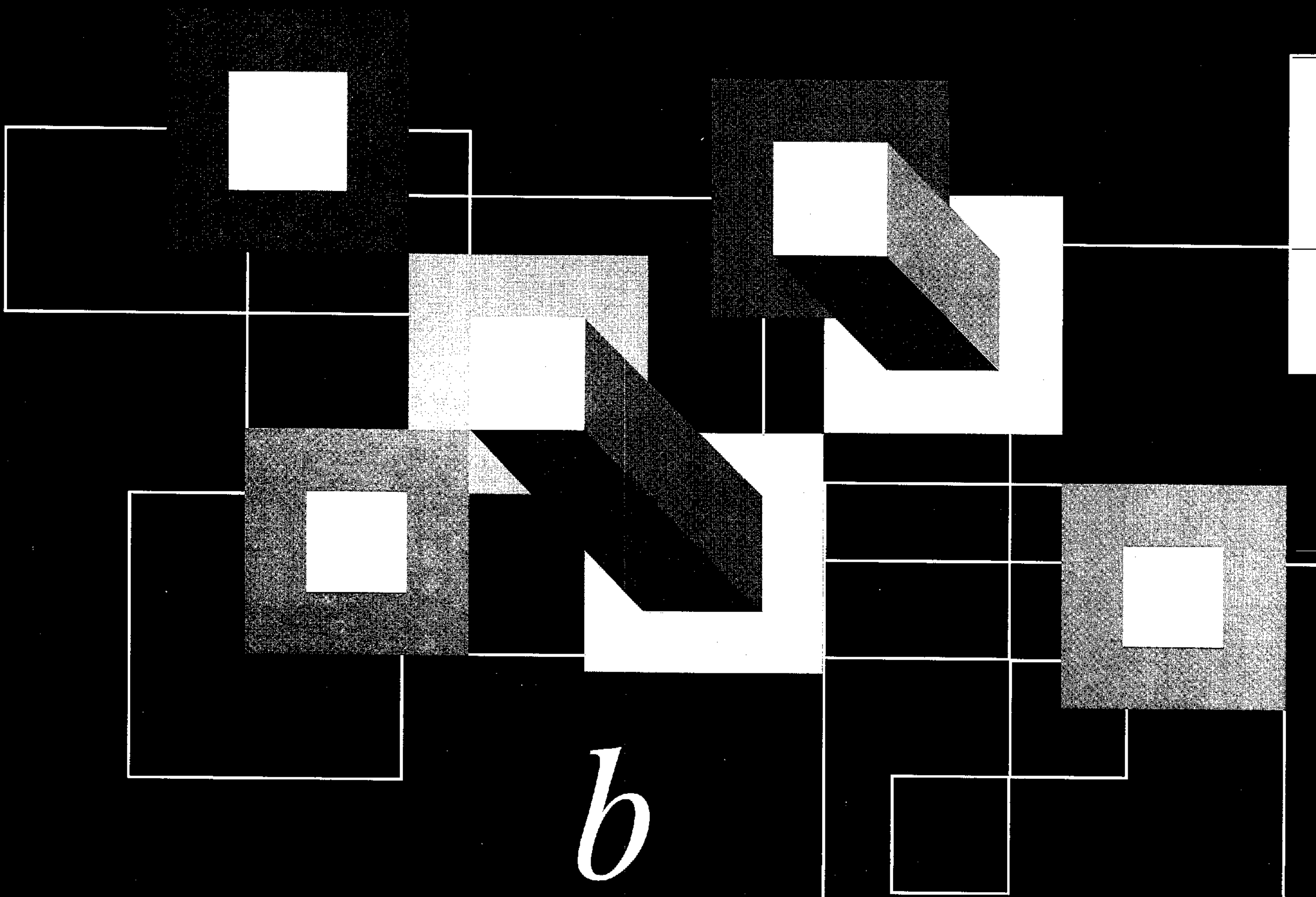
BARRY 1

THE CONSTRUCTION OF BUILDINGS

SEVENTH EDITION



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Volume 1

SEVENTH EDITION

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THE CONSTRUCTION OF BUILDINGS

Volume 1

SEVENTH EDITION

R. BARRY
Architect

FOUNDATIONS and OVERSITE CONCRETE – WALLS – FLOORS – ROOFS

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Preface

The initial concept on which the series was prepared was that of principles of building under the headings functional requirements, common to all building, with diagrams to illustrate the application of the requirements to the elements of building. Subsequent changes in the use of traditional materials and the use of new materials in novel forms of construction have illustrated the value of the concept of functional requirements as a measure of the suitability of materials and construction for both traditional and novel forms of construction.

The text has been revised and rearranged to improve the sequence of subject matter to more clearly follow principles of building, with notes on the history of such changes in use of materials, largely dictated by economics and fashion, and the consequences of such changes.

A new page layout has been adopted for the series which is more suited to setting diagrams next to the relevant text than the old format. The text is set in a wide right hand column with smaller diagrams set in a left hand column which also contains headings for quick reference. These changes to the text and layout have helped to underline more clearly the original concept on which the series was based.

Notes on the properties and uses of both traditional and new materials are included in each chapter. Such notes on the changes in Building Regulations that have occurred over the years that are relevant to principles have been included without extensive use of reference to standards and the use of tables.

As appropriate to the sense of the material, diagrams have been altered, rearranged and augmented with new diagrams to update the series.

The basis for the series is an explanation of the principles of building through an understanding of the nature, properties and uses of materials in the construction of buildings adequate to the work of designing and construction.

R. Barry

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My thanks are due to my friend Ross Jamieson who redrafted all of my original diagrams for the five volume series; to Mrs Sue Moore for advice and help in the new page layout and to Polly Andrews who is now three fifths of the way through typing my drafts of the five volumes of the revised series.

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1: Foundations and Oversite Concrete

HISTORY

Up to the latter part of the nineteenth century, when Portland cement first came into general use for making concrete, the majority of buildings were built directly off the ground. Walls of stone or brick were built on a bed of rough stones or brick footings and timber framed buildings on a base of rough stones or brick. As walls were built their weight gradually compressed soils such as clay, sand or gravel to form a sound, adequate foundation.

Local experience of the behaviour of soils and rocks, under the load of buildings, generally provided sufficient information to choose a foundation of the required depth and spread by this method of construction.

Where a small variation of the degree of compression of soils under buildings occurred the natural arching effect of the small, bonded units of stone and brick and the flexibility of lime mortar would allow a transfer of load to the sound foundation without damage to the building.

From the beginning of the twentieth century concrete was increasingly used as a foundation base for walls. Initially concrete bases were used for the convenience of a solid, level foundation on which to lay and bond stone and brick walls. Brick walls which, prior to the use of concrete, had been laid as footings, illustrated in Fig. 1, to spread the load, were built on a concrete base wider than the footings for the convenience of bricklaying below ground. This massive and unnecessary form of construction was accepted practice for some years.

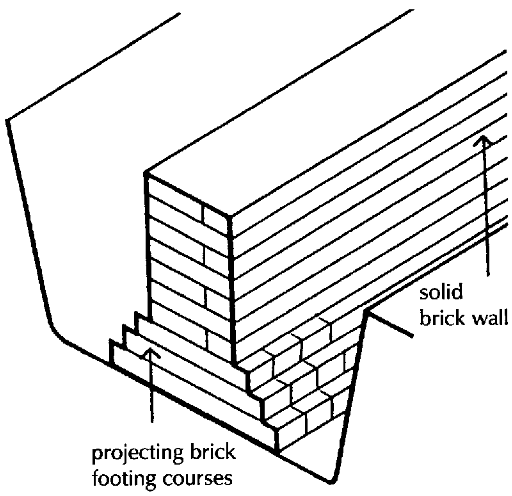


Fig. 1 Brick footings.

With the introduction of local and, more recently, general building regulations in this century, standard forms of concrete foundations have become accepted practice in this country along with more rigorous investigation of the nature and bearing capacity of soils and rocks.

The move from the practical, common sense approach of the nineteenth century to the closely regulated systems of today has to an extent resulted in some foundations so massive as to exceed the weight of the entire superstructure above and its anticipated loads. This tendency to over design the foundations of larger buildings has been exacerbated by the willingness of building owners to seek compensation for damage, caused by the claimed negligence of architects, engineers and builders who, in order to control the amount of premium they pay for insurance against such claims, have tended to over design as an insurance.

FOUNDATIONS

The foundation of a building is that part of walls, piers and columns in direct contact with and transmitting loads to the ground. The building foundation is sometimes referred to as the artificial, and the ground on which it bears as the natural foundation.

Ground is the general term for the earth's surface, which varies in composition within the two main groups, rocks and soils. Rocks include hard, strongly cemented deposits such as granite and soils the loose, uncemented deposits such as clay. Rocks suffer negligible compression and soils measurable compression under the load of buildings.

The size and depth of a foundation is determined by the structure and size of the building it supports and the nature and bearing capacity of the ground supporting it.

ROCKS

Rocks may be divided into three broad groups as igneous, sedimentary and metamorphic.

Igneous rocks

Igneous rocks, such as granite, dolerite and basalt, are those formed by the fusion of minerals under great heat and pressure. Beds of strong igneous rock occur just below or at the surface of ground in Scotland and Cornwall as Aberdeen and Cornish granite. The nature and suitability of such rocks as a foundation may be distinguished by the need to use a pneumatic drill to break up the surface of sound, incompressible rock to form a roughly level bed for foundations.

Because of the density and strength of these rocks it would be sufficient to raise walls directly off the rock surface. For convenience it is usual to cast a bed of concrete on the roughly levelled rock surface as a level surface on which to build. The concrete bed need be no wider than the wall thickness it supports.

Sedimentary rocks

Sedimentary rocks, such as limestone and sandstone, are those formed gradually over thousands of years by the settlement of particles of calcium carbonate or sand to the bottom of bodies of water where the successive layers of deposit have been compacted as beds of rock by the weight of water above. Because of the irregular and varied deposit of the sediment, these rocks were formed in layers or laminae. In dense rock beds the layers are strongly compacted and in others the layers are weakly compacted and may vary in the nature of the layers and so have poor compressive strength. Because of the layered nature of these rocks the material should be laid as a building stone with the layers at right angles to the loads.

Many of the beds of sound limestone and sandstone in this country have been quarried for the production of natural building stones such as Portland and Bath limestones and Darly Dale and Crosland Hill sandstones. The suitability of sound limestone and sandstone as a foundation may be determined by the need to use a pneumatic drill to level the material ready for use as a foundation. As with igneous rock it is usual to cast a concrete base on the roughly levelled rock for the convenience of building.

Metamorphic rocks

Metamorphic rocks such as slates and schists are those changed from igneous, sedimentary or from soils into metamorphic by pressure or heat or both. These rocks vary from dense slates in which the layers of the material are barely visible to schists in which the layers of various minerals are clearly visible and may readily split into thin plates. Because of the mode of the formation of these rocks the layers or planes rarely lie horizontal in the ground and so generally provide an unsatisfactory or poor foundation.

SOILS

Soil is the general term for the upper layer of the earth's surface which consists of various combinations of particles of disintegrated rock such as gravel, sand or clay with some organic remains of decayed vegetation generally close to the surface.

Top soil

The surface layer of most of the low lying land in this country, which is most suited to building, consists of a mixture of loosely compacted particles of sand, clay and an accumulation of decaying vegetation. This layer of top soil, which is about 100 to 300 mm deep, is sometimes referred to as vegetable top soil. It is loosely compacted, supports growing plant life and is unsatisfactory as a foundation. It should be stripped from the site of buildings because of its poor bearing strengths and its ability to retain moisture and support vegetation which might adversely affect the health of occupants of buildings.

Subsoil

Subsoil is the general term for soil below the top soil.

It is unusual for a subsoil to consist of gravel, sand or clay by itself. The majority of subsoils are mixes of various soils. Gravel, sand and clay may be combined in a variety of proportions. To make a broad assumption of the behaviour of a particular soil under the load on foundations it is convenient to group soils such as gravel, sand and clay by reference to the size and nature of the particles.

The three broad groups are coarse grained non-cohesive, fine grained cohesive and organic. The nature and behaviour under the load on foundations of the soils in each group are similar.

Coarse grained non-cohesive soils

Soils which are composed mainly of, or combinations of, sand and gravel consist of largely siliceous, unaltered products of rock weathering. They have no plasticity and tend to lack cohesion, especially when dry. Under pressure of the loads on foundations the soils in this group compress and consolidate rapidly by some rearrangement of the coarse particles and the expulsion of water.

A foundation on coarse grained non-cohesive soils settles rapidly by consolidation of the soil, as the building is erected, so that there is no further settlement once the building is completed.

Gravel

Gravel consists of particles of a natural coarse grained deposit of rock fragments and finer sand. Many of the particles are larger than 2 mm.

Sand

Sand is a natural sediment of granular, mainly siliceous, products of rock weathering. Particles are smaller than 2 mm, are visible to the naked eye and the smallest size is 0.06 mm. Sand is gritty, has no real plasticity and can be easily powdered by hand when dry.

Dense, compact gravel and sand requires a pick to excavate for foundation trenches. A test of the suitability of these soils as a foundation is that it is difficult to drive a 5 mm wooden peg more than some 150 mm into compact gravel or sand.

As a foundation for small buildings, such as a house, it is sufficient to spread and level a continuous strip of concrete in the excavated trenches as a level base for load bearing walls.

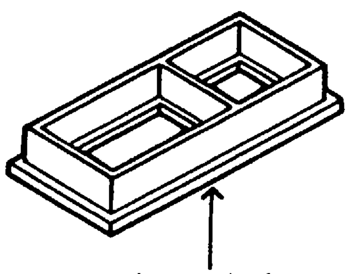


Fig. 2 Strip foundation.

Figure 2 is a diagram illustrating a strip foundation. The continuous strip of concrete is spread in the trenches excavated down to an undisturbed level of compact soil. The strip of concrete may well need to be no wider than the thickness of the wall. In practice the concrete strip will generally be wider than the thickness of the wall for the convenience of covering the whole width of the trench and to provide a wide enough level base for bricklaying below ground. A continuous strip foundation of concrete is the most economic form of foundation for small buildings on compact soils.

Fine grained cohesive soils

Fine grained cohesive soils, such as clays, are a natural deposit of the finest siliceous and aluminous products of rock weathering. Clay is smooth and greasy to the touch, shows high plasticity, dries slowly and shrinks appreciably on drying. Under the pressure of the load on foundations clay soils are very gradually compressed by the expulsion of water through the very many fine capillary paths, so that buildings settle gradually during building work and this settlement may continue for some years after the building is completed.

The initial and subsequent small settlement by compression during and after building on clay subsoils will generally be uniform under most small buildings, such as houses, to the extent that no damage is caused to the structure and its connected services.

Volume change

Firm, compact shrinkable clays suffer appreciable vertical and horizontal shrinkage on drying and expansion on wetting due to seasonal changes. Seasonal volume changes under grass extend to about 1 m below the surface in Great Britain and up to depths of 4 m or more below large trees.

The extent of volume changes, particularly in firm clay soils, depends on seasonal variations and the proximity of trees and shrubs. The greater the seasonable variation, the greater the volume change. The more vigorous the growth of shrubs and trees in firm clay soils, the greater the depth below surface the volume change will occur.

As a rough guide it is recommended that buildings on shallow foundations should not be closer to single trees than the height of the tree at maturity, and one-and-a-half times the height at maturity of groups of trees, to reduce the risk of damage to buildings by seasonal volume changes in clay subsoils.

When shrubs and trees are removed to clear a site for building on firm clay subsoils there will, for some years after the clearance, be ground recovery as the clay gradually recovers moisture previously withdrawn by the shrubs and trees. This gradual recovery of water by the clay and consequent expansion may take several years. The depth at which the recovery and expansion is appreciable will be roughly proportional to the height of the trees and shrubs removed, and the design and depth of foundations of buildings must allow for this gradual expansion to limit damage by differential settlement. Similarly, if vigorous shrub or tree growth is stopped by removal, or started by planting, near to a building on firm clay subsoil with foundations at a shallow depth, it is most likely that gradual expansion or contraction of the soil will cause damage to the building by differential movement.

At the recommended depth of at least 0.9 m it is not generally economic to use the traditional strip foundation and hence the narrow strip or trench fill foundation (Fig. 9) has been used. A narrow trench 400 mm wide is excavated by machine and filled with concrete to just below the surface. If the concrete is placed immediately after the excavation there is no need to support the sides of the trench in stiff clays, the sides of the trench will not be washed away by rain and the exposed clay will not suffer volume change.

The foundations of buildings sited adjacent to past, present or future deep-rooted vegetation can be affected at a considerable depth below the surface by the gain or removal of ground moisture and consequent expansion or shrinkage. Appreciable expansion, following the removal of deep-rooted vegetation, may continue for some years as the subsoil gains moisture. Significant seasonal volume change, due to deep-rooted vegetation, will be pronounced during periods of drought and heavy continuous rainfall.

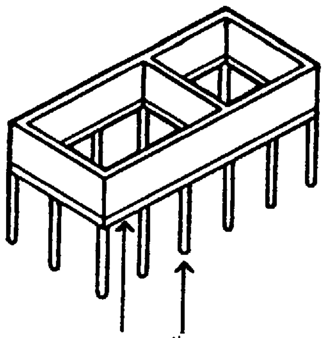


Fig. 3 Pile foundation.

The vigorous growth of newly planted deep-rooted vegetation adjacent to buildings may cause continuous shrinkage in clay soils for some years. The most economical and effective foundation for low rise buildings on shrinkable clays close to deep-rooted vegetation is a system of short-bored piles and ground beams (Fig. 3). The piles should be taken down to a depth below which vegetation roots will not cause significant volume changes in the subsoil. Single deep-rooted vegetation such as shrubs and trees as close as their mature height to buildings, and groups of shrubs and trees one-and-a-half times their mature height to buildings, can affect foundations on shrinkable clay subsoils.

Many beds of clay consist of combinations of clay with sand or silt in various proportions. The mix of sand or silt to clay will affect the behaviour of these soils as a foundation. In general where the proportion of sand or silt to clay is appreciable the less dense the soil will be. Because of variations in the proportion of clay to sand or silt and the general loose or soft nature of the soil it is practice to assume that their bearing capacity is less than that of clay.

Frost heave

Where the water table is high, that is near the surface, soils, such as silts, chalk, fine gritty sands and some lean clays, near the surface may expand when frozen. This expansion, or frost heave, is due to crystals of ice forming and expanding in the soil and so causing frost heave. In this country, ground water near the surface rarely freezes at depths of more than 0.5 m, but in exposed positions on open ground during frost it may freeze up to a depth of 1 m. Even in exposed positions during severe frost it is most unlikely that ground water under and adjacent to the foundations of heated buildings will freeze because of the heat stored in the ground under and around the building. There is, therefore, no need to consider the possibility of ground movement due to frost heave under and around heated buildings.

For unheated buildings and heated buildings with insulated ground floors, a foundation depth of 450 mm is generally sufficient against the possibility of damage by ground movement due to frost heave.

Made up ground

Areas of low lying ground near the coast and around rivers close to towns and cities have been raised by tipping waste, refuse and soil from excavations. Over the years the fill will have settled and consolidated to some extent. Areas of made up ground are often used for buildings as the towns and cities expand. Because of the varied nature of the materials tipped to fill and raise ground levels and the uncertainty of the bearing capacity of the fill, conventional foundations may well be unsatisfactory as a foundation.

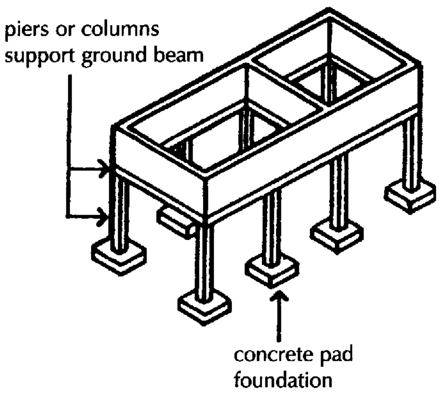


Fig. 4 Pad foundation.

An example of made up ground is the area of Westminster now known as Pimlico where the soil excavated during the construction of the London docks was transported by barge to what was low lying land that was usually flooded when high tides and heavy rainfall caused the Thames river to overflow. The raised land was subsequently heavily built on.

A uniformly stable, natural, sound foundation may well be some 3 or more metres below the surface of made up ground. To excavate to that level below the surface for conventional strip foundations would be grossly uneconomic. A solution is the use of piers on isolated pad foundations supporting reinforced concrete ground beams on which walls are raised, as illustrated in Fig. 4.

Unstable ground

There are some extensive areas of ground in this country where mining and excavations for coal and excavations for taking out chalk for use as a fertiliser and making lime and others for extracting sand and gravel may have made the ground unstable. The surface of the ground under deep and shallow excavations below the surface may well be subject to periodic, unpredictable subsidence.

Where it is known that ground may be unstable and there is no ready means of predicting the possibility of mass movement of the subsoil and it is expedient to build, a solution is to use some form of reinforced concrete raft under the whole of the buildings, as illustrated in Fig. 5.

The concrete raft, which is cast on or just below the surface, is designed to spread the load of the building over the whole of the underside of the raft so that in a sense the raft floats on the surface.

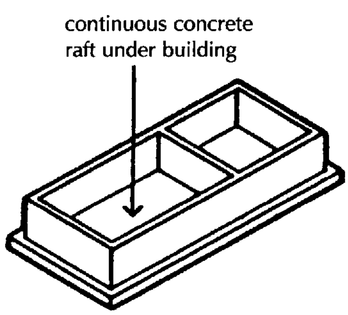


Fig. 5 Raft foundation.

SITE INVESTIGATION

To select a foundation from tables, or to design a foundation, it is necessary to calculate the loads on the foundation and determine the nature of the subsoil, its bearing capacity, its likely behaviour under seasonal and ground water level changes and the possibility of ground movement. Where the nature of the subsoil is known from geological surveys, adjacent building work or trial pits or borings and the loads on foundations are small, as for single domestic buildings, it is generally sufficient to excavate for foundations and confirm, from the exposed subsoil in the trenches, that the soil is as anticipated.

Under strip and pad foundations there is a significant pressure on the subsoil below the foundations to a depth and breadth of about one-and-a-half-times the width of the foundation. If there were, in this area below the foundation, a soil with a bearing capacity less than that below the foundation, then appreciable settlement of the foundation might occur and damage the building. It is important, therefore, to know or ascertain the nature of the subsoil both at the level of the foundation and for some depth below.

Where the nature of the subsoil is uncertain or there is a possibility of ground movement or a need to confirm information on subsoils, it is wise to explore the subsoil over the whole of the site of the building.

As a first step it is usual to collect information on soil and subsoil conditions from the County and Local Authority, whose local knowledge from maps, geological surveys, aerial photography and works for buildings and services adjacent to the site may in itself give an adequate guide to subsoil conditions. In addition geological maps from the British Geological Survey, information from local geological societies, Ordnance Survey maps, mining and river and coastal information may be useful.

Site visit

A visit to the site and its surroundings should always be made to record everything relevant from a careful examination of the nature of the subsoil, vegetation, evidence of marshy ground, signs of ground water and flooding, irregularities in topography, ground erosion and ditches and flat ground near streams and rivers where there may be soft alluvial soil. A record should be made of the foundations of old buildings on the site and cracks and other signs of movement in adjacent buildings as evidence of ground movement.

Trial pits

To make an examination of the subsoil on a building site, trial pits or boreholes are excavated. Trial pits are usually excavated by machine or hand to depth of 2 to 4 m and at least the anticipated depth of the foundations. The nature of the subsoil is determined by examination of the sides of the excavations. Boreholes are drilled by hand auger or by machine to withdraw samples of soil for examination. Details of the subsoil should include soil type, consistency or strength, soil structure, moisture conditions and the presence of roots at all depths. From the nature of the subsoil the bearing capacity, seasonal volume changes and other possible ground movements are assumed. To determine the nature of the subsoil below the foundation level it is either necessary to excavate trial pits some depth below the foundation or to bore in the base of the trial hole to withdraw samples. Whichever system is adopted will depend on economy and the nature of the subsoil. Trial pits or boreholes should be sufficient in number to determine the nature of the subsoil over and around the site of the building and should be at most say 30 m apart.

Ground movements that may cause settlement are:

(1) compression of the soil by the load of the building
(2) seasonal volume changes in the soil

(3) mass movement in unstable areas such as made up ground and mining areas where there may be considerable settlement
(4) ground made unstable by adjacent excavations or by dewatering, for example, due to an adjacent road cutting.

It is to anticipate and accommodate these movements that site investigation and exploration is carried out. For further details of site investigation and exploration see Volume 4.

FUNCTIONAL REQUIREMENT

The functional requirement of a foundation is: strength and stability.

Strength and stability

The requirements from the Building Regulations are, as regards 'Loading', that 'The building shall be so constructed that the combined, dead, imposed and wind loads are sustained and transmitted to the ground safely and without causing such deflection or deformation of any part of the building, or such movement of the ground, as will impair the stability of any part of another building' and as regards 'ground movement' that 'The building shall be so constructed that movements of the subsoil caused by swelling, shrinkage or freezing will not impair the stability of any part of the building'.

A foundation should be designed to transmit the loads of the building to the ground so that there is, at most, only a limited settlement of the building into the ground. A building whose foundation is on sound rock will suffer no measurable settlement whereas a building on soil will suffer settlement into the ground by the compression of the soil under the foundation loads.

Foundations should be designed so that settlement into the ground is limited and uniform under the whole of the building. Some settlement of a building on a soil foundation is inevitable as the increasing loads on the foundation, as the building is erected, compress the soil. This settlement should be limited to avoid damage to service pipes and drains connected to the building. Bearing capacities for various rocks and soils are assumed and these capacities should not be exceeded in the design of the foundation to limit settlement.

In theory, if the foundation soil were uniform and foundation bearing pressure were limited, the building would settle into the ground uniformly as the building was erected, and to a limited extent, and there would be no possibility of damage to the building or its connected services or drains. In practice there are various possible ground movements under the foundation of a building that may cause one part of the foundation to settle at a different rate and to a different extent than another part of the foundation.

This different or differential settlement must be limited to avoid damage to the superstructure of the building. Some structural forms can accommodate differential or relative foundation movement without damage more than others. A brick wall can accommodate limited differential movement of the foundation or the structure by slight movement of the small brick units and mortar joints, without affecting the function of the wall, whereas a rigid framed structure with rigid panels cannot to the same extent. Foundations are designed to limit differential settlement, the degree to which this limitation has to be controlled or accommodated in the structure depends on the nature of the structure supported by the foundation.

FOUNDATION CONSTRUCTION

Strip foundations

Strip foundations consist of a continuous strip, usually of concrete, formed centrally under load bearing walls. This continuous strip serves as a level base on which the wall is built and is of such a width as is necessary to spread the load on the foundations to an area of subsoil capable of supporting the load without undue compaction. Concrete is the material principally used today for foundations as it can readily be placed, spread and levelled in foundation trenches, to provide a base for walls, and it develops adequate compressive strength as it hardens to support the load on foundations. Before Portland cement was manufactured, strip foundations of brick were common, the brick foundation being built directly off firm subsoil or built on a bed of natural stones.

The width of a concrete strip foundation depends on the bearing capacity of the subsoil and the load on the foundations. The greater the bearing capacity of the subsoil the less the width of the foundation for the same load.

A table in Approved Document A to the Building Regulations sets out the recommended minimum width of concrete strip foundations related to six specified categories of subsoil and calculated total loads on foundations as a form of ready reckoner. The widths vary from 250 mm for a load of not more than 20 kN/linear metre of wall on compact gravel or sand through 450 mm for loads of 40 kN/linear metre on firm clay, to 850 mm for loads not exceeding 30 kN/linear metre on soft silt, clay or sandy clay.

The dimensions given are indicative of what might be acceptable in the conditions specified rather than absolutes to be accepted regardless of the conditions prevailing on individual sites.

The strip foundation for a cavity external wall and a solid internal, load bearing wall illustrated in Fig. 6 would be similar to the width recommended in the Advisory Document for a firm clay subsoil when the load on the foundations is no more than 50 kN/linear metre. In practice the linear load on the foundation of a house would be appreciably less than 50 kN/linear metre and the foundation may well be made wider than the minimum requirement for the convenience of

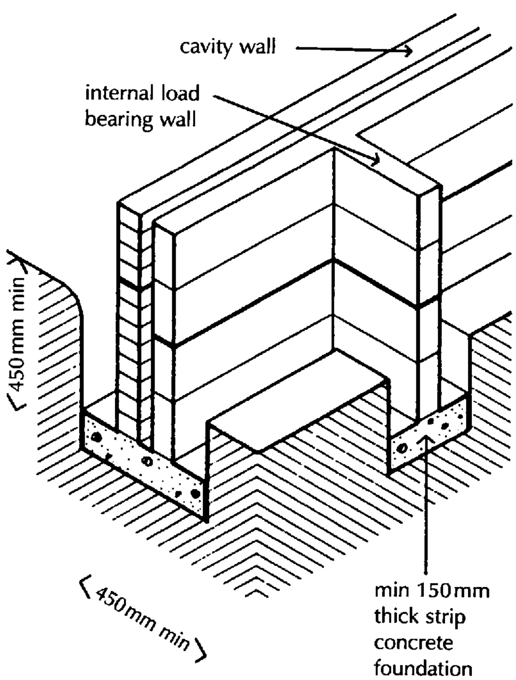


Fig. 6 Strip foundation.

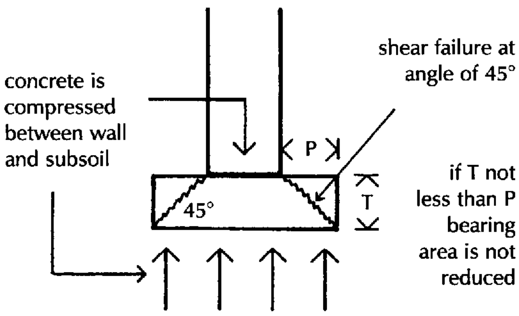


Fig. 7 Shear failure.

filling a wider trench with concrete for the convenience of laying brick below ground.

The least thickness of a concrete strip foundation is determined in part by the size of the aggregate used in the concrete, the need for a minimum thickness of concrete so that it does not dry too quickly and lose strength and to avoid failure of the concrete by shear.

If the thickness of a concrete strip foundation were appreciably less than its projection each side of a wall the concrete might fail through the development of shear cracks by the weight of the wall causing a 45° crack as illustrated in Fig. 7. If this occurred the bearing surface of the foundation on the ground would be reduced to less than that necessary for stability.

Shear is caused by the two opposing forces of the wall and the ground acting on and tearing or shearing the concrete as scissors or shears cut or shear materials apart.

Wide strip foundation

Strip foundations on subsoils with poor bearing capacity, such as soft sandy clays, may need to be considerably wider than the wall they support to spread the load to a sufficient area of subsoil for stability. The concrete strip could be as thick as the projection of the strip each side of the wall which would result in concrete of considerable uneconomic thickness to avoid the danger of failure by shear.

The alternative is to form a strip of reinforced concrete, illustrated in Fig. 8, which could be no more than 150 mm thick.

The reason for the use of reinforcement of steel in concrete is that concrete is strong in compression but weak in tension. The effect of the downward pressure of the wall above and the supporting pressure of the soil below is to make the concrete strip bend upwards at the edges, creating tensile stress in the bottom and compressive stress under the wall. These opposing pressures will tend to cause the shear cracking illustrated in Fig. 7. It is to reinforce and strengthen concrete in tension that steel reinforcing bars are cast in the lower edge because steel is strong in tension. There has to be a sufficient cover of concrete below the steel reinforcing rods to protect them from rusting and losing strength.

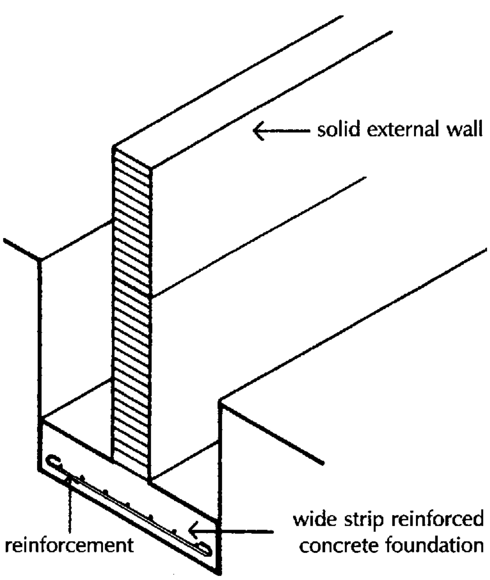


Fig. 8 Wide strip foundation.

Narrow strip (trench fill) foundation

Stiff clay subsoils have good bearing strength and are subject to seasonal volume change. Because of seasonal changes and the withdrawal of moisture by deep rooted vegetation it is practice to adopt a foundation depth of at least 0.9 m to provide a stable foundation.

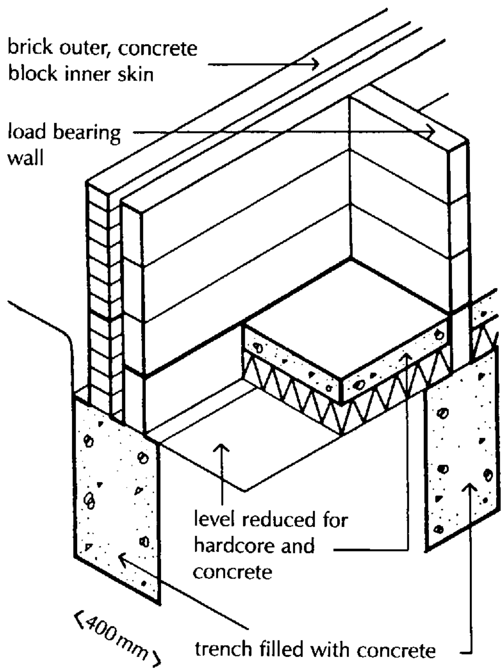


Fig. 9 Narrow trench fill foundation.

Because of the good bearing capacity of the clay the foundation may need to be little wider than the thickness of the wall to be supported. It would be laborious and uneconomic to excavate trenches wide enough for laying bricks down to the required level of a strip foundation.

Practice today is to use a mechanical excavator to take out the clay down to the required depth of at least 0.9 m below surface and immediately fill the trenches with concrete up to a level just below finished ground level, as illustrated in Fig. 9. The width of the trench is determined by the width of the excavator bucket available, which should not be less than the minimum required width of foundation.

The trench is filled with concrete as soon as possible so that the clay bed exposed does not dry out and shrink and against the possibility of the trench sides falling in, particularly in wet weather.

With the use of mechanical excavating equipment to dig the trenches and to move the excavated soil and spread it over other parts of the site or cart it from site, and the use of ready mixed concrete to fill the trenches this is the most expedient, economic and satisfactory method of making foundations on stiff, shrinkage subsoils for small buildings.

Short bored pile foundation

Where the subsoil is of firm, shrinkable clay which is subject to volume change due to deep rooted vegetation for some depth below surface and where the subsoil is of soft or uncertain bearing capacity for some few metres below surface, it may be economic and satisfactory to use a system of short bored piles as a foundation.

Piles are concrete columns which are either precast and driven (hammered) into the ground or cast in holes that are augered (drilled) into the ground down to a level of a firm, stable stratum of subsoil.

The piles that are used as a foundation down to a level of some 4 m below the surface for small buildings are termed short bore, which refers to the comparatively short length of the piles as compared to the much longer piles used for larger buildings. Short bored piles are generally from 2 to 4 m long and from 250 to 350 mm diameter.

Holes are augered in the ground by hand or machine. An auger is a form of drill comprising a rotating shaft with cutting blades that cuts into the ground and is then withdrawn, with the excavated soil on the blades that are cleared of soil. The auger is again lowered into the

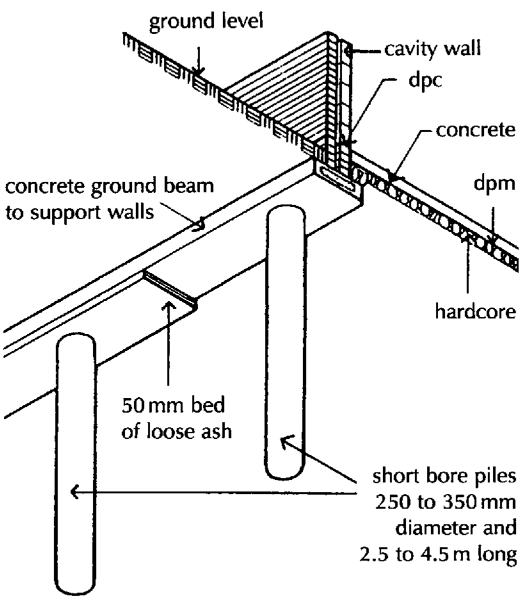


Fig. 10 Short bored pile foundation.

ground and withdrawn, cleared of soil and the process repeated until the required depth is reached.

The advantage of this system of augered holes is that samples of the subsoil are withdrawn, from which the bearing capacity of the subsoil may be assessed. The piles may be formed of concrete by itself or, more usually, a light, steel cage of reinforcement is lowered into the hole and concrete poured or pumped into the hole and compacted to form a pile foundation.

The piles are cast below angles and intersection of load bearing walls and at intervals between to reduce the span and depth of the reinforced ground beam they are to support. A reinforced concrete ground beam is then cast over the piles as illustrated in Fig. 10. The ground beam is cast in a shallow trench on a 50 mm bed of ash with the reinforcement in the piles linked to that in the beams for continuity. The spacing of the piles depends on the loads to be supported and on economic sections of ground beam.

Pad foundations

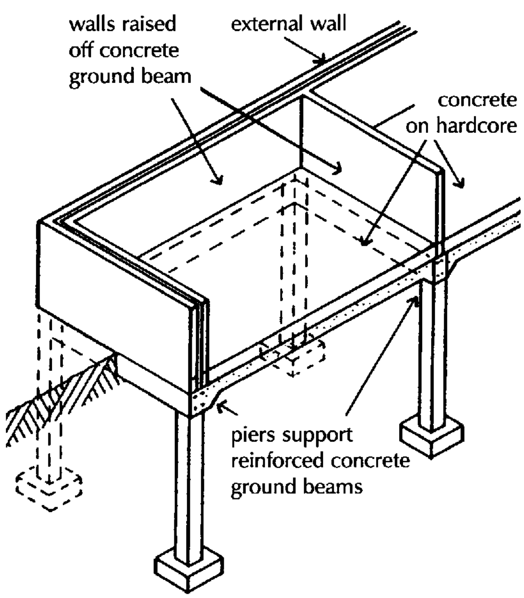


Fig. 11 Pad foundations.

On made up ground and ground with poor bearing capacity where a firm, natural bed of, for example, gravel or sand is some few metres below the surface, it may be economic to excavate for isolated piers of brick or concrete to support the load of buildings of some four storeys in height. The piers will be built at the angles, intersection of walls and under the more heavily loaded wall such as that between windows up the height of the building.

Pits are excavated down to the necessary level, the sides of the excavation temporarily supported and isolated pads of concrete are cast in the bottom of the pits. Brick piers or reinforced concrete piers are built or cast on the pad foundations up to the underside of the reinforced concrete beams that support walls as illustrated in Fig. 11. The ground beams or foundation beams may be just below or at ground level, the walls being raised off the beams.

The advantage of this system of foundation is that pockets of tipped stone or brick and concrete rubble that would obstruct bored piling may be removed as the pits are excavated and that the nature of the subsoil may be examined as the pits are dug to select a level of sound subsoil. This advantage may well be justification for this labour intensive and costly form of construction.

Raft foundations

A raft foundation consists of a raft of reinforced concrete under the whole of a building. This type of foundation is described as a raft in the sense that the concrete raft is cast on the surface of the ground which supports it, as water does a raft, and the foundation is not fixed by foundations carried down into the subsoil.

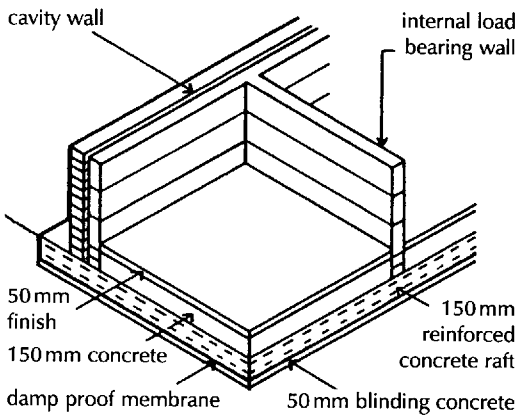


Fig. 12 Flat slab raft.

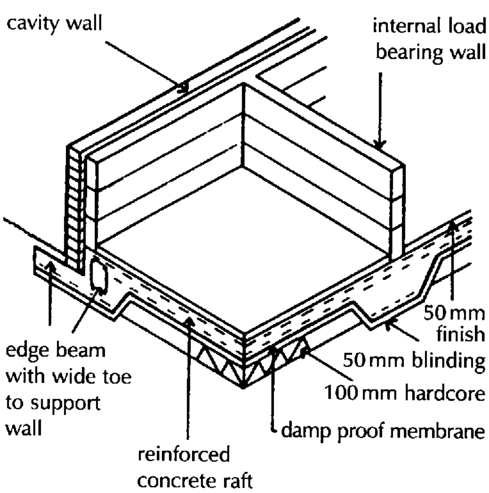


Fig. 13 Edge beam raft.

Raft foundations may be used for buildings on compressible ground such as very soft clay, alluvial deposits and compressible fill material where strip, pad or pile foundations would not provide a stable foundation without excessive excavation. The reinforced concrete raft is designed to transmit the whole load of the building from the raft to the ground where the small spread loads will cause little if any appreciable settlement.

The two types of raft foundation commonly used are the flat raft and the wide toe raft.

The flat slab raft is of uniform thickness under the whole of the building and reinforced to spread the loads from the walls uniformly over the under surface to the ground. This type of raft may be used under small buildings such as bungalows and two storey houses where the comparatively small loads on foundations can be spread safely and economically under the rafts.

The concrete raft is reinforced top and bottom against both upward and downward bending. Vegetable top soil is removed and a blinding layer of concrete 50 mm thick is spread and levelled to provide a base on which to cast the concrete raft. A waterproof membrane is laid, on the dry concrete blinding, against moisture rising into the raft. The top and bottom reinforcement is supported and spaced preparatory to placing the concrete which is spread, consolidated and finished level.

When the reinforced concrete raft has dried and developed sufficient strength the walls are raised as illustrated in Fig. 12. The concrete raft is usually at least 150 mm thick.

The concrete raft may be at ground level or finished just below the surface for appearance sake. Where floor finishes are to be laid on the raft a 50 mm thick layer of concrete is spread over the raft, between the walls, to raise the level and provide a level, smooth finish for floor coverings. As an alternative a raised floor may be constructed on top of the raft to raise the floor above ground.

A flat slab recommended for building in areas subject to mining subsidence is similar to the flat slab, but cast on a bed of fine granular material 150 mm thick so that the raft is not keyed to the ground and is therefore unaffected by horizontal ground strains.

Where the ground has poor compressibility and the loads on the foundations would require a thick, uneconomic flat slab, it is usual to cast the raft as a wide toe raft foundation. The raft is cast with a reinforced concrete, stiffening edge beam from which a reinforced concrete toe extends as a base for the external leaf of a cavity wall as shown in Fig. 13. The slab is thickened under internal load bearing walls.

Vegetable top soil is removed and the exposed surface is cut away to roughly form the profile of the underside of the slab. As necessary

100 mm of hardcore or concrete is spread under the area of the raft and a 50 mm layer of blinding concrete is spread, shaped and levelled as a base for the raft and toes. A waterproof membrane is laid on the dried concrete blinding and the steel reinforcement fixed in position and supported preparatory to placing, compacting and levelling the concrete raft.

The external cavity and internal solid walls are raised off the concrete raft once it has developed sufficient strength. The extended toe of the edge beam is shaped so that the external brick outer leaf of the cavity wall is finished below ground for appearance sake. A floor finish is laid on 50 mm concrete finish or a raised floor constructed.

Raft foundation on sloping site

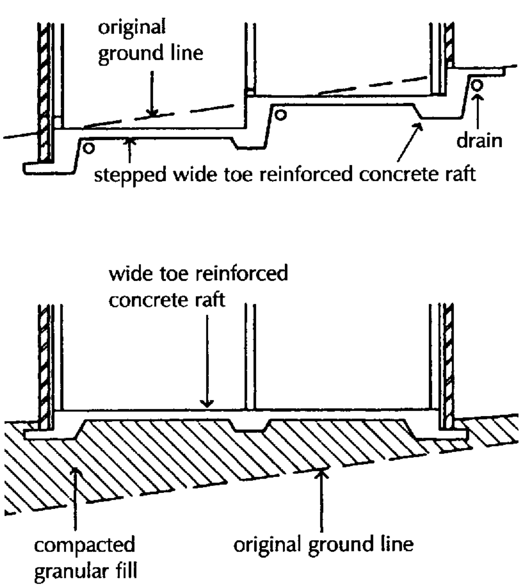


Fig. 14 Raft on sloping site.

On sites where the slope of the ground is such that there is an appreciable fall in the surface across the width or length of a building, and a raft foundation is to be used, because of the poor bearing capacity of subsoil, it is necessary either to cut into the surface or provide additional fill under the building or a combination of both to provide a level base for the raft.

It is advisable to minimise the extent of disturbance of the soft or uncertain subsoil. Where the slope is shallow and the design and use of the building allows, a stepped raft may be used down the slope, as illustrated in Fig. 14.

A stepped, wide toe, reinforced concrete raft is formed with the step or steps made at the point of a load bearing internal wall or at a division wall between compartments or occupations. The drains under the raft are to relieve and discharge surface water running down the slope that might otherwise be trapped against steps and promote dampness in the building.

The level raft illustrated in Fig. 14 is cast on imported granular fill that is spread, consolidated and levelled as a base for the raft. The disadvantage of this is the cost of the additional granular fill and the advantage a level bed of uniform consistency under the raft.

As an alternative the system of cut and fill may be used to reduce the volume of imported fill.

Raft foundations are usually formed on ground of soft subsoil or made up ground where the bearing capacity is low or uncertain, to minimise settlement. There is some possibility of there being some slight movement of the ground under the building which would fracture drains and other service pipes entering the building through the raft. Service pipes rising through the raft should run through collars, cast in the concrete, which will allow some movement of the raft without fracturing service pipes.

Foundations on sloping sites

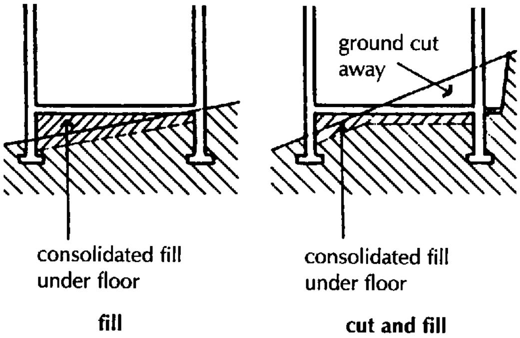


Fig. 15 Fill and cut and fill.

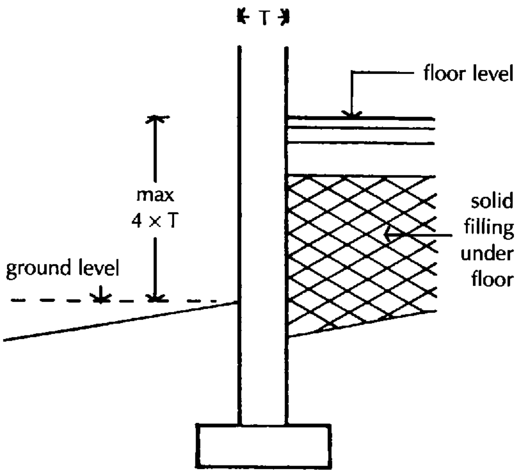


Fig. 16 Solid filling.

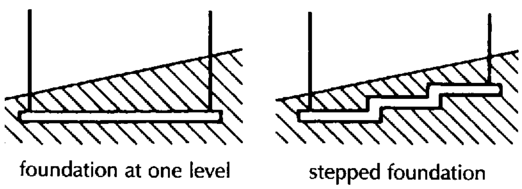


Fig. 17 Foundation on sloping site.

The natural surface of ground is rarely level to the extent that there may be an appreciable slope either across or along or both across and along the site of most buildings.

On sloping sites an initial decision to be made is whether the ground floor is to be above ground at the highest point or partly sunk below ground as illustrated in Fig. 15.

Where the ground floor is to be at or just above ground level at the highest point, it is necessary to import some dry fill material such as broken brick or concrete hardcore to raise the level of the oversite concrete and floor. This fill will be placed, spread and consolidated up to the external wall once it has been built.

The consolidated fill will impose some horizontal pressure on the wall. To make sure that the stability of the wall is adequate to withstand this lateral pressure it is recommended practice that the thickness of the wall should be at least a quarter of the height of the fill bearing on it as illustrated in Fig. 16. The thickness of a cavity wall is taken as the combined thickness of the two leaves unless the cavity is filed with concrete when the overall thickness is taken.

To reduce the amount of fill necessary under solid floors on sloping sites a system of cut and fill may be used as illustrated in Fig. 15. The disadvantage of this arrangement is that the ground floor is below ground level at the highest point and it is necessary to form an excavated dry area to collect and drain surface water that would otherwise run up to the wall and cause problems of dampness.

To economise in excavation and foundation walling on sloping sites where the subsoil, such as gravel and sand, is compact it is practice to use a stepped foundation as illustrated in Fig. 17, which contrasts diagrammatically the reduction in excavation and foundation walling of a level and a stepped foundation.

Figure 18 is an illustration of the stepped foundation for a small building on a sloping site where the subsoil is reasonably compact near the surface and will not be affected by volume changes. The foundation is stepped up the slope to minimise excavation and walling below ground. The foundation is stepped so that each step is no higher than the thickness of the concrete foundation and the foundation at the higher level overlaps the lower foundation by at least 300 mm.

The load bearing walls are raised and the foundation trenches around the walls backfilled with selected soil from the excavation. The concrete oversite and solid ground floor may be cast on granular fill no more than 600 mm deep or cast or placed as a suspended reinforced concrete slab. The drains shown at the back of the trench fill are laid to collect and drain water to the sides of the building.

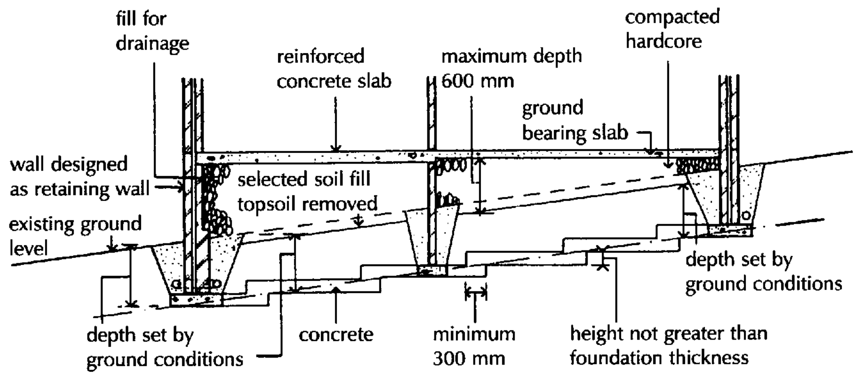


Fig. 18 Stepped foundation.

SITE PREPARATION

Turf and vegetable top soil should be removed from the ground to be covered by a building, to a depth sufficient to prevent later growth. Tree and bush roots, that might encourage later growth, are grubbed up and any pockets of soft compressible material, that might affect the stability of the building, are removed. The reasons for removing this vegetable soil are firstly to prevent plants, shrubs or trees from attempting to grow under the concrete. In growing, even the smallest of plant life exerts considerable pressure, which would quite quickly rupture the concrete oversite. The second reason for removing the vegetable top soil is that it is generally soft and compressible and readily retains moisture which would cause concrete over it to be damp at all times. The depth of vegetable top soil varies and on some sites it may be necessary to remove 300 mm or more vegetable top soil.

In practice most of the vegetable top soil over a building site is effectively moved by excavations for foundations, levelling and drain and other service pipes to the extent that it may be necessary to remove top soil that remains within or around the confines of a building.

Contaminants

In Approved Document C to the Building Regulations is a list of possible contaminants in or on ground to be covered by a building, that may be a danger to health or safety. Building sites that may be likely to contain contaminants can be identified from planning records or local knowledge of previous uses. Sites previously used as asbestos, chemical or gas works, metal works, munitions factories, nuclear installations, oil stores, railway land, sewage works and land fill are some examples given.

Site drainage

Surface water (stormwater) is the term used for natural water, that is rainwater that falls on the surface of the ground including open ground such as fields, paved areas and roofs. Rainwater that falls on paved areas and from roofs generally drains to surface water (stormwater) drains and thence to soakaways (see Volume 5), rivers, streams or the sea. Rainwater falling on natural open ground will in part lie on the surface of impermeable soils, evaporate to air, run off to streams and rivers and soak into the ground. On permeable soils much of the rainwater will soak into the ground as ground water.

Ground water is that water held in soils at and below the water table (which is the depth at which there is free water below the surface). The level of the water table will vary seasonally, being closest to the surface during rainy seasons and deeper during dry seasons when most evaporation to air occurs.

In Part C of the Building Regulations is a requirement for subsoil drainage, to avoid passage of ground moisture to the inside of a building or to avoid damage to the fabric of the building.

In Approved Document C to the Regulations are provisions for the need for subsoil drainage where the water table can rise to within 0.25 m of the lowest floor and where the water table is high in dry weather and the site of the building is surrounded by higher ground.

Paved areas are usually laid to falls to channels and gullies that drain to surface water drains (Volume 5).

Subsoil drains

Subsoil drains are used to improve the run off of surface water and the drainage of ground water to maintain the water table at some depth below the surface for the following reasons:

(1) to improve the stability of the ground
(2) to avoid surface flooding
(3) to alleviate or avoid dampness in basements
(4) to reduce humidity in the immediate vicinity of buildings.

Ground water, or land or field, drains are either open jointed or jointed, porous or perforated pipes of clayware, concrete, pitch fibre or plastic (see Volume 5). The pipes are laid in trenches to follow the fall of the ground, generally with branch drains discharging to a ditch, stream or drain.

On impervious subsoils, such as clay, it may be necessary to form a system of drains to improve the run off of surface water and drain subsoil to prevent flooding. Some of the drain systems used are natural, herring bone, grid, fan and moat or cut-off.

Natural system

This system, which is commonly used for field drains, uses the natural contours of the ground to improve run off of surface ground water to spine drains in natural valleys that fall towards ditches or streams. The drains are laid in irregular patterns to follow the natural contours as illustrated in Fig. 19A.

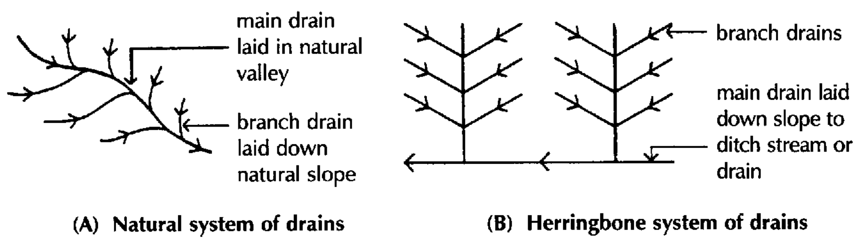


Fig. 19 (A) Natural system. (B) Herring bone system.

Herring bone system

In this system, illustrated in Fig. 19B, fairly regular runs of drains connect to spine drains that connect to a ditch or main drain. This system is suited to shallow, mainly one way slopes that fall naturally towards a ditch or main drain and can be laid to a reasonably regular pattern to provide a broad area of drainage.

Grid system

This is an alternative to the herring bone system for draining one way slopes where branch drains are fed by short branches that fall towards a ditch or main drain, as illustrated in Fig. 20A. This system may be preferred to the herring bone system, where the run off is moderate, because there are fewer drain connections that may become blocked.

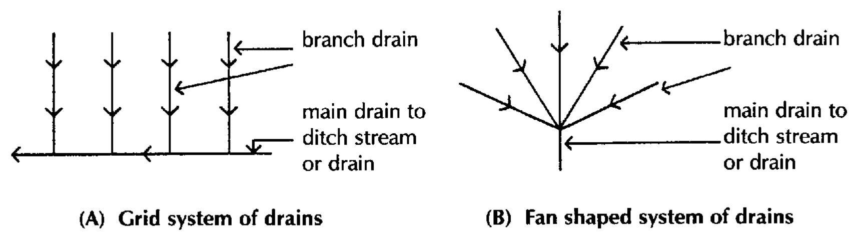


Fig. 20 (A) Grid system. (B) Fan systems.

Fan system

A fan shaped layout of short branches, illustrated in Fig. 20B, drains to spine drains that fan towards a soakaway, ditch or drain on narrow sites. A similar system is also used to drain the partially purified outflow from a septic tank, (see Volume 5), to an area of subsoil where further purification will be effected.

On sloping building sites on impervious soil where an existing system of land drains is already laid and where a new system is laid to prevent flooding a moat or cut off system is used around the new building to isolate it from general land drains, as illustrated in Fig. 21.

The moat or cut off system of drains is laid some distance from and around the new building to drain the ground between it and the new building and to carry water from the diverted land drains down the slope of the site. Plainly the moat drains should be clear of paved areas around the house.

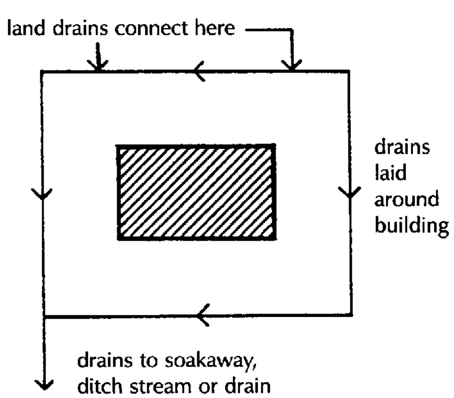


Fig. 21 Moat or cut off system.

Laying drains

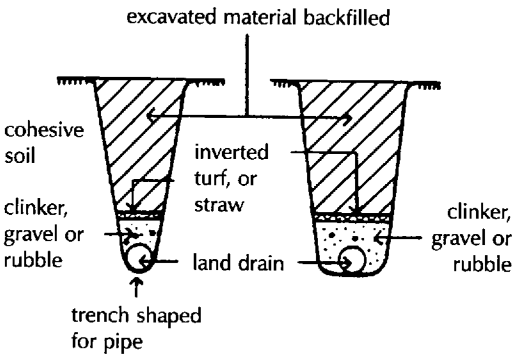


Fig. 22 Land drains.

Ground water (land) drains are laid in trenches at depths of 0.6 and 0.9 m in heavy soils and 0.9 to 1.2 m in light soils. The nominal bore of the pipes is usually 75 and 100 mm for main drains and 65 or 75 mm for branches.

The drain pipes are laid in the bed of the drain trench and surrounded with clinker, gravel or broken pervious rubble which is covered with inverted turf, brushwood or straw to separate the back fill from the pipes and their surround. Excavated material is backfilled into the drain trench up to the natural ground level.

The drain trench bottom may be shaped to take and contain the pipe or finished with a flat bed as illustrated in Fig. 22, depending on the nature of the subsoil and convenience in using a shaping tool.

Where drains are laid to collect mainly surface water the trenches are filled with clinker, gravel or broken rubble to drain water either to a drain or without a drain as illustrated in Fig. 23 in the form known as a French drain. Whichever is used will depend on the anticipated volume of water and the economy of dispensing with drainpipes.

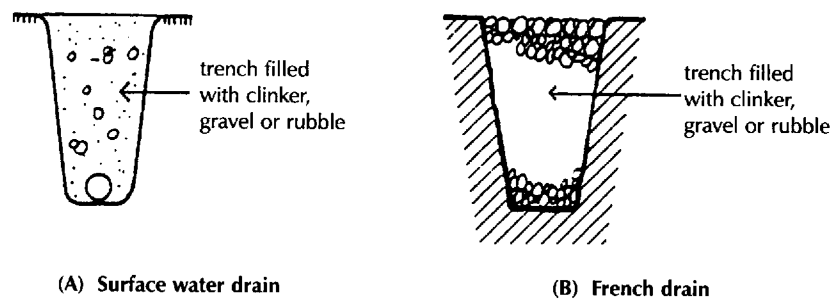


Fig. 23 (A) Surface water drain. (B) French drain.

RESISTANCE TO GROUND MOISTURE

Up to about the middle of the nineteenth century the ground floor of most buildings was formed on compacted soil or dry fill on which was laid a surface of stone flagstones, brick or tile or a timber boarded floor nailed to battens bedded in the compacted soil or fill. In lowland areas and on poorly drained soils most of these floors were damp and cold underfoot.

A raised timber ground floor was sometimes used to provide a comparatively dry floor surface of boards, nailed to timber joists, raised above the packed soil or dry fill. To minimise the possibility of the joists being affected by rising damp it was usual to ventilate the space below the raised floor. The inflow of cold outside air for ventilation tended to make the floor cold underfoot.

OVERSITE CONCRETE

When Portland cement was first continuously produced, towards the end of the nineteenth century, it became practical to cover the site of buildings with a layer of concrete as a solid level base for floors and as a barrier to rising damp. From the early part of the twentieth century

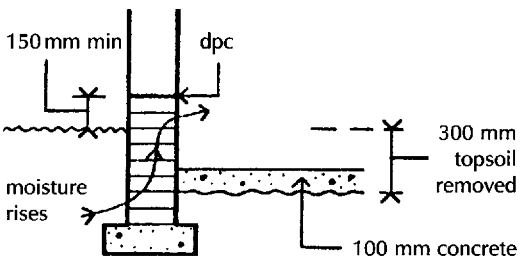


Fig. 24 Diagram to illustrate the need for hardcore.

it became accepted practice to cover the site of buildings with a layer of concrete some 100 mm thick, the concrete oversite or oversite concrete. At the time, many ground floors of houses were formed as raised timber floors on oversite concrete with the space below the floor ventilated against stagnant damp air.

With the shortage of timber that followed the Second World War, the raised timber ground floor was abandoned and the majority of ground floors were formed as solid, ground supported floors with the floor finish laid on the concrete oversite. At the time it was accepted practice to form a continuous horizontal damp-proof course, some 150 mm above ground level, in all walls with foundations in the ground.

With the removal of vegetable top soil the level of the soil inside the building would be from 100 to 300 mm below the level of the ground outside. If a layer of concrete were then laid oversite its finished level would be up to 200 mm below outside ground level and up to 350 mm below the horizontal dpc in walls. There would then be considerable likelihood of moisture rising through the foundation walls, to make the inside walls below the dpc damp, as illustrated in Fig. 24.

It would, of course, be possible to make the concrete oversite up to 450 mm thick so that its top surface was level with the dpc and so prevent damp rising into the building. But this would be unnecessarily expensive. Instead, a layer of what is known as hardcore is spread oversite, of sufficient thickness to raise the level of the top of the concrete oversite to that of the dpc in walls. The purpose of the hardcore is primarily to raise the level of the concrete oversite for solid, ground supported floors.

The layer of concrete oversite will serve as a reasonably effective barrier to damp rising from the ground by absorbing some moisture from below. The moisture retained in the concrete will tend to make solid floor finishes cold underfoot and may adversely affect timber floor finishes. During the second half of the twentieth century it became accepted practice to form a waterproof membrane under, in or over the oversite concrete as a barrier to rising damp, against the cold underfoot feel of solid floors and to protect floor finishes. Having accepted the use of a damp-proof membrane it was then logical to unite this barrier to damp, to the damp-proof course in walls, by forming them at the same level or by running a vertical dpc up from the lower membrane to unite with the dpc in walls.

Even with the damp-proof membrane there is some appreciable transfer of heat from heated buildings through the concrete and hardcore to the cold ground below. In Approved Document L to the Building Regulations is the inclusion of provision for insulation to ground floors for the conservation of fuel and power. The requirement can be met by a layer of insulating material under the site concrete, under a floor screed or under boarded or sheet floor finishes to provide a maximum U value of $0.45 W/m^2K$ for the floor.

The requirement to the Building Regulations for the resistance of the passage of moisture to the inside of the building through floors is met if the ground is covered with dense concrete laid on a hardcore bed and a damp-proof membrane. The concrete should be at least 100 mm thick and composed of 50 kg of cement to not more than $0.11 m^3$ of fine aggregate and $0.16 m^3$ of coarse aggregate of BS 5328 mix ST2. The hardcore bed should be of broken brick or similar inert material, free from materials including water soluble sulphates in quantities which could damage the concrete. A damp-proof membrane, above or below the concrete, should ideally be continuous with the dpc in the walls.

It is practice on building sites to first build external and internal load bearing walls from the concrete foundation up to the level of the dpc, above ground, in walls. The hardcore bed and the oversite concrete are then spread and levelled within the external walls.

If the hardcore is spread over the area of the ground floor and into excavations for foundations and soft pockets of ground that have been removed and the hardcore is thoroughly consolidated by ramming, there should be very little consolidation settlement of the concrete ground supported floor slab inside walls. Where a floor slab has suffered settlement cracking, it has been due to an inadequate hardcore bed, poor filling of excavation for trenches or ground movement due to moisture changes. It has been suggested that the floor slab be cast into walls for edge support. This dubious practice, which required edge formwork support of slabs at cavities, will have the effect of promoting cracking of the slab, that may be caused by any slight consolidation settlement. Where appreciable settlement is anticipated it is best to reinforce the slab and build it into walls as a suspended reinforced concrete slab.

Hardcore

Hardcore is the name given to the infill of materials such as broken bricks, stone or concrete, which are hard and do not readily absorb water or deteriorate. This hardcore is spread over the site within the external walls of the building to such thickness as required to raise the finished surface of the site concrete. The hardcore should be spread until it is roughly level and rammed until it forms a compact bed for the oversite concrete. This hardcore bed is usually from 100 to 300 mm thick.

The hardcore bed serves as a solid working base for building and as a bed for the concrete oversite. If the materials of the hardcore are hard and irregular in shape they will not be a ready path for moisture to rise by capillarity. Materials for hardcore should, therefore, be clean and free from old plaster or clay which in contact with broken brick or gravel would present a ready narrow capillary path for moisture to rise.

The materials used for hardcore should be chemically inert and not appreciably affected by water. Some materials used for hardcore, for example colliery spoil, contain soluble sulphate that in combination with water combine with cement and cause concrete to disintegrate. Other materials such as shale may expand and cause lifting and cracking of concrete. A method of testing materials for soluble sulphate is described in Building Research Station (BRS) Digest 174.

The materials used for hardcore are:

Brick or tile rubble

Clean, hard broken brick or tile is an excellent material for hardcore. Bricks should be free of plaster. On wet sites the bricks should not contain appreciable amounts of soluble sulphate.

Concrete rubble

Clean, broken, well-graded concrete is another excellent material for hardcore. The concrete should be free from plaster and other building materials.

Gravel and crushed hard rock

Clean, well-graded gravel or crushed hard rock are both excellent, but somewhat expensive materials for hardcore.

Chalk

Broken chalk is a good material for hardcore providing it is protected from expansion due to frost. Once the site concrete is laid it is unlikely to be affected by frost.

Blinding

Before the oversite concrete is laid it is usual to blind the top surface of the hardcore. The purpose of this is to prevent the wet concrete running down between the lumps of broken brick or stone, as this would make it easier for water to seep up through the hardcore and would be wasteful of concrete. To blind, or seal, the top surface of the hardcore a thin layer of very dry coarse concrete can be spread over it, or a thin layer of coarse clinker or ash can be used. This blinding layer, or coat, will be about 50 mm thick, and on it the site concrete is spread and finished with a true level top surface. Figure 25 is an illustration of hardcore, blinding and concrete oversite. Even with a good hardcore bed below the site concrete a dense hard floor finish, such as tiles, may be slightly damp in winter and will be cold underfoot. To reduce the coldness experienced with some solid ground floor finishes it is good practice to form a continuous damp-proof membrane in the site concrete.

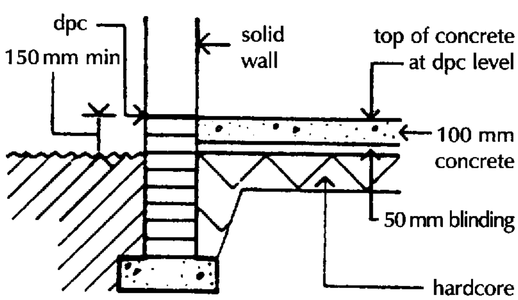


Fig. 25 Hardcore and blinding.

CONCRETE

Concrete (see also Volume 4) is the name given to a mixture of particles of stone bound together with cement. Because the major part of concrete is of particles of broken stones and sand, it is termed the aggregate. The material which binds the aggregate is cement and this is described as the matrix.

Aggregate

The materials commonly used as the aggregate for concrete are sand and gravel. The grains of natural sand and particles of gravel are very hard and insoluble in water and can be economically dredged or dug from pits and rivers. The material dug from many pits and river beds consists of a mixture of sand and particles of gravel and is called 'ballast' or 'all-in aggregate'. The name ballast derives from the use of this material to load empty ships and barges. The term 'all-in aggregate' is used to describe the natural mixture of fine grains of sand and larger coarse particles of gravel.

All-in aggregate

Ballast

All-in aggregate (ballast) is one of the cheapest materials that can be used for making concrete and is used for mass concrete work, such as large open foundations. The proportion of fine to coarse particles in an all-in aggregate cannot be varied and the proportion may vary from batch to batch so that it is not possible to control the mix and therefore the strength of concrete made with all-in aggregate. Accepted practice today is to make concrete for building from a separate mix of fine and coarse aggregate which is produced from ballast by washing, sieving and separating the fine from the coarse aggregate.

Fine aggregate and coarse aggregate

Fine aggregate is natural sand which has been washed and sieved to remove particles larger than 5 mm and coarse aggregate is gravel which has been crushed, washed and sieved so that the particles vary from 5 up to 50 mm in size. The fine and coarse aggregate are delivered separately. Because they have to be sieved, a prepared mixture of fine and coarse aggregate is more expensive than natural all-in aggregate. The reason for using a mixture of fine and coarse aggregate is that by combining them in the correct proportions, a concrete with very few voids or spaces in it can be made and this reduces the quantity of comparatively expensive cement required to produce a strong concrete.

Cement

The cement most used is ordinary Portland cement. It is manufactured by heating a mixture of finely powdered clay and limestone with water to a temperature of about 1200°C, at which the lime and clay fuse to form a clinker. This clinker is ground with the addition of a little gypsum to a fine powder of cement. Cement powder reacts with water and its composition gradually changes and the particles of cement bind together and adhere strongly to materials with which they are mixed. Cement hardens gradually after it is mixed with water.

Some thirty minutes to an hour after mixing with water the cement is no longer plastic and it is said that the initial set has occurred. About 10 hours after mixing with water, the cement has solidified and it increasingly hardens until some 7 days after mixing with water when it is a dense solid mass.

Water–cement ratio

The materials used for making concrete are mixed with water for two reasons. Firstly to cause the reaction between cement and water which results in the cement acting as a binding agent and secondly to make the materials of concrete sufficiently plastic to be placed in position. The ratio of water to cement used in concrete affects its ultimate strength, and a certain water–cement ratio produces the best concrete. If too little water is used the concrete is so stiff that it cannot be compacted and if too much water is used the concrete does not develop full strength.

The amount of water required to make concrete sufficiently plastic depends on the position in which the concrete is to be placed. The extreme examples of this are concrete for large foundations, which can be mixed with comparatively little water and yet be consolidated, and concrete to be placed inside formwork for narrow reinforced concrete beams where the concrete has to be comparatively wet to be placed. In the first example, as little water is used, the proportion of cement to aggregate can be as low as say 1 part of cement to 9 of aggregate and in the second, as more water has to be used, the proportion of cement to aggregate has to be as high as say 1 part of cement to 4 of aggregate. As cement is expensive compared with aggregate it is usual to use as little water and therefore cement as the necessary plasticity of the concrete will allow.

Proportioning materials

The materials used for mass concrete for foundations were often measured out by volume, the amount of sand and coarse aggregate being measured in wooden boxes constructed for the purpose. This is a crude method of measuring the materials because it is laborious to have to fill boxes and then empty them into mixers and no account is taken of the amount of water in the aggregate. The amount of water in aggregate affects the finished concrete in two ways: (a) if the aggregate is very wet the mix of concrete may be too weak, have an incorrect ratio of water to cement and not develop full strength and, (b) damp sand occupies a greater volume than dry. This increase in volume of wet sand is termed bulking.

The more accurate method of proportioning the materials for concrete is to measure them by weight. The materials used in reinforced concrete are commonly weighed and mixed in large concrete mixers. It is not economical for builders to employ expensive concrete mixing machinery for small buildings and the concrete for foundations, floors and lintels is usually delivered to site ready mixed, except for small batches that are mixed by hand or in a portable petrol driven mixer. The materials are measured out by volume and providing the concrete is thoroughly mixed, is not too wet and is properly consolidated the finished concrete is quite satisfactory.

Concrete mixes

British Standard 5328: Specifying concrete, including ready-mixed concrete, gives a range of mixes. One range of concrete mixes in the Standard, ordinary prescribed mixes, is suited to general building work such as foundations and floors. These prescribed mixes should be used in place of the traditional nominal volume mixes such as 1:3:6 cement, fine and coarse aggregate by volume, that have been used in the past. The prescribed mixes, specified by dry weight of aggregate, used with 100 kg of cement, provide a more accurate method of measuring the proportion of cement to aggregate and as they are measured against the dry weight of aggregate, allow for close control of the water content and therefore the strength of the concrete.

The prescribed mixes are designated by letters and numbers as C7.5P, C10P, C15P, C20P, C25P and C30P. The letter C stands for 'compressive', the letter P for 'prescribed' and the number indicates the 28-day characteristic cube crushing strength in newtons per square millimetre (N/mm^2) which the concrete is expected to attain. The prescribed mix specifies the proportions of the mix to give an indication of the strength of the concrete sufficient for most building purposes, other than designed reinforced concrete work.

Table 1 equates the old nominal volumetric mixes of cement and aggregate with the prescribed mixes and indicates uses for these mixes.

Table 1 Concrete mixes.

Nominal volume mix	BS 5328 Standard mixes	Uses
1:8 all-in 1:3:6	ST1	Foundations
1:3:6 1:2:4	ST2 ST3	Site concrete
1:1½:3	ST4	Site concrete reinforced

Ready-mixed concrete

The very many ready-mixed concrete plants in the United Kingdom are able to supply to all but the most isolated building sites. These plants prepare carefully controlled concrete mixes which are delivered to site by lorries on which the concrete is churned to delay setting.

Because of the convenience and the close control of these mixes, much of the concrete used in building today is provided by ready-mixed suppliers. To order ready-mixed concrete it is only necessary to specify the prescribed mix, for example C10P, the cement, type and size of aggregate and workability, that is medium or high workability, depending on the ease with which the concrete can be placed and compacted.

Soluble sulphates

There are water soluble sulphates in some soils, such as plastic clay, which react with ordinary cement and in time will weaken concrete. It is usual practice, therefore, to use one of the sulphate-resistant cements for concrete in contact with sulphate bearing soils.

Portland blast-furnace cement

This cement is more resistant to the destructive action of sulphates than ordinary Portland cement and is often used for concrete foundations in plastic clay subsoils. This cement is made by grinding a mixture of ordinary Portland cement with blast-furnace slag. Alternatively another type of cement known as 'sulphate resisting cement' is often used.

Sulphate resisting Portland cement

This cement has a reduced content of aluminates that combine with soluble sulphates in some soils and is used for concrete in contact with those soils.

OVERSITE CONCRETE (CONCRETE OVERSITE)

On firm non-cohesive subsoils and rocks such as sand, gravel and sound rock beds which are near the surface, under vegetable top soil and are well drained or dry it is satisfactory to lay the concrete oversite directly on a bed of hardcore or broken rock rubble as there is little likelihood of any appreciable amount of moisture rising and being absorbed by the concrete. The concrete is laid within the confines of the external walls and load bearing internal walls and consolidated and levelled to a thickness of 100 mm ready for solid floor finishes or a raised ground floor.

On much of the low lying land that is most suitable for building, the subsoil such as clay retains moisture which will tend to rise through a hardcore bed to concrete oversite. The damp concrete will be cold underfoot and require additional energy from heating systems to maintain an equable indoor temperature. It is practice today to form a continuous layer of some material that is impervious to water under, in or over the concrete oversite as a damp-proof membrane on the site of all inhabited buildings where there is a likelihood of moisture rising to the concrete.

DAMP-PROOF MEMBRANE

Concrete is spread oversite as a solid base for floors and as a barrier to moisture rising from the ground. Concrete is to some degree permeable to water and will absorb moisture from the ground; a damp oversite concrete slab will be cold and draw appreciable heat from rooms.

A requirement of the Building Regulations is that floors shall adequately resist the passage of moisture to the inside of the building. As concrete is permeable to moisture, it is generally necessary to use a damp-proof membrane under, in or on top of ground supported floor slabs as an effective barrier to moisture rising from the ground. The membrane should be continuous with the damp-proof course in walls, as a barrier to moisture rising between the edges of the concrete slab and walls.

A damp-proof membrane should be impermeable to water in either liquid or vapour form and be tough enough to withstand possible damage during the laying of screeds, concrete or floor finishes. The damp-proof membrane may be on top, sandwiched in or under the concrete slab.

Being impermeable to water the membrane will delay the drying out of wet concrete to ground if it is under the concrete, and of screeds to concrete if it is on top of the concrete.

Damp-proof membrane below site concrete

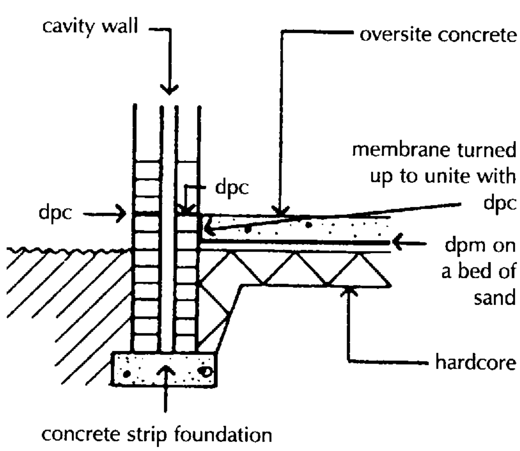


Fig. 26 Below concrete damp-proof membrane.

The obvious place to use a continuous damp-proof membrane is under the oversite concrete. The membrane is spread on a layer of comparatively dry concrete, clinker or ash which is spread and levelled over the hardcore as illustrated in Fig. 26. The edges of the membrane are turned up the face of external and internal walls ready for concrete laying so that it may unite and overlap the dpc in walls.

The membrane should be spread with some care to ensure that thin membranes are not punctured by sharp, upstanding particles in the blinding and that the edge upstands are kept in place as the concrete is laid.

The advantage of a damp-proof membrane under the site concrete is that it will be protected from damage during subsequent building operations. A disadvantage is that the membrane will delay the drying out of the oversite concrete that can only lose moisture by upwards evaporation to air.

Where underfloor heating is used the membrane should be under the concrete.

Surface damp-proof membrane

Floor finishes such as pitch mastic and mastic asphalt that are impermeable to water can serve as a combined damp-proof membrane and floor finish. These floor finishes should be laid to overlap

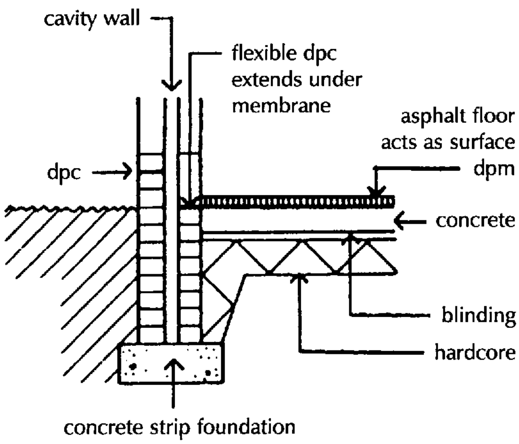


Fig. 27 Surface damp-proof membrane.

the damp-proof course in the wall as illustrated in Fig. 27 to seal the joint between the concrete and the wall.

Where hot soft bitumen or coal tar pitch are used as an adhesive for wood block floor finishes the continuous layer of the impervious adhesive can serve as a waterproof membrane.

The disadvantage of impervious floor finishes and impervious adhesives for floor finishes as a damp-proof membrane are that the concrete under the floor finish and the floor finish itself will be cold underfoot and make calls on the heating system and if the old floor finish is replaced with another there may be no damp-proof membrane.

Damp-proof membrane below a floor screed

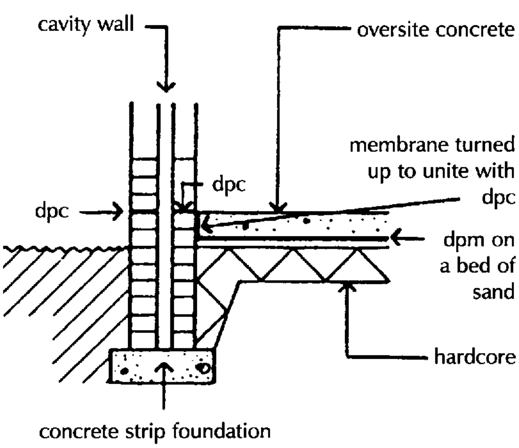


Fig. 28 Sandwich damp-proof membrane.

The oversite concrete is laid during the early stages of the erection of buildings. It is practice to lay floor finishes to solid ground floors after the roof is on and wet trades such as plastering are completed to avoid damage to floor finishes. By this time the site concrete will have thoroughly dried out. A layer of fine grained material such as sand and cement is usually spread and levelled over the surface of the dry concrete to provide a true level surface for a floor finish. As the wet finishing layer, called a screed, will not strongly adhere to dry concrete it is made at least 65 mm thick so that it does not dry too quickly and crack. Electric conduits and water service pipes are commonly run in the underside of the screed.

As an alternative to under concrete or surface damp-proof membranes a damp-proof membrane may be sandwiched between the site concrete and the floor screed, as illustrated in Fig. 28. At the junction of wall and floor the membrane overlaps the damp-proof course in the wall.

Materials for damp-proof membrane

The materials used as damp-proof membrane must be impermeable to water both in liquid and vapour form and sufficiently robust to withstand damage by later building operations.

Polythene and polyethylene sheet

Polythene or polyethylene sheet is commonly used as a damp-proof membrane with oversite concrete for all but severe conditions of dampness. It is recommended that the sheet should be at least 0.25 mm thick (1200 gauge). The sheet is supplied in rolls 4 m wide by 25 m long. When used under concrete oversite the sheet should be laid on a blinding layer of sand or compacted fuel ash spread over the hardcore.

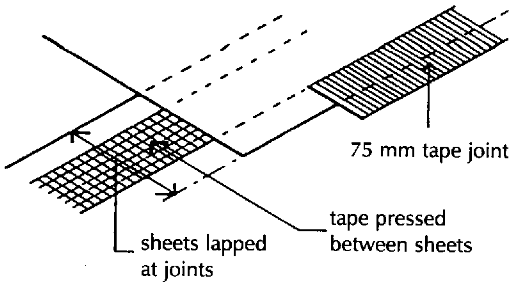


Fig. 29 Jointing laps in polythene sheet.

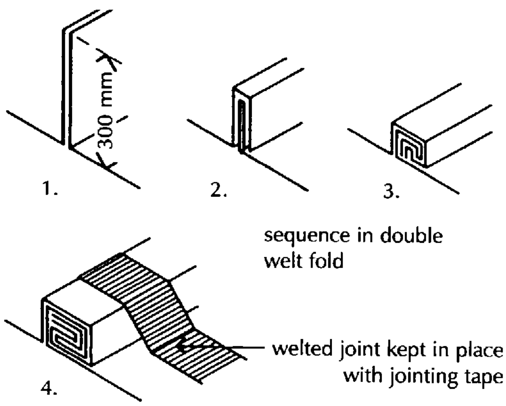


Fig. 30 Double welted fold joint in polythene sheet.

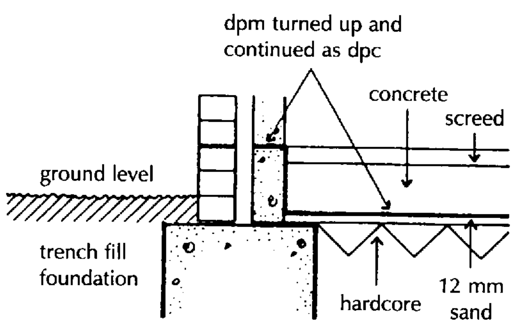


Fig. 31 Damp-proof membrane turn up.

The sheets are spread over the blinding and lapped 150 mm at joints and continued across surrounding walls, under the dpc for the thickness of the wall.

Where site conditions are reasonably dry and clean, the overlap joints between the sheets are sealed with mastic or mastic tape between the overlapping sheets and the joint completed with a polythene jointing tape as illustrated in Fig. 29.

For this lapped joint to be successful the sheets must be dry and clean else the jointing tape will not adhere to the surface of the sheets and the joint will depend on the weight of the concrete or screed pressing the joint sufficiently heavily to make a watertight joint. As clean and dry conditions on a building site are rare, this type of joint should be only used where there is unlikely to be heavy absorption of ground moisture.

Where site conditions are too wet to use mastic and tape, the joint is made by welting the overlapping sheets with a double welted fold as illustrated in Fig. 30, and this fold is kept in place by weighing it down with bricks or securing it with tape until the screed or concrete has been placed. The double welt is formed by folding the edges of sheets together and then making a welt which is flattened.

The plastic sheet is effectively impossible to fold and so stiff and elastic that it will always tend to unfold so that it requires a deal of patience to fold, hold in place and then contrive to fold along the joint. By using the maximum size of sheet available it is possible to minimise the number of joints.

The sheet should be used so that there are only joints one way as it is impractical to form a welt at junctions of joints.

Where the level of the damp-proof membrane is below that of the dpc in walls it is necessary to turn it up against walls so that it can overlap the dpc or be turned over as dpc as illustrated in Fig. 31. To keep the sheet in place as an upstand to walls it is necessary to keep it in place with bricks or blocks laid on the sheet against walls until the concrete has been placed and the bricks or blocks removed as the concrete is run up the wall.

At the internal angle of walls a cut is made in the upstand sheet to facilitate making an overlap of sheet at corners. These sheets which are commonly used as a damp-proof membrane will serve as an effective barrier to rising damp, providing they are not punctured or displaced during subsequent building operations.

Hot pitch or bitumen

A continuous layer of hot applied coal-tar pitch or soft bitumen is poured on the surface and spread to a thickness of not less than 3 mm. In dry weather a concrete blinding layer is ready for the membrane 3 days after placing. The surface of the concrete should be brushed to remove dust and primed with a solution of coal-tar pitch or bitumen solution or emulsion. The pitch is heated to 35°C to 45°C and bitumen to 50°C to 55°C.

Properly applied pitch or bitumen layers serve as an effective damp-proof membrane both horizontally and spread up inside wall faces to unite with dpcs in walls and require less patient application than plastic sheet materials.

Bitumen solution, bitumen/rubber emulsion or tar/rubber emulsion

These cold applied solutions are brushed on to the surface of concrete in three coats to a finished thickness of not less than 2.5 mm, allowing each coat to harden before the next is applied.

Bitumen sheet

Sheets of bitumen with hessian, fibre or mineral fibre base are spread on the concrete oversite or on a blinding of stiff concrete below the concrete, in a single layer with the joints between adjacent sheets lapped 75 mm. The joints are then sealed with a gas torch which melts the bitumen in the overlap of the sheets sufficient to bond them together. Alternatively the lap is made with hot bitumen spread between the overlap of the sheets which are then pressed together to make a damp-proof joint. The bonded sheets may be carried across adjacent walls as a dpc, or up against the walls and then across as dpc where the membrane and dpc are at different levels.

The polythene or polyester film and self-adhesive rubber/bitumen compound sheets, described in Volume 4 under 'Tanking', can also be used as damp-proof membranes, with the purpose cut, shaped cloaks and gussets for upstand edges and angles. This type of membrane is particularly useful where the membrane is below the level of the dpc in walls.

Bitumen sheets, which may be damaged on building sites, should be covered for protection as soon as possible by the screed or site concrete.

Mastic asphalt or pitch mastic

These materials are spread hot and finished to a thickness of at least 12.5 mm. This expensive damp-proof membrane is used where there is appreciable water pressure under the floor and as 'tanking' to basements as described in Volume 4.

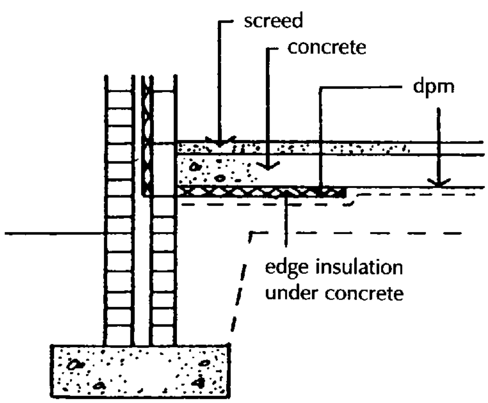
RESISTANCE TO THE PASSAGE OF HEAT

The requirements of the Building Regulations and practical advice in Approved Document L include provision for insulation to some ground floors. The requirement is that ground floors should have a maximum insulation value (U value) of 0.45 W/m^{2}K. Some ground floor slabs that are larger than 10 m in both length and breadth may not need the addition of an insulating layer to provide the U value of 0.45.

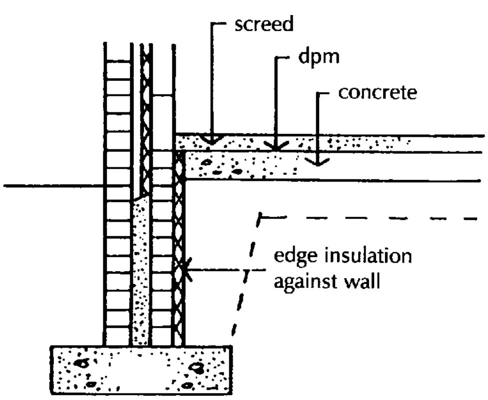
Of the heat that is transferred through a solid, ground supported floor a significant part of the transfer occurs around the perimeter of the floor to the ground below, foundation walls and ground around the edges of the floor, so that the cost of insulating the whole floor is seldom justified. Insulation around or under the edges of a solid floor will significantly reduce heat losses to the extent that overall insulation is unnecessary.

In the CIBS guide to the thermal properties of building structures, the U value of an uninsulated solid floor 20 × 20 m on plan, with four edges exposed, is given as 0.36 W/m^{2}K and one 10 × 10 m as 0.6 W/m^{2}K. The 20 × 20 floor has a U value below that in the requirement of the Building Regulations and will not require insulation. The U value of a 10 m^2 floor can be reduced by the use of edge insulation. With edge insulation of a metre deep all around and under the floor, the U value can be reduced to 0.48 W/m^{2}K which is somewhat higher than the U value in the requirement of the Building Regulations and may necessitate some small overall insulation. This is the basis for the assumption that floor slabs that are larger than 10 m in both length and width may not need an overall insulation layer.

To reduce heat losses through thermal bridges around the edges of solid floors that do not need overall insulation, and so minimise problems of condensation and mould growth, it may be wise to build in edge insulation, particularly where the wall insulation is not carried down below the ground floor slab. Edge insulation is formed either as a vertical strip between the edge of the slab and the wall or under the slab around the edges of the floor as illustrated in Fig. 32. The depth or width of the strips of insulation vary from 0.25 m to 1 m and the thickness of the insulation will be similar to that needed for overall insulation.



Edge insulation under concrete



Edge insulation vertical

Fig. 32 Perimeter insulation to ground slab.

The only practical way of improving the insulation of a solid ground floor to the required U value is to add a layer of some material with a high insulation value to the floor. The layer of insulation may be laid below a chipboard or plywood panel floor finish or below a timber boarded finish or below the screed finish to a floor or under the concrete floor slab. With insulation under the screed or slab it is important that the density of the insulation board is sufficient to support the load of the floor itself and imposed loads on the floor. A density of at least 16 kg/m^3 is recommended for domestic buildings.

The advantage of laying the insulation below the floor slab is that the high density slab, which warms and cools slowly (slow thermal response) in response to changes in temperature of the constant low output heating systems, will not lose heat to the ground. The damp-proof membrane may be laid under or over the insulation layer or under the floor screed. The damp-proof membrane should be under insulation that absorbs water and may be over insulation with low water absorption and high resistance to ground contaminants.

With the insulation layer and the dpm below the concrete floor slab

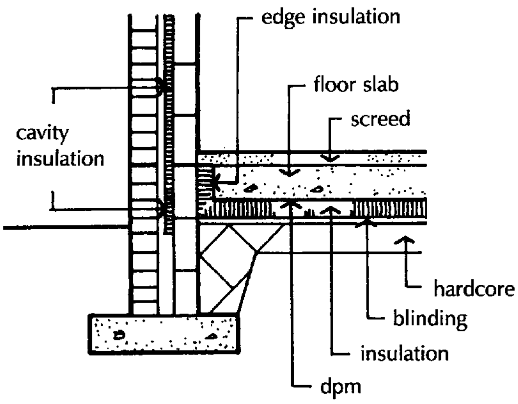


Fig. 33 dpm over insulation under floor slab.

it is necessary to continue the dpm and insulation up vertically around the edges of the slab to unite with the dpc in walls as illustrated in Fig. 33.

One method of determining the required thickness of insulation is to use a thickness of insulation related to the U value of the chosen insulation material, as for example thicknesses of 25 mm for a U value of $0.02\,W/m^2K$, 37 mm for $0.03\,W/m^2K$, 49 mm for $0.04\,W/m^2K$ and 60 mm for $0.05\,W/m^2K$, ignoring the inherent resistance of the floor.

Another more exacting method is to calculate the required thickness related to the actual size of the floor and its uninsulated U value, taken from a table in the CIBS guide to the thermal properties of building structures. For example, from the CIBS table the U value of a solid floor $10 \times 6\,m$, with four edges exposed is $0.74\,W/m^2K$.

The inherent resistance of the floor $= \dfrac{1}{0.74} = 1.36\,m^2K/W$

Thermal resistance required $= \dfrac{1}{0.45} = 2.22\,m^2K/W$

Additional resistance required $= 2.22 - 1.36$
$= 0.86\,m^2K/W$

Assume an insulant with U value of $0.04\,W/m^2K$

Thickness of insulation layer required $= 0.86 \times 0.04 \times 1000$
$= 34.4\,mm$ (49)
or with an insulation value of $0.03\,W/m^2K = 25.8\,mm$ (37)

These thicknesses are appreciably less than those given by the first method, shown in brackets.

Where the wall insulation is in the cavity or on the inside face of the wall it is necessary to avoid a cold bridge across the foundation wall and the edges of the slab, by fitting insulation around the edges of the slab or by continuing the insulation down inside the cavity, as illustrated in Fig. 34.

An advantage of fitting the dpm above the insulation is that it can be used to secure the upstand edge insulation in place while concrete is being placed.

The disadvantage of the dpm being below the concrete floor slab is that it will prevent the wet concrete drying out below and so lengthen the time required for it to adequately dry out, to up to 6 months. A concrete floor slab that has not been sufficiently dried out may adversely affect water sensitive floor finishes such as wood.

The advantage of laying the insulation layer under the screed is that it can be laid inside a sheltered building on a dried slab after the roof is

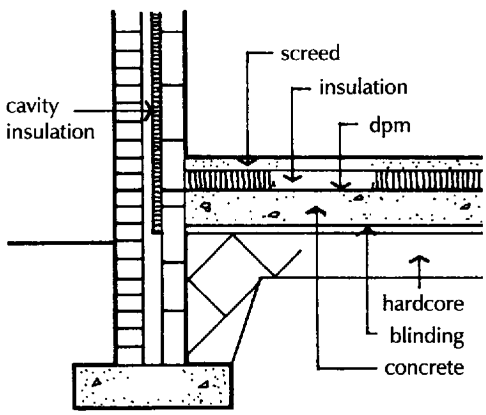


Fig. 34 dpm under insulation and screed.

finished and that the dpm, whether over or under the insulation layer, can more readily be joined to the dpc in walls, as illustrated in Fig. 34. Where the wall insulation is in the cavity it should be continued down below the floor slab to minimise the cold bridge across the wall to the screed as illustrated in Fig. 34.

If the dpm is laid below the insulation it is necessary to spread a separating layer over the insulation to prevent wet screed running into the joints between the insulation boards. The separating layer should be building paper or 500 gauge polythene sheet.

To avoid damage to the insulation layer and the dpm it is necessary to take care in tipping, spreading and compacting wet concrete or screed. Scaffold boards should be used for barrowing and tipping concrete and screed and a light mesh of chicken wire can be used over separating layers or dpms over insulation under screeds as added protection.

Materials for underfloor insulation

Any material used as an insulation layer to a solid, ground supported floor must be sufficiently strong and rigid to support the weight of the floor or the weight of the screed and floor loads without undue compression and deformation. To meet this requirement one of the rigid board or slab insulants is used. The thickness of the insulation is determined by the nature of the material from which it is made and the construction of the floor, to provide the required U value.

Some insulants absorb moisture more readily than others and some insulants may be affected by ground contaminants. Where the insulation layer is below the concrete floor slab, with the dpm above the insulation one of the insulants with low moisture absorption characteristics should be used.

The materials commonly used for floor insulation are rockwool slabs, extruded polystyrene, cellular glass and rigid polyurethane foam boards.

DAMP-PROOF COURSES

The function of a dpc is to act as a barrier to the passage of moisture or water between the parts separated by the dpc. The movement of moisture or water may be upwards in the foundation of walls and ground floors, downwards in parapets and chimneys or horizontal where a cavity wall is closed at the jambs of openings.

One of the functional requirements of walls (see Chapter 2) is resistance to moisture. A requirement of the Building Regulations is that walls shall adequately resist the passage of moisture to the inside of the building. To meet this requirement it is necessary to form a barrier to moisture rising from the ground in walls. This barrier is the horizontal, above ground, dpc.

Damp-proof courses above ground

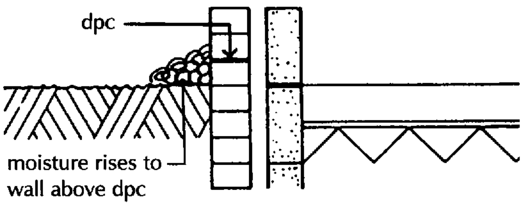


Fig. 35

There should be a continuous horizontal dpc above ground in walls whose foundations are in contact with the ground, to prevent moisture from the ground rising through the foundation to the wall above ground, which otherwise would make wall surfaces damp and damage wall finishes. The dpc above ground should be continuous for the whole length and thickness of the wall and be at least 150 mm above finished ground level to avoid the possibility of a build up of material against the wall acting as a bridge for moisture from the ground as illustrated in Fig. 35.

Material for damp-proof courses above ground

It is convenient to group the materials used for dpcs as flexible, semi-rigid and rigid. Flexible materials such as metal, bitumen and polythene sheet can accommodate moderate settlement movement in a building which may fracture the semi-rigid material mastic asphalt and will probably fracture the rigid materials brick and slate.

Flexible dpcs

Lead

Lead for use as a dpc should weigh not less than 19.5 kg/m^2 (Code No 4, 1.8 mm thick). Lead is an effective barrier to moisture and water. It is liable to corrosion in contact with freshly laid lime or cement mortar and should be protected by a coating of bitumen or bitumen paint applied to the mortar surface and both surfaces of the lead. Lead is durable and flexible and can suffer distortion due to moderate settlement in walls without damage. Lead is an expensive material and is little used today other than for ashlar stonework or as a shaped dpc in chimneys. Lead should be laid in rolls the full thickness of the wall or leaf of cavity walls and be lapped at joints along the length of the wall and at intersections at least 100 mm or the width of the dpc.

Copper

Copper as a dpc should be annealed, at least 0.25 mm thick and have a nominal weight of 2.28 kg/m^2. Copper is an effective barrier to moisture and water, it is flexible, has high tensile strength and can suffer distortion due to moderate settlement in a wall without damage. It is an expensive material and is little used today as a dpc above ground. When used as a dpc, it may cause staining of wall surfaces due to the oxide that forms. It is spread on an even bed of mortar and lapped at least 100 mm or the width of the dpc at running joints and intersections.

Bitumen damp-proof course

There are four types of bitumen dpc, as follows:

(1) bitumen dpc with hessian base
(2) bituman dpc with fibre base

(3) bituman dpc with hessian base and lead
(4) bitumen dpc with fibre base and lead.

Bitumen dpcs are reasonably flexible and can withstand distortion due to moderate settlement in walls without damage. They may extrude under heavy loads without affecting their efficiency as a barrier to moisture. Bitumen dpcs, which are made in rolls to suit the thickness of walls, are bedded on a level bed of mortar and lapped at least 100 mm or the width of the dpc at running joints and intersections.

Bitumen is much used for dpcs because it is at once economical, flexible, reasonably durable and convenient to lay. There is little to choose between hessian or fibre as a base for a bitumen dpc above ground. The fibre base is cheaper but less tough than hessian.

The lead cored dpc, with a lead strip weighing not less than 1.20 kg/m^2, joined with soldered joints, is more expensive and more effective than the bitumen alone types. It is generally used as the horizontal dpc for houses.

The combination of a mortar bed, bitumen dpc and the mortar bed over the dpc for brickwork makes a comparatively deep mortar joint that may look unsightly.

Polythene sheet

Polythene sheet for use as a dpc should be black, low density polythene sheet of single thickness not less than 0.46 mm, weighing approximately 0.48 kg/m^2. Polythene sheet is flexible, can withstand distortion due to moderate settlement in a wall without damage and is an effective barrier against moisture. It is laid on an even bed of mortar and lapped at least the width of the dpc at running joints and intersections. Being a thin sheet material, polythene makes a thinner mortar joint than bitumen dpc, and is sometimes preferred for that reason.

Its disadvantage as a dpc is that it is fairly readily damaged by sharp particles in mortar or the coarse edges of brick.

Polymer-based sheets

Polymer-based sheets are thinner than bitumen sheets and are used where the thicker bitumen dpc mortar joint would be unsightly. This dpc material, which has its laps sealed with adhesive, may be punctured by sharp particles and edges.

Semi-rigid damp-proof courses

Mastic asphalt

Mastic asphalt, spread hot in one coat to a thickness of 13 mm, is a semi-rigid dpc, impervious to moisture and water. Moderate settlement in a wall may well cause a crack in the asphalt through which moisture or water may penetrate. It is an expensive form of dpc, which shows on the face of walls as a thick joint, and it is rarely used as a dpc.

Rigid damp-proof courses

Up to the twentieth century, damp-proof courses in walls were not common. The inevitability of some moisture rising in walling on damp soils was accepted. Infrequently a few courses of dense bricks might be used at the base of walls as a solid bearing for walls and to act as a dpc to an extent. With the extensive building, both commercial and domestic, that occurred after the Industrial Revolution it became more common to use one of the rigid systems of dpc in the form of bricks in lowland areas and slates where the natural material was quarried and was comparatively cheap. With the introduction of bitumen felts, and later the synthetic sheet materials, bricks and slates were largely abandoned as dpcs.

Slate damp-proof courses

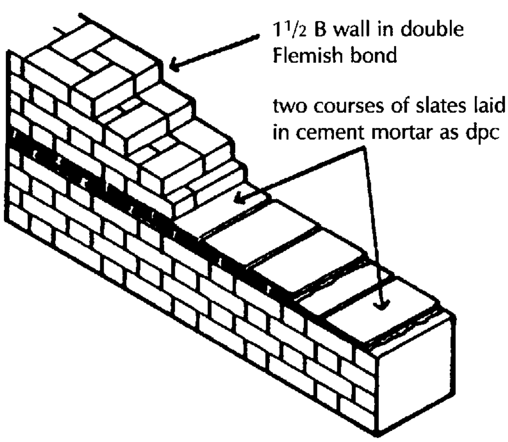


Fig. 36 Slate damp-proof course.

Beds of natural slate were quarried and the heavily compressed, dense material that was formed in layers was split to thin slates that were sufficiently impermeable to water to serve as an effective dpc.

Two courses of dense Welsh slates were laid at first in lime or hydraulic lime and sand, and later in cement and sand. The slates were laid on a bed of mortar in two courses, breaking joint as illustrated in Fig. 36. Because of the small units of slate and the joints being staggered this dpc could remain reasonably effective where moderate settlement occurred.

To be effective the edges of the slates should be exposed on a wall face and not be covered, which made a deep, somewhat ugly joint.

The majority of external brick walls are built as a cavity today and it would be laborious, wasteful and therefore expensive to use a separate slate dpc in each leaf of the wall.

Brick damp-proof courses

Two or three courses of dense, semi-engineering or engineering bricks were laid in hydraulic lime and later cement mortar. There is little likelihood of these dense bricks fracturing under moderate settlement.

Because of the dissimilar colour and texture of these bricks to that of facing bricks and the cost of the material this form of dpc is little used.

Damp-proof courses in cavity walls

A cavity wall is built as two leaves separated by a cavity. The purpose of the cavity is to act as a barrier to the penetration of rainwater to the inside of buildings. It is practice to build a cavity wall directly off the foundation so that the cavity extends below ground. A requirement of the Building Regulations is that the cavity should be carried down at least 150 mm below the level of the lowest dpc.

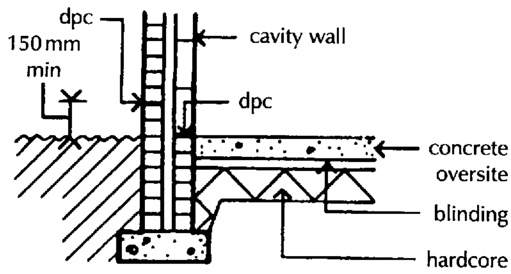


Fig. 37 Damp-proof course at different levels.

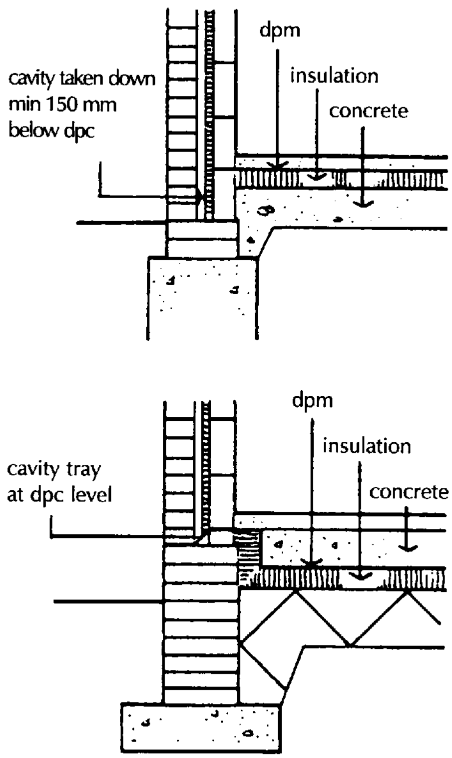


Fig. 38 Damp-proof courses in cavity walls.

A dpc in external walls should ideally be at the same level as the dpm in the concrete oversite for the convenience of overlapping the two materials to make a damp-proof joint.

Where the dpcs in both leaves of a cavity wall are at least 150 mm above outside ground level and the floor level is at, or just above, ground level, it is necessary to dress the dpm up the wall and into the level of the dpc. This is a laborious operation which makes it difficult to make a moisture tight joint at angles and intersections.

The solution is to lay the dpc in the inner leaf of the cavity wall, level with the dpm in the floor, as illustrated in Fig. 37.

Where the level of the foundation is near the surface, as with trench fill systems, it may be convenient to build two courses of solid brickwork up to ground level on which the cavity wall is raised, as illustrated in Fig. 38. As little vegetable top soil has been removed the floor level finishes some way above ground and the dpm in the floor can be united with the dpc at the same level.

The cavity insulation is taken down to the base of the cavity to continue wall insulation down to serve in part as edge insulation to the floor construction.

It is accepted practice to finish the cavity in external walling at the level of the dpc, at least 150 mm above ground, where the wall is built as a solid wall up to the dpc, as illustrated in Fig. 38. This form of construction may be used where the inner leaf of the cavity wall was built with light weight concrete blocks, used for their insulating property. These blocks fairly readily absorb moisture, expand when wet and might be affected by frost and deteriorate, whereas solid brickwork below ground will provide a stable base.

With this arrangement the requirements of the Building Regulations recommend the use of a cavity tray at the bottom of the cavity. This tray takes the form of a sheet of a flexible, impermeable material such as one of the flexible dpc materials which is laid across the cavity from a level higher in the inner leaf so that it falls towards the outer leaf to catch and drain any snow or moisture that might enter the cavity. The cavity thus acts as both tray and dpc to the cavity wall leaves.

In this detail of construction the under concrete insulation is below the lowest level of the cavity and should be turned up against the outer walls as edge insulation.

SUPPORT FOR FOUNDATION TRENCHES

The trenches which have to be dug for the foundations of walls may be excavated by hand for single small buildings but where, for example, several houses are being built at the same time it is often economical to use mechanical trench diggers.

If the trenches are of any depth it may be necessary to fix temporary timber supports to stop the sides of the trench from falling in. The

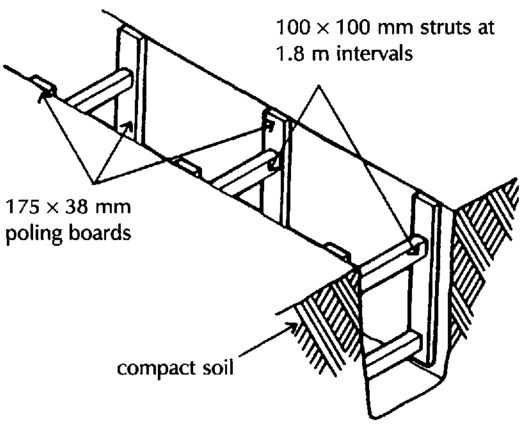


Fig. 39 Struts and poling boards.

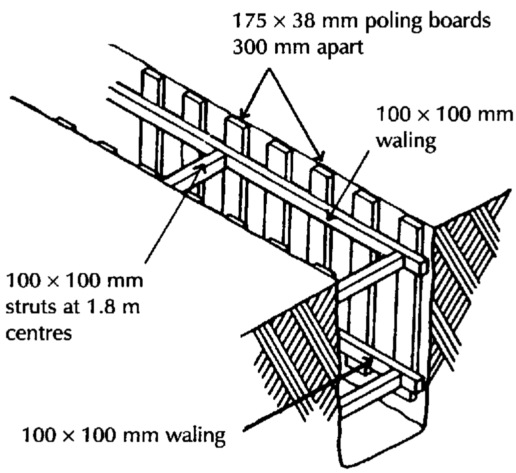


Fig. 40 Struts, waling and poling boards.

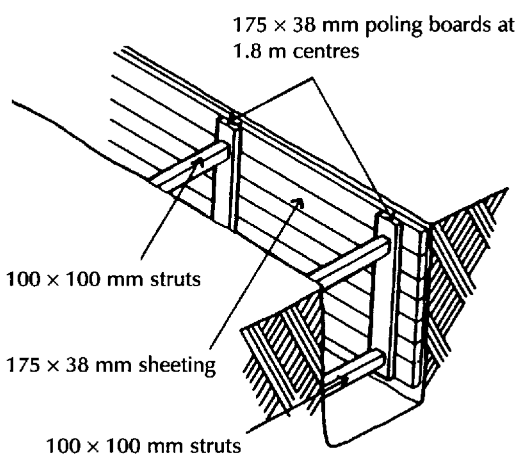


Fig. 41 Struts, poling boards and sheeting.

nature of the soil being excavated mainly determines the depth of trench for which timber supports to the sides should be used.

Soft granular soils readily crumble and the sides of trenches in such soil may have to be supported for the full depth of the trench. The sides of trenches in clay soil do not usually require support for some depth, say up to 1.5 m, particularly in dry weather. In rainy weather, if the bottom of the trench in clay soil gets filled with water, the water may wash out the clay from the sides at the bottom of the trench and the whole of the sides above may cave in.

The purpose of temporary timbering supports to trenches is to uphold the sides of the excavation as necessary to avoid collapse of the sides, which may endanger the lives of those working in the trench, and to avoid the wasteful labour of constantly clearing falling earth from the trench bottoms.

The material most used for temporary support for the sides of excavations for strip foundations is rough sawn timber. The timbers used are square section struts, across the width of the trench, supporting open poling boards, close poling boards and walings or poling boards and sheeting.

Whichever system of timbering is used there should be as few struts, that is horizontal members, fixed across the width of the trench as possible as these obstruct ease of working in the trench. Struts should be cut to fit tightly between poling or waling boards and secured in position so that they are not easily knocked out of place.

For excavations more than 1.5 m deep in compact clay soils it is generally sufficient to use a comparatively open timbering system as the sides of clay will not readily fall in unless very wet or supporting heavy nearby loads. A system of struts between poling boards spaced at about 1.8 m intervals as illustrated in Fig. 39 will usually suffice.

Where the soil is soft, such as soft clay or sand, it will be necessary to use more closely spaced poling boards to prevent the sides of the trench between the struts from falling in. To support the poling boards horizontal walings are strutted across the trench, as illustrated in Fig. 40.

For trenches in dry granular soil it may be necessary to use sheeting to the whole of the sides of trenches. Rough timber sheeting boards are fixed along the length and up the sides of the trench to which poling boards are strutted, as illustrated in Fig. 41.

The three basic arrangements of timber supports for trenches are indicative of some common system used and the sizes given are those that might be used.

2: Walls

A wall is a continuous, usually vertical structure, thin in proportion to its length and height, built to provide shelter as an external wall or divide buildings into rooms or compartments as an internal wall.

Prime function

The prime function of an external wall is to provide shelter against wind, rain and the daily and seasonal variations of outside temperature normal to its location, for reasonable indoor comfort. The basic function of shelter may be served by crude systems of interlaced branches of trees covered with dried mud, the more permanent protection of a brick wall or a screen of sheets of glass fixed to or hung from a structural frame.

Strength and stability

To provide adequate shelter a wall should have sufficient strength and stability to be self-supporting and to support roofs and upper floors. To differentiate the structural requirements of those walls that carry the loads from roofs and upper floors in addition to their own weight from those that are freestanding and only carry their own weight, the terms loadbearing and non-loadbearing are used. In practice non-loadbearing, internal walls are often described as partitions.

Thermal resistance

For reasonable indoor comfort a wall should provide resistance to excessive transfer of heat both from inside to outside and from outside to inside during periods of cold or hot, seasonal, outside temperatures.

The materials that are most effective in resisting heat transfer are of a fibrous or cellular nature in which very many small pockets of air are trapped to act as insulation against the transfer of heat.

Because of their lightweight nature these materials do not have sufficient strength to serve as part of the structure of a wall by themselves. Lightweight insulating materials are either sandwiched between materials that have strength or behind those that resist penetration of wind and rain, or serve as internal wall finishes.

The majority of walls for traditional small buildings, such as houses, are constructed with solid blocks such as brick or are framed from small sections of timber. Which one of the two types of wall is used will generally depend on the availability of materials, such as clay for making bricks, stone for making blocks or timber for frames.

Walls may be classified as solid or framed. A solid wall (sometimes called a masonry wall) is constructed of either brick, or blocks of stone, or concrete laid in mortar with the blocks laid to overlap in

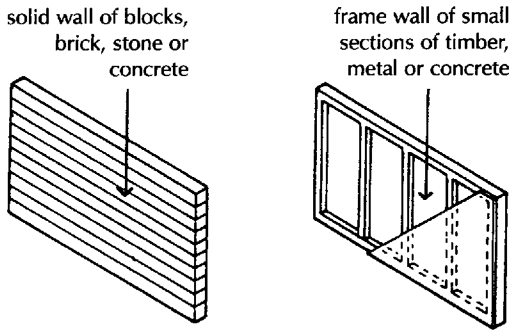


Fig. 42 Types of wall.

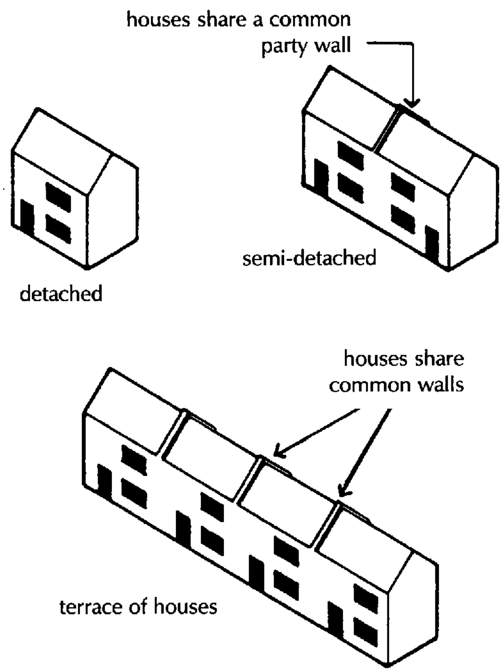


Fig. 43 Types of house.

some form of what is called bonding or as a monolith, that is, one solid uninterrupted material such as concrete which is poured wet and hardens into a solid monolith (one piece of stone). A solid wall of bricks or blocks may be termed a block (or masonry) wall, and a continuous solid wall of concrete, a monolithic wall.

A frame wall is constructed from a frame of small sections of timber, concrete or metal joined together to provide strength and rigidity, over both faces of which, or between the members of the frame, are fixed thin panels of some material to fulfil the functional requirements of the particular wall. Figure 42 is a diagram of the two types of wall.

Each of the two types of wall may serve as internal or external wall and as a loadbearing or non-loadbearing wall. Each of the two types of wall has different characteristics in fulfilling the functional requirements of a wall so that one type may have good resistance to fire but be a poor insulator against transfer of heat. There is no one material or type of wall that will fulfil all the functional requirements of a wall with maximum efficiency.

Traditional small buildings, such as houses, are commonly built as a square or rectangular box of enclosing walls as the most economical means of enclosing space. The walls of a single detached building are exposed on all sides to wind, rain and the variations of outside temperature.

Two buildings constructed on each side of a common separating wall, usually described as semi-detached, enjoy the advantage of a shared internal dividing wall and only three external walls exposed to wind and rain, as illustrated in Fig. 43. A disadvantage of the shared dividing wall is that it may not serve as an effective sound barrier.

A continuous terrace of houses enjoys the benefit of shared, common dividing walls, reduction in exposure to wind and rain and the likely disadvantage of the poor sound insulation through two common dividing walls.

FUNCTIONAL REQUIREMENTS

The function of a wall is to enclose and protect a building or to divide space within a building.

To provide a check that a particular wall construction satisfies a range of functional requirements it is convenient to adopt a list of specific requirements. The commonly accepted requirements of a wall are:

Strength and stability
Resistance to weather and ground moisture
Durability and freedom from maintenance
Fire safety

Resistance to the passage of heat
Resistance to airborne and impact sound
Security

Strength and stability

Strength

The strength of the materials used in wall construction is determined by the strength of a material in resisting compressive and tensile stress and the way in which the materials are put together. The usual method of determining the compressive and tensile strength of a material is to subject samples of the material to tests to assess the ultimate compressive and tensile stress at which the material fails in compression and in tension. From these tests the safe working strengths of materials in compression and in tension are set. The safe working strength of a material is considerably less than the ultimate strength, to provide a safety factor against variations in the strength of materials and their behaviour under stress. The characteristic working strengths of materials, to an extent, determine their use in the construction of buildings.

The traditional building materials timber, brick and stone have been in use since man first built permanent settlements, because of the ready availability of these natural materials and their particular strength characteristics. The moderate compressive and tensile strength of timber members has long been used to construct a frame of walls, floors and roofs for houses.

The compressive strength of well burned brick combined with the durability, fire resistance and appearance of the material commends it as a walling material for the more permanent buildings.

The sense of solidity and permanence and compressive strength of sound building stone made it the traditional walling material for many larger buildings.

Steel and concrete, which have been used in building since the Industrial Revolution, are used principally for their very considerable strength as the structural frame members of large buildings where the compressive strength of concrete, separately or in combination with steel, is used for both columns and beams.

In the majority of small buildings, such as houses, the compressive strength of brick and stone is rarely fully utilised because the functional requirements of stability and exclusion of weather dictate a thickness of wall in excess of that required for strength alone. To support the very modest loads on the walls of small buildings the thinnest brick or stone wall would be quite adequate.

Stability

The stability of a wall may be affected by foundation movement (see Chapter 1), eccentric loads, lateral forces (wind) and expansion due to temperature and moisture changes.

Eccentric loads, that is those not acting on the centre of the

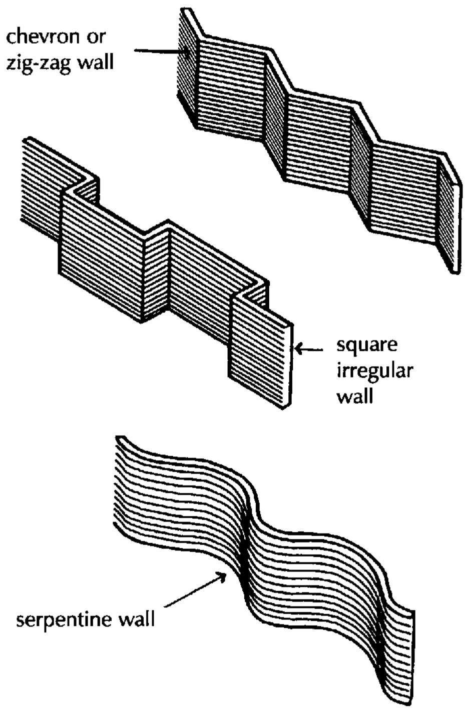


Fig. 44 Irregular profile walls.

thickness of the wall, such as from floors and roofs, and lateral forces, such as wind, tend to deform and overturn walls. The greater the eccentricity of the loads and the greater the lateral forces, the greater the tendency of a wall to deform, bow out of the vertical and lose stability. To prevent loss of stability, due to deformation under loads, building regulations and structural design calculations set limits to the height or thickness ratios (slenderness ratios) to provide reasonable stiffness against loss of stability due to deformation under load.

To provide stiffness against deformation under load, lateral, that is horizontal, restraint is provided by walls and roofs tied to the wall for stiffening up the height of the wall and by intersecting walls and piers that are bonded or tied to the wall as stiffening against deformation along the length of walls.

Irregular profile walls have greater stiffness against deformation than straight walls because of the buttressing effect of the angle of the zigzag, chevron, offset or serpentine profile of the walls, illustrated in Fig. 44. The more pronounced the chevron, zigzag, offset or serpentine of the wall, the stiffer it will be.

Similarly the diaphragm and fin walls, described in Volume 3, are stiffened against overturning and loss of stability by the cross ribs or diaphragms built across the wide cavity to diaphragm walls and the fins or piers that are built and bonded to straight walls in the fin wall construction.

Resistance to weather and ground moisture

A requirement of the Building Regulations is that walls should adequately resist the passage of moisture to the inside of the building. Moisture includes water vapour and liquid water. Moisture may penetrate a wall by absorption of water from the ground that is in contact with foundation walls or through rain falling on the wall.

To prevent water, which is absorbed from the ground by foundation walls, rising in a wall to a level where it might affect the inside of a building it is necessary to form a continuous, horizontal layer of some impermeable material in the wall. This impermeable layer, the damp-proof course, is built in, some 150 mm above ground level, to all foundation walls in contact with the ground and is joined to the damp-proof membrane in solid ground floors as described and illustrated in Chapter 1.

The ability of a wall to resist the passage of water to its inside face depends on its exposure to wind driven rain and the construction of the wall. The exposure of a wall is determined by its location and the extent to which it is protected by surrounding higher ground, or sheltered by surrounding buildings or trees, from rain driven by the prevailing winds. In Great Britain the prevailing, warm westerly winds from the Atlantic Ocean cause more severe exposure to driving rain along the west coast of the country than do the cooler easterly winds on the east coast.

British Standard 5628: Part 3 defines five categories of exposure as: very severe; moderate/severe; sheltered/moderate; sheltered; and very sheltered. A map of Great Britain, published by the Building Research Establishment, shows contours of the variations of exposure across the country. The contour lines, indicating the areas of the categories of exposure, are determined from an analysis of the most severe likely spells of wind driven rain, occurring on average every 3 years, plotted on a 10 km grid. The analysis is based on the 'worst case' for each geographical area, where a wall faces open country and the prevailing wind, such as a gable end wall on the edge of a suburban site facing the prevailing wind or a wall of a tall building on an urban site rising above the surrounding buildings and facing the prevailing wind.

Where a wall is sheltered from the prevailing winds by adjacent high ground or surrounding buildings or trees the exposure can be reduced by one category in sheltered areas of the country and two in very severe exposure areas of the country. The small-scale and large-scale maps showing categories of exposure to driving rain provide an overall picture of the likely severity of exposure over the country. To estimate the likely severity of exposure to driving rain, of the walls of a building on a particular site, it is wise to take account of the categories of exposure shown on the maps, make due allowance for the overlap of categories around contour lines and obtain local knowledge of conditions from adjacent buildings and make allowance for shelter from high ground, trees and surrounding buildings.

The behaviour of a wall in excluding wind and rain will depend on the nature of the materials used in the construction of the wall and how they are put together. A wall of facing bricks laid in mortar will absorb an appreciable amount of the rain driven on to it so that the wall must be designed so that the rain is not absorbed to the inside face of the wall. This may be effected by making the wall of sufficient thickness, by applying an external facing of say rendering or slate hanging, or by building the wall as a cavity wall of two skins or leaves with a separating cavity.

A curtain wall of glass (see Volume 4) on the other hand will not absorb water through the impermeable sheets of glass so that driving rain will pour down the face of the glass and penetrate the joints between the sheets of glass and the supporting frame of metal or wood, so that close attention has to be made to the design of these joints that at once have to be sufficiently resilient to accommodate thermal movement and at the same time compact enough to exclude wind and rain.

It is generally accepted practice today to construct walls of brick, stone or blocks as a cavity wall with an outer and inner leaf or skin separated by a cavity of at least 50 mm. The outer leaf will either be sufficiently thick to exclude rain or be protected by an outer skin of rendering or cladding of slate or tile and the inner leaf will be constructed of brick or block to support the weight of floors and roofs with either the inner leaf providing insulation against transfer of heat or the cavity filled with some thermal insulating material.

Durability and freedom from maintenance

The durability of a wall is indicated by the frequency and extent of the work necessary to maintain minimum functional requirements and an acceptable appearance. Where there are agreed minimum functional requirements such as exclusion of rain and thermal properties, the durability of walls may be compared through the cost of maintenance over a number of years. Standards of acceptable appearance may vary widely from person to person, particularly with unfamiliar wall surface materials such as glass and plastic coated sheeting, so that it is difficult to establish even broadly-based comparative standards of acceptable appearance. With the traditional wall materials there is a generally accepted view that a wall built of sound, well burned bricks or wisely chosen stone 'looks good' so that there is to a considerable extent a consensus of acceptable appearance for the traditional walling materials.

A wall built with sound, well burned bricks laid in a mortar of roughly the same density as the bricks and designed with due regard to the exposure of the wall to driving rain, and with sensible provisions of dpcs to walls around openings and to parapets and chimneys, should be durable for the anticipated life of the majority of buildings and require little if any maintenance and repair. In time, these materials exposed to wind and rain will slowly change colour. This imperceptible change will take place over many years and is described as weathering, that is a change of colour due to exposure to weather. It is generally accepted that this change enhances the appearance of brick and stone walls.

Walls built of brick laid in lime mortar may in time need repointing, to protect the mortar joints and maintain resistance to rain penetration and to improve the appearance of the wall.

Fire safety

Fires in buildings generally start from a small source of ignition, the 'outbreak of fire', which leads to the 'spread of fire' followed by a steady state during which all combustible material burns steadily up to the final 'decay stage'. It is in the early stages of a fire that there is most danger to the occupants of buildings from smoke and noxious fumes. The Building Regulations set standards for means of escape, limitation of spread of fire and containment of fire.

Fire safety regulations are concerned to assure a reasonable standard of safety in case of fire. The application of the regulations, as set out in the practical guidance given in Approved Document B, is directed to the safe escape of people from buildings in case of fire rather than the protection of the building and its contents.

The requirements of Part B of Schedule 1 to the Building Regulations are concerned to:

(1) provide adequate means of escape
(2) limit internal fire spread (linings)
(3) limit internal fire spread (structure)
(4) limit external fire spread
(5) provide access and facilities for the fire services

Means of escape

The requirements for means of escape from one and two storey houses are that each habitable room either opens directly on to a hallway or stair leading to the entrance, or that it has a window or door through which escape could be made and that means are provided for giving early warning in the case of fire. With increased height and size, where floors are more than 4.5 m above ground, it is necessary to protect internal stairways or provide alternative means of escape. Where windows and doors may be used as a means of escape their minimum size and the minimum and maximum height of window cills are defined.

Smoke alarms

To ensure the minimum level of safety it is recommended that all new houses should be fitted with self-contained smoke alarms permanently wired to a separately fused circuit at the distribution board. Battery-operated alarms are not acceptable. Where more than one smoke alarm is fitted they should be interconnected so that the detection of smoke by any one unit operates in all of them.

Internal fire spread (linings)

Fire may spread within a building over the surface of materials that encourage spread of flame across their surfaces, when subject to intense radiant heat, and those which give off appreciable heat when burning.

In Approved Document B is a classification of the performance of linings relative to surface spread of flame over wall and ceiling linings and limitations in the use of thermoplastic materials used in rooflights and lighting diffusers.

Internal fire spread (structure)

The premature failure of the structural stability of a building during fires is restricted by specifying a minimum period of fire resistance for the elements of the structure. An element of structure is defined as part of a structural frame, a loadbearing wall and a floor.

The requirements are that the elements should resist collapse for a minimum period of time in which the occupants may escape in the event of fire. Periods of fire resistance vary from 30 minutes for dwelling houses with a top floor not more than 5 m above ground, to 120 minutes for an industrial building, without sprinklers, whose top floor is not more than 30 m above ground.

For information on the requirements for buildings other than dwellings, concerning purpose groups, compartments, concealed spaces, external fire spread and access for the Fire Services, see Volume 4.

Resistance to the passage of heat

The traditional method of heating buildings was by burning wood or coal in open fireplaces in England and in freestanding stoves in much of northern Europe. The ready availability of wood and coal was adequate to the then modest demands for heating of the comparatively small population of those times. The highly inefficient open fire had the advantage of being a cosy focus for social life and the disadvantage of generating draughts of cold air necessary for combustion. The more efficient freestanding stove, which lacked the obvious cheery blaze of the open fire, was more suited to burning wood, the fuel most readily available in many parts of Europe.

The considerable increase in population that followed the Industrial Revolution and the accelerating move from country to town and city increased demand for the dwindling supplies of wood for burning. Coal became the principal fuel for open fires and freestanding stoves.

During the eighteenth century town gas became the principal source for lighting and by the nineteenth century had largely replaced solid fuels as the heat source for cooking. From about the middle of the twentieth century oil was used as the heat source for heating. Following the steep increase in the price of oil, town gas and later on natural gas was adopted as the fuel most used for heating.

Before the advent of oil and then gas as fuels for heating, it was possible to heat individual rooms by means of solid fuel burning open fires or stoves and people accepted the need for comparatively thick clothing for warmth indoors in winter.

With the adoption of oil and gas as fuels for heating it was possible to dispense with the considerable labour of keeping open fires and stoves alight and the considerable area required to store an adequate supply of solid fuels. With the adoption of oil and gas as fuel for heating it was practical to heat whole buildings and there was no longer the inconvenience of cold corridors, toilets and bathrooms and the draughts of cold air associated with open fireplaces. The population increasingly worked in heated buildings, many in sedentary occupations, so that tolerance of cold diminished and the expectation of thermal comfort increased.

For a description of the history of the development of heating appliances over the centuries and the increased use of thermal insulation, see Volume 2, Fires and Stoves.

Of recent years the expectation of improved thermal comfort in buildings, the need to conserve natural resources and the increasing cost of fuels have led to the necessity for improved insulation against transfer of heat. To maintain reasonable and economical conditions of thermal comfort in buildings, walls should provide adequate insulation against excessive loss or gain of heat, have adequate thermal storage capacity and the internal face of walls should be at a reasonable temperature.

For insulation against loss of heat, lightweight materials with low conductivity are more effective than dense materials with high conductivity, whereas dense materials have better thermal storage capacity than lightweight materials.

Where a building is continuously heated it is of advantage to use the thermal storage capacity of a dense material on the inside face of the wall with the insulating properties of a lightweight material behind it. Here the combination of a brick or dense block inner leaf, a cavity filled with some lightweight insulating material and an outer leaf of brick against penetration of rain is of advantage.

Where buildings are intermittently heated it is important that inside faces of walls warm rapidly, otherwise if the inside face were to remain cold, the radiation of heat from the body to the cold wall face would make people feel cold. The rate of heating of smooth wall surfaces is improved by the use of low density, lightweight materials on or immediately behind the inside face of walls.

The interior of buildings is heated by the transfer of heat from heaters and radiators to air (conduction), the circulation of heated air (convection) and the radiation of energy from heaters and radiators to surrounding colder surfaces (radiation). This internal heat is transferred through colder enclosing walls, roofs and floors by conduction, convection and radiation to colder outside air.

Conduction

The rate at which heat is conducted through a material depends mainly on the density of the material. Dense metals conduct heat more rapidly than less dense gases. Metals have high conductivity and gases low conductivity. Conductivity is the amount of heat per unit area, conducted in unit time through a material of unit thickness, per degree of temperature difference. Conductivity is expressed in watts per metre of thickness of material per degree kelvin (W/mK) and usually denoted by the Greek letter λ (lambda).

Convection

The density of air that is heated falls, the heated air rises and is replaced by cooler air. This in turn is heated and rises so that there is a continuing movement of air as heated air loses heat to surrounding cooler air and cooler surfaces of ceilings, walls and floors. Because the rate of transfer of heat to cooler surfaces varies from rapid transfer through thin sheet glass in windows to an appreciably slower rate of transfer through insulated walls, and because of the variability of the rate of exchange of cold outside air with warm inside air by ventilation, it is not possible to quantify heat transfer by convection. Usual practice is to make an assumption of likely total air changes per hour or volume (litres) per second and then calculate the heat required to raise the temperature of the incoming cooler air introduced by ventilation.

Radiation

Radiant energy from a body, radiating equally in all directions, is partly reflected and partly absorbed by another body and converted to heat. The rate of emission and absorption of radiant energy depends on the temperature and the nature of the surface of the radiating and receiving bodies. The heat transfer by low temperature radiation from heaters and radiators is small, whereas the very considerable radiant energy from the sun that may penetrate glass and that from high levels of artificial illumination is converted to appreciable heat inside buildings. An estimate of the solar heat gain and heat gain from artificial illumination may be assumed as part of the heat input to buildings.

Transmission of heat

Because of the complexity of the combined modes of heat transfer through the fabric of buildings it is convenient to use a coefficient of heat transmission as a comparative measure of transfer through the external fabric of buildings. This air-to-air heat transmittance coefficient, the U value, takes account of the transfer of heat by conduction through the solid materials and gases, convection of air in cavities and across inside and outside surfaces, and radiation to and from surfaces. The U value, which is expressed as W/m^2K, is the rate of heat transfer in watts through one square metre of a material or structure when the combined radiant and air temperatures on each side of the material or structure differ by 1 degree kelvin (1°C). A high rate of heat transfer is indicated by a high U value, such as that for single glazing of 5.3 (W/m^2K), and a low rate of heat transfer by a low U value, such as that for PIR insulation of 0.022 W/m^2K.

The U value may be used as a measure of the rate of transfer of heat through single materials or through a combination of materials such as those used in cavity wall construction.

Conservation of fuel and power

Standard assessment procedure (SAP) rating

The requirement in the Building Regulations for the conservation of fuel and power for dwellings alone is that the person carrying out building work of creating a new dwelling shall calculate the energy rating of the dwelling by a standard assessment procedure (SAP) and give notice of that rating to the local authority.

The SAP rating is based on an energy cost factor on a scale of 1 to 100, 1 being a maximum and 100 a minimum energy use to maintain a comfortable internal temperature and use of energy in water heating. While there is no obligation to achieve a particular rating, a rating of 60 or less indicates that there is inadequate insulation or inefficient heating systems or both, and the dwelling does not comply with the regulations.

Details of the notification of the SAP rating for new dwellings are held by the local authority. A prospective purchaser of the dwelling may well be put off where the rating is 60 or less and the local authority has not issued a Certificate of Compliance with the Regulations, whereas the purchaser will be encouraged by a rating of say 85, which shows compliance with the Regulations.

The SAP rating is calculated by the completion of a four page worksheet by reference to 14 tables. The sequential completion of up to 99 entries by reference to the 14 tables is so tedious and difficult to follow as to confound all but those initiated in their use, and is hardly calculated to inform householders in a way that is simple and easy to understand as claimed by the authors of Approval Document L.

Calculation methods

Three methods of calculating the figures necessary for the SAP for dwellings are proposed in Approved Document L. They are:

(1) an elemental method
(2) a target U value method
(3) an energy rating method.

In the elemental method standard U values for the exposed elements of the fabric of buildings are shown under two headings: (a) for dwellings with SAP ratings of 60 or less and (b) for those with SAP ratings over 60. The standard U values are 0.2 and 0.25 W/m^2K for roofs, 0.45 W/m^2K for exposed walls, 0.35 and 0.45 W/m^2K for exposed floors and ground floors, 0.6 W/m^2K for semi-exposed walls and floors and 3.0 and 3.3 W/m^2K for windows, doors and rooflights, the two values being for headings (a) and (b), respectively. The basic allowance for the area of windows, doors and rooflights together is 22.5% of the total floor area. The area of windows, doors and rooflights, larger than those indicated by the percentage value, may be used providing there is a compensating improvement in the average U value by the use of glazing with a lower U value.

As it is unlikely that the SAP rating of the majority of new dwellings, complying with standard U values, will fall below 60, the over 60 rating values are the relevant ones.

The target U value method for dwellings is used to meet the requirement for conservation of fuel and power by relating a calculated average U value to a target U value, which it should not exceed. The average U value is the ratio of:

$$\frac{\text{total rate of heat loss per degree}}{\text{total external surface area}}$$

The target U value is:

$$\frac{\text{total floor area} \times 0.57}{\text{total area of exposed elements}} + 0.36 \text{ for dwellings with SAP ratings 60 or less, and}$$

$$\frac{\text{total floor area} \times 0.64}{\text{total area of exposed elements}} + 0.40 \text{ for dwellings with SAP ratings of more than 60}$$

The total area of exposed floors, windows, doors, walls and roof and the standard U values in the elemental method are used to calculate the heat loss per degree. Where the calculated average U value exceeds the target U value it is necessary to improve the thermal resistance of walls, windows or roof either separately or together so that the average U value does not exceed the target U value. As an option, account may be taken of solar heat gains other than those allowed for in the equation on which the method is based. This method is based on the assumption of a boiler with an efficiency of at least 72%. Where a boiler with an efficiency of 85% is used the target U value may be increased by 10%. The use of the elemental or target U value methods of showing compliance does not give exemption from the requirement to give notice of an SAP rating.

The energy rating method is a calculation based on SAP which allows the use of any valid conservation measures. The calculation takes account of ventilation rate, fabric losses, water heating requirements and internal and solar heat gains.

The requirement for conservation of fuel and power will be met if the SAP energy rating for the dwelling, or each dwelling in a block of flats or converted building, is related to the floor area of the dwelling and ranges from 80 for dwellings with a floor area of 80 m^2 or less to 85 for dwellings with a floor area of more than 120 m^2.

As there is a requirement to complete the SAP worksheet to determine an SAP rating, which has to be notified to the local authority, whichever method of showing compliance is used the most practical and economic method of approach is to use the standard U values for SAP ratings over 60 set out in the elemental method in the initial stages of design, and then to complete the SAP worksheet at a later stage and make adjustments to the envelope insulation, windows and boiler efficiency as is thought sensible to achieve a high SAP rating.

For a description of the requirements for conservation of fuel and power for all buildings other than dwellings see Volume 4.

Ventilation

The sensation of comfort is highly subjective and depends on the age, activity and to a large extent on the expectations of the subject. The young 'feel' cold less than the old and someone engaged in heavy manual work has less need of heating than another engaged in sedentary work. It is possible to provide conditions of thermal comfort that suit the general expectations of those living or working in a building. None the less, some may 'feel' cold and others 'feel' hot.

For comfort and good health in buildings it is necessary to provide means of ventilation through air changes through windows or ventilators, that can be controlled, depending on wind speed and direction and outside air temperature, to avoid the sensation of 'stuffiness' or cold associated with too infrequent or too frequent air changes respectively. As with heating, the sensation of stuffiness is highly subjective.

Air changes

For general guidance a number of air changes per hour is recommended, depending on the activity common to rooms or spaces. One air change each hour for dwellings and three for kitchens and sanitary accommodation is recommended. The more frequent air changes for kitchen and sanitary accommodation is recommended to minimise condensation of moisture-laden, warm air on cold internal surfaces in those rooms.

Condensation

Condensation is the effect of moisture from air collecting on a surface colder than the air, for example in a bathroom or kitchen where water from warm moisture-laden air condenses on to the cold surfaces of walls and glass. To minimise condensation, ventilation of the room to exchange moisture-laden air with drier outside air and good insulation of the inner face of the wall are required.

A consequence of the need for internal air change in buildings is that the heat source must be capable of warming the incoming air to maintain conditions of thermal comfort, and the more frequent the air change the greater the heat input needed. The major source of heat loss through walls is by window glass which is highly conductive to heat transfer. This heat loss can be reduced to some small extent by the use of double glazing. Most of the suppliers of double glazed windows provide one of the very effective air seals around all of the opening parts of their windows. These air seals are very effective in excluding the draughts of cold air that otherwise would penetrate the necessary gaps around opening windows and so serve to a large extent to reduce the heat loss associated with opening windows to an extent that they may reduce air changes to an uncomfortable level.

There is a fine balance between the need for air change and the expectations of thermal comfort that receives too little consideration in the design of windows.

Resistance to the passage of sound

Sound is transmitted as airborne sound and impact sound. Airborne sound is generated as cyclical disturbances of air from, for example, a radio, that radiate from the source of the sound with diminishing intensity. The vibrations in the air caused by the sound source will set up vibrations in enclosing walls and floors which will cause vibrations of air on the opposite side of walls and floors.

Impact sound is caused by contact with a surface, as for example the slamming of a door or footsteps on a floor which set up vibrations in walls and floors that in turn cause vibrations of air around them that are heard as sound.

The most effective insulation against airborne sound is a dense barrier such as a solid wall which absorbs the energy of the airborne sound waves. The heavier and more dense the material of the wall the more effective it is in reducing sound. The Building Regulations require walls and floors to provide reasonable resistance to airborne sound between dwellings and between machine rooms, tank rooms, refuse chutes and habitable rooms. A solid wall, one brick thick, or a solid cavity wall plastered on both sides is generally considered to provide reasonable sound reduction between dwellings at a reasonable cost. The small reduction in sound transmission obtained by doubling the thickness of a wall is considered prohibitive in relation to cost.

For reasonable reduction of airborne sound between dwellings one above the other, a concrete floor is advisable.

The more dense the material the more readily it will transmit impact sound. A knock on a part of a rigid concrete frame may be heard some considerable distance away. Insulation against impact sound will therefore consist of some absorbent material that will act to cushion the impact, such as a carpet on a floor, or serve to interrupt the path of the sound, as for example the absorbent pads under a floating floor.

Noise generated in a room may be reflected from the walls and ceilings and build up to an uncomfortable intensity inside the room, particularly where the wall and ceiling surfaces are hard and smooth. To prevent the build-up of reflected sound some absorbent material should be applied to walls and ceilings, such as acoustic tiles or curtains, to absorb the energy of the sound waves.

BRICK AND BLOCK WALLS

The majority of the walls of small buildings in this country are built of brick or block. The external walls of heated buildings, such as houses, are built as a cavity wall with an outer leaf of brick, a cavity and an inner leaf of concrete blocks. Internal walls and partitions are built, in the main, of concrete blocks.

BRICKS

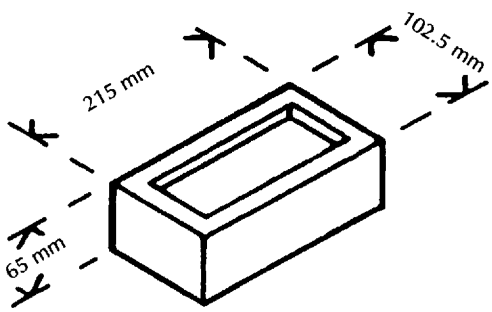


Fig. 45 Standard brick.

The word brick is used to describe a small block of burned clay of such size that it can be conveniently held in one hand and is slightly longer than twice its width. Blocks made from sand and lime or concrete are manufactured in clay brick size and these are also called bricks. The great majority of bricks in use today are of clay.

The standard brick is 215 × 102.5 × 65 mm, as illustrated in Fig. 45, which with a 10 mm mortar joint becomes 225 × 112.5 × 75 mm.

Materials from which bricks are made

Clay

In this country there are very extensive areas of clay soil suitable for brickmaking. Clay differs quite widely in composition from place to place and the clay dug from one part of a field may well be quite different from that dug from another part of the same field. Clay is ground in mills, mixed with water to make it plastic and moulded, either by hand or machine, to the shape and size of a brick.

Bricks that are shaped and pressed by hand in a sanded wood mould and then dried and fired have a sandy texture, are irregular in shape and colour and are used as facing bricks due to the variety of their shape, colour and texture.

Machine made bricks are either hydraulically pressed in steel moulds or extruded as a continuous band of clay. The continuous band of clay, the section of which is the length and width of a brick, is cut into bricks by a wire frame. Bricks made this way are called 'wire cuts'.

Wire cuts

Press moulded bricks generally have a frog or indent and wire cuts have none. The moulded brick is baked to dry out the water and burned at a high temperature so that part of the clay fuses the whole mass of the brick into a hard durable unit. If the moulded brick is burned at too high a temperature part of the clay fuses into a solid glass-like mass and if it is burned at too low a temperature no part of the clay fuses and the brick is soft. Neither overburned nor underburned brick is satisfactory for building purposes.

A brick wall has very good fire resistance, is a poor insulator against transference of heat, does not, if well built, deteriorate structurally and requires very little maintenance over a long period of time. Bricks are cheap because there is an abundance of the natural material from which they are made, that is clay. The clay can easily be dug out of the ground, it can readily be made plastic for moulding into brick shapes and it can be burned into a hard, durable mass at a temperature which can be achieved with quite primitive equipment.

Because there is wide variation in the composition of the clays suitable for brick making and because it is possible to burn bricks over quite a wide range of temperatures sufficient to fuse the material into a durable mass, a large variety of bricks are produced in this country. The bricks produced which are suitable for building vary in colour from almost dead white to practically black and in texture from almost as smooth as glass to open coarse grained. Some are quite light in weight and others dense and heavy and there is a wide selection of colours, textures and densities between the extremes noted.

It is not possible to classify bricks simply as good and bad as some are good for one purpose and not for another. Bricks may be classified in accordance with their uses as commons, facing and engineering bricks or by their quality as internal quality, ordinary quality and special quality. The use and quality classifications roughly coincide, as commons are much used for internal walls, facing or ordinary quality for external walls and engineering or special quality bricks for their density and durability in positions of extreme exposure. In cost, commons are cheaper than facings and facings cheaper than engineering bricks.

Types of brick

Commons

These are bricks which are sufficiently hard to safely carry the loads normally supported by brickwork, but because they have a dull texture or poor colour they are not in demand for use as facing bricks which show on the outside when built and affect the appearance of buildings. These 'common' bricks are used for internal walls and for rear walls which are not usually exposed to view. Any brick which is sufficiently hard and of reasonably good shape and of moderate price may be used as a 'common' brick. The type of brick most used as a common brick is the Fletton brick.

Facings

This is by far the widest range of bricks as it includes any brick which is sufficiently hard burned to carry normal loads, is capable of withstanding the effects of rain, wind, soot and frost without breaking up and which is thought to have a pleasant appearance. As there are as many different ideas of what is a pleasant looking brick as there are bricks produced, this is a somewhat vague classification.

Engineering bricks

These are bricks which have been made from selected clay, which have been carefully prepared by crushing, have been very heavily moulded and carefully burned so that the finished brick is very solid and hard and is capable of safely carrying much heavier loads than other types of brick. These bricks are mainly used for walls carrying exceptionally heavy loads, for brick piers and general engineering works. The two best known engineering bricks are the red Southwater brick and the blue Staffordshire brick. Both are very hard, dense and do not readily absorb water. The ultimate crushing resistance of engineering bricks is greater than $50\,N/mm^2$.

Semi-engineering bricks

These are bricks which, whilst harder than most ordinary bricks, are not so hard as engineering bricks. It is a very vague classification without much meaning, more particularly as a so-called semi-engineering brick is not necessarily half the price of an engineering brick.

Composition of clay

Clays suitable for brick making are composed mainly of silica in the form of grains of sand and alumina, which is the soft plastic part of clay which readily absorbs water and makes the clay plastic and which melts when burned. Present in all clays are materials other than the two mentioned above such as lime, iron, manganese, sulphur and phosphates. The proportions of these materials vary widely and the following is a description of the composition, nature and uses of some of the most commonly used bricks classified according to the types of clay from which they are produced.

Flettons

There are extensive areas of what is known as Oxford clay. The clay is composed of just under half silica, or sand, about one-sixth alumina, one-tenth lime and small measures of other materials such as iron, potash and sulphur. The clay lies in thick beds which are economical to excavate. In the clay, in its natural state, is a small amount of mineral oil which, when the bricks are burned, ignites and assists in the burning.

Because there are extensive thick beds of the clay, which are economical to excavate, and because it contains some oil, the cheapest of all clay bricks can be produced from it. The name Fletton given to these bricks derives from the name of a suburb of Peterborough around which the clay is extensively dug for brickmaking. Flettons are cheap and many hundreds of millions of them are used in building every year. The bricks are machine moulded and burned and the finished brick is uniform in shape with sharp square edges or arises. The bricks are dense and hard and have moderately good strength; the average pressure at which these bricks fail, that is crumble, is around 21 N/mm^2

The bricks are light creamy pink to dull red in colour and because of the smooth face of the brick what are known as 'kiss marks' are quite distinct on the long faces. These 'kiss marks' take the form of three different colours, as illustrated in Fig. 46.

The surface is quite hard and smooth and if the brick is to be used for wall surfaces to be plastered, two faces are usually indented with grooves to give the surface a better grip or key for plaster. The bricks are then described as 'keyed Flettons'. Figure 47 is an illustration of a keyed Fletton.

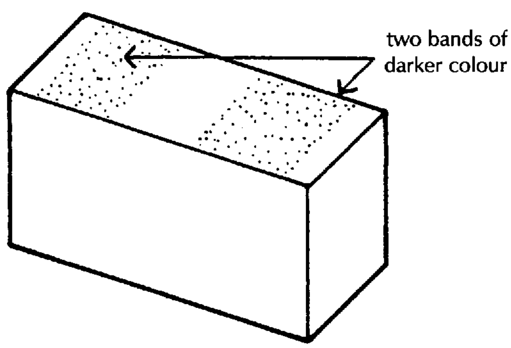


Fig. 46 Fletton brick showing kiss marks.

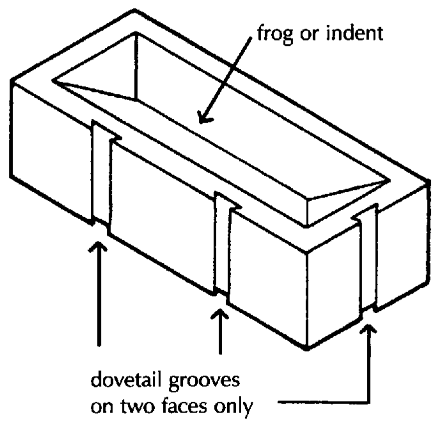


Fig 47 Keyed Fletton.

Stocks

The term 'stock brick' is generally used in the south-east counties of England to describe the London stock brick. This is a brick manufactured in Essex and Kent from clay composed of sand and alumina to which some chalk is added. Some combustible material is added to the clay to assist burning. The London stock is usually predominantly yellow after burning with shades of brown and purple. The manufacturers grade the bricks as 1st Hard, 2nd Hard and Mild, depending on how burned they are. The bricks are usually irregular in shape and have a fine sandy texture. Because of their colour they are sometimes called 'yellow stocks'. 1st Hard and 2nd Hard London stocks were much used in and around London as facings as they weather well and were of reasonable price. In other parts of England the term stock bricks describes the stock output of any given brick field.

Marls

By origin the word marl denotes a clay containing a high proportion of lime (calcium carbonate), but by usage the word marl is taken to denote any sandy clay. This derives from the use of sandy clays, containing some lime, as a top dressing to some soils to increase fertility. In most of the counties of England there are sandy clays, known today as marls, which are suitable for brick making. Most of the marl clays used for brick making contain little or no lime. Many of the popular facing bricks produced in the Midlands are made from this type of clay and they have a good shape, a rough sandy finish and vary in colour from a very light pink to dark mottled red.

Gaults

The gault clay does in fact contain a high proportion of lime and the burned brick is usually white or pale pink in colour. These bricks are of good shape and texture and make good facing bricks, and are more than averagely strong. The gault clay beds are not extensive in this country and lie around limestone and chalk hills in Sussex and Hampshire.

Clay shale bricks

Some clay beds have been so heavily compressed over the centuries by the weight of earth above them that the clay in its natural state is quite firm and has a compressed flaky nature. In the coal mining districts of this country a considerable quantity of clay shale has to be dug out to reach coal seams and in those districts the extracted shale is used extensively for brick making. The bricks produced from this shale are usually uniform in shape with smooth faces and the bricks are hard and durable. The colour of the bricks is usually dull buff, grey, brown or red. These bricks are used as facings, commons and semi-engineering, depending on their quality.

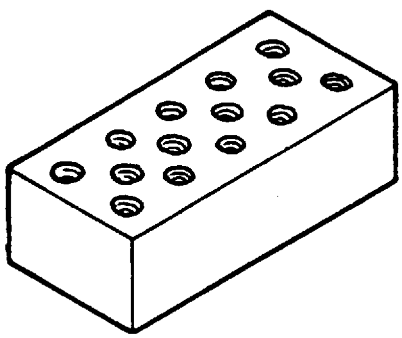
Calcium silicate bricks

Calcium silicate bricks are generally known as sand-lime bricks. The output of these bricks has increased over the past few years, principally because the output of Fletton bricks could not keep pace with the demand for a cheap common brick and sand-lime bricks have been mainly used as commons. The bricks are made from a carefully controlled mixture of clean sand and hydrated lime which is mixed together with water, heavily moulded to brick shape and then the moulded brick is hardened in a steam oven. The resulting bricks are very uniform in shape and colour and are normally a dull white. Coloured sand-lime bricks are made by adding a colouring matter during manufacture. These bricks are somewhat more expensive than Flettons and because of their uniformity in shape and colour they are not generally thought of as being a good facing brick. The advantage of them however is that the material from which they are made can be carefully selected and accurately proportioned to ensure a uniform hardness, shape and durability quite impossible with the clay used for most bricks.

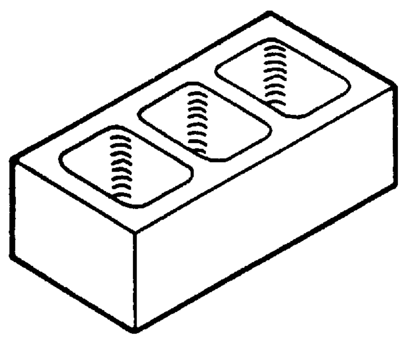
Flint-lime bricks

Flint-lime bricks are manufactured from hydrated lime and crushed flint and are moulded and hardened as are sand-lime bricks. They are identical with sand-lime bricks in all respects.

Cellular and perforated bricks, illustrated in Fig. 48, are machine press moulded from plastic clays, either pressed from wire cuts or separately formed. The purpose of forming the hollows and perforations is to reduce the volume of moulded, wet clay, the better to control shrinkage and deformation during drying and burning to produce more uniformly shaped bricks.



perforated brick



cellular pressed brick

Fig. 48 Cellular and perforated bricks.

These bricks, which have good crushing strength and are of semi-engineering quality, are used extensively in the brick enclosures to inspection pits and chambers for underground cable, for foundations and basements where the uniform shape and the density of the brick is an advantage.

They may be used for external walls as the perforations and hollows do not affect the weathering properties of the wall and may provide some little increase in insulation.

Special bricks

A range of special bricks is made for specific uses in fairface brickwork. These bricks are made from fine clays to control and reduce shrinkage deformation during firing. The finished bricks are dense, to

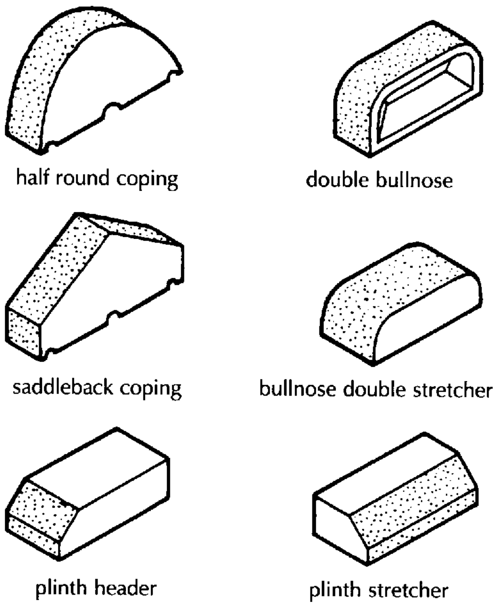


Fig. 49 Special bricks.

resist damage by exposure to rain and cold in the exposed positions in which they are most used. Figure 49 is an illustration of some typical specials.

The two coping bricks, the half round and the saddleback, are for use as coping to a 1B thick parapet wall. The bricks are some 50 mm or more wider than the thickness of a 1B wall so that when laid they overhang the wall each side to shed rainwater and the grooves on the underside of the hangover form a drip edge.

The two bullnose specials are made as a capping or coping for 1B walls. They are of the same length as the thickness of the wall on which they are laid, to provide protection and a flush finish to the wall.

The plinth bricks are used to provide and cap a thickening to the base of walls, a plinth, for the sake of appearance. A plinth at the base of a wall gives some definition to the base of a wall as compared to the wall being built flush out of the ground. A plinth may be formed by the junction of a solid $1\frac{1}{2}$B wall built from the foundation up to a cavity wall.

Properties of bricks

Hardness

This is a somewhat vague term commonly used in the description of bricks. By general agreement it is recognised that a brick which is to have a moderately good compressive strength, reasonable resistance to saturation by rainwater and sufficient resistance to the disruptive action of frost should be hard burned. Without some experience in the handling, and of the behaviour, of bricks in general it is very difficult to determine whether or not a particular brick is hard burned.

A method of testing for hardness is to hold the brick in one hand and give it a light tap with a hammer. The sound caused by the blow should be a dull ringing tone and not a dull thud. Obviously different types of brick will, when tapped, give off different sorts of sound and a brick that gives off a dull sound when struck may possibly be hard burned.

Compressive strength

This is a property of bricks which can be determined accurately. The compressive strength of bricks is found by crushing 12 of them individually until they fail or crumble. The pressure required to crush them is noted and the average compressive strength of the brick is stated as newtons per mm of surface area required to ultimately crush the brick. The crushing resistance varies from about 3.5 N/mm^2 for soft facing bricks up to 140 N/mm^2 for engineering bricks.

The required thickness of an external brick wall is determined primarily by its ability to absorb rainwater to the extent that water does not penetrate to the inside face of the wall. In positions of moderate exposure to wind driven rain a brick wall 215 mm thick may absorb so much water that it penetrates to the inside face.

The bearing strength of a brick wall 215 mm thick is very much greater than the loads a wall will usually carry. The current external wall to small buildings such as houses is built as a cavity wall with a 102.5 mm external leaf of brick, a cavity and an inner leaf of block. The external leaf is sufficiently thick, with the cavity, to prevent penetration of rain to the inside face and more than thick enough to support the loads it carries.

It is for heavily loaded brick piers and walls that the crushing strength of brick is a prime consideration.

The average compressive strength of some bricks commonly used is:

Mild (i.e. soft) stocks	3.5 N/mm^2
2nd Hard stocks	17.5 N/mm^2
Flettons	21 N/mm^2
Southwater A	70 N/mm^2

Absorption

Scientific work has been done to determine the amount of water absorbed by bricks and the rate of absorption, in an attempt to arrive at some scientific basis for grading bricks according to their resistance to the penetration of rain. This work has to date been of little use to those concerned with general building work. A wall built of very hard bricks which absorb little water may well be more readily penetrated by rainwater than one built of bricks which absorb a lot of water. This is because rain will more easily penetrate a small crack in the mortar between bricks if the bricks are dense than if the bricks around the mortar are absorptive.

Experimental soaking in water of bricks gives a far from reliable guide to the amount of water they can absorb as air in the pores and minute holes in the brick may prevent total absorption and to find total absorption the bricks have to be boiled in water or heated. The amount of water a brick will absorb is a guide to its density and therefore its strength in resisting crushing, but is not a reasonable guide to its ability to weather well in a wall. This term 'weather well' describes the ability of the bricks in a particular situation to suffer rain, frost and wind without losing strength, without crushing and to keep their colour and texture.

Frost resistance

A few failures of brickwork due to the disruptive action of frost have been reported during the last 30 years and scientific work has sought to determine a brick's resistance to frost failure. Most of the failures reported were in exposed parapet walls or chimney stacks where brickwork suffers most rain saturation and there is a likelihood of damage by frost. Few failures of ordinary brick walls below roof level have been reported. Providing sensible precautions are taken in the design of parapets and stacks above roof level and brick walls in general are protected from saturation by damaged rainwater gutters or blocked rainwater pipes there seems little likelihood of frost damage in this country.

Parapet walls, chimney stacks and garden walls should be built of sound, hard burned bricks protected with coping, cappings and damp-proof courses.

Efflorescence

Clay bricks contain soluble salts that migrate, in solution in water, to the surface of brickwork as water evaporates to outside air. These salts will collect on the face of brickwork as an efflorescence (flowering) of white crystals that appear in irregular, unsightly patches. This efflorescence of white salts is most pronounced in parapet walls, chimneys and below dpcs where brickwork is most liable to saturation. The concentration of salts depends on the soluble salt content of the bricks and the degree and persistence of saturation of brickwork.

The efflorescence of white salts on the surface is generally merely unsightly and causes no damage. In time these salts may be washed from surfaces by rain. Heavy concentration of salts can cause spalling and powdering of the surface of bricks, particularly those with smooth faces, such as Flettons. This effect is sometimes described as crypto efflorescence. The salts trapped behind the smooth face of bricks expand when wetted by rain and cause the face of the bricks to crumble and disintegrate.

Efflorescence may also be caused by absorption of soluble salts from a cement rich mortar or from the ground, that appear on the face of brickwork that might not otherwise be subject to efflorescence. Some impermeable coating between concrete and brick can prevent this (see Volume 4). There is no way of preventing the absorption of soluble salts from the ground by brickwork below the horizontal dpc level, although the effect can be reduced considerably by the use of dense bricks below the dpc.

Sulphate attack on mortars and renderings

When brickwork is persistently wet, as in foundations, retaining walls, parapets and chimneys, sulphates in bricks and mortar may in time crystallise and expand and cause mortar and renderings to disintegrate. To minimise this effect bricks with a low sulphate content should be used.

BONDING BRICKS

In building a wall it is usual to lay bricks in regular, horizontal courses so that each brick bears on two bricks below. The bricks are said to be bonded as they bind together by being laid across each other along the length of the wall, as illustrated in Fig. 50.

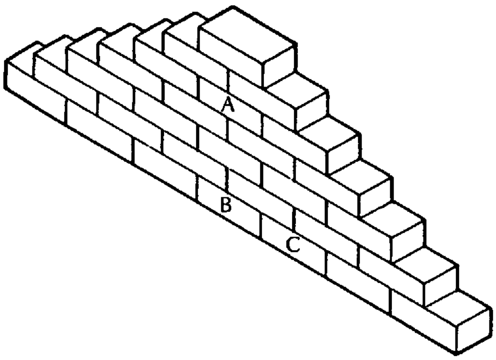


Fig. 50 Bricks stacked pyramid fashion.

The advantage of bonding is that the wall acts as a whole so that the load of a beam carried by the topmost brick in Fig. 50 is spread to the two bricks below it, then to the three below that and so on down to the base or foundation course of bricks.

The failure of one poor quality brick such as 'A in a wall and a slight settlement under part of the foundation such as 'B' and 'C' in Fig. 50 will not affect the strength and stability of the whole wall as the load carried by the weak brick and the two foundation bricks is transferred to the adjacent bricks.

Because of the bond, window and door openings may be formed in a wall, the load of the wall above the opening being transferred to the brickwork each side of the openings by an arch or lintel.

The effect of bonding is to stiffen a wall along its length and also to some small extent against lateral pressure, such as wind.

Stretcher bond

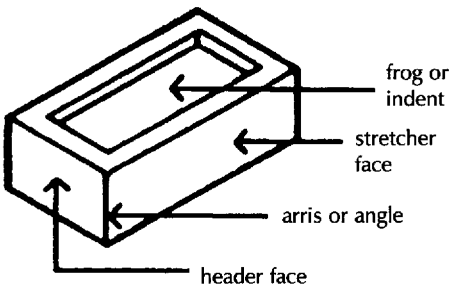


Fig. 51 Brick faces.

The four faces of a brick which may be exposed in fairface brickwork are the two, long, stretcher faces and the two header faces illustrated in Fig. 51. The face on which the brick is laid is the bed. Some bricks have an indent or frog formed in one of the bed faces. The purpose of the frog or indent is to assist in compressing the wet clay during moulding. The frog also serves as a reservoir of mortar on to which bricks in the course above may more easily be bedded.

The thickness of a wall is dictated primarily by the length of a brick. The length of bricks varies appreciably, especially those that are hand moulded and those made from plastic clays that will shrink differentially during firing.

It has been practice for some time to describe the thickness of a wall by reference to the length of a brick as a 1 B (brick) wall, a $1\frac{1}{2}$ B wall or a 2 B wall, rather than a precise dimension.

The external leaf of a cavity wall is often built of brick for the advantage of the appearance of brickwork. The most straightforward way of laying bricks in a thin outer leaf of a cavity wall is with the stretcher face of each brick showing externally. So that bricks are bonded along the length of the wall they are laid with the vertical joints between bricks lying directly under and over the centre of bricks in the courses under and over. This is described as stretcher bond as illustrated in Fig. 52. This wall is described as a $\frac{1}{2}$ B thick wall.

At the intersection of two half brick walls at corners or angles and at the jambs, sides of openings, the bricks are laid so that a header face shows in every other course to complete the bond, as illustrated in Fig. 52.

The appearance of a wall laid in stretcher bond may look somewhat monotonous because of the mass of stretcher faces showing. To

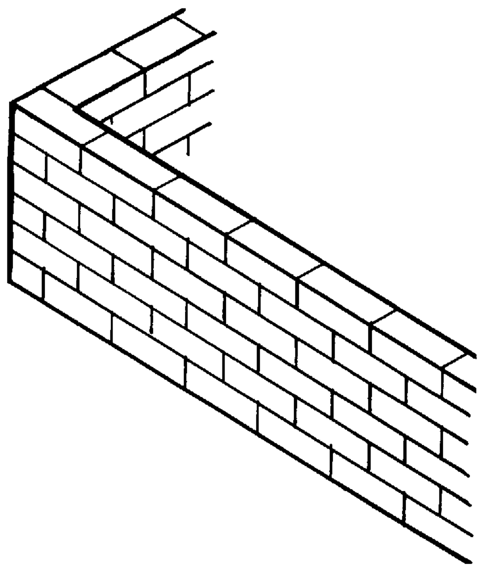


Fig. 52 Stretcher bond.

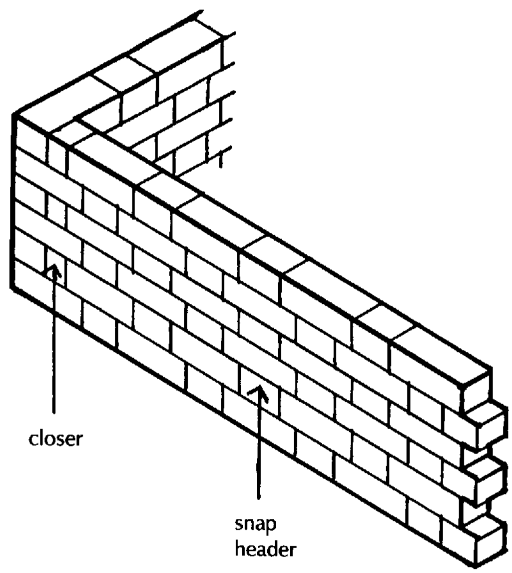


Fig. 53 Flemish bond with snap headers.

provide some variety the wall may be built with snap headers so that a stretcher face and a header face show alternately in each course with the centre of the header face lying directly under and over the centre of the stretcher faces in courses below and above, as illustrated in Fig. 53.

This form of fake Flemish bond is achieved by the use of half bricks, hence the name 'snap header'. The combination and variety in colour and shape can add appreciably to the appearance of a wall. Obviously the additional labour and likely wastage of bricks adds somewhat to cost.

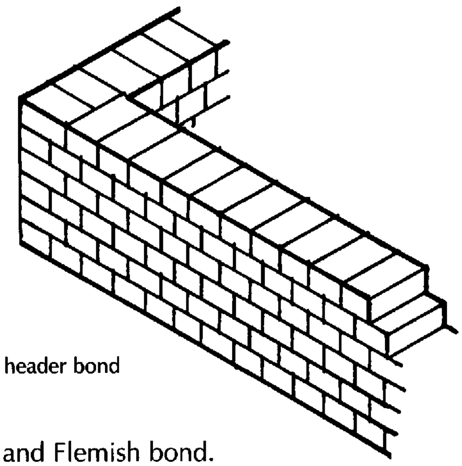
English and Flemish bond

Because brick by itself does not provide adequate resistance to the transfer of heat, to meet the requirements of the Building Regulations for the conservation of fuel and power, it is used in combination with other materials in external cavity walling for most heated buildings. In consequence brick walling 1 B and thicker is less used than it was.

Solid brick walls may be used for heated and unheated buildings for arcades, screen walling and as boundary and earth retaining walling for the benefit of the appearance and durability of the material.

For the same reason that a $\frac{1}{2}$ B wall is bonded along its length a solid wall 1 B and thicker is bonded along its length and through its thickness.

The two basic ways in which a solid brick wall may be bonded are with every brick showing a header face with each header face lying directly over two header faces below or with header faces centrally over a stretcher face in the course below, as illustrated in Fig. 54.



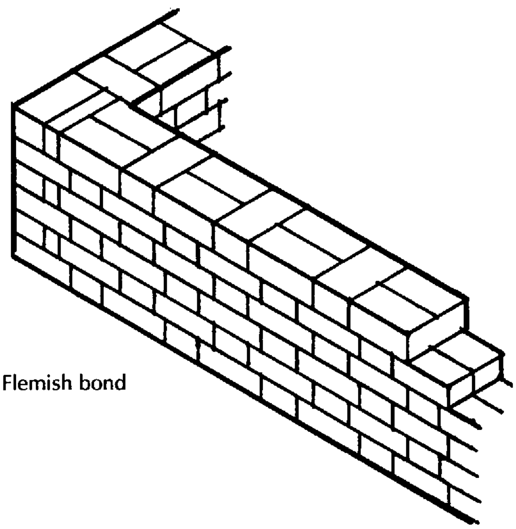


Fig. 54 Header and Flemish bond.

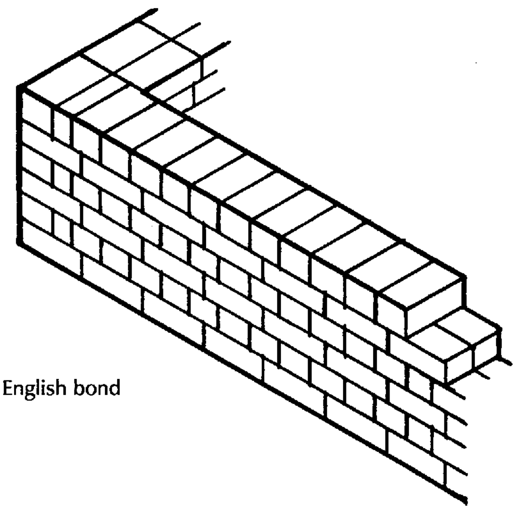


Fig. 55 English bond.

The bond in which header faces only show is termed 'heading' or 'header bond'. This bond is little used as the great number of vertical joints and header faces is generally considered unattractive.

The bond in which header faces lie directly above and below a stretcher face is termed Flemish bond. This bond is generally considered the most attractive bond for facing brickwork because of the variety of shades of colour between header and stretcher faces dispersed over the whole face of the walling. Figure 54 illustrates brickwork in Flemish bond.

English bond, illustrated in Fig. 55, avoids the repetition of header faces in each course by using alternate courses of header and stretcher faces with a header face lying directly over the centre of a stretcher face below. The colour of header faces, particularly in facing bricks, is often distinctly different from the colour of stretcher faces. In English bond this difference is shown in successive horizontal courses. In Flemish bond the different colours of header and stretcher faces are dispersed over the whole face of a wall, which by common consent is thought to be a more attractive arrangement.

Bonding at angles and jambs

At the end of a wall at a stop end, at an angle or quoin and at jambs of openings the bonding of bricks has to be finished up to a vertical angle. To complete the bond a brick $\frac{1}{4}$ B wide has to be used to close or complete the bond of the $\frac{1}{4}$ B overlap of face brickwork.

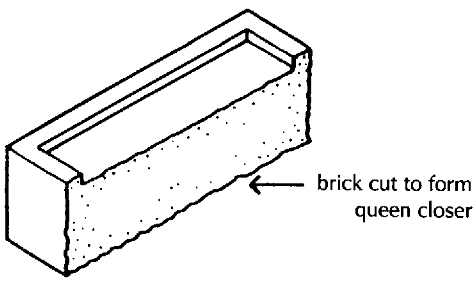


Fig. 56 Queen closer.

A brick, cut in half along its length, is used to close the bond at an angle. This cut brick is termed a 'queen closer', illustrated in Fig. 56. If the narrow width queen closer were laid at the angle, it might be displaced during bricklaying. To avoid this possibility the closer is laid next to a header, as illustrated in Fig. 57. The rule is that a closer is laid next to a quoin (corner) header.

There is often an appreciable difference in the length of facing bricks so that a solid wall 1 B thick may be difficult to finish as a wall fairface both sides. The word fairface describes a brick wall finished with a reasonably flat and level face for the sake of appearance. Where a 1 B wall is built with bricks of uneven length it may be necessary to select bricks of much the same length as headers and use longer bricks as stretchers. This additional care and labour will add appreciably to costs.

Walls $1\frac{1}{2}$ B thick may be used for substantial walling for larger buildings, such as industrial, storage and civic, for the sake of the appearance of the brickwork and the durability and sense of solidity and permanence where the walling is finished fairface both sides.

To complete the bond of a solid wall $1\frac{1}{2}$ B thick in double Flemish bond, that is Flemish bond on both faces, it is necessary to use cut half bricks in the thickness of the wall as illustrated in Fig. 57. At angles and stop ends of wall, queen closers are laid next to quoin headers and a three quarter length cut brick is used, as illustrated in Fig. 57.

Cutting the many half length bricks ($\frac{1}{2}$ bats) and three quarter length bricks and closers is time consuming and wasteful as it is not

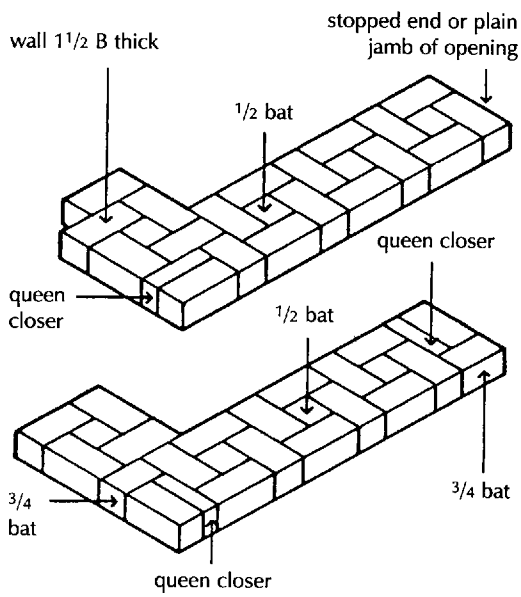


Fig. 57 Double Flemish bond.

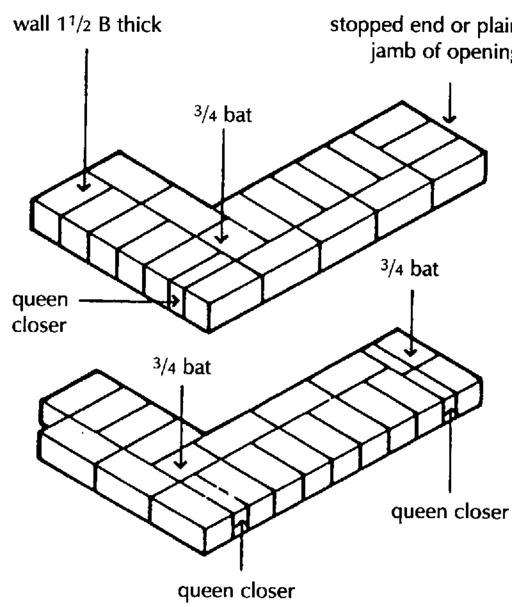


Fig. 58 English bond.

always possible to cut a brick in half cleanly. This adds considerably to the cost of this walling, which is selected for appearance rather than economy.

A $1\frac{1}{2}$B thick wall, finished fairface both sides and showing English bond both sides, requires considerably less cutting of bricks to complete the bond, as illustrated in Fig. 58. It is only necessary to cut closers and three quarter length bricks to complete the bond at angles and stop ends.

Walls $1\frac{1}{2}$B thick that are to be finished fairface on one side only may be built with facing bricks for the fairface side and cheaper common bricks for the rest of the thickness of the wall, where the inside face is to be covered with plaster.

Garden wall bonds

Walls, such as garden walls, that are to be finished fairface both sides and built 1 B thick are often built in one of the garden wall bonds.

Because of the variations in size and shape of many facing bricks it is difficult to finish a 1 B wall fairface both sides because of the differences in length of bricks that are bonded through the thickness of the wall.

Garden wall bonds are designed specifically to reduce the number of through headers to minimise the labour in selecting bricks of roughly the same length for use as headers.

Usual garden wall bonds are three courses of stretchers to every one course of headers in English garden wall bond and one header to every three stretchers in Flemish garden wall bond, as illustrated in Fig. 59.

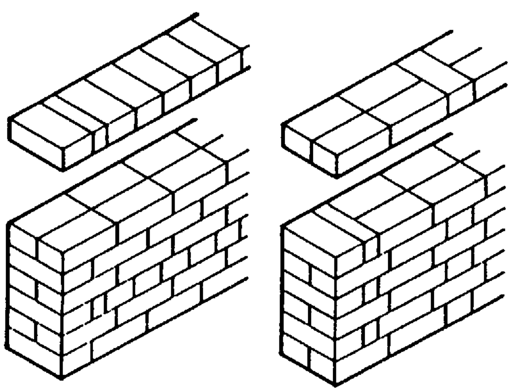


Fig. 59 Garden wall bonds.

The reduction in the number of through headers does to an extent weaken the through bond of the brickwork. This is of little consequence in a freestanding garden wall. Other combinations such as two or four stretchers to one header may be used.

The tops of garden walls are finished with one of the special coping bricks illustrated in Fig. 49 or one of the brick or stone cappings, coping, described for parapet walls in Chapter 4.

BUILDING BLOCKS

Building blocks are wall units, larger in size than a brick, that can be handled by one man. Building blocks are made of concrete or clay.

Concrete blocks

These are used extensively for both loadbearing and non-loadbearing walls, externally and internally. A concrete block wall can be laid in less time and may cost up to half as much as a similar brick wall. Lightweight aggregate concrete blocks have good insulating properties against transfer of heat and have been much used for the inner leaf of cavity walls with either a brick outer leaf or a concrete block outer leaf.

A disadvantage of some concrete blocks, particularly lightweight aggregate blocks, as a wall unit is that they may suffer moisture movement which causes cracking of applied finishes such as plaster. To minimise cracking due to shrinkage by loss of water, vertical movement joints should be built into long block walls, subject to moisture movement, at intervals of up to twice the height of the wall. These movement joints may be either a continuous vertical joint filled with mastic or they may be formed in the bonding of the blocks.

Because the block units are comparatively large, any settlement movement in a wall will show more pronounced cracking in mortar joints than is the case with the smaller brick wall unit.

For some years it was fashionable to use concrete blocks as a fairface external wall finish. The blocks were accurately moulded to uniform sizes and made from aggregates to provide a variety of colours and textures. Blocks made to give an appearance of natural stone with plain or rugged exposed aggregate finish were used.

These special blocks are less used that they were, particularly because of the fairly rapid deterioration in the appearance of the blocks due to irregular weather staining of smooth faced blocks and the patchy dirt staining of coarse textured blocks.

Concrete blocks are manufactured from cement and either dense or lightweight aggregates as solid, cellular or hollow blocks as illustrated in Fig. 60. A cellular block has one or more holes or cavities that do not pass wholly through the block and a hollow block is one in which the holes pass through the block. The thicker blocks are made with cavities or holes to reduce weight and drying shrinkage.

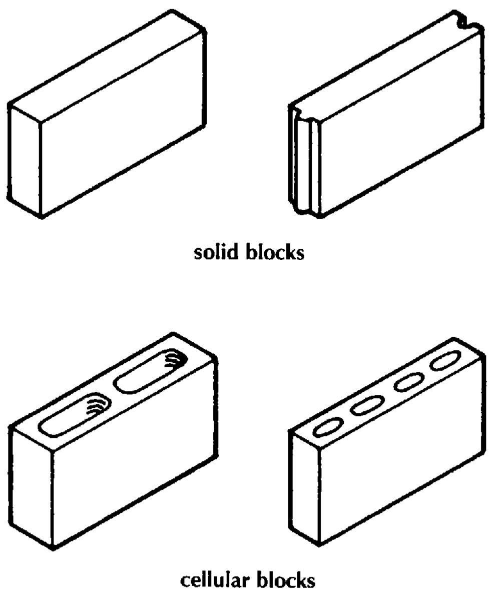


Fig. 60 Concrete blocks.

The most commonly used size of both dense and lightweight concrete blocks is 440 mm long × 215 mm high. The height of the block is chosen to coincide with three courses of brick for the convenience of building in wall ties and also bonding to brickwork. The length of the block is chosen for laying in stretcher bond.

For the leaves of cavity walls and internal loadbearing walls 100 mm thick blocks are used. For non-loadbearing partition walls 60 or 75 mm thick lightweight aggregate blocks are used. Either 440 mm × 215 mm or 390 × 190 mm blocks may be used.

Concrete blocks may be specified by their minimum average compressive strength for:

(1) all blocks not less than 75 mm thick and
(2) a maximum average transverse strength for blocks less than 75 mm thick, which are used for non-loadbearing partitions.

The usual compressive strengths for blocks are 2.8, 3.5, 5.0, 7.0. 10.0, 15.0, 20.0 and 35.0 N/mm^2. The compressive strength of blocks used for the walls of small buildings of up to three storeys, recommended in Approved Document A to the Building Regulations, is 2.8 and 7 N/mm^2, depending on the loads carried.

Concrete blocks may also be classified in accordance with the aggregate used in making the block and some common uses.

Dense aggregate blocks for general use

The blocks are made of Portland cement, natural aggregate or blast-furnace slag. The usual mix is 1 part of cement to 6 or 8 of aggregate by volume. These blocks are as heavy per cubic metre as bricks, they are not good thermal insulators and their strength in resisting crushing is less than that of most well burned bricks. The colour and texture of these blocks is far from attractive and they are usually covered with plaster or a coat of rendering. These blocks are used for internal and external loadbearing walls, including walls below ground.

Lightweight aggregate concrete blocks for general use in building

The blocks are made of ordinary Portland cement and one of the following lightweight aggregates: granulated blast-furnace slag, foamed blast-furnace slag, expanded clay or shale, or well burned furnace clinker. The usual mix is 1 part cement to 6 or 8 of aggregate by volume.

Of the four lightweight aggregates noted, well burned furnace clinker produces the cheapest block which is about two-thirds the weight of a similar dense aggregate concrete block and is a considerably better thermal insulator. Blocks made from foamed blast-furnace slag are about twice the price of those made from furnace clinker, but they are only half the weight of a similar dense aggregate block and have good thermal insulating properties. The furnace clinker blocks are used extensively for walls of houses and the foamed blast-furnace slag blocks for walls of large framed buildings because of their lightness in weight.

Lightweight aggregate concrete blocks primarily for internal non-loadbearing walls

These thin blocks, usually 60 or 75 mm thick, are made with the same lightweight aggregate as those in Class 2. These blocks are more expensive than dense aggregate blocks and are used principally for non-loadbearing partitions. These blocks are manufactured as solid, hollow or cellular depending largely on the thickness of the block.

The thin blocks are solid and either square edged or with a tongue and groove in the short edges so that there is a mechanical bond between blocks to improve the stability of internal partitions. The poor structural stability may be improved by the use of storey height door linings which are secured at floor and ceiling level.

Thin block internal partitions afford negligible acoustic insulation and poor support for fittings, such as book shelves secured to them.

The thicker blocks are either hollow or cellular to reduce weight and drying shrinkage.

Moisture movement

As water dries out from precast concrete blocks shrinkage that occurs, particularly with lightweight blocks, may cause serious cracking of plaster and rendering applied to the surface of a wall built with them. Obviously the wetter the blocks the more they will shrink. It is essential that these blocks be protected on building sites from saturation by rain both when they are stacked on site before use and whilst walls are being built. Clay bricks are small and suffer very little drying shrinkage and therefore do not need to be protected from saturation by rain. Only the edges of these blocks should be wetted to increase their adhesion to mortar when the blocks are being laid.

Clay blocks

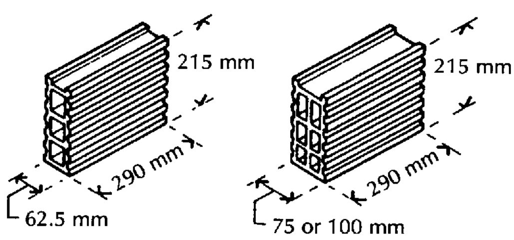


Fig. 61 Clay blocks.

Hollow clay building blocks are made for use as a wall unit. The blocks are made from selected brick clays that are press moulded and burnt. These hard, dense blocks are hollow to reduce shrinkage during firing and reduce their weight and they are grooved to provide a key for plaster, as illustrated in Fig. 61. The standard block is 290 long × 215 mm high and 62.5, 75, 100 and 150 mm thick.

Clay blocks are comparatively lightweight, do not suffer moisture movement, have good resistance to damage by fire and poor thermal insulating properties. These blocks are mainly used for non-loadbearing partitions in this country. They are extensively used in southern Europe as infill panel walls to framed buildings where the tradition is to render the external face of buildings on which the blocks provide a substantial mechanical key for rendering and do not suffer moisture movement that would otherwise cause shrinkage cracking.

Bonding blocks

Blocks are made in various thicknesses to suit most wall requirements and are laid in stretcher bond.

Thin blocks, used for non-loadbearing partitions, are laid in running stretcher bond with each block centred over and under blocks above and below. At return angles full blocks bond into the return wall in every other course, as illustrated in Fig. 62. So as not to disturb the full width bonding of blocks at angles, for the sake of stability, a short length of cut block is used as closer and infill block.

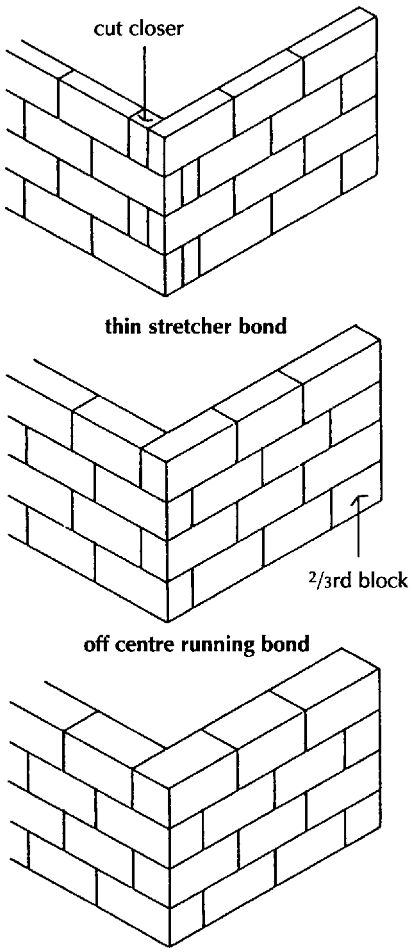


Fig. 62 Bonding building blocks.

Thicker blocks are laid in off centre running bond with a three quarter length block at stop ends and sides of openings. The off centre bond is acceptable with thicker blocks as it avoids the use of cut blocks to complete the bond at angles, as illustrated in Fig. 62.

Thick blocks, whose length is twice their width, are laid in running (stretcher) bond as illustrated in Fig. 62, and cut blocks are only necessary to complete the bond at stop ends and sides of opening.

At the 'T' junctions of loadbearing concrete block walls it is sometimes considered good practice to butt the end face of the intersecting walls with a continuous vertical joint to accommodate shrinkage movements and to minimise cracking of plaster finishes.

Where one intersecting wall serves as a buttress to the other, the butt joint should be reinforced by building in split end wall ties at each horizontal joint across the butt joint to bond the walls. Similarly, non-loadbearing block walls should be butt jointed at intersections and the joint reinforced with strips of expanded metal bedded in horizontal joints across the butt joint.

Concrete block walls of specially produced blocks to be used as a fairface finish are bonded at angles to return walls with specially produced quoin blocks for the sake of appearance, as illustrated in Fig. 63. The 'L' shaped quoin blocks are made to continue the stretcher bond around the angle into the return walls.

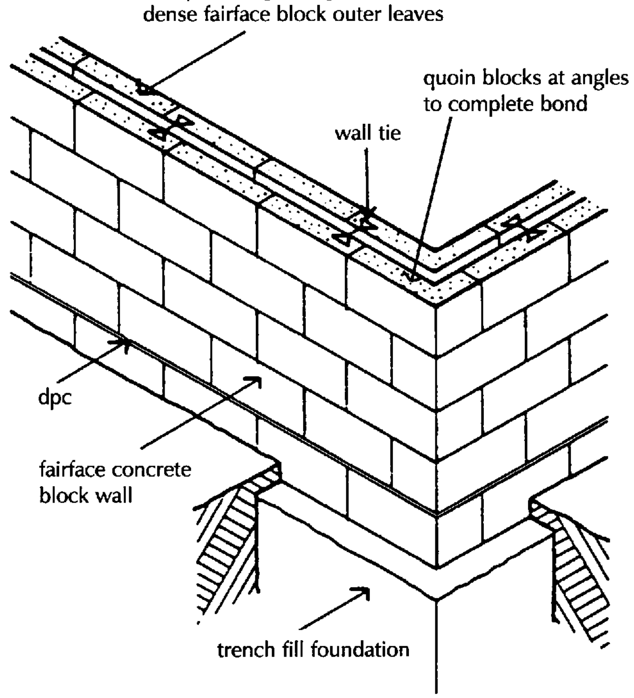


Fig. 63 Bonding block walls.

Quoin blocks are little used for other than fairface work as they are liable to damage in handling and use and add considerably to the cost of materials and labour.

MORTAR FOR BRICKWORK AND BLOCKWORK

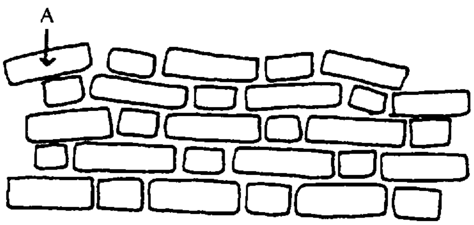


Fig. 64 Badly shaped facing bricks laid without mortar.

Clay bricks are rarely exactly rectangular in shape and they vary in size. Some facing bricks are far from uniform in shape and size and if a wall were built of bricks laid without mortar and the bricks were bonded the result might be as shown, exaggerated, in Fig. 64.

Because of the variations in shape and size, the courses of bricks would not lie anywhere near horizontal. One of the functions of brickwork is to support floors and if a floor timber were to bear on the brick marked A it would tend to cause it to slide down the slope on which it would be resting. It is essential, therefore, that brickwork be laid in true horizontal courses, and the only way this can be done with bricks of differing shapes and sizes is to lay them on some material which is sufficiently plastic, while the bricks are being laid, to take up the difference in size, and which must be able to harden to such an extent that it can carry the weight normally carried by brickwork.

The material used is termed mortar. The basic requirements of a mortar are that it will harden to such an extent that it can carry the weight normally carried by bricks, without crushing, and that it be sufficiently plastic when laid to take the varying sizes of bricks. It must have a porosity similar to that of the bricks and it must not deteriorate due to the weathering action of rain or frost.

Sand is a natural material which is reasonably cheap and which, if mixed with water, can be made plastic, yet which has very good strength in resisting crushing. Its grains are also virtually impervious to the action of rain and frost. The material required to bind the grains of sand together into a solid mass is termed the matrix and the two materials used for this purpose are lime or cement.

Aggregate for mortar

Sand

The aggregate or main part of mortar is sand. The sand is dredged from pits or river beds and a good sand should consist of particles ranging up to 5 mm in size. In the ground, sand is usually found mixed with some clay earth which coats the particles of sand. If sand mixed with clay is used for mortar, the clay tends to prevent the cement or lime binding the sand particles together and in time the mortar crumbles. It is therefore important that the sand be thoroughly washed so that there is no more than 5% of clay in the sand delivered to the site.

Soft sand and sharp sand

Sand which is not washed and which contains a deal of clay in it feels soft and smooth when held in the hand, hence the term soft sand. Sand which is clean feels coarse in the hand, hence the term sharp. These are terms used by craftsmen. When soft sand is used, the mortar is very smooth and plastic and it is much easier to spread and to bed the bricks in than a mortar made of sharp or clean sand.

Naturally the bricklayer prefers to use a mortar made with soft or unwashed sand, often called 'builders' sand'. A good washed sand for mortar should, if clenched in the hand, leave no trace of yellow clay stains on the palm.

Matrix for mortar

The material that was used for many centuries before the advent of Portland cement as the matrix (binding agent) for mortar was lime. Lime, which mixes freely with water and sand, produces a material that is smooth, buttery and easily spread as mortar, into which the largely misshapen bricks in use at the time could be bedded.

The particular advantage of lime is that it is a cheap, readily available material that produces a plastic material ideal for bedding bricks. Its disadvantages are that it is a messy, laborious material to mix and as it is to an extent soluble in water it will lose its adhesive property in persistently damp situations. Protected from damp, a lime mortar will serve as an effective mortar for the life of most buildings.

Portland cement, which was first manufactured on a large scale in the latter part of the nineteenth century, as a matrix for mortar, produces a hard dense material that has more than adequate strength for use as mortar and is largely unaffected by damp conditions. A mixture of cement, sharp sand and water produces a coarse material that is not plastic and is difficult to spread. In use, cement has commonly been used with 'builders' sand' which is a natural mix of sand and clay. The clay content combines with water to make a reasonably plastic mortar at the expense of loss of strength and considerable drying shrinkage as the clay dries.

'Compo' mortar

During the last 50 years it has been considered good practice to use a mortar in which the advantages of lime and cement are combined. This combination or 'compo' mortar is somewhat messy to mix.

Mortar plasticiser

As an alternative to the use of lime it has become practice to use a mortar plasticiser with cement in the mix of cement mortars. A plasticiser is a liquid which, when combined with water, effervesces to produce minute bubbles of air that surround the coarse grains of sand and so render the mortar plastic, hence the name 'mortar plasticiser' mixes.

Ready mixed mortar

Of recent years ready mixed mortars have come into use particularly on sites where extensive areas of brickwork are laid. The wet material is delivered to site, ready mixed, to save the waste, labour and cost of mixing on site.

A wide range of lime and sand, lime cement and sand and cement and sand mixes is available. The sand may be selected to provide a chosen colour and texture for appearance sake or the mix may be pigmented for the same reason.

Lime mortar is delivered to site ready to use within the day of delivery. Cement mix and cement lime mortar is delivered to site ready mixed with a retarding admixture.

The retarding admixture is added to cement mix mortars to delay the initial set of cement. The initial set of ordinary Portland cement occurs some 30 minutes after the cement is mixed with water, so that an initial hardening occurs to assist in stiffening the material for use as rendering on vertical surfaces for example.

The advantages of ready mixed mortar are consistency of the mix, the wide range of mixes available and considerable saving in site labour costs and the inevitable waste of material common with site mixing.

Cement mortar

Cement is made by heating a finely ground mixture of clay and limestone, and water, to a temperature at which the clay and limestone fuse into a clinker. The clinker is ground to a fine powder called cement. The cement most commonly used is ordinary Portland cement which is delivered to site in 50 kg sacks. When the fine cement powder is mixed with water a chemical action between water and cement takes place and at the completion of this reaction the nature of the cement has so changed that it binds itself very firmly to most materials.

The cement is thoroughly mixed with sand and water, the reaction takes place and the excess water evaporates leaving the cement and sand to gradually harden into a solid mass. The hardening of the mortar becomes noticeable some few hours after mixing and is complete in a few days. The usual mix of cement and sand for mortar is from 1 part cement to 3 or 4 parts sand to 1 part of cement to 8 parts of sand by volume, mixed with just sufficient water to render the mixture plastic.

A mortar of cement and sand is very durable and is often used for brickwork below ground level and brickwork exposed to weather above roof level such as parapet walls and chimney stacks.

Cement mortar made with washed sand is not as plastic however as bricklayers would like it to be. Also when used with some types of bricks it can cause an unsightly effect known as efflorescence.

This word describes the appearance of an irregular white coating on the face of bricks, caused by minute crystals of water soluble salts in the brick. The salts go into solution in water inside the bricks and when the water evaporates in dry weather they are left on the face of bricks or plaster. Because cement mortar has greater compressive strength than required for most ordinary brickwork and because it is not very plastic by itself it is sometimes mixed with lime and sand.

Lime mortar

Lime is manufactured by burning limestone or chalk and the result of this burning is a dirty white, lumpy material known as quicklime. When this quicklime is mixed with water a chemical change occurs during which heat is generated in the lime and water, and the lime expands to about three times its former bulk. This change is gradual and takes some days to complete, and the quicklime afterwards is said to be slaked, that is it has no more thirst for water. More precisely the lime is said to be hydrated, which means much the same thing. Obviously the quicklime must be slaked before it is used in mortar otherwise the mortar would increase in bulk and squeeze out of the joints. Lime for building is delivered to site ready slaked and is termed 'hydrated lime'.

When mixed with water, lime combines chemically with carbon dioxide in the air and in undergoing this change it gradually hardens into a solid mass which firmly binds the sand.

A lime mortar is usually mixed with 1 part of lime to 3 parts of sand by volume. The mortar is plastic and easy to spread and hardens into a dense mass of good compressive strength. A lime mortar readily absorbs water and in time the effect is to reduce the adhesion of the lime to the sand and the mortar crumbles and falls out of the joints in the brickwork.

Mortar for general brickwork may be made from a mixture of cement, lime and sand in the proportions set out in Table 2. These mixtures combine the strength of cement with the plasticity of lime, have much the same porosity as most bricks and do not cause efflorescence on the face of the brickwork.

The mixes set out in Table 2 are tabulated from rich mixes (1) to weak mixes (2). A rich mix of mortar is one in which there is a high proportion of matrix, that is lime or cement or both, to sand as in the 1:3 mix and a weak mix is one in which there is a low proportion of lime or cement to sand as in the mix 1:3:12. The richer the mix of mortar the greater its compressive strength and the weaker the mix the greater the ability of the mortar to accommodate moisture or temperature movements.

Table 2 Mortar mixes.

Mortar designation	Cement:lime:sand	Air-entrained mixes: Masonry cement:sand	Air-entrained mixes: Cement:sand with plasticiser
1	1:0 to $\frac{1}{4}$:3		
2	1:$\frac{1}{2}$: 4 to $4\frac{1}{2}$	1:$2\frac{1}{2}$ to $3\frac{1}{2}$	1:3 to 4
3	1:1:5 to 6	1:4 to 5	1:5 to 6
4	1:2:8 to 9	1:$5\frac{1}{2}$ to $6\frac{1}{2}$	1:7 to 8
5	1:3:10 to 12	1:$6\frac{1}{2}$ to 7	1:8

Taken from BS 5628:Part 3:1985 (Table 15)

Proportions by volume

The general uses of the mortar mixes given in Table 2 are as mortar for brickwork or blockwork as follows:

Mix 1 For cills, copings and retaining walls
Mix 2 Parapets and chimneys
Mix 3 Walls below dpc
Mix 4 Walls above dpc
Mix 5 Internal walls and lightweight block inner leaf of cavity

Hydraulic lime

Hydraulic lime is made by burning a mixture of chalk or limestone that contains clay. Hydraulic lime is stronger than ordinary lime and will harden in wet conditions, hence the name. Ordinary Portland cement, made from similar materials and burnt at a higher temperature, has largely replaced hydraulic lime which is less used today.

Mortar plasticisers

Liquids known as mortar plasticisers are manufactured. When these liquids are added to water they effervesce, that is the mixture becomes bubbly like soda water. If very small quantities are added to mortar, when it is mixed, the millions of minute bubbles that form surround the hard sharp particles of sand and so make the mortar plastic and easy to spread. The particular application of these mortar plasticisers is that if they are used with cement mortar they increase its plasticity and there is no need to use lime. It seems that the plasticisers do not adversely affect the hardness and durability of the mortar and they are commonly and successfully used for mortars.

JOINTING AND POINTING

Jointing

Jointing is the word used to describe the finish of the mortar joints between bricks, to provide a neat joint in brickwork that is finished fairface. Fairface describes the finished face of brickwork that will not be subsequently covered with plaster, rendering or other finish.

Most fairface brickwork joints are finished, as the brickwork is raised, in the form of a flush or bucket handle joint. When the mortar

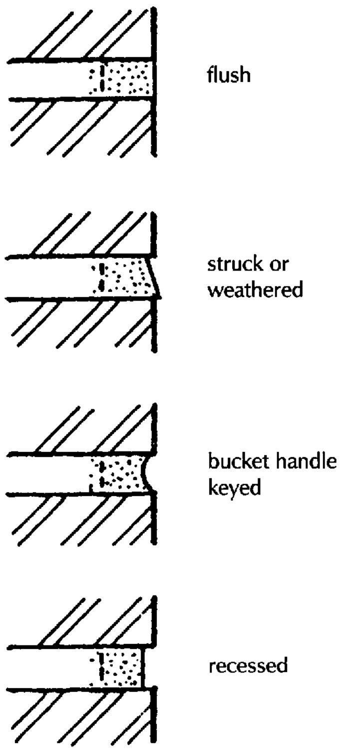


Fig. 65 Jointing and pointing.

has gone off, that is hardened sufficiently, the joint is made. Flush joints are generally made as a 'bagged' or a 'bagged in' joint. The joint is made by rubbing coarse sacking or a brush across the face of the brickwork to rub away all protruding mortar and leaving a flush joint. This type of joint, illustrated in Fig. 65, can most effectively be used on brickwork where the bricks are uniform in shape and comparatively smooth faced, where the mortar will not spread over the face of the brickwork.

A bucket handle joint is made by running the top face of a metal bucket handle or the handle of a spoon along the joint to form a concave, slightly recessed joint, illustrated in Fig. 65. The advantage of the bucket handle joint is that the operation compacts the mortar into the joint and improves weather resistance to some extent. A bucket handle joint may be formed by a jointing tool with or without a wheel attachment to facilitate running the tool along uniformly deep joints.

Flush and bucket handle joints are mainly used for jointing as the brickwork is raised.

The struck and recessed joints shown in Fig. 65 are more laborious to make and therefore considerably more expensive. The struck joint is made with a pointing trowel that is run along the joint either along the edges of uniformly shaped bricks or along a wood straight edge, where the bricks are irregular in shape or coarse textured, to form the splayed back joint. The recessed joint is similarly formed with a tool shaped for the purpose, with such filling of the joint as may be necessary to complete the joint.

Of the joints described the struck joint is mainly used for pointing the joints in old brickwork and the recessed joint to emphasise the profile, colour and textures of bricks for appearance sake to both new and old brickwork.

Pointing

The words jointing and pointing are commonly loosely used. Jointing is the operation of finishing off a mortar joint as the brickwork is raised, whereas pointing is the operation of filling the joint with a specially selected material for the sake of appearance or as weather protection to old lime mortar.

Pointing is the operation of filling mortar joints with a mortar selected for colour and texture to either new brickwork or to old brickwork. The mortar for pointing is a special mix of lime, cement and sand or stone dust chosen to produce a particular effect of colour and texture. The overall appearance of a fairface brick wall can be dramatically altered by the selection of mortar for pointing. The finished colour of the mortar can be affected through the selection of a particular sand or stone dust, the use of pigmented cement, the addition of a pigment and the proportion of the mix of materials.

The joints in new brickwork are raked out about 20 mm deep when the mortar has gone off sufficiently and before it has set hard and the joints are pointed as scaffolding is struck, that is taken down.

The mortar joints in old brickwork that was laid in lime mortar may in time crumble and be worn away by the action of wind and rain. To protect the lime mortar behind the face of the joints it is good practice to rake out the perished jointing or pointing and point or repoint all joints. The joints are raked out to a depth of about 20 mm and pointed with a mortar mix of cement, lime and sand that has roughly the same density as the brickwork. The operation of raking out joints is laborious and messy and the job of filling the joints with mortar for pointing is time consuming so that the cost of pointing old work is expensive.

Pointing or repointing old brickwork is carried out both as protection for the old lime mortar to improve weather resistance and also for appearance sake to improve the look of a wall.

Any one of the joints illustrated in Fig. 66 may be used for pointing.

WALLS OF BRICK AND BLOCK

Strength and stability

Up to the middle of the twentieth century the design and construction of small buildings, such as houses, was based on tried, traditional forms of construction. There were generally accepted rule of thumb methods for determining the necessary thickness for the walls of small buildings. By and large, the acceptance of tried and tested methods of construction, allied to the experience of local builders using traditional materials in traditional forms of construction, worked well. The advantage was that from a simple set of drawings an experienced builder could give a reasonable estimate of cost and build and complete small buildings, such as houses, without delay.

With the increasing use of unfamiliar materials, such as steel and concrete, in hitherto unused forms, it became necessary to make calculations to determine the least size of elements of structure for strength and stability in use. The practicability of constructing large multi-storey buildings provoked the need for standards of safety in case of fire and rising expectations of comfort and the need for the control of insulation, ventilation, daylight and hygiene.

During the last 50 years there has been a considerable increase in building control, that initially was the province of local authorities through building bylaws, later replaced by national building regulations. The Building Regulations 1985 set out functional requirements for buildings and health and safety requirements that may be met through the practical guidance given in 11 Approved Documents that in turn refer to British Standards and Codes of Practice.

In theory it is only necessary to satisfy the requirements of the Building Regulations, which are short and include no technical details of means of satisfying the requirements. The 11 Approved

Documents give practical guidance to meeting the requirements, but there is no obligation to adopt any particular solution in the documents if the requirements can be met in some other way.

The stated aim of the current Building Regulations is to allow freedom of choice of building form and construction so long as the stated requirements are satisfied. In practice the likelihood is that the practical guidance given in the Approved Documents will be accepted as if the guidance were statutory as the easier approach to building, rather than proposing some other form of building that would involve calculation and reference to a bewildering array of British Standards and Codes and Agrément Certificates.

In Approved Document A there is practical guidance to meeting the requirements of the Building Regulations for the walls of small buildings of the following three types:

(1) residential buildings of not more than three storeys
(2) small single storey non-residential buildings, and
(3) small buildings forming annexes to residential buildings (including garages and outbuildings).

Limitations as to the size of the building types included in the guidance are given in a disjointed and often confusing manner.

Height

The maximum height of residential buildings is given as 15 m from the lowest ground level to the highest point of any wall or roof, whereas the maximum allowable thickness of wall is limited to walls not more than 12 m. Height is separately defined, for example, as from the base of a gable and external wall to half the height of the gable. The height of single storey, non-residential buildings is given as 3 m from the ground to the top of the roof, which limits the guidance to very small buildings. The maximum height of an annexe is similarly given as 3 m, yet there is no definition of what is meant by annexe except that it includes garages and outbuildings.

Width

The least width of residential buildings is limited to not less than half the height. A diagram limits the dimensions of the wing of a residential building without defining the meaning of the term 'wing', which in the diagram looks more like an annexe than a wing. Whether the arms of a building which is 'L' or 'U' shaped on plan are wings or not is entirely a matter of conjecture. How the dimensions apply to semi-detached buildings or terraces of houses is open to speculation.

In seeking to give practical guidance to meeting functional requirements for strength and stability and at the same time impose limiting dimensions, the Approved Document has caused confusion.

One further limitation is that no floor enclosed by structural walls on all sides should exceed 70 m^2 and a floor without a structural wall on one side, 30 m^2. The floor referred to is presumably a suspended floor, though it does not say so. As the maximum allowable length of wall between buttressing walls, piers or chimneys is given as 12 m and the maximum span for floors as 6 m, the limitation is in effect a floor some 12 × 6 m on plan. It is difficult to understand the need for the limitation of floor area for certain 'small' buildings.

Strength

The guidance given in the Approved Document for walls of brick or block is based on compressive strengths of 5 N/mm^2 for bricks and 2.8 N/mm^2 for blocks for walls up to two storeys in height, where the storey height is not more than 2.7 m and 7 N/mm^2 for bricks and blocks of walls of three storey buildings where the storey height is greater than 2.7 m.

Stability

Thickness of walls

The general limitation of wall thickness given for stability is that solid walls of brick or block should be at least as thick as one-sixteenth of the storey height. This is a limiting slenderness ratio relating thickness of wall to height, measured between floors and floor and roof that provide lateral support and give stability up the height of the wall. The minimum thickness of external, compartment and separating walls is given in a table in Approved Document A, relating thickness to height and length of wall as illustrated in Fig. 66. Compartment walls are those that are formed to limit the spread of fire and separating walls (party walls) those that separate adjoining buildings, such as the walls between terraced houses.

Cavity walls should have leaves at least 90 mm thick, cavity at least 50 mm wide and the combined thickness of the two leaves plus 20 mm, should be at least the thickness required for a solid wall of the same height and length.

Internal loadbearing walls, except compartment and separating walls, should be half the thickness of external walls illustrated in Fig. 66, minus 5 mm, except for the wall in the lowest storey of a three storey building which should be of the same thickness, or 140 mm, whichever is the greater.

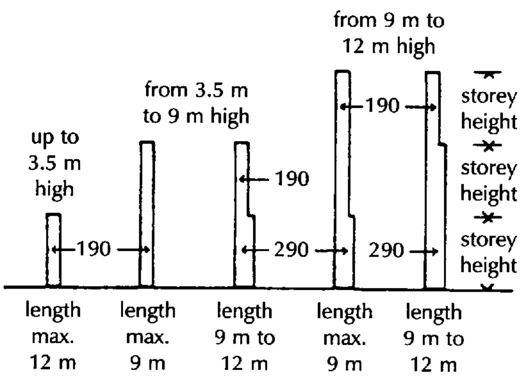


Fig. 66 Minimum thickness of walls.

Stability

Lateral support

For stability up the height of a wall lateral support is provided by floors and roofs as set out in Table 3.

Walls that provide support for timber floors are given lateral support by 30 × 5 mm galvanised iron or stainless steel 'L' straps fixed to the side of floor joists at not more than 2 m centres for houses up to three storeys and 1.25 m centres for all storeys in all other buildings. The straps are turned down 100 mm on the cavity face of the inner leaf of cavity walls and into solid wallings, as illustrated in Fig. 67.

Table 3 Lateral support for walls.

Wall type	Wall length	Lateral support required
Solid or cavity: external compartment separating	Any length	Roof lateral support by every roof forming a junction with the supported wall
	Greater than 3 m	Floor lateral support by every floor forming a junction with the supported wall
Internal loadbearing wall (not being a compartment or separating wall)	Any length	Roof or floor lateral support at the top of each storey

Taken from Approved Document A (Table 11)
The Building Regulations

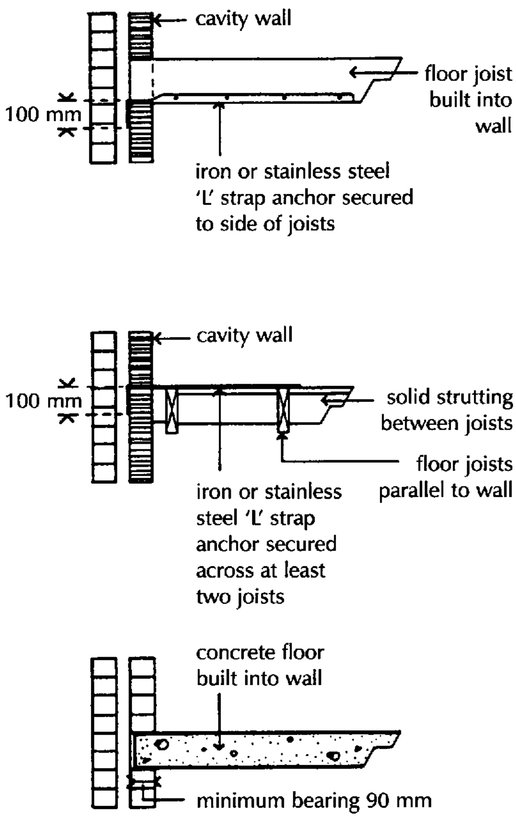


Fig. 67 Floors providing lateral restraint to walls.

Lateral support from timber floors, where the joists run parallel to the wall, is provided by 30 × 5 mm galvanised iron on stainless steel strap anchors secured across at least two joists at not more than 2 m centres for houses up to three storeys and 1.25 m for all storeys in all other buildings.

The 'L' straps are turned down a minimum of 100 mm on the cavity side of inner leaf of cavity walls and into solid walling. Solid timber strutting is fixed between joists under the straps as illustrated in Fig. 67.

Solid floors of concrete provide lateral support for walls where the floor bears for a minimum of 90 mm in both solid and cavity walls, as illustrated in Fig. 67.

To provide lateral support to gable end walls to roofs pitched at more than 15° a system of galvanised steel straps is used. Straps 30 × 5 mm are screwed to the underside of timber noggings fixed between three rafters, as illustrated in Fig. 68, with timber packing pieces between the rafter next to the gable and the wall.

The straps should be used at a maximum of 2 m centres and turned down against the cavity face of the inner leaf of a whole building block or down into a solid wall.

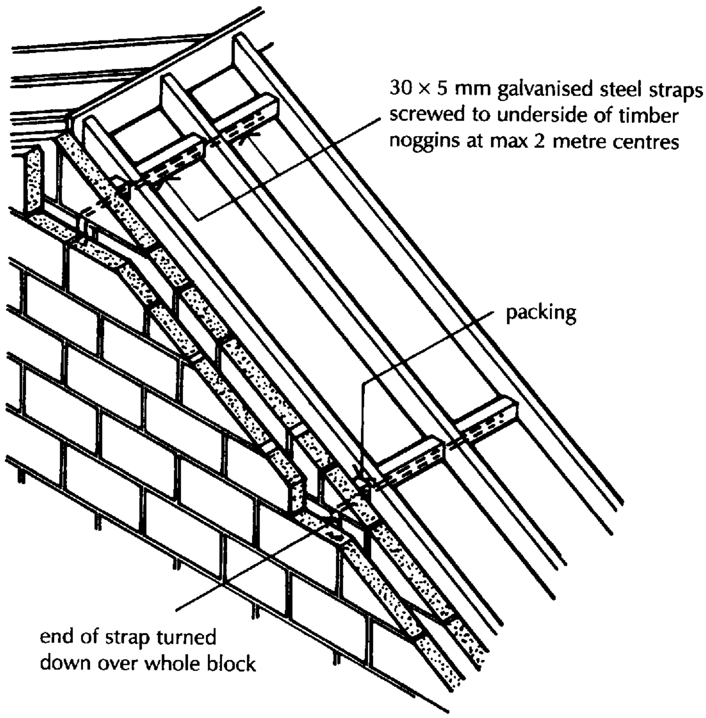


Fig. 68 Lateral support to gable ends.

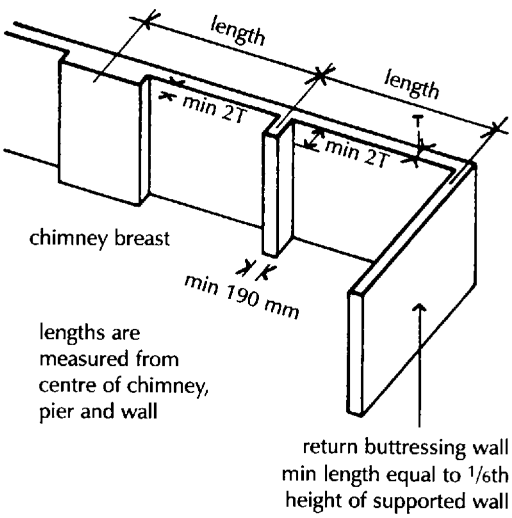


Fig. 69 Length of walls.

To provide stability along the length and at the ends of loadbearing walls there should be walls, piers or chimneys bonded to the wall at intervals of not more than 12 m, to buttress and stabilise the wall.

The maximum spacing of buttressing walls, piers and chimneys is measured from the centre line of the supports as illustrated in Fig. 69. The minimum length of a return buttressing wall should be equal to one-sixth of the height of the supported wall.

To be effective as buttresses to walls the return walls, piers and chimneys must be solidly bonded to the supported wall.

Chases in walls

To limit the effect of chases cut into walls in reducing strength or stability, vertical chases should not be deeper than one-third of the thickness of solid walls or a leaf of a cavity wall and horizontal chases not deeper than one-sixteenth. A chase is a recess, cut or built in a wall, inside which small service pipes are run and then covered with plaster or walling.

CAVITY WALLS

Resistance to weather

Between 1920 and 1940 it became more usual for external walls of small buildings to be constructed as cavity walls with an outer leaf of brick or block, an open cavity and an inner leaf of brick or block. The outer leaf and the cavity serve to resist the penetration of rain to the inside face and the inner leaf to support floors, provide a solid internal wall surface and to some extent act as insulation against transfer of heat.

The idea of forming a vertical cavity in brick walls was first proposed early in the nineteenth century and developed through the century. Various widths of cavity were proposed from the first 6 inch cavity, a later 2 inch cavity followed by proposals for 3, 4 or 5 inch wide cavities. The early cavity walls were first constructed with bonding bricks laid across the cavity at intervals, to tie the two leaves together. Either whole bricks with end closers or bricks specially made to size and shape for the purpose were used. Later on, during the middle of the century, iron ties were used instead of bond bricks and accepted as being adequate to tie the two leaves of cavity walls.

From the middle of the twentieth century it became common practice to construct the external walls of houses as a cavity wall with a 2 inch wide cavity and metal wall ties. It seems that the 2 inch width of cavity was adopted for the convenience of determining the cavity width, by placing a brick on edge inside the cavity so that the course height of a brick, about 65 mm, determined cavity width rather than any consideration of the width required to resist rain penetration. This was adapted to the 2 inch (50 mm) wide cavity for walls that became common until recent years.

In constructing the early open cavity walls it was considered good practice to suspend a batten of wood in the cavity to collect mortar droppings. The batten was removed from time to time, cleaned of mortar, and put back in the cavity as the work progressed. The practice, which was largely ignored by bricklayers as it impeded work, has since been abandoned in favour of care in workmanship to avoid mortar droppings becoming lodged inside the cavity.

With the increase in the price of fuels and expectations of thermal comfort, building regulations have of recent years made requirements for the thermal insulation of external walls that can best be met by the introduction of materials with high thermal resistance. The most convenient position for these lightweight materials in a cavity wall is inside the cavity, which is either fully or partially filled with insulation. A filled or partially filled cavity may well no longer be an efficient barrier to rain penetration so that, with the recent increase in requirement for the thermal insulation of walls it has now been accepted that the width of the cavity may be increased from the traditional 50 to 100 mm to accommodate increased thickness of insulation and still maintain a cavity against rain penetration.

Strength and stability

The practical guidance in Approved Document A to the Building Regulations accepts a cavity of from 50 to 100 mm for cavity walls having leaves at least 90 mm thick, built of coursed brickwork or blockwork with wall ties spaced at 450 mm vertically and from 900 to 750 mm horizontally for cavities of 50 to 100 mm wide respectively. As the limiting conditions for the thickness of walls related to height and length are the same for a solid bonded wall 190 mm thick as they are for a cavity wall of two leaves each 90 mm thick, it is accepted that the wall ties give the same strength and stability to two separate leaves of brickwork that the bond in solid walls does.

Wall ties

Iron ties which were used to tie the leaves of the early cavity walls were later replaced by mild steel ties that became standard for many years.

In contact with moisture, mild steel progressively corrodes by the formation of oxide of iron, called rust, which expands fiercely to the extent that brickwork around ties may become rust stained and disintegrate. Standard mild steel ties are coated with zinc to inhibit rust corrosion. The original zinc coating for ties, which was comparatively thin, has been increased in thickness in the current British Standard Specification, for improved resistance to corrosion. As added protection, the range of standard wall ties can be coated with plastic on a galvanised undercoating.

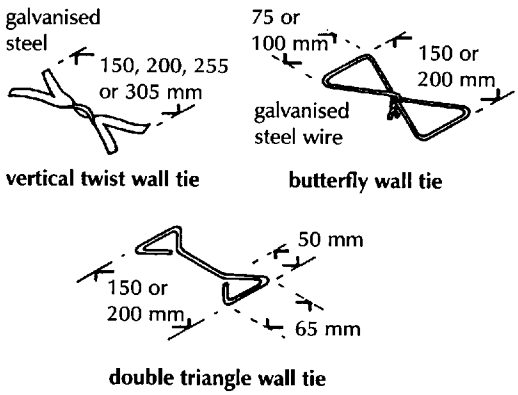


Fig. 70 Cavity wall ties.

On the majority of building sites wall ties are not commonly protected during delivery, storage, handling and use against the inevitable knocks that may perforate the toughest coating to mild steel and the consequent probability of rust occurring. There are, on the market, a range of standard and non-standard section wall ties made from stainless steel that will not suffer corrosion rusting during the useful life of buildings. It seems worthwhile to make the comparatively small additional expenditure on stainless steel ties as a precaution against staining and spalling of brickwork or blockwork around rusting mild steel ties.

The standard section wall ties, illustrated in Fig. 70, are the vertical twist strip, the butterfly and double triangle wire ties. As a check to moisture that may pass across the tie, the butterfly type is laid with the twisted wire ends hanging down into the cavity to act as a drip. The double triangle tie may have a bend in the middle of its length and the strip tie has a twist as a barrier to moisture passing across the tie. Of the three standard types the butterfly is more likely to collect mortar droppings than the others.

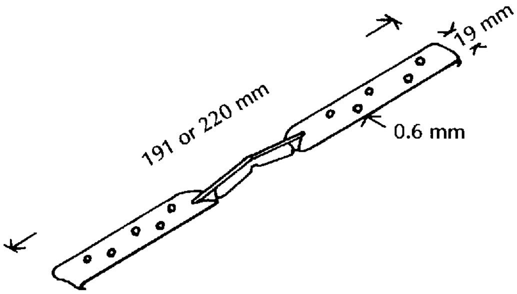


Fig. 71 Stainless steel wall tie.

The wall tie illustrated in Fig. 71 is made from corrosion resistant Austenitic stainless steel. The ridge at the centre of the length of the tie is designed for strength and to provide as small as possible a surface for the collection of mortar droppings. The perforations are to improve bond to mortar.

The length of wall ties varies to accommodate different widths of cavity and the thickness of the leaves of cavity walls. For a 50 mm cavity with brick leaves, a 191 mm or 200 mm long tie is made. For a 100 mm cavity with brick leaves, a 220 mm long tie is used.

Spacing of ties

The spacing of wall ties built across the cavity of a cavity wall is usually 900 mm horizontally and 450 mm vertically, or 2.47 ties per square metre, and staggered, as illustrated in Fig. 72, for the conventional 50 mm wide cavity, with the spacing reduced to 300 mm around the sides of openings. In Approved Document A to the Building Regulations, the practical guidance for the spacing of ties is given as 900 and 450 mm horizontally and vertically for 50 to 75 mm cavities, 750 and 450 mm horizontally and vertically for cavities from 76 to 100 mm wide and 300 mm vertically at unbonded jambs of all openings in cavity walls within 150 mm of openings to all widths of cavities.

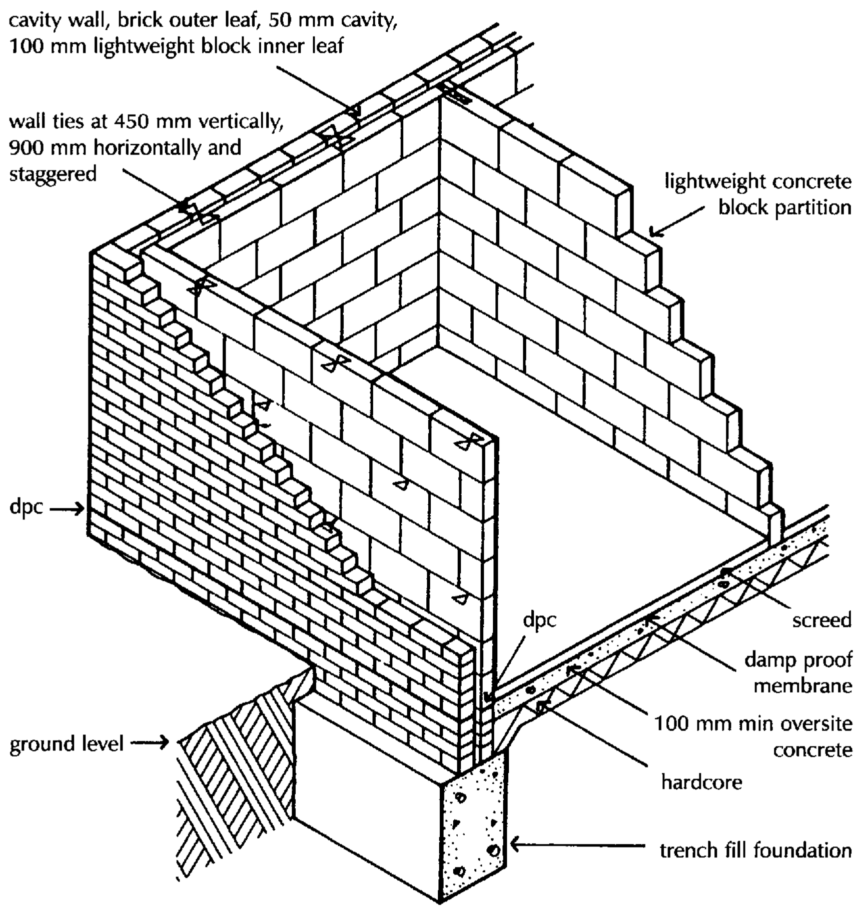


Fig. 72 Cavity wall.

Openings in walls

The practical guidance in Approved Document A in regard to openings in walls states that the number, size and position of openings should not impair the stability of a wall to the extent that the combined width of openings in walls between the centre line of buttressing walls or piers should not exceed two-thirds of the length of that wall together with more detailed requirements limiting the size of opening and recesses. There is a requirement that the bearing end of lintels with a clear span of 1200 mm or less may be 100 mm and above that span, 150 mm.

Figure 73 is an illustration of a window opening in a brick wall with the terms used to describe the parts noted.

For strength and stability the brickwork in the jambs of openings has to be strengthened with more closely spaced ties and the wall over the head of the opening supported by an arch, lintels or beams. The term jamb derives from the French word jambe, meaning leg. From Fig. 73, it will be seen that the brickwork on either side of the opening acts like legs which support brickwork over the head of the opening. The term jamb is not used to describe a particular width either side of openings and is merely a general term for the brickwork for full height of opening either side of the window. The word 'reveal' is used more definitely to describe the thickness of the wall revealed by cutting the opening and the reveal is a surface of brickwork as long as the height of the opening. The lower part of the opening is a cill for windows or a threshold for doors.

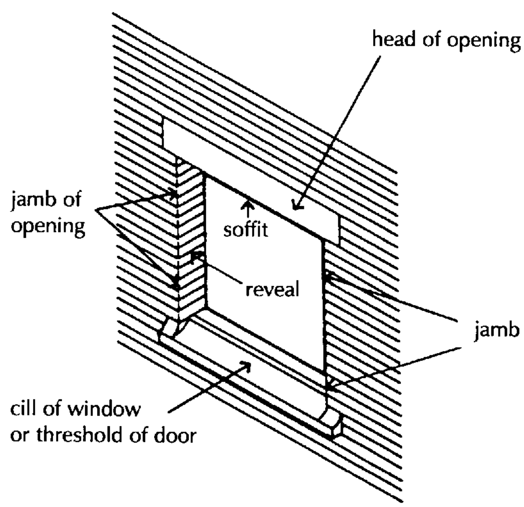


Fig. 73 Opening in wall.

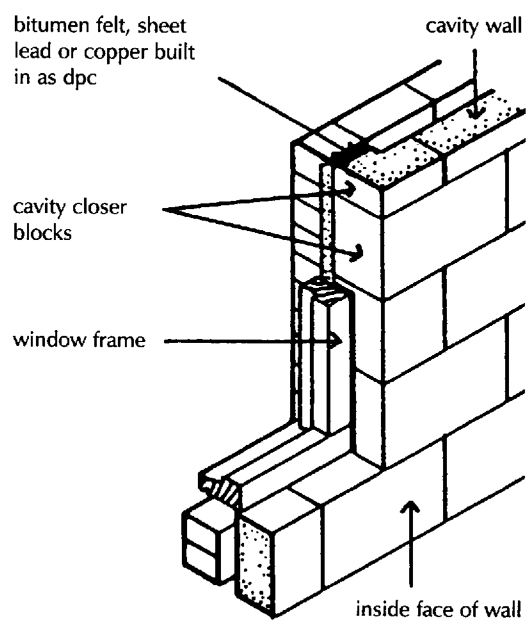


Fig. 74 Solid closing of cavity at jambs.

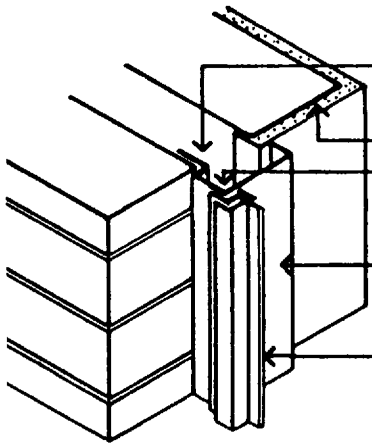


Fig. 75 Cavity closed with frame.

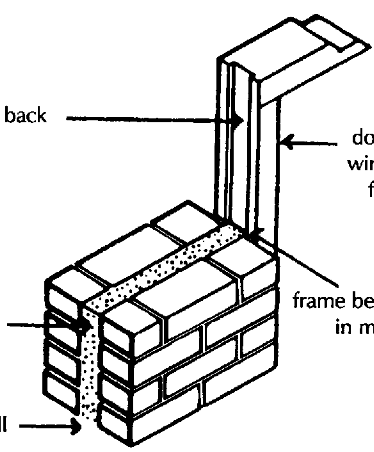


Fig. 76 Cavity fill insulation.

The jambs of openings may be plain or square into which the door or window frames are built or fixed or they may be rebated with a recess, behind which the door or window frame is built or fixed.

The cavity in a cavity wall serves to prevent penetration of water to the inner leaf. In the construction of the conventional cavity wall, before the adoption of cavity insulation, it was considered wise to close the cavity at the jambs of openings to maintain comparatively still air in the cavity as insulation. It was practice to build in cut bricks or blocks as cavity closers. To prevent penetration of water through the solid closing of cavity walls at jambs, a vertical dpc was built in as illustrated in Fig. 74. Strips of bitumen felt or lead were nailed to the back of wood frames and bedded between the solid filling and the outer leaf as shown.

As an alternative to solidly filling the cavity at jambs with cavity closers, window or door frames were used to cover and seal the cavity. Pressed metal subframes to windows were specifically designed for this purpose, as illustrated in Fig. 75. With mastic pointing between the metal subframe and the outer reveal, this is a satisfactory way of sealing cavities.

At the time when it first became common practice to fill the cavity solidly at jambs, there was no requirement for the insulation of walls. When insulation first became a requirement it was met by the use of lightweight, insulating concrete blocks as the inner leaf and the practice of solid filling of cavity at jambs, with a vertical dpc continued.

With the increasing requirement for insulation it has become practice to use cavity insulation as the most practical position for a layer of lightweight material. If the cavity insulation is to be effective for the whole of the wall it must be continued up to the back of window and door frames, as a solid filling of cavity at jambs would be a less effective insulator and act as a thermal or cold bridge.

With the revision of the requirement of the Building Regulations for enhanced insulation down to a standard U value of $0.45\,W/m^2K$ for the walls of dwellings it has become practice to use cavity insulation continued up to the frames of openings, as illustrated in Fig. 76, to avoid the cold bridge effect caused by solid filling. Door and window frames are set in position to overlap the outer leaf with a resilient mastic pointing as a barrier to rain penetration between the frame and the jamb. With a cavity 100 mm wide and cavity insulation as partial fill, it is necessary to cover that part of the cavity at jambs of openings, that is not covered by the frame. This can be effected by covering the cavity with plaster on metal lath or by the use of jamb linings of wood, as illustrated in Fig. 77.

With this form of construction at the jambs of openings there is no purpose in forming a vertical dpc at jambs.

The advantages of the wide cavity is that the benefit of the use of the cavity insulation can be combined with the cavity air space as resistance to the penetration of water to the inside face of the wall.

Cills and thresholds of openings

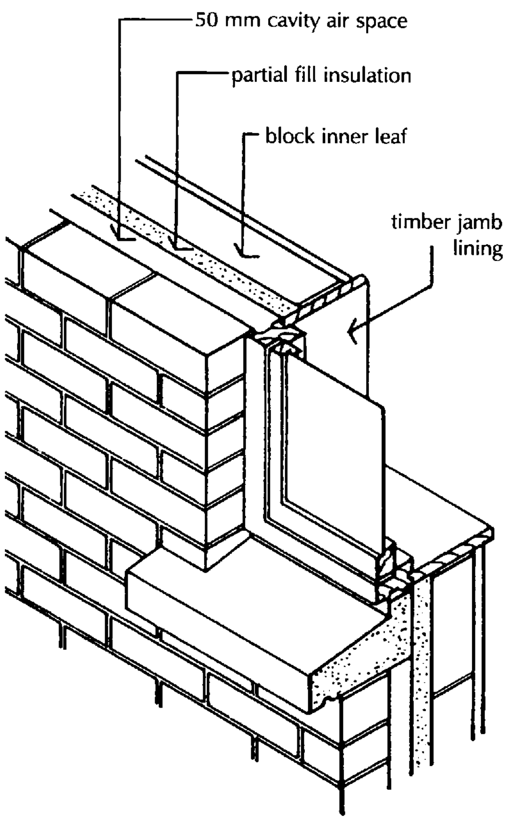


Fig. 77 Jamb lining to wide cavity.

A cill is the horizontal finish to the wall below the lower edge of a window opening on to which wind driven rain will run from the hard, smooth, impermeable surface of window glass. The function of a cill is to protect the wall below a window. Cills are formed below the edge of a window and shaped or formed to slope out and project beyond the external face of the wall, so that water runs off. The cill should project at least 45 mm beyond the face of the wall below and have a drip on the underside of the projection.

The cavity insulation shown in Fig. 77 is carried up behind the stone cill to avoid a cold bridge effect and a dpc is fixed behind the cill as a barrier to moisture penetration.

A variety of materials may be used as a cill such as natural stone, cast stone, concrete, tile, brick and non-ferrous metals. The choice of a particular material for a cill depends on cost, availability and to a large extent on appearance. Details of the materials used and the construction of cills are given in Volume 2.

As a barrier to the penetration of rain to the inside face of a cavity wall it is good practice to continue the cavity up and behind the cills as illustrated in Volume 2. Where cills of stone, cast stone and concrete are used the cill may extend across the cavity. As a barrier to rain penetration it has been practice to bed a dpc below these cills and extend it up behind the cill, as illustrated in Volume 2. Providing the cill has no joints in its length, its ends are built in at jambs and the material of the cill is sufficiently dense to cause most of the rainwater to run off, there seems little purpose in these under sill dpcs or trays.

The threshold to door openings serves as a finish to protect a wall or concrete floor slab below the door, as illustrated in Volume 2. Thresholds are commonly formed as part of a step up to external doors as part of the concrete floor slab with the top surface of the threshold sloping out. Alternatively, a natural stone or cast stone threshold may be formed.

Head of openings in cavity walls

The brickwork and blockwork over the head of openings in cavity walls has to be supported. Because of the bonding of brickwork and blockwork over the opening it is necessary to provide support for the weight of the brickwork or blockwork within a 45° isosceles triangle formed by the stretcher bond and the weight of floors and roofs carried by the wall over the opening.

The comparatively small loads over small openings are carried by a lintel or arch. With the adoption of cavity insulation as a principal method of enhancing the resistance of walls to the transfer of heat and the need to continue cavity insulation up to the back of window and door frames to minimise cold bridges, it is practice today to use lintels to support the inner and outer leaves over openings.

Steel lintels

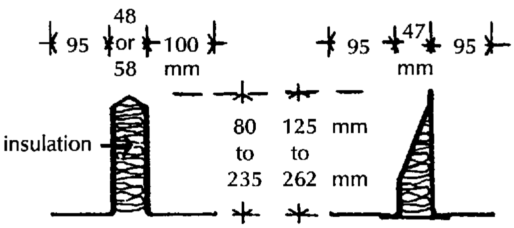


Fig. 78 Lintels for cavity walls.

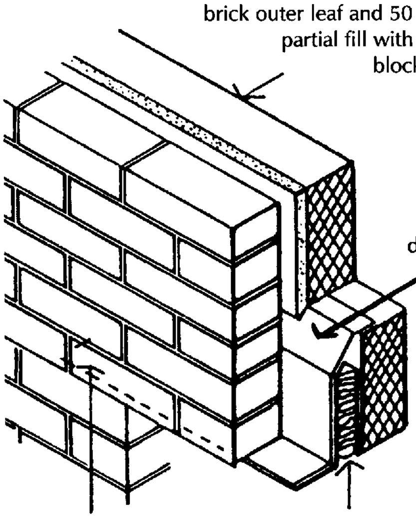


Fig. 79 Top hat lintel.

Most loadbearing brick or blockwork walls over openings, where the cavity insulation is continued down to the head of the window or door frame, are supported by steel section lintels. The advantage of these lintels is that they are comparatively lightweight and easy to handle, they provide adequate support for walling over openings in small buildings and once they are bedded in place the work can proceed without delay. Because of their ease of handling and use these lintels have largely replaced concrete lintels.

The lintels are formed either from mild steel strip that is pressed to shape, and galvanised with a zinc coating to inhibit rust, or from stainless steel. The lintels for use in cavity walling are formed with either a splay to act as an integral damp-proof tray or as a top hat section over which a damp-proof tray is dressed. Typical sections are illustrated in Fig. 78.

The splay section lintels are galvanised and coated with epoxy powder coating as corrosion protection and the top hat section with a galvanised coating. For insulation the splay section and top hat section lintels are filled with expanded polystyrene.

The top hat section steel lintel is built into the jambs of both the inner and outer leaf to provide support for both leaves of the cavity wall, as illustrated in Fig. 79. The two wings at the bottom of the lintel provide support for the brick outer and block inner leaves over the comparatively narrow openings for windows and doors. Where the cavity is partly filled with insulation it is usual to dress a flexible dpc from the block inner leaf down to a lower brick course or down to the underside of the brick outer leaf. The purpose of the damp-proof course or tray is to collect any water that might penetrate the outer leaf and direct it to weep holes in the wall.

The splay section lintel is built into the jambs of openings to provide support for the outer and inner leaf of the cavity wall over the

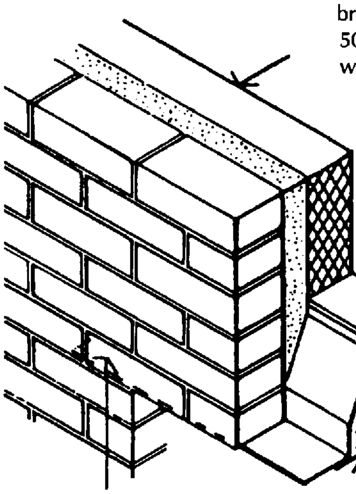


Fig. 80 Splay lintel.

openings, as illustrated in Fig. 80. Where the cavity is filled with insulation there is no need to build in a damp-proof course or tray. Any water that might penetrate the outer leaf will be directed towards the outside by the splay of the lintel.

Unless the window or door frame is built-in or fixed with its external face close to the outside face of the wall, the edge of the wing of the lintel will be exposed on the soffit of the opening. In handling and building in, there is a possibility that the edge of this wing might suffer damage to the protective galvanised coating. On the external face of a wall, water may penetrate the zinc coat and cause corrosion of the steel below. Rust very quickly spreads around the initial fracture of the protective coating. It is worthwhile making the comparatively small outlay on a stainless steel lintel as insurance against a possibly much larger expenditure on replacement of a corroded galvanised steel lintel.

Fairface brickwork supported by steel lintels may be laid as horizontal course brickwork or as a flat brick on edge or end lintel.

Concrete lintels

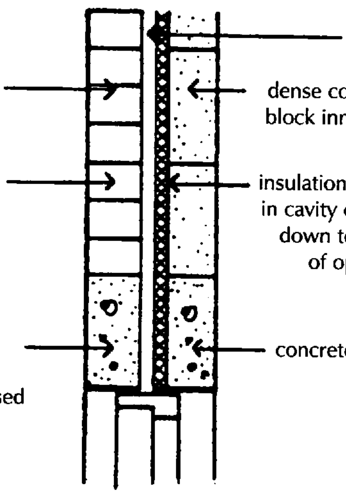


Fig. 81 Concrete lintels.

As an alternative to the use of steel lintels reinforced concrete lintels may be used to support the separate leaves over openings. This construction may be used where the appearance of a concrete lintel over openings in fairface brick is acceptable and where an outer leaf of brick or block is to be rendered to enhance protection against rain penetration or for appearance sake.

A range of precast reinforced concrete lintels is available to suit the widths of most standard door and window openings with adequate allowance for building in ends of lintels each side of openings. For use with fairface brickwork the lintel depth should match the depth of brick course heights to avoid untidy cutting of bricks around lintel ends.

These comparatively lightweight lintels are bedded on walling as support for outer and inner leaves.

The partial fill cavity insulation shown in Fig. 81 is carried down between the leaves of the wall to the head of the window or door frame.

Cavity trays

In positions of severe exposure to wind driven rain, the outer leaf of a cavity wall may absorb water to the extent that rainwater penetrates to the cavity side of the outer leaf. It is unlikely, however, that water will enter the cavity unless there are faults in construction.

Where the mortar joints in the outer leaf of a cavity wall are inadequately flushed up with mortar, or the bricks in the outer leaf are grossly porous and where the wall is subject to severe or very severe exposure, there is a possibility that wind driven rain may penetrate through the outer leaf to the cavity.

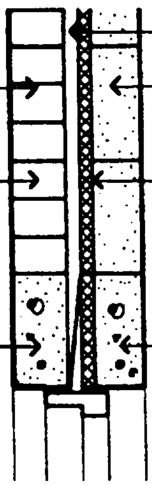


Fig. 82 Dpc and tray.

Where rain penetrates the outer leaf and enters the cavity, it is certain that either the construction of the wall is poorly executed, or the bricks have been unwisely chosen or the outer leaf is of inadequate thickness for the position of exposure in which it is built. The solution is to choose some alternative form of construction such as a thicker outer leaf, more suited to the position of exposure.

Some consider it good practice to use some form of impermeable cavity tray above all horizontal breaks in a cavity wall against the possibility of rainwater penetrating the outer leaf. The dubious argument is that freely flowing water may enter the cavity in sufficient volume and run down on to horizontal breaks in walls, such as openings, and cause damp staining. Having been persuaded that it is sense to accept this idea, it has become common practice to build in some form of damp-proof course or tray of flexible, impermeable material to direct freely flowing water out to the external face of walls. A strip of polymer based polythene, bitumen felt or sheet lead is used for the purpose. The dpc and tray shown in Fig. 82 is built in at the top of the inner lintel and dressed down to the underside of the outer lintel over the head of the window. As an alternative the dpc tray could be built in on top of the second block course and dressed down to the top of the outer lintel, with weep holes in the vertical brick joints.

If there were a real need for these trays it would be common to observe the evidence of water seeping through these weep holes to the outer face of cavity walls. No such evidence exists where cavity walls are sensibly designed and soundly constructed. A disadvantage of the weep holes is that cold air may enter and cool the air space and increase thermal transmission.

Where the cavity is solidly filled with insulation any water penetrating the outer leaf will be trapped between closed cell insulation and the wall or saturate open cell insulation.

Good sense dictates that the notion of the dpc trays in cavity walls be abandoned.

Resistance to the passage of heat

Because thin solid walls of brick or block may offer poor resistance to the penetration of wind driven rain, many loadbearing walls are built with two leaves of brick or block separated by a cavity, whose prime purpose is as a barrier to rain penetration.

Because the resistance to the passage of heat of a cavity wall by itself is poor, it is necessary to introduce a material with high resistance to heat transfer to the wall construction.

Most of the materials, thermal insulators, that afford high resistance to heat transfer are fibrous or cellular, lightweight, have comparatively poor mechanical strength and are not suitable by themselves for use as part of the wall structure. The logical position for such material in a cavity wall, therefore, is inside the cavity.

Cavity wall insulation

Partial fill

The purpose of the air space in a cavity wall is as a barrier to the penetration of rainwater to the inside face of the wall. If the clear air space is to be effective as a barrier to rain penetration it should not be bridged by anything other than cavity ties. If the cavity is then filled with some insulating material, no matter how impermeable to water the material is, there will inevitably be narrow capillary paths around wall ties and between edges of insulation boards or slabs across which water may penetrate. As a clear air space is considered necessary as a barrier to rain penetration there is good reason to fix insulation material inside a cavity so that it only partly fills the cavity and a cavity is maintained between the outer leaf and the insulating material. This construction, which is described as partial fill insulation of cavity, requires the use of some insulating material in the form of boards that are sufficiently rigid to be secured against the inner leaf of the cavity.

In theory a 25 mm wide air space between the outer leaf and the cavity insulation should be adequate to resist the penetration of rain providing the air space is clear of all mortar droppings and other building debris that might serve as a path for water. In practice, it is difficult to maintain a clear 25 mm wide air gap because of protrusion of mortar from joints in the outer leaf and the difficulty of keeping so narrow a space clear of mortar droppings. Good practice, therefore, is to use a 50 mm wide air space between the outer leaf and the partial fill insulation.

To meet insulation requirements and the use of a 100 mm cavity with partial fill insulation it may be economic to use a lightweight block inner leaf to augment the cavity insulation to bring the wall to the required U value.

Usual practice is to build the inner leaf of the cavity wall first, up to the first horizontal row of wall ties, then place the insulation boards in position against the inner leaf. Then as the outer leaf is built, a batten may be suspended in the cavity air space and raised to the level of the first row of wall ties and the batten is then withdrawn and cleared of droppings. Insulation retaining wall ties are then bedded across the cavity to tie the leaves and retain the insulation in position and the sequence of operations is repeated at each level of wall ties.

The suspension of a batten in the air space and its withdrawal and cleaning at each level of ties does considerably slow the process of brick and block laying.

Insulation retaining ties are usually standard galvanised steel or stainless steel wall ties to which a plastic disc is clipped to retain the edges of the insulation, as illustrated in Fig. 83. The ties may be set in line one over the other at the edges of boards, so that the retaining clips retain the corners of four insulation boards.

The materials used for partial fill insulation should be of boards, slabs or batts that are sufficiently rigid for ease of handling and to be retained in a vertical position against the inner leaf inside the cavity without sagging or losing shape, so that the edges of the boards remain close butted throughout the useful life of the building. For small dwellings the Building Regulations do not limit the use of combustible materials as partial fill insulation in a cavity in a cavity wall.

To provide a clear air space of 50 mm inside the cavity as a barrier to rain penetration and to provide sufficient space to keep the cavity clear during building, an insulant with a low U value is of advantage if a nominal 75 mm wide cavity is formed between the outer and inner leaves.

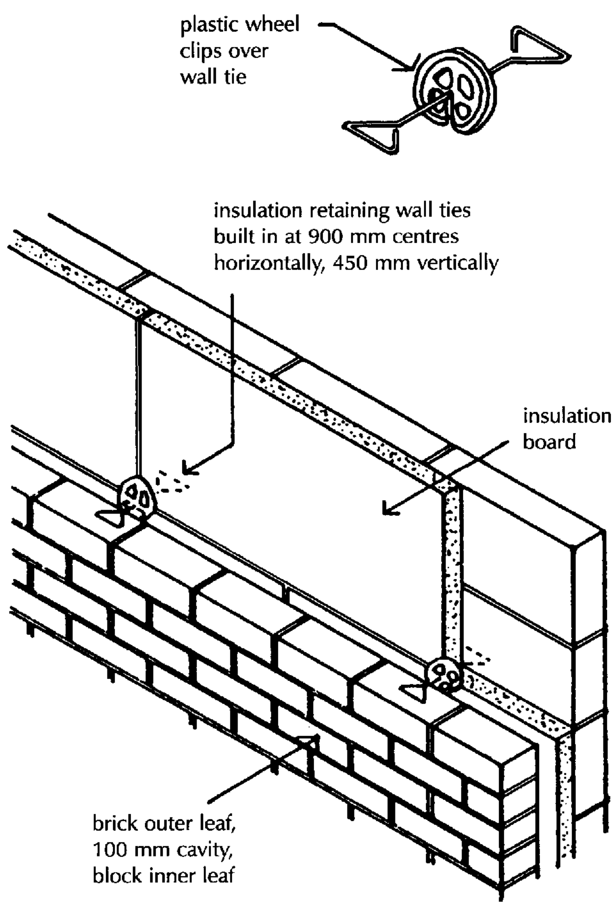


Fig. 83 Partial fill cavity insulation.

Insulation materials

The materials used as insulation for the fabric of buildings may be grouped as inorganic and organic insulants.

Inorganic insulants are made from naturally occurring materials that are formed into fibre, powder or cellular structures that have a high void content, as for example, glass fibre, mineral fibre (rockwool), cellular glass beads, vermiculite, calcium silicate and magnesia or as compressed cork.

Inorganic insulants are generally incombustible, do not support spread of flame, are rot and vermin proof and generally have a higher U value than organic insulants.

The inorganic insulants most used in the fabric of buildings are glass fibre and rockwool in the form of loose fibres, mats and rolls of felted fibres and semi-rigid and rigid boards, batts and slabs of compressed fibres, cellular glass beads fused together as rigid boards, compressed cork boards and vermiculite grains.

Organic insulants are based on hydrdocarbon polymers in the form of thermosetting or thermoplastic resins to form structures with a high void content, as for example polystyrene, polyurethane, isocyanurate and phenolic. Organic insulants generally have a lower U value than inorganic insulants, are combustible, support spread of flame more readily than inorganic insulants and have a comparatively low melting point.

The organic insulants most used for the fabric of buildings are expanded polystyrene in the form of beads or boards, extruded polystyrene in the form of boards and polyurethane, isocyanurate and phenolic foams in the form of preformed boards or spray coatings.

The materials that are cheapest, most readily available and used for cavity insulation are glass fibre, rockwool and EPS (expanded polystyrene), in the form of slabs or boards, in sizes to suit cavity tie spacing. With the recent increase in requirements for the insulation of walls it may well be advantageous to use one of the somewhat more expensive organic insulants such as XPS (extruded polystyrene), PIR (polyisocyanurate) or PUR (polyurethane) because of their lower U value, where a 50 mm clear air space is to be maintained in the cavity, without greatly increasing the overall width of the cavity.

Table 4 gives details of insulants made for use as partial fill to cavity walls.

Insulation thickness

A rough guide to determine the required thickness of insulation for a wall to achieve a U value of 0.45 W/m^{2}K is to assume the insulant provides the whole or a major part of the insulation by using 30 mm thickness with a U value of 0.02, 46 with 0.03, 61 with 0.04, 76 with 0.05 and 92 with 0.06 W/m^{2}K.

Table 4 Insulating materials.

Cavity wall partial fill	Thickness mm	U valve W/m²K
Glass fibre rigid slab 455 × 1200 mm	30, 35, 40, 45	0.033
Rockwool rigid slab 455 × 1200 mm	30, 40, 50	0.033
Cellular glass 450 × 600	40, 45, 50	0.042
EPS boards 450 × 1200 mm	25, 40, 50	0.037
XPS boards 450 × 1200 mm	25, 30, 50	0.028
PIR boards 450 × 1200 mm	20, 25, 30, 35, 50	0.022
PUR boards 450 × 1200 mm	20, 25, 30, 35, 40, 50	0.022

EPS expanded polystyrene
XPS extruded polystyrene
PIR rigid polyisocyanurate
PUR rigid polyurethane

A more exact method is by calculation as follows.

Thermal resistance required $= \frac{1}{0.45} = 2.22\,\text{m}^2\text{K/W}$

Thermal resistance of construction is:

external surface	$0.06\,\text{m}^2\text{K/W}$
102 brick outer leaf	0.12
cavity at least 50	0.18
115 block inner leaf	1.05
13 plasterboard	0.03
inside surface	0.12
Total	1.56

Additional resistance to be provided by insulation $= 2.22 - 1.56$
$= 0.66\,\text{m}^2\text{K/W}$

Assuming insulation with a U value of 0.03, then the thickness of insulation required $= 0.66 \times 0.03 \times 1000 = 19.8$ mm. This thickness is about one-third of that proposed by the first method that takes little account of the resistance of the rest of the wall construction.

Total fill

The thermal insulation of external walls by totally filling the cavity has been in use for many years. There have been remarkably few reported incidents of penetration of water through the total fill of cavities to the inside face of walls and the system of total fill has become an accepted method of insulating cavity walls.

The method of totally filling cavities with an insulant was developed after the steep increase in the price of oil and other fuels in the mid-1960s, as being the most practical way to improve the thermal insulation of existing cavity walls. Small particles of glass or rock wool fibre or foaming organic materials were blown through holes drilled in the outer leaf of existing walls to completely fill the cavity.

This system of totally filling the cavity of existing walls has been very extensively and successfully used. The few reported failures due to penetration of rainwater to the inside face were due to poor workmanship in the construction of the walls. Water penetrated across wall ties sloping down into the inside face of the wall, across mortar droppings bridging the cavity or from mortar protruding into the cavity from the outer leaf.

From the few failures due to rain penetration it would seem likely that the cavity in existing walls that have been totally filled was of little, if any, critical importance in resisting rain penetration in the position of exposure in which the walls were situated. None the less it is wise to provide a clear air space in a cavity wherever practical, against the possibility of rain penetration.

Where insulation is used to fill totally a nominal 50 mm wide cavity there is no need to use insulation retaining wall ties.

With a brick outer and block inner leaf it is preferable to raise the outer brick leaf first so that mortar protrusions from the joints, sometimes called snots, can be cleaned off before the insulation is placed in position and the inner block leaf, with its more widely spaced joints is built, to minimise the number of mortar snots that may stick into the cavity. This sequence of operations will require scaffolding on both sides of the wall and so add to the cost.

Insulation that is built in as the cavity walls are raised, to fill the cavity totally, will to an extent be held in position by the wall ties and the two leaves of the cavity wall. Rolls or mats of loosely felted glass fibre or rockwool are often used. There is some likelihood that these materials may sink inside the cavity and gaps may open up in the insulation and so form cold bridges across the wall. To maintain a continuous, vertical layer of insulation inside the cavity one of the mineral fibre semi-rigid batts or slabs should be used. Fibre glass and rockwool semi-rigid batts or slabs in sizes suited to cavity tie spacing are made specifically for this purpose.

As the materials are made in widths to suit vertical wall tie spacing there is no need to push them down into the cavity after the wall is built, as is often the procedure with loose fibre rolls and mats, and so displace freshly laid brick or blockwork. There is no advantage in using one of the more expensive organic insulants such as XPS, PIR or PUR that have a lower U value than mineral fibre materials for the total cavity fill, as the width of the cavity can be adjusted to suit the required thickness of insulation.

The most effective way of insulating an existing cavity wall is to fill the cavity with some insulating material that can be blown into the cavity through small holes drilled in the outer leaf of the wall. The injection of the cavity fill is a comparatively simple job. The complication arises in forming sleeves around air vents penetrating the wall and sealing gaps around openings.

When filling the cavity of existing walls became common practice, a foamed organic insulant, ureaformaldehyde, was extensively used. The advantage of this material was that it could be blown, under pressure, through small holes in the outer leaf and as the constituents mixed they foamed and filled the cavity with an effective insulant. This material was extensively used, often by operatives ill trained in the sensible use of the material. The consequence was that through careless mixing of the components of the insulant and careless workmanship, the material gave off irritant fumes when used and later, when it was in place, these entered buildings and caused considerable distress to the occupants. Approved Document D of the Building Regulations details provisions for the use of this material in relation to the construction of the wall and its suitability, the composition of the materials, and control of those carrying out the work. As a result of past failures this material is less used than it was.

Glass fibre, granulated rockwool of EPS beads are used for the injection of insulation for existing cavity walls. These materials can also be used for blowing into the cavity of newly built walls.

Table 5 gives details of insulants for total cavity fill.

The required thickness of insulation can be taken from the two methods suggested for partial fill. In a calculation for total fill, the thermal resistance of the cavity is omitted.

Thermal bridge

A thermal bridge, more commonly known as a cold bridge in cold climates, is caused by appreciably greater thermal conductivity through one part of a wall than the rest of the wall. Where the cavity in a wall is partially or totally filled with insulation and the cavity is bridged with solid filling at the head, jambs or cill of an opening, there will be considerably greater transfer of heat through the solid filling than through the rest of the wall. Because of the greater transfer of

Table 5 Insulating materials.

Cavity wall total fill	Thickness mm	U value W/m²K
Glass fibre		
semi-rigid batt 455 × 1200 mm	50, 65, 75, 100	0.036
glass fibres for blown fill		0.039
Rockwool		
semi-rigid batt 455 × 900 mm	50, 65, 75, 100	0.036
granulated for blown fill		0.037
EPS		
beads for blown fill		0.04

EPS expanded polystyrene

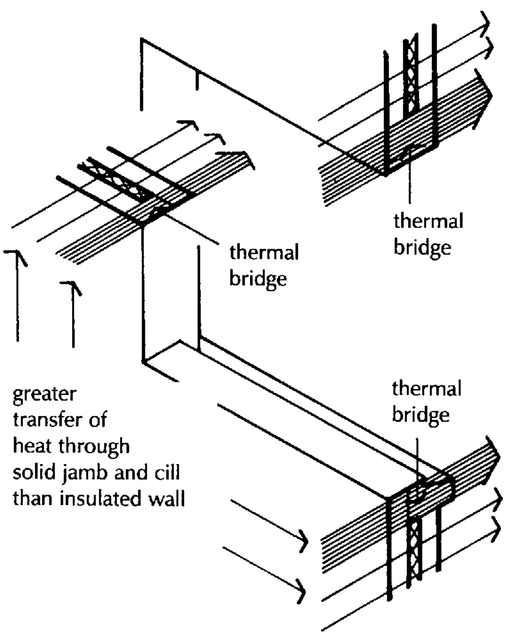


Fig. 84 Thermal bridge.

heat through the solid filling illustrated in Fig. 84, the inside face of the wall will be appreciably colder in winter than the rest of the wall and cause some loss of heat and encourage warm moist air to condense on the inside face of the wall on the inside of the cold bridge. This condensation water may cause unsightly stains around openings and encourage mould growth.

Thermal bridges around openings can be minimised by continuing cavity insulation to the head of windows and doors and to the sides and bottom of doors and windows.

Of late an inordinate fuss has been made about 'cold bridges' as though a cold bridge was some virulent disease or a heinous crime.

Solid filling of cavities around openings will allow greater transfer of heat than the surrounding insulated wall and so will window glass, both single and double, and window frames. To minimise heat transfer, cavity insulation should continue up to the back of window and door frames.

Where solid filling of cavities around openings is used the area of the solid filling should be included with that of the window and its frame for heat loss calculation.

SOLID WALLS

Up to the early part of the twentieth century walls were generally built as solid brickwork of adequate thickness to resist the penetration of rain to the inside face and to safely support the loads common to buildings both large and small.

At the time it was accepted that the interior of buildings would be cold during winter months when heating was provided by open fires and stoves, fired by coal or wood, to individual rooms. The people of northern Europe accepted the inevitability of a degree of indoor cold and dressed accordingly in thick clothing both during day and night time. There was an adequate supply of coal and wood to meet the expectations for some indoor heating for the majority.

The loss of heat through walls, windows and roofs was not a concern at the time. Thick curtains drawn across windows and external doors provided some appreciable degree of insulation against loss of heat.

From the middle of the twentieth century it became practical to heat the interior of whole buildings, with boilers fired by oil or gas. It is now considered a necessity to be able to heat the whole of the interior of dwellings so that the commonplace of icy cold bathrooms and corridors is an experience of the past.

In recent years an industry of scare stories has developed. Ill considered and unscientific claims by 'experts' that natural resources of fossil fuels such as oil and gas will soon be exhausted have been broadcast. These dire predictions have prompted the implementation of regulations to conserve fuel and power by introducing insulating materials to the envelope of all new buildings that are usually heated.

This 'bolting the stable door after the horse has gone' action will for very many years to come only affect new buildings, a minority of all buildings.

A consequence is that the cavity in external walls of buildings, originally proposed to exclude rain, has been converted to function as a prime position for lightweight insulating materials with exclusion of rain a largely ignored function of a cavity wall.

Resistance to weather

A solid wall of brick will resist the penetration of rain to its inside face by absorbing rainwater that subsequently, in dry periods, evaporates to outside air. The penetration of rainwater into the thickness of a solid wall depends on the exposure of the wall to driving rain and the permeability of the bricks and mortar to water.

The permeability of bricks to water varies widely and depends largely on the density of the brick. Dense engineering bricks absorb rainwater less readily than many of the less dense facing bricks. It would seem logical, therefore, to use dense bricks in the construction of walls to resist rain penetration.

In practice, a wall of facing bricks will generally resist the penetration of rainwater better than a wall of dense bricks. The reason for this is that a wall of dense bricks may absorb water through fine cracks between dense bricks and dense mortar, to a considerable depth of the thickness of a wall, and this water will not readily evaporate through the fine cracks to outside air in dry periods, whereas a wall of less dense bricks and mortar will absorb water to some depth of the thickness of the wall and this water will substantially evaporate to outside air. It is not unknown for a wall of dense bricks and mortar to show an outline of damp stains on its inside face through persistent wetting, corresponding to the mortar joints.

The general rule is that to resist the penetration of rain to its inside face a wall should be constructed of sound, well burned bricks of moderate density, laid in a mortar of similar density and of adequate thickness to prevent the penetration of rain to the inside face.

A solid 1 B thick wall may well be sufficiently thick to prevent the penetration of rainwater to its inside face in the sheltered positions common to urban settlements on low lying land. In positions of moderate exposure a solid wall $1\frac{1}{2}$ B thick will be effective in resisting the penetration of rainwater to its inside face.

In exposed positions such as high ground and near the coast a wall 2 B thick may be needed to resist penetration to inside faces. A wall 2 B thick is more than adequate to support the loads of all but heavily loaded structures and for resistance to rain penetration a less thick wall protected with rendering or slate or tile hanging is a more sensible option.

External weathering to walls of brick and block

In exposed positions such as high ground, on the coast and where there is little shelter from trees, high ground or surrounding buildings it may well be advisable to employ a system of weathering on the outer face of both solid and cavity walling to provide protection against wind driven rain. The two systems used are external rendering and slate or tile hanging.

Rendering

The word rendering is used in the sense of rendering the coarse texture of a brick or block wall smooth by the application of a wet mix of lime, cement and sand over the face of the wall, to alter the appearance of the wall or improve its resistance to rain penetration, or both. The wet mix is spread over the external wall face in one, two or three coats and finished with either a smooth, coarse or textured finish while wet. The rendering dries and hardens to a decorative or protective coating that varies from dense and smooth to a coarse and open texture.

Stucco is a term, less used than it was, for external plaster or rendering that was applied as a wet mix of lime and sand, in one or two coats, and finished with a fine mix of lime or lime and sand, generally in the form imitating stone joints and mouldings formed around projecting brick courses as a background for imitation cornices and other architectural decorations. To protect the comparatively porous lime and sand coating, the surface was usually painted.

The materials and application of the various smooth, textured, rough cast and pebble dash rendering are described in Volume 2.

The materials of an external rendering should have roughly the same density and therefore permeability to water as the material of the wall to which it is applied. There are many instances of the application of a dense rendering to the outside face of a wall that is permeable to water, in the anticipation of protecting the wall from rain penetration. The result is usually a disaster.

A dense sand and cement rendering, for example, applied to the face of a wall of porous bricks, will, on drying, shrink fiercely, pull away from the brick face or tear off the face of the soft bricks, and the rendering will craze with many fine hair cracks over its surface. Wind driven rain will then penetrate the many hair cracks through which water will be unable to evaporate to outside air during dry spells and the consequence is that the wall behind will become more water logged than before and the rendering will have a far from agreeable appearance.

Slate and tile hanging

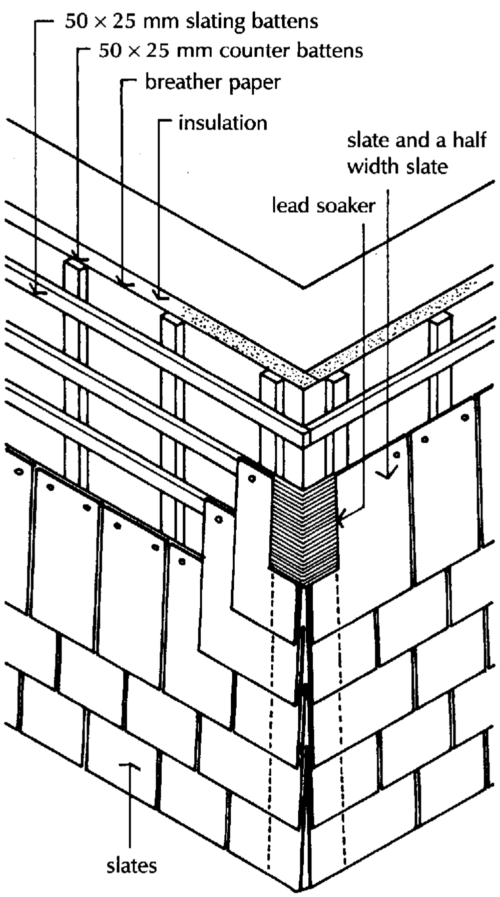


Fig. 85 Slate hanging.

In positions of very severe exposure to wind driven rain, as on high open ground facing the prevailing wind and on the coast facing open sea, it is necessary to protect both solid and cavity walls with an external cladding. The traditional wall cladding is slate or tile hanging in the form of slates or tiles hung double lap on timber battens nailed to counter battens. Slate hanging has generally been used in the north and tile in the south of Great Britain. Either natural or manufactured slates and tiles can be used.

As a fixing for slating or tiling battens, 50 × 25 mm timber counter battens are nailed at 300 mm centres up the face of the wall to which timber slating or tiling battens are nailed at centres suited to the gauge (centres) necessary for double lap slates or tiles, as illustrated in Fig. 85.

As protection against decay, pressure impregnated softwood timber battens should be used and secured with non-ferrous fixings to avoid the deterioration and failure of steel fixings by rusting.

Where slate or tile hanging is used as cladding to a solid wall of buildings normally heated, then the necessary insulation can be fixed to the wall behind the counter battens. Rigid insulation boards of organic or inorganic insulation are fixed with a mechanically operated hammer gun that drives nails through both the counter battens, a breather paper and the insulation boards into the wall.

The continuous layer of breather paper, that is fixed between the counter battens and the insulation, is resistant to the penetration of water in liquid form but will allow water vapour to pass through it. Its purpose is to protect the outer surface of the insulation from cold air and any rain that might penetrate the hanging and to allow movement of vapour through it.

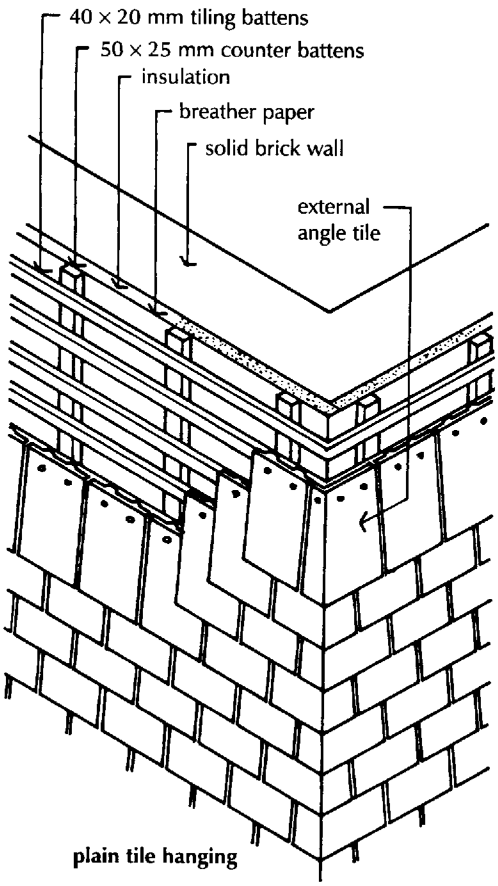


Fig. 86 Tile hanging.

For vertically hung slating it is usual to use one of the smaller slates such as 405 × 205 mm slate which is headnailed to 50 × 25 mm battens and is less likely to be lifted and dislodged in high wind than longer slates would be. Each slate is nailed with non-ferrous nails to overlap two slates below, as illustrated in Fig. 85, and double lapped by overlapping the head of slates two courses below.

At angles and the sides of openings a slate one and a half the width of slates is used to complete the overlap. This width of slate is specifically used to avoid the use of a half width slate that might easily be displaced in wind.

Internal and external angles are weathered by lead soakers – hung over the head of slates – to overlap and make the joint weathertight. Slate hanging is fixed either to overlap or butt to the side of window and door frames with exposed edges of slates pointed with cement mortar or weathered with lead flashings.

At lower edges of slate hanging a projection is formed on or in the wall face by means of blocks, battens or brick corbel courses on to which the lower courses of slates and tiles bell outwards slightly to throw water clear of the wall below.

Tile hanging is hung and nailed to 40 × 20 mm tiling battens fixed at centres to counter battens to suit the gauge of plain tiles. Each tile is hung to battens and also nailed, as security against wind, as illustrated in Fig. 86.

At internal and external angles special angle tiles may be used to continue the bond around the corner, as illustrated in Fig. 86. As an alternative and also at the sides of openings tile and a half width tiles may be used with lead soakers to angles and pointing to exposed edges or weathering to the sides of the openings.

As weather protection to the solid walls of buildings with low or little heat requirements the hanging is fixed directly to walling and to those buildings that are heated the hanging may be fixed to external or internal insulation for solid walling and directly to cavity walling with cavity insulation.

OPENINGS IN SOLID WALLS

For the strength and stability of walling the size of openings in walls is limited by regulations for both solid and cavity walls.

Jambs of openings

The jambs of openings for windows and doors in solid walls may be plain (square) or rebated.

Plain or square jambs are used for small section window or door frames of steel and also for larger section frames where the whole of the external face of frames is to be exposed externally. The bonding of brickwork at square jambs is the same as for stop ends and angles with a closer next to a header in alternate courses to complete the bond.

Rebated jambs

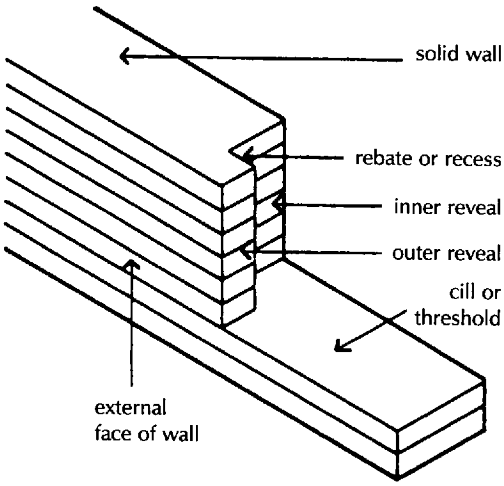


Fig. 87 Rebated jamb.

Window and door frames made of soft wood have to be painted for protection from rain, for if wood becomes saturated it swells and in time may decay. With some styles of architecture it is thought best to hide as much of the window frame as possible. So either as a partial protection against rain or for appearance sake, or for both reasons, the jambs of openings are rebated.

Figure 87 is a diagram of one rebated jamb on which the terms used are noted.

As one of the purposes of a rebated jamb is to protect the frame from rain the rebate faces into the building and the frame of the window or door is fixed behind the rebate.

The thickness of brickwork that shows at the jamb of openings is described as the reveal. With rebated jambs there is an inner reveal and an outer reveal separated by the rebate.

The outer reveal is usually $\frac{1}{2}$ B wide for ease of bonding bricks and may be 1 B wide in thick solid walling. The width of the inner reveal is determined by the relative width of the outer reveal and wall thickness.

The depth of the rebate is either $\frac{1}{4}$B (about 51 mm) or $\frac{1}{2}$B (102.5 mm). A $\frac{1}{4}$B rebate is used to protect and mask solid wood frames and the $\frac{1}{2}$B deep rebate to protect and mask the box frames to vertically sliding wood sash windows. The $\frac{1}{2}$B deep rebate virtually covers the external face of cased wood frames (see Volume 2) to the extent that a window opening appears to be glass with a narrow surround of wood.

Bonding of bricks at rebated jambs

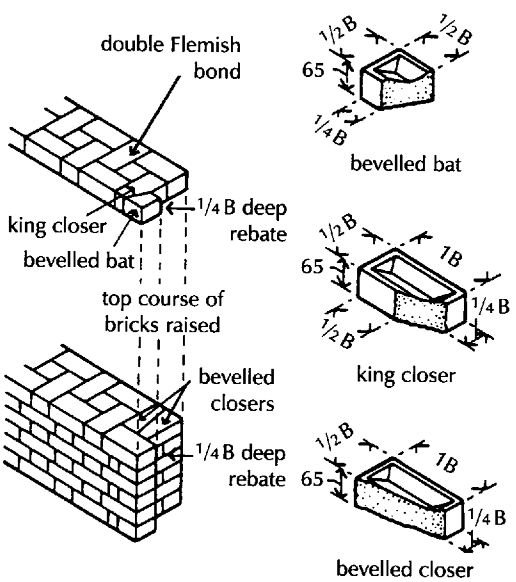


Fig. 88 Bonding at rebated jambs.

Just as at an angle or quoin in brickwork, bricks specially cut have to be used to complete, or close, the $\frac{1}{4}$B overlap caused by bonding, so at jambs special closer bricks $\frac{1}{4}$B wide on face have to be used.

Provided that the outer reveal is $\frac{1}{2}$B wide, the following basic rules will apply irrespective of the sort of bond used or the thickness of the wall. If the rebate is $\frac{1}{4}$B deep the bonding at one jamb will be arranged as illustrated in Fig. 88. In every other course of bricks a header face and then a closer of $\frac{1}{4}$B wide face must appear at the jamb or angle of the opening. To do this and at the same time to form the $\frac{1}{4}$B deep rebate and to avoid vertical joints continuously up the wall, two cut bricks have to be used.

These are a bevelled bat (a 'bat' is any cut part of a brick), which is shaped as shown in Fig. 88, and a king closer, which is illustrated in Fig. 88. Neither of these bricks is made specially to the shape and size shown, but is cut from whole bricks on the site.

In the course above and below, two other cut bricks, called bevelled closers, should be used behind the stretcher brick. These two bricks are used so as to avoid a vertical joint. Figure 88 shows a view of a bevelled closer.

Where the rebate is $\frac{1}{2}$B deep the bonding is less complicated. An arrangement of half bats as quoin header and two bevelled closers in alternate courses for English bond and half bats and king closers in alternate courses for Flemish bond is used.

Head of openings in solid walls

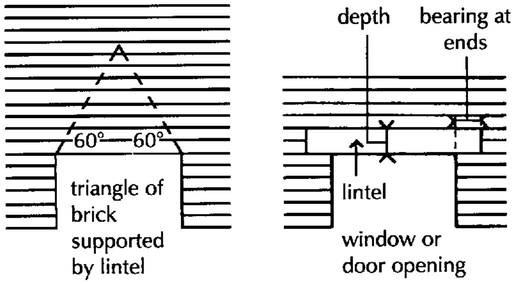


Fig. 89 Head of openings.

Solid brickwork over the head of openings has to be supported by either a lintel or an arch. The brickwork which the lintel or arch has to support is an isosceles triangle with 60° angles, formed by the bonding of bricks, as illustrated in Fig. 89. The triangle is formed by the vertical joints between bricks which overlap $\frac{1}{4}$B. In a bonded wall if the solid brickwork inside the triangle were taken out the load of the wall above the triangle would be transferred to the bricks of each side of the opening in what is termed 'the arching effect'.

Lintel is the name given to any single solid length of timber, stone, steel or concrete built in over an opening to support the wall over it, as shown in Fig. 89. The ends of the lintel must be built into the brick or blockwork over the jambs to convey the weight carried by the lintel to the jambs. The area of wall on which the end of a lintel bears is termed its bearing at ends. The wider the opening the more weight the lintel has to support and the greater its bearing at ends must be to transmit the load it carries to an area capable of supporting it. For convenience its depth is usually made a multiple of brick course height, that is about 75 mm, and the lintels are not usually less than 150 mm deep.

Timber lintels

Up to the beginning of the twentieth century it was common practice to support the brickwork over openings on a timber lintel. Wood lintels are less used today because wood may be damaged during a fire and because timber is liable to rot in conditions of persistent damp.

Concrete lintels

Since Portland cement was first mass produced towards the end of the nineteenth century it has been practical and economic to cast and use concrete lintels to support brickwork over openings.

Concrete is made from reasonably cheap materials, it can easily be moulded or cast when wet and when it hardens it has very good strength in resisting crushing and does not lose strength or otherwise deteriorate when exposed to the weather. The one desirable quality that concrete lacks, if it is to be used as a lintel, is tensile strength, that is strength to resist being pulled apart. To provide the necessary tensile strength to concrete steel reinforcement is cast into concrete.

For a simple explanation for the need and placing of reinforcement in concrete lintels suppose that a piece of india rubber were used as a lintel. Under load any material supported at its ends will deflect, bend, under its own weight and loads that it supports. India rubber has very poor compressive and tensile strength so that under load it

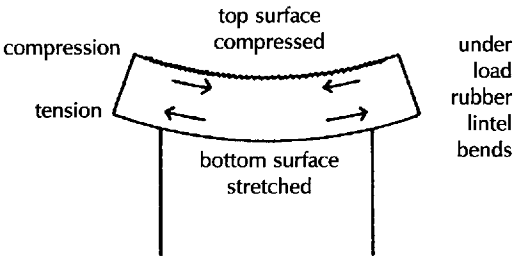


Fig. 90 Bending under load.

will bend very noticeably, as illustrated in Fig. 90. The top surface of the rubber becomes squeezed, indicating compression, and the lower surface stretched, indicating tension. A close examination of the india rubber shows that it is most squeezed at its top surface and progressively less to the centre, and conversely most stretched and progressively less up from its bottom surface to the centre of depth.

A concrete lintel will not bend so obviously as india rubber, but it will bend and its top surface will be compressed and its bottom surface stretched or in tension under load. Concrete is strong in resisting compression but weak in resisting tension, and to give the concrete lintel the strength required to resist the tension which is maximum at its lower surface, steel is added, because steel is strong in resisting tension. This is the reason why rods of steel are cast into the bottom of a concrete lintel when it is being moulded in its wet state.

Lengths of steel rod are cast into the bottom of concrete lintels to give them strength in resisting tensile or stretching forces. As the tension is greatest at the underside of the lintel it would seem sensible to cast the steel rods in the lowest surface. In fact the steel rods are cast in some 15 mm or more above the bottom surface. The reason for this is that steel very soon rusts when exposed to air and if the steel rods were in the lower surface of the lintel they would rust, expand and rupture the concrete around them, and in time give way and the lintel might collapse. Also if a fire occurs in the building the steel rods would, if cast in the surface, expand and come away from the concrete and the lintel collapse. The rods are cast at least 15 mm up from the bottom of the lintel and 15 mm or more of concrete below them is called the concrete cover.

Reinforcing rods

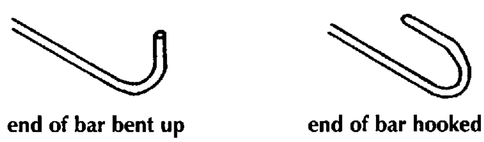


Fig. 91 Ends of reinforcing rods.

Reinforcing rods are usually of round section mild steel 10 or 12 mm diameter for lintels up to 1.8 m span. The ends of the rods should be bent up at 90° or hooked as illustrated in Fig. 91.

The purpose of bending up the ends is to ensure that when the lintel does bend the rods do not lose their adhesion to the concrete around them. After being bent or hooked at the ends the rods should be some 50 or 75 mm shorter than the lintel at either end. An empirical rule for determining the number of 12 mm rods required for lintels of up to, say, 1.8 m span is to allow one 12 mm rod for each half brick thickness of wall which the lintel supports.

Casting lintels

The word 'precast' indicates that a concrete lintel has been cast inside a mould, and has been allowed time to set and harden before it is built into the wall.

The words 'situ-cast' indicate that a lintel is cast in position inside a timber mould fixed over the opening in walls. Whether the lintel is precast or situ-cast will not affect the finished result and which method is used will depend on which is most convenient.

It is common practice to precast lintels for most normal door and window openings, the advantage being that immediately the lintel is placed in position over the opening, brickwork can be raised on it, whereas the concrete in a situ-cast lintel requires a timber mould or formwork and must be allowed to harden before brickwork can be raised on it.

Lintels are cast in situ, that is in position over openings, if a precast lintel would have been too heavy or cumbersome to have been easily hoisted and bedded in position.

Precast lintels must be clearly marked to make certain that they are bedded with the steel reinforcement in its correct place, at the bottom of the lintel. Usually the letter 'T' or the word 'Top' is cut into the top of the concrete lintel whilst it is still wet.

Prestressed concrete lintels

Prestressed, precast concrete lintels are used particularly over internal openings. A prestressed lintel is made by casting concrete around high tensile, stretched wires which are anchored to the concrete so that the concrete is compressed by the stress in the wires. (See also Volume 4.) Under load the compression of concrete, due to the stressed wires, has to be overcome before the lintel will bend.

Two types of prestressed concrete lintel are made, composite lintels and non-composite lintels.

Composite and non-composite lintels

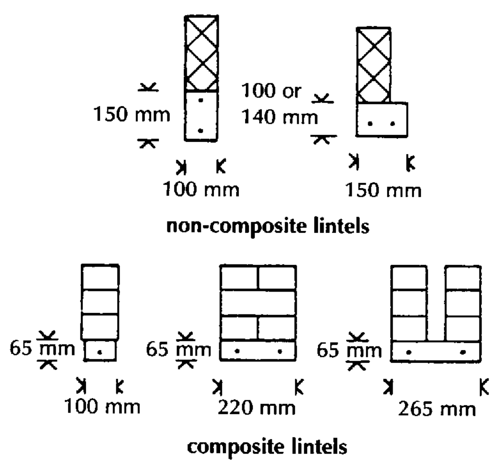


Fig. 92 Prestressed lintels.

Composite lintels are stressed by a wire or wires at the centre of their depth and are designed to be used with the brickwork they support which acts as a composite part of the lintel in supporting loads. These comparatively thin precast lintels are built in over openings and brickwork is built over them. Prestressed lintels over openings more than 1200 mm wide should be supported to avoid deflection, until the mortar in the brickwork has set. When used to support blockwork the composite strength of these lintels is considerably less than when used with brickwork.

Non-composite prestressed lintels are made for use where there is insufficient brickwork over to act compositely with the lintel and also where there are heavy loads.

These lintels are made to suit brick and block wall thicknesses, as illustrated in Fig. 92. They are mostly used for internal openings, the inner skin of cavity walls and the outer skin where it is covered externally.

Precast, or prestressed lintels may be used over openings in both internal and external solid walls. In external walls prestressed lintels are used where the wall is to be covered with rendering externally and for the inner leaf of cavity walls where the lintel will be covered with plaster.

Precast reinforced concrete lintels may be exposed on the external face of both solid and cavity walling where the appearance of a concrete surface is acceptable.

Boot lintels

When concrete has dried it is a dull, light grey colour. Some think that a concrete lintel exposed for its full depth on the external face of brick walls is not attractive. In the past it was for some years common practice to hide the concrete lintel behind a brick arch or brick lintel built over the opening externally.

A modification of the ordinary rectangular section lintel, known as a boot lintel, was often used to reduce the depth of the lintel exposed externally. Figure 93 is an illustration of a section through the head of an opening showing a boot lintel in position. The lintel is boot-shaped in section with the toe part showing externally. The toe is usually made 65 mm deep. The main body of the lintel is inside the wall where it does not show and it is this part of the lintel which does most of the work of supporting brickwork. Some think that the face of the brickwork looks best if the toe of the lintel finishes just 25 or 40 mm back from the external face of the wall, as in Fig. 94. The brickwork built on the toe of the lintel is usually $\frac{1}{2}$B thick for openings up to 1.8 m wide. The 65 mm deep toe, if reinforced as shown, is capable of safely carrying the two or three courses of $\frac{1}{2}$B thick brickwork over it. The brickwork above the top of the main part of the lintel bears mainly on it because the bricks are bonded. If the opening is wider than 1.8 m the main part of the lintel is sometimes made sufficiently thick to support most of the thickness of the wall over, as in Fig. 94.

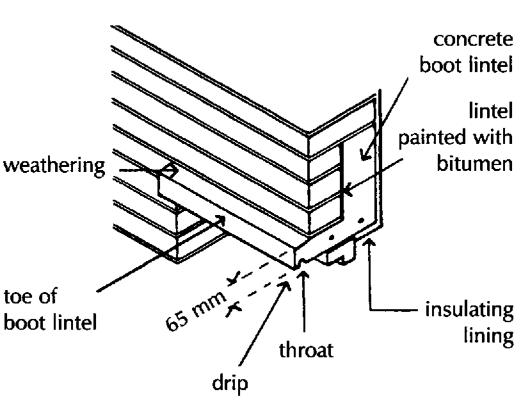


Fig. 93 Boot lintel.

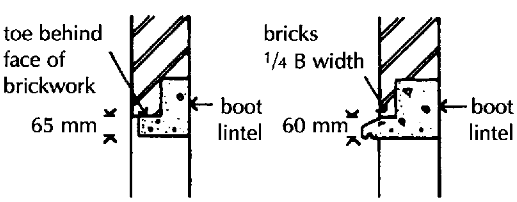


Fig. 94 Boot lintels.

The brickwork resting on the toe of the lintel is built with bricks cut in half. When the toe of the lintel projects beyond the face of the brickwork it should be weathered to throw rainwater out from the wall face and throated to prevent water running in along soffit or underside, as shown in Fig. 93.

When the external face of brickwork is in direct contact with concrete, as is the brickwork on the toe of these lintels, an efflorescence of salts is liable to appear on the face of the brickwork. This is caused by soluble salts in the concrete being withdrawn when the wall dries out after rain and being left on the face of the brickwork in the form of unsightly white dust. To prevent the salts forming, the faces of the lintel in direct contact with the external brickwork should be painted with bituminous paint as indicated in Fig. 93. The bearing at ends where the boot lintel is bedded on the brick jambs should be of the same area as for ordinary lintels.

Pressed steel lintels

Galvanised pressed steel lintels may be used as an alternative to concrete as a means of support to both loadbearing and non-loadbearing internal walls.

Mild steel strip is pressed to shape, welded as necessary and galvanised. The steel lintels for support over door openings in loadbearing internal walls are usually in hollow box form, as illustrated in Fig. 95. A range of lengths and sections is made to suit standard openings, wall thicknesses, course height for brickwork and adequate bearing at ends. For use over openings in loadbearing concrete block internal walls it is usually necessary to cut blocks around the bearing ends of these shallow depth lintels.

Over wide openings it may be necessary to fill the bearing ends of these hollow lintels with concrete to improve their crushing resistance.

The exposed faces of these lintels are perforated to provide a key for plaster.

To support thin, non-loadbearing concrete blocks over narrow door openings in partition walls, a small range of corrugated, pressed steel lintels is made to suit block thickness. These shallow depth, galvanised lintels are made to match the depth of horizontal mortar joints to avoid cutting of blocks.

The corrugations provide adequate key for plaster run over the face of partitions and across the soffit of openings, as illustrated in Fig. 96.

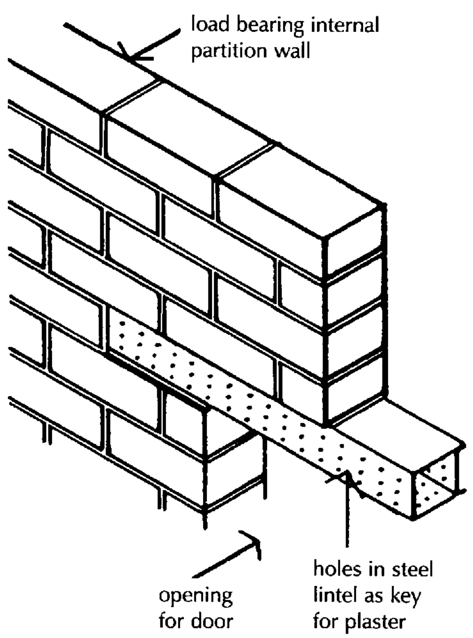


Fig. 95 Steel lintels in internal walls.

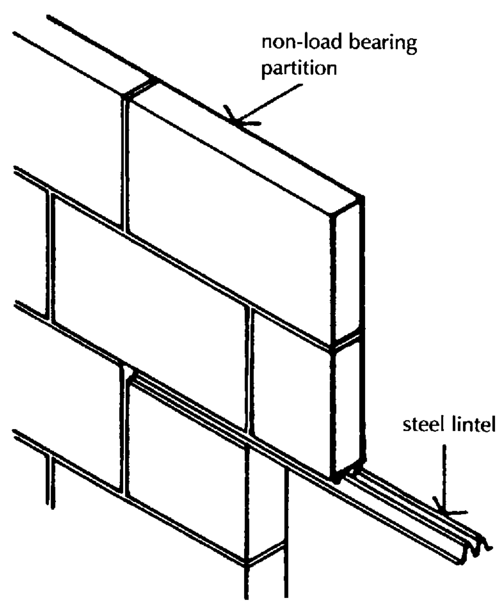


Fig. 96 Corrugated steel lintel in internal wall.

These shallow depth lintels act compositely with the blocks they support. To prevent sagging they should be given temporary support at mid-span until the blocks above have been laid and the mortar hardened.

Brick lintels

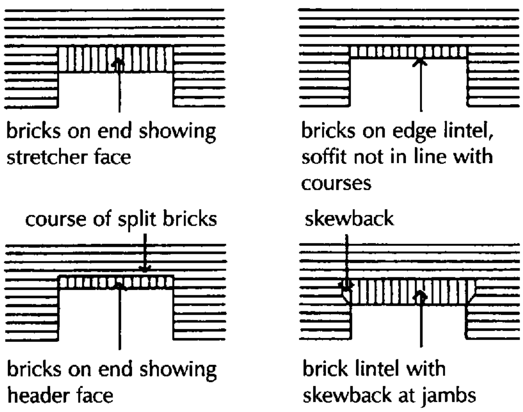


Fig. 97 Brick lintels.

A brick lintel may be formed as bricks on end, bricks on edge or coursed bricks laid horizontally over openings. The small units of brick, laid in mortar, give poor support to the wall above and usually need some form of additional support.

A brick on-end lintel is generally known as a 'soldier arch' or 'brick on end' arch. The word arch here is wrongly used as the bricks are not arranged in the form of an arch or curve but laid flat. The brick lintel is built with bricks laid on end with stretcher faces showing, as illustrated in Fig. 97. In building a brick lintel, mortar should be packed tightly between bricks.

A brick on end or soldier arch was a conventional method of giving the appearance of some form of support over openings in fairface brickwork.

For openings up to about 900 mm wide it was common to provide some support for soldier arches by building the lintel on the head of timber window and door frames. The wood frame served as temporary support as the bricks were laid, and support against sagging once the wall was built.

A variation was to form skew back bricks at each end of the lintel with cut bricks so that the slanting surface bears on a skew brick in the jambs, as illustrated in Fig. 97. The skew back does give some little extra stability against sagging.

For openings more than 900 mm wide a brick on end lintel may be supported by a 50 × 6 mm iron bearing bar, the ends of which are built into jambs as illustrated in Fig. 98A. The bearing bar provides little effective support and may in time rust. As a more effective alternative a steel 50 or 75 mm angle is built into jambs to give support to the lintel. The 50 mm flange of the angle supports the back edge of the bricks and may be masked by the window or door frame.

Another method of support was to drill a hole in each brick of the lintel. This can only successfully be done with fine grained bricks such as marls or gaults. Through the holes in the bricks a round-section mild steel rod is threaded and the ends of the rod are built into the brickwork either side of the lintel. This method of supporting the lintel is quite satisfactory but is somewhat expensive because of the labour involved.

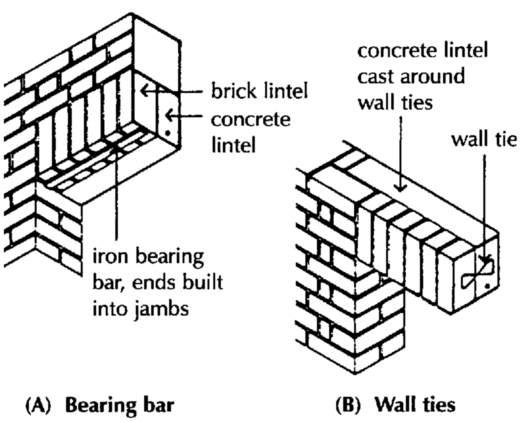


Fig. 98 (A) Bearing bar for lintel. (B) Wall tie support for lintel.

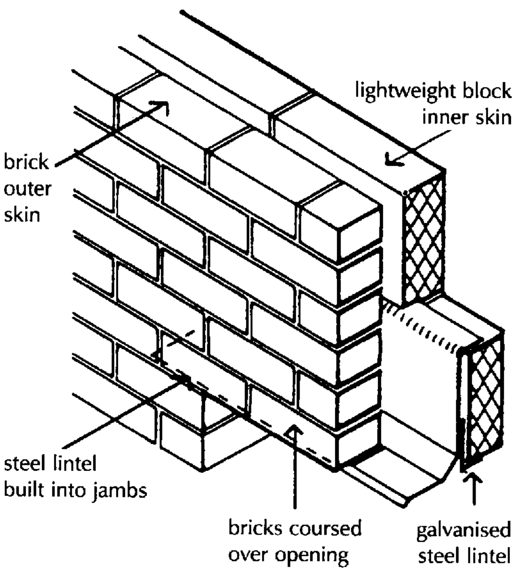


Fig. 99 Steel lintel support.

A more satisfactory method of providing support for brick on edge lintels is by wall ties cast into a concrete lintel. The lintel bricks are laid on a temporary supporting soffit board. As the bricks are laid wall ties are bedded between joints. An in situ reinforced concrete lintel is then cast behind the brick lintel so that when the concrete has set and hardened the ties give support, as illustrated in Fig. 98B.

Bricks laid on edge, showing a header face, were sometimes used as a lintel. Where the soffit of the lintel is in line with a brick course there has to be an untidy split course of bricks, some 37 mm deep above. Alternatively, the top of the lintel may be in line with a course, as illustrated in Fig. 97.

As support for coursed brickwork over openings a galvanised, pressed steel lintel is used. The lintel illustrated in Fig. 99 is for use with cavity walling to provide support for both the brick outer leaf and the block inner.

Brick arches

Semi-circular arch

An arch, which is the most elegant and structurally efficient method of supporting brickwork, has for centuries been the preferred means of support for brickwork over the small openings for doors and windows and for arcades, viaducts and bridges. The adaptability and flexibility of the small units of brick, laid in mortar, is demonstrated in the use of accurately shaped brick in ornamental brickwork and large span, rough archwork for railway bridges.

The traditional skills of bricklaying have for many years been in decline. Of recent years the use of brick arching has, to an extent, come back into fashion in the form of arched heads to openings in loadbearing walls, brick facework to framed buildings and arcading.

The most efficient method of supporting brickwork over an opening is by the use of a semi-circular arch which transfers the load of the wall it supports most directly to the sides of the opening through the arch. Figure 100 is an illustration of a semi-circular brick arch with the various terms used noted.

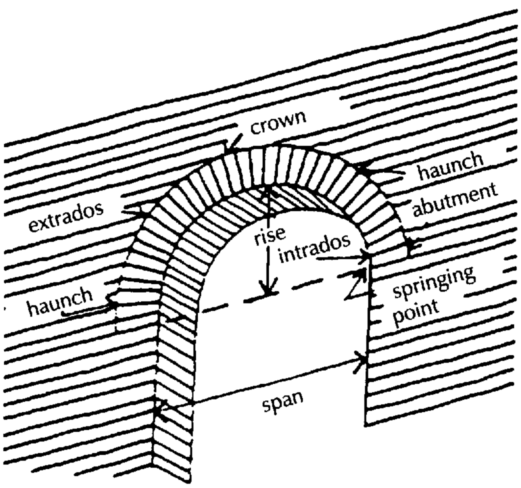


Fig. 100 Semi-circular brick arch.

A segmented arch, which takes the form of a segment (part) of a circle is less efficient in that it transmits loads to the jambs by both vertical and outward thrust.

Rough and axed arches

The two ways of constructing a curved brick arch are with bricks laid with wedge shaped mortar joints or with wedge-shaped bricks with mortar joints of uniform thickness, as illustrated in Fig. 101.

An arch formed with uncut bricks and wedge shaped mortar joints is termed a rough brick arch because the mortar joints are irregular

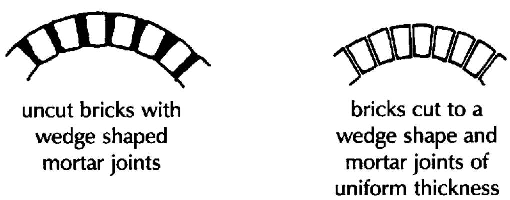


Fig. 101 Rough and axed arches.

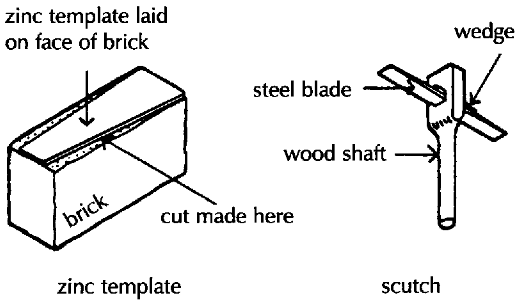


Fig. 102 Axed brick.

and the finished effect is rough. In time the joints, which may be quite thick at the crown of the arch, may tend to crack and emphasise the rough appearance. Rough archwork, which may be used for its rugged appearance with irregularly shaped bricks, is not generally used for fairface work.

Arches in fairface brickwork are usually built with bricks cut to wedge shape with mortar joints of uniform width. The bricks are cut to the required wedge shape by gradually chopping them to shape, hence the name 'axed bricks'.

Any good facing brick, no matter how hard, can be cut to a wedge shape either on or off the building site. A template, or pattern, is cut from a sheet of zinc to the exact wedge shape to which the bricks are to be cut. The template is laid on the stretcher or header face of the brick as illustrated in Fig. 102. Shallow cuts are made in the face of the brick either side of the template. These cuts are made with a hacksaw blade or file and are to guide the bricklayer in cutting the brick. Then, holding the brick in one hand the bricklayer gradually chops the brick to the required wedge shape. For this he uses a tool called a scutch, illustrated in Fig. 102. When the brick has been cut to a wedge shape the rough, cut surfaces are roughly levelled with a coarse rasp, which is a steel file with coarse teeth.

From the description this appears to be a laborious operation but in fact the skilled bricklayer can axe a brick to a wedge shape in a few minutes. The axed wedged-shaped bricks are built to form the arch with uniform 10 mm mortar joints between the bricks.

Gauged bricks

The word gauge is used in the sense of measurement, as gauged bricks are those that have been so accurately prepared to a wedge shape that they can be put together to form an arch with very thin joints between them. This does not improve the strength of the brick arch and is done entirely for reasons of appearance. Hard burned clay facing bricks cannot be cut to the accurate wedge shape required for this work because the bricks are too coarse grained, and bricks which are to be gauged are specially chosen. One type of brick used for gauged brickwork is called a rubber brick because its composition is such that it can be rubbed down to an accurate shape on a flat stone.

Rubber bricks are made from fine grained sandy clays. The bricks are moulded and then baked to harden them, and the temperature at which these bricks are baked is lower than that at which clay bricks are burned, the aim being to avoid fusion of the material of the bricks so that they can easily be cut and accurately rubbed to shape. Rubber bricks have a fine sandy texture and are usually 'brick red' in colour, although grey, buff and white rubber bricks are made. These bricks are usually somewhat larger than most clay bricks.

Sheet zinc templates, or patterns, are cut to the exact size of the wedge-shaped brick voussoirs. These templates are placed on the stretcher or header face of the brick to be cut and the brick is sawn to a wedge shape with a brick saw. A brick saw consists of an 'H' shaped wooden frame across which is strung a length of twisted steel wires. Because rubber bricks are soft this twisted wire quickly saws through them.

After the bricks have been cut to a wedge shape they are carefully rubbed down by hand on a large flat stone until they are the exact wedge shape required as indicated by the sheet zinc template.

The gauged rubber bricks are built to form the arch with joints between the bricks as thin as 1.5 mm thick. A mortar of coarse sand and lime or cement, is too coarse for narrow joints and the mortar used between the gauged bricks is composed of either fine sand and cement and lime or lime and water, depending on the thickness of joint selected. The finished effect of accurately gauged red bricks with thin white joints between them was considered very attractive. Gauged bricks are used for flat camber arches.

A disadvantage of thin, lime mortar joints with fine grained rubber bricks is that bricks may become saturated with rainwater and crumble due to the effect of frost and the lime mortar joints may break up.

Two ring arch

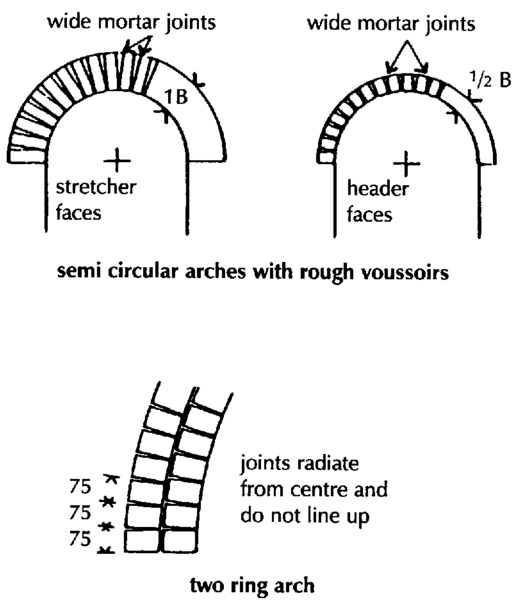


Fig. 103 Two ring arch.

Rough and axed bricks are used for both semi-circular and segmental arches and gauged brick for segmental and flat camber arches to avoid the more considerable cutting necessary with semi-circular arches.

Rough, axed or gauged bricks can be laid so that either their stretcher or their header face is exposed. Semi-circular arches are often formed with bricks showing header faces to avoid the excessively wedge-shaped bricks or joints that occur with stretcher faces showing. This is illustrated by the comparison of two arches of similar span first with stretcher face showing and then with header face showing, as illustrated in Fig. 103. If the span of the arch is of any considerable width, say 1.8 m or more, it is often practice to build it with what is termed two or more rings of bricks, as illustrated in Fig. 103.

An advantage of two or more rings of bricks showing header faces is that the bricks bond into the thickness of the wall. Where the wall over the arch is more than 1 B thick it is practical to effect more bonding of arch bricks in walls or viaducts by employing alternate snap headers (half bricks) in the face of the arch.

Segmental arch

The curve of this arch is a segment, that is part of a circle, and the designer of the building can choose any segment of a circle that he thinks suits his design. By trial and error over many years bricklayers have worked out methods of calculating a segment of a circle related to the span of this arch, which gives a pleasant looking shape, and which at the same time is capable of supporting the weight of brickwork over the arch. The recommended segment is such that the rise of the arch is 130 mm for every metre of span of the arch.

Centering

As temporary support for brick arches it is necessary to construct a rough timber framework to the profile of the underside of the arch on which the arch bricks are laid and jointed with mortar.

The timber frame is described as centering. It is fixed and supported in the opening while the bricks of the arch are being built and the coursed brickwork over the arch laid. Once the arch and brickwork above are finished the centering is removed.

A degree of both skill and labour is involved in arch building, in setting out the arch, cutting bricks for the arch and the abutment of coursed brickwork to the curved profile of the arch so that an arched opening is appreciably more expensive than a plain lintel head.

Flat camber arch

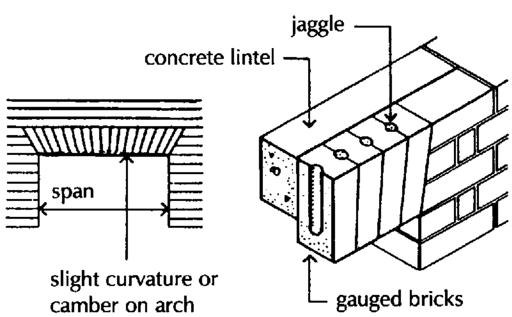


Fig. 104 Flat gauged camber arch.

This is not a true arch as it is not curved and might well be more correctly named flat brick lintel with voussoirs radiating from the centre, as illustrated in Fig. 104.

The bricks from which the arch is built may be either axed or gauged to the shape required so that the joints between the bricks radiated from a common centre and the widths of voussoirs measured horizontally along the top of the arch are the same. This width will be 65 mm or slightly less so that there are an odd number of voussoirs, the centre one being a key brick.

The centre from which the joints between the bricks radiate is usually determined either by making the skew or slating surface at the end of the arch 60° to the horizontal or by calculating the top of this skew line as lying 130 mm from the jamb for every metre of span.

If the underside or soffit of this arch were made absolutely level it would appear to be sagging slightly at its centre. This is an optical illusion and it is corrected by forming a slight rise or camber on the soffit of the arch. This rise is usually calculated at 6 or 10 mm for every metre of span and the camber takes the form of a shallow curve.

The camber is allowed for when cutting the bricks to shape. In walls built of hard coarse grained facing bricks this arch is usually built of axed bricks. In walls built of softer, fine grained facing bricks the arch is usually of gauged rubber bricks and is termed a flat gauged camber arch. This flat arch must be of such height on face that it bonds in with the brick course of the main walling. The voussoirs of this arch, particularly those at the extreme ends, are often longer overall than a normal brick and the voussoirs have to be formed with two bricks cut to shape.

Flat gauged camber arch

The bricks in this arch are jointed with lime and water, and the joints are usually 1.5 mm thick. Lime is soluble in water and does not adhere strongly to bricks as does cement. In time the jointing material, that is lime, between the bricks in this arch may perish and the bricks may slip out of position. To prevent this, joggles are formed between the bricks. These joggles take the form of semi-circular grooves cut in both bed faces of each brick, as shown in Fig. 104, into which mortar is run.

Solid walls

Thermal insulation

A requirement of the Building Regulations is that measures be taken, in new buildings, for the conservation of fuel and power. There is no requirement for particular forms of construction to meet the requirement. The practical guidance to the regulation, contained in Approved Document L for dwellings, is based on assumed levels of heating to meet the expectation of indoor comfort of the majority of the largely urban population of this country who are engaged in sedentary occupations.

The advice in the Approved Document is based on an assumption that walls will be of cavity construction with the insulation in the cavity, which is the optimum position for insulation. In consequence it is likely that insulated cavity wall construction will be the first choice for the walls of dwellings for some time to come.

The regulations do make allowance for the use of any form of construction providing the calculated energy use of such buildings is no greater than that of a similar building with recommended insulated construction.

To provide the insulation required to meet the standard for conservation with a solid wall it is necessary to fix a layer of some lightweight insulating material to either the external or the internal face of the wall.

For external insulation it is necessary to cover the insulation material with either rendering, tile, slate or some sheet metal covering as protection against weather. Internal insulation has to be protected with plasterboard or some other solid material to provide an acceptable finish. The cost of the additional materials and the very considerable labour involved is so great that it is an unacceptable alternative to the more straightforward, less expensive and more satisfactory use of cavity wall insulation for new buildings.

Internal insulation

Internal insulation may be fixed to the solid brick walls of existing buildings where, for example, there is to be a change of use from warehouse to dwelling to enhance the thermal insulation of the external walls.

Insulating materials are lightweight and do not generally have a smooth hard finish and are not, therefore, suitable as the inside face of the walls of most buildings. It is usual to cover the insulating layer with a lining of plasterboard or plaster so that the combined thickness of the inner lining and the wall have a U value of 0.45 W/m^2K, or less.

Internal linings for thermal insulation are either of preformed, laminated panels that combine a wall lining of plasterboard glued to an insulation board or of separate insulation material that is fixed to the wall and then covered with plasterboard or wet plaster. The method of fixing the lining to the inside wall surface depends on the surface to which it is applied.

Adhesive fixing

Adhesive fixing directly to the inside wall face is used for preformed, laminate panels and for rigid insulation boards. Where the inside face of the wall is clean, dry, level and reasonably smooth, as, for example, a sound plaster finish or a smooth and level concrete, brick or block face, the laminate panels or rigid insulation boards are secured with organic based, gap filling adhesive that is applied in dabs and strips to the back of the boards or panels or to both the boards and wall. The panels or boards are then applied and pressed into position against the wall face and their position adjusted with a foot lifter.

Where the surface of the wall to be lined is uneven or rough the laminated panels or insulation boards are fixed with dabs of plaster bonding, applied to both the wall surface and the back of the lining. Dabs are small areas of wet plaster bonding applied at intervals on the surface with a trowel, as a bedding and adhesive. The lining is applied and pressed into position against the wall. The wet dabs of bonding allow for irregularities in the wall surface and also serve as an adhesive. Some of the lining systems use secondary fixing in addition to adhesive. These secondary fixings are non-ferrous or plastic nails or screws driven or screwed through the insulation boards into the wall.

Figure 105 is an illustration of laminated insulation panels fixed to the inside face of a solid wall.

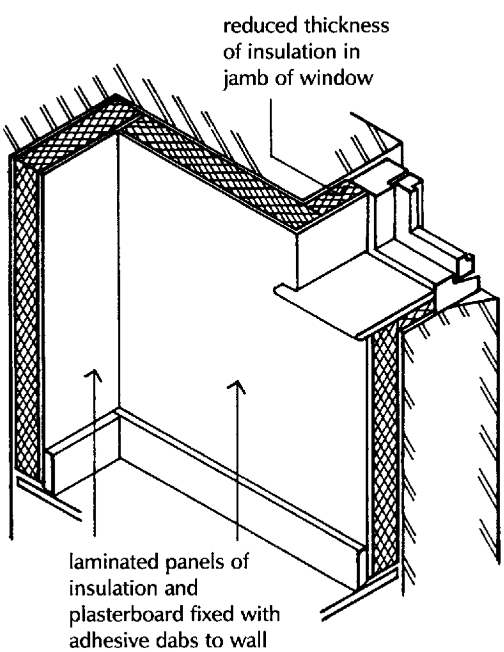


Fig. 105 Internal insulation.

Internal insulation is used where solid walls have sufficient resistance to the penetration of rain, an alteration to the external appearance is not permitted or is unacceptable and the building is not occupied. A disadvantage of internal insulation is that as the insulation is at, or close to, the internal surface, it will prevent the wall behind from acting as a heat store where constant, low temperature heating is used.

The principal difficulty with both external and internal insulation to existing buildings is that it is not usually practical to continue the insulation into the reveals of openings to avoid thermal bridges, because the exposed faces of most window and door frames are not wide enough to take the combined thickness of the insulation and rendering or plaster finish.

Mechanical fixing

As alternative to adhesive fixing, the insulating lining and the wall finish can be fixed to wood battens that are nailed to the wall with packing pieces as necessary, to form a level surface. The battens should be impregnated against rot and fixed with non-ferrous fixings. The insulating lining is fixed either between the battens or across the battens and an internal lining of plasterboard is then nailed to the battens, through the insulation.

The thermal resistance of wood is less than that of most insulating materials. When the insulating material is fixed between the battens there will be cold bridges through the battens that may cause staining on wall faces.

Details of some insulating materials used for internal lining are given in Table 6.

Table 6 Internal insulating materials.

Solid wall internal insulation	Thickness	U value W/m^2K
Glass fibre		
laminated panel glass fibre slab and plasterboard	30, 40, 60	0.031
Rockwool		
laminated panel rockwool slab and plasterboard	25, 32, 40, 50	0.033
EPS		
laminated panel EPS board and plasterboard	25, 32, 40, 50	0.037
XPS		
boards keyed for plaster	25, 50, 75, 110	0.033
PIR		
boards reinforced with glass fibre tissue both sides	25, 30, 35, 40	0.022
PUR		
laminated panel PUR board and plasterboard	12.5, 15, 20, 25, 30	0.022

EPS expanded polystyrene
XPS extruded polystyrene
PIR rigid polyisocyanurate
PUR rigid polyurethane

Internal finish

An inner lining of plasterboard can be finished by taping and filling the joints or with a thin skim coat of neat plaster. A plaster finish of lightweight plaster and finishing coat is applied to the ready keyed surface of some insulating boards or to expanded metal lathing fixed to battens. (For details of plaster, see Volume 2.)

Laminated panels of insulation, lined on one side with a plasterboard finish are made specifically for the insulation of internal walls. The panels are fixed with adhesive or mechanical fixings to the inside face of the wall. For internal lining the organic insulants such as XPS, PIR and PUR have the advantage of least thickness of material necessary due to their low U value.

Vapour barrier

Vapour check

The moisture vapour pressure from warm moist air inside insulated buildings may find its way through internal linings and condense to water on cold outer faces. Where the condensation moisture is absorbed by the insulation it will reduce the efficiency of the insulation and where condensation saturates battens, they may rot. With insulation that is permeable to moisture vapour, a vapour check should be fixed on the room side of insulation. A vapour barrier is one that completely stops the movement of vapour through it and a vapour check is one that substantially stops vapour. As it is difficult to make a complete seal across the whole surface of a wall including all overlaps of the barrier and at angles, it is in effect impossible to form a barrier and the term vapour check should more properly be used. Sheets of polythene with edges overlapped are commonly used as a vapour check, providing the edges of panels or boards of these materials can be tightly butted together.

External insulation

Insulating materials by themselves do not provide a satisfactory external finish to walls against rain penetration or for appearance sake and have to be covered with a finish of cement rendering, paint or a cladding material such as tile, slate or weatherboarding. For rendered finishes, one of the inorganic insulants, rockwool or cellular glass in the form of rigid boards, is most suited. For cladding, one of the organic insulants such as XPS, PIR or PUR is used because their low U values necessitate least thickness of board.

As a base for applied rendering the insulation boards or slabs are first bedded and fixed in line on dabs of either gap filling organic adhesive or dabs of polymer emulsion mortar and secured with corrosion resistant fixings to the wall. As a key for the render coats, either the insulation boards have a keyed surface or expanded metal lath or glass fibre mesh is applied to the face of the insulation. The weather protective render is applied in two coats by traditional wet

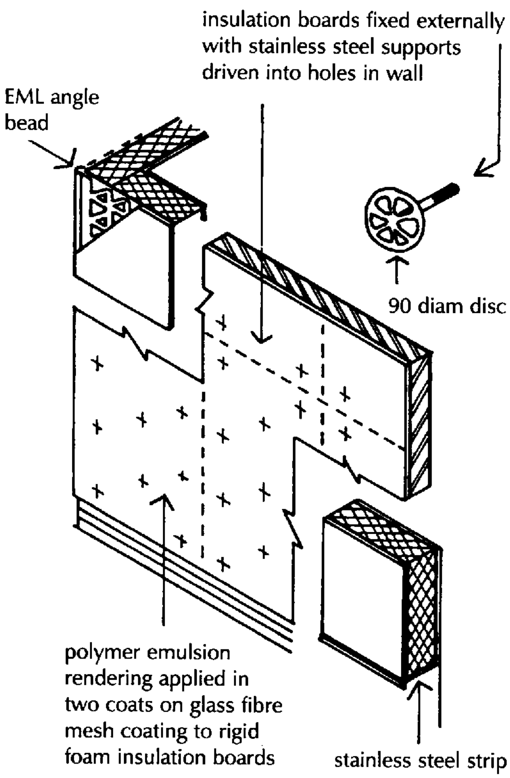


Fig. 106 External insulation.

render application, by rough casting or by spray application and finished smooth, coarse or textured. Coarse, spatter dash or textured finishes are preferred as they disguise hair cracks that are due to drying shrinkage of the rendering.

Because the rendering is applied over a layer of insulation it will be subject to greater temperature fluctuations than it would be if applied directly to a wall, and so is more liable to crack. To minimise cracking due to temperature change and moisture movements, the rendering should be reinforced with a mesh securely fixed to the wall, and movement joints should be formed at not more than 6 m intervals. The use of a light coloured finish and rendering incorporating a polymer emulsion will reduce cracking.

As the overall thickness of the external insulation and rendering is too great to be returned into the reveals of existing openings it is usual to return the rendering by itself, or fix some non-ferrous or plastic trim to mask the edge of the insulation and rendering. The reveals of openings will act as thermal bridges to make the inside face of the wall around openings colder than the rest of the wall. Figure 106 is an illustration of insulated rendering applied externally.

Tile and slate hanging, timber weatherboarding and profiled sheets can be fixed over a layer of insulating material behind the battens or sheeting rails to which these cladding materials are fixed.

Slabs of compressed rockwool are cut and shaped with bevel edges to simulate the appearance of masonry blocks. The blocks are secured to the external face of the wall with stainless steel brackets, fixed to the wall to support and restrain the blocks that are arranged with either horizontal, bonded joints or vertical and horizontal continuous joints. An exterior quality paint is then applied to the impregnated surface of the blocks. At openings, non-ferrous or plastic trim is fixed around outer reveals.

Details of insulating materials are given in Table 7.

Resistance to the passage of sound

The requirement of Part E of Schedule 1 to the Building Regulations is that walls which separate a dwelling from another building or from another dwelling shall have reasonable resistance to airborne sound.

Where solid walls of brick or block are used to separate dwellings the reduction of airborne sound between dwellings depends mainly on the weight of the wall and its thickness. A cavity wall with two leaves of brick or block does not afford the same sound reduction as a solid wall of the same equivalent thickness because the stiffness of the two separate leaves is less than that of the solid wall and in consequence is more readily set into vibration.

The joints between bricks or blocks should be solidly filled with mortar and joints between the top of a wall and ceilings should be filled against airborne sound transmission.

Table 7 External insulating materials.

Solid wall external insulation	Thickness mm	U value W/m^2K
Rockwool		
rigid slab with polymer cement finish	30, 40, 50, 60, 75, 100	0.033
Cellular glass		
boards for rendering on EML	30, 35, 40, 50, 60, 70	0.042
XPS		
boards T & G on long edges for cladding	25, 50	0.025
PIR		
boards behind cladding	25, 30, 35, 40	0.022
PUR		
boards behind cladding	20, 25, 30, 35, 40, 50	0.022

XPS extruded polystyrene
PIR rigid polyisocyanurate
PUR rigid polyurethane

In Approved Document E, giving practical guidance to meeting the requirements of the Building Regulations in relation to walls between dwellings, is a table giving the minimum weight of walls to provide adequate airborne sound reduction. For example, a solid brick wall 215 mm thick, plastered both sides, should weigh at least 300 kg/m^2 including plaster, and a similar cavity wall 255 mm thick, plastered both sides, should weigh at least 415 kg/m^2 including plaster, and a cavity block wall 250 mm thick, plastered both sides, should weigh at least 425 kg/m^2, including plaster.

STONE MASONRY WALLS

Before the Industrial Revolution, many permanent buildings in hill and mountain districts and many large buildings in lowland areas in this country were built of natural stone. At that time the supply of stone from local quarries was adequate for the buildings of the small population of this country. The increase in population that followed the Industrial Revolution was so great that the supply of sound stone was quite inadequate for the new buildings being put up. Coal was cheap, the railway spread throughout the country and cheap mass produced bricks largely replaced stone as the principal material for the walls of all but larger buildings.

Because natural stone is expensive it is principally used today as a facing material bonded or fixed to a backing of brickwork or concrete (see Volume 4). Many of the larger civic and commercial buildings are faced with natural stone because of its durability, texture, colour and sense of permanence. Natural stone is also used as the outer leaf of cavity walls for houses in areas where local quarries can supply stone at reasonable cost.

In recent years much of the time consuming and therefore expensive labour of cutting, shaping and finishing building stone has been appreciably reduced by the use of power operated tools, edged or surfaced with diamonds. This facility has improved output in the continuing and extensive work of repair and maintenance to stone buildings and encourages the use of natural stone as a facing material for new buildings.

Because natural stone is an expensive material, cast stone has been used as a cheaper substitute. Cast stone is made from either crushed natural stone or natural aggregate and cement and water which is cast in moulds. The cast stone blocks are made to resemble natural stone.

Natural stone

The natural stones used in building may be classified by reference to their origin as:

(1) igneous
(2) sedimentary
(3) metamorphic.

Igneous stone

Igneous stones were formed by the cooling of molten magma as the earth's crust cooled, shrank and folded to form beds of igneous rock. Of the igneous stones that can be used for building such as granite, basalt, diorite and serpentine, granite is most used for walls of buildings.

Granite consists principally of crystals of felspar, which is made up of lime and soda with other minerals in varying proportions and small grains of quartz and mica which give a sparkle to the surface of the stone. The granite that is native to these islands that is most used for walling is sometimes loosely described as Aberdeen granite as it is mined from deep beds of igneous rock near that town in Scotland. The best known Aberdeen granites are Rubislaw which is blue grey, Kemnay which is grey and Peterhead which is pink in colouring. All of these granites are fine grained, hard and durable and can be finished to a smooth polished surface. Aberdeen granites have been much used for their strength and durability as a walling material for large buildings and are now used as a facing material.

Cornish and Devon granites are coarse grained, light grey in colour with pronounced grains of white and black crystals visible. The stone is very hard and practically indestructible. Because these granites are coarse grained and hard they are laborious to cut and shape and cannot easily be finished with a fine smooth face. These granites have been principally used in engineering works for bridges, lighthouses and docks and also as a walling material for buildings in the counties of their origin.

Sedimentary stone

Sedimentary stone was formed gradually over thousands of years from the disintegration of older rocks which were broken down by weathering and erosion or from accumulations of organic origin, the resulting fine particles being deposited in water in which they settled in layers, or being spread by wind in layers that eventually consolidated and hardened to form layers of sedimentary rocks and clays. Because sedimentary stone is formed in layers it is said to be stratified. The strata or layers make this type of stone easier to split and cut than hard, igneous stones that are not stratified. The strata also affect the way in which the stone is used, if it is to be durable, as the divisions between the layers or strata are, in effect, planes of weakness. A general subdivision of sedimentary stones is

limestone
sandstone

The limestones used for walling consist mainly of grains of shell or sand surrounded by calcium carbonate, which are cemented together with calcium carbonate. The limestones most used for walling are quarried from beds of stone in the south-west of England, those most used being Portland and Bath stone. Because limestone is a stratified rock, due to the deposit of layers, it must be laid on its natural bed in walls.

Portland stone

Portland stone is quarried in Portland Islands on the coast of Dorset. There were extensive beds of this stone which is creamy white in colour, weathers well and used to be particularly popular for walling for larger buildings in towns. Many large buildings have been built in Portland stone because an adequate supply of large stone was available, the stone is fine grained and delicate mouldings can be cut on it and it weathers well even in industrial atmospheres.

Among the buildings constructed with this stone are the great banqueting hall in Whitehall (1639), St Paul's Cathedral (1676), the British Museum (1753) and Somerset House (1776). More recently, many large buildings have been faced with this stone.

In the Portland stone quarries are three distinct beds of the stone, the base bed, the whit bed and the roach. The base bed is a fine, even grained stone which is used for both external and internal work to be finished with delicate mouldings and enrichment. The whit bed is a hard, fairly fine grained stone which weathers particularly well, even in towns whose atmosphere is heavily polluted with soot and it was extensively used as a facing material for large buildings.

The roach is a tough, coarse grained stone which has principally been used for marine construction such as piers and lighthouses.

The stones from the different beds of Portland limestone look alike to the layman. It is sometimes difficult for even the trained stonemason to distinguish base bed from whit bed. Roach can be distinguished by its coarse grain and by the remains of fossil shells embedded in it. When taken from the quarry the stone is moist and comparatively soft, but gradually hardens as moisture (quarry sap) dries out.

Bath stone

Many of the buildings in the town of Bath were built with a limestone quarried around the town. This limestone is one of the great oolites and a similar stone was also quarried in Oxfordshire. Bath stone from the Tayton (Oxfordshire) quarry was extensively used in the construction of the early colleges in Oxford (St Johns, for example) during the twelfth, thirteenth and fourteenth centuries. Many of the permanent buildings in Wiltshire and Oxfordshire were built of this stone, which varies from fine grained to coarse grained in texture and light cream to buff in colour. Most of the original quarries are no longer being worked.

The durability of Bath stone varies considerably. Some early buildings constructed with this stone are well preserved to this day, but others have so decayed over the years and been so extensively repaired that little of the original stone remains. Extensive repair of the Bath stone fabric of several of the colleges in Oxford has been carried out and continuing repair is necessary.

Sandstone

Sandstone was formed from particles of rock broken down over thousands of years by the action of wind and rain. The particles were washed into and settled to the beds of lakes and seas in combination with clay, lime and magnesia and gradually compressed into strata of sandstone rock. The particles of sandstone are practically indestructible and the hardness and resistance to the weather of this stone depends on the composition of the minerals binding the particles of sand. If the sand particles are bound with lime the stone often does not weather well as the soluble lime dissolves and the stone disintegrates. The material binding the sand particles should be insoluble and crystalline. Sandstones are generally coarse grained and cannot be worked to fine mouldings.

The stratification of most sandstones is visible as fairly close spaced divisions in the sandy mass of the stone. It is essential that this type of stone be laid on its natural bed in walls.

Most sandstones have been quarried in the northern counties of England where for centuries this stone has been the material commonly used for the walls of buildings. Some of the sandstones that have been used are:

Crosland Hill (Yorkshire). A light brown sandstone of great strength which weathers well and is used for masonry walls as a facing material and for engineering works. It is one of the stones known as hard York stone, a general term used to embrace any hard sandstone not necessarily quarried in Yorkshire.

Blaxter stone (Northumberland). A hard, creamy coloured stone used for wall and as a facing.

Doddington (Northumberland). A hard, pink stone used for walling.

Darley Dale (Derbyshire). A hard, durable stone of great strength much used for engineering works and as walling. It is hard to work and generally used in plain, unornamented wall. Buff and white varieties of this stone were quarried.

Forest of Dean (Gloucestershire). A hard, durable, grey or blue grey stone which is hard to work but weathers well as masonry walling.

Metamorphic stone

Metamorphic stones were formed from older stones that were changed by pressure or heat or both. The metamorphic stones used in building are slate and marble.

Slate

Slate was formed by immense pressure on beds of clay that were compressed to hard, stratified slate which is used for roofing and as cills and copings in building. Riven, split, Welsh slate has for centuries been one of the traditional roofing materials used in this country. The stone can be split to comparatively thin slates that are hard and very durable.

Marble

The description marble is used to include many stones that are not true metamorphic rocks, such as limestones, that can take a fine polish. In the British Isles true marble is only found in Ireland and Scotland. Marble is principally used as an internal facing material in this country.

Durability of natural stone

Natural stone has been used in the construction of buildings because it was thought that any hard, natural stone would resist the action of wind and rain for centuries. Many natural stones have been used in walling and have been durable for a hundred or more years and are likely to have a comparable life if reasonably maintained.

There have been some notable failures of natural stone in walling, due in the main to a poor selection of the material and poor workmanship. The best known example of decay in stonework occurred in the fabric of the Houses of Parliament, the walls of which were built with a magnesian limestone from Ancaster in Yorkshire. A Royal Commission reported in 1839 that the magnesian limestone quarried at Bolsover Moor in Yorkshire was considered the most durable stone for the Houses of Parliament. After building work had begun it was discovered that the quarry was unable to supply sufficient large stones for the building and a similar stone from the neighbouring quarry at Anston was chosen as a substitute. The quarrying, cutting and use of the stone was not supervised closely and in consequence many inferior stones found their way into the building and many otherwise sound stones were incorrectly laid.

Decay of the fabric has been continuous since the Houses of Parliament were first completed and extensive, costly renewal of stone has been going on for many years. At about the same time that the Houses of Parliament were being built, the Museum of Practical Geology was built in London of Anston stone from the same quarry that supplied the stone for the Houses of Parliament, but the quarrying, cutting and use of the stones was closely supervised for the museum, whose fabric remained sound.

The variability of natural stone that may appear sound and durable, but some of which may not weather well, is one of the disadvantages of this material which can, when carefully selected and used, be immensely durable and attractive as a walling material.

Seasoning natural stone

Some natural stones are comparatively soft and moist when first quarried but gradually harden. Building stones should be seasoned (allowed to harden) for periods of up to a few years, depending on the size of the stones. Once stone has been seasoned it does not revert to its original soft moist state on exposure to rain, but on the contrary hardens with age.

Bedding stones

Natural stones that are stratified, limestone and sandstone, must be used in walling so that they lie on their natural bed to support compressive stress. The bed of a stone is its face parallel to the strata (layer) of the stones in the quarry and the stress that the stone suffers in use should be at right angles to the strata or bed which otherwise might act as a plane of weakness and give way under compressive stress. The stones in an arch are laid with the bed or strata radiating roughly from the centre of the arch so that the bed is at right angles to the compressive stress acting around the curve of the arch.

Cast stone

Cast stone is one of the terms used to describe concrete cast in moulds to resemble blocks of natural stone. When the material first came into use some 50 years ago it was called artificial stone. To avoid the use of the pejorative term artificial, the manufacturers now prefer the description reconstructed stone.

Reconstructed stone

Reconstructed stone is made from an aggregate of crushed stone, cement and water. The stone is crushed so that the maximum size of the particles is 6 mm and it is mixed with cement in the proportions of 1 part cement to 3 or 4 parts of stone. Either portland cement, white cement or coloured cement may be used to simulate the colour of a natural stone as closely as possible. A comparatively dry mix of cement, crushed stone and water is prepared and cast in moulds. The mix is thoroughly consolidated inside the moulds by vibrating and left to harden in the moulds for at least 24 hours. The stones are then taken out of the moulds and allowed to harden gradually for 28 days.

Well made reconstructed stone has much the same texture and colour as the natural stone from which it is made and can be cut, carved and dressed just like natural stone. It is not stratified, is free from flaws and is sometimes a better material than the natural stone from which it is made. The cost of a plain stone, cast with an aggregate of crushed natural stone, is about the same as that of a similar natural stone. Moulded cast stones can often be produced more cheaply by repetitive casting than similar natural stones that have to be cut and shaped.

A cheaper, inferior, form of cast stone is made with a core of ordinary concrete, faced with an aggregate of crushed natural stone and cement. This material should more properly be called cast concrete.

The core is made from clean gravel, sand and Portland cement and the facing from crushed stone and cement to resemble the texture and colour of a natural stone. The crushed stone, cement and water is first spread in the base of the mould to a thickness of about 25 mm, the core concrete is added and the mix consolidated. If the stone is to be exposed on two or more faces the natural stone mix is spread up the sides and the bottom of the mould. This type of cast stone obviously cannot be carved as it has only a thin surface of natural looking stone.

As an alternative to a facing of reconstructed stone, the facing or facings can be made of cement and sand pigmented to look somewhat like the colour of a natural stone.

Cast stones made with a surface skin of material to resemble stone do not usually weather in the same way that natural stone does, by a gradual change of colour. The material tends to have a lifeless, mechanical appearance and may in time tend to show irregular, unsightly dirt stains at joints, cracks and around projections.

Reconstructed stone is used as an ashlar facing to brick or block backgrounds for both solid and the outer leaf of cavity walls and as facings (see Volume 4).

Functional requirements

Strength and stability

The strength of sound building stone lies in its very considerable compressive strength. The ultimate or failing stress of stone used for walling is about 300 to 100 N/mm^3 for granite, 195 to 27 N/mm^3 for sandstone and 42 to 16 N/mm^3 for limestone. The considerable compressive strength of building stone was employed in the past in the construction of massive stone walls for fortifications and in other large structures. The current use of stone as a facing material makes little use of the inherent compressive strength of the material.

The stability of a stone wall is affected by the same limitations that apply to walls of brick or block. The construction of foundations and the limits of slenderness ratio, the need for buttressing walls, piers and chimneys along the length of walls and the requirements for lateral support from floors and roofs up the height of walls apply to stone walls as they do for brick and block walls.

Resistance to weather and ground moisture

To prevent moisture rising from the ground through foundation walls it is necessary to form a continuous horizontal dpc some 150 mm above ground level. One way of achieving this is to construct foundation walls of dense stone, such as granite, that does not readily absorb moisture. More usually one of the damp-proof materials described for use with brickwork is used. A sheet lead dpc is commonly used as it is less likely to be squeezed out and forms a comparatively thin and therefore less unsightly joint than a bitumen felt dpc.

The resistance to the penetration of wind driven rain was not generally a consideration in the construction of solid masonry walls. The very considerable thickness of masonry walls of traditional large buildings was such that little, if any, rain penetrated to the inside face.

With the use of stone, largely as a facing material for appearance sake, it is necessary to construct walls faced with stone as cavity walling with a brick or block inner leaf separated by a cavity from the stone faced outer leaf, as illustrated in Fig. 107.

The outer leaf illustrated in Fig. 107 is built with natural stone blocks bonded to a brick backing, with full width stones in every other course and the stones finished on face in ashlar masonry. This is an expensive form of construction because of the considerable labour costs in preparing the ashlared stones. As alternatives the outer leaf of small buildings may be constructed with stone blocks by themselves for the full thickness of the outer leaf, or with larger buildings the outer leaf may be constructed of brick to which a facing of stone slabs is fixed (see Volume 4).

The leaves of the cavity are tied with galvanised steel or stainless steel wall ties in the same way that brick and block walls are constructed and the cavity is continued around openings, or dpcs are formed to resist rain penetration at head, jambs and cills of openings.

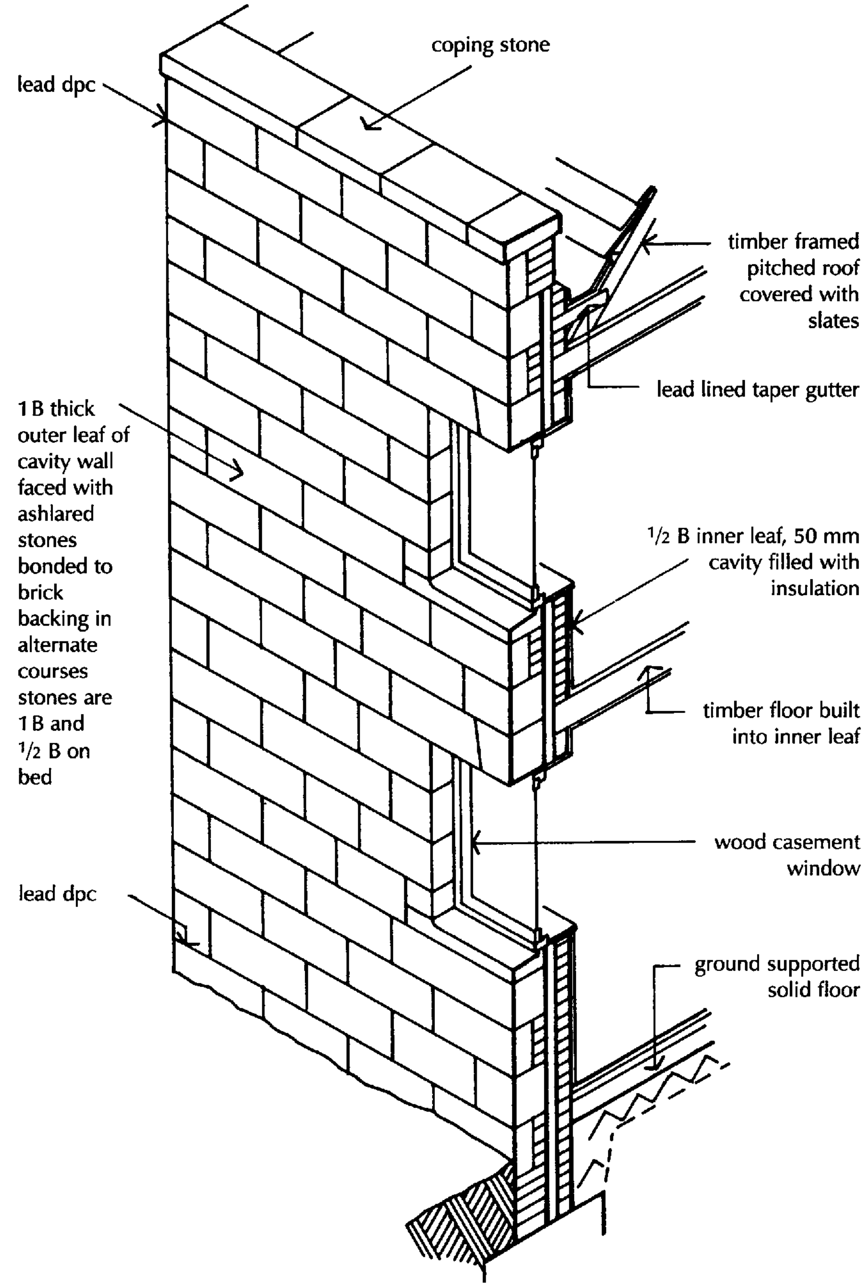


Fig. 107 Cavity wall faced with ashlared stone and brick backing.

Durability and freedom from maintenance

Sound natural stone is highly durable as a walling material and will have a useful life of very many years in buildings which are adequately maintained.

Granite is resistant to all usual weathering agents, including highly polluted atmospheres, and will maintain a high natural polished surface for a hundred years or more. The lustrous polish will be enhanced by periodic washing.

Hard sandstones are very durable and inert to weathering agents but tend to dirt staining in time, due to the coarse grained texture of the material which retains dirt particles. The surface of sandstone may be cleaned from time to time to remove dirt stains by abrasive blasting with grit or chemical processes and thorough washing.

Sound limestone, sensibly selected and carefully laid, is durable for the anticipated life of the majority of buildings. In time the surface weathers by a gradual change of colour over many years, which is commonly held to be an advantage from the point of view of appearance. Limestones are soluble in rainwater that contains carbon dioxide so that the surface of a limestone wall is to an extent self-cleansing when freely washed by rain, while protected parts of the wall will collect and retain dirt. This effect gives the familiar black and white appearance of limestone masonry. The surface of limestone walls may be cleaned by washing with a water spray or by steam and brushing to remove dirt encrustations and the surface brought back to something near its original appearance.

In common with the other natural walling material, brick, a natural stone wall of sound stone sensibly laid will have a useful life of very many years and should require little maintenance other than occasional cleaning.

Fire resistance

Natural stone is incombustible and will not support or encourage the spread of flame. The requirements of Part B of Schedule 1 to the Building Regulations for structural stability and integrity and for concealed spaces apply to walls of stone as they do for walls of block or brick masonry.

Resistance to the passage of heat

The natural stones used for walling are poor insulators against the transfer of heat and will contribute little to thermal resistance in a wall. It is necessary to use some material with a low U value as cavity insulation in walls faced with stone in the same way that insulation is used in cavity walls of brick or blockwork.

Resistance to the passage of sound

Because natural building stone is dense it has good resistance to the transmission of airborne sound and will provide a ready path for impact sound.

Ashlar walling

Ashlar walling is constructed of blocks of stone that have been very accurately cut and finished true square to specified dimensions so that the blocks can be laid, bedded and bonded with comparatively thin mortar joints, as illustrated in Fig. 107. The very considerable labour involved in cutting and finishing individual stones is such that this type of walling is very expensive. Ashlar walling has been used for the larger, more permanent buildings in towns, and on estates where the formal character of the building is pronounced by the finish to the walling. Ashlar walling is now used principally as a facing material (see Volume 4).

Openings to stone walls

Stone walls over door and window openings are supported by flat stone lintels or by segmental or semi-circular arches.

Lintels

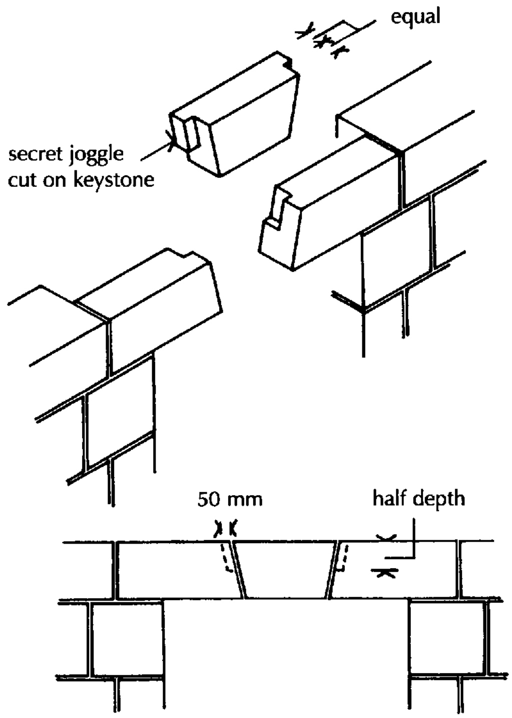


Fig. 108 Stone lintel with secret joggle joints.

A stone lintel for small openings of up to about a metre wide can be formed of one whole stone with its ends built into jambs and its depth corresponding to one or more stone courses. The poor tensile strength of stone limits the span of single stone lintels unless they are to be disproportionately deep.

Over openings wider than about a metre it is usual to form lintels with three or five stones cut in the form of a flat arch. The stones are cut so that the joints between the ends of stones radiate from a common centre so that the centre, or key stone, is wedge-shaped, as illustrated in Fig. 108. The stones are cut so that the lower face of each stone occupies a third or a fifth of the width of the opening.

To prevent the key stone sinking due to settlement and so breaking the line of the soffit, it is usual to cut half depth joggles in the ends of the key stone to fit to rebates cut in the other stones. The joggles and rebates may be cut the full thickness of each stone and show on the face of the lintel or more usually the joggles and rebates are cut on the inner half of the thickness of stones as secret joggles, which do not show on the face, as illustrated in Fig. 108. The depth of the lintel corresponds to a course height, with the ends of the lintel built in at jambs as end bearing. Stone lintels are used over both ashlar and rubble walling.

The use of lintels is limited to comparatively small openings due to the tendency of the stones to sink out of horizontal alignment. For wider openings some form of arch is used.

Arches

A stone arch consists of stones specially cut to a wedge shape so that the joints between stones radiate from a common centre, the soffit is arched and the stones bond in with the surrounding walling. The individual stones of the arch are termed 'voussoirs', the arched soffit the 'intrados' and the upper profile of the arch stones the 'extrados'.

Figure 109 is an illustration of a stone arch whose soffit is a segment of a circle. The choice of the segment of a circle that is selected is to an extent a matter of taste, which is influenced by the appearance of strength. A shallow rise is often acceptable for small openings and a greater rise for larger, as the structural efficiency of the arch increases the more nearly the segment approaches a full half circle. The voussoirs of the segmental arch illustrated in Fig. 109 are cut with steps that correspond in height with stone courses, to which the stepped extrados is bonded.

The stones of an arch are cut so that there is an uneven number of voussoirs with a centre or key stone. The key stone is the last stone to be put in place as a key to the completion and the stability of the arch, hence the term key stone.

The majority of semi-circular arches are formed with stones cut to bond in with the surrounding stonework in the form of a stepped extrados similar to that shown for a segmental arch in Fig. 109.

Crossetted arch

The semi-circular arch, illustrated in Fig. 110, is formed with stones that are cut to bond into the surrounding walling to form a stepped extrados and also to bond horizontally into the surrounding stones. The stones, voussoirs, are said to be crossetted, or crossed. This extravagant cutting of stone is carried out purely for appearance sake. This is not a structurally sound idea as a very slight settlement might cause the crossetted end of a stone to crack away from the main body of the stone, whereas with plain voussoirs the slight settlement would be taken up by the joints.

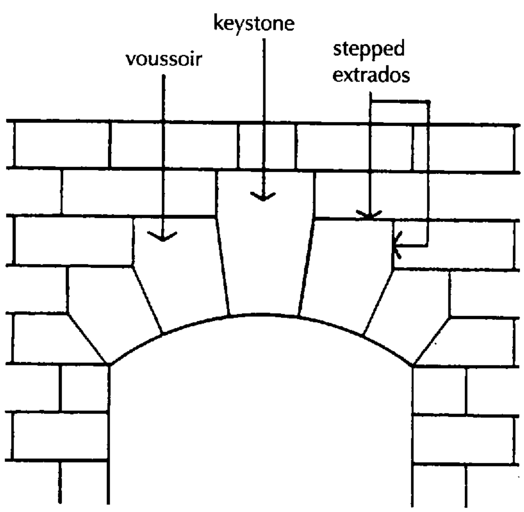


Fig. 109 Segmental stone arch.

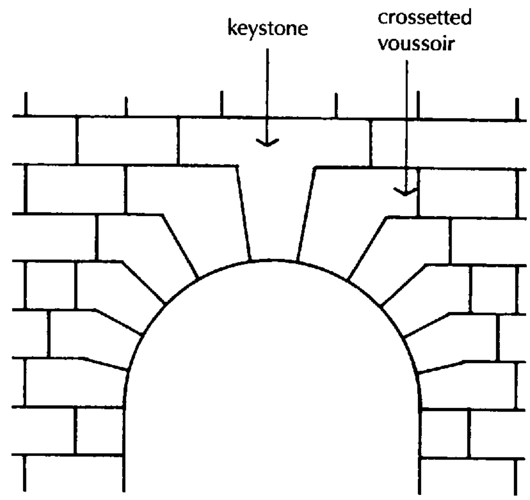


Fig. 110 Semi-circular stone arch with crossetted voussoirs.

The stones radiate from a common centre with an odd number of stones arranged around the half circle so that there is a central key stone. The extent that the crossetted top of each stone extends into the surrounding masonry is not necessarily dictated by the stretcher bond of the main walling. Any degree of bond into the main wall may be chosen and the bond of masonry adjusted accordingly. No matter which dimension of crossetted end is chosen the key stone has to be wastefully cut from one large stone.

The effect of the crossetted voussoir is to emphasise the arch as structurally separate from the coursed masonry and is chosen for that effect.

Ashlar masonry joints

Ashlar stones may be finished with smooth faces and bedded with thin joints, or the stones may have their exposed edges cut to form a channelled or 'V' joint to emphasise the shape of each stone and give the wall a heavier, more permanent appearance. The ashlar stones of the lower floor of large buildings are often finished with channelled or V joints and the wall above with plain ashlar masonry to give the base of the wall an appearance of strength. Ashlar masonry finished with channelled or V joints is said to be rusticated. A channelled joint (rebated joint) is formed by cutting a rebate on the top and one side edge of each stone, so that when the stones are laid, a channel rebate appears around each stone, as illustrated in Fig. 111A. The rebate is cut on the top edge of each stone so that when the stones are laid, rainwater which may run into the horizontal joint will not penetrate the mortar joint.

A V joint (chamfered joint) is formed by cutting all four edges of stones with a chamfer so that when they are laid a V groove appears on face, as illustrated in Fig. 111B. Often the edges of stones are cut with both V and channelled joints to give greater emphasis to each stone.

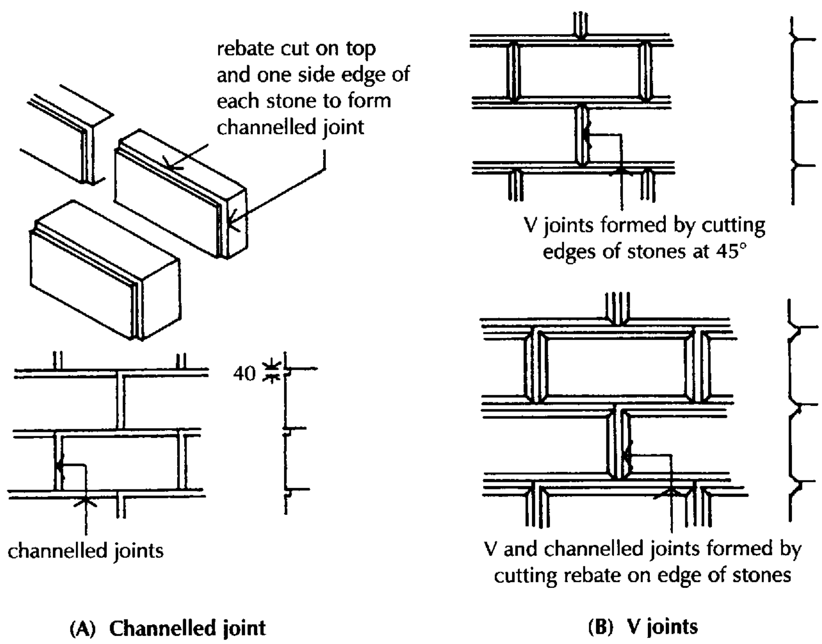


Fig. 111 (A) Channelled joint. (B) V joint.

Tooled finish

Plain ashlar stones are usually finished with flat faces to form plain ashlar facing. The stones may also be finished with their exposed faces tooled to show the texture of the stone. Some of the tooled finishes used with masonry are illustrated in Fig. 112. It is the harder stones such as granite and hard sandstone that are more commonly finished

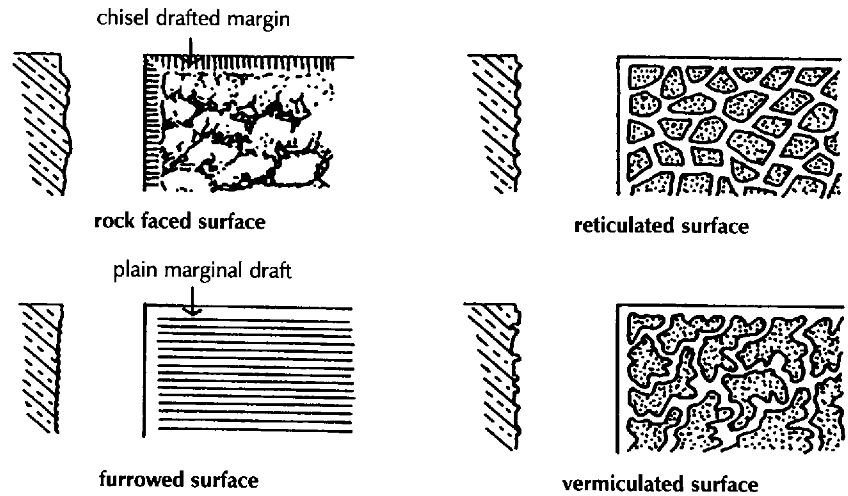


Fig. 112 Tooled finishes.

with rock face, pitched face, reticulated or vermiculated faces. The softer, fine grained stones are usually finished as plain ashlar.

Cornice and parapet walls

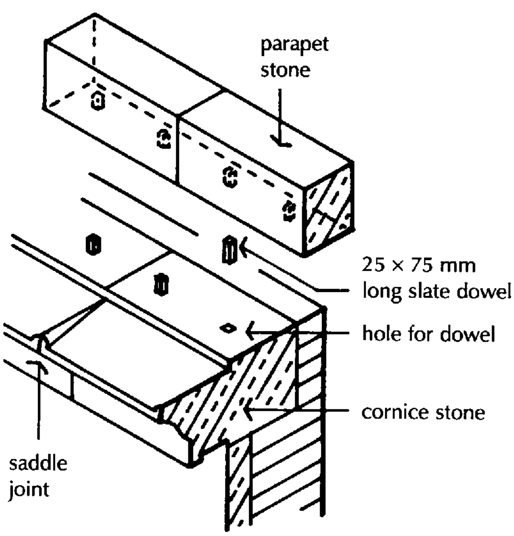


Fig. 113 Cornice and parapet.

It is common practice to raise masonry walls above the levels of the eaves of a roof, as a parapet. The purpose of the parapet is partly to obscure the roof and also to provide a depth of wall over the top of the upper windows for the sake of appearance in the proportion of the building as a whole.

In order to provide a decorative termination to the wall, a course of projecting moulded stones is formed. This projecting stone course is termed a cornice and it is generally formed some one or more courses of stone below the top of the parapet. Figure 113 is an illustration of a cornice and a parapet wall to an ashlar faced building. An advantage of the projecting cornice is that it affords some protection against rain to the wall below.

The parapet wall usually consists of two or three courses of stones capped with coping stones bedded on a dpc of sheet metal. The parapet is usually at least 1 B thick or of such thickness that its height above roof is limited by the requirements of the Building Regulations as described in Chapter 4 for parapet walls. The parapet may be built of solid stone or stones bonded to a brick backing.

The cornice is constructed of stones of about the same depth as the stones in the wall below, cut so that they project and are moulded for appearance sake. Because the stones project, their top surface is weathered (slopes out) to throw water off.

Saddle joint

The projecting, weathered top surface of coping stones is exposed and rain running off it will in time saturate the mortar in the vertical joints between the stones. To prevent rain soaking into these joints it is usual to cut the stones to form a saddle joint as illustrated in Fig. 113.

The exposed top surface of the stones has to be cut to slope out (weathering) and when this cutting is executed a projecting quarter circle of stone is left on the ends of each stone. When the stones are laid, the projections on the ends of adjacent stones form a protruding semi-circular saddle joint which causes rain to run off away from the joints.

Weathering to cornices

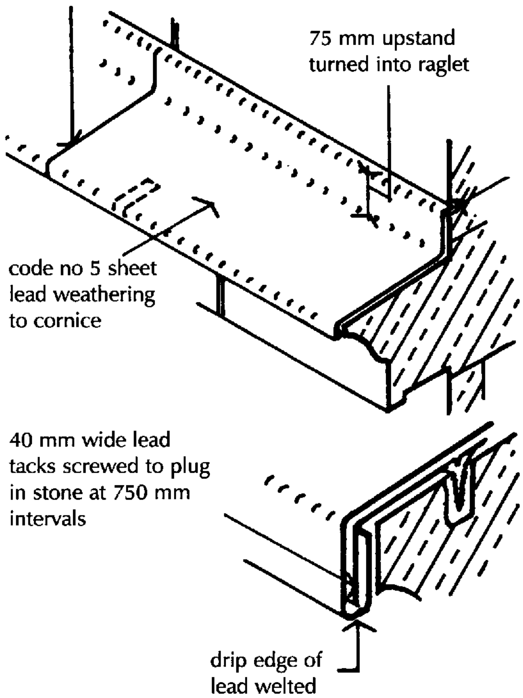


Fig. 114 Lead weathering to cornice.

Because cornices are exposed and liable to saturation by rain and possible damage by frost, it is good practice to cover the exposed top surface of cornice stones cut from limestone or sandstone with sheet metal. The sheet metal covering is particularly useful in urban areas where airborne pollutants may gradually erode stone.

Sheet lead is preferred as a non-ferrous covering because of its ductility, that facilitates shaping, and its impermeability.

Sheets of lead, code No 5, are cut and shaped for the profile of the top of the cornice, and laid with welted (folded) joints at 2 m intervals along the length of the cornice. The purpose of these comparatively closely spaced joints is to accommodate the inevitable thermal expansion and contraction of the lead sheet. The top edge of the lead is dressed up some 75 mm against the parapet as an upstand, and turned into a raglet (groove) cut in the parapet stones and wedged in place with lead wedges. The joint is then pointed with mortar.

The bottom edge of the lead sheets is dressed (shaped) around the outer face of the stones and welted (folded). To prevent the lower edge of the lead sheet weathering being blow up in high winds, 40 mm wide strips of lead are screwed to lead plugs set in holes in the stone at 750 mm intervals, and folded into the welted edge of the lead, as illustrated in Fig. 114.

Where cornice stones are to be protected with sheet lead weathering there is no purpose in cutting saddle joints.

Cement joggle

Cornice stones project and one or more stones might in time settle slightly so that the decorative line of the mouldings cut on them would be broken and so ruin the appearance of the cornice. To prevent this possibility shallow V-shaped grooves are cut in the ends of each stone so that when the stones are put together these matching V grooves form a square hole into which cement grout is run. When the cement hardens it forms a joggle which locks the stones in their correct position.

Dowels

To maintain parapet stones in their correct position in a wall, slate dowels are used. The stones in a parapet are not kept in position by the weight of walling above and these stones are, therefore, usually fixed with slate dowels. These dowels consist of square pins of slate that are fitted to holes cut in adjacent stones, as illustrated in Fig. 113.

Cramps

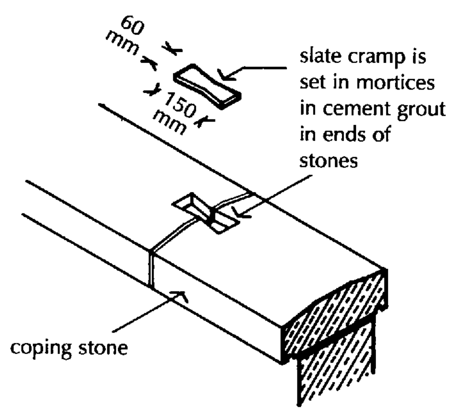
Coping stones are bedded on top of a parapet wall as a protection against water soaking down into the wall below. There is a possibility that the coping (capping) stones may suffer some slight movement and cracks in the joints between them open up. Rain may then saturate the parapet wall below and frost action may contribute to some movement and eventual damage.

To keep coping stones in place a system of cramps is used. Either slate or non-ferrous metal is used to cramp the stones together.

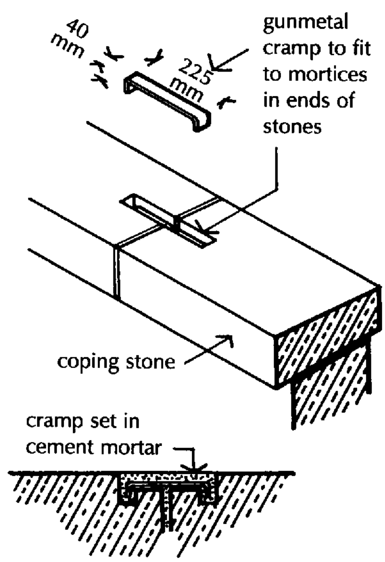
A short length of slate, shaped with dovetail ends, is set in cement grout (cement and water) in dovetail grooves in the ends of adjacent stones, as illustrated in Fig. 115A.

As an alternative a gunmetal cramp is set in a groove and mortice in the end of each stone and bedded in cement mortar, as illustrated in Fig. 115B.

For coping stones cut from limestone or sandstone a sheet metal weathering is sometimes dressed over coping stones. The weathering of lead is welted and tacked in position over the stones.



(A) Slate cramp



(B) Metal cramp

Fig. 115 (A) Slate cramp. (B) Metal cramp.

Rubble walling

Rubble walling has been extensively used for agricultural buildings in towns and villages in those parts of the country where a local source of stone was readily available. The term rubble describes blocks of stones as they come from the quarry. The rough rubble stones are used in walling with little cutting other than the removal of inconvenient corners. The various types of rubble walling depend on the nature of the stone used. Those stones that are hard and laborious to cut or shape are used as random rubble and those sedimentary stones that come from the quarry roughly square are used as squared rubble.

The various forms of rubble walling may be classified as random rubble and squared rubble.

Random rubble

Uncoursed random rubble

Uncoursed random rubble stones of all shapes and sizes are selected more or less at random and laid in mortar, as illustrated in Fig. 116A. No attempt is made to select and lay stones in horizontal courses. There is some degree of selection to avoid excessively wide mortar joints and also to bond stones by laying some longer stones both along the face and into the thickness of the wall, so that there is a bond stone in each square metre of walling. At quoins, angles and around openings selected stones or shaped stones are laid to form roughly square angles.

Random rubble brought to course

Random rubble brought to course is similar to random rubble uncoursed except that the stones are selected and laid so that the walling is roughly levelled in horizontal courses at vertical intervals of from 600 to 900 mm, as illustrated in Fig. 116B. As with uncoursed rubble, transverse and longitudinal bond stones are used.

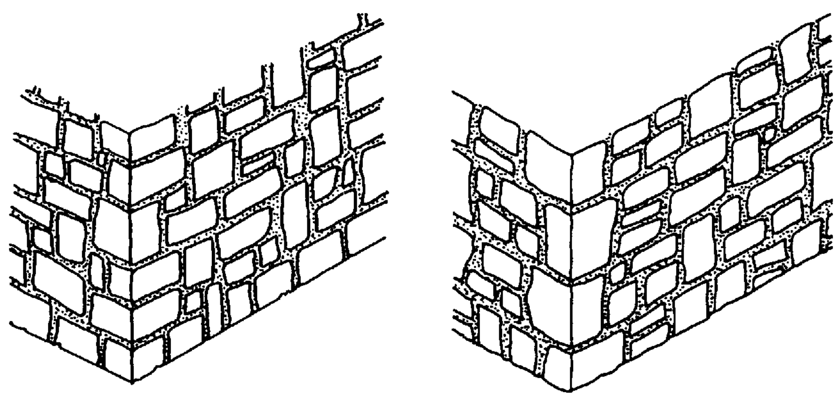


Fig. 116 (A) Random rubble uncoursed. (B) Random rubble coursed.

Squared rubble

Squared rubble uncoursed

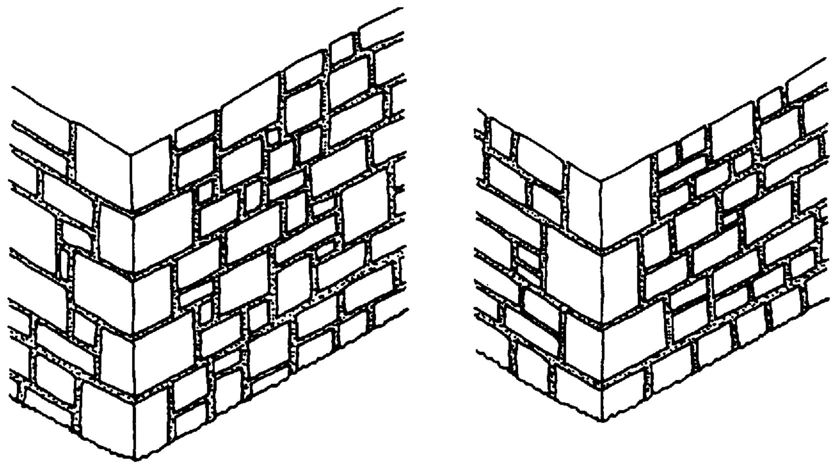
Squared rubble uncoursed is laid with stones that come roughly square from the quarry in a variety of sizes. The stones are selected at random, are roughly squared with a walling hammer and laid without courses, as illustrated in Fig. 117A. As with random rubble, both transverse and longitudinal bond stones are laid at invervals.

Snecked rubble

Snecked rubble is a term for squared rubble in which a number of small squared stones, snecks, are laid to break up long continuous vertical joints. Snecked rubble is often difficult to distinguish from squared random rubble.

Squared rubble brought to course

Squared rubble brought to course is constructed from roughly square stone rubble, selected and squared so that the work is brought to courses every 300 to 900 mm intervals, as illustrated in Fig. 117B.



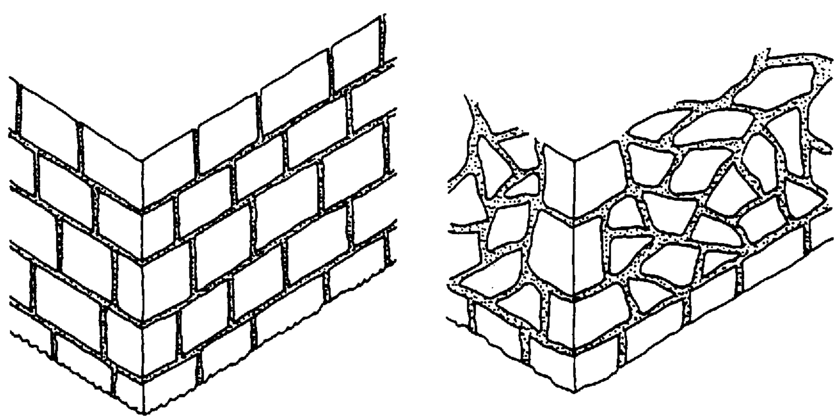
(A) (B)

Fig. 117 (A) Squared rubble uncoursed. (B) Squared rubble coursed.

Squared rubble coursed is built with stones that are roughly squared so that the stones in each course are roughly the same height and the courses vary in height, as illustrated in Fig. 118A. The face of the stones may be roughly dressed to give a rock faced appearance or dressed smooth to give a more formal appearance.

Polygonal walling

Stones that are taken from a quarry where the stone is hard, have no pronounced laminations and come in irregular shapes can be laid as polygonal walling. The stones are selected and roughly dressed to fit when laid, to an irregular pattern, with no attempt at regular courses or vertical joints. At corners and as a base, roughly square edged stones are used, as illustrated in Fig. 118B.



(A) (B)

Fig. 118 (A) Squared rubble coursed. (B) Polygonal walling.

Flint walling

Flint walling is traditional to East Anglia and the south and south-east of England. Both field and shore flints are used. The flints used for walling are up to 300 mm in length and from 75 to 250 mm in width and thickness. The flints or cobbles may be used whole or split to show the heart of the flint, and also knapped or snapped so that they show a roughly square face.

Flint walling is built with a dressing of stone or brick at angles and in horizontal lacing courses that level the wall at intervals. Figure 119A is an illustration of whole flints laid without courses in brick dressing to angles and as lacing and Fig. 119B an illustration of knapped flints laid to courses in stone dressing.

Rubble walling is generally considerably thicker than a wall of square bricks or blocks because of the inherent instability of a wall built of irregular shaped blocks. Rubble walling for buildings is usually at least 400 mm thick.

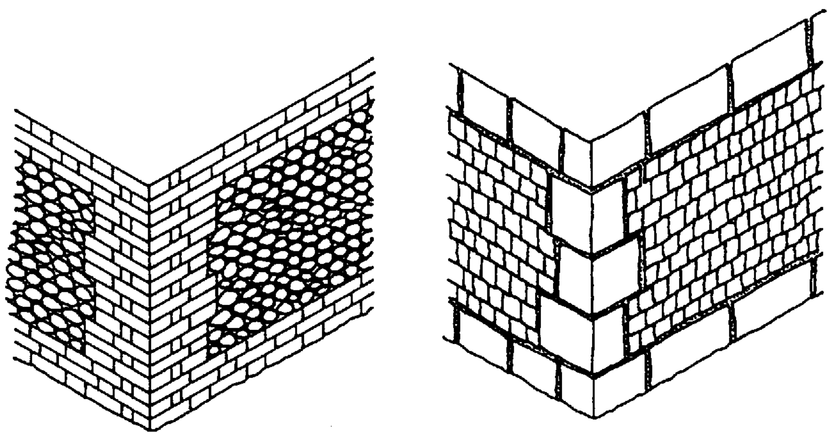


Fig. 119 (A) Whole flint wall. (B) Knapped flint wall.

TIMBER FRAMED WALLS

TIMBER

The word timber describes wood which has been cut for use in building.

Timber has many advantages as a building material. It is a light-weight material that is easy to cut, shape and join by relatively cheap and simple hand or power operated tools in the production of wall, floor and roof panels, timber joists, and for rafters, walls, floors and roofs and joinery generally.

As a structural material it has favourable weight to cost, weight to strength and weight to modulus of elasticity ratios and coefficients of thermal expansion, K values, density and specific heat. With sensible selection, fabrication and fixing and adequate protection it is a reasonably durable material in relation to the life of most buildings.

Wood burns at temperatures of about 350°C and chars, the charred outer faces of the wood protecting the unburnt inner wood for periods adequate for escape during fires, in most buildings.

In this age of what the layman calls 'plastics' and 'synthetic' materials some people remark that timber is old-fashioned and suggest that more modern materials such as reinforced concrete should be used for floors and roofs. At present the cost of a timber upper floor for a house is about half that of a similar reinforced concrete floor and as the timber floor is quite adequate for its purpose it seems senseless to double the cost of the floor just to be what is called modern.

Much of the timber used in buildings today is cut from the wood of what are called 'conifers'. A coniferous tree is one that has thin needle-like leaves that remain green all year round and whose fruit is carried in woody cones. Examples of this type of tree are fir and pine.

Softwood

Hardwood

In North America and northern Europe are very extensive forests of coniferous trees, the wood from which can be economically cut and transported. The wood of coniferous trees is generally less hard than that of other sorts of trees, for example oak, and the wood from all conifers is classified as softwood, whilst the wood from all other trees which have broad leaves is termed hardwood.

The cost of a typical softwood used today is about half that of a typical hardwood.

Softwood is made up of many very thin, long cells with their long axis along the length of the trunk or branch. These cells are known as tracheids and they give softwood its strength and texture, and serve to convey sap. The structure of hardwood is more complicated and in most hardwoods the bulk of the wood consists of long fibres. In addition to the fibres there are long cells, called vessels, which conduct water from the roots of the tree to its crown.

Trees whose wood is used for building are all exogens, meaning growing outwards, as each year most of these trees form new layers of wood under the bark. Beneath the protective bark around tree trunk and branches is a slimy light green skin. This is termed the cambium and it consists of a layer of wood cells which begin each spring to divide several times to form a layer of new wood cells. All these new wood cells are formed inside the cambium and the first wood cells formed each year are termed spring wood, and the cells formed later are termed summer wood.

The wood cells which are formed first are thinner walled than those formed in the summer and in any cross section cut of wood there are distinct circular rings of light coloured spring wood then darker coloured and thinner rings of summer wood. As a new spring and summer ring is formed each year they are called annual rings, which

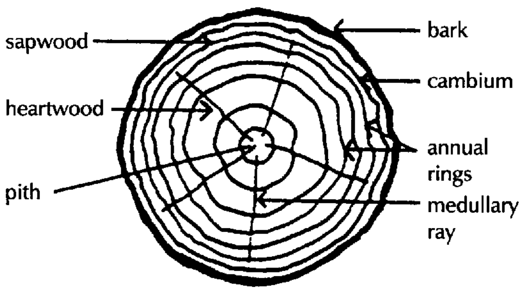


Fig. 120 Section through growing wood.

are shown in Fig. 120. The wood of the annual rings most recently formed close to the bark is less dense than that close to the centre of the tree. The outer wood is sapwood and that towards the centre is heartwood. In the conversion of wood to timber there should ideally be as little sapwood as possible.

In the diagram are shown a number of irregular radial lines marked medullary rays. These rays consist of specialised wood cells whose main purpose is to store food in readiness for it to be conveyed to any part of the tree that may require it.

Seasoning of timber

Up to two-thirds of the weight of growing wood is due to water in the cells of the wood. When the tree is felled and the wood is cut into timber this water begins to evaporate to the air around the timber, and the wood gradually shrinks as water is removed from the cell walls. As the shrinkage in timber is not uniform the timber may lose shape and it is said to warp.

It is essential that before timber is used in buildings, either it should be stacked for a sufficient time in the open air for most of the water in it to dry out, or it should be artificially dried out. If wet timber is used in building it will dry out and shrink and cause cracking of plaster and twisting of doors and windows. The process of allowing, or causing, newly cut wood to dry out is called seasoning, and timber which is ready for use in building is said to have been properly seasoned. The amount of water in wood varies, and it is not sufficient to allow all timber to dry out for some specific length of time, as one piece of timber may be well seasoned and dried out, whilst another similar piece stacked for the same length of time may still be too wet to use immediately.

Moisture content of timber

It is necessary to specify that there shall be a certain amount of water, and no more or less, in timber suitable for building. It is said that timber shall have a certain moisture content, and the moisture content is stated as a percentage of the dry weight of the timber. The dry weight of any piece of timber is its weight after it has been so dried that further drying causes it to lose no more weight. This dry weight is reasonably constant for a given cubic measure of each type of wood and is used as the constant against which the moisture content can be assessed. Table 8 sets out moisture contents for timber.

The moisture content of timber should be such that the timber will not appreciably gain or lose moisture in the position in which it is fixed in a building.

Table 8 Moisture content of timber.

Position of timber in building	1 %	2 %
External uses fully exposed	20 or more	—
Covered and generally unheated	18	24
Covered and generally heated	15	20
Internal and continuously heated building	12	20

Column 1 Average moisture content likely to be attained in service conditions
Column 2 Moisture content which should not be exceeded in individual pieces at time of erection
Taken from BS 5268 : Part 2:1996 (issue 2, May 1997)

Natural dry seasoning

When logs have been cut into timber it is stacked either in the open or in a rough open sided shed. The timbers are stacked with battens between them to allow air to circulate around them. The timbers are left stacked for a year or more, until most of the moisture in the wood has evaporated. Softwoods have to be stacked for a year or two before they are sufficiently dried out or seasoned, and hardwoods for up to ten years. The least moisture content of timber that can be achieved by this method of seasoning is about 18%.

Artificial or kiln seasoning

Because of the great length of time required for natural dry seasoning and because sufficiently low moisture contents of wood cannot be achieved, artificial seasoning is largely used today. After the wood has been converted to timber it is stacked with battens between the timber and they are then placed in an enclosed kiln. Air is blown through the kiln, the temperature and humidity of the air being regulated to effect seasoning more rapidly than with natural seasoning, but not so rapidly as to cause damage to the timber. If the timber is seasoned too quickly by this process it shrinks and is liable to crack and lose shape badly. To avoid this it is common practice to allow timber to season naturally for a time and then complete the process artificially as described.

Conversion of wood into timber

The method of cutting a log into timber will depend on the ultimate use of the timber.

Most large softwood logs are converted into timbers of different sizes so that there is the least wastage of wood. Smaller softwood logs are usually converted into a few long rectangular section timbers. Most hardwood today is converted into boards.

The method of converting wood to timber affects the timber in two ways: (a) by the change of shape of the timber during seasoning and (b) in the texture and differences in colour on the surface of the wood. Because the spring wood is less dense than the summer wood the

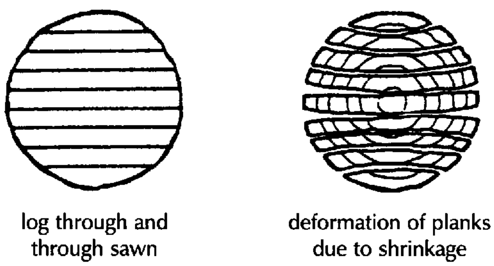


Fig. 121 Conversion of log to timber.

Fig. 122 Log quartered and converted into boards.

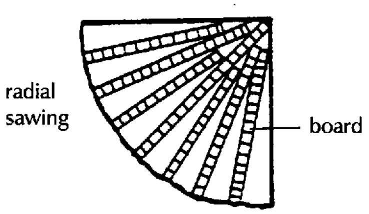


Fig. 123 Radial sawn boards.

shrinkage caused when the wood is seasoned (dried) occurs mainly along the line of the annual rings. The circumferential shrinkage is greater than the radial shrinkage. Because of this the shrinkage of one piece of timber cut from a log may be quite different from that cut from another part of the log.

This can be illustrated by showing what happens to the planks of a log converted by the 'through and through' cut method shown in Fig. 121. When the planks have been thoroughly seasoned their deformation due to shrinkage can be compared by putting them together in the order in which they were cut from the log as in Fig. 121. From this it will be seen that the plank which was cut with its long axis on the radius of the circle of the log, lost shape least noticeably and was the best timber after seasoning.

It is apparent that timber which is required to retain its shape during seasoning, such as good quality boarding, must somehow be cut as nearly as possible along the radius of the centre of the log. As it is not practicable to cut a log in the way we cut a slice out of an apple, logs which are to be cut along their radius are first cut into quarters. Each quarter of the log is then cut into boards or planks. This can be done in a variety of ways. Two of the most economical ways of doing this are shown in Fig. 122. It will be seen from these diagrams that one or two boards or planks are cut very near a radius of the circle, whilst the rest are cut somewhat off the radius and the former will lose shape least.

In describing the structure and growth of a tree the medullary rays were described as being narrow radial lines of wood cells of different shape and structure than the main wood cells. If the face of a timber is cut on a radius of the circle of the log, the cells of the medullary rays may be exposed where the cut is made. With many woods this produces very pleasing texture and colour on the surface of the wood and it is said that the 'figure' of the wood has been exposed. To expose the figure of the wood by cutting along the medullary rays a quarter of a log has to be very wastefully cut, as shown in Fig. 123. The radial cutting of boards as shown is very expensive and is employed only for high-class cabinet making and panneling timbers where the exposed figure of the wood will be used decoratively.

Decay in timber

Any one of a number of wood-destroying fungi may attack timber that is persistently wet and has a moisture content of over 20%.

Fungal decay

Dry rot

This is the most serious form of fungal decay and is caused by Seupula lacrymans which can spread and cause extensive destruction of timber. The description dry rot derives from the fact that timber which has been attacked appears dry and powdery.

The airborne spores of this fungus settle on timber and if its moisture content is greater than 20% they germinate. (If the moisture content is less than 20%, germination does not occur.) The spore forms long thread-like cells which pierce the wood cells and use the wood as a food. The thread-like cells multiply, spreading out long white thread-like arms called mycelium which feed on other wood cells. This fungus can spread many tens of feet from the point where the spore first began to thrive, and is capable of forming thick greyish strands which can find their way through lime mortar and softer bricks.

Timber which is affected by this fungus turns dark brown and shrinks and dries into a cracked powdery dry mass which looks as though it has been charred by fire.

It is generally accepted that there is little risk of fungal decay in softwood if the timber is maintained at a moisture content of 20% or less. Fungal decay will only occur when the moisture content is above 20%.

Prevention of dry rot

Do not use unseasoned timber in buildings. Prevent seasoned timber becoming so wet that it can support the fungus by:

(1) building in a good horizontal dpc;
(2) either ventilating the space below or around timber floors or by designing the building so that these spaces do not become damp;
(3) immediately repairing all leaking water, rainwater and drain pipes which otherwise might saturate timber to such an extent as to make it liable to dry rot.

Replacement of timber affected by dry rot

The cause of the persistent dampness that has raised the moisture content of timber above 20%, such as by leaking gutters or water pipes, must be corrected. Timber which has been affected by the fungus or is in close proximity to it should be taken out or cut out of the building, and this timber should be burnt immediately. The purpose of burning the affected timber is to ensure that none of it is used in the repairs and to kill any spore that might cause further rot.

All walls on which, or against which, the fungus grew must be thoroughly cleaned and sterilised by application of a fungicidal solution. Any old lime plaster on which or through which the rot has spread should be hacked off and renewed. New timber used to replace affected timer should be treated with a wood preservative before it is fixed or built in.

Wet rot

Wet rot is caused principally by Coniophora puteana, the cellar fungus, which occurs more frequently, but is less serious, than dry rot. Decay of timber due to wet rot is confined to timber that is in damp situations such as cellars, ground floors without dpcs and roofs. The rot causes darkening and longitudinal cracking of timber and there is often little or no visible growth of fungus on the surface of timber.

Prevention of wet rot

Timber should not be built into or in contact with any part of the structure that is likely to remain damp. Damp-proof courses and damp-proof membranes above and at ground level and sensibly detailed flashings and gutters to roofs and chimneys will prevent the conditions suited to the growth of wet rot fungus.

Replacement of timber affected by wet rot

Affected timber should be cut out and replaced by sound new timber treated with a preservative. It is not necessary to sterilise brickwork around the area of affected timber.

Insect attack on wood

In this country the three sorts of insect which most commonly cause damage to timber are the furniture beetle, the death-watch beetle and the house longhorn beetle. Insect attack on wood in occupied buildings is much less common than is generally supposed.

Furniture beetle

The common furniture beetle (Anobium punctatum) is the beetle whose larvae most commonly attack timber and furniture and its attack is generally known as 'wood worm'. Between June and August the beetles fly around and after mating the female lays small eggs in the cracks and crevices of any dry softwood or hardwood. The eggs hatch and a small white grub emerges. These grubs (larvae) have powerful biting jaws with which they tunnel into the wood, using the wood as food. The grubs tunnel along the grain of the wood for a year or two until they are fully grown, then they bore to just below the surface of the wood where they pupate or change into beetles. These emerge in June to August and the life cycle of the beetle is repeated. The hole which each grub makes is very small and timber is structurally weakened only if a great number of these holes tunnelled by a number of grubs are formed over many years. The holes are very unsightly, particularly if the beetle infests furniture or panelling.

Death-watch beetle

The grubs of the death-watch beetle (Xestobium rufovillosum) thrive particularly well on very old timbers that have suffered decay and rarely attack softwoods. The beetle lays eggs which hatch into grubs (larvae) which, in turn, do as the larvae of the furniture beetle, tunnel along the wood for from one to several years. The name death-watch beetle derives from the ticking sound made by the beetles as they tap their heads on timber during the mating season in May and June. Again only after years of infestation by this beetle is the strength of the timber seriously affected.

House longhorn beetle

House longhorn beetle (Hylotrupes bajulus) is a large insect that, in recent years, has been active in London and the home counties and that attacks mainly softwood. It has a life cycle of up to 11 years and can cause such extensive damage that only a thin shell of sound timber is left. There is little external evidence of the infestation except some unevenness of wood surfaces due to boring just below the surface. The Building Regulations specify areas of the south of England in which the softwood timbers of roofs are required to be treated with a suitable preservative against attack by the longhorn beetle.

Control of attack by beetles

Timber which has been affected by the larvae of these beetles should be sprayed or painted with a preservative that contains an insecticide during early summer and autumn. These preservatives prevent the larvae changing to beetles at the surface of the wood and so arrest further infestation.

Wood preservatives

Wood may be preserved as a precaution against fungal decay or insect attack. There is very little likelihood of softwood timber in buildings, which are maintained at a moisture content below 20 to 22%, being affected by fungal attack and little possibility of attack by beetles.

Over recent years it has become fairly common practice to preserve softwood used in buildings, where the risks barely warrant the expenditure, because of lurid accounts of the very few instances of attack that have occurred. Fungal decay has occurred where simple, commonsense care was not taken to avoid persistent damp from leaking gutters and pipes. The few instances of beetle attack have been blown up out of all proportion.

The consequence is that regulations have become over cautious and builders and makers of preservative promote preservation as a sales advantage.

Where it is decided to adopt preservation the two types of preservative in general use are water borne or organic solvent formulations where water or a volatile solvent serves as a vehicle for the active fungicide or insecticide components.

Water borne preservatives

The most commonly used water borne preservative is based on solutions of copper sulphate, sodium dichromate and arsenic pentoxide, abbreviated to CCA. The liquid preservative is applied by pressure in a pressure tank.

The degree to which a water borne preservative will penetrate timber depends on the species. A lateral penetration of 6 to 19 mm in about 2 to 3 hours occurs under pressure with European Redwood and 3 to 6 mm with Canadian Douglas Fir for example.

To gain the maximum advantage of preservation, all timber should be cut and notched as necessary before preservative treatment. Any cutting after treatment, particularly where the cutting penetrates below the surface penetration, should be treated with preservative.

Preservation with a water borne preservative causes a considerable increase in the moisture content of the timber, an increase in the cross section and a rise in the surface grain. After preservation timber has to be dried to the required moisture content.

Water borne CCA preservatives are most suited for use with sawn structural timbers such as floor joists, roof rafters and stud framing where the raised grain of the wood is of no consequence.

Organic solvent preservation

These preservative solutions comprise an organic solvent such as white spirits with fungicides such as pentachlorophenol and zinc naphthenate. An insecticide is added as required. The liquid preservative is applied by double vacuum process and by immersion. The organic solvent evaporates to air, leaving the fungicide in the wood to the depth of penetration depending on the species of wood.

An organic solvent is commonly used for cut joinery sections both plain and moulded because the solvent dries quickly, does not cause an increase in section and does not noticeably affect the surface of the prepared joinery sections.

Tar oil preservatives

Tar oil preservatives, such as creosote, are used for the preservation of wood used for fences where the strong smell of this material is not offensive. Because of the appreciable additional cost in the preservative treatment of timber it should be used sparingly where there is a real risk of fungal or insect attack.

Surface finishes for timber

There are three types of surface finish for wood, paint, varnish and stains. The traditional finishes paint and varnish are protective and decorative finishes which afford some protection against water externally and provide a decorative finish which can easily be cleaned internally. Paints are opaque and hide the surfaces of the wood whereas varnishes are sufficiently transparent for the texture and grain of the wood to show.

Of recent years stains have been much used on timber externally. There is a wide range of stains available, from those that leave a definite film on the surface to those that penetrate the surface and range from gloss through semi-gloss to matt finish. The purpose of this finish is to give a selected uniform colour to wood without masking the grain and texture of the wood. Most stains contain a preservative to inhibit fungal surface growth. These stains are most effective on rough sawn timbers.

TIMBER WALLS

The construction of a timber framed wall is a rapid, clean, dry operation. The timbers can be cut and assembled with simple hand or power operated tools and once the wall is raised into position and fixed it is ready to receive wall finishes. A timber framed wall has adequate stability and strength to support the floors and roof of small buildings, such as houses. Covered with wall finishes it has sufficient resistance to damage by fire, good thermal insulating properties and reasonable durability providing it is sensibly constructed and protected from decay. In North America, timber is as commonly used for walls as brick is in the United Kingdom. A timber framed house can be constructed on site by two men in a matter of a few days.

There has been a prejudice against timber buildings in this country for many years. For some years after the end of the Second World War (1945) timber framed houses were built as a means of satisfying the need for new housing, by the rapid building possible with this form of construction. Comparatively few such houses were built, partly because of an inherent feeling that timber was not as solid or durable a material as brick and through the unwillingness of building societies to lend money for the construction or purchase of these houses.

More recently, timber framed houses have been constructed and once again the timber wall frame has been given a bad name because of a few problems of condensation in the fabric of walls due to ill considered design.

It is irrational to construct a timber frame that has by itself adequate strength to support the floors and roof of a house and then enclose it with a brick or block wall purely for the sake of appearance. The combination of these two systems of construction impedes the rapid construction possible with timber and confuses the 'wet trades' system of the construction of solid walling with that of the 'dry system' of timber framed construction.

Strength of timber

The strength of timber varies with species and is generally greater with dense hardwoods than less dense softwoods. Strength is also affected by defects in timber such as knots, shakes, wane and slope of the grain of the wood.

Stress grading of timber

There is an appreciable variation in the actual strength of similar pieces of timber which had led in the past to very conservative design in the use of timber as a structural material. Uncertain of the strength of individual timbers, it was practice to over design, that is, make allowance for the possibility of weakness in a timber and so select timbers larger than necessary.

Of recent years systems of stress grading have been adopted, with the result that a more certain design approach is possible with a reduction of up to 25% in the section of structural timbers. Stress grading of structural timbers, which was first adopted in the Building Regulations 1972, is now generally accepted in selecting building timber.

There are two methods of stress grading: visual grading and machine grading.

Visual grading

Trained graders determine the grade of a timber by a visual examination from which they assess the effect on strength of observed defects such as knots, shakes, wane and slope of grain. There are two visual grades, general structural (GS) and special structural (SS), the allowable stress in SS being higher than in GS.

Machine grading

Timbers are subjected to a test for stiffness by measuring deflection under load in a machine which applies a specified load across overlapping metre lengths to determine the stress grade. This mechanical test, which is based on the fact that strength is proportional to stiffness, is a more certain assessment of the true strength of a timber than a visual test. The machine grades, which are comparable to the visual grades, are machine general structural (MGS) and machine special structural (MSS). There are in addition two further machine grades, M50 and M75. The stress of M50 lies between MGS and MSS and M75 is the highest stress grade in the series.

Stress graded timbers are marked GS and SS at least once within the length of each piece for visually graded timber together with a mark to indicate the grader or company. Machine graded timber is likewise marked MGS, M50, MSS and M75 together with the BS kitemark and the number of the British Standard, 4978.

Approved Document A, which gives practical guidance to meeting the requirements of the Building Regulations for small buildings, includes tables of the sizes of timber required for floors and roofs, related to load and span.

Stability

The stability of a timber framed wall depends on a reasonably firm, stable foundation on which a stable structure can be constructed. In common with other systems of walling the foundation to a timber framed wall should serve equally for the timber framed walls of small buildings, depending on ground conditions.

Because timber framing is a lightweight form of construction it will depend less on support from the foundation than will a similar brick construction and more on being firmly anchored to the foundation against uplift due to wind forces. Figure 124 is an illustration of the base of a timber framed wall set on a brick upstand raised from a strip foundation. The 150 × 50 mm timber sole plate is bedded on a horizontal dpc, with 13 mm bolts at 2 m centres built into the wall to

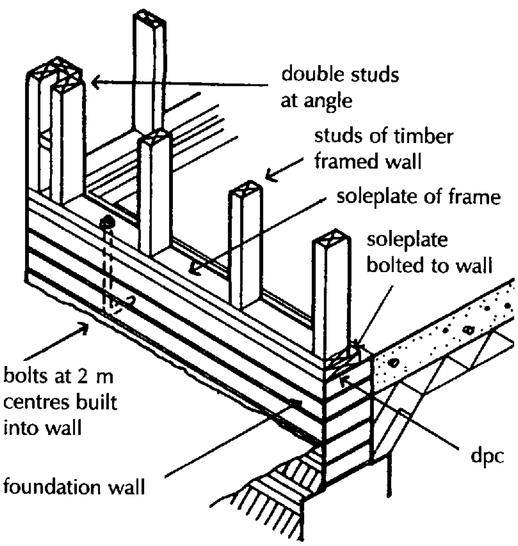


Fig. 124 Base of timber framed wall.

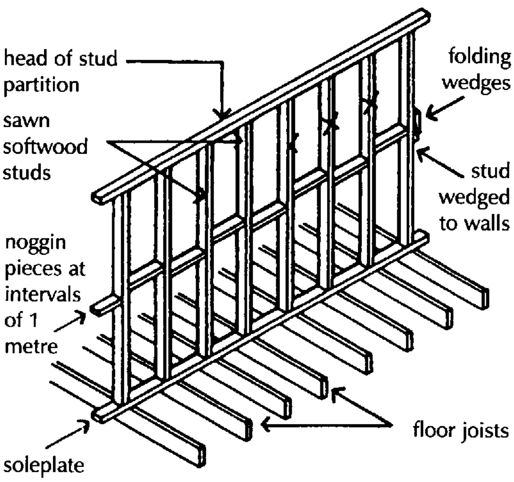


Fig. 125 Timber stud frame.

anchor the plate against wind uplift. As an alternative the bolts may be shaped so that the bottom flange is built into the wall, run up on the inside face of the wall with a top flange turned over the top of the plate.

Where a concrete raft serves as foundation the upstand kerb of the raft serves as a base for the timber wall with the anchor bolts set into the concrete curbs and turned over the top of the sole plate.

The vertical 100 × 50 mm studs are nailed to the sole plate at 400 to 600 mm centres with double studs at angles to facilitate fixing finishes.

A timber stud wall consists of small section timbers fixed vertically between horizontal timber head and sole plates, as illustrated in Fig. 125. The vertical stud members are usually spaced at centres of 400 to 600 mm to support the anticipated loads and to provide fixing for external and internal linings. The horizontal noggins fixed between studs are used to stiffen the studs against movement that might otherwise cause finishes to crack.

By itself a timber stud wall has poor structural stability along its length because of the non-rigid, nailed connection of the studs to the head and sole plate which will not strongly resist racking deformation. A timber stud wall must, therefore, be braced (stiffened) against racking.

As an internal wall or partition a timber stud frame may be braced by diagonal timbers framed in the stud wall or by being wedged between solid brick or block walls, as illustrated in Fig. 125, or a combination of the two systems of bracing.

As an external wall a timber stud frame may be braced between division walls and braced at angles where one wall butts to another, as illustrated in Fig. 124. In addition an external stud frame wall is braced by diagonally fixed boarding or plywood sheathing fixed externally as a background for finishes.

Because of its small mass, a timber frame wall has poor lateral stability against forces such as wind that tend to overturn the wall. For stability along the length of the wall, connected external and internal walls or partitions will serve as buttresses.

For stability up the height of the wall, timber upper floors and roof connected to the wall will serve as buttresses. Buttressing to timber walls that run parallel to the span of floor joists and roof frames is provided by steel straps that are fixed across floor joists and roof rafters and fixed to timber walls in the same way that straps are used to buttress solid walls as previously described.

The usual method of supporting and fixing the upper floor joists to the timber wall frame is by using separate room height wall frames. The heads of the ground floor frames provide support for the floor joists on top of which the upper floor wall frame is fixed, as illustrated in Fig. 126. The roof rafters are notched and fixed to the head of the upper floor wall frame.

As an alternative a system of storey height wall frames may be used with the top of the head of the lower frame in line with the top of the floor joists which are supported by a timber plate nailed to the studs, as illustrated in Fig. 127. The upper frame is formed on the lower frame. The advantage of this system is that there is continuity of the wall frame and the disadvantage a less secure connection and therefore lateral bracing.

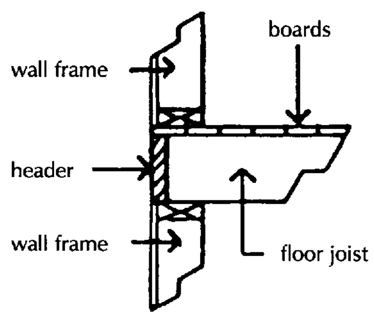


Fig. 126 Support for floor joists.

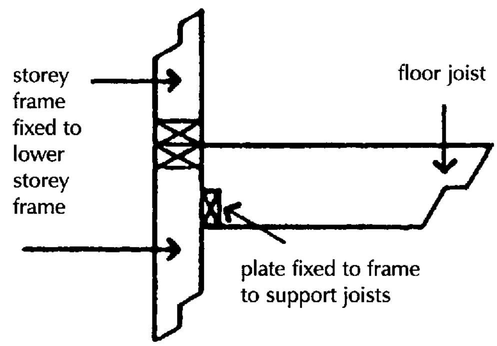


Fig. 127 Storey frame.

Resistance to weather

The traditional weather envelope for timber walls is timber weatherboarding nailed horizontally across the stud frame. The weather boards are shaped to overlap to shed water. Some typical sections of boarding are illustrated in Fig. 128.

The wedge section, feather edge boarding, is either fixed to a simple overlap or rebated to lie flat against the studs as illustrated. The shaped chamfered and rebated and tongued and grooved shiplap boarding is used for appearance sake, particularly when the boarding is to be painted for protection and decoration.

To minimise the possibility of boards twisting it is practice to use boards of narrow widths of as little as 100 and usually 150 mm.

As protection against rain and wind penetrating the weatherboarding it is usual to fix sheets of roofing underlay or breather paper behind the weatherboarding. Breather paper serves to act as a barrier to water and at the same time allow the release of moisture vapour, under pressure to move through the sheet.

Instead of nailing weatherboarding directly to the studs of the wall frame it is usual to fix either diagonally fixed boarding or sheets of plywood across the external faces of the stud frame. The boarding and ply sheets serve as a brace to the frame and as a sheath to seal the frame against weather. Figure 129 is an illustration of weatherboarding fixed to plywood sheathing with insulation fixed between studs.

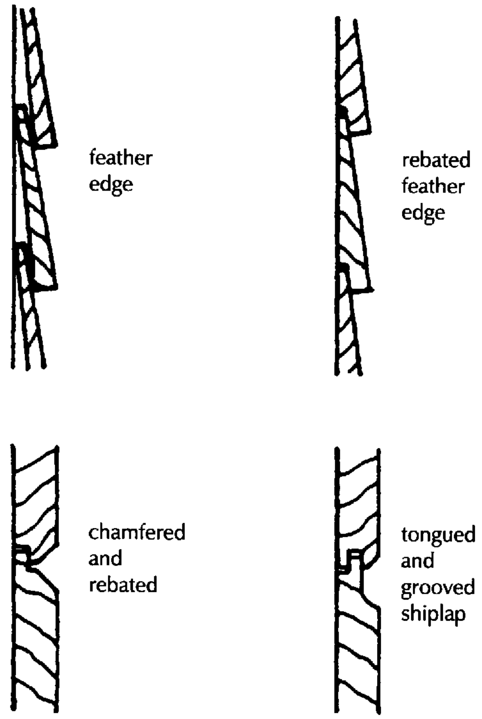


Fig. 128 Timber weatherboarding.

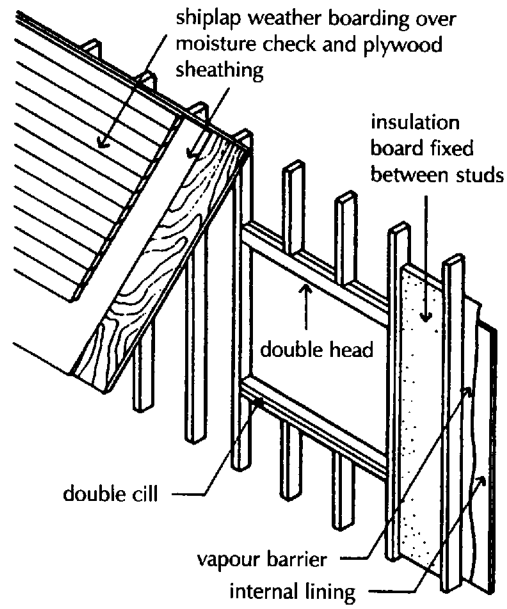


Fig. 129 Weather envelope.

Around openings to windows and doors the weatherboarding and ply sheath may be butted to the back of window and door frames fixed to project beyond the stud frames for the purpose. At the head of the opening the head of the frame may be reduced in depth so that the boarding runs down over the face of the frame. The weatherboarding butts up to the underside of a projecting cill. For extra protection sheet lead may be fixed behind the weatherboarding and nailed and welted to window and door frames.

At external angles the weatherboarding may be mitred or finished square edged. As a seal and finish to the joint between the weatherboarding at external angles timber cover mouldings have been used without much success as the mouldings soon become saturated, swell and defeat the object of their use. A more straightforward and effective weathering is to fix a strip of lead behind the weatherboarding to form a sort of secret gutter.

In exposed positions weatherboarding may not provide adequate protection. Tile or slate hanging may be used to provide more satisfactory protection.

Brick and timber framed wall

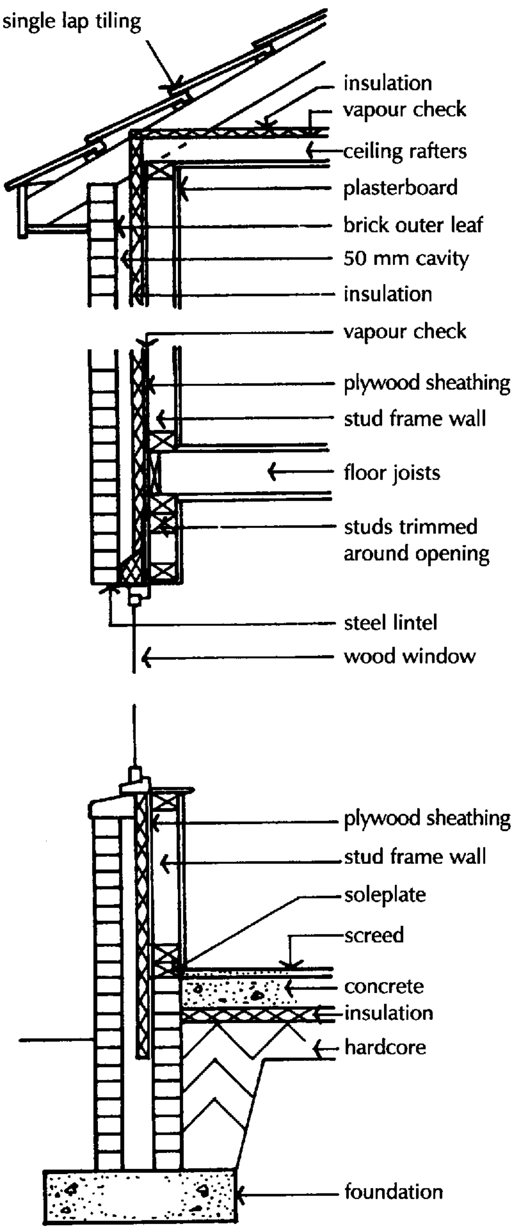


Fig. 130 Brick outer and timber framed cavity wall.

The external walls of small buildings such as houses have been constructed as a cavity wall with a brick outer leaf and a timber framed inner leaf or frame. This seemingly perverse form of construction which combines the 'wet trade' form of construction with a 'dry trade' form of construction may be justified by the permanence and appearance of an outer brick wall.

The external brick leaf may well overcome the prejudice of buyer and building society surveyor that timber is a temporary building form, by providing the sense of weather resistance and durability that brickwork gives.

A sensible argument for this odd form of construction could be speed of erection and completion of building work by combining the rapid framing of a timber wall, floor and roof structure that could be completed and covered in a matter of a few days, with a brick outer leaf and speedy installation of electrical, water and heating services and dry linings.

Figure 130 is an illustration of a two storey house with timber walls, floor and roof with a brick outer leaf.

For strength the timber inner leaf, floor and roof are adequate to the small loads. For stability the upper floor and roof are adequate to stiffen the walls. It could be demonstrated that the external brick outer leaf, buttressed at angles, has sufficient stability by itself, or the use of ties across the cavity at first floor level and roof to the timber structure could be used to augment stability if need be.

For resistance to weather a brick outer leaf is generally accepted as being thick enough to prevent penetration of rain to the inside.

For thermal resistance one of the thermal insulation boards is fixed to a vapour check and plywood sheathing nailed to the stud frame. The thermal insulation is carried up in the cavity to unite with the roof insulation laid on a vapour check. The plywood sheathing is used to diagonally brace the stud frame.

Internal plasterboard linings to the timber framed walls, the soffit of the first floor and the ceiling will provide a sufficient period of fire resistance to meet the requirements for a two floor house.

The requirement for barriers in external cavity walls to small houses applies only to the junction of a cavity and a wall separating buildings.

Prefabricated timber frames

With the use of a wide range of wood working tools that are available it is practice to prefabricate timber wall frames, particularly in North America and Scandinavia where there is a plentiful supply of timber and a traditional use of timber for small buildings.

The advantage of using frames that are fabricated either on or off site complete with outer and inner finishes is speed of erection. Where

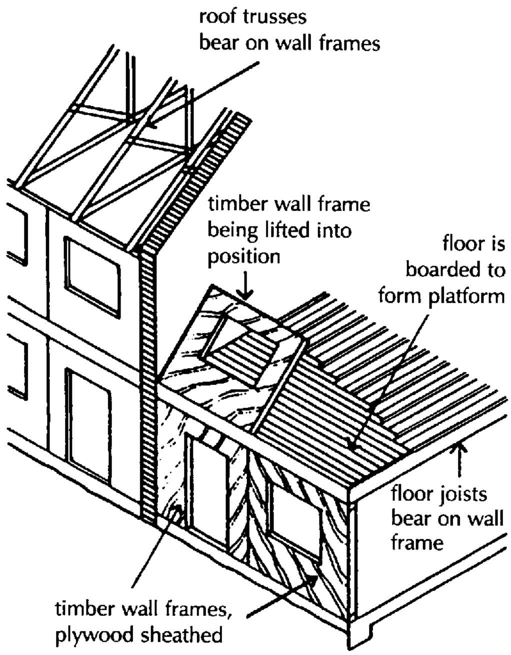


Fig. 131 Platform frame.

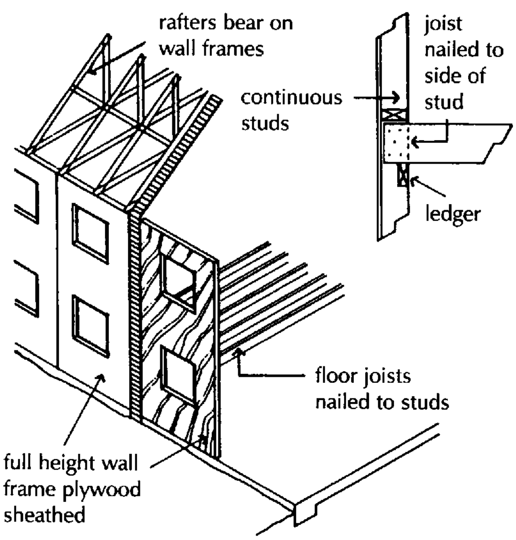


Fig. 132 Balloon frame.

a number of houses is to be built it is possible to complete a building in a matter of days.

Prefabricated timber wall frames have been little used in England mainly because of a prejudice against timber. Prefabrication has been used to some extent in the external walls of terrace housing where the walls can readily be erected as timber framed front and back walls, complete with windows and doors, between solid brick separating walls.

The systems most used are either platform or storey frames.

The platform frame system of construction employs prefabrication frames that are floor to ceiling level high, with the sole of the lower stud frame bearing on the foundation and the head of the frame supporting first floor joists, as illustrated in Fig. 131. The first floor can then be used as a working platform from which the upper frames are set on top of the lower.

The wall frames or panels may be the full width of the front and rear walls of narrow terrace houses or made in two or more panels. The first floor joists and roof provide sufficient bracing up the height and the separating wall will brace across the width of the wall.

The wall frames may be prefabricated as stud frames sheathed with plywood or made complete with finishes both sides.

Storey frames are made the height of a storey, floor to floor so that the top of the head of a frame is level with the top of floor joists. The joists are supported by a bearer fixed to the stud frame. This arrangement provides continuity of the stud framing up the height of the wall at the expense of some loss of secure anchor of floor joists to wall.

A balloon wall frame is fabricated as one continuous panel the height of the two floors of small houses, as illustrated in Fig. 132. This system is most used in North America and Scandinavia where timbers of the required length are more available than they are in England.

The advantage of the balloon frame is speed of fabrication and erection, and the least number of joints between frames that have to be covered and weathered externally.

Fire safety

The requirements for means of escape from one or two storey houses are that each habitable room either opens directly on to a hallway or stair leading to the entrance, or that it has a window or door through which escape could be made and that means are provided for giving early warning in the event of fire.

With increased height and size, where floors are more than 4.5 m above ground, it is necessary to protect internal stairways or provide alternative means of escape. Where windows and doors may be used as a means of escape their minimum and maximum size and the minimum and maximum height of the window cill are defined.

All new houses should be fitted with self-contained smoke alarms permanently wired to a separate fused circuit at the distribution board.

Internal fire spread (structure)

The premature failure of the structural stability of a building is restricted by specifying a minimum period of fire resistance for the elements of structure. A timber framed wall covered with plasterboard internally satisfies the requirement for houses of up to two storeys.

External fire spread

To prevent the spread of fire between buildings, limits to the size of 'unprotected areas' of walls and finishes to roofs close to boundaries are set out in the Building Regulations. By reference to the boundaries of the site the control will limit spread of fire. Unprotected areas are those parts of external walls that may contribute to spread of fire and include glazed windows, doors and those parts of a wall that may have less than a notional fire resistance.

Limits are set on the use of roof coverings that will not provide adequate protection against the spread of fire across their surface to adjacent buildings.

Resistance to the passage of heat

Timber is a comparatively good insulator having a U value of 0.13 for softwood and 0.15 for hardwood. The sections of a timber frame do not by themselves generally afford sufficient insulation to meet the requirements of the Building Regulations and a layer of some insulating material has to be incorporated in the construction.

The layer of insulation is fixed either between the vertical studs of the frame or on the outside or inside of the framing.

The disadvantage of fixing the insulation between the studs is that there may be a deal of wasteful cutting of insulation boards to fit them between studs and to the extent that the U value of the timber stud is less than that of the insulation material, there will be a small degree of thermal bridge across the studs.

The advantage of fixing the insulation across the outer face of the timber frame is simplicity in fixing and the least amount of wasteful cutting and that the void space between the studs will augment insulation and provide space in which to conceal service pipes and cables.

The disadvantage of external insulation is that the weathering finish such as weatherboarding has to be fixed to vertical battens screwed or nailed through the insulation to the studs. Unless the insulation is one of the rigid boards it may be difficult to make a fixing for battens sufficiently firm to nail the battens to.

Internal insulation is usually in the form of one of the insulation boards that combine insulation with a plasterboard finish.

Vapour check

A high level of insulation required for walls may well encourage moisture vapour held by warm inside air, particularly in bathrooms and kitchens, to find its way due to moisture vapour pressure into a timber framed wall and condense to water on the cold side of the insulation. The condensation moisture may then damage the timber frame.

As a barrier to warm moist air there should be some form of vapour check fixed on the warm side of the insulation. Closed cell insulating materials such as extruded polystyrene, in the form of rigid boards, are impermeable to moisture vapour and will by themselves act as a vapour check. The boards should either be closely butted together or supplied with rebated or tongued and grooved edges so that they fit tightly and serve as an efficient vapour check.

Where insulation materials that are pervious to moisture vapour, such as mineral fibre, are used for insulation between studs, a vapour check of polythene sheet must be fixed right across the warm side of the insulation. The polythene sheet should be lapped at joints and continued up to unite with any vapour check in the roof and should, as far as practical, not be punctured by service pipes.

Electrical cables that are run through the members of a timber wall and the insulation between the studs may overheat due to the surrounding insulation, with a risk of short circuit or fire. To prevent overheating of cables run through insulation, the cables should be derated by a factor of 0.75 by using larger cables than specified, which will generate less heat. So that cables are not run through insulation it is wise to fix the inside dry lining to timber frames that are filled with insulation, on timber battens nailed across the frame so that there is a void space in which cables can be safely run.

Insulation for timber walls

The inorganic materials glass fibre and rockwool are most used for insulation between studs as there is no advantage in using the more expensive organic materials, as the thickness of insulation required is not usually greater than the width of the studs. Either rolls of loosely felted fibres or compressed semi-rigid batts or slabs of glass fibre or rockwool are used. The material in the form of rolls is hung between the studs where it is suspended by top fixing and a loose friction fit between studs, which generally maintains the insulating material in position for the comparatively small floor heights of domestic buildings. The friction fit of semi-rigid slabs or batts between studs is generally sufficient to maintain them, close butted, in position.

For insulating lining to the outside face of studs one of the organic insulants such as XPS or PIR provides the advantage of least thickness of insulating material for given resistance to the transfer of heat. The more expensive organic insulants, in the form of boards, are fixed across the face of studs for ease of fixing and to save wasteful cutting.

A vapour check should be fixed on to or next to the warm inside face of insulants against penetration of moisture vapour. Organic insulants, such as XPS, which are substantially impervious to moisture vapour can serve as a vapour check, particularly when rebated edge boards are used and the boards are close butted together.

Table 9 lists some of the insulants suited for use in timber framed walls.

Table 9 Insulating materials.

	Thickness mm	**U value W/m^2K**
Timber framed wall (insulation between studs)		
Glass fibre		
rolls	50, 80, 90, 100	0.04
semi-rigid batts	80, 90, 100, 120, 140, 160	0.04
Rockwool		
rolls	60, 80, 90, 100, 150	0.037
semi-rigid slabs	60, 80, 90, 100	0.037
Timber framed wall (insulation fixed to face of studs)		
XPS		
boards T & G on long edges	25, 50	0.025
PIR		
boards with heavy duty aluminium facings	20, 25, 30, 35, 50	0.02

XPS extruded polystyrene
PIR rigid polyisocyanurate

Resistance to the passage of sound

The small mass of a timber framed wall affords little resistance to airborne sound and does not readily conduct impact sound. The insulation necessary for the conservation of heat will give some reduction in airborne sound and the use of a brick or block outer leaf will appreciably reduce the intrusion of airborne sound.

3: Floors

FUNCTIONAL REQUIREMENTS

The functional requirements of a floor are:

Strength and stability
Resistance to weather and ground moisture
Durability and freedom from maintenance
Fire safety
Resistance to passage of heat
Resistance to the passage of sound

Strength

The strength of a floor depends on the characteristics of the materials used for the structure of the floor, such as timber, steel or concrete. The floor structure must be strong enough to safely support the dead load of the floor and its finishes, fixtures, partitions and services and the anticipated imposed loads of the occupants and their movable furniture and equipment. BS 6399: Part 1 is the Code of Practice for dead and imposed loads for buildings.

Where imposed loads are small, as in single family domestic buildings of not more than three storeys, a timber floor construction is usual. The lightweight timber floor structure is adequate for the small loads over small spans and appreciably cheaper than a reinforced concrete floor.

For larger imposed loads and wider spans a reinforced concrete floor is used both for strength in support and also for resistance to fire.

Approved Document A to the Building Regulations includes tables of recommended sizes and spacing for softwood timber floor joists of two strength classes, for various dead loads and spans.

Stability

A floor is designed and constructed to serve as a horizontal surface to support people and their furniture, equipment or machinery. The floor should have adequate stiffness to remain reasonably stable and horizontal under the dead load of the floor structure and such partitions and other fixtures it supports and the anticipated static and live loads it is designed to support. The floor structure should also support and accommodate, either in its depth, or below or above, electrical, water, heating and ventilating services without affecting its stability. For stability there should be adequate support for the floor structure and the floor should have adequate stiffness against gross deflection under load.

Upper or suspended floors are supported by walls or beams and should have adequate stiffness to minimise deflection under load. Under load a floor will deflect and bend and this deflection or bending should be limited to avoid cracking of rigid finishes such as plasterboard and to avoid the sense of apprehension in those below the floor that they might suffer, if the deflection or bending were obvious. A deflection of about 1/300 of the span is generally accepted as a maximum in the design of floors.

Solid ground and basement floors are usually built off the ground from which they derive support. The stability of such floors depends, therefore, on the characteristics of the concrete under them. For small domestic loads the site concrete, without reinforcement, provides adequate stability. For heavier loads, such as heavy equipment or machinery, a reinforced concrete slab is generally necessary with, in addition, a separate foundation under heavy machinery.

On shrinkable clay soils it may be necessary to use a suspended reinforced concrete slab against differential expansion or contraction of the soil, especially where there are deep rooted trees near the building.

Resistance to weather and ground moisture

The ground floor of a building, especially a heated building, will tend to encourage moisture from the ground below to rise and make the floor damp and feel cold and uncomfortable. This in turn may require additional heating to provide reasonable conditions of comfort. An appreciable transfer of moisture from the ground to the floor may promote conditions favourable to wood rot and so cause damage to timber ground floors and finishes.

Obviously, the degree of penetration of moisture from the ground to a floor will depend on the nature of the subsoil, the water table and whether the site is level or sloping. On a gravel or coarse grained sand base, where the water table throughout the year is well below the surface, there will be little penetration whereas on a clay base, with the water table close to the surface, there will be appreciable penetration of moisture from the ground to floors. In the former instance a concrete slab alone may be sufficient barrier and in the latter a waterproof membrane on, in, or under the concrete slab will be necessary to prevent moisture rising to the surface of the floor.

The requirements of the Building Regulations for the resistance of the passage of moisture to the inside of buildings are described in Chapter 1.

Durability and freedom from maintenance

Ground floors on a solid base protected against rising moisture from the ground, and suspended upper floors solidly supported and adequately constructed and protected inside a sound envelope of walls and roof, should be durable for the expected life of the building and require little maintenance or repair.

The durability and freedom from maintenance of floor boards and finishes to solid floors will depend on the nature of the materials used and the wear that they are subject to.

Fire safety

Suspended upper floors should be so constructed as to provide resistance to fire for a period adequate for the escape of the occupants from the building. The notional periods of resistance to fire, from $\frac{1}{2}$ to 4 hours, depending on the size and use of the building, are set out in the Building Regulations. In general a timber floor provides a lesser period of resistance to fire than a reinforced concrete floor. In consequence timber floors will provide adequate resistance to fire in small domestic buildings, and concrete floors the longer periods of resistance to fire required in large buildings.

Resistance to the passage of heat

A floor should provide resistance to transfer of heat where there is normally a significant air temperature difference on the opposite sides of the floor, as, for example, where an open car port is formed under a building and the floor over the port is exposed to outside air, the floor over should be insulated and have a U value the same as an exposed wall.

Obviously a ground floor should be constructed to minimise transfer of heat from the building to the ground or the ground to the building. Both hardcore and a damp-proof membrane on, under or sandwiched in the oversite concrete will assist in preventing the floor being damp and feeling cold and so reduce heating required for comfort and reduce transfer of heat. The use of insulation under solid ground floors is described in Chapter 1.

Where under floor heating is used it is essential to introduce a layer of insulation below and around the edges of the floor slab to reduce transfer of heat to the ground.

Resistance to the passage of sound

Upper floors that separate dwellings, or separate noisy from quiet activities, should act as a barrier to the transmission of sound. The comparatively low mass of a timber floor will transmit airborne sound more readily than a high mass concrete floor, so that floors between dwellings, for example, are generally constructed of concrete.

The resistance to sound transmission of a timber floor can be improved by filling the spaces between the timber joists with either lightweight insulating material or a dense material. The additional cost of filling to a new floor for the comparatively small reduction in sound transmission may not be worthwhile where, for a modest increase in cost, a concrete floor will be more effective.

Where existing buildings, with timber floors, are to be converted into flats the only reasonable way of improving sound insulation between floors is the use of filling between joists or some form of floating floor.

The reduction of impact sound is best effected by a floor covering such as carpet or a resilient layer under the floor surface, that deadens the sound of footsteps on either a timber or a concrete floor.

The hard surfaces of the floor and ceiling of both timber and concrete floors will not appreciably absorb airborne sounds which will be reflected and may build up to an unacceptable level. The sound absorption of a floor can be improved by carpet or felt, and a ceiling by the use of one of the absorbent 'acoustic' tile or panel finishes.

CONCRETE GROUND FLOORS

Ground supported slab

The majority of ground floors are constructed as ground supported in-situ cast concrete slabs on a hardcore bed with a damp-proof membrane and insulation, as described in Chapter 1.

Suspended concrete slabs

Where ground under a floor is sloping, has poor or uncertain bearing capacity, or is liable to volume change due to seasonal loss or gain of moisture and a ground supported slab might sink or crack due to settlement, it may be wise to form the ground floor as a suspended reinforced concrete slab, supported by external and internal loadbearing walls, independent of the ground.

Suspended concrete slabs are constructed with one of the pre-cast reinforced concrete plank, slab or beam and block floor systems described later for upper floors, because there is no ready means of constructing centering on which to cast an in-situ concrete floor. The one way spanning, pre-cast concrete floor bears on internal and external loadbearing foundation walls with endbearing of at least 90 mm, and is built into the walls. The depth of the plank, slab or beams depends on the loads to be carried and the span between supporting walls.

Damp-proof membrane

Where the suspended ground floor slab is formed above the ground level inside the building, with an air space of at least 75 mm below the underside of the slab and the air space is ventilated to outside air, then it may not be necessary to use a dpm. The purpose of ventilating the space below a suspended floor is to prevent the build-up of stagnant moist air in the space, which would otherwise tend to make the slab damp.

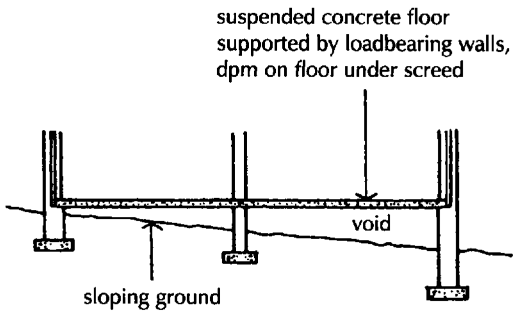


Fig. 133 Suspended concrete floor and damp-proof membrane.

Where there is a likelihood of an accumulation of gas building up in the space below the floor, which might lead to an explosion, then the space below the floor should be at least 150 mm clear and there should be ventilation on opposite sides of the space. The ventilation openings should be at least equivalent to 1500 mm for each metre run of wall.

Where the ground level inside a building under a suspended slab is below the surrounding level or the site slopes, it may be necessary to provide drainage to prevent a build-up of water. In these situations it is wise to form a dpm in the suspended slab under the screed, as illustrated in Fig. 133.

Insulation

Suspended concrete ground floor slabs that are constructed above the ground on well drained subsoils, with an unventilated void below the slab, may not require insulation.

Where there is a likelihood of the void space below a suspended concrete floor becoming damp or causing a build-up of gases it is necessary to ventilate the space. For the ventilation to be effective there should be a reasonably vigorous flow of air across the space which in winter will cause an appreciable transfer of heat through the floors.

In this situation the floor slab should be insulated to reduce heat transfer and with a built in dpm to maintain a reasonably comfortable dry floor temperature. The best place for the layer of floor insulation is on top of the concrete floor either over the dpm or below it on to which the floor screed is laid, as illustrated in Fig. 134. The dpm should be laid at the same level as the dpc in the internal leaf of the cavity wall.

Where the dpm is under the insulation, the top surface of the concrete slab should be covered with a thin layer of cement and sand levelled off to protect the dpm from damage by irregularities in the top of the slab.

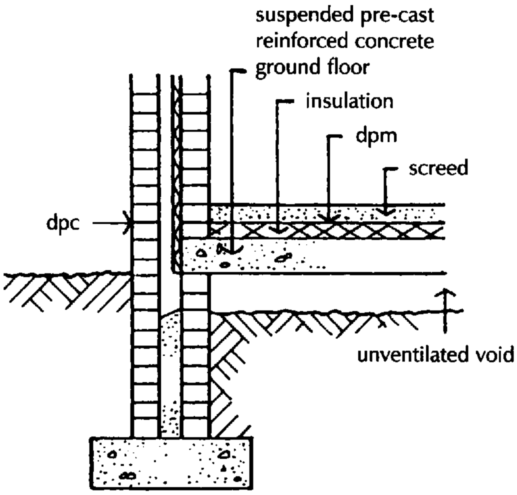


Fig. 134 Suspended concrete ground floor, insulation.

Floor surface

The term floor surface is generally used to describe the top surface of a floor structure. The level top surface of a structural concrete floor and the top surface of the floor boards that are an integral part of a structural timber floor are the floor surface. The concrete and timber board surface may be used as a finished floor surface.

The term floor finish is generally used to describe the material or materials that are applied to a floor surface as a finished surface, such as tiles and thin sheets of plastic to concrete.

For sheds, workshops, stores and garages, the finished top surface of the oversite concrete is sometimes used as the finished floor surface to save the cost of an applied floor finish. Concrete is not generally satisfactory as a finished floor surface, because even though it can be given a smooth finish with a power float, many of the fine particles of sand and cement are brought to the surface. These particles have poor resistance to wear and in a short time the surface of the concrete 'dusts' and requires frequent vigorous brushing. Being a coarse grained material, concrete cannot be washed clean and if it becomes stained the stains are permanent.

Extensive areas of concrete floor may be levelled and finished by power floating as a satisfactory base for the thicker floor finishes such as mastic asphalt, tiles and wood blocks. For the thin finishes such as plastic, linoleum, rubber sheet and tile, the more precisely level, smooth surface of a screeded base is necessary.

Floor screeds

The purpose of a floor screed is to provide a level surface to which a floor finish can be applied.

The word screed is used to describe the narrow strips of the wet mix that are first laid in bays across the length and width of the floor. The screed strips are carefully levelled in both directions to set out a precise level finish. The main bulk of the wet mix is then spread and levelled between the screeds.

The usual materials for a floor screed are cement, sand and water which are thoroughly mixed, spread over the surface of the concrete base, compacted, levelled and trowelled to a smooth finish. The thickness of the screed and the mix of cement and sand depends on the surface on which the screed is laid. The cement-rich mix used in a screed will shrink as it dries out and the thinner the screed the more rapidly it will dry and the more it will shrink and crack.

On the majority of building sites the concrete ground and upper floors are cast and roughly levelled as a working platform for subsequent building operations. To avoid damage to screeded surfaces that will serve as a finished floor surface or as a level base or substrate to applied floor finishes it is usual to lay a screed after the concrete floor has dried and hardened.

Where it is practical to lay a screed on a concrete base, within 3 hours of placing the concrete it will bond strongly to the concrete and dry slowly with the concrete so that drying shrinkage and cracking of the screed relative to that of the concrete will be minimised. For this monolithic construction of screed a thickness of 12 mm of screed will suffice.

A screed laid on a concrete base that has set and hardened should be at least 40 mm thick. To provide a good bond between the screed and the concrete, the surface of the concrete should be hacked by mechanical means, cleaned and dampened and then covered by a thin grout, or wet mix, of water and cement before the screed is laid. With a good bond to the concrete base a separate screed at least 40 mm thick will dry sufficiently slowly to avoid serious shrinkage cracking.

Where a screed is laid on an impermeable dpm there will be no bond between the screed and the concrete base so that drying shrinkage of the screed is unrestrained. So that the screed does not dry too rapidly and suffer shrinkage cracking, the screed in this unbonded construction should be at least 50 mm thick.

A screed laid on a layer of compressible thermal or sound insulating material should be at least 65 mm thick for domestic and 75 mm for other buildings, if this floating construction is not to crack due to drying shrinkage and the deflection under loads on the floor.

For screeds up to 40 mm thick, a mix of Portland cement and clean sand in the proportions by weight of 1:3 to 1:4½ is used. The lower the proportion of cement to sand the less the drying shrinkage. For screeds over 40 mm thick a mix of fine concrete is often used in the proportions of 1:1½:3 of cement, fine aggregate and coarse aggregate with a maximum of 10 mm for the coarse aggregate.

Screed should be mixed with just sufficient water for workability. The material is spread over the surface of the base and thoroughly compacted by tamping to the required thickness and level and then it is finished with a wood or steel float. A wood float finish is used for wood block and thick tile floors and a steel finish for the thin sheet and tile finishes. The screed should be cured, that is allowed to dry out slowly over the course of several days, by covering it with sheeting, such as polythene, to minimise rapid drying shrinkage and cracking.

Premixed cement screed materials, dry bagged ready for use on site, are used to avoid messy, wasteful site mixing. Just sufficient water is added to the dry mix for workability. The mix may include polymer fibre for reinforcement.

FLOOR SURFACE FINISHES

The traditional floor surface and finish for ground floors was natural stone slabs, thick clay tiles or brick laid on a bed of lime and sand on a consolidated earth base. These natural materials which provided a reasonably level, solid surface required considerable effort to keep clean and were cold underfoot because they were ready conductors of cold from the soil below.

To provide some insulation against cold and damp rising from the ground, a timber boarded floor was often used. The timber boards were nailed to timber battens set in the consolidated earth base or raised on small walls which supported timber joists to which the floor boards were nailed. This raised timber floor construction was in use, particularly for houses, for many years before the introduction of the concrete ground slab in the late nineteenth century.

The disadvantage of the timber boarded ground floor was that the battens laid on the ground would in time rot and the raised timber floor required ventilation of the space below the joists to clear moist air, which made the floor cold under foot.

The use of a solid concrete floor slab as a barrier to rising damp provided a solid surface on which a variety of materials could be laid as a floor finish. The later use of a continuous membrane and a layer of insulation provided a barrier against rising damp and insulation against transfer of heat.

The materials that were used as a finished floor surface in the early days were clay tiles, sheets of linoleum or timber boards nailed to battens. More recently a wide range of plastic sheet and tiles has been used to provide a floor surface to meet the demands for an easily cleaned surface that is reasonably durable.

Most recently plastic floor finishes have to an extent lost favour because of the dull, insipid colours that were used initially with the material, in favour of traditional materials such as linoleum, clay tiles, natural stone slabs and timber.

Floor finishes for concrete floors

A floor finish should generally be level, reasonably resistant to the wear it will be subject to and capable of being easily cleaned. For specific areas the surface should be non-slip, smooth for cleaning and polishing, resistant to liquids likely to be spilled, seamless for hygiene or substantially dust free. There is no one finish that will satisfy the possible range of general and specific requirements. There is a wide range of finishes available from which one may be selected as best suited to a particular requirement.

For the small floor areas of rooms in houses and flats the choice of floor finish is dictated largely by appearance and ease of cleaning. For the larger floor areas of offices, public and institutional buildings ease of cleaning is a prime consideration where power operated cleaning and polishing equipment is used.

It is convenient to make a broad general classification of floor finishes as:

Jointness
Flexible thin sheet and tile
Rigid tiles and stone slabs
Wood and wood based

Jointless floor finishes

This group includes the cement and resin based screeds and mastic asphalt that are laid while plastic and do not show joints and seams other than movement joints where necessary.

Cement screeds

A cement and sand screed finish to a concrete floor may be an acceptable, low cost finish to small area floors of garages, stores and outhouses where the small area does not justify the use of a power float and considerations of ease of cleaning are not of prime importance.

Fibre reinforced cement screed

Premixed, dry bagged cement and sand screed material reinforced with polymer fibre is available. The fibre reinforces against drying, shrinkage and cracking.

Surface hardeners

To produce improved surface resistance to wear and resistance to the penetration of oils and grease a dry powder of titanium alloy with cements may be sprinkled on to the wet surface of concrete or screed and trowelled in.

Granolithic paving

The traditional cement screed finish to the floors of factories, stores, garages and other large floor areas, which have to withstand heavy wear, is granolithic paving or screed.

Granolithic paving consists of a mixture of crushed granite which has been carefully sieved so that the particles are graded from coarse to very fine in such proportions that the material, when mixed, will be particularly free of voids or small spaces, and when mixed with cement will be a dense mass. The usual proportions of the mix are $2\frac{1}{2}$ of granite chippings to 1 of Portland cement by volume. These materials are mixed with water and the wet mix is spread uniformly and trowelled to a smooth flat surface. When this paving has dried and hardened it is hard wearing.

Every material which has a matrix (binding agent) of cement shrinks with quite considerable force as it dries out and hardens. Granolithic paving is rich in cement and when it is spread over a concrete base it shrinks as it dries out and hardens. This shrinkage is resisted by the concrete. If the concrete is dense and hard, and its surface has been thoroughly brushed to remove all dust or loose particles, it will successfully restrain the shrinkage in the granolithic paving. If, however, the concrete on which the granolithic paving is spread is of poor quality, or if the surface of the concrete is covered with dust and loose particles, the shrinkage of the granolithic paving will be unrestrained and it will crack and, in time, break up.

If the granolithic paving is laid as soon as the oversite concrete is hard enough to stand on, then the paving can be spread 15 mm thick. This at once economises in the use of the granolithic material, which is expensive, and at the same time, because the wet granolithic binds firmly to the still damp concrete, there is little likelihood of the paving cracking as it dries out.

On the surface of newly laid concrete that has dried out it is necessary to clean the surface thoroughly by mechanical hacking to remove the surface layer to expose aggregate, thoroughly wetting overnight and covering the surface with a thin grout of cement and water before the granolithic is laid. The granolithic is laid to a thickness of 40 mm, consolidated, levelled and trowelled smooth.

Granolithic paving laid on surfaces such as poor concrete, surfaces fouled with oil or grease and on a waterproof membrane to which the material will not bond, should be laid to a thickness of up to 75 mm. Because of the cost of the material and the skilled labour needed such a thickness is not a sensible or economic floor finish. It would be as economic and more satisfactory to break up the old concrete, lay new and then apply a floor finish.

There are a number of additives variously described as 'sealers' or 'hardeners' that may be added to the granolithic mix to produce improved resistance to surface wear. A thin surface dressing of carborundum granules trowelled into the surface improves resistance to wear.

With the decline of heavy industry in this country and the availability of epoxy resin finishes and epoxy sealers, granolithic paving is less used than it was.

Anhydrite floor finish

Premixed, dry bagged screed material of anhydrite and sand is used as a floor finish. Anhydrite is a mineral product of heating gypsum which will, when mixed with water, act as a cement to bind the grains into a solid mass as the material dries and hardens. The advantage of anhydrite is that it readily combines with water and does not shrink and crack as it dries out and hardens.

The wet mix of anhydrite and sand may be pumped and spread over the concrete base as a self-levelling screed or spread and trowelled by hand. The material may be pigmented.

A disadvantage of the material is that it fairly readily absorbs water and is not suited to use in damp situations.

Resin based floor finish

A range of resin emulsion finishes is available for use where durability, chemical resistance and hygiene are required in laboratories, hospitals and food preparation buildings. This specialist application finish is composed of epoxy resins as binders with cement, quartz, aggregates and pigments. The material is spread on a power floated or cement screed base by pumping and trowelling to a thickness of up to 12 mm. The aggregate may be exposed on the surface as a non-slip finish and as decoration.

This specialist floor finish is little used for small domestic or office floors. On larger floor areas it is used for the advantage of a seamless finish that can be cleaned by a range of power operated devices designed for the purpose.

Polymer resin floor surface sealers

Polyester, epoxy or polyurethane resin floor sealers are specialist thin floor finishes used for their resistance to water, acids, oils, alkalis and some solvents. The materials are spread and levelled on a level power floated or screed surface to provide a seamless finish to provide an easily cleaned surface.

Polyester resin, the most expensive of the finishes, is spread to a finished thickness of 2 to 3 mm to provide the greatest resistance.

Epoxy resin provides a less exacting resistance. It is sprayed or pumped to a self-levelling or trowelled thickness of 2 to 6 mm.

Polyurethane resin, which has moderate resistance, can be spread on a somewhat uneven base by virtue of its possible thickness. It is pumped to be self-levelling for thin finish and trowelled for the thicker. Thicknesses of 2 to 10 mm are used.

Mastic asphalt floor finish

Mastic asphalt for flooring is made from either limestone aggregate, natural rock or black pitch-mastic in the natural colour of the material or coloured. Mastic asphalt serves both as a floor finish and a dpm. It is a smooth, hardwearing, dust free finish, easy to clean but liable to be slippery when wet. The light duty grade is fairly readily indented by furniture. Mastic asphalt has been less used as a floor finish since the advent of the thin plastic tiles and sheets.

The light duty, non-industrial grade, which is laid in one coat to a finished thickness from 15 to 20 mm, is used for offices, schools and housing. The medium grade is laid in one coat to a thickness of 20 to 25 mm and the heavy duty in one coat to a thickness of 30 to 50 mm. Mastic asphalt can be laid on a level, power floated concrete finish or on a level, smooth cement and sand screed. The asphalt finish can be coloured in one of the red or brown shades available.

Flexible thin sheet and tile

The original thin sheet floor finish was linoleum that was extensively used as a smooth, easily cleaned finish to both boarded timber and solid floors. Linoleum, commonly known as 'cork lino', was laid loose on an underlay of paper felt to accommodate structural, thermal and moisture movement of the finish, relative to the floor surface. The sheets of linoleum were laid loose for at least 48 hours to allow maximum expansion at room temperature and were then laid butt jointed between rolls.

Providing the floor surface was reasonably firm and level the linoleum finish provided moderate resistance to wear. On boarded floors this finish would provide poor wear resistance over the edges of boards that twisted due to drying shrinkage. On damp, solid floors the linoleum would deteriorate fairly rapidly.

Linoleum is made from oxidised linseed oil, rosin, cork or wood flour, fillers and pigments compressed on a jute canvas backing. The sheets are made in 2 m widths, 9 to 27 m lengths and thicknesses of 2.0, 2.5, 3.2 and 4.5 mm in a variety of colours. The usual thickness of sheet is 2.5 mm. Tiles 300 and 500 mm square are 3.2 and 4.5 mm thick.

Linoleum should be laid on a firm level base of plywood or particle board on timber floors or on hardboard over timber boarded floors and on a trowelled screed on concrete floors. The material is laid flat for 48 hours at room temperature and then laid on adhesive and rolled flat with butt joints between sheets.

Linoleum has a semi-matt finish, is quiet and warm underfoot and has moderate resistance to wear for the usual 2.5 mm thick sheets and good resistance to wear for the thicker sheets and tiles.

Of late linoleum has been used instead of vinyl for the advantage of the strong colours available in the form of sheets and also in the form of decorative patterns by combining a variety of colours in various designs from cut sheet material.

Flexible vinyl sheet and tiles

Polyvinylchloride (PVC), generally referred to as vinyl, is a thermoplastic used in the manufacture of flexible sheets and tiles as a floor finish. The material combines PVC as a binder with fillers, pigments and plasticisers to control flexibility. The resistance to wear and flexibility vary with the vinyl content, the greater the vinyl content the better the wear and the poorer the flexibility.

Since it was first introduced, vinyl sheet flooring has become the principal sheet flooring used where consideration of cost and ease of cleaning combine with moderate resistance to wear. Sheet thickness from 1.5 to 4.5 mm in widths from 1200 to 2100 mm wide are produced in lengths of up to 27 m.

A wide range of colours and textures is produced from the early thin sheets coloured to produce an insipid imitation of marbled and other grained finishes to the later thicker, less flexible sheets with bright colours and greater resistance to wear.

Foam backed vinyl sheet is produced to provide a resilient surface for the advantage of resilience and quiet underfoot at the expense of the material being fairly easily punctured.

The material is extensively used in domestic kitchens and bathrooms and offices where a low cost, easily cleaned surface is suited to moderate wear.

The thin sheet material should be laid on a smooth, level screeded surface particularly free from protruding hard grains that might otherwise cause undue wear. The thicker, less flexible sheet may be laid on a power floated concrete finish. The sheets are bonded on a thin bed of epoxy resin adhesive and rolled to ensure uniformity of adhesion.

For large areas of flooring the sheets may be heat welded to provide a seamless finish for the sake of hygiene.

A range of flexible vinyl tiles is produced in a variety of colours and textures in 225, 250 or 300 mm squares by 1.5 to 3 mm thicknesses.

Various shapes of cut sheet may be used to provide single or multi-coloured designs.

Vinyl sheets and tiles may be coated with a water–wax emulsion polish for appearance and ease of cleaning with a damp mop and occasional polishing.

Flexible rubber sheet

Before the introduction of vinyl sheet, rubber was extensively used in lieu of linoleum. Natural or synthetic, vulcanised rubber with fillers and pigments was used in the production of sheets 3.8 to 12.7 mm thick, 910 to 1830 mm wide and up to 30 m long. This thick, comparatively expensive floor finish was used because of its resilience and quiet underfoot, good wear resistance and ease of cleaning.

It is made in a wide range of colours and textures from plain black to white.

Since the introduction of vinyl, sheet rubber is less used than it was. It is often preferred as an easily cleaned finish with good resistance to wear in common access corridors and changing rooms. The surface of the sheet may be textured with ribs or studs to provide a non slip, hard wearing surface.

It is bonded to a screeded or power floated concrete surface with an epoxy resin adhesive on to which the sheet is laid under the pressure of a roller.

Rigid tiles and stone slabs

Clay floor tiles

Natural clay floor tiles have been used for centuries as a hard, durable floor surface and finish for both domestic and agricultural ground floors. Before the advent of concrete the thicker tiles were often bedded on consolidated ground and the thinner tiles on a bed of sand. This hard finish could be laid reasonably level and could be cleaned by brushing and washing. Because of the nature of the material the floor would be both cold and noisy underfoot.

The two types of tile may be distinguished as floor quarries and clay floor tiles. The word quarry is derived from the French *carré* meaning square.

Floor quarries

Floor quarries have been manufactured in Staffordshire and Wales from natural plastic clays. The clay is ground and mixed with water and then moulded in hand operated presses. The moulded clay tile is then burned in a kiln. If the clay is of good quality and the tile is burned at the correct temperature the finished tiles will be very hard, dense and will wear extremely well. But as there is no precise examination of the clays used, nor accurate control of pressing or burning, the tiles produced vary considerably in quality, from very hard well burned quarries to soft underburned quarries unsuitable for any use in buildings.

The manufacturers grade the tiles according to their hardness, shape and colour. The first or best quality of these clay floor quarries are so hard and dense that they will suffer the hardest wear on floors for centuries without noticeably wearing. Because they are made from plastic clay, which readily absorbs moisture, quarries shrink appreciably when burned, and there is often a noticeable difference in the size of individual tiles in any batch. The usual colours are red, black, buff and heather brown.

Some common sizes are 100 × 100 × 12.5 mm thick, 150 × 150 × 12.5 mm thick and 229 × 229 × 32 mm thick.

Plain colours

Plain colours are manufactured from natural clays selected for their purity. The clay is ground to a fine dry powder and a small amount of water is added. The damp powder is heavily dust pressed into tile shape and the moulded tiles are burned. Because finely ground clay is used the finished tiles are very uniform in quality and because little water is used in the moulding, very little shrinkage occurs during burning. The finished tiles are uniform in shape and size and have smooth faces. The tiles are manufactured in red, buff, black, chocolate and fawn.

Because of their uniformity of shape these tiles provide a level surface, that is resistant to all but heavy wear, does not dust through abrasion, is easily cleaned with water and has a smooth, non-gloss finish which is reasonably non-slip when dry. They are used for kitchens, bathrooms and halls where durability and ease of cleaning are an advantage.

Some common sizes are 300 × 300 × 15 mm thick, 150 × 150 × 12 mm thick and 100 × 100 × 9 mm thick.

Vitreous floor tiles

The two types of vitreous (glass like) tiles are vitreous and fully vitreous. Vitreous tiles are made from clay and felspar which gives the tile a semi-gloss finish. Fully vitreous tiles contain a higher proportion of the vitrifying agent either in the tile itself or as a surface finish.

These tiles are made from felspar or other material which melts when the tile is burned and causes it to have a hard, smooth, glass-like surface which is impervious to water. By itself felspar would make the tile too brittle for use and it is mixed with both clay and flint. The materials are ground to a fine powder, a little water is added and the material is heavily pressed into tile shape and then burned.

The tiles are uniform in shape and size and have a very smooth semi-gloss or gloss surface which does not absorb water or other liquids and can be easily cleaned by mopping with water. Both vitreous and fully vitreous tiles may be moulded with a textured finish to provide a moderately non-slip surface.

A very wide range of both native and imported vitreous and fully vitreous floor tiles is available in the full range of colours possible. Sizes are generally similar to those of plain colour tiles.

The tiles are chosen in the main for the appearance of the semi- or fully gloss finish which enhances the colour and ease of cleaning. The gloss finish is impervious to most liquids, dust free and liable to be slippery, particularly when wet.

Laying clay floor tiles

The considerations that affect the choice of a method of laying floor tiles are

(1) provision of a material into, or onto, which the tile may be laid to take up variations in tile thickness to produce a reasonably level finish
(2) good adhesion to the base to provide solid support, particularly for thin tiles, to avoid cracking and
(3) to provide a means of accommodating relative structural, moisture and thermal movements between the base and the finish to prevent arching of the tile floor.

The following are the common methods of laying clay floor tiles.

Direct bedding method

The traditional method of laying tiles is to bed them on a layer of wet cement and sand spread over a screeded or level concrete floor. This direct bedding method is satisfactory for all but larger floor areas where it may be wise to form movement joints.

Quarry tiles are laid and bedded in sharp sand and cement, 1:3 or 1:4 mix, spread to a level thickness of 15 to 20 mm depending on the thickness of the tiles, on a fully dry concrete base. The cement and sand should be mixed with just sufficient water for workability and pressing the tiles into the bed. Too wet a mix will cause excess drying shrinkage. The main purpose of the bed is to accommodate the appreciable variations in thickness of the quarries to provide a reasonably level finish.

While there will be some little adhesion of the cement sand bed to the concrete, adhesion is not a prime consideration. The bed will provide a solid base for the heavy wear such surfaces are usually used for.

The joints between the quarries will be up to 15 mm wide, to allow for variations in shape, and filled with cement and sand and finished level with the floor surface, or just below the surface, to emphasise the individual tiles.

The direct bedding method of laying is used for plain colour clay tiles on a bed some 10 mm thick and with joints between 5 and 10 mm wide depending on variations in the size of tiles and the need to adjust tile width to that of a whole number of tiles with joints to suit a particular floor size.

Separating layer method

Some few instances of tiled floors 'arching' have been widely publicised and made much more of than is reasonable. The word arching is the effect of some tiles, usually in the centre of the floor, rising above their bed in the form of a shallow arch. Arching is caused by expansion of the tiles relative to their bed or contraction of the bed relative to the tiles.

Arching can be caused by shrinkage of the concrete base, or the bedding being too cement rich, wet mix shrinks on drying out. Other less usual causes are thermal shrinkage of the concrete base due to the greater thermal movement of concrete to that of clay, thermal expansion of tiles due to the use of hot water washing and creep (jelly like) deflection of concrete. Arching will be more pronounced with tightly edged butted tiles.

Where there is a realistic likelihood of arching the tiles may be laid on a bed spread over a separating layer so that movement of either the tiles or the base will not affect the floor finish.

A layer of polythene film, bitumen felt or building paper is spread with 100 mm lapped joints over the concrete floor. The tiles are then laid and bedded on a cement/sand mix spread and levelled to a thickness of from 15 to 25 mm, depending on the thickness of the tiles, and jointed in the same way as for direct bedding.

As an alternative to using a water impermeable separating layer a layer of dry sand may be used. A layer of dry sand or crushed stone, thoroughly sieved to remove large grains, is spread and raked level on the fully dried concrete base and the tiles are bedded and levelled directly on the dry sand.

This dry sand, separating layer method is suitable for thin tiles and is commonly used in southern European countries as a bed for thin stone slab floor surfaces, such as marble. The sand bed will accommodate relative movements and serve as a sound bed for thin tiles and slabs that are subject to all but the heaviest wear.

Thin bed adhesive method

The majority of the thin, vitreous tiles that are used today are bedded and laid on an adhesive that is principally used as a bond between the tiles and the base and to some small extent as a bed to allow for small variations in tile thickness.

The adhesives that are used are rubber latex cement, bitumen emulsion and sand and epoxy resins. These adhesives are spread on a level power floated concrete or a screed finish, to a thickness of from 3 to 5 mm, combed to assist bedding and the tiles are pressed and levelled in position.

Where the thin bed, epoxy resins are used as an adhesive for thin, vitreous tiles there should be no large protruding particles of aggregate or sand in the floor surface over which the brittle tile will crack under load.

Concrete tiles

Concrete tiles made of cement and sand, which is hydraulically pressed to shape as floor tiling, have been used as a substitute for quarry and plain colour clay tiles. The usual size of tiles is 300 × 300 × 25 mm, 225 × 225 × 19 mm and 150 × 150 × 16 mm. The material may be pigmented or finished to expose aggregate. The density and resistance to wear depend on quality control during manufacture and the nature of the materials used.

Because of the poor quality of colour possible by pigmentation, the necessarily coarse surface of the tile, which is not easy to clean, and the bad name given by poor quality tiles that have been produced, these tiles have lost favour.

They are laid on a level power floated concrete or screed surface and jointed in the same way as quarries and plain colours.

Stone slabs

The word tile is used in a general sense to describe square or rectangular units, thin relative to their length or width, of burned clay used as a floor or wall finish. The word slab is used to describe natural stone in units that are generally larger than tiles such as those used for outdoor paving which are also called paviours. A small slab could as well be described as a tile or a paviour when used for flooring.

A wide range of natural stone slabs is used as a floor finish, from the very hard slabs of granite to the less dense soft marbles. Stone is selected principally for the decorative colour, variations in colour, grain and polished finish that is possible and durability and freedom from dusting.

Because of their composition, all stones are hard and noisy underfoot and cold where the floor is not insulated.

The method of bedding natural stone slabs as an internal floor finish varies with the thickness, size, nature and anticipated wear on the surface.

Large, thick slabs of limestone or sandstone up to 50 mm thick are laid by the direct or separating layer method on cement and sand with cement and sand joints depending on the area to be covered and the anticipated, relative shrinkage of the bedding material. The bedding material may be of cement, or lime and sand.

Comparatively thick slabs of slate are bedded in the same material as thick slabs of limestone.

Thin slabs of granite and marble are laid by the thin bed adhesive method or the dry sand bed method, which is particularly used for marble.

Joints

The width of the joints between tiles and slabs as an internal floor finish is determined by the uniformity of shape of the material used. For quarries, joints of up to 12 mm may be necessary to allow for the considerable variations in size, and joints as little as 1 mm may be possible with very accurately cut and finished, thin slabs of granite and marble.

The disadvantage of wide joints is that the material used, such as cement and sand for quarries, will be more difficult to clean and will more readily stain than the floor material. Thin joints are used for highly polished, accurately cut granite slabs to provide the least obvious joint possible for appearance sake.

Ideally a jointing material should have roughly the same density, resistance to wear and ease of cleaning as the floor finish.

Movement joints

To an extent the joints between tiles and slabs will serve the purpose of accommodating some movement of the floor finish relative to the bedding and the concrete floor. Some small expansion or contraction of the floor finish will be taken up in the joints through slight cracks or crushing of the very many joints.

In any large structure it is practice to form movement joints (see Volume 4) to accommodate structural, moisture and thermal movement. These flexible joints should be continued through the rigid floor finishes as a flexible joint.

Because of a few failures of rigid floor finishes it has become practice to form movement joints whether they are reasonably necessary or not. A principal cause of the failure of rigid floor finishes is the use of cement rich mixes of bedding material or the concrete base. On drying cement shrinks fiercely. The richer the cement mix used, the greater the amount of water necessary in the mix and the greater the shrinkages.

By control of the mix of concrete, screeds and bedding to provide a workable mix using the least amount of cement and water, drying shrinkage may be minimised. There has been a recommendation to form movement joints around the perimeter of floors with an elastic sealant joint, others recommend dividing rigid floor finishes into bays of a variety of areas to be on the 'safe side'.

The considerable disadvantage of these joints is that the joint material is necessarily softer than the surrounding surface, difficult to keep clean and will encourage wear of the edges of the finish next to the joint. Good sense dictates the use of movement joints only where there is sound reason to anticipate gross relative movements.

Wood floor finishes

Natural wood floor finishes such as boards, strips and blocks are used for the advantage of the variety of colour, grain and texture of this natural material which is warm, resilient and comparatively quiet underfoot. The disadvantages of wood finishes is that they are difficult to clean and at the same time maintain their original attractive appearance. In those countries where wood is much used as a floor finish it is not uncommon for the visitor to be firmly invited to change outdoor shoes for slippers to avoid damage to polished wood floors.

Floor boards

Floor boards, described in more detail for upper floors, may be used as floor surface and finish for concrete floors. Either plain edge or tongued and grooved boards are used. The boards are nailed to wood battens set in a screed or to battens secured in floor clips. More usually wood strip flooring is used.

Wood strip flooring

The most pronounced drying shrinkage of wood is across the long grain so that wood boards shrink across their width. As the shrinkage is circumferential to the round section of the log from which the boards are cut, the boards will both shrink across their width and deform out of the flat section. Plainly the wider the board, the greater the loss of width and the greater the loss of shape. The purpose in cutting narrow strips of board is to minimise loss of width and shape that is due to the inevitable drying shrinkage.

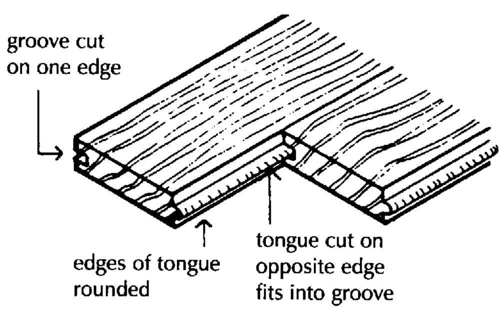
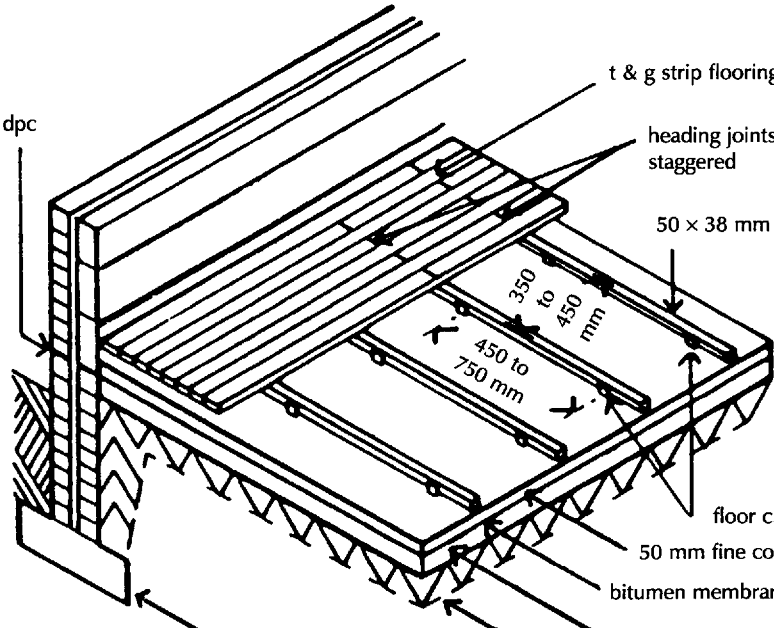


Fig. 135 Tongue and groove strip flooring.

Strips of hardwood or softwood of good quality, specially selected so as to be particularly free of knots, are prepared in widths of 90 mm or less and 19, 21 or 28 mm in thickness. The type of wood chosen is one which is thought to have an attractive natural colour and decorative grain. The edges of the strip are cut so that one edge is grooved and the other edge tongued, so that when they are put together the tongue on one fits tightly into the groove in its neighbour, as illustrated in Fig. 135. The strips are said to be tongued and grooved, usually abbreviated to T & G. The main purpose of the tongue and groove is to cause the strips to interlock so that any slight twisting of one strip is resisted by its neighbour.

There is always some tendency for wood strips to twist out of flat, due to the wood drying out, and to resist this the strips have to be securely nailed to wood battens which are secured to the concrete floor, either by means of galvanised metal floor clips, or in a cement and sand screed. The illustration of part of a concrete floor finished with wood strips nailed to battens, as in Fig. 136, will explain the arrangement of the parts.

The floor clips are of galvanised sheet steel which is cut and stamped to the shape shown in Fig. 136. These are usually set into the concrete or screed whilst it is still wet. They are placed in rows 350 to 450 mm apart and the clips in each row are spaced 450 to 750 mm apart so that when the concrete has hardened, the clips are firmly bedded in it. The strip flooring is usually laid towards the end of building operations and the 50 × 38 mm or 50 × 25 mm softwood battens are wedged up until they are level and the clips are then nailed to them. The strip flooring is then nailed to the battens.



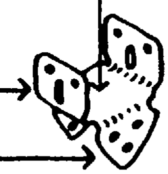


Fig. 136 Strip flooring fixed to battens and clips.

The advantage of the floor clips is that the battens may be wedged up to a true finished level and as the strips are fixed across battens there will be some resilience of the surface to provide the feeling of some springy softness underfoot.

Because wood strip flooring is an expensive, decorative, floor finish the strips of wood are nailed to the battens so that the heads of the nails do not show on the finished surface of the floor. This is termed secret nailing. If the strips have tongued and grooved edges the nails are driven obliquely through the tongues into the battens below so that the groove in the edge of the next board hides the nail. Even though the nails used have small heads they may split the narrow tongue off the edge of the strip and obstruct a close fit of tongues to grooves, so that there may be a poor fixing. To avoid this, the edges of

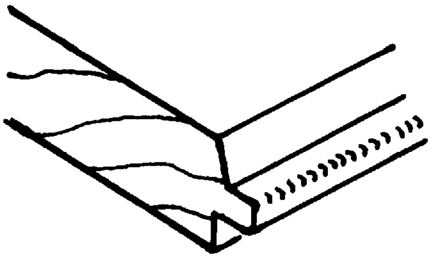


Fig. 137 Splayed tongued and grooved strip.

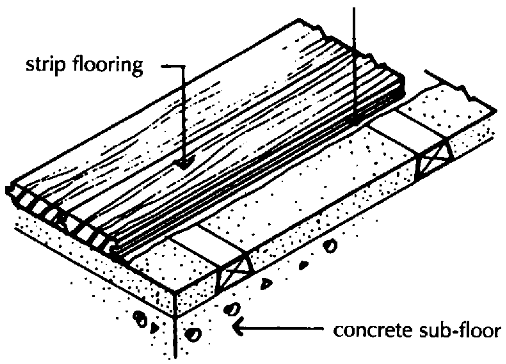


Fig. 138 Strip fixed to battens in screed.

the strips can be cut with splayed tongued and grooved joints as illustrated in Fig. 137.

An alternative method of securing battens to a concrete floor, that has been used, is to bed dovetailed wood battens in a sand and cement screed spread and levelled on a concrete base, as illustrated in Fig. 138. The disadvantages of this method of fixing are that it adds considerably to the labour of laying a wet screed. The moisture from the wet screed will cause the battens to expand and then shrink as the screed dries out. Even though the screed may make good adhesion to the concrete there is some possibility that deformation of the strips may lift a batten and the screed around it. This method of fixing has been largely abandoned.

Of recent years wood strip flooring has been fixed by the thin bed adhesive method. Comparatively short lengths of wood strip, 300 mm long, with tongued and grooved edges and joints, are used to minimise drying deformation. The strips are bedded on an epoxy resin adhesive spread over a true level screed on to which the strips are laid and pressed or rolled to make sound, adhesive contact. The strips are usually laid with staggered end joints.

This is a perfectly satisfactory method of laying wood strip flooring as the narrow width and short length of strip is unlikely to suffer drying deformation likely to tear strips away from the adhesive bed.

If timber is in contact with a damp surface it may rot and it is important to protect both the battens and the strip flooring from damp which may rise from or through the concrete subfloor. The battens should be impregnated with a preservative before they are fixed and either the surface of the concrete subfloor should be covered with a coat of bitumen or a waterproof membrane should be used in or under the concrete oversite.

Wood strip flooring is used as an expensive, decorative floor finish which is used where wear is light, as in households where the considerable care and labour required to maintain the colour and texture of the material is accepted.

After the finish is laid it is usually sanded to remove the thin top surface which is initially and subsequently polished with wax. Over the years a thin, hard wax finish is developed. This thin, non-gloss surface enhances the colour and grain of the wood. The surface is cleaned by dry mopping or dusting and polishing. To minimise labour it is not uncommon to apply a silicone seal to the surface which can then be mopped with a damp cloth or mop to remove dust. The seal provides a semi-gloss finish that obscures the colour and texture of the wood.

Wood block floor finish

Blocks of wood are used as a floor finish where resistance to heavy wear is required, as in halls, corridors and schools, to provide a surface which is moderately resilient, warm and quiet underfoot. An advantage of the comparatively thick blocks is that after wear the top surface may be sanded to reduce the block to a level surface. The word 'sanded' describes the operation of running a power driven sanding machine over the surface. The sanding machine has a rotating plate surfaced with carborundum or sand paper which removes the top surface.

Blocks of some softwood or hardwood with good resistance to wear are cut. The blocks are usually 229 to 305 mm long by 75 mm wide by from 21 to 40 mm thick. The blocks are laid on the floor in a bonded, herringbone or basket weave pattern. The usual patterns are illustrated in Fig. 139. Moisture movement across the long grain of the blocks is balanced by alternating and cross laid blocks.

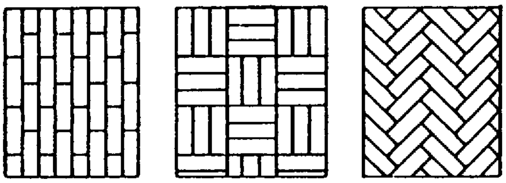


Fig. 139 Wood blocks patterns.

Wood blocks are laid on a thoroughly dry, clean, level cement and sand screeded surface which has been finished with a wood float to leave its surface rough textured. The traditional method of laying blocks is to spread a thin layer of hot bitumen over the surface of the screed into which the blocks are pressed. The lower edges of the blocks of wood are usually cut with a half dovetail incision so that when the blocks are pressed into the bitumen some bitumen squeezes up and fills these dovetail cuts and so assists in binding the blocks to the bitumen, as illustrated in Fig. 140.

If the wood blocks have been thoroughly seasoned (dried) and they are firmly pressed into the bitumen they will usually be securely fixed to the floor. It is possible, however, that one or more blocks may not be firmly fixed and will come up. To prevent this happening good quality wood blocks 25 mm thick and over have either tongues and grooves cut on their edges or wood dowels to joint them, as illustrated in Fig. 140.

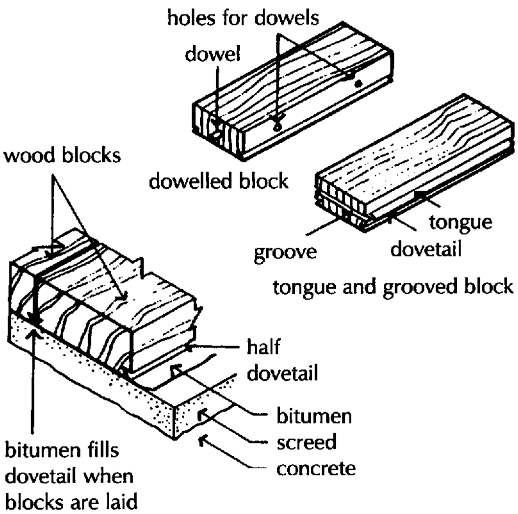


Fig. 140 Joints for wood blocks.

After the surface has been sanded to provide a level finish a seal is applied to provide an easily cleaned finish. Either a wax polish is used, which requires effort to maintain, or a polyurethane seal for ease of cleaning.

SUSPENDED TIMBER GROUND FLOORS

Many houses built in this country from about 1820 up to about 1939 were constructed with timber ground floor raised 300 mm or more above the packed earth, brick rubble or site concrete below. The purpose of raising the ground floor was to have the surface of the ground floor living rooms sufficiently above ground level to prevent them being cold and damp in winter. At that time imported softwood timber was cheap and this ground floor construction was both economical and satisfactory.

Since the end of the Second World War (1945), imported softwood timber has been expensive and for some years after the war its use was restricted by government regulations. Most ground floors today are formed directly off the site concrete and this is covered with one of the surface finishes described previously.

A suspended or raised timber ground floor is constructed as a timber platform of boards nailed across timber joists bearing on $\frac{1}{2}$B brick walls raised directly off the packed earth, brick rubble or site concrete, as illustrated in Fig. 141. The raised timber floor is formed inside the external walls and internal brickwork partitions, and is supported on brick sleeper walls.

Sleeper walls are $\frac{1}{2}$B thick and built directly off the site concrete up to 1.8 m apart. These sleeper walls are generally built at least three courses of bricks high and sometimes as much as 600 mm high. The walls are built honeycombed to allow free circulation of air below the floor, the holes in the wall being $\frac{1}{2}$B wide by 65 mm deep, as illustrated in Fig. 142.

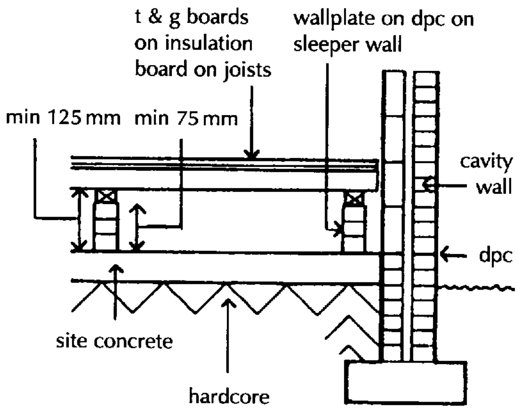


Fig. 141 Suspended timber floor.

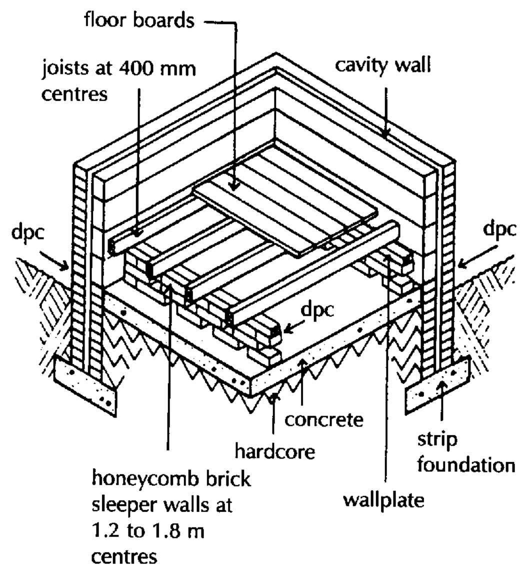


Fig. 142 Sleeper walls, joists and boards.

The practical guidance in Approved Document C to the Building Regulations requires a space of at least 75 mm from the top of the concrete to the underside of a wall plate and at least 150 mm to the underside of the floor joists, concrete oversite at least 100 mm thick on a hardcore bed or concrete at least 50 mm thick on a dpm of 1200 gauge polythene on a bed which will not damage it. Underfloor ventilation should have a free path between opposite sides, with openings equivalent to 1500 mm^2 for each metre run of wall.

Wall plate

A wall plate is a continuous length of softwood timber which is bedded in mortar on a dpc. The wall plate is bedded so that its top surface is level along its length and it is also level with the top of wall plates on the other sleeper walls.

A wall plate is usually a 100 × 75 mm timber and is laid on one 100 mm face so that there is a 100 mm surface width on which the timber joists bear. The function of a wall plate for timber joists is two-fold. It forms a firm level surface on which the timber joists can bear and to which they can be nailed and it spreads the point load from joists uniformly along the length of the wall below.

Floor joists

Floor joists are rectangular sections of sawn softwood timber laid with their long sectional axis vertical and laid parallel spaced from 400 to 600 mm apart. Floor joists are from 38 to 75 mm thick and from 75 to 225 m deep. The span of a joist is the distance measured along its length between walls that support it. The sleeper walls built to support the joists are usually 1.8 m apart or less, and the span of the joists in this type of floor is therefore 1.8 m or less.

Timber, chipboard or plywood boards are laid across the joists and they are nailed to them to form a firm, level floor surface.

From a calculation of the dead and imposed loads on the floor the most economical size and spacing of joists can be selected from the tables in Approved Document A to the Building Regulations and from this the spacing of the sleeper walls to support the joists.

Similarly the thickness of the floor boards to be used will determine the spacing of the joists, the thicker the board the greater the spacing of the joists.

Floor boards

Any length of timber 100 mm or more wide and under 50 mm thick is called a board. Floor boards for timber floors are usually, 16, 19, 21 or 28 mm thick and 65, 90, 113 or 137 mm wide and in length up to about 5.0 m. The boards are cut from whitewood, which is moderately cheap, or from redwood which is more expensive but which provides better wear. The edges of the boards may be cut square, or plain edged, which is the cheapest way of cutting them. But as these boards shrink, ugly cracks may appear between them.

The usual way of cutting boards is with a projecting tongue on one edge and a groove on the opposite edge of each board, as in Fig. 135. The boards are then said to be tongued and grooved, abbreviated to T & G. The boards are laid across the floor joists and cramped together. Cramping describes the operation of forcing the edges of the boards tightly together so that the tongues fit firmly into the grooves and there are no open cracks between the boards. The boards, as they are cramped up, are nailed to the joists with two nails to each board bearing on each joist.

Heading joints

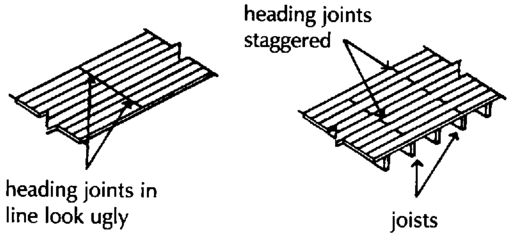


Fig. 143 Heading joints.

Floors of small rooms can often be covered with boards sufficiently long to run in one length from wall to wall, but in most rooms the ends of boards have to be cut to butt together. The joint between the end of one board and the end of another is described as the heading joint. The appearance of a boarded floor is spoiled if the heading joints run in a continuous line across the floor because the cut ends of the boards tend to be somewhat ragged and the continuous joint looks ragged and ugly (Fig. 143). The heading joints in floor boards should always be staggered in some regular manner. Obviously the heading joint ends of boards must be cut so that the ends of both boards rest on a joist to which the ends are nailed. A usual method of staggering heading joints is illustrated in Fig. 143.

End matched flooring

Hardwood strips are often prepared with tongues and grooves on the ends of the strips so that their ends firmly interlock and do not have to lie over a joist. The strips of flooring are said to be end matched. The end joint so formed provides a neater finish than a sawn end of ordinary boarding.

End support of floor joists

The floor joists of a raised timber ground floor bear on wall plates on sleeper walls and the best method of supporting the ends of the joists at external walls and at internal brick partitions is to build a honeycombed sleeper wall some 50 mm away from loadbearing walls to carry the ends of the joists , as illustrated in Fig. 142. The sleeper wall is built away from the main wall to allow air to circulate through the holes in the honeycomb of the sleeper wall. The ends of the joists are cut so that they are clear of the inside face of the wall by 50 mm.

Damp-proof course

A dpc should be spread and bedded on top of the sleeper walls under the wall plate to prevent any moisture rising through site concrete without a dpm and through sleeper walls to the timber floor. Any of the materials described in Chapter 1 may be used for this purpose.

Ventilation

The space below this type of floor is usually ventilated by forming ventilation gratings or bricks in the external walls below the floor so that air from outside the building can circulate at all times under the floor. The usual practice is to build air bricks into the external walls. An air brick is a special brick made of terra cotta (meaning earth burned) with several square or round holes in it and its size is 215 × 65, 215 × 140 or 215 × 215 mm (Fig. 144). These bricks are built into external and internal walls for each floor to provide 1500 mm of ventilation for each metre run of wall. The bricks are built in just above ground level and below the floor, as illustrated in Fig. 144.

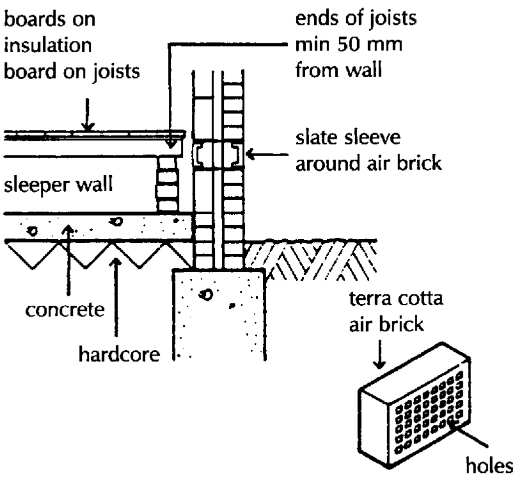


Fig. 144 Ventilation of raised timber floor.

The purpose of the air bricks is to cause air to circulate under the floor and so avoid stagnant damp air which might induce fungus to grow. The disadvantage of ventilating the space below this type of floor is that in winter the floor is liable to be cold. It is usual, therefore, to fix an insulating board or quilt under the floor boards to minimise transfer of heat to the ventilated spaces below the floor.

It is common practice today to prevent cold air from outside entering the cavity of a cavity wall to avoid the inner skin becoming cold. When ventilating air bricks are built into a cavity wall some means must be devised of preventing cold air getting into the cavity through the air brick. One common method of doing this is to build a roofing slate sleeve around the air bricks and across the cavity, as illustrated in Fig. 144, or a short length of pipe. A duct is made out of four pieces of slate which are built into the wall around the air bricks. Providing mortar droppings do not accumulate on top of the slate sleeve the slate will not convey water from the outer to the inner skin of the wall.

Thermal insulation

To meet the requirements of the Building Regulations for resistance to heat transfer through ground floors it may be necessary to insulate suspended timber ground floors that have a ventilated space below. The most practical way of insulating a suspended timber ground floor is to fix mineral wool roll, mat or quilt or semi-rigid slabs between the joists. Rolls or quilt of loosely felted glass fibre or rockwool are supported by a mesh of plastic that is draped over the joists and stapled in position to support the insulation. Semi-rigid slabs or batts of fibre glass or rockwool are supported between the joists by nails or battens of wood nailed to the sides of the joists.

Raised concrete ground floors

As an alternative to timber a raised ground floor may be constructed in concrete. It is not uncommon today to construct a raised concrete ground floor for the advantage of a solid floor surface raised above the ground level. This raised floor will not require protection against the possibility of damp causing rot in timber and provides the sense of being elevated above the surrounding ground, particularly in bungalows.

A concrete ground slab at least 100 mm thick is cast on the ground, after vegetable top soil has been stripped, with a damp proof membrane formed below the slab where the ground below the floor has been excavated below the surrounding ground level.

The space between the top of the concrete ground slab and the underside of the raised concrete is determined by the need to raise the floor level above the dpc in the walls. Where there is a risk of an accumulation of gas in the space, which might lead to an explosion, then the space between ground slab and underside of floor should be at least 150 mm and the space should be ventilated with openings at least 1500 mm^2 for each metre run of wall to provide cross ventilation.

Usual practice is to build a brick or concrete block sleeper walls on the ground slab to support the raised floor. The floor is constructed with one of the precast inverted 'T' beam and hollow concrete infill blocks described for use with upper floors. Spacing between sleeper walls is dictated by an economical span for the inverted 'T' beams. Concrete topping is spread and levelled over the precast concrete units.

UPPER FLOORS

Timber floors

Timber upper floors for houses and flats are about half the cost of comparable reinforced concrete floors. For upper floors of offices, factories and public buildings timber floors are not much used today because the resistance to fire of a timber floor, plastered on the underside, is not sufficient to comply with building regulations for all but small buildings. Concrete floors are used instead because of their better resistance to fire, and better resistance to sound transmission.

Strength and stability

Floor joists

A timber floor is framed, or carcassed, with sawn softwood timber joists which are usually 38 to 75 mm thick and 75 to 235 mm deep. The required depth of joists depends on the dead and imposed loads and the span. The spacing of the joists is usually 400, 450 or 600 mm measured from the centre of one joist to the next. Tables in Approved Document A to the Building Regulations set out the required size of timber joists for given spans and two strength classes, with given spacing of joists for various loads for single family dwellings of up to three storeys.

Where rigid plasterboard is used as the soffit (ceiling) of timber floors it is practice to use regularised joists. The depth of sawn softwood timbers may vary to the extent that where the joists are framed with their top surface level for floorboards the underside may be so out of level that plasterboard fixed to it will be noticeably out of level. The process of regularising sawn timber joists is carried out to produce joists of regular depth.

To economise in the use of timber, the floor joists of upper floors usually span (are laid across) the least width of rooms, from external walls to internal loadbearing partitions. The joists in each room span the least width. The maximum economical span for timber joists is between 3.6 and 4.0 m. For spans greater than 4.0 m it is economic to reduce the span of the joists by the use of steel beams.

Double floors

Where the span of a timber floor is greater than the commercially available length of timber and where, for example, joists span parallel to a cross wall, it is convenient and economic to use a steel beam or

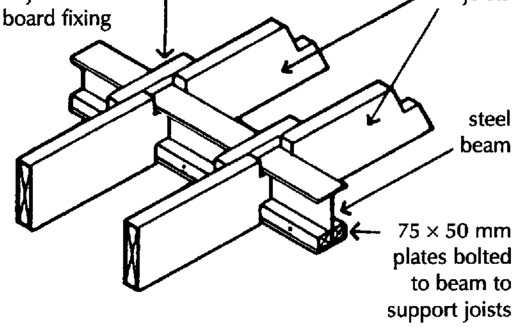


Fig. 145 Double floor.

timber beam to provide intermediate support for timber joists. This combination of beam and the joists is described as a double floor. Steel beams are generally used because of their small section.

The supporting steel beam may be fixed under the joists or wholly or partly hidden in the depth of the floor. To provide a fixing for the ends of the joists, timber plates are bolted to the bottom flange of the beam and the ends of the joists are scribed (shaped) to fit into the joist over the plates to which they are nailed. To provide a fixing for floor boards timber bearers are nailed to the sides of joists across the supporting steel beam, as illustrated in Fig. 145.

The ends of the supporting steel beam are built into loadbearing walls and bedded on a pad stone to spread the load along the wall.

Where the supporting steel beam projects below the ceiling it is cased in plasterboard as fire protection.

Strutting between joists

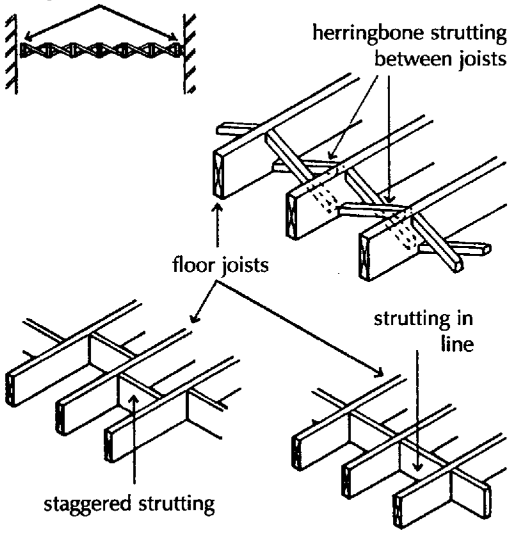


Fig. 146 Strutting between joists.

When timber is seasoned it shrinks, and timber such as in floor joists, which is not cut on the radius of the circle of the log, does not shrink uniformly. The shrinkage will tend to make the floor joists twist, or wind out of the vertical. To maintain joists in the vertical position in which they were initially fixed, timber strutting is used.

The type of strutting most used is that known as herringbone strutting. This consists of short lengths of softwood timber about 50 × 38 mm nailed between the joists, as illustrated in Fig. 146.

Each strut is cut with oblique faced ends to bear between the top and bottom edges of adjacent joists. A second system of struts is fixed across the first, as illustrated in Fig. 146. As the struts are nailed between the joists they tend to spread and secure the joists in an upright position. To provide rigid strutting between walls, wedges are fixed between the joists and walls at both ends of the strutting.

The recommendation in Advisory Document A to the Building Regulations is that joists which span less than 2.5 m do not require strutting, those that span from 2.5 to 4.5 m require one row of struts at mid-span and those more than 4.5 m span require two rows of struts spaced one-third of the span.

As an alternative to herringbone strutting a system of solid strutting may be used. This consists of short lengths of timber of the same section as the joist which are nailed between the joists either in line or staggered, as in Fig. 146. This is not usually so effective a system of strutting as the herringbone system, because unless the short solid lengths are cut very accurately to fit the sides of the joists they do not firmly strut between the joists.

As with herringbone strutting the end joists are blocked and wedged up to the surrounding walls.

End support for floor joists

For stability, the end of floor joists must have adequate support from walls or beams. If the floor is to be durable, timber joists should not be built into external walls where their ends may be persistently damp and suffer decay. Timber joists should not be built into or across separating or compartment walls where they may encourage spread of fire. Floor joists are, therefore, either built into internal and external walls or they are supported in hangers, or corbels projecting from the face of walls.

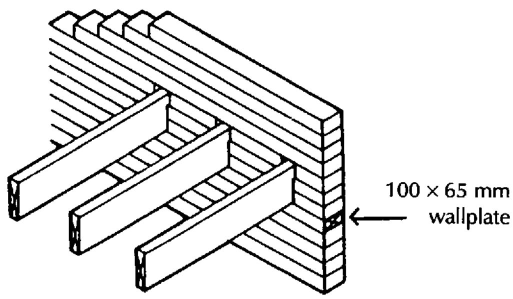


Fig. 147 Joists built into wall.

Timber floor joists that are built into walls may bear on a wall plate of timber or metal, which serves to spread the load from the floor along the length of the walls and as a level bed on which the joists bear.

Timber wall plates are of sawn softwood, 100 × 65 mm, to course into brickwork, and laid with one 100 mm face horizontal. The wall plate is bedded level in mortar to take the ends of the joists which are nailed in position to the timber plate and the wall is then raised between and above the floor, as illustrated in Fig. 147, which illustrates joists built into an internal loadbearing brick wall.

A timber wall plate generally has sufficient compressive strength to support the loads from a wall above. For greater loads a steel wall plate may be used or the joist fixed to bear directly on the wall. Where joists both sides of an internal wall bear on the wall the joist ends of one side bear alongside those on the other side.

A disadvantage of building in the ends of floor joists is that there is a deal of wasteful cutting of bricks or blocks around joist ends, as illustrated in Fig. 148. Cutting around joist ends is more straightforward with the small units of brick than around larger blocks.

Timber joists built into the inner skin of a cavity wall must not project into the cavity and it may be wise to treat the ends of the joists with a preservative against the possibility of decay due to moisture penetration. The ends of joists built into a cavity wall may bear on a timber wall plate, which may also be treated with a preservative. The wall plate is bedded on the blockwork inner skin. As an alternative, a mild steel bar of 75 × 6 mm may be used. This metal wall plate is tarred and sanded and bedded level in mortar, and the joist ends bear on the plate, as illustrated in Fig. 148.

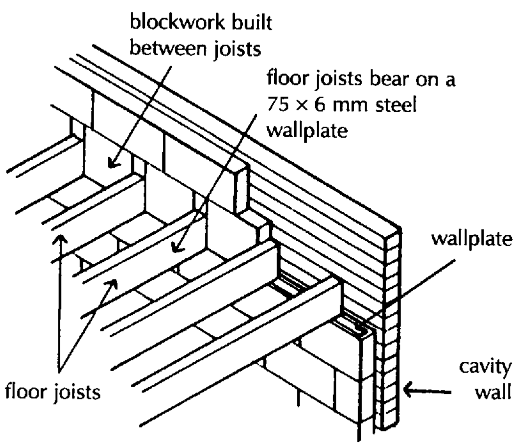


Fig. 148 Joist ends built into cavity wall.

Instead of using a timber or a metal wall plate the joists may bear directly on the brick or block wall with tile or slate slips in mortar packed under each joist end to level the joists. This is a somewhat laborious procedure and the slips may be displaced and the joists move out of level during subsequent building operations.

As an alternative to building in the ends of timber joists, joist hangers are used. Galvanised, pressed steel joist hangers are made with straps for building into horizontal courses and a stirrup to support a joist end, as illustrated in Fig. 149. The joist hangers are built into horizontal brick or blockwork as walls are raised and the joists fitted and levelled later or the joists, with the hangers nailed to their ends, are given temporary support as the brick or blockwork is raised and the hangers are built into horizontal courses.

The advantage of joist hangers is that joist ends are not exposed to possible damp, and there is no need for cutting brick or block to fit around joists.

Before the use of cavity external walls became common and today for buildings such as sheds and stores where a cavity wall is considered unnecessary, the ends of timber joists are supported by corbel brackets, or on brick courses corbelled out for the purpose as illustrated in Fig. 150. The purpose of the projecting corbel arrangement is to avoid building in the ends of timber joists to solid external walls where damp penetration might well cause rot.

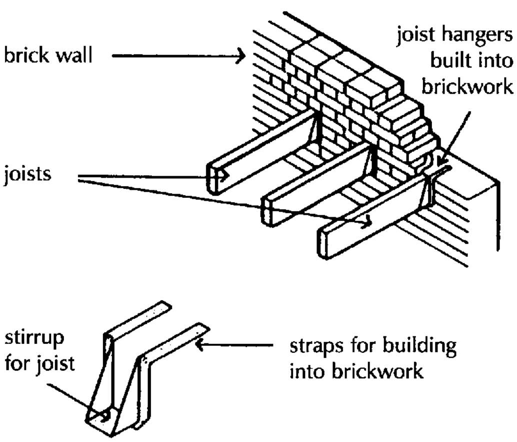


Fig. 149 Galvanised pressed steel joist hanger.

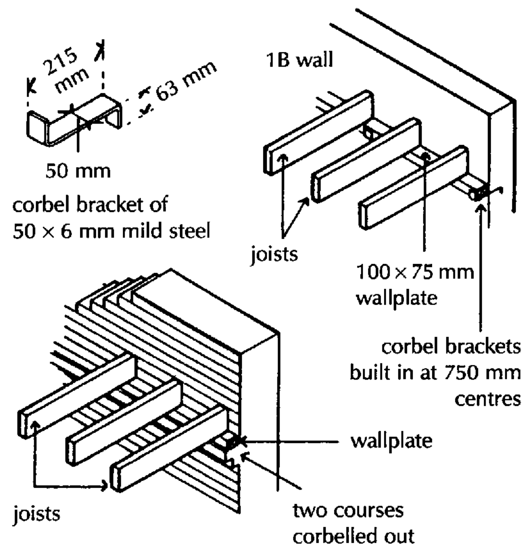


Fig. 150 Corbels to support joists.

The forged steel corbel brackets are usually coated in bitumen or tar and sanded and are built in at 750 mm centres as support for a timber wall plate to which the joists are nailed.

Two courses of brick are built to project $\frac{1}{4}$B from the face to provide a $\frac{1}{2}$B projecting corbel to support a wall plate to which the joists are nailed.

The projection of the corbel support is of no consequence in sheds and stores where walls are not decorated. When, in the past, corbels were used it was practice to disguise them with plaster cornices as part of the plaster finish to buildings.

Lateral restraint for walls

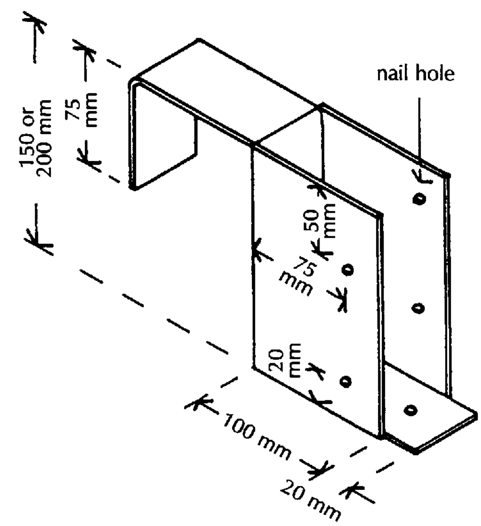


Fig. 151 Galvanised steel restraint joist hanger.

To provide lateral support to walls by floors Approved Document A to the Building Regulations recommends the use of straps or joist hangers to provide lateral support for walls at each storey floor level above ground to transfer lateral forces on walls, such as wind, to floors.

Lateral support is required to any external, compartment or separating wall longer than 3 m at every floor, roof and wall junction and any internal loadbearing wall, not being a compartment or separating wall, of any length at the top of each storey and roof.

Walls should be strapped to floors above ground level at intervals of not more than 2 m by the 30 × 5 mm straps illustrated in Fig. 67, shown in Chapter 2.

Straps are not required in the longitudinal direction of joists in houses of not more than two storeys if the joists are at no more than 1.2 m centres and where the joists are supported by restraint type joist hangers, illustrated in Fig. 151, at not more than 2 m centres.

Notches and holes

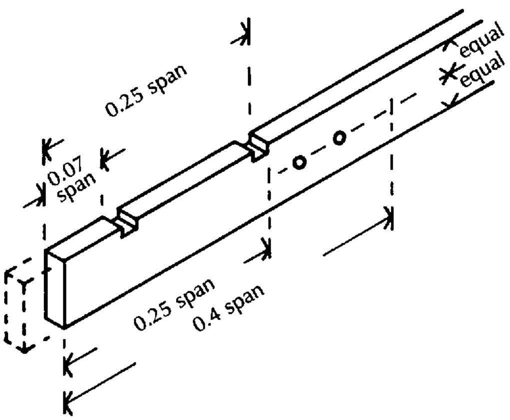


Fig. 152 Notches and holes in timber joists.

So that notches and holes cut in timber joists for electric cables and water and gas service pipes run in the floor do not seriously weaken the strength of the floor, limitations of size are given as practical guidance to meeting the requirements of the Building Regulations for small domestic buildings.

Notches should be no deeper than 0.125 times the depth of a joist and cut no closer to the support than 0.07 of the span nor further away than 0.25 times the span.

Holes should be of no greater diameter than 0.25 the depth of joist, drilled on a neutral axis and not less than 2 diameters apart (centre to centre) and located between 0.25 and 0.4 times the span from the support, as illustrated in Fig. 152.

Floor boards

The surface of a timber framed upper floor is formed by nailing tongued and grooved (T & G) softwood boards across the joists as a finished floor surface or, more usually, as a base for carpet or one of the plastic sheet or tile finishes. The boards are cramped, nailed and laid with staggered heading joints as described for raised timber ground floors.

The recommendation in Approved Document A to the Building Regulations is T & G boards nailed to joists spaced at up to 500 mm should be at least 16 mm finished thickness and at wider spacings up to 600 mm, 19 mm finished thickness.

Manmade boards of compressed wood chips, chipboard, are commonly used today as a substitute for T & G boards as a base for carpets or one of the sheet or tile finishes. The use of large tongued and grooved chipboards minimises joints. The boards are nailed or screwed to joists.

Fire safety

Structural floors of dwelling houses of two or three storeys are required to have a minimum period of fire resistance of half an hour. Timber floors with tongued and grooved boards or sheets of plywood or chipboard at least 15 mm thick, joists at least 37 mm wide and a ceiling of 12.5 mm plasterboard with 5 mm neat gypsum plaster finish or at least 21 mm thick tongued and grooved boards or sheets of plywood or chipboard on joists at least 37 mm wide with a ceiling of 12.5 mm plasterboard with joints taped and filled, will both have a resistance to fire of half an hour.

Resistance to the passage of heat

Timber upper floors that are exposed to outside air, such as floors over car ports, have to be insulated against heat transfer to meet the requirements of the Building Regulations. The maximum U value of exposed floors has to be $0.45\,W/m^2K$, the same as external walls. Insulation between joists in the form of low density glass fibre or rockwool rolls, mats or quilts can be laid on to ceiling finish or semi-rigid batts, slabs or boards of fibre glass or rockwool which are friction fitted between joists and supported by nails or wood battens nailed to the sides of joists. To avoid cold bridges the insulation must extend right across the floor in both directions up to surrounding walls.

Resistance to the passage of sound

A boarded timber floor with a rigid plasterboard ceiling affords poor resistance to the transmission of sound.

Airborne sound

Sound is transmitted through a floor by vibrations of air from the source of sound, such as a loudspeaker, which spread out and set up vibrations in the floor which in turn set up vibrations in the air on the opposite side of the floor. This is sometimes described as transmission of 'airborne sound'.

Impact sound

The other source of sound is caused by impact on a hard surface, such as footsteps on a boarded floor. The footsteps cause the floor structure to vibrate. Vibration of the ceiling below in turn causes vibration of air in the form of what is sometimes called 'impact sound'.

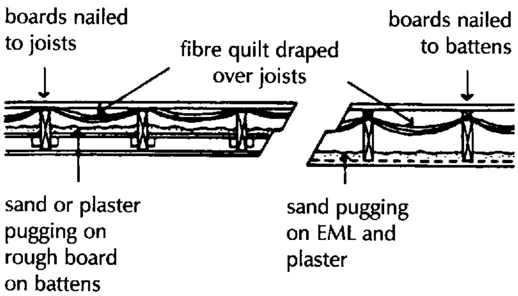


Fig. 153 Sound insulation of timber floor.

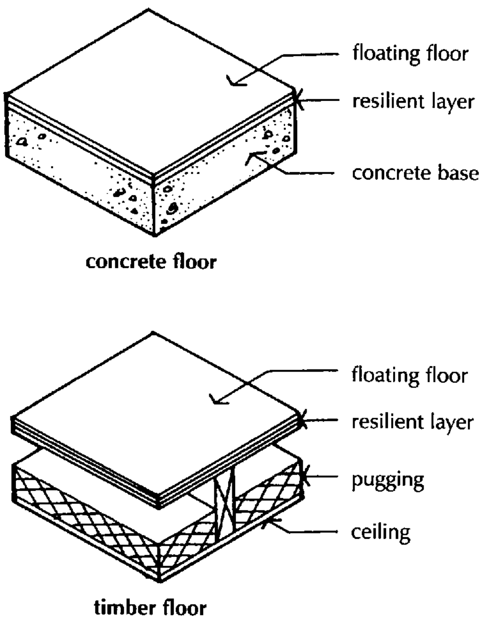


Fig. 154 Sound insulation of floors.

To reduce the transmission of airborne sound it is necessary to increase the mass of a floor to restrict the flow of energy through it. To reduce the transmission of impact sound it is necessary to provide some soft material, such as a carpet, between the cause of the impact and the hard surface.

The traditional method of insulating timber floors against sound was to spread a layer of plaster or sand on rough boarding fixed between the joists or sand on expanded metal lath and plaster, as illustrated in Fig. 153. The layer of plaster or sand was termed pugging. Pugging is effective in reducing the transmission of airborne sound but has little effect in deadening impact sound. To deaden impact sound it is necessary to lay some resilient material on the floor surface or between the floor surface material and the structural floor timbers. The combination of a resilient layer under the floor surface and pugging between joists will effect appreciable reduction of impact and airborne sound. Where the floor boards are nailed directly to joists, through the resilient layer, as illustrated in Fig. 153, much of the impact sound deadening effect is lost.

Approved Document E, giving practical guidance to the requirements of the Building Regulations for resistance to the passage of sound, includes specifications for the construction of concrete and timber floors.

For concrete floors the resistance to airborne sound depends mainly on the mass of the concrete. Resistance to impact sound may be provided by a soft covering of carpet. As an alternative the resistance to airborne sound is provided mainly by the mass of the concrete floor and partly by a floating top layer. The top layer consists of a platform of T and G boards or T & G chipboard nailed to timber battens that are laid on a 13 mm thickness of resilient material as indicated in Fig. 154, with the edges of the resilient layer turned up around the edges of the floating top layer. This floating layer is laid loose on the concrete base as a surface for one of the plastic sheet or tile finishes.

For timber floors pugging is placed or fixed between the joists for resistance to airborne sound and a floating floor as resistance to impact sound and to some extent resistance to airborne sound, as indicated in Fig. 155.

This platform floor is constructed as a floor of 18 mm thick T & G boards or chipboard with all joints glued. The boarded platform is spot bonded to a base of 19 mm thick plasterboard. The boarded platform is laid on a 25 mm thick layer of resilient mineral fibre on a floor base of 12 mm thick boarding or chipboard nailed to the joints, as illustrated in Fig. 155.

The ceiling is two layers of plasterboard, with joints staggered, to a

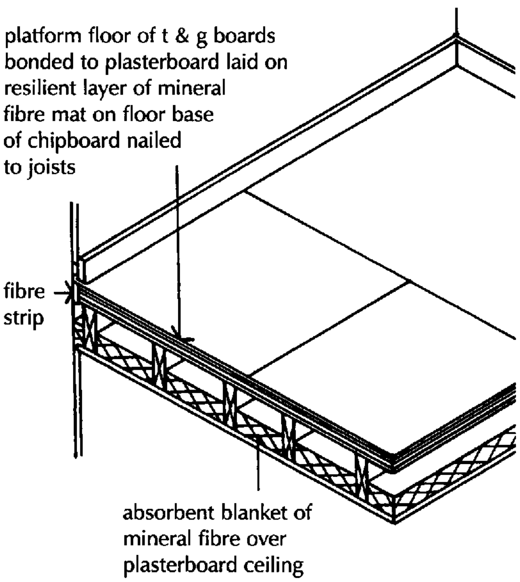


Fig. 155 Platform floor.

finished thickness of 30 mm on which 100 mm of absorbent mineral fibre is laid.

To provide a level floor surface for platform floors it is necessary to fix the floor boards by nailing to battens or by fixing the boards to a firm level base of plasterboard or similar material, so that the boards can be cramped together. The boards are bonded to the plasterboard base with strips or pads of adhesive to keep them flat, as the tongues in the edges of the boards are cramped up into the grooves of adjacent boards to produce a level floor finish. In this operation it is plainly simpler to cramp up the joints between large chipboards than the much less wide timber boards, which are only used when they are to be the finished floor surface.

To minimise flanking transmission of sound from the floor surface to the surrounding walls, a strip of resilient fibre material is fixed between the edges of platform and ribbed floors and surrounding solid walls, and a gap of at least 3 mm is left between skirtings and floating floors. To limit the transmission of airborne sound through gaps in the construction it is important to seal all gaps at junctions of wall and ceiling finishes and to avoid or seal breaks in the floor around service pipes.

The materials used as resilient layer in platform floors and as strips under ribbed floors are fibre glass or rockwool in rolls or mat and the materials used as absorbent pugging between joists are fibre glass or rockwool in the form of rolls or semi-rigid slabs.

The construction of the platform and ribbed floors detailed in Approved Document E is so laborious and costly that good sense would dictate the use of a reinforced concrete floor instead of timber. The concrete floor would be little if any more expensive than timber and have the added advantage of better resistance to fire.

REINFORCED CONCRETE UPPER FLOORS

Reinforced concrete floors have a better resistance to damage by fire and can safely support greater superimposed loads than timber floors of similar depth. The resistance to fire, required by building regulations for most offices, large blocks of flats, factories and public buildings, is greater than can be obtained with a timber upper floor so some form of reinforced concrete floor has to be used.

The types of reinforced concrete floor that are used for small buildings are self-centering 'T' beams and infill blocks, hollow beams and monolithic in situ cast floors. The word centering is used to describe the temporary platform on which in situ cast concrete floors are constructed and supported until the concrete has sufficient strength to be self-supporting. The term self-centering is used to define those precast concrete floor systems that require no temporary support.

Precast 'T' beam and infill block floor

This type of reinforced concrete floor is much used for comparatively small spans and loads. The great advantage of this floor system is that the small units can be handled by two men without the need for lifting gear.

Solid reinforced concrete beams usually shaped like an inverted T in section are precast in the manufacturer's yard to the required length. The depth of the beams is from 130 to 250 mm and 20 mm wide at the bottom. The beams are made in lengths of up to 6 m. The 'T' beams are reinforced with mild steel reinforcing bars to provide adequate support for the dead weight of the floor and anticipated dead and live loads.

Hollow precast lightweight concrete infill blocks are made to fit between and bear on the 'T' beams. These blocks are hollow and made for lightness in handling and to minimise the weight of the floor.

The beams are placed at 270 mm centres with their ends built into walls or bearing on beams of at least 90 mm. The blocks are placed in position and the floor completed with a layer of constructional concrete topping, 50 mm thick spread and levelled ready for a screed or power floated finish as illustrated in Fig. 156. The purpose of the

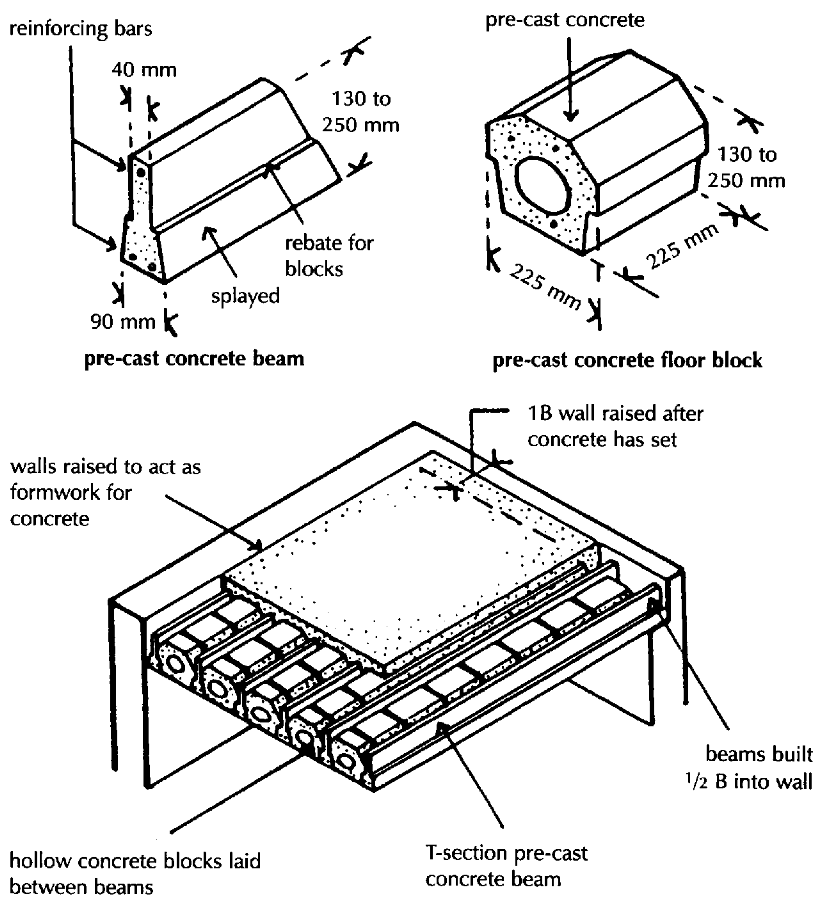


Fig. 156 Pre-cast concrete beam and block floor.

constructional concrete topping is to spread the loads on the floor over the blocks and beams.

The underside or soffit of the floor is covered with plaster or will provide support for a suspended ceiling.

This comparatively cheap floor system provides reasonable resistance to airborne sound and resistance to fire. This floor system is particularly suited for use as a raised (suspended) ground floor.

Hollow beam floor units

Hollow, reinforced concrete beams are precast around inflatable formers to produce the hollow cross section. The beams are rectangular in section with the steel reinforcement cast in the lower angles of the beam. The sides of the beams are indented to provide a key for the concrete topping, as illustrated in Fig. 157.

These beams are usually 355 mm wide, from 130 to 205 mm deep and up to 6 m long. The depth of the beam depends on the superimposed loads and the span.

Because of their length and weight, lifting gear is necessary to raise and lower the beams into place.

The beams are placed side by side with their ends bearing $\frac{1}{2}$B on or into brick loadbearing walls or on to steel beams. If the ends of the beams are built into walls the ends should be solidly filled with concrete as the hollow beam is not strong enough to bear the weight of heavy brickwork.

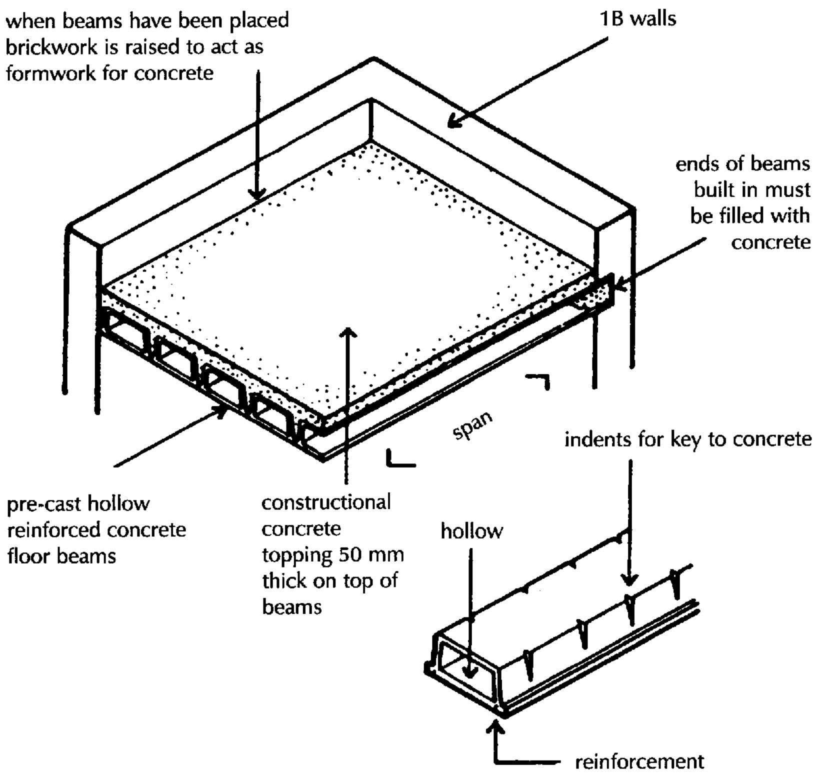


Fig. 157 Hollow concrete beam floor.

The walls of the beams are made thin so that they are light in weight for transporting and hoisting into position. The thin walls of the beams are not strong enough to carry the direct weight of say furniture, and over them is spread a layer of concrete usually 50 mm thick which serves to spread point loads. The concrete is termed constructional concrete topping, and it is an integral part of this floor system. The concrete is mixed on the building site and is spread and levelled on top of the beams as illustrated in Fig. 157.

The hollow beam floor system is particularly suited to multi-storey buildings where lifting equipment such as the tower crane is used. This floor system was used with structural steel frame construction with the beams bearing on steel beams.

Reinforced concrete and clay block floor

The resistance to damage by fire of a reinforced concrete floor depends on the protection, or cover, of concrete underneath the steel reinforcement. Under the action of heat, concrete is liable to expand and come away from its reinforcement. If, instead of concrete, pieces of burned clay tile are cast into the floor beneath the reinforcing bars the floor has a better resistance to fire than it would have with a similar thickness of concrete.

The particular advantage of this type of floor is its good resistance to damage by fire, and it is sometimes termed 'fire-resisting reinforced concrete floor'.

To keep the dead weight of the floor as low as possible, compatible with strength, it is constructed of in situ reinforced concrete beams with hollow terra cotta infilling blocks cast in between the beams. The words terra cotta mean 'earth burned'. The words terra cotta are used in the building industry to describe selected plastic clays which contain in their natural state some vitrifying material. After burning, the clay has a smooth hard surface which does not readily absorb water. The blocks are made hollow so that they will be light in weight and the smooth faces of the blocks are indented with grooves during moulding, to give a good 'key' for plaster and concrete.

A typical TC (terra cotta) block is shown in Fig. 158. This type of floor has to be given temporary support with timber or steel centering. The TC blocks and the reinforcement are set out on the centering, and pieces (slips) of clay tile are placed underneath the reinforcing bars. Concrete is then placed and compacted between the TC blocks and spread 50 mm thick over the top of the blocks. Figure 158 is an illustration of part of one of these floors.

The floor is built into walls $\frac{1}{2}$B thick as shown. This type of floor can span up to 5.0 m and the depth of the blocks, the depth of the finished floor and the size and number of reinforcing bars depend on the superimposed loads and span. This type of floor, which is much less used today in this country than it was because of the considerable

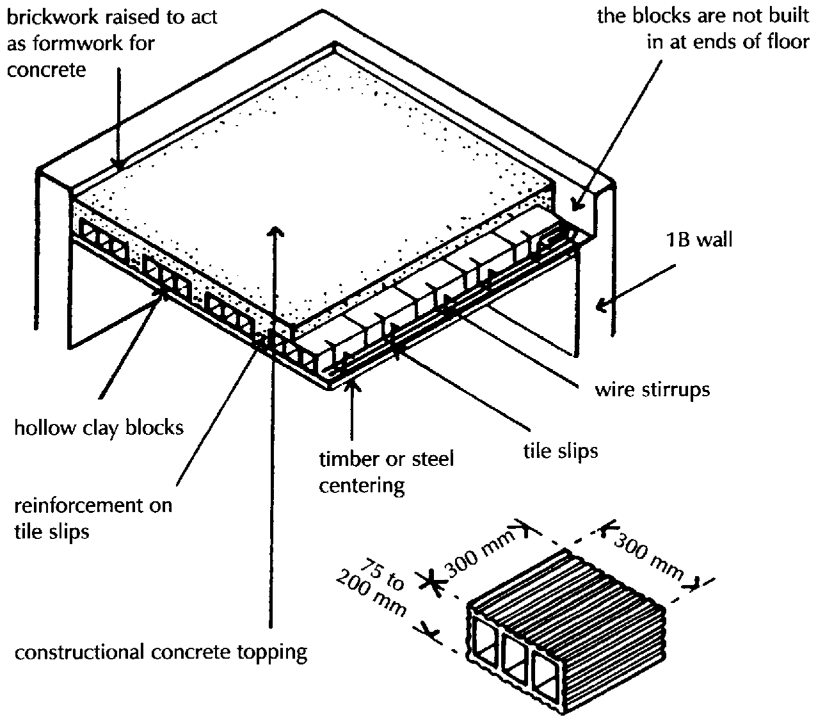


Fig. 158 Terra cotta block floor.

labour in placing the hollow TC pots and reinforcement and need for temporary support, is suited to those countries where hollow clay blocks are extensively used for infill walls to reinforced concrete frame buildings.

Monolithic reinforced concrete floor

The word monolithic is used to describe one unbroken mass of any material. A monolithic reinforced concrete floor is one unbroken solid mass, between 100 and 300 mm thick, of in situ cast concrete, reinforced with mild steel reinforcing bars. To support the concrete while it is still wet and plastic, and for 7 days after it has been placed, temporary centering has to be used. This takes the form of rough timber boarding, plywood, block board or steel sheets, supported on timber or steel beams and posts. The steel reinforcement is laid out on top of the centering and raised 20 mm or more above the centering by means of small blocks of fine concrete which are tied to the reinforcing bars with wire or by plastic spacers (see Volume 4). The wet concrete is then placed and spread on the centering, and it is compacted and levelled off.

It is usual to design the floor so that it can safely span the least width of rooms and two opposite sides of the concrete are built into walls and brick partitions $\frac{1}{2}$B each end or where the floor gives lateral support to walls it may be built in parallel to its span. Figure 159 illustrates a single monolithic concrete floor with part of the concrete taken away to show reinforcement and timber centering.

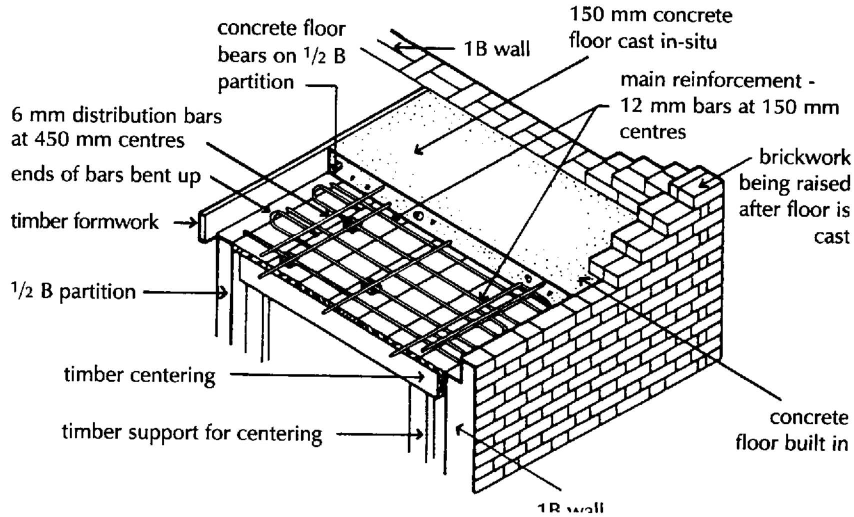


Fig. 159 Monolithic reinforced concrete floor.

Centering

The temporary timber, plywood, blockboard or sheet steel support for monolithic concrete floors or roofs is termed centering. The word centering was originally used for the timber formwork on which brick and stone arches and vaults were formed, but today it is used to include the temporary support for concrete floors even though there is no curvature to the underside of the floor.

Reinforcement of concrete

A concrete floor has to carry loads, just as a concrete lintel does, and when loaded tends to bend in the same way. The steel reinforcing bars are cast into the underside of the floor with 20 mm or more of concrete cover below them to prevent the steel rusting and to give it protection in case of fire. The thicker the concrete cover to reinforcement the greater the resistance of the floor to fire.

When the engineer designs a reinforced concrete floor he usually calculates the amount of steel reinforcement required for an imaginary strip of floor 300 mm wide spanning between walls, as though the floor were made up of 300 mm wide concrete beams placed side by side. The engineer will first calculate the combined superimposed and dead load that the floor has to support. The superimposed load is determined just as it is for timber floors and the dead load will include the actual weight of the concrete, the floor finish and the plaster on the soffit.

From the loads and the span the required thickness of concrete will be determined and then the cross-sectional area of steel reinforcement for every 300 mm width of floor calculated. A rough method of determining the thickness of concrete will be decided and then the cross-sectional area of steel reinforcement for every 300 mm width of floor calculated. A rough method of determining the thickness of concrete required for floors of houses and flats is to allow 15 mm thickness of concrete for every 300 mm of span. The main reinforcement consists usually of 12 mm diameter mild steel rods spaced from 150 to 225 mm apart, and these span across the floor between walls supporting the floor.

The 6 mm diameter mild steel rods wired across the main reinforcement are spaced at 450 to 900 mm apart and are called distribution rods or bars. These rods are tied to the main reinforcement with wire and keep the main reinforcing rods correctly spaced whilst the concrete is being placed and their main purpose is to assist in distributing point loads on the floor uniformly over the mass of the concrete.

In designing a reinforced concrete floor, as though it consisted of 300 mm wide beams, it is presumed that it bends in one direction only when loaded. In fact a monolithic concrete floor bends just as the skin of a drum does, when it is pressed in the middle. In presuming that the floor acts like a series of 300 mm wide beams the engineer can quite simply design it. But as no allowance is made for bending across the span, the floor as designed will be heavier and more expensive than it need be to safely carry its loads. The work involved in allowing for the bending that actually occurs in monolithic floors is considerably more than that required if it is presumed that the floor is a series of beams 300 mm wide.

Of recent years several firms have specialised in designing and constructing reinforced concrete and in order to be competitive their engineers make the more complicated calculation so as to economise in concrete and reinforcement.

Because the centering required to give temporary support to a monolithic concrete floor tends to obstruct and delay building operations 'self-centering' concrete floors are largely used today for multi-storey buildings with monolithic concrete floors used for heavily loaded and specially designed construction and for stairs, ramps and small spans.

Cold rolled steel deck and concrete floor

Of recent years profiled cold rolled steel decking, as permanent formwork and the whole or a part of the reinforcement to concrete, has become one of the principal floor systems for multi-storey framed buildings, as described in Volume 4.

Fire safety

The resistance to fire of a reinforced concrete floor depends on the thickness of concrete cover to steel reinforcement, as the expansion of the steel under heat will tend to cause the floor to crack and ultimately give way. The practical guidance given in Approved Document B to the Building Regulations specifies least cover of concrete for reinforcement to give a specific notional period of fire resistance.

Resistance to the passage of heat

A reinforced concrete upper floor that is exposed to outside air and one that separates a heated from an unheated space has to be insulated against excessive transfer of heat by a layer of some insulating material that is usually laid on the top of the floor under a screed or boarded platform floor surface.

Resistance to the passage of sound

The mass of a concrete floor will provide some appreciable resistance to the transfer of airborne sound. Where it is necessary to provide resistance to impact sound a form of floating floor surface may be necessary.

4: Roofs

HISTORY

Pitched roofs

Before the development of the railway system in the nineteenth century the form of roof common to most buildings in this country was dictated by the availability of local materials used as roof coverings.

Thatch

In lowland areas, such as Norfolk and Suffolk, thatch was common. Long straight stalks of water and marsh plants, reeds, were cut, dried, bound together and laid up the slopes of pitched (sloping) roofs as thatch. Thatch efficiently drains rainwater, excludes wind and acts as an effective insulator against transfer of heat, a combination of advantages that no other roof covering offers.

The disadvantage of thatch is that the dry material readily ignites and burns vigorously and the thick layer of thatch is an ideal home for small birds, rodents and insects.

Tiles

Extensive beds of clay in midland and southern England, suited to pressing and burning to the shape of roof tiles, provided a ready supply of material for making the small, thin slabs of burned clay used as a roof covering to the traditional pitched roof form of most buildings in the area.

The advantage of the small, flat units of tile is that laid overlapping up the slopes of pitched roofs they effectively drain rainwater, accommodate the structural, moisture and thermal movements common to roofs and are durable for the life of most buildings. A disadvantage is that the very many joints between tiles do not exclude wind and tiles do not serve as an efficient insulator against transfer of heat by themselves.

Slates

In rocky upland areas such as Cornwall, Wales, northern England and parts of Scotland, beds of rock that can be split into comparatively smooth plates were used as a roof covering.

Welsh slates can be split into thin, uniform thickness slabs of rock suited to cutting into standard sizes. Most Cornish, Westmorland, northern England and Scottish rocks can at best be split into comparatively thick, uneven surfaced slabs which are more laborious and wasteful to cut to standard sizes. These slates, which are often used in random sizes, are sometimes described as stone tiles.

Laid overlapping up the slopes of pitched roofs slates effectively and rapidly drain rainwater, accommodate structural, moisture and thermal movement and are durable for the life of most buildings. Like tiles, slates do not exclude wind or serve as an effective insulator against heat transfer by themselves.

With the development of an extensive railway system in the nineteenth century, the use of the common roofing materials, tile and slate, was no longer confined to the original local areas of use.

Flat roofs

The least slope or pitch necessary for tile and slate coverings had for centuries determined the symmetrical pitch form of roof common to the majority of buildings.

Bitumen felt

Asphalt

During the first half of the twentieth century the fashion for flat roofs led to the use of materials such as bitumen felt and asphalt that had previously been used as a temporary roof covering and for paving roads, respectively.

Initially two or three layers of bitumen felt on timber roofs and asphalt on concrete roofs were used with a modest degree of success providing they were renewed every 20 to 25 years. At the time there was no requirement to insulate buildings against transfer of heat to outside.

With the introduction of statutory requirements to minimise transfer of heat it became necessary to introduce a layer of some insulating material to roofs. A layer of insulating material was formed under flat roof coverings. The very considerable temperature fluctuations that a roof covering suffers between hot days and cold nights were no longer borne by both the coverings and the roof below to the detriment of felt and asphalt coverings that rapidly deteriorated and failed.

With the introduction of more exacting requirements for the conservation of energy and increased insulation the flat roof form has lost favour to the extent that many flat roofs have been rebuilt as pitched roofs to minimise repair and replacement costs.

Low pitch roofs

At about the same time that the flat roof form was adopted it became fashionable to use low pitch roofs, particularly for single storey buildings, as a revolt against the traditional pitched roof forms. The roofs of comparatively wide span, low rise buildings were pitched at from 5° to 10° to the horizontal, a slope too shallow for the traditional tile or slate coverings.

Instead of using felt or asphalt flat roof coverings it became fashionable to employ sheets of non-ferrous metals such as copper and aluminium joined with standing seams down the slope and welted seams across the slope. This form of covering was also used as a weather surface to arched and curved reinforced concrete roof forms. The appearance and durability of this sheet metal covering justified the cost.

Today the majority of new houses are built with traditional pitched roof structures covered with tile or slate to satisfy the inbred prejudice against the modern in favour of the sense of the majority of house buyers, that a house should look like a house.

FUNCTIONAL REQUIREMENTS

The functional requirements of a roof are:

Strength and stability
Resistance to weather
Durability and freedom from maintenance
Fire safety
Resistance to the passage of heat
Resistance to the passage of sound

Strength and stability

The strength and stability of a roof depend on the characteristics of the materials from which it is constructed and the way in which the materials are formed as a horizontal platform or as a triangular framework.

Flat roof

A roof may be constructed as a flat roof, that is a timber, metal or concrete platform which is usually horizontal or inclined at up to 5° to the horizontal.

The strength and stability of a flat roof depend on adequate support from walls or beams and sufficient depth or thickness of timber joists or concrete relative to span to avoid gross deflection under the dead load of the roof itself and the load of snow and wind pressure or uplift that it may suffer.

Sloping roof

A sloping or sloped roof is inclined at between 5° and 10° to the horizontal, either as a sloping platform or as a shallow frame, as illustrated in Fig. 160. Both the monopitch roof and the butterfly roof are constructed with shallow timber or metal trussed rafters designed to support the dead load of the roof and imposed loads of snow and wind.

The butterfly roof is in effect two monopitch roofs which depend for support on a central beam which is carried on internal columns or end walls.

Both the monopitch and the butterfly roofs depend for strength and stability on the depth of the trussed rafters.

The monopitch roof with sloping soffit is constructed as a flat roof inclined out of horizontal, with timber or metal rafters providing strength and stability. Because of the shallow slope, this roof does impose some small lateral pressure on the wall under the lowest edge of the roof, which is designed to support both the lateral and horizontal pressure from the roof.

Pitched roof

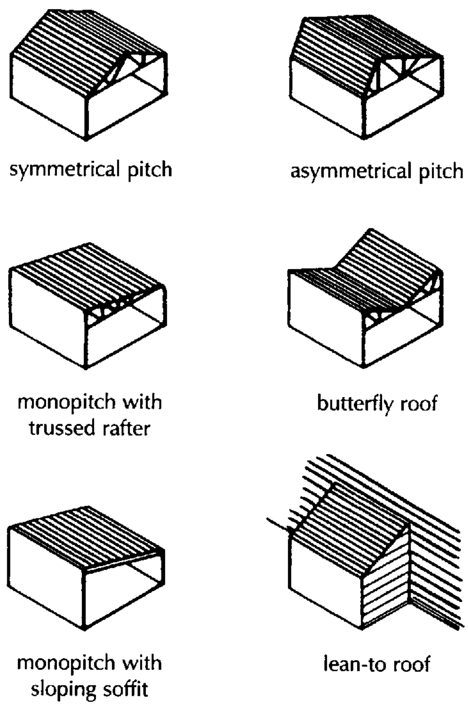


Fig. 160 Sloping roofs.

The use of the word pitch derives from the word describing the form of a tent, in which slender lengths of wood are pitched, thrown up to a central point as a framework. The word pitch is used to describe the angle of inclination to horizontal of the rafters that are pitched up at an angle of more than 10° to a ridge.

The traditional pitched roof has rafters at equal slopes rising to a central ridge in the form of a symmetrical pitch roof, as illustrated in Fig. 160. A variant of this form is the asymmetrical roof illustrated in Fig. 160, where the slopes are different.

The usual construction of this roof is as triangular frames of sloping rafters tied, trussed, together with horizontal ceiling joists, usually with a system of struts and ties for economy in the use of timber and rigidity.

The strength and stability of this form of roof depends on the depth of the triangular frames at mid-span. There is an inherent instability across the slopes of this roof, parallel to the ridge, to the extent that wind pressure may cause the frames to rack or fall over like a stack of books on a shelf. To resist racking the frames are braced by gable end walls, hipped ends or by cross-bracing of diagonal roof boarding or braces across slopes.

The lean-to roof illustrated in Fig. 160 is a monopitch roof supported by an external wall and walls enclosing an annexe or addition, with a pitch to suit the roof covering used.

Resistance to weather

A roof excludes rain through the material with which it is covered, varying from the continuous impermeable layer of asphalt covering that can be laid horizontal to exclude rain, to the small units of clay tiles that are laid overlapping down slopes so that rain runs down to the eaves.

In general, the smaller the unit of roof covering, such as tile or slate, the greater must be the pitch or slope of the roof to exclude rain that runs down in the joints between the tiles or slates on to the back of another tile or slate lapped under and so on down the roof. Larger units such as profiled sheets (see Volume 3) can be laid at a lower pitch than that required for tiles. Impermeable materials such as asphalt and bitumen that are laid without joints can be laid flat and sheet metals such as lead and copper that are overlapped or joined with welts can be laid with a very shallow fall.

The small open jointed units of tile and slate which provide little resistance to the penetration of wind into the roof require a continuous layer of felt or paper to exclude wind.

A roof structure will be subject to movements due to variations in loading by wind pressure or suction, snow loads and movements due to temperature and moisture changes. The great advantage of the traditional roofing materials slate and tile, is that as the small units are hung, overlapping down the slope of roofs, the very many open joints between the tiles or slates can accommodate movements in the roof structure without breaking slates or tiles or letting in rainwater, whereas large, unit size materials and continuous roof coverings may fail if there is inadequate provision of movement joints.

Durability and freedom from maintenance

The durability of a roof depends on the ability of the roof covering to exclude rain, snow and the destructive action of frost and temperature fluctuations. Persistent penetration of water into the roof structure may cause or encourage decay of timber, corrosion of steel or disintegration of concrete.

The traditional materials, slates and tiles, when laid at an adequate pitch (slope) and properly double lapped to exclude rain, will, if undisturbed, have a useful life of very many years and will require little if any maintenance and may survive the anticipated life of buildings. Because of the variations in shape, colour and texture of natural slates and handmade clay tiles it is generally accepted that these traditional materials are often an initial and continuing attractive feature of buildings. The uniformity of shape, colour and texture of machine made slates and tiles have, by common acceptance, a less pleasing appearance.

The non-ferrous sheet metal coverings, lead, copper, zinc and aluminium, overlapped and jointed and fixed to accommodate movement and with a slope adequate for rainwater to run off, will have a useful life of many years and should require little if any maintenance during the life of most buildings. As these durable roof coverings are not a familiar part of the appearance of the majority of buildings in this country, there is no broad consensus of opinion as to their effect on the appearance of buildings.

The flat roof materials asphalt and bitumen felt are, by their nature, short to medium term life materials due to the gradual oxidisation and hardening of the material which has a useful life of some 20 to 30 years at most. While the covering to a flat roof is not generally one of the more visible features of buildings, it is generally accepted that these roofing materials do not have an attractive appearance.

Fire safety

The requirements for fire safety in the Building Regulations are concerned for the safe escape of occupants to the outside of buildings. The regulations require adequate means of escape, and limitation to internal and external fire spread. On the assumption that the structure of a roof will ignite after the occupants have escaped there is no requirement for resistance to fire of most roofs.

The requirements do limit the external spread of fire across the surface of some roof coverings to adjacent buildings by limits to the proximity of buildings. Bitumen felt roof coverings, by themselves, do to an extent encourage spread of flame unless they are covered with stone chippings at least 12.5 mm deep, non-combustible tiles, sand and cement screed or macadam.

Resistance to the passage of heat

The materials of roof structures and roof coverings are generally poor insulators against the transfer of heat and it is usually necessary to use some material which is a good insulator, such as lightweight boards, mat or loose fill to provide insulation against excessive loss or gain of heat. The requirement of the Building Regulations for the insulation of roofs of dwellings is a maximum U value of $0.25\,W/m^2K$.

The most economical method of insulating a pitched roof is to lay or fix some insulating material between or across the ceiling joists, the area of which is less than that of the roof slope or slopes. This insulating layer will at once act to reduce loss of heat from the building to the roof space, and reduce gain of heat from the roof space to the building. As the roof space is not insulated against loss or gain of heat it is necessary to insulate water storage cisterns and pipes in the roof against possible damage by freezing. Where the space inside a pitched roof is used for storage or as part of the building it is usual to insulate the roof slopes.

With insulation at ceiling level in a pitched roof it may be necessary to ventilate the roof space so that moisture vapour that might condense on cold surfaces does not adversely affect the performance of insulation or the structure. In warmer climates than the United Kingdom it is often practice to provide ventilation to the roof to reduce the temperature inside the roof.

With the insulation at ceiling level the roof will be roughly at outside air temperature. This is a form of cold construction, or a cold roof. With the insulation fixed across the roof rafters, under the roof covering, the roof is insulated against changes in outside air temperature and is a form of warm construction or a warm roof. Obviously the roof space below insulation across roof rafters need not be ventilated to outside air.

Insulating materials may be applied to the underside or top of flat roofs or between the joists of timber flat roofs. Rigid structural materials, such as wood wool slabs, that serve as a roof deck, and rigid insulation boards are laid on the top of the roof and non-rigid materials either between joists or on top of the roof below some form of decking.

The position for insulation will be affected by the type of flat roof structure, the nature of the insulation material, the most convenient place to fix it and the material of the roof finish. The most practical place to fix the insulation is on top of the timber or concrete roof deck or structure, under the roof covering.

With insulation on top of the roof deck the structure will be insulated from outside air and maintained at roughly the inside air temperature. This arrangement is sometimes described as warm construction, as the roof structure is as warm as the inside of the building, or the roof is said to be a warm roof. The advantage of the warm roof, particularly with timber roofs, is that there is no necessity to ventilate the roof itself against condensation moisture.

The very considerable disadvantage of the warm roof is that as the insulation is directly under the roof covering, the material of the covering will suffer very considerable temperature fluctuations between hot sunny days and cold nights, as the roof structure will absorb little if any of the heat or cold that the roof covering is subjected to. These very considerable temperature fluctuations will cause tar and bitumen coverings, such as asphalt and felt, to oxidise more rapidly, become brittle and fail and cause severe mechanical strain in other coverings. An inverted or upside down warm roof, with the insulation on top of the roof covering, will protect the roof covering from severe temperature fluctuations.

With the insulation below, the roof structure is subject to the fluctuations of temperature between hot sunny days and cold nights, and the construction is sometimes referred to as cold construction or cold roof. The disadvantage of cold construction or cold roof is that the moisture vapour pressure of warm inside air may cause vapour to penetrate the insulation and condense to water on the cold side of the insulation, where it may adversely affect the performance of the insulant. Cold roofs are often protected by a vapour check on the warm side of the insulation and roofs may be ventilated against build-up of moisture.

Vapour check

To control the movement of warm moist air from inside a building to the cold side of insulation, it is practice to fix a layer of some impermeable material, such as polythene sheeting, to the underside, the warm side, of insulation that is permeable to moisture vapour, as a check to the movement of moisture vapour. By definition a vapour check is any material that is sufficiently impermeable to check the movement of moisture vapour without being an impenetrable barrier.

The term vapour barrier is sometimes unwisely used in lieu of the term vapour check. The use of the word barrier suggests that the material serves as a complete check to the movement of vapour. The practical difficulties of forming an unbroken barrier between sheets of polythene at the junction of walls and ceiling and around roof lights and pipes suggest the term vapour check is more appropriate.

Some insulating materials, such as the organic, closed cell boards, for example extruded polystyrene, are substantially impermeable to moisture vapour. When these boards can be close butted together or provided with rebated or tongued and grooved edges and cut and close fitted to junctions with walls and around pipes, they will serve as a vapour check and there is no need for an additional layer of vapour check material.

Resistance to the passage of sound

The resistance of a roof to the penetration of airborne sound is not generally considered unless the building is close to a busy airport. The mass of the materials of a roof is the main consideration in the reduction of airborne sound. A solid concrete roof will more effectively reduce airborne sound than a similar timber roof. The introduction of mineral fibre slabs, batts or boards to a timber roof will have some effect in reducing intrusive, airborne sound.

PITCHED ROOFS

Strength and stability

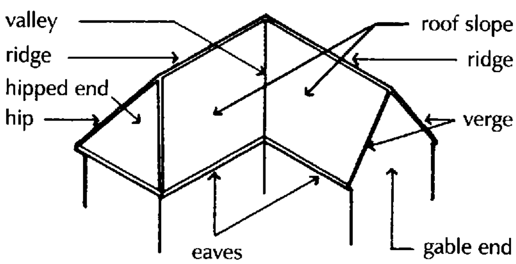


Fig. 161 Pitched roof.

The majority of pitched roofs are constructed as symmetrical pitch roofs with equal slopes pitched to a central ridge. The least slope of a pitched roof is determined by the minimum slope necessary for the roof covering to exclude and drain rainwater to eaves or valley gutters. The term used to describe the parts of a pitched roof are illustrated in Fig. 161.

The ridge is the highest, usually central horizontal part of a pitched roof. Eaves is a general term to describe the lowest part of a slope from which rainwater drains to a gutter or to ground.

A gable end is the triangular part of a wall that is built up to the underside of roof slopes, and the junction of slopes at right angles to a wall, the verge. A valley is the intersection of two slopes at right angles. A hipped end is formed by the intersection of two, generally similar slopes, at right angles.

The traditional pitched roof is constructed with slopes pitched at least 20° to the horizontal for slates and 40° to 60° for tiles.

Couple roof

The simplest form of pitched roof structure consists of timber rafters pitched up from supporting walls to a central ridge. This form of pitched roof is termed a couple roof as each pair of rafters acts like two arms pinned at the top and the mechanical term for such an arrangement is a couple. Figure 162 is an illustration of a couple roof.

Pairs of rafters are nailed each side of a central ridge board. The lower part or foot of each rafter bears on, and is nailed to, a timber wall plate which is bedded on the walls.

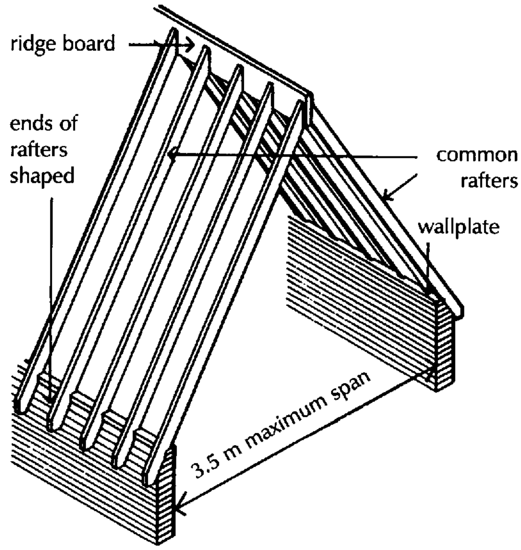


Fig. 162 Couple roof.

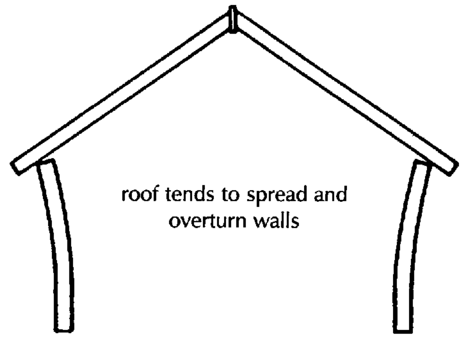


Fig. 163 Couple roof tends to spread and overturn walls.

When this form of roof is covered with slates or tiles and subject to wind pressure there is a positive tendency for the foot of the rafters to spread and overturn the walls on which they bear, as illustrated in Fig. 163. Spreading of rafters is only weakly resisted by the nailed connection of rafters to ridge board which does not act as an effective tie. The maximum span of this roof is generally limited to 3.5 m.

Couple roofs have been used to provide shelter for farm buildings and stores with the ends of such buildings formed with gable ends built in brick or stone or timber framed and rough boarded.

The most straightforward way of providing a tie to resist the spread of the foot of rafters is to fix a metal tie rod between the foot of pairs of rafters. A round or flat section of wrought iron was bolted between the foot of the fourth to sixth pair of rafters. By this device working spans of up to 5 m are practical.

Rafters are spaced at from 400 to 600 mm apart to provide support for tiling or slating battens. Tiles are hung on and nailed to battens and slates nailed to battens.

The necessary size of rafter depends in part on the spacing of rafters and mainly on the clear span, measured up the length of the rafter from the support on the wall plate to the ridge. Sawn softwood rafters for a typical couple roof would be 100 mm deep by 38 mm thick to provide reasonable support for the roof, its covering and wind and snow loads.

Ridge board

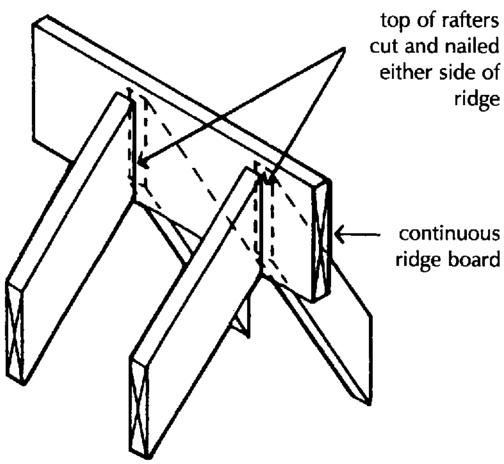


Fig. 164 Ridge board.

The purpose of the ridge board is to provide a means of fixing the top of pairs of rafters. A softwood board is fixed with its long axis vertical and its length horizontal. The top of rafters is cut on the splay so that pairs of rafters fit closely to opposite sides of the ridge board to which they are nailed, as illustrated in Fig. 164.

The ridge board is one continuous length of softwood usually 32 mm thick. The depth of the ridge board is determined by the depth of the splay cut ends of rafters that must bear fully each side of the board. Obviously the necessary depth of ridge board is set by the pitch of the roof and the depth of the rafters. A steeply pitched roof and deep rafters will need a deeper ridge board than a shallow pitched roof.

The ridge board is usually some 50 mm deeper than required as bearing for rafter ends, to provide fixing for battens.

Wall plate

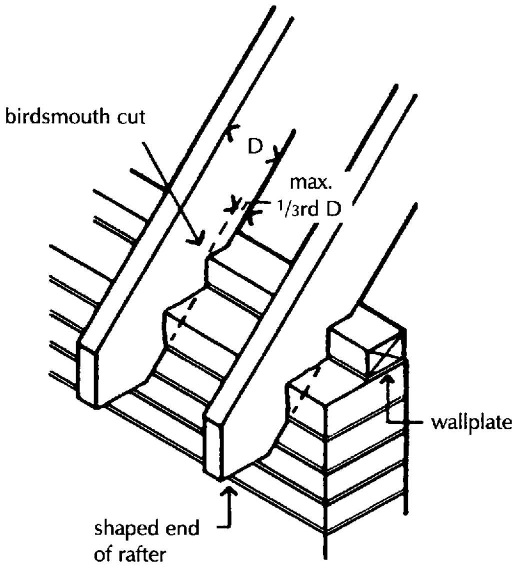


Fig. 165 Wall plate.

A continuous timber wall plate is bedded in mortar on walls as a means of providing support and fixing for the foot of rafters. The sawn softwood plate, usually 100 × 75 mm in section, which is laid on its 100 mm face, serves to spread the load from rafters along the length of the wall.

A birdsmouth cut is made in the top of each rafter to fit closely round the wall plate, as illustrated in Fig. 165. Rafters are nailed to the wall plate. The birdsmouth cut should not be greater than one-third of the depth of a rafter to limit loss of strength in rafters that often extend beyond the wall face as a projecting eaves.

The lower or eaves ends of rafters are cut to form a vertical face as fixing for a gutter board to support gutters and a lower horizontal face to provide fixing for a soffit board to form a closed eaves to exclude wind. As an alternative the soffit board is omitted to form open eaves for farm buildings and sheds.

The bearing of the rafter ends on the wall plate does not effectively resist the tendency of a couple roof to spread under load, to the extent that the plate may be moved by the spreading action of the roof.

Close couple roof

Pitched roofs to small buildings such as houses and bungalows are framed with rafters pitched to a central ridge board with horizontal ceiling joists nailed to the side of the foot of each pair of rafters, as illustrated in Fig. 166. The ceiling joists serve the dual purpose of ties to resist the natural tendency of rafters to spread and as support for ceiling finishes. Because the ceiling joists act as ties to the couple of

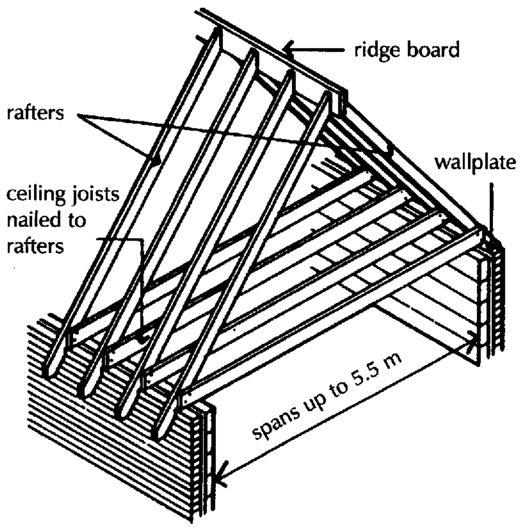


Fig. 166 Close couple roof.

pairs of rafters, this form of roof construction is a close couple or closed couple roof.

Ceiling joists are usually 38 or 50 mm thick and 97 to 220 mm deep sawn softwood, the size of the joists depending on their spacing and span between supports. The maximum span between supporting walls for the close couple roof illustrated in Fig. 166 is 5.5 m. For this span, ceiling joists with no intermediate support from internal walls would be 220 mm deep by 50 mm thick to support ceiling finishes without undue deflection.

The advantage of the triangular space inside the roof above the ceiling joists is that it will to some extent provide insulation, provide a convenient space for water storage cisterns and provide the storage space that is lacking in most modern house designs.

The disadvantage of the close couple roof structure by itself is that the considerable clear spans of rafters and ceiling joists require substantial timbers as compared to similar roofs where there is intermediate support to rafters from purlins and to ceiling joists from binders.

Collar roof

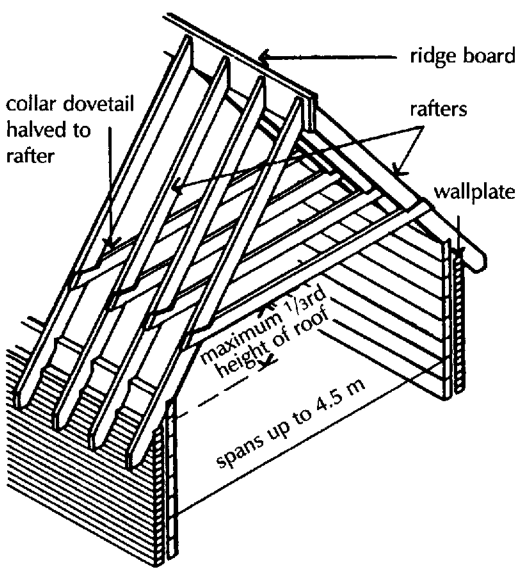


Fig. 167 Collar roof.

Another form of tied couple roof is framed with collars joined across pairs of rafters, at most one-third up the height of the roof, as illustrated in Fig. 167. The purpose of this arrangement is to extend first floor rooms into the roof space and so limit the largely unused roof space. A disadvantage of this arrangement is that the head of windows formed in a wall will be some distance below ceiling and give less penetration of light. To provide normal height windows a form of half dormer window is often used with the window partly built into the wall and partly as a dormer window in the roof.

A collar, fixed at up to a third up the height of a roof, does not so effectively tie pairs of rafters as does a ceiling joist fixed to the foot of rafters. To provide a secure joint between the ends of collars and rafters, a dovetail half depth joint is formed. The ends of collars are cut to half their width in the shape of a half dovetail to fit into a similar half depth housing in rafters and the two nailed together, as illustrated in Fig. 167.

Because a collar is a less effective tie than a ceiling joist the maximum span of this roof is limited to 4.5 m. To provide solid framing the rafters are usually 125 × 44 mm and the collars 125 × 44 mm.

A collar roof provides substantially less storage space and limited head room for access to water storage cisterns. For insulation, the roof space insulation has to be extended down the lower part of roof slopes, between rafters.

Purlin or double roofs

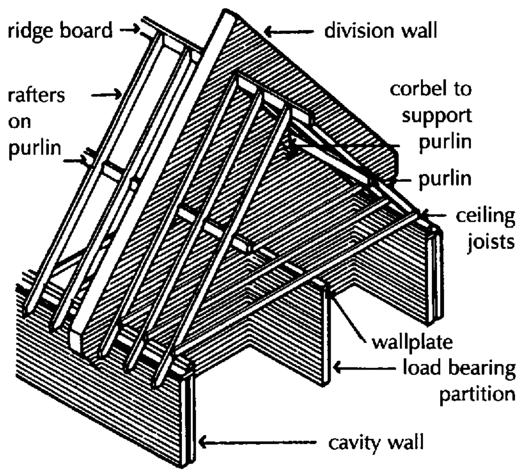


Fig. 168 Purlin roof.

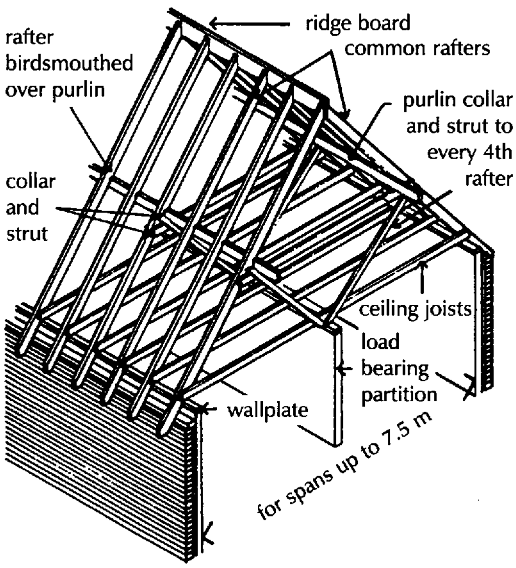


Fig. 169 Double roof.

To economise in the section of roof rafters it has been practice to provide intermediate support up the slope of roofs by the use of purlins. Purlins are horizontal timbers supported by end walls or struts to internal loadbearing walls to support rafters usually half way up slopes. By the use of a comparatively substantial timber purlin an appreciable saving in timber rafter size can be effected.

The most economic form of housing is as a terrace with solid brick or block division walls carried up to or above roof level. To limit spread of fire between houses no combustible material such as wood may be built into division or separating walls.

Timber purlins to provide support for roof rafters are supported on brick, stone or concrete corbels built to project from separating walls or on metal joist hangers built into walls. The word corbel describes any solid material solidly built into and projecting out some 100 mm to provide support. The purlins are fixed with their long axis vertical to span between separating walls, as illustrated in Fig. 168.

The roof illustrated in Fig. 168 is framed with purlins for support for rafters and an internal loadbearing wall to provide intermediate support for ceiling joists to economise in timber sizes. The purlins illustrated are 175 × 75 mm, the rafters 125 × 50 mm and the ceiling joists 125 × 50 mm sawn softwood.

Where there are no separating or gable end walls to provide support for purlins an internal loadbearing wall can be used to support timber struts fixed between the wall and rafters, as illustrated in Fig. 169.

The purlins are fixed with their long axis vertical with rafters notched over and nailed to purlins. Horizontal collars are nailed to the side of every fourth pair of rafters under purlins. Pairs of struts are notched around a wall plate bedded on the internal wall, notched under and around purlins and nailed to the side of collars. Ceiling joists nailed to the foot of rafters and bearing on the internal wall serve as ties to the close couple roof and as ceiling support.

Struts 75 × 75 mm support 150 × 50 mm purlins with 125 × 50 mm collars, 150 × 50 mm rafters and 125 × 50 mm sawn softwood ceiling joists.

An advantage of this somewhat complicated pitched roof, sometimes referred to as a double roof, is that it is singularly suited to hipped end roofs. The system of struts, collars and purlins can more readily be returned under the sloping hipped end than other forms of roof framing. A disadvantage is that the struts and collars impede head room and access for storage.

Hipped ends of roof

To limit the expanse of roof to detached buildings such as houses, for appearance sake, the ends of a pitched roof are sometimes formed as slopes described as hipped ends. The hipped, sloping ends of pitched roofs are usually framed at the same slope as the main roof. To provide fixing and support for the short length of rafters which are pitched up to the intersection of roofs, a hip rafter is used as illustrated in Fig. 170.

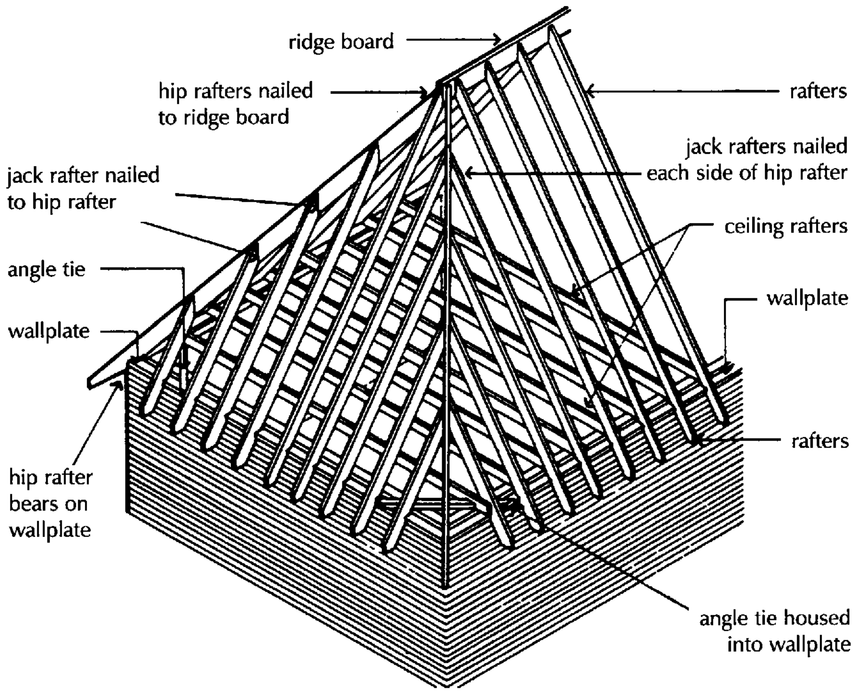


Fig. 170 Hipped end.

To provide adequate bearing for the splay cut ends of rafters pitched up to it, the hip rafter is usually 200 to 250 mm deep and 38 mm thick. The short lengths of rafter pitched to the hip rafter are the same size as the rafters of the main roof.

Jack rafters

These shorter lengths of rafter, commonly termed jack rafters, are nailed to the hip rafter, and finished with shaped ends for gutter and soffit boards.

The hip rafters are oblique, splay cut to bear each side of the ridge board to which they are nailed. The foot of hip rafters is notched to fit around the wall plate to which it is nailed.

A hip rafter provides bearing and support for the ends of jack rafters which support the roof covering and wind and snow loads. Because of the considerable load that a hip rafter carries it will tend to spread and displace the junctions of the wall plates on which it bears and overturn the walls which support it. To maintain the right angles junction of wall plates and wall against the spread of a hip rafter it is necessary to form a tie across the right angle junction.

Angle tie

Angle ties are cut from 100 × 75 mm sawn softwood timbers. These ties are either bolted to the wall plate or dovetail housed into the wall plates some 600 mm from the angle across which they are fixed, as illustrated in Fig. 170.

The hip end illustrated in Fig. 170 is shown as a close couple roof. More usually this form of roof is framed as a purlin or double roof, as previously described and illustrated.

An advantage of a hip end roof is that the hip end acts to provide stability to the main roof against the tendency of a pitched roof to rack and overturn parallel to its ridge. The disadvantage of a hip end roof is the very considerable extra cost in the wasteful cutting of timber and roof covering at the hips.

Valleys

The valley formed at the internal angle junction of two pitched roofs is framed in much the same way, in reverse, as a hip end. A valley rafter is pitched up from the junction of the wall plates at the internal angle junction of walls to the intersection of ridge boards, splay end cut to fit to ridge and notched and housed over wall plate and nailed in position.

The 38 or 50 mm thick valley rafter is of the depth required to provide a bearing for the full depth of the splay cut ends of the rafters it supports and finish level with the tops of these rafters. The cut, jack, rafters are nailed to the side of the ridge board and valley rafter respectively.

The valley rafter is fixed in position with its top edge level with adjoining rafters so that it does not obstruct battens run down into the valley for valley tiles or valley boards for a non-ferous metal valley gutter.

Trussed roof construction

The span of a close couple roof is limited to 5.5 m, which is less than the width of most buildings. A purlin roof which can span up to 7.5 m depends for support on loadbearing walls conveniently placed and these partitions often restrict freedom in planning the rooms of buildings.

A traditional method of constructing pitched roofs, with spans adequate to the width of most buildings, that do not need intermediate support from internal partitions was to form timber trusses. The word truss means tied together and a timber roof truss is a triangular frame of timbers securely tied together. The traditional timber roof truss was constructed with large section timbers that were cut and jointed with conventional mortice and tenon joints that were strapped with iron straps screwed or bolted to the truss. The traditional large section timber king post and queen post trusses supporting timber purlins and rafters were designed to be used without intermediate support over barns, halls and other comparatively wide span buildings.

The combination of shortage of timber that followed the end of the Second World War (1945) and the need for greater freedom in planning internal partitions prompted the development of the economical timber truss designed by the Timber Development Association. The timbers of the truss were bolted together with galvanised iron timber connectors, illustrated in Fig. 171, bolted between timbers at connections. The strength of the truss was mainly in the rigidity of the connection.

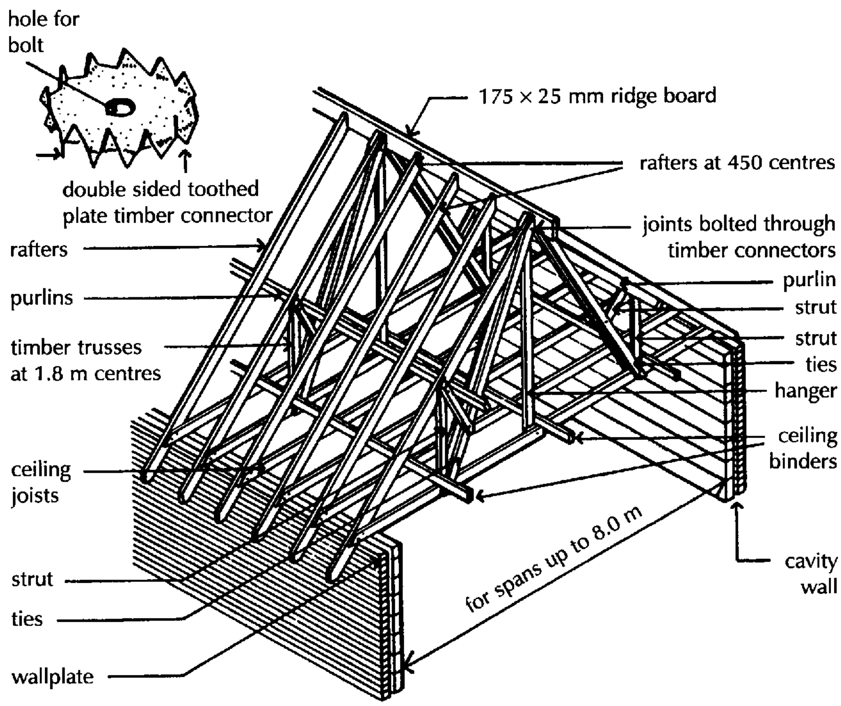


Fig. 171 Trussed roof.

These timber trusses were designed for spans up to 8 m. Each truss was framed with timbers of the same section as the rafters and ceiling joists they provided intermediate support to, through the purlins and binders they supported. The prefabricated timber trusses were fixed in position at 1.8 m centres bearing on and nailed to wall plates. The 175 × 25 mm ridge board was fixed and nailed to trusses. Purlins, 150 × 50 mm, were placed in position supported by struts and nailed to struts and rafters. Ceiling binders 125 mm deep by 50 mm wide were placed in position on 100 × 38 mm ceiling joists.

To complete the roof framing 100 × 38 mm rafters were cut to bear on the ridge board, notched over purlins and wall plate and nailed in position. Ceiling joists were nailed to the foot of rafters and the underside of ceiling binders.

These trusses were designed to use the same roof rafter and ceiling joist sections for continuity of level for fixing of roof covering and ceiling finish and trussed to provide strength in supporting purlins and binders.

The advantage of this trussed roof construction is that the continuity of the ridge board, purlins and binders along the length of the roof together with roofing battens provided adequate stability against racking.

Trussed roof construction has been largely replaced by trussed rafter roofs that require somewhat less timber and can be and are very often fixed by unskilled labour to effect a comparatively small cost saving relative to the total cost of a building. The consequence has been the failure of trussed rafter roofs due to inherent instability parallel to the ridge and poor workmanship.

Trussed rafter roof

For the maximum economy in site labour and timber the trussed rafter roof form was first used in this country in 1964. Each pair of rafters and ceiling joist to a pitched roof was formed as a truss, as illustrated in Fig. 172.

Trussed rafters are fabricated from light section, stress graded timbers that are accurately cut to shape, assembled and joined with galvanised steel connector plates. Much of the preparation and fabrication of these trussed rafters is mechanised, resulting in accurately cut and finished rafters that are delivered to site ready to

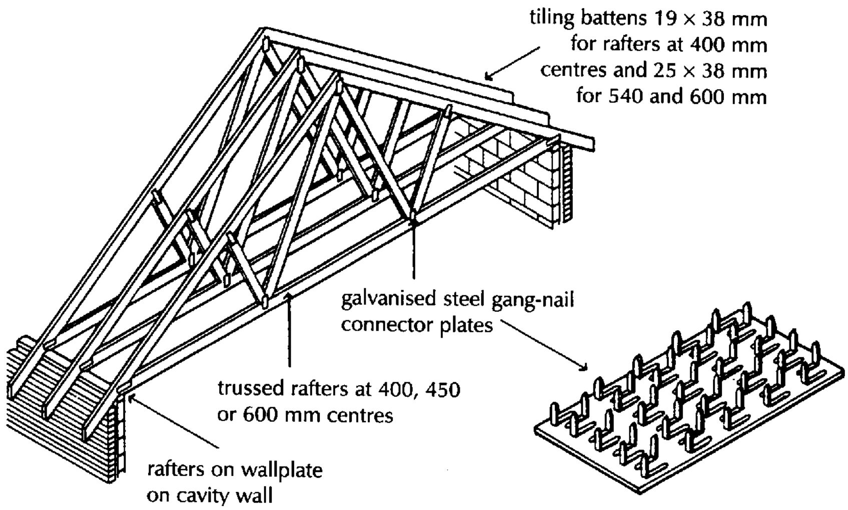


Fig. 172 Trussed rafter roof.

be lifted and fixed as a roof frame with the minimum of site labour.

The members of the truss are joined with steel connector plates with protruding teeth that are pressed into timbers at connections to make a rigid joint. Trussed rafters, that serve as rafters and ceiling joists, are fixed at from 400 to 600 mm centres, as illustrated in Fig. 172 for spans up to 12 m for roofs pitched at 15° to 40°. The trussed rafters bear on and are nailed to wall plates. As the rafters are trussed there is no need for a ridge board to provide a bearing and fixing for rafters.

Since they were first introduced into this country, trussed rafters have been very extensively used for houses, particularly on housing estates of similar buildings where repetitive production of similar trusses provided the greatest economy.

A consequence of the pressure for economy by the use of slender timber sections for trussed rafters spaced at maximum centres and careless workmanship, has been the failure of some trussed rafter roofs due to the inherent instability of a pitched roof parallel to the ridge and buckling of the slender section trussed rafters.

Approved Document A, giving practical guidance to meeting the requirements of the Building Regulations for small buildings, states that for stability, trussed rafter roofs should be braced to the recommendations in BS 5268: Part 3.

Because the members of a trussed rafter roof are delivered to site as framed, triangulated units, it has been common to employ unskilled labour in the erection of these roofs. The result has been that trusses, which were often not accurately spaced nor erected and fixed true vertical, have buckled under load. To take account of practical factors regarding the use of trussed rafters on site and the limit of experience of their behaviour under test and in service, there are recommendations in BS 5268: Part 3 for their use, erection and stability bracing. For the roofs of domestic buildings the members of trussed rafters with spans up to 11 m should be not less than 35 mm thick and those with spans of up to 15 m, 47 mm thick.

These slender section trusses are liable to damage in storage and handling. They should be stored on site either horizontal on a firm level base or in a vertical position with adequate props to avoid distortion. In handling into position each truss should be supported at eaves rather than mid-span to avoid distortion. The trussed rafters should be fixed vertical on level wall plates at regular centres and maintained in position with temporary longitudinal battens and raking braces. The rafters should be fixed to wall plates with galvanised steel truss clips that are nailed to the sides of trusses and wall plates. A system of stability bracing should then be permanently nailed to the trussed rafters. The bracing that is designed to maintain the rafters in position and to reduce buckling under load is illustrated in Fig. 173. The bracing members should be 25 × 100 mm and nailed with two 3.35 × 75 mm galvanised, round wire nails at each cross-over.

The longitudinal brace at the apex of trusses acts in much the same way as a ridge board and those halfway down slopes like purlins to maintain the vertical stability of trusses. The longitudinal braces, also termed binders, at ceiling level serve to resist buckling of individual trussed rafters. The diagonal, under rafter braces and the diagonal web braces serve to stiffen the whole roof system of trussed rafters by acting as deep timber girders in the roof slopes and in the webs.

The bracing shown in Fig. 173 is for stability. Depending on the position of exposure of the building, additional bracing may be necessary against wind pressures.

The implication of the recommendations in BS 5268: Part 3 is that some control and better workmanship is required in the erection of trussed rafter roofs than has been common. There is thus less saving in site labour and materials than previously and the economic advantage of the trussed rafter roof over, for example, the TDA truss roof is considerably less than it was.

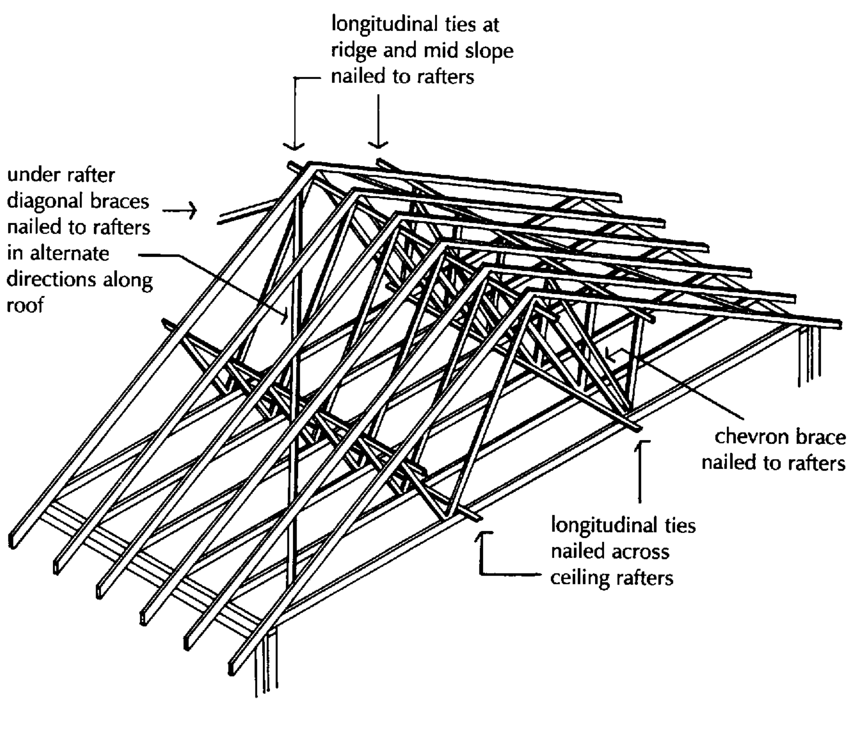


Fig. 173 Stability bracing to trussed rafters.

Eaves

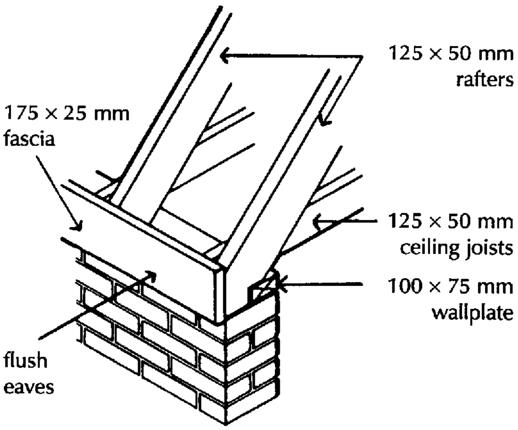


Fig. 174 Flush eaves.

Eaves is a general term used to describe the lowest courses of slates or tiles and the timber supporting them. The eaves of most pitched roofs are made to project some 150 to 300 mm beyond the external face of walls. In this way the roof gives some protection to the walls, and enhances the appearance of a building.

The eaves of the roof of sheds, outhouses and other outbuildings are sometimes finished flush with the face of the external wall of the building. The purpose of this is to economise in timber and roof covering. The construction of flush eaves is illustrated in Fig. 174. The ends of the rafters and ceiling joists are cut flush with the outside face of the wall below. A fascia or gutter board 25 mm thick is nailed to rafters and ceiling joist ends.

The necessary depth of the gutter board is such that it covers the cut ends of rafters and projects some 25 to 30 mm above the top of rafters to act as a bearing for the lowest courses of tiles or slates which project over it some 25 mm to discharge rainwater into a gutter fixed to the gutter board. Because the gutter board covers the ends of rafters this form of eaves is effectively a type of closed eaves.

Projecting eaves

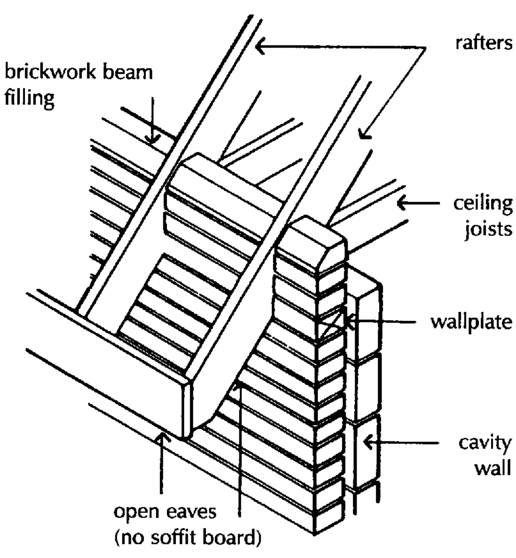


Fig. 175 Open eaves.

Projecting eaves are constructed as either open eaves or closed eaves.

Open eaves project with the ends of roof rafters exposed or open beyond the face of the wall below, as illustrated in Fig. 175. Open eaves may be constructed where the eaves project some distance beyond the face of the wall to provide protection for the wall below and rainwater runs off the edge of slopes to the ground or paved surface below.

An advantage of this arrangement is that there are no gutters and down pipes to keep clear of debris and maintain by periodic painting. The disadvantage is that the appreciable projection may obstruct penetration of light through the head of windows formed close to eaves level. Where the ground, such as sand or gravel, readily absorbs water and where paved areas fall to drains there will be little danger of rainwater falling off roofs causing adverse damp in walls.

The ends of roof rafters may be cut to provide a fixing for a fascia board for appearance sake or the rafter ends may be left exposed. Rafter ends should be stained or painted for protection and appearance sake.

To exclude wind and nesting birds brick or stonework is built between the rafters as beam filling, as illustrated in Fig. 175.

The conventional finish to projecting eaves to the majority of small buildings in this country is with a fascia or gutter board and a horizontal soffit, as illustrated in Fig. 176.

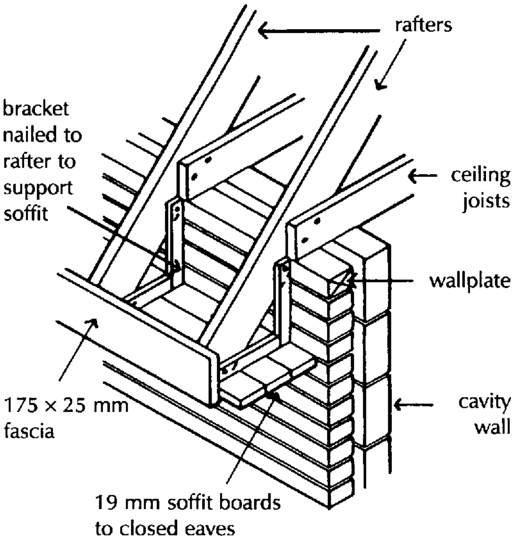


Fig. 176 Closed eaves.

The ends of rafters are shaped to provide a vertical face for fixing the gutter board and a horizontal face for fixing the soffit. The top edge of the gutter board finishes some 25 mm or more above the top of rafters as bearing for eaves tiles or slates and some 25 mm or more below the rafter ends to cover the soffit board.

The closed (enclosed) soffit to the rafter ends is fixed to a system of 50 × 25 mm softwood brackets nailed to the side of each rafter end, as illustrated in Fig. 176. Either tongued and grooved softwood boards or one of the external quality plywood or wood particle boards is nailed to the soffit brackets.

Both the gutter board and the soffit are primed and painted for protection and appearance sake.

The disadvantage of this boarded, closed eaves is that it requires comparatively frequent painting for protection and appearance.

Dormer windows

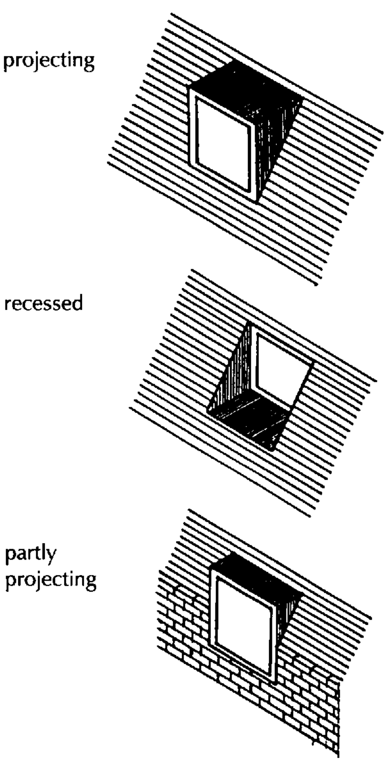


Fig. 177 Dormer windows.

Dormer windows are framed in a slope of pitched roofs as a vertical window for daylight to rooms inside the roof space whereas roof lights are formed as a glazed opening in the slope of the roof.

Dormer windows may be framed as a projection from the roof slope, recessed behind the slope or partly projecting from the roof and partly in the face of the wall below, as illustrated in Fig. 177.

A projecting dormer window will give limited penetration of daylight into rooms, because of the projection of the window head, some limitation of diffusion of light because of the dormer sides or cheeks and a wide angle of view out. A recessed dormer will give better penetration and diffusion of light into rooms than a projecting dormer, but a restricted angle of view out because of the recessed cheeks.

Projecting and partly projecting dormer windows are the traditional means of providing daylight to rooms formed wholly or partly inside the space in steeply pitched roofs. Dormer windows to roofs pitched at the shallow slopes suited to slates are little use because of the restricted useful head room inside such roofs.

To prevent an appreciable volume of rainwater running down the face of a projecting dormer window it is necessary to drain the roof of the dormer to run down the sides or cheeks. A disadvantage of the partly projecting dormer is that the lower part of the window, set in the wall below, will interrupt eaves gutters and require additional and unsightly rainwater pipes.

A recessed dormer window is particularly suited to a Mansard form of roof. Mansard roofs have been used in buildings in northern European cities where notional angles of light were imposed to provide some penetration of daylight to ground floor windows of

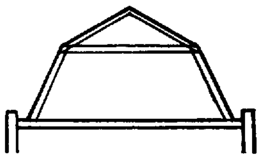


Fig. 178 Mansard roof.

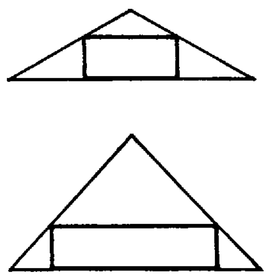


Fig. 179 Space in roofs.

buildings facing streets. It was a requirement that no part of a building project beyond a line drawn at 60° to the horizontal, drawn from the junction of opposite buildings and the street. To provide the maximum number of floors it was practice to form one or several floors inside a roof sloping at 60° with recessed dormer windows to provide daylight.

The advantage of the Mansard slope form of pitched roof, illustrated in Fig. 178, is that it provides maximum useful floor area. Where there are no restricting angles of light a Mansard roof space may be formed with projecting dormer windows.

The very limited clear headroom and restricted useful floor area inside a shallow slope roof pitched at 30°, suited to slate covering, does not justify the use of dormer windows. The more extensive head room and useful floor area inside a roof pitched at 45° has the disadvantage of an appreciable volume and area of roof above that does not provide useful space, as illustrated in Fig. 179.

The most advantageous roof form for dormer windows is a Mansard type roof with the rooms and dormer windows in the steeply pitched roof slopes and a shallow pitch or flat roof above.

Dormer window framing

The opening in roof rafters for dormer windows is framed between trimming rafters and head and cill trimmers which provide support for the trimmed rafters pitched up from the top trimmer and bearing on the bottom trimmer, as illustrated in Fig. 180. For narrow width dormers a normal rafter will serve and for wider windows the trimming rafter thickness is some 25 mm more than that of the main rafters.

The lower or cill trimmer is usually fixed vertically between trimming rafters as a base for the cill of the window. The depth of the cill trimmer is such that it will provide bearing and fixing for the trimmed roof rafters and will extend above the top level of rafters to accommodate a flashing of lead dressed down over the roof covering. The top or head trimmer may be fixed normal to rafters or vertical depending on convenience in constructing the dormer roof. Both top and bottom timber trimmers are through tennoned to trimming rafters.

To gain the maximum penetration of daylight the top, head trimmer should be close to the ceiling of rooms. Whether framed in the slope of a steeply pitched roof or in a Mansard slope it is convenient that a purlin of timber or steel coincides with the head of a dormer window so that it may be designed to carry the weight of the roof above the dormer and such framing to the dormer roof as is necessary. In a Mansard roof the head trimmer should ideally support the shallow pitch or flat roof above the Mansard slope.

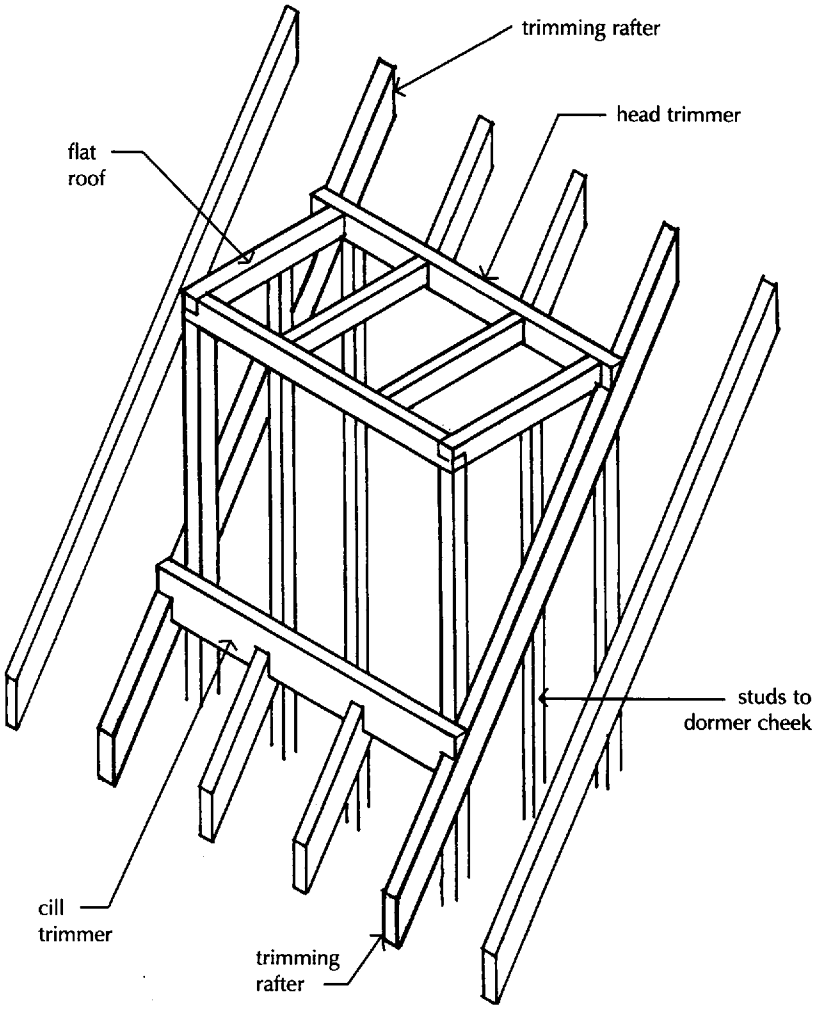


Fig. 180 Dormer window framing.

For the least timber framing and wasteful cutting of timber and roof covering a flat roof dormer is selected. The construction of a small pitched roof over a dormer with a main roof involves a deal of labour in forming valleys and cutting of slates or tiles.

The cheeks, sides, of a dormer are framed with 75 × 50 mm vertical timber studs, at centres suited to fixing internal and external finishes. The ends of the studs are either oblique cut and nailed to the trimming rafters with a corner stud as fixing for the window, or the studs are carried down to the floor.

The flat roof of the dormer should be framed to fall towards a gutter at the junction of the dormer roof and that of the main roof or to fall towards the sides of the dormer to avoid an unsightly gutter over the head of the dormer window. The 75 × 50 mm rafters of the flat roof span towards the main roof or side to side as fixing for tapered, timber firring pieces to provide the necessary fall for the non-ferrous metal roof covering. The rafters are supported by the head of the window or a head and the top trimmer or by a head to dormer cheek framing depending on the fall, slope, of the flat roof covering.

The roof and cheeks of the dormer are boarded for lead or copper sheet. The junction of the main roof covering with the sheet metal covering of the roof and cheeks of the dormer is weathered with lead or copper flashings and gutter.

PITCHED ROOF COVERING

The traditional covering for pitched roofs in England and northern European countries has been clay tile and natural slate. These traditional roof coverings are still extensively used for new houses and other small buildings for their appearance, durability and freedom from maintenance.

TILES

From the earliest human settlements clay tiles have been used as a common form of roof covering for the majority of permanent buildings. Readily available local clay was hand pressed to shape and burned with crude equipment in the making of roofing tiles.

Flat, plain tiles were used in the wet climates of northern Europe and half round and flat unders with round overs in the drier climates of southern Europe and the Mediterranean basin. These roughly moulded and crudely burnt tiles varied noticeably in both shape and colour.

For the last hundred years many clay tiles have been made with selected, fine clay that is machine pressed to shape and burned in controlled kilns. Machine pressed tiles, which are uniform in shape, can be pressed to form tiles that combine flat unders with round overs in one tile, called a pantile. Pantiles can be accurately moulded with grooves in their edges that interlock to exclude wind and rain.

Plain tiles

Plain tiles continue to be one of the chosen roof coverings for small buildings, such as houses, in this country for their durability and appearance as a familiar roof covering.

A plain tile is a rectangular roofing unit of burned clay. Plain tiles are made in the standard size which was set by 'An Act for the making of Tile' passed in 1477 in the reign of Edward IV at $10\frac{1}{2}$ inches long, $6\frac{1}{4}$ inches wide and $\frac{1}{2}$ to $\frac{1}{8}$ inches thick (265 × 165 mm), to facilitate the replacement of missing or broken tiles by the imposition of a standard size.

Plain tiles are made with a small upward camber, so that when laid overlapping, the tail of a tile bears directly on the back of a tile below.

Early plain tiles were made with two holes for oak pegs on which the tiles were hung on battens. Plain tiles are now made with two nibs for hanging to battens, as illustrated in Fig. 181. The two holes near the head of the tile are for nailing tiles to battens.

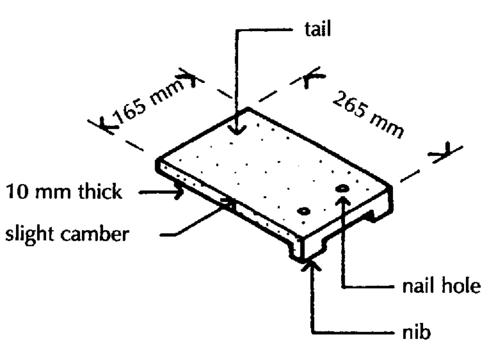


Fig. 181 Plain tile.

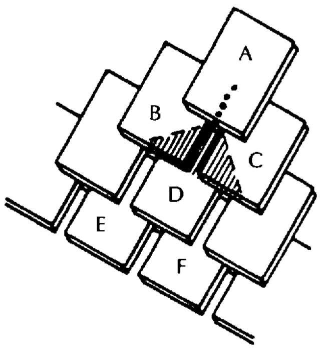


Fig. 182

Plain tiles are hung on battens in overlapping horizontal courses with the butt, side joints between tiles bonded up the roof so that rain runs down the slope from tile to tile to the eaves.

There are at least two thicknesses of tile at any point on the roof and also a 65 mm overlap of the tail of each tile over the head of tiles two courses below. The reason for this extra overlap is that, were the tiles laid in a straightforward overlap rain might penetrate the roof.

Rain running off tile A in Fig. 182 will run into the gap between tiles B and C, and spread over the back of tile D, as indicated by hatching, and probably run over the head of tiles E and F into the roof. It is against this possibility that a double end lap is made.

Lap, gauge and margin

With a 65 mm double end lap, plain tiles are laid to overlap 100 mm $\left(\frac{265-65}{2}\right)$ up the roof slope. The softwood battens on which the tiles are hung must therefore be fixed at a gauge (measurement) of 100 mm centres. The tail end of each tile shows 100 mm of the length, which is described as the margin, as illustrated in Fig. 183.

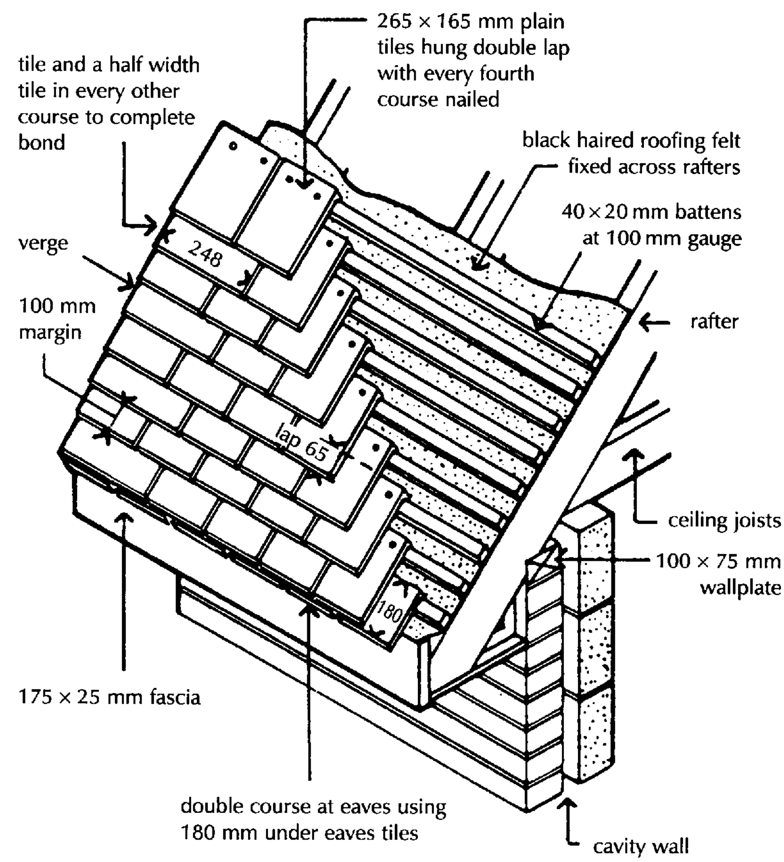


Fig. 183 Plain tiling.

Minimum slope of roof

The minimum roof slope for plain tiles depends on the density of the burned tile. Hand made tiles which fairly readily absorb water should not be laid on a roof slope pitched at less than 45° and the more dense machine pressed tiles at not less than 35°. Because of the thickness and double lap of these tiles the actual slope of a tile on a roof will be a few degrees less than that of the roof slope.

Roofing felt

The open butt, side joints of tiles and inexact fit of tile over tile would allow wind to blow into the roof space. To exclude wind it is practice to cover roof slopes with roofing felt. Rolls of bitumen impregnated roofing felt 813 mm wide are laid across roof rafters from the eaves upward with widths of felt lapped 75 to 150 mm up to the ridge. The felt covering is secured by timber battens, as illustrated in Fig. 183.

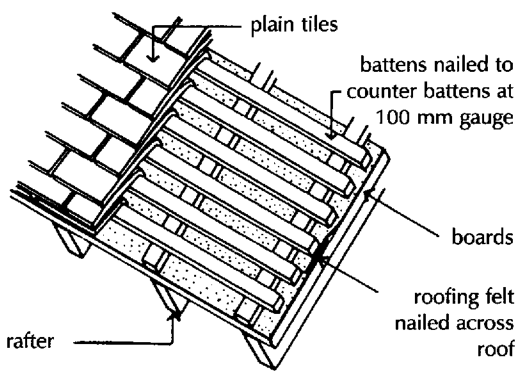


Fig. 184 Roof boarding and counter battens.

When it is planned to use a roof space for dry storage it is usual to cover roof slopes with either plain edge or tongued and grooved boarding laid across and nailed to rafters to prevent wind and dust entering more effectively. Rather than nail tiling battens directly to roof boarding it is usual to fix counter battens up the slopes, over roofing felt as illustrated in Fig. 184. The roofing felt will then conduct any water that penetrates the tiles down to eaves.

An advantage of roof boarding, sometimes called sarking, is that it acts to brace a pitched roof against its inherent instability across slopes.

Tiling battens

Plain tiles are hung on 38 × 19 mm or 50 × 25 mm sawn softwood battens which are nailed across rafters at 100 mm centres (gauge). As protection against the possibility of rain penetrating tiles and causing damage to battens by rot, the battens should be impregnated with a preservative. So that nails do not rust and perish they should be galvanised or made of a non-ferrous alloy.

The tiles in every fourth course are nailed to battens as a precaution against high wind lifting and dislodging tiles. In exposed positions every tile should be nailed.

Eaves

So that there are two thicknesses of tile at the eaves a course of eaves tile is used. These special length tiles are 190 mm long so that when hung to battens their tails lie directly under the tail of the course of full tiles above, as illustrated in Fig. 183. The tails of both the eaves tiles and full tiles above bear on the gutter board and project beyond the face of the board to discharge run off water into the gutter.

At the ridge a top course of tiles is used to overlap the course of full length tiles below to maintain the necessary two thicknesses of tile. These top course tiles are 190 mm long and hung on 40 × 40 mm battens which are thicker than normal battens, so that top course tiles ride over the tiles below. The ridge tiles are bedded on the back of the top course tiles so that the usual margin of tile is showing, as illustrated in Fig. 185.

The traditional and still commonly used method of covering the ridge of plain tile covered roofs is by one of the sections of clay ridge tiles made for the purpose. Half round and segmental ridge tiles are made for use in lower pitch roofs and the angle and hog back ridge tiles for more steeply pitched roofs. Figure 186 is an illustration of these tiles.

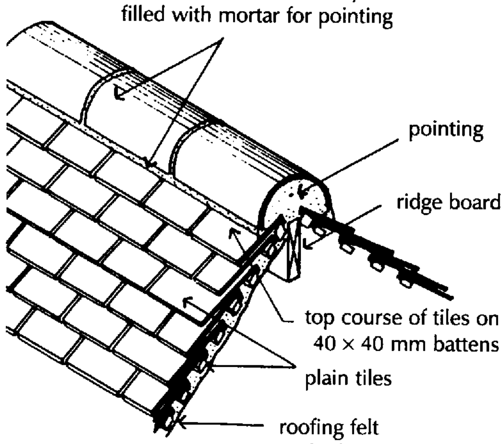


Fig. 185 Ridge.

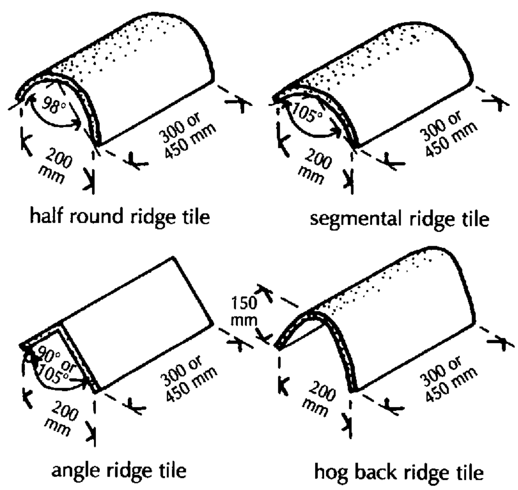


Fig. 186 Ridge tiles.

The ridge tiles are bedded in cement and sharp sand mortar on to the back of the top course of tiles. The ends of the ridge tiles are solidly filled with mortar as a backing for the mortar pointing which is run in the butt end joints between ridge tiles, as illustrated in Fig. 185.

Which of the four sections of ridge tile is used depends in part on the slope of the roof and also on appearance. In addition to the ridge tiles illustrated a range of 'specials' is produced for decorative purposes.

Verges

The bonding of tiles at verges of plain tile roofing at the junction of a roof with a gable end and the junction of square abutments of slopes to parapet walls is completed with tile and a half width tiles

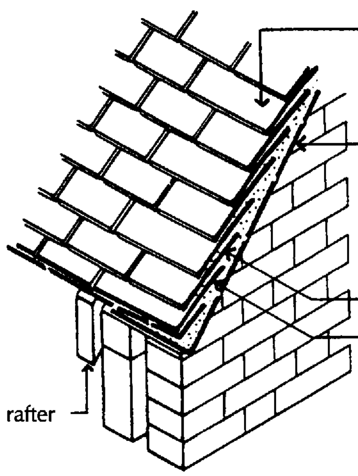


Fig. 187 Verge.

248 mm wide in every other course. The use of tile and a half width tiles at the verge of a tiled roof and a gable end is illustrated in Fig. 187. For details of the abutment and weathering to chimney stacks see Volume 2.

Tile and a half width tiles should be used instead of half width tiles, which might be dislodged by subsequent building work or by a heavy wind. In the gable end verge illustrated in Fig. 187, the verge tiling is hung to overhang the gable end wall by some 25 mm and the tiles are tilted slightly towards the roof slope to encourage rain to run down the roof slope rather than down the gable end wall.

As a bed for cement mortar pointing a layer of tiles without nibs is bedded in mortar on the gable end wall. On this layer of tiles cement mortar is spread as pointing between the verge tiles as weathering and for appearance sake.

Hip ends

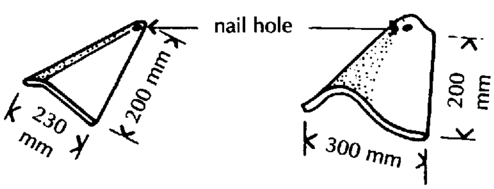


Fig. 188 Hip tiles.

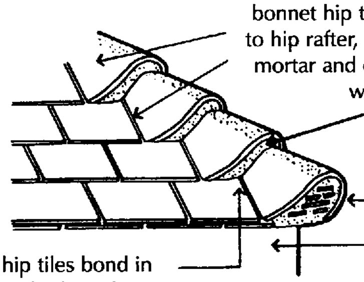


Fig. 189 Bonnet hip.

The hip ends of plain tile roofing slopes may be covered with one of the ridge tiles illustrated in Fig. 186. The plain tile courses each side of the hip are cut to fit the angle of the junction of the main slope and the hip end slope, using tile and a half width tiles as necessary, and the ridge tiles are bedded in and pointed with cement mortar as are ridge tiles on ridges. To prevent these tiles slipping down the slope of the hip a galvanised iron or wrought iron hip iron is fixed to the hip end or fascia to support the end hip tile.

Hip tiles are manufactured to bond in with the courses of tile in the adjacent slopes to provide a more pleasing appearance to the roof. Two sections of hip tile are produced. The angular and the bonnet hip tile, illustrated in Fig. 188, have holes for nailing the tiles to the hip rafter.

The hip tiles are nailed to the hip rafter up the slope of the hip and overlapping so that the tail of each tile courses in with a course of plain tiles. The hip tiles are bedded in mortar on the back of plain tiles which are cut to fit close to the hip and the end of hip tiles is filled with cement mortar as illustrated in Fig. 189. For the sake of appearance the end hip tile is filled with mortar with slips of cut tile bedded in the mortar.

Of the two hip tiles used the bonnet hip tile provides the most satisfactory appearance of continuing the course of tiles from a main roof slope to the hip end slope by the sweep of the bonnet hip end.

Valleys

At the junction of plain tile covered roof slopes in a valley, formed by an internal angle of walling, either a lead gutter is formed or special valley tiles are used.

The more usual valley is formed as a lead lined gutter dressed into a gutter formed by timber valley boards. The valley gutter should be

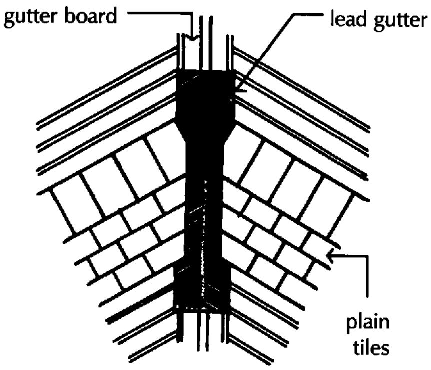


Fig. 190 Lead valley gutter.

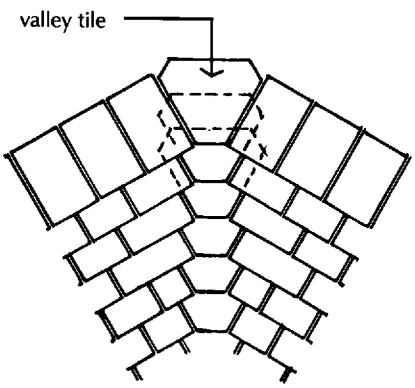


Fig. 191 Valley tiles.

wide enough to allow such debris as dust and leaves to be washed down to eaves without being obstructed and so blocking the gutter. A clear width of at least 125 mm is usual.

Gutter boards 25 or 38 mm thick and some 200 mm wide are nailed to the top of rafters, each side of the valley, with a triangular fillet of wood in the bed of the gutter as illustrated in Fig. 190. Tiling battens are continued down over the edges of the gutter boards. Roofing felt is laid under battens and over a double depth batten nailed at the cut ends of roofing battens.

A sheet or lapped end sheets of Code No 4 or 5 lead is laid on sheathing felt in the bed of the gutter, dressed up and nailed to the double depth battens. Plain tiles and tile and a half width tiles are cut to the rake of the valley and hung to battens as an under tile, over which full tiles are hung.

As an alternative to a valley gutter special valley tiles may be used to course in with the tile slopes each side of the valley.

Some of the specialist manufacturers of tiles provide valley tiles of the same material as their plain tiles. These valley tiles are shaped so that they bond in with tiles on main slopes pitched at specific angles. The length of the tile provides for the normal end lap. The dished tile tapers towards its tail, as illustrated in Fig. 191. The valley tiles are nailed to tiling battens continued down to the valley with plain tiling hung to side butt to valley tiles using tile and a half width tiles as necessary.

The advantage of this arrangement is that the tiled slope on one side is swept down into and around the internal angle of the valley to the adjoining slope for the sake of appearance. Because of the limitation of slope to suit standard valley tiles they are used principally for roofs that are a feature of the design where the roof is a clearly visible feature.

Concrete plain tiles

Concrete plain tiles were for a time used as a substitute for clay tiles. The tiles are made from a mixture of carefully graded sand, Portland cement and water which is compressed in a mould. A thin top dressing of sand, cement and colouring matter is pressed into the top surface of the tile. The moulded tiles are then left under cover for some days to allow them to harden.

Concrete tiles are uniform in shape, texture and colour. The colours in which these tiles have been made are poor when compared to natural clay tiles. The colouring of these tiles is only in the top surface and in course of time the colour bleaches in the sun and tends to be washed out, leaving anaemic looking tiles. For this reason concrete plain tiles have lost favour.

Single lap tiling

Single lap tiling is so called because each tile is laid to end lap the tile below down the slope of a roof and to side lap over and under the tiles next to it, in every course of tiles. The two types of single lap tile that have, for very many centuries, been used throughout the world are the rounded unders (channel) and overs (cover) and the flat unders (channel) and round overs (cover) tiles illustrated in Fig. 192. These traditional tiles are called Spanish and Italian tiles respectively in this country, even though they are not specific to those countries.

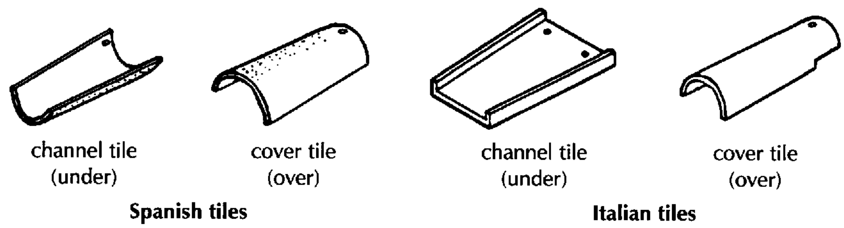


Fig. 192 Single lap tiles.

Spanish tiles

The traditional, rounded, tapering unders and overs of these tiles have been hand pressed or turned from local clay and burned in crude kilns to the shapes illustrated in Fig. 192 in a variety of sizes. Typical sizes are 350 mm length for both unders and overs, 180 and 130 mm width for unders, 200 and 155 mm width for overs and 70 and 100 mm depth for unders and overs respectively. After moulding, tiles may be perforated with nail holes in the bed of the head of unders and the sides of overs for fixing.

In hot, dry climates the tiles have been laid between and over rough roof rafters. Unders are laid between rafters, spaced for the purpose, with the wider head of the unders nailed to the sides of rafters and the narrower tail of the unders overlapping the lower under by some 75 mm. The narrower head of the overs is nailed to a rafter to overlap unders and end lap over the back of the over below.

The crudely shaped overs and unders were laid at slopes of as little as 20° to provide cover against rain with the open joints between tiles unfilled to encourage circulation of air into and out of the roof space to minimise build-up of heat.

Used in colder, wetter climates these tiles have more recently been laid as covering to roofs pitched at 20° to 30°. Plain edge roof boarding covered with roofing felt is nailed across the rafters. Battens 75 × 50 mm are nailed with the long axis vertical at centres to suit the unders. The unders are nailed to the side of battens and the overs to the top of battens with 75 mm end laps, as illustrated in Fig. 193.

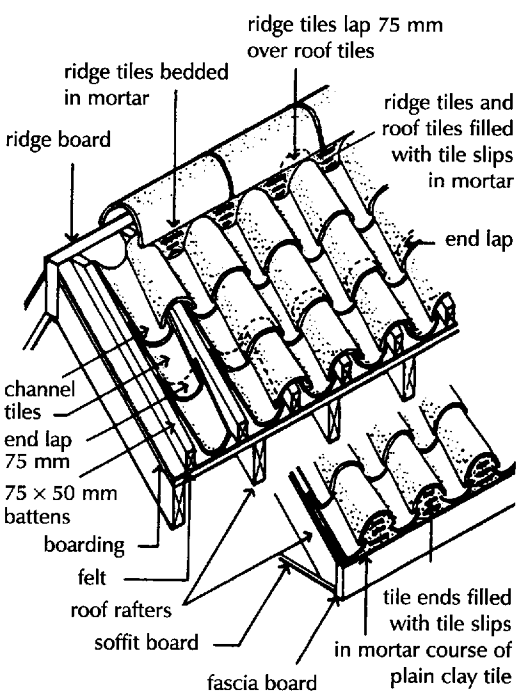


Fig. 193 Spanish tiles.

Ridge tiles are bedded in mortar on the back of tiles and butt end joints pointed. At eaves the ends of unders and overs overhang the gutter board to shed water and the open ends of overs are filled with mortar and tile slips on the back of plain tiles.

The roof boarding and felt is used to exclude wind from the roof space as a more sophisticated wind check than the bedding of the overlap of tiles in some form of mortar which has been used in the past.

Italian tiles

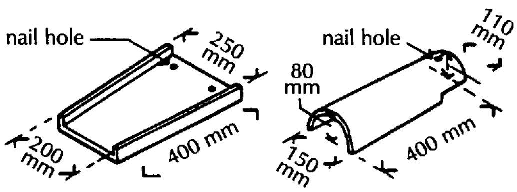


Fig. 194 Italian tiles.

The traditional flat channel (under) tile and rounded cover (over) tile of Italian tiles, illustrated in Fig. 194, were laid as roof covering in the same way as Spanish tiles with the head of unders nailed to roof boarding and the over to battens with an end lap of 75 mm. Ridge tiles are bedded in mortar and the open ends of overs at eaves filled with mortar, as illustrated in Fig. 195.

Spanish and Italian tiles which are little used in this country have been replaced by pantiles in which the rounded unders and overs are combined as one pantile and the flat unders and rounded overs of Italian tiles are combined as single and double Roman tiles, illustrated in Fig. 196.

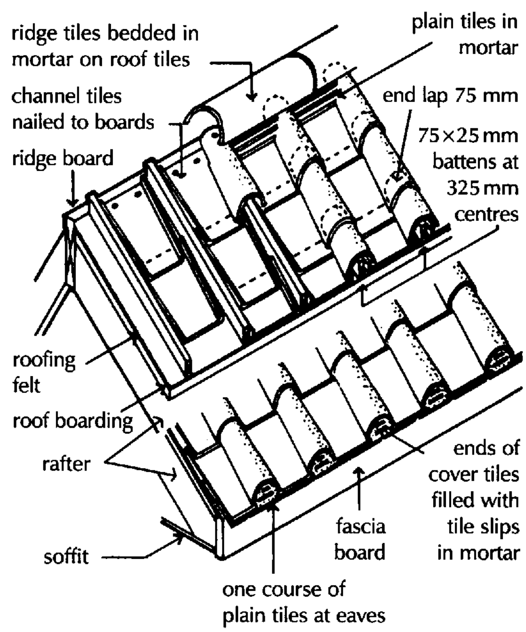


Fig. 195 Italian tiles.

Pantiles

A pantile incorporating the rounded unders and overs of Spanish tiles in one tile is illustrated in Fig. 196. By the use of selected clays or cement and sand and machine pressing this larger tile can be produced in standard sizes of uniform shape. The advantage of this tile is that it can be hung to be comparatively close fitting to exclude wind and rain.

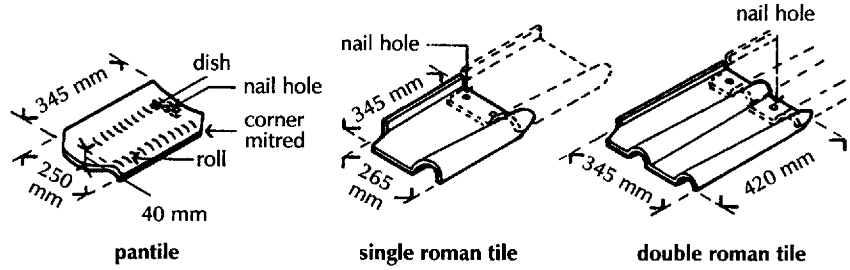


Fig. 196 Pantiles.

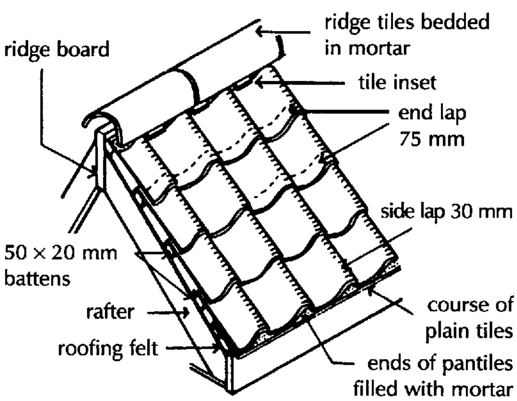


Fig. 197 Pantiles.

Both clay and concrete pantiles were fairly extensively used before the advent of interlocking tiles. Clay pantiles have been made with a fired on glazed finish to all exposed faces and edges, in a range of vivid colours, for the dramatic effect of this roof covering.

Like plain tiles, pantiles are made with a nib for hanging on to battens and a nail hole for securing tiles by nailing to battens against wind uplift. The tiles are hung on to 50 × 20 mm sawn softwood battens, nailed to rafters over roofing felt. The tiles are hung with an end lap of 75 mm at a gauge of 270 mm. The purpose of the mitred corners of pantiles is to facilitate fixing. But for the mitred corners there would be four thicknesses of tile at the junction of horizontal and vertical joints which would make it impossible to bed tiles properly.

Ridge tiles are bedded over the backs of pantiles and pointed at butt joints in cement and sand. As a bed for mortar filling, a course of plain tiles is hung at eaves on which mortar and tile slips are used to end fill pantiles. The pitch of roof for pantiles may be as low as 20° to 35°, depending on exposure. Figure 197 is an illustration of a roof covered with pantiles.

Interlocking single lap tiles

By careful selection of clay or sand and cement and machine pressing, a range of clay and concrete interlocking tiles is produced. Grooves in the vertical long edges of tiles are designed to interlock under and over the edges of adjacent tiles to exclude wind and rain. A range of profiles is made from the interlocking double pantile to the flat pantile illustrated in Fig. 198. There is a wider range of concrete than clay pantiles because of the difficulty of controlling shrinkage of clay during firing to produce a satisfactory interlock at edges.

There is no accepted standard size of interlocking tile although they are of similar size of about 420 mm long by 330 mm wide for concrete and about 320 mm long by 210 mm wide for clay.

These comparatively thick tiles are made with nibs and hung on 38 by 25 mm sawn softwood battens on a roofing felt underlay on rafters at a pitch of from 15° to $22\frac{1}{2}$° to horizontal. A single end lap of 75 mm is usual with the side butt lap dictated by the system of interlock, as illustrated in Fig. 199.

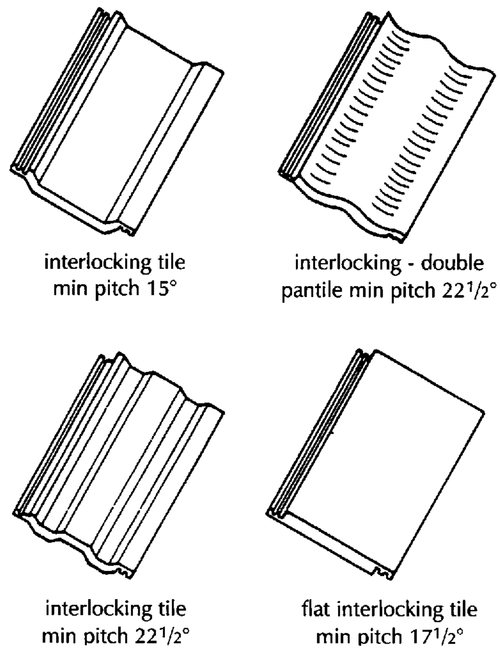


Fig. 198 Interlocking tiles.

These tiles are not usually made with holes for nails, instead a system of aluminium clips is used. The aluminium clips hook over an upstand side edge at the head of a tile, under the end lap, and are nailed or screwed to the back edge of battens. Clips are used in every course in severe exposure or every other course or more for less exposed conditions.

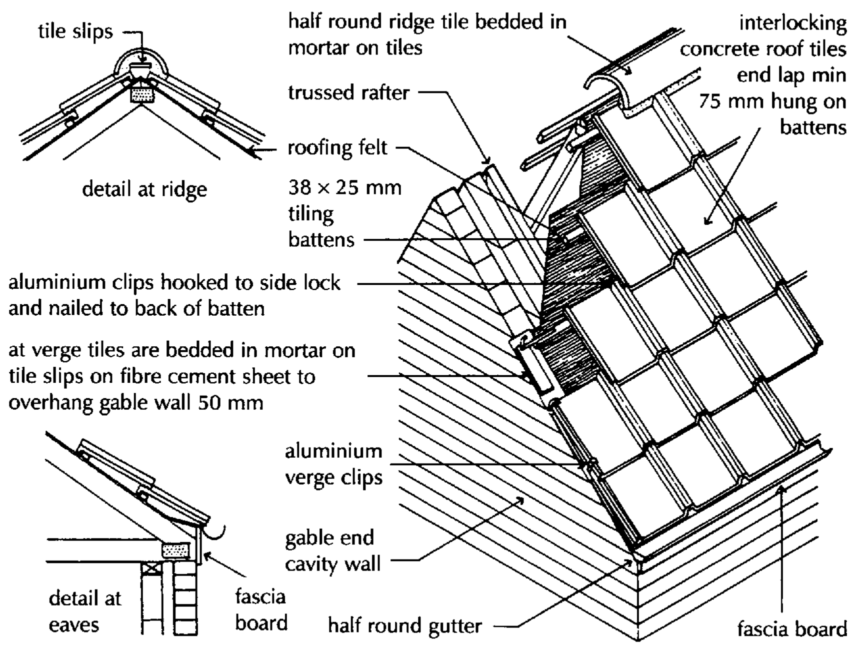


Fig. 199 Interlocking tiles.

At the ridge a half round ridge tile is bedded in mortar with end joints pointed. At the eaves a course of plain tiles provides a bed for mortar filling to the open ends of profiled tiles. Because of their size these tiles are best suited to the larger expanses of roof slopes.

Hips and valleys

At hips and valleys profiled tiles have to be cut to fit either under hip tiles or to a lead lined gutter to valleys. Because of the thickness of the tiles they have to be cut mechanically to provide a neat cut edge. No matter how carefully cut, the junction of profiled tiles with hips and valleys provides a ragged finish.

SLATES

Thin slabs of natural stone have for many centuries been a traditional roof covering material in areas where natural stone can be split and shaped as a slate, sometimes called stone tiles. The thickness, size and durability of natural stone slate depends on the nature of the stone and its ease of splitting into a useable size. Natural stone slates vary from the smooth thin Welsh slate, to the thicker rough Westmorland slate and the thick stone slabs used in the highlands of Scotland.

Welsh slates

Welsh slates were extensively quarried in the mountains of Wales up to the middle of the twentieth century, and continue, to a limited extent, to be today. Many buildings covered with these slates survive today throughout this country.

The stone from which they are split is hard and dense and varies in colour from light grey to purple. In the quarry the stone consists of thin layers or laminae of hard slate with a very thin, somewhat softer, layer of slate between the layers. By driving a wedge of steel into the stone between the layers it can be quickly split into fairly large, quite thin slates of thicknesses varying from 4 to 10 mm. The splitting results in slates of varying thickness and the thicker slates are classified as best, strong best and medium, and the thinner slates as seconds and thirds.

Traditional sizes of slate were 24 × 12, 20 × 10, 18 × 9 and 16 × 8 old Imperial inches, the equivalent metric sizes being 600 × 300, 500 × 250, 450 × 225 and 400 × 200 mm.

Good quality Welsh slates are hard and dense and do not readily absorb water. They are not affected by frost or the dilute acids in industrial atmospheres and will have a useful life as a roof covering of very many years.

Reclaimed slates

Because of the considerable cost of new Welsh slates it has been practice for some years to use reclaimed slates recovered from demolition work. The disadvantage of these reclaimed slates is that they may vary in quality, be damaged by being stripped from old roofs and there is little likelihood of recovering the slate and a half width slates necessary to complete the bond at verges and abutments.

Westmorland slates

Westmorland slates are quarried from stone in the mountain region of the Lake District. The stone varies in colour from blue to green with flecks and streaks of browns and greys. The stone is very hard and dense, and consists of irregular layers or laminae of hard stone, separated by very slightly softer stone. The laminae do not run in regular flat planes as in Welsh slate and the stone is more difficult to split than the Welsh. As a consequence it is not so economic to split slates and cut them to uniform size and Westmorland slates are very hard and so dense that they absorb practically no water no matter how long they are immersed in water. These slates are practically indestructible. Because of the considerable labour required to cut the stone and fix slates in random courses these slates are expensive and less used than they were.

Spanish slates

For some years now natural stone Spanish slates have been imported. These slates, which are considerably cheaper than new Welsh slates, are of a uniform dark grey colour, comparatively thin and smooth faced and cut to the traditional English slate size. Some of these slates have flecks of what is called fools' gold in them, which may affect their density and durability. These natural looking slates which have been in use for some years now appear to be a satisfactory substitute for Welsh slates. Their long term durability in this climate has yet to be tested.

Chinese slates

More recently, Chinese slates have been imported in traditional English sizes. They have much the same appearance as Spanish slates. It is too early to judge their durability.

Fibre cement slates

From the middle of the twentieth century slates made from asbestos fibres, cement and water were used as a cheap substitute for Welsh slates. Because of the hazard to the health of those making these slates, by the use of asbestos, they are now made with natural and synthetic fibres.

These slates are made from pigmented Portland cement and water, reinforced with natural and synthetic fibres. The wet mix is compressed to slates which are cured to control the set and hardening of the material. The standard slate, known by the trade name 'Eternit', is 4 mm thick, with a matt coating of acrylic finish and a protective seal on the underside against efflorescence and algal growth. The standard slate is rectangular and holed for nail and rivet fixing. These slates are made in three colours, blue/black, brown and rose and with either square tails or curved, angled or chamfered tails for decoration.

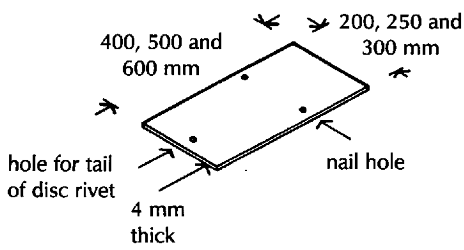


Fig. 200 Fibre cement slate.

The standard fibre cement slate is uniform in shape, colour and texture. Fibre cement slates have a useful life of about 30 years in normal circumstances as compared to a useful life of 100 years or more for sound natural Welsh slates.

Standard fibre cement slates are made in sizes of 600 × 300, 500 × 250 and 400 × 200 mm, as illustrated in Fig. 200, with a comprehensive range of fittings for ridge, eaves, verges and valleys.

Two somewhat more expensive forms of fibre cement slates are made to simulate the appearance of natural slate in colour and texture and the other with a random brick coloured surface.

Fixing natural slates

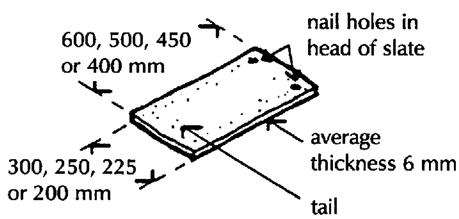


Fig. 201 Natural slate.

Slates are nailed to 50 × 25 mm sawn softwood battens with copper composition or aluminium nails driven through holes which are punched in the head of each slate. Galvanised steel nails should not be used as they will in time rust and allow the slates to slip out of position. Two holes are punched in each slate some 25 mm from the head of the slate and about 40 mm in from the side of the slate, as illustrated in Fig. 201.

The battens are nailed across the roof rafters over roofing felt and the slates nailed to them so that at every point on the roof there are at least two thicknesses of slate and so that the tail of each slate laps 75 mm over the head of the slate two courses below. This is similar to the arrangement of plain tiles and is done for the same reason. Because the length of slates varies and the end lap is usually constant it is necessary to calculate the spacing or gauge of the battens. The formula for this calculation is

$$\text{gauge} = \frac{\text{length of slate} - (\text{lap} + 25)}{2}$$

For example the gauge of the spacing of the battens for 500 mm long slates is:

$$\frac{500 - (75 + 25)}{2} = 200$$

The 25 that is added to the lap represents the 25 mm that the nail holes are punched below the head of the slate so that the 75 mm end lap is measured from the nail hole.

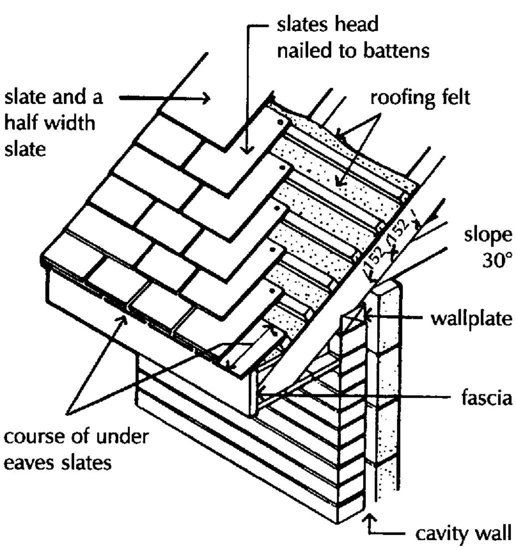


Fig. 202 Head nailed slates.

Figure 202 is an illustration of natural slates head nailed to preservative treated softwood battens with an end lap of 75 mm and the side butt joints between slates breaking joint up the slope of the roof. The roof is pitched at 25° to the horizontal, which is the least slope generally recommended for slates.

At verges and square abutments a slate and a half width slate is used in every other course to avoid using a half width slate to complete the bond.

Eaves

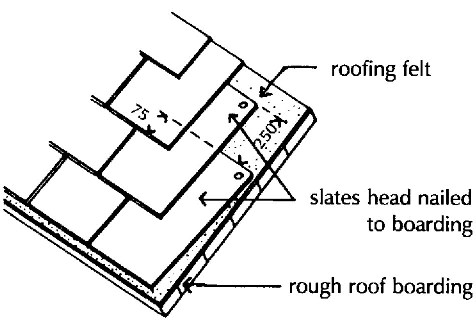


Fig. 203 Slates fixed to boards.

So that there shall be two thicknesses of slates at the eaves a course of undereaves slate is used. These slates are cut to a length equal to the gauge + lap + 25 of the slating, as illustrated in Fig. 202.

When the roof slopes are boarded to provide a wind tight, dry roof space the slates may be nailed directly through roofing felt to the boarding, as illustrated in Fig. 203.

To provide a space between the slates and the felt and boarding, down which any water that penetrates the slates may run to eaves, it is good practice to fix a system of counter battens up roof slopes, as illustrated in Fig. 184 for tiles.

Slates are usually fixed by means of nails driven through holes in the head of slates. This is the best method of fixing slates as the nail holes are covered with two thicknesses of slate so that even if one slate cracks, water will not get in. But if long slates such as 600 mm are head nailed on a shallow slope of, say, 30° or less it is possible that in a high wind the slates may be lifted so much that they snap off at the nail holes.

Centre nailed slates

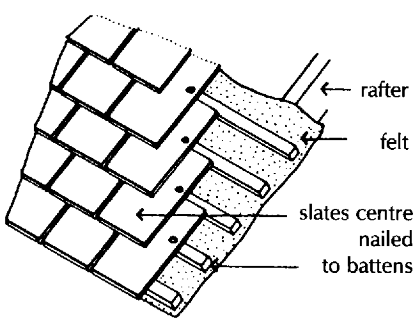


Fig. 204 Centre nailed slates.

In exposed positions on low pitch roofs it is common to fix the slates by centre nailing them to battens. The nails are not driven through holes exactly in the centre of the length of the slate, but at a distance equal to the gauge down from the head of the slate, so that the slate can double lap at tails as illustrated in Fig. 204. With this method of fixing there is only one thickness of slate over each nail hole so that if that slate cracks water may get into the roof.

The arrangement of a double course at eaves and ridge and the use of slate and a half width slates at square abutments and battens and roofing felt is the same for both head and centre nailed slates.

Ridge

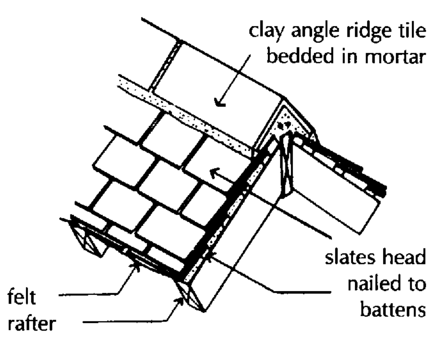


Fig. 205 Tile ridge.

Common practice is to cover the ridge, at the intersection of two slated slopes, with clay ridge tiles. So that there is a double thickness of slate a top course of slates is used at ridges. These shorter slates are usually the gauge plus lap plus 50 or 75 mm long and head nailed to a double thickness batten.

The dark colour, clay, angle ridge tiles are bedded in cement mortar on the back of the top course slates. Their ends are solidly filled with and joints pointed in cement mortar, as illustrated in Fig. 205.

A somewhat more expensive, and durable, finish is to use a sheet lead ridge capping, as illustrated in Fig. 206.

A wood roll, cut from a 50 mm square softwood section, is nailed to

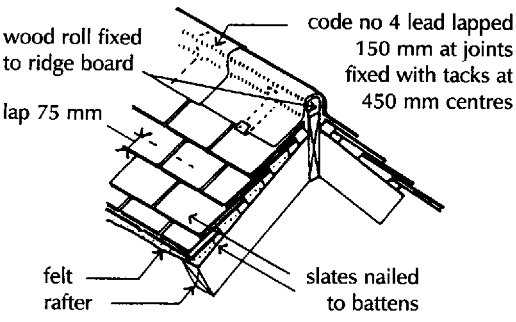


Fig. 206 Lead ridge.

the ridge board which is deeper than usual. Code No 4 sheet lead about 450 mm wide is dressed around the wood roll and down to the slates both sides.

At joints between sheets of lead capping, there is a 150 mm overlap. To prevent the wings of the sheet lead being blown up in high wind, a system of 50 mm wide strips of sheet lead is nailed to the roll under the lead at 450 mm centres. These lead tacks are turned up and around the edges of the wings of the lead capping to keep them in place.

Hips

At hipped ends of roof, slates and slate and a half width slates in every other course are cut to the splay angle up to the hip. The hip is then weathered with clay ridge tiles bedded in cement mortar or with a sheet lead capping similar to the ridge capping.

Valleys

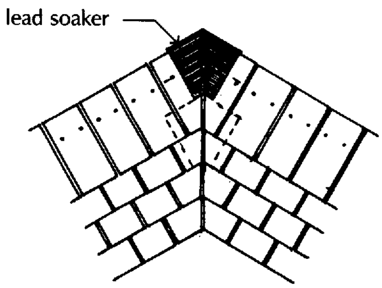


Fig. 207 Slate valley.

At the internal angle intersection of slated roof slopes the full and slate and a half width slates are splay cut up to the valley. A system of shaped lead soakers is used to weather the mitred valley. A shaped lead soaker cut from Code No 4 sheet lead is hung over the head of each course of slates. A similar soaker is hung over the head of slate courses above to overlap the soaker below, as illustrated in Fig. 207.

This involves a deal of wasteful cutting of slates. By careful cutting of slates and careful arrangement of bonding of slates a neat, mitred, watertight valley can be made.

Fixing fibre cement slates

Fibre cement slates are fixed double lap up the slope of roofs pitched at a minimum slope of 20° with a usual slope of 25° to the horizontal. The slates are fixed with the double end lap used with natural slates. The end lap may be the usual 75 mm, which is usually increased to 100 mm to provide cover for the centre nail fixing and the rivet hole.

These comparatively thin, brittle slates are centre nailed to avoid cracking the slate were it head nailed. Each slate is nailed with copper composition or aluminium nails to 38 × 25 mm or 50 × 25 mm, impregnated, sawn softwood battens nailed over roofing felt to rafters, as illustrated in Fig. 208. The gauge, spacing, of battens is calculated by the same formula used for natural slates.

To secure these thin, lightweight slates against wind uplift copper disc rivets are used. The disc of these rivets fits between slates in the under course and the tail of the rivet fits through a hole in the tail of the slate above. The tail of the rivet is bent up to hold the slate in position, as illustrated in Fig. 208.

At verges and square abutments, slate and a half width slate are used in every other course to complete the bond of slates up roof slopes.

At eaves two under eaves courses of slate are used. These cut or specially made short lengths of slate are head nailed to battens, as illustrated in Fig. 208.

At the ridge, special flanged end, fibre cement angle ridges are used. These 900 mm long ridge fittings are weathered by the overlap of the flanged ends, as illustrated in Fig. 209, and secured as illustrated with screws and plastic washers. The wings of the ridge fittings bear on the back of an under ridge course of slates without the need for cement and sand pointing.

At hips and valleys the slates are mitre cut to fit up to the hip or valley and the mitre cut slates weathered with lead soakers hung over the head of slates.

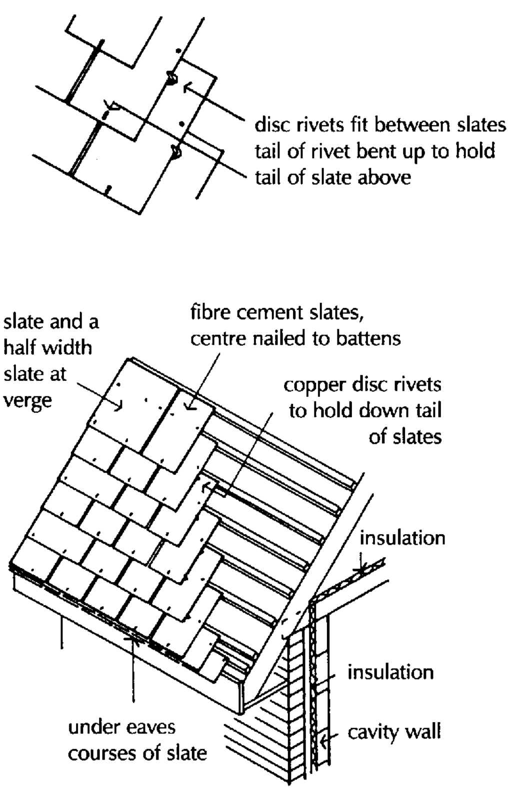


Fig. 208 Fibre cement slating.

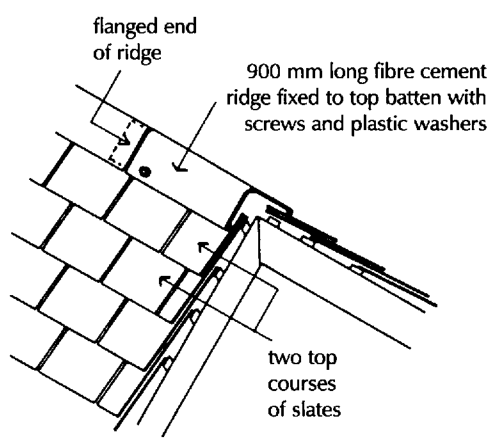


Fig. 209 Fibre cement slate ridge.

SHEET METAL COVERING TO LOW PITCH ROOFS

For many years from the middle of this century it was the fashion to construct low pitched roofs for houses, schools and other buildings. A pitched roof is generally defined as one with slopes of 10° or more to the horizontal and a low pitched roof has slopes of from 10° to 30° to the horizontal. The disadvantages of a flat roof were known and a steeply pitched roof is not always an attractive feature of small buildings. For example, a small bungalow with a pitched roof covered with tiles does not usually look attractive as the great areas of tiles dominates the lesser area of wall below. A low pitched roof is a happy compromise between flat and steeply pitched roofs. It at once looks attractive, gives reasonable insulation against loss of heat and provides roof space in which water storage cisterns can be housed.

The principal coverings for low pitched roofs are copper and aluminium strips, both of which are comparatively light in weight and therefore do not require heavy timbers to support them, and both have a useful life as a roof covering of very many years. The roofs are constructed as single slope roofs or as low pitched roofs with timber rafters pitched to a central ridge board with or without hipped ends. The construction of the rafters and their support with purlins and struts, or purlins and light timber trusses, is similar to that for other pitched roofs as previously explained.

Copper or aluminium strips 450 or 600 mm wide and up to 8.0 m long are used to cover these low pitched roofs. No drips or double lock cross welts or other joints transverse, across, the fall are used with strips up to 8.0 m long and because of this the labour in jointing the sheets is less than that required for the batten or conical roll systems used for lead sheet, consequently copper or aluminium strip coverings are cheaper. Because of the great length of each strip the fixing cleats used to hold the metal strips in position have to be designed to allow the metal to contract and expand freely.

Standing seams

Both copper and aluminium sheet are sufficiently malleable, workable, to be bent and folded without damage to the material in the formation of standing seam joints down roof slopes.

The strips of metal are jointed by means of a standing seam joint, which is a form of double welt and is left standing up from the roof as shown in Fig. 210, which is an illustration of part of a low pitched roof. The completed standing seam is constructed so that there is a gap of some 13 mm at its base which allows the metal to expand without restraint, and this is illustrated in Fig. 210. The lightweight metal strips have to be secured to the roof surface at intervals of 300 mm along the length of the standing seams. This close spacing of the fixing cleats is necessary to prevent the metal drumming due to uplift in windy weather.

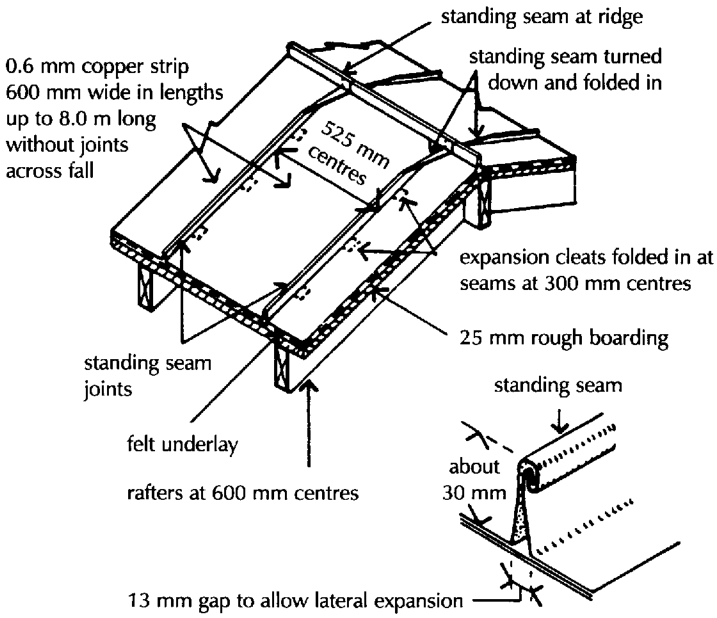


Fig. 210 Copper standing seam roofing.

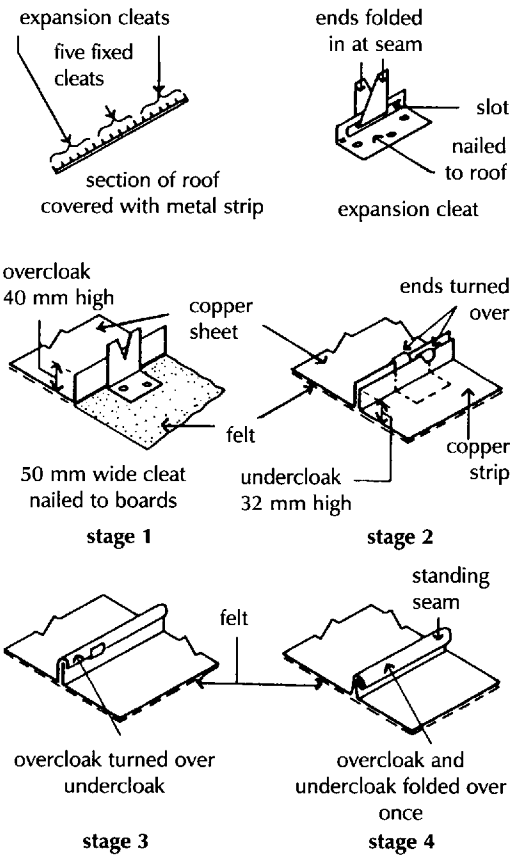
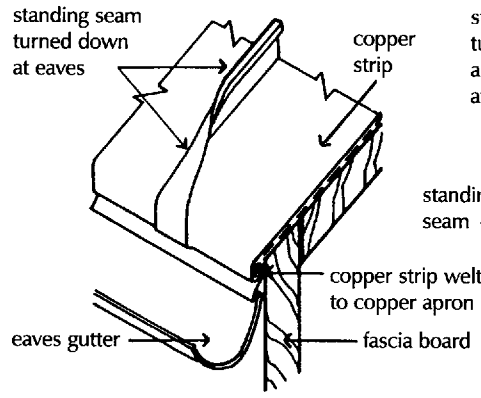


Fig. 211 Holding down cleats.

Two types of cleats are used, fixed cleats and expansion cleats. Five fixed cleats are fixed in the centre of the length of each strip and the rest of the cleats are expansion cleats. Figure 211 illustrates the arrangement of these cleats. The fixed cleats are nailed to the roof boarding through the felt underlay and Fig. 211 illustrates the formation of a standing seam and shows how the fixed cleat is folded in.

The expansion cleats are made of two pieces of copper strip folded together so that one part can be nailed to the roof and the second piece, which is folded in at the standing seam, can move inside the fixed piece. Figure 211 illustrates one type of expansion cleat used.

The ridge is usually finished with a standing seam joint, as illustrated in Fig. 212A, but as an alternative a batten roll or conical roll may be used. Whichever joint is used at the ridge, the standing seams on the slopes of the roof have to be turned down so that they can be folded in at the ridge. This is illustrated in Fig. 212A. Because copper and aluminium are generally considered to be attractive coverings to roofs, the roof is not hidden behind a parapet wall, and the roof slopes discharge to an eaves gutter, as illustrated in Fig. 212B.



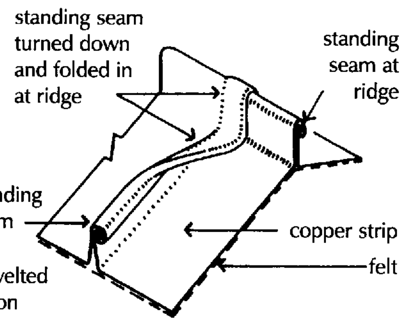


Fig. 212 (A) Ridge. (B) Eaves.

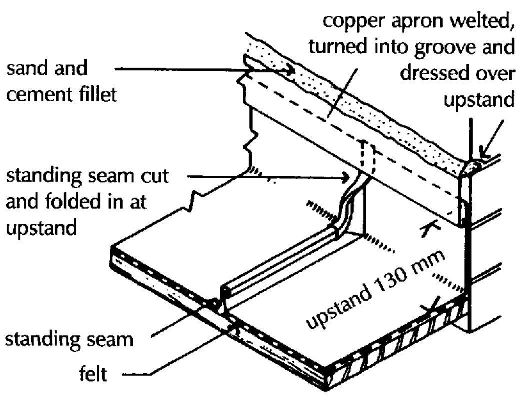


Fig. 213 Upstand.

Where the slope of the roof finishes at the parapet or wall, the strips of metal are turned up as an upstand and finished with an apron flashing. This is illustrated in Fig. 213, which also illustrates the cutting and turning down of the standing seam.

The verge of low pitched roofs can be finished with batten roll or conical roll, as illustrated for flat roof coverings.

Felt underlay

It is of importance that strip metal coverings be laid on an underlay of bitumen-impregnated roofing felt laid across the roof boards and nailed to the boards with butt side joints. The felt allows the metal strips to expand and contract without restraint.

Fire safety

The space inside a pitched roof is a void space that should be separated from other void spaces or cavities by cavity barriers that seal the junction of the cavities to prevent unseen spread of smoke and flames. The cavity in a wall is generally separated from the cavity in a pitched roof by the cavity barrier at the top of the cavity in the wall.

Separating walls, party walls, between semi-detached and terraced houses should resist the spread of fire from one house to the other by being raised above the level of the roof covering or by being built up to the underside of the roof covering so that there is a continuous fire break.

The traditional roof coverings, slate, tile and non-ferrous sheet metal, do not encourage spread of flame across their surface and are, therefore, not limited in use in relation to spread of fire between adjacent buildings.

Resistance to the passage of heat

Since the earliest requirement for thermal insulation to heated buildings, the requirements for, what is now termed, conservation of fuel and power have become increasingly stringent. The consequence of thermal insulation was at first not taken into account, so that the common sense need for moisture vapour barriers, ventilation and limits to cold draughts of air entering around ill fitting windows has been added from time to time. Most recently a standard assessment (SAP) energy rating procedure, which applies only to dwellings, has been added (see Chapter 2).

In the latest requirements in Approved Document L to the Building Regulations there should be a maximum U value of 0.2 W/m^{2}K for roofs to dwellings with an SAP rating of 60 or less and 0.25 W/m^{2}K for those with an SAP rating of over 60. For heated buildings other than dwellings a U value of 0.25 W/m^{2}K for roofs is required.

Two methods for the determination of the thickness of insulation required for roofs are suggested in Approved Document L. The first method is to relate the thickness of insulation required to the thermal conductivity of the insulating material to be used, ignoring the thermal resistance of the roof itself. This produces an indication of the insulation thickness required because the thermal resistance of the roof is small in comparison to that of the insulation.

As an example, if an insulant with a thermal conductivity of 0.04 W/m^{2}K is used and a U value of 0.25 W/m^{2}K is required the necessary thickness of insulation required can be read from a table as 227 mm for insulation between ceiling joists.

The second method is to make an allowance for the thermal resistance of other materials of the roof and so make some reduction in the thickness of insulation. The base thickness of insulation may be reduced by

	1 mm for roof tiles
	6 mm for roof space
	3 mm for 10 mm plasterboard
Total	10 mm reduction

The above figures are read off from a table in Approved Document L and related to an insulation with 0.04 W/m^{2}K conductivity and a U value of 0.25 W/m^{2}K for the roof.

As there is usually no advantage in using one of the thin, low conductivity, expensive insulating materials in a roof space, considerations of cost and convenience in fixing or laying are determining factors.

Insulating pitched roofs

Cold roof

The most convenient, economical and usual place for insulation in a pitched roof is either across the top of, or between, the ceiling joists. With insulation at ceiling joist level the roof is described as a cold roof.

Warm roof

A more expensive place to fix insulation is above, between or below the rafters of a pitched roof. Because the area of a pitched roof surface is greater than that of a horizontal ceiling there is a greater area to cover with insulation. The advantage of this arrangement is that the roof space will be warmed by heat rising from the heated building below and will, in consequence, be comparatively warm and dry for use as a storage place. With the insulation at roof level the roof is described as a warm roof.

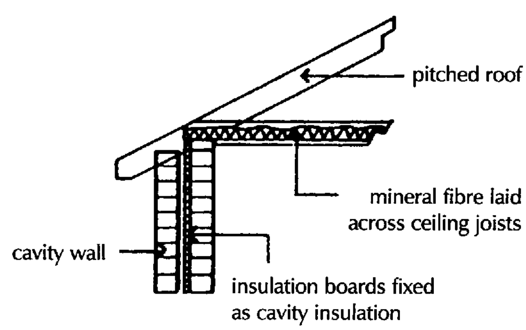


Fig. 214 Cold roof insulation.

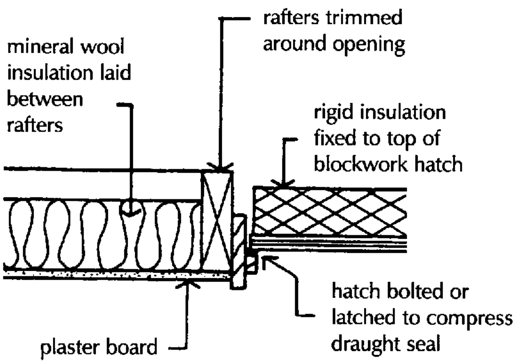


Fig. 215 Insulation to loft hatch.

The materials most used for cold roof insulation are mineral wool mats or rolls of fibre glass or rockwool spread across or between the joists or loose fill spread between the joists on top of the ceiling finish. The most straightforward way of providing a layer of insulation is to spread rolls of mineral fibre across the top of ceiling joists right across ceilings in both directions and extended up to and overlapping insulation in walls, as illustrated in Fig. 214.

So that the layer of insulation is continuous over the whole of the ceiling area it is recommended that loft hatches, giving access to roof spaces, be insulated and draught sealed, as illustrated in Fig. 215, and that where service pipes penetrate ceiling finishes some effective form of draught seal be formed.

All water carrying service pipes and water storage cisterns or tanks inside cold roof spaces must be effectively protected by a sheath of insulating material, called lagging, against the possibility of water freezing, expanding and damaging them.

With mats or rolls of mineral fibre spread across ceiling joists there is a possibility of the loose material being compressed and losing efficiency as an insulator, under walkways for access in roof spaces. Boarded access ways inside roofs should, therefore, be raised on battens above the level of the insulation.

The disadvantage of spreading or laying mineral fibre insulation or insulation boards between ceiling joists is that there will be a deal of wasteful cutting in fitting the material closely between joists. Where insulation is fixed between ceiling joists an allowance for the different thermal conductivity of wood and the insulant has to be made in calculations of thermal insulation requirements.

The insulating materials most used for cold, pitched roofs are set out in Table 10.

Table 10 Insulation materials for cold roofs.

Pitched roof cold roof	Thickness mm	U value W/m^2K
Glass fibre		
rolls laid across or between ceiling joists	60, 80, 100, 150, 200	0.04
semi-rigid batts laid across or between ceiling joists	80, 90, 100, 120, 140, 180, 200	0.04
Rockwool		
rolls laid across or between ceiling joists	80, 100, 150	0.037
granulated fibre spread between ceiling joists		0.043

Warm roof insulation

The most practical and economic place to fix insulation for a warm roof is on top of rafters where there will be the least wasteful cutting of the thin, expensive, insulation boards.

One of the comparatively thin organic insulants is used in the form of rigid boards which are used as a form of sarking, the word used to describe materials that exclude wind that would otherwise blow through tiled and slated roofs. To limit thickness, one of the materials with a low U value, such as XPS, PIR or PUR, is used.

These insulation boards are nailed directly to the roof rafters with their edges close butted or with tongued and grooved edges for a tight fit. Roofing felt is spread over the insulation boards and sawn softwood counter battens are nailed through the insulation boards to rafters to provide a fixing for tiling or slating battens.

Details of insulants for warm roofs are given in Table 11.

Condensation

A consequence of the general adoption of space heating and the requirement for thermal insulation in dwellings has been an increase in the likelihood of warm, moisture laden air condensing on cold indoor surfaces such as window glass.

The limited capacity of air to take up water in the form of moisture vapour increases with temperature. With the general demand for warm indoor temperature there has been an increase in condensation from such rooms as kitchens and bathrooms.

There have been instances of warm, moist air penetrating cracks in ceilings, due to moisture vapour pressure, and condensing to water on cold surfaces such as the underside of roofing felt. The consequent unsightly staining of ceiling finishes is due to an appreciable volume of condensate, in the form of water, running on to the ceiling.

Table 11 Insulation for warm roofs.

Pitched roof warm roof	Thickness mm	U value W/m²K
Glass fibre		
semi-rigid batts friction fit between rafters 1175 × 570 or 370	80, 90, 100, 120, 140, 180, 200	0.04
XPS		
boards fixed on top of rafters as sarking 2500 × 600	30, 40, 50, 60, 70, 80	0.025
PIR		
boards aluminium foil faced fixed on top of rafters as sarking 2400 × 1200	20, 25, 30, 35, 50	0.022
PUR		
boards glass tissue and aluminium foil faced fixed to top of rafters as sarking 1200 × 600 or 450	20, 25, 30, 35, 40, 50	0.022

XPS extruded polystyrene
PIR rigid polyisocyanurate
PUR rigid polyurethane

Where fibrous, open texture material such as glass wool is used as over ceiling insulation and warm, moist air penetrates a ceiling it may condense to water on the cold upper side of the insulation and so saturate it that the insulation property of the insulant is appreciably reduced.

Vapour barrier

In the early days when insulation was used in dwellings and condensation occurred in roof spaces the first reaction was to call for the installation of a water and moisture vapour impermeable barrier between warm, moist air below and cold surfaces above ceilings. Sheets of polythene were spread across the underside of ceiling joists, over ceiling joists under insulation or as an integral backing to plasterboard to ceilings. Efforts were made to seal the joints between sheets of polythene and plasterboards and seals around edges of ceiling and wall junction and also around pipework that penetrated ceiling finishes.

Vapour check

It was soon realised that, in spite of the most meticulous attention to detail, it was impractical to form a moisture vapour barrier. It is now accepted that a moisture vapour check is practical and the term vapour barrier has been abandoned.

The usual form of vapour check is sheets of 250 gauge polythene sheet with the edges overlapped and spread under insulation over ceiling joists with edges taped around pipes and cables that penetrate ceiling finishes. As an alternative, closed cell insulants, in the form of boards, such as extruded polystyrene, which are substantially impermeable to water vapour may be fixed across the top of ceiling joists and close side butted to serve as a vapour check.

Ventilation

A requirement from Part F to the Building Regulations is that adequate provision be made to prevent excessive condensation in a roof. The practical guidance in Approved Document F is that cold roof spaces should be ventilated to outside air to reduce the possibility of condensation.

There is no definition of what constitutes excessive, relative to condensation, or whether the roof ventilation is an alternative to a moisture vapour check, or an addition.

A more rational approach to reducing the possibility of warm, moist air penetrating a cold roof space is the recommendation for provision of both background and mechanical extract ventilation to kitchens and bathrooms contained in Approved Document F. Where such ventilation is installed and effectively used in bathrooms and kitchens below cold roofs there seems little sense in either ventilating cold roof spaces or using moisture vapour checks.

Recommendations for ventilation

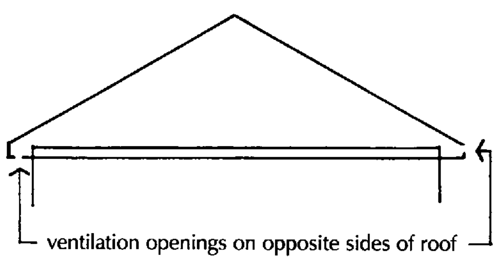


Fig. 216 Roof ventilation.

The practical guidance in Approved Document F is that cold, pitched roof spaces should have ventilation openings at eaves level to promote cross ventilation, as illustrated in Fig. 216. The openings indicated in the soffit of the eaves in Fig. 216 should have an area on opposite sides of the roof at least equal to continuous ventilation running the full length of the eaves and 10 mm wide. Plastic grilles with fine wire mesh to exclude insects are designed to fit in the soffit board of projecting eaves. Obviously there should be a clear space between the top of roof insulation and the underside of the roof covering. As an alternative to soffit ventilation the suppliers of tiles and slates offer a range of special fittings to provide roof ventilation through eaves, ridge and in roof slopes. A typical under eaves ventilator for slate is illustrated in Fig. 217. The plastic ventilator is fixed between roof rafters before the roofing felt is laid. It is fitted with insect screens over openings that provide ventilation to roofs. The roofing felt and slate are laid over the ventilators. A sufficient number of ventilators is used to provide the requisite ventilation area.

The movement of air, which is unpredictable, will vary from still, cold, to gusty, windy weather. For the system of roof ventilation proposed in Advisory Document F to be effective there would have to be an appreciable difference of, and pressure between, outside and inside. The chance of there being sufficient air pressure difference to promote ventilation, coinciding with the generation of moisture vapour laden air inside a bathroom under a cold roof are very slight. As the Building Regulations require adequate provision to prevent excessive condensation, common sense suggests that effective mechanical ventilation of bathrooms will by itself be effective in preventing excessive condensation and separate roof ventilation is unnecessary.

This is particularly true where rooms are formed in roof spaces and the ceiling follows the whole or part of the roof line. Here the guidance in Approved Document F is that the space between the roof covering and the insulation be at least 50 mm wide, as illustrated in Fig. 218. The chance of appreciable, continuous ventilation flowing through the tortuous, narrow space is slight.

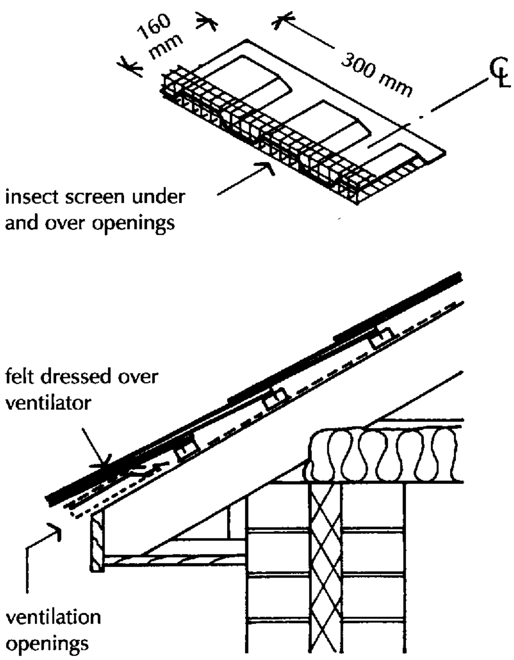


Fig. 217 Under eaves ventilator.

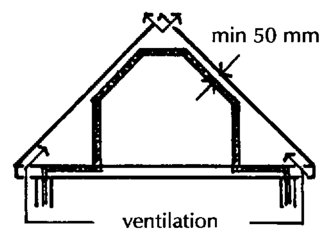


Fig. 218 Roof space ventilation.

FLAT ROOFS

History

From the earliest settlements in this country a pitched roof form as shelter from rain and wind has been common, from the early thatched houses to the traditional tile and stone slate roofed buildings. Flat roofs have not been a practical means of shelter in the rainy, northern European climate of this country. In arid, dry climates closer to the equator a flat roof has served as protection from the mainly overhead sun during the day and a roof platform on which to enjoy cooler air at night.

A flat roof was used to cover small areas of roof over the extensions, internal courts and as a cover to parts of extensive roofs. Traditional sheet metal coverings were used, lead in England and zinc in France.

Early in the twentieth century a building form, commonly known as the modern movement, adopted a severe horizontal flat roof form devoid of applied decoration. At the time the early use of reinforced concrete for floors facilitated the use of reinforced concrete as a roof platform.

Materials such as asphalt and bitumen impregnated felt, that had previously been used for road paving and temporary cover to sheds respectively, were adapted for use as covering to flat roofs.

Before the inclusion of thermal insulation in the fabric of buildings these flat roof coverings worked reasonably well for their anticipated useful life of some 20 to 30 years. The inclusion of a layer of efficient thermal insulation was a disaster.

Previously the heat generated by the overhead sun was in part dispersed from the covering down to the roof below. With insulation below, very little heat was transferred below and the covering endured the full heat of sun and chill of night. The asphalt and bitumen rapidly hardened and failed.

In consequence, flat roofs acquired and deserved a bad name to the extent that existing buildings have had pitched roofs constructed to replace flat ones.

FLAT ROOF COVERINGS

A roof is defined as flat when its weather plane is finished at a slope of 1° to 5° to the horizontal.

The shallow slope to flat roofs is necessary to encourage rainwater to flow towards rainwater gutters or outlets and to avoid the effect known as ponding. Where there is no slope or fall or a very shallow slope it is possible that rainwater may not run off the roof where deflection under load has caused the roof to sink and cause rainwater to lie as a shallow pond. This water may in time cause deterioration of a membrane and consequent failure.

The minimum falls (slope) for flat roof coverings are 1:60 for copper, aluminium and zinc sheet, and 1:80 for sheet lead and for mastic asphalt and built-up bitumen felt membranes.

To allow for deflection under load and for inaccuracies in construction it is recommended that the actual fall or slope should be twice the minimum and allowance made where slopes intersect so that the fall at the mitre of intersection is maintained.

The traditional materials that are used as a weather covering for flat roofs, lead, copper and zinc sheet, are laid as comparatively small sheets dressed over rolls at junctions of sheet down the slope of the roof and with small steps (drips) at junctions of sheet across the slope.

The size of the sheet is limited to prevent excessive expansion and contraction that might otherwise cause the sheet to tear. The upstand rolls down the slope and the steps or drips across the slope provide a means of securing the sheets against wind uplift and as a weathering to shed water away from the laps between sheets. More recently aluminium sheet has also been used.

Lead, copper and aluminium are not affected by normal weathering agents, do not progressively corrode and have a useful life of very many years. Zinc is less durable than the other non-ferrous metals used for roof covering.

Because of the cost of the material and the very considerable labour costs involved in covering a roof with one of these metals, the continuous membrane materials, asphalt and bitumen felt, came into use early this century. Asphalt is a dense material that is spread while hot over the surface of a roof to form a continuous membrane which is impermeable to water. It is generally preferred as a roof covering to concrete flat roofs. Bitumen impregnated felt is laid in layers bonded in hot bitumen to form a continuous membrane that is impermeable to water. Bitumen felt is comparatively lightweight and commonly preferred for timber flat roofs for that reason.

Both asphalt and bitumen felt oxidise and gradually become brittle and have a useful life of at most 20 years. Bitumen felt will become brittle in time and may tear due to expansion and contraction caused by temperature fluctuations. Of recent years fibre-based bitumen felts have lost favour due to premature failures and polyester-based felts are now more used for their greater resistance to tear and lower rates of oxidisation and embrittlement.

With the use of insulation under flat roof coverings the temperature fluctuations that the covering will suffer are considerable and the consequent strain on continuous coverings accelerates failures. Because of the rainfall common to northern Europe it would seem wise to avoid, where possible, the use of flat roofs, particularly for large areas of roof.

TIMBER FLAT ROOF CONSTRUCTION

The construction of a timber flat roof is similar to the construction of a timber upper floor. Sawn softwood timber joists 38 to 75 mm thick and from 97 to 220 mm deep are placed on edge from 400 to 600 mm apart with the ends of the joists built into or on to or against brick walls and partitions.

Tables in Approved Document A, giving practical guidance to meeting the requirements for dwellings of up to three storeys for single families, give sizes of joists for flat roofs related to span and loads for roofs with access only for maintenance and repair and also for roofs not limited to access for repair and maintenance.

Strutting between joists

Solid or herringbone strutting should be fixed between the roof joists for the same reason and in like manner to that used for upper timber floors.

Roof deck

Boards which are left rough surfaced from the saw are the traditional material used to board timber flat roofs. This is called rough boarding and is usually 19 mm thick and cut with square, that is plain, edges. Plain edged rough boarding was the cheapest obtainable and used for that reason. Because square edged boards often shrink and twist out of level as they dry, chipboard or plywood is mostly used today to provide a level roof deck. For best quality work tongued and grooved boards were often used.

End support of joists

If there is a parapet wall around the roof, the ends of the roof joists may be built into the inner skin of cavity walls or supported in metal hangers. The joists can bear on a timber or metal wall plate or be packed up on slate or tile slips as described for upper floors. The ends of the roof joists are sometimes carried on brick corbel courses, timber plate and corbel brackets or on hangers in precisely the same way that upper floor joists are supported. The end of roof joists built into solid brick walls should be given some protection from dampness by treating them with a preservative.

Timber firring

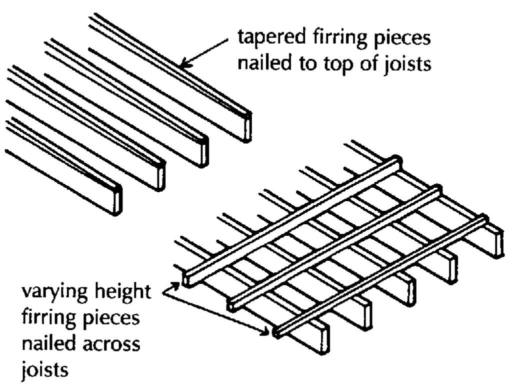


Fig. 219 Firring to timber flat roof.

Flat roofs should be constructed so that the surface has a slight slope or fall towards rainwater outlets. This slope could be achieved by fixing the joists to a slight slope but the ceiling below the roof would then also be sloping. It is usual to provide a sloping surface to the roof by means of firring pieces. These consist of either tapered lengths of fir (softwood) nailed to the top of each joist or varying depth lengths of softwood nailed across the joists, as shown in Fig. 219.

Varying depth firring is used where rough boarding is fixed as the deck for flat roof sheet metal coverings. By this arrangement the boards are fixed down the slope so that any variation in the surface of the boards, due to shrinkage or twisting, does not impede the flow of rainwater down the shallow slope.

Tapered firring is used where the roof deck is formed by chipboard or plywood sheets nailed to firring with close butted edges to form a level surface.

As an alternative to timber firring, insulation boards that are made or cut to a shallow wedge section can be used to provide the necessary shallow fall.

Sheet metal covering to timber flat roofs

Sheet metal is used as a covering because it gives excellent protection against wind and rain; it is durable and lighter in weight than asphalt, tiles or slates. Four metals in sheet form are used, lead, copper, zinc and aluminium.

Sheet lead

Lead is a heavy metal which is comparatively soft, has poor resistance to tearing and crushing and has to be used in comparatively thick sheets as a roof covering. It is malleable and can easily be bent and beaten into quite complicated shapes without damage to the sheets. Lead is resistant to all weathering agents including mild acids in rainwater in industrially polluted atmospheres. On exposure to the atmosphere a film of basic carbonate of lead oxide forms on the surface of the sheets. These films adhere strongly to the lead and as they are non-absorbent they prevent further corrosion of the lead below them. The useful life of sheet lead as a roof covering is upwards of a hundred years.

Rolled sheet lead for roof work is used in thicknesses of 1.8, 2.24 and 2.5 mm. These thicknesses are described as Code Nos 4, 5 and 6 respectively, the Code corresponding to the Imperial weight of a given area of sheet.

No sheet of lead should be larger than $1.6\,m^2$ so that the joints between the sheets are sufficiently closely spaced to allow the metal to contract without tearing away from its fixing. Another reason for limiting the size of sheet, which is peculiar to lead, is to prevent the sheet from creeping down the roof.

The expression creep describes the tendency of the sheet to elongate. As the temperature of the metal rises the sheet expands, but owing to its weight and poor mechanical strength it may not be able to contract fully as the temperature falls. The consequence is that the sheet gradually elongates over many years and becomes thinner and may in time let in water. It is not likely that this will happen on a flat roof with a sheet not larger than $1.6\,m^2$.

The joints across the fall of the roof are made in the form of a 50 mm drip or step down to encourage flow of water. To reduce excessive increases in the thickness of the roof due to these drips, they are spaced up to 2.3 m apart and the rolls (joint longitudinal to fall) 600 to 800 mm apart. Figure 220 illustrates part of a lead covered flat roof showing the general layout of the sheets and a parapet wall around two sides of the roof.

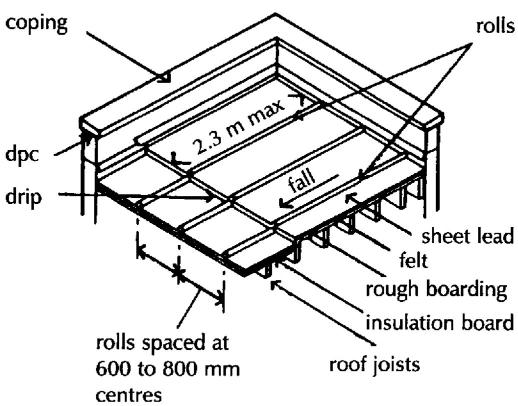


Fig. 220 Lead flat roof.

Wood rolls

The edges of sheets longitudinal to the fall are lapped over a timber which is cut from lengths of timber 50 mm square to form a wood roll. Two edges of the batten are rounded so that the soft metal can be dressed over it without damage from sharp edges. Two sides of the batten are slightly splayed and the waist so formed allows the sheet to be clenched over the roll. Figure 221 is an illustration of a wood roll. An underlay of bitumen impregnated felt or stout waterproof building paper is first laid across the whole of the roof boarding and the wood rolls are then nailed to the roof at from 600 to 800 mm centres. The purpose of the underlay of felt or building paper is to

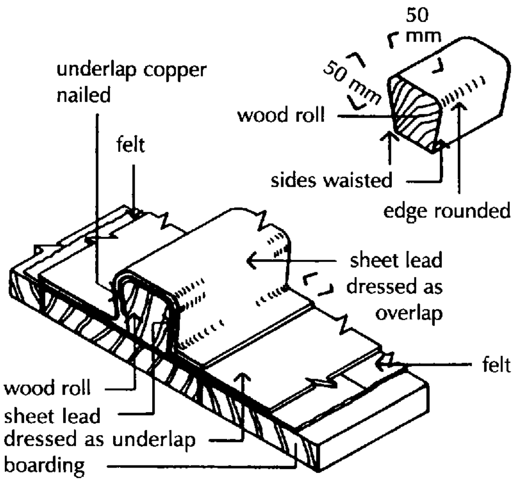


Fig. 221 Wood rolls.

provide a smooth surface on which the sheet lead can contract and expand freely.

The roof boarding on roofs to be covered with sheet lead may be fixed diagonally so that the joints between the boards are 45° to the fall. It is wasteful of timber to lay boards diagonally as the end of each board has to be cut off at 45° and boards are, therefore, laid so that they run along the fall of the roof. The reason for laying the boards either diagonally or along the fall is so that if a board shrinks and warps it will not obstruct the flow of rain off the roof or tear the lead.

The edges of adjacent sheets are dressed over the wood roll in turn. In sheet metalwork the word dressed is used to describe the shaping of the sheet. The edge of the sheet is first dressed over as underlap or undercloak and is nailed with copper nails to the side of the roll. The edge of the next sheet is then dressed as overlap or overcloak. A section through one roll is shown in Fig. 221. One edge of each sheet is dressed as underlap and nailed and the opposite edge is then dressed as overlap to the next roll. In this way no sheet is secured with nails on both sides, so that if it contracts it does not tear away from the nails.

Drips

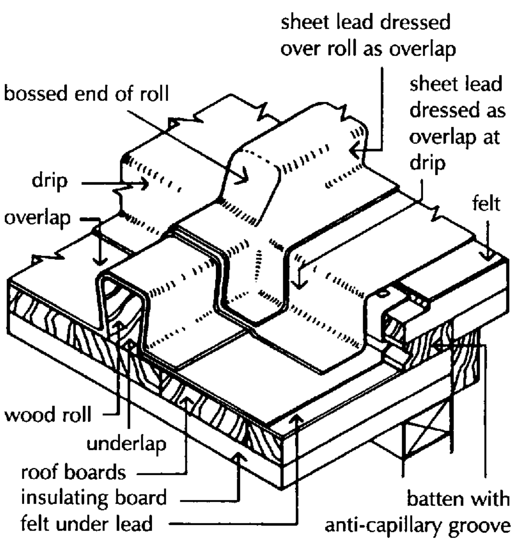


Fig. 222 Drip.

Drips 50 mm deep are formed in the boarded roof by nailing a 50 × 25 mm fir batten between the roof boards of the higher and lower bays. The drips are spaced at not more than 2.3 m apart down the fall of the roof. The edges of adjacent sheets are overlapped at the drip as underlap and overlap and the underlap edge is copper nailed to the boarding in a cross-grained rebate, as shown in Fig. 222. An anti-capillary groove formed in the 50 × 25 mm batten is shown into which the underlap is dressed. This groove is formed to ensure that no water rises between the sheets by capillary action.

Figure 222 also shows the junction of wood rolls with a drip and illustrates the way in which the edges of the four sheets overlap. This arrangement is peculiar to sheet lead covering which is a soft, very ductile material that can be dressed as shown without damage. The end of the wood roll on the higher level is cut back on the splay (called a bossed end) to facilitate dressing the lead over it without damage.

This seemingly complicated junction of four sheets of lead, which is formed to provide a watertight overlap, encourages steady run off of rainwater and makes allowance for thermal movement of lead, can be surprisingly quickly made by a skilled plumber.

Where there is a parapet wall around the roof or where the roof is built up against a wall the sheets of lead are turned up against the wall about 150 mm as an upstand. The tops of these upstands are not fixed in any way so that the sheets can expand and contract without restraint. To cover the gap between the upstand and the wall, strips of sheet lead are tucked into a raked out horizontal brick joint, wedged in place with strips of lead sheet and then dressed down over the upstand as an apron flashing. To prevent the apron from being blown up by the wind, lead clips are fixed as shown in Fig. 223A and B, which illustrates the junction of roll and drip with upstands.

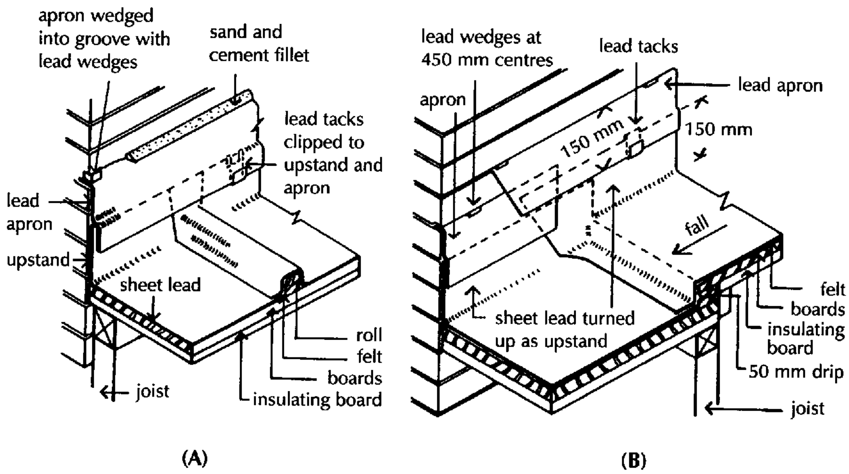


Fig. 223 (A) Junction of roll and upstand. (B) Junction of drip and upstand.

Lead gutter

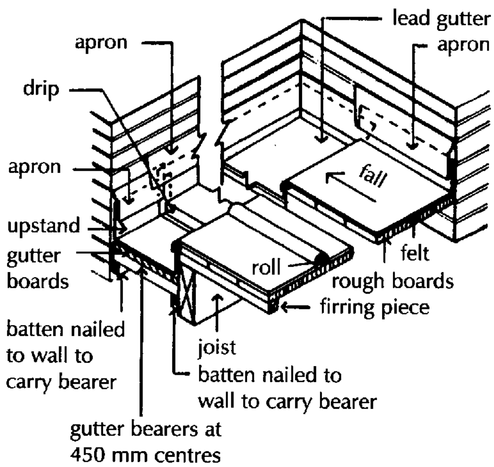


Fig. 224 Lead lined gutter.

Where the lead flat roof is surrounded on all sides by parapet walls it is necessary to collect the rainwater falling off at the lowest point of the roof. A shallow timber framed gutter is constructed and this gutter is lined with sheets of lead jointed at drips and with upstand and flashings similar to those on the roof itself. The gutter is constructed to slope or fall towards one or more rainwater outlets. The gutter is usually made 300 mm wide and is formed between one roof joist, spaced 300 mm from a wall, and the wall itself.

The gutter bed is supported by 50 × 50 mm gutter bearers fixed at 450 mm centres supported by 50 × 25 mm battens which are nailed to the wall and the joist to provide the necessary fall in the gutter. Gutter boards, 19 mm thick, are fixed along the length of the gutter as a gutter bed.

At drips into the gutter from the roof and at drips in the length of the gutter, the apron upstand to the parapet wall, and the apron flashing tucked into the wall are staggered and overlapped.

Figure 224 is an illustration of a lead lined gutter.

Where the roof is surrounded by a parapet wall and a rainwater pipe can be fixed to the outside of the wall, an opening is formed in the wall as an outlet usually 225 × 225 mm square. A rainwater head is fixed to the wall below the outlet.

The sheet lead gutter lining is continued through the outlet and dressed to discharge into the rainwater head. Both upstands to the gutter lining are dressed into the sides of the rainwater outlet in the parapet wall and dressed against the wall face to form a shute to direct water into the rain water head, as illustrated in Fig. 225.

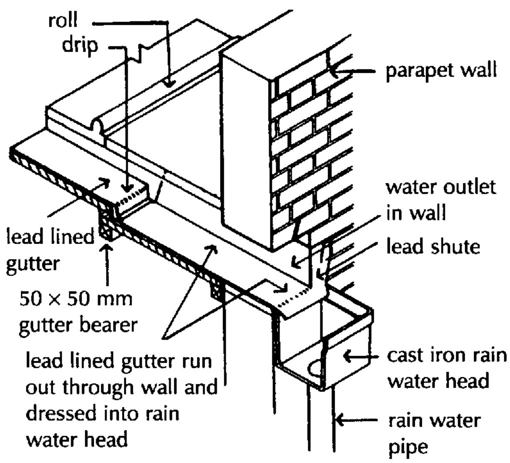


Fig. 225 Rainwater outlet.

Where it is not possible or is unacceptable for appearance sake, to fix a rainwater pipe and head externally the gutter has to be formed to discharge to a cesspool. A conventional lead lined gutter is formed to fall each side of a lead lined cesspool, as illustrated in Fig. 226.

The purpose of this lead lined box, cesspool or catchpit is as a reservoir so that during a heavy storm, when the rainwater pipe may not be able to carry the water away quickly enough, the cesspool prevents flooding of the roof.

The cesspool is formed as a box of 25 mm thick boards holed for a pipe outlet. The cesspool is 300 × 300 × 150 mm deep and supported on 50 × 50 mm bearers. The cesspool is lined with one piece of lead which is dressed to shape with upstands to be dressed up and under the lead sheet to the gutter, flat roof and upstand to parapet wall.

A lead down pipe is connected to the cesspool and run down as a down pipe or connected to a down pipe.

Where there is no parapet wall on one side of the roof it can discharge rainwater directly to a gutter fixed to a fascia board on the external face of the wall. The lead flat roof covering is dressed to discharge into the gutter, as illustrated in Fig. 227.

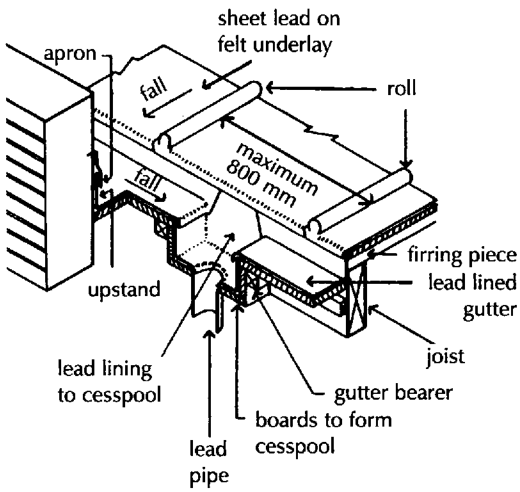


Fig. 226 Cesspool.

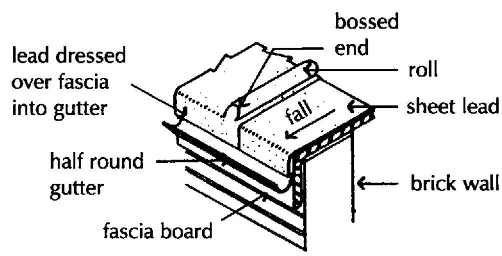


Fig. 227 Gutter.

Copper sheet

Copper is a metal which has good mechanical strength and is sufficiently malleable in sheet form that it can be bent and folded without damage. Like lead, on exposure to atmosphere a thin coat of copper oxide forms on the surface of the copper sheets, which is tenacious, non-absorbent and prevents further oxidisation of the copper below it. Copper is resistant to all normal weathering agents and its useful life as a roof covering is as long as that of lead.

The usual thickness of copper sheet for roofing is 0.6 mm. An oxide of copper forms on the surface of copper sheet and in the course of some few years the sheets become entirely covered with a light green compound of copper. This light green coating is described as a patina and is generally thought to give the copper sheets pleasing colour and texture. But in atmospheres heavily polluted with soot the patina is black instead of green. The patina, usually basic copper carbonate, is impervious to all normal weathering agents and protects the copper below it.

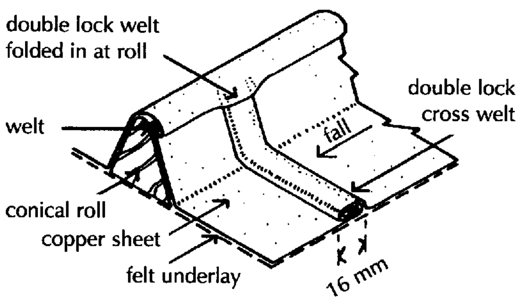


Fig. 228 Double lock welt.

The standard sizes of sheet supplied for roofing are 1.2 m and 1.8 m × 900 mm. The minimum fall for a copper covered roof is 1 in 60 and the fall is provided by means of firring pieces just as it is for lead covered roofs.

The traditional method of fixing copper sheet to a flat roof has been by the use of wood rolls down the shallow slope, over which adjacent sheets are shaped with welted joints and drips across the slope.

Copper sheets for roofing, which cannot be shaped over rolls and drips as easily as can lead, are joined by the use of double lock welts which are a double fold at the edges of adjacent sheets. These double lock welts are used for joints of sheet over the wood rolls and at joints across the fall, as illustrated in Fig. 228. Because of the difficulty of forming a double lock welt it is necessary to stagger these joints to avoid the difficulty of forming this joint at the junction of four sheets of copper.

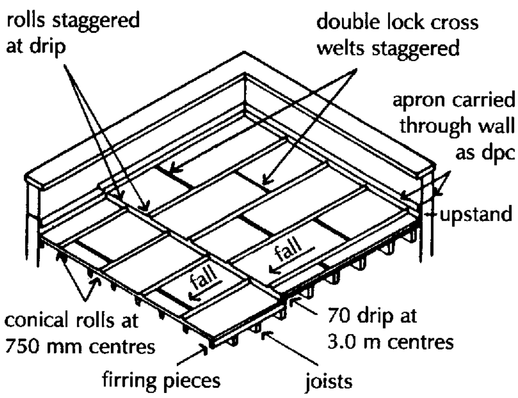


Fig. 229 Copper flat roof.

Figure 229 is an illustration of a copper sheet covered flat roof. The wood rolls along the fall of the roof are fixed at centres to suit the standard width of sheet, for example 750 mm. At drips the rolls are staggered to avoid welts at the junction of four sheets.

Drips are formed across the slope at from about 2 to 3 m to suit the size of standard sheet with staggered double lock cross welts between drips and drip and parapet wall. Drips are formed with a 40 × 50 mm batten which is nailed between the upper and lower roof boarding on the firring pieces on joists, as illustrated in Fig. 230.

At the drip the sheets of copper are welted with the upstand of the lower sheet shaped to the end of the roll and welted to the overcloak as illustrated in Fig. 230.

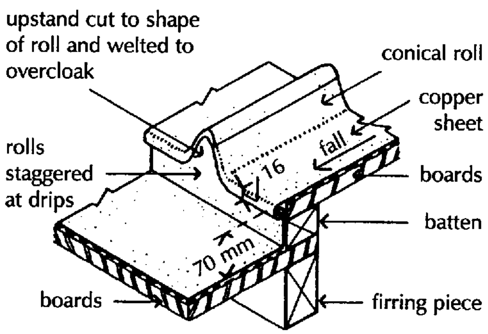


Fig. 230 Copper drip.

The conical rolls formed down the fall of the roof are formed around 63 × 50 mm sections of softwood which are shaped in the section of a cone with a round top. The shape is selected to facilitate shaping the metal. The wood rolls are nailed through a felt underlay to the roof boarding and also 50 mm wide strips of copper sheet at 450 mm centres as cleats. The felt underlay serves to allow the sheets to expand and contract without restraint.

The copper strips are used to restrain the sheets against wind uplift by being folded into the welted joint formed over the roll, as illustrated in Fig. 231.

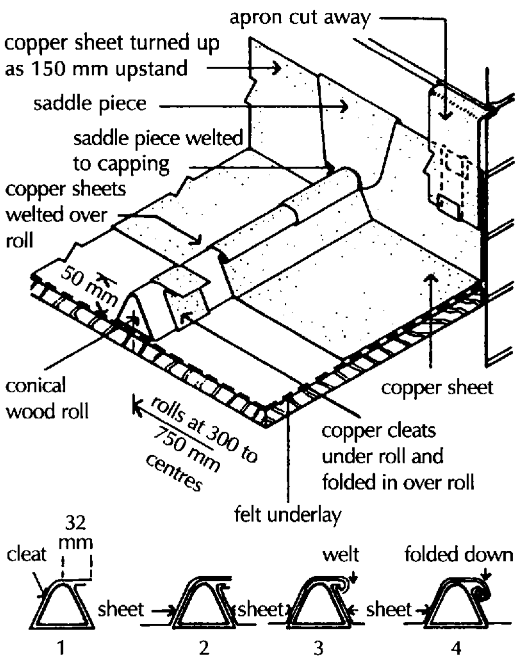


Fig. 231 Conical roll.

At upstands to parapet walls the sheets are turned up at the upstand and covered with an apron flashing which is wedged into a brick joint. At the junction of the conical roll and the upstand it is necessary to use a separate saddle piece of copper sheet that is welded to the capping and dressed up to cover the joint between adjacent upstands, as illustrated in Fig. 231.

As with lead sheet the copper covered roof may discharge to a verge gutter or to a parapet wall gutter formed in the roof and lined with copper.

As an alternative to the use of a conical roll down the slope or fall of copper roofs a batten roll may be used with drips and double lock cross welts across the fall or slope of the roof.

A wood roll with slightly shaped sides is nailed through a felt underlay and also 50 mm wide strips of copper at 450 mm centres as cleats. The sides of adjacent sheets of copper are shaped as upstand sides to the roll and the roll is covered with a separate strip of copper as a capping. The cleats are folded into the double lock welts formed between the upstand of sheets and the edges of the capping. This is the type of joint longitudinal to falls that is also used with zinc sheet roof covering.

Zinc sheet

Zinc, a dull, light grey metal, is used in sheet form as a covering for timber flat roofs.

It is the cheapest of the metals used for roofs and has been extensively used in northern European countries such as France, where it can economically be produced. In England where it has been much less used it has served as a cheap substitute for lead both as a roof covering and for flashings.

Zinc sheet is appreciably more difficult to bend and fold than copper. Being a brittle material it is liable to crack if bent or folded too closely.

As a flat roof covering the standard 2.4 m, 900 mm and 1 or 0.8 mm thick sheets are bent up to the sides of softwood batten rolls. The batten rolls are nailed at 850 mm centres through felt underlay and clips at 750 mm centres. The clips are welted over the upstand edges of the sheets.

Because of the difficulty of making a double lock welt of zinc sheet the capping is shaped to fit over the batten rolls. The lower edges of the capping are bent in, feinted, to grip the sheets.

To secure the capping, zinc holding down clips are nailed to the batten over the end of a lower capping and the end of the upper capping tucked into the fold, as illustrated in Fig. 232.

Drips are formed across the slope at 2.3 m intervals, with beaded drips and splayed cappings to roll ends, as illustrated in Fig. 233.

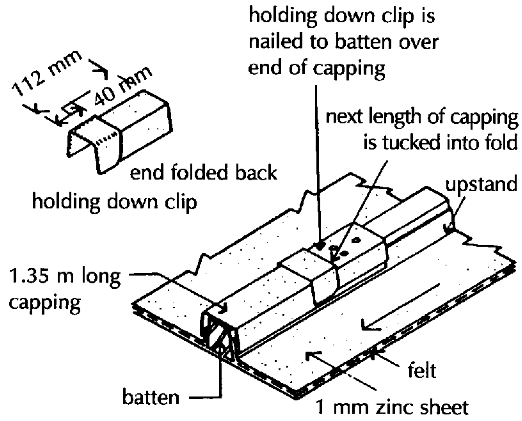


Fig. 232 Zinc batten rolls.

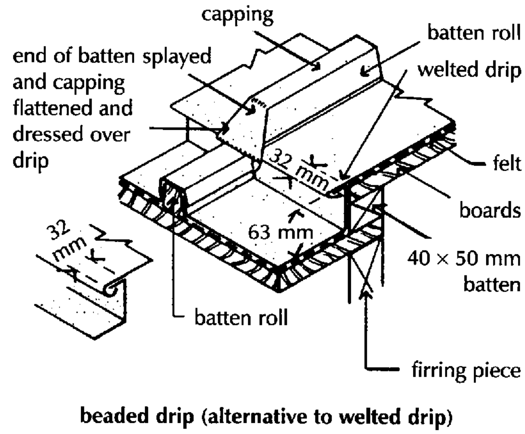


Fig. 233 Zinc drip.

At parapets the sheets are turned up as upstand and covered with a zinc apron that is wedged into a brick joint. The end of a batten capping is folded and flattened to cover the edges of adjacent sheets.

WATERPROOF MEMBRANES FOR TIMBER FLAT ROOFS

The two materials that have been used as a waterproof membrane for timber framed roofs are asphalt as a continuous membrane and bitumen felt laid in layers to form a membrane or skin.

Asphalt

Mastic asphalt

Asphalt, which is sometimes spelt asphalte, is described in the relevant British Standard as mastic asphalt. The material, which is soft and has a low softening (melting) point, is an effective barrier to the penetration of water.

Natural rock asphalt is mined from beds of limestone which were saturated, or impregnated, with asphaltic bitumen thousands of years ago. The rock is chocolate brown in colour and is mined in several districts around the Alps and Europe. The rock is hard and because of the bitumen with which it is impregnated it does not as readily absorb water as ordinary limestone.

Natural lake asphalt is dredged principally from the bed of a dried up lake in Trinidad. It contains a high percentage of bitumen with some water and finely divided solid material.

Asphalt is manufactured either by crushing natural rock asphalt and mixing it with natural lake asphalt, or by crushing natural limestone and mixing it with bitumen whilst the two materials are sufficiently hot to run together. The heated asphalt mixture is run into moulds in which it solidifies as it cools.

The solid blocks of asphalt are heated on the building site and the hot plastic material is spread over the surface of the roof in two layers breaking joint to a finished thickness of 20 mm. As it cools it hardens and forms a continuous, hard, waterproof surface.

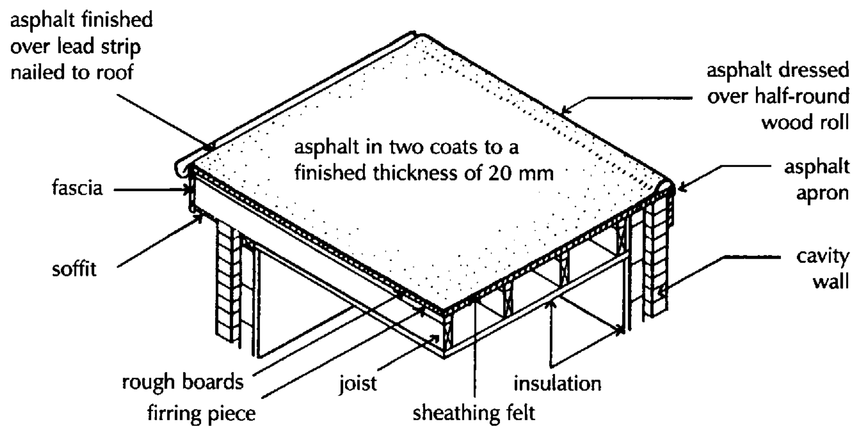


Fig. 234 Asphalt covered flat roof.

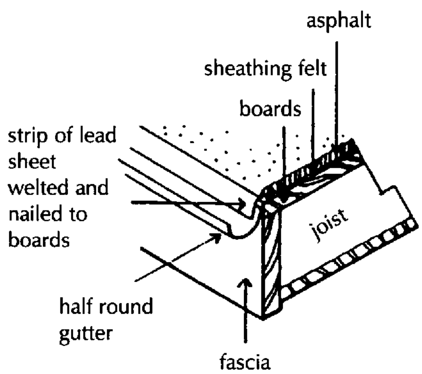


Fig. 235 Detail at eaves.

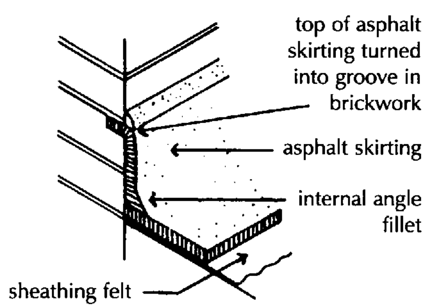


Fig. 236 Asphalt skirting.

If there is no parapet wall around the roof it is usually designed to overhang the external walls, to give them some protection, and the asphalt drains to a gutter over the strip of sheet lead which is dressed down into a gutter, as illustrated in Fig. 234, which is an illustration of a timber flat roof covered with asphalt. Figure 235 illustrates a detail of sheet lead dressed into a gutter.

If the roof has parapet walls around it, or adjoins the wall of a higher building, an asphalt skirting or upstand, 150 mm high, is formed and this skirting is turned into horizontal brick joints purposely cut about 25 mm deep to take the turn-in of the asphalt skirting, as illustrated in Fig. 236. For strengthening, an internal angle fillet is run at the junction of the flat and the asphalt skirting.

An alternative detail is to form the skirting as an upstand only, with the upstand weathered by a sheet lead apron that is wedged into a raked out brick joint and dressed down over the upstand. The advantage of this finish is that structural, thermal or moisture movements of the roof are less likely to cause cracking of the asphalt either at the internal angle fillet or at the turn in the wall.

It is essential that asphalt be laid on an isolating membrane underlay of black haired felt so that slight movements in the structure are not reflected in the asphalt membrane.

A properly laid asphalt covering to a roof will not absorb water at all and the finished surface of the asphalt can be absolutely flat as any rainwater that lies on it, due to ponding, will eventually evaporate. But it is usual to construct flat roofs so that the asphalt is laid to a slight fall, of at least 1:80, so that the rainwater drains away to a rainwater outlet or gutter.

Asphalt is a comparatively cheap roof covering and if the asphalt is of good quality and is properly laid it will have a useful life of some 20 years or more. The asphalt should be renewed about every 20 years if the roof is to be guaranteed watertight.

Built-up bitumen felt roofing

The word felt is used for fibres, such as animal hair, that are spread at random around a large, slowly rotating drum on which a mat of loosely entwined fibres, mixed with size, is built up. The mat is cut, rolled off the drum and compressed to form a sheet of felted (matted) fibres. For use as a roof surface material the felt is impregnated or saturated with bitumen.

A variety of felts is made from animal, vegetable, mineral or polyester fibre or filament for use as flat roof covering.

Sheathing and hair felts

These felts are made from long staple fibres, loosely felted and impregnated with bitumen (black felt) or brown wood tars or wood pitches (brown felt). They are used as underlays for mastic asphalt roofing and flooring to isolate the asphalt from the structure.

Fibre base bitumen felts

Fibre base bitumen felts are the original material used as covering for the pitched roofs of sheds and outhouses, in either one or two layers.

These felts are made as a base of animal or vegetable fibres that are felted, lightly compressed and saturated with bitumen. Fine granule surfaced felts may be used as a lower layer in built-up roofing and as a top layer on flat roofs that are subsequently surfaced with bitumen and mineral aggregate finish as a comparatively cheap roof finish.

Mineral surfaced fibre base felt is finished on one side with mineral granules for appearance and protection for use as a top layer on sloping roofs.

Fibre base bitumen felts have been used as a covering for small area pitched roofs. The material is either bonded to a boarded finish with bitumen in two layers, breaking joint or nailed and bonded at joints and edges for the first coat and bonded with bitumen as top coat.

The top layer of this felt covering is often surfaced with bitumen and a light coloured mineral aggregate finish for appearance sake and the benefit of reflection from the mineral. This is a cheap, perfectly satisfactory, though somewhat unattractive, weather protection to pitched roofs with a useful life of up to 20 years.

Used on flat and shallow pitch roofs the material may deteriorate quite rapidly, after a few years, once water penetrates and saturates the felt base due to oxidisation and cracking of the bitumen coat.

Reinforced fibre based felts have a layer of jute hessian embedded in the coating on one side and are used under slates and tiles where the felt is not fully supported by boarding.

Glass fibre based bitumen felts

Glass fibre based felts have for many years largely replaced natural fibre based felts as the material used for built-up felt roofing for flat roofs. The material is made from felted glass fibres that are saturated and coated with bitumen.

The felted glass fibre base forms a tenacious mat that is largely unaffected by structural, thermal and moisture movement of the roof deck and does not deteriorate due to moisture penetration.

The fine granule coated, glass fibre based felt is used as underlay and as top layer on flat roofs that are subsequently surfaced with bitumen and mineral aggregate. Mineral surfaced glass fibre based felts may be used as a top layer on flat roofs as low cost finish and on sloping roofs as a finish layer.

A perforated, glass fibre based felt is produced for use as a venting first layer on roofs where partial bonding is used.

The durability of glass fibre based felt depends principally on the bitumen with which it is saturated. In time the bitumen coating will oxidise on exposure to the radiant energy from the sun, harden and ultimately crack and let in water. A layer of insulation under the felt will appreciably increase the rise in temperature and expansion of the surface and so accelerate the cracking of the hardened top surface. A generous layer of light colour mineral aggregate dressed over the surface will, to an extent, give some protection.

The serviceable life of this weathering is of the order of 20 to 30 years.

It is generally accepted that the appearance of this roof finish is unattractive.

Polyester base bitumen felts

A polyester base of staple fibre or filament, formed by needling or spin bonding, is impregnated with bitumen. The fibre or filament base of polyester has higher tensile strength than the true felt bases. Because of this greater strength this 'felt' is better able to withstand the strains due to structural, thermal and moisture movement without rupture that a flat roof covering will suffer.

The fine granule surfaced felt is used as a base, intermediate or top layer of built-up roofing which is to be subsequently covered with bitumen and mineral aggregate finish. The mineral surface felt is for use as a top layer where there is no additional surface treatment.

Polyester base felt, which is generally used for the three layers of built-up roofing, is sometimes used as top coat to underlays of glass fibre based felt as an economy.

High performance roofing

The so called high performance bitumen coated bases are made with a polyester fabric that is coated with polymer modified bitumen. The bitumen is modified with styrene butadiene styrene (SBS) or atactic polypropylene (APP) to provide improved low temperature flexibility, improved creep resistance at high temperatures and greatly improved fatigue endurance to the bitumen.

These high performance bitumen bases, which are generally used in two layers, are more expensive than other built-up roofings and are used for their appreciably improved resistance to the strains common to flat roof coverings.

Mineral surface dressing

The finished top surface of built-up felt roof covering is often finished with a dressing of mineral aggregate spread over a bitumen coating. The purpose of this mineral dressing is to act as a reflective, protective layer of light coloured particles to reduce the oxidising and hardening effect of direct sunlight on the bitumen bonding compound and also for the sake of the appearance of this singularly unattractive covering.

Light coloured mineral aggregate, graded in size from 16 to 32 mm, is spread to a thickness of at least 12.5 mm on a layer of bitumen.

Fire safety

A requirement of the Building Regulations concerning safety is that roof coverings should not contribute to the spread of fire between adjacent buildings. To meet the requirement flat roofs covered with bitumen felt should have a surface finish of stone chippings at least 12.5 mm thick, tiles of an incombustible material, sand and cement screed or macadam.

Laying built-up bitumen felt roofing

Unlike asphalt, which is a comparatively heavy roof covering, it is necessary to provide some bond of felt to the roof deck against wind uplift and to allow some freedom for movement of the felt independent of the roof.

In the early days of the use of bitumen felt roofing it was practice to nail the first layer to the roof boarding, a practice that persists today.

Nailing may not provide sufficient freedom of movement for the felt relative to the roof deck with the consequent possibility of the felt expanding, permanently stretching to form visible ripples between fixings and so impeding run off of rainwater. Over the course of a few years the persistent wetting in troughs may cause the felt to deteriorate and let in water.

Where the surface of the roof deck for both low pitched and flat roofs is formed with rough, square edged boarding it was, and still is to an extent, practice to nail the first layer with clout nails at 150 mm staggered centres over the area of each sheet and at 50 mm centres on the centre line of all 50 mm overlaps of sheets. The reason for this is that the boards may shrink, twist and lose shape in drying out and so not provide a level base for a bitumen bond by itself.

The first layer is then covered with a further layer of felt fully bitumen bonded for short term cover or with two layers for longer term cover.

Practice today is to bond the first layer of felt to the roof deck with bitumen spread over the whole surface of the roof or more usually in a system of partial bonding with bitumen to allow some freedom of movement relative to the roof.

Bitumen felt is applied to flat roofs in three layers, the first, intermediate and top layers. The rolls of felt are spread across the roof with a side lap of 75 mm minimum between the long edges of rolls and with a head, or end, lap of at least 75 mm for felts and 150 mm for polyester based felts. To avoid an excessive build-up of thickness of felt at laps, the side lap of rolls of felt is staggered by one-third of the width of each roll between layers so that the side lap of each layer does not lie below or above that of other layers, as illustrated in Fig. 237.

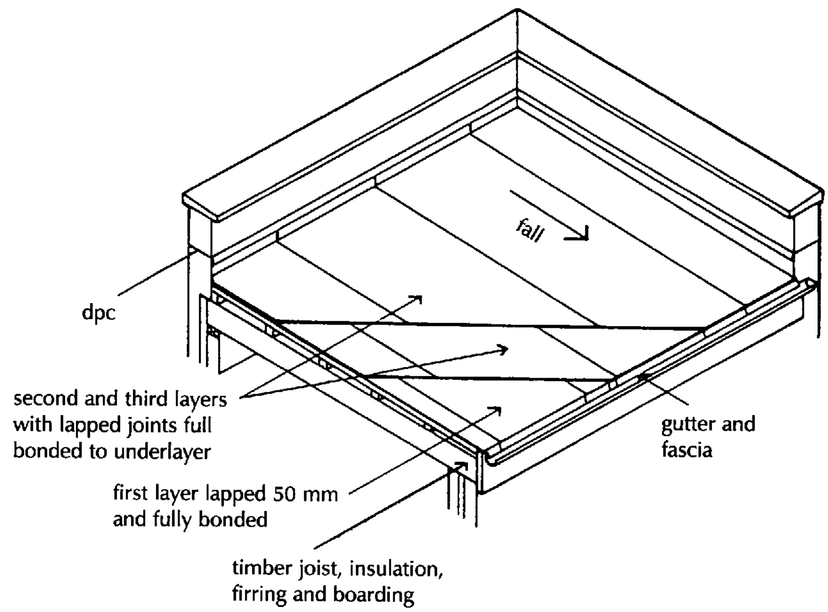


Fig. 237 Built-up felt covering to timber flat roof.

Laying felt roofing

Full bond

The traditional method of fixing felt roofing is by fully bonding the felt to the roof deck and the layers of felt to one another by the 'pour and roll' technique in which hot bitumen is poured on the roof deck and the rolls of felt are continuously rolled out as the bitumen is poured. The pour and roll method of bonding is used for all three layers in the full bonding method and for the two top layers in the partial bond method. The purpose of the bitumen is initially to bond the first layer to the roof deck against wind uplift and then to bond the succeeding layers to each other and form a watertight seal at overlaps of rolls of felt.

The majority of timber framed flat roofs today are formed with a deck of sheets of plywood or particle board, for economy in labour and to provide a stable, level surface for built-up bitumen felt roofing.

The joints between the boards are first covered with strips of self-adhesive tape and the three layers of felt are fully bonded to the deck or a perforated first layer of felt is laid loose over the deck. This first layer is of fibre glass based felt which is perforated with holes. The intermediate layer is then fully bonded in bitumen to the perforated layer so that the hot bitumen runs through the perforations to bond with the deck as a form of partial bonding. The final layer is then fully bonded in bitumen to the intermediate layer.

The full bond method is used where appreciable wind uplift is anticipated in exposed positions and the perforated bottom layer where wind uplift is low in sheltered positions that will also allow some freedom of movement of the felt relative to the roof.

Partial bond

Where it is anticipated that wind uplift will be moderate it is usual to use a perforated, glass fibre based felt as a first layer to allow some movement of the deck independent of the felt covering. The perforated first layer is laid loose over the deck and the intermediate layer is fully bonded to it. The hot bitumen bed will penetrate the perforated bottom layer to effect a partial bond to the deck. The top layer is then fully bonded to the intermediate layer.

On a roof deck covered with insulation boards the method of bonding the first layer depends on the composition of the insulation. The majority of insulation boards either have a surface to which hot bitumen can be applied or are coated to assist the bond of bitumen. On polyurethane and polyisocyanurate boards, provision should be made for the escape of gases generated by the use of hot bitumen, by using a perforated venting first layer of felt that is laid loose over the boards.

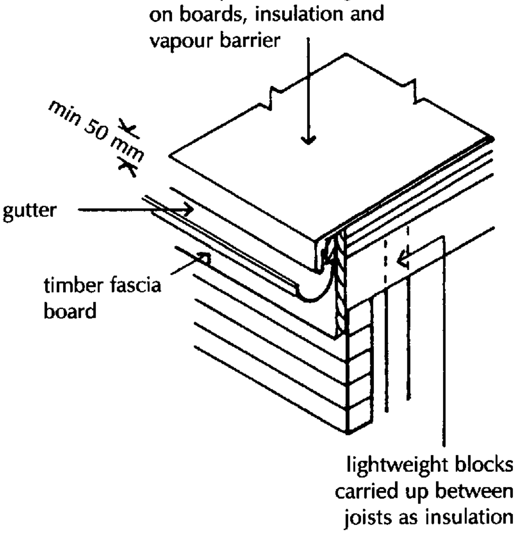


Fig. 238 Eaves gutter.

Built-up bitumen felt roof coverings should be laid to a shallow fall so that rainwater will run off to a gutter. The most straightforward way of draining these flat roofs is by a single fall to one side to discharge directly to a gutter fixed right across one side of the roof, as illustrated in Fig. 238. Here the roof is enclosed inside a parapet wall on three sides.

The roof joist ends are carried over the wall to provide a fixing for a softwood timber fascia board which supports a gutter, as illustrated in Fig. 238. To direct the run off of water into the gutter a strip of felt is nailed to the fascia board, welted and then turned up on the roof and bonded between the first and intermediate layers of felt.

Because felt is difficult to welt without damage a strip of sheet lead may be used as an alternative to the felt strip.

For continuity of insulation a lightweight insulation inner leaf of wall or cavity insulation is carried up to the level of the roof insulation.

At the junction of a felt covered flat roof and a parapet or a wall the top two layers of three-ply bitumen felt are dressed up the wall over an angle fillet as an upstand 150 mm high. The top of the felt upstand is covered with a lead flashing which is tucked into a raked out brick joint and dressed over the upstand, as illustrated in Fig. 239.

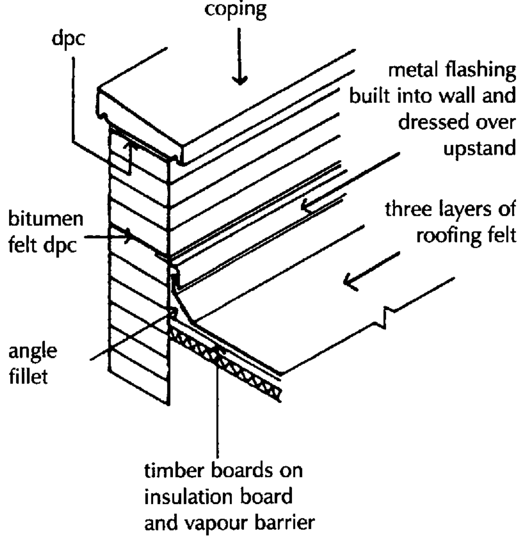


Fig. 239 Upstand and flashing.

Single-ply roofing

For details of single-ply, polymeric roof membranes see Volume 3.

Inverted or upside down roof

An effective layer of insulation laid or fixed below flat roof coverings will appreciably increase the temperature fluctuations that a roof covering will suffer between hot, overhead sun and cold nights. Without the insulation the extremes of temperature are reduced by transmission through the covering to the roof structure.

Bitumen felt coverings are particularly affected by direct sunlight which causes oxidisation of the bitumen which hardens and becomes brittle and liable to crack.

The most rational place for the layer of insulation on a flat roof, particularly those covered with bitumen felt and, to a lesser extent, asphalt, is on top of the covering to reduce temperature fluctuations.

In this form of construction one of the organic closed cell insulation boards such as those made of coalesced glass beads, which do not absorb water and are sufficiently dense to support the overlay of stones or paving slabs, is used.

The roof covering of bitumen felt, asphalt or one of the single-ply membranes described in Volume 3 is laid on the roof deck with upstands carried up to 150 mm above the finished level of the loading stones or paving slabs. The roof covering may be laid to slight falls to rainwater outlets or laid flat to outlets. The insulation boards are laid, butt side jointed, on top of the roof covering.

To protect the insulation against wind uplift the roof is covered with a layer of mineral aggregate, stones, of sufficient depth to hold the insulation in place. Where the flat roof serves as a terrace, paving stones are used as a loading coat, as illustrated in Fig. 240. The paving stones are laid, open jointed, on a filter layer of dry sand or mineral fibre mat as a bed and filter for rainwater.

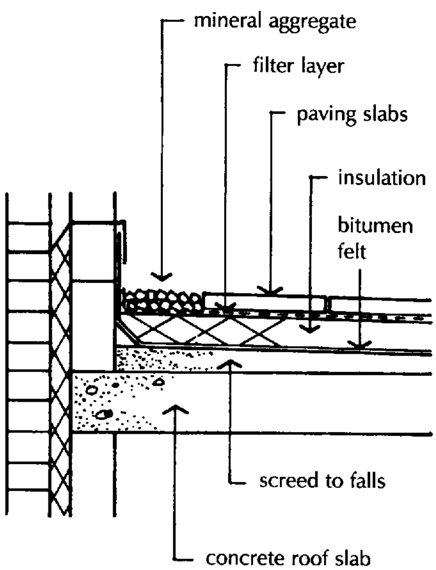


Fig. 240 Inverted or upside down roof.

Rain falling on the roof will in part be retained by the stone or paving slab covering and the filter layer, and will in part drain through the insulation to the covering. During dry periods much of the rain retained by the stones or paving slabs will evaporate to air.

For access to clear any blockages that might occur in rainwater outlets it is wise to provide a margin, around the edge of the roof, of loose aggregate over a narrow strip of insulation that can be lifted to clear blockages.

The disadvantage of the inverted roof is that where leaks occur in the covering the whole top layer may have to be removed. Because of the protection afforded by the two top layers, faults in the covering are less likely than with coverings laid on the insulation.

Concrete flat roofs

Reinforced concrete flat roofs for small buildings are constructed in the same way as reinforced concrete floors with hollow beam, beam and filler blocks or in situ cast concrete slab, reinforced to support the self-weight of the roof, rain, snow and wind pressure or uplift. Roofs are designed to provide support for access for maintenance or for use as a terrace. The roof is supported by external walls with intermediate support as necessary from internal loadbearing walls or beams.

To provide a smooth level surface ready for the roof covering the concrete or concrete topping may be power floated. More usually a cement and sand screed is used as a finish which can be spread and finished to the level or levels necessary to provide a fall to drain rainwater off the roof. A screed can be finished to one way, two way or four way falls to rainwater outlets with the necessary currents at intersections of falls.

When insulation of roofs first became necessary to meet the early requirements of the Building Regulations it was quite common practice to use lightweight screeds composed of lightweight aggregate and cement to provide the necessary surface and serve as thermal insulation to meet the early modest requirements for insulation.

All wet, cement mix materials take time to thoroughly dry out and this is singularly true of lightweight aggregate screeds which may, during the drying period, absorb rainwater and so increase the drying out time. A consequence was that water drying out from these screeds, trapped below asphalt and bitumen felt coverings, would expand to moisture vapour due to direct sunlight and raise blisters and possibly rupture the weather membrane. The remedy was to provide complicated ventilation paths and systems of ventilation to relieve moisture vapour pressure.

With the current more stringent requirements for conservation of fuel the use of lightweight aggregates, which provide only modest insulation, has been largely abandoned.

With the use of a layer of insulation under flat roof coverings it is sometimes considered necessary to provide ventilation against the possibility of water drying out from cement concrete and screeds penetrating the insulation, expanding to moisture vapour and so rupturing the weather covering.

Asphalt roof covering

The conventional wisdom is that asphalt is best suited as a covering to concrete and felt to timber roofs. The sense is that the comparative stability and freedom from shrinkage movement of concrete is best suited to the heavy, inflexible nature of asphalt, whereas the lighter, more flexible nature of built-up bitumen felt is better suited to a timber roof.

Hot asphalt is spread over a layer of loose laid sheathing felt on a dry screed finish in two layers to a finished thickness of 20 mm and covered with a dusting of dry, fine, sharp sand to absorb the 'fat' of the neat asphaltic bitumen that is worked to the surface by hand spreading. On a screed laid to falls and currents the asphalt drains to

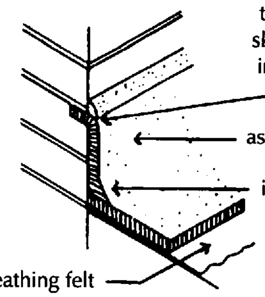


Fig. 241 Asphalt skirting.

outlets formed in parapet walls as illustrated in Fig. 242. The asphalt skirting is dressed into the outlet in the parapet over a lead chute dressed down over a rainwater head.

A reinforcing, internal angle, fillet of asphalt is formed at the junction of the flat roof and the parapet wall and the 150 mm high asphalt skirting. The top of the skirting may be turned into a groove cut in a horizontal brick joint, as illustrated in Fig. 241.

As an alternative the asphalt skirting may be run up the face of the wall by itself or over plastic vents placed at intervals to provide ventilation for moisture vapour. The top of the skirting is then covered with a sheet lead flashing, tucked into and wedged in a raked out brick joint and dressed down over the upstand asphalt skirting.

The spacing and size of skirting vents and the need and frequency of vents in the surface of the asphalt is indeterminate. First or second hand knowledge of past failures of asphalt by blisters may dictate the assumption of the need for vents rather than soundly based need.

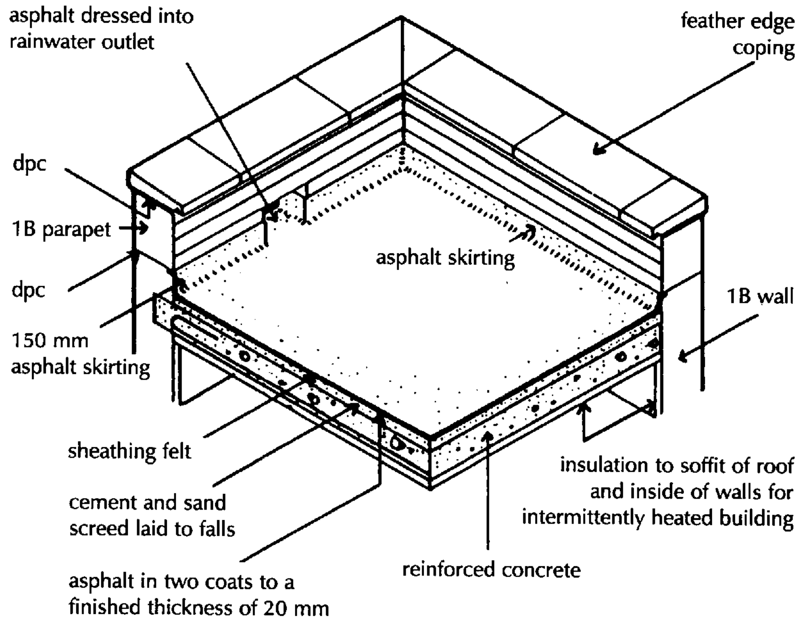


Fig. 242 Asphalt covering to concrete flat roof.

Built-up bitumen felt covering

As a precaution against the possibility of water drying out from screeded concrete roofs and rising to the surface under bitumen felt coverings, expanding and causing blisters, it is usual to use the partial bonding method.

With the partial bonding method the first layer of felt is bonded to the surface of the screed with perimeter and intermediate strips of bitumen with 180 mm wide vents between the strips of bitumen to allow moisture vapour to vent to perimeter and central vents.

The surface of the screed is first coated with a bitumen primer to improve the bond of bitumen to screed. Perimeter strips of bitumen 450 mm wide are spread around the roof with 150 mm wide vents at intervals for moisture vapour to vent to the perimeter. Strips of bitumen are spread over the body of the roof, as illustrated in Fig. 243.

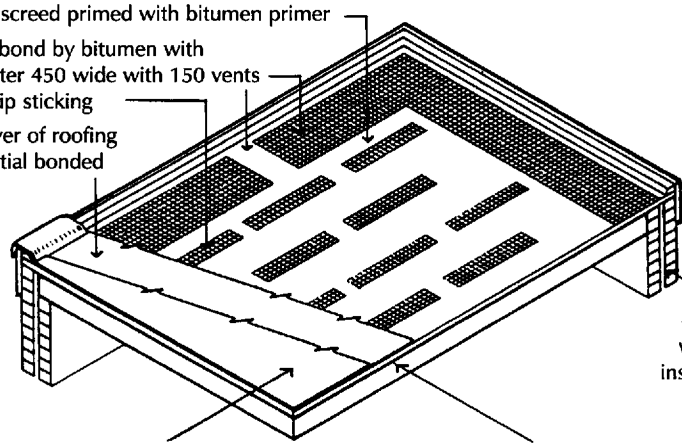


Fig. 243 Partial bond of felt roofing to concrete.

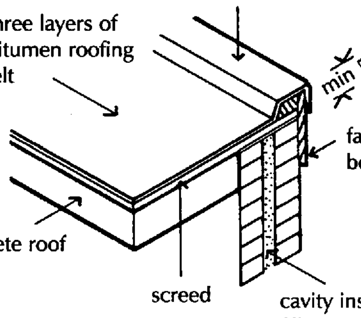


Fig. 244 Verge.

The principal adhesion of the felt covering, against wind uplift, is effected by the perimeter bonding. The size and spacing of the strips of bitumen is chosen as a matter of judgement between the need for adhesion to keep the felt covering flat and the assumed need to provide ventilation paths for moisture vapour pressure.

The first layer of felt is rolled out on to the hot bitumen and the intermediate and final layers of felt are rolled out and fully bonded and lapped as described for laying built-up bitumen felt roofing on timber.

At verges the intermediate and final layers of felt can be shaped over a splayed wood block and then covered with a strip of felt that is welted to a timber batten and turned over on to the roof, as illustrated in Fig. 244.

Where there is a parapet wall around the roof the intermediate and top layers of felt are turned up against the wall some 150 mm and covered with a lead sheet flashing which is turned into and wedged in a raked out brick joint.

Because the end laps of rolls of felt are made to overlap down the slope or fall of a roof it is difficult to form cross falls and currents to slopes of roof to a parapet wall rainwater outlet; it is usual to drain felt roofing to one continuous verge gutter.

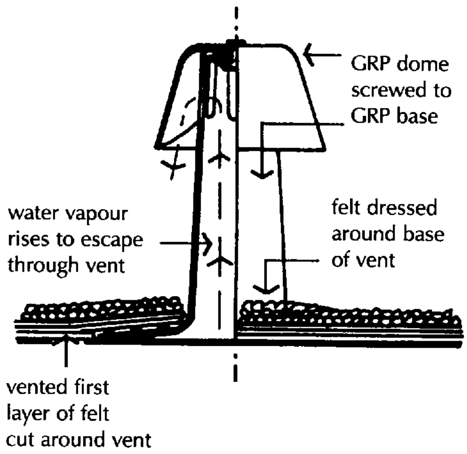


Fig. 245 Ventilator.

Where a built-up bitumen felt covering is laid to falls to parapet wall outlets it is impossible to avoid an untidy build-up of overlaps at oblique cuts of felt.

The usual method of providing ventilation for moisture vapour pressure is plastic ventilators that are fixed behind the felt upstand to parapet walls and to the felt overlap at verges. The parapet ventilators are covered with the apron flashing.

On larger roofs, where it is deemed necessary to provide additional ventilators in the surface of the roof, glass fibre reinforced plastic vents are fixed in the roof at about 6 m centres. These ventilators, illustrated in Fig. 245, are fixed to the roof and the intermediate and top layers of felt are cut and bitumen bonded around the vents.

Conservation of fuel and power

The requirement contained in the Building Regulations for the conservation of fuel and power is that 'Reasonable provision shall be made for the conservation of fuel and power in buildings by limiting the heat loss through the fabric of the building'. In Approved Document L to the regulations is practical guidance on meeting the regulations. There is no obligation to adopt the guidance contained in the Approved Document.

One additional requirement in the Building Regulations, that applies only to new dwellings, is that the calculation by a standard assessment procedure (SAP) of energy rating for the new dwelling should be submitted to the building control body. There is no obligation to achieve a particular SAP rating providing reasonable provision is made to conserve fuel and energy.

Resistance to the passage of heat

The resistance of flat roofs to the transfer of heat is poor. To achieve improved resistance to the transfer of heat Approved Document L advises the inclusion of a material with good resistance to heat transfer, insulation, in the construction of the roof.

As a practical, sensible measure of the maximum transfer of heat that should be allowed to conserve fuel and energy Advisory Document L suggests standard U values for roofs of 0.2 W/m^2K for dwellings, with an SAP rating of 60 or less, 0.25 W/m^2K for those with an SAP rating of over 60 and a U value of 0.25 W/m^2K for all other buildings.

The U value is a measure of how much heat will pass through one square metre of a structure when the air temperatures on either side differ by one degree, expressed as watts per square metre per degree temperature difference as W/m^2K. The U value, coefficient of thermal transmittance, is used as a convenience to determine the transfer of heat through a structure made of various materials.

Most of the materials used in the construction of flat roofs, separately or together, provide insufficient resistance to the transfer of heat to meet the requirement of the Building Regulations. It is necessary, therefore, to build in or fix some material with high resistance to heat transfer to act as a thermal insulation.

The most practical position for a layer of insulation for a flat roof is on top of the roof structure either under or over the weathering cover. In this position the insulation boards can be fixed or laid without undue wasteful cutting to provide insulation for the roof structure and utilise the heat store capacity of a concrete roof to provide some heat during periods when the heating is turned off.

As an alternative to fixing insulation on top of a flat roof it may be fixed between the ceiling joists of a timber roof so that the thermal resistance of the timber joists combines with the greater resistance of the insulation material. Tables in Approved Document L provide details of the thickness of insulation required for common insulating materials for a range of U values for insulation between joists.

The disadvantage of fixing insulation between the joists of timber flat roofs is the wasteful cutting necessary to fit the material between the joists, the labour necessary to support or wedge the material in position and the need for oversize electrical cables run in the insulation.

Thermal bridge

For efficient insulation against heat loss through the fabric of a building it is advisable to unite the system of insulation used in walls with that used in roofs and minimise those parts of the construction that provide a low resistance path to transfer of heat across, what have been called, thermal bridges.

The extent to which a detail of construction will act as a thermal bridge will depend on the difference in thermal resistance of the thermal bridge, and that of the adjoining construction. Where the difference is gross an appreciable concentration of condensation may appear on the colder surface of the bridge and cause unsightly stains and mould growth and adversely affect materials such as iron and steel.

To reduce the thermal bridge effect at the junction of a concrete roof built into a cavity wall and the inner leaf carried up as a parapet, the cavity insulation should be carried up the cavity face of a concrete block inner leaf to minimise the possibility of condensate stains on the soffit of the concrete roof at the intersection of ceiling and wall, as illustrated in Fig. 246.

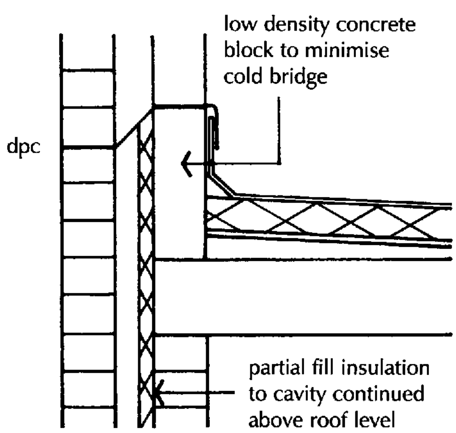


Fig. 246 Junction of roof and wall.

Similarly the cavity insulation of a wall should be carried up to unite with the roof level insulation of a timber flat roof to minimise condensation stains at the ceiling and wall junction, as illustrated in Fig. 247.

In buildings such as offices and places of assembly where the building is intermittently heated with high temperature radiant hea-

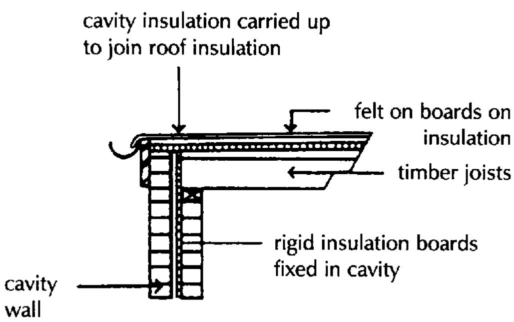


Fig. 247 Wall insulation joined to roof insulation.

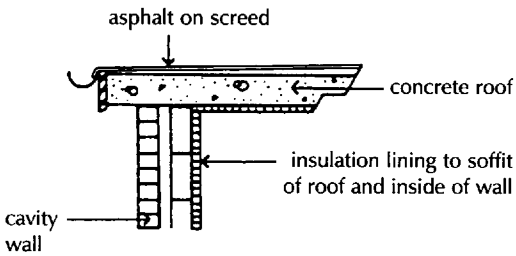


Fig. 248 Internal insulation.

ters it is often practice to fix the insulation to the fabric on the inside face of walls and ceilings in the form of insulation backed plasterboard, as illustrated in Fig. 248. In this way the radiant heat, when first turned on, immediately heats inside instead of expending some of its energy on heating the fabric.

Where a flat roof projects beyond the face of an external wall as a projecting verge to provide some protection for the wall below, or for the sake of appearance, it may not be practical to unite the wall insulation with that of the roof. In consequence there may be a path for the more rapid transmission of heat than in the surrounding fabric.

Heat may well be more readily conducted from inside through the concrete roof to outside than elsewhere in the detail illustrated in Fig. 249. To limit the thermal bridge effect in the construction illustrated it has been suggested that insulation is fixed behind a timber soffit board and behind a timber fascia board, as illustrated in Fig. 249.

The edge and soffit insulation will reduce the external surface area for thermal bridging but leave a possible path from inside to outside through the concrete and the external leaf to outside. The probability is that the extended thermal bridge of the concrete roof will provide adequate thermal resistance by itself and the edge and soffit insulation are unnecessary.

Similarly with the overhanging verge of a timber flat roof it has been suggested that edge and soffit insulation be used as illustrated in Fig. 250. The probability here is that the extended thermal bridge from inside, through the roof to outside, is in all likelihood sufficient to provide adequate thermal resistance, taking into account the

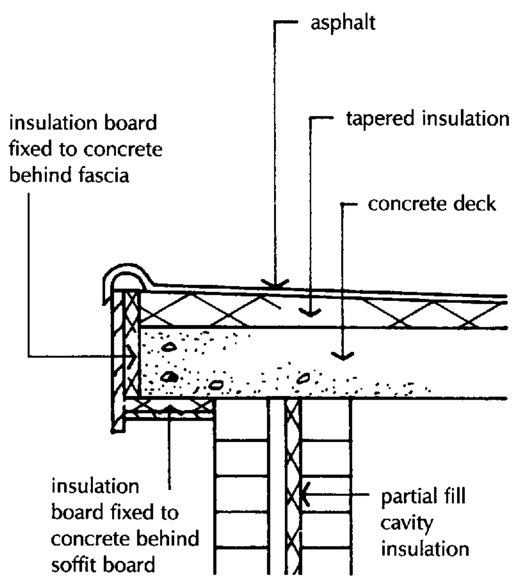


Fig. 249 Insulation to overhang.

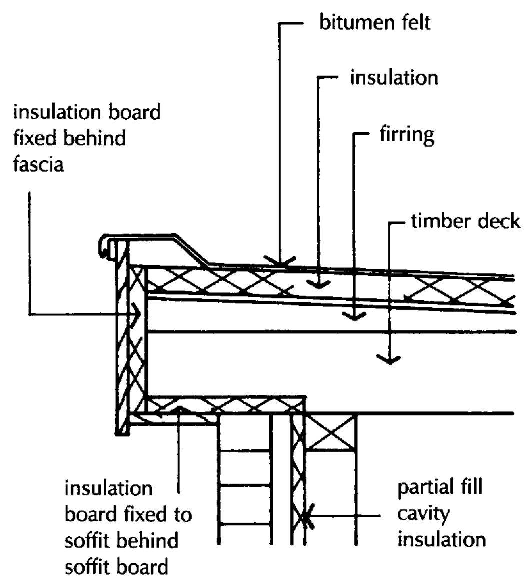


Fig. 250 Insulation to overhang.

thermal resistance of the timber joists, fascia and soffit boards and air between joists where the roof space is not ventilated.

Insulation materials

To provide the required thermal resistance for a flat roof one of the semi-rigid insulation boards is used for roof level insulation. The cheapest material that is used is rockwool slabs either of uniform thickness or cut to provide falls for roof drainage, particularly for asphalt finishes.

Expanded and extruded polystyrene boards are the cheapest of the inorganic materials made in boards of uniform thickness or tapered for falls to roofs with expanded polystyrene.

The three inorganic material boards PIR, PUR and PUR have the lowest U value. They are the more expensive of the materials and are faced with glass fibre tissue for protection and as a finish impermeable to moisture vapour so that they may be used without the need for a moisture vapour check.

Some details of these materials are set out in Table 12.

Ventilation

The requirement of Part F to the Building Regulations is that 'adequate provision be made to prevent excessive condensation in a roof or a roof void above an insulated ceiling'.

Condensation is the effect caused by the reduction in temperature of warm, moisture vapour laden air coming into contact with a cold surface on which water is deposited as condensation. Where the condensation is excessive it may so saturate open texture insulation that it appreciably reduces the thermal resistance of the insulation and may cause unsightly damp stains and mould growth on decorated surfaces.

To minimise the extent of such an effect it has been practice to form a moisture vapour check on the warm side of insulation to reduce the penetration of moisture vapour to insulation. This practice, which is in all probability unnecessary, persists today.

The principal sources of warm, moist air are enclosed bathrooms and kitchens. The current requirement of Part G to the Building Regulations is that there shall be both natural and mechanical ventilation to bathrooms and kitchens to extract moist, warm air to outside. The combination of effective extract ventilation to the sources of warm, moist air, the use of moisture vapour checks and the use of moisture vapour impermeable insulation has reduced the likelihood of excessive condensation occurring.

There is a recommendation in Approved Document F to the Building Regulations that where there is a likelihood of excessive condensation in roof voids above insulated ceilings, the void space or spaces in this cold roof form of construction should be ventilated to outside air.

Table 12 Insulation materials.

Flat roof warm roof	**Thickness mm**	**U value W/m²K**
Rockwool		
slab 1200 × 60	30, 40, 50, 60, 70, 80, 90, 100	0.036
slab cut to falls 1200 × 890	30, 40, 50, 60, 70, 80, 90, 100	0.036
Cellular glass		
board 1200 × 600	30, 35, 40, 50, 60, 70, 80	0.042
EPS		
board uniform in thickness or tapered	from 20 up in 5 increments	0.034
XPS		
board 1250 × 600	50, 75, 90, 100, 120	0.025
PIR		
board faced with glass fibre tissue 1200 × 750	35, 40, 50	0.022
PUR		
board bitumen impregnated glass fibre tissue faced 1200 × 750	26, 32 35, 40, 50, 75	0.022
PUR		
board glass tissue fibre faced 2400 × 1200	25, 30, 35, 50, 55	0.022

EPS expanded polystyrene
XPS extruded polystyrene
PIR rigid polyisocyanurate
PUR rigid polyurethane

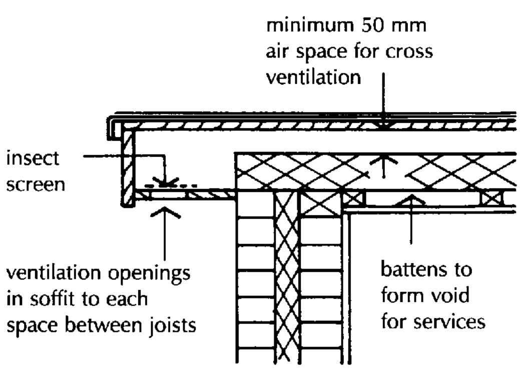


Fig. 251 Ventilation.

In the unlikely event of excessive condensation occurring it is recommended that there be formed a clear air space of at least 50 mm above the insulation. This space should be ventilated by continuous strips at least equal to continuous strips 25 mm wide running the full length of eaves on opposite sides of the roof. The ventilating openings are formed in the soffit of the overhang by plastic ventilators fitted with insect screens.

Where the insulation is laid or fixed between the joists there should be a clear space above the top of the insulation and underside of the roof of at least 50 mm for air to circulate across the roof from opposite sides, as illustrated in Fig. 251. So that electric cables are not run in the insulation the ceiling is fixed to battens to provide a space in which to run cables.

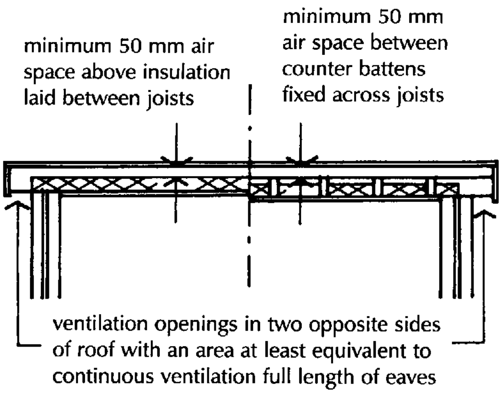


Fig. 252 Ventilation.

Where rolls of mineral fibre are laid between joists to the extent that there is not a clear 50 mm space between joists above the insulation, it is necessary to fix timber counter battens across the ceiling joists to provide the recommended 50 mm, minimum ventilation space as illustrated in Fig. 252.

Because of unpredictable, variable weather, it is uncertain whether the ventilation suggested will be effective in providing appreciable air movement to cause ventilation. Unless there is some realistic likelihood of there being excessive condensation in a timber flat roof, in spite of ventilation to bathrooms and kitchens, there seems little sense in the ventilation proposed.

PARAPET WALLS

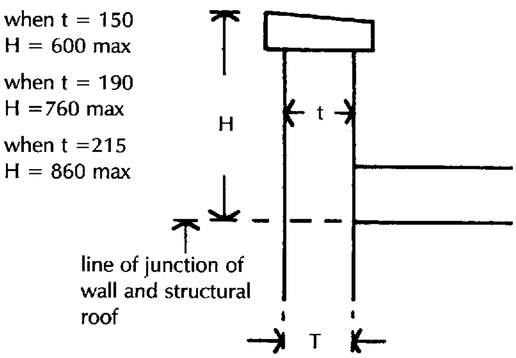


Fig. 253 Solid parapet wall.

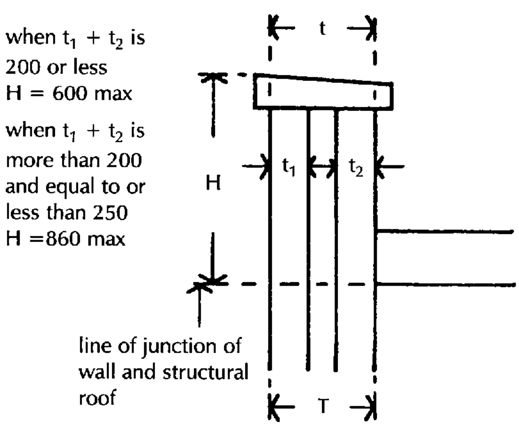


Fig. 254 Cavity parapet wall.

External walls of buildings are raised above the level of the roof as parapet walls for the sake of the appearance of the building as a whole. Parapet walls which are exposed on all faces to driving rain, wind and frost are more liable to damage than external walls below eaves level.

Because parapet walls are freestanding their height is limited in relation to their thickness for the sake of stability. Approved Document A, giving practical guidance to the requirements of the Building Regulations for houses and other small buildings, sets limits to the thickness and height of solid parapet walls, as illustrated in Fig. 253. Where the height (H) of the parapet walls is not more than 600 mm it should be not less than 150 mm thick, where H is 760 mm the thickness should be not less than 190 mm thick and where it is not more than 860 mm the thickness should not be less than 215 mm.

Where an external cavity wall is carried up as a parapet wall, as illustrated in Fig. 254, the limits of height (H) are not more than 600 mm where the combined thickness of the two leaves ($t_1 + t_2$) is equal to or less than 200 mm and 860 mm where the combined thickness of the two leaves ($t_1 + t_2$) is greater than 200 mm and equal to or less than 250 mm.

To protect the top surface of a parapet wall which is exposed directly to rain, it is essential that it should be covered or capped with some dense material to prevent rain saturating the wall. Natural stone was commonly used for this purpose as it is at once protective and decorative. The stones which are described as coping stones are cut so that they have a sloping surface when laid which is described as weathering. The stones usually project some 50 mm or more each side of the parapet wall so that rainwater running from them drips clear of the face of the wall. Three common sections employed for coping stones are shown in Fig. 255.

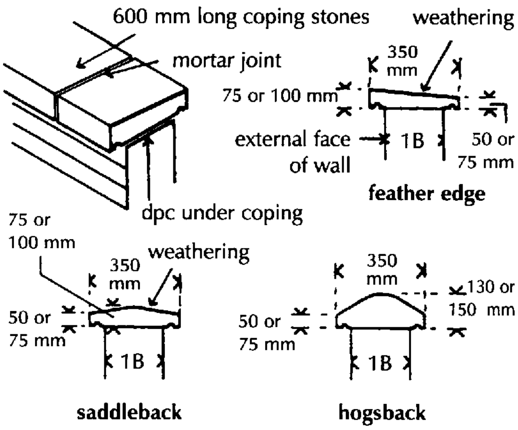


Fig. 255 Coping stones.

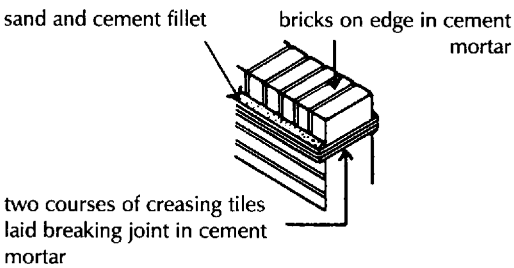


Fig. 256 Brick capping.

To encourage rainwater to run off the coping stones, clear of the wall faces, it is practice to cut semi-circular grooves in the underside of the overhang edges of the stones so that water runs off the extreme drip edges of the stones. Featheredge copings are laid so that the weathered top surface slopes towards the roof to minimise staining fair face external brick faces.

The stones are bedded in cement mortar on the parapet wall and butt end joints between stones are filled and pointed in cement mortar.

For economy, cast stone copings are used instead of natural stone copings. These stones are made as artificial stone with a core of concrete faced with a mixture of crushed stone particles and cement. The surface of cast stone may soon show irregular, unsightly staining.

Coping stones are usually in lengths of 600 mm with the joints between them filled with cement mortar. In time the mortar between the joints may crack and rainwater may penetrate and saturate the parapet wall below. If frost occurs, the parapet wall may be damaged. To prevent the possibility of rainwater saturating the parapet through the cracks in coping stones it is common practice to build in a continuous dpc of bituminous felt, copper or lead below the stones, as illustrated in Fig. 255.

Another method of capping parapet walls is to form a brick on edge and tile creasing capping. This consists of a top course of bricks laid on edge, and two courses of clay creasing tiles laid breaking joint in cement mortar, as illustrated in Fig. 256. The bricks of the capping are laid on edge, rather than on bed, because many facing bricks have sand faced stretcher and header faces. By laying the bricks on edge only the sanded faces show, whereas if the bricks were laid on bed, the bed face which is not sanded would show. Also a brick on edge capping looks better than one laid on bed. Creasing tiles are made of burned clay and are usually 265 mm long by 165 mm wide and 10 mm thick. The tiles are laid in two courses breaking joint in cement mortar.

The tiles overhang the wall by 25 mm to throw water away from the parapet below. A weathered fillet of cement and sand is formed on top of the projecting tile edges to assist in throwing water away from the wall. Two courses of good creasing tiles are generally sufficient to prevent water soaking down into the wall and no dpc is usually necessary under them. Parapet walls should be built with sound, hard, well burned bricks which are less liable to frost damage than common bricks. The bricks should be laid in cement mortar mix 1 cement to 3 of sand.

Parapet wall dpc

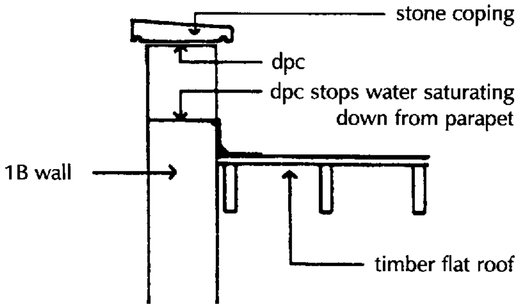


Fig. 257 Solid parapet.

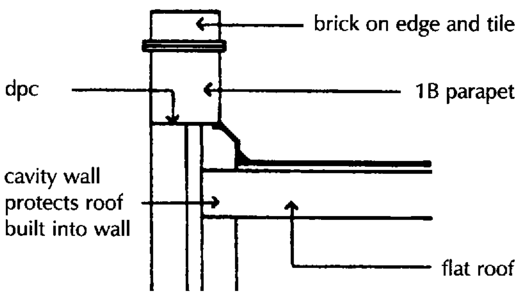


Fig. 258 Cavity parapet wall.

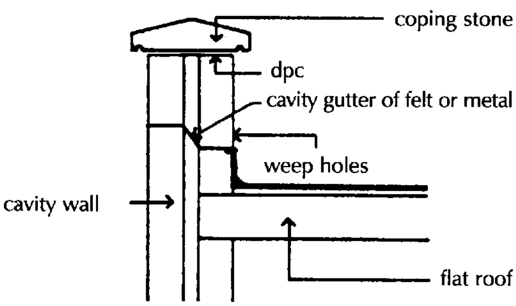


Fig. 259 Cavity carried above roof.

It has been practice for some years to form a horizontal dpc in parapet walls at the level of the top of upstand aprons and flashings to flat roof coverings. The purpose of this dpc is as insurance against the possibility of moisture in the exposed parapet wall penetrating down the wall to the roof itself. In reasonably sheltered positions this dpc is probably unnecessary in a wall built of sound bricks.

A parapet dpc to a solid brick parapet wall is illustrated in Fig. 257.

To provide protection to the roof structure it is usual to extend a cavity external wall up to the level of the top of the upstand of the roof covering to flat roofs as illustrated in Fig. 258. In this construction cavity insulation can be continued up to the level of insulation under roof coverings. A horizontal dpc is usually built in at the level that the solid brick parapet wall is raised on the cavity external wall, as illustrated in Fig. 258.

A cavity external wall is sometimes continued up as a parapet wall, as illustrated in Fig. 259. The only advantage of this arrangement is to continue the normal stretcher bond of external brickwork up to the parapet instead of having to change from stretcher to English or Flemish bond in a solid parapet, for the sake of appearance. Otherwise a cavity parapet serves no useful purpose and is probably an inconvenience as rainwater may penetrate to the cavity, particularly in exposed positions.

As a precaution against water penetrating to the cavity in a parapet wall it is practice to form a cavity dpc and tray which is continued across the cavity and built in one course lower in the roof side, as illustrated in Fig. 259. To collect and drain any water that may enter the cavity, weep holes are formed with raked out vertical joints in brickwork so that water runs down on to the roof.

The material best suited to this cavity dpc and tray is sheet lead that can more easily be dressed to shape across the cavity and over the upstand of the roof covering. An advantage of the lead dpc is that it will make a thinner, less ugly, horizontal joint on the external face of the wall than would a thicker felt dpc.

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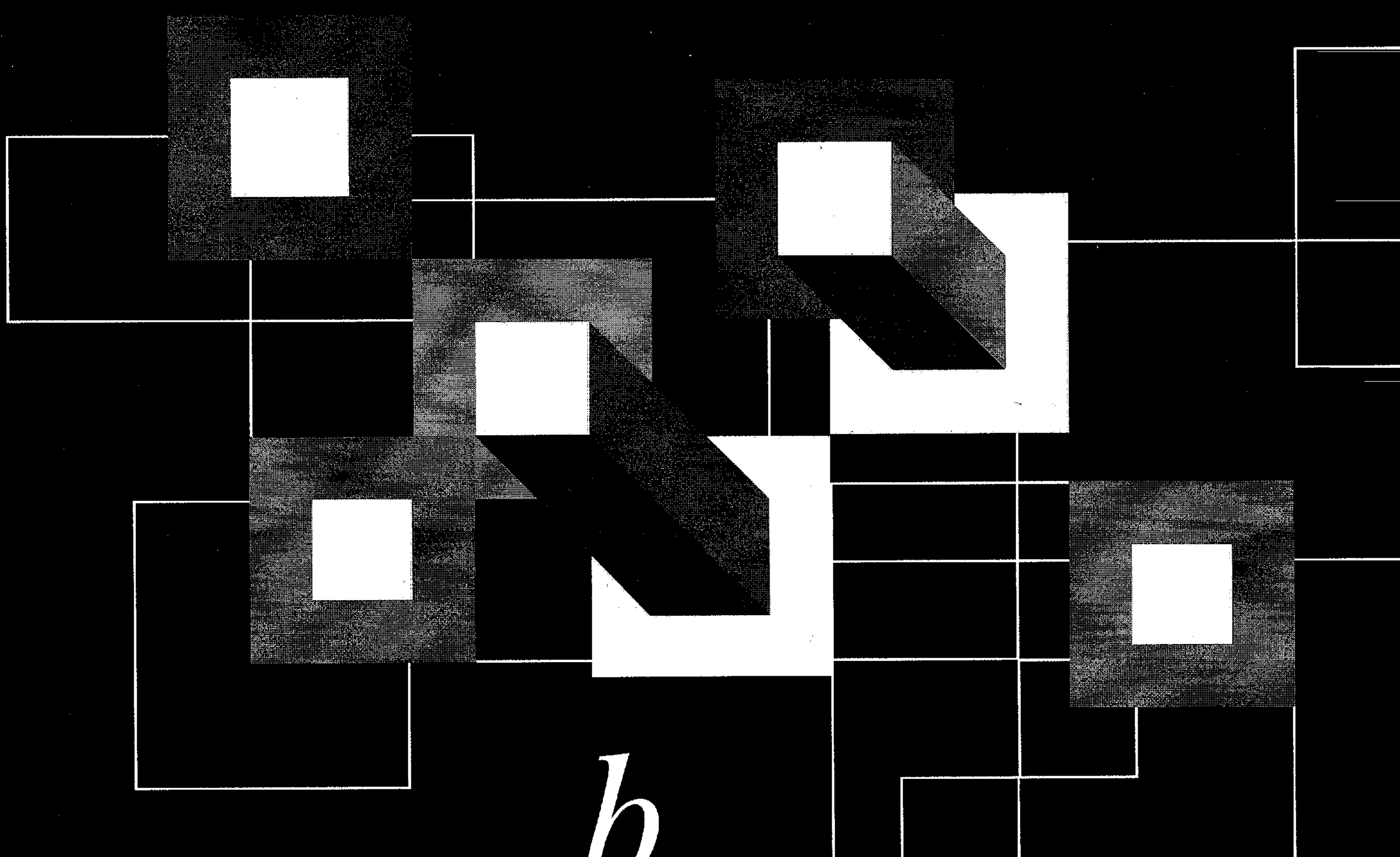

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Preface

Since publication of the first volume of *The Construction of Buildings* in 1958, the five volume series has been used by both lecturers and students of architecture, building and surveying, and by those seeking guidance for self-build housing and works of alteration and addition.

In this latest revision to Volume 2 a wide right hand column of text has been adopted to facilitate the inclusion of smaller diagrams in the left hand column and larger diagrams within the text column so that, wherever possible, the diagram is adjacent to the relevant text for ease of reference. Bold subheadings in the left hand column provide a quick reference for the reader.

Volume 2 deals with windows, doors, stairs, fires and chimneys, and finishes. The use of the revised page layout has provided a way of emphasising functional requirements such as daylight as the prime function of a window. The introduction and emphasis of thermal resistance as a function has of recent years taken precedence to the extent that the prime function of admission of daylight has been relegated to a minor need. In this revision it is hoped that daylight has reasserted itself as a prime function.

Through a rearrangement of the text and the new page layout it has been possible to give due weight to the prime functions of the elements of building.

The new edition has been updated as necessary to include relevant changes in regulations and practice, as well as a thoroughgoing revision of the text on plastering to take account of the current widespread use of gypsum plaster as an internal wall and ceiling finish.

Acknowledgements

My thanks to Ross Jamieson for redrafting my original drawings and to Mrs Sue Moore for advice and help in the new page layout.

1: Windows

FUNCTIONAL REQUIREMENTS

The primary function of a window is:

Admission of daylight

Daylight

A window is an opening formed in a wall or roof to admit daylight through some transparent or translucent material fixed in the window opening. This primary function of a window is served by a sheet of glass fixed in a frame in the window opening. This simple type of window is termed a fixed light or dead light because no part of the window can be opened.

As the window is part of the wall or roof envelope to the building, it should serve to exclude wind and rain, and act as a barrier to excessive transfer of heat, sound and spread of fire in much the same way that the surrounding wall or roof does. The functional material of a window, glass, is efficient in admitting daylight and excluding wind and rain but is a poor barrier to the transfer of heat, sound and the spread of fire.

Ventilation

The traditional window is usually designed to ventilate rooms through one or more parts that open to encourage an exchange of air between inside and outside. Ventilation is not a necessary function. Ventilation can as well be provided through openings in walls and roofs that are either separate from windows or linked to them to perform the separate function of ventilation. The advantage of separating the functions of daylighting and ventilation is that windows may be made more effectively wind and weathertight and ventilation can be more accurately controlled. An advantage of the opening parts of windows is as a means of cleaning the outside of glass, in windows above ground, from inside.

Figure 1 is an illustration of a casement window which combines a top hung ventlight, and side hung casement with a fixed light (deadlight). The fixed or deadlight provides the maximum area of glass for admission of daylight and the ventlight and casement means of ventilation and cleaning glass from inside. The clearance gaps around the ventlight and casement to allow them to open, need rebated frame members and weatherseals to serve as barriers to wind and rain.

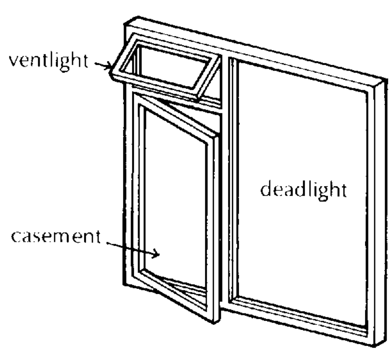


Fig. 1 Casement window.

DAYLIGHT

The prime function of a window is to admit adequate daylight for the efficient performance of daytime activities. Good sense dictates taking the maximum advantage of this free source of illumination when the modern alternative, electric light, is so extravagantly wasteful of natural fuel sources and grossly expensive.

Quantity of daylight

The quantity of light admitted depends in general terms on the size of the window or windows in relation to the area of the room lit, and the depth inside the room to which useful light will penetrate depends on the height of the head of windows above floor level. Common sense and observation suggest that the quantity of daylight in rooms is proportional to the area of glass in windows relative to floor area and this is confirmed by measurement.

Intensity of daylight

The intensity of daylight at a given point diminishes progressively into the depth of the room away from windows. For general activity purposes, such as in living rooms, an adequate overall level of daylight illumination is sufficient, whereas a minimum level of illumination in a particular area is necessary for such activities as drawing.

Daylight factor

Unlike artificial lighting, daylight varies considerably in intensity both hourly and daily due to the rotation of the earth and the consequent relative position of the sun, and also due to climatic variations from clear to overcast skies. In order to make a prediction of the relative level of daylight indoors, it is necessary to make an assumption. In Britain and north-west Europe it is current practice to calculate daylight in terms of a 'daylight factor' which is the ratio of internal illumination to the illumination occurring simultaneously out of doors from an unobstructed sky, rather than using the absolute value, that is lux, commonly used for artificial lighting. In the calculation of the daylight factor it is assumed that the illumination from an unobstructed sky, in the latitude of Britain, is 5000 lux and that a daylight factor of 2% means that 2% of the 5000 lux outdoors is available as daylight illumination at a specified point inside.

The assumption of a standard overcast sky, which represents the condition of poor outdoor illumination that may occur in autumn, winter and spring in northern Europe, is taken as a minimum standard on which to make assumptions. The term 'unobstructed sky' defines the illumination available from a hemisphere of sky free of obstructions such as other buildings, trees and variations in ground level, a condition that rarely occurs in practice.

The concept of a daylight factor has the advantage that it is a comparative value of the intensity of daylight indoors at different points so that even though the intensity of daylight outdoors will vary, the relative indoor intensity will remain more or less the same. The daylight factor concept provides a better indication of the subjective impression of daylight than would be the case were an absolute

Table 1 Recommended average daylight factors.

Building type	Location	Daylight factor
Dwellings	Living rooms	1.5
	Bedrooms	1
	Kitchens	2
Work places	Offices Libraries Schools Hospitals Factories	5
All buildings	Residential	2
All buildings	Entrances Public areas Stairs	2

Taken from DD73: 1982.

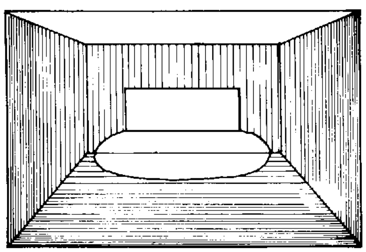


Fig. 2 Long low window.

value given. In the assumption of a standard overcast sky the effect of direct sunlight is excluded. The International Commission on Illumination (CIE) defines daylight factor as 'the ratio of the daylight illumination at a given point on a given plane due to the light received directly or indirectly from a sky of assumed or known luminance distribution, to the illumination on a horizontal plane due to an unobstructed hemisphere of this sky. Direct sunlight is excluded for both values of illumination'.

The intensity of illumination or luminance of the standard sky is assumed to be uniform to facilitate calculation of levels of daylight. In practice sky luminance varies, with luminance at the horizon being about one third of that at the sun's zenith. Average daylight factors for various activities are given in Table 1.

Where artificial illumination is used to supplement daylighting it is often practice to determine a working level of illumination in values of lux and convert this value to an equivalent daylight factor by dividing the lux value by 50 to give the daylight factor. For example, a lux value of 100 is equivalent to a daylight factor of 2. The average daylight factor in side-lit rooms is roughly equal to one fifth of the percentage ratio of glass to floor area.

In a room with a window on one long side, as illustrated in Fig. 2, with no external obstructions and a room surface reflectance of 40%, where the glass area is one fifth or 20% of floor area, the average daylight factor will be 4 and the minimum about half that figure. Conversely, to obtain an average daylight factor of, say 6, in a room with a floor area of 12m^2, a glass area of about $6 \times 12 \times 5/100 = 3.6\text{m}^2$ will be required. This broad average calculation is generally sufficient when used for general activity purposes such as in living rooms, and it is an adequate base for preliminary assumptions of window to floor area which can be adjusted later by a more accurate calculation of the light required for activities in which the lighting is critical.

Daylight penetration

A broad measure of the penetration of useful daylight into rooms is, taking an average figure of 2 as a daylight factor, the depth of penetration in line with the centre of windows as equal to the height of the window head above floor level, as illustrated in Fig. 3.

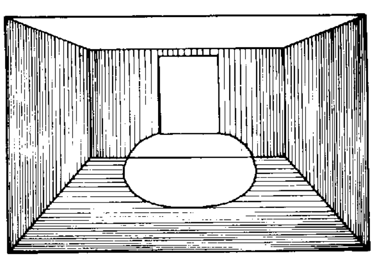


Fig. 3 Tall narrow window.

The quantity and quality of daylight illumination in side-lit rooms is affected to an extent by the light reflected from floors, walls and ceilings which will augment light coming directly through windows. Plainly the effect of this reflected light will be affected by the colour and texture of the reflective surfaces. Similarly some daylight, reflected from pavings and nearby external obstructions such as buildings and trees, will to an extent add to both the direct penetration of light and internally reflected light.

Reflected light

In the assumption of a daylight factor, account is taken of the contribution of what is termed 'the internally reflected component' and the 'externally reflected component' of indoor daylight illumination. Obviously the extent to which both the internal and external reflected light adds to or augments the indoor lighting will be least with low levels of overall daylight and dark, rough textured reflective surfaces, and will be most with higher levels of overall daylight and light coloured, smooth textured reflective surfaces.

The shape, size and position of windows affect the distribution of daylight in rooms and the view out. Tall windows give a better penetration of light than low windows, as illustrated in Fig. 4. The tall, narrow windows illustrated in Fig. 4 provide good penetration of daylight into rooms which may be augmented by the reflection from white painted, splayed internal reveals to the windows. Some distribution of daylight between the windows is provided by the overlap of penetration between the two windows.

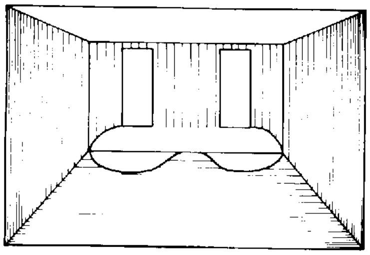


Fig. 4 Tall narrow windows.

Separate windows give a less uniform distribution of light than continuous windows. Windows in adjacent walls give good penetration and reduce glare by lighting the area of wall surrounding the adjacent window, as illustrated in Fig. 5. Windows in opposite walls of narrow rooms give good penetration and reduce glare by lighting opposite walls around windows.

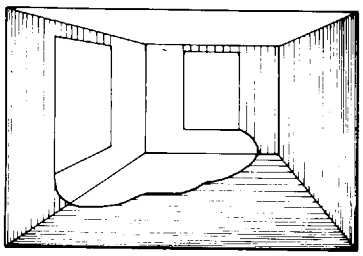


Fig. 5 Windows in adjacent walls.

In the calculation of daylight factors it is usual to determine the quantity of daylight falling on a horizontal working plane 850 mm above floor level to correspond with the height of working surfaces such as tables, desks or benches.

Area of glass

It is advantageous to be able to make a reasonably accurate estimate of the area of glass in windows, necessary to provide the average daylight factor recommended for the activity for which the room or space is designed. The averaged or average daylight factor represents the overall visual impression of the daylighting in a room or space taking into account the distribution of light in the space and the effect of reflected light.

The penetration and distribution of daylight in rooms will increase by internal reflection of light from ceilings, walls and floors. Where the reflectance from light coloured smooth surfaces is good, the net area of glass required to provide a daylight factor of 2, will be 1.28 m as compared to 1.60 m where reflectance is low from dark rough surfaces in a room 3 m square with a 3 m ceiling height.

Calculation of daylight factor

Where daylighting by itself or in combination with artificial lighting is critical for the performance of activities, such as drawing at a fixed point or points in a room, it is necessary to estimate the minimum daylighting available at a point. For this purpose there are a number of aids, such as the artificial sky and the overlays for scale drawings.

An artificial sky provides luminance comparable to the standard overcast sky, through an artificially lit dome which is laid over a scale model of the building in which photometers are used to measure the light available. The graphical aids in the form of overlays include Waldram diagrams, BRS protractors and the dot or pepper pot diagrams of which the dot diagram is the most straightforward to use.

The dot diagram has the appearance of a sheet of paper onto which a pepper pot has deposited grains of pepper, hence the name pepper pot diagram. The grains of pepper, the dots, represent a small proportion of the daylight illumination available at that point. The greater the density of dots the greater the illumination.

Pepper pot diagram

The pepper pot diagram is a transparent overlay on which dots are printed above a horizontal line representing the horizon. The diagram is drawn to a scale of 1 : 100 as an overlay to drawings to the same scale. Each dot represents 0.1% of the sky component. The overlay shown in Fig. 6 is for daylight through side-lit windows with the CIE standard overcast sky. To use the overlay, draw the outline of a window to a scale of 1 : 100 so that the outline represents the glass area to scale. The diagram is designed to determine the sky component of daylight on a line 3 m back from the window. Place the overlay on the scale elevation of the window with the horizontal line

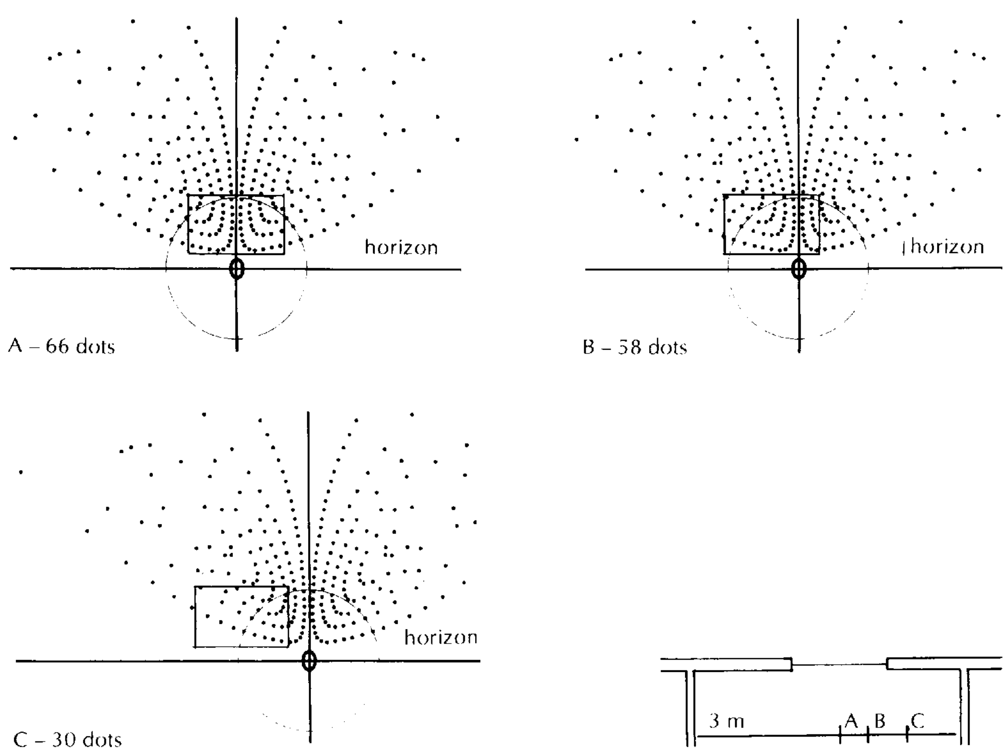


Fig. 6 Sky component.

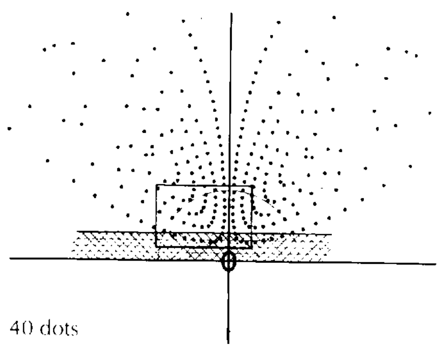


Fig. 7 Sky component.

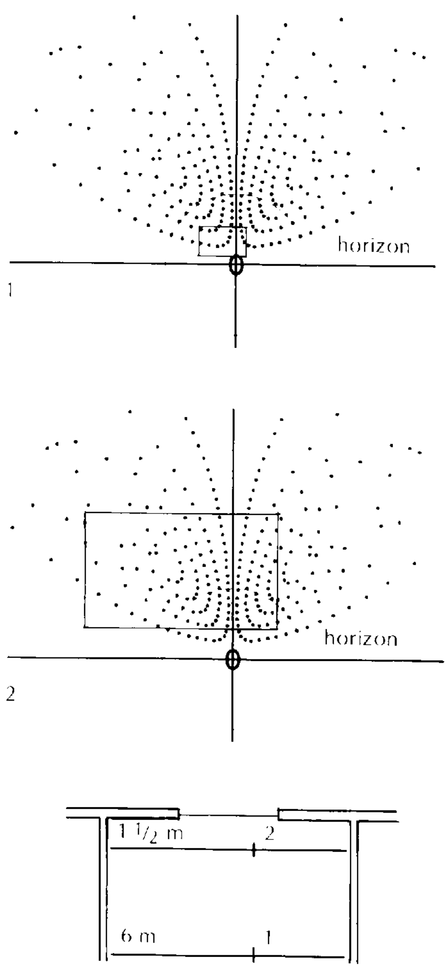


Fig. 8 Sky component.

of the overlay on the line of the working plane, that is 850 mm above the floor, drawn to scale on the window elevation. To determine the sky component at a point 3 m back on the centre of the window, place the vertical line of the overlay on the centre of the window as illustrated in Fig. 6A, then count the dots inside the window outline. The 66 dots inside the window outline represent a sky component of 66 10, that is 6.6% at a point 3 m back from the centre of the window on the working plane.

To find the sky component on the line 3 m back from the window at other points, slide the overlay horizontally across the window outline until the vertical line of the overlay coincides with the chosen point inside the room, either inside or outside the window outline, as illustrated in Figs 6B and C. Count the dots inside the window outline to determine the sky component at the chosen points.

Where there are obstructions outside windows, such as adjacent buildings, which obscure some of the daylight, the overlay can be used to determine both the loss of light due to the obstruction and the externally reflected component of light due to reflection of light off the obstruction and into the room through the window. A simple example of this is where a long low building will obstruct daylight at a point 3 m inside the room on the centre of the window at the working plane. The outline of the long obstruction is shown in Fig. 7 by the shaded area. The height of the obstruction above the horizon is represented by the height to distance ratio of the obstruction relative to the point on the working plane inside the window. This ratio is 0.1 for each 3 mm above the horizon on the scale drawing of the window. The number of dots inside the window outline above the shaded obstruction gives the sky component as 40% and the number of dots 12 inside the shaded area, the externally reflected component. These dots represent 0.01% of the externally reflected component.

To find the sky component at points on a line other than the line 3 m back from the window drawn to a scale of 1 : 100, it is necessary to adjust the scale of the window outline. If the scale of the window is doubled, it will represent the sky component at points 1.5 m back from the window, and if the scale is halved, 6 m back from the window, as illustrated in Fig. 8 for points on the centre of the window. In adjusting the scale of the window outline it is also necessary to adjust the scale height of the working plane above the floor by doubling or halving the scale as shown in Fig. 8.

The particular use of this diagram is to test the sky component of daylight inside rooms at an early stage in the design of buildings. By the use of window outlines drawn freehand to scale on graph paper, with the overlay, a comparative assessment of the effect of window size and position on the sky component of daylight inside rooms can quickly be made. This will provide a reasonably accurate assessment of comparative daylight levels in rooms to be used for many activities where the exact level of daylight is not critical.

Quality of daylight

Glare

Glare is defined as 'a condition of vision in which there is discomfort or a reduction in the ability to see significant objects or both, due to an unsuitable distribution or range of luminance, or to extreme contrasts in space or time'. The two distinct aspects of glare are defined as disability glare and discomfort glare.

Disability glare

Disability glare, which is defined as 'glare which impairs the vision of objects without necessarily causing discomfort', is caused when a view of bright sky obscures objects close to the source of glare. An example of this is where a lecturer is standing with his back to a window so that he is obscured by the bright sky behind him. Disability glare can be avoided by a sensible arrangement of the position of windows and people, whose vision of objects might otherwise be obscured.

Discomfort glare

Discomfort glare, defined as 'glare which causes discomfort without necessarily impairing the vision of objects', is created by large areas of very bright sky viewed from inside a building which causes distraction, dazzle and even pain. With vertical windows discomfort glare is caused, in the main, by the contrast between visible sky and the room lighting and this contrast can be usefully reduced by splaying window reveals and painting them a light colour to provide a graded contrast between the bright sky and the darker interior. This 'contrast grading' effect can be used with many window shapes and sizes. With very large windows such as the continuous horizontal strip windows which face southwards, discomfort glare is difficult to avoid owing to the large unbroken area of glazing and here some form of shading device will be required.

The degree of glare can be determined numerically and stated in the form of a 'glare index' from a formula suggested by The Building Research Station.

Form and texture

For the best visual enjoyment of solid objects the direction of light is important in relation to modelling by shadows and for appreciation of texture the quantity and area of the light source has most effect. These known subjective effects are difficult to quantify. It is generally accepted that light from the side is more agreeable than light from above and that side lighting from tall vertical windows provides better modelling of solid objects than large wide side windows. A single bright source of light emphasises texture and gives hard shadows whereas a light from a large diffuse source such as a window gives softer shadows and texture but appreciable modelling of form, and a very large diffuse source, such as rooflighting or overall ceiling illumination, may cause all but the most coarse texture to disappear and give poor modelling.

View out

As well as admitting daylight it is generally accepted that windows perform the useful function of providing a view out of buildings as a link with the outside and to provide the variations of interest that stimulate and break the monotony of repetitive tasks. Studies have been made to deduce possible optimum sizes and spacing of windows to provide a view out.

These studies have been inconclusive in detail but have established that the majority of people in sedentary occupations, such as office workers, derive benefit from a view out.

SUNLIGHT

In the late nineteenth century, concern for what were considered to be the poor living conditions in urban areas of northern European countries turned to the effects of sunlight on health. Early research sought to relate mortality and disease to the availability of sunlight in rooms and the courtyards of, for example, back-to-back dwellings. It is now plain that sunlight is not essential for hygiene, biological or therapeutic purposes. Later research seeking a norm of preference for sunlight in buildings has been inconclusive in determining a chosen minimum amount of sunlight because preferences varied so widely. From all the surveys that have been undertaken it is apparent that the majority preference is for a satisfying view, some sunlight, particularly in living rooms, and visual privacy.

In this country, where the norm seems to be overcast dull skies, the cheerful aspect of sunlight is cherished. The fashion in recent years for large windows, sometimes called picture windows, reflects the wish of a mainly indoor people to enjoy sunlight and a view. With the recent increase in the cost of fuels there has been a move towards smaller windows to reduce heat losses and solar heat gain that can cause discomfort in the summer. The pendulum of fashion that has swung from maximum glass area towards minimum glass area has yet to settle towards a sensible mean between the two.

The fashion for large windows and large areas of glass ('curtain walls' in Volume 4), prompted by the comparatively low cost of glass, has changed as glass is no longer a comparatively cheap building envelop material and its disadvantages as a thermal and sound insulator are now more widely known. Nonetheless the subjective preference for sunlight and a view out, and the economic advantage of freely available daylight and controlled solar heat gain, prompt the optimum use of glazing compatible with reasonable thermal and sound insulation.

A Code of Practice (since withdrawn) recognised the preference for sunlight in rooms by setting out recommended minimum periods of sunlight penetration. A Draft for Development included criteria for the insolation of dwellings, giving recommendations for the orientation of rooms and therefore the planning and siting of buildings. These recommendations did not include recommendations for the size and shape of windows.

Insolation

The criteria for insolation (exposure to sun's rays) suggest minimum possible or probable standards for sunlight on buildings as a guide in the design and layout of dwellings to gain the advantage of both sunlight and solar heat.

Colour fading

Sunlight causes most coloured materials to fade. It is the ultra-violet radiation in sunlight that has the most pronounced effect on coloured materials by causing the chemical breakdown of the colour in such materials as textiles, paints and plastics by oxidative bleaching, that is fading. The bleaching effect is more rapid and more noticeable with bright colours. The lining of colour-sensitive curtains on the window side with a neutral coloured material and the use of window blinds are necessary precautions to prolong the life of colour-sensitive materials.

Solar heat gain

In the calculation of energy use in maintaining equable indoor temperature and necessary insulation to limit heat loss, described later, allowance is made for solar heat gain. A calculation is made of the probable solar heat gain as part of the necessary energy input to maintain indoor temperature.

Because of the orbit of the earth round the sun and the simultaneous rotation of the earth on its axis inclined at 22.5° to the plane of orbit, the apparent movement of the sun around the earth varies throughout the solar year and penetration of sunlight through windows varies in intensity and depth. To plot the penetration of sunlight throughout the year would be a lengthy and tedious task. For the majority of buildings in the temperate climate of Britain such an exercise is unnecessary, except where it is anticipated that bright sunlight could cause discomfort or danger in performing tasks in static positions inside rooms or buildings or where solar heat gain might cause considerable discomfort or uneconomic use of internal heat.

There are geometric sunpath diagrams that may be used to check whether the face of a building will receive sunlight and when, the depth of penetration and the resultant patch of sunlight on room surfaces and the shading by obstructions at various times of the day throughout the year. An example of the use of 'gnomonic' projections to deduce sunlight patterns on room surfaces throughout the day is shown in Fig. 9. The diagram shows the floor of a single room with a south east facing window and the walls on which the sun will shine at half hourly intervals on 15 January.

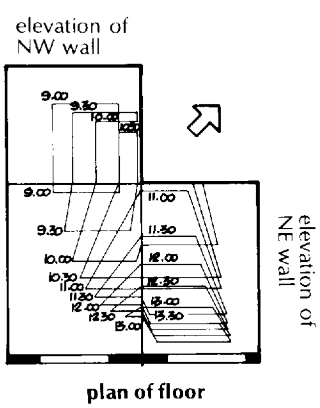


Fig. 9 Gnomic projection.

These sunpath diagrams may also, with suitable overlays, be used to predict the intensities of direct and diffuse solar radiation and the consequent solar heat gain. Recently a computer program has become available that will predict energy consumption for heat loss and heat input calculations and will make allowances for the variable of solar heat gain through windows so that modifications in both window sizes and the heat input from heating plant can be adjusted at the design stage. This facility has taken over the tedium of calculation by sunpath diagrams.

Sun controls and shading devices

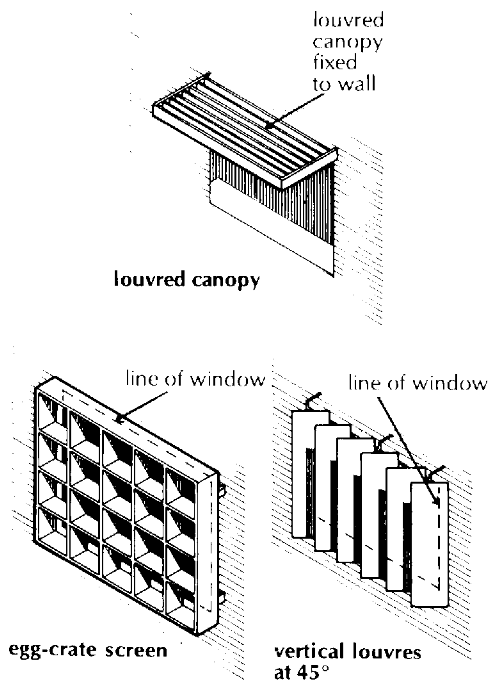


Fig. 10 Shading devices.

The traditional temperate climate means of controlling the penetration of sunlight to rooms are the slatted wooden louvre shutters common to the French window, and awnings and blinds that can be opened or closed. These controls are adjustable between winter and summer conditions, graduated from no shade and the maximum penetration of daylight in winter through some shade and some daylight to full shading in high summer.

Fixed projections above windows, such as canopies and balconies, are also used as sun controls in temperate climates to provide shade from summer sun while allowing penetration of sun at other times of the year for the advantage of sunlight and solar heat gain.

In tropical and semi-tropical climates fixed sun controls or shading devices in the form of canopies, screens or louvres are used, as illustrated in Fig. 10.

Sun controls serve to exclude sunlight to reduce glare or solar heat gain or both. To control and reduce solar heat gain sun controls should be fixed outside windows where they absorb solar heat which is then dissipated to the outside, whereas where sun controls are fitted internally, e.g. blinds, the solar heat they absorb is dissipated inside the room.

VENTILATION

Up to the middle of the twentieth century the principal means of heating was by solid fuel burning fires and stoves. The considerable intake of air required for combustion of wood, coal or coke in fires and stoves at the same time provided more than adequate changes of air for the ventilation of rooms, to the extent that cold draughts of air drawn in during winter months through cracks around opening windows and doors caused discomfort. At the time the concern was to control draughts of incoming cold air rather than considerations of ventilation. With the introduction of oil and gas fired central heating boilers, it was practical to heat the whole of buildings from one central boiler that drew air for combustion directly from outside and so reduced draughts of cold air from outside. The rapidly increasing use of oil and gas from the middle of the twentieth century prompted concern for the need to conserve the limited sources of energy. Initially regulations required minimum standards of insulation in the roofs and walls of new buildings.

The current trend towards conservation of energy, by more efficient use of insulation against excessive transfer of heat, has led to the installation of double glazing to windows in both new and old buildings and the fitting of effective weather-stripping around the opening parts of windows and doors to reduce draughts of cold air entering the building. Open fires are uncommon in modern buildings and many open fireplaces in older buildings have been sealed, so blocking flues that provided some ventilation. This means that there is less provision for permanent changes of air. The air in rooms may become 'stuffy' and uncomfortable and at worst unhealthy.

So that there is some provision for natural ventilation the Building Regulations now require means of ventilation to habitable rooms, kitchens, bathrooms and sanitary accommodation to provide air change by natural or mechanical ventilation and also to reduce condensation in rooms where warm, moisture vapour laden air may condense to water. The provisions are for opening windows and vents and some mechanical ventilation to kitchens, bathrooms and sanitary accommodation.

Air changes

For the comfort and well-being of people it is necessary to ventilate rooms by allowing a natural change of air between inside and outside or to cause a change by mechanical means. The necessary rate of change will depend on the activities and numbers of those in the room. The rate of change of air may be given as air changes per hour, as for example one per hour for living and up to four for work places, or as litres per second as a more exact requirement where mechanical ventilating is used, because it gives a clear indication of the size of inlets, extracts, ducts and pressures required.

The size of a ventilating opening, by itself, gives no exact indication of the likely air change as the ventilating effect of an opening depends on air pressure difference between inside and outside and the size of the opening or openings through which air will be evacuated to cause air flow. The actual ventilating effect of a window, by itself, is unpredictable as it will, when open, in all likelihood act to intake and extract air at the same time.

The rate of exchange of air will depend on variations between inside and outside pressure and heat, and the size and position of other openings in the room such as doors and open fireplaces that may play a part in air exchange. An open window, by itself, may well not

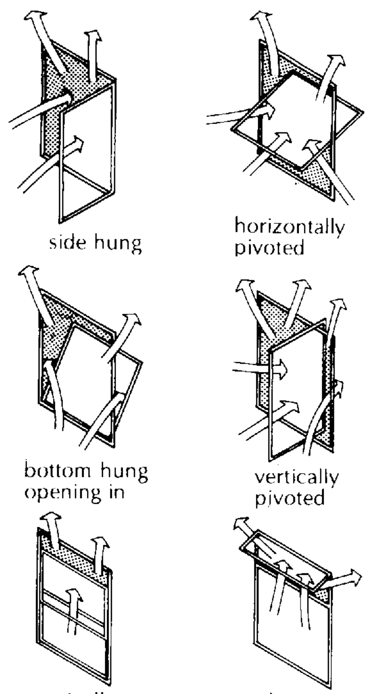


Fig. 11 Ventilation.

thoroughly ventilate a room. For thorough ventilation, that is complete air change, circulation of air is necessary between the window and another or other openings distant from the window, otherwise pockets of stagnant air may be undisturbed in those parts of the room distant from the window.

Ventilation air changes are necessary to minimise condensation which is caused when warm airborne moisture vapour precipitates in droplets on cold surfaces such as glass and metal. By ventilating, the warm moist air is exchanged with drier air that is less likely to cause condensation.

The probable ventilating action of the various types of window in comparatively still air conditions due to the exchange of warmed inside and cooler outside air is illustrated in Fig. 11.

The traditional method of ventilating is through opening lights in windows. The advantage of opening lights is that they can be opened or closed to suit the individual choice of the occupant of rooms regardless of notional optimum rates of air change for comfort and well being. The facility of 'flinging wide the casement to fresh air' has long been cherished and is unlikely to be abandoned in the foreseeable future. The disadvantages of opening lights are that they are difficult to open just sufficient for ventilation without letting in cold draughts or gusts of wind; the necessary clearance gaps around opening lights may allow an excess of air leakage and rain leakage; the necessary framing around them reduces the area available for glass; and they present a high security risk.

For control of ventilation the vertically sliding window is the most efficient as it can be operated to provide either small gap ventilation between meeting rails and sashes and frame, or opened to nearly half its total area, and the degree of opening can be closely controlled between these extremes. Side-hung casements are less efficient as they are difficult to open to provide closely controlled gap ventilation around the three open edges of the sash and for this reason top-hung ventlights are often used.

Top-hung lights are reasonably efficient but less readily controlled than the sliding sash in that there is the likelihood of both the extraction of air from below and the intake of air from the sides. Bottom-hung windows will operate to encourage the intake of air over them and extraction from the sides. Pivot windows are generally less efficient in the control of ventilation as they are difficult to open sufficiently to prevent variable gusts of wind and cold draughts being directed in at low level. In addition large pivot windows, when open, may be distorted by heavy gusts of wind and may then be difficult to close tight unless there is a mechanism to lock the sash shut at several points. Horizontally pivoted windows should be capable of being locked shut both top and bottom else the top, opening in part of the

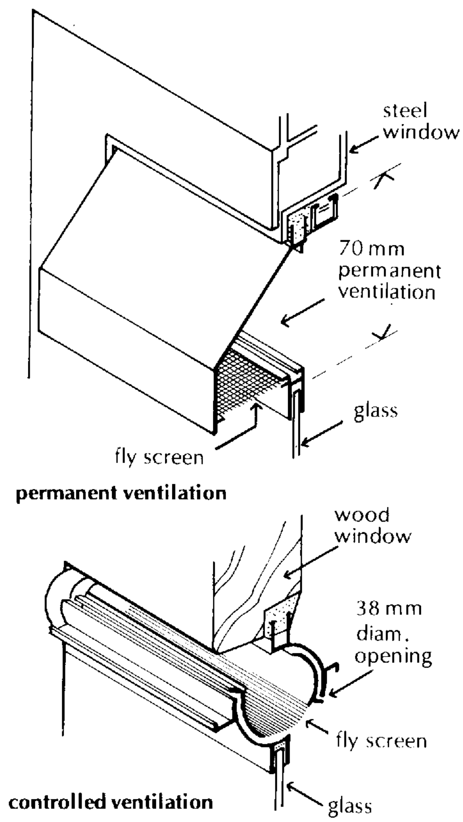


Fig. 12 Ventilators.

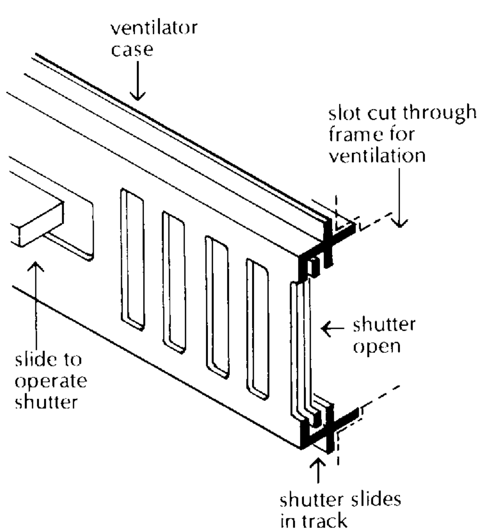


Fig. 13 Trickle ventilator.

sash, may be forced in by high winds and allow considerable air seepage.

Apart from the wish to fling windows wide open there is every reason to dispense with opening lights and replace them with ventilators designed to control air movement only. These ventilators can be included in windows either in place of part of the glass or as part of the window head or cill construction, or they may be fixed separate from the windows. For ventilation alone these ventilators need only small apertures that can be opened and closed by means of simple 'hit and miss' control or hinged or pivoted flaps operated by cord and pulley or winding gear.

The ventilators illustrated in Fig. 12 are fixed in the rebated glazing opening above the glass. The ventilator shown in the upper diagram is for permanent ventilation and that in the lower diagram for controlled ventilation.

Approved Document F gives practical guidance to meeting the requirements of the Building Regulations for the provision of means of ventilation for dwellings. The requirements are satisfied for habitable rooms, such as living rooms and bedrooms when there are:

(1) For rapid ventilation – one or more ventilation openings, such as windows, with a total area of at least $\frac{1}{20}$ of the floor area of the room, with some part of the ventilating opening at least 1.75 m above the floor.
(2) For background ventilation – a ventilation opening or openings having a total area of not less than 4000 mm^2, which is controllable, secure and located so as to avoid undue draughts, such as the trickle ventilator, illustrated in Fig. 13.

For kitchens the requirements are satisfied when there is both:

(1) Mechanical extract ventilation for rapid ventilation, rated as capable of extracting at a rate of not less than 60 litres per second (or incorporated within a cooker hood and capable of extracting at 30 litres a second) which may be operated intermittently for instance during cooking, and
(2) Background ventilation, either by a controllable and secure ventilation opening or openings having a total area of not less than 4000 mm^2, located so as to avoid draughts, such as a trickle ventilator or by the mechanical ventilation being in addition capable of operating continuously at nominally one air change per hour.

For bathrooms the requirements are satisfied by the provision of mechanical extract ventilation capable of extracting at a rate of not less than 15 litres a second, which may be operated intermittently.

For sanitary accommodation the requirements are satisfied by either:

(1) Provision for rapid ventilation by one or more ventilation openings with a total area of at least $\frac{1}{20}$ of the floor area of the room and with some part of the ventilation opening at least 1.75 m above the floor level, or
(2) Mechanical extract ventilation, capable of extracting air at a rate of not less than three air changes per hour, which may be operated intermittently with 15 minutes overrun.

FUNCTIONAL REQUIREMENTS

As a component part of a wall or roof a window should satisfy the same functional requirements as a wall or roof, namely:

Strength and stability
Resistance to weather
Durability and freedom from maintenance
Fire safety
Resistance to the passage of heat
Resistance to the passage of sound
Security

Safety requirements

Two safety requirements from Parts K and N to the Building Regulations concern the opening parts of windows in buildings other than dwellings.

The requirement in Part K is that measures be taken to prevent people, moving in or about the building, from colliding with open windows. This requirement is met where the projection of a window, either internally or externally, is more than 100 mm horizontally and the lowest part of the projection is more than 2 m above floor or ground.

The requirements in Part N are that windows, skylights and ventilators can be opened, closed or adjusted safely and that there is safe access for cleaning windows.

The requirement for access for operating applies to controls that are more than 1.9 m above floor. The requirement for access of cleaning windows, inside and out, where there is a danger of falling more than 2 m, will be met if provision is made for safe means of access.

Strength and stability

A window should be strong enough when closed to resist the likely pressures and suctions due to wind, and when open be strong and stiff enough to resist the effect of gale force winds on opening lights. A window should also have sufficient strength and stiffness against pressures and knocks due to normal use and appear to be safe, particularly to occupants in high buildings. A window should be securely fixed in the wall opening for security, weathertightness and the strength and stiffness given by fixings.

Wind loading

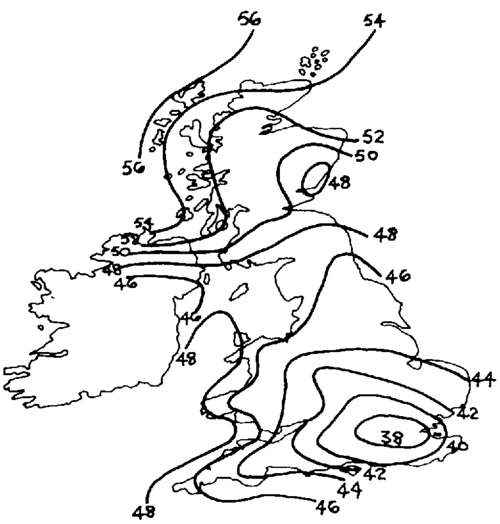


Fig. 14 Basic wind speeds.

The direction and strength of wind fluctuates to the extent that sophisticated electronic equipment is necessary to measure the changes in pressure that occur. To determine the wind pressures that a window is likely to suffer it is convenient to define these as maximum gust speed, averaged over 3 second periods, which are likely to be exceeded on average only once in 50 years. These gust speeds have been measured by the Meteorological Office and plotted as basic wind speeds on a map of the United Kingdom (Fig. 14). The wind speeds are expressed in metres per second rather than miles per hour, the index used in weather reports in the United Kingdom.

To determine probable wind loads on buildings the method given in BS 6262 can be used for buildings that are of simple rectangular shape and up to 10 m high from eaves to ground level. The basic wind speed is determined from the map of the United Kingdom (Fig. 14).

The basic wind speed is then multiplied by a correction factor that takes account of the shelter afforded by obstructions and ground roughness as set out in Table 2 to arrive at a design wind speed. The left hand column in Table 2, 'Height above ground', relates to height of window above ground as plainly the higher above ground the less will ground roughness and obstructions provide shelter.

The four categories of protection by obstructions and ground roughness run from 1 with effectively no protection in open country to 4 with maximum protection from surrounding buildings in city centres. A degree of judgement is necessary in selecting the correction category suited to the site of a particular building as the purpose is to select a window construction suited to the most adverse conditions that will occur on average once in 50 years.

The probable maximum wind loading is then obtained from Table 3 by reference to the design wind speed. The wind loading is used to select the test pressure class of window construction necessary and graphs are used to select the required thickness of glass.

Windows are tested in a laboratory to determine test pressure classes; a sample of manufactured windows complete with opening lights and glass is mounted in a frame to represent the surrounding walls. The criterion of success in the pressure test is that after the test the window should show no permanent deformation or other damage and there should be no failure of fastenings.

Table 2 Correction factors for ground roughness and height above ground.

Height above ground (m)	Category 1	Category 2	Category 3	Category 4
3 or less	0.83	0.72	0.64	0.56
5	0.88	0.79	0.70	0.60
10	1.00	0.93	0.78	0.67

Category 1: Open country; with no obstructions. All coastal areas.
Category 2: Open country; with scattered wind breaks.
Category 3: Country; with many wind breaks; e.g. small towns; city outskirts.
Category 4: Surfaces with large and frequent obstructions; e.g. city centres.
Taken from BS 6262.

Table 3 Probable maximum wind loading.

Design wind speed (m/s)	Wind loading (N/m^2)	Design wind speed (m/s)	Wind loading (N/m^2)
28	670	42	1510
30	770	44	1660
32	880	46	1820
34	990	48	1980
36	1110	50	2150
38	1240	52	2320
40	1370		

Taken from BS 6262.

Resistance to weather

To conserve heat and avoid cold draughts it is good practice to design windows so that there is little unnecessary leakage of air. Air movement through closed windows may occur between the window frame and the surrounding wall, through cracks between glass and the framing, through glazing joints, and more particularly through clearance gaps between opening lights and the window frame.

Air permeability (airtightness)

Leakage of air around window frames, around glass and through glazing joints can be avoided by care in design, construction and maintenance. The necessary clearance gaps around opening lights can be made reasonably airtight by care in design and the use of weatherstripping.

For comfort in living and working conditions in buildings some regular change of air is necessary. The necessary ventilation should be provided through controlled ventilators, through opening lights, or by mechanical ventilation. It is not satisfactory to rely on leakage of air through windows for ventilation as this leakage cannot be controlled, and it may be excessive for ventilation and conservation of heat or too little for ventilation.

Air leakage

While air leakage through windows will contribute to wastage of heat by an excess of cold air entering, other parts of the building envelope may add considerably to heat loss by leakage of air through construction cracks. An example of this is where a weep hole in the external brick leaf of a cavity wall faces construction gaps around timber joist ends built into the inner skin, so that in high wind measurable volumes of cold air blow into the timber floor. The need for and use of weep holes in cavity walls is questionable, particularly as they will allow cold air to enter the cavity and so reduce the insulating properties of this construction. In many traditionally constructed buildings some one third or more of all air leakage is through construction gaps and cracks. Close attention should therefore be paid to the solid filling or sealing of all potential construction gaps and cracks as well as controlling leakage through windows.

The flow of air through windows is caused by changes in pressure and suction caused by wind that may cause draughts of inward flowing cold air and loss of heat by excessive inflow of cold and outflow of warmed air. It is to control this air movement that systems of check rebates and weatherstripping are used in windows, as illustrated in Fig. 15.

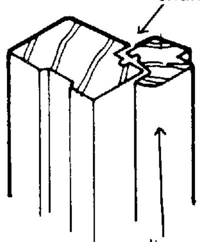


Fig. 15 Weatherstrip and check rebates.

The performance of windows with regard to airtightness is based on predicted internal and external pressure coefficients which depend on the height and plan of the building. These are related to the design wind pressure which is determined from the exposure of the window and basic wind speed from the map in Fig. 14. From these, test pressure classes are established for use in the tests for air permeability and watertightness to set performance grades.

Watertightness

Penetration of rain through cracks around opening lights, frames or glass occurs when rain is driven on to vertical windows by wind, so that the more the window is exposed to driving rain the greater the likelihood of rain penetration.

Because of the smooth, impermeable surface of glass, driven rain will be driven down, across and up the surface of glass thus making seals around glass and clearance gaps around opening lights vulnerable to rain penetration.

The tests for watertightness of windows are based on predictions similar to those used for air infiltration in determining design wind speed, exposure grades and test pressure classes to set performance standards.

On sites where there is high exposure to wind-driven rain it may be reasonable to adopt a higher performance for watertightness than that used for strength and stability, to ensure watertightness and to avoid the need for thick mullions, transomes and glass.

To minimise the penetration of driven rain through windows, it is advantageous to:

(1) Set the face of the window back from the wall face so that the projecting head and jamb will to some extent give protection by dispersing rain.
(2) Ensure that external horizontal surfaces below openings are as few and as narrow as practicable to avoid water being driven into the gaps.
(3) Ensure that there are no open gaps around opening lights by the use of lapped and rebated joints and that where there are narrow joints that may act as capillary paths there are capillary grooves.
(4) Restrict air penetration by means of weatherstripping on the room side of the window so that the pressure inside the joint is the same as that outside; a pressure difference would drive water into the joint.
(5) Ensure that any water entering the joints is drained to the outside of the window by open drainage channels that run to the outside.

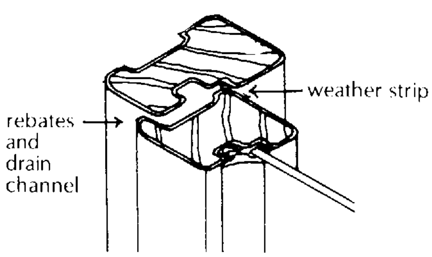


Fig. 16 Drainage channel.

In modern window design weatherstripping is used on the room side of the gaps around opening lights to exclude wind and reduce air filtration, and rebates and drain channels are used on the outside to exclude rain as illustrated in Fig. 16.

Durability and freedom from maintenance

Wood windows

The durability of the traditional material for windows – wood, has been established over centuries. The majority of wood windows are of softwood that suffers moisture movement with change of moisture content and may rot where water enters open joints, if it is not adequately protected by paint or other protective coating. A wood window strongly framed from sound well-seasoned wood protected by a sufficiently elastic paint coating, that is adequately maintained, may have a useful life comparable to that of most buildings. The disadvantage of softwood windows is that they need comparatively frequent maintenance expenditure at intervals of 5 to 7 years. It is the maintenance cost of wood windows that has led, over recent years, to the large market in 'replacement windows' of uPVC and aluminium.

Steel windows

Steel windows have acquired a bad name due to the progressive, corrosive rusting that occurred with the early use of mild steel sections which were not protected with a galvanised zinc coating. Steel windows have been unable to regain favour in competition with uPVC and aluminium windows, and because a galvanised coating does not give total protection against corrosion, these windows need comparatively frequent painting.

Aluminium windows

On exposure to air, aluminium forms an oxide that generally protects the aluminium below it from further corrosion. The oxide coating that forms on aluminium is coarse textured, dull and silver-grey in colour which readily collects dirt, it not easily cleaned and has an unattractive appearance. For these reasons aluminium is usually coated by anodising, polyester powder, organic or acrylic coatings, to inhibit corrosion and for appearance sake. Anodised finishes may fail after some years, whereas organic powder coating and acrylic coatings survive for many years and require cleaning by washing with water from time to time to maintain appearance. The powder and acrylic coatings are applied in a full range of colours. White is preferred as it does not suffer colour bleaching as do the stronger colours.

uPVC windows

Windows made from PVC sections have been in use for more than 30 years. The material has maintained its original characteristics over this period in various climatic conditions and there is reason to suppose uPVC windows have a useful life similar to that of most buildings. Strongly coloured uPVC will, after some years, bleach due to the effect of ultraviolet light. The colour loss is irregular and unsightly and overpainting of uPVC is not generally successful. The use of white or off-white is recommended. The smooth surface of this material will, after some time, collect a layer of grime that can be easily removed by washing with water. Other than occasional washing these windows need no maintenance.

Glass

A layer of grime will collect on the surface of glass over the course of a month or two, to the extent that it is unsightly and reduces light transmission. To maintain its lustrous, fire-glazed finish, glass needs cleaning at intervals of one to two months by washing with water and polishing dry with a linen scrim cloth.

An extremely thin protective coating of copolymer which can be sprayed over the surface of glass, appreciably reduces the build-up of a dirt film and facilitates cleaning. This sprayed on coating can only be applied in factory conditions to glass cut ready for glazing.

Fire safety

The requirements from Part B of Schedule 1 to the Building Regulations are concerned to:

Provide adequate means of escape
Limit internal fire spread (linings)
Limit internal fire spread (structure)

Limit external fire spread
Provide access and facilities for the fire service

The current advisory document giving practical guidance to meeting the requirements of the Building Regulations is Approved Document B, entitled Fire Safety. It is concerned with the escape of people from buildings after the outbreak of fire rather than the protection of the building and its contents.

External fire spread

The requirement in the Regulations that concerns windows is external fire spread. To limit the spread of fire between buildings, limits to the area of 'unprotected areas' in walls and finishes to roofs, close to boundaries, are imposed by the Building Regulations. The term 'unprotected area' is used to include those parts of external walls that may contribute to the spread of fire between buildings. Windows are unprotected areas, as glass offers negligible resistance to the spread of fire. In Approved Document B rules are set out that give practical guidance to meeting the requirements of the Building Regulations in regard to minimum distances of walls from boundaries and maximum unprotected areas.

Resistance to the passage of heat

A window, which is a component part of a wall or roof, will affect thermal comfort in two ways, firstly by transmission (passage) of heat and secondly through the penetration of radiant heat from the sun, that causes 'solar heat gain'. Glass, which forms the major part of a window, offers poor resistance to the passage of heat and readily allows penetration of solar radiation.

The transfer of heat through a window is a complex of conduction, convection and radiation. Conduction is the direct transmission of heat through a material, convection the transmission of heat in gases by circulation of the gases, and radiation the transfer of heat from one body of radiant energy through space to another.

U value

Because of the variable complex of these modes of transfer it is convenient to adopt a standard average thermal transmittance coefficient (U) as a comparative practical measure of heat loss through materials in steady state conditions. This comparative standard measure of heat transfer, known as the 'U' value, is the heat in Watts that will be transferred through 1 m^2 of a construction where there is a difference of 1 degree between the temperature of the air on opposite sides W/m^2K. In using this unit of measure of heat transfer, assumptions are made about the moisture content of materials, the rate of heat transfer to surfaces by radiation and convection, the rates of air flow in ventilated spaces, and heat bridge effects.

Glass has low insulation and high transmittance value. The U value of a single sheet of 6 mm thick glass (single glazing) is 5.4 W/m^2K and that of a double glazed unit with two 6 mm thick sheets of glass spaced 12 mm apart is 3.0 W/m^2K, as compared to that of an insulated cavity wall of 0.45 W/m^2K. Because glass has relatively poor resistance to the passage of heat as compared to that of an insulated wall, it is advantageous to limit the area of glass in buildings for the conservation of energy. This is the assumption in the Building Regulations.

In Approved Document L, to the Building Regulations, three methods are given for determining limitation of heat loss through the building fabric to provide reasonable conservation of fuel and power.

Elemental method

The first method, an Elemental method which applies to dwellings and buildings other than dwellings, is used to select elements of building that will provide satisfactory thermal performance through achieving the Standard U values given for the elements of building. The Elemental method is used as a standard of annual energy use, as a measure against which the annual energy use, determined by the other two methods, is judged.

Elemental method dwellings

The Elemental method used for dwellings (houses and flats) depends on a table of Standard U values applied to the elements of building, roofs, walls, floors and windows. U values are given for an SAP Energy rating of 60 or less and for an SAP Energy rating over 60.

Standard assessment procedure (SAP)

The SAP rating, which is used for dwellings only, is calculated by the completion of a worksheet of four pages with reference to the accompanying 14 tables. The sequential completion of up to 99 entries on the worksheet by reference to the 14 tables is laborious. The end result is an SAP rating on a scale of 0 to 100; the higher the performance number, the better the thermal performance of the building in limiting the use of energy and power. SAP ratings of 60 or less are assumed to provide thermal performance below that set by the Regulations.

Windows

The Standard U values for dwellings are set out in Table 4. The Standard U value for windows in a building with an SAP rating of over 60 is 3.3 W/m^2K where the area of windows does not exceed 22.5% of the total floor area.

The U value of a window depends on the type of glazing and the materials of the window framing. As single glazing does not provide a sufficiently low U value, some form of double glazing is necessary. The overall U value of a window varies to some extent on the materials used in window framing, as wood and uPVC frames provide better insulation against heat transfer than metal. The overall U value

Table 4 Standard U values (W/m^2K) for dwellings.

	For SAP Energy Ratings of:	
Element	**60 or less (a)**	**over 60 (b)**
Roofs[1]	0.2	0.25[2]
Exposed walls	0.45	0.45
Exposed floors and ground floors	0.35	0.45
Semi-exposed walls and floors	0.6	0.6
Windows, doors and rooflights	3.0	3.3

Notes
1. Any part of a roof having a pitch of 70° or more may have the same U-value as a wall.
2. For a flat roof or the sloping parts of a room-in-the-roof construction it will be acceptable if a U value of 0.35 W/m^2K is achieved.

of a wood or uPVC window frame with a sealed double glazed unit with a 6 mm air gap is 3.3 W/m^2K, whereas one with a metal frame and similar double glazing is 4.2 W/m^2K.

Modification of basic allowance

The basic allowance for the area of windows, 22.5% of the total floor area, may be modified where there is compensating improvement in the average U value of windows. An example of this is where a wood frame window is glazed with a double glazed unit with a 12 mm sealed air gap which is filled with low E (Emissivity) Argon gas. Here the U value of the window and frame is taken as 2.2 W/m^2K and the modified allowance for the maximum area of the window is 36.5% of the total floor area.

Elemental method, buildings other than dwellings

The Elemental method of determining the required limitation of heat loss for buildings other than dwellings is similar to that for dwellings except that the SAP rating is not used. Standard U values are set out in Table 5.

The basic allowance of area for windows is expressed as a percentage of exposed wall area. These percentages vary from 15% for industrial and storage buildings to 40% for shops and offices. Similarly there is a modification of the basic allowance for the area of windows where the average U value is less than that allowed in Standard U values.

The two other methods of showing compliance with requirements for limitation of heat loss for dwellings are a Target U value method and an Energy rating method and those for buildings other than dwellings are a Calculation method and an Energy Use method.

The three methods of showing compliance with requirements for limitation of energy use for dwellings and for buildings other than

Table 5 Standard U values (W/m^{2}K) for buildings other than dwellings.

Element	U-value
Roofs$^{(1)}$	0.25$^{(2)}$
Exposed walls	0.45
Exposed floors and ground floors	0.45
Semi-exposed walls and floors	0.6
Windows, personnel doors and rooflights	3.3
Vehicle access and similar large doors	0.7

Notes
1. Any part of a roof having a pitch of 70° or more may have the same U value as a wall.
2. For a flat roof or insulated sloping roof with no loft space it will be acceptable if a U-value of 0.35 W/m^{2}K is achieved for residential buildings or 0.45 W/m^{2}K for other buildings.

dwellings and the SAP rating calculation are described in more detail in Volume 1.

Solar heat gain

The term 'radiation' describes the transfer of heat from one body through space to another. When the radiant energy from the sun passing through a window reaches, for example, a floor, part of the radiant energy is reflected and part absorbed and converted to heat. The radiant energy reflected from the floor will in part be absorbed by a wall and converted into heat and partly reflected. The heat absorbed by the floor and wall will in turn radiate energy that will be absorbed and converted to heat.

This process of radiation, reflection, absorption, conversion to heat and radiation will produce rapidly diminishing generation of heat. The heat generated by radiation will be dissipated by conduction in solid materials such as walls, and by convection in air.

The wavelength of radiant energy depends on the temperature of the radiating body: the higher the temperature the shorter the wavelength. Part of the radiation of energy from the extremely high temperature of the sun is short wave which will pass through clear glass with little absorption, whereas the comparatively low temperature and long wavelength of an electric fire and a floor or wall will mostly be absorbed by glass.

Where the balance of gain of heat from radiation is greater than that dissipated by conduction and convection, there will be a gradual build-up of heat that can cause discomfort in rooms due to solar heat gain.

Plainly the degree of solar heat gain is affected by the size and orientation of windows. Large windows facing south in the northern hemisphere will be more affected than those facing east or west. The time of year will also have some effect between the more intense summer radiation which will not penetrate deeply into rooms at midday to the less intense but more deeply penetrating radiation of spring and autumn.

In the temperate climate of northern Europe discomfort from solar heat has not, until recently, been a concern. Sunlight is welcome as a relief from preponderant, dull overcast days. In middle and southern Europe systems of shutters and blinds are used to provide shade from the more intense radiation of summer sun.

Discomfort from solar heat gain has mainly been a consequence of the fashion to use large areas of glass as a sealed walling material for offices and other non-domestic buildings, where the build-up of heat can make working conditions uncomfortable. The transmission of solar radiation can be effectively reduced by the use of body tinted, surface modified or surface coated glass to control solar heat gain.

Resistance to the passage of sound

Sound is the sensation produced through the ear by vibrations caused by air pressure changes superimposed on the comparatively steady atmospheric pressure. The rate or frequency of the air pressure changes determines the pitch as high pitch to low pitch sounds. The audible frequencies of sound are from about 20 Hz to 15 000 or 20 000 Hz, the abbreviation Hz representing the unit Hertz where one Hertz is numerically equal to one cycle per second. The sound pressure required for audibility is generally greater at very low frequencies than at high frequencies.

Because of the variation in the measured sound pressure and that perceived by the ear over the range of audible frequencies, a simple linear scale will not suffice for the measurement of sound. The measurement that is used is based on a logarithmic scale that is adjusted to correspond to the ear's response to sound pressure.

The unit of measurement used for ascribing values to sound levels is the decibel (dB). Table 6 gives sound pressure levels in decibels for some typical sounds. Because the sensation of sounds at different frequencies, although having the same pressure or energy, generally appears to have different loudness, a sound of 100 dB is not twice as loud as one of 50 dB, it is very much louder. The scale of measurement used to correlate to the subjective judgement of loudness, which is particularly suitable for traffic noise, is the A weighting with levels of sound stated in dB (A) units.

The word loud is commonly taken to indicate the degree of strongly or clearly audible sound, and the word noise as distracting sound.

To provide a measure of generally accepted tolerable levels of audible sound, which will not distract attention or be grossly intrusive, tolerance noise levels are set out in Table 7.

Table 6 Sound pressure levels for some typical sounds.

Sound	**Sound pressure level (dB)**
Threshold of hearing	0
Leaves rustling in the wind	10
Whisper or ticking of a watch	30
Inside average house, quiet street	50
A large shop or busy street	70
An underground train	90
A pop group at 1.25 m	110
Threshold of pain	120
A jet engine at 30 m	130

Table 7 Tolerance noise levels.

Location	dB(A)
Large rooms for speech such as lecture theatre, conference rooms etc.	30
Bedrooms in urban areas	35
Living rooms in country areas	40
Living rooms in suburban areas	45
Living rooms in busy urban areas	50
School classrooms	45
Private offices	45–50
General offices	55–60

Airborne sound

Impact sound

Sound is produced when a body vibrates, causes pressure changes in the air around it and these pressure changes are translated through the ear into the sensation of sound. Sound is transmitted to the ear directly by vibrations in air pressure – airborne sound, or partly by vibrations through a solid body that in turn causes vibrations of air that are heard as sound – impact sound. The distinction between airborne and impact sound is made to differentiate the paths along which sound travels, so that construction may be designed to interrupt the sound path and so reduce sound levels. Airborne sound is, for example, noise transmitted by air from traffic through an open window into a room and impact sound from a door slamming shut that causes vibrations in a rigid structure that may be heard some distance from the source.

The sensation of sound is affected by the general background level of noise to the extent that loud noise may be inaudible inside a busy machine shop, while comparatively low levels of sound may be disturbing inside a quiet reading room.

For the majority of people, who live and work in built-up areas, the principal sources of noise are external traffic, airborne sound, and internal noise from neighbouring radios, televisions and impact of doors and footsteps on hard surfaces, impact and airborne sounds.

Windows and doors are a prime source for the entry of airborne sound both through glass, which affords little insulation against sound, and by clearance gaps around opening parts of windows and doors. Appreciable reduction of intrusive airborne sound can be effected by weatherstripping around the opening parts of windows and doors.

The transmission of sound through materials depends mainly on their mass; the more dense and heavier the material the more effective it is in reducing sound. The thin material of a single sheet of glass provides poor insulation against airborne sound.

A small increase in insulation or sound reduction of glass can be

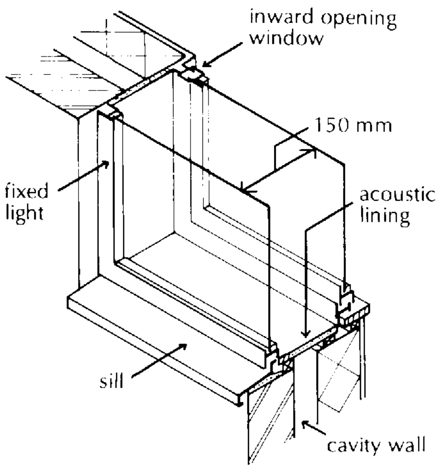


Fig. 17 Double window for sound insulation.

effected by the use of thicker glass, where an average reduction of 5dB is obtained by doubling the thickness of glass. There is no appreciable sound reduction by using the sealed double glazed units that are effective in heat insulation, as the small cavity is of no advantage, so that sealed double glazing is no more effective than the combined thickness of the two sheets of glass. For appreciable reduction in sound transmission double windows are used where two separate sheets of glass are spaced from 100 to 300 mm apart. An average reduction of 39 dB with 100 mm space and 43 dB with 200 mm space can be obtained with 4 mm glass. This width of air space is more than the usual window section can accommodate and it is necessary to use some form of double window.

The double window illustrated in Fig. 17 comprises two windows, a fixed outer and an inward opening inner window with the glass spaced 50 mm apart. Acoustic lining to the sill, jambs and head between the windows absorbs sound. The hinged inner sash facilitates cleaning glass.

Security

Windows and doors are the principal route for illegal entry to buildings. Of the recorded cases of illegal entry, burglary, about 30% involve entry through unlocked doors and windows. Of the remaining 70% some 20% involve breaking glass to gain entry by opening catches, and the remaining 80% by forcing frames or locks. As speed is of the essence in successful burglary, well-lit and exposed windows and doors are less likely to be attacked than out-of-sight rear windows and doors.

Locks, bolts and catches to windows and doors are forced open by inserting a tool in the clearance gap between the opening parts of windows and doors and the frame so that the lock, bolt or catch is disengaged from the frame. Plainly flimsy frame, sash and door material can more readily be prised apart than solid material, and lightweight single locks that shoot shut a small distance into frames are more readily prised open than heavy locks that shoot shut some distance into frames. Similarly flimsy or ill-fitted hinges can be prised loose from frames. Window and door frames insecurely fixed can be prised away from the surrounding wall.

Of the materials used for windows, uPVC can more easily be deformed than more rigid wood, steel or aluminium sections, to prise locks open particularly where lock and bolt fittings are not secured to the steel or aluminium reinforcement in uPVC sections.

Security against locks, bolts, catches and hinges being forced open depends on reasonably rigid frame and opening window sections, and strong lock, bolt, catch and hinge material being securely fixed. Plainly where more than one substantial lock or bolt is used with sound frame and window material the better the security.

Even though glass is comparatively easy to smash or cut, breaking glass is the least favoured method of illegal entry, principally because the distinctive sound of breaking glass may alert householders. Small panes of glass in putty glazing are more difficult to break than large panes and jagged edges of glass left in the putty are themselves a hazard to entry. The majority of uPVC and aluminium windows are glazed with beads, often fixed externally. It is fairly easy to remove these beads that are either screwed in place or are of the 'pop-in' type where the beads fit to projections in the sash or frame and are held by friction. Where there is ease of access, beads should either be of the shuffle type which require considerable force to be removed from outside or they should be fixed internally. Once beads have been removed it is usually easy to take out the glass. To make it more difficult the glass can be secured with double-sided tape or glass retaining clips. The purpose of breaking glass is to open catches to windows from outside for ease of entry. It is only after the glass has been broken that the burglar may find that the catches are locked shut.

Wired glass, which can easily be broken, will make it more difficult to make a clear opening because much of the broken glass will remain attached to the wire and so impede access. Toughened glass, which is considerably more difficult to break than ordinary glass, may deter all but the most determined burglar. Laminated glass is the best protection against burglary as the glass, which is not easily broken, will not shatter but break to small fragments which have to be removed for access. Double glazing is only more secure than single to the extent that there are two sheets of glass to break.

All security measures involve extra cost in better quality frames, sashes, locks, bolts, hinges and glass. It is wise, therefore, to employ security measures on those windows and doors most vulnerable to attack. From recorded cases it is clear that 62% of burglaries occur at the rear of buildings where there is ease of access to the 14–17 year old age group of preponderant opportunist burglars, and where access is out of sight.

A disadvantage of security against illegal entry from outside is that means of escape to the outside is made that much more difficult in case of need. The balance of advantage is to provide reasonable security to those windows and doors most vulnerable to burglary, with some allowance for ease of escape where burglary is least likely.

The practical guidance in Approved Document N to the Building Regulations recommends the use of safety glass to windows and glazed panels up to a level of 800 mm above finished floor level. It is at this low level above the floor that children are particularly vulnerable.

MATERIALS USED FOR WINDOWS

Wood windows

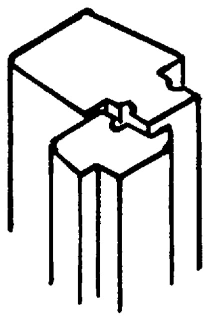


Fig. 18 Wood window sections.

The material traditionally used for windows is wood, which is easy to work by hand or machine and can readily be shaped for rebates, drips, grooves and mouldings, as illustrated in Fig. 18. It has a favourable strength to weight ratio, and thermal properties (see Volume 1, Timber) such that the window members do not act as a thermal bridge to heat transfer.

The disadvantages of wood are the considerable moisture movement that occurs across the grain with moderate moisture changes, and liability to rot. The dimensional changes can cause joints to open to admit water, which increases the moisture content that can lead to rot. It is of prime importance, therefore, that the moisture content of timber at the time of assembly be 17% or less, that the timber be treated with a preservative, and that the assembled window has a protective coating such as paint which is regularly maintained. It is necessary to maintain a sound paint film over the end grain of wood as it is more vulnerable than the long grain, in particular the end grain on the end of the stiles at the top of casements which are exposed to rain.

The majority of wood frames are cut from softwood timbers such as Baltic redwood (red and yellow deal), red pine and fir. Ideally sapwood should be excluded from timber for joinery as it is more liable to decay than heartwood (see Volume 1). In practice it is not economically possible to exclude sapwood. There is, therefore, good reason for preservative treatment of softwood to minimise the likelihood of rot. Preservative-treated softwood should none the less be protected with paint.

It is the need for regular and costly painting that is the particular disadvantage of softwood windows.

Steel windows

Following the industrial revolution it became practical and economic to produce mild steel sections which were developed by Crittall's in the early 1880s as hot rolled, steel section window frames and sashes. The comparatively small sections used for these windows were adopted more for aesthetic than practical reasons. The slim section steel window became the modern fashion of the late nineteenth and early twentieth centuries. These early steel windows were protected by paint which was not successful in preventing progressive, corrosive rusting and the steel window lost favour until the 1940s when steel windows, protected with hot-dip galvanising, were introduced. The galvanised zinc coating greatly reduced the onset of rusting. The limited sections that are practical with the hot rolled method of forming steel limited the types of window that could be made, made it difficult to accommodate double glazing and effective draught seals and contributed to the loss of favour of these windows.

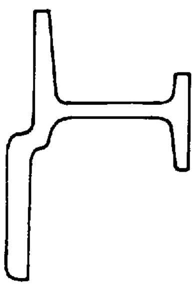


Fig. 19 Steel window section.

The advantage of steel for windows is the slender sections for both frame and opening lights that are possible due to the inherent strength and rigidity of the material. Figure 19 is an illustration of a steel window section. The disadvantages are high thermal conductivity that makes the window framing act as a cold bridge to the transfer of heat, the very necessary regular painting required to protect the steel from rusting, and the fact that narrow sections do not readily accommodate double glazing.

The majority of steel sections for windows are made from hot-rolled steel bars which is an expensive process from which only a limited range of sections can be produced economically. In Europe, pressed or rolled sheet steel sections and cold deformed tube sections have been used to produce a greater variety of sections for window manufacture. Rolled steel section windows are much less used today than they were.

Aluminium windows

Aluminium windows were first used in this country in the early 1930s and have been in use since then. These windows are made from aluminium alloy to BS 4873:1986, that is extruded in channel and box sections with flanges and grooves for rebates and weatherstripping. These thin-walled channel and box sections give the material adequate strength and stiffness for use as window sections, as illustrated in Fig. 20. The material can be readily welded and has good resistance to corrosion.

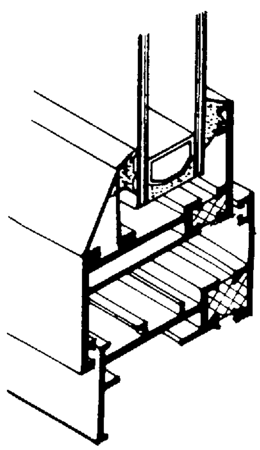


Fig. 20 Aluminium window section.

The aluminium alloy used is resistant to corrosion that might cause loss of strength, yet the surface of the material will fairly rapidly lose lustre owing to white corrosion products and some pitting caused particularly in marine and industrially polluted atmospheres. This corrosive effect may be inhibited by anodising or liquid organic or powder coating. To maintain the initial lustre of the surface of these windows it is necessary to wash them at regular intervals.

Aluminium windows are generally more expensive than comparable wood or steel windows. The advantages of aluminium windows are the variety of sections available for the production of a wide range of window types, and the freedom from destructive corrosion. The disadvantage is the high thermal conductivity of the material which acts as a cold bridge to heat transfer. To prevent aluminium section windows acting as a thermal bridge, they are constructed as two sections mechanically linked by a plastic bridge that acts as a thermal break. As an alternative the inner face of the aluminium is covered with a plastic, clip-on facing.

Stainless steel windows

This expensive corrosion-resistant steel product is made from an alloy of steel with chromium, nickel and molybdenum in the proportions of 18, 10 and 3 as a percentage of the whole to steel. This costly material is used in windows as a thin surface coating to other materials such as wood and aluminium for its appearance and freedom from corrosion. To keep its initial lustre the stainless steel finish requires regular washing.

Bronze windows

In the late nineteenth and early twentieth centuries bronze windows were used for large monumental scale buildings such as banks and civic buildings. These very expensive windows of strong, slender section metal, which does not rust and maintains its attractive colour, were the fashion for many large buildings at the time.

Manganese brass is the material commonly used for bronze windows. The material is rolled or extruded to form window sections. This very expensive material is less used today. Its advantages are freedom from corrosion, high strength to weight ratio, and the attractive colour and texture of the material.

Plastics, uPVC windows

The word plastics is used in a general sense to embrace a wide range of semi-synthetic and synthetic materials that soften and become plastic at comparatively low temperatures so that they can be shaped by extrusion or pressure moulding or both.

In the middle of the nineteenth century semi-synthetic plastics such as vulcanite or ebonite were produced from rubber and processed by the addition of sulphur to make tyres and imitation jewellery. Later in the century casein, which is made from milk curds treated with formaldehyde, was used to make ornamental articles. Celluloid, made from nitric acid, sulphuric acid and cellulose, was formed by heating, moulding and carving in the production of a wide range of decorative objects such as hand mirrors, combs and knife handles as a substitute for ivory and also for photographic film.

In the early years of the twentieth century the first synthetic plastics were produced in the form of a synthetic resin, Bakelite. Subsequent developments led to the synthesis and use of a range of synthetic plastics called polymers, which is the name of the range of plastics in common use today for building and a wide range of domestic products.

The polymer, polyvinyl-chloride (PVC) was first extensively used in forming window sections in Germany during the middle of the twentieth century. The polymer in the form of unplasticised (rigid) polyvinyl-chloride (uPVC) is softened by heating, extruded through a die and pressure formed to produce hollow box sections for window frames and sashes.

High impact modified uPVC

More recently, modifiers such as acrylic have been added to the constituent materials of uPVC to improve the impact resistance of the material which is, by itself, fairly readily subject to damage by slight

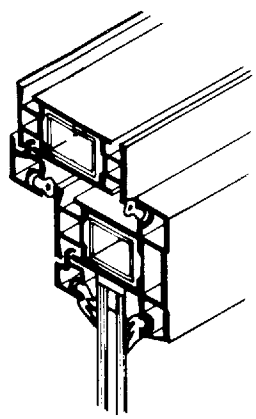


Fig. 21 uPVC window section.

knocks or abrasions. The addition of modifiers affects the speed at which the heated material is extruded, otherwise the finished product is liable to surface ripples and variations in thickness, if the speed of extrusion is too rapid.

The particular advantage of this material is that it is maintenance free and will maintain its smooth textured surface for the useful life of the material with occasional washing to remove grime. As the material is formed by extrusion it is practical to form a variety of rebates and grooves to accommodate draught seals, as illustrated in Fig. 21. The basic colour of the material is off-white which is colourfast on exposure to ultraviolet light for the useful life of the material. A range of coloured plastics can be produced either with the colour integral to the whole of the material or as a surface finish. Dark colours are more susceptible to bleaching and loss of colour in ultraviolet light from sun than light ones.

Because uPVC has less strength and rigidity than metal sections, it is formed in comparatively bulky, hollow box sections that are not well suited for use in small windows such as casements. The comparatively large coefficient of expansion and contraction of the material with the change of temperature and its poor rigidity require the use of reinforcing metal sections fitted into the hollow core of the sections to strengthen it and to an extent restrain expansion and contraction. The uPVC sections are screwed to the galvanised steel or aluminium reinforcement to fix the reinforcement in position, restrain deformation due to temperature movement and serve as secure fixing for hardware such as hinges, stays and bolts.

Some manufacturers use reinforcement only for frame sections over 1500 mm in length and casement or sash sections over 900 mm in length. For the advantage of a secure fixing for hardware and fixing bolts it is wise to use reinforcement for all uPVC sections.

uPVC windows are now extensively used both for new buildings and largely as 'replacement windows'.

WINDOW TYPES

Fixed lights

The term fixed light or dead light is used to describe the whole or part of a window in which glass is fixed so that no part of the glazing can be opened. Typically fixed lights are one sheet of glass, several sheets of glass in glazing bars, or lead or copper lights glazed (fixed) directly to the window frame.

Opening light

An opening light is the whole or part of a window that can be opened by being hinged or pivoted to the frame or which can slide open inside the frame.

Windows with opening lights may be classified according to the manner in which the opening lights are arranged to open inside the frame, as illustrated in Fig. 22.

Hinged	Side hung Top hung Bottom hung
Pivoted	Horizontally pivoted Vertically pivoted
Sliding	Vertically sliding Horizontally sliding
Composite action	Side hung projected Top hung projected Bottom hung projected Sliding folding

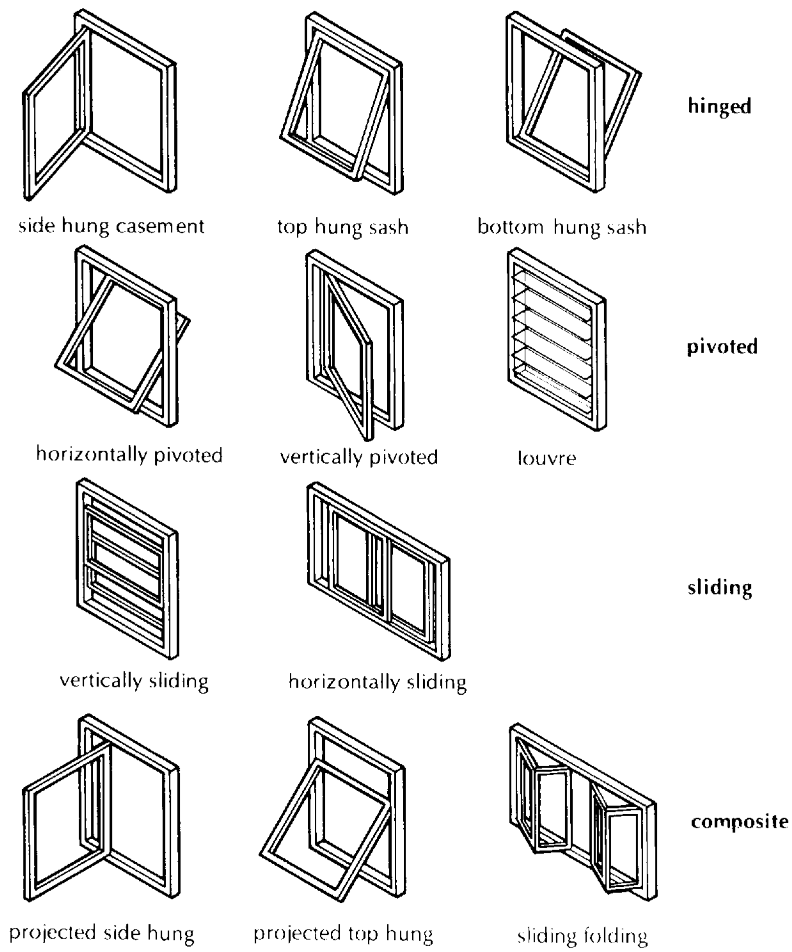


Fig. 22 Types of opening light.

Hinged opening lights

The traditional wood casement or cottage window comprised one or more comparatively small opening casements, generally with glazing bars to suit the comparatively small panes of glass that were available before the production of drawn sheet and float glass. These small windows provided sufficient daylight for indoor activities and the

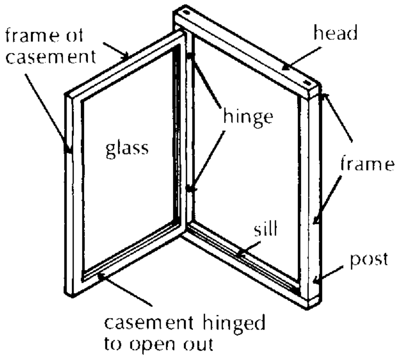


Fig. 23 Side hung casement window.

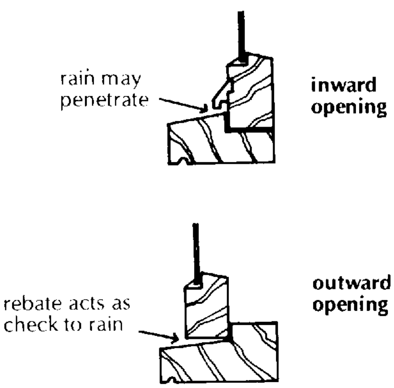


Fig. 24

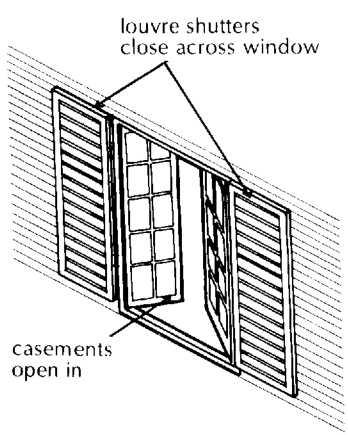


Fig. 25 French casement.

least heat loss through glass and draughts of cold air from cracks around casements, for the indoor comfort of the majority of the population who, before the industrial revolution, spent the major part of their lives in the open.

A casement consists of a square or rectangular window frame of wood with the opening light or casement hinged at one side to the frame to open in or out. The side-hung opening part of the window is termed the casement and it consists of glass surrounded and supported by a wooden frame as shown in Fig. 23, which is an illustration of a simple one-light casement opening out.

Because a casement is hinged on one side, its other side tends to sink due to the weight of the casement when it is open. If any appreciable sinking occurs the casement will bind in the window frame and in time may be impossible to open. Obviously, the wider a casement the greater its weight and the more likely it is to sink. It would be possible to increase the size of the members of the frame of a wide casement to strengthen it against sinking. It is not considered satisfactory to do this as the larger frame members would decrease the area of glass.

It is generally considered unwise to construct casements wider than say 600 mm. A casement window wider than 600 mm will consist of two or more casements or a casement and a dead light.

The traditional English casement is hinged to open out. The advantage of this is that an outward opening casement can more readily be made to exclude wind and rain than one opening inwards.

With an outward opening window the casement is forced into the outward facing rebate of the window frame by wind pressure, whereas with an inward opening casement the casement is forced away from the inward facing rebate of the window frame, as illustrated in Fig. 24, and so acts as a less effective seal against wind and rain.

Another advantage of the outward facing casement is that it will not obstruct curtains when they are drawn together.

In Europe the traditional casement is hung to open in, generally in the form of a pair of casements that often extend to the floor in the form of a pair of fully glazed doors, termed French casements, that may either serve as windows or give access to a balcony and serve as doors and windows.

The French casements, illustrated in Fig. 25, have been adopted for the warmer southern European countries where the casements may be opened inward and externally fixed, louvred wood shutters closed over the opening to exclude sun and allow some ventilation through the louvres.

A casement window may be framed with a pair of casements hinged

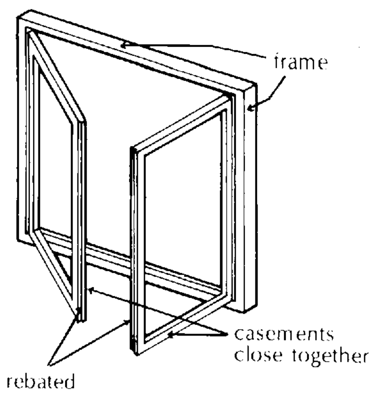


Fig. 26 Pair of casements.

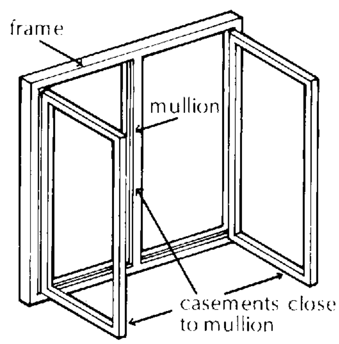


Fig. 27 Casements and mullion.

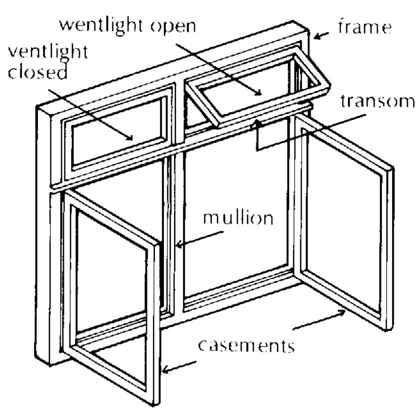


Fig. 28 Casements and ventlights.

to close together inside the frame as illustrated in Fig. 26. The vertical meeting stiles of the two casements are rebated to exclude wind and rain when the casements are closed. The advantage of this arrangement is that there is the least width of framing members to obstruct the glazed area.

The disadvantages of this arrangement is that the casements will need top and bottom bolts, in addition to a central catch, to close them firmly into the window frame to exclude wind and rain. Any slight loss of shape of either one or both of the casements, due to sinking, may cause them to bind inside the frame, make them difficult to open or close and result in further distortion of shape. Such poorly fitting casements will be ineffective in excluding wind and rain.

A sounder method of framing a two light casement window is by the use of a central window frame member so that each casement is hinged to open and close into a separate framed opening as illustrated in Fig. 27. The frame member that separates the casement is termed a mullion. The additional frame member, the mullion, does to an extent reduce the area available for glazing.

The advantage of this arrangement is that distortion of one casement will not affect the closing of the other and that each casement can be adequately secured with a latch to exclude wind and rain.

It may not be possible to open a casement just sufficient for ventilation without allowing gusts of wind to enter. It has been common to provide small opening lights, called ventlights, which are usually hinged at the top to open out to provide more closely controlled ventilation.

So that the ventlights can be opened independently of the casements, the window frame is made with a horizontal member, called a transom to which casements and ventlights close as illustrated in Fig. 28. Casements with ventlights are usually designed so that the transom is above the average eye level of people using the room, for obvious reasons.

The disadvantages of a casement window are that the casements, ventlights, mullions and transom reduce the possible unobstructed area of glass and therefore daylight through a window and that the many clearance gaps around opening casements and ventlights emphasise the problem of making the window weathertight.

An outward-opening casement may be difficult to clean from inside and is not suited to tall buildings where there is no outside access. The many corners of glass to the comparatively small casements and ventlights make window cleaning laborious such that corners of glass are not cleaned and become grimy, further restricting the area of clear glass available for daylight penetration.

Ventlights that are left open when a building is unoccupied provide a means of entry by putting an arm through the ventlight to open the catch of casements below.

Dead lights

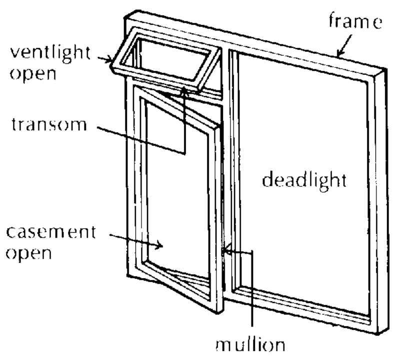


Fig. 29 Casement window with deadlight.

Of recent years it has been fashionable to use windows with as large an unobstructed area of glass as possible and the casement window, with its mullions and transom and comparatively small casements, has lost favour. The manufacturers of standard casement windows now make a range of windows which provide a large dead light by itself, or a dead light with a casement alongside it and a ventlight above, as illustrated in Fig. 29.

This type of window combines the advantage of a large area of glazing for maximum daylight with the facility for ventilation from a casement or ventlight. That part of a window which cannot be opened is termed a dead light or fixed light. The advantage of a dead light is that there is no limitation in width as it does not open and there are no clearance gaps to admit wind and rain.

Rolled steel section windows, which were generally made as casements with ventlights and deadlights in much the same form as wood casements, had the advantage of maximum area of glazing due to the small section of the frame and casement framing members.

Aluminium was initially used as a substitute for rolled steel in similar sections for use in casement windows, the small section aluminium having the advantage that it did not progressively corrode.

Because of their considerable bulk, hollow uPVC window sections are not best suited for casement windows.

Top and bottom hung windows

These opening lights are principally used for ventilation, the ventilation being controlled by the degree to which the light is opened. Top hung lights open out and bottom hung open in so that the slope of the sash and its glass directs rain outside the building. Usual practice is to position top hung lights at high level, as in the casement window, to encourage warmed air from inside to escape at the sides of the open sash and cold replacement air to enter below the sash as illustrated in Fig. 11. Top hung outward-opening lights are also fixed at high level so that their projection outside is at high level. Bottom hung opening-in lights are generally fixed at low level so that cold air can enter above the open light and some warmed air from inside can escape at the sides of the sash. Bottom hung opening-in lights are sometimes described as hoppers.

Top hung and bottom hung lights are often used in schools, places of assembly and factories, either opened by hand or by winding gear to control circulation of air between inside and outside. Because they are top or bottom hung these lights must have a positive opening and stay mechanism, otherwise they bang shut or fully open and would be subject to wind pressure. There is therefore a limit to their opening.

Being top or bottom hung the opening lights are not so subject to distortion due to their own weight as is the side hung casement, and comparatively large lights with small section frames are practical. A modification of these lights in the form of projected top and bottom hung lights has gained favour recently where the lights have a composite opening action of both sliding and pivoting to open. The disadvantage of these lights is that they may be left open and therefore be a security risk, and the bottom hung light may obstruct curtains.

These lights are made in the same way as side hung casements in wood, metal and plastic and the details of the framing of the lights and the window frame are the same as for side hung casements.

While the bottom hung lights may be cleaned both sides from the inside the top hung lights cannot.

Pivoted opening lights

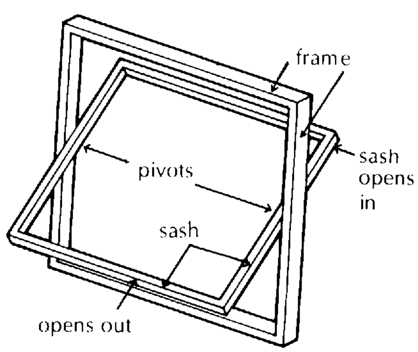


Fig. 30 Horizontally pivoted sash.

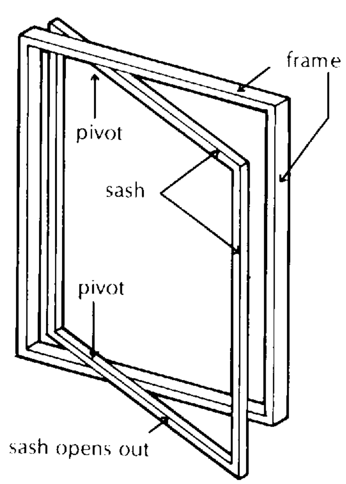


Fig. 31 Vertically pivoted sash.

With the introduction of continuously drawn, clear sheet glass in the middle of the nineteenth century, it became possible to use large single sheets of glass in windows. This facility was at first used to dispense with the many glazing bars previously necessary in casement and vertically sliding windows.

With the availability and demand for the comfort of central or space heating from the middle of the twentieth century, came the demand for larger unobstructed areas of glass. The width of a casement is limited by the strength of the framing in supporting its weight. The advantage of a pivoted opening light is that the weight of the frame and glass is balanced over the pivots that are fixed centrally up the height or over the width of the window, so that framing sections can be the same as those for a casement half the width.

The sashes may be either horizontally or vertically pivoted to open. Horizontally-pivoted sashes are usually pivoted at the centre of the height of the window, as illustrated in Fig. 30, to balance the weight of the sash over the pivots, and vertically-pivoted to open in by one third of their width to provide least obstruction inside as illustrated in Fig. 31. Because the weight of the sash is balanced over the pivots a large sash with small section framing is possible and cleaning the glass on both sides of the window is possible from inside the building. As part of pivoted sashes opens in, it obstructs the movement of curtains. Close control of ventilation with these windows is not possible as they have to open both top and bottom or both sides and they may act like a sail and catch and direct gusts of wind into the building.

Because of the pivot action of these windows the rebate between the sash and the frame has to be reversed around the pivot from inward opening to outward opening and a clearance for the opening action and the pivot has to be provided. This makes it difficult to ensure a weathertight seal around the pivot where the rebate and any weatherstripping has to be discontinued if the sash is to open. For this reason pivoted sashes are not recommended in positions of severe exposure.

An advantage of pivoted windows is that the glass both inside and outside can be cleaned from inside the building. This advantage may be a cause of danger, particularly in tall buildings, where there are no safety stays to horizontally pivoted sashes. Where someone is cleaning glass from within and the sash is free to pivot and the person cleaning leans too far out to clean the lower edges of glass, he or she may, by accident, fall out of the window. For security, positive stays must be provided to prevent such occurrences.

Sliding windows

The word casement is properly used to describe the framing material and glass of a side hung window. The frame material for other opening lights is termed a sash in the same sense that a sash in clothing is used to surround and support.

Vertically sliding sash window

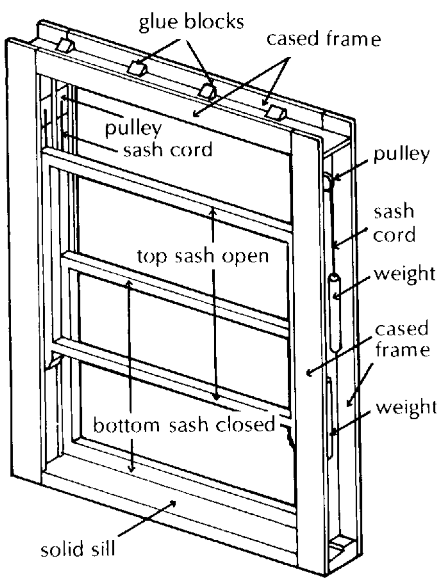


Fig. 32 Vertically sliding sash window.

During the seventeenth century the large casement window with two long, inward-opening sashes, generally extending down to the floor, was developed in France. This French casement or French window was accepted and has remained a principal form of window on the continent of Europe.

At the same time the vertically sliding window, commonly known as a 'double hung sash window', was developed in England and became the common, singularly English window for all but small domestic or cottage windows. The earlier forms of this window operated by supporting the vertically sliding sashes in position by pegs fitted to holes in the side of the frame or by spring cams. The later method of hanging the sliding sashes was by means of ropes or chains over pulleys in the frame, connected to counter weights concealed inside the box frame of the window, as illustrated in Fig. 32.

The advantage of the vertically sliding sash is that as the weight of the sashes is hung vertically on ropes or chains, the sashes do not tend to distort and in consequence large sashes can be framed from small sections and large unobstructed areas of glass are possible. By setting the bulky box frame of these windows behind a rebate in the surrounding wall, the external appearance of the window is of a large area of glass framed in slim members.

Because of the sliding action, the sashes neither project into or out of the building and close control of ventilation is possible between a lower limit of a slight raising of a sash to allow some ventilation between the meeting rails, to an upper limit of opening nearly half the window area. The sliding action facilitates the use of draught seals between sashes and frame.

The disadvantage of this window is that it is not easy to clean glass on both sides from inside the building. This difficulty has been overcome in recent window design in which it is possible to swing the sashes inwards for cleaning.

In time the traditional sash cords will fray and break and it is comparatively laborious to fit new ones. Sashes suspended in spring balances avoid this.

Horizontally sliding sash window

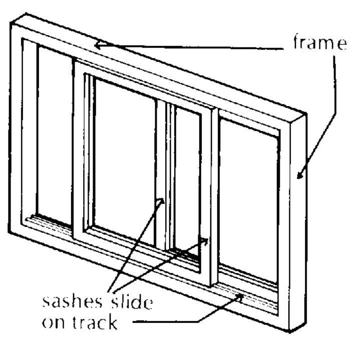


Fig. 33 Horizontally sliding sash window.

A traditional form of horizontally sliding wood window is that known as a Yorkshire light or cottage window, illustrated in Fig. 33. This crude form of small window comprised two timber-framed sashes that slid horizontally on wood runners inside a solid timber frame. As there had to be clearance for moving the sashes it was impossible to make this window weathertight and because of the tendency of the sashes to rack, i.e. move out of the vertical, they were liable to jam and be difficult to open and close. This simple form of window is little used today.

The advantage of this type of window is that there are no internal or external projections from opening sashes and it can be opened to give reasonable control of ventilation. It is difficult to clean the glass both sides from inside and the clearance required for movement of the sashes makes it difficult to weatherseal for conditions of severe exposure.

A recent adaptation of the horizontally sliding window is the so called 'patio window' which is in effect a combined fully glazed door and window. The large area of glass provides daylight and a wide, full length view out. These patio windows or doors are made as two full height sliding sashes or frames, one or both of which slide horizontally on an overhead track from which the sash hangs and slide on guide runners at the bottom. Because of the large area of glass, double glazing units are used to reduce heat loss and weatherstripping is fitted around sashes to exclude wind.

Because of their comparatively flimsy construction in plastic or aluminium sections these doors are sometimes prised open to gain entry.

Composite action windows

Composite action windows are designed to act like side-, top-or bottom-hung windows for normal ventilation purposes, by opening on pivots which can be unlocked so that the pivots then slide in grooves in the frame and open on hinged side stays to facilitate cleaning, as illustrated in Fig. 34. Of the three methods of opening, the top-hung projected window has been the most popular.

To clean this window the sash is projected to a horizontal or near horizontal position to clean the outside glass. The person cleaning will need to bear some of his weight on the open horizontal sash to reach the extreme outside edge and because of this there have been some

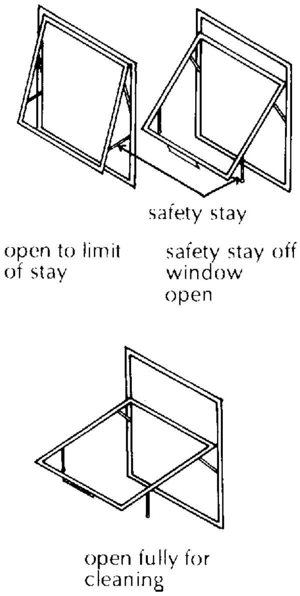


Fig. 34 Projected top-hung window.

serious accidents due to the supporting pivots coming out of the grooves.

The projected top-hung window can be projected down from the top of the window to allow both top and bottom ventilation.

This type of window was developed specifically to facilitate cleaning windows inside and out in conditions of comparative safety on upper floors of multi-storey blocks of flats. Because the sash may be projected into the room there is less danger of accidents than there is with a horizontally pivoted window.

The advantage of cleaning both sides of these windows from inside, by means of a long-handled squeegee if the sash is of any considerable size, should be weighed against the likelihood of the complicated mechanism becoming fouled and not operating properly.

A variation of the top-hung projected sash is the projected awning window in which three or more shallow sashes at high level open as if top-hung and can be projected for ease of cleaning from inside. The three sashes are ganged to open and be projected together through operating levers. Because of the comparatively shallow sashes each can be cleaned in safety from inside by hand.

Tilt and turn window

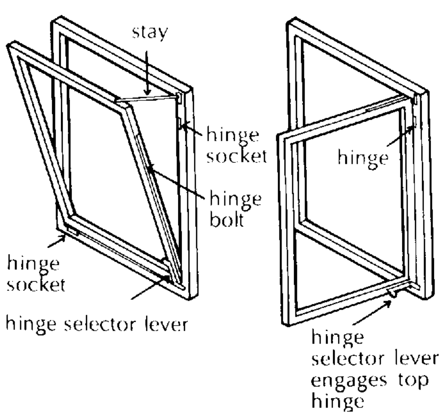


Fig. 35 Tilt and turn window.

This type of window is made specifically for ease of cleaning window glass both sides in safety, from inside the room. For normal operation the sash is bottom-hinged (hung) to open in for ventilation, as illustrated in Fig. 35. A stay limits the extent to which the head of the sash will open for safety reasons. The opening operation does not provide close control of ventilation, particularly in the gusty wind conditions common to upper floors of multi-storey blocks of flats.

For window cleaning the window can be converted to a side-hung sash when closed.

A lever operates to release bolts which disengage one bottom hinge and simultaneously shoots a side bolt in to engage a top hinge. The sash may then be opened in for cleaning glass both sides from within. In common with other bottom-hung sashes, opening in, the sash when open may foul curtains.

Due to misuse or lack of maintenance to provide free movement of bolts and hinges this type of window may jam shut.

The frame and sash can be made in wood, metal or plastic with sections similar to an ordinary opening-in hinged window but fitted with a handle that locks the side hinge pins, enabling the window to be opened for cleaning.

Sliding folding windows

The sashes in this type of opening window are hinged to each other and fold horizontally in concertina fashion to one or both sides of the window to provide a clear unobstructed opening as illustrated in Fig. 36. This opening light system is used as either a horizontal window or fully glazed doors where indoor and outdoor areas can be combined.

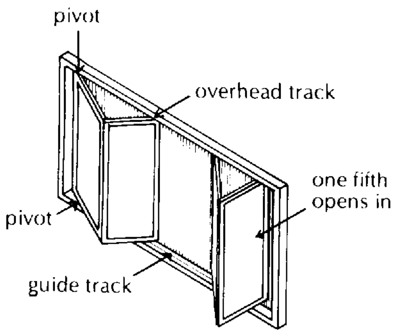


Fig. 36 Sliding folding sash window.

Each glazed sash is hung on a pivoted wheel that runs in an overhead track fixed to the top of the window frame. The lower edge of each sash is fixed to a pivoted wheel that runs in a track to guide the movement of the sash and maintain it in the vertical position.

A part of the width of each sash, when open, extends into the room, with the rest external so that the weight of the sashes is to some extent balanced each side of the overhead track.

This type of opening window is best suited for use as fully glazed doors giving access to balconies in warm climates, where a projecting overhead balcony gives some protection from rain and the clearance gaps top and bottom for the opening action may be acceptable.

Some maintenance is necessary to maintain the top track in working order and to clear the bottom track else the windows will be difficult to open. These windows are manufactured from steel or aluminium sections.

WINDOW FRAMING

Wood casement windows

Figure 37 illustrates the arrangement of the parts of a wood casement window, the members of the frames, casements and ventlights being joined with mortice and tenon joints. It will be seen that casements and ventlights fit into rebates cut in the members of the frame. These rebates, which are usually 13 mm deep, serve as a check to wind and rain in normal positions of exposure.

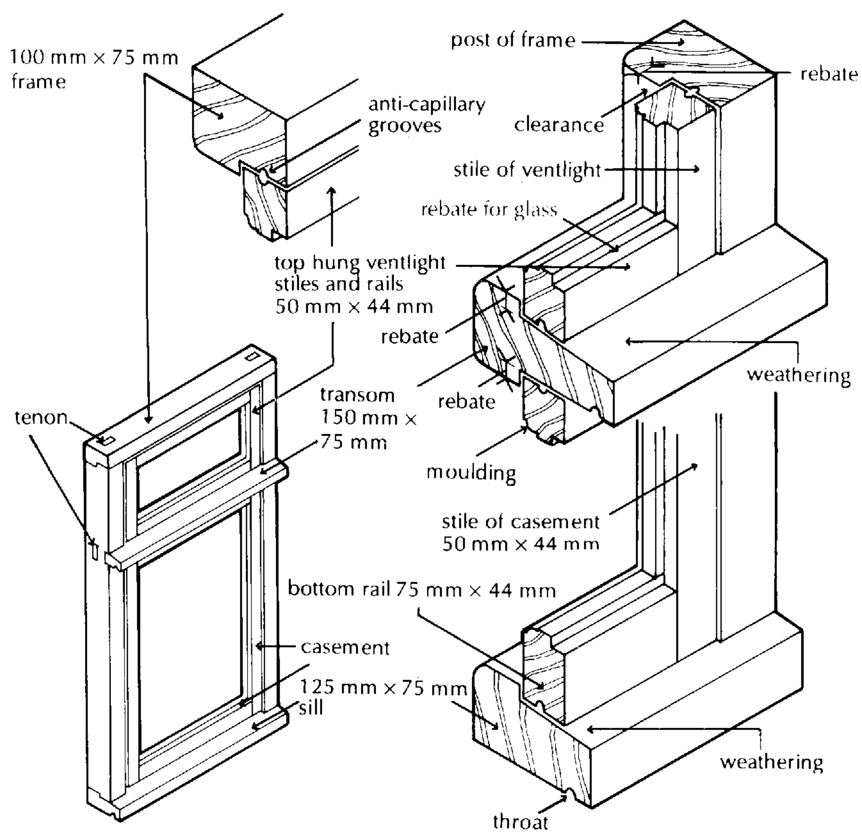


Fig. 37 Wood casement window.

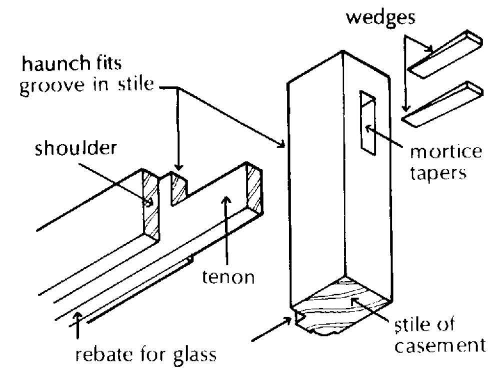


Fig. 38 Mortice and tenon joint.

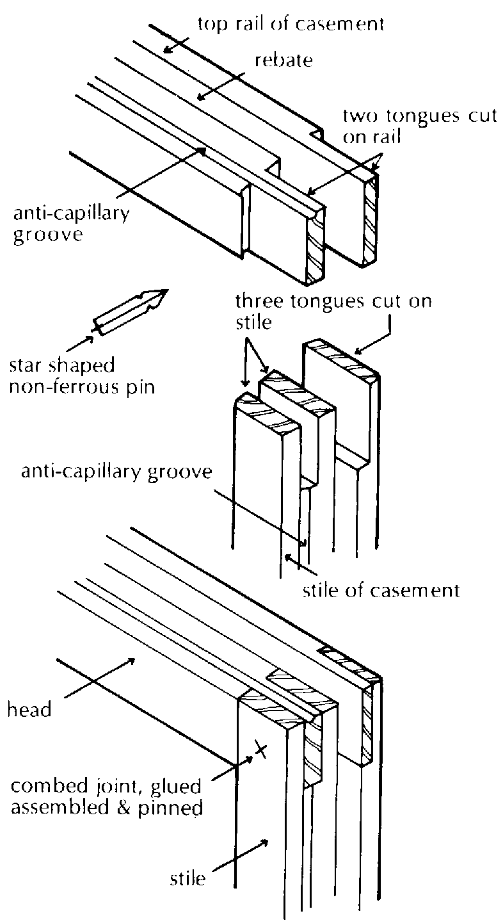


Fig. 39 Combed joint. Taken apart [top] and assembled [bottom].

To provide adequate strength and stiffness in the frame, casements and ventlights of casement windows and to accommodate rebates for casements and ventlights and for glazing, timber of adequate section has to be used and joined.

The traditional joint used is the mortice and tenon joint in which a protruding tenon, cut on the end of one section, fits into a matching mortice on the other, the joint being made secure with glue and wedges as illustrated in Fig. 38. This traditional wood jointing technique which is still to a considerable extent used was formed with hand tools to make a strong joint adequate for frames and casements.

The craft of accurately cutting and joining the timber members of windows and doors is termed joinery and those who practise it are called joiners. For centuries the joiner's craft was executed with hand tools used for preparing, cutting and assembling timbers. A mortice and tenon joint can readily be cut and made by skilled joiners and as it very rigidly joins timbers it was the joint always used in framing the members of windows and doors up to some seventy years ago.

During the present century woodworking machinery has been increasingly used to prepare, cut and assemble windows and doors so that today standard windows and doors are machine made. The skilled joiner can quickly cut and assemble a mortice and tenon joint but the time taken by machinery to cut and assemble this joint is greater than that required to cut and assemble a combed or dowelled joint. In consequence mortice and tenon joints are used less than they were.

The casements of mass-produced wood windows are joined with the combed joint illustrated in Fig. 39, which consists of interlocking tongues cut on the ends of members which are put together, glued and pinned. With the use of modern glue techniques this joint is as strong as a mortice and tenon joint. The combed joint is used in mass-produced windows as it can more rapidly be cut and assembled by woodworking and assembly machines than a mortice and tenon joint.

It is usual to specify the sizes of timber for joinery for windows, doors and frames as being ex 100 × 75 mm, for example. The description 'ex' denotes that the member is to be cut from a rough sawn timber size 100 × 75 mm, which after being planed on all four faces would be about 95 × 70 mm finished size. This system of specifying the sawn sizes of members is used when joinery is to be prepared by hand operated tools so that the member may be wrought or planed down to a good surface finish without limitation of a precise finished size, yet maintaining the specified size of window. Where joinery is wrought or planed by machine it is practice to specify the precise finished size of each member as this is the dimension the operator needs to know when setting up the machine and it is up to him to select the size of sawn timber to be used to produce the finished size.

Casement

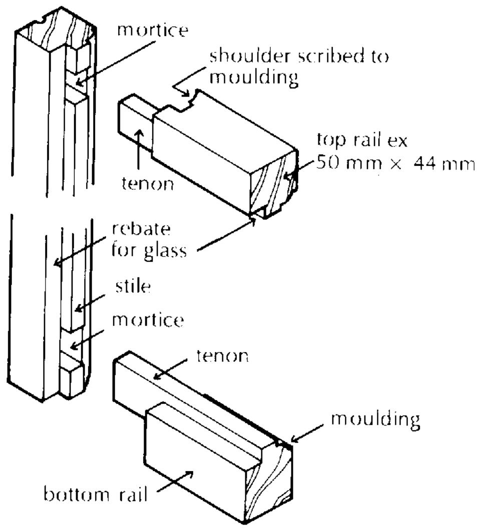


Fig. 40 Wood casement taken apart.

A casement is framed from four members, the two vertical stiles and top and bottom rails. The stiles and top rail are cut from 50 × 44 mm timber and the bottom rail from 75 × 44 mm timber. In the selection of a section of timber suited to framing a casement a balance is struck between adequate width of section to make a sound mortice and tenon joint and least width to provide maximum glazed area and sufficient thickness for a glazing rebate.

The stiles and rails are rebated for glass and rounded or moulded for appearance sake The rail ends are tenoned, shouldered and scribed to fit to the glazing rebate and moulding on the stiles. The rail tenons which are fitted to the mortices in the stiles are put together in glue, the tenons are wedged into the tapering mortices and the frame members are cramped tightly together until the glue has set.

The tenons are cut with their faces in line with the rebate for glass and moulding to minimise the number of faces cut across the grain. Figure 40 is an illustration of the framing members of a casement taken apart.

Ventlight

The four members of the ventlight are cut from timbers the same size as the stiles of the casement and are rebated, moulded and joined in the same way as the casement.

Window frame

A casement window frame consists of a head, two posts (or jambs) and a sill joined with mortice and tenon joints, together with one or more mullions and a transom, depending on the number of casements and ventlights.

The members of the frame are joined with wedged mortice and tenon joints as illustrated in Fig. 41. The posts (jambs) of the frame are tenoned to the head and sill with the ends of the sill and head projecting some 40 mm or more each side of the frame as horns. These projecting horns can be built into the wall in the jambs of openings or they may be cut off on site if the frame is built in flush with the outside of the wall. The reason for using a haunched tenon joint between posts and head is so that when the horn is cut off there will still be a complete mortice and tenon left.

It will be seen from Fig. 41 that one face of the tenon is cut in line with the rebate for the casement. It is usual practice in joinery to cut one or both faces of tenons in line with rebates or mouldings to keep the number of faces cut across the grain to a minimum. The mortice and tenon joints are put together in glue, cramped up and wedged.

When there is a transom in the frame it is joined to the posts by means of tenons fitted and wedged to mortices. Mullions are joined to head and sill with tenons wedged to mortices and to the transom with stub tenons fitted into a mortice. A stub tenon is one which does not go right through the timber into which it is fitted.

The members of a wood window frame are cut from 100 × 75 mm or 100 × 63 mm for sill and transom.

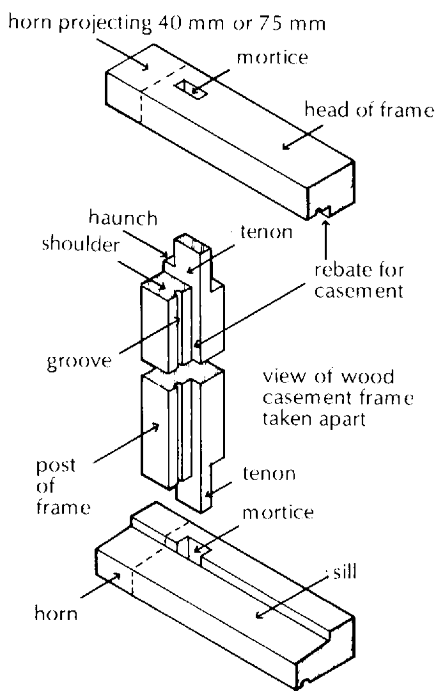


Fig. 41 Joints of casement window frame.

Standard wood casement

The manufacturers of wood windows produce a range of standard windows. Standard sizes and designs are offered, the advantage being the economy of mass production. In line with the move to dimensionally co-ordinate building components and assemblies, some of the standard ranges of windows are designed to fit basic spaces, with such allowances for tolerances and joints as appropriate. The purpose of dimensional co-ordination is to rationalise the production of building components and assemblies through the standardisation of sizes, within a framework of basic spaces into which the standard components and assemblies may fit.

The difficulty has been to adapt this factory assembly technique to conditions on the average building site, without recourse to cutting components on site to fit and the use of gap-filling or gap-covering materials. The difficulty has yet to be overcome because of the deep-rooted tradition in building of roughly putting together and cutting and filling to make a fit.

The casements and ventlights are cut so that their edges lip over the outside faces of the frame by means of a rebate in their edges, as illustrated in Fig. 42. These lipped edges are in addition to the rebate in the frame so that there are two checks to the entry of wind and rain

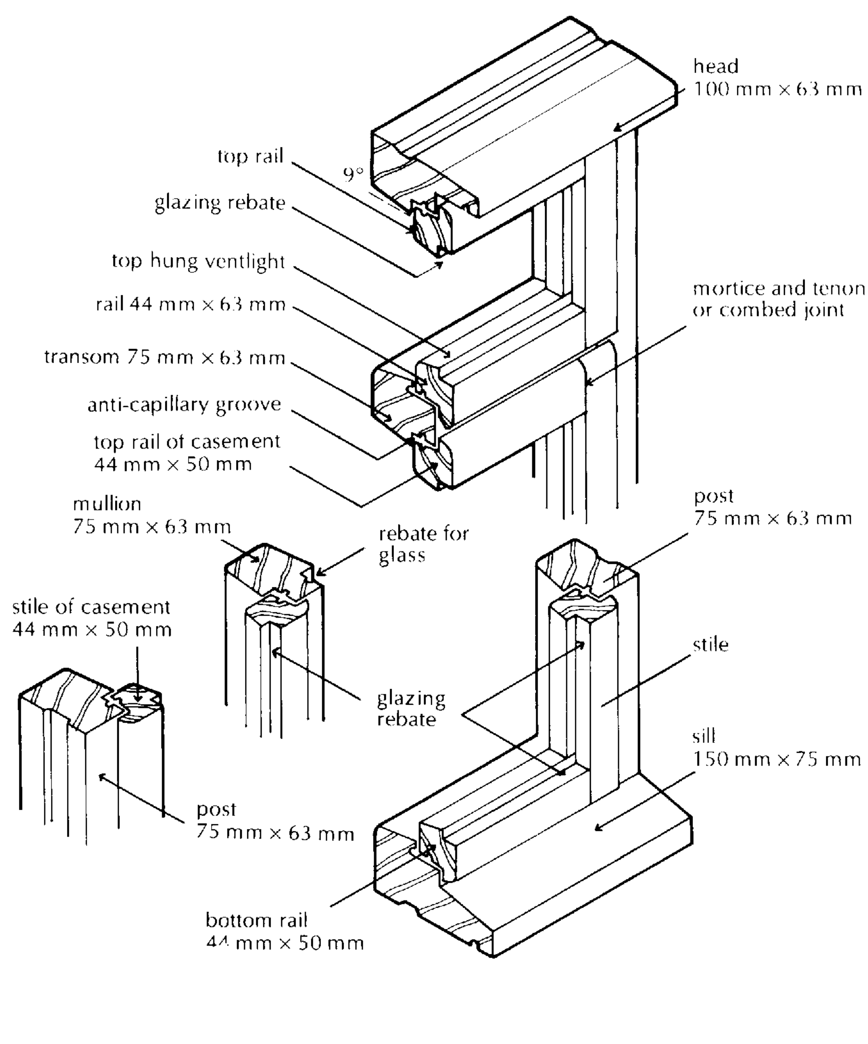


Fig. 42 Standard wood casement window.

between opening lights and the frame. The members of the frame and of the opening lights may be joined with mortice and tenon or combed joints.

Weatherstripping

For some years now a largely urban, self-indulgent northern European population has grown accustomed to conditions of internal warmth more common to the Mediterranean climates that they seek on holiday and in retirement. Such conditions were alien to their ancestors who accepted the rigours of working outdoors in the damp cold weather. usual for a large part of each year. As a result there has been an increasing call on the limited sources of energy to provide heating.

Current building regulations set standards of insulation for the external fabric of new buildings which include a recommendation for the use of double glazing in windows to conserve energy resources. The majority of modern windows include systems of weatherstripping around all opening parts of windows to exclude wind, such as those illustrated in Figs 43 and 44. This weatherstripping serves as an effective seal against the uncontrolled exchange of cold outside and warmed internal air to the extent that rooms become 'stuffy' due to

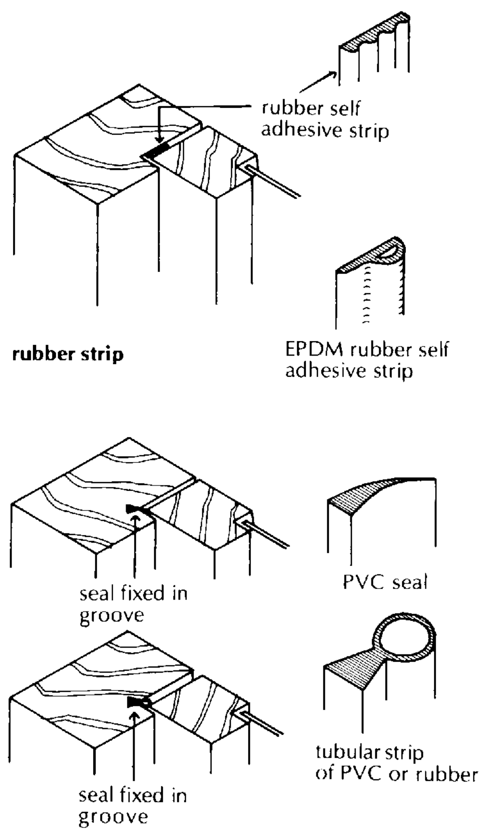


Fig. 43 Weatherstrips.

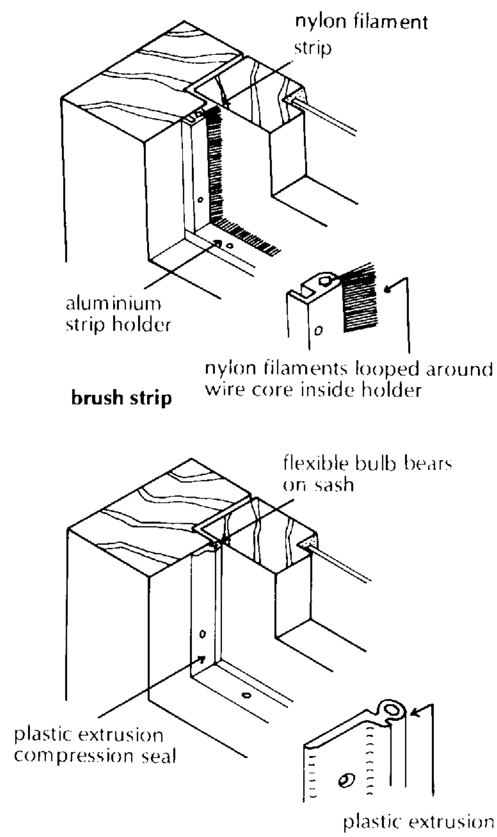


Fig. 44 Weatherstrips.

lack of ventilation. To counter this the most recent regulations require permanent ventilation.

In addition to acting as an effective barrier to the entry of draughts of cold air, the systems of weatherstripping also serve as an effective barrier to airborne sound.

In sheltered positions the outward facing rebate in the frame into which opening lights close will generally prevent rain penetration. The rebate will not, however, prevent draughts of cold air being blown through the clearance gaps around opening lights by wind pressure. To minimise cold draughts and to act as a seal against wind-driven rain in all positions of exposure, it is practice today to fit weatherstripping to all opening lights of new and old windows.

The two forms of weatherstripping that are commonly used are a flexible bulb or strip of rubber, synthetic rubber or plastic which is compressed between the frame and opening light (Figs 43 and 44) or a strip of nylon filament pile between the frame and opening light (Fig. 44).

For a maximum effect these seals should be fitted or fixed on the back face of the rebate or the inner face of the frame so that the rebate acts as a first defence against driven wind and rain.

The synthetic rubber strips illustrated in Fig. 43 are tacked inside the rebate of a wood window frame up to the outward facing rebate or may be self adhesive for fixing to metal or plastic windows. The advantage of these tacked in place or stuck on strips is that they can easily be replaced when they have lost elasticity in use. Of the two sections illustrated the bulb strip is probably the most effective.

The plastic strips illustrated in Fig. 43 are designed specifically to fit into shallow grooves in wood, metal or plastic windows. The strip is fitted to the dovetail groove with a machine that forces the end of the strip into the groove to make a tight fit. Because of the tight fit these strips are difficult to replace when they have lost elasticity.

The weatherstripping system illustrated in Fig. 44 consists of an aluminium section into which a strip of nylon filament is fitted. The aluminium section is tacked or screwed to the wood frame so that the flexible bulb bears on the sash when closed, as illustrated in Fig. 44.

Both weatherstripping systems illustrated in Fig. 44 are supplied mainly for fixing to existing windows.

Hardware

Hinges, fasteners and stays

Wood casements, ventlights and sashes are hung on a pair of pressed steel butt hinges similar to those used for doors. To inhibit rusting the hinges are galvanised and finished with a lacquer coating. As an alternative, metal offset hinges may be used for casements, in which the pin is offset outside the casement so that when the casement is

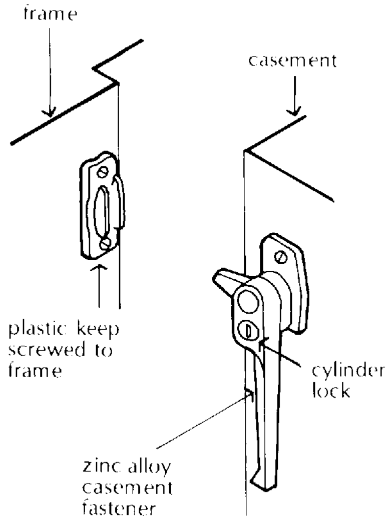


Fig. 45 Lockable casement fastener.

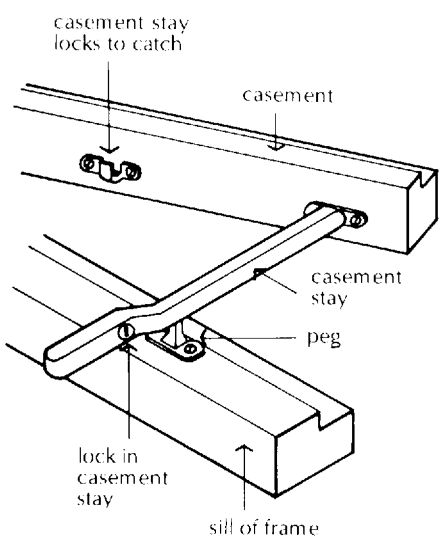


Fig. 46 Lockable casement peg stay.

open there is a gap between the hinged edge of the casement and the frame sufficient to allow for cleaning the outside of glass from inside the building.

To secure casements, sashes and ventlights in the closed position a casement or window fastener or latch is fitted halfway up the height of casements and in the centre of ventlights. These fasteners operate through a latch, which is fixed to the opening casement, and engages a keep fixed to the frame as illustrated in Fig. 45. The handle of the latch is raised to release the latch to open the window.

For security the majority of window latches are lockable by a loose key that operates a lock in the latch. Obviously the loose key should not be left in the lock when the window is closed as it would invite a break in by breaking the glass. Too often these small loose keys are mislaid.

Some care should be taken in fitting casement fasteners and keeps so that when the fastener is closed it firmly closes the casement on to flexible weatherstripping fixed in the rebate of the window frame around the opening light.

Casement fasteners are made of cast zinc, aluminium or steel, usually finished with a protective coating of anodising, powder or liquid organic coating or plastic.

To maintain opening lights in a window in a chosen open position, casement stays are fitted to the bottom rail of opening lights, as illustrated in Fig. 46. The conventional form of these stays is a casement stay fixed to the bottom rail of the sash, which engages a casement peg fixed to the sill of the window frame. Holes in the stay provide a selection of possible openings. The stay, which pivots in its fixing, can be secured in a catch, fixed to the bottom rail of the sash when the window is in the closed position.

Some casement stays have been designed to operate through the frictional resistance between a two piece stay to maintain the casement in a selected open position. These have not been particularly successful, as the frictional resistance required to maintain the casement in an open position in gusty wind conditions is such that it requires considerable force to operate the stay.

Stays are made of cast zinc, aluminium or steel usually finished to match the protective coating of fasteners.

Fixing windows

The traditional method of fixing windows in position in a wall is to build solid walling around them. The window is said to be 'built-in'. The advantage of this is that there is a good fit of the wall to the window and that secure fixings may be solidly bedded in horizontal courses as the wall is raised around the window. The majority of softwood joinery and metal windows are built-in, as

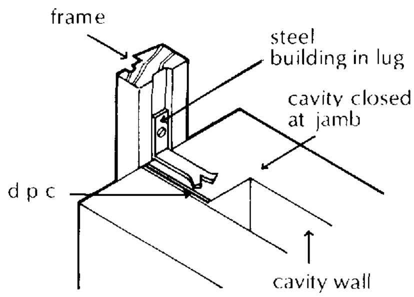


Fig. 47 Fixing wood window.

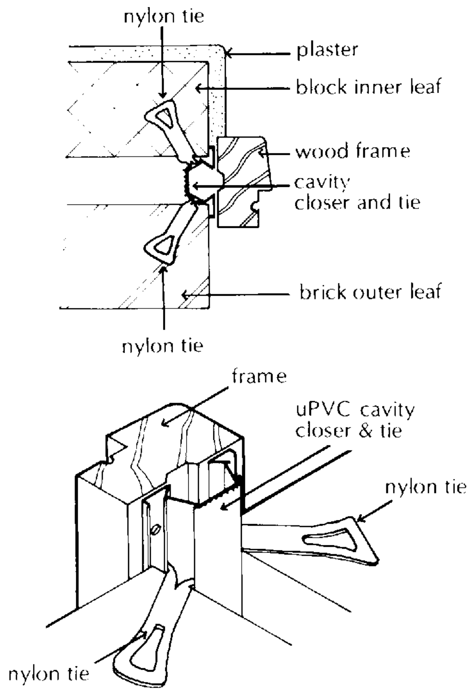


Fig. 48 uPVC cavity closer and ties.

any slight damage to the frame will be masked by subsequent painting.

The alternative method is to 'fix-in' the window after the wall has been built, which requires some care in building to ensure that there is sufficient clearance for fitting the window in position.

Hardwood windows are often fixed-in to avoid damage to the wood surface, which will not be covered with paint. Similarly ready glazed plastic and aluminium windows are fixed-in to avoid damage to surfaces and glazing.

Softwood window frames are secured in position in solid walls by means of 'L' shaped galvanised steel cramps or lugs that are screwed to the back of the frame and built into horizontal brick or block courses as the wall is raised. Figure 47 is an illustration of a fishtail ended lug 50 × 75 mm in size built into a horizontal course of a brick cavity wall.

Where the cavity of a wall is continued up to the jambs of a window opening, a system of plastic cavity closers and ties may be used. A preformed uPVC cavity closer is screwed to the back of the window frame as illustrated in Fig. 48. Nylon wall ties are slotted into the sides of the cavity closer and built into horizontal courses to secure the frame in place. One cramp, lug or tie is used for each 300 or 450 mm of height of window each side of the frame.

Where hardwood frames are fixed-in after the walling is completed, one method of fixing frames is to leave pockets in the jambs of the wall into which lugs can be fitted and the walling then made up. The term 'pocket' is used to describe the operation of bedding a few bricks in dry sand so that they may be removed after the wall is built for the building in of lugs at a later stage. As an alternative the window frames may be secured by galvanised iron straps screwed to the back of the frame and screwed to plugs in the inner reveal of the opening where they will be hidden by subsequent plastering.

Perimeter sealing to wood windows

Most wood window frames are bedded in mortar as the frame is built-in, with the mortar pointed as a perimeter seal. Where frames are fixed-in the gap between the back of the frame and the surrounding walling is sealed against weather with one of the elastic sealants described later.

Steel casement windows

The steel section window has lost favour principally because of the ill repute it gained from rapid deterioration by rusting, before the introduction of hot-dip galvanising in the 1940s. The strong slender sections of this type of window were at one time considered its most attractive feature. Changes in fashion mean that the steel window does not have the popularity it enjoyed between 1930 and 1950. The

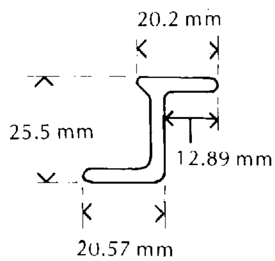


Fig. 49 Standard Z section.

disadvantages of the steel window are that the small section will not comfortably accommodate the thickness of double glazing, and the material being a good conductor of heat acts as a cold bridge to transfer of heat and encourages condensation which in turn may encourage rust.

Steel casement windows are made either of the standard Z section hot-rolled steel illustrated in Fig. 49 or the universal section illustrated in Fig. 50. The latter section is made with channels to take weatherstripping.

Standard steel casement windows are made from the hot-rolled steel Z section which is used both for the frame, casements and ventlights. The section is cut to length, mitred and welded at the corners. The assembled parts of the window are thoroughly cleaned and then 'rustproofed' by the hot-dip galvanising process in which the parts are dipped in a bath of molten zinc. The zinc adheres strongly to the steel in the form of a thin coating which protects the steel from corrosive rusting. This protective coating will be effective for many years, the effective useful life of the window depending on the thickness of the coating. The thicker the coating the longer the life.

The casement and frame sections fit together as illustrated in Fig. 51, making a reasonably close fit to exclude rain in all but exposed positions. Where there are a casement ventlight and dead light as illustrated in Fig. 52, two specially rolled steel sections are used as mullion and transom. The mullion section is scribed (cut) to fit to the profile of the frame and welded in position as is the transom which is welded to the mullion and the frame. The assembled parts are cleaned and hot-dip galvanised.

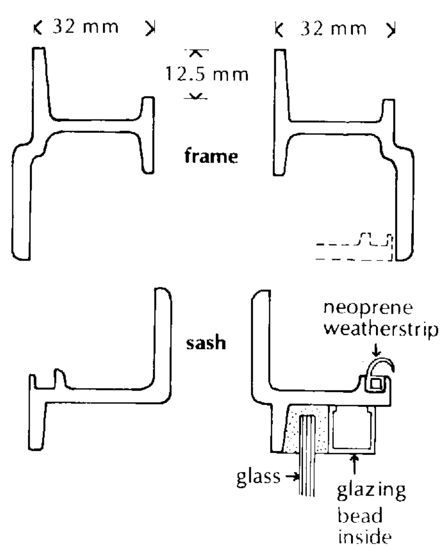


Fig. 50 W20 steel window sections.

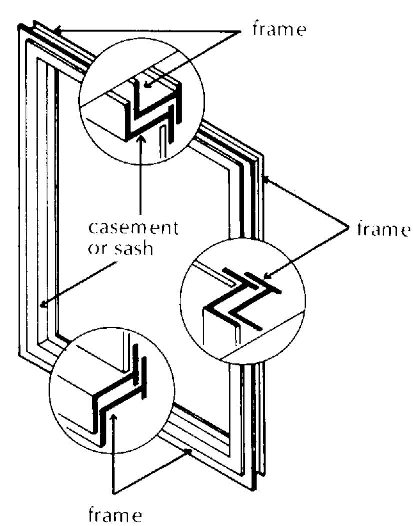


Fig. 51 Standard metal casement.

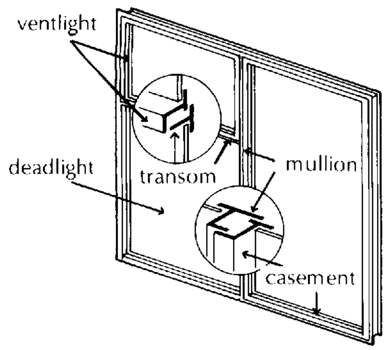


Fig. 52 Standard metal window.

As an alternative to the standard Z section the universal or W20 steel section may be used. These heavier sections, illustrated in Fig. 50, may be used for frame, casements and ventlights with mullion and transom sections. The assembled parts are hot-dip galvanised after assembly. Universal sections are generally used for larger casement and pivoted windows where the greater variety of section available is of advantage in making up the more complicated requirements of frame and sash sections and for the fixing of weatherstripping and to accommodate double glazing units.

There is no straightforward method of overcoming the disadvantage of the conductivity of steel windows to the transfer of heat and the possibility of some condensation forming on inside faces, particularly in humid atmospheres such as kitchens and bathrooms. Where there is adequate ventilation in kitchens and bathrooms, condensation can be minimised and rust inhibited by sound protective coating. The comparatively small surface area of steel in these windows compared to the total area of outside walling will cause little significant loss of heat.

Steel casement windows are fitted with steel butt hinges or projecting hinges welded to the frame and opening lights. The projecting hinge illustrated in Fig. 53 is projected outside the face of the window by steel plate brackets and an angle which are welded to the frame. The pin around which the opening light hinges is offset so that when the casement is open there is a sufficient gap to make it possible to clean the outside of the glass from inside the room.

Lever fasteners and peg stays similar to those used for wood windows are welded to the frame and opening lights as illustrated in Fig. 53.

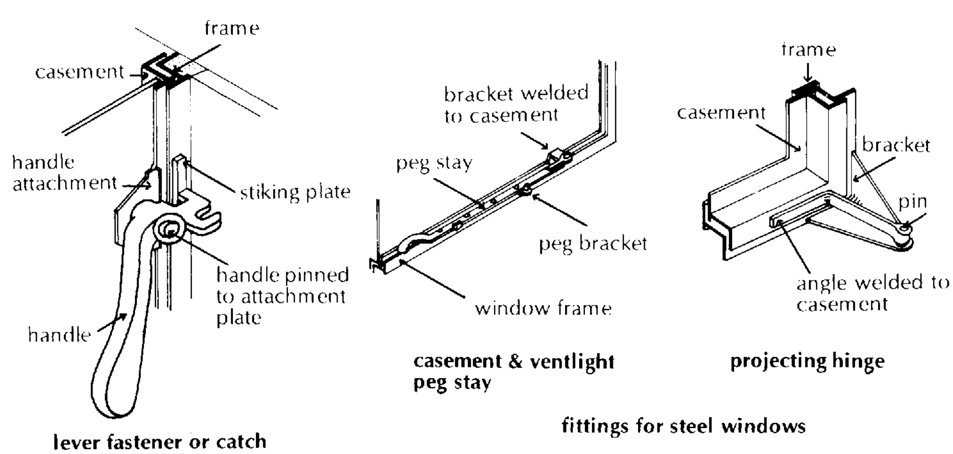


Fig. 53 Hinges and fasteners.

Fixing steel windows

Standard steel casement windows are usually built-in to openings in solid walls and secured in position with 'L' shaped lugs that are bolted to the frame as illustrated in Fig. 54. The lugs are adjustable to suit brickwork courses. Where these steel windows are fixed-in, after walls have been built, a galvanised steel lug is bolted to the back of the frame and its projecting arm is then screwed to a plug in the inner reveal of the wall. These lugs will later be obscured by plaster.

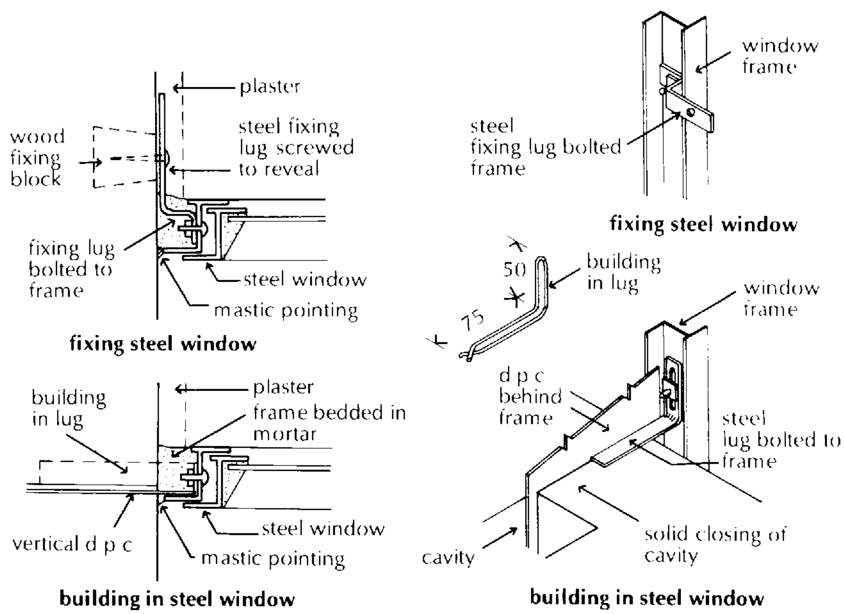


Fig. 54 Fixing steel windows.

Steel windows finished with hot-dip galvanising coating should be painted both as added protection against corrosion and as a decorative finish over the dull, grey, zinc coating.

As an alternative to painting, galvanised steel windows may be finished with a polyester powder coating to provide additional protection against corrosion and as a decorative finish.

The galvanised windows are cleaned, chromated and electrostatically coated with polyester powder which is then stoved at a temperature of 200°C. The usual colour of this coating is white, but black, red and Van Dyke brown are also used. The powder coating should not require painting for many years.

For unheated buildings such as warehouses and farm buildings, galvanised and powder coated steel windows will provide a perfectly adequate and durable source of daylight through walls.

Timber sub-frame for steel windows

The sections used for steel windows are slender and may be damaged in transit or during handling on site. The manufacturers of these windows will supply wood surrounds for their steel windows to give added strength and rigidity or to provide a more substantial surround to the window for appearance sake. The wood surrounds are usually cut from 75 × 75 mm, or 50 × 75 mm softwood timber which is wrought (planed smooth), rebated and joined with mortice and tenon or dowelled joints solidly glued. Figure 55 is an illustration of the section of a wood surround with the steel windows in position.

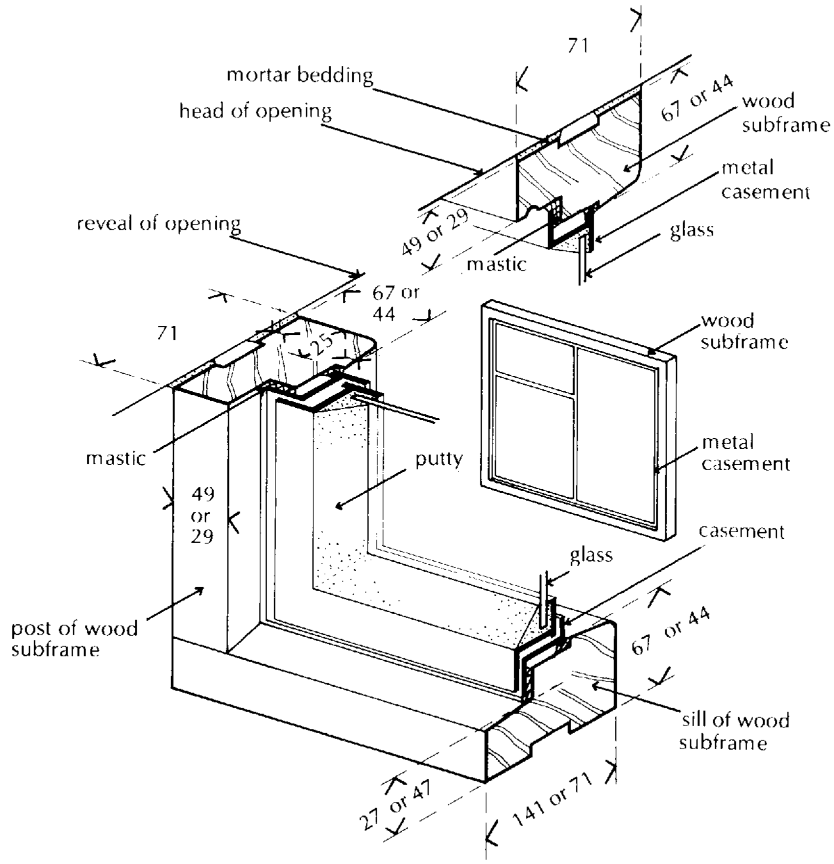


Fig. 55 Timber sub-frame for metal window.

The steel window is secured to the wood surround with countersunk headed wood screws driven through holes in the steel frame into the wood sub-frame. Mastic is packed between the steel frame and the timber sub-frame to exclude rain. The two rebates cut in the wood sub-frame are so spaced that they accommodate the flanges of the steel frame. The wood surround is secured with L-shaped lugs or ties that are screwed to the back of the frame and built into horizontal joints of brick or blockwork.

The particular advantage of the wood surround is that it provides an appreciable surface around the slim section of metal which gives emphasis to the windows.

Steel windows and sub-frames for steel windows are usually built-in as the surrounding walls are raised and are bedded and pointed in mortar as a perimeter seal. Where these windows and their sub-frames are fixed-in to prepared openings, so that coatings are not damaged, the perimeter seal is made with a sealant in the same way that aluminium windows are finished.

Aluminium casement windows

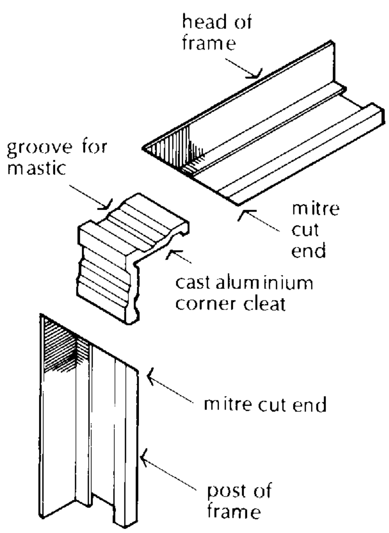


Fig. 56 Corner cleat for aluminium window.

Aluminium windows were originally made as a substitute for hot-rolled steel section windows, in small sections similar to those of steel. Aluminium windows of small solid sections are less used now than they were, partly due to changing fashion and more particularly because the small section, which acts as a thermal bridge to encourage condensation, does not take the wider, double glazed, insulated glazing (IG) units in use today.

The majority of aluminium windows that are made today are of sections extruded from aluminium alloy in a wide range of channel and box sections with grooves for lips for weatherstripping and double glazing.

In the extrusion process through which these window sections are formed, molten metal is forced through a die as thin sections of material. The extrusion process allows for a wide range of sections which are more straightforward to vary than comparable uPVC sections. This is a particular advantage of aluminium as a window material where special sections are required.

The sections are mitre cut and mechanically cleated or screwed at joints which are sealed against entry of water as illustrated in Fig. 56. The fabricated frames and opening lights are then given a protective coating by anodising, polyester powder or liquid organic coating.

A disadvantage of aluminium as a window material is that it is a good conductor of heat and in consequence moisture vapour in warm air will condense to water on the cold inner surfaces of these window sections in periods of cold outside temperature. In most rooms this condensation on the comparatively slim sections will be merely a nuisance. In rooms such as kitchens, where air will be heavily saturated with moisture vapour, the condensation may spoil decorations and affect the seal to double glazing. Here it is advantageous to use the 'thermal break' window construction illustrated in Fig. 57. Separate aluminium window sections are mechanically linked to the main window sections, through plastic thermal break sections. The IG, double glazed units are secured with aluminium beads and the window is weatherstripped with preformed synthetic rubber seals.

Fixing

The aluminium frame is secured to the surrounding wall by aluminium lugs that clip to the back of the frame at centres of up to 600 mm and also adjacent to hinges and fasteners, with the lugs screwed to plugs in the wall.

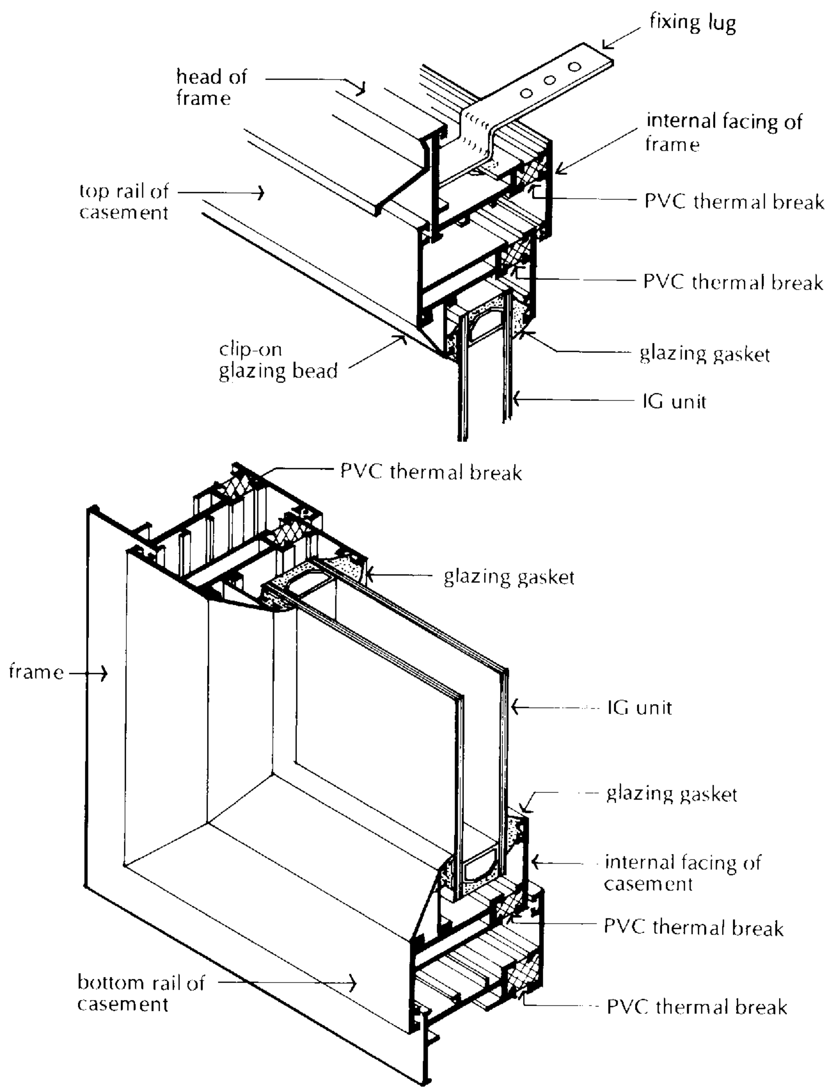


Fig. 57 Thermal break aluminium casement window.

Hardware

Hardware of hinges, lockable casement fasteners and stays is made of anodised finish, cast aluminium or die-cast zinc alloy, chromium plated.

Protective coating

On exposure to air aluminium forms an oxide, surface coating which is a coarse textured light grey finish. This coarse surface will attract grime which is difficult to clean. Because of the unattractive appearance of the natural oxide finish, aluminium window sections are usually finished with anodised, polyester powder or liquid organic coatings as protection against oxidisation and as a decorative coating that can be easily cleaned.

Anodised finish

An aluminium oxide coating is formed by the sulphuric acid electrolytic method. Metal oxides are deposited on the surface of the aluminium as an alternating current is applied across the bath of sulphuric acid. A limited range of colours can be produced by various electrolytes. The usual range of colours is from silver grey through bronze to black. The anodised finish is covered with a clear, thin coating of lacquer to protect it against alkaline materials used in building operations.

In the past some anodised finishes have failed due to the finish being damaged by building operations or other causes, and unsightly corrosion of the aluminium below has occurred and spread. Because of this and the limited colour range, anodised finish is less popular.

Polyester powder organic coatings

After the window frames and opening lights have been cleaned, etched and chromate, conversion coat treated, the polyester powder is sprayed on to the windows. The coating is then stoved at 200°C to form a hard, smooth, durable coating.

Liquid organic, acrylic coating

After pre-treatment the same as that for the powder coating, the acrylic is applied in liquid form by electrophoretic dip for white or by electrostatic spray for colours. The liquid finish is then stoved at 200°C to form a hard, smooth durable coating.

A range of bright colours is practical with both the polyester powder and the liquid acrylic coatings, from white through blue, green, red and black. These organic finishes provide a decorative, protective, durable coating that requires only occasional cleaning with water to remove grime. In time the stronger colours may bleach due to the effect of ultra-violet light.

Perimeter sealing around frames

Wood windows that are built-in provide a wide flat surface between the back of the frame and the jamb of the surrounding wall that can be filled with mortar to exclude rain.

The thin-walled section and hollow at the back of both aluminium and plastic windows do not provide the facility for filling with mortar. These window frames require sealing around their edges with one of the sealants.

SEALANTS

A sealant is a material that is initially sufficiently liquid or plastic for application and which cures or changes to a material that will adhere to surrounding surfaces, retain its shape and accommodate some small movement without loss of seal against wind and rain.

Plastoelastic sealant

Sealants used for sealing perimeter joints around window frames are classed as plastoelastic, elastoplastic or elastic. Plastoelastic sealants, which have some elastic property, remain predominantly plastic and can be moulded.

Elastoplastic sealant

Elastoplastic sealants, which develop predominantly elastic properties as they cure, will return to their former shape when stress is removed and also retain some plastic property when stressed over long periods.

Elastic sealant

Elastic sealants will, after curing, have predominantly elastic properties in that they will continue to resume their former shape once stress is removed, during the anticipated useful life of the material.

Acrylic

Polysulphide

Polyurethane

Silicone

The materials that may be used for perimeter sealing around window and door frames are acrylic, polysulphide, polyurethane and silicone. Of these acrylic is classed as plastoelastic, polysulphide as elastoplastic and polyurethane and silicone as elastic. In general the plastoelastic material is easier to use because of its predominantly plastic nature, but it will not form so tough and elastic a surface as elastoplastic materials that have some plastic property. The elastic materials need some experience and skill in use for successful application.

One-part sealant

Polysulphide and polyurethane sealants are produced as either one-part sealants ready to use, or as two-part sealants which have to be mixed before use. The one-part sealants are more straightforward to use as there is no mixing and the material cures or loses plasticity fairly slowly, allowing adequate time for running into joints and compacting by tooling.

Two-part sealant

The two-part sealants require careful, thorough mixing and as they cure fairly rapidly require skill in application. The advantage of the two-part sealants is that as they cure fairly rapidly they are less likely to slump and lose shape and adhesion than the more slow curing one-part sealants Silicone sealants which cure fairly rapidly to form a tough, elastic material require rapid application and tooling for compaction.

As the prime function of a sealant to perimeter gaps around window frames in traditional walling is as a filler to exclude wind and rain, it should adhere strongly to enclosing surfaces, be resistant to the scouring action of weather and sufficiently elastic to accommodate small thermal movements for the anticipated life of the material. The expected useful life of sealants, after which they should be renewed, is up to 15 years for acrylic and up to 20 years for

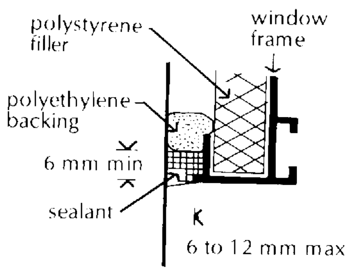


Fig. 58 Butt joint.

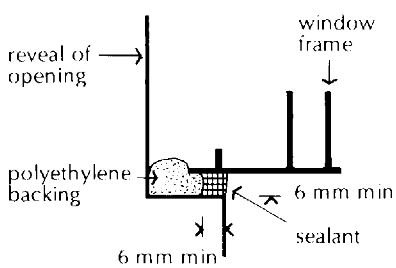


Fig. 59 Sealed lap joint.

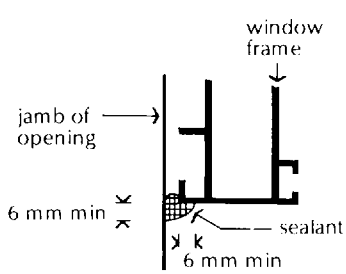


Fig. 60 Fillet seal.

polysulphide, polyurethane and silicone. For appearance, the sealant should not be too obvious.

To ensure maximum adhesion, the surfaces on to which a sealant is run should be clean, dry and free from dust, dirt and grease. Rough surfaces such as open textured brick, textured rendering, scratched finishes and textured masonry paints are unsatisfactory as a base; the sealant will not readily adhere and would produce an unsightly appearance. Some window surfaces such as aluminium and plastic will require solvent cleaning to remove oil, grease and other coatings if the sealant is to make satisfactory adhesion. Sealants are usually run into joints from a gun operated by hand pressure or air pump.

The form of sealant joint used depends on the width of the perimeter gap between window frame and surrounding wall and whether the frame is set in a rebate. The types of joint used are butt joint, lap joint and fillet seal. The most commonly used is the butt joint (Fig. 58), formed between the back of the frame and the reveal of the opening. Foamed polyethylene is first run into the gap as a backing for the sealant. The sealant is then run into the joint and tooled with a spatula to compact the material and make good adhesion to the two surfaces. It is finished with a slight concave finish up to the edge of the window frame.

The best gap width for the joint is from 6 to 12 mm which is wide enough for application of the sealant, small enough to contain the sealant and not too obvious. Butt joints up to 25 mm are practical with the depth of the sealant being half that of the gap. These wider joints tend to look somewhat unsightly. To prevent the sealant adhering to the outside face of the window frame it is good practice to use masking tape up to the edge of the outside face of the frame. Once the sealant is sufficiently cured the masking tape is stripped towards the sealant. Polysulphide or polyurethane two-part sealants are commonly used by skilled operatives.

A lap point is formed where the window frame is set behind an accurately formed rebate in wood, metal, masonry or concrete surrounds (Fig. 59). The sealant is run into the gap over a polyethylene backing and tooled to a slight concave finish to masking tape. It is more difficult to form or renew this joint, which is less obvious than a butt joint.

A gap of less than 6 mm between the window frame and the opening in the wall is too narrow for gunned in sealant. Here a fillet seal is used, which is formed to adhere to the outside face of the frame and the wall opening (Fig. 60). The fillet seal is run as a convex fillet to provide sufficient depth of sealant, which is finished as it comes from the gun. This type of sealant finish tends to have a somewhat untidy appearance.

uPVC casement windows

These windows are fabricated from extruded, high-impact strength, white, uPVC (unplasticated polyvinyl chloride). Modifiers, such as acrylic, are added to the PVC material to improve impact strength. Pigment may be added to produce body coloured uPVC. The heated, plastic material is forced through dies from which it extrudes as thin-walled hollow box sections, complete with rebates, grooves and nibs for beads, weatherseals, glazing seals and for fixing hardware.

The wide range of sections are made in multi-cell form for rigidity, with one main central cell and two or more outer or surrounding cells. Main wall thickness varies from 3 mm for the bulkier German section, 2.8 mm for British and 2.2 mm for some French sections.

Tests for uniformity of section, colour and freedom from visible distortion of surfaces are carried out by reputable extruders. The dozen or so extruders in this country produce some hundreds of differing profiles. Some extruders also fabricate uPVC windows. The majority of the 6000–7000 fabricators take their sections from the handful of extruders.

Metal reinforcement

The extruded sections are mitre cut to length, metal reinforcement is fitted and secured inside the main central cell, and the corner joins are welded together by an electrically heated plate that melts the end material, with the ends then brought together to fuse weld. The process of cutting and welding is fully automated, which makes it a comparatively simple operation to set the machine to make one-off sizes of windows for the replacement window market. This advantage is singular to uPVC windows.

Mitred, welded corners

At the mitred, welded corner joints a rough, curled edge of weld material protrudes from the face of the sections. This excess material is cut away for appearance, either flush with the external faces or more usually as a shallow groove, the material around the joint being routed out to a depth of about 0.25 mm. This latter finish tends to mask the slight difference in texture at the joint more than the flush finish.

Reinforcement is fixed inside the hollows of the uPVC cells to

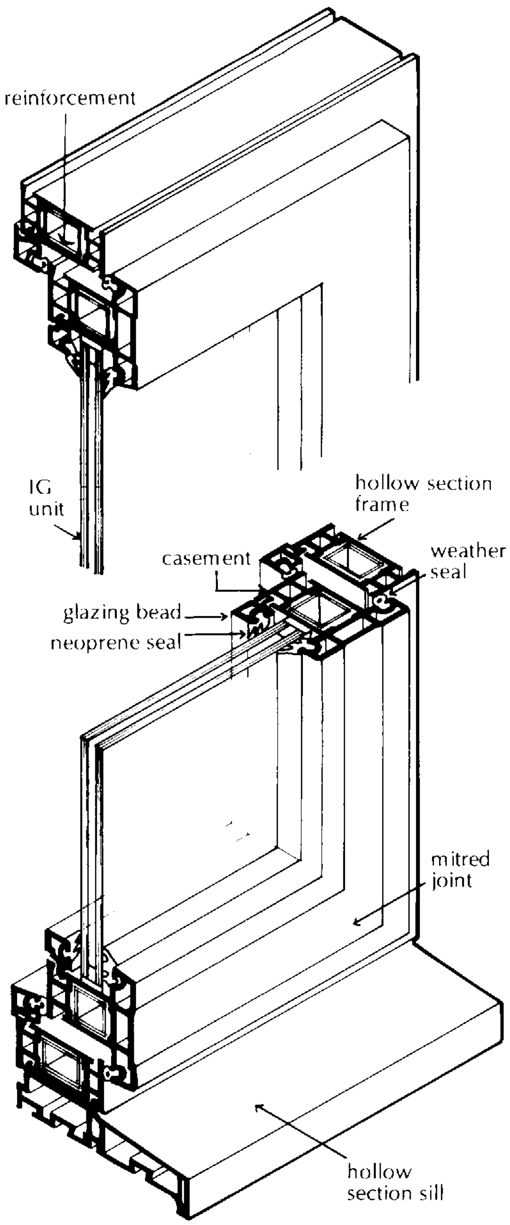


Fig. 61 uPVC casement window.

provide rigidity to the sections that might otherwise distort due to thermal movement, handling, fixing and in use as opening lights. Reinforcement should be fitted to all frames more than 1500 mm long and all opening lights more than 900 mm long. For fixing frames to surrounding walls and for secure fixing of hardware it is advantageous to use reinforcement to all window sections.

Reinforcement is either of galvanised, rolled steel or extruded aluminium sections, aluminium having the advantage that it does not destructively corrode and expand where water may find its way into the hollow sections.

In use, coloured uPVC material, particularly dark colours, may bleach in an irregular, unsightly manner after some years due to ultraviolet light, so white to off-white uPVC is recommended.

In fire, uPVC, which does not readily ignite, will only burn when the source of heat is close to the material and will not appreciably contribute to the spread of flame. The rate of generation of smoke and fumes produced when uPVC is subject to fire is no greater than that of other combustible materials used in building. Recent reports from Germany of the dangers of toxic fumes from these windows in fires, were given publicity to the extent that some German authorities did for a time ban their use. In the event it has been established that PVC gives no more toxic fumes than other materials that may ignite in fires and is thus but a part of the hazard of fire.

Other than occasional washing with water to remove dirt these windows require no maintenance and this is their principal advantage.

The uPVC casement illustrated in Fig. 61 is glazed with an IG double glazed unit set in synthetic rubber seals and fitted with weatherstripping and reinforcement of galvanised steel or aluminium sections.

Because most uPVC sections are bulky they are not suited for use in the comparatively small casement window. The extruders of uPVC sections make a less bulky section specifically for use in casement windows.

Hardware

Hardware is made from cast aluminium alloy and die-cast zinc alloy with anodised, powder or organic liquid coatings for lockable fasteners and stays that are screwed through the outer wall of the uPVC sections into the reinforcement.

Fixing uPVC frames

To avoid damage to the frames during building operations these windows are usually fixed in position after the surrounding walls have been built. Fixing is usually by driving strong screws through holes in the frame and reinforcement into surrounding walls or by means of lugs bolted to the back of frames which are screwed to plugs in walls. Fixings are at 250 and 600 mm centres and from 150 to 250 mm from corners.

Perimeter seals to uPVC windows

The gap between the window and the surrounding wall is sealed with silicone or polyurethane sealant with backing of foamed, compressible, pre-formed strips or gunned in expanded, adhesive foam for joints more than 6 mm wide.

Pivoted windows

Horizontally-pivoted wood window

Figure 62 is an illustration of a double-glazed horizontally-pivoted wood window. The frame is solid and rebated. Stop beads are fixed to the sash above and the frame below the pivots. The sash is made as separate inner and outer sashes, each of which is glazed and the sashes are normally locked together.

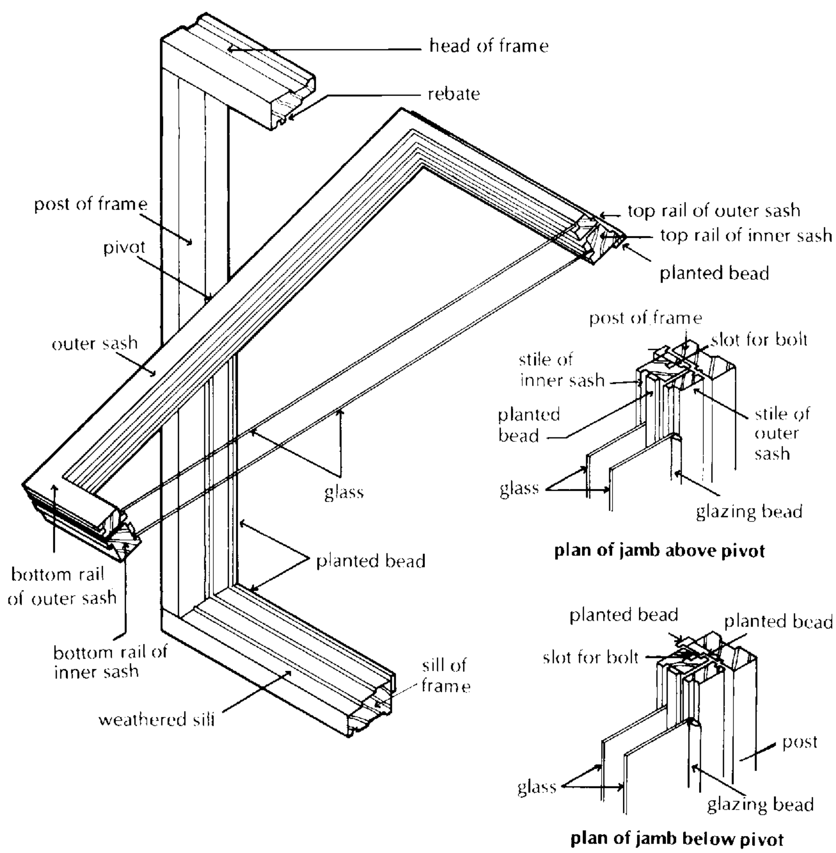


Fig. 62 Horizontally-pivoted reversible window.

The purpose of forming the sash as two separate parts is so that the two parts of the sash may be opened for cleaning glass inside the space between the two parts. This is achieved by reversing the sash through 180° so that the outer part of the sash may be unlocked and hinge to

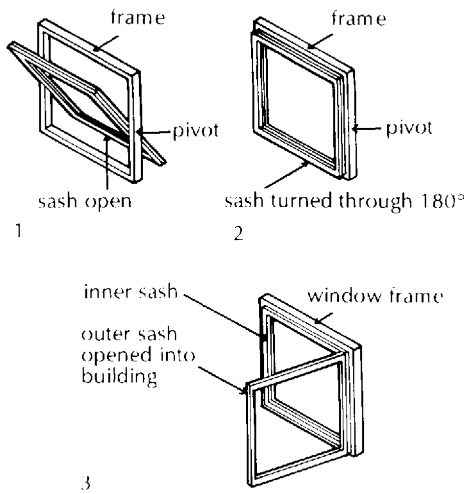


Fig. 63 Sash reversed for cleaning glass.

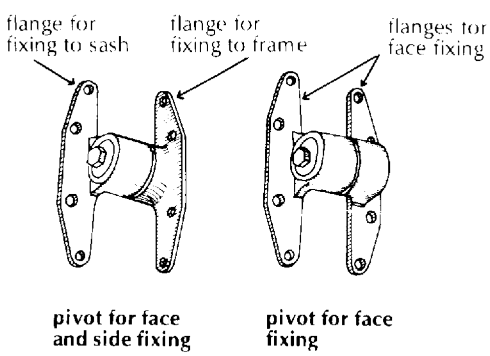


Fig. 64 Pivots for horizontally pivoted windows.

open into the room as illustrated in Fig. 63. In this position both sides of the glass in the outer part of the sash and the side of the glass of the inner part, facing the air space, may be cleaned in safety from inside the building.

The window is opened against the action of the friction pivots illustrated in Fig. 64 and locked shut with lever operated espanolite bolts that secure the sash at four points, top and bottom, against weatherstripping.

This may seem a somewhat complicated window construction when the majority of pivot windows today are supplied with IG units.

The advantage of a system designed for safety in cleaning glass and freedom from the need to replace faulty double glazing units at comparatively frequent intervals should be weighed against the somewhat complex construction.

Because the friction pivots must not be too stiff to make opening difficult they may not be strong enough to resist gusts of wind in exposed positions; it is necessary to fit some form of stay.

The majority of windows fixed in recent years are glazed with IG units. The perimeter of the units is sealed around the two sheets of glass and the space between them to exclude moist air that might cause condensation on the inner face of the two sheets of glass.

Many suppliers of insulated glazing units give an assurance and guarantee that their units will maintain the perimeter seal and so prevent the entry of moisture and condensation on the inner faces of glass for up to 20 years. It is of little use the building owner calling in the guarantee if the units fail after some few years as many of the suppliers go into liquidation well before the expiry of the guarantee.

Vertically pivoted steel windows

Figure 65 is an illustration of a steel section, hot-dip galvanised pivot window. The frame and sash of this vertically pivoted window are fabricated from universal sections that are welded together at angles and each side of the pivot where different sections join. The frame is fitted with compression weatherstripping to bear on and seal the clearance gap between frame and sash. The sash is pivoted so that two thirds of the width opens out and one third in, to minimise internal obstruction.

Providing the steel sections are adequately galvanised and protected with paint or a coating this window should survive the useful life of most buildings. The cold bridge effect of the thin metal sections is unavoidable with this material.

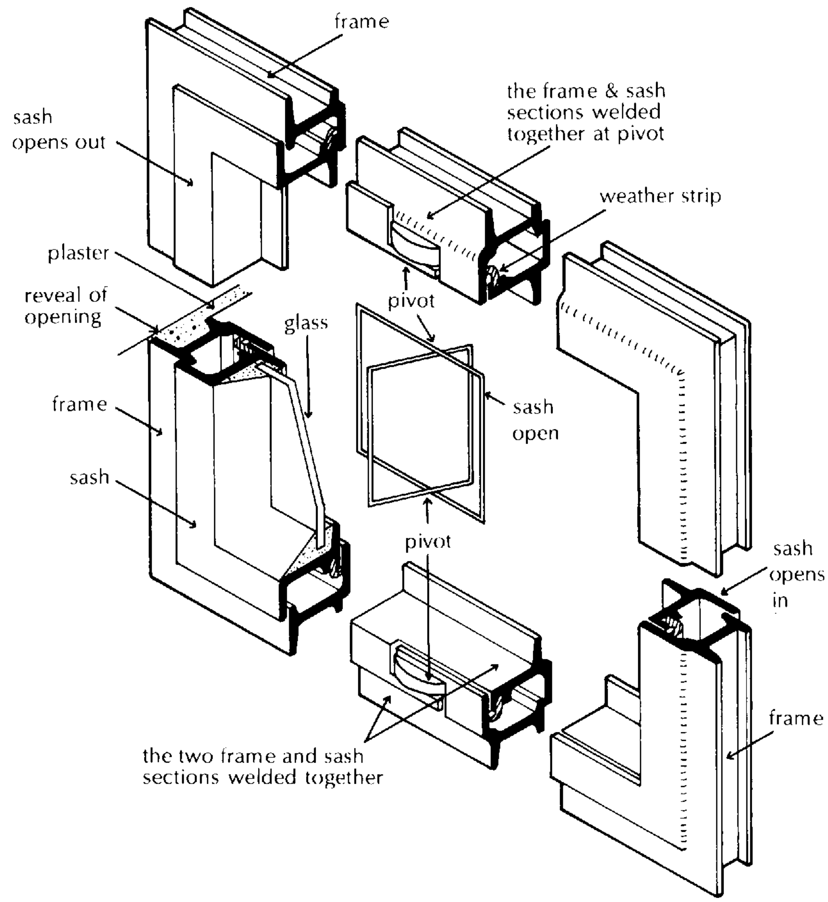


Fig. 65 Vertically pivoted steel window.

Sliding windows

Vertically sliding wood sash window (double-hung sash)

This traditional window is framed from thin section timbers to form a box or cased frame inside which the counterbalance weights are suspended to support the sliding sashes which are suspended on cords that run over pulleys fixed to the frame.

The jambs of the frame are cased from three thin members tongued, grooved and glued together as illustrated in Fig. 66. The pulley stile, in which the pulley supporting the sash cords is fixed, is usually 7 mm thicker than the outer and inner linings because it carries the weight of the sashes and the weights. A thin strip of wood, the parting slip, is suspended inside the cased jambs to separate the weights of the sashes. A strip of plywood or hardboard is nailed across the back of the linings as a back lining, to prevent the weights catching the reveals of the opening.

The size of the cased jambs depends on the thickness of the sashes. If the sashes are cut from 38 mm thick timbers the inside of the cased jamb is usually 85 mm wide and 50 mm deep, and the sashes cut from 44 mm thick timbers, 105 mm wide and 50 mm deep. The head of the cased frame is usually constructed from three thin members put together with glued tongued-and-grooved joints, or a solid rectangular section of timber 38 mm deep may be used.

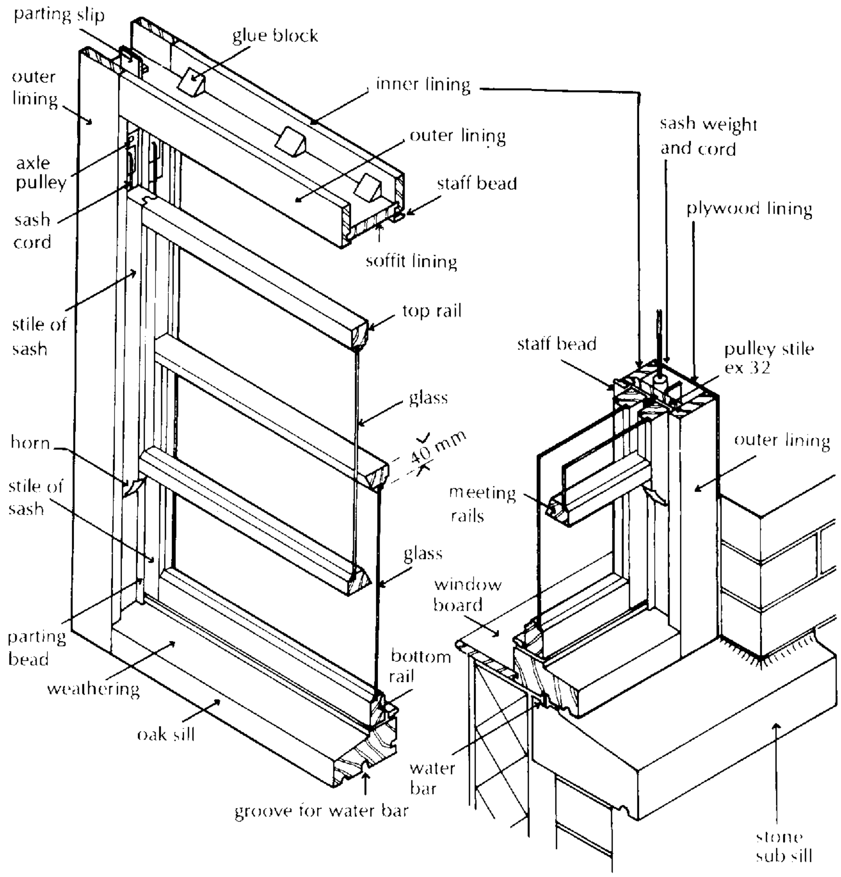


Fig. 66 Wood vertically sliding (double-hung) sash window with cased frame.

The sill of the frame is cut from a solid section of hardwood, such as oak, 75 mm deep and as wide as the cased frame overall. The sill is weathered and sunk on its top surface. The word weathered denotes that the top surface of the sill is cut to slope outwards to throw rainwater off. The sinking, which is a shallow rebate some 6 mm deep in line with the face of the lower sash, serves to prevent rainwater being blown between the sill and the sash. A 12 mm wide semi-circular groove on the underside of the sill forms a throat-and-drip edge and the rectangular groove takes a 25 × 3 mm galvanised steel or wrought iron water bar which is bedded in mastic in the oak sill and in cement in the stone sub-sill. The head of the frame, which is cut to fit between the linings of the jambs and the pulley stile, is tongued to a groove in the soffit lining. Similarly the sill is cut to fit between the jamb linings, and the pulley stile is wedged into a groove in the sill. The outer linings of the jambs and head project 13 mm beyond the face of the pulley stiles to act as guides for the top sash. Parting beads 10 × 32 mm are set into grooves in the pulley stiles to separate and act as guides to the sashes, and a staff bead is screwed to the edge of the inner linings to act as a removable guide for the lower sash. Brass axle pulleys, two to each sash, are fixed in the pulley stiles as illustrated in Fig. 66.

To renew sash cords, the staff beads and parting beads are removed and the sashes are lifted out into the room. Small traps cut in the bottom of the pulley stiles, called pockets, are taken out so that the new sash cords can be attached to the weights inside the cased frames.

Sashes are usually of the same depth so that the meeting rails come together in the middle of the height of the window.

The stiles and top rail of sashes are cut from 38 or 44 mm thick × 50 mm deep timbers, rebated for glass and moulded inside. Meeting rails are cut from 63 × 38 mm timbers rebated and splayed to meet and rebated for glass. The bottom rail of bottom sashes is cut from timber 38 or 44 mm thick × 63 or 75 mm deep, rebated for glass and moulded. The top rail of top sashes and bottom rail of bottom sashes are tenoned, wedged and glued to mortices in the stiles, and the meeting rails, which are tenoned to the stiles, are extended as horns to make a tenon the full depth of the thin meeting rails as illustrated in Fig. 66.

Sash cords are made from twisted or braided flax and cotton cord some 6 mm thick. In time the cord frays and breaks and needs fairly frequent renewal. Cords made from a mixture of nylon fibre and flax have a longer life. Heavy sashes are often hung on brass chains for durability.

The sashes are secured in the closed position by a sash fastener fixed across the meeting rails. Pivoted bar or fitch fasteners are used as illustrated in Fig. 67. Either type of fastener may be fitted with a security lock operated by a loose key. For additional security, screw bolts may be fixed through the meeting rails as illustrated in Fig. 68, or a lock attachment fixed to the sashes, which allows them to be opened sufficient for ventilation and no more, operated by a loose key.

To facilitate opening and closing sashes it is usual to fit sash lifts to the bottom rail of the lower sash and cords and pulleys for raising and lowering the top sash.

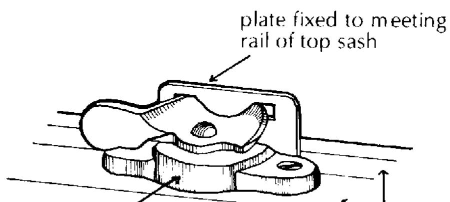


Fig. 67 Cam (fitch) catch for vertically sliding windows.

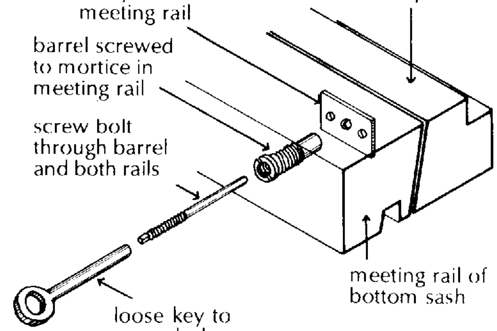


Fig. 68 Dual screw securing bolt for vertically sliding windows.

Vertically sliding wood sash window with solid frame

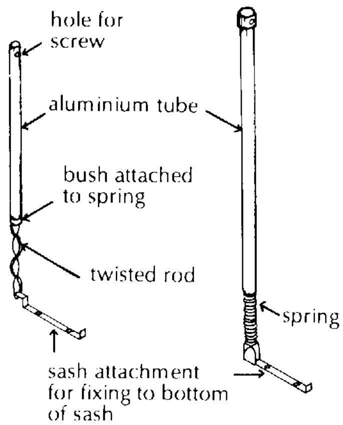


Fig. 69 Sash balances for vertically sliding windows.

As an alternative to the traditional system of cords, pulleys and weights to hang vertically sliding sashes, spiral sash balances have been used for the past 50 years. The spiral balance consists of a metal tube inside which a spiral spring is fixed at one end. Fixed to the other end of the spring is a metal cap through which a twisted metal bar runs. The tube is fixed to the window frame and the twisted bar to the bottom of the sashes. As the sash is raised or lowered the twisted bar tensions the spring which supports the weight of the sashes, enabling the sashes to be raised or lowered with little effort. Figure 69 shows one of these sash balances.

Because of the sash balance there is no need for hollow cased frames to take counterbalances and the frame members can be made of solid sections as illustrated in Fig. 70. The window frame is constructed from four solid rectangular sections of timber, two posts (jambs), head and sill. The posts are joined to the head and sill with combed joints glued and pinned, similar to those described for standard casements. The sashes are similar to those for windows with cased frames, the members being joined with mortice and tenon or combed joints.

A range of vertically sliding wood windows with solid frames cut from standard sections and put together in a range of standard sizes is

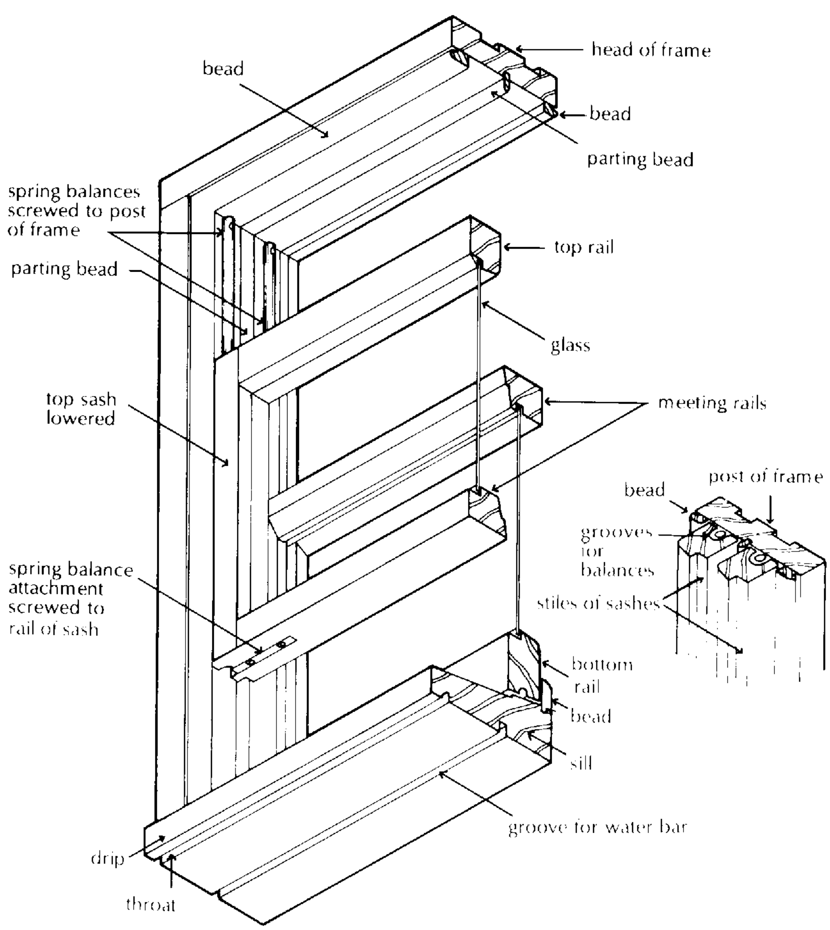


Fig. 70 Vertically sliding sash window with solid frame and balances.

manufactured with the sashes being grooved for and hung on spring balances (Fig. 70).

Weatherstripping

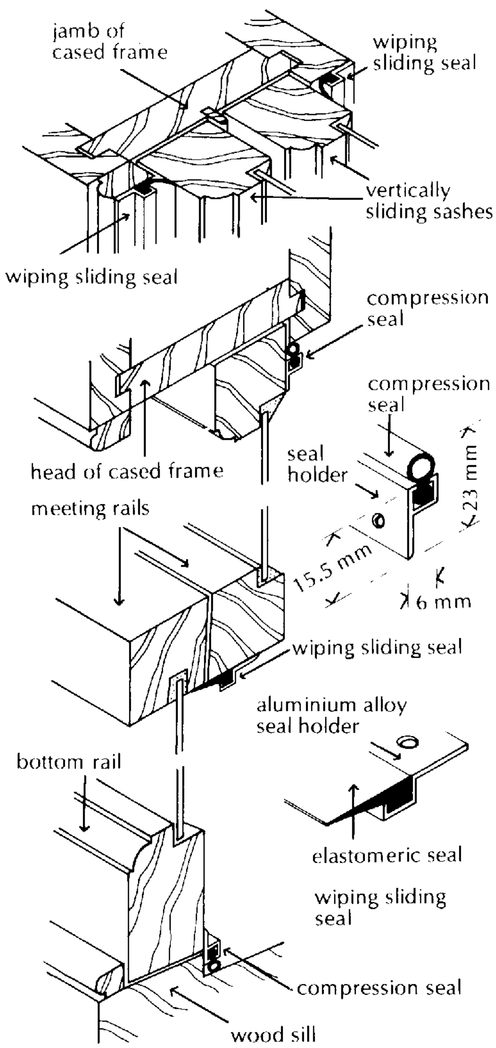


Fig. 71 Weather seals for vertically sliding wood windows.

Vertically sliding sash windows are comparatively simple to weatherstrip to exclude wind and rain. Because of the vertically sliding movement of the sashes a system of wiping, sliding seals is effective for the stiles or sides of the window, with compression seals to the head and sill of the window.

The system illustrated in Fig. 71 employs extruded aluminium alloy holders into which the elastomeric seals fit. The aluminium seal holders are screwed in position.

The wiping, sliding seals are fixed to the staff bead and to the outer lining of the frame so that the flexible seal blades press on to the face of the inner and outer sashes. The wiping sliding action of the seal effectively excludes wind and rain and allows free movement of the sashes.

A special wiping, sliding seal is fixed to the bottom of the outer sash so that when both sashes are closed the flexible seal closes the gap between the meeting rails of the two sashes.

A compression seal is fixed to the bottom rail of the inner sash and the top rail of the outer sash so that when the sashes are closed the seals close the gap between sashes and frames.

A disadvantage of this system is that the small section, aluminium seal holders are visible and that for workmanlike repainting the seals should be removed and refixed after painting.

An alternative system of weatherstripping for vertically sliding windows employs nylon filament and thin plastic blade seals that are housed in plastic holders. To seal the stiles of both sashes to the frame, extruded plastic parting beads are fixed in place of the usual wood parting beads. Plastic seal holders and seals are fixed into grooves in each side of the parting beads to serve as wiping, sliding seals to both sashes.

Plastic seal holders and seals are fitted to grooves in the staff beads to the sides and top and bottom of the frame to act as wiping, sliding seals to the sashes and a seal holder and seal is fitted to the meeting rail of the bottom sash to seal the gap between the sashes.

The advantage of these seals is that they are, by and large, invisible.

Fixing vertically sliding sash windows

It used to be common to fix vertically sliding cased frame windows in rebated jambs of solid masonry walls behind a $\frac{1}{2}$ B deep rebate so that most of the frame was covered and only the sashes showed externally to give the appearance of a window consisting almost entirely of glass. The frame was wedged in position with wood wedges driven between the frame and the brick jambs. This is not a particularly secure method of fixing. Solid frame windows are fixed with lugs or ties screwed to the back of the frame and built into horizontal brick or block joints.

Perimeter sealing

These windows are generally built-in and bedded and pointed in mortar.

Aluminium vertically sliding sash window

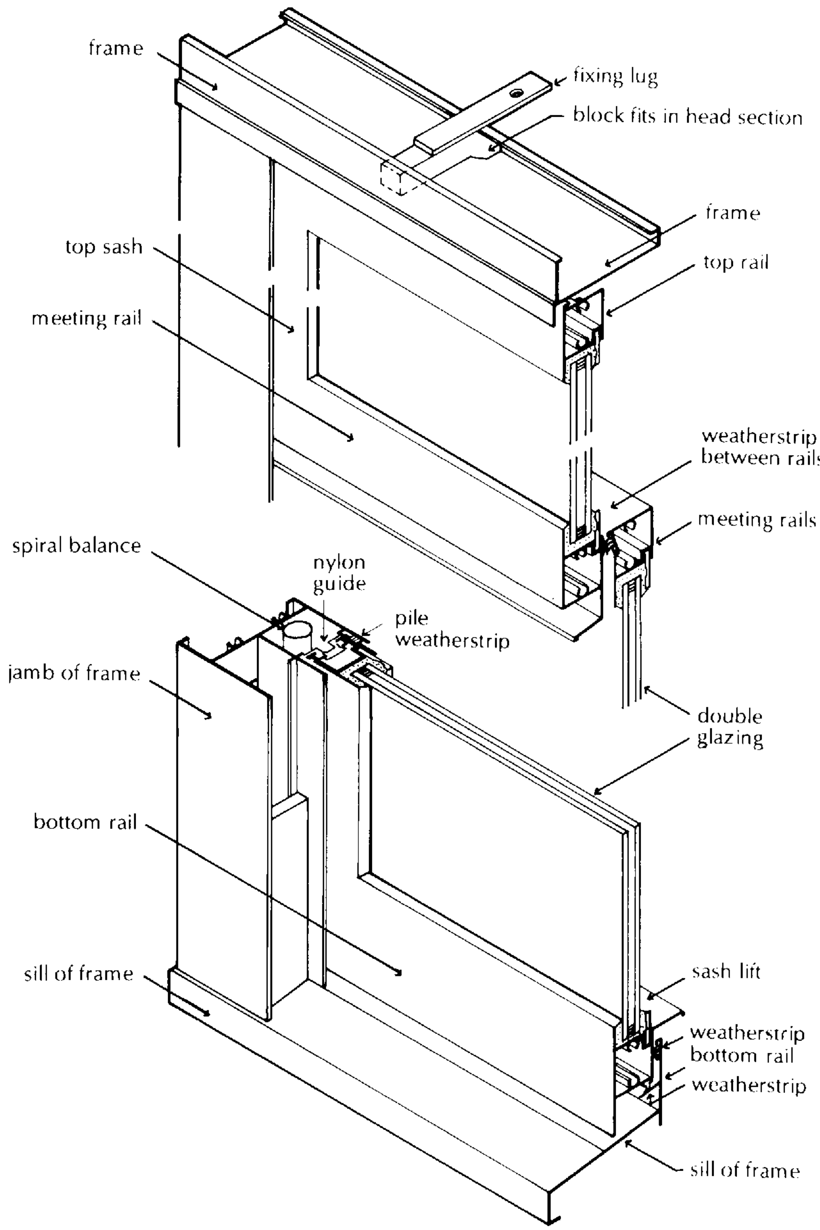


Fig. 72 Aluminium vertically sliding sash window.

With the slender sections of extruded aluminium alloy practical for use in the frame and sashes of this type of window, and because the material needs no painting at frequent intervals, aluminium vertically sliding windows have become increasingly popular. The extruded aluminium sections are joined with screw nailed butt joints, mechanical mortice and tenons or mitred and cleated joints with stainless steel screws. The windows are mill finished, anodised or have a stoved powder or acrylic finish.

Figure 72 is an illustration of a typical vertically sliding aluminium window. The jamb section houses the spiral spring balances and acts as a guide for the sashes which have nylon runners and pile weatherstrips. The hollow head section is fitted with pile weatherstrip and a neoprene seal and the sill with weatherstrip. The wider sash sections take either single or double glazing, have integral sash lifts and the meeting rails close to a neoprene seal and are secured with a fitch fastener.

As it is not practical to make this type of window in thermal break construction, these windows are not best suited where warm, moist air may condense to water on the cold metal.

uPVC vertically sliding sash window

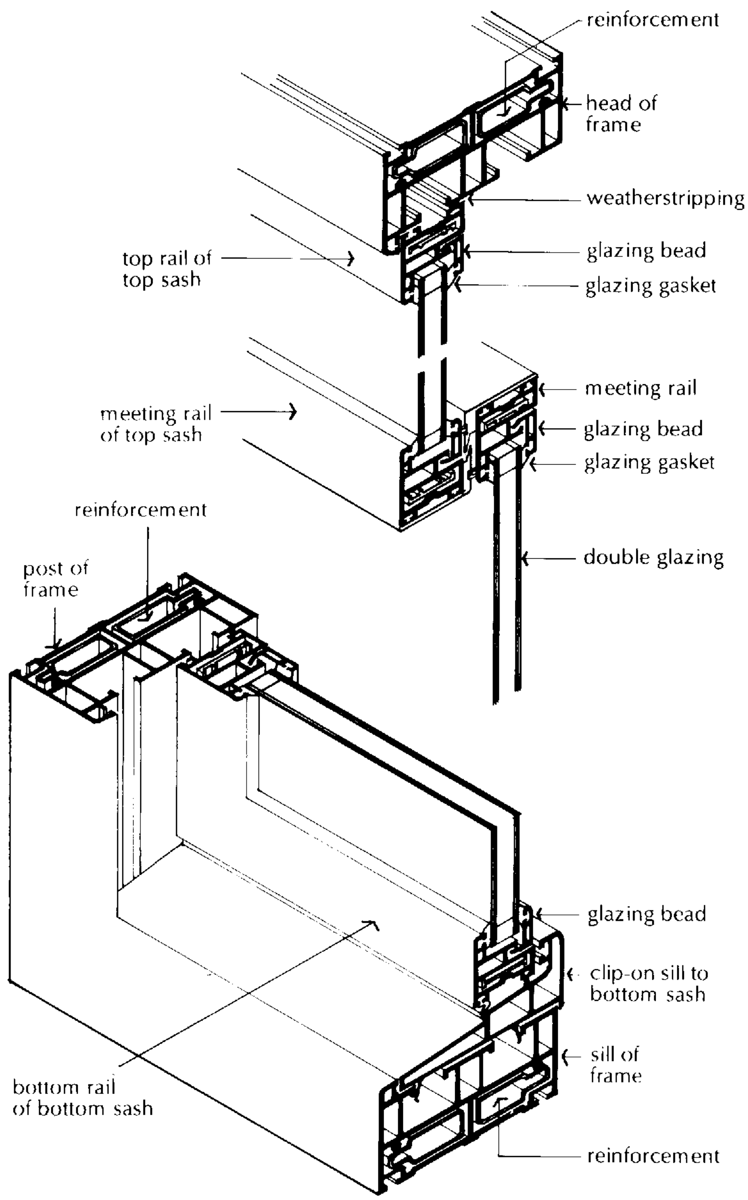


Fig. 73 uPVC vertically sliding sash window.

uPVC vertically sliding sash windows have been used as replacement windows for old wood framed windows for the advantage of freedom from maintenance in regular painting and the facility for fitting weatherstripping to grooves formed in the window sections. The vertically sliding, uPVC sash window illustrated in Fig. 73 is framed with comparatively bulky hollow sections that are reinforced with metal box sections. The hollow box section sash members are designed to take double glazing units.

The sashes are suspended on spiral balances that are housed in hollows in the frame section that are extruded specifically for the purpose.

The comparatively bulky hollow sections of both the frame and sashes are not an entirely satisfactory substitute for the slender sections possible with wood windows.

Horizontally sliding windows

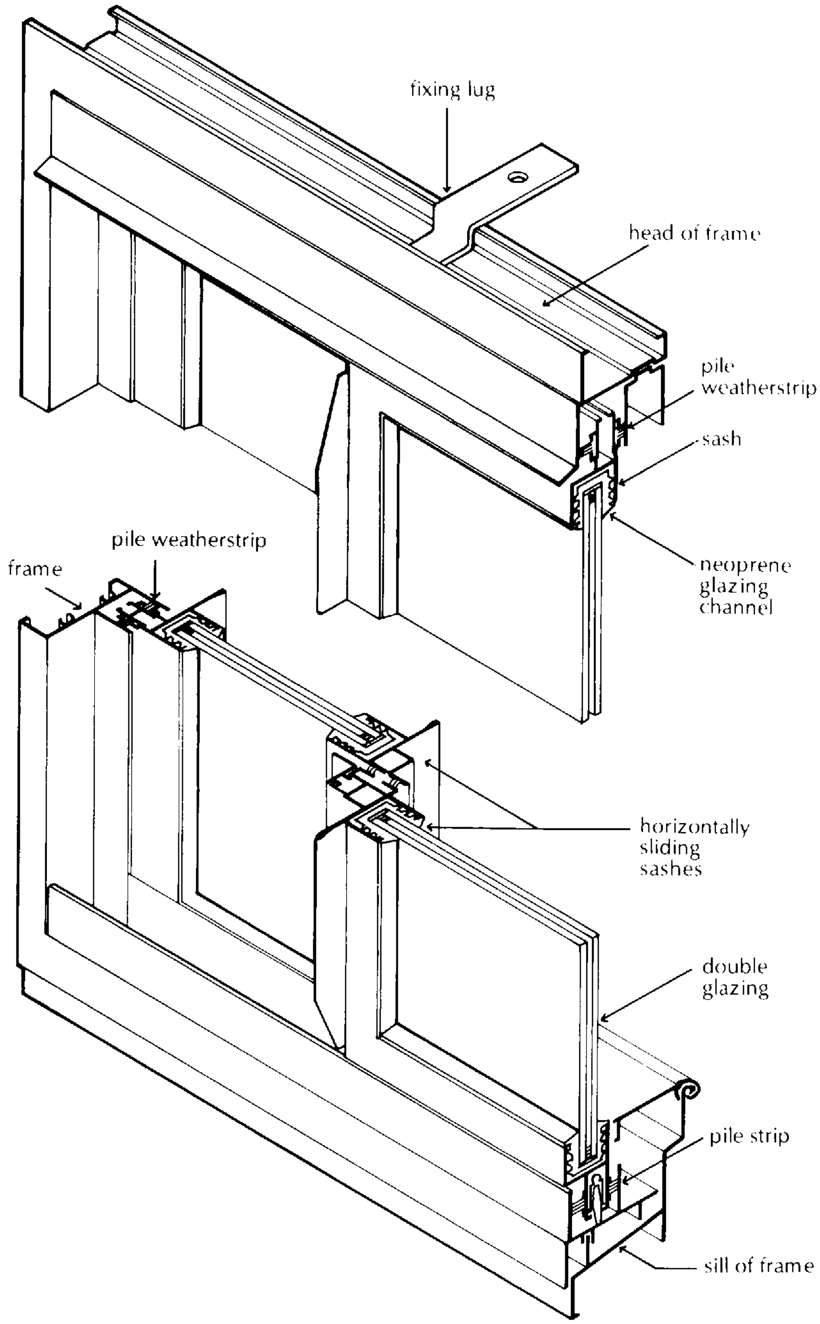


Fig. 74 Aluminium horizontally sliding sash window.

The aluminium section horizontally sliding sash window illustrated in Fig. 74 slides on a bottom track with nylon filament, pile weatherstripping acting as weatherseal and as guide to both top and bottom rails and with pile weatherstripping to stiles. To avoid having over bulky sections, this window is not designed as a thermal break window and the frame and sashes will in consequence be a source of condensation in warm moist atmospheres.

As grit may in time collect around the track, it is often somewhat difficult to open these windows which, if forced open or closed, may tend to jamb on the track and so be more difficult to open.

The most common use of this type of window today is as fully glazed horizontally sliding doors, commonly called patio doors.

The aluminium frame and sash sections may be finished with one of the decorative, protective coatings that will not require renewal for many years.

GLASS

Glass is made by heating soda, lime and silica (sand) to a temperature at which they melt and fuse. Molten glass is either drawn, cast, rolled or run on to a bed of molten tin to form flat glass.

Glass may be classified into three groups:

(1) Annealed flat glasses.
(2) Processed flat glasses.
(3) Miscellaneous glasses.

(1) Annealed flat glasses

There are two types of annealed flat glass, float or polished plate glass and sheet glass.

Float or polished plate glass

Clear float or polished plate glass is transparent with surfaces that are flat and parallel so that they provide clear undistorted vision and reflection.

Float glass

Float glass is made by running molten glass continuously on to a bed of molten tin on which the glass floats and flows until the surfaces are flat and parallel. The continuous ribbon of molten glass is then run into an annealing lehr or chamber in which the temperature is gradually reduced to avoid distortion of the glass. The glass gradually solidifies and the solid glass is cut. The natural thickness of the sheet of glass is 6.5 mm. To produce thinner glass the molten ribbon of glass is cooled and stretched between rollers and to make thicker glass the spread of the molten ribbon is restricted to produce the required thickness.

Float glass has largely replaced sheet and plate glass in this country, and is made in thicknesses of 3, 4, 5, 6, 10, 12, 15, 19 and 25 mm.

Polished plate glass

Polished plate glass is made by grinding and polishing both surfaces of rough cast glass. This type of glass has been superseded by float glass.

Body tinted glass

Body tinted float glass or polished plate glass is transparent glass in which the whole body of the glass is tinted. This type of glass reduces solar radiation transmission by increased absorption. This material is commonly termed 'solar control glass'. Tints are usually green, grey, blue or bronze and thicknesses 4, 6, 10 and 12 mm.

Surface modified glass

Surface modified tinted float glass is transparent glass which during manufacture has a coloured layer of metal ions injected on to the glass. Solar control properties are provided by an increase in reflection and absorption. Thicknesses are 6, 10 and 12 mm.

Surface coated glass

Surface coated float glass (reflective float glass) is transparent glass which has a reflective surface layer applied either during or after manufacture. The reflective layer may be on a clear or a body tinted glass. Transmission of solar radiation is reduced by increase in reflection and absorption and the glass has a coloured metallic appearance. Colours are silver, blue and bronze by reflection.

Surface modified and surface coated glasses are solar control glasses that are also referred to as low-emissivity glasses. The effect of the surface coating is to reflect back into the building the long wave energy generated by heating, lighting and occupants, while permitting the transmission of short wave solar energy from outside. This type of glass is designed for use in the inner pane or sheet of glass in sealed double glazing units where the greater inside surface temperature of the glass reduces condensation and the effect of 'cold spot' discomfort.

Sheet glass

Clear sheet glass

Clear sheet (drawn sheet) glass is transparent glass manufactured by the flat drawn process in which a continuous sheet is drawn from a bath of molten glass in thicknesses of 3, 4, 5 and 6 mm. The continuous sheet is gradually cooled to minimise distortion and then cut into sheets as it solidifies. The drawn sheet is not exactly flat or uniform in thickness and will cause some distortion of vision.

Sheet glass is no longer manufactured in England.

Body tinted sheet glass

Body tinted sheet glass is transparent glass in which the whole body of the glass is tinted to give solar control properties. Tints are usually green, grey or bronze and thicknesses are 3, 4, 5 and 6 mm.

Cast glass (also known as patterned glass)

Clear cast glass is translucent glass made by the rolling process. The deeper the pattern the greater the obscuration and diffusion.

Body tinted glass

Body tinted glass is similar, with the whole of the glass tinted for solar control and decorative purposes.

Wired glass

Wired glass is cast or rolled with wire completely embedded in it. One type of wire is available: Georgian 13 mm square mesh. Cast wired glass is translucent with a cast or patterned surface. Polished wired glass is transparent, through grinding and polishing.

(2) Processed flat glasses

Toughened glass

Toughened (tempered) glass is made by heating annealed glass and then rapidly cooling it to cause high compression in the surfaces and compensating tension in the centre of the thickness of the glass. This is a safety glazing material that is less liable to break on impact, and when broken, it fragments into comparatively harmless small pieces.

Clear float, sheet, polished plate and solar control glass may be toughened.

Laminated glass

Laminated glass is made of two or more sheets (panes) of glass with an interlayer of reinforcing material between the sheets. The interlayers are permanently bonded to the enclosing sheets of glass. This glass is resistant to impact shock and when broken the reinforcing layer prevents extensive spalling of fragments. The reinforcing interlayer is usually in sheet form and made of polyvinyl butyral. This type of glass is specified as three ply, that is two sheets of glass and one of reinforcement and similarly five ply, with three sheets of glass and two of reinforcement.

This type of glass is often described as safety or security glass.

Safety glass

Toughened glass and laminated glass are described as flat safety glass which, on breaking, result in a small clear opening by disintegration into small detached fragments that are neither sharp nor pointed and are unlikely to cause cutting or piercing injuries.

The practical guidance in Approved Document N to the Building Regulations defines critical locations where safety glass should be used. These critical locations are in glazed panels in internal walls and partitions between floor and 800 mm above that level and in glazed doors and door side panels, between floor and 1500 mm above that level.

Polycarbonate sheet

Flat plastic sheets made of polycarbonate are manufactured as transparent, translucent and colour tinted sheets for use as safety glazing. The sheets are 2, 3, 4, 5, 6, 8, 9.5 and 12 mm thick.

The principal characteristic of this material is its high impact resistance to breakage. These sheets do not have the lustrous, fire glazed finish of glass nor are they as resistant to abrasion scratching and defacing. A special abrasion resistant grade is produced.

Polycarbonate sheet, which is about half the weight of a comparable glass sheet, has a high coefficient of thermal expansion. To allow for this, deeper rebates and greater edge clearance are recommended than for glass. To allow for the flexibility of the material and thermal expansion, one of the silicone compounds is recommended for use with solid bedding.

(3) Miscellaneous glasses

In this group of glasses is included double glazing, roof and pavement lens lights, copper lights, leaded lights and hollow glass blocks.

Insulating glass (IG) units, double glazing

Because of increased demand for thermal comfort in buildings, together with the requirements of the Building Regulations for energy conservation, and the continually increasing cost of fuel, it has become common for some years to fit double glazing to the majority of new and replacement windows. The term double glazing describes the use of two sheets or panes of glass in a window or door. The type of double glazing most commonly used today is the insulating glass unit (IG unit) which comprises two sheets or panes of glass spaced some 6, 10, 12, 16 or 20 mm apart with a perimeter seal so that the air or gas trapped between the glass serves as thermal insulation to reduce transfer of heat through windows.

The U value (thermal transmittance) of a single sheet of 6 mm thick glass is 5.4 W/m^2K and that of an IG unit with two sheets of 6 mm thick glass spaced 12 mm apart is 3.0 W/m^2K.

The advantages of insulating glass (IG) units are that there is some reduction of heat loss or gain as compared to single glazing and that because of the lower U value, that is better insulation against transfer of heat, a larger area of glass in windows may be used in complying with the requirements of the Building Regulations for conservation of energy. There is in addition some small reduction in airborne sound transmission.

Cold spots

Because of the greater thermal insulation of double glazing as compared to single glazing there may well be a noticeable reduction of 'cold spots' near large areas of glass. 'Cold spots' is the term used to describe the sensation of cold, experienced close to large areas of cold surface in a room, caused by the automatic response of the body in radiating heat towards the cold surface in an attempt to maintain normal skin temperature.

There is reduced condensation of moisture vapour from air because of the higher temperature on the inside of the double glazing as compared to single glazing, particularly in bathrooms and kitchens.

The principal causes of heat loss from rooms are by transfer of heat through glass in windows and doors and by draughts of cold air being forced by pressure through gaps around opening parts of windows and doors, into rooms. Double glazing which will appreciably reduce transfer of heat through glazing will, by itself, effect no reduction in draughts of cold air into rooms. Draught stripping or sealing around opening parts of windows and doors will substantially reduce draughts of cold air irrespective of whether the glazing is single or double.

The considerable initial cost of double glazing and the subsequent cost of replacing double glazed units will at best be covered by savings in fuel costs over very many years, 25 or more. The comparatively small cost of weatherstripping around opening parts of windows and doors provides a much better return on capital than the installation of double glazing. The majority of double glazed windows include effective weatherstripping or seals to all opening windows and doors.

There is no obligation to use double glazing in windows to comply with the requirement in the Building Regulations to conserve fuel and power. Single glazing may be used providing the heat loss through the fabric of the building is limited. Where single glazing is used in windows, particularly those facing the arc of south west, south and south east, account may be taken of solar heat gain to balance the loss through single glazing. Weatherstripping to single glazed windows will appreciably reduce heat loss.

In rooms where hot moist air is common, such as bathrooms and kitchens, it is probably wise to install double glazing to limit condensation of the inside face of windows.

Insulating glass (IG) units, sealed double glazing units

The terms double glazing, sealed double glazing and insulating glass are generally interchangeable. The term double glazing embraces all systems of double glazing whether the glazing is unsealed as in double windows or sealed as in IG units. The term sealed double glazing more precisely describes the system of glazing than the term favoured by the trade, IG units.

Insulating glass units are made up from two sheets (panes or squares) of glass that are hermetically sealed to a continuous spacer in the perimeter of the unit. This spacer maintains the space between the two sheets of glass and supports the sealant. The usual space between the two sheets of glass is 6, 10, 12, 16 or 20 mm.

The failure of sealed double glazed units is caused by the entry of moisture vapour into the cavity between the two sheets of glass. This moisture vapour will condense to water on the cavity face of glass in the IG unit, obscure the glass and the condensate water will run down on to the edge seal. In time this water lying in the cavity will cause further deterioration of the edge seal and the likely entry of further moisture vapour.

The prime cause of the failure of IG units is liquid water both from outside rain and inside condensation that may run down and penetrate faulty edge seals, particularly at corners, and cause deterioration of the adhesive properties of the edge seal.

The durability of a sealed double glazed unit depends on a sound edge seal and sealants around the edges of the unit in the window rebate or sound edge seals and a system of drainage to remove water that may lie in the rebate.

Space tube or bar

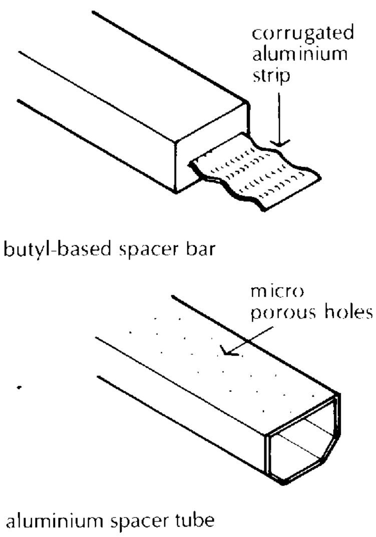


Fig. 75 Spacer bar and tube.

The spacer which serves to seal and support the adhesive that holds the sheets of glass together is either a hollow aluminium section or a butyl-based bar with an integral aluminium strip, as illustrated in Fig. 75.

Aluminium spacer tubes are either cut to length and connected with metal or nylon corner keys or the space tube is bent to the required shape and the ends of the tube welded together to form a continuous spacer. The usual width of spacer tubes is from 5.5 mm to 19.5 mm to provide a space between sheets of glass from 6 to 20 mm. The narrow widths are made for use in narrow sections of timber and steel windows and the wider for the wider section of uPVC and aluminium windows.

The butyl-based bar, with integral aluminium strip, consists of a preformed section with a corrugated, integral aluminium strip as illustrated in Fig. 75. The aluminium strip serves as reinforcement and in part as a barrier to moisture. A desiccant is embedded in the surface of the bar. The advantage of the bar, commonly known as 'Swiggle strip', is that it is continuous and being self adhesive makes fitting more rapid than using a spacer tube and sealant.

The useful life of a sealed double glazing unit depends on the dehydrated air or gas sealed between the sheets of glass remaining dry. The spacer tube, which serves as a significant barrier to moisture vapour, also serves to support and control the depth of the sealant used.

Desiccant

To ensure that the air or gas in the sealed cavity between the sheets of glass remains dry, it is necessary to fill the hollow of the spacer tubes with a desiccant which will absorb moisture vapour which might otherwise condense to water on the inside faces of the glass of the unit. The visible face of the spacer tubes is perforated with micro-porous holes to facilitate absorption of moisture vapour by the desiccant. The butyl-based spacer bar has desiccant in the face of the bar.

The sealed space between the two sheets of glass is usually filled with dehydrated air. To provide somewhat better thermal insulation the space may be filled with Argon gas and for better sound insulation it can be filled with SF gas.

Edge seals

The two edge seals that are used are the single seal and the dual seal.

Single seal

To hermetically seal the two sheets of glass to the spacer tube it is necessary to run some material around the outside of the spacer tube that will adhere strongly to both the spacer tube and the sheets of glass. To hold the spacer tube in place between the two sheets of glass as an aid to assembly, it is common to use double-sided tape. The sealant in liquid form is then gunned into the space between the two sheets of glass and the spacer tube. The sealants commonly used are polysulphide, polyurethane, silicone, expoxypolysulphide or hot melt butyl. As the double-sided tape does not act as a permanent sealant, this type of seal is described as a single seal (Fig. 76).

Dual seal

As an alternative to the double-sided tape a hot-melt bead of butyl or polyisobutylene is applied to the sides of the spacer on to which the sheets of glass are pressed to keep them in place and then the seal is run in the space between the sheets of glass and the spacer tube. Properly applied the hot-melt butyl will act as a primary seal and the edge sealant as a secondary seal. This dual seal method may provide a longer useful life than the single seal. Figure 76 is an illustration of edge seals to IG units.

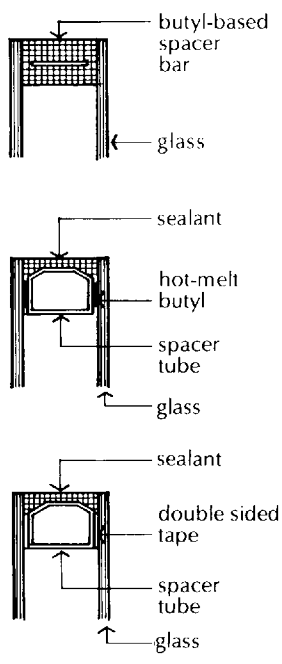


Fig. 76 Edge seals.

As an alternative to hollow spacer tubes an extruded butyl-based bar with integral aluminium strip may be used, as illustrated in Fig. 76. The bar is self adhesive and at once serves to keep the two sheets of glass in place and acts as an edge seal by virtue of the aluminium strip and the butyl bar. This single seal much facilitates the fabrication of IG units and is extensively used.

For appearance, the overall depth of spacer tube and edge sealant and depth of spacer bar should be such that the edges of the face of the spacer that are visible through the glass, the sight faces, should not be visible from outside the glazed unit when it is fixed in position in the window. Likewise for appearance, the sight faces of spacer tubes can be finished, colour coated or anodised.

The useful life of a double glazed unit depends mainly on the integrity of the seal or seals as a barrier to moisture vapour penetrating the space between the sheets of glass, to the extent that the desiccant is unable to absorb most of the moisture vapour that will in consequence condense to water on the cold inside face of the glass. Double seal units generally have a somewhat longer life than single seal units.

It is generally accepted that the useful life of sealed double glazed units is at best up to 20 years. Some assemblies give conditional guarantees of up to 15 years, conditional on workmanship in handling and fixing the units and on the glazing materials used.

GLAZING

The operation of fixing glass in windows, doors and other openings is termed glazing.

The purpose of glazing is to secure glass in position in window frames and sashes and to make a weathertight seal against penetration of rain around the edges of the glass.

The choice of a method of glazing depends on:

(1) the anticipated structural and thermal movement of the window and
(2) the degree of exposure of the window to wind and rain.

The common method of glazing for single glazing to softwood and metal frames is putty glazing, and to hardwood, aluminium and uPVC frames is bead glazing with non-setting compounds and tapes for both single and double glazing and gasket glazing for extruded, hollow section aluminium and uPVC frames.

Single glazing

Putty glazing

Putty is a material that is initially sufficiently plastic to be moulded by hand, spread in the glazing rebate as a bed for glass and finished outside as a weathered front or face putty. The putty sets or hardens over the course of a few days to secure the glass in position and serve as an effective seal against rainwater penetration.

Glazing with putty, which dries and sets to a hard finish, is used to secure glass in wood or steel frames where there is little structural and thermal movement. Putty is not used on aluminium or plastic frames where the larger structural and thermal movement of these materials might cause the putty to crack, lose adhesion and allow rain to penetrate.

Linseed oil putty

Linseed oil putty, which is used for glazing to softwood and absorbent hardwood frames, adheres to both glass and wood and hardens by absorption of some of the oil into the wood and by oxidisation. To prevent too great an absorption, softwood windows should be primed before glazing.

Putty is spread by hand in the glazing rebate.

Setting and location blocks

To provide an edge clearance of 2 mm between the edges of the glass and the rebate, to allow for variations in the sash and in the glass and to facilitate setting the glass in place, setting and location blocks are

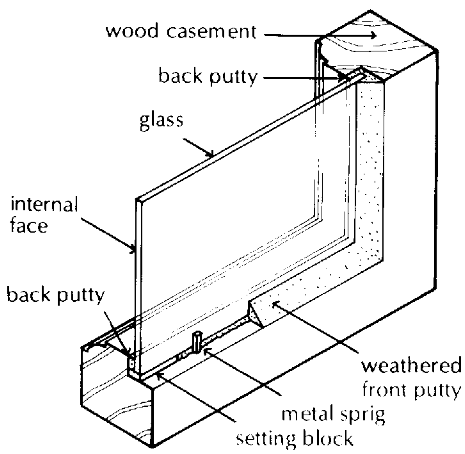


Fig. 77 Putty glazing to wood sash.

used. Setting and location blocks, which are of PVC, hammered lead, hard nylon or hardwood are 2 mm thick and 150 mm long. Setting blocks are pushed into the soft rebate putty in the bottom edge rebate to support the glass and the location blocks into both side rebates to centre the glass.

Figure 77 is an illustration of linseed oil putty glazing to a softwood sash.

The glass, which has been accurately cut to provide an edge clearance, is placed on the setting blocks and pushed firmly into the putty to squeeze surplus putty between the glass and the upstand of the rebate as a back putty bed 1.5 mm thick.

Glass is then secured in position, until the putty has hardened, with metal sprigs that are tapped into the rebate at not more than 300 mm spacing. Sprigs are small, cut, headless nails.

Additional putty is then spread by hand in the glazing rebate around the edges of the glass and finished with a putty knife at an angle from the edge of the glazing rebate up to about 2 mm below the sight line as a seal against rain penetration. Surplus back putty is stripped and the back putty is finished at an angle up to the glass to shed any condensation water from the inside face of the glass.

The finished putty should be left to harden for at least 7 days and then painted with the usual undercoat and finish coats of paint to prevent further hardening of the putty. The painted surface should be finished on to the glass as a seal against rain penetration behind the putty.

Metal casement putty

Metal casement putty is designed specifically for use on non-porous surfaces such as galvanised steel frames, sealed timber and sealed concrete with or without glazing beads. It is made from a blend of vegetable oils selected to adhere to and set on non-porous surfaces. It is not suitable for glazing to aluminium, stainless steel, bronze or plastic finishes.

This putty hardens and sets and will accommodate the relatively small amount of movement that occurs in steel frames due to temperature change. The putty hardens within 7 to 14 days and should then be painted to prevent further hardening.

Where the galvanised surface of steel frames has been weathered, exposed to atmosphere or treated, the metal casement putty may be applied directly to the frame.

Putty is spread by hand in the glazing rebate. Setting and location blocks are pressed into the putty in the bed of the glazing rebate to maintain the edge clearance of 2 mm around the glass. The glass, which has been accurately cut with a 2 mm edge clearance, is then

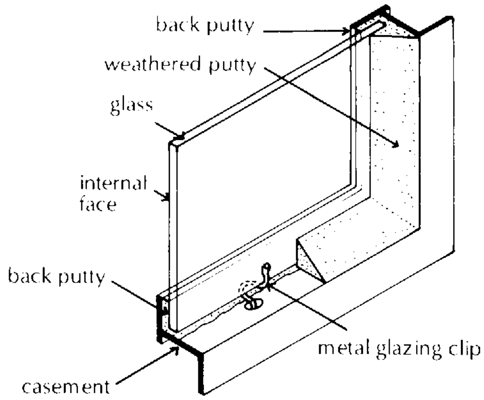


Fig. 78 Putty glazing to metal sash.

positioned on the setting blocks and pressed into the putty to form a 1.5 mm back putty bed.

Metal glazing clips are then fixed in position in holes in the metal frame and in the edge clearance spaces between the glass and the frame to hold the glass in place until the putty has hardened. Putty is then spread in the rebate up to the edges of the glass and finished with a putty knife as a weathered front putty sloping from the edge of the rebate up to about 2 mm below the sight line, as illustrated in Fig. 78. The back putty is trimmed and finished with a slight slope.

When the putty has hardened it should be painted and covered just above the line of the putty to provide a seal against the penetration of rain.

Glazing with beads

As an alternative to putty glazing for single glazing, which may not always provide a neat finish, bead glazing may be used, where a bead secures the glass in place.

The choice of internal or external fixing of glazing beads depends on the material of the bead, the ease of access for reglazing, appearance and security.

For durability inside glazing is preferable, particularly when softwood beads are used because the joints between the bead, the glass and the frame are vulnerable to the penetration of rain.

For access for reglazing inside beads are best as they are also for security to ground floor windows.

For appearance sake, where stained, oiled or varnished hardwood is used as a decorative and protective finish, glazing beads of the same material and finish are used internally.

Glazing with putty and beads

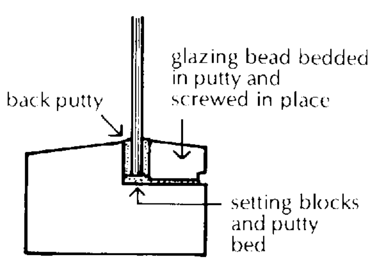


Fig. 79 Glazing with putty and beads.

Glazing with putty and beads may be used for softwood, absorbent hardwood and galvanised steel frames. In sheltered positions the beads may be external, for other exposures they should be internal.

Sufficient putty is spread all round the rebate to provide adequate back putty. Setting blocks are pressed into the putty in the platform rebate and location blocks as necessary. The glass is placed on the setting blocks and pressed firmly into the rebate so that putty 1.5 mm thick is squeezed between the glass and the back of the rebate as back putty bedding as illustrated in Fig. 79.

For fixing externally beads should be bedded with putty against the glass and to the bed of the rebate. The beads are pressed firmly against the glass and then secured with pins or screws. Where beads are fixed internally it is not usual to bed them in putty. Back and front putty beds are trimmed and finished with a slope up to the glass. The exposed putty should be painted some 7 to 14 days after glazing.

For putty glazing to non-absorbent hardwood and galvanised steel frames metal glazing putty is used.

Glazing with tape and beads

As an alternative to putty glazing for large squares of glass for both wood and galvanised steel frames, load bearing mastic tape and a sealant may be used.

Load bearing mastic tape is made from compressed fabric and butyl in various widths and thicknesses. The tape which is used as a bedding for glass will serve as a sealant to exclude rain when it is adequately compressed. It is comparatively easy to use and often preferred to putty.

A strip of the mastic tape is pressed into position all round the rebate upstand so that it finishes some 3 to 6 mm below the sight line and setting blocks are placed in the rebate base. Glass is placed on the setting blocks and firmly pressed into the rebate to compress the tape to the rebate upstand. Location blocks are fixed in the side edge clearances to centre the glass.

A second strip of mastic tape is fixed around the outside edges of the glass and the internal glazing beads are fitted in place, pressed firmly against the mastic tape and screwed into position. A sealant is run, by gun, into the edges of the outside of the glass and finished with a smooth chamfer or slope to shed water as illustrated in Fig. 80.

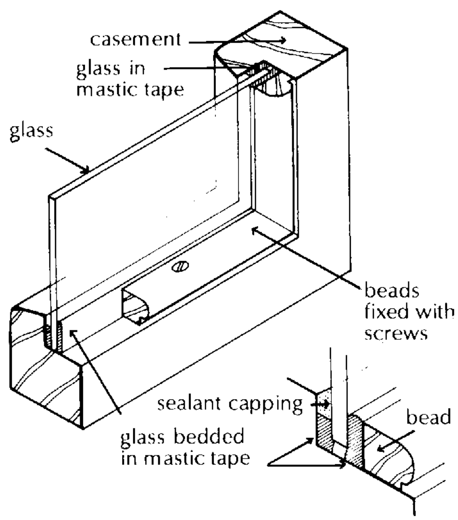


Fig. 80 Glazing to wood with beads.

Glazing IG units

Insulating glass units are hermetically sealed and subject, therefore, to continuous flexing due to changes in atmosphere and temperature. Glazing materials that are used must allow for thermal and structural movement of both the IG unit and the window framing. The glazing method used should allow for movement and prevent water penetrating to the edges of the IG unit.

Setting and location blocks

To accommodate movement between glass and window frames, casements or sashes, due to different thermal and mechanical movements, a minimum clearance must be allowed all round IG units of from 3 mm for glass up to 2 m wide to 5 mm for glass over 2 m wide at sides and top of unit, and 6 mm at sill level.

Setting blocks and location blocks should be of some resilient, non-absorbent material such as sealed teak or mahogany, hammered lead, extruded uPVC, plasticised PVC or neoprene. The width of setting

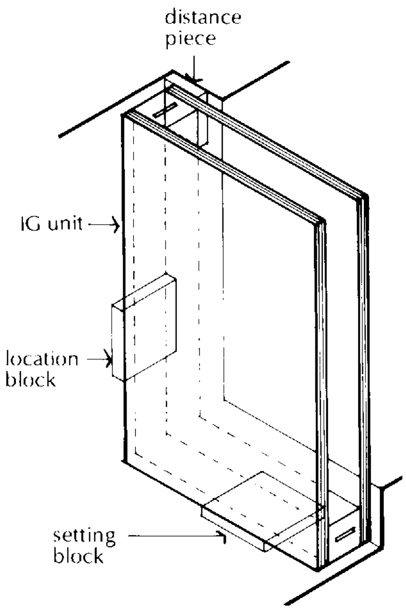


Fig. 81 Blocks for IG units.

blocks should be equal to the thickness of the IG unit plus the backface clearance and at least 25 mm long. Location blocks should be 3 mm wider than the IG unit and at least 25 mm long.

Distance pieces are used to prevent displacement of glazing compounds or sealants by wind pressure on the glass, by retaining the IG unit firmly in the window. Distance pieces should be used except where load bearing tapes or putty are used for stepped units. Distance pieces should be the same thickness as face clearance and made of a resilient, non-absorbent material similar to that for setting blocks. Figure 81 is an illustration of the use of these blocks.

Sight size is the actual size of the opening that admits daylight and the sight line is the perimeter of the sight size. The sight line is determined by the edges of the frame, casement or sash and the exposed edge of the glazing material. The practice is to fix or apply glazing material so that the sight line on the inside of the glass coincides with that on the outside and just above the exposed face of the spacer tube or bar in the IG units, for appearance sake.

Factory glazing, site glazing

Insulating glass units may be delivered to site factory glazed to windows. The advantage of factory glazing is that the operation of glazing can be carried out under cover in conditions most suited to making a good job. The disadvantage of factory glazing is the possibility of damage to the glazed window in transit and through handling on site. The best conditions for glazing are clean, dry surfaces to which bedding and sealant materials can adhere. Because such conditions are rare on most building sites, factory glazing should have advantage over the other option, site glazing.

Glazing methods

The two systems of glazing used for insulating glass (IG) units are solid bedding and drained methods.

Solid bedding

The solid bedding method depends on the use of mastic bedding materials around the edges of the IG unit, inside the glazing rebate, with sealants to prevent the penetration of water to the edges of the unit. This method of bedding is most suited to window frames with plain, square sections and rebates such as wood or steel windows into which the unit may be bedded and secured with beads.

Drained glazing

The drained method of glazing is designed to encourage water, that may have penetrated the glazing rebate around the edge of the IG unit, to drain to the outside. This method of glazing, which is particularly suited for use with the systems of gasket glazing commonly used with extruded, hollow sections of uPVC and aluminium windows, may be employed with plain section wood, steel, aluminium and uPVC windows.

Whichever method is used, the first defence against penetration of water to the edge seal of the IG units is the mastic or rubberised edge seals to glass which should at once accommodate movement and act as a seal against water. Drainage is a back up to drain any water that has penetrated. To be effective the drainage system should at once be adequate to drain water, be protected against wind-blown rain and remain clear of obstruction during the useful life of the window, conditions that may be difficult to achieve satisfactorily.

Solid bedding

Solid bedding depends on the use of solid beads, firmly fixed to the frame, to contain or compress the mastic or plastic bedding material around the edges of the IG units, to prevent the penetration of water to the IG unit edge seal.

Beads with non-setting compound

This is the most straightforward method of bedding IG units in window frames of wood or metal, where one material is used both as bedding and sealant.

The bedding-sealant materials that may be used are non-setting compounds of synthetic rubber, oils and filters or low permeability one- or two-part curing sealants such as polysulphide, silicone or urethane base.

The clean rebates and wood beads are first primed or sealed. A generous fillet of bedding material is spread in the rebate into which setting blocks and distance pieces are pressed. The distance pieces are necessary to maintain the correct thickness of bedding, behind the glass, against wind pressure on the glass. The glass is then placed on the setting blocks and pressed firmly into the rebate against the distance pieces to provide a 3 mm thick back bedding.

Location blocks are fixed in the side edge clearance. Bedding material is spread around the edges of the glass to fill the edge clearance gaps around the IG unit. A substantial fillet of bedding material is spread in the glazing rebate. The wood beads are bedded in position and pressed firmly into the bedding material so that there is 3 mm of bedding between the glass and the bead and a thin bedding below the bead. The wood beads are secured in place with screws at maximum 200 mm centres and no more than 75 mm from corners.

The bedding inside and out is trimmed and finished with a smooth chamfer or slope to shed water as illustrated in Fig. 82.

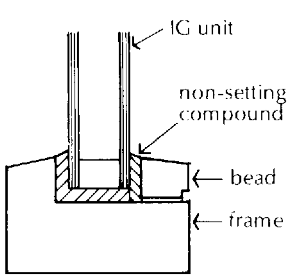


Fig. 82 Solid bedding glazing.

Beads with load-bearing tape and sealant

An alternative method of solid bedding for IG units glazed to wood and metal frames uses load-bearing mastic tape or cellular, adhesive sections as face bedding and non-setting sealant as capping and bed for units.

Preformed load-bearing mastic tape is made from a fabric base, saturated in butyl (synthetic rubber) or polyisobutylene polymers in various widths and thicknesses. The tape is compressed during manufacture so that it has adequate load bearing capacity as bedding for glass, to resist wind pressure on the unit.

A strip of mastic tape is fixed to the rebate upstand with its top edge about 6 mm below the sight line and setting blocks are placed in the rebate platform to support the IG unit. The IG unit is placed on the setting blocks and pressed firmly into the rebate up to the mastic tape in the upstand of the rebate.

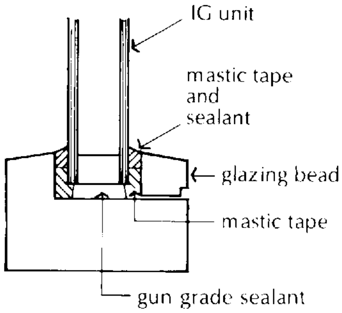


Fig. 83 Solid bedding glazing.

One-part or two-part sealant of polysulphide, silicone or urethane is run into the clearance gap between the lower edge of the IG unit and the rebate as bedding and as a thin bed for the glazing bead.

A strip of load-bearing tape is run around the outside edge of the unit or the back face of the bead so that its top edge finishes some 6 mm below the sight line. The beads are fixed in place and pressed in firmly to compress the tape and bed the wood beads, which are screwed in place at a maximum of 200 mm and no more than 75 mm from corners.

Sealant capping is run around both sides of the glass and finished with a slope or chamfer as illustrated in Fig. 83.

Various combinations of load-bearing tapes and sealants, non-setting compounds and sealants and sealants by themselves may be used as bedding and sealants for solid bedding glazing of IG units, depending on the nature of the materials of the window framing and convenience in the operation of glazing.

Drained glazing

The drained method of glazing for IG units is designed to remove any water that has penetrated to the bottom rebate by drainage and to some extent by ventilation. Any water that lies for some time in the bottom rebate will adversely affect the adhesive edge seal to IG units.

Insert gasket glazing

The majority of extruded, hollow section uPVC and aluminium window frames employ gasket glazing systems. Gaskets are preformed sections of synthetic rubber that are shaped for insertion between the nibs around a groove in the glazing bead or the frame of the window and so positioned that the blades or bearing edges of the gasket make firm contact with glass faces as illustrated in Fig. 84, to exclude rain and allow for some structural and thermal movement between frame and IG unit.

Gaskets should be inserted in the nibs in grooves provided in one

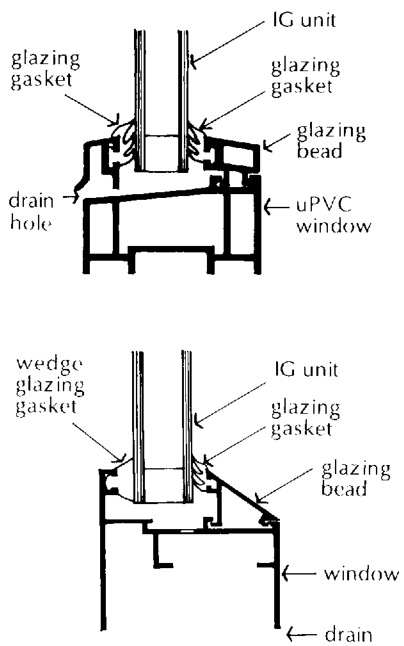


Fig. 84 Drained glazing.

length. The gaskets are nicked at corners to ease bending and the joint of the gasket ends should be at the centre of the top of the frame.

Because there is some possibility that wind-driven rain may penetrate the junction of gasket and glass, it is common practice to provide a means of removing any water that has run to the bottom glazing rebate.

Plastic blocks are placed on the platforms of the bottom rebate to support the IG unit. The unit is placed on the setting block and pressed on to the inside gaskets and centred by means of location blocks wedged between the side of the IG unit and frame. The beads with gasket in place are then fixed in position on the outside of the frame in clip-in nibs around grooves or by means of screws, so that the gaskets bear firmly on the glass face.

The void spaces between the edges of the IG unit and the frame are left unobstructed so that any water that penetrates outside gaskets can run down to the bottom rebate and out through drainage holes as illustrated in Fig. 84.

The points in this system of glazing that are most vulnerable to rain penetration are the corners of the window where the outside beads are mitred and butt together.

Drainage to square section frames

As an alternative to solid bedding for square section wood and metal frames, systems of face bedding or gasket glazing with drainage to the bottom rebate may be used. For drainage the bottom rebate platform should be cut to slope out at an angle 10° to the horizontal.

For face bedding systems tapered setting blocks are placed in position. Load-bearing mastic tape is fixed to the upstand of the rebate, finishing about 6 mm below the sight line. The IG unit is placed on the setting blocks and pressed firmly on to the mastic tape. Mastic tape is fixed to the lower edges of the outside glass or the glazing beads, finishing about 6 mm below the sight line, and the beads are placed in position and pressed firmly up to the edge tape and the beads secured with screws.

A capping of silicone or other sealant is run into the 6 mm space around both inside and outside glass and finished with a slope or chamfer to shed water.

Any water that penetrates the outer bedding and seal will drain out through 10 mm diameter holes cut in the underside of the wider bottom bead, as illustrated in Fig. 85.

As an alternative to face bedding and sealant, profiled, closed cell, synthetic sections or strips, with self adhesive backing, may be used.

The self adhesive strip is fixed to the upstand of the rebate. Setting blocks are placed in position and the IG unit is placed on the setting blocks and pressed up to the back face of the rebate. Self adhesive tape is fixed to the glazing beads which are pressed up to the IG unit

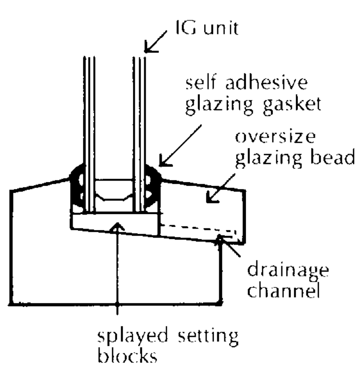


Fig. 85 Drained glazing.

and the beads are screwed into position. Drainage of water is through holes in the underside of the oversize bottom bead.

Double glazing for sound insulation

A major part of the penetration of sound through windows is transmitted as airborne sound through gaps between opening sashes and frames of windows.

Appreciable reduction of sound transmission through windows can be achieved by fitting weatherseals around all opening parts. Reduction of sound by weatherstripping can be appreciated by comparing sound penetration through an open and a closed weatherstripped window facing a busy urban road.

Where indoor quiet is at a premium and windows are necessary for daylight, double glazing with a comparatively wide air space between sheets of glass may be used for additional reduction of sound transmission. In effect two windows are built into the opening, separated and not connected, by some 150 mm between the two sheets of glass as illustrated in Fig. 17.

The outer window consists of a fixed light and the inner window is hinged to open in for the purpose of cleaning glass facing the cavity. This opening light is fitted with weatherstripping. The inside of the cavity is lined with an acoustic lining made of a material that will absorb some of the energy causing the air movement that causes sound. By fixing the two windows separately, vibrations of the outer sheet of glass, caused by airborne sound, will be reduced by the still air in the wide cavity and so have less effect on the inner sheet of glass.

A disadvantage of this sound insulation arrangement is that the wide air space will be less effective, as thermal insulation, than a narrow cavity up to 20 mm would be. The reason for this is that the air inside the wide cavity has more volume in which convection currents can circulate and so transmit more heat between the two sheets of glass and so increase heat loss, than a narrow cavity of say 12 mm would.

WINDOW SILLS

It is good practice to set the outside face of windows back from the outside face of the wall in which they are set, so that the reveals of the opening give some protection against driving rain. Wind-driven rain, which will run down the impermeable surface of the window glass to the bottom of the window, should be run out from the window by some form of sill. The function of an external sill is to conduct the water that runs down from the windows away from the window, and to cover the wall below the window and exclude rain from the wall. The material from which the sill is made should be sufficiently impermeable and durable to perform this function during the life of the building.

External window sills are formed either as an integral part of the window frame, as an attachment to the underside of the window, or as a sub-sill, which is in effect a part of the wall designed to serve as a sill. Most materials used for external sills are pre-formed so that the dimensions of the sill determine the position of the window in relation to the face of the wall. As a component part of a wall external sills should serve to exclude wind and rain and provide adequate thermal insulation to the extent that the sill does not act as a thermal bridge to heat transfer.

The internal sill of a window serves the purpose of a finish to cover the wall below the window inside the building, and as a stop for wall plaster. The material used for internal sills should be easy to clean and materials commonly used are painted softwood, plastic, metal and clay tiles.

External sub-sills

These sills are constructed as a capping to a solid wall below windows, as a weathering to run water away from the window, to protect the wall below and as a finish between the wall and the window. The materials used are natural stone, cast stone, concrete, tile and brick. Natural sedimentary igneous and metamorphic stone sills are less used than cast stone, concrete, tile and brick sills due to the scarcity and cost of the material. Slate sills, which are readily available but comparatively expensive, are used to some extent.

Natural stone sills

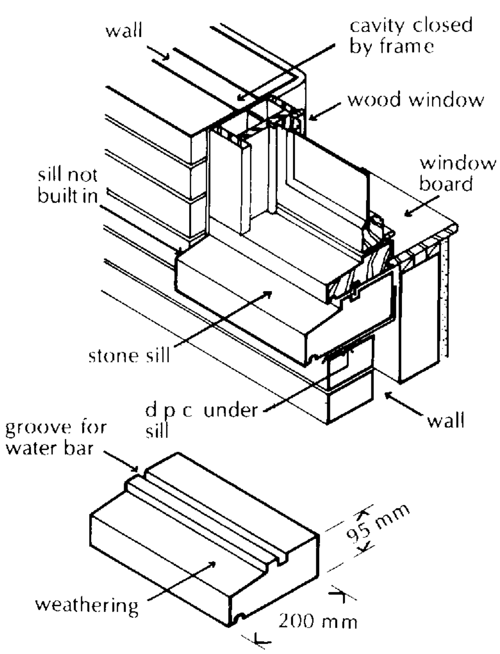


Fig. 86 Natural stone or cast stone sill for wood window.

Natural stone sills of sedimentary or igneous stone such as limestone, sandstone or granite (see Volume 1) are specially cut to section to provide a weathered surface, a groove for water bar and overhanging drip edge as illustrated in Fig. 86.

The top surface of the sill is finished flat, as a bed for the window sill. A groove is cut in the top of the sill to take a metal water bar that is set in mastic in the stone sill and the underside of the wood window sill. The water bar acts as a check against wind-driven rainwater that might otherwise penetrate between the stone sub-sill and the wood window sill.

A shallow sinking is cut in the top of the sill down to a weathered face that slopes out to shed water. The shallow sinking acts as a check against wind-driven rain being blown up the weathered sill face. A shallow groove is cut near the outside edge of the underside of the sill to form a drip edge to encourage rainwater to run off.

The sub-sill shown in Fig. 86 is cut to length to fit between the jambs of the window opening. The ends of the sill are bedded and pointed in mortar. The mortar joint between the end of the sub-sill and brick may not be entirely watertight, particularly in exposed positions. It is for this reason that the under-sill damp proof course

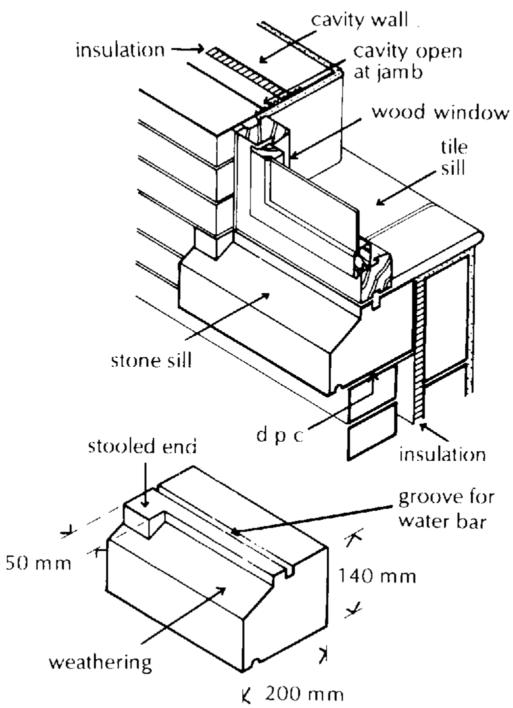


Fig. 87 Natural stone or cast stone sill.

(dpc) is extended half a brick beyond the jambs as shown in Fig. 88. The projection of the outer face of the sub-sill beyond the face of the wall below is usually about 30 mm.

As an alternative to plain end sills, that fit between the jambs of window openings, the ends of a sill may be stooled for building into the jambs of openings as illustrated in Fig. 87.

A stooled end is cut on each end of the sill as a bearing for the brickwork or stonework that is built up in the jambs of the opening. To allow for the necessary depth of stone required to cut weathering, sinking and a substantial thickness of stone at the overhang, sills with stooled ends should be two courses of brickwork deep to avoid untidy cutting of bricks.

Stooled ends to stone sills provide a solid bearing to walling at jambs and a weatherseal against water penetrating between sill and jamb. Sills with stooled ends are commonly used with stone walling so that the sill may bond in with stonework.

Stone sub-sills are bedded in mortar on the under-sill dpc, bearing on the outer brick leaf of the cavity wall. As the sill does not extend to the insulating block inner skin of the cavity wall or across cavity insulation, it will not act as a thermal bridge (see Volume 1).

Reconstructed and precast concrete sills

Reconstructed stone is made from a mix of natural stone, crushed to a maximum size of 6 mm, cement and just sufficient water for moulding and setting. The mix is cast inside timber moulds formed to the shape of a weathered stone sill such as that illustrated in Fig. 87. The reconstructed stone sill may be made with either ordinary or white cement to produce a product that closely resembles the texture and colour of the natural stone from which it is made. Well made reconstructed stone may be indistinguishable from the natural material from which it is made.

Precast concrete sills are made from ordinary natural aggregate concrete and cement which is cast and compacted by vibration in moulds, with either a natural concrete finish or an integral cast finish of crushed natural stone and cement as facing to exposed faces.

Precast concrete sills, which may initially resemble the colour and texture of natural stone, do not weather like natural stone and are liable to irregular and unsightly stains in a few years.

Sub-sills of stone, reconstructed stone and precast concrete with stooled ends built in to the surrounding walling should be hollow bedded. The term 'hollow bedded' describes the operation of laying a few courses of the stone or brickwork below the sill in dry sand.

The purpose of this operation is to make allowance for the likelihood of the more heavily loaded walling at jambs of openings sinking somewhat more than the less heavily loaded walls under sills. If the sill had been solidly bedded in mortar the sinking of walling at jambs might cause the sill to break its back and crack at about the centre of the sill length. On completion of the walling, the stones or bricks below the sill which were hollow bedded in sand are taken out and laid in mortar up to the underside of the sill.

Damp proof course below sills

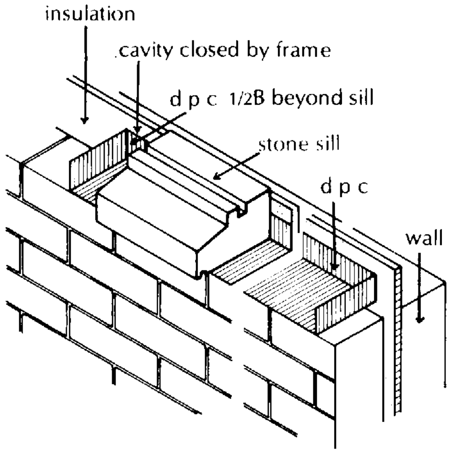


Fig. 88 Under-sill dpc.

Sub-sills of stone, reconstructed stone and precast concrete with square ends and sills of small units such as brick and tile may not be entirely effective in excluding rain that may penetrate joints in and at the ends of sills to the wall below, particularly in exposed positions. It is practice, therefore, to build in a sub-sill dpc as illustrated in Fig. 88.

The material most used as dpc is sheet lead which can be worked and shaped to the required shape and size without damage and which will prevent penetration of water to the walling below the sill. A sheet of Code 4 or 5 lead is shaped to lie as a bed under stone sills with upstand ends behind and to the ends of the sill.

Where the stone sill has plain ends for building-in between jambs of opening the lead under-sill dpc is extended $\frac{1}{2}$ B beyond the sill ends as protection against entry of water through the mortar joint between sill ends and jamb walling to the walling below.

Other materials that may be used instead of lead sheet are bitumen felt and plastic sheet. Both of these materials are difficult to apply in one sheet to the bed and up the back and ends of stone sub-sills.

Slate sills

Slate sills are cut from some fine-grained natural slate and finished in a range of standard and purpose-made sections to suit either timber or metal windows. The slate is finished with a sawn, sanded or fine-rubbed finish. The natural colour of the slate varies from light grey and green to blue and black. This dense, durable material is impermeable to water, requires no maintenance, is a poor thermal insulator and being brittle may crack due to movement of the building fabric. These sills should be cut and finished in one length to avoid the difficulty of making a weathertight joint in the material, a limitation

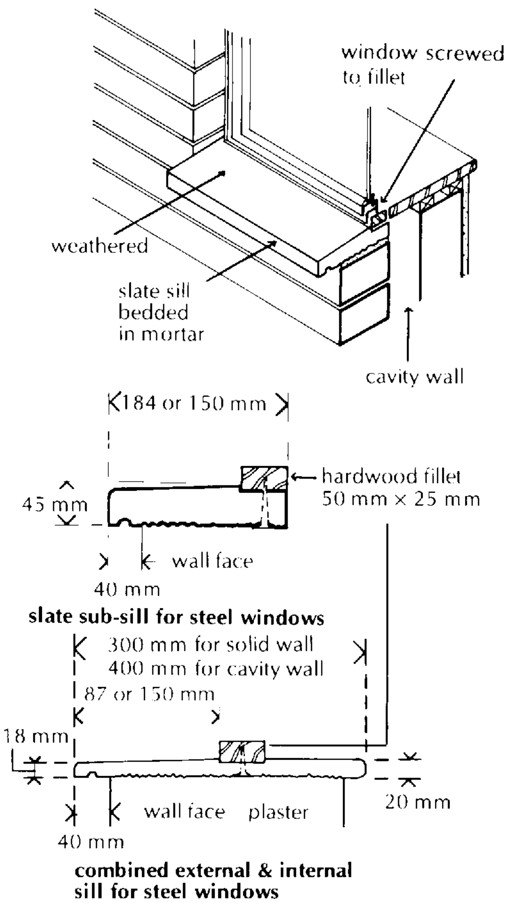


Fig. 89 Slate sills for steel windows.

which restricts their use to comparatively narrow windows unless a generous thickness of slate is used.

The two standard sections illustrated in Fig. 89 are for use with standard steel windows which are screwed to the fillet fixed to the sill. Sills for use with wood windows are finished with a groove for a water bar. These sills are bedded in mortar on the wall below the window with the drip edge projected some 38 mm beyond the face of the wall.

The sill shown in Fig. 89 is cut in one length to fit between the jambs of the window opening, with the vertical joint between the end of the sill and the jamb filled with mortar and pointed with non-setting mastic compound. This is a satisfactory joint for normal exposure to driving rain. In positions of severe exposure it is wise to incorporate a lead dpc tray under the sill, cut and shaped to extend some ½ B each side of the opening to exclude water.

These sills may be cut and finished with stooled ends for building into the jambs of openings. This costly end detail does not provide a satisfactory finish unless the sill is a full brick thickness, otherwise untidy cutting of brickwork is necessary. Where the ends of these comparatively thin sills are built in, differential settlement between the more heavily loaded walls at the jambs and the less heavily loaded walling under the window may cause the sill to crack.

The combined external and internal sill shown in Fig. 89 acts as a cold bridge across the thickness of the wall and will encourage condensation on the top of the internal sill. Because it is comparatively thin, the sill is liable to crack due to handling and slight movements in the wall and is used for only narrow window openings.

Brick sills

A common method of forming a sub-sill to window openings in walls of fairface brickwork is with a course of bricks laid on edge or a course of bricks specially made for the purpose. Whichever method is used the bricks should be sufficiently dense and weather resistant to stand the appreciable volume of rainwater that will run off the impermeable surface of the glass above. It may not be sufficient to use the bricks that are used for the surrounding brickwork.

The reason for this is that brickwork resists the penetration of water to the inside face of a wall by absorbing a considerable amount of the rain that falls, which evaporates to air during dry spells, without suffering damage. The bricks in sills suffer greater saturation

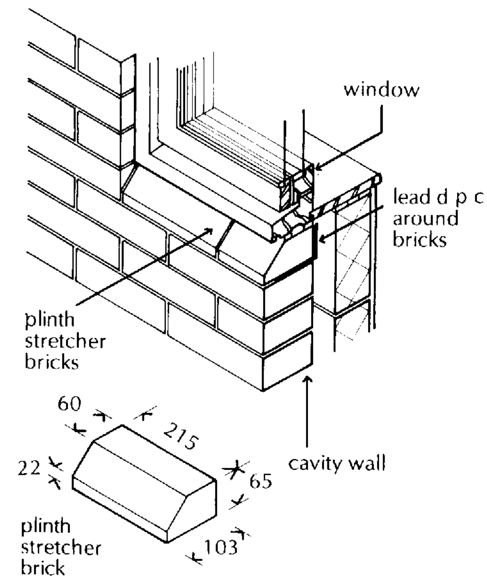


Fig. 90 Brick sill.

by rain and may, unless they are dense, suffer damage by frost action due to the expansion of the water in the bricks. For this reason, dense, well burnt bricks such as semi-engineering or engineering bricks are used in sills.

Standard size bricks are laid on edge as sills with one stretcher face and one header face exposed. The stretcher face top surface of the sill may be laid to a slight fall to shed water. The bricks are laid and pointed in cement mortar with the back edge of the bricks at least 30 mm behind the window sill edge and finished either flush with or projecting from the wall face as a drip edge.

The special plinth bricks, illustrated in Fig. 90, are made from dense clay and formed with a sloping weather face to shed rain water. The bricks are laid on bed in cement mortar with the back face of the bricks set well back under the window sill so that there is a generous overhang of the drip edge of the wood sill above. A lead dpc is bedded below the sill bricks, turned up behind them and continued $\frac{1}{2}$ B beyond the jambs of the window opening.

Tile sub-sill

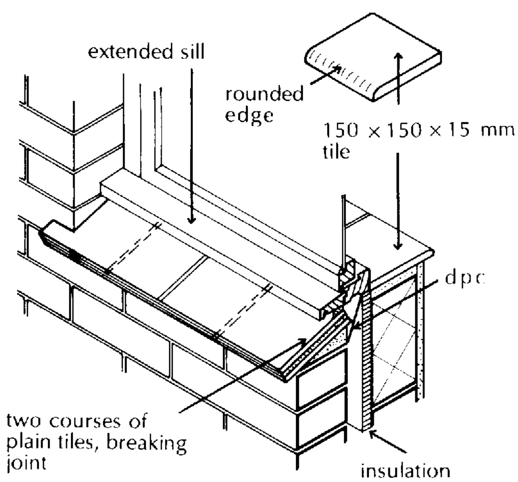


Fig. 91 Plain tile sill.

As a comparatively cheap form of sub-sill, two courses of clay or concrete plain tiles are laid, breaking joint, in cement mortar. The majority of clay tiles which absorb water fairly readily, should be laid at a slope of 40 to 45° to the horizontal if they are to avoid suffering frost damage. Such a steep slope for a tile sill would be too great to ensure secure bedding. Machine pressed or concrete plain tiles, which may resist the likelihood of frost damage at a slope of 30° are therefore used.

The tiles may be laid with their long axis parallel to the wall face to avoid cutting tiles or with their long axis at right angles to the wall and cut as necessary to suit the position of the window. The tiles may be finished square to the jambs of the window opening or notched around the angle of the jambs for appearance sake, as illustrated in Fig. 91.

The tiles should be laid with their back edge well back under the window sill, so that there is a generous overhang of the window sill, and project out beyond the wall face about 38 mm as a drip edge. A lead or bitumen felt dpc should be bedded below the tile sill and bedding.

Many consider this form of sub-sill to be an untidy, unattractive finish to the bottom of a window opening.

Metal sills

Most metal window manufacturers provide standard section metal sills for fixing to the frame of their windows to give cover and protection to the wall below the window. The projection of the sill beyond the face of the wall is determined by the 25 mm width of the welded-on stop ends, which in turn determines the position of the window in the thickness of the wall. The joint between the ends of the sill and the jambs should be pointed with mastic. The steel sill itself will exclude rainwater but the end joints may be vulnerable to water, particularly in positions of severe exposure. A dpc in the course below the sill, extending either side of the opening, might be a wise precaution in conditions of severe exposure.

Similarly, extruded aluminium section sills are made to suit aluminium windows as an integral part of the window.

Plastic sills

Most plastic windows have an integral sill as part of the window, which fits over some form of sub-sill. Some manufacturers provide a separate hollow section plastic sill which is weathered to slope out and is designed to cover and protect the wall below the window. These separate sill sections are clipped or screwed to the frame, as illustrated in Fig. 61.

Wood sills

Most standard section wood windows can be supplied with a wood sill section that is tongued to a groove in the sill of the frame so that it projects beyond the window either to cover and protect the wall below or to overlap a sub-sill. The sill is designed to project some 25 to 38 mm from the face of the wall as a drip edge.

Because softwood sills must be protected with a sound paint film which must be regularly maintained, otherwise rain penetration will cause rapid deterioration of the wood, it is sensible to use hardwood sills in positions of moderate and severe exposure. The sill fits between the jambs of the opening, and the end butt joints should be bedded in mortar and pointed with mastic.

Internal sills, windowboards

The internal sill surface to a window is covered for appearance with a painted softwood window board, clay tiles, slate, metal or plastic sections designed for the purpose. The surface of the internal sill should be such that it can easily be kept clean.

A common form of internal sill is a softwood board termed a window board, cut from 19 or 25 mm boards and wrought smooth on one face and square or rounded on one edge. The board may be tongued to fit to a groove in wood window frames. The board is nailed to plugs or bearers nailed to the wall so that it projects some 25 mm or more from the finished face of plaster, as illustrated in Fig. 86.

Clay or concrete tiles may be used as an internal sill. The tiles are bedded in mortar on the wall and pointed in cement, as illustrated in Fig. 92. Rounded edge tiles are used and laid to project beyond the plaster face.

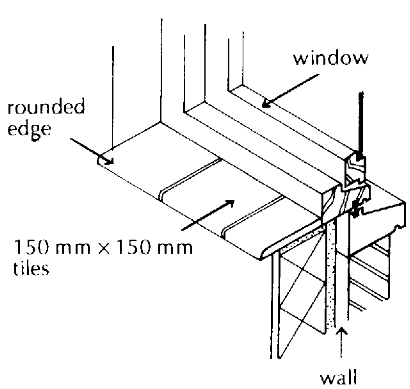


Fig. 92 Tile internal sill.

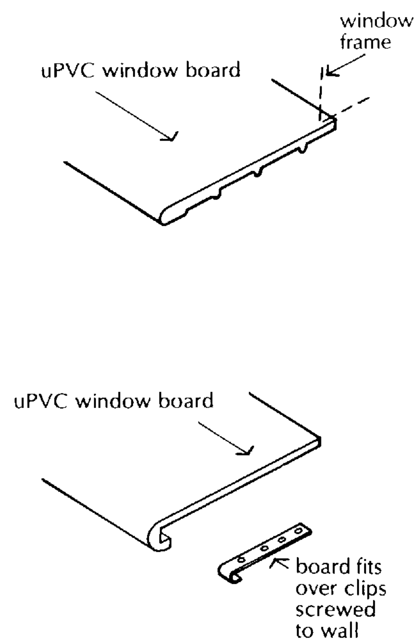


Fig. 93 Plastic windowboards.

Various sections of plastic windowboard are made for use with uPVC and other windows and as replacement windowboards. The thin sections are of co-extruded uPVC with a closed cell, cellular core and an integral, impact modified uPVC skin. The thicker sections are of chipboard to which a uPVC finish is applied on exposed faces.

The advantage of these windowboards is that they do not require painting and are easily cleaned. The disadvantage is that they are fairly readily defaced by sharp objects and the damage cannot be made good.

Plastic windowboards are cut to length and width with woodworking tools and fixed with concealed fixing clips, mortar bedding or silicone sealant adhesive, or are nailed or screwed to prepared timber grounds with the nail or screw heads covered with plastic caps (Fig. 93).

2: Doors

HISTORY

Since the first early settlements, wood has been the traditional material for doors. The ready availability of the natural material which can be cut, shaped and joined with simple hand tools, made it the obvious material for making doors. In the construction of doors, from the crude cottage door of boards nailed to battens to the larger, sophisticated framed, panelled and moulded doors, there is a wide variety of types of wood to choose from to suit utility and appearance. The grain and colour of the chosen wood may be used as a decorative feature by the application of oil, wax, polish or varnish.

Wood doors are still today commonly chosen for both internal and external use. For a time, early in the twentieth century, steel, framed as fully glazed doors, was in vogue to match the then fashionable steel window. Due to the progressive, destructive corrosion these suffered and due to change of fashion, the steel door soon lost favour. Aluminium, framed mainly as fully glazed doors, was and is today used as a substitute for steel.

During the last few years plastic and steel doors have been made and used, principally as a substitute for wood doors to avoid the expense of the comparatively frequent painting that wood needs for maintenance.

Plastic doors made as a frame of corner-welded, hollow extrusions of uPVC with moulded panels of fibre glass or acrylic, pressed to resemble the appearance of a framed, panelled wood door, do not look much like a wood door, offer poor security and do not for long stand up to normal use.

Sheet steel doors pressed to shape as either flush faced doors or pressed to resemble wood panelling have been much used in North America and Northern Europe. These comparatively sturdy doors are used for domestic and commercial buildings and as fire check doors.

A door is a solid barrier that is fixed in a doorway or opening in a wall or partition to hinge, pivot or slide open or to close for access to and from buildings and between rooms, compartments, corridors, landings and stairs.

Function

Before central or space heating of whole buildings was as common as it is today, doors served the useful purpose of containing the heat from open fires and stoves in individual rooms or compartments. Today, where buildings enjoy space heating, there is no longer a need for doors in openings to confine heating to separate rooms.

The so called 'open plan' living and working arrangements are much used, with common living areas and office working spaces.

Doors are still required for specific needs such as privacy in toilets and bathrooms, quiet in study areas, as barriers to the spread of fire and as weather barriers and security in external walls.

DOOR TYPES

Doors are supported in openings (doorways) on hinges as side hung, on pivots as double swing and on tracks as sliding or folding doors as illustrated in Fig. 94.

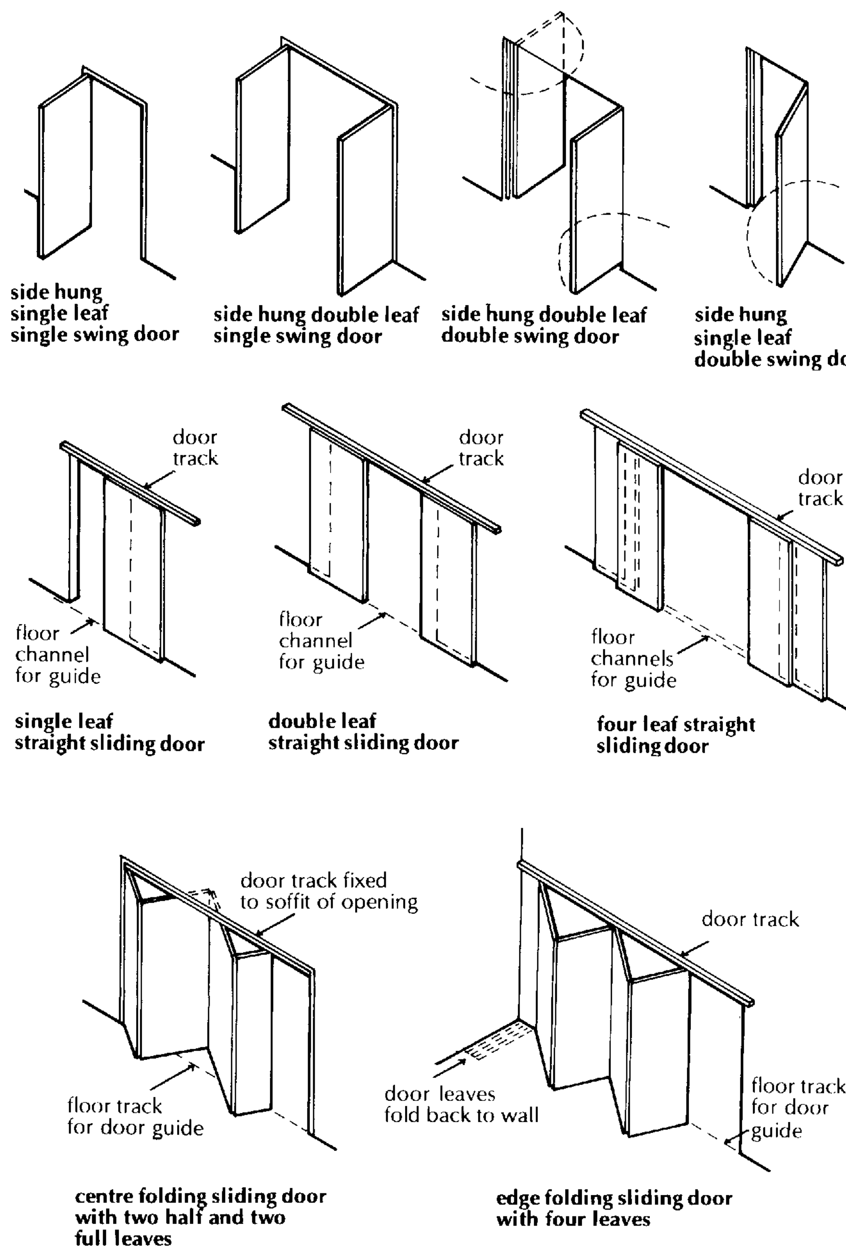


Fig. 94 Hinged, sliding and sliding folding doors.

Hinged, single swing, side hung doors are for frequent use between rooms and between rooms and corridors or landings.

Hinged and pivoted side hung, double swing doors are for frequent use along corridors to accommodate two way foot traffic.

Sliding and sliding folding doors hung on overhead track are for occasional use in openings between rooms to convert single rooms into larger double rooms.

Combinations of single swing, double swing and sliding and folding doors may be used for specific purposes.

The primary function of a door when open is:

Means of access

FUNCTIONAL REQUIREMENTS

The functional requirements of a door, when closed, are:

Privacy
Strength and stability
Resistance to weather
Durability and freedom from maintenance
Fire safety
Resistance to the passage of heat
Resistance to the passage of sound
Security

For access alone, a doorway or opening in a wall or partition will suffice. A door is used as a barrier which can be opened for access and closed for privacy, as a barrier to transfer of heat, sound and weather and as a barrier to the spread of fire.

Before central or space heating of whole buildings was as common as it is today and when open fires and stoves were the common form of heating, doors served the very useful purpose of containing heat in separate rooms. Today this is no longer a need where whole buildings have space heating, and with changed patterns of living and working there has been a move to dispense with doors in both residential and office buildings. The so called, 'open plan' living and working arrangements are much used, with common living areas and office working spaces, and doors confined to use in toilets, bathrooms and private study or work places in houses and offices and as smoke and fire barriers.

Safety requirement

The Approval Document to Part M of The Building Regulations suggests means of approach and minimum door sizes for doors for access to buildings for disabled people. From 25 October 1999 amendments to the Approved Document to Part M require there to be reasonable access for disabled people to and within all new dwellings, as well as other types of new buildings. The safety requirements in the Approved Document to Part K applies to devices to stop doors that slide or open upwards from falling.

Means of access

A door opening should be sufficiently wide and high for reasonably comfortable access of people. An accepted standard width and height of 762 and 1981 mm (the metric equivalent of the former imperial sizes of 2′6″ × 6′6″) has been established for single leaf doors. A narrower width may be adequate for a single person yet not comfortable for a person carrying things. The standard height makes allowance for all but the few exceptionally tall people. For large spaces or rooms a greater width is often adopted for appearance. The standard width and height has been chosen as convenient for the majority of people. Double leaf doors are commonly used for access to grand, large spaces or rooms for appearance, and for convenience in busy corridors.

The side on which the door is hung by hinges or pivots, its hand or handing and whether it opens into or out of a space or room, are a matter of convenience in use. By convention doors usually open into the room of which they are part of the enclosure. When single rooms were separately heated it was common to hang doors so that they opened with the leaf of the door moving towards the centre of the room, to avoid too vigorous an inrush of colder outside air. This inconvenient arrangement is reversed with space heated buildings. There have been systems of describing the hand of doors by reference to opening in or out and as either left hand, right hand or clockwise, anti-clockwise. These are of very little use because of the difficulty of clearly defining what is outside and what inside.

Privacy

Doors should serve to maintain privacy inside rooms to the same extent that the enclosing walls or partitions do. For visual privacy, doors should be as obscure as the walls or partitions. For acoustic privacy doors should offer the same reduction in sound as the surrounding walls or partitions and be close fitting to the door frame or lining and be fitted with flexible air seals all round. These seals should fit sufficiently to serve as an airborne sound barrier but not so tightly as to make opening and closing the door difficult.

Strength and stability

Whether it be side hinged, top and bottom pivoted, or on tracks to slide and fold, a door must have adequate strength to support its own weight and suffer knocks and minor abuses in service, as well as adequate shape stability for ease of opening and accuracy of closing to the frame or lining. Both strength and shape stability depend on the materials from which a door is made and the manner in which the materials are framed as a door.

British Standards Institution Draft for Development 171 : 1987 Guide to specifying performance requirements for hinged or pivoted doors gives guidance on performance criteria and was published as a prelude to the publication of a Standard.

The tests suggested are applied in general to complete door assemblies of door leaf, frame or lining and hardware because the performance of a door is affected by the component parts of door assemblies. Provision is also made for performance requirements for door leaves in isolation, to assist those manufacturers, the majority, who make doors alone rather than door sets or assemblies.

To allow for the wide range of use of doors, categories of duty related to use are suggested, from Light Duty (LD) through Medium Duty (MD) and Heavy Duty (HD) to Severe Duty (SD).

The functional requirements of doors are specified, relating to both the component parts and the whole of the door sets or assemblies, as:

Strength
Operation, the ability to be operated
Stability or freedom from excessive distortion in use
Fire resistance
Sound insulation

For external doors the additional requirements are:

Weather resistance
Thermal insulation
Security

Strength

A door assembly should be strong enough to sustain the conditions of use without undue damage. The suggested tests are for resistance to damage by slamming shut or open, heavy body impact, hard body impact, torsion due to the leaf being stuck in the frame, resistance to jarring vibrations and misuse of doorhandles.

Operation

A door should be easy to open, close, fasten or unfasten and should stay closed when shut. Tests for the forces required to operate door assemblies by 95% of females in the specified age groups are defined.

Dimensional stability

A door should not bow, twist or deform in normal use to the extent that its appearance is unacceptable or it is difficult to open or close.

The dimensional stability of wood, metal and plastic doors is affected by temperature and humidity differences. Wood doors are affected mainly by temperature and humidity, metal doors by temperature, and plastic by thermal and hygrothermal movements.

Bow in doors is caused by differences in temperature and humidity on opposite faces, which may cause the door to bow with a curvature that is mainly in the height of the door and should not exceed 10 mm.

Twist is caused, particularly in panelled wood doors, where movement of the spiral grain, due to changes of moisture content, causes one free corner to move away from the frame. This should not exceed 10 mm.

Durability and freedom from maintenance

In the introduction to DD 171 the authors state that because aspects of performance are related to appearance, which is a subjective criterion, and the aspect of durability includes a number of factors that can be described but not quantified, they have limited the recommended tests to those concerning strength.

Fire safety

Doors may serve two functions in the event of fire in buildings, firstly as a barrier to limit the spread of smoke and fire and secondly to protect escape routes.

To limit the spread of fire it is usual to divide larger buildings into compartments of restricted floor area by means of compartment floors and walls. Where doors are formed in compartment walls the door must, when closed, act as a barrier to fire in the same way as the walls. For this purpose doors must have a notional integrity, which is the period in minutes that they will resist the penetration of fire.

In Approved Document B, giving practical guidance to meeting the requirements of the Building Regulations, Table B1 of Appendix B gives provisions of tests for fire resistance of doors, with minimum requirements in minutes for the integrity of doors. These are usually stated as, for example FD 20, being a provision of 20 minutes minimum integrity for a fire door.

There should be adequate means of escape from buildings in case of fire, to a place of safety outside, which is capable of being safely and effectively used at all times. To meet this basic requirement it is usual to define escape routes from most buildings along corridors and stairways which are protected by fire barriers and doors from the effects of fire for defined periods. This latter function of a fire door is described as smoke control. The majority of doors along escape routes will need to serve as fire doors to resist spread of fire and to control smoke.

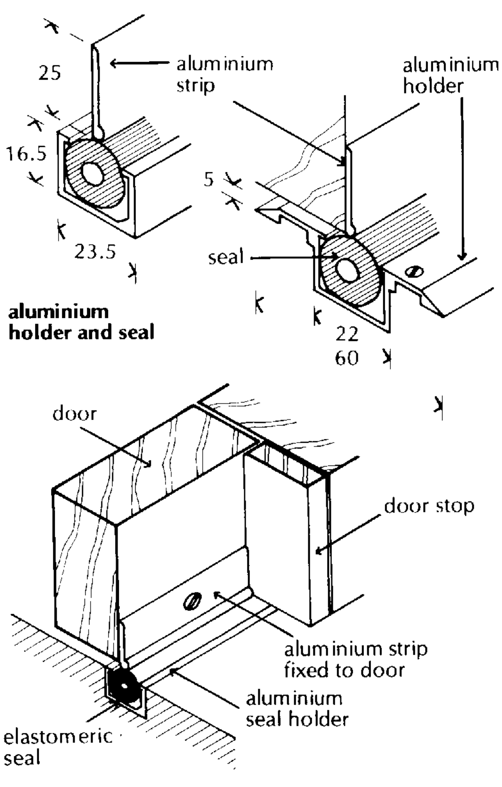


Fig. 95 Threshold seal for internal doors.

Doors, which do not usually form a major part of the area of external walls, make little contribution to overall heat loss when closed, so considerations of operation, strength, stability and security are of more importance in the construction of a door than resistance to heat transfer. To minimise air infiltration and draughts, weatherstripping should be fitted where it will not appreciably impede ease of operation. As glass offers poor resistance to heat transfer it is sensible to fix double glazing to reduce heat loss through fully glazed doors.

A door should afford reduction of sound for the sake of privacy and for those functions, such as lecture rooms, where the noise level is of importance. The heavier and more massive a door the more effective a barrier it is in reducing sound transmission. A solid panel door is more effective than a flimsy hollow-core flush door. To be effective as a sound barrier a door should be fitted with air seals all round as a barrier against airborne sound. Figure 95 shows threshold seals that can be used to improve insulation against airborne sound.

Weather resistance

As a component part of an external wall a door should serve to exclude wind and rain depending on the anticipated conditions of exposure described for windows.

The justification and advantages of weatherstripping around an external door depend on the normal use of the door. While the advantage of weatherstripping in conserving heat and excluding draughts may outweigh the disadvantage of resistance to operating in domestic doors, which are only occasionally opened, the disadvantage of weatherstripping that reduces ease of operation in more frequently opened doors, such as shop doors, may suggest dispensing with weatherstripping.

For doors that may with advantage be weatherstripped, tests similar to those for windows are suggested.

Laboratory tests on doors show that external doors, particularly those opening inwards, are more susceptible to water leakage than windows. It is most difficult to design an inward opening external door that will meet the same standards of water tightness that are expected of windows, without the protection of some form of porch or canopy. For maximum watertightness a door will need effective weatherstripping which will to an extent make opening more difficult, and a high or complex threshold which may obstruct ease of access.

The recommendations in DD 171, therefore, suggest requirements for limited resistance to rain penetration.

Security

An external door, particularly at the rear or sides of buildings, out of sight, is obviously a prime target for forced entry. Glazing and thin panels of wood, brittle fibre-glass and beaded plastic panels invite breakage with a view to opening bolts or latches. Solid hinges, locks and loose key bolts to a solidly framed door in a soundly fixed solid frame are the best security against forced entry.

The practical guidance in Approved Document N to the Building Regulations recommends the use of safety glass to doors and door side panels up to a level of 1500 mm above finished floor level. It is up to this level that hands, wrists and arms are vulnerable to injuries from broken glass.

WOOD DOORS

Wood doors may be classified as (Fig. 96):

Panelled doors
Glazed doors
Flush doors
Matchboarded doors

The traditional door is formed from solid softwood or hardwood members framed around panels. This traditional construction has

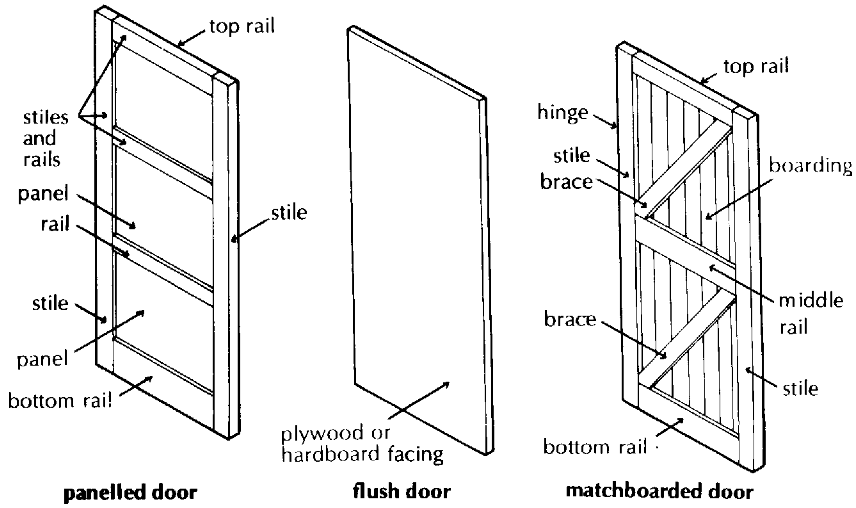


Fig. 96 Wood doors.

been in use for centuries with little modification other than in changes in jointing techniques due to machine assembly and the use of substitute materials for wood.

During the early part of the twentieth century it became fashionable to use flush doors with plain, flat surfaces both sides, devoid of decorative moulding that matched the then current trend for plain surfaces that was considered 'modern'. This fashion persisted well into the century and it is only in recent years that it is being abandoned in favour of the old, familiar, traditional look of the panelled door. These latter doors are often by construction flush doors, with a panelled appearance.

Panelled doors

Panelled doors are framed with stiles and rails around a panel or panels of wood or plywood. The stiles and rails are cut from timbers of the same thickness and some of the more usual sizes of timber used are: stiles and top rail 100 mm by 38 mm or 100 mm by 50 mm; middle rail, 175 mm by 38 mm or 175 mm by 50 mm; bottom rail 200 mm by 38 mm or 200 mm by 50 mm. Because the door is hinged on one side to open, it tends to sink on the lock stile. The stiles and rails have to be joined to resist the tendency of the door to sink and the two types of joint used are a mortice and tenon joint and a dowelled joint.

Mortice and tenon joint

This is the strongest type of joint used to frame members at right angles in joinery work. Figure 97 shows the stiles and rails of a panelled door before they are put together and glued, wedged and cramped around the panels, which are not shown.

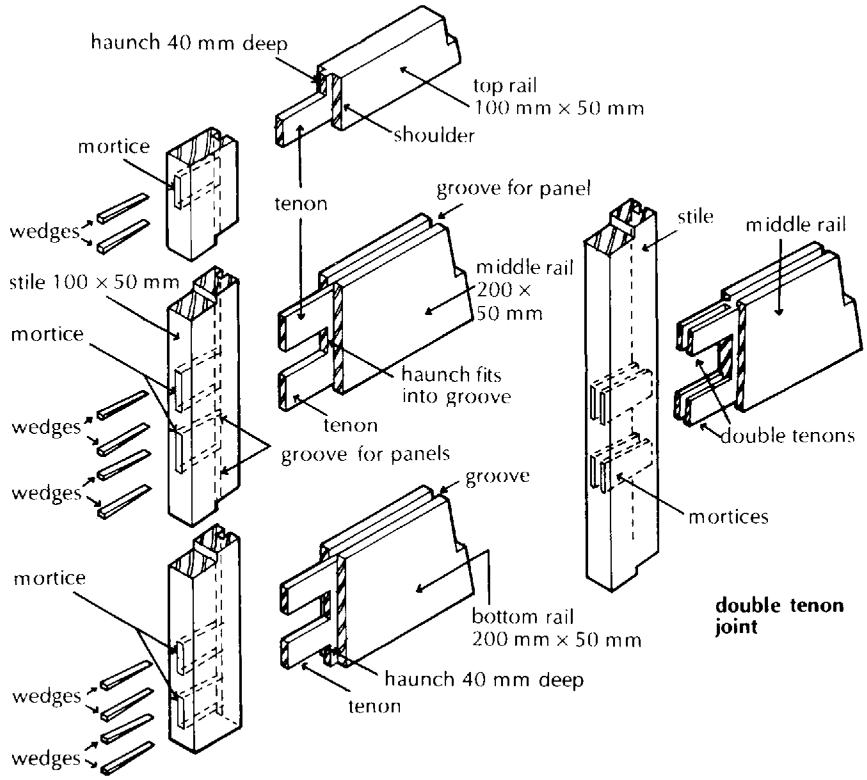


Fig. 97 Mortice and tenon joint.

Haunched tenon

Obviously the tenons cut on the ends of the top rail cannot be as deep as the rail if they are to fit into enclosing mortices, so a tenon about 50 mm deep is cut. It is possible that the timber of the top rail may twist as it dries. To prevent the top rail moving out of upright, a small projecting haunch is cut on top of the tenon, which fits into a groove in the stile.

Two tenons are cut on the ends of the middle and bottom rails. It would be possible to cut one tenon the depth of the rails but the wood around the mortice might bow out and so weaken the joint. Also a tenon as deep as the rail might shrink and become loose in the mortice. To avoid this a tenon should not be deeper than five times its thickness, hence the use of two tenons on the middle and bottom rails. Double tenons are sometimes cut on the ends of the middle rail as illustrated in Fig. 97. The purpose of these double tenons is to provide a space into which a mortice lock can be fitted without damaging the tenons.

It is apparent that the joints between the middle and bottom rails and stiles are stronger than that between the top rail and stile because of their greater depth of contact. For strength it would seem logical to make the top rail as deep as the middle rail. But a panelled door with a top rail deeper than the width of the stiles does not look attractive and by tradition the top rail is made as deep as the width of the stiles. The top and bottom faces of mortices are tapered in towards the centre of the doors so that when the tenons are fitted, small wood wedges can be driven in to make a tight fit.

Glueing, wedging and cramping

The word cramp describes the operation of forcing the tenons tightly into mortices. The members of the door are cramped together with metal cramps which bind the members together until the glue in the joints has hardened. Before the tenons are fitted into the mortices both tenon and mortice are coated with glue. When the members of the door have been cramped together small wood wedges are knocked into the mortices top and bottom of each tenon. When the glue has hardened the cramps are released and the projecting ends of tenon and wedges are cut off flush with the edges of the stiles.

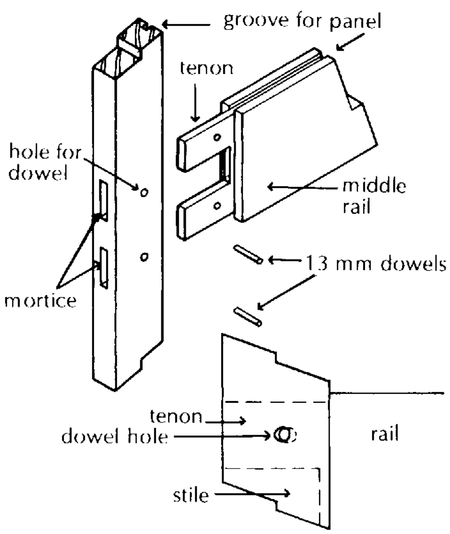


Fig. 98 Pinned mortice and tenon.

If the timber from which a door is made shrinks, the mortice and tenon joints may in time become loose, and the door will lose shape. To prevent this, panelled doors are sometimes put together with pinned mortice and tenon joints. The mortices and tenons are cut in the usual way and holes are cut through the tenons and the sides of the mortices, as illustrated in Fig. 98. The tenons are fitted to the mortices, and oak pins (dowels) 13 mm diameter are driven through both mortice and tenon. Because the holes in the tenons and mortices are cut slightly off centre the pins, as they are driven in, draw the tenons into the mortices. Pinned mortice and tenon joints are glued and wedged. This joint should be used for heavy panelled doors.

The economic advantage of woodworking machinery cannot be exploited to the full in the cutting, shaping and assembly of mortice and tenon joints because of the number of separate hand operations involved. It is practice, therefore, to use a jointing system better fitted to woodworking machine operations in the cutting and assembly of mass produced doors

Dowelled joints

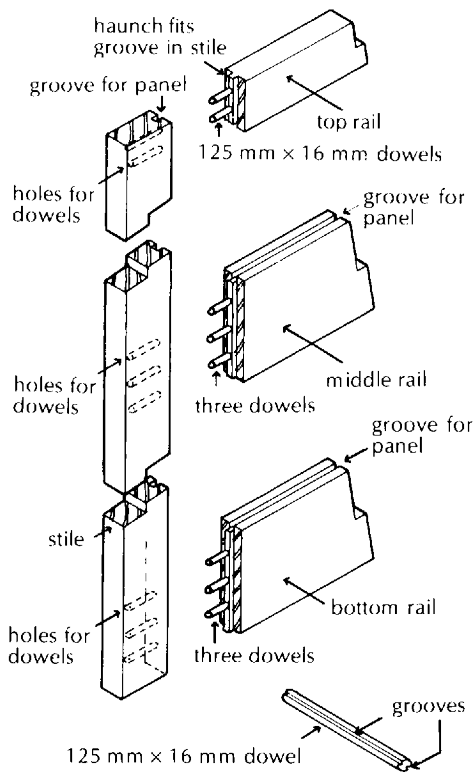


Fig. 99 Dowelled joints.

With the dowelled joint which is used to frame standard size panelled doors, continuous grooves are cut in the edges of the stiles and rails to take the panels and continuous, protruding haunches on the ends of rails as illustrated in Fig. 99. The haunches on the ends of the rails fit into the grooves cut in the edges of stiles to secure and level the members. By this arrangement the cutting of grooves and haunches are continuous operations suited to the use of woodworking machinery. Wood, plywood or wood particle board, plain panels are cut to size to fit into the grooves cut in the stiles and rails.

The rails and stiles are joined by wood dowels or pins of hardwood or the same wood as the door. Dowels which are 125 × 16 mm, are grooved as illustrated in Fig. 99. The two grooves, cut along the length of each dowel, allow excess glue and air trapped in the holes to escape as the dowels are fitted in place.

At least two dowels are used for the top rail and three for the middle and bottom rails. Dowels should be spaced not more than 57 mm apart and fit half their length into each member joined. Dowels are glued and fitted to holes drilled in the members to be joined and the door is assembled with panels glued and fitted to grooves in stiles and rails and the members are cramped up. Because of improvements in glues, this type of joint will strongly frame the members of a panelled door.

Panels

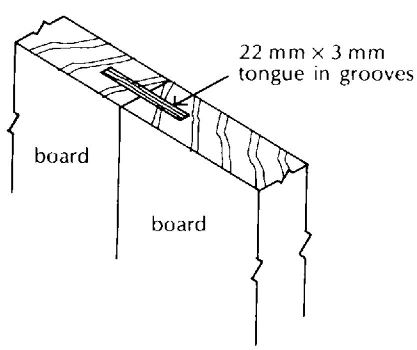


Fig. 100 Boards through tongued to form panels.

The comparatively thin wood from which panels are made will in time shrink due to loss of moisture, particularly in heated buildings. As drying shrinkage of wood occurs mainly across the long grain, panels may develop unsightly vertical cracks. On repainting, it is difficult to fill cracks successfully, as opening and closing doors tends to dislodge the filling.

To minimise shrinkage cracking of wood panels it is practice to make panels, that are more than 250 mm wide, from boards that are tongued together.

The term 'tongued' describes the operation of jointing boards by cutting grooves in their edges into which a thin tongue or feather of wood is cramped and glued as illustrated in Fig. 100. By using boards rather than one panel, shrinkage cracking may be avoided.

To avoid shrinkage of panels, plywood may be used. Plywood is made from three, five, seven or nine plies of thin sheets of wood firmly glued together, so that the long grain of one play is at right angles to

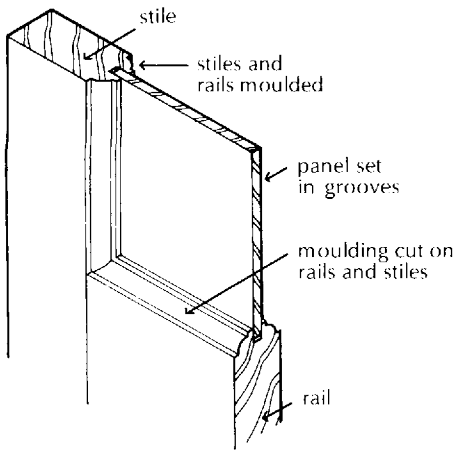


Fig. 101 Framing moulded around panels.

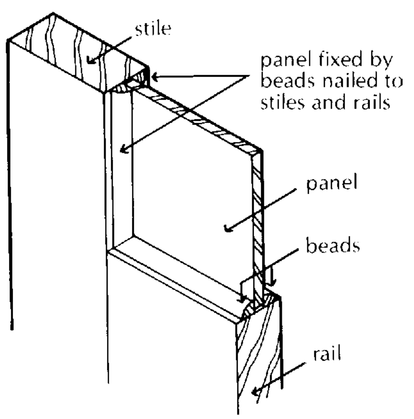


Fig. 102 Planted moulding.

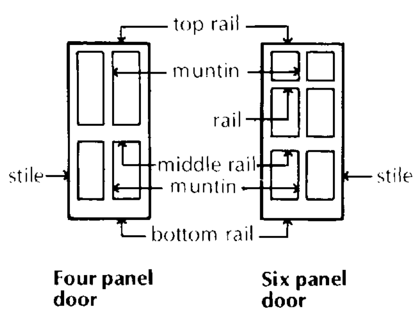


Fig. 103 Traditional panelled doors.

the long grain of the plies to which it is bonded. The opposed long grain of the plies strongly resists shrinkage cracking. Three-ply wood 5 or 6.5 mm thick is generally used for panels.

The traditional method of fixing and securing panels in doors is to set them into the grooves cut in the edges of the stiles and rails. To allow for drying shrinkage and any framing movements there should be a clearance of 2 mm between the edges of the panels and the bottom of the grooves in which they are set.

The advantages of setting panels in grooves in the framing members is that the panels are securely fixed in place and that shrinkage and movement of the frame will not cause visible cracks to open up around panels.

Panels set in grooves in stiles and rails with square edges may have a plain, unfinished look. To improve the appearance of a panelled door, mouldings are cut on the edges of the stiles and rails around panels as illustrated in Fig. 101. For this finish the ends of rails have to be scribed to fit around the moulding cut on the stiles. The term 'scribed' describes the operation of cutting the wood to shape to fit closely around the moulding which is cut continuously down the length of the stile.

A cheaper, inferior method of giving the appearance of mouldings around panels is to plant (nail) moulded timber beads around each panel as illustrated in Fig. 102. Due to the inevitable drying shrinkage, cracks will in all likelihood open up between the planted beads and the framing and panels of doors.

The traditional panelled door was constructed with four or six panels with central framing members, termed muntins, tenoned to rails as illustrated in Fig. 103. The advantage of this arrangement is that the width of the panels is limited to reduce the possibility of shrinkage cracks and the shape of the panels emphasises the verticality of the door. The four panel design is for small and the six panel design for larger doors. For appearance sake the six panel door is usually finished with mouldings cut on stiles, muntins and rails both sides.

The joint between the vertical muntins and the rails in the frame of four and six panelled doors is usually made with a stub tenon. A stub tenon cut on the ends of muntins fits to a mortice not cut right through the top and bottom rails to avoid the end grain of a tenon being exposed. These stub (short) tenons are glued and cramped up with the framing members around the panels.

For the sake of economy in using woodworking machinery and a change in fashion, standard, panelled wood doors are made without

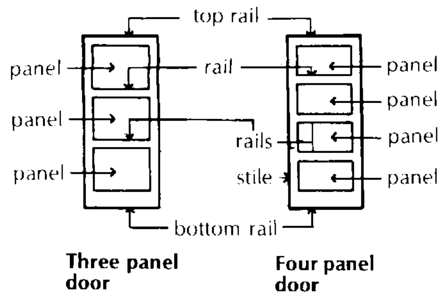


Fig. 104 Standard interior panelled doors.

muntins with panels between the stiles of the framing as illustrated in Fig. 104. These comparatively wide panels are usually of plywood, to minimise shrinkage cracking, and set in grooves in the framing members. For economy these doors are often finished with square edges framing around the panels.

These standard doors which are moderately robust for use as internal doors are not suited for use as external doors for other than sheltered positions.

Doors with raised panels

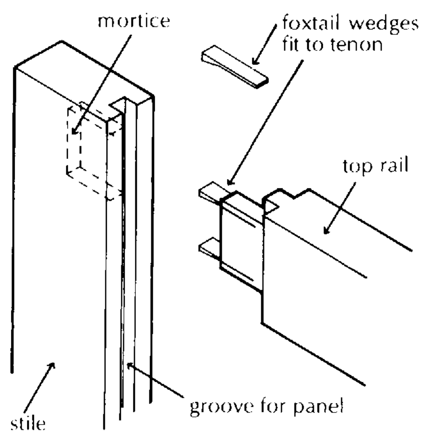


Fig. 105 Foxtail wedges.

For appearance sake, entrance doors and doors to principal rooms in both domestic and public buildings are often made more imposing and attractive by the use of panels that are raised, so that the panel is thicker at the centre than at the edges. This involves a deal of wasteful cutting of wood. Such doors are often made of hardwood which is finished to display the colour and grain of the wood by polish or French polish.

To avoid the ends of tenons showing on the edges of the door, it is practice to use stub tenons which are secured with foxtail wedges as illustrated in Fig. 105. The foxtail wedges fit to saw cuts in the ends of the stub tenons so that when the tenon is cramped into the mortice the wedges spread the tenon to bind to the mortice. This type of joint, which has to be very accurately cut, makes a sound joint. As an alternative dowelled joints may be used.

Raised panels are either bevel raised, bevel raised and fielded, or square raised and fielded.

Bevel raised panels

The panels are cut with four similar bevel faces each with a shallow rise from the edges of the panel to a point with square panels and ridge with rectangular panels as illustrated in Fig. 106A.

Bevel raised and fielded panels

The panels are cut with four similar bevel faces rising from the edges of the panel to a flat surface, termed the field, which is emphasised by a slight sinking cut around it as illustrated in Fig. 106B. At the field the panel is either as thick as or slightly less thick than the stiles. The proportion of the fielded surface to the whole panel is a matter of taste.

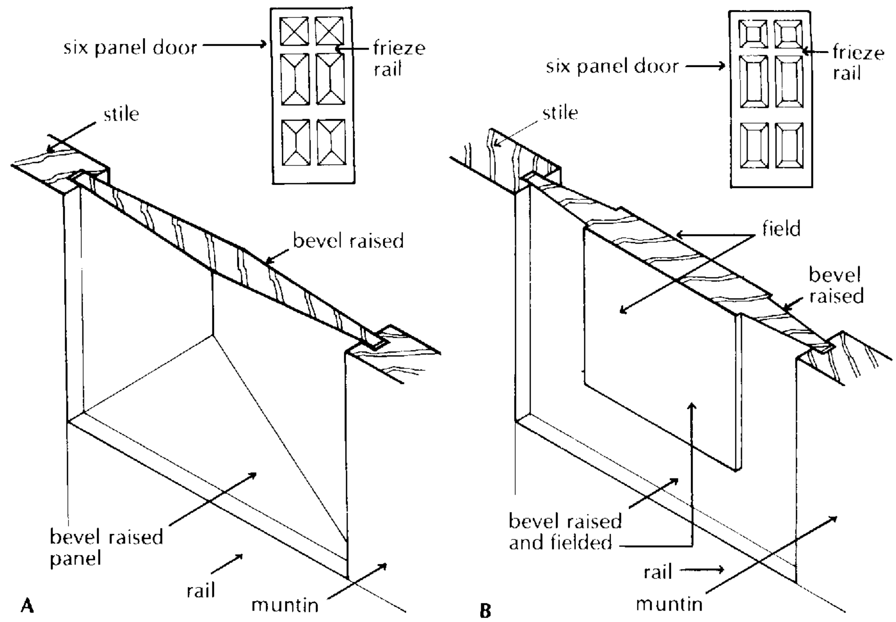


Fig. 106 A bevel raised panels. B bevel raised and fielded panels.

Raised and fielded panel

The panel, which is of uniform thickness around the edges, is raised to a flat field at the centre with a shallow sinking as illustrated in Fig. 107A, the field being square or rectangular depending on the shape of the panel.

Panels may be raised on both sides, as shown in Fig. 106A, or on one side only, as illustrated in Fig. 107A.

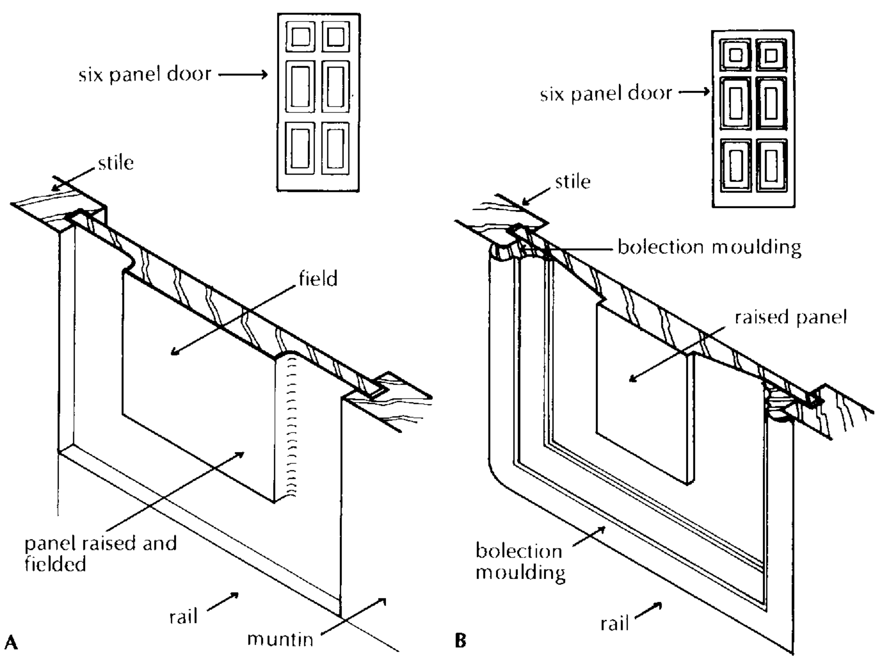


Fig. 107 A raised and fielded panels. B bolection moulding.

Bolection moulding

A bolection moulding is planted (nailed) around the panels of a door for the sake of appearance. The moulding is cut so that when it is fixed it covers the edges of the stiles and rails around the panel for the sake of emphasis, as illustrated in Fig. 107B. This particular section of wood moulding may be used with both raised and fielded panels on one or both sides of a door.

Practice is to employ bolection mouldings around the panels of large doors as this moulding looks clumsy and bulky around small panels.

Double margin door

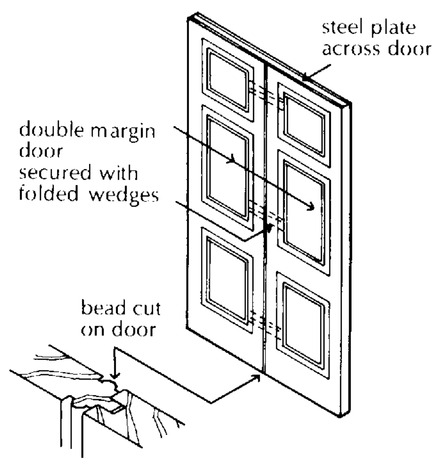


Fig. 108 Double margin door.

A wide panelled door may be constructed as one door or as two doors hinged to meet in the middle. A single door would tend to look clumsy with over size panels, whereas two doors would each be too narrow for comfortable access when only one leaf is opened. As a compromise such doors can be made up as if they were two doors with the two doors fixed together and acting as a single door as illustrated in Fig. 108.

The two leaves of this door are framed as conventional panelled doors, with plain or raised or fielded panels, and the stile of one leaf tongued into a groove in the other. A bead (quirk) is cut on the edges of the stiles in the middle of the door to distinguish the two separate leaves.

To fix the two leaves of this single door together pairs of folding wedges are fitted to mortices in the joining stiles and glued and cramped together. Folding wedges are tapered sections of wood, cut from a piece of wood, and fitted together on their tapered edges so that when they are forced together along the taper, they expand inside the mortice.

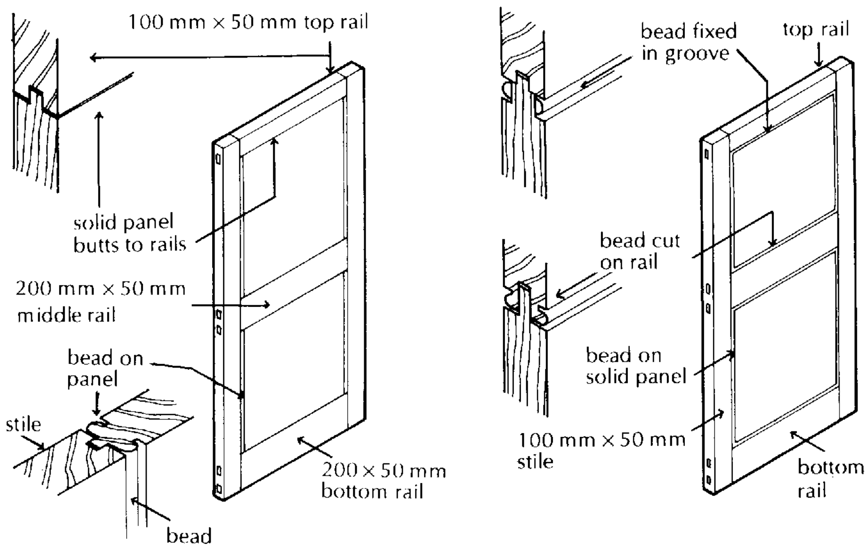
To provide additional bonding of the two leaves of this door, steel plates are set in a groove in the top and bottom edge and secured with screws.

Solid panels – flush panels

Solid panel doors are constructed with panels as thick as the stiles and rails around them for strength, security or where the door acts as a fire check door.

These doors are usually constructed of hardwood, such as oak, that has a better resistance to damage by fire than softwood. The solid panels are tongued to grooves in the stiles and rails and are either cut with a bead on their vertical edges or with a bead all round each panel for appearance sake.

Timber shrinks more across than along its long grain and because the long grain in these panels is arranged vertically the shrinkage at the sides of the panels will be more than at top and bottom. For this reason beads are cut on the vertical edges of the panels to mask any shrinkage cracks that might appear, as illustrated in Fig. 109. Where beads are cut top and bottom they are cut on the rails as it is easier to cut a bead along the grain of the rails than across the end long grain of the panels. A panel with beads on its vertical edges only is described as bead butt and one with beads all round as bead flush (Fig. 109). As an alternative to horizontal beads cut on the stiles a planted bead can be used, as illustrated in Fig. 109. This is not satisfactory with external doors as water may get behind the bead which may then swell and come away.



A Door with solid panels bead butt

B Door with solid panels finished bead flush

Fig. 109 A Solid panels bead butt. B Solid panels bead flush.

Double swing doors

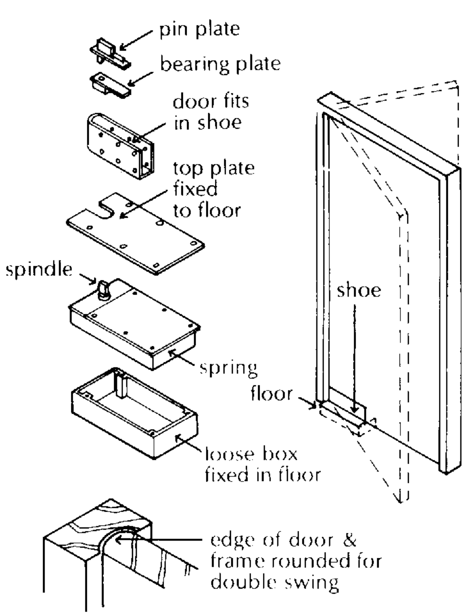


Fig. 110 Double swing door.

Double swing doors are used at the end of and along busy corridors and as shop entrance doors for the convenience of two way foot traffic. As it is easier and quicker to push than pull a door open, this type of door is used for the convenience of passing through the doorway in either direction. To avoid the danger of the door being pushed simultaneously from both sides these doors are constructed with either a glazed top panel or they are fully glazed.

To allow for the double swing action of the door the vertical edges of the door are rounded to rotate inside a rounded rebate in the timber door frame as illustrated in Fig. 110.

The door is either hung on double action hinges designed to accommodate the double swing or supported by double action floor springs and a top pivot as illustrated in Fig. 110. The door is supported by a shoe that fits to the spindle of the double action spring which fits into a box set in the floor. A top plate, which is screwed to the spring box, finishes flush with the floor.

A bearing plate, fixed to the top of the door, fits to a pin protruding from a plate fixed to the door frame.

Because of the necessary clearance gaps around the door, it provides poor thermal and acoustic resistance.

Sliding and sliding folding doors

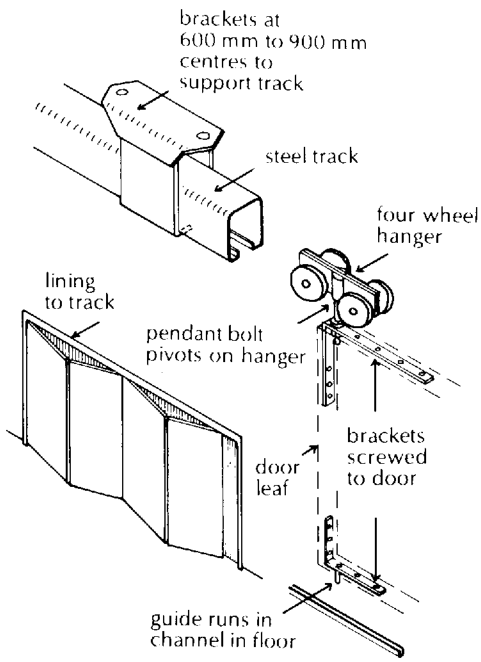


Fig. 111 Sliding folding door.

Sliding doors are designed mainly for occasional use to provide either a clear opening or act as a barrier between adjacent rooms or spaces to accommodate change of use or function and where it is necessary to avoid the obstruction caused by a hinged leaf.

Sliding doors can only be used where there is room for the door or doors to slide to one or both sides of the opening. These doors may slide as two leaves, one to each side or as one leaf to one side of the opening.

Sliding folding doors are used to separate rooms or spaces where it is convenient to be able to join the two rooms or spaces for their full width each side of the opening. Because of the folding sliding action the hinged leaves of the door can slide and fold back against a wall to occupy little space.

Sliding and sliding folding doors should be hung on an overhead track fixed to the timber or steel beam over the opening. An inverted 'U' shaped track is fixed to the beam with brackets as illustrated in Fig. 111. Hangers, in the form of a four wheeled trolley, run in the overhead track and support the door leaves through brackets screwed to the doors.

At the bottom of the door a channel, set and fixed in the floor, acts as a guide to a pin or wheel fixed by brackets to the door. To maintain a reasonably easy movement of sliding doors it is necessary to keep the bottom guide track free from dirt that might obstruct movement and to keep the hangers reasonably oiled.

The door leaves of both sliding and sliding folding doors may be of either panelled or flush construction. The lighter the doors, the easier their movement and the heavier the better they serve as a sound barrier.

GLAZED DOORS

Doors with one or more glazed panels of glass or fully glazed are used to give some daylight to spaces such as halls that have no windows and to give some light from a window, through an internal door, to an otherwise unlit space. Fully glazed doors fixed in an external wall serve as both door and window in the form of the fully glazed, sliding patio doors, described and illustrated in the previous chapter.

Purpose made glazed doors

A common form of traditional wood door for external use has glazed upper panels to admit daylight to halls. This door is framed as solid lower panels with upper glazed panels. The door may be framed as a normal panelled door with continuous width stiles or with diminishing stiles to provide a greater width for glazing as illustrated in Fig. 112.

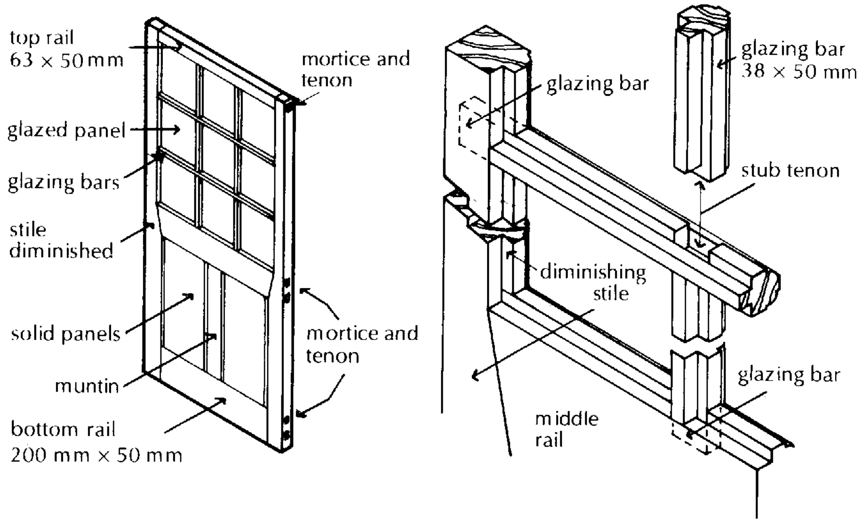


Fig. 112 Glazed door with diminishing (gun stock) stiles.

The lower panels are made solid and bead butt. The upper part of the door may be glazed in one square of glass or more usually as several squares of glass in putty or glazing beads in glazing bars. The glazing bars are through tenoned to stiles and stub tenoned to rails as illustrated in Fig. 112. Because the stiles are diminished in width at the middle rail, they are sometimes referred to as 'gunstock stiles' for their resemblance to the stock of a gun.

French casement

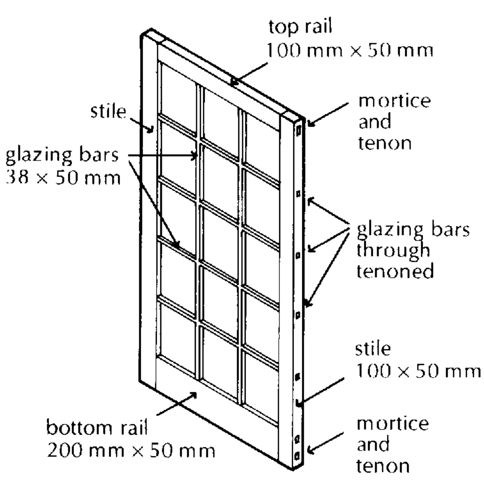


Fig. 113 Casement door (French casement).

The traditional form of first floor window to many French and northern Mediterranean countries is in the form of a timber framed door, fully glazed as illustrated in Fig. 113. The door is made with vertical and horizontal glazing bars as part of the framing.

These doors serve as windows to the first floor rooms and as doors, opening in, for access to balconies and ventilation during summer. Louvred timber shutters are hung externally to close over the window opening to exclude summer sun and provide ventilation.

These French casements (French doors) are framed with timber stiles and rails through tenoned together with the horizontal glazing bars through tenoned to the stiles as part of the frame structure.

Because they are hung to open in it is difficult to provide a weathertight seal, particularly at the sill of the door frame. These external doors need careful maintenance as protection against wind-driven rain else they will deteriorate and become difficult to open and close. As security against wind pressure they are usually fitted with bolts top and bottom.

FLUSH DOORS

Since they were first introduced early in the twentieth century flush doors have been much used internally in flats and houses. The plain, flat faces of these doors, without panels, appealed to the urban dwellers of the expanding towns of the time and their low cost to the builders. Fashions change and 'flush' doors today are made with faces press moulded to provide a poor imitation of a panelled door to satisfy the nostalgia for the old that is current today.

A variety of flush doors is manufactured with plain flush faces both sides and fibreboard facings press moulded, often with comparatively shallow sinkings, to resemble the appearance of panelled doors.

The shape stability of these doors depends to an extent on the fixing of the flush or moulded facings to the core; the lighter and thinner the core the more the facings are used to provide stability. With a lightweight cellular or skeleton core the fixing of the facings is generally adequate to maintain the square face and shape of the door but may well not be substantial enough to resist torsion, where one free corner of the door will no longer fit closely into the rebate of the frame or lining.

With cellular core and skeleton framed doors there may be a tendency for the flush facings to show the pattern of the core or skeleton, particularly where the faces are painted with a gloss paint.

The heavier solid core flush doors with a core of laminated timber, flaxboard, chipboard or compressed fibre strips will tend to maintain shape stability and uniformity of surface facings better than the light cellular and skeleton core doors.

Where the facings are of hardboard, press moulded to simulate door panels, the core is of light section softwood framed as a fixing for the four edges of the door and the fake internal rails and muntins.

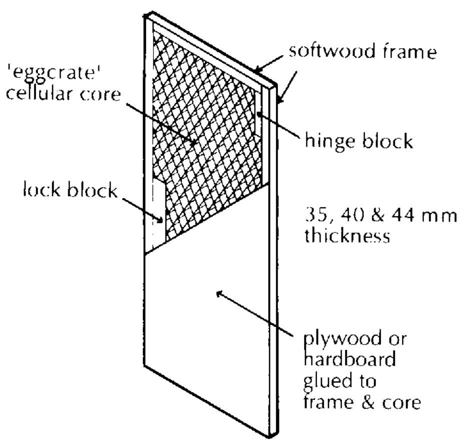


Fig. 114 Cellular core flush door.

Cellular core flush doors are made with a cellular, fibreboard or paper core in a light softwood frame with lock and hinge blocks, covered with plywood or hardboard facings glued to the frame and core both sides as illustrated in Fig. 114.

These flimsy, lightweight doors are for light duty such as internal domestic doors. They do not withstand rough usage such as the movements of boisterous children and provide poor acoustic privacy, security or fire resistance. They are mass produced in a small range of standard sizes and are cheap.

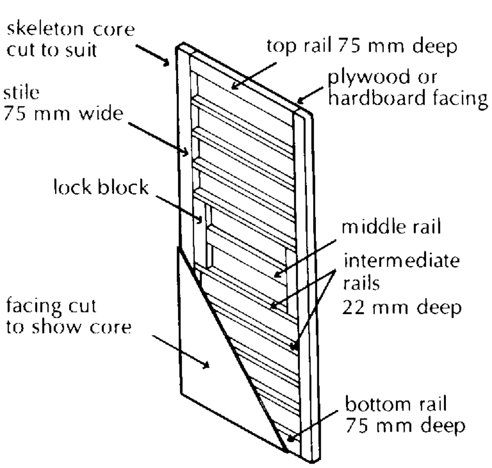


Fig. 115 Skeleton core flush door.

Skeleton core flush doors are made with a core of small section timbers, as illustrated in Fig. 115. The main members of this structural core are the stiles and rails, with intermediate rails as shown, as a base for the facing of plywood or hardboard. The framing core members are joined with glued, tongued-and-grooved joints. The door illustrated in Fig. 115 has a skeleton core occupying from 30% to 40% of the core of the door. This is a light duty door suitable for internal domestic use. A similar skeleton core flush door with more substantial intermediate rails in the core, where the core occupies

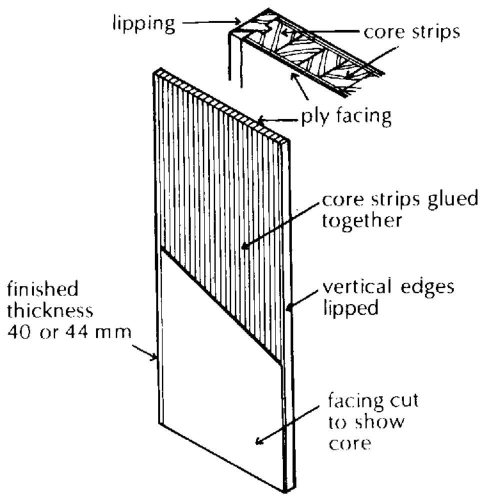


Fig. 116 Solid core (laminate) flush door.

from 50% to 60% of the core, is a medium duty door suitable for use internally in domestic and public buildings and for external use in sheltered positions.

This somewhat more substantial door will withstand normal use and maintain its shape stability better than a cellular core door.

Solid core flush doors are made with a core of timber, chipboard, flaxboard or compressed fibre board strips. The solid core door illustrated in Fig. 116 has a core of timber strips glued together, with plywood facings both sides glued to the solid core. The door is edged with vertical lipping to provide a neat finish.

Because of the solid core these doors have somewhat better shape and surface stability and acoustic resistance than the cellular or skeleton core flush doors.

The chipboard, flaxboard and compressed fibre board strip core doors are made with a solid core enclosed in a light timber frame to which hardboard or plywood is fixed. These solid core doors are more expensive than cellular core or skeleton core doors.

Solid core flush doors may be used as fire doors with an integrity rating of 20 or 30 minutes.

FIRE DOORS

Fires in buildings start, more often than not, by the heating of some material of the contents to ignition and the beginning of a fire. In the early stages of the growth of a fire the considerable volume of smoke produced rises to fill rooms from the ceiling downwards and spreads through gaps around doors and through unsealed void space, making a danger to people in the building. Fires grow and spread through the release of the hot, flammable, gaseous products of combustion to other materials of the building and its contents.

Means of escape

To provide safe means of escape for the occupants of buildings in the early stages of a fire, smoke control fire doors are fixed in enclosures to and along escape routes.

To limit the spread of fire in buildings it is usual to divide all but small buildings into compartments surrounded by floors and walls capable of limiting the spread of fire for a stated period of minutes or hours. Doors in compartment walls and doors to a protected escape route should be capable of resisting the spread of fire to the same extent that the enclosing walls do. These doors, which in the past have been variously described as fire check doors, fire break doors, fire protection doors and fire resisting doors, are now simply termed fire doors.

Fire doors serve to protect escape routes and the contents and structure of buildings by limiting the spread of smoke and fire. Fire doors that are fixed for smoke control only should be capable of withstanding smoke at ambient (surrounding) temperatures and limited smoke at medium temperatures by self closing devices and flexible seals. Fire doors that are fixed to protect means of escape routes should withstand smoke at ambient and limited smoke at medium temperatures and have a minimum fire resistance, for integrity only, of 20 minutes.

Fire doors that are fixed as part of a fire compartment and as isolation of special risk areas should have a minimum fire resistance, for integrity only, of a period of minutes or hours appropriate to the periods set out in Approved Document B giving practical guidance for the requirements of the Building Regulations, Fire safety.

Fire resistance integrity

To conform to international practice, doors and other non-load-bearing elements are no longer assessed for stability (resistance to collapse) or insulation. The test for integrity is assumed to include performance in regard to stability and insulation. The notation for fire doors is FD followed by the figure in minutes for integrity, as for example FD 20 or FD 30, and doors that serve for smoke control as for example FD 20S.

The performance test for fire doors that serve as barriers to the spread of fire is determined from the integrity of a door assembly or door set in its resistance to penetration by flame and hot gases. The test is carried out on a door assembly which includes all hardware, supports, fixings, door leaf and frame, representative of a door assembly that will be used in practice. Each face of the door assembly is exposed separately to prescribed heating conditions from a furnace, on a temperature-time relationship, to determine the time to failure of integrity. Failure of integrity occurs when flame or hot gases penetrate gaps or cracks in the door assembly and cause flaming of a cotton wool pad on the side of the assembly opposite to the furnace.

The door leafs illustrated in Fig. 117 are constructed and faced to provide 30 and 60 minutes for integrity. The 30 minute skeleton core flush door is protected with plasterboard panels fixed to the skeleton core under the plywood or hardboard facings as illustrated in Fig. 118.

The 30 minute, solid core fire doors are protected with wood strips or high density chipboard covered with plywood or hardboard facings.

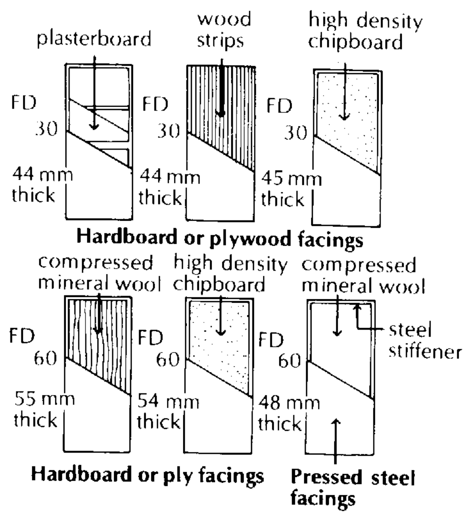


Fig. 117 Fire doors.

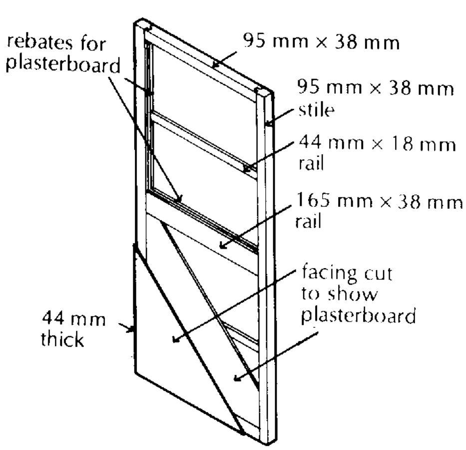


Fig. 118 Standard $\frac{1}{2}$ hour fire door.

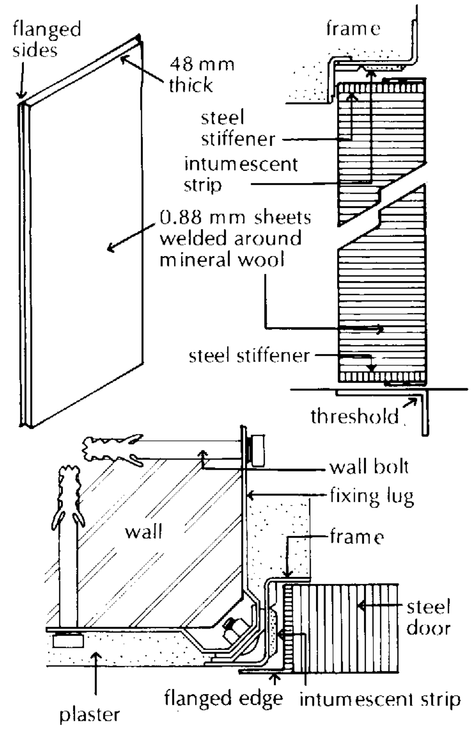


Fig. 119 Flush steel fire door.

The 60 minute, solid core fire doors are protected with compressed mineral wool or high density chipboard and hardboard or plywood facings.

The flush, steel fire door to provide 60 minutes protection, shown in Fig. 117 and illustrated in Fig. 119, has welded sheet steel facings. The casing is pressed around steel stiffeners and a core of compressed mineral wool. The door is provided with intumescent seals and is hung on a pressed steel frame.

A fire door should at once be easy to operate, serve as an effective barrier to the spread of smoke and fire when closed and be fitted with some effective self closing device. For ease of operation there must be clearance gaps around the door leaf. These clearance gaps are effectively sealed when a door leaf closes into and up to the rebate in a door frame. Where a door leaf has distorted in use and when the leaf is distorted by the heat of a fire, then the leaf will no longer fit tightly inside the rebate of the frame and smoke and flame can spread through the gaps around the door leaf. As a barrier to the spread of smoke, flexible seals should be fixed between door leafs and frames and as a barrier to the spread of fire, heat activated (intumescent) seals should be fitted.

Smoke control door assemblies (FDS) that serve only as a barrier to the spread of smoke without any requirement for fire resistance, such as fire doors along an escape route, may be fitted in rebated frames or hung to open both ways. To provide an effective seal against the spread of smoke through gaps around these doors, flexible seals should be fitted.

Smoke control door assemblies that serve as a barrier to the spread of smoke and fire, such as doors leading to a protected escape route, should be hung in rebated frames and tested for a minimum integrity of 30 minutes against the spread of fire, and should be fitted with heat activated (intumescent) seals and flexible edge seals against the likelihood of the door leaf deforming.

Fire door assemblies fixed in compartment walls and to enclosures to special risk areas should be hung in rebated frames and tested for integrity for not less than 30 minutes or such period as detailed in Advisory Document B to the Building Regulations, and should be fitted with the intumescent seals. The currently accepted minimum size of a softwood door frame for a fire door is 70 × 30 mm exclusive of a planted stop.

Heat activated intumescent seals

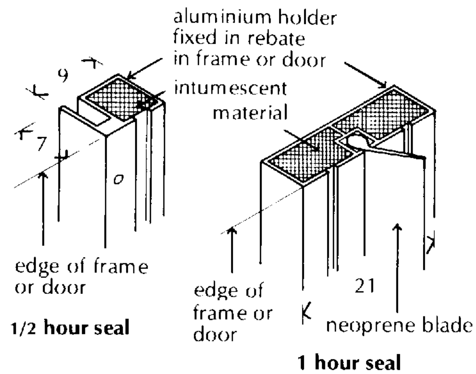


Fig. 120 Intumescent fire seal.

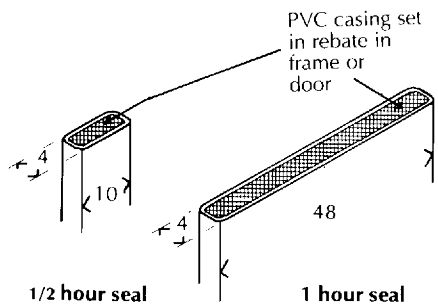


Fig. 121 Intumescent fire seal.

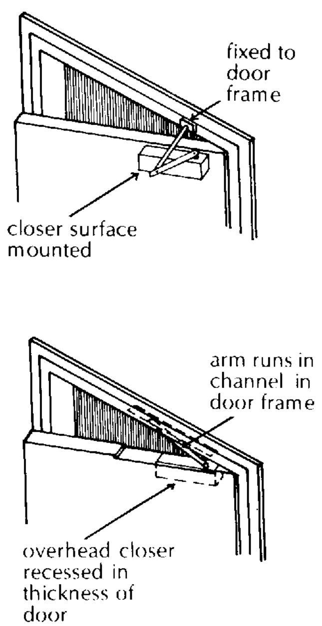


Fig. 122 Overhead door closer.

An intumescent seal is made of a material that swells by foaming and expanding at temperatures between 140°C and 300°C.

The intumescent seals illustrated in Fig. 120 consist of aluminium holders inside which the intumescent material is held. The aluminium holders are fixed in a rebate to the edges of doors or to the door frames. When the temperature rises sufficiently the intumescent material inside the holders expands out through the vertical slots in the holder and effectively seals the door in the frame as a barrier to the spread of flame.

The neoprene blade shown in the 1 hour seal acts as a seal against smoke that occurs in the early stages of a fire before the intumescent material is sufficiently hot to expand.

The intumescent seals shown in Fig. 121 comprise a PVC casing in which the intumescent material is held. The seals are set in rebates in the edges of the door or in the rebate of the frame. As the temperature rises the thermoplastic PVC casing gradually softens so that when the temperature has risen sufficiently, the intumescent material expands, ruptures the PVC casing and acts as a seal around the door.

For a fire door to be effective against smoke and the spread of fire it should, when not in use, be positively closed to the frame by some self closing device. The door closers that are used are overhead door closers or one of the floor springs illustrated in Fig. 110.

The overhead door closers illustrated in Fig. 122 consist of a hydraulically operated cylinder in a metal casing that is either screwed to the door face or set in a housing in the top of the door leaf for appearance sake. Pivoted arms, one to the housing and one attached to the door frame, act to automatically close the door to the frame, after the door has been opened.

Because these door closers are fixed to doors that are generally in frequent use they require regular maintenance if they are to serve their purpose.

The current requirement for fire doors is that complete door assemblies be tested in accordance with BS 476 and certified as meeting the recommendations of performance for integrity and noted, for example, as FD20, FD30 as satisfying the requirements for 20 and 30 minutes integrity respectively.

MATCHBOARDED DOORS

These utilitarian doors are made with a facing of tongued, grooved and V-jointed boards which are nailed to horizontal ledges, braces between ledges or to a frame. These relatively crude doors are sometimes described as 'matchboarded' doors because of the comparatively thin boards from which they are made or as 'cottage doors' for their use in the traditional country cottage.

The simple ledged doors are used for sheds and cellars and the framed doors for garages and industrial buildings where the width of the door and its use as an external door justify the more expensive construction. Appearance is not considered as an important consideration in the choice of these doors.

Ledged matchboard doors

Ledged matchboard doors are made by nailing matchboards to horizontal ledges, as illustrated in Fig. 123A. The nailing of the boards to the ledges does not strongly frame the door, which is liable to sink and lose shape. This door is used for narrow openings only.

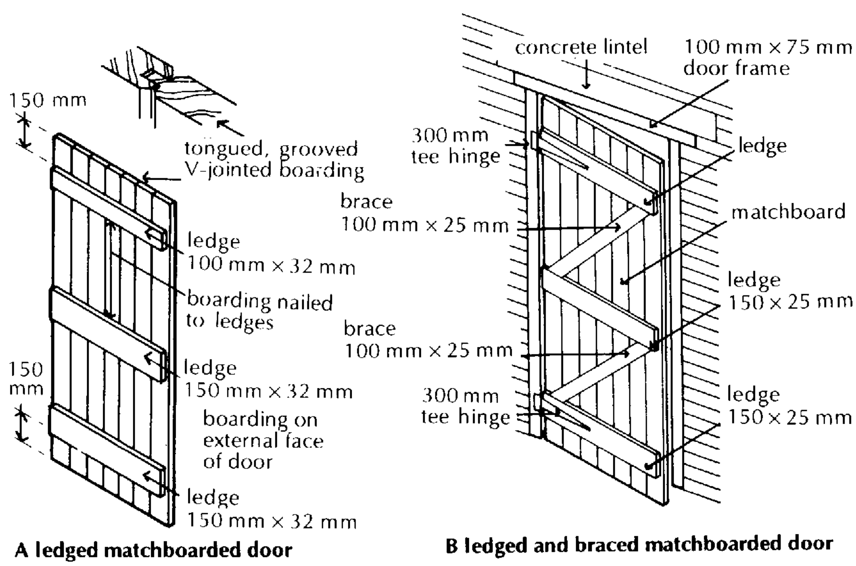


Fig. 123 A ledged matchboarded door. B ledged and braced matchboarded door.

Ledged and braced matchboarded door

Ledged and braced matchboarded doors are strengthened against sinking, with braces fixed between the rails at an angle to resist sinking on the lock edge (Fig. 123B). The matchboarding is nailed to ledges and braces.

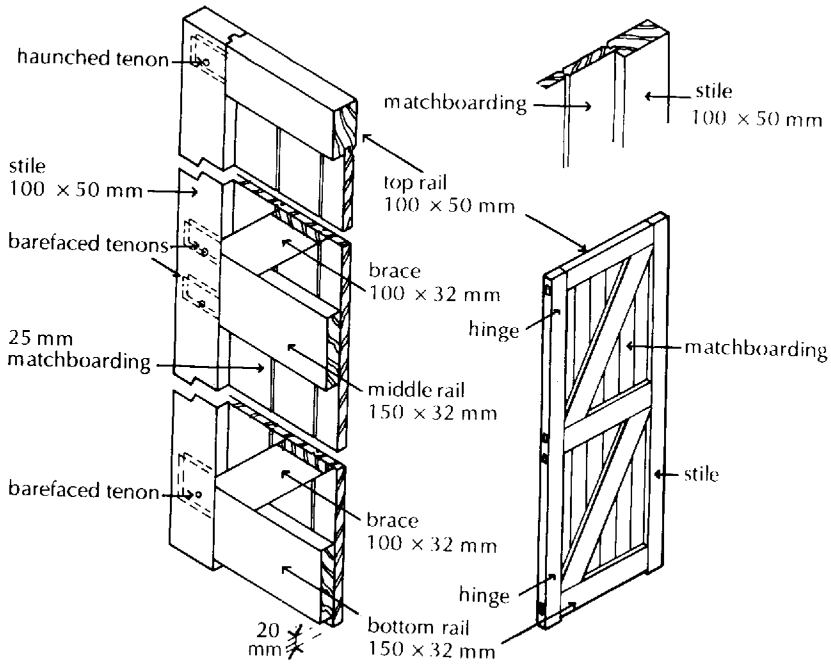


Fig. 124 Framed and braced matchboarded door.

Framed and braced matchboarded door

Framed and braced matchboarded doors are made by nailing matchboarding to a frame of stiles and rails that are framed with mortice and tenon joints with braces to strengthen the door against sinking, as illustrated in Fig. 124. The boarding runs from the underside of the top rail, to protect the end grain of the boards from rain, and is carried down over both middle and bottom rails. To allow for the boards running over them the middle and bottom rails are less thick than the stiles to which they are joined with a barefaced tenon joint (Fig. 125). This joint is used instead of the normal joint with two shoulders, so that the tenon is not too thin. These doors are used for large openings to garages, factories and for entrance gates.

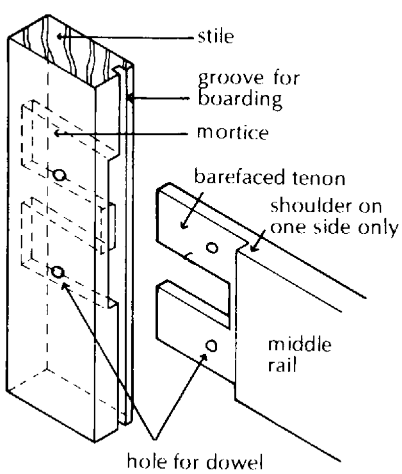


Fig. 125 Barefaced tenon.

DOOR FRAMES AND LININGS

A door frame is made of timbers of sufficient cross section to support the weight of a door and to serve as a surround to the door into which it closes. The majority of door frames are rebated to serve as a stop for one way swing doors. The door frame is secured in the wall or partition opening to support external doors and heavier internal doors.

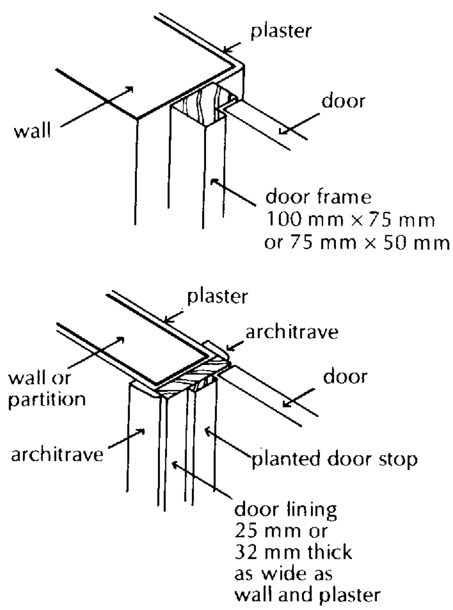


Fig. 126 Door frame and door lining.

Door linings are thin sections of wood or metal that are fixed securely in a doorway or opening as a lining around the reveal (thickness) of the wall or partition.

A door lining which may not be substantial enough by itself to support the weight of a door will depend on its fixing to the wall or partition for support. Figure 126 illustrates the difference between a door frame and a lining.

The choice of a door frame or lining is to an extent a matter of appearance and convenience in fixing and methods of masking the junction between plaster finishes and frames and linings.

Door linings are generally used for internal doors in thin partitions where the width of the lining is the same as the thickness of the partition and wall plaster both sides. In this way the junction of the plaster and lining can be masked by an architrave and the door opening emphasised by the lining and architrave.

Door frames, commonly used for external doors and heavier internal doors, may not be as wide as the thickness of the wall in which they are fixed as illustrated in Fig. 126. It is necessary, therefore, to run plaster finishes around the angle of the wall, into the reveal and up to the door frame. In time the junction between the plaster and frame will open up as an unsightly crack. A wood bead fixed to hide this potential crack, may itself show cracks in time. More substantial linings, or combinations of frames and linings, are used for panelled doors in walls that are one brick or more thick to combine the strength of a frame with the appearance of a lining.

Door frames are usually built-in as the brick or block partition is raised for the convenience of building around the frame. A disadvantage of this is that the frame may suffer damage during subsequent operations. Door linings which are fixed in position after the roof of the building is on, will suffer less damage than built-in frames.

Wood door frame

Wood door frames are assembled from three members for internal doors and four to most external doors. The members of the frame are two side posts, a head and a sill for external doors where Regulations do not prohibit an upstanding sill which would obstruct access for the disabled in wheelchairs.

The members of the frame are usually cut with a rebate into which the door closes or a wood stop may be planted on a plain faced timber, as a door stop.

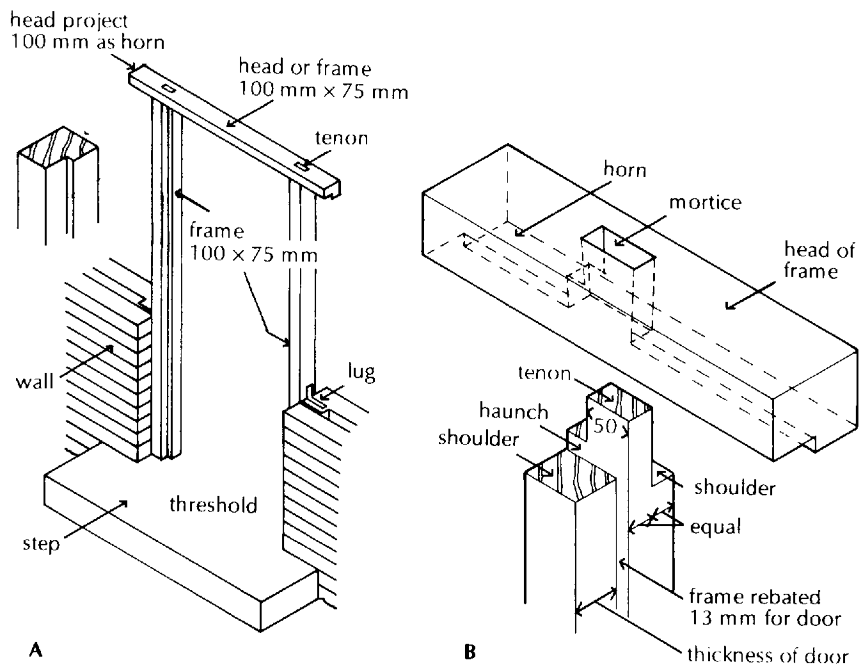


Fig. 127 A Door frame. B Mortice and tenon joint.

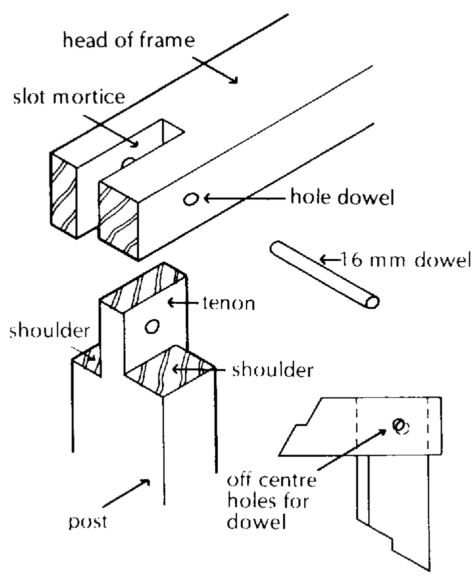


Fig. 128 Slot mortice and tenon.

Because the frame is made to carry the weight of the door by itself, the members are joined with mortice and tenon joints to provide a rigid joint that will maintain the frame true square as illustrated in Fig. 127A. The haunched mortice and tenon joints between the posts and head of the door frame are formed as illustrated in Fig. 127A and in detail in Fig. 127B. The joint is formed by projecting the head of the frame some 100 mm each side of the posts as horns. These horns also provide a means of securing the frame by building them into surrounding brickwork where the frame is set at least $\frac{1}{2}$ B back from the external face of the wall.

Where it is not convenient to build in horns when the door frame is fixed closed to the external face of a wall, the head is finished flush with the back of the posts. As it is not possible to form an enclosing mortice a slot mortice and tenon joint is formed as illustrated in Fig. 128. The tenon is secured in the slot mortice with a 16 mm dowel driven through the mortice and tenon.

To secure the foot of the posts of a door frame without a threshold it is usual to fix a steel dowel (rod) 12 mm diameter and 50 mm long, half into the foot of the frame and half into the concrete threshold.

Door frames to external walls are usually built-in. To maintain the

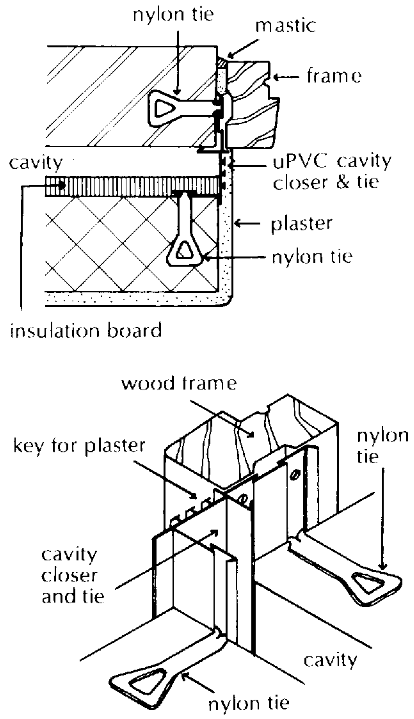


Fig. 129 uPVC cavity closer and tie.

frame in position against the frequent use of a front door and for reasons of security against forced entry, the frame is secured with building in lugs that are built into horizontal courses of brickwork or blockwork as the walls are raised.

The usual form of building in lug used to secure wood window and door frames in solid walls is 'L' shaped, formed from steel and galvanised. One tail of the lug is screwed to the back of the frame and the other is bedded in a horizontal brick or block course. Three lugs to each post are used.

Providing these lugs, illustrated in Fig. 127A, are solidly bedded in mortar they will adequately secure the frame in position.

A uPVC cavity closer and ties, illustrated in Fig. 129, is designed to close the cavity of a wall and allow the cavity insulation to be carried up to the back of the closer, so that there is no thermal bridge around the openings and to provide secure fixing for a door frame through nylon ties. The cavity closer is nailed to the back of the frame and the nylon ties are adjusted in slots for building into horizontal brick or block courses as the frame is built-in.

Threshold

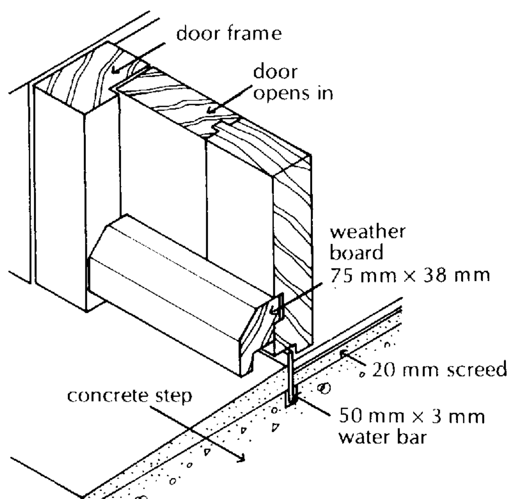


Fig. 130 Water bar and weatherboard.

The threshold of a doorway or opening is the surface at the bottom of the opening which is level for internal doors and may be level or formed as a wood sill as part of the door frame. A level threshold may be formed for ease of access for the disabled who have need of the use of a wheelchair. The considerable disadvantage of this is that there is no positive check to wind-driven rain that runs down the door face and will be blown in under the closed door.

As a barrier to wind-driven rain running in under a door, a galvanised steel weather or water bar may be set in the threshold to stick up sufficiently above the level of the threshold so that when the door is closed it makes contact with the bar as a seal against the entry of rain as illustrated in Fig. 130. To direct rain water out from the door a weatherboard of timber or metal is often fixed to the bottom of the door.

The disadvantage of the water bar is that it is of small section and not always obvious to the unwary who may trip over it.

The ground floor of many buildings, particularly houses, is usually finished above the level of the ground surface outside as a convenience in uniting the damp proof course in the walls with that under the solid floor. External doors are usually approached from outside by climbing one or more steps. It is common, therefore, to hang

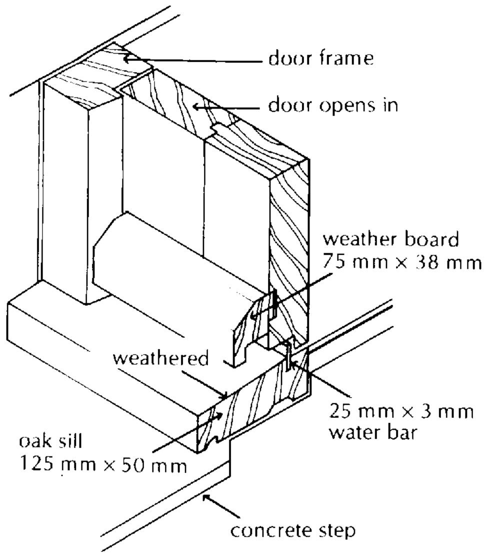


Fig. 131 Oak sill.

external doors to open inwards to avoid the danger of people hurrying out of externally opening doors and tumbling down the outside steps.

The disadvantage of an inward opening external door is that the rebate in the door frame, into which the door fits when closed, does not so positively act as a check to wind and rain as it does with an outward opening door. Wind pressure on an inward opening door may force it away from the rebate to the extent that wind and rain may penetrate.

The traditional external door frame was made up with a wood sill as part of the framing with the posts of the frame tenoned to mortices in the sill. The sill was often cut from oak for the sake of the durability of that hard wood. The oak sill, which is of a wider section than the posts, is weathered and cut with a drip on its lower edge to throw water off as illustrated in Fig. 131.

The sill may be rebated as housing for the door when closed or finished flush with the floor. A metal weather bar is set in the oak sill to stick up sufficient to fit into a rebate cut in the underside of the door as weather check. A wood weatherboard was usually fixed to the bottom of the outside of the door to throw rain out from the bottom of the door. Unless the protective paint film is well maintained over the door surface, the wood weatherboard will before long become saturated and rot. A range of aluminium sections is available for use as weatherboards.

Weatherstripping

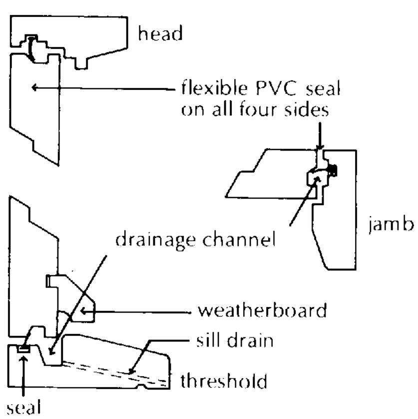


Fig. 132 Inward opening external door with weather strips.

As a check to wind-driven rain and draughts of cold outside air that penetrate clearance gaps around external doors it is practice today to fit weatherstripping around doors to limit damage caused to wood doors by rain and heat loss to cold air. The two systems of weatherstripping that are used are flexible seals fixed towards the inside face and compression seals fixed up to the outside face of doors.

Flexible seals are made from PVC or synthetic rubber in the form of a strip for housing in the frame from which a flexible blade makes contact with the edges of the door. The seal may be fitted into an aluminium channel holder which is fixed into a groove cut in the frame. The flexible seal does not make it difficult to open or close the door, but is sufficiently resilient to make positive contact with the closed door.

The members of the door frame and door illustrated in Fig. 132 are cut with rebates to form a drainage channel up to the outer

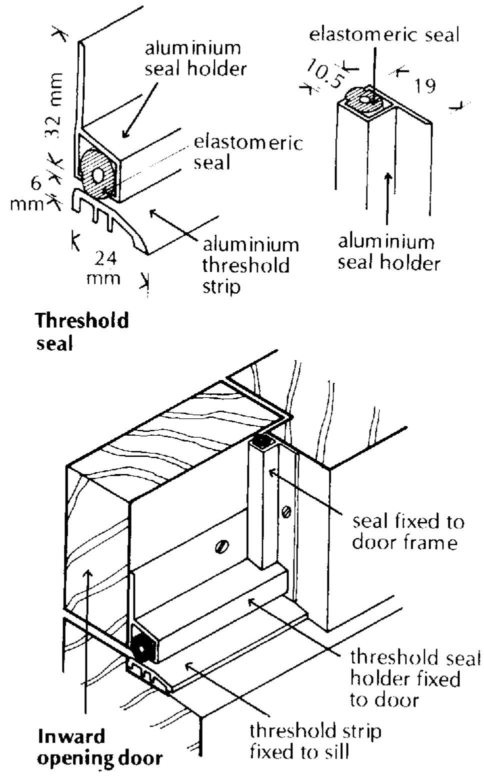


Fig. 133 Threshold and side weather seal to inward opening external door.

face of the flexible seals. This small channel serves the purpose of drainage channel and to reduce wind pressure on the flexible seal.

The synthetic rubber seals are similar to those described and illustrated for use with wood casement windows.

Compression seals consist of hollow ball section strips of synthetic rubber in an aluminium alloy holder. The holders are screwed or pinned to the head and posts of the door frame so that the elastic seal presses against the closed outside of the door as a weather seal.

The bottom edge of the door is sealed by a holder, fixed to the door, in which an elastic bulb presses on an aluminium alloy threshold strip fixed to the sill as illustrated in Fig. 133. Unlike the flexible blade weatherstripping these compression seals and their holders are visible, which may be unacceptable to some.

Both the flexible PVC blade strip and the compression seal bulb will after some years lose resilience and be less effective as seals. They should be replaced from time to time. When regular painting of doors and frame is carried out care should be taken to avoid painting over the blade seal and the compression seal as a dried, painted film will make them less effective.

As an alternative to the compression seals illustrated in Fig. 133 one of the self adhesive weatherstrips may be used.

Wood door linings

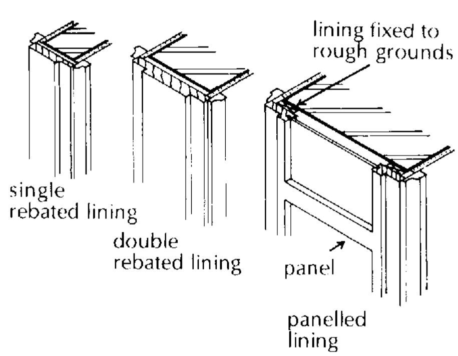


Fig. 134 Door linings.

Wood door linings (door casings) may be plain and rebated or plain with planted stops, double rebated for appearance sake or panelled as illustrated in Fig. 134.

Plain linings with either a rebate or a planted stop are used for light doors in thin partitions, double rebated linings for thicker brick or block partitions and panelled linings for heavier panelled doors in thicker walls or partitions.

Linings are fixed in position in the door opening before plastering to walls is carried out, so that the finished plaster level is flush with the edges of the lining. The linings are nailed to rough wood grounds. Rough grounds are sections of plain sawn wood that are nailed to the surrounding brick or block partition to provide a level fixing to which the lining is nailed. The purpose of this is to avoid damaging the lining by driving large nails through the lining to find a fixing in the brick or block partition.

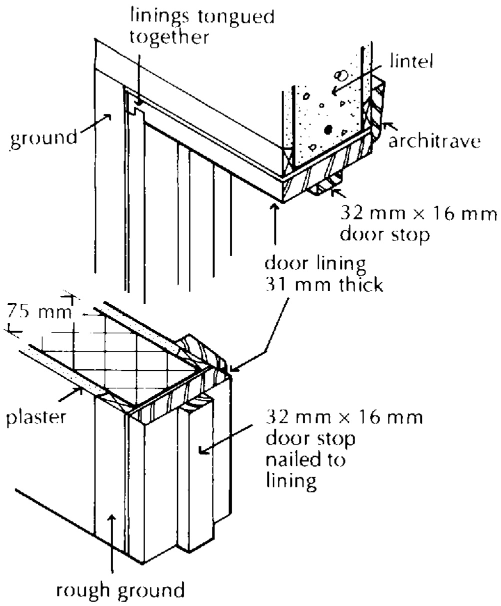


Fig. 135 Door linings.

To provide a secure fixing for all but very narrow wood architraves around doors it is practice to fix rough, wood grounds each side of the lining and as thick as the plaster as illustrated in Fig. 135.

Linings are cut to the overall thickness of partitions and the thickness of plaster both sides. Plain linings are usually cut from timber 47 or 54 mm thick for rebated linings and 31 or 38 mm thick for linings with planted stops. Planted door stops effect some small economy in wood.

Figure 135 is an illustration of a plain lining with planted stops fixed to a partition. The sides of the lining are jointed to the head with a tongued and grooved joint to secure the three sections in position.

Standard door frames and linings

Door manufacturers offer a range of standard frames and linings for standard size doors. The door frames are cut from sections of 102 × 64 mm and 89 × 64 mm rebated for doors and with sills for external doors. Door linings, or casings as they are sometimes called, are cut from sections 138 × 38, 138 × 32, 115 × 38 mm and 115 × 32 mm rebated for doors. The width of these linings which is chosen to suit common partition and plaster thicknesses may not match the overall thickness of some partitions and finishes.

Door sets

Door sets (door assemblies) are combinations of doors with door frames or linings and hardware such as hinges and furniture, prepared as a package ready for use on site. This plainly makes economic sense where many similar doors are to be used and packets of doors can be ordered and delivered instead of separately ordering doors, frames and hardware.

There is often inadequate fixing for a door frame or lining in a thin non-loadbearing partition so that the door, in use, may cause some movement in the frame or lining relative to the partition, to the extent that cracks in finishes around the frame or lining and particularly in the partition over the head of the door may appear. To provide a more secure fixing for doors in thin partitions it is often practice to use storey-height frames that can be fixed at floor and ceiling level.

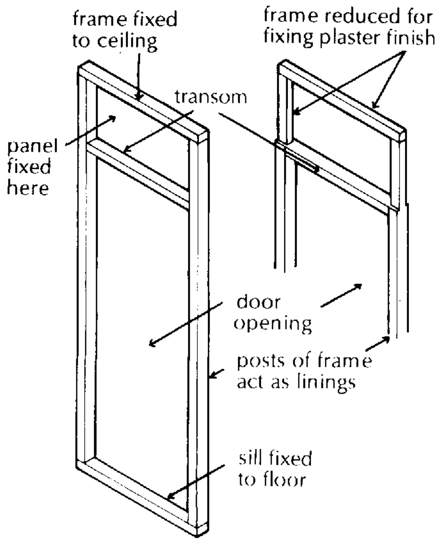
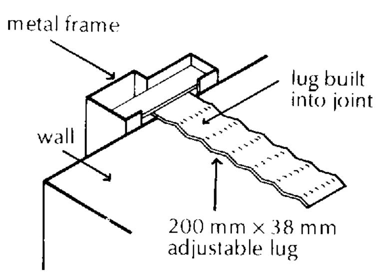


Fig. 136 Storey height door frame.



Adjustable building in lug for metal door frames

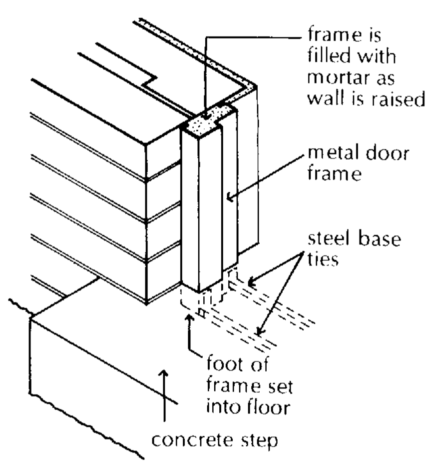


Fig. 137 Metal door frame.

These storey-height or floor-height frames are cut to line the reveal of the door opening and in that sense serve as linings, and are put together with floor-height posts, a head that can be fixed to the ceiling, a transom at the head of the door and also a sill for fixing to the floor, as illustrated in Fig. 136. The frame sections may be rebated for the door or be plain with planted stops. The frame may be of uniform width for the full height with a panel fixed in the space over the door, or the width of the frame may be reduced over the door so that finishes, such as plaster, may be run across the frame over the door.

The sill of the storey-height door frame may be fixed to the floor so that floor boards can be fixed over it or finished flush with the floor finish for carpeted finishes.

The advantage of these frames is that they provide a degree of stability to block, non-loadbearing partitions.

Metal door frames are manufactured from mild steel strip pressed into one of three standard profiles. The same profile is used for head and jambs of the frame. The three pressed steel members are welded together at angles. After manufacture the frames are hot-dip galvanised to protect the steel against corrosion. Two loose pin butt hinges are welded to one jamb of the frame and an adjustable, lock strike plate to the other. Two rubber buffers are fitted into the rebate of the jambs to which the door closes to cushion the impact of sound of the door closing. Figure 137 is an illustration of a standard metal door frame. The frames are made to suit standard door sizes. The frames are provided with steel, base ties welded across the foot of the posts of the frame to maintain the correct spacing of the posts.

Metal door frames are built-in and secured with adjustable, metal building-in lugs that are bedded in the horizontal joints of brick or blockwork, three to each side. The frames are bedded in mortar and filled with mortar.

These frames are made to suit standard external and internal wood doors. When used for internal doors in non-loadbearing partitions a profile of metal frame is selected that is wider than the combined thickness of the partition and plaster both sides. In this way the metal frame serves as a door lining that projects some 16 mm each side of the finished plaster. Plaster is run up to and under the lipped edges of the frame to avoid the necessity for an architrave to mask the junction between plaster and frame.

METAL DOORS

Glazed steel doors

Glazed steel doors are fabricated from the hot rolled W20 steel sections used for windows. The sections are assembled with welded corner joints. The doors and frames, which are hot dip galvanised after manufacture, may be finished with an organic powder coating. Single glass is either putty or clip-on aluminium bead glazed. Double glazing is bedded in mastic tape and secured with clip-on aluminium beads. Glazed steel doors, which have largely been superseded by aluminium doors, are mainly used for replacement work.

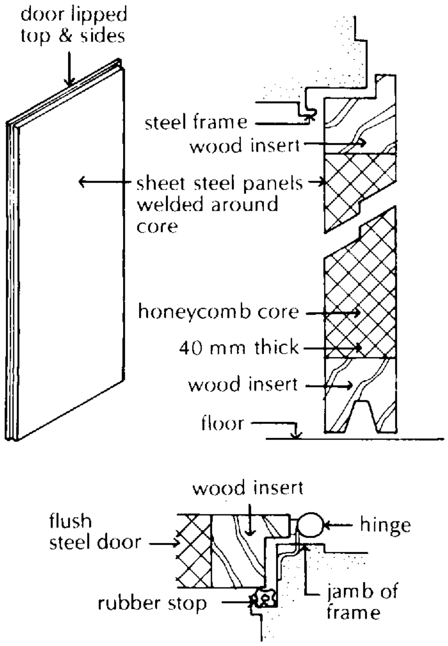


Fig. 138 Flush steel door.

Flush steel doors are manufactured from sheet steel which is pressed to shape, often with lipped edges, hot dip galvanised and either seam welded or joined with plastic, thermal break seals around a fibre board, chip board or foamed insulation core, generally with edge, wood inserts as framing and to facilitate fixing of hardware. The sheet steel facings may be flush faced or pressed to imitate wood panelling or with glazed panels. The exposed faces of the doors may be finished ready for painting or with a stoved on organic powder or liquid coating.

These comparatively expensive, robust, heavy duty doors are generally used in this country in commercial and industrial buildings and as fire doors. In North America and parts of Northern Europe they are extensively used in all types of buildings. These doors are generally supplied as door sets complete with frame, door leaf and hardware fittings. Figure 138 is an illustration of a flush faced steel door.

ALUMINIUM DOORS

An extensive range of partly-glazed and fully-glazed doors is manufactured from extruded aluminium sections. The slender sections possible with the material in framing the doors provide the maximum area of glass. These glazed doors, commonly advertised as 'patio doors', are made as both single-and multi-leaf doors to hinge, slide or slide and fold to open. Glazed doors serve as a window by virtue of the large area of glass which provides no privacy, and as doors by the facility to open them from floor level. As windows they afford little insulation against loss of heat, unless double glazed, and as doors give poor security because of the extensive use of glass. The particular use of these doors is to provide a large area of clear glass for an unobstructed view out to gardens and to give ready access from inside to outside.

Figure 139 is an illustration of an aluminium section glazed door designed to slide open. The doors are double glazed to reduce heat loss and have weatherstripping and drainage channels to exclude wind and rain.

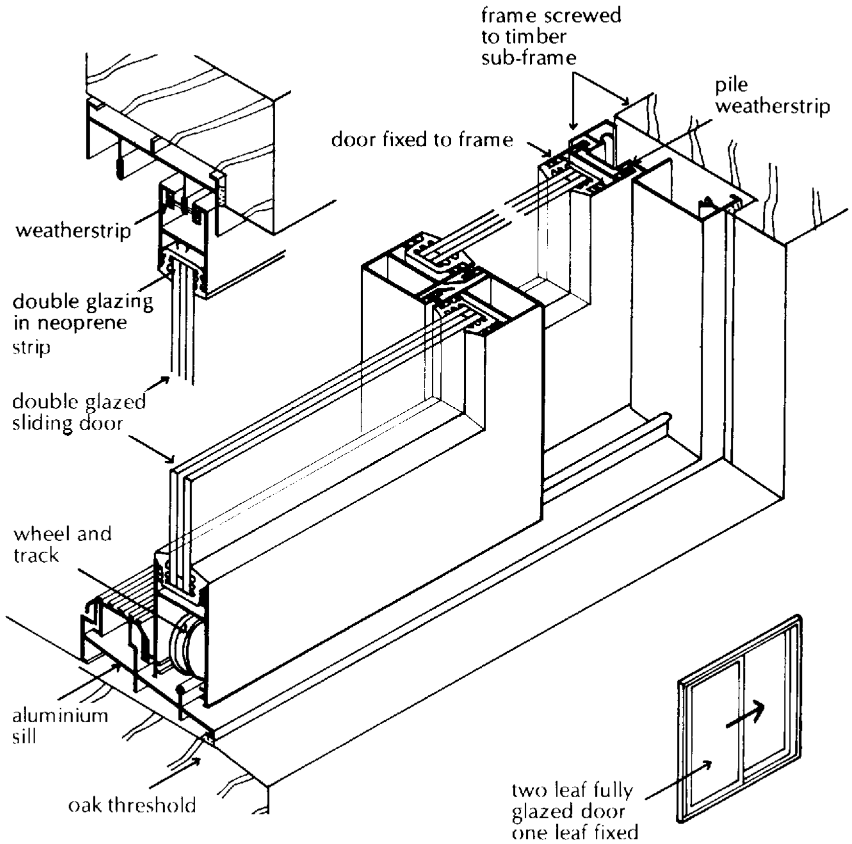


Fig. 139 Fully glazed aluminium horizontally sliding door.

A disadvantage of these doors is that there may be appreciable condensation on the inside faces of the aluminium framing. To minimise condensation on the inside faces of these double glazed doors it is practice to fabricate them as thermal break doors. The main framing sections of the doors, which are joined with corner cleats, are fixed to aluminium facings through plastic sections that act as a thermal break.

Of recent years single-leaf aluminium doors have been made to resemble traditional panelled wood doors. These, so called, residential doors are framed from extruded aluminium sections in the same way that windows and fully glazed doors are fabricated with the addition of a middle, horizontal rail to imitate the middle or lock rail of a wood door. The sections are made to take either glazed or solid panels secured with internal pop-in glazing beads. The solid panels, which are fabricated from PVC or glass fibre reinforced plastic sheets around an insulating core, may be moulded to imitate traditional wood panels.

An advantage of these doors is that they may be finished in a range of coloured powder or liquid coatings that do not require periodic painting for maintenance. These doors are sufficiently robust for use in domestic buildings and may be fabricated as thermal break construction to minimise condensation on the internal faces of the aluminium framing.

These residential, aluminium doors do not look like the traditional panelled wood doors they are made to replicate and may be a poor security risk unless the panels are reinforced with an aluminium sheet in the core and the panels are fixed with screwed or secured beads.

uPVC DOORS

Following the success of uPVC windows as replacement for wood windows, the extruders and fabricators of uPVC sections have in the last few years produced single-leaf uPVC doors for replacement or substitution of traditional panelled wood doors. These doors are fabricated from a frame of comparatively bulky, extruded uPVC hollow sections similar in size to the stiles and rails of wood framed doors. The hollow framing sections are reinforced with galvanised steel or aluminium sections in the main cell of the hollow sections that are mitred and heat fusion welded at corners. A mid rail member is fitted to match the middle or lock rail of a wood door. These door leafs are hung to extruded, hollow section uPVC frames and thresholds as illustrated in Fig. 140.

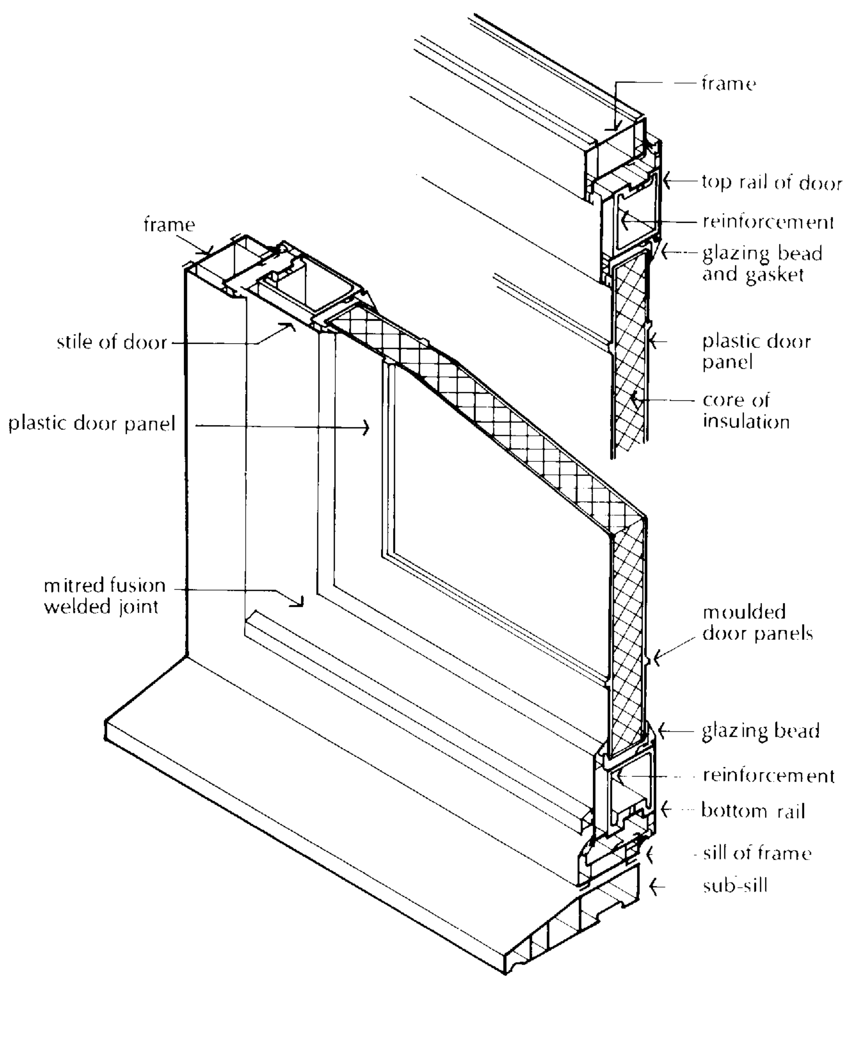


Fig. 140 uPVC door and frame.

The uPVC door leafs which are framed for glazing with single or double glazing secured with internal pop-in beads are weathered with wedge and blade gaskets. As an alternative to glazed panels a variety of plastic panels is produced from press moulded acrylic, generally moulded to imitate wood door panels either as full door height panels or as two panels fitted to a middle rail. The panels which have plain edges for fitting to the rebate and glazing beads of the hollow uPVC framing, are moulded to represent the stiles, rails and panels of wood doors. In consequence these doors do not look like the panelled wood doors they are fabricated to replicate.

The hollow panels may have a core of some insulating material and a foil or thin sheet of aluminium as a barrier to breaking and entering by fracturing the panel.

The majority of these doors are made as white or off white impact modified uPVC to minimise the considerable thermal expansion that this material suffers due to solar radiation. Coloured and wood grain finishes are also supplied.

The advantage of uPVC doors is that they require no maintenance during their useful life, other than occasional washing. The disadvantage of these doors is that they may jam shut due to thermal expansion, knocks and indentations cannot be disguised by painting and they are not as robust to heavy use as a traditional wood framed door.

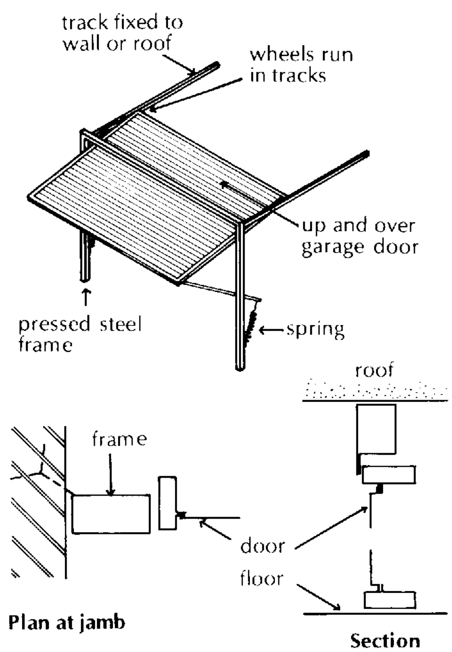


Fig. 141 Steel 'up-and-over' garage door.

Pressed metal doors are suited for use as garage doors because they are lightweight and have adequate stiffness and shape stability for a balanced 'up-and-over' opening action. The doors are manufactured from pressed steel or aluminium sheet which is profiled to give the thin sheet material some stiffness. The sheet is welded or screwed to a light frame to give the door sufficient rigidity. Steel doors are hot-dip galvanised and primed for painting or coated with PVC, and aluminium doors are anodised. Figure 141 is an illustration of a steel up-and-over garage door.

To open, the door is lifted to slide on wheels in overhead tracks under the roof of the garage. Spring loaded side stays attached by pivots to the base of the door serve to steady the upward and downward movement of the door leaf and serve to balance the movement so that it may easily be raised and lowered by hand. The advantage of the overhead action is that the door does not obtrude on the outside.

HARDWARE FOR DOORS

Hardware is the general term for the hinges, locks, bolts, latches and handles for a door. Ironmongery was a term used when most of these were made of iron or steel. The term 'door furniture' is sometimes used to describe locks, handles and levers for doors.

Pressed steel butt hinges are the cheapest and most commonly used

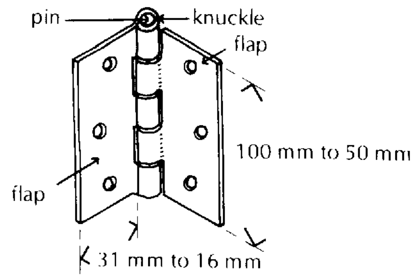


Fig. 142 Pressed steel butt hinges.

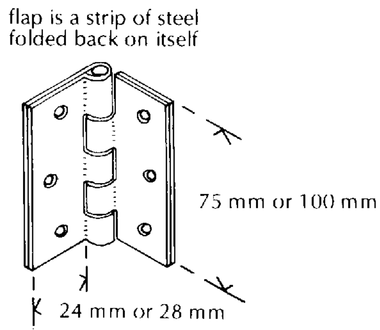


Fig. 143 Double pressed heavy steel butt hinge.

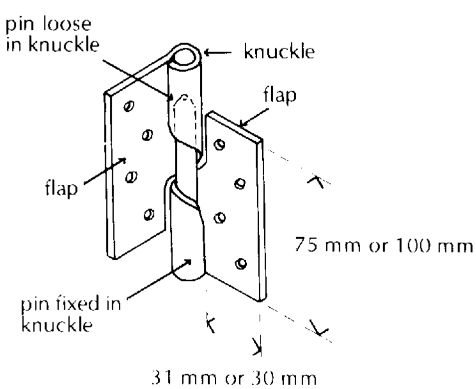


Fig. 144 Steel skew butt hinge (rising butt hinge).

hinges. They are made from steel strip which is cut and pressed around a pin, as illustrated in Fig. 142. They are used for hanging doors, casements and ventlights. The pin of the standard butt hinge is fixed inside the knuckle.

These hinges are also made as loose pin butt hinges, with the flap, that is screwed to the edge of the door, loose inside the knuckle so that the doors can be taken off by lifting. This avoids the necessity of unscrewing one flap of each hinge to take the door off for adjustment and for repair. These hinges are usually galvanised as protection against corrosion.

The two flaps of the hinge are screwed in position into shallow sinkings cut in the wood frame and edge of the door respectively so that they are flush with the wood faces and with the knuckle of the hinge protruding from the face of the door.

Double pressed, heavy, steel butt hinges are made of two strips of steel each folded back on itself as a flap and pressed and cut to form the knuckle around the pin as illustrated in Fig. 143. Because of the double thickness of steel strip from which they are made, these hinges serve as heavy duty to support larger, thicker doors.

The traditional hinges for panelled doors were made of cast iron. The comparatively thick section of the cast iron butts and knuckle, folded around a pin, was strong enough to carry the weight of the heaviest panelled door. An advantage of the cast iron from which these hinges are made is that it does not progressively and destructively rust as does mild steel and a disadvantage that the metal is brittle and liable to crack.

These comparatively expensive hinges are less used today other than for external doors.

The bearing surfaces of the knuckle of both flaps of the rising butt hinge are cut on the skew so that as the hinge opens one flap rises, as illustrated in Fig. 144. Because of the action of the hinge, as it opens, these hinges are generally described as 'rising butt hinges'.

These hinges are used for hanging doors so that as the door opens it rises over and so clears such floor coverings as fitted carpets to reduce wear.

The action of the skew butt will tend to make the weight of all but the lightest doors, self closing.

Steel tee hinges comprise a rectangular steel flap and a long tail or hinge which are pressed around a pin as knuckles. The form of the hinge gives it its name.

These hinges are made for use with matchboarded doors and garage and other wide doors where the length of the long tail of the

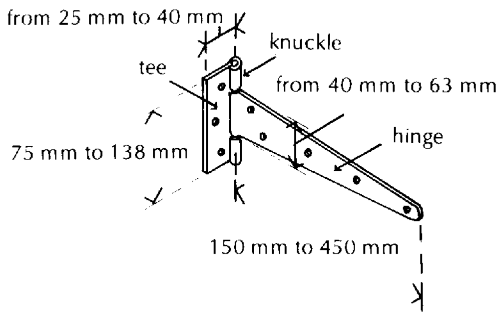


Fig. 145 Steel tee hinge.

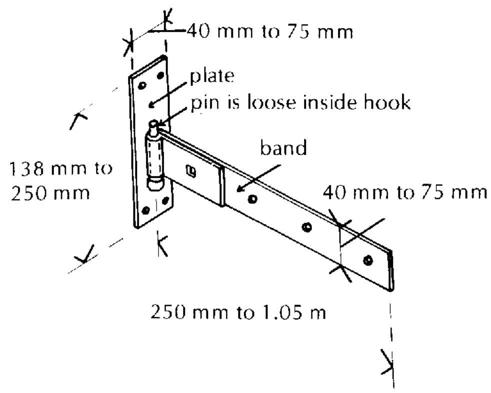


Fig. 146 Hook and band hinge.

hinge will give support across the face of the door rather than at the edge. They are pressed from mild steel strip and either galvanised or painted ready for fixing.

This hinge, illustrated in Fig. 145, is fixed in a housing in the wood door frame and to the face of the door. They should be protected with a sound paint film to prevent destructive rusting of the mild steel from which they are made.

Hook and band hinges are made of more substantial thickness of steel than tee hinges to support heavy wood doors such as those to garages and workshops. The plate has a pin welded to it, around which the knuckle of the band fits as illustrated in Fig. 146. The band is reinforced with a second plate of steel at the knuckle end. As protection against rusting the hinge is galvanised after manufacture.

To provide secure support for the doors the band is holed towards its knuckle end for a coach bolt that is fitted to a hole in the stile of the door and bolted in place to provide solid support. For convenience in taking doors off for easing (trimming to fit) the hinge fits to a loose pin on the plate.

The plate is screwed to a housing in the door frame and the band bolted and screwed to the face of the door. These hinges should be protected against corrosion with a sound paint film.

Latches and locks

The word latch is used to describe any wood or metal device that is attached to a door or window to keep it closed. The latch consists of a plain bar of wood or metal which is attached to a door or gate and is pivoted so that it can be raised by hand above a hook or keep attached to the door or window frame. These simple, crude devices serve the purpose of keeping the door or window in the closed position. They do not lock the door.

A lock is any device of wood or metal which is attached to a door or window to keep it closed by the operation of a bolt that moves horizontally into a striking plate or staple fixed to the door or window frame. Most locks are made of steel or brass and combine the operation of keeping doors and windows closed with a latch bolt operated by a handle or lever and keeping doors and windows securely shut by the operation of a loose key to move a lock bolt.

Mortice lock

The mechanism most used today for doors is the mortice lock, so called because the metal case containing the operating parts is set into a mortice cut in the door. Locks for external doors and internal doors, where security is a consideration, consist of a latch bolt and a lock

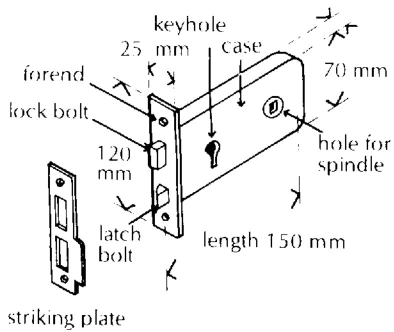


Fig. 147 Horizontal two bolt mortice lock.

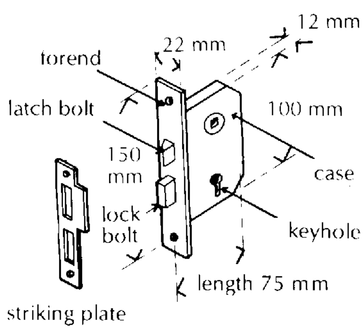


Fig. 148 Upright two bolt mortice lock.

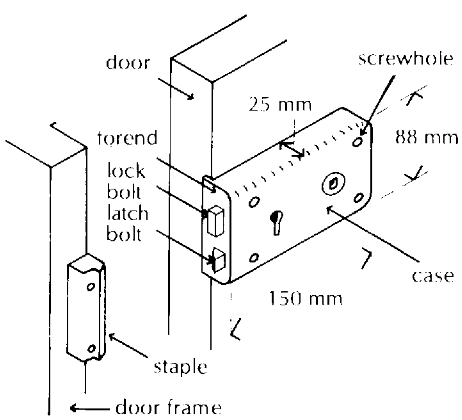


Fig. 149 Horizontal two bolt rim lock.

bolt. For internal doors in continuous use the locks contain a single latch bolt to keep the door closed.

A mortice lock for an external door is set inside a mortice cut in the stile and middle rail of the door. The horizontal, two bolt mortice lock, illustrated in Fig. 147, consists of a case, a forend and a striking plate. The case fits into a mortice in the door through which holes have been drilled for a loose key and for the spindle for knobs or handles. The lock may be made with a forend plate that is screwed into position flush with the edge of the door or finished with a forend and cover plate of brass for appearance sake.

A striking plate is fixed over mortices cut in the door frame to house the two bolts. This plate is termed a striking plate, as it serves the purpose of directing the shaped end of the latch bolt into the plate as the door is shut.

For flush doors and those without a middle rail an upright two bolt mortice lock is used. The lock, illustrated in Fig. 148, is designed specifically for this use.

Two bolt mortice locks are supplied with two loose keys to operate the lock bolt. Knobs, lever handles and a spindle are supplied separately from the locks to which they are fitted, as what is sometimes described as 'door furniture'.

Single bolt mortice locks which are supplied for internal doors comprise a case, forend and striking plate with one latch bolt which is operated by knobs or lever handles and a spindle. As they do not lock the door, these devices should properly be called latches.

Light duty internal doors which are often too thin to accommodate a mortice lock may be secured with a rim lock. These locks are designed for fixing to the face of doors. The case and the forend are screwed to the face of the door as illustrated in Fig. 149. The latch bolt and lock bolt fit into a metal staple fixed to the face of the door frame with the staple shaped to guide the latch bolt into position as the door is closed. Rim locks may be single bolt as latches or two bolt for security.

Because of their somewhat clumsy appearance these locks are not much used. As they are usually fixed to comparatively flimsy doors which themselves offer poor security, there does not seem too much sense in using a two bolt rim lock other than for the sense rather than the reality of security.

Mortice dead lock

A mortice dead lock consists of a single bolt which is operated by a loose key. There is no latch bolt. It is a dead lock in the sense that once the bolt is shot, moved into the closed position, and the key removed it is dead to being operated. These locks are used in conjunction with and separate from a cylinder night latch for security.

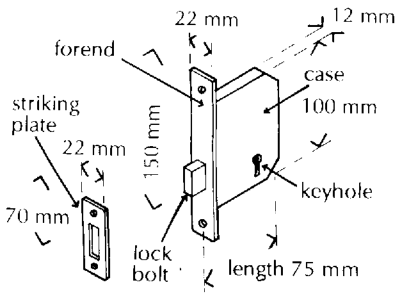


Fig. 150 Mortice dead lock.

The upright case is housed in a mortice cut in the stile of the door and screwed through the forend to the edge of the door. The lock bolt is shot, closed, into a lock plate screwed over a mortice cut in the door frame. Figure 150 is an illustration of a typical dead lock.

The security of this locking device depends to an extent on the number of so called levers that are operated by the key. The greater the number of levers the greater the security. This type of lock may be used for both wood doors and wood casement windows where the stile of the casement is wide enough to house the lock case.

Cylinder rim night latch (springlatch)

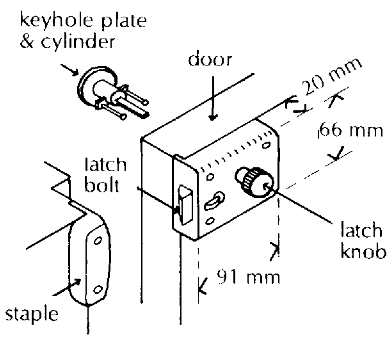


Fig. 151 Cylinder rim night latch.

A cylinder night latch is designed to act as a latch from inside and a lock from outside for convenience in use on front doors. It is made as a rim latch for fixing to the inside face of doors (Fig. 151). There is one bolt, shaped as a latch for convenience in closing, which is opened by a knob or lever from the inside. For security the latch bolt can only be opened with a loose key from outside. This type of latch offers poor security as it is fairly easy to push back the latch from outside by means of a piece of thin plastic or metal inserted between the door and frame.

A more secure type of night latch is designed as a mortice lock which is opened as a latch from inside by means of a lever and from outside by a loose key. The lock has a double throw action which, by two turns of the key from outside, locks the latch in position so that it cannot be pushed back from outside.

As it is the most convenient means of keeping external front doors closed by use of a latch bolt and offers some small security through its operation of opening from outside by a loose key, this lock is much favoured. It should be used in conjunction with a mortice lock to entrance doors to houses and flats.

Rack bolt

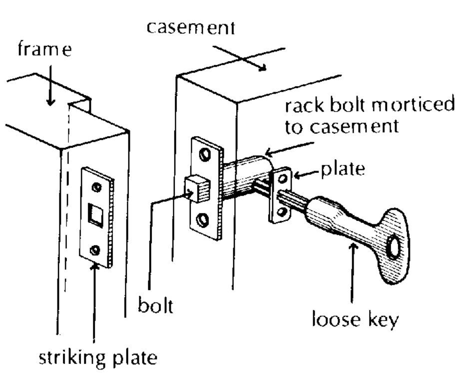


Fig. 152 Rack bolt for security for wood windows and doors.

A rack bolt is a single locking device used for locking wood doors and casement windows. It consists of a cylindrical case and bolt which is fitted into a mortice cut in the stile of doors and casements of windows as illustrated in Fig. 152. The bolt is operated by a loose key from inside the door or window.

The bolt is fitted to a mortice in the door or window and the forend screwed to a shallow housing in the door or window edge. A striking plate is fixed over a mortice in the frame and screwed in position in a shallow housing.

Two of these rack bolts fitted top and bottom to doors and casements or one to small casements serve as an economical and very effective means of locking shut.

3: Stairs

For access between floors and different levels in buildings a ladder, stair or ramp is used.

Ladders

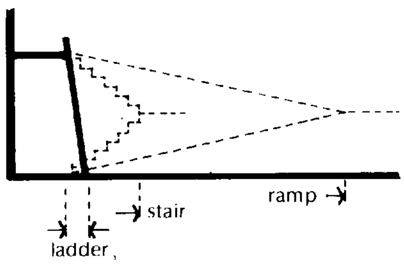


Fig. 153 Ladder.

A ladder is made as a series of narrow horizontal steps (rungs), fixed between two uprights of wood or metal, on which a person usually ascends (climbs up) or descends (climbs down) facing the ladder. A ladder may be fixed in an upright, vertical position or more usually at a shallow slope to the vertical for ease of use. Because a ladder is fixed near vertical it occupies the least floor area of any of the three means of access between floors as illustrated in Fig. 153.

Because it is fixed near vertical it is necessary to hold on to a ladder for safety, which makes it unsuitable for the very young, elderly and handicapped and as a means of escape in case of fire.

Approved Document K to the Building Regulations recommends that a ladder should only be used for access to a loft conversion of one room, where there is not enough space for a stair, and that the ladder be fixed in position and fitted with handrails both sides.

Stepladders

A stepladder consists of a series of comparatively narrow, flat, horizontal steps, fixed between two vertical uprights, which provide a more comfortable and secure support for the foot than the slim, usually round rungs of a ladder.

Stairs

A stair, or stairway, is the name given to a set of steps formed or constructed to make it possible to pass to another level on foot by putting one foot after the other on alternate steps to climb up or down the stair.

A stair may be formed as a series of steps rising in one direction between floors as a straight flight of steps. More usually a stair is formed as two or more straight flights of steps arranged to make a quarter or half turn at intermediate landings between floors to limit the number of steps in each flight for safety in use.

Because of the slope of the stair and the need to limit the number of steps in each flight a typical half turn stair occupies a considerable space in small houses as illustrated in Fig. 154.

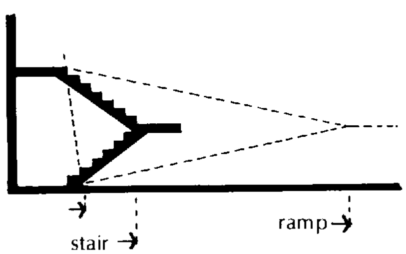


Fig. 154 Half turn stair.

Ramps

A ramp is a surface, sloping uniformly as an inclined plane up and down which a person may pass on foot between levels. A ramp is formed or constructed at a slope of at least 1 in 20 (1 m rise vertically in 20 m horizontally). Because of the comparatively shallow slope of a

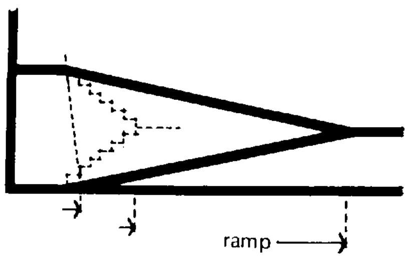


Fig. 155 Ramp.

ramp it occupies a considerable area as illustrated in Fig. 155, and is best suited to long low buildings as an adjunct.

A stair is the conventional means of access between floors in buildings. It should be constructed to provide ready, easy, comfortable and safe access up and down with steps that are neither laborious nor difficult to climb, within a compact area, so as not to take up excessive floor space.

The minimum dimensions for stairways are set out in Approved Document K giving practical guidance to meeting the requirements of the Building Regulations.

FUNCTIONAL REQUIREMENTS

The functional requirements of a stair are:

Strength and stability
Safety in use
Fire safety

Strength and stability

A stair and its associated landings serves much the same function as a floor in the support of the occupants of a building, with the stepped inclined plane of flights serving as support for movement between floors. The requirements for strength and stability in supporting dead and imposed loads for floors apply equally to stairs.

Safety in use

The practical guidance in Approved Document K to the Building Regulations is concerned with the safety of users in determining the rise, going and headroom of stairs and the dimensions of handrails and guarding.

Fire safety

Stairs are the principal means of escape to the outside in case of fires in buildings. A stair should be constructed of materials that are capable of maintaining strength and stability for a period of time sufficient for those in a building to escape to the outside. The size of the steps and the width of the stair should be adequate for the safe escape of those in the building.

Flight

The word flight describes an uninterrupted series of steps between floors or between floor and landing, or between landing and landing. A flight should have no fewer than three and no more than 16 risers in it otherwise it might be dangerous, particularly for the young or elderly. The rise and going of each step in one flight and in flights and landings between floors should be equal. Variations in the rise of steps will interrupt the rhythm of going up or down, may trip people and be dangerous. The usual ubobstructed width of a flight is from 800 mm for houses to 1000 mm for other buildings.

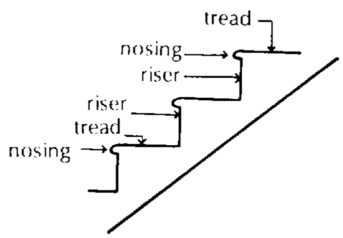


Fig. 156 Tread, riser and nosing of steps.

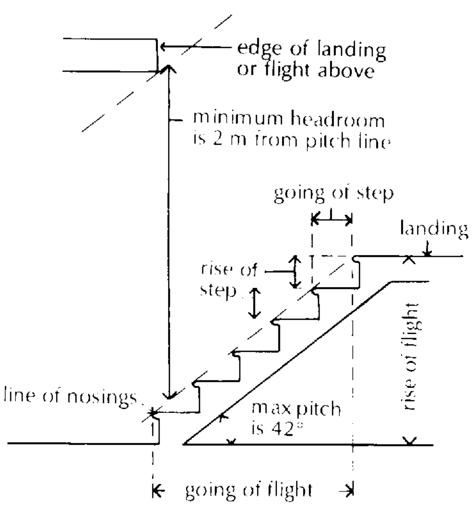


Fig. 157 Rise, going and headroom for stairs.

The steps of a stair may be constructed as a series of horizontal open treads with a space between the treads or as enclosed steps with a vertical face between the treads, called a riser.

The horizontal surface of a step is described as the tread and the vertical or near vertical face as the riser. A stair which is constructed with horizontal treads with a space between them is often described as an open riser stair.

From 25 October 1999 reference should be made to Approved Document to Part M for stair dimensions for access for disabled people.

With enclosed steps the treads usually project beyond the face of the riser as a nosing to provide as wide a surface of tread as practicable. Figure 156 illustrates the use of the terms tread, riser and nosing.

The word rise describes the distance measured vertically from the surface of one tread to the surface of the next or the distance from the bottom to the top of a flight. The word going describes the distance, measured horizontally, from the face of the nosing of one riser to the face of the nosing of the next riser, as shown in Fig. 157. The dimensions of the rise and going of steps determine whether a stair is steep or shallow.

In Approved Document K to the Building Regulations the recommended rise and going for stairs is:

Private stair for one dwelling.

> Any rise between 155 mm and 220 mm maximum used with any going between 245 mm and 260 mm or
>
> Any rise between 165 mm and 200 mm used with any going between 223 and 300 mm

Institutional and assembly stair serving a building where a substantial number of people are gathered.

> Any rise between 135 mm and 180 mm maximum used with any going between 280 mm minimum and 340 mm.

Other stairs in all other buildings.

> Any rise between 150 mm and 190 mm maximum used with any going between 250 mm minimum and 320 mm.

The steeper stair is accepted for houses because the occupants are familiar with the stair and a shallow stair would occupy more area on plan and thus reduce the available living area. The

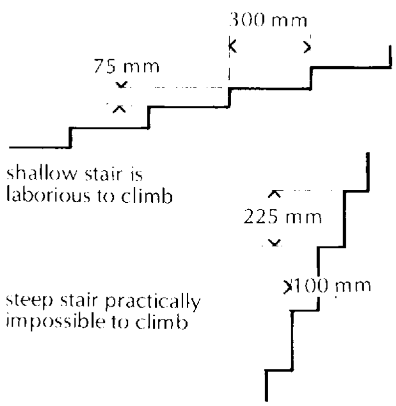


Fig. 158

shallower a stair the more risers are required for a given height and therefore the more treads and greater plan area occupied by the stair. The shallow stair recommended for public buildings is designed to minimise danger to the public escaping via the stairs during emergency.

Where a stair is appreciably more shallow or steep than those recommended in Approved Document K as illustrated in Fig. 158, it would be laborious or practically impossible to climb.

The inclination of a stair can be described either by the rise and going of the steps or as the pitch of the stair, which is the angle of inclination of the stair to the horizontal, as illustrated in Fig. 157. Stairs are pitched at not more than 42° for stairs to single dwellings and not more than 38° for common stairs.

Head room

For people and for moving goods and furniture a minimum head room of 2 m, measured vertically, is recommended between the pitch line of the stair and the underside of the stairs, landings, and floors above the stair as illustrated in Fig. 157.

Before standards were set for the rise and going of steps it was practice to determine the pitch of a domestic stair from the simple formula: twice rise plus going equals some notional figure, between 550 and 700 mm, where an assumption of some convenient rise was made.

To set out a stair it is necessary to select a suitable rise and adjust it, if necessary, to the height from floor to floor so that the rise of each step is the same, floor to floor, and then either select a suitable going or use the formal $2R + G =$ between 550 and 700 mm to determine the going.

The three basic ways in which stairs with parallel treads are planned are illustrated in Fig. 159. These are:

A straight flight stair
A quarter turn stair
A half turn stair

TYPES OF STAIR

Straight flight stair

A straight flight stair, illustrated in Fig. 159, rises from floor to floor in one direction with or without an intermediate landing, hence the name straight flight. A straight flight stair, sometimes called a cottage stair, was commonly used in the traditional 'two-up two-down' cottage with the stair in the centre of the plan running from front to back giving access to the two upper rooms each side of the head of the stair, with access to the two ground floor rooms from the small hall at

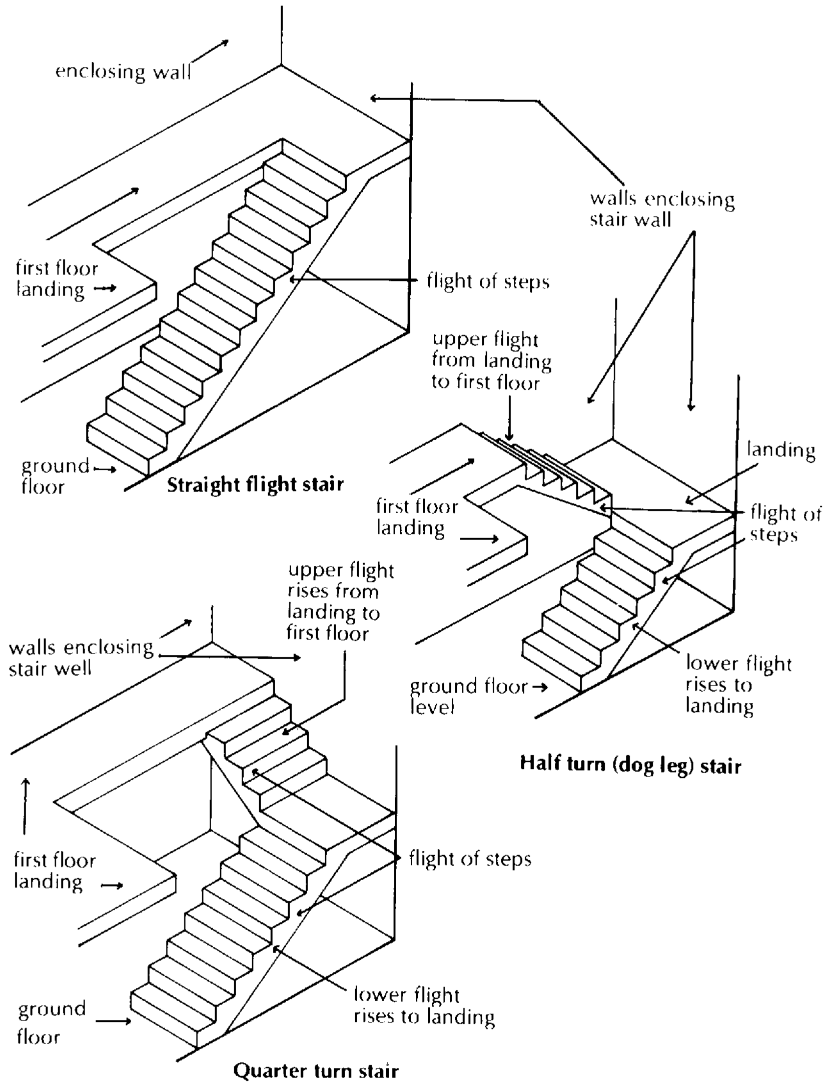


Fig. 159 Stairs.

the foot of the stair. This, the most economical use of the straight flight, does rigidly determine access to the rooms top and bottom if wasteful landings are to be avoided.

Quarter turn stair

A quarter turn stair rises to a landing between two floors, turns through 90°, then rises to the floor above, hence 'quarter turn'. This type of staircase was much used in the two floor semi-detached houses built in the first half of the twentieth century, for its great economy in compact planning. The quarter space or quarter turn landing shown in Fig. 159 was often replaced with winders for further economy in the use of space.

Half turn, dog leg stair

A half turn stair rises to a landing between floors, turns through 180°, then rises parallel to the lower flight to the floor above, hence 'half turn'. The landing is described as a half space or half turn landing. A half turn stair is often described as a 'dog leg' stair because it looks somewhat like the hind leg of a dog in section. This, the most common arrangement of stairs, has the advantage in planning that it lands at, or roughly over, the starting point of the stair which can be constructed within the confines of a vertical stair well, as a means of access to and escape from similar floors.

Stair well

Stairs are sometimes described as 'open well stairs'. The description refers to a space or well between flights. A half turn or dog leg stair can be arranged with no space between the flights or with a space or well between them and this arrangement is sometimes described as an open well stair. A quarter turn stair can also be arranged with a space or well between the flights when it is also an open well stair. As the term 'open well' does not describe the arrangement of the flights of steps in a stair, it should only be used in conjunction with the more precise description straight flight, quarter or half turn stair (e.g. half turn stair with open well).

Geometrical stairs

Geometrical stairs are constructed with treads that are tapered on plan, with the tapered treads around a centre support as a spiral (helical) stair, an open well circular stair or as an ellipse or part of an ellipse or plan as illustrated in Fig. 160.

A spiral (helical) stair with the treads tapering to a central, vertical support is the most economical way of planning a stair as it takes up little floor area. Because the treads taper sharply to the central post and the need to make sharp turns up and down this type of stair it is difficult to use and may be dangerous to the very young or elderly. Spiral stairs, which form a helix around a central column or post, are used where space is limited for access to an intermediate floor of one room. A spiral stair is illustrated in Fig. 160.

Circular or elliptical stairs are constructed around a generous open well with the treads having a shallow taper towards the well. These stairs, which are extravagant in the use of space, are used as a feature for grand means of access in large buildings. An elliptical stair is illustrated in Fig. 160.

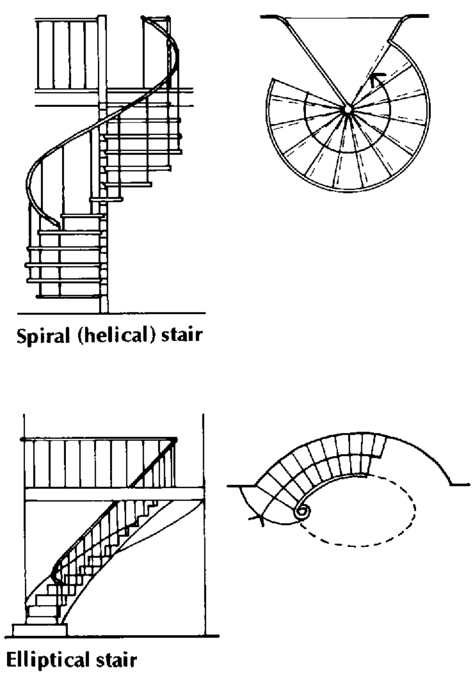


Fig. 160 Geometrical stairs.

Stairs may be constructed of timber, stone, reinforced concrete or metal, with timber and stone being the traditional materials used before the advent of steel and reinforced concrete following the industrial revolution.

TIMBER STAIRCASE

A staircase, which is a stair with treads and risers constructed from timber boards put together in the same way as a box or case, hence the term staircase, is the traditional stair for houses of two or more floors where the need for resistance to fire does not dictate the use of concrete.

Each flight of a staircase is made up (cased) in a joiner's shop as a complete flight of steps, joined to strings. Landings are constructed on site and the flight or flights are fixed in position between landings and floors. The members of the staircase flight are string (or stringers), treads and risers. The treads and risers are joined to form the steps of the flight and are housed in, or fixed to, strings whose purpose is to support them. Because the members of the flight are put together like a box, thin boards can be used and yet be strong enough to carry the loads normal to stairs. The members of the flight are usually cut from timbers of the following sizes: treads 32 or 38 mm, risers 19 or 25 mm and strings 38 or 44 mm.

Figure 161 is an illustration of a flight of a staircase with some of the treads and risers taken away to show the housings in the string into which they fit and the construction of a landing.

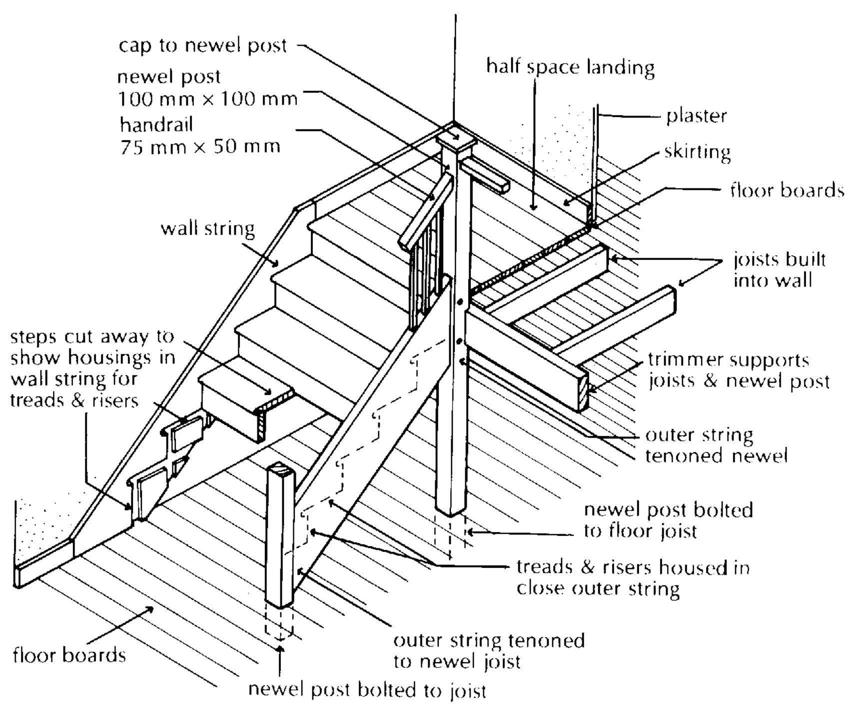


Fig. 161 Lower flight of half turn staircase.

Joining risers to treads

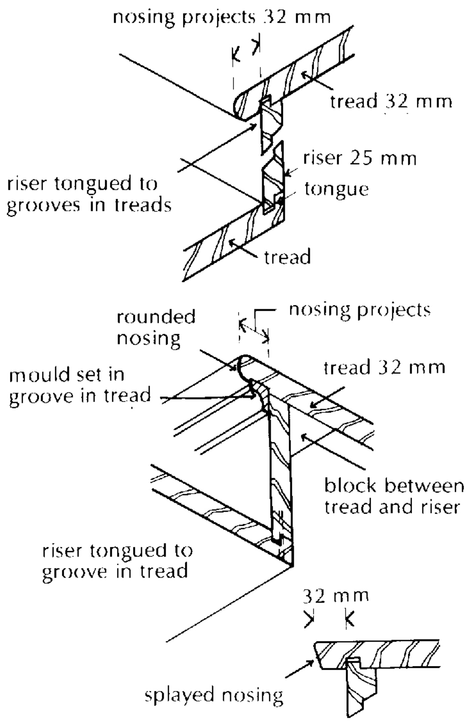


Fig. 162 Method of jointing risers to treads

The usual method of joining risers to treads is to cut tongues on the edges of the risers and fit them to grooves cut in the treads, as illustrated in Fig. 162. Another method is to butt the top of the riser under the tread with the joint between the two, which would otherwise be visible, masked by a moulded bead housed in the tread, as illustrated in Fig. 162. The tread of the stair tends to bend under the weight of people using it. When a tread bends, the tongue on the bottom of the riser comes out of the groove in the tread and the staircase 'creaks'. To prevent this it is common practice to secure the treads to the risers with screws (Fig. 162).

The nosing on treads usually projects 32 mm, or the thickness of the tread, from the face of the riser below. A greater projection than this would increase the likelihood of the nosing splitting away from the tread and a smaller projection would reduce the width of the tread. The nosing is rounded for appearance. Figure 162 illustrates the more usual finishes to nosings.

Strings (stringers) are cut from boards 38 or 44 mm thick and of sufficient width to contain and support the treads and risers of a flight of steps. Staircases are usually enclosed in a stair well. The stair well is formed by an external wall or walls and partitions, to which the flights and landings are fixed. The string of a flight of steps which is fixed against a wall or partition is the wall string and the other string the outer string, unless it is also fixed to a wall or partition when it is also a wall string (this will occur with a straight flight between walls).

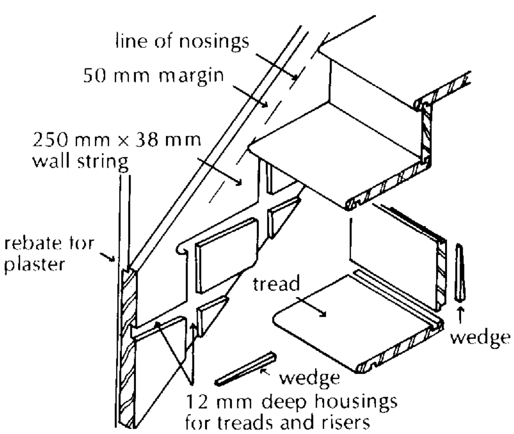


Fig. 163 Housing treads and risers in close string.

A string which encloses the treads and risers it supports is termed a close or closed string. It is made wide enough to enclose the treads and risers and its top edge projects some 50 or 63 mm above the line of the nosings of treads. The width of the string above the line of nosings is described as the margin. Figure 163 shows a closed string. A string 250 or 280 mm wide is generally sufficient to contain steps with any one of the dimensions of rise and going and a 50 mm margin.

Wall strings are generally made as close strings so that wall plaster can be finished down on them. Outer strings can be made as closed strings or as open (cut) strings.

The ends of the treads and risers are glued and wedged into shallow grooves cut in closed string. The grooves are cut 12 mm deep into strings and tapering slightly in width to accommodate treads, risers and the wedges which are driven below them, as illustrated in Fig. 163.

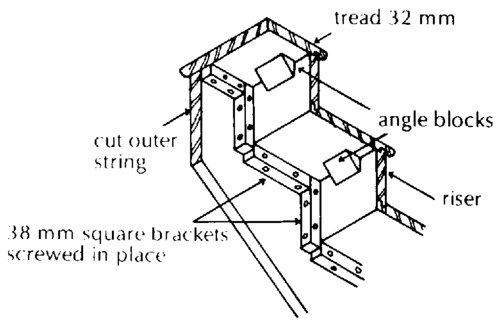


Fig. 164 Underside of flight to show fixing of treads, and risers to cut outer string.

After the treads and risers have been put together and glued and wedged into their housings in the string, angle blocks are glued in the internal angles between the underside of treads and risers and treads and risers and string. Angle glue blocks are triangular sections of softwood cut from say 50 mm square timber and each 120 mm long. Their purpose is to strengthen the right angled joints between treads, risers and strings. Three or four blocks are used at each junction of tread and riser and one at junctions of treads, risers and string. Angle blocks are shown in Fig. 164.

Cut or open string

A closed outer string looks somewhat lumpy and does not show the profile of the treads and risers it encloses. The appearance of a staircase is considerably improved if the outer string is cut to the profile of the treads and risers. This type of string is termed a cut or open string. Because more labour is involved, a flight with a cut string is more expensive than one with closed strings.

As the string is cut to the outline of the treads and risers they cannot be supported in housings in the string and are secured to brackets screwed to both treads and risers and string, as illustrated in Fig. 164. It is difficult to cut a neat nosing on the end grain of treads to overhang the cut string, so planted nosings are fitted as shown in Fig. 165. The planted nosings are often secured to the ends of treads by slot screwing. This is a form of secret fixing used to avoid having the heads of screws exposed. Countersunk head wood screws are driven into the ends of treads so that their heads protrude some 12 mm. The heads of these screws fit into holes cut in the nosing. The nosing is then knocked into position so that the screw head bites into slots cut next to the holes in the nosing. It will be seen from Fig. 165 that the planted nosings are mitred to the nosing of the tread. The ends of the risers are cut at 45° to the face of the string. Because the string is thicker than the riser it partly butts and is partly mitred to it, as a mitre and butt joint.

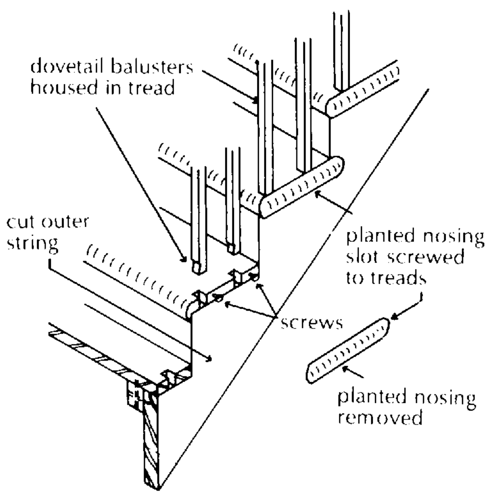


Fig. 165 Cut string.

Landings

Half space (turn) landing

A half space landing is constructed with a sawn softwood trimmer which supports sawn softwood landing joists or bearers and floor boards, as illustrated in Fig. 166. As well as giving support to the joists of the half turn landing the trimmer also supports a newel or newel posts. Newel posts serve to support handrails and provide a means of fixing the ends of outer strings.

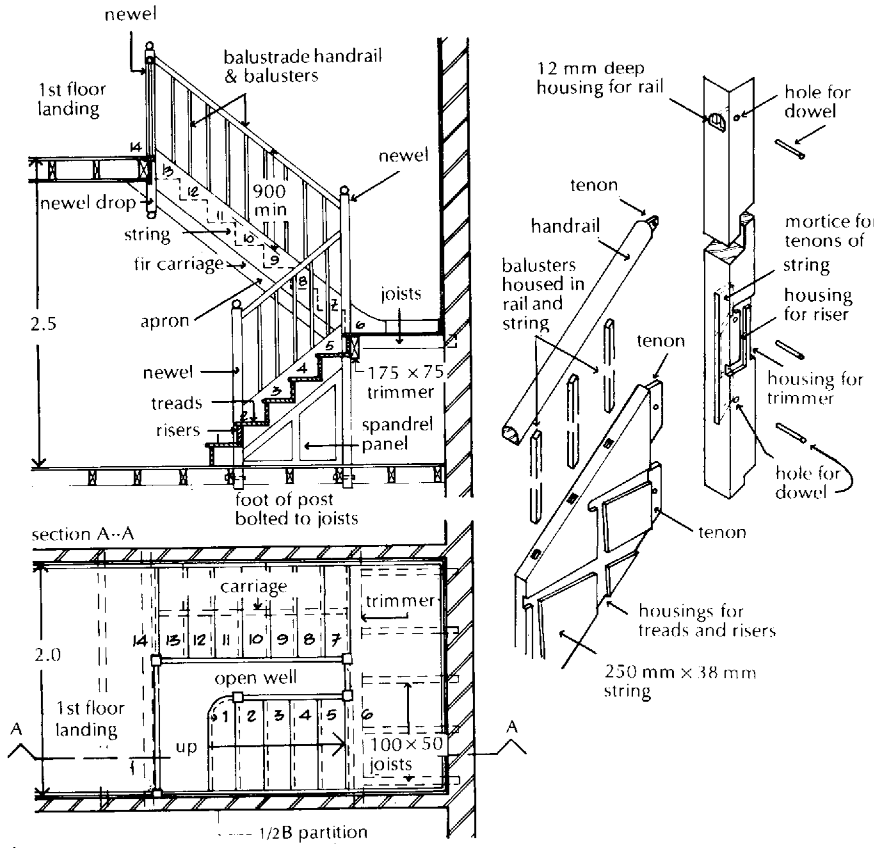


Fig. 166 Half turn open well staircase.

Newel posts

The newel posts are cut from 100 × 100 mm timbers and are notched and bolted to the trimmer. The outer string fits to mortices cut in the newel, as illustrated in Fig. 166. For appearance, the lower end of the newel post is usually about 100 mm below the flights and moulded. As it projects below the stair it is called a drop newel.

Balustrade

Open balustrade

The traditional balustrade consists of newel posts, handrail, and timber balusters, as illustrated in Fig. 166. The newel posts at half turn landings and at landings at first floor level are housed and bolted to trimmers. These newels are fixed in position so that the faces of the risers at the foot and head of flights are in line with the centre line of the newel.

Handrail

The top of the handrail is usually fixed a minimum height of 900 mm vertically from the pitch line to the top of the handrail and 900 mm above landings for domestic stairs in a single house and 900 to 100 mm above the pitch line for other stairs. The handrail is cut from

75 × 50 mm timber which is shaped and moulded.The ends of the handrail are tenoned to mortices in the newels.

Balusters

Balusters may be 25 or 19 mm square or moulded. They are either tenoned or housed in the underside of the handrail and tenoned into the top of closed strings or set into housings in the treads of flights with cut string, as shown in Fig. 165.

To prevent children under 5 years of age from becoming stuck between them balusters should be so spaced that a 100 mm sphere cannot pass between them.

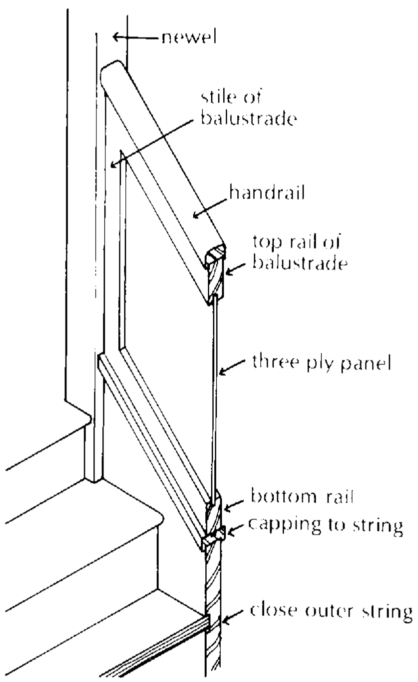


Fig. 167 Enclosed balustrade.

The traditional balustrade of vertical balusters, either plain or moulded, may not provide a satisfactory looking enclosure to stairs for some. A fashion for so called modern looking balustrades in the form of closed balustrades of panels of wood or plywood was taken up from time to time, in the first half of the twentieth century. The disadvantage of the enclosed panel balustrade is that it makes the stair somewhat dark.

More recently the fashion has been for enclosed glass panelled balustrades with the glass set in a metal channel above the pitch line to concrete steps or stairs and set into a channel fixed under or below a handrail.

An enclosed balustrade to a close string stair is illustrated in Fig. 167, with a plywood panel set in a softwood frame fixed between the top of a close, outer string and the underside of the handrail.

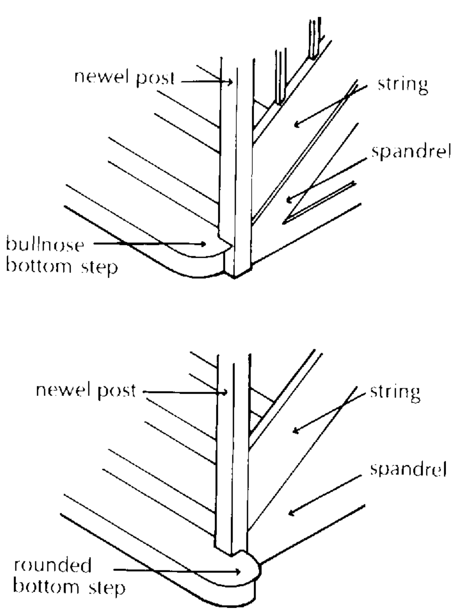


Fig. 168 Shaped steps.

For the sake of appearance the bottom step of a timber staircase may be framed to project beyond the newel post and be shaped as either a quarter or a half circle as illustrated in Fig. 168. By projecting from the enclosing strings into the floor the bottom step gives the sense of the stair belonging to the floor as well as the staircase.

The bullnose, quarter circle and the rounded, half circle, end steps are made by cutting the riser to the thickness of a veneer of thin wood which is shaped around three shaping blocks to which the reduced thickness of the riser is screwed as illustrated in Fig. 169. A block left on the end of the riser is wedged to the blocks to shape the riser tightly around the blocks.

The tread is cut with a projecting nosing to return around the shaped bottom step.

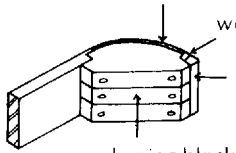


Fig. 169 Bullnose step.

The triangular space between the underside of the lower flight of a stair and the floor is the spandrel. It may be left open and be a nuisance to keep clean or more usually it is enclosed with spandrel filling of a sheet of plywood or other board or closed with timber framed panelling as illustrated in Fig. 168. Where the length of the spandrel filling is sufficient, the panelling may be framed around a door so that the spandrel space below the stair may be used for storage.

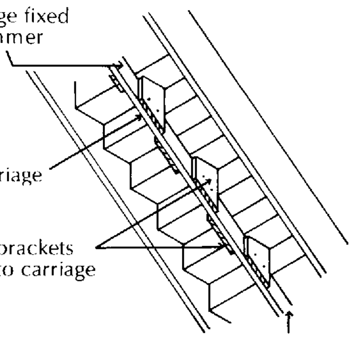


Fig. 170 Underside of flight showing carriage and brackets.

A sawn softwood carriage is usually fixed below flights of a staircase to give support under the centre of each step. The fir (softwood) carriage illustrated in Fig. 170 is 100 × 75 mm in section and nailed to landing trimmers or joists for support with the top surface of the carriage directly under the angle of junction of treads and risers.

Short offcuts from 175 × 25 mm boards are nailed alternate sides of the carriage, so that the top edge of these brackets bears under treads to reduce creaking of the stair.

Where the soffit of flights of staircases is to be plastered two additional fir carriages should be fixed, one next to the wall and the other next to the outer string as fixing for plasterboard.

Winders

Winders is the name given to tapered treads that wind round quarter or half turn stairs in place of landings to reduce the number of steps required in the rest of the stair and to economise in space. These winders may be used in domestic stairs. They present some hazard to the young and elderly and are not recommended for use in means of escape stairs or stairs in public buildings. The winders illustrated in Fig. 171 are constructed as three taper treads at the quarter turn of a half turn stair with a quarter turn landing leading down to the lower flight.

The newel post is continued down to and supported at the floor below so that it may support the trimmer for the quarter space landing and the bearers for the winders. The treads of the winders are made of two boards tongued and grooved together. To support the edge of winders 75 × 50 mm bearers are housed in the newel post and wall string.

Because of the extra width of the tread of winders where they are housed in wall strings the wall string has to be made of two boards into which both treads and risers are housed in 12 mm grooves and wedged and glued.

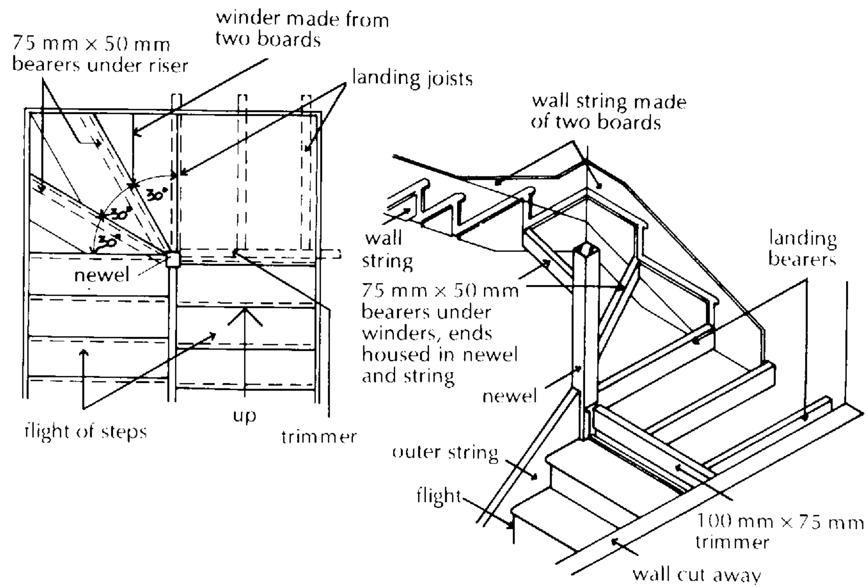


Fig. 171 Winders and quarter space landing.

OPEN RISER OR LADDER STAIR

An open riser or ladder stair consists of strings with treads and no risers so that there is a space between the treads, with treads overlapping each other at least 16 mm.

Open riser stairs have become fashionable particularly in open plan houses and flats with the open riser stair used as a feature. Various materials and forms of construction are used for exposed open riser stairs such as wood strings, treads and handrail, reinforced concrete strings and treads, reinforced concrete central carriage with cantilever treads, steel strings and treads to steel handrail supporting glass treads hung from the handrails.

More traditional open riser stairs are illustrated in Fig. 172. The strings may be either close or cut to the outline of the treads. The treads, which gain no support from risers, should be cut from 38 or 44 mm thick timbers which are housed in closed strings, as illustrated in Fig. 172, and secured in position with glued wood dowels.

To strengthen the fixing of the treads to the strings against shrinkage and twisting, 10 or 13 mm tie rods, one to every fourth tread, are bolted under the treads through the strings, as illustrated in Fig. 172. The strings are fixed to the floor with steel plates which are bolted to the sides of the timber strings and bolted to timber trimmers or cast into concrete floors (Fig. 172). The treads are screwed to the cut top edge of the strings and this fixing is sufficient to tie the strings together without the use of the rods. A cut string will generally need to be deeper than a similar close string because the effective depth of the cut string is the narrow waist below the junction of the back of a tread and the underside of the string.

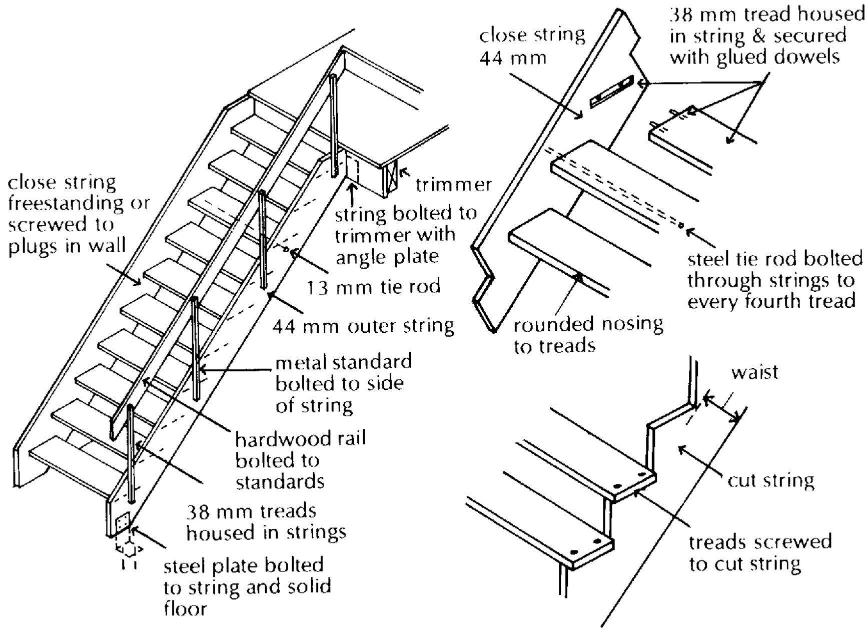


Fig. 172 Open riser stair with closed or cut string.

Open riser wood stair

Open riser wood stairs are often constructed as straight flight stairs between floors and there is no newel post to provide a fixing for the handrail. The handrail and balustrade are fixed to the sides of the strings, as illustrated in Fig. 172.

STONE STAIRS

The traditional stone stairs were constructed of steps of natural stone of rectangular or triangular section built into an enclosing wall so that each stone was bedded on the stone below in the form of a stair. Each stone was built into the wall of the stair well from which it cantilevered and took some bearing on the stone below in the form of a prop cantilever. The steps were either of uniform rectangular section with a stepped soffit or rectangular section cut to triangular section to form a flush soffit, as illustrated in Fig. 173. The ends of the crude rectangular section steps were built into a wall. The ends of the triangular section steps had their rectangular ends built in. These steps had splayed rebated joints and nosings cut on the edge of the tread surface, as illustrated in Fig. 173. Landings were constructed with one or more large slabs of natural stone built into enclosing walls and bearing on the step below.

Because of the scarcity and cost of natural stone, this type of step is now made of cast stone or cast concrete which is usually reinforced and cast in the same sections as those illustrated for natural stone, or as a combined tread and riser with a rectangular end for building into walls and a stepped soffit.

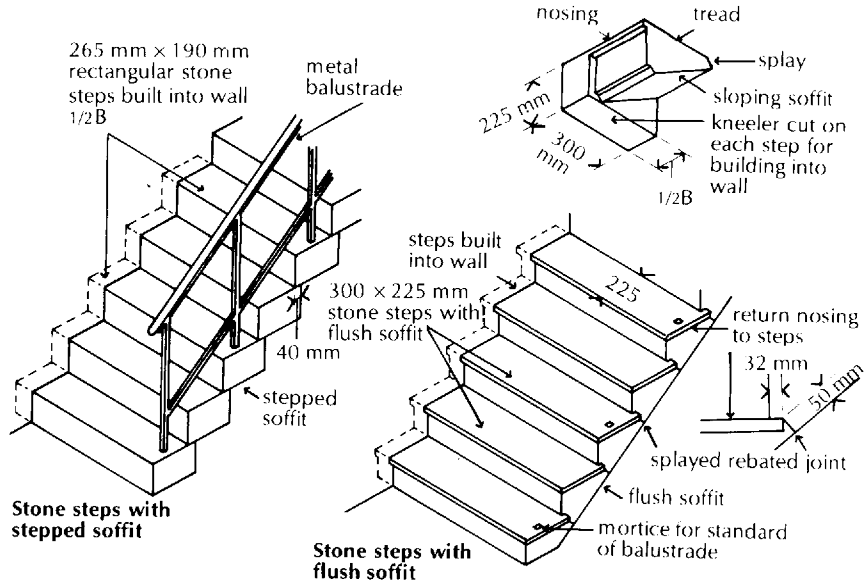


Fig. 173 Stone steps.

REINFORCED CONCRETE STAIRS

With the use of the reinforced concrete skeleton frame (see Volume 4), as one of the principal structural frames for the majority of buildings of more than three or four floors, a reinforced concrete stair, either cast in situ, precast or a combination of in situ and precast, is the usual form of stair today.

Fire safety

A reinforced concrete stair, which has better resistance to damage by fire than the conventional timber staircase, is used for access and means of escape stairs in most buildings of more than three or four storeys. The width, rise, going and headroom for these stairs and the arrangement of the flights of steps as straight flight, quarter turn, half turn and geometrical stairs is the same as for timber stairs.

The usual form of a reinforced concrete stair is as a half turn (dog leg) stair either with or without an open well. The construction of the stair depends on the structural form of the building and the convenience in casting the stair in situ or the use of reinforced concrete supports and precast steps.

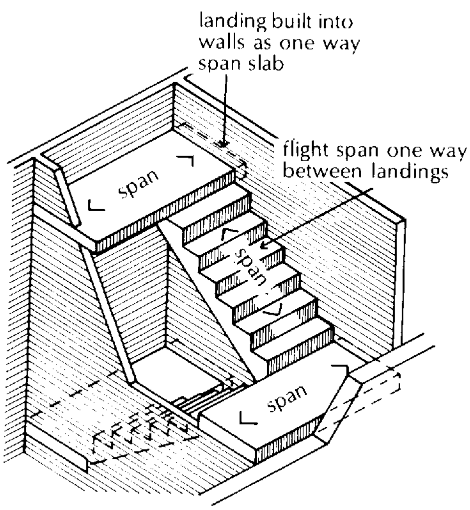


Fig. 174 Inclined slab stair.

Where there are load bearing walls around the stair it is generally economic to build the landings into the side walls as one-way spanning slabs and construct the flights as inclined slabs between the landings as illustrated in Fig. 174. This form of stair is of advantage where the enclosing walls are of brick or block as it would involve a great deal of wasteful cutting of bricks or blocks were the flights to be built into the walls and the bricks or blocks cut to fit to the steps.

As an alternative the stair may be designed and constructed as a cranked (bent) slab spanning through landing, flight and landing as one slab with no side support as shown in Fig. 175A. This is a more costly construction than using the landings as slabs to support the flights as the span and therefore the cost of the stair is greater. This form of construction is used where the landings cannot gain support each side of the stair.

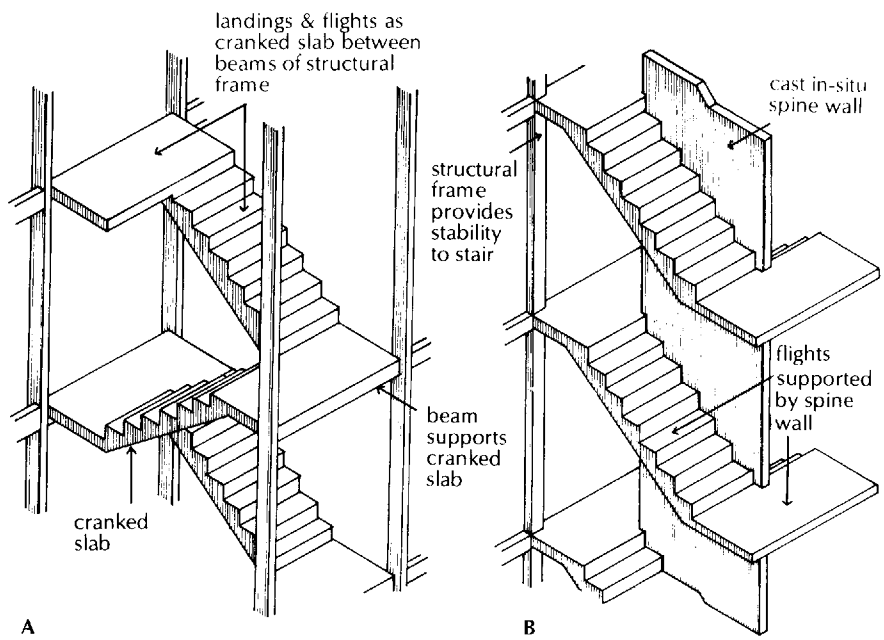


Fig. 175 A Cranked slab stair.
B Cantilevered spine wall stair.

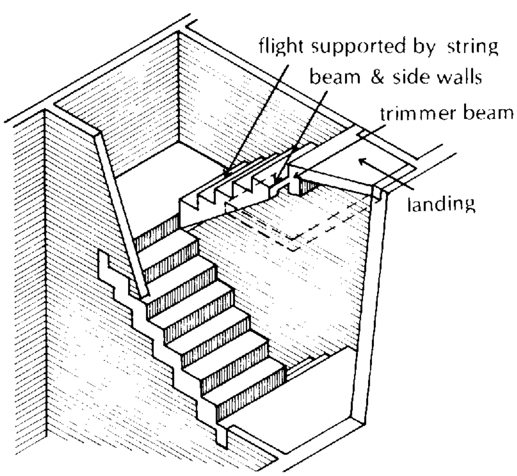


Fig. 176 String and trimmer stair.

Another construction is to form a reinforced concrete frame of beams to landings supporting inclined beams to flights, as illustrated in Fig. 176. The landing beams are supported by side walls or the beams of a frame and in turn support inclined beams that support the steps. This is a somewhat clumsy form of construction with a very untidy soffit or underside to the stair. It is best suited to the use of precast concrete steps that bear on the inclined beam under the flight with step ends built into enclosing walls or on two inclined beams and the use of precast landings.

Where a reinforced concrete half turn stair is constructed around a reinforced concrete centre spine wall between the flights, the stair may be constructed to cantilever from this spine wall, as illustrated in Fig. 175B, or partly cantilever from the spine wall and be supported by the enclosing frame or walls.

The reinforcement of a concrete stair depends on the system of construction adopted. The stair illustrated in Fig. 177 is designed and built with the landings built into the enclosing walls as a two-way

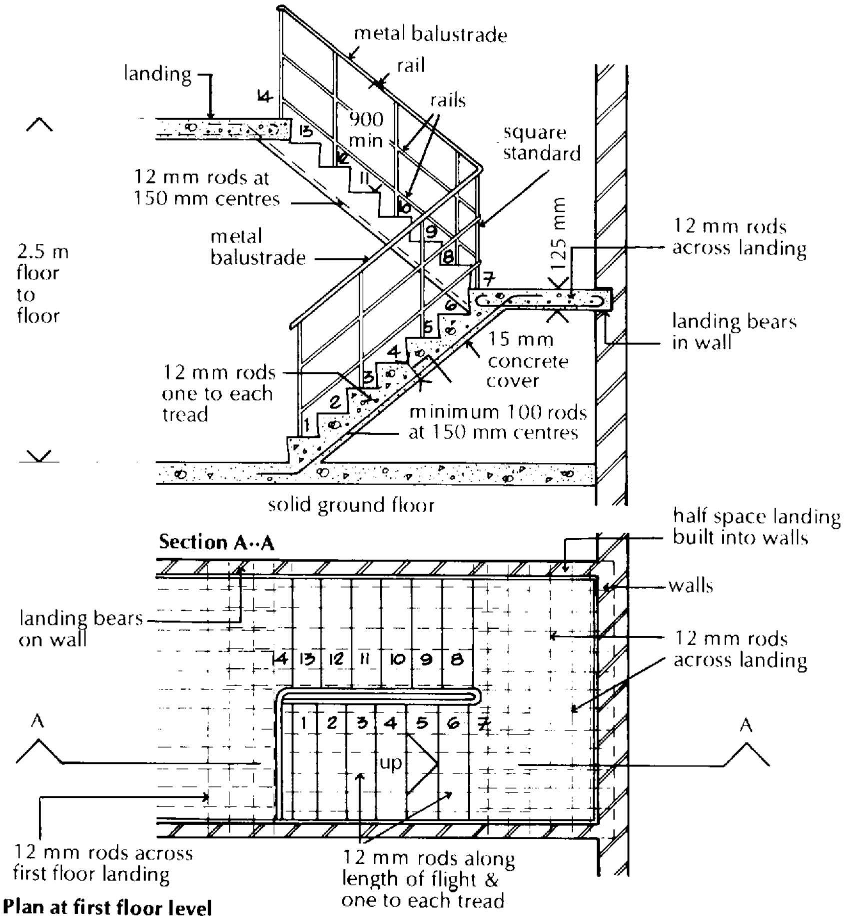


Fig. 177 Half turn reinforced concrete stair.

slab, and an inclined slab as flights spanning between landings independent of the side walls. The main reinforcement of the landings is both ways across the bottom of the slab, and the main reinforcement of the flights is one way down the flights. The effective depth of the inclined slab that forms the flights is at the narrow waist formed on section by the junction of tread and riser and the soffit of the flight. It is this thickness of the slab that has constructional strength and the steps play no part in supporting loads. The reinforcement has to have cover of concrete around it to inhibit rust and protect steel rods against damage by fire.

Balustrade

The balustrade to a stone, cast stone or reinforced concrete stair is usually of metal, the uprights of which are either bolted to the sides of the flights to studs cast or grouted into the material or bolted through the material or set in mortices either cast or cut in the material. These vertical metal supports or standards in turn support rails as a balustrade for security and a handrail.

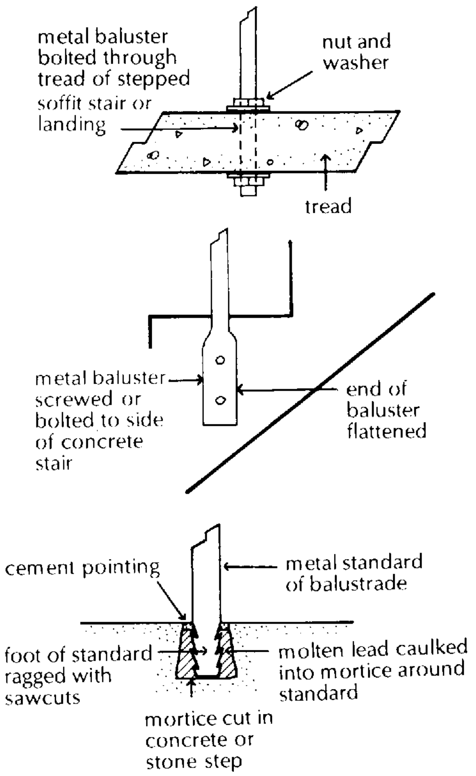


Fig. 178 Setting metal standard in stone or concrete step.

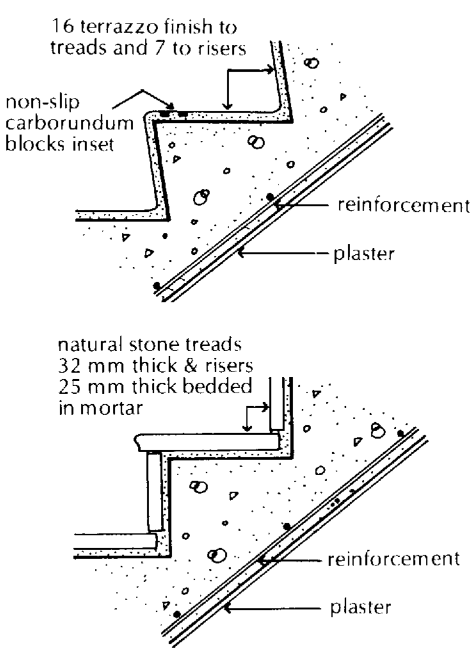


Fig. 179 Finishes to concrete steps.

To provide maximum rigidity for the uprights which support a balustrade and handrail for stone or concrete stairs and landings, the uprights should be bolted through the thickness of the flights and landings as illustrated in Fig. 178. The metal uprights are bolted with nuts and washers through the depth of the stair. Uprights at some 900 to 1200 mm intervals will support a frame fixed just above pitch line and up to and including a handrail.

As an alternative fixing, for flush sloping soffit flights for example, the uprights may be secured by expanding bolts to the side of a reinforced concrete stair as illustrated in Fig. 178.

The traditional method of fixing the metal uprights, standards or balusters to natural stone stairs and landings is by fixing the end of the verticals into a mortice cut in the stone. The ragged end of the verticals is then set in the mortice and molten lead is run into the mortice and caulked (rammed) to complete the joint as illustrated in Fig. 178.

As this fixing for the uprights of a balustrade is not so rigid or secure as bolting through, the uprights have to be at fairly close intervals of 400 to 600 mm to support the balustrade frame and handrails.

Hard, durable, natural stone steps and landings may be left as a natural finish for the benefit of the appearance of the stone. Even the hardest natural stone will become scuffed and dirty in time and is laborious to keep clean.

Usually stone and concrete stairs are given an applied finish to create a surface which is easy to clean and for appearance. Any one of the floor finishes used for solid floors, as described in Volume 1, may be used for stairs. In situ or precast terrazzo is often used for its appearance and ease of cleaning, with carborundum inserts as a non-slip surface, as illustrated in Fig. 179. Wood treads of hardwood screwed to plugs in each step provide an attractive, durable and quiet-in-use surface. Stone treads and risers may be bedded as a surface finish for reinforced concrete stairs, as illustrated in Fig. 179.

4: Fires, Stoves and Chimneys

HISTORY

For centuries the fuel used for heating and cooking was wood. Prior to the Industrial Revolution the ready availability of this free source of fuel was adequate to the modest needs of the comparatively small population of England.

In the early years of the Industrial Revolution the development of deep coal mining provided a source of fuel for heating and cooking for the increasing population of urban dwellers as a substitute for the depleted sources of wood.

The disadvantage of the solid fuels wood and coal as a fuel is that they are laborious to deliver, bulky to store and dirty in use and produce ash which is tedious and messy to dispose of.

The advantage of coal is that it is plentiful, provides a cheerful flame or glow when it burns and provides a traditional focal point in a room. Smokeless fuels and coke, derivatives of coal, are lighter, cleaner and produce less ash than household coal but nonetheless require space for storage and effort in use, unlike the convenience fuels gas, oil and electricity.

During the last 50 years there has been a move away from the use of solid fuel burning fires and stoves for heating to the use of gas, oil and electricity for heating for the convenience in using these sources of energy for heating and because of legislation to create smokeless zones to control fog.

The most convenient method of heating is by electricity which can be controlled by the touch of a switch, requires only slender cables to distribute energy and needs very little attention from the consumer. It is extravagant to convert natural fuels such as coal, gas and oil to electricity which is the most costly source of energy for heating. Oil, which is a comparatively cheap source of energy for heating and requires bulky storage containers, has by and large been replaced by natural gas as the principal source of energy for heating.

Solid fuels

The solid fuels available are bituminous coal (house coal), anthracite, smokeless fuels, coke, wood and peat.

Coal

Bituminous coal or house coal is a natural coal that ignites easily and burns with a bright flame. It is the traditional solid fuel for the open fire, much enjoyed for its bright flame and cheerful glow and equally hated for the need for frequent fuelling, cleaning of ash and the smoke pollution in towns that was a prime cause of fog. In smoke control areas, only authorised fuels may be used and house coal is generally prohibited.

Anthracite

Anthracite is a dense natural fuel that burns slowly and is a natural smokeless fuel. The limited supplies of this fuel are used in stoves and boilers.

Smokeless fuels

Smokeless fuels are produced by processing coal to produce a smokeless fuel, for use in smoke control areas. Smokeless fuel is less dense and cleaner to handle than natural coal, burns with a glow rather than a flame and produces a fine ash.

Coke is the by-product of the conversion of coal to town gas (see Volume 5). It is light in weight, clean to handle, burns with a glow and is smokeless, but produces hard clinker and ash which is messy to dispose of.

Wood

There are limited supplies of wood for use as fuel for heating in this country. The large volume of wood required for heating necessitates large open fires or stoves and considerable storage space.

Peat

Peat, which is compressed, decayed vegetation, is cut and used as a fuel mainly in Ireland and the west of England.

FUNCTIONAL REQUIREMENTS

The functional requirements of fires and chimneys are:

Strength and stability
Resistance to weather
Fire safety
Resistance to the passage of heat
Ventilation

Strength and stability

Conventional flues to open fires and stoves are constructed as chimneys built into chimney breasts as part of a wall or internal division. In effect the chimney is part of the wall or internal division into which it is built and should be constructed to meet the requirements for strength and stability that apply to the wall. Freestanding chimneys of brick or block are similar to freestanding piers and should meet the requirements for strength and stability that apply to piers.

Resistance to weather

Brick and block chimneys that are formed as part of an external wall and are carried up above roofs to discharge the products of combustion should be constructed to meet the requirements to resist the penetration of rainwater to the inside of the building in the same way that external walls and parapets do.

Fire safety

The requirements for fire safety are set out in Approved Document J, Heat Producing Appliances, to the Building Regulations. The requirements set minimum thickness and dimensions of non-combustible materials around fires, flues and hearths and minimum dimensions for the proximity of combustible materials to fires and flues.

Resistance to the passage of heat

Open fires inset in an opening in a chimney breast constructed as part of an external wall transmit a large part of the heat produced by burning fuel to the surrounding wall which will conduct heat to the outside. To minimise this wasteful loss of heat, the wall behind a fireplace should be constructed as an insulated cavity wall to gain the maximum benefit of the radiation of heat from the wall into the building.

Ventilation

For combustion, fuel requires a continuous intake of air both for the process of burning and to carry the products of combustion to outside air. Solid fuels, such as wood and coal, burning vigorously in open fires draw in considerable volumes of air. The necessary air intake is advantageous in providing beneficial air changes and disadvantageous in the inevitable draughts of cold air intake from windows and doors that are a feature of open fires.

SOLID FUEL BURNING APPLIANCES

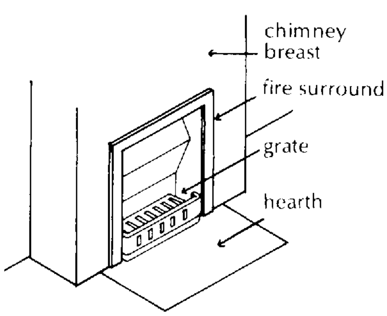


Fig. 180 Open fire inset in recess.

Solid fuels are burned in open fires, room heaters or stoves and boilers for heating and hot water.

The traditional open fire consists of a grate inset in a fireplace recess formed in a brick chimney breast, as illustrated in Fig. 180. As its name implies, an open fire is clearly visible and this is its chief attraction. The disadvantage of an open fire is that much of the air drawn into the fire and up the chimney by convection is not necessary for combustion or burning the fuel and this excess air wastefully takes a large proportion of the heat from the fire up the chimney. The air drawn into the fire is replaced by air drawn into the room which causes draughts of cool air which are uncomfortable and wasteful of heat. An open fire inset in a recess in a chimney built into an external wall will heat the brickwork or blockwork in which it is contained. Some of the heat will be lost to outside air by conduction.

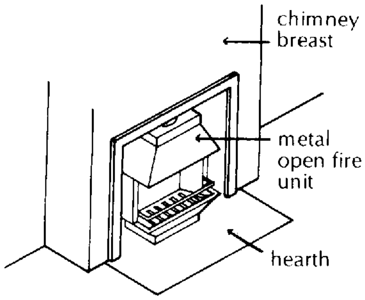


Fig. 181 Freestanding open fire in recess in chimney breast.

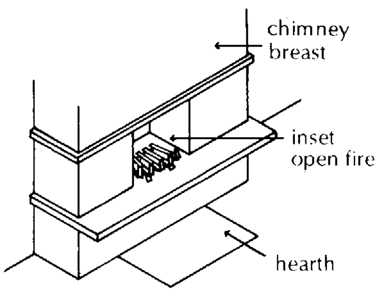


Fig. 182 Open fire inset above floor in brick or block chimney breast.

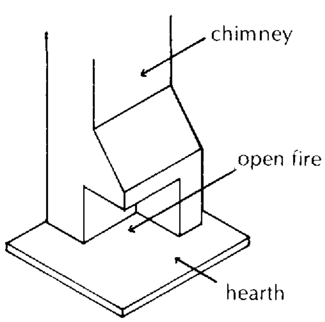


Fig. 183 Freestanding open fire with brick or block chimney.

The freestanding open fire illustrated in Fig. 181 has some advantage in that the fire is contained inside the freestanding metal surround and hood, which will radiate heat into the room and around which air will circulate to transfer heat by convection. Plainly the degree to which these effects will occur will depend on the extent to which the fire is set outside the recess in the chimney. To limit the volume of air drawn into the fire, to that necessary for burning, the hood of these fires is connected by a short length of stove pipe that connects to the flue through a hole in a plate fixed across the bottom of the flue.

The conventional open fire is formed at floor level on a solid hearth as part of a concrete floor or constructed in a timber floor for the sake of convenience in construction. In this position the fire will radiate much of its heat at floor level. So that an open fire will radiate heat more uniformly into the body of a room the fire may be raised above floor level as illustrated in Fig. 182. A raised hearth of stone or concrete is built into the chimney breast to project from the face of the chimney to collect so much of the burning fuel as might otherwise fall on to the floor. As a safeguard a hearth is formed at floor level in timber floors to collect any burning material that falls from the upper hearth. As an alternative a grate may be set in a perforation in the upper hearth so that burning material and ash fall into a metal ash can set below the upper hearth.

An advantage of this arrangement is that the comparatively small opening of conventional open fires is more visible.

The most convenient place for an open fire in the comparatively small rooms of most houses is centrally in one long wall. In larger living areas the fire may be built as a freestanding structure or fitting where it is visible from one or more sides and where the heat generated by the fire will radiate from all four sides more generally to the living space.

A freestanding open fire may be constructed as a brick or block chimney rising above the open hearth as illustrated in Fig. 183, where the fire is open and visible on two sides, or open on all four sides. The chimney is a form of freestanding pier, the dimensions of which are determined by the required cross-sectioned area to support the load of the chimney and slenderness ratio to resist overturning.

As an alternative a freestanding open fire may be formed as a hearth over which a metal hood and flue pipe are either supported from the floor or suspended from a ceiling.

Room heater is a term recently used to describe an enclosed adaptation of the open fire designed for the more efficient use of solid fuel. It is a modern version of the traditional stove. The advantages of the

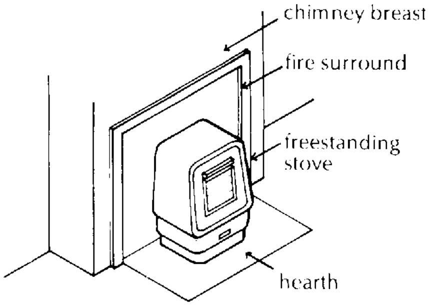


Fig. 184 Freestanding stove (room heater).

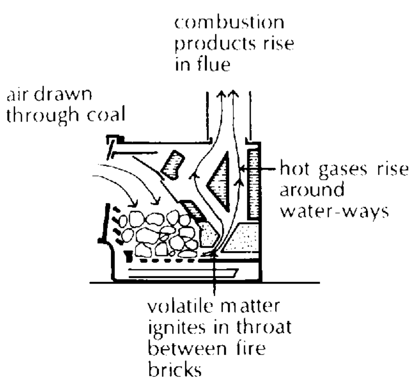


Fig. 185 Down draught solid fuel burning heater.

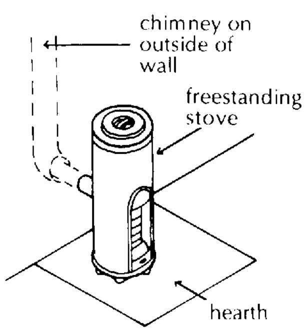


Fig. 186 Freestanding stove connected to chimney.

room heater are that air intake and combustion can be controlled to appreciably reduce the intake of excess air and so reduce the wasteful flow of heated air passing up the chimney, and the whole of the surface area of a freestanding room heater is used to heat the room by radiation and convection of air around the heater. The room heater is set on a hearth in front of the chimney breast with a short length of flue pipe run from the back of the heater through a hole in the plate that seals the fireplace recess, as illustrated in Fig. 184. These heaters may be set inside a fireplace recess or set as freestanding heaters inside the room, depending on the room available in front of the heater and appearance.

A hinged fuel door or panel in the front of the heater is glazed to give a view of the fire.

The most efficient form of room heater is designed so that the primary combustion air intake is drawn down, through the bed of coal in the grate, and then up to the flue as illustrated in Fig. 185. For maximum efficiency a down draught room heater is combined with a back boiler to take advantage of the heated combustion gases passing from the fire up the chimney. These back boilers are used to heat water and radiators.

The cast iron back boiler is formed with flue ways running between the hollow cast iron waterways to provide maximum area of waterways exposed to hot combustion gases rising up to the flue. Fire bricks behind the grate and below the back boiler are chosen to take up and retain heat to ignite volatile gases flowing up through the back boiler flue ways. A steel plate damper which is adjustable to control air intake is opened when the fire is first lit and later when refuelled to promote a vigorous draught of air up the flue and subsequently closed to reduce air intake to promote steady, efficient ignition of fuel. The traditional room heater used in most parts of central Europe is a stove in the form of an enclosed solid fuel burning appliance of cast iron, steel or brick. The smaller iron or steel stoves are used to burn wood or coal or both to heat small rooms and the large brick stoves burn wood to heat larger rooms.

The traditional stove is set freestanding in rooms adjacent to a wall into which, or against which, a metal flue pipe is run to open air. Like room heaters the advantages of a stove are that air intake can be controlled for maximum efficiency and the whole of the heated outer surface of the stove is exposed for maximum radiation and convection of heat to rooms. Figure 186 is an illustration of a freestanding iron stove suited to heating small rooms and fuelled by wood or coal or both which are fed to the stove through a loose top cover plate.

A boiler is an enclosed appliance in which fuel is burned specifically to heat water for a hot water supply or for space heating or both. The fuel burned in a hearth heats water run inside cast iron sections around the hearth, the heated water flowing either by gravity or pump to hot water cylinders and radiators and back to the boiler for reheating.

CHIMNEYS AND FLUES

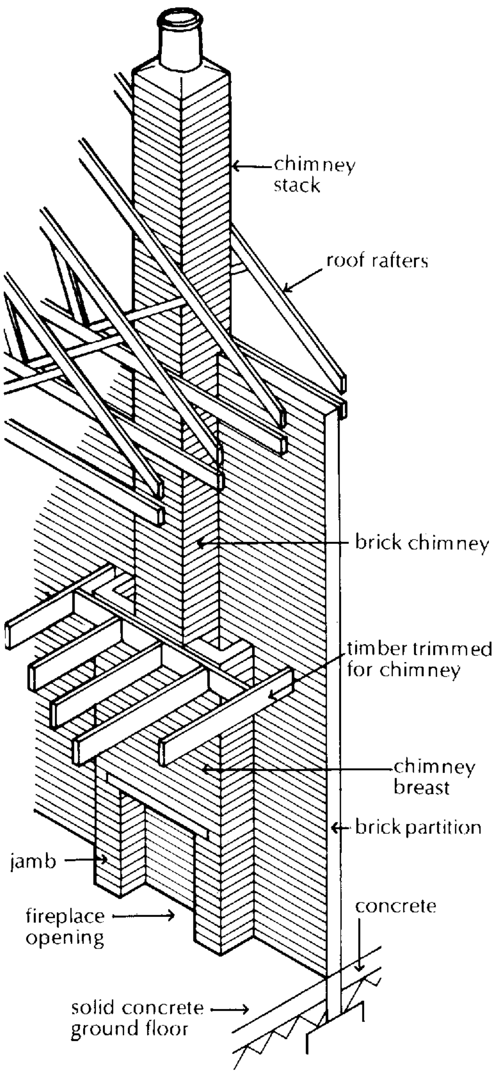


Fig. 187 Brick chimney and chimney breast.

A flue is a shaft, usually vertical, to induce an adequate flow of combustion air to a fire and to remove the products of combustion to the outside air. The material which encloses the flue, brick, block, stone or metal, is termed a chimney. A chimney may take the form of a pipe run to the outside or be constructed of solid brick, block or stone either freestanding or as part of the construction of a partition or wall. The conventional chimney for open fires and stoves is constructed of block, brick or stone and consists of a fireplace recess contained between jambs over which a chimney breast gathers into a chimney that is carried above roof level as a chimney stack (Fig. 187). Because a fireplace and the enclosing jambs are wider than the chimney and flue above, the chimney breast is constructed to accommodate the gathering in of the fireplace opening to the smaller flue.

Some of the heat of combustion of fires and stoves will be transferred to the chimney, which heats the structure and air surrounding it. To take the maximum advantage of this heat the best position for a chimney is as a freestanding structure in the centre of a room or building where it is surrounded by inside air. As an alternative the chimney may be built as part of an internal partition. Where buildings are constructed with a common separating or party wall it is convenient to construct chimneys back to back on each side of the separating wall. Chimneys constructed as part of an external wall suffer the disadvantage that some of the heat will be transferred to the cold outside air. This loss can be minimised by continuing the cavity of an external wall and cavity insulation behind the chimney. The four positions for a chimney are illustrated in Fig. 188.

It is usual to construct chimney breasts and chimneys as projections into rooms heated by open fires as illustrated in Fig. 188, with the chimney breast projecting into the ground floor room and the chimney projecting into the room above. The advantages of this arrangement are that the heated surfaces of the breast and chimney will transfer some heat to inside by radiation and convection and that the projecting breast will give some emphasis to the comparatively small fireplace openings.

As an alternative the chimney breast and chimney may be constructed to project from the face of the internal or external wall

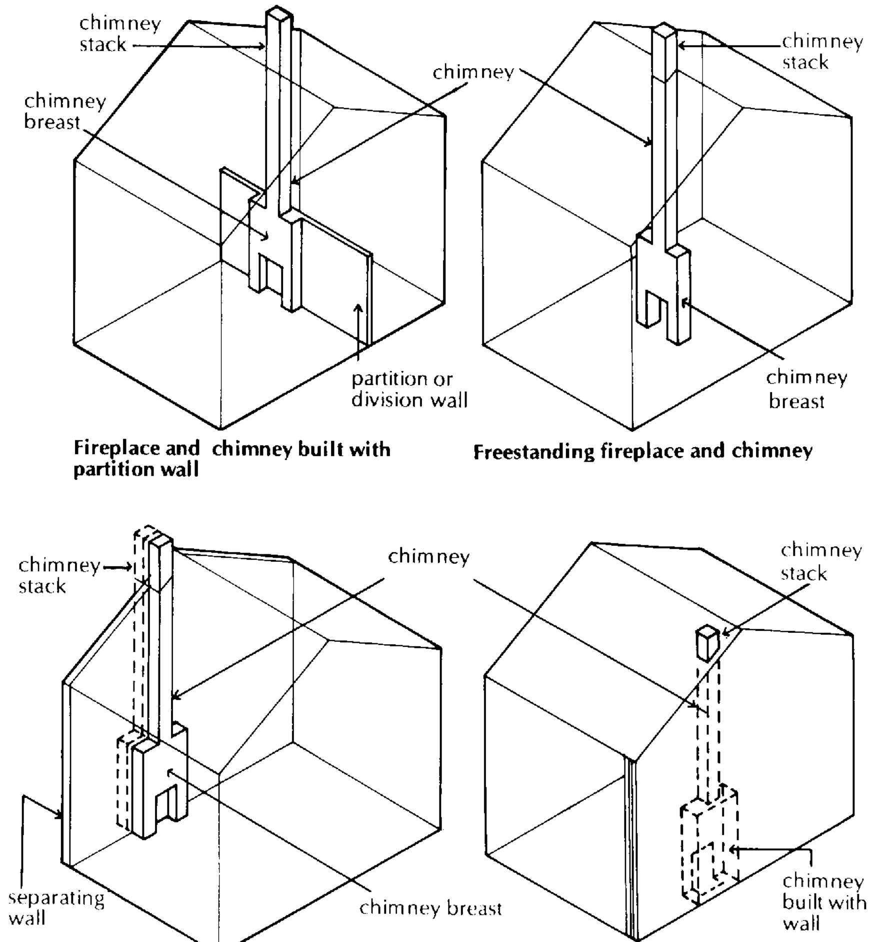


Fig. 188 The four positions of fireplace and chimney.

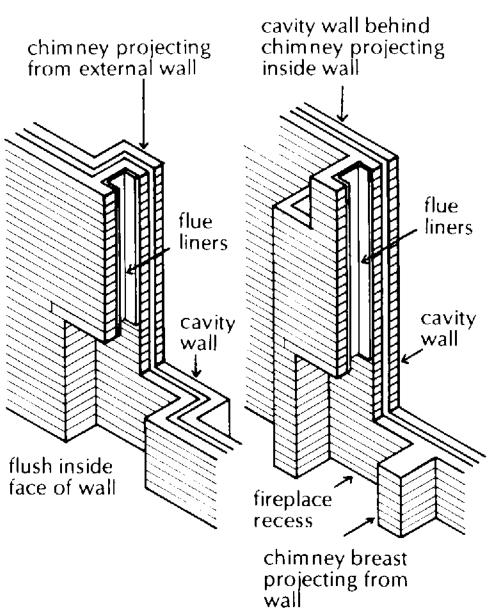


Fig. 189 Fireplace and chimney in cavity wall.

opposite to that of the fireplace recess, as illustrated in Fig. 189. Whether the chimney and breast projection is inside or outside of an external wall it is necessary to continue the cavity and any necessary cavity insulation behind fireplace openings and flues to exclude rain penetration and provide adequate resistance to heat transfer as illustrated in Fig. 189.

A fireplace or appliance recess is formed in the projecting chimney breast or wall into which the open fire or stove is set and above which the flue rises in the chimney breast. To support the brick or block work of the chimney breast over the fireplace opening, two piers are built either side of the recess. These piers, which are described as jambs (legs), support a brick arch or reinforced concrete lintel which supports the chimney breast. It is common to use a reinforced concrete raft lintel over the fireplace recess to support the chimney breast. The lintel is holed for the flue as illustrated in Fig. 190.

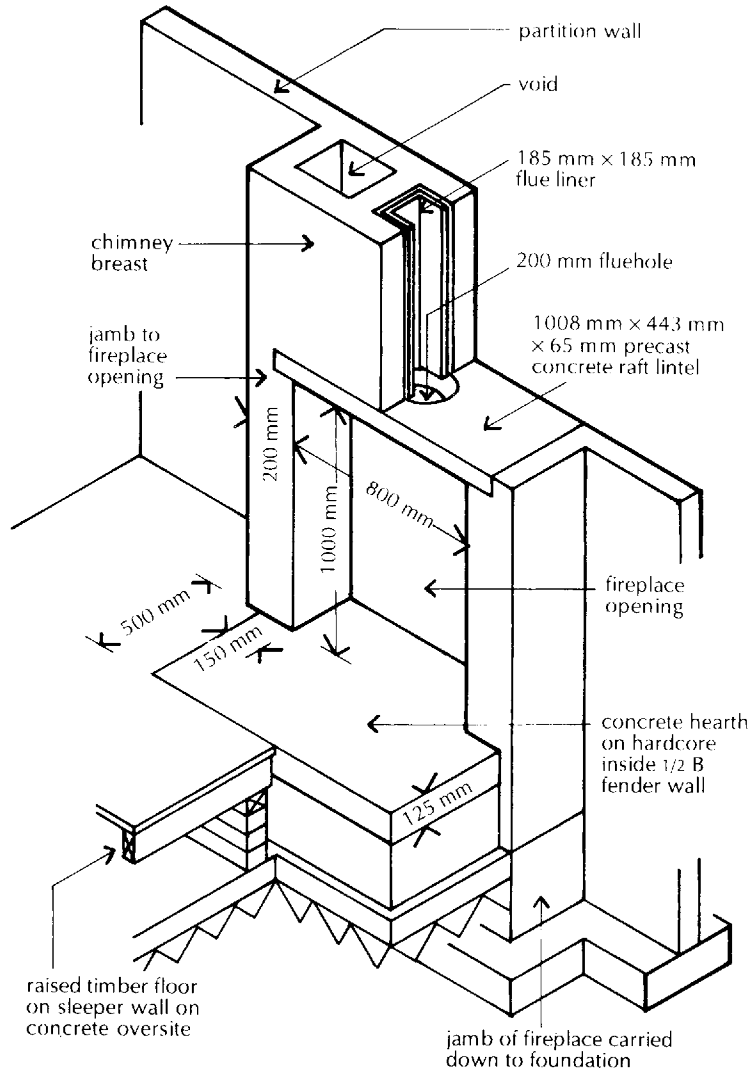


Fig. 190 Fireplace, hearth and chimney.

The traditional fireplace recess was usually about 580 mm wide and 625 mm high to accommodate a small domestic open fire. A larger opening 800 mm wide and 1000 mm high is often used to provide for wider open fires or for fitting in room heaters as illustrated in Fig. 190.

FIRE SAFETY

A requirement of the Building Regulations is that heat producing appliances be so installed and fireplaces and chimneys so constructed as to reduce to a reasonable level the risk of the building catching fire in consequence of their use.

Fireplace recesses

The practical guidance given in Approved Document J, Heat Producing Appliances, to the Building Regulations, gives recommendations for the position and thickness of solid, non-combustible materials to be used in surrounds to open fireplaces and the thickness

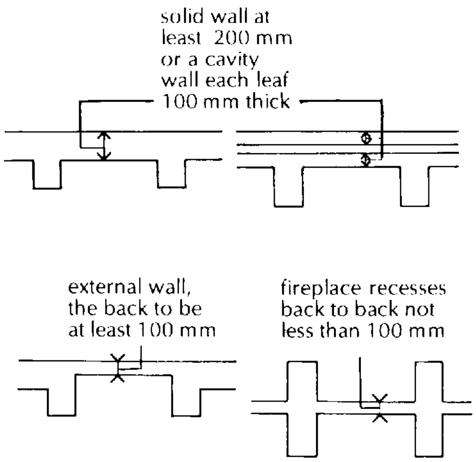


Fig. 191 Thickness at back of fireplace recess.

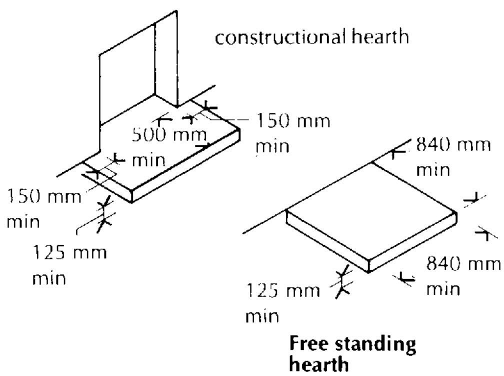


Fig. 192 Constructional hearths.

and dimensions of solid, non-combustible materials in hearths under open fireplaces in, and in front of, open fireplace recesses.

The solid, non-combustible materials to enclose an open fire recess are brick, concrete block or concrete. The least thickness of these materials at the back of a fire place recess should be at least 200 mm of solid walling or each leaf of a cavity wall at least 100 mm and where fireplaces are built back to back at least 100 mm. As illustrated in Fig. 191. In an external wall with no combustible cladding there should be at least 100 mm of solid backing.

The least width of the jambs, 200 mm, at the sides of a fireplace opening is indicated in Fig. 190. This dimension applies whether the jambs project from a wall to support a projecting chimney breast or are part of the wall into which the recess is formed with the chimney breast or chimney projecting from the opposite side of the wall.

There should be an area of solid, non-combustible material in and projecting from fireplace recesses and under stoves, room heaters and other heat producing appliances. Where the floor under the fireplace recess and under heat producing appliances is at least 125 mm thickness of solid concrete the floor may be accepted as a hearth.

The minimum area and thickness of solid, non-combustible hearths in and in front of fireplaces and freestanding hearths are illustrated in Figs. 190 and 192.

Combustible material should not be under a hearth unless it is to support the edges of a hearth or there is an air space of at least 50 mm between the material and the underside of the hearth or there is a distance of at least 250 mm between the material and the top of the hearth.

A freestanding hearth should extend at least 840 mm around the back and sides of an enclosed heat producing appliance.

A heat producing appliance should be separated from combustible materials by some solid non-combustible material 200 mm thick if the appliance is 50 mm or less from the non-combustible material, and 75 mm thick if it is between 50 and 150 mm from the non-combustible material. The non-combustible material should extend at least 300 mm above the top of the appliance.

FLUES

A flue is a shaft or pipe above a fireplace to induce combustion air to flow and carry away the products of combustion. Approved Document J gives practical guidance to meeting the requirements of Part J of Schedule 1 to the Building Regulations for an adequate supply of air to fixed heat producing appliances for combustion and the efficient working of flue-pipes or chimneys.

Section 2 of the guidance, which applies to solid fuel burning appliances with a rated output up to 45 kW, requires a ventilation opening direct to external air of at least 50% of the appliance throat opening area, for open appliances, and at least 550 mm for each kW of rated output.

The requirements for an air supply for combustion, like the requirements for room ventilation, are dictated by the trend over recent years to air sealed windows and doors to contain heat and avoid draughts. The requirement for an adequate air supply for combustion must of necessity suppose a draught of cold outside air entering a room in which an open fire is burning vigorously, unless the fire or appliance is fitted with a separate air intake.

The practical guidance in Approved Document J to the Building Regulations sets out the minimum flue size shown in Table 8.

Table 8 Size of flues.

Installation	Minimum flue size
Fireplace recess up to 500 mm × 550 mm	200 mm diameter or square of equivalent area
Inglenook recess appliances	Free area 15% of area of the recess opening
Open fire	200 mm diameter or square of equivalent area
Closed appliance up to 20 kW output burning bituminous coal	150 mm diameter or square of equivalent area
Closed appliance up to 20 kW output	125 mm diameter or square of equivalent area
Closed appliance above 20 kW and up to 30 kW output	150 mm diameter or square of equivalent area
Closed appliance above 30 kW and up to 45 kW output	175 mm diameter or square of equivalent area

Taken from Approved Document J, The Building Regulations 1991, HMSO.

For maximum efficiency the flue should be straight and vertical without offsets. As the heated products of combustion pass up the flue they cool and tend to condense on the surface of the flue in the form of small droplets. This condensate will combine with brick, block or stone work surrounding the flue to form water-soluble crystals which expand as they absorb water and may cause damage to the chimney and finishes such as plaster and paint. To protect the chimney from possible damage from the condensate, to encourage a

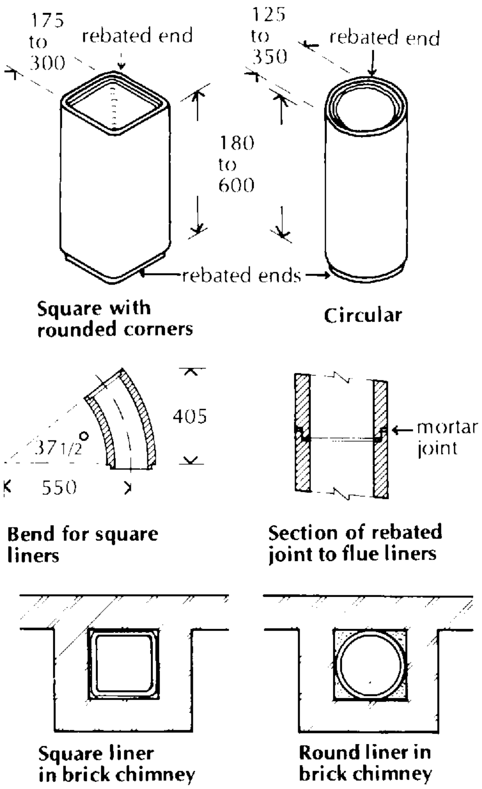


Fig. 193 Clay flue liners.

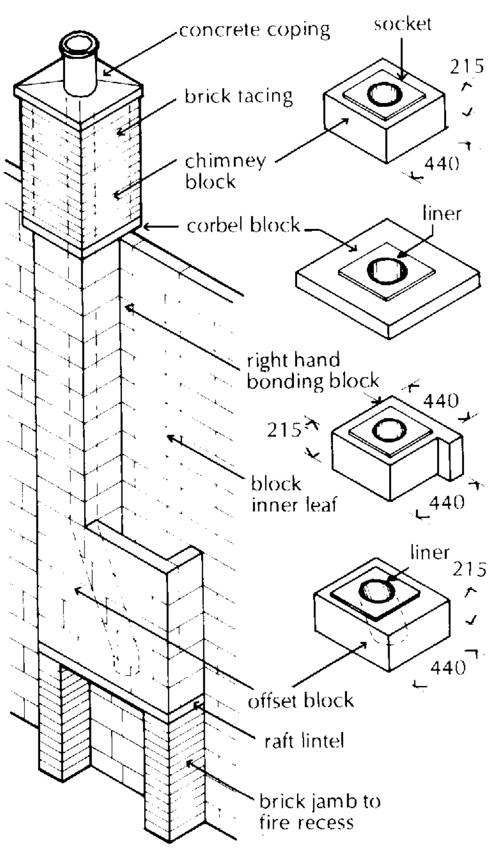


Fig. 194 Precast concrete block chimney.

free flow of air up the flue and to facilitate cleaning the flue, flue liners are built into flues.

Flue liners are made of burnt clay or concrete. Clay flue liners are round or square with rounded corners in section and have rebated ends (Fig. 193). These liners are built in as the chimney is raised and supported on raft lintels over fireplace openings, and the liners are surrounded with mortar and set in place with the liner socket uppermost so that condensate cannot run down through the joint into the surrounding chimney. Bends are made of the same cross sections for use where flues offset.

Concrete flue liners are made of high alumina cement and an aggregate of fired diatomaceous brick or pumice cast in round sections with rebated ends.

Clay drain pipes with socket and spigot ends may be used instead of flue liners. The pipes are set in place as the chimney is raised with the spigot ends of the pipes uppermost. Because of the appreciable projection of the socket ends of these drain pipes a chimney built with them is larger than one with purpose-made flue liners.

Liners should be jointed with fire-proof mortar and spaces between the liners and the brickwork of flues should be filled with a weak mortar or insulating concrete.

The inner leaf of the majority of external cavity walls and most internal walls is built of concrete blocks for the sake of economy. It is convenient to build the chimney breast and chimney to open, inset fires in the same material. To match the dimensions and bonding of concrete blocks, a range of purpose made precast concrete flue blocks is made for building into concrete walls as flue and liner.

These blocks are made in depths to suit standard concrete building blocks and allow for bonding to the surrounding block walling.

Flue blocks are made of expanded clay aggregate concrete with a flue lining of high alumina cement and are rebated and socketed as illustrated in Fig. 194. Both straight and offset blocks are produced to suit bends in flue as shown in Fig. 194.

At the junction of the chimney and the roof, a corbel block is used to provide support for the chimney blocks and the brick facing to the chimney above roof level. The brick facing is used as protection against rain penetration and for appearance sake. A precast concrete coping block caps the chimney and provides a bed for the flue terminal.

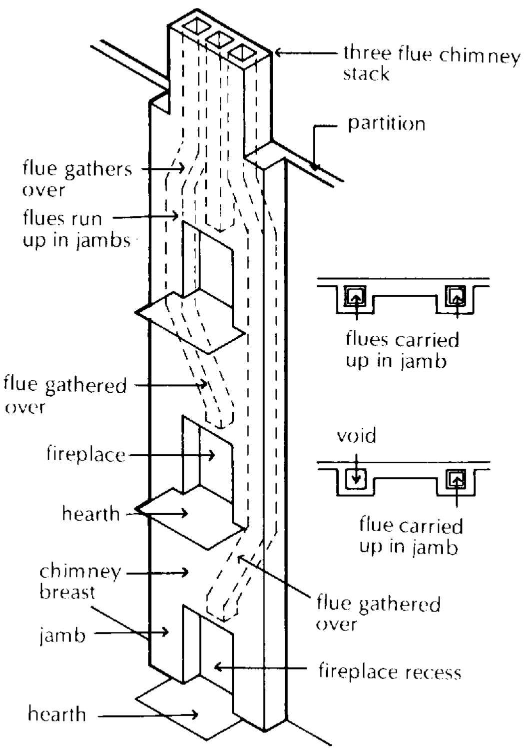


Fig. 195 Chimney to fireplaces on three floors.

Before the use of space heating by oil and gas central heating boilers became general it was common to construct inset, open fireplaces one above the other in multi-storey buildings. To accommodate flues being carried up at the sides of upper level fireplaces it was necessary to construct wide, projecting chimney breasts. An advantage of this arrangement was that the projecting breast would transmit some of the heat from flues to the inside.

As a massive brick pier the chimney breast would provide structural stability to external walls. The considerable weight of the massive chimney breast might also impose so heavy a weight on shallow foundations that settlement cracks appeared at the junction of the chimney breast and the surrounding less heavily loaded walling.

To bypass fireplace openings on floors above, it was necessary to construct flues so that they gathered over to one side to pass upper fireplaces as illustrated in Fig. 195. So that upper fireplaces could be located in the centre of the chimney breast, flues would be gathered over to pass the righthand or lefthand of upper fireplaces with the flue from the uppermost fireplace being carried up straight.

The inside of the traditional brick flue was lined with mortar as the flue was built to provide a smooth lining to assist the flow of combustion gases and air and facilitate sweeping flues to clear soot. This mortar lining of brick flues was termed pargetting. Current Building Regulations call for liners to flues.

When gas burning open fires and gas fired appliances are connected to existing unlined brick built flues it is necessary to line the flue with flexible stainless steel liners that are drawn up the flue and connected to the appliance and a terminal.

Factory made insulated chimneys

As an alternative to constructing a flue for solid fuel burning open fires, room heaters and stoves a purpose made, factory made, insulated chimney may be used. These chimneys are made specifically to be freestanding inside buildings where the appearance of an exposed chimney is acceptable. Because of the neat, unobtrusive appearance and considerable cost of these chimneys they are used freestanding both in new and old buildings.

The advantages of these chimneys are their comparatively small cross section, ease of installation, high thermal insulation which conserves heat, and smooth faces to encourage draught and facilitate cleaning. These flue sections require some support at roof and intermediate floor levels and can be fixed anywhere in rooms.

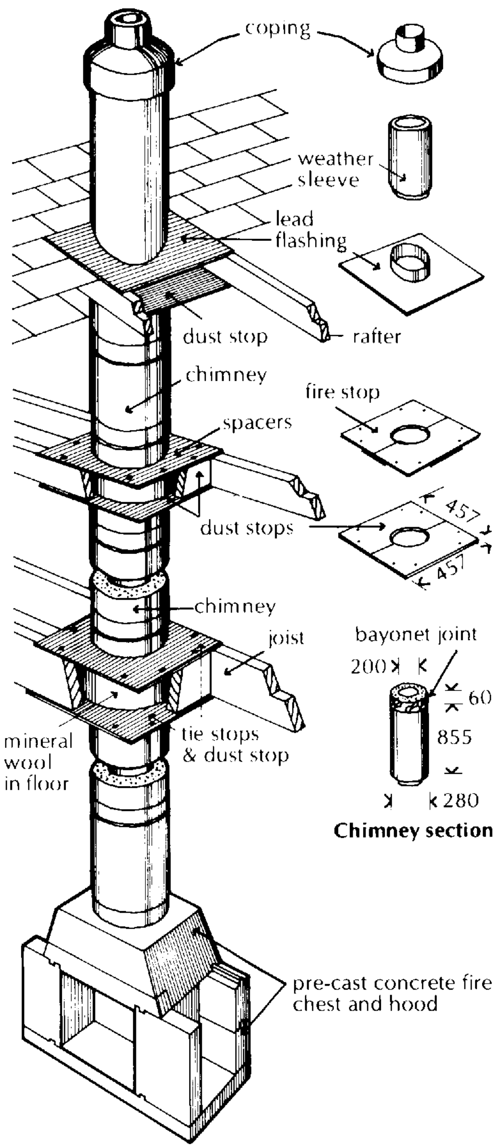


Fig. 196 Factory built insulated chimney.

These factory made chimneys are made in sections that have socket and spigot ends that lock or are clamped together. These sections have stainless steel inner linings and either stainless steel or galvanised steel outer linings around a core of mineral insulation that conserves heat and prevents condensation in the flue. Because of the insulation and construction of these flue sections, structural timbers may be as close as 50 mm to the outside of the flue, which avoids the need for trimming timbers and facilitates supporting the chimney at floor and roof level. Figure 196 is an illustration of factory made chimney sections and fittings.

The cylindrical flue sections are joined with socket and spigot ends that are locked together with a bayonet locking joint. Where the chimney passes through timber floor and roofs, metal fire stop plates, that fit around the chimney, are nailed to the underside and top of the joists around the flue and to timber dust stops nailed between the joists. Mineral wool fibre is packed around the flue sections and the joists and dust stops.

At roof level a lead flashing dressed under the covering and around the flue fits into the spigot end of a weather sleeve section on to which a coping cap is fitted.

Precast, fire resisting concrete sections are used to construct a fire chest for freestanding inset open fires or room heaters. The fire chest comprises a hearth, sides, back and hood on to which the flue sections fit.

Because of the effective insulation between the outer and inner linings of these sections there is little likelihood of the temperature of the outside of the liners being sufficiently hot to cause burns, if touched.

Proximity of combustible materials to chimneys

Combustible materials such as timber floor joists and timber rafters should be separated from flues in brick or blockwork chimneys and fireplace recesses to minimise the possibility of them becoming so hot as to catch fire.

The practical guidance in Approved Document J to the Building Regulations recommends that timber, a combustible material, be at least 200 mm from a flue and 40 mm from the outer surface of a brick or blockwork chimney or fireplace recess unless it is a floorboard, skirting, dado or picture rail, mantelshelf or architrave. Metal fixings in contact with combustible materials should be at least 50 mm from a flue.

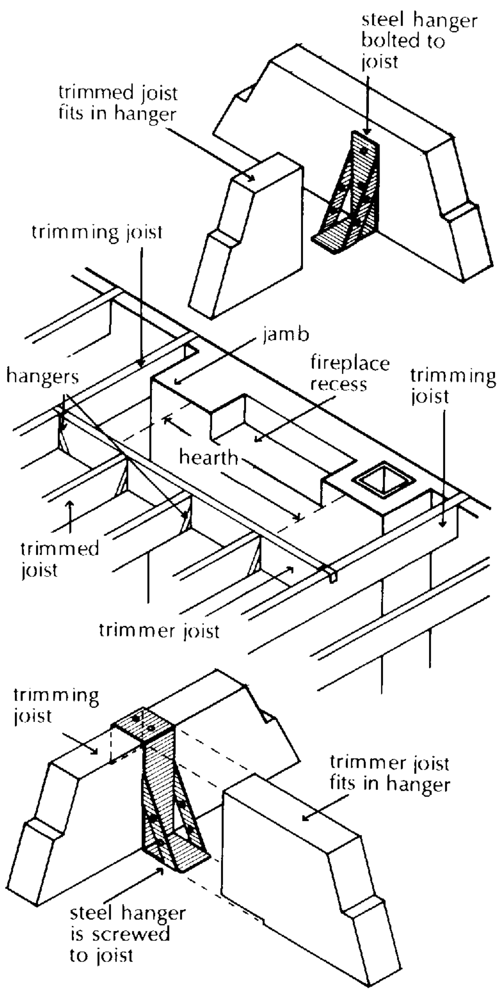


Fig. 197 Trimming floor with metal hanger fixings.

So that a solid incombustible hearth, of concrete, may be formed inside and in front of a fireplace recess in an upper timber floor it is necessary to trim the floor timbers around the hearth. So that no combustible material is closer than 200 mm to a flue it is necessary to build in the ends of trimming joist each side of the chimney breast as illustrated in Fig. 197. The trimmer joist that supports the ends of the trimmed joists is supported by the trimming joists.

The concrete hearth may be a precast concrete slab that is built into the walls surrounding the fireplace recess and supported by a steel shelf angle bolted to the trimmer joist or cast in situ on temporary boarding and supported by a shelf angle bolted to the trimmer joist.

Timber cradling pieces are fixed each side of the projecting hearth to provide support and fixing for the ends of floor boards running into the side of the hearth. These cradling pieces are supported on steel corbel plates built into the chimney breast and the trimmer.

So that there is a strong, secure joint between the trimming, trimmer and trimmed floor joists either pressed steel hangers or the traditional handcut timber joints are used.

For the sake of economy, galvanised steel joist hangers are much used today. The ends of the trimmer joist are supported by steel hangers that fit around the top and sides of the trimming joist to which they are screwed. The trimmer joist end fits into the hanger to which it is nailed. The ends of the trimmed joist may be supported by similar joist hangers or by a joist hanger that is screwed to the side of the trimmer joist as illustrated in Fig. 197.

These steel joist hangers provide a perfectly satisfactory means of support and fixing for timber floor joists.

The traditional handcut joints between timber floor and roof joists were the tusk tenon and the housing joint. The tusk tenon joint is cut with a tenon that fits to a mortice cut on the centre line of the depth of the joists being joined. In this position the mortice will least weaken the strength of the timber which is cut. A tusk and a horn bear in the joined timber and the protruding tenon is secured by a wedge as illustrated in Fig. 198 to make a secure joint.

As it is not practical to use a tusk tenon joint between the trimmed and trimmer joists because of the concrete hearth, a half depth housed joint is used. The ends of the trimmed joists are half depth, square or dovetail housed in matching housings cut in one side of the trimmer joist as illustrated in Fig. 199. The advantage of the dovetail joint is that the dovetail locks the end of the joist firmly in place.

A skilled carpenter can cut and assemble these handcut joints in little time and there is no appreciable cost saving in using steel joist hangers.

Where the outside dimensions of a chimney stack, such as the one flue stack shown in Fig. 188, are less than the spacing of the roof

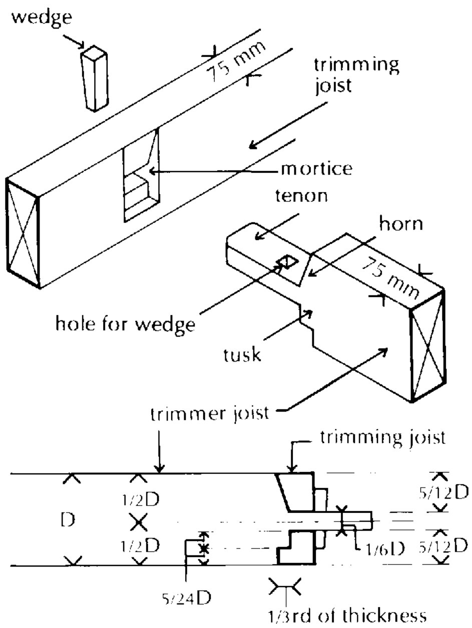


Fig. 198 Tusk tenon joint.

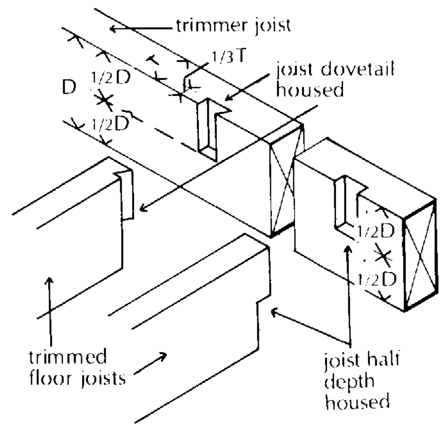


Fig. 199 Methods of housing trimmed joists to trimmer.

trusses, there is no need to trim either the roof or the ceiling timbers around the chimney. Where a chimney stack is wider overall than the spacing of the trusses or rafters it is necessary to trim the timbers around the stack using either timber joints or hangers.

Chimney stacks above roof

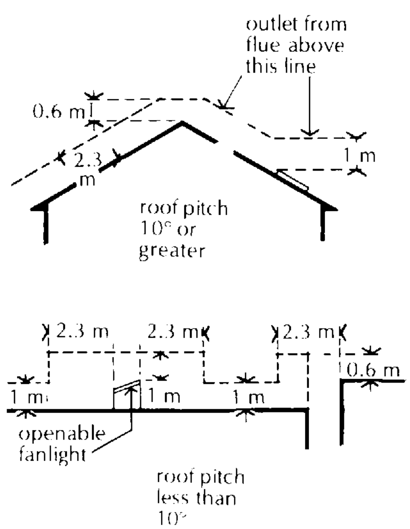


Fig. 200 Outlets from flues.

Chimney stacks are raised above roofs to encourage the products of combustion to rise from the flue to the open air by avoiding down draught. The practical guidance in Advisory Document J to the Building Regulations sets minimum dimensions for the outlet of flues above roof level as illustrated in Fig. 200.

For roofs pitched at less than 10° the outlet of any flue in a chimney or flue pipe should be at least 1 m above the highest point of contact between the chimney or flue pipe, and for roofs pitched at 10° or more should be 2.3 m measured horizontally from the roof surface.

The outlet of any flue in a chimney or flue pipe should be at least 1 m above the top of any openable part of a window or skylight or any ventilator or similar opening which is in the roof or external wall and is not more than 2.3 m horizontally from the top of the chimney or flue pipe.

The outlet of any flue in a chimney, or any flue pipe, should be at least 600 mm above the top of any part of an adjoining building which is not more than 2.3 m horizontally from the top of the chimney or flue pipe.

For the sake of strength and stability the practical guidance in Approved Document A to the Building Regulations sets the least height of masonry chimneys at 4.5 times the least width of chimneys measured from the highest point of intersection of roof and chimney to the top of chimney pots or terminals, where the density of the masonry is greater than 1500 kg/m^3.

Chimney pots, terminals

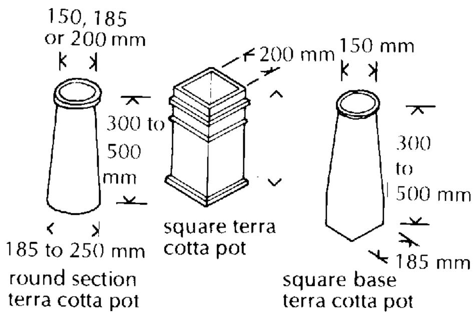


Fig. 201 Flue terminals (chimney pots).

The traditional method of finishing the top of a brick chimney stack above roof is with a chimney pot. Either round or square section chimney pots are used. The purpose of the chimney pot is to provide a smooth sided outlet to encourage the outflow of combustion gases to outside air and to provide a neat terminal to stacks which, with cement and sand flaunching around the pots, will provide resistance to weather. Some typical terra cotta (burned earth) chimney pots are illustrated in Fig. 201.

The internal dimensions of these pots should be similar to that of the flue and the pots should be at least 150 mm high. The pots are bedded in cement and sand on the stack and flaunched around in coarse sand and cement and weathered to slope out as illustrated in Fig. 204.

A variety of chimney pots and galvanised steel terminals is produced with louvred sides, horizontal outlets and metal terminals designed to rotate with changes of wind direction to minimise down draught in flues, caused by deflection of wind due to adjoining buildings, trees and higher adjacent land. These special pots and terminals are generally used in the hope of preventing down draught in flues, more in hope than anticipation.

Resistance to weather

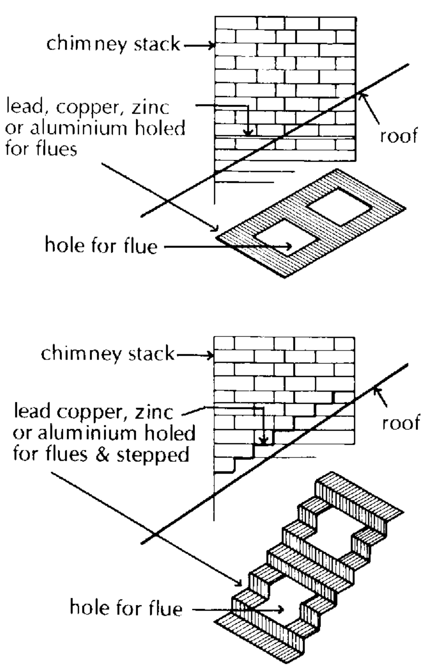


Fig. 202 Damp proof courses in chimney stacks.

A brick or masonry chimney stack above roof level is exposed to wind-driven rain and liable to become saturated with water, particularly in exposed positions. A chimney stack constructed with porous brick or stone may become so saturated that the stack below roof level becomes damp where the natural cycles of wet and dry weather do not cause sufficient evaporation of water.

For exposed positions, chimney stacks built of porous bricks or stone should be separated from the chimney below roof level by some form of damp proof course (dpc). A sheet of lead, holed for flues, should be built in to the chimney stack either in a horizontal course of brick or stone or built in and stepped to coincide with stepped lead flashings as illustrated in Fig. 202.

With the horizontal dpc there will be a small area of brick or stone work above and below the dpc where some dampness may occur. The stepped dpc, which avoids this, involves a considerable degree of additional labour in dressing the lead to shape and cutting of brick or stone to match the steps.

In sheltered positions where more dense and less absorbent brick or stone is used it is probably unnecessary to use a dpc.

WEATHERING AROUND CHIMNEYS

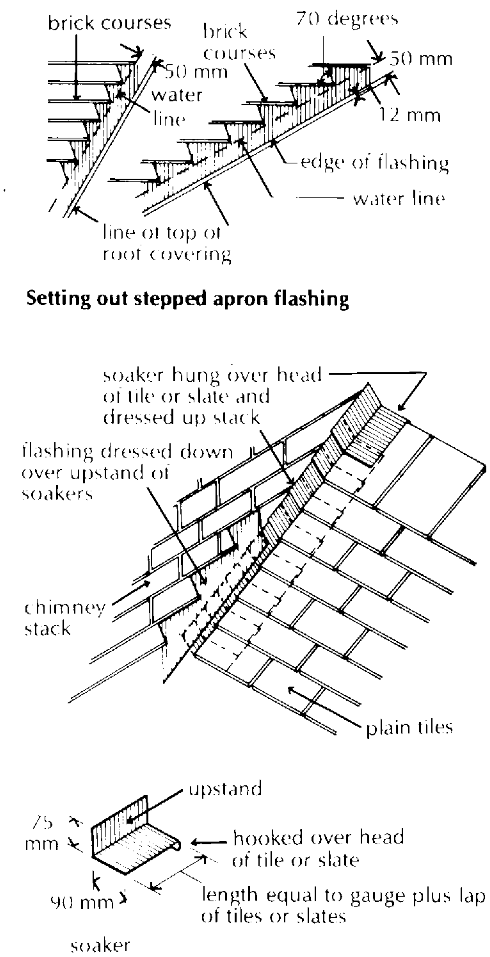


Fig. 203 Stepped flashing and soakers.

At the junction of roof coverings and chimney stacks it is necessary to provide some form of weathering to prevent the penetration of rain into the roof.

The cheapest and most commonly used method of weathering around chimney stacks is to form a fillet of coarse, sharp sand and cement spread and levelled up to the stack and down on to the tile or slate roof covering. The disadvantages of this system of weathering are that the rigid cement and sand fillet will not accommodate the inevitable slight movements of the roof due to wind pressure and moisture and thermal movements and the cement fillet will suffer drying shrinkage and crack.

The best method of excluding rain is to form and fix a system of lead flashings that will accommodate movement between roof and stack.

The junction of pitched roof coverings and brick or stone stacks is weathered by stepped lead flashings that are cut for building into horizontal joints in the form of steps and cut for dressing over lead soakers that are hung over the head of each tile or slate and dressed up under the stepped flashing as illustrated in Figs 203 and 204. The stepped apron flashing overlaps the upstand of soakers by 50 mm and soakers overlap one another by the gauge of the roof covering. The edge of each step of the flashing is wedged into a raked out horizontal brick joint and pointed in mortar.

At the junction of the ridge of the roof and a stack a saddle piece is used and at the front of a stack, which is at right angles to the slope of the roof, a front apron flashing is used as illustrated in Fig. 204. These flashings are tucked into horizontal brick joints, wedged and pointed.

At the junction of side lap roof tiles and a chimney stack the stepped lead flashing is dressed down over the tiles to exclude rain-water as illustrated in Fig. 205. Here there is no need for soakers as the flashing dressed over the roll will suffice.

At the junction of a roof slope down towards a chimney stack it is necessary to form a lead back gutter to collect water running down the slope and divert it to run each side of the stack. The back gutter is shaped out of one sheet of lead to form an upstand, gutter bed and apron to dress under the roof covering as illustrated in Fig. 205. The upstand of the back gutter is weathered by a cover flashing that is tucked into a horizontal brick joint, wedged and pointed and dressed down over the back gutter upstand. The particular advantage of lead as weathering to stacks is that it is malleable and can be shaped to the form of a back gutter without tearing or suffering appreciable loss of thickness.

Lead is the metal, in sheet form, best suited to use as weatherings to stacks and roofs. It is used in thicknesses of number or code 5 or 4 which numbers coincide with the old 5 lb and 4 lb weight of lead.

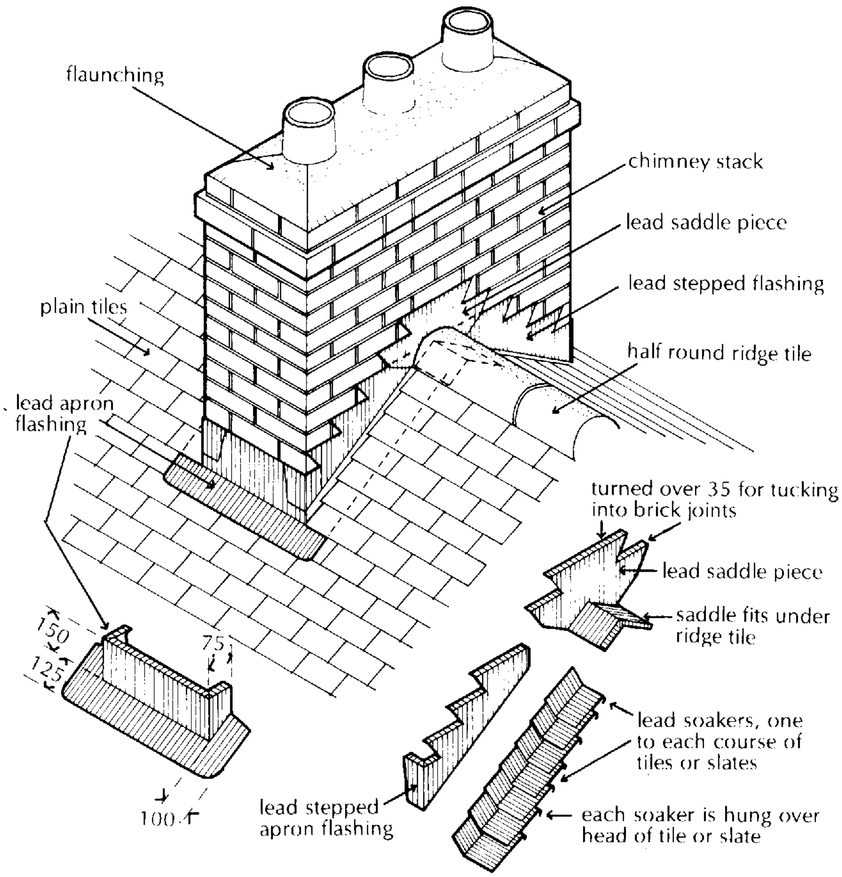


Fig. 204 Lead flashings around chimney stack.

The other metals in sheet form that may be used as weathering around chimney stacks are copper, aluminium or zinc. Copper, which is moderately malleable, suffers the disadvantage that it forms a blue oxide of copper in combination with water, which will be washed on to roof coverings to form an unsightly blue stain. Aluminium is moderately malleable and unlikely to cause stains. Zinc sheet is stiff and difficult to bend and shape as compared to other metals. Its low cost is outweighed by the difficulty in shaping the sheet.

For use as weatherings around chimney stacks above roof, copper, aluminium and zinc sheet are folded to shape around the stack and the back gutter and front apron are completed with a welded or soldered joint as illustrated in Fig. 206. Soakers are folded from metal sheet without difficulty. Because of the difficulty of shaping these sheets of metal and the complication of joints necessary they are much less used than lead sheet.

At the junction of flat roofs and chimney stacks the sheet metal, asphalt or built up felt roofing is dressed up to the sides of the stack with an upstand of about 150 mm.

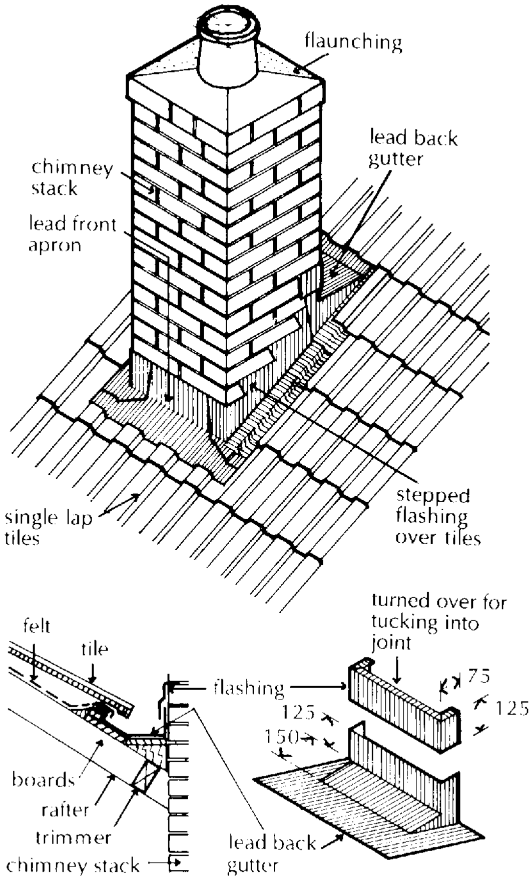


Fig. 205 Single flue chimney stack through one slope of roof.

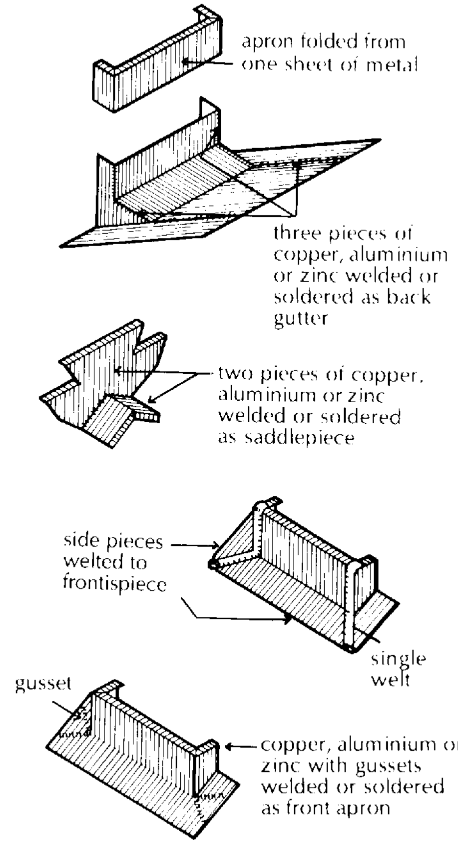


Fig. 206 Non-ferrous metal flashings to chimney stack.

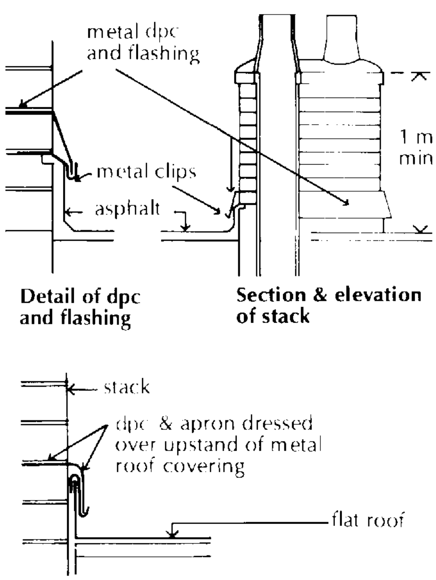


Fig. 207 Weathering of chimney stack and flat roofs.

Asphalt is run up against the stack sides as an upstand that is continued into a groove, purpose cut in a brick joint. The hot asphalt is worked into the groove and the joint later pointed with mortar. This skirting and tuck-in may be a satisfactory weathering for the useful life of asphalt. As a safeguard, a lead flashing may be tucked into a brick joint and dressed down over the asphalt skirting as illustrated in Fig. 207 against the possibility of the top of the asphalt skirting cracking due to movement of the roof relative to the stack.

Sheet metal roof coverings of lead, copper or aluminium are dressed up to the sides of the stack with a 150 mm upstand.

The top edge of the upstand is protected by a flashing, of the same metal as the coverings, which is tucked and wedged into a brick joint and dressed down over the upstand. To prevent the apron flashing being blown up in high wind, strips of the sheet are folded over the top of the upstand and the lower edge of the upstand at 400 mm centres.

With felt roof covering the felt is dressed up to the sides of the stack as a 150 mm upstand and a sheet metal apron flashing is dressed down over the upstand.

Inset open fireplace

An inset open fire is formed in a recess inside a chimney breast or wall under a flue built in the chimney breast. The fire is inset in a recess to contain the burning fuel and is open to transfer heat to the room by radiation and convection and for the benefit of a view of the fire.

Wood burning open fires are often laid to burn inside the fairface brick jambs and back of a recess to provide room for the considerable bulk of wood necessary to provide sufficient heat, particularly for the larger rooms.

Inset open fires for the normal domestic room are generally for burning coal on an iron grate to contain the burning coals and provide some draught of air under and through the coals.

The traditional grate is set in a fireback. Figure 208 is an illustration of a typical fireback, grate and fret. The fireback is made from fire clays, which are clays that contain a high proportion of sand with

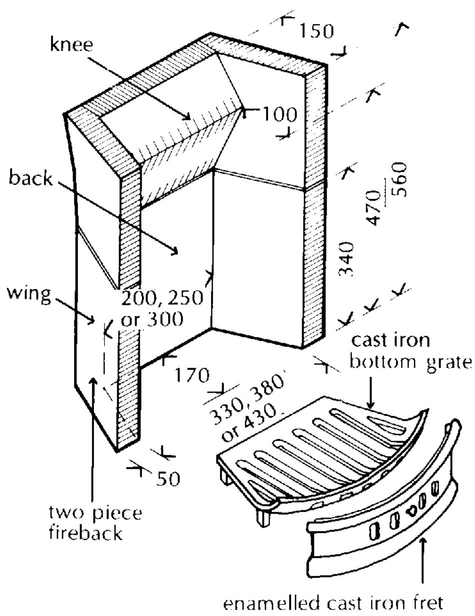


Fig. 208 Fireback, grate and fret for open fire.

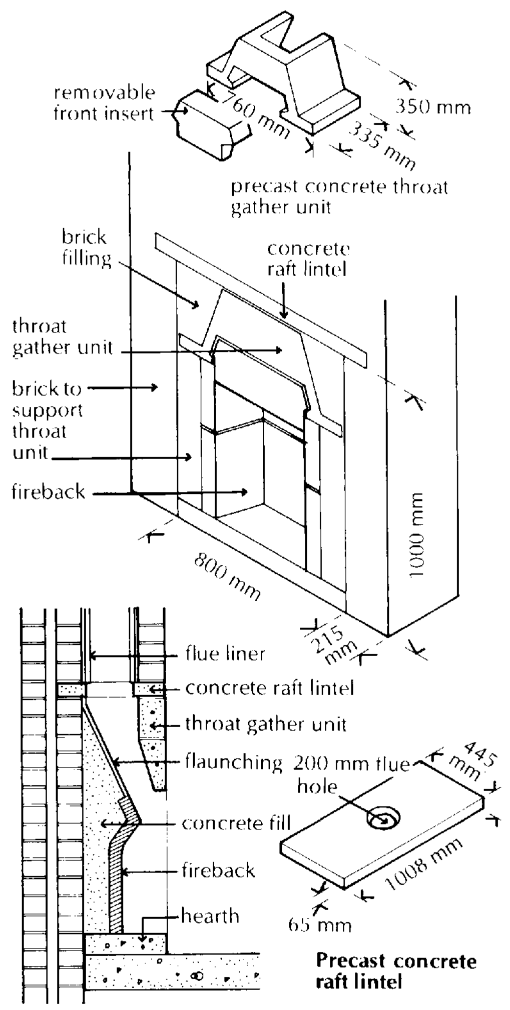


Fig. 209 Precast concrete throat gather unit.

some alumina. The clay is moulded, dried and fired in a kiln. The burned fireclay is able to withstand considerable heat without damage and is used for that reason. The fireback illustrated in Fig. 208 is a standard two-piece fireback for 350, 400 and 450 mm wide open inset fires. The fireback may be in one, two, four or six pieces, the four and six piece backs being made to facilitate replacing an existing damaged fireback.

The fireback is set in position on a level concrete back hearth as illustrated in Fig. 209, and vermiculite concrete fill is cast behind it as insulation and flaunched up to the flue.

To reduce the width of the flue to that of the fireback, brickwork is constructed to gather in, in offset brick courses from the top of the fireback to the width of the flue above. As an alternative a precast concrete throat gather unit may be used. The unit is made in two pieces as a throat unit and a front insert as illustrated in Fig. 209.

When the fireback has been set in place, brickwork is built up in the spaces each side of the fireback and the recess. The throat gather unit is then bedded on the fireback and jamb filling brickwork and the front inset set in place as illustrated in Fig. 209. Brickwork filling is built up between the top of the throat unit and the raft lintel.

The advantage of the throat gather unit is that it provides a smooth surface for the draught of combustion gases up the flue to accelerate updraught.

To support the brickwork of the chimney breast over the fireplace recess a precast, reinforced concrete raft lintel is often used. The lintel, illustrated in Fig. 209, is holed for the flue and is built in, bearing on the jambs of the fireplace opening.

The removable cast iron grate and stove enamelled fret are set in place inside the fireback. The purpose of the fret is to contain the hot embers that fall through the grid of the grate and to adjust the draught through the grate by opening or closing a sliding plate cover to the holes in the fret. This provides a facility to create maximum draught through a newly lit or freshly fuelled fire.

For appearance a fire surround is usually fixed in front of the fireplace opening as illustrated in Fig. 210. The surround is usually set in a chromium plated steel angle, fire frame and the surround may be of any incombustible material such as decorative stone or tiles bedded in cement and sand with the surround contained within a wood surround or returned into the wall.

SUNK HEARTH OPEN FIRE

The traditional open fire draws air from the room in which it is installed with the effect that there will be appreciable draughts of air from gaps around doors and windows when the fire is burning vigorously on a cold, clear day. Such draughts, of what is usually cold air, will cause discomfort to those around the fire and be wasteful of

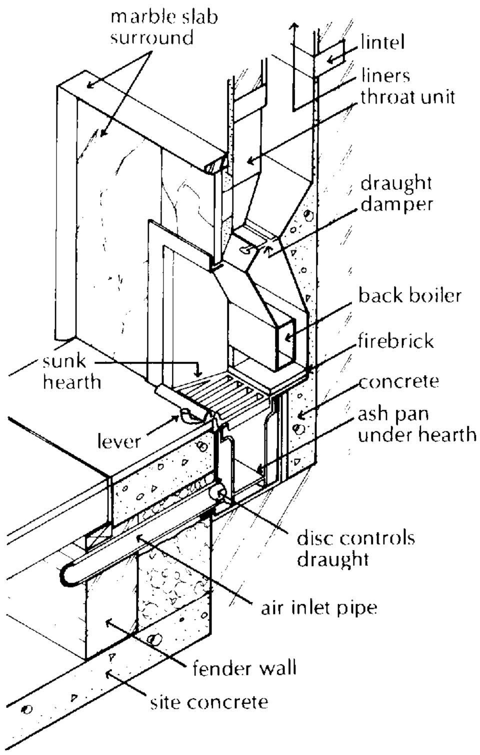


Fig. 210 Sunk hearth open fire.

the heat generated by the fire in drawing air and heat up the chimney.

Where weatherseals are fitted around the opening parts of windows and doors there may well be an inadequate source of replacement air in rooms heated with open fires to the extent that the fire will not burn adequately due to lack of air for combustion.

A sunk hearth open fire is designed to draw air into the fire from outside, independent of the room that is heated. The loose, cast iron fire grate is placed over a sunken pit in which is an ash pan. Outside air is drawn from outside through a pipe laid under a hollow timber floor or below a solid concrete floor. The pipe is run under the floor to a balancing chamber from which pipes are run to the outside on opposite sides of the building.

Where the air inlet pipe connects to the pit below the hearth there is a disc, fitted to swivel inside the pipe and operated by a lever to control air intake. The loose grate can be lifted to take out the ash pan for emptying.

The sunk hearth illustrated in Fig. 210 is fitted with a back boiler, set in place with the fireback, to use heat from the fire that might otherwise be wasted, for heating hot water.

The efficiency of the sunk hearth fire depends on a draught of warmed air flowing up the flue to create reduced air pressure that will cause air from outside to be drawn through the underfloor pipes that should be as straight, short and large as practical.

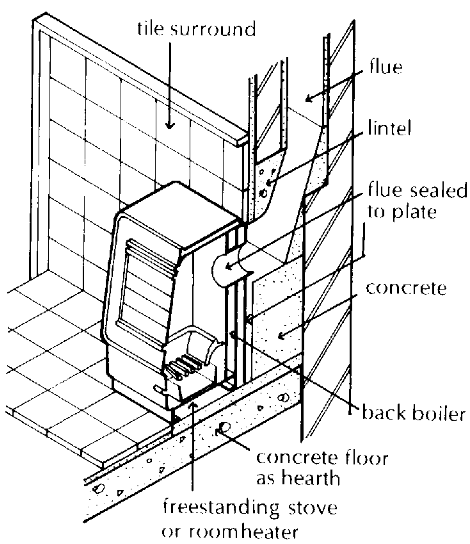


Fig. 211 Freestanding stove.

Room heater, which is the term sometimes used to describe a free-standing stove, may as well be used to describe an electric bulb which is a form of heater. A cast iron stove, which was much used when room heating by solid fuels was more general than it is today, is illustrated in Fig. 211. For maximum efficiency in transferring heat to a room the stove should be freestanding so that energy in the form of heat is transferred by radiation and convection air currents around the whole of the outer surface of the stove.

The stove enamelled stove, illustrated in Fig. 211, is set on a projecting hearth with a steel flue pipe from the back of the stove passing through a hole in the steel register plate, fixed behind the stove, to the flue. A hinged door in the front of the stove is used to fuel the stove. This door is usually covered with a sheet or sheets of mica to provide an awareness of the glow of the fire. Many of the stoves were made with a back boiler that provided a source of heat for water, to augment the domestic hot water supply.

5: Internal Finishes and External Rendering

PLASTER

Plaster is the word used to describe the material that is spread (plastered) over irregular and coarse textured wall and ceiling surfaces to provide a smooth level finish.

History

During the many centuries before Portland cement first came into general use, in the latter part of the nineteenth century, lime was the material used as the matrix (binding agent) for plaster. The advantage of lime is that it is a cheap, readily available material that, used with sand and water for levelling undercoats and by itself with water as a smooth finish, is comparatively easy to spread and level as an interior wall and ceiling finish.

The disadvantage of the material is that it does not provide a hard surface resistant to knocks and over the years it loses strength and is liable to lose adhesion to surfaces on which it is applied.

From the beginning of the twentieth century the then new wonder material Portland cement largely replaced lime as the material used for undercoats of plaster. The advantage of cement is that it sets and dries to form a hard, dense surface coating, resistant to knocks. The disadvantage of cement for plaster is that it is more laborious to spread and level than lime and as it dries it shrinks fiercely and may develop cracks and lose adhesion to weak surfaces over which it is spread.

From the middle of the twentieth century gypsum first came into general use as a material for both undercoat and finish plaster and has by now to a large extent replaced both lime and cement. The advantage of gypsum is that it does not shrink on drying out and it forms a sufficiently dense surface to resist normal knocks. It is supplied pre-mixed for undercoats and is less messy to use than fine, dry lime and cement powder. Gypsum plaster is comparatively easy to spread and level.

The disadvantage of gypsum is that it is more expensive than lime or cement. The cost disadvantage of gypsum should be weighed against the advantages and the fact that the labour cost is appreciably greater than that of materials in plastering.

Old habits die hard and it is not uncommon for cement plaster to be used today on the basis that it forms a hard surface more resistant to knocks than is generally necessary and the mistaken belief that it effectively resists the penetration of damp through porous backgrounds such as brick.

PLASTERING

Plaster is used to render, turn, an uneven surface into a smooth, level surface by plastering (spreading) a material over its surface. The initially wet material is spread and levelled over uneven backgrounds such as brickwork, and over lath fixed to the underside of timber floor joists so that as it hardens and dries it forms a smooth, level wall and ceiling finish.

The purpose of plaster is to provide a smooth, hard, level finish which can be painted for the sake of appearance and as a light coloured finish to gain the advantage of reflected daylight.

Fashions change and it is not uncommon today for one or all of the walls of rooms in modern houses to be finished with brick, block or stone exposed for the sake of the appearance of the materials or with the surface of brick and block wall painted.

Plaster undercoats and finish coat

The finished surface of plaster should be flat and fine textured (smooth). It would seem logical, therefore, to spread some fine grained material, such as lime or gypsum mixed with water, over the surface and trowel it smooth and level. The maximum thickness to which a wet, fine grained material can be spread and levelled is about 3 mm. The irregularities in the surface of even the most accurately laid brick or blockwork are often more than 3 mm and it would be necessary to apply two coats to achieve a satisfactory finish.

Instead of applying a fine grained plaster in two coats to irregular surfaces it is practice to spread some cheaper, coarse grained material that is easily spread as one or two coats to render the surface level and then finish with a thin coat of fine grained material to provide a smooth finish.

The coarse grained coat or coats of plaster are termed undercoats and the fine grained final coat a finish or finishing coat.

Three coat plaster

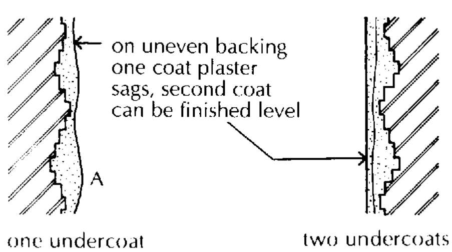


Fig. 212 The advantage of two undercoats.

Before the introduction and use of cement and, later, gypsum for use in plastering, lime was the material used. At the time most external walls were of solid brickwork. Many of the bricks then used were of irregular shape and size so that a solid wall finished flush externally had a particularly irregular inner face which required the use of two undercoats of lime and sand to produce a sufficiently level surface.

If one thick undercoat were spread and levelled on an irregular surface it would tend to sag, as illustrated by line A in Fig. 212, due to the weight of the still plastic, wet plaster. If, however, a thinner first undercoat is spread and allowed to harden, a second undercoat can be spread to take out variations in level as indicated in Fig. 212. The first undercoat was called the render and the second the float coat.

Two coat plaster

Most brick and block external walls today are built as cavity walls with the inner leaf of regularly shaped bricks or blocks whose comparatively regular surface can be successfully plastered in two coats, one undercoat of cement and sand or more usually one gypsum undercoat and one gypsum finish coat.

Dubbing out

Where some part of the surface of brick or block is particularly uneven it is practice to fill the hollows with undercoat plaster up to the general level of the wall face. This practice is termed dubbing out, ready for two coat plaster finish.

One coat plaster

One coat plaster is gypsum plaster which combines the qualities of both undercoat and finish plaster in one product. The material, which is spread and built up by hand to a thickness of 11 to 13 mm thickness on brick and block backgrounds, is progressively trowelled to a reasonably level, smooth matt finish ready for decoration.

The material, which is mainly used as a do-it-yourself (DIY) plaster, can be harder work to apply than a two coat plaster.

MATERIALS USED IN PLASTER

Lime plaster

Lime is mixed with sand and water in the proportion of 1 of lime to 3 parts of sand by volume, with water for use as undercoat and by itself with water as a finish coat.

As lime plaster dries and hardens it shrinks and fine hair cracks may appear on the surface. To restrain shrinkage and to reinforce the plaster, long animal hair is included in the wet undercoat mix, 5 kg of hair being used for every square metre of the lime undercoat (coarse stuff). The resulting haired, coarse stuff is plastic and dries out and hardens without appreciable shrinkage and cracking. Three coat lime plaster is finished to a thickness of about 18 mm.

Lime plaster may be damaged by knocks and in time becomes dry and powdery. As lime is soluble in water it should not be used in damp or moist situations.

Lime plaster is used today in the restoration and preservation of ancient buildings. Many purists insist on the use of original materials in restoration work.

Cement plaster

The properties of Portland cement were described in Volume 1. It is used as a fine grey powder which, when mixed with water, hardens to a solid, inert mass. It is mixed with sand and water for use as an undercoat for application to brick and block walls and partitions. It is used on strong backgrounds as 1 part of cement to 3 or 4 parts of clean, washed sand by volume.

A wet mix of cement and clean sand (sharp sand) is not plastic and requires a deal of labour to spread. It is usual, therefore, to add either lime or more usually a plasticiser to the wet mix to produce a material that is at once plastic and sets and hardens to form a hard surface. Usual mixes are 1 of cement, 1/4 lime to 3 of sand, 1 of cement, 1 of lime to 6 of sand or a mix of 1 of cement to 4 sand with a mortar plasticiser by volume.

Mortar plasticiser

A mortar plasticiser is a liquid that, when mixed with water, effervesces so that tiny bubbles of gas that are generated act to cushion the sharp particles of sand and make the mix plastic and easy to spread.

Cement and sand undercoats are the cheapest in use today.

As an undercoat of cement and sand dries out, it shrinks fiercely and cracks may appear on the surface. In general the more cement used the greater the shrinkage. The extent of the cracking that may appear depends on the strength of the surface to which the plaster is applied and the extent to which the plaster binds to the surface.

For example, the surface of keyed fletton brickwork is strong and affords sufficient mechanical key to restrain shrinkage whereas the surface of lightweight blocks is not strong enough to restrain the shrinkage of cement rich mixes.

A cement and sand undercoat may be used on a backing of hard coarse textured brick and dense blocks. On other brick and block surfaces a mix of 1 of cement, 1/4 lime to 3 of sand may be used and on lightweight blocks a mix of 1 cement, 1 lime to 6 sand. A cement and sand undercoat with a gypsum finish will be spread to a thickness of about 12 mm.

Gypsum plaster

During the last 70 years the use of gypsum plaster has increased greatly for both undercoat and finish plaster to the extent that it has largely replaced lime and cement.

The advantage of gypsum plasters is that they expand very slightly on setting and drying and are not, therefore, likely to cause cracking of surfaces.

Gypsum is a chalk like mineral. It is available as both natural gypsum, which is mined in areas all over the world, and as a synthetic by-product of major industries such as fossil fuelled power stations.

Gypsum is a crystalline combination of calcium sulphate and water ($CaSO_42H_2O$).

Hemihydrate gypsum plaster (plaster of Paris)

When powdered gypsum is heated to about 170° C it loses about three quarters of its combined water and the result is described as hemihydrate gypsum plaster ($CaSO_4\frac{1}{2}H_2O$). This material is better known as plaster of Paris.

Anhydrous gypsum plaster

When gypsum is heated to a considerably higher temperature than 170°C it loses practically all its combined water and the result is anhydrous gypsum plaster.

British Standard 1191

British Standard 1191 Parts 1 and 2 cover the manufacture of all traditional and modern gypsum based plasters.

It is convenient to categorise gypsum plasters relative to their use as wall and ceiling plasters as casting, undercoat, finish, one coat and machine applied plasters.

Casting plaster

Finely ground hemihydrate gypsum (plaster of Paris) when mixed with water sets and hardens so quickly (about 10 minutes) that it is unsuitable for use as a wall or ceiling plaster. It is ideal for making plaster casts for medical casts and cast plaster work for buildings.

Wet plaster of Paris is brushed into moulds to provide cornices and other decorative plaster work. The wet plaster is usually reinforced with open weave hessian and is generally referred to as fibrous cast plaster or fibrous work.

Undercoat plaster

To provide a solid, true background as an undercoat for finish plaster for wall and ceiling surfaces, pre-mixed gypsum plaster is the generally preferred material used today.

Retarded hemihydrate gypsum plaster

The gypsum used for undercoats is retarded hemihydrate gypsum in which a retarding agent is added to plaster of Paris to delay the setting time for $1\frac{1}{2}$ to 2 hours to allow time for spreading and levelling the wet material as undercoat.

For general use as an undercoat the retarded hemihydrate gypsum powder is mixed with lightweight aggregates, such as expanded perlite or vermiculite, as a dry mix powder which is delivered to site in bags as pre-mix undercoat.

Pre-mix gypsum undercoat

The advantage of this material is that the pre-mix avoids the messy, wasteful operation of mixing dry powdered lime or cement with sand. The wet mix is comparatively easy to spread and level and the lightweight aggregate gives a small degree of thermal insulation. A disadvantage of the material is that the lightweight aggregate may not provide adequate resistance to damage by knocks.

This material is applied as one undercoat to a finished thickness of 8 to 11 mm.

In addition to the standard lightweight aggregate undercoat, other gypsum undercoat plasters are produced for specific background and use situations.

Bonding undercoat

Where the undercoat plaster is to be applied to a surface with particularly low suction, which does not readily absorb water, gypsum bonding undercoat is formulated to provide adequate adhesion.

High impact undercoat

In some situations where it is anticipated that rough or careless usage may damage standard undercoat plaster, high impact gypsum undercoat is used. A dense aggregate such as grains of silica are used in the pre-mix in lieu of the usual lightweight aggregate to provide improved resistance to knocks.

Finish plaster

Finish plaster is powdered, retarded hemihydrate gypsum by itself for use as a thin finish coat for both gypsum undercoats and to plasterboards. Mixed with water the plaster is spread and finished to a thickness of about 2 to 5 mm and sets in about 1 to 2 hours. This plaster, which is polished to a smooth surface, is also used as a finish to cement and sand undercoats.

Anhydrous gypsum plaster

Anhydrous gypsum plaster was commonly used as a thin finish coat to cement based undercoats. The powdered gypsum is mixed with a mineral sulphate to accelerate its set, which otherwise would be so slow as to make it unsuitable for use as a finish plaster.

A characteristic of this gypsum plaster is that it can be brought back (retempered) by sprinkling the stiff surface to make it plastic for trowelling smooth. Because of its characteristic of being brought back, this finish is unsuited for use in damp or moist situations. This finish is less used than it was.

One coat gypsum plaster

One coat plasters are retarded hemihydrate plasters which combine the properties of an undercoat and a finish coat. One coat is applied to a thickness of up to 20 mm as an undercoat. As the plaster begins to set (stiffen) it is sponged with water and trowelled to bring the fine particles to the surface so that it may have a finish comparable to that of a separate finish coat.

Because of the considerable labour required to build up and level the surface, this plaster is not extensively used.

Machine applied gypsum plaster

Machine applied, or projection, plasters are one coat gypsum plasters designed to provide a longer setting time to allow for mixing, pumping, spreading and trowelling. The material is mixed with water, pumped and applied to the wall by a projection machine which effectively halves the application time it would take to spread by hand.

As the wet plaster covers the wall it is treated in the same way as one coat plaster by trowelling level and smooth.

Because of the additional labour in mixing and pumping and the necessary work of cleaning equipment after use, this type of plaster may be most economically used on large flat areas of wall.

BACKGROUND SURFACES FOR PLASTER

The surface of walls to be plastered will affect the type of plaster used and its application.

The surface of rough textured bricks and concrete blocks and the face of keyed fletton bricks afford a key for the mechanical adhesion of plaster to the background wall. As the wet plaster undercoat is spread and pressed into the surface, wet plaster fills the irregularities and the key in flettons so that as it hardens it forms a mechanical key to the background.

Key for plaster

With smooth faced bricks or blocks the mortar joints should be raked out some 12 mm, as the wall is built, to provide a key for plaster. An advantage of the key is that it will restrain shrinkage of cement based undercoats.

Suction

Dense, smooth wall surfaces such as concrete and machine pressed bricks do not readily absorb water to the extent that a normal wet plaster will not adhere as it is spread, through lack of suction. The word suction is used to describe the degree to which a surface will absorb water and so assist in the adhesion of plaster to a surface.

Some lightweight concrete blocks readily absorb water and have high suction to the extent that wet plaster applied to them may lose so much water that it is difficult to spread and may not fully set due to loss of water. Suction may be reduced by spraying the surface with water prior to plastering or by the use of a liquid primer.

The most straightforward way of testing the suction of a surface is to spray it with water to judge the degree of absorption of water. There are liquid pre-treatments that can be applied to control the suction of surfaces.

PVA bonding agent

There are two main types of treatment to improve the adhesion of plaster to surfaces with low suction, such as concrete, to avoid the laborious process of hacking the surface to provide a key.

The first is based on polyvinyl acetate (PVA) which is brushed or sprayed on to the surface. The plaster is applied before the PVA has fully dried and is still tacky. The tackiness provides the bond.

Polymer bonding agent

The second pre-treatment is polymer based and incorporates silica sand. Once the polymer is fully dry the plaster is applied and gains bond through the silica grains and does not, therefore, depend on applying plaster as soon as the bonding agent is tacky.

Where suction is high, as with lightweight blocks, the suction may be controlled by spraying with water or by spraying the surface with a liquid primer designed for the purpose.

Reinforcement for angles

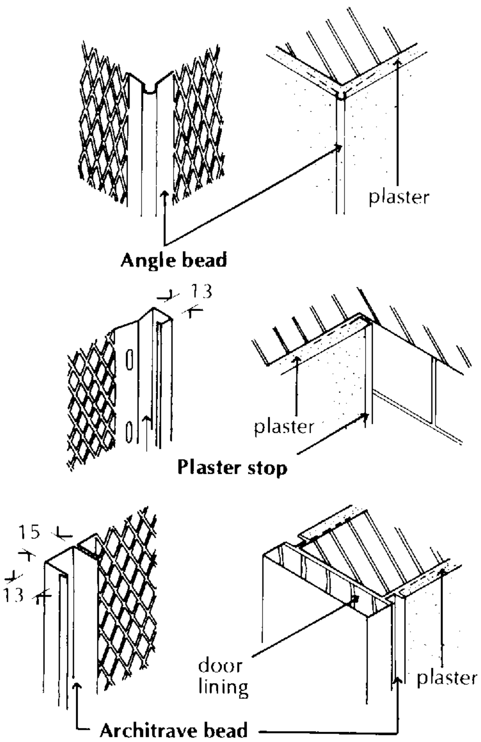


Fig. 213 Metal beads and stops for plaster.

A range of galvanised steel beads and stops is made for use with plaster and plasterboard as reinforcement to angles and stops at the junction of wall and ceiling plaster and plaster to other materials.

An angle bead is pressed from steel strip to form reinforcement to angles. The bead has expanded metal wings, as shown in Fig. 213. The wings of the bead are bedded in plaster dabs each side of the angle. The bead is then squared and plaster run up to it (Fig. 213).

A metal stop with an expanded metal wing is pressed from steel strip and used as a stop to make a neat finish at the junction of plaster with other materials at angles, skirtings and around doors and windows, as illustrated in Fig. 213. The stop is either bedded in plaster or nailed to timber and the plaster is run up to the stop. These stops make a neat, positive break at junctions that would otherwise tend to crack or require some form of cover mould or bead to mask the joint. They are particularly useful at the junction of ceiling plaster or board on timber joists and wall plaster or fairface finishes where a crack might open at the junction of plaster to another material which would be untidy.

Another bead or stop is designed for use at the junction of plaster and door and window frames to provide a definite break in surface between different materials, as illustrated in Fig. 213. The stop is either bedded in plaster dabs or nailed to wood.

The advantage of these beads is that they act as a break at the junction of dissimilar materials where they will mask any crack that may open. They are used instead of architraves.

PLASTER FINISHES TO TIMBER JOISTS AND STUDS

The traditional method of forming a level finished surface to the ceiling of timber floors and roofs and to stud partitions was to spread plaster over timber lath. This laborious procedure has for the last 70 years been abandoned in favour of the use of gypsum plasterboard.

Fir lath

Before the twentieth century the usual method of preparing timber ceilings and timber stud walls and partitions for plaster was to cover them with fir lath spaced about 7 to 10 mm apart to provide a key for the plaster. The usual size of lath is 25 mm wide by 5 to 7 mm thick, in lengths of 900 mm. The lath is either split or sawn from Baltic fir (soft wood). Split lath is usually described as riven lath and is prepared by splitting along the grain of the wood. Because the grain of the wood is never absolutely straight neither is riven lath, so that when it is fixed the spaces left between the laths as a key for the plaster are not uniform. This may prevent the plaster being forced

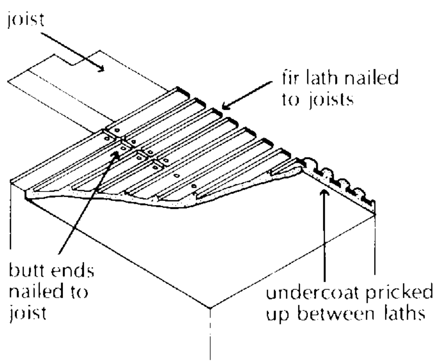


Fig. 214 Fir lath and plaster.

between the laths and it will not therefore bind firmly to them. Sawn lath, on the other hand, is uniformly straight and can be fixed with uniform spaces to give a good key for plaster. Fir lath must be adequately seasoned and free from fungal decay. The fir lath is nailed across the joists or timber studs. Obviously the ends of the laths must be fixed to a joist or stud, as illustrated in Fig. 214, and the butt end joints of laths staggered to minimise the possibility of cracks in the plaster along the joints.

Fir lath is covered with three coats of plaster. The first coat is spread and forced between the lath so that it binds to it. This coat is described as pricking up. A second undercoat, termed the float coat, is spread and finished level and then covered with the finish or setting coat.

Before the twentieth century the undercoats consisted of haired coarse stuff (1 part lime to 3 parts sand, with hair) gauged with plaster of Paris, and the finishing coat of lime and water gauged with plaster of Paris. The purpose of the gauge (addition of a small amount) of plaster of Paris is to cause the material to harden more quickly so that vibration due to the applications of the next coat, or vibrations of the floor above, will not cause the plaster to come away from the lath before it is hard.

The cost of fir laths and three coats of plaster today is about three times that of a plasterboard finish and in consequence is less used than it was other than for restoration work.

Metal laths (EML)

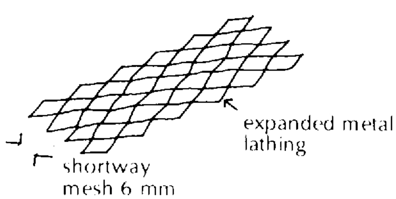


Fig. 215 Expanded metal lathing.

This lath is made by cutting thin sheets of steel so that they can be stretched into a diamond mesh of steel, as shown in Fig. 215. This lath is described as EML (expanded metal lath). The thickness of the steel sheet which is cut and expanded for plasterwork is usually 0.675 mm and the lath is described by its shortway mesh. A mesh of 6 mm shortway is generally used for plaster. To prevent expanded steel lath rusting it is either coated with paint or galvanised. As a background for plaster on timber joists and studs, the lath, which is supplied in sheets of 2438 × 686 mm, is fixed by nailing with galvanised clout nails or galvanised staples at intervals of about 100 mm along each joist or stud. During fixing, the sheet of lath should be stretched tightly across the joists. Edges of adjacent sheets of the lath should be lapped at least 25 mm.

Metal lath was originally used as a substitute for fir lath. It may be used as a base for three coat lime plaster. It was much used in the late nineteenth and early twentieth century as a base for cement and sand undercoats with a gypsum finish to ceilings. It was, and still is, used to some extent as a background for ceilings suspended below concrete floors and as a base for shaped, decorative plaster.

GYPSUM PLASTERBOARD

Gypsum plasterboard consists of a core of set (hard) gypsum plaster enclosed in and bonded to two sheets of heavy paper. The heavy paper protects and reinforces the gypsum plaster core which otherwise would be too brittle to handle and fix without damage. Plasterboard is made in thickness of 9.5 mm, 12.5 mm, 15 mm and 19 mm for use either as a dry lining or as a background for plaster in boards of various sizes.

Plasterboard is extensively used as a lining on the soffit (ceiling) of timber floors and roofs and on timber stud partitions. The advantage of this material as a finish is that it provides a cheaper finish and can be fixed and plastered more speedily than lath and plaster. All gypsum plasterboards have inherently good fire resisting properties due to the incombustible core. The disadvantages are that, because it is a fairly rigid material, it may crack due to vibration or movement in the joists to which it is fixed, and it is a poor sound insulator. Many types of gypsum plasterboard are made for specific applications as dry linings.

Gypsum wallboard

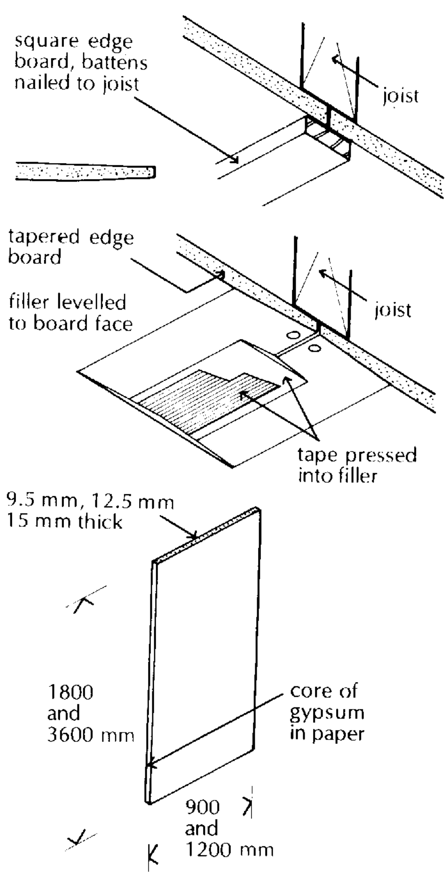


Fig. 216 Gypsum wallboard.

Gypsum wallboard, which is the most commonly used board, is principally made for use as a dry lining wallboard to timber or metal stud frames with the joints between the boards filled ready for direct decoration.

The boards have one ivory coloured surface for direct decoration and one grey face. The boards are 9.5, 12.5 and 15 mm thick, from 900 mm wide and up to 3600 mm long as illustrated in Fig. 216. The length of the boards is chosen as a multiple of standard timber joist or stud spacings such as 400 or 450 mm to minimise wasteful cutting of boards.

The boards are made with two different edges as illustrated in Fig. 216, tapered for smooth seamless jointing and square for cover strip jointing.

Wallboard is fixed to timber or metal supports with its length at right angles to the line of joists or studs. Timber or metal noggins are fixed between supports to provide support and fixing for the ends of boards which do not coincide with a support. Noggins are short lengths of timber, 50 × 50 mm in section, nailed between supports.

The boards are fixed with galvanised nails, 30 mm long for 9.5 mm and 40 mm long for 12.5 mm thick boards, or self tapping screws for metal studs. Nails and screws should be driven home to leave a shallow depression ready for spot fitting.

Square edged boards are designed for use with a cover strip over all joints either for a panelled effect or for demountable partitions. Wood, metal or plastic strips are nailed or glued over joints.

It is not uncommon for wallboard to be used as a base for a thin skim coat of gypsum plaster even though the smaller baseboard is more convenient to use, particularly to ceilings.

Tapered edge boards are made for jointing with a smooth, flush finish ready for direct decoration. The shallow depression at the joint between boards is first filled with joint filler, made of gypsum and water, into which a 50 mm wide paper jointing tape is pressed. The joint is completed with filler which is finished flush with the board as illustrated in Fig. 216. Nail heads are covered with filler, finished smooth as spot filling.

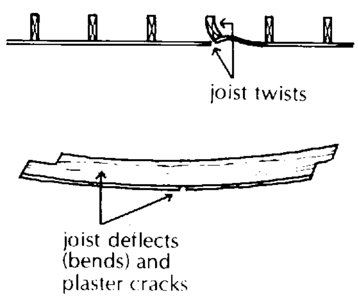


Fig. 217 Cracking in plasterboard finishes.

The principal causes of cracking in these finishes are twisting and other moisture movements of timber joists or studs to which they are fixed and deflection of timber joists under load. New timber is often not as well seasoned as it should be and as the timbers dry out they tend to shrink and lose shape. Joists may wind (twist) and cause the rigid boards fixed to them to move and joints open up as illustrated in Fig. 217. Strutting between joists will restrain movement and minimise cracking.

Under the load of furniture and persons, timber floor joists bend slightly. The degree to which they bend is described as their deflection under load. Even with very small deflection under load a large rigid plasterboard will bend and cracks appear at joints as illustrated in Fig. 217. One way of minimising cracking with large boards is to use joists some 50 mm deeper than they need be to carry the anticipated loads. This additional depth of joist reduces deflection under load and the possibility of cracking. Baseboard, made specifically for a plaster finish, is smaller than full size wallboard and may, therefore, be less liable to show cracks due to shrinkage and movement cracks.

Gypsum baseboard

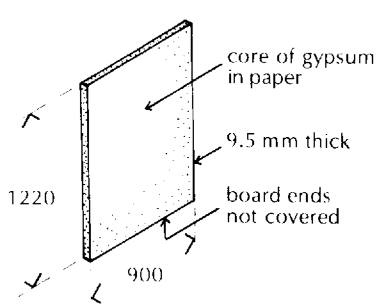


Fig. 218 Gypsum baseboard.

Gypsum baseboard is designed specifically for use as a base for gypsum plaster. The boards are 9.5 mm thick, 900 mm wide and 1220 mm long, and are chosen for use as ceiling lining for their manageable size. The boards have square edges as illustrated in Fig. 218.

The boards are fixed with 30 mm nails at 150 mm centres with a gap of about 3 mm at joints. The joints are filled with filler into which reinforcing paper tape is pressed and the boards are covered with board finish gypsum plaster that is spread and trowelled smooth to a thickness of 2 to 5 mm as illustrated in Fig. 219.

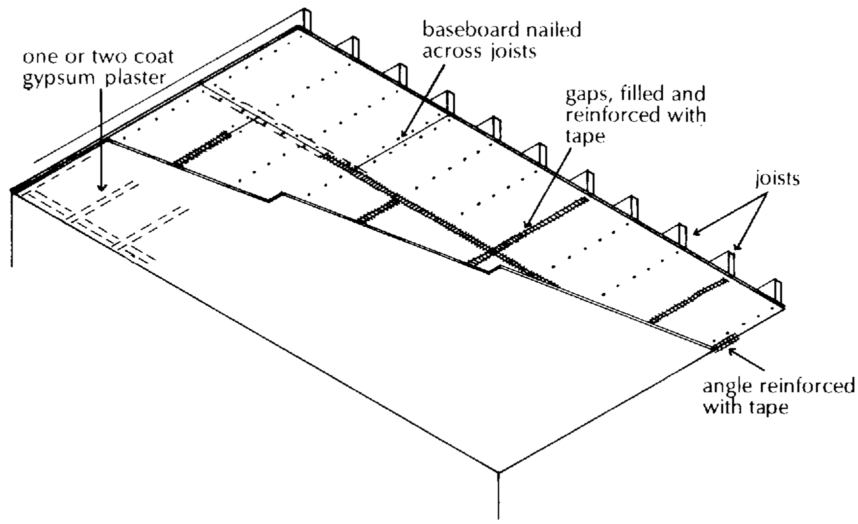


Fig. 219 Fixing baseboard for plastering.

Gypsum plank

Gypsum plank is 19 mm thick, 600 mm wide and 2350 and 3000 mm long with either tapered edges for seamless jointing for direct decoration or square edges for plastering. This thicker board, which may be used for enhanced fire resistance or a small increase in sound insulation, may be fixed at 600 mm centres with 60 mm nails.

For direct decoration the tapered edge boards are jointed and finished as described for wallboard. For plastering the square edge boards are fixed with a gap of about 3 mm into which plaster or filler is run and reinforced with 50 mm wide paper tape. Gypsum finish plaster is then spread over the surface of the boards, levelled and trowelled to a smooth finish to a thickness of 2 to 5 mm.

Gypsum lath

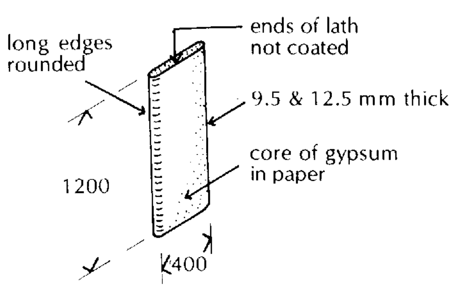


Fig. 220 Gypsum lath.

These comparatively small boards are made specifically as a base for ceiling lining for the ease of holding and fixing and as a base for plaster either as a thin skim coat or more particularly for a two coat finish. The two coat finish is preferred as the undercoat will facilitate accurate levelling over the many joints.

Lath is 400 mm wide, 1200 mm long and 9.5 and 12.5 mm thick. The long edges of the boards are rounded as illustrated in Fig. 220. The lath is fixed to timber joists and ceiling with a gap of not more than 3 mm between boards. The joints do not have to be reinforced with tape. The lath is covered and finished with one finish coat to a thickness of up to 5 mm or more, usually with a gypsum undercoat 8 mm thick and a finish coat of about 2 mm thickness.

The thicker board with a two coat gypsum plaster finish will provide improved resistance to fire and some increase in sound insulation.

SKIRTINGS AND ARCHITRAVES

Skirting

A skirting is a narrow band, usually projecting, formed around the base (skirt) of walls at the intersection of wall and floor. It serves to emphasise the junction of vertical and horizontal surfaces and is made from some material sufficiently hard to withstand knocks.

The types of skirting commonly used are timber, metal, tile and Magnesite.

Timber skirting board

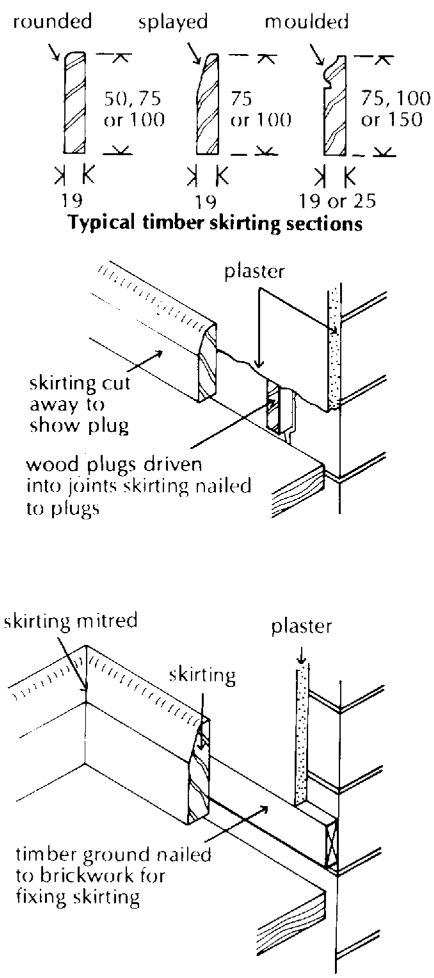


Fig. 221 Fixing timber skirtings.

A timber skirting is the traditional finish used at the junction of timber floors and plastered walls, to mask the junction of floor finish and plaster which would, if exposed, look ugly and collect dirt.

Soft wood boards, 19 or 25 mm thick, from 50 to 150 mm wide and rounded or moulded on one edge are generally used. The skirting boards are nailed to plugs, grounds or concrete fixing blocks at the base of walls after plastering is completed. Figure 221 illustrates some typical sections of skirting board and the fixing of the board.

Plugs are wedge-shaped pieces of timber which are driven into brick or block joints from which the mortar has been cut out as illustrated in Fig. 221. This rough method of providing a fixing is usually unsatisfactory as it is not always possible to drive the wedge into a joint without damage and it is difficult to ensure that the face of the plug finishes at the required level. Nailing into the end grain of the wood plug may not provide a secure hold.

An alternative is to nail soldiers to the wall. Soldiers are short offcuts of sawn soft wood timber 38 or 50 mm wide and the same thickness as finished plaster. The soldiers are fixed vertically at intervals of 300 to 400 mm apart as a fixing for the skirting board. Soldiers, which provide a more secure fixing than plugs, are laborious to fix.

Grounds are small section lengths of sawn soft wood timber, 38 or 50 mm wide and as thick as the plaster on the wall. These timber grounds are nailed horizontally to the wall as a background to which the skirting can be nailed as illustrated in Fig. 221. Grounds are generally fixed before plastering is commenced so that the plaster can be finished down on to and level with them.

Concrete fixing blocks are either purpose made or cut from lightweight concrete building blocks and built into brick walls at intervals of 300 to 400 mm as a fixing for skirtings.

A recently used method of fixing wood skirtings is to run wall plasters down to floor level and fix the skirting with an adhesive directly to the plaster. The contact adhesive is spread on the back of the skirting and the plaster from a hand operated cartridge gun. These adhesives provide a secure bond to plaster. With long runs of skirting it is probably wise to supplement the adhesive bond with two or more screws, driven through the skirting into plugs in the wall to resist such shrinkage twisting of the wood skirting that may occur and would otherwise pull the skirting from its adhesive fixing.

Metal skirting

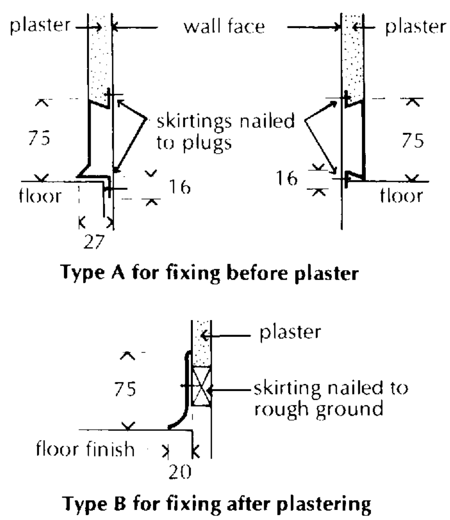


Fig. 222 Metal skirtings.

The traditional wood skirting was initially used to mask the joint between wall plaster and timber floor finishes where it was impossible to make a neat joint between lime plaster and boarded floors.

The more solid cement and sand and gypsum and sand undercoats and gypsum finish used today for plaster are less liable to shrinkage cracking and may be finished directly on to solid floor finishes or down on to pressed metal skirtings. These metal skirtings are used as a finish which is less liable to damage by knocks at floor level than plaster and coincide with the fashion for plain unornamented finishes such as plaster stops around door frames and linings.

A range of pressed steel skirtings is manufactured for fixing either before or after plastering. The skirting is pressed from mild steel strip and is supplied painted with one coat of red oxide priming paint. Figure 222 illustrates these sections and their use.

It will be seen that the skirting is fixed by nailing it directly to lightweight blocks or to plugs in brick and block joints or to a timber ground. Special corner pieces to finish these skirtings at internal and external angles are supplied.

These skirtings may be painted in with wall finishes or a different colour and type of paint, such as gloss or eggshell finish for the facility of cleaning by washing.

Tile skirting

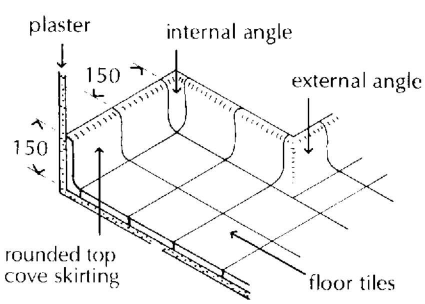


Fig. 223 Tile skirting.

The manufacturers of floor quarries and clay floor tiles make skirting to match the colour and size of their products. The skirting tiles have rounded top edges and a cove base to provide an easily cleaned rounded internal angle between skirting and floor.

The skirting tiles are first thoroughly soaked in water and then bedded in sand and cement against walls and partitions as the floor finish is laid. Special internal and external angle fittings are made. Figure 223 illustrates the use of these skirting tiles.

Skirting tiles make a particularly hardwearing, easily cleaned finish at the junction of floor and walls and are commonly used with quarry and clay tile finishes to solid floors in rooms and places where the conditions are wet and humid, such as kitchens, bathing areas and laundries. To avoid excessive condensation on smooth, hard surfaces such as tiles, they should be applied to floor and external walls surfaces that are adequately insulated.

Magnesite and anhydrite skirtings

When solid floors are finished with one of the jointless floor finishes such as magnesium oxychloride or anhydrite it is quite usual for the material to be used as a skirting with a cove formed at the junction of floor and skirting. As with cove tile skirtings this makes a neat, easily cleaned finish.

Architrave

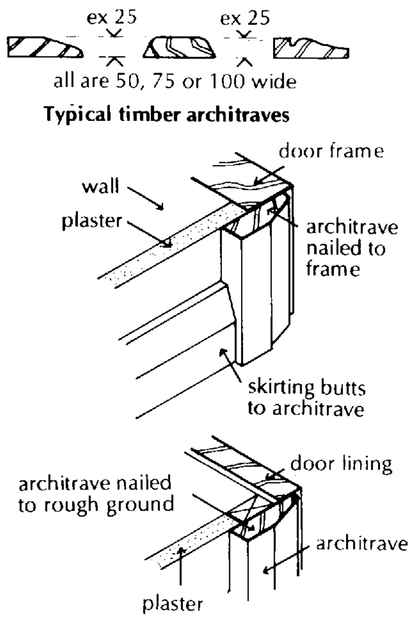


Fig. 224 Architraves.

The word architrave describes a decorative moulding fixed or cut around doors and windows to emphasise and decorate the opening. An architrave can be cut or moulded on blocks of stone, concrete or clay, built around openings externally. Internal architraves usually consist of lengths of moulded wood nailed around doors and windows. An internal wood architrave serves two purposes, to emphasise the opening and to mask the junction of wall plaster and timber door or window frame. If an architrave is not used an ugly crack tends to open up between the back of frames, linings and wall plaster. It is to hide this crack that the architrave is fixed.

A timber architrave is usually 19 or 25 mm thick and from 50 to 100 mm wide. It may be finished with rounded edges, or splayed into the door or decorated with some moulding. Usual practice is to fix architraves so that they diminish in section towards the door or window. Narrow architraves can be fixed by nailing them to the frame or lining of the door or window. Wide architraves are usually fixed to sawn soft wood grounds nailed to the wall around the frame or lining as a background to which the architrave can be securely nailed. Architraves are mitre cut (45° cut) at angles. Figure 224 illustrates some typical sections and fixing of architraves.

As an alternative to wood architraves one of the metal, plaster stops may be used. For these to be successful in masking the joint between door linings or frames the linings and frames must be securely fixed else closing doors will cause cracks to open up.

EXTERNAL RENDERING

Owing to their colour and texture, common bricks and concrete and clay blocks do not provide what is commonly considered to be an attractive external finish for buildings. The external faces of walls built with these materials are often rendered with two or three coats of cement and lime mixed with natural aggregate and finished either smooth or textured.

In exposed positions, walls may become so saturated by rain that water penetrates to their inside face. Because an external rendering generally improves the resistance of a wall to rain penetration, the walls of buildings on the coast and on high ground are often rendered externally.

As an applied external finish to walls as additional weather protection, renderings depend on a strong bond to the background wall, on the mix used in the rendering material and on the surface finish. The rendering should have a strong bond or key to the background wall as a mechanical bond between the rendering and the wall and so that the bond resists the drying shrinkage inevitable in any wet applied mix of rendering. The surface of the background wall should provide a strong mechanical key for the rendering by the use of keyed flettons, raking out the mortar joints, hacking or scoring otherwise dense concrete surfaces and hacking smooth stone surfaces.

If there is not a strong bond of rendering to background walls the rendering may shrink, crack and come away from the background and water will enter the cracks and saturate the background from which it will not readily evaporate. As a general rule the richer the mix of cement in the rendering material the stronger should be the background material and key. It is idle to cover poor quality bricks with a cement-rich rendering, which will crack, let in water and make and maintain the wall in a more saturated condition than it would be if not rendered.

The mixes for renderings depend on the background wall, lean mixes of cement and lime being used for soft porous materials and the richer cement and lime mixes for the more dense backgrounds so that the density and porosity of the rendering corresponds roughly to that of the background.

The types of external rendering used are smooth (wood float finish), scraped finish, textured finish, pebbledash (drydash), roughcast (wet dash) and machine applied finish.

Smooth, wood float finish

Smooth (wood float finish) rendering is usually applied in two coats. The first coat is spread by trowel and struck off level to a thickness of about 11 mm. The surface of the first coat is scratched before it dries to provide key for the next coat. The first coat should be allowed to dry out. The next coat is spread by trowel and finished smooth and level to a thickness of about 8 mm. The surface of smooth renderings should be finished with a wood float rather than a steel trowel. A steel trowel brings water and the finer particles of cement and lime to the surface which, on drying out, shrink and cause surface cracks. A wood float (trowel) leaves the surface coarse textured and less liable to surface cracks. Three coat rendering is used mostly in exposed positions to provide a thick protective coating to walls. The two undercoats are spread, scratched for key and allowed to dry out to a thickness of about 10 mm for each coat; the third or finishing coat is spread and finished smooth to a thickness of from 6 to 10 mm.

Spatterdash

Smooth, dense wall surfaces such as dense brick and situ-cast concrete afford a poor key and little suction for renderings. Such surfaces can be prepared for rendering by the application of a spatterdash of wet cement and sand. A wet mix of cement and clean sand (mix 1 : 2, by volume) is thrown on to the surface and left to harden without being trowelled smooth. When dry it provides a surface suitable for the rendering, which is applied in the normal way.

Scraped-finish rendering

An undercoat and finish coat are spread as for a smooth finish and the finished level surface, when it has set, is scraped with a steel straight edge or saw blade to remove some 2 mm from the surface to produce a coarse textured finish.

Textured-finish

The colour and texture of smooth rendering appear dull and unattractive to some people and they prefer a broken or textured surface.

Textured rendering is usually applied in two coats. The first coat is spread and allowed to dry as previously described. The second coat is then spread by trowel and finished level. When this second coat is sufficiently hard, but still wet, its surface is textured with wood combs, brushes, sacking, wire mesh or old saw blades. A variety of effects can be obtained by varying the way in which the surface is textured.

An advantage of textured rendering is that the surface scraping removes any scum of water, cement and lime that may have been brought to the surface by trowelling and which might otherwise have caused surface cracking.

Pebbledash (drydash) finish

This finish is produced by throwing dry pebbles, shingle or crushed stone on to, and lightly pressed into, the freshly applied finish coat of rendering so that the pebbles adhere to the rendering but are mostly left exposed as a surface of pebbles. Pebbles of from 6 to 13 gauge are used. The undercoat and finish coat are of a mix suited to the background and are trowelled and finished level. The advantage of this finish is that any hair cracks that may open due to the drying shrinkage of the rendering are masked by the pebble dash.

Roughcast (wetdash) finish

A wet mix of rendering is thrown on to the matured undercoat by hand to a thickness of from 6 to 13 mm to produce a rough irregular textured finish. The finish is determined by the gauge of the aggregate used in the wet mix.

Machine applied finish

A wet mix of rendering is thrown on to a matured undercoat by machine to produce a regular coarse textured finish. The texture of the finish is determined by the gauge of the aggregate used in the final wetdash finish which may have the natural colour of the materials or be coloured to produce what are called Tyrolean finishes.

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CONTENTS

PREFACE

For this new edition a major rearrangement has taken place to accommodate the most recent developments in the construction of single-storey buildings. The functional requirements of the various construction elements are given more prominence. The use of new materials, such as deep profiled, trapezoidal, plastic coated sheeting and single-ply roof membranes, are covered and new construction methods, such as tilt-up construction, are introduced. The important areas of the influence of enhanced insulation on roof shape and the provisions for moisture vapour checks are covered.

Chapter One has been revised to describe the development of the single-storey shed frame. It covers the early closely spaced triangular truss frames, suited initially to slate roofing, and that were for many years adapted to suit corrugated iron, steel and asbestos cement sheeting, through to the more widely spaced lattice beam and portal frames suited to the low pitch, trapezoidal section steel sheeting that is commonly used today. The development of cold formed purlins, lattice purlins and solid web I-section purlins for widely spaced structural frames is described, together with wind and structural bracing necessary for stability. The comparatively recent use of composite frames of precast reinforced concrete columns with lattice steel roof beams for low pitch roof coverings is also considered.

Roof and wall cladding, thermal insulation and flat roof coverings, previously included in separate chapters, have now been consolidated in Chapter Two to embrace the functional requirements common to roof and wall cladding. The development of profiled cladding from the early shallow section corrugated iron, steel and asbestos cement sheeting to the now generally used trapezoidal section, plastic coated metal sheeting, including standing seam sheeting, together with thermal insulation, form the main part of Chapter Two. The development of flat roof weathering from asphalt and fibre felt to high performance and single ply weathering is described and illustrated.

Chapter Three considers the functional requirements of rooflights and describes the use of glass and plastic sheeting.

Chapter Four considers the original material covering diaphragm and fin wall construction together with a description of a recent innovation in the use of tilt-up reinforced concrete wall panels as wall enclosure and support for lattice beam roofs as a form of rapid, solid construction for single-storey buildings.

Finally, Chapter Five deals with shell structures.

INTRODUCTION

The small-scale buildings described in Volumes 1 and 2 are constructed with traditional materials such as brick, timber, slate, tile and non-ferrous metals that have been used for centuries and have stood the test of time. The useful life of such buildings, if reasonably well maintained, is up to 100 years or more.

This volume, Volume 3, describes the construction of single-storey buildings, such as sheds, warehouses, factories and other buildings generally built on one floor, which account for about 40% of the expenditure on building in this country.

Over the past 50 years most single-storey buildings have been constructed with a structural frame of steel or reinforced concrete supporting lightweight roof and wall coverings to exclude wind and rain and to provide insulation against loss of heat. The small imposed loads on roofs can be supported by thin, lightweight sheets fixed to comparatively slim structural frames to provide wide clear spans between internal supports. The thin, lightweight materials that are used for economy in weight and first cost are not robust and do not withstand for long the destructive effects of weather, dimensional changes and damage in use that occur in buildings.

The consequence of the adoption of lightweight materials for roof and wall coverings, for the sake of economy, is that many single-storey buildings have a useful life of only 20 to 30 years before considerable works of repair or renewal are necessary to maintain minimum standards of comfort and appearance.

The concept of functional requirements for the elements of building is now generally accepted as a necessary guide to the performance criteria of materials and combinations of materials used in the construction of the elements of building. In traditional building forms one material could serve several functional requirements, for example, a brick wall which provides strength, stability, exclusion of wind and rain, resistance to fire and, to some extent, thermal insulation.

The materials used in the construction of lightweight structures are, in the main, selected to perform specific functions. Steel sheeting is used as a weather envelope and to support imposed loads, layers of insulation for thermal resistance, thin plastic sheets for daylight, and a slender frame to support the envelope and imposed loads. The inclusion of one material for a specific function may affect the performance of another included for a different function which may in turn necessitate the inclusion of yet another material to protect the first from damage caused by the use of the second material, for example, where a vapour barrier is used to reduce condensation on cold steel roof sheeting.

Recently the demand for space heating and the consequent inclusion of materials with high thermal resistance has led to problems in building unknown to past generations who accepted much lower standards of heating and more ventilation of their homes and work places. The inclusion of layers of thermal insulation in the fabric of buildings, to meet current regulations and expectations of thermal comfort, has led to the destructive effects of condensation from warm moist air and also to the large temperature fluctuations of materials on the outside of buildings which has been one of the prime causes of the failure of flat roof coverings.

The use of thin, lightweight materials for the envelope of buildings has been for the sake of economy in first cost with little regard to the life of the building or subsequent maintenance and renewal costs. Where the cost of one material used in the construction is compared to the cost of another, account should be taken of the relative costs of the elements of typical buildings as a measure of the value of saving. A guide to the comparative costs of the elements of single-storey buildings is as follows:

• Drainage and works below ground	15%
• Structural frame	15%
• Cladding including windows and rain-water goods	35%
• Floors and finishes	10%
• Heating, electrical and other works	25%

NOTE ON METRIC UNITS

For linear measure all measurements are shown in either metres or millimetres. A decimal point is used to distinguish metres and millimetres, the figures to the left of the decimal point being metres and those to the right millimetres. To save needless repetition, the abbreviations 'm' and 'mm' are not used, with one exception. The exception to this system is where there are at present only metric equivalents in decimal fractions of a millimetre. Here the decimal point is used to distinguish millimetres from fractions of a millimetre, the figures to the left of the decimal point being millimetres and those to the right being fractions of a millimetre. In such cases the abbreviations 'mm' will follow the figures, e.g. 302.2 mm.

R. BARRY

CHAPTER ONE

LATTICE TRUSS, BEAM, PORTAL FRAME AND FLAT ROOF STRUCTURES

Up to the latter part of the nineteenth century the majority of single-storey buildings were of traditional construction with timber, brick or stone walls supporting timber-framed roofs covered with slate or tile. The limited spans, practicable with timber roofs, constrained the rapid expansion of manufacturing activity that was occurring during the nineteenth century to meet the demands of the rapidly increasing population of England and the very considerable export of finished goods.

The introduction of continuous hot-rolled steel sections in 1873 led to the single-storey shed frame form of construction for most new factories and warehouses. This shed frame form of construction consisted of brick side walls or steel columns supporting triangular frames (trusses) fabricated from small section steel members, pitched at 20°, to support purlins, rafters and slate roofing. The minimum pitch (slope) for slates dictated the shape and construction of the steel roof trusses. This simple construction was economical in first cost in the use of materials, light in weight, easy to handle and quickly erected to provide the limited requirements of shelter expected of such small structures at the time. A symmetrical pitch single-bay shed frame is illustrated in Fig. 1.

The introduction of corrugated iron sheets in 1880 and corrugated asbestos cement sheets in 1910 made it practical to construct roofs with a minimum pitch of 10° to exclude rain. Nonetheless the single-storey shed frame of triangular trusses pitched at 20° continued for many years as the principal form of construction because of the simplicity of fabrication, economy in the use of materials and speed of erection.

Natural lighting to the interior of shed frames was provided by windows in side walls and roof glazing in the form of timber or metal glazing bars fixed in the roof slopes to support glass. To avoid sun glare and overheating in summer the north light roof profile was introduced, a light section steel roof truss asymmetrical in profile with the steeply sloping roof fully glazed and facing north. A single bay, north light shed frame is illustrated in Fig. 1.

With increase in the span of a triangular roof truss the volume of unused roof space and the roof framing increases and it is, therefore, of advantage to combine several bays of the shed frame construction to provide cover with the least volume of roof space and roof framing. To minimise the number of internal columns that would otherwise obstruct the floor, the 'umbrella' or cantilever roof was adopted. Lattice girders constructed at mid span in each bay support the trusses and widely spaced internal columns in turn support the lattice girders to provide maximum unobstructed floor space (Fig. 1).

The flat roof form of construction for single-storey buildings was, to a large extent, for appearance. The beam or lattice girder grid on columns affords no advantage in unobstructed floor space and little reduction in unused roof volume over the umbrella roof. The clean flat roof line and strong horizontal emphasis was accepted at the expense of many failures of flat roof coverings. In recent years improvements in materials and detailing of junctions have gone some way to repair the ill-repute of flat roofs. A typical single-storey flat roof frame is illustrated in Fig. 1.

With the improvements in cold metal forming techniques that were developed towards the middle of the twentieth century, a range of deep profile steel sheets was produced that could be used as a successful roof covering at a pitch of as little as 6°, so that the traditional triangular roof truss frame was no longer the most economic or satisfactory form of roof frame. It was then that the low pitch portal frame and the low pitch lattice beam frame came into general use to combine the benefits of low pitch profiled sheetings and the consequent reduction in unused roof space to be heated and insulated.

The plastic theory of design proposed by Professor Baker led to the use of the rigid steel portal frame for single-storey buildings. The rafters of the portal frame are rigidly connected to the posts in the form of a slender frame that is free of lattice members and can most economically have a shallow pitch suited to the profiled steel roof sheeting and decking that came into production in about 1960. Figure 1 illustrates a portal frame.

To reduce the volume of unusable roof space that has to be heated and the visible area of roof, for appearance

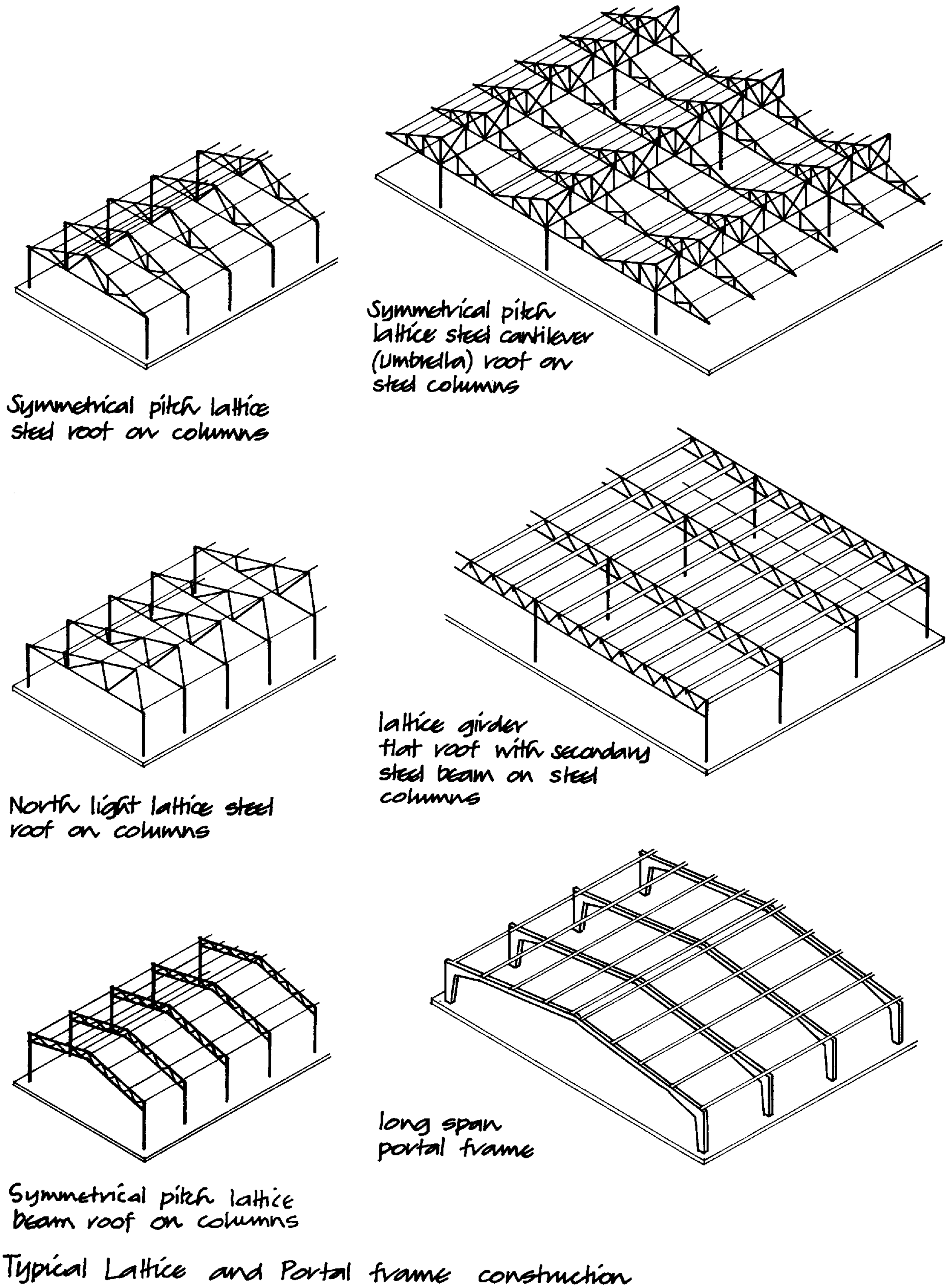

Symmetrical pitch lattice steel cantilever (umbrella) roof on steel columns
Symmetrical pitch lattice steel roof on columns
lattice girder flat roof with secondary steel beam on steel columns
North light lattice steel roof on columns
long span portal frame
Symmetrical pitch lattice beam roof on columns
Typical Lattice and Portal frame construction

Fig. 1

sake, it has become common practice to construct single-storey buildings with low pitch roof frames either as portal frames or as lattice beam or rafter frames. A lattice roof frame is fabricated as a lattice of small section members welded together in the form of a beam cranked (bent), a symmetrical pitch roof or as a multi-bay butterfly roof with valley beams, or as a single or double very low pitch beam. A single bay symmetrical pitch lattice beam or rafter roof is illustrated in Fig. 1. With the recent introduction of long lengths of profiled roof sheeting with standing seams that can provide cover in one length without end laps at a pitch (slope) of as little as $2\frac{1}{2}°$, the lattice beam roof frame has become the most commonly used form of roof structure for most single-storey buildings.

FUNCTIONAL REQUIREMENTS

The functional requirements of framed structures are:

Strength and stability
Durability and freedom from maintenance
Fire safety.

Strength and stability

The strength of a structural frame depends on the strength of the material used in the fabrication of the members of the frame and the stability of the frame or frames on the way in which the members of the frame are connected, and on bracing across and between frames.

Steel is the material that is most used in framed structures because of its good compressive and tensile strength and favourable strength to weight ratio. The continuous process of hot rolling steel and cold forming steel strip produces a wide range of sections suited to the fabrication of economical structural frames.

Concrete has good compressive and poor tensile strength. It is used as reinforced concrete in structural frames for the benefit of the combination of the tensile strength of steel and the compressive strength of concrete, and the protection against corrosion and damage by fire that the concrete gives to the steel reinforcement cast in it.

Timber is often used in the fabrication of roof frames because it has adequate tensile and compressive strength to support the comparatively light loads normal to roofs. Timber, which can be economically cut, shaped and joined to form lightweight roof frames is used instead of similar steel frames for the sake of economy, durability and ease of handling and fixing.

Durability and freedom from maintenance

On exposure to air and moisture, unprotected steel corrodes to form an oxide coating, i.e. rust, which is permeable to moisture and thus encourages progressive corrosion which may in time adversely affect the strength of the material. To inhibit rust, steel is either painted or coated with zinc. Painted surfaces require periodic repainting. Zinc coatings that are perforated by cutting and drilling will not protect the exposed steel below which will corrode progressively.

Concrete which is solidly compacted around steel reinforcement will provide very good protection against corrosion of the steel reinforcement. Hair cracks that may form in concrete encasement to steel, due to the drying shrinkage of concrete, will allow moisture to penetrate to the steel reinforcement which will corrode. The rust formed by corrosion expands and will in time cause the concrete cover to spall away from steel and encourage progressive corrosion.

As protection against corrosion the reinforcement may be zinc coated or stainless steel reinforcement may be used. Zinc coating adds little to cost whereas stainless steel adds appreciably. Thoroughly mixed, solidly consolidated concrete will have a dense, smooth surface that requires no maintenance other than occasional steam cleaning.

Adequately seasoned (dried), stress-graded timber preserved against fungal and insect attack should require no maintenance during the useful life of a building other than periodic staining or painting for appearance.

Fire safety

The requirements for the fire resistance of structure in the Building Regulations 1991 do not apply to roof structures unless the roof is used as a floor, nor to single-storey structures supporting a roof except where a wall is close to a boundary and is required to have resistance to the spread of fire between adjacent buildings having regard to the height, use and position of the building.

LATTICE TRUSS CONSTRUCTION

'Truss', in connection with roof frames, is used in the sense of defining the action of a triangular roof framework where the spread under load of sloping rafters is resisted by the horizontal tie member, secured to the feet of the rafters, which trusses or ties them against spreading. 'Lattice' is used in the sense of an open grid or mesh of slender members fixed across or between each other, generally in some regular pattern of cross-diagonals or as a rectilinear grid.

Symmetrical pitch steel lattice truss construction

The simple, single bay shed frame illustrated in Fig. 2 is to this day one of the cheapest forms of structure. The small section, mild steel members of the truss can be cut and drilled with simple tools, assembled with bolted connections and speedily erected without the need for heavy lifting equipment. The small section, steel angle members of the truss are bolted to gusset plates. The end plates of trusses are bolted to columns and purlins, and sheeting rails are bolted to cleats bolted to rafters and columns respectively, to support roof and side wall sheeting. The considerable depth of the roof frames at mid span provides adequate strength in supporting dead and imposed loads and rigidity to minimise deflection under load. The structural frames and their covering provide basic shelter for a variety of uses.

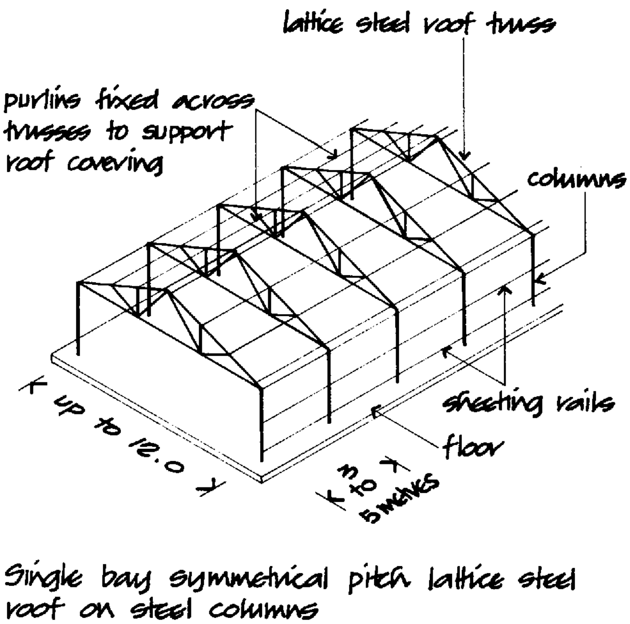


Fig. 2

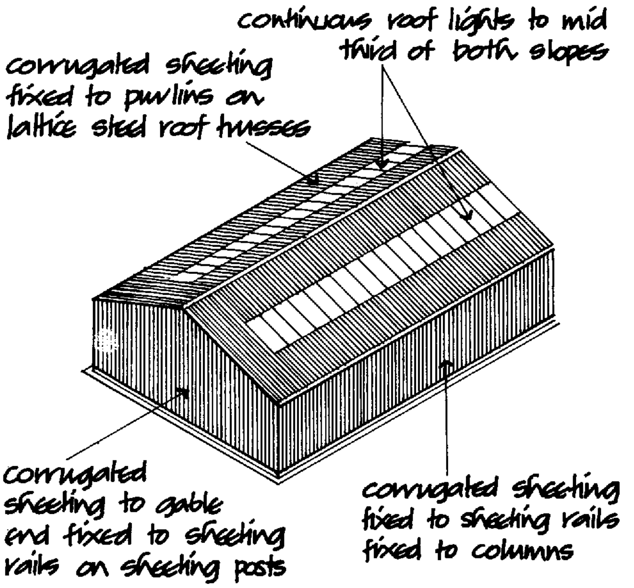
The advantage of this simple, single-storey, single-bay frame is economy in the use of materials by the use of small section angle, tubular or flat standard mild steel sections for the trusses that can be economically fabricated and quickly erected on comparatively slender mild steel I-section columns fixed to concrete pad foundations.

The disadvantages of this structural framework are the very considerable volume of roof space inside the triangular roof frames that cannot be used for any purpose other than housing services such as lighting and heating, and the considerable visible area of roof that is not generally accepted as an attractive feature of small single-storey buildings. Where the activity enclosed by the building requires heating, the roof space has to be wastefully heated as well as the useful space below. For maximum structural efficiency the slope or pitch of the rafters of these frames should be not less than about 17° to the horizontal. For economy in the use of small-section framing for the trusses and to limit the volume of unused roof space, these trusses are generally limited to spans of 12.0 and for economy in the use of small section purlins and sheeting rails the spacing of trusses is usually betwen 3.0 to 5.0.

The bolted, fixed base connection of the foot of the columns to the concrete foundation bases provides sufficient strength and stability against wind pressure on the side walls and roof. Wind bracing provides stability against wind pressure on the end walls and gable ends of the roof.

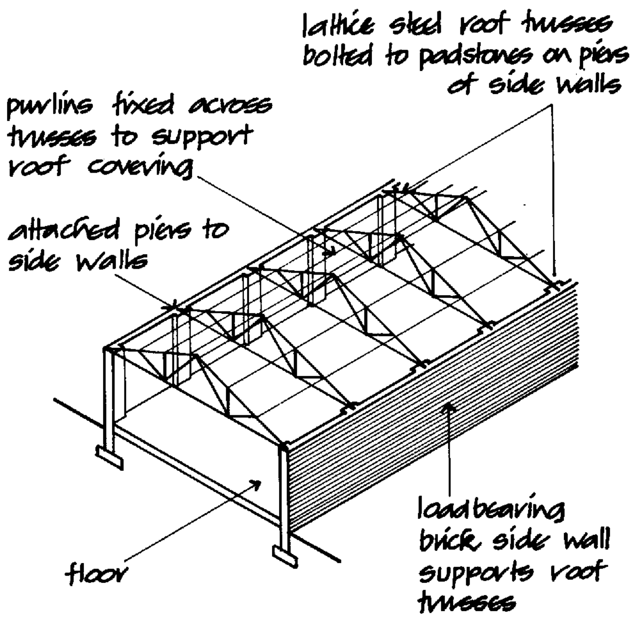
Because of the limited penetration of daylight through side wall windows, a part of the roof is often covered with glass or translucent plastic sheets which are fixed in the slope of roofs, usually in the middle third of each slope as illustrated in Fig. 3, to provide reasonable penetration of daylight to the working surfaces in the building.

The thin sheets of profiled steel sheet that are commonly used to provide cover to the walls of these buildings have poor resistance to damage by knocks. As an alternative to steel columns to support the roof trusses, brick side walls may be used for single-bay buildings to provide support for the roof frames, protection against wind and rain and solid resistance to damage by knocks. Figure 4 is an illustration of a single-bay single-storey building with brick side walls supporting steel roof trusses. The side walls are stiffened by piers formed in them under the roof trusses. As an alternative, a low brick upstand wall may be raised either outside of or between the columns as protection against knocks, with wall sheeting above.



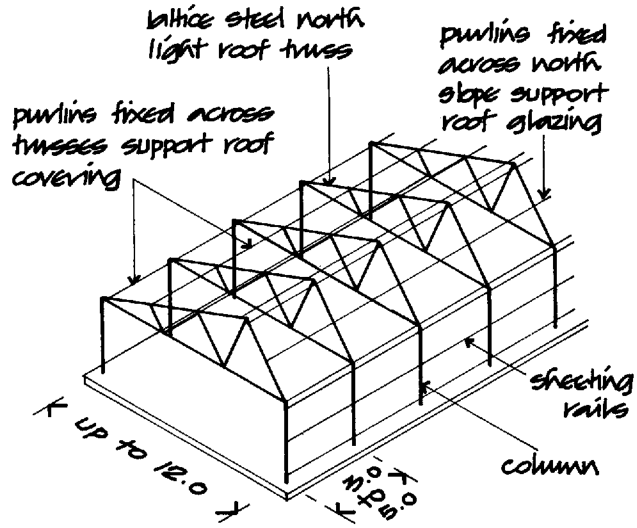
Single bay symmetrical pitch lattice steel roof on columns with corrugated sheeting

Fig. 3



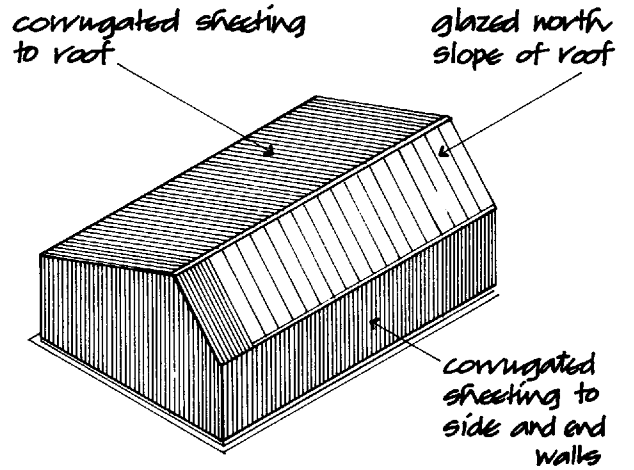
Single bay symmetrical pitch lattice steel roof on brick side walls

Fig. 4



Single bay north light lattice steel roof trusses on steel columns

Fig. 5



Single bay lattice steel north light roof on columns with corrugated sheeting

Fig. 6

North light steel lattice truss construction

Rooflights in the slopes of symmetrical pitch roofs, which are generally set in east and west facing slopes, may cause discomfort through overheating in summer and disrupt manufacturing activities by the glare from sunlight. To avoid these possibilities the north light roof is used. The north light roof has an asymmetrical profile with the south facing slope at 17° or more to horizontal and the north facing slope at from 60° to vertical. Figure 5 is an illustration of a single-bay, single-storey building with north light, steel lattice trusses on columns. The whole of the south slope is covered with profiled sheets and the whole of the north facing slope with glass or clear or translucent plastic sheeting as illustrated in Fig. 6.

Because of the steep pitch of the north facing slope the space inside the roof trusses of a north light roof is considerably greater than that of a symmetrical pitch roof of the same span as illustrated in Fig. 7. To limit the volume of roof space that cannot be used and has to be wastefully heated, most north light roofs are limited to spans of up to about 10.0.

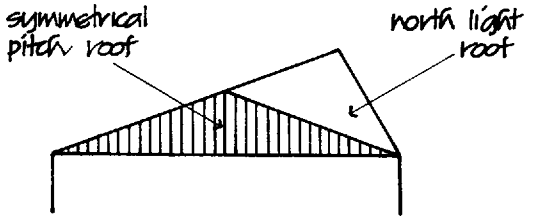


Fig. 7

Multi-bay lattice steel roof truss construction

There is no theoretical limit to the span of a single-bay, steel roof truss to provide clear unobstructed floor area. For structural efficiency a triangular truss should have a pitch of not less than 17° to the horizontal. With increase in span there is an increase in the volume of unused space inside the roof trusses and the length of truss members. To cover large areas it is, therefore, usual to use two or more bays of symmetrical pitch roofs to limit the volume of roof space and length of members of the trusses. Figure 8 is an illustration of the comparative volume of a single long span roof and four smaller roof bays covering the same floor area.

To avoid the use of closely spaced internal columns to support roof trusses it is usual with multi-bay roofs to use either valley beams or lattice girders inside the depth of the trusses to reduce the number of internal columns that would otherwise obstruct the working floor area.

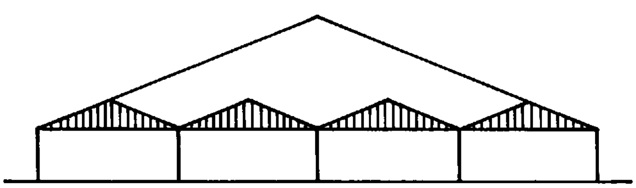


Fig. 8

Multi-bay valley beam lattice steel roof truss construction

A beam under the valley of adjacent roofs supports the ends of roof trusses between the internal columns that support the valley beam as illustrated in Fig. 9. Plainly the greater the span or space between internal columns supporting a valley beam the greater will be the depth of the valley beam, so that for a given required clear working height, an increase in the depth of the valley beam will increase the volume of unused roof space above the underside or soffit of the valley beam as illustrated in Fig. 10.

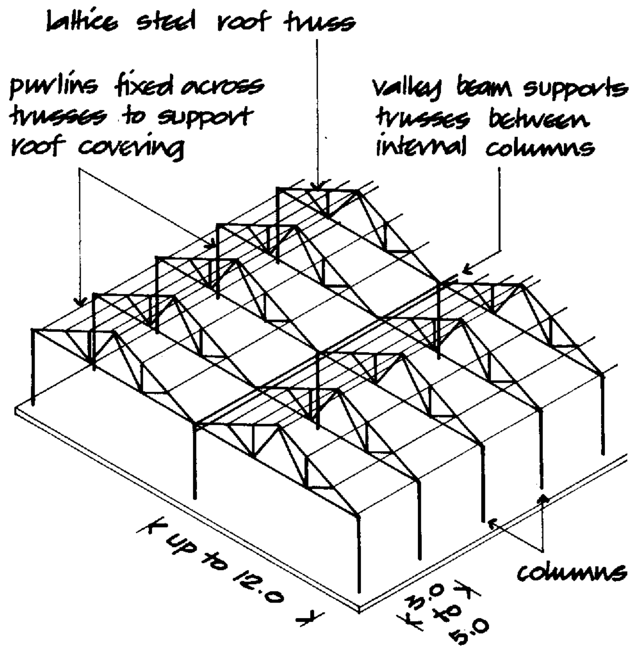


Fig. 9

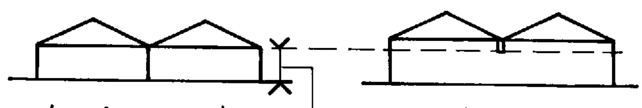
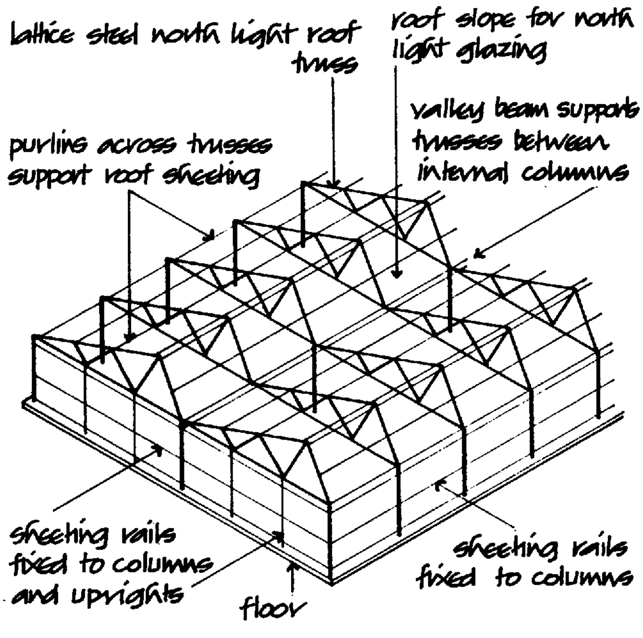


Fig. 10

Similarly a valley beam may be used in multi-bay north light truss roofs as illustrated in Fig. 11.

A disadvantage of the multi-bay valley beam form of construction is that there is very limited depth alongside the valley beam for the fall (slope) of rainwater pipes from valley gutter outlets to rainwater down pipes fixed to internal columns. The shallow fall rainwater pipes that are run alongside valley beams will require sealed joints and the shallow fall pipe will more readily become blocked than a straight down pipe from valley outlets.

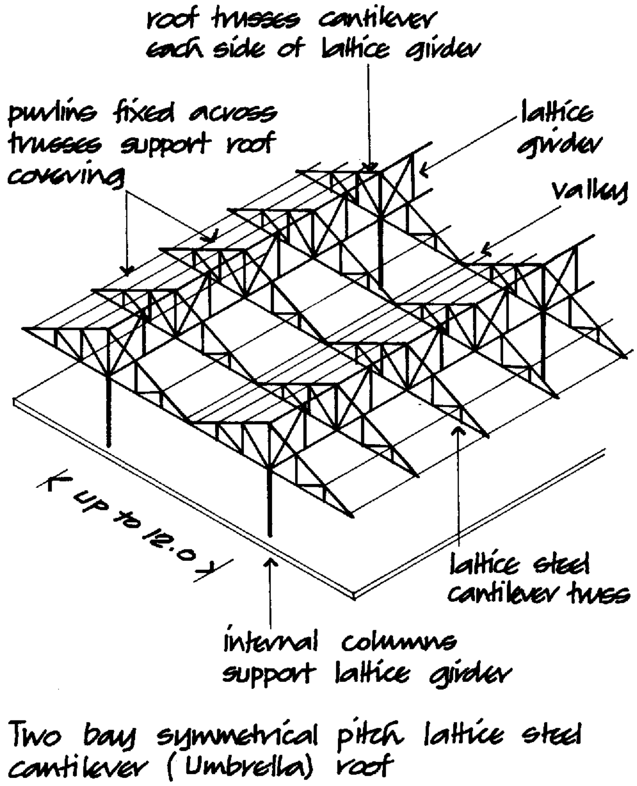


Two bay north light lattice steel roof with columns and valley beam

Fig. 11

Cantilever (umbrella) multi-bay lattice steel truss roof construction

A lattice girder constructed inside the depth of each bay of symmetrical pitch roof trusses will, because of its great depth, be capable of supporting the roof between comparatively widely spaced internal columns and will not project below the underside of trusses. Figure 12 is an illustration of a cantilever or umbrella roof with lattice steel girders constructed inside the depth of each bay of trusses at mid span. The lattice girder supports half of each truss with each half cantilevered each side



Two bay symmetrical pitch lattice steel cantilever (Umbrella) roof

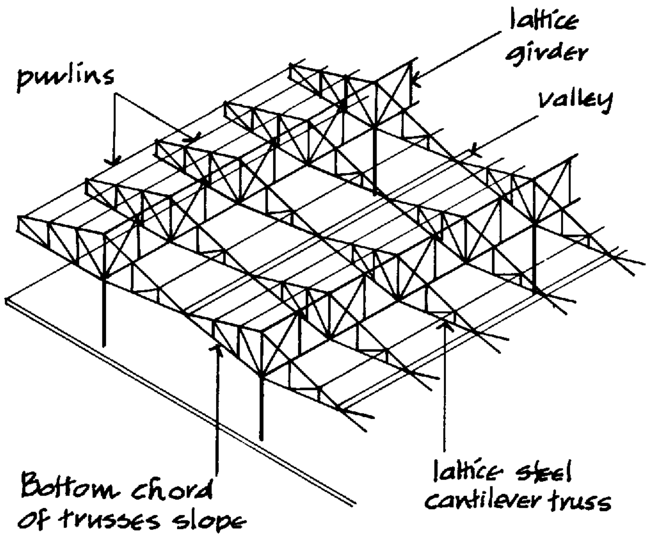
Fig. 12

of the truss, hence the name 'cantilever truss' roof. The outline in section of the column and the truss cantilevered each side of the lattice girder resembles an umbrella, hence the name 'umbrella' roof.

The principal disadvantage of the umbrella roof form of construction is that the comparatively widely spaced internal columns provide very little fall for rainwater pipes from valley gutter outlets to rainwater down pipes fixed to internal columns under the lattice girders inside roof frames. To provide an appreciable fall to rainwater pipes a modified form of umbrella roof is used with the tie or chord member of trusses framed on the slope as illustrated in Fig. 13 to provide some fall for rainwater pipes draining from valley gutters.

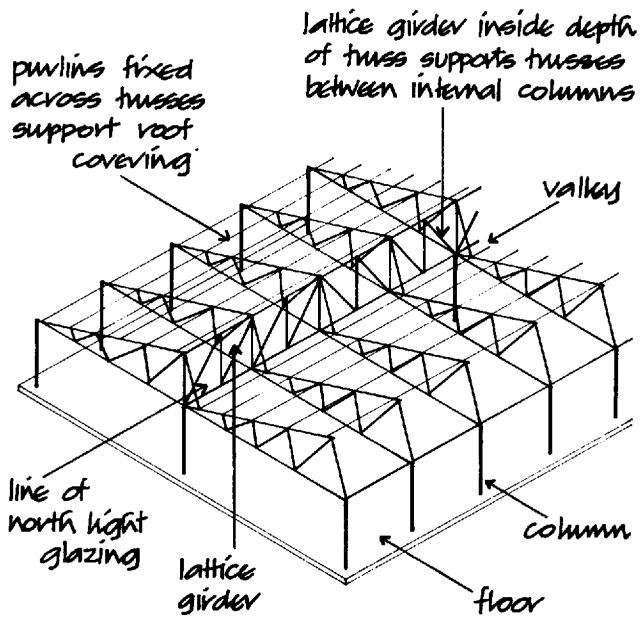
North light multi-bay lattice steel truss construction

North light trusses may be supported by a lattice girder, as illustrated in Fig. 14, with widely spaced internal columns to cover large areas with the least obstruction. The profile of a multi-bay north light roof resembles the teeth of a saw, hence the name 'saw-tooth' roof that is often used for this type of roof.



Symmetrical pitch lattice truss with sloping chord

Fig. 13



Two bay north light lattice steel roof trusses with lattice girder supported on internal columns

Fig. 14

The disadvantage of the cantilver roof form is the great number of lattice members in the roof of both trusses and the lattice girders as these will collect dust and dirt, need frequent painting to inhibit rust and will, to some extent, obstruct natural light from roof lights.

Lattice steel truss construction

For the sake of economy in using one standard section, lattice steel trusses are often fabricated from one standard steel angle section with two angles, back to back, for the rafters and main tie and a single angle for the internal struts and ties as illustrated in Fig. 15.

The usual method of joining the members of a steel truss is by the use of steel gusset plates that are cut to shape to contain the required number of bolts at each connection. The flat steel gusset plates are fixed between the two angle sections of the rafters and main tie and to the intermediate ties and struts, as illustrated in Fig. 15. Bearing plates fixed to the foot of each truss provide a fixing to the cap of columns. The members of the truss are bolted together through the gusset plates.

Standard I-section steel columns are used to support the roof trusses. A steel base plate is welded or fixed with bolted connections with gusset plates and angle cleats to the base of the columns. The column base plate is levelled on a grout of cement on the concrete pad foundation to which it is rigidly fixed with four holding down bolts, cast or set into the foundation, as illustrated in Fig. 16. The rigid fixing of the columns to the foundation bases provides stability to the columns which act as vertical cantilevers in resisting lateral wind pressure on the side walls and the roof of the building. A cap is welded or fixed with bolted connections to the top of each column and the bearing plates of truss ends are bolted to the cap plate as illustrated in Fig. 16.

Lattice trusses can be fabricated from tubular steel sections that are cut, mitred and welded together as illustrated in Fig. 17. Because of the labour involved in cutting and welding the members, a tubular steel section truss is more expensive than an angle section truss. From the economy of fabricating standard trusses and the economy of repetition in producing many similar trusses a tubular section truss may be only a little more expensive than a similar one-off angle section truss.

The advantages of the tubular section truss are the greater structural efficiency of the tubular section over the angle section and the comparatively clean line of the tubulars and their welded connections which reduce the surface area liable to collect dust and requiring paint. The truss illustrated in Fig. 17 has a raised tie, the middle third of the length of the main tie being raised above the level of the foot of the trusses. This raised tie affords some increase in working height below the raised part of the tie which plainly is only of advantage with medium and long span roofs.

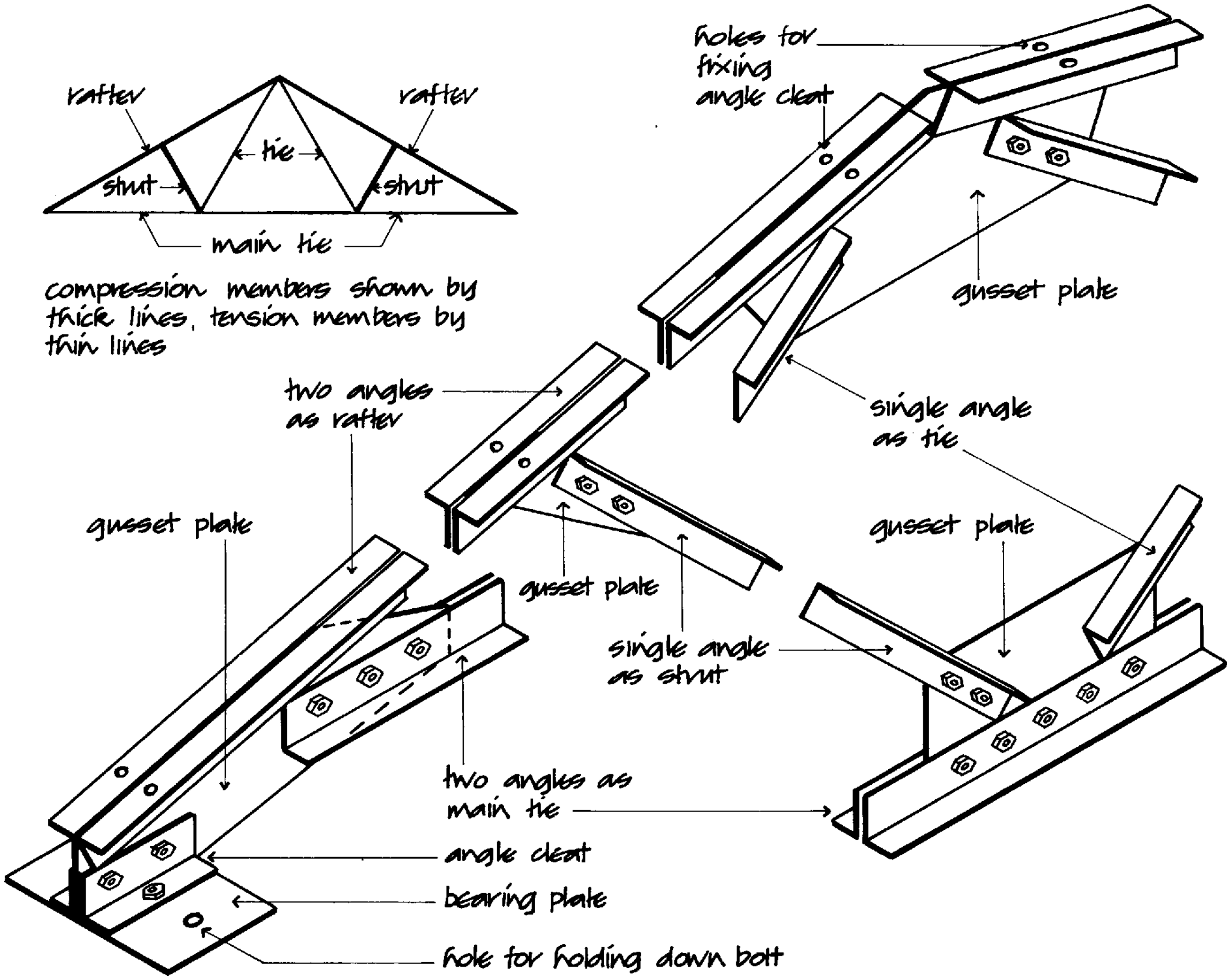


Fig. 15

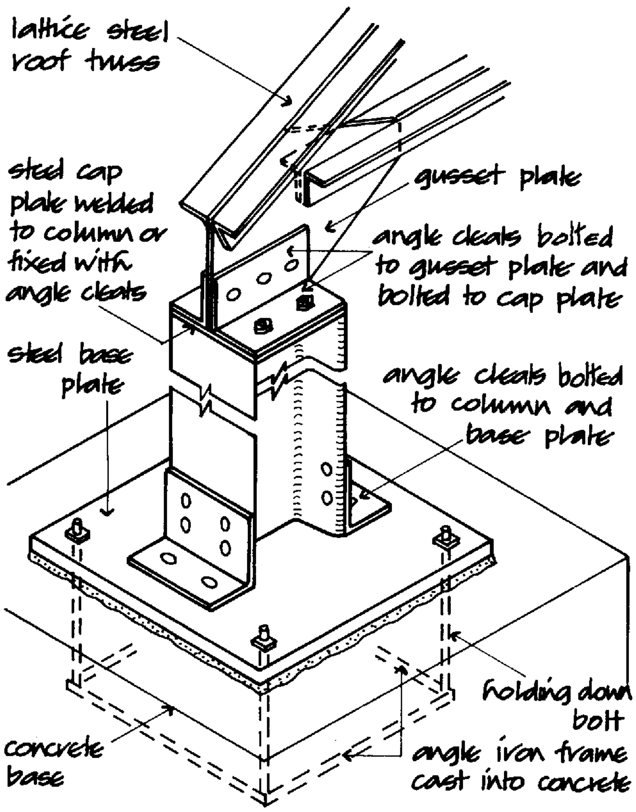
STEEL LATTICE BEAM ROOF CONSTRUCTION

The introduction of deep profiled steel sheeting, which can be laid as a roof covering to roofs pitched as low as 6° to the horizontal, coincided with the general adoption of space heating for many single-storey buildings and regulations requiring insulation to conserve fuel. In consequence the traditional lattice truss form of roof was no longer the most economical or suitable form of roof for buildings that required heating because of the considerable volume of unusable roof space and the requirement of a pitch of at least 17° for the structural efficiency of a truss roof. The two structural forms best suited to the use of deep profiled steel roof sheeting are lattice beam and portal frame forms of construction.

The simplest form of lattice beam roof is a single-bay symmetrical pitch roof constructed as a cranked lattice beam or rafter as illustrated in Fig. 18. Lattice beam roof frames are fabricated as uniform depth, symmetrical pitch cranked (bent) beams, uniform depth monopitch roofs, tapering depth butterrfly roofs and tapering depth beams.

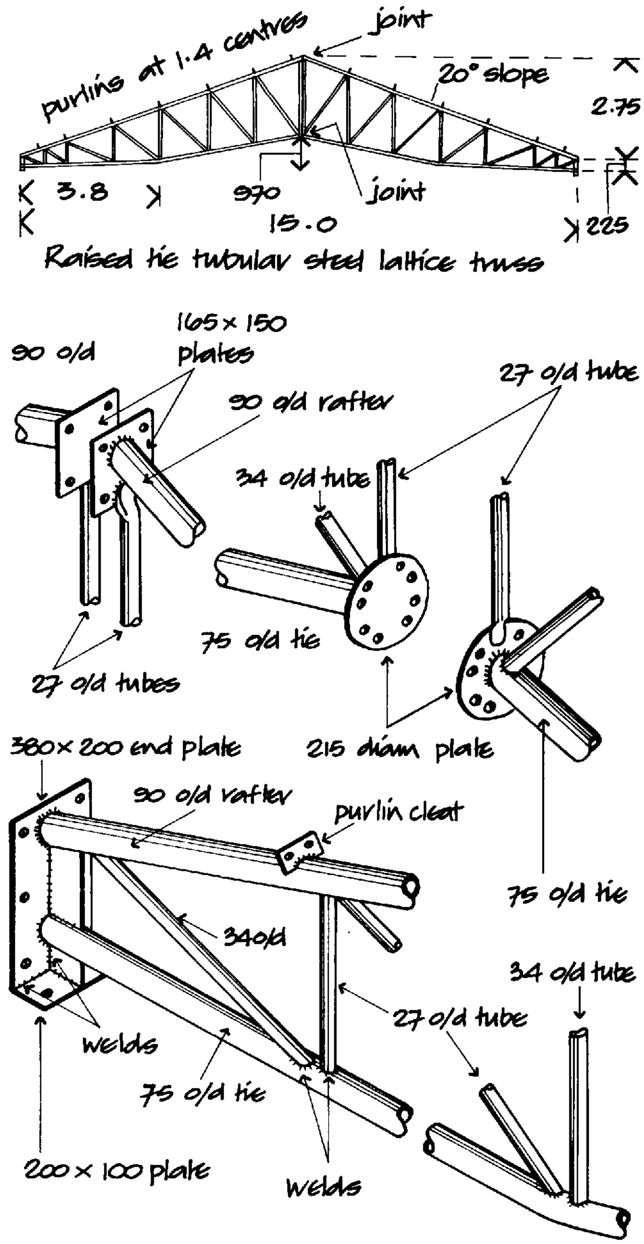
Symmetrical pitch lattice steel beam roof construction

The uniform depth lattice beam is cranked to form a symmetrical pitch roof with slopes of from 5° to 10° to the horizontal as illustrated in Fig. 18. The beams are generally fabricated from tubular and hollow rectangu-



Cap and base of steel column support for lattice steel truss

Fig. 16



Raised tie tubular steel lattice truss

Fig. 17

lar section steel sections that are cut and welded together with bolted site connections at mid span to facilitate transport of half lengths. For convenience in making straight, oblique cut ends to the intermediate tubulars of the lattice members, the top and bottom chord of the beams are usually of hollow rectangular section. End plates welded to the lattice beams are bolted to the flanges of I-section columns. With lattice beam roof frames, service pipes and small ducts may be run through the lattice frames and larger ducts slung below the beams inside the unused roof space. Because of the low pitch or slope of this roof form there is little unused roof space inside the shallow lattice beams and below the beams.

Multi-bay symmetrical pitch valley beam lattice beam roof construction

Because of the shallow depth of the lattice beam it is not practical to construct an umbrella type of roof with a deep beam inside the depth of frames below the ridge. For multi-bay symmetrical pitch lattice beam roofs it is usual to fabricate a form of valley beam roof as illustrated in Fig. 19. So that there is no increase in unused roof space the valley beam has to be of the same shallow depth as the beams and in consequence may only provide support for every other internal system of roof frames and thus give only a small increase in free floor space. The shallow depth of the valley beams provides minimum fall for rainwater pipes run from valley gutter outlets to down pipes fixed to internal columns.

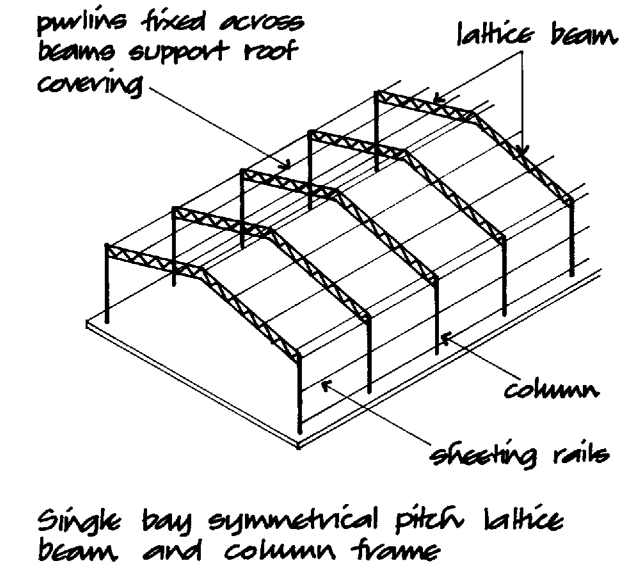


Fig. 18

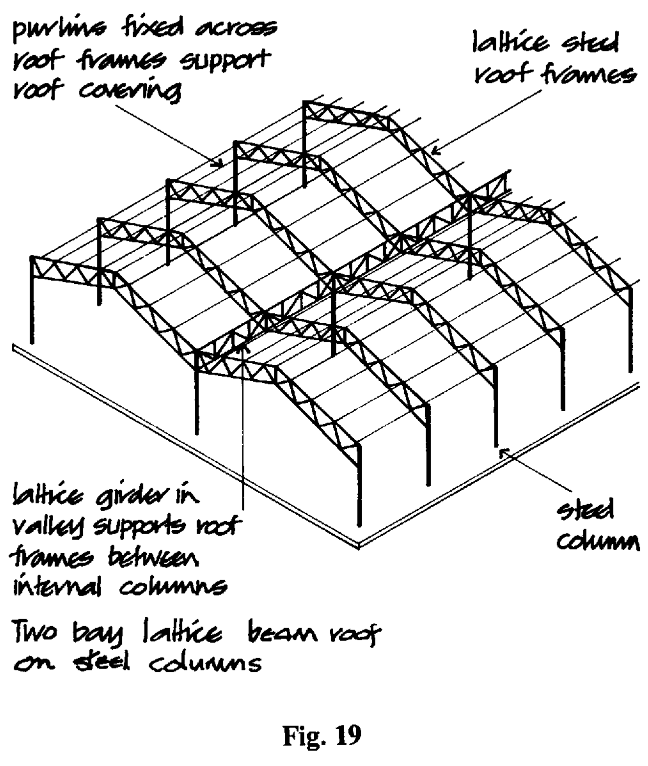


Fig. 19

Multi-bay symmetrical pitch valley beam lattice steel beam (butterfly) roof construction

To provide the maximum free floor area a form of butterfly roof, with deep valley beams supporting tapered lattice beams, is used as illustrated in Fig. 20. The lattice beams taper from the supporting valley beams up to the ridge in each bay. The deeper the valley beams the greater the spacing between internal columns and the greater the unused roof space inside and below the frames. The depth of the valley beams provides adequate depth for the fall of rainwater pipes run to down pipes.

The name of this roof form, butterfly, derives from the shape of the tapered rafters that resembles the wings of a butterfly.

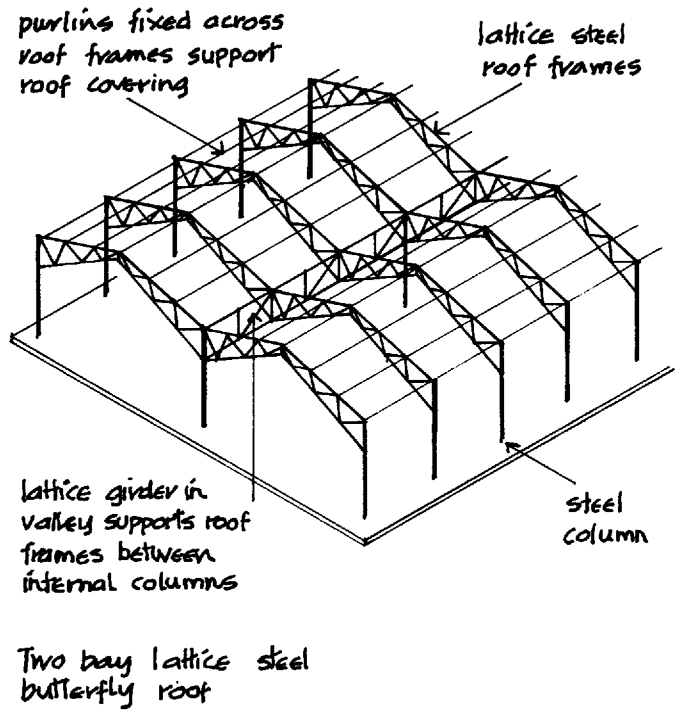


Fig. 20

Multi-bay monopitch north light (sawtooth) lattice steel beam roof construction

Because the depth of a lattice beam roof frame minimises deflection under load, it can be used as a monopitch form of construction for low or very low pitch roofs, either as a single bay roof or as a multi-bay roof.

The two bay monopitch roof illustrated in Fig. 21 is fabricated as a north light form of roof with a deep valley beam at the junction of adjacent roofs to allow wide spacing of columns. The depth of the lattice beam depends on the span and slope of the adjacent monopitch roofs, the greater the span and slope of the roofs, the deeper the valley beam, the wider the spacing of internal columns and the greater the unused roof space.

The lattice beams shown in Fig. 21 taper towards the eaves to reduce, to some extent, the volume of unused roof space and the braces from the roof frames to columns provide some stiffening against overturning. There is very little depth below valley gutters in this form of roof for an adequate fall of rainwater pipes run from valley gutter outlets to down pipes fixed to internal columns.

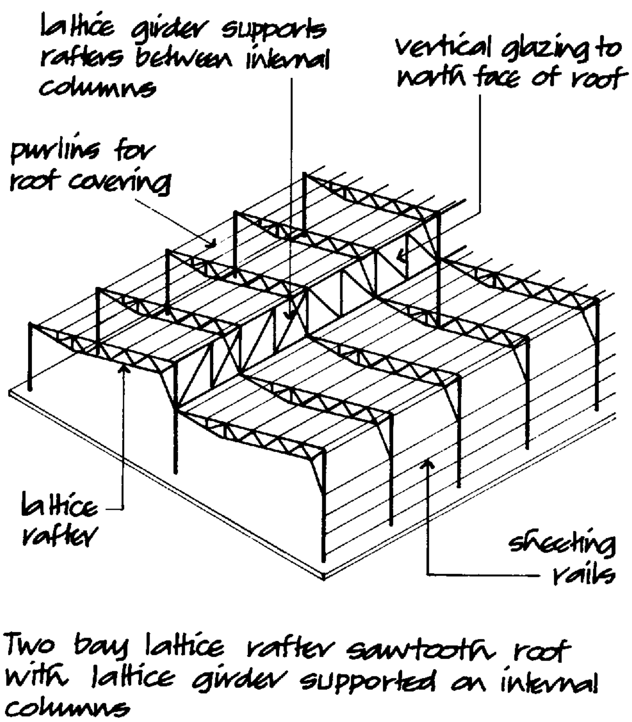


Fig. 21

PORTAL FRAMES

Steel portal frames

Following the acceptance of the plastic theory of design, proposed by Professor Baker, rigid portal frames became an economic alternative to lattice truss and lattice beam roofs.

The application of the plastic theory in place of the previous, generally used, elastic method of design (see Volume 4) is particularly relevant to rigid frames of a ductile material such as steel. The plastic theory takes account of the distribution of moments through the whole of the rigid frame under working loads so that sections lighter and more slender than sections determined by the elastic method of design may be used safely.

To be effective a pitched roof portal frame should have as low a pitch as practical to minimise spread at the knee of the portal frame (spread increases with the pitch of the rafters of a portal frame). The knee of a portal frame is the rigid connection of the rafter to the post of the portal.

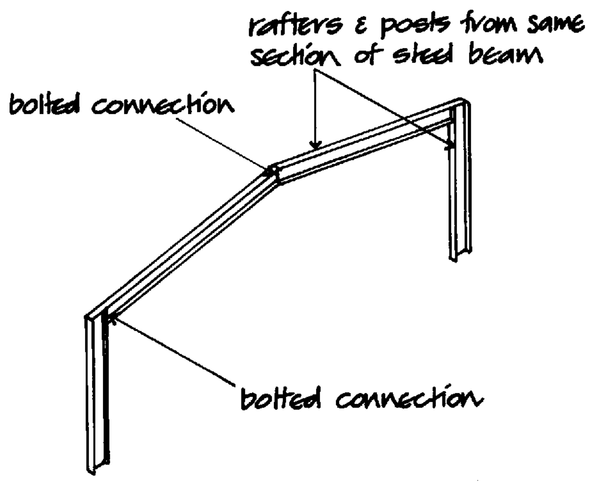
The early use of the rigid portal frame coincided with the introduction of a wide range of cold formed, profiled steel sheets for roofing, which could be fixed at a low pitch and be weather-tight. The combination of low pitch steel portal frames and profiled steel roof sheeting and decking has led to the adoption of this form of structure, particularly for single-bay single-storey buildings.

A portal frame is distinguished by the rigid connection of the rafters to the posts of the frame so that under load moments are distributed through the rafter and the post. For short- and medium-span frames the apex or ridge, where the rafters connect, is generally made as an on-site, rigid bolted connection for convenience in transporting half portal frames. Long-span portal frames may have a pin joint connection at the ridge to allow some flexure between the rafters of the frame which are pin jointed to foundation bases to allow flexure of posts due to spread at the knees under load.

For economy in the use of a standard section, short- and medium-span steel portal frames are often fabricated from one mild steel I-section for both rafters and posts, with the rafters welded to the posts without any increase in depth at the knee as illustrated in Fig. 22.

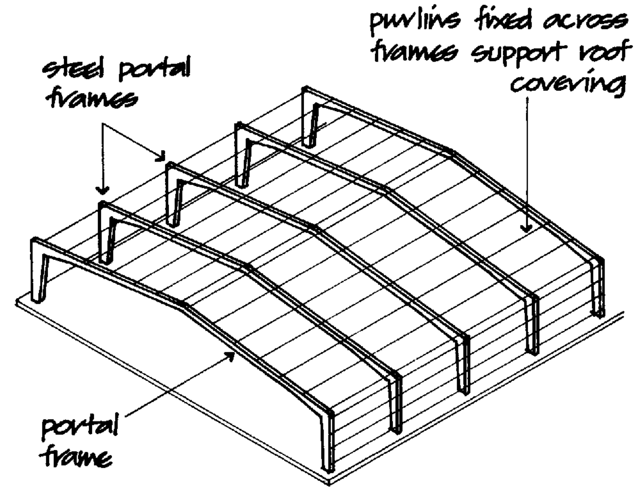
Short-span portal frames may be fabricated off site as one frame. Medium-span portal frames are generally fabricated in two halves for ease of transport and are assembled on site with bolted connections of the rafters at the ridge, with high strength friction grip (hsfg) bolts (see Volume 4).

Many medium- and long-span steel portal frames have the connection of the rafters to the posts at the knee, haunched to make the connection deeper than the main rafter section for additional stiffness as illustrated in Fig. 23. In long-span steel portal frames the posts and lowest length of the rafters, towards the knee, may



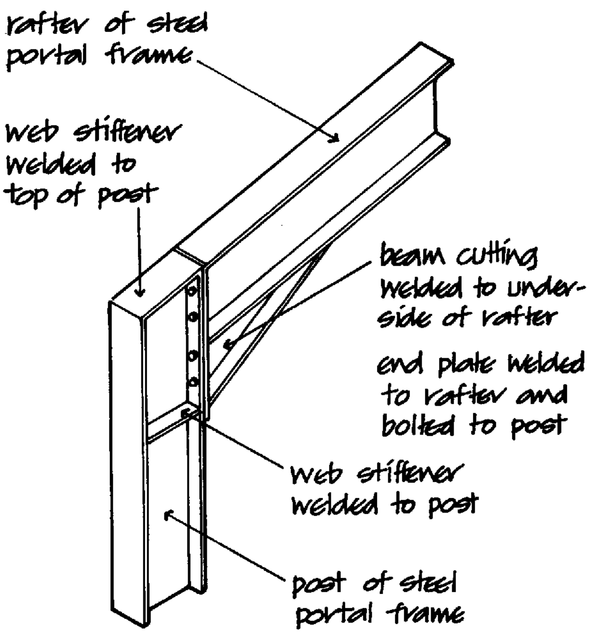
Short span steel portal frame

Fig. 22



Long span steel portal frames

Fig. 24



Haunch to steel portal frame

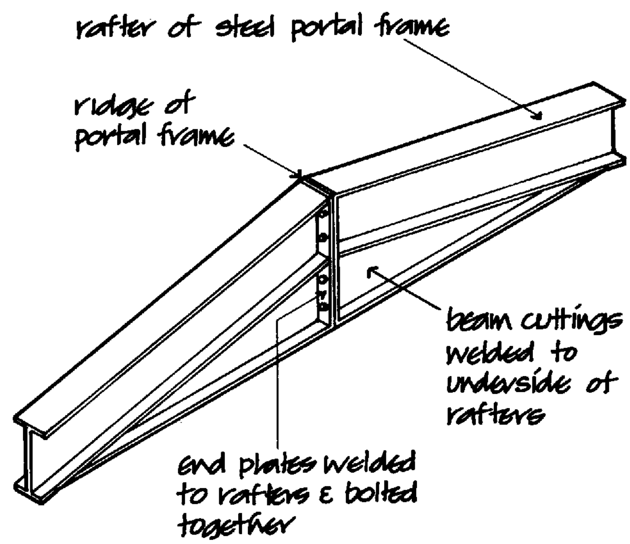
Fig. 23

often be fabricated from cut and welded I-sections so that the post section and part of the rafter is wider at the knee than at the base and ridge of the rafter (Fig. 24).

The haunched connection of the rafters to the posts can be fabricated either by welding a cut I-section to the underside of the rafter, as illustrated in Fig. 23, or by cutting and bending the bottom flange of the rafter and welding in a steel gusset plate.

The junction of the rafters at the ridge is often stiffened by welding cut I-sections to the underside of the rafters at the bolted site connection as shown in Fig. 25.

Steel portal frames may be fixed to or pinned to bases to foundations. For short-span portal frames, where there is comparatively little spread at the knee or



Stiffening at ridge of steel portal frame

Fig. 25

haunch, a fixed base is often used. It will be seen from Fig. 26 that the steel base plate, which is welded through gusset plates to the post of the portal frame, is set level on a bed of cement grout on the concrete pad foundation and is secured by four holding-down bolts set or cast into the concrete foundation.

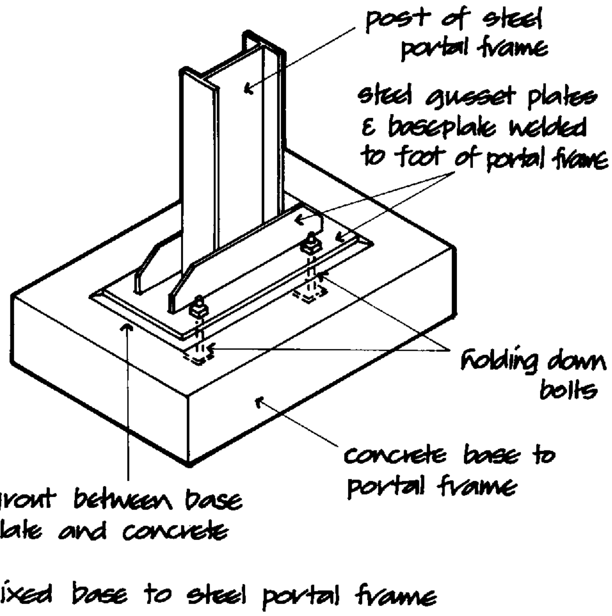


Fig. 26

A pinned base is made by sitting the portal base plate on a small steel packing on to a separate base plate bearing on the concrete foundation. Two anchor bolts, either cast or set into the concrete pad foundation, act as holding-down bolts to the foot of the portal frame as illustrated in Fig. 27. This type of base is described as a pinned base as the small packing between the two plates allows some flexure of the portal post independent of the foundation which in consequence may be less substantial than a comparable fixed base.

Portal frames with a span of up to 15.0 are defined as short span, frames with a span of 16.0 to 35.0 as medium span and frames with a span of 36.0 to 60.0 as long span.

Short-span portal frames are usually spaced at from 3.0 to 5.0 apart and medium-span portal frames at from 4.0 to 8.0 apart to suit the use of angle or cold formed purlins and sheeting rails. Long-span steel portal frames are usually spaced at from 8.0 to 12.0 apart to economise in the number of comparatively expensive frames, with channel, I-section or lattice purlins and

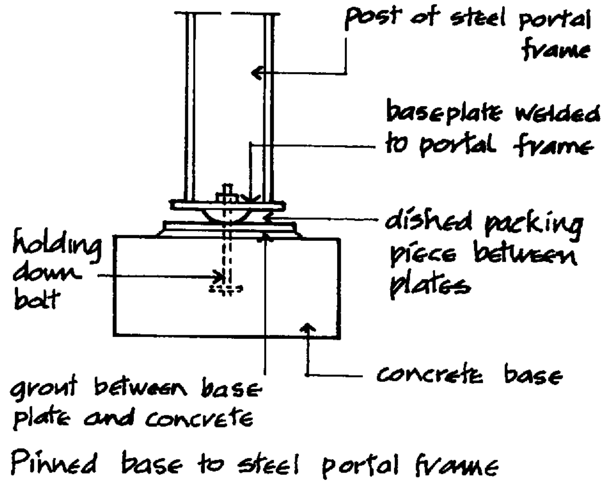


Fig. 27

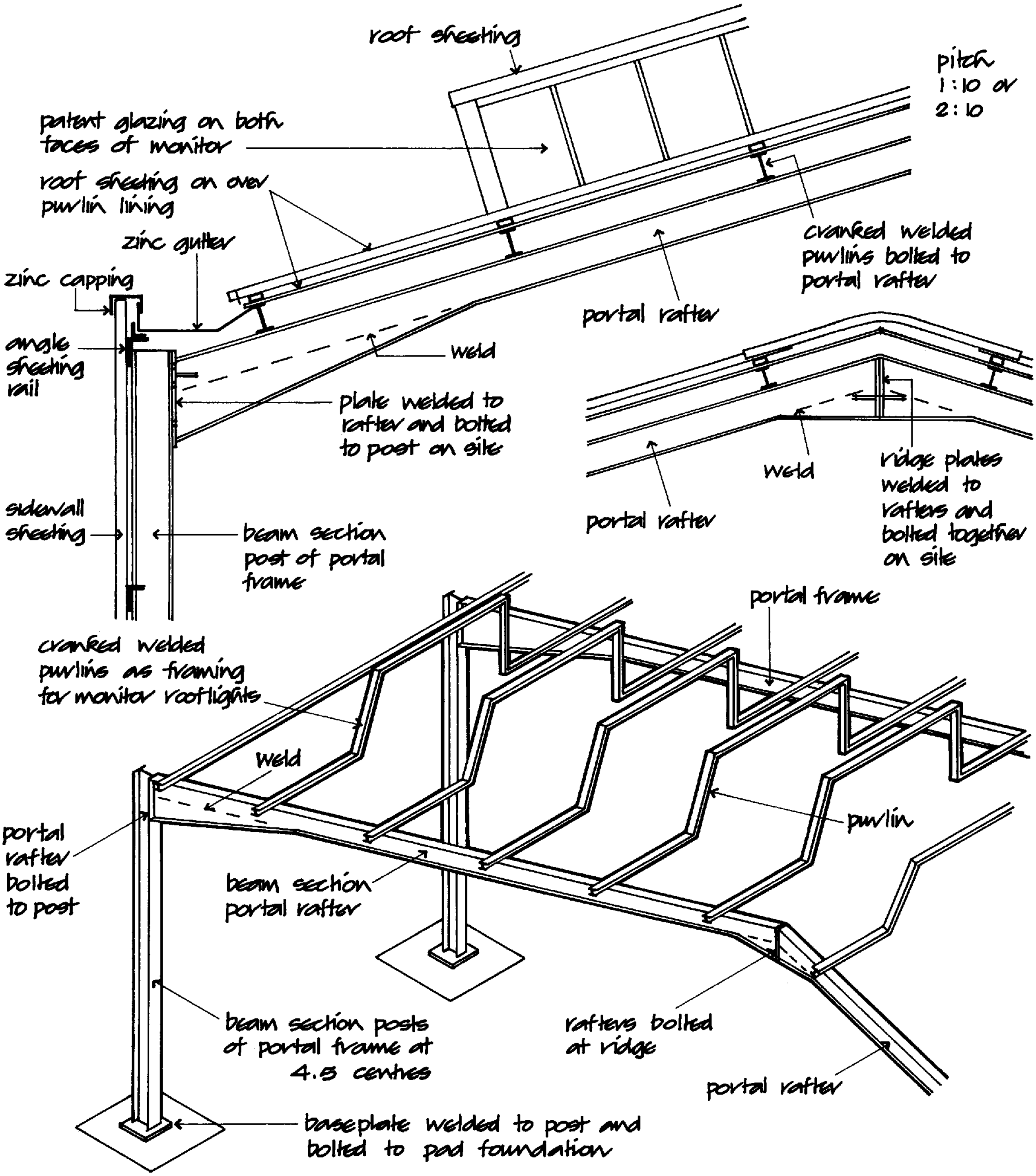
sheeting rails to support roof sheeting or decking and walling.

With flat or low pitch steel portal frames it is difficult to ensure a watertight system of roof glazing fixed in the slope of the roof, with either glass or plastic sheets. For natural roof lighting a system of monitor roof lights is sometimes used. These lights are formed by welded, cranked I-section steel purlins fixed across the portal frames as illustrated in Fig. 28. The monitor lights project above the roof with two upstand faces that may be vertical or sloping. The monitor lights shown in Fig. 28 are designed with the vertical faces facing south to minimise the direct penetration of sunlight and the sloping faces facing north to provide a good distribution of natural light to the interior. The monitor lights can be constructed to provide natural or controlled ventilation. The monitor lights finish short of the eaves to avoid the difficulty of the finish at eaves that would otherwise occur.

Because of the very considerable spans practical with steel portal frames there is little if any advantage in the use of multi-bay steel portal systems.

Bracing

Wind bracing The side wall columns (stanchions) and their fixed bases that support the roof frames of a single-bay, single-storey structure are designed to act as vertical cantilevers to carry the loads in bending and shear that act on them from horizontal wind pressure on the sheeting fixed to purlins and roof frames and



Solid web steel portal frame with monitor roof lights

Fig. 28

side wall sheeting fixed to sheeting rails. The rigid knee joint of rafters to posts of portal frames is generally sufficient to carry the loads from horizontal wind pressure on roof and side wall sheeting.

Where internal columns to multi-bay, single-storey buildings are comparatively widely spaced under roof lattice girders or beams supporting intermediate roof frames of valley, umbrella, butterfly, north light and saw tooth roof systems, it is generally necessary to use a system of eaves bracing to assist in the distribution of horizontal loads from wind pressure on side walls and roof, between the external and the more widely spaced internal columns. The system of eaves bracing shown in Fig. 29 consists of steel sections fixed between the tie or bottom chord of roof frames and columns.

between roof frames serve to stabilise the frames against probable uplift due to wind pressure.

The vertical bracing in the adjacent wall frames at gable end corners assists in setting out and squaring up the building and also serves as bracing against wind pressure on the gable ends of the building.

Purlins and sheeting rails

Purlins are fixed across rafters and sheeting rails across the columns of single-storey frames to provide support and fixing for roof and wall sheeting and insulation. The spacing of the purlins and sheeting rails depends on the type of roof and wall sheeting used. The deeper the

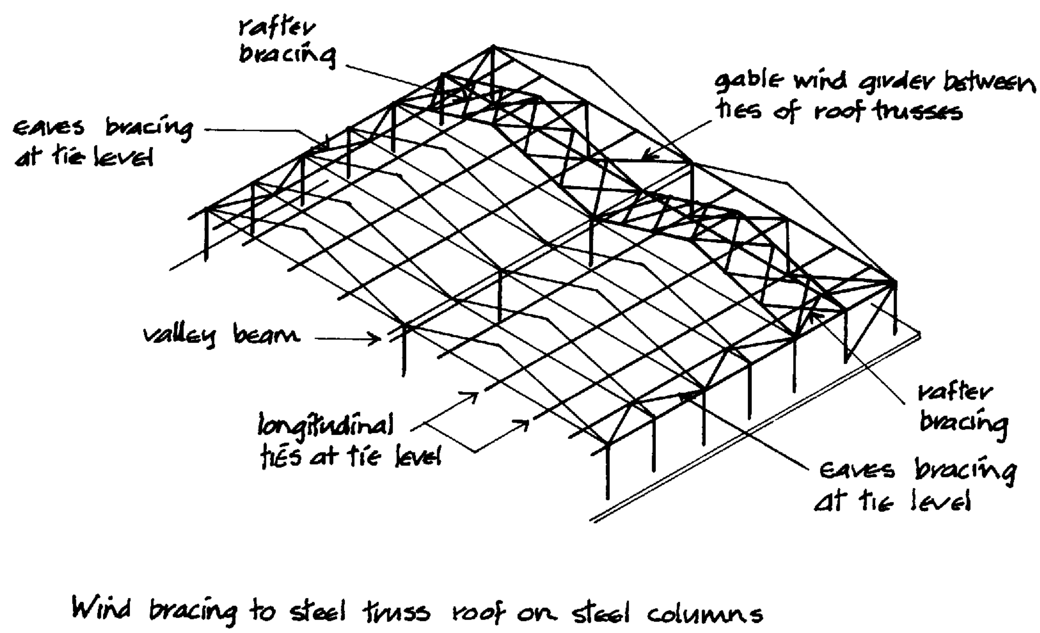


Fig. 29

profile of sheeting the greater its safe span and the further apart the purlins and sheeting rails may be fixed.

To transfer the loads from wind pressure on the end wall sheeting and vertical sheeting rails of gable ends, a system of horizontal gable girders is formed at tie or bottom chord level as illustrated in Fig. 29.

Structural bracing Other bracing to the frames is used to assist in setting out the building, to stabilise the roof frames and square up the ends of the building.

The rafter bracing between the end frames, illustrated in Fig. 29 serves to assist in setting out the building frames and to stabilise the rafters of the roof frames. Longitudinal ties, illustrated in Fig. 29,

The section of the purlins and sheeting rails depends on the most economic spacing of the structural frames. The greater the spacing of frames the greater the deadweight of sheeting and imposed loads, and the deeper the section of purlin and rail necessary to support the weight of the roof and wall covering and loads from wind and snow.

Before 1960 most purlins and sheeting rails were of standard mild steel sections, angle sections being common for closely spaced frames and channel sections for more widely spaced frames. Angle and channel sections were suited to the hook bolt fixings then used for corrugated asbestos cement and steel sheeting.

Angle and channel section purlins and sheeting rails are fixed to short lengths of steel angle cleat bolted to the top flange of rafters and to columns. Figure 30 is an illustration of the bolted fixing of steel angle purlins to cleats with a short length of cleat for fixing along the length of a purlin and a longer length of cleat to make connection and provide fixing at butt ends of purlin connections. Similar angle section sheeting rails are bolted to cleats welded or bolted to columns.

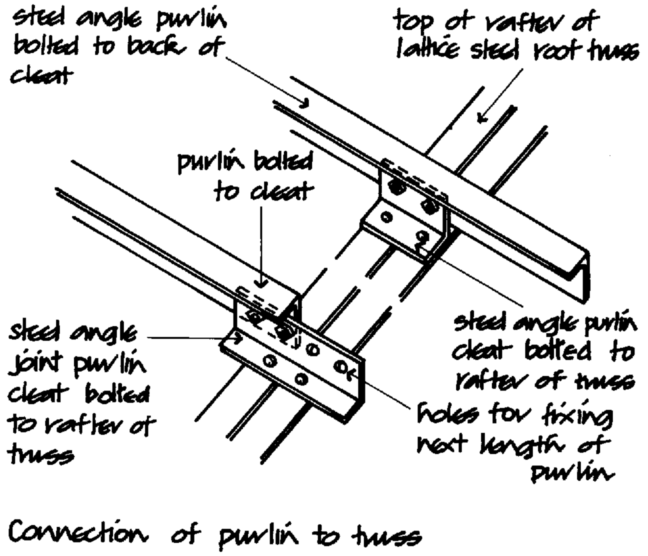


Fig. 30

Gable end wall sheeting is supported by and fixed to sheeting rails that are in turn fixed to steel gable posts of tee, channel or I-sections, bolted to a concrete pad, strip foundation, an upstand kerb or the concrete floor and fixed to the gable end truss as illustrated in Fig. 31. The gable end posts are fixed at centres to suit angle sheeting rails and gable wall sheeting.

Standard mild steel angles are not the most economical section for use as purlins and sheeting rails as the section is often considerably thicker than that required to support the dead weight and imposed loads on the roof and wall sheeting and the thickness of the standard angle is too great for the use of self-drilling fasteners that are used for fixing profiled steel sheeting.

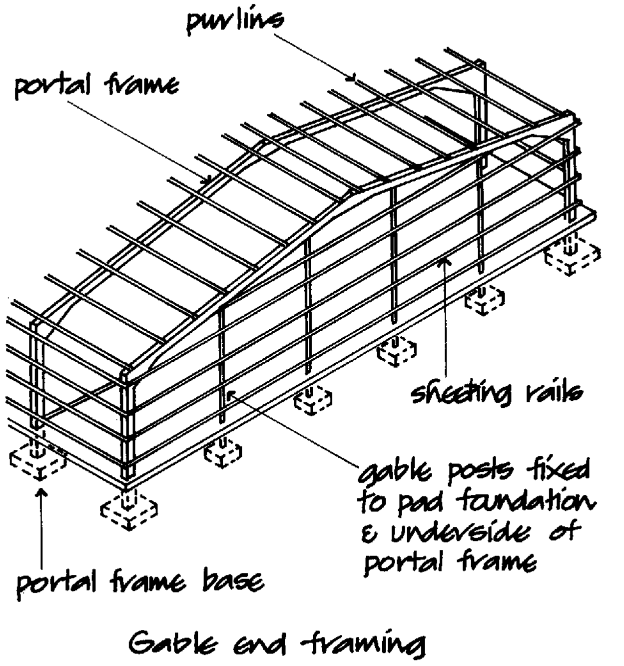


Fig. 31

Since about 1960 a range of galvanised, cold formed steel strip purlins and sheeting rails has been produced and designed specifically for the purpose. A range of standard sections and specifically designed purlins and rails is available.

The advantage of cold formed steel purlins and rails is economy in the use of material and flexibility in the design of the section to meet specific conditions of loading and use. The disadvantage of these purlins and rails is that due to the comparatively thin section of the material from which they are formed, various systems of anti-sag bars, braces and braces between purlins and rails are necessary to prevent gross distortion of the sections while sheeting is being fixed, distortion due to wind uplift and distortion due to the weight of side wall sheeting.

The sections most used are Zed and Sigma as illustrated in Fig. 32. More complex sections with stiffening ribs are also produced.

An advantage of the thin section of these purlins and rails is that it facilitates direct fixing of sheeting by self-tapping screws. The section of purlin and rail used depends on the type of profiled sheeting used. This determines the maximum spacing and the span between support from structural frames that subsequently determines the depth and section of the purlin and rail. Purlins and rails may be used in single or

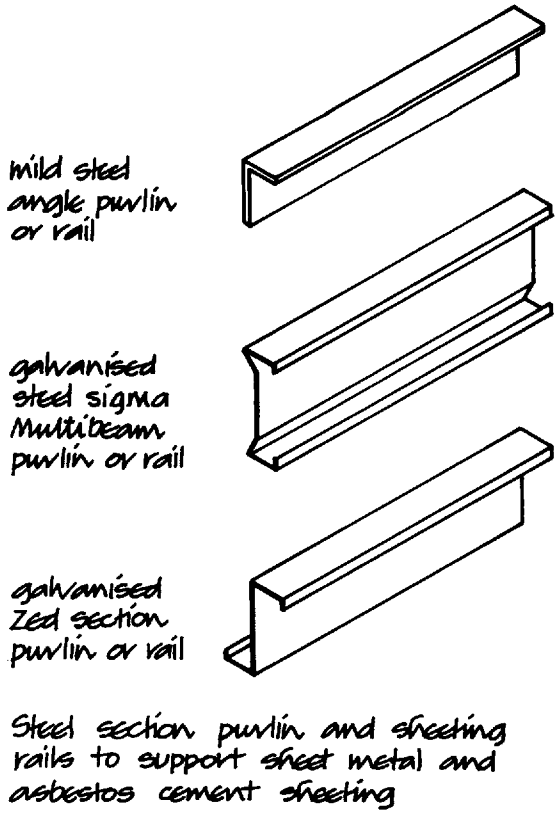


Fig. 32

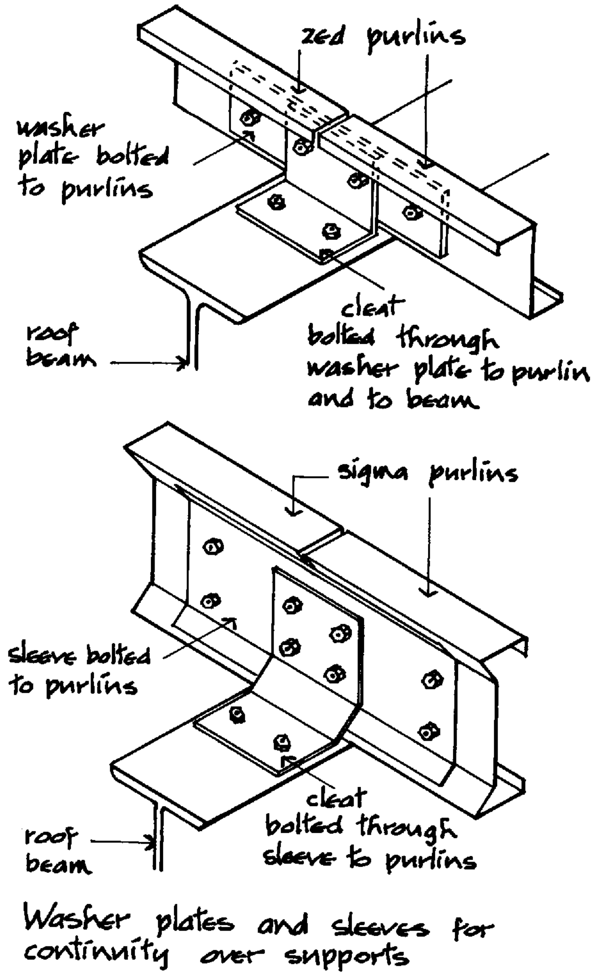


Fig. 33

double lengths between supports to which they are fixed with cleats to supports, washer plates and sleeves to provide continuity over supports. The typical cleats, washer plates and sleeves, illustrated in Fig. 33, are holed for bolts for fixing to purlins, rails and structural frame supports. Anti-sag bars are fixed between cold formed purlins to stop them twisting during the fixing of roof sheeting and to provide lateral restraint to the bottom flange against uplift due to wind pressure. When the sheeting has been fixed, the purlins derive a large measure of stiffness from the sheeting which acts as a roof membrane. Anti-sag bars should be used where the span of purlins, between support from the structural frames, exceeds 4.6 and at such intervals that the unsupported length of purlins does not exceed 3.8.

Anti-sag bars and apex ties are made from galvanised steel rod that is either hooked or bolted between purlins as illustrated in Fig. 34. The apex ties provide continuity over the ridge. For the system of anti-sag bars to be effective there must be some form of stiffening brace or strut at eaves as illustrated by the eaves brace in Fig. 34, which acts as a strut between the eaves purlin and eaves beam or structural framework.

The secret fixing for standing seam roof sheeting for low and very low pitched roofs does not provide lateral restraint for cold formed purlins either during sheet fixing or from wind uplift. With standing seam roof sheeting it is necessary to use a system of braces between purlins. These braces, which are manufactured from galvanised steel sections, are bolted between purlins as illustrated in Fig. 35, with purpose-made apex braces.

Sheeting rails are fixed across or between colums or the vertical members of frames at intervals to suit the profiled sheeting to be used. The Zed or Sigma section rails which are fixed with the flange of the section at right angles to the support are bolted to cleats and then bolted to the structural frame. A system of side rail

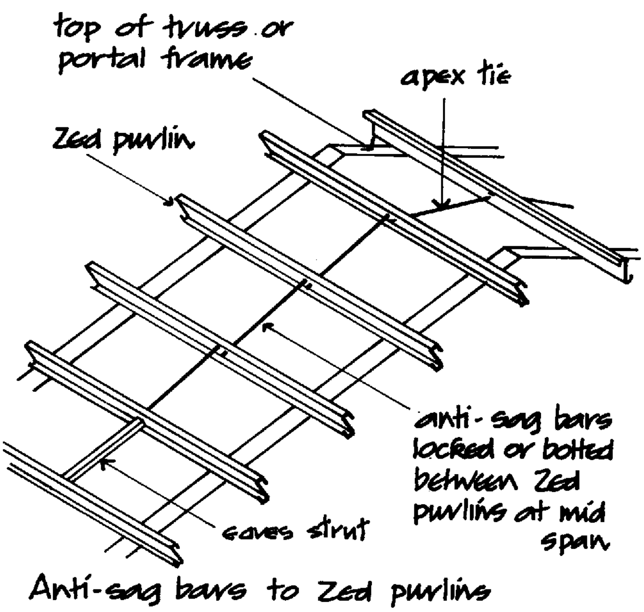


Fig. 34

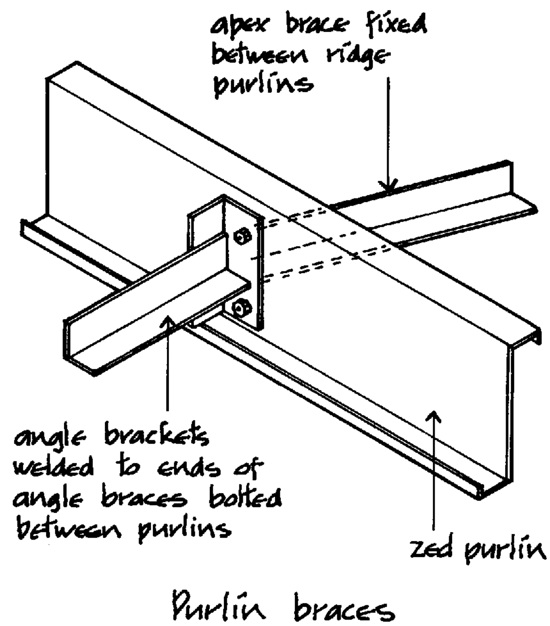


Fig. 35

struts is fixed between rails to provide strength and stability against the weight of the sheeting. For spans up to 6.0 one set of supports is used and above 6.0 two sets are used.

These side rail struts are fabricated from lengths of mild steel angle, to each end of which is welded a fixing plate which is bolted to the sheeting rails. In addition, a system of tie wires is fixed between the bottom two rows of rails and bolted to brackets fixed under cleats and supports. The fabricated struts, tie wires and clips are galvanised after manufacture. Fig. 36 is an illustration of side rails, struts and tie wires.

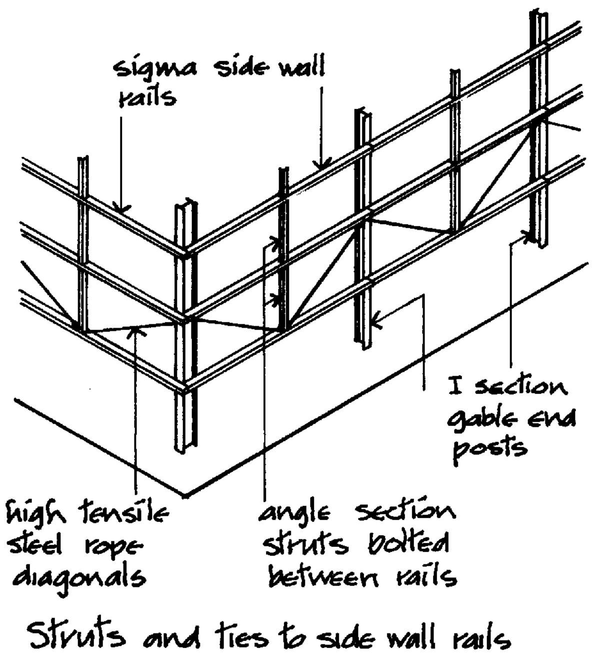


Fig. 36

As an alternative to angle iron or cold formed steel purlins, timber has been used for short- and medium-span purlins between structural roof frames. The durable, non-corrosive nature of timber allied to simplicity of cutting and fixing makes timber a practical and economic alternative to steel.

For economy in the use of materials, widely spaced roof frames are commonly used as support for deep profile and standing seam roof sheeting, laid over low and very low pitch roofs and fixed to either standard I-section or lattice steel purlins. The composite construction structural frames illustrated later in Fig. 53 employ I-section solid web, steel beam purlins which are sufficiently robust to need no lateral restraint.

Pre-cast reinforced concrete portal frames

For several years following the end of the Second World War (1945) there was a considerable shortage of structural steel in this country and it was then that the reinforced concrete portal frame came into common use for agricultural, storage, factory and other single-storey buildings.

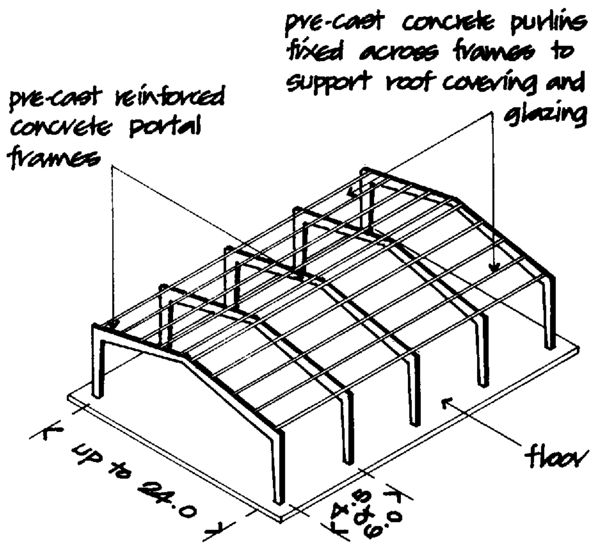
A limited range of standard, pre-cast reinforced concrete portal frames was supplied for the economic benefit of repetitive casting in standard moulds and close control of mixing, placing and compaction of concrete that is possible in factory conditions. The immediate advantage of these building frames was that there was a ready supply of a limited range of standard frames that could rapidly be transported, erected and finished at an economic cost so avoiding the delays consequent on obtaining the necessary licence for the use of steel that was required at the time. The advantages of speed of erection and economy in the use of a limited range of standard sizes continued for some years after steel became more freely available.

The advantages of reinforced concrete portal frames are that they require no maintenance during the useful life of the building and the frame has a somewhat better resistance to collapse during fires than an unprotected steel frame. The principal disadvantage of these frames is that as they have to be formed in standard size moulds, for the sake of economy, there is only a limited range of sizes. The comparatively small spans that are practicable and the bulky somewhat unattractive appearance of the members of the frame have led to the loss of favour of this building system which is much less in use than it once was.

Due to the non-ductile nature of the principal material of these frames, i.e. concrete, the advantage of economy of section area gained by the use of the plastic method of design in the design of steel frames is considerably less with reinforced concrete. Because of the necessary section area of concrete and the cover of concrete to the steel reinforcement to inhibit rust and give protection to the steel reinforcement against damage during fires, the sections of the frames are large compared to steel frames of similar span. Damage to the frames and shrinkage cracks may rapidly cause rusting of the reinforcement particularly in wet and humid conditions. For convenience in casting, transport and erection on site, pre-cast concrete portal frames are generally cast in two or more sections which are bolted together on site either at the point of contraflexure in rafters or at the junction of post and rafter, or both, as illustrated in Fig. 38.

The point of contraflexure is that position along the rafters where negative or upward bending changes to positive or downward bending. At this point the member is presumed to be suffering no bending stresses so that structurally this is the soundest point to make a connection. Concrete portal frames are usually spaced at from 4.5 to 6.0 apart to support pre-cast reinforced concrete purlins and sheeting rails, cast in lengths to span between frames and hooked or bolted to the rafters and posts. As an alternative cold-formed steel Zed purlins and sheeting rails may be used for the fixing of profiled steel sheeting.

The bases of concrete portal frames are placed in mortices cast in concrete pad or strip foundations and grouted in position.



Single bay symmetrical pitch portal frames

Fig. 37

Symmetrical pitch reinforced concrete portal frame construction

This is the most structurally efficient and most commonly used type of concrete portal frame.

It has been used for factories, warehouses, barns, sheds and single-storey places of assembly. Figure 37 is an illustration of a single bay symmetrical pitch pre-cast reinforced concrete portal frame. The slope of the rafters and spacing of purlins and sheeting rails is usually arranged to suit fibre cement or profiled steel sheeting.

Figure 38 is an illustration of the details of a two-bay symmetrical pitch concrete portal frame. It will be seen that the rafter, which is cast as one unit, is bolted to the

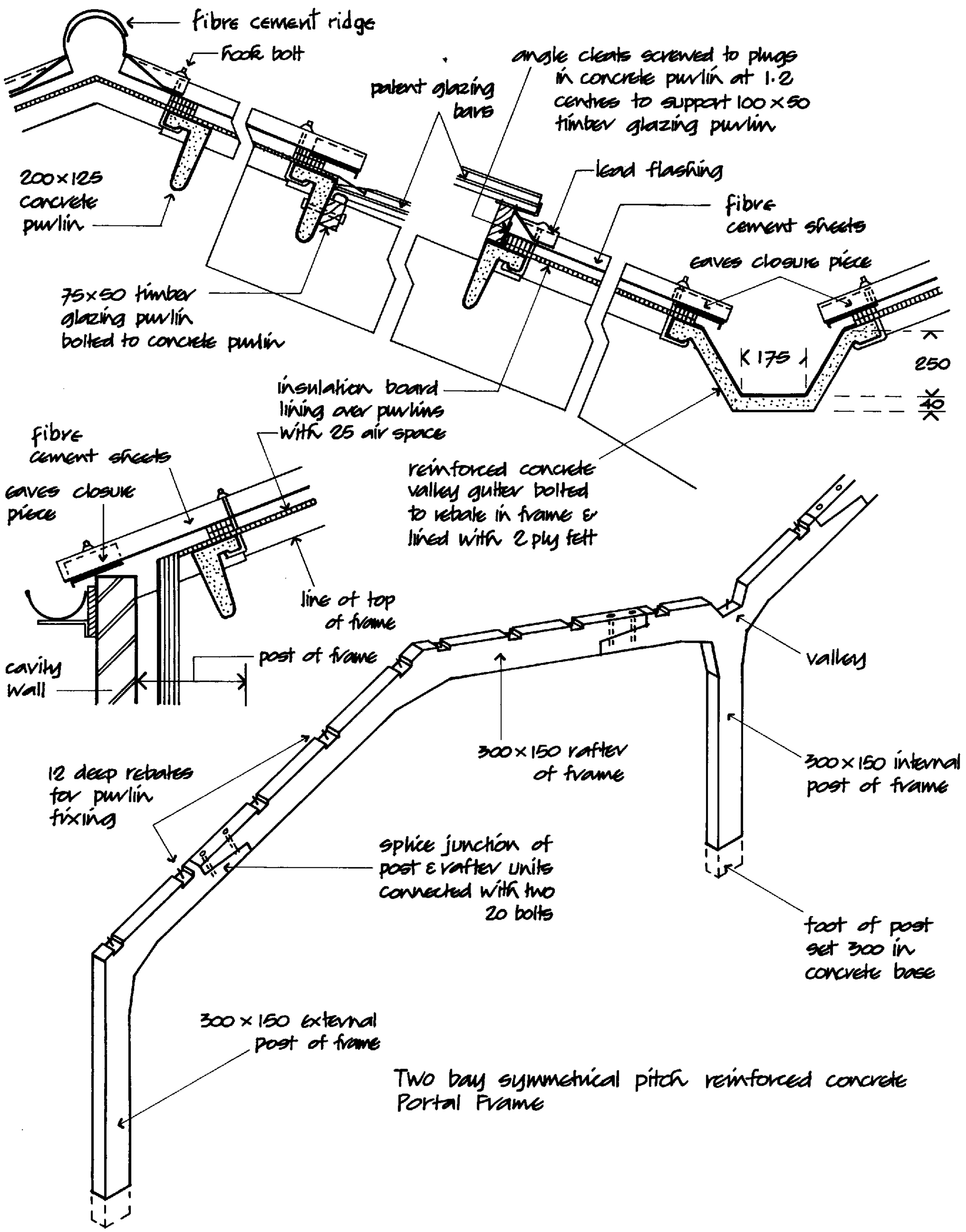
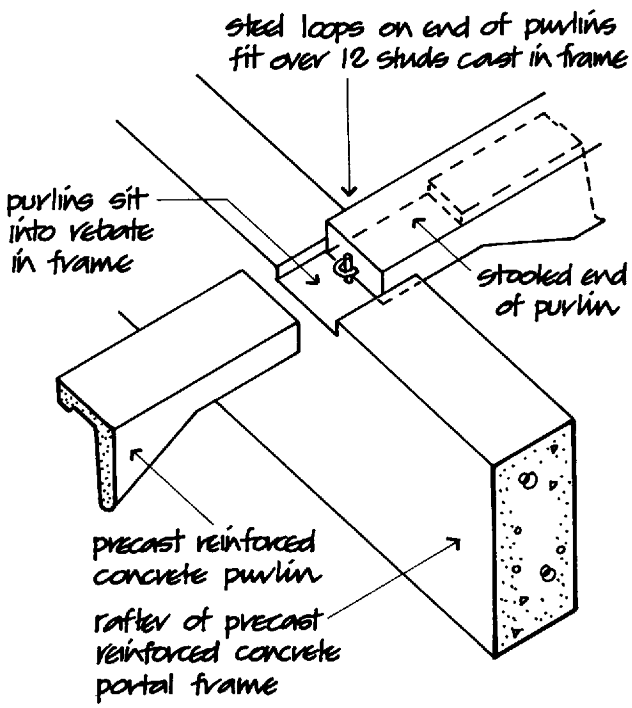

fibre cement ridge
hook bolt
angle cleats screwed to plugs in concrete purlin at 1.2 centres to support 100 × 50 timber glazing purlin
patent glazing bars
lead flashing
200 × 125 concrete purlin
fibre cement sheets
eaves closure piece
75 × 50 timber glazing purlin bolted to concrete purlin
175
250
40
insulation board lining over purlins with 25 air space
fibre cement sheets
eaves closure piece
reinforced concrete valley gutter bolted to rebate in frame & lined with 2 ply felt
line of top of frame
cavity wall
post of frame
valley
300 × 150 rafter of frame
300 × 150 internal post of frame
12 deep rebates for purlin fixing
splice junction of post & rafter units connected with two 20 bolts
foot of post set 300 in concrete base
300 × 150 external post of frame
Two bay symmetrical pitch reinforced concrete Portal Frame

Fig. 38

posts at the point of contraflexure as previously described. A single post supports the rafters of the frames below the valley in the roof and these posts are shaped to receive a pre-cast reinforced concrete valley gutter, bolted to the rafters, which is laid without fall to rainwater pipes and lined with felt. The spacing of the internal columns below valleys may be increased by the use of a pre-cast concrete valley beam to support every other internal roof frame. The bulky valley beam will obstruct clear head room and add considerably to the cost of the structure. The disadvantage of this multi-bay form of concrete portal frame is the number of comparatively bulky internal columns obstructing a free working area.

The pre-cast reinforced concrete purlins are usually of angle section with stiffening ribs and cast in lengths to span between portal frames. The purlins are fixed by loops protruding from their ends which fit over and are bolted to studs cast in the rafters, with the joint being completed with in-situ-cast cement- and sand-mortar, as illustrated in Fig. 39.

Corrugated fibre cement sheeting is hook bolted to the concrete purlins over an insulating lining laid over the purlins as illustrated in Fig. 38. As an alternative, profiled steel sheeting with an insulating lining may be fixed to Zed purlins bolted to the portal frames. Walls may be of solid brick or concrete blocks fixed between or across the posts of the portal frames, or fibre cement or profiled steel sheeting may be used.



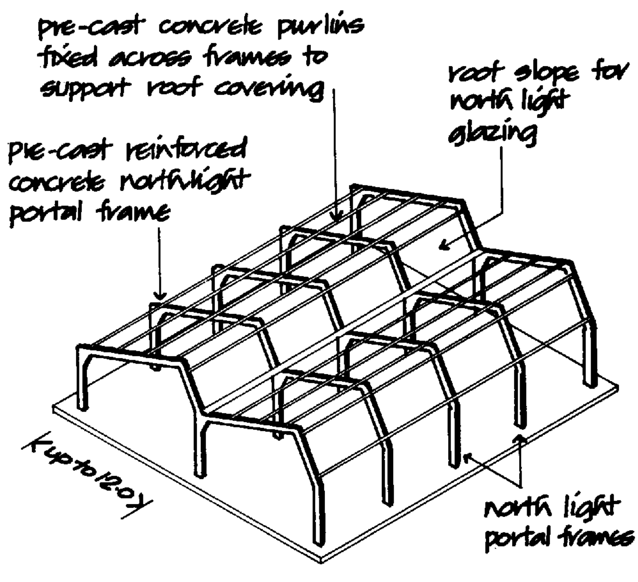
Connection of concrete purlins to concrete portal frame

Fig. 39

North light pre-cast reinforced concrete portal frame construction

The most economical span for this profile of frame is up to about 9.0 to minimise the volume of roof space inside the frames and to avoid the large sections of frame that would be necessary with greater spans.

The south-facing slope is pitched at 22° and the north-facing slope at 60° to the horizontal. Figure 40 is an illustration of the frames of a typical two-bay north light concrete portal frame.



Two bay north light portal frames

Fig. 40

From Fig. 41 it will be seen that for convenience in casting and transport the rafter is cast in two sections which are bolted together at the point of contraflexure and in turn bolted to the posts. A pre-cast reinforced concrete valley gutter may be bolted to the frames as previously described.

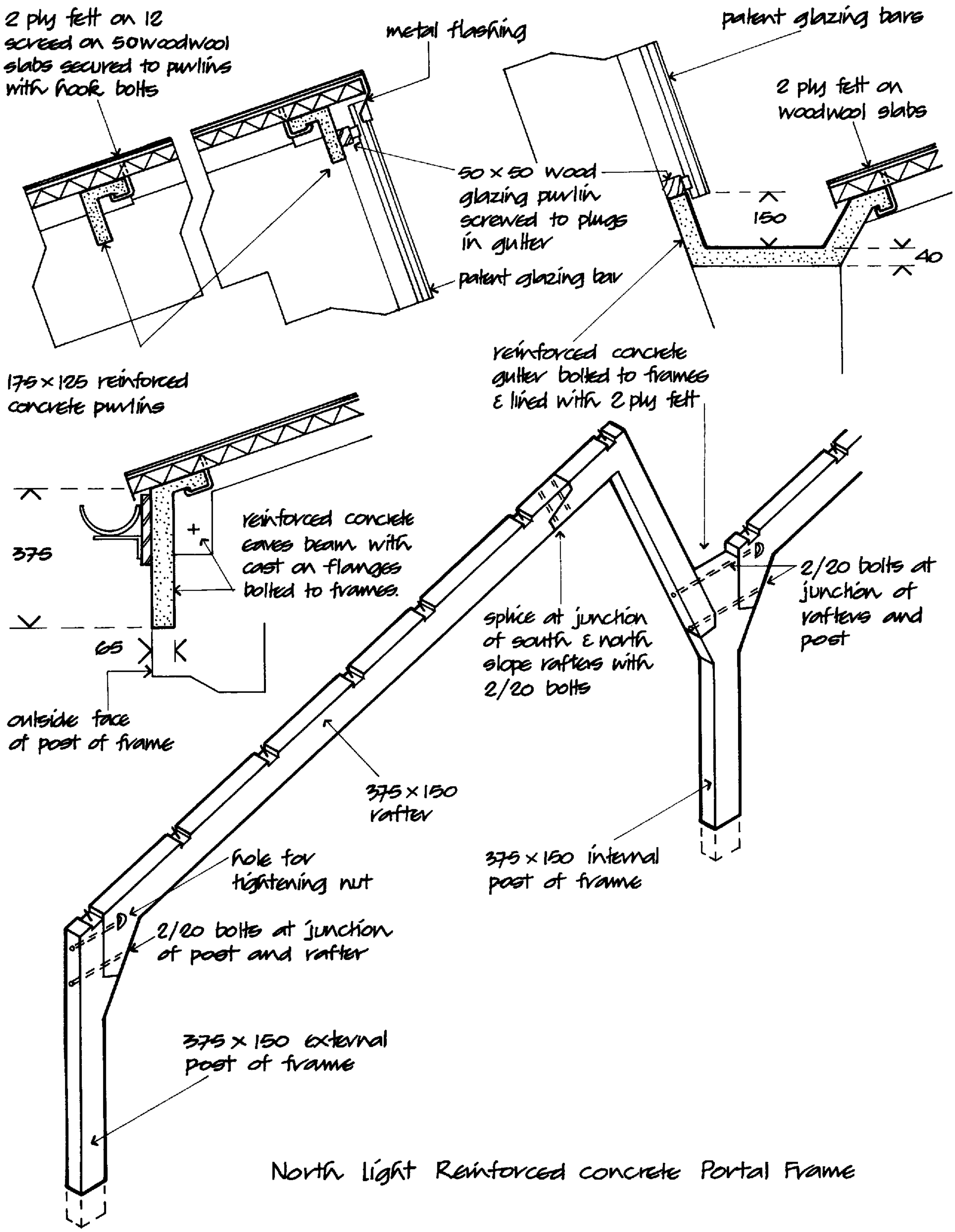

2 ply felt on 12 screed on 50 woodwool slabs secured to purlins with hook bolts
metal flashing
patent glazing bars
2 ply felt on woodwool slabs
50 x 50 wood glazing purlin screwed to plugs in gutter
150
40
patent glazing bar
175 x 125 reinforced concrete purlins
reinforced concrete gutter bolted to frames & lined with 2 ply felt
375
reinforced concrete eaves beam with cast on flanges bolted to frames.
65
outside face of post of frame
splice at junction of south & north slope rafters with 2/20 bolts
2/20 bolts at junction of rafters and post
375 x 150 rafter
hole for tightening nut
375 x 150 internal post of frame
2/20 bolts at junction of post and rafter
375 x 150 external post of frame
North light Reinforced concrete Portal Frame

Fig. 41

Pre-cast reinforced concrete purlins or steel Zed purlins are bolted to the rafters to support wood wool slabs, fibre cement or profiled steel sheets and north light glazing is fixed to timber purlins. In the example illustrated in Fig. 41 a pre-cast reinforced concrete eaves beam serves as purlin and provides support for the eaves gutter.

Because of the limited spans and the obstruction of many internal columns, this type of frame is much less used than it was.

Timber portal frames

Timber Up to about 1970 the conventional method of assessing the strength of timber, to be used structurally, was by visual examination of the surfaces of known specie of wood to assess a strength grade. An experienced grader could give a reasonable strength or stress grade. These visual grades tended to be on the conservative side, as the visual examination took no account of the density of the wood which has a large influence on both stiffness and strength. Once the relationship between stiffness and strength of timber had been established, it became practical to use non-destructive machines to measure the stiffness of timber as it passed through a machine to measure either the force required to produce a fixed deflection or to measure deflection caused by a known force at a particular point.

The majority of timber used for structural work is now machine-graded within nine strength classes and a wide range of stress grade/specie combinations from which suitable timber may be selected with confidence for structural use.

Fungal attack Timber has a natural resistance to fungal decay, which varies with the specie of timber, and is affected by the moisture content. Providing the moisture content of a timber is maintained at 20%–22% or less its natural resistance will protect it from fungal decay.

Insect attack The likelihood of attack by the most common form of beetle to attack wood in this country, the furniture beetle, is unpredictable. The attack, which is generally on internal dried sapwood, takes the form of holes bored along the long grain of the wood which may in time affect the strength of the wood. Insect attack, which is not as widespread as is generally believed, can be prevented by impregnating timber with an insecticide preservative. The house longhorn beetle may attack softwood in roof voids, where there is sufficient warmth, in an area of the Home Counties around London. In this area it is a requirement of the Building Regulations that softwood timber in roof voids be adequately protected.

Fire resistance Timber, which is a combustible material, is not easy to ignite in the sizes usual to buildings. Once ignited, timber burns very slowly and forms a protective layer of charcoal on its surface which insulates the remainder or residual section from the worst effects of fire.

It is possible to make a reasonably accurate estimate of the extent of the depletion or loss of timber in a fire and calculate the strength of the residual timber in supporting anticipated loads.

Surface spread of flame To limit rapid spread of fires in buildings it is a requirement of the Building Regulations that the surfaces of exposed elements have limited rates of surface spread of flame. The majority of softwoods used in buildings have a medium flame spread classification. In situations where there is a requirement for a low or very low rate of flame spread, the surface of softwood timber can be treated with flame retardants to achieve the necessary rate of flame spread.

Portal frames

Combinations of slender timber sections glued, or glued and nailed together, are used in portal frames for medium- and long-span roofs for such buildings as churches, assembly halls, sports halls and other single-storey structures where the timber portal frames are exposed for appearance sake. The advantages of timber as a structural material in this form are its low self-weight and the comparatively little maintenance required to preserve and maintain its strength and appearance, particularly where there are levels of high humidity as in swimming pools.

Symmetrical-pitch glued laminated timber portal These portal frames are usually fabricated in two sections for ease of transport and are bolted together at the ridge as illustrated in Fig. 42. These comparatively expensive portal frames are spaced fairly widely apart to support timber or steel purlins which can be covered with any of the sheet materials, slates or tiles.

The laminations of timber from which the portal is

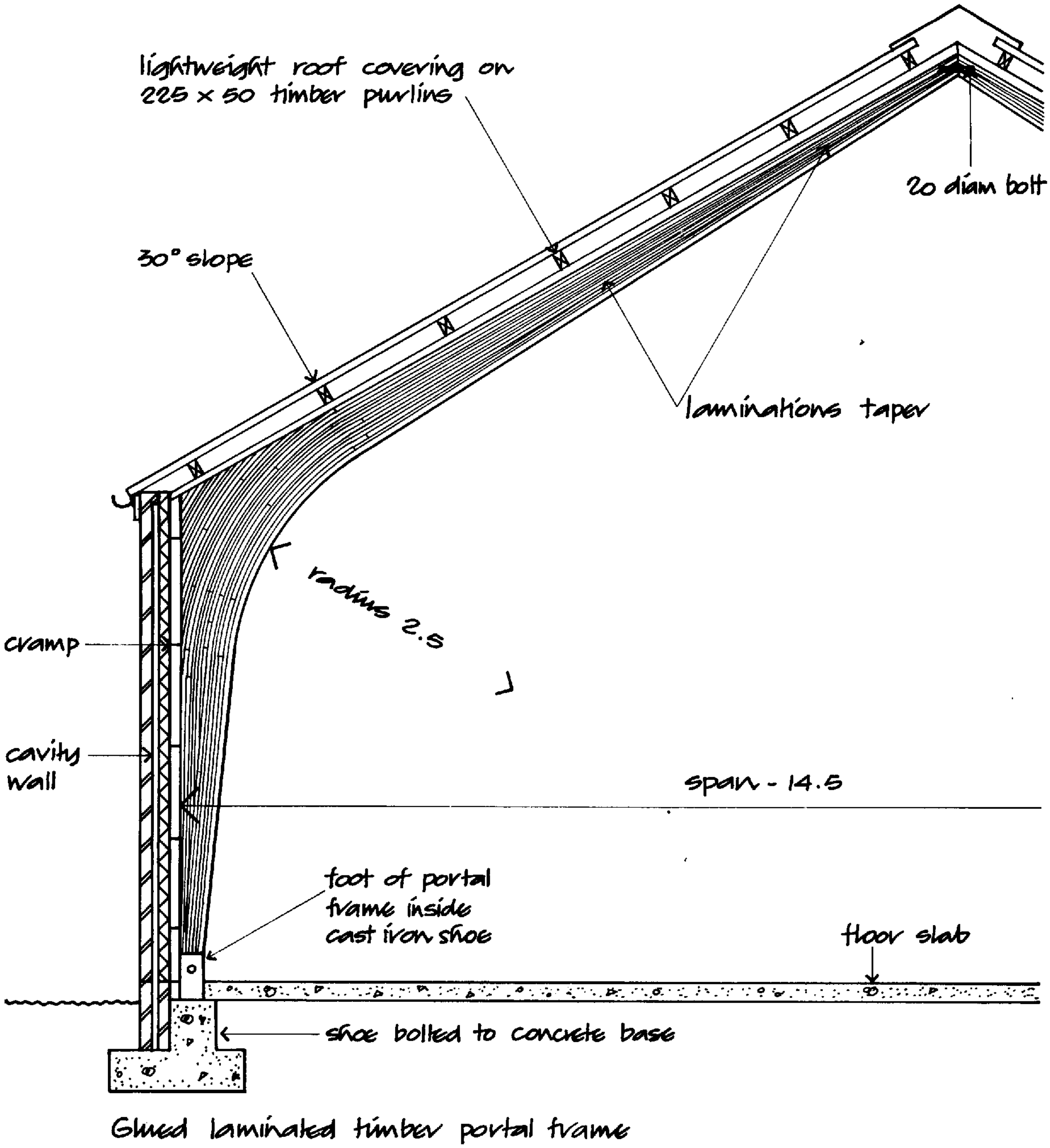


Fig. 42

made are arranged to taper in both the rafter and the post so that the depth is greatest at the knee, where the frame tends to spread under load, and slender at the apex or ridge and the foot of the post, where least section is required for strength and rigidity.

Because of their graceful arch-like appearance, glued laminated portal frames are used as much for appearance as practicality.

Flat glued-and-nailed timber portal The timber portal illustrated in Fig. 43 is a one-off design for an aircraft hanger. The flat portal frame is designed for the most economic use of timber and consists of a web of small section timbers glued together with the top and bottom booms of glued laminate with webb stiffeners. The portal frames are widely spaced to support metal decking on the roof and profiled sheeting on the walls.

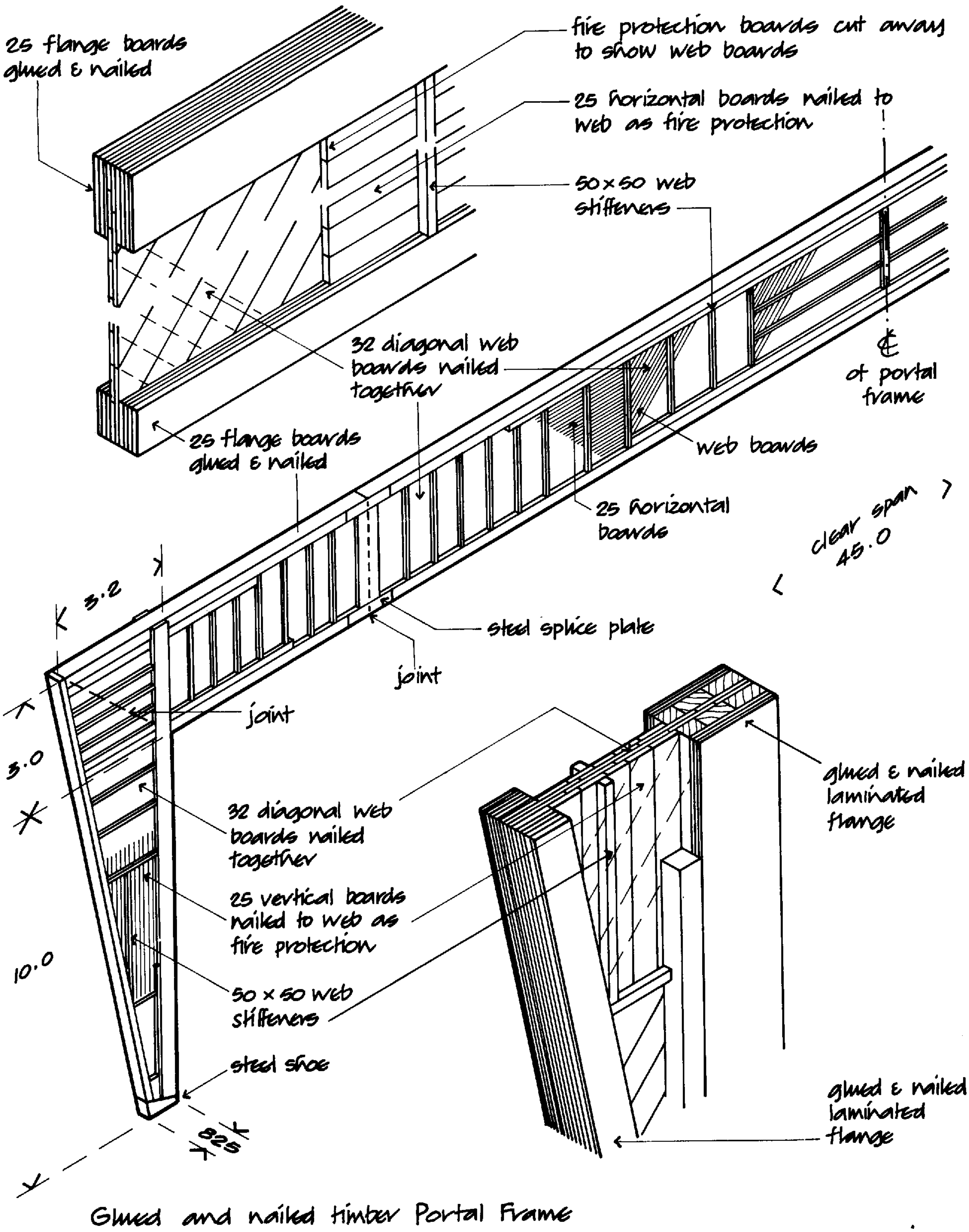

25 flange boards glued & nailed
fire protection boards cut away to show web boards
25 horizontal boards nailed to web as fire protection
50 × 50 web stiffeners
32 diagonal web boards nailed together
℄ of portal frame
25 flange boards glued & nailed
web boards
25 horizontal boards
clear span 45.0
3.2
steel splice plate
joint
joint
3.0
32 diagonal web boards nailed together
glued & nailed laminated flange
25 vertical boards nailed to web as fire protection
10.0
50 × 50 web stiffeners
steel shoe
825
glued & nailed laminated flange
Glued and nailed timber Portal Frame

Fig. 43

This structural form was chosen both for appearance and the long span structure which is lightweight, free from maintenance and has adequate fire resistance.

FLAT ROOF FRAME CONSTRUCTION

The design of buildings is often more subject to the dictates of fashion than economy in first cost, utility and maintenance. The appearance of single-storey buildings, such as factories covering large floor areas, is influenced by the profile of the roof structure. For some years it was fashionable to adopt the strong horizontal roof lines of a flat roof structure on the grounds that it was modern, rather than the more economical single or multi-bay pitched roof profile. Over the years these large areas of flat roof have come into disrepute due to the failure of flat roof coverings which have not remained watertight because of movements of the covering relative to the decking and structure and failures at junctions to parapets and rooflights.

Recent improvements in flat roof coverings to enhance strength and elasticity of the material and delay brittle hardening by oxidation, together with improvements in design detailing to allow for movements of the weather surface and roof support, have improved the useful life of flat roofs to compare favourably with profiled sheet coverings.

Medium- and long-span flat roof structures are less efficient structurally and therefore somewhat more expensive than truss, lattice or portal frames. The main reason for this is the need to prevent too large a deflection of the flat roof structure under load to the accepted 1/250 of span and to limit deflection to prevent ponding of rainwater on flat roofs. For these reasons flat roof beams and girders have to be deeper than is necessary for strength alone. Ponding is the word used to describe the effect of rainwater lying in the centre of flat roofs, where deflection under load is greatest, in the form of a shallow pool of water that cannot drain to the rainwater outlets. A static pool or pond of water will plainly penetrate faults in the roof covering more readily than water running off to gutters and outlets. To avoid ponding the roof surface has to have a positive fall to outlets under load. A fall or slope of at least $2\frac{1}{2}°$ is considered as an absolute minimum, so that at mid-span there is some fall to boundary outlets.

An advantage of flat roof frames is that there is comparatively little unused roof space to be heated.

Main and secondary beam flat roof construction

Figure 44 is an illustration of a single-bay flat roof structure with solid web I-section main beams supported by steel columns with I-section secondary beams between the main beams. To provide a positive fall (slope) to eaves gutters at each side of the roof, it is necessary to fix tapered depth bearers of steel or timber across the secondary beams to provide the necessary fall from the centre to each side of the roof for the decking and weathering finish. This heavy construction is not structurally efficient because of the considerable depth required in the main beams to limit deflection under load. This type of structure is used for single-bay short- or medium-span roofs where the main beams are used to provide support for travelling cranes and other lifting gear. Because services have to be incorporated below the solid web beams of the roof structure there is a considerable increase in the volume of unused roof space that may have to be heated.

Lattice beam (girder) flat roof construction

The required depth of beams for flat roof construction is determined by the need to limit deflection under load

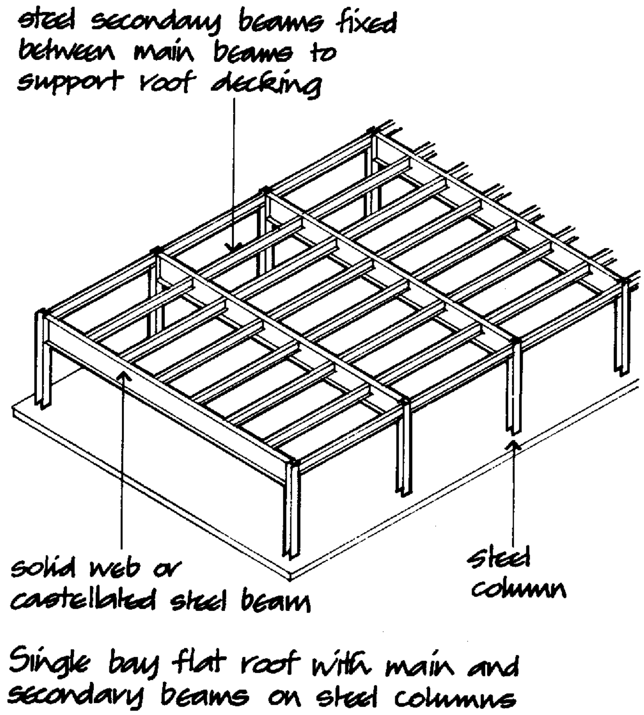


Fig. 44

and by the rigidity of depth more than the weight of the material in the beam. A lattice beam or girder of comparatively small section members, fixed between the top and bottom boom, at once provides adequate stiffness and economy in the use of materials and low self-weight. Because lattice beams and girders have to be fabricated it is generally an advantage to taper the top boom to provide a positive fall or slope for the roof decking and weathering. A taper or low pitch lattice beam or girder may be specially fabricated or one of the standard beams, with either one way or two way taper, can be used.

The terms beam and girder are used in a general sense to describe a lattice construction, 'beam' being used for comparatively small depths such as those used for roofs, and 'girder' for those of appreciable depth used to support heavier loads such as those in bridge construction.

Short-span beams that support comparatively light loads may be constructed from cold-formed steel strip top and bottom booms with a lattice of steel rods welded between them as illustrated in Fig. 45. The top and bottom booms are formed as 'top hat' sections designed to take timber inserts for fixing roof decking and ceiling finishes. These beams are finished with a stove-enamelled primer ready for painting. These standard beams are considerably cheaper than one-off beams, through the economy of mass production.

The majority of lattice beams used for flat and low pitch roofs are fabricated from hollow round and rectangular steel sections. A lattice of hollow round sections is welded to hollow rectangular section top and bottom booms, with end plates for fixing to supports. Hollow rectangular section booms are preferred for the economy in making straight, oblique cuts to the ends of the lattice round sections and the convenience of roof fixings. Where round section booms are used it is necessary to make a more complicated oblique mitre cut to the ends of the lattice members.

Both for flat and low pitch roofs it is generally convenient to fabricate taper lattice beams with the top booms with a one-way or two-way slope to provide the necessary falls or slope to drain to rainwater outlets. For most low pitch roofs to be covered with profiled sheeting a slope of 6° is provided. The lattice beams are either hot dip galvanised, stove enamel primed or spray primed after manufacture. Figure 46 is an illustration of a typical lattice roof beam fabricated from hollow steel sections.

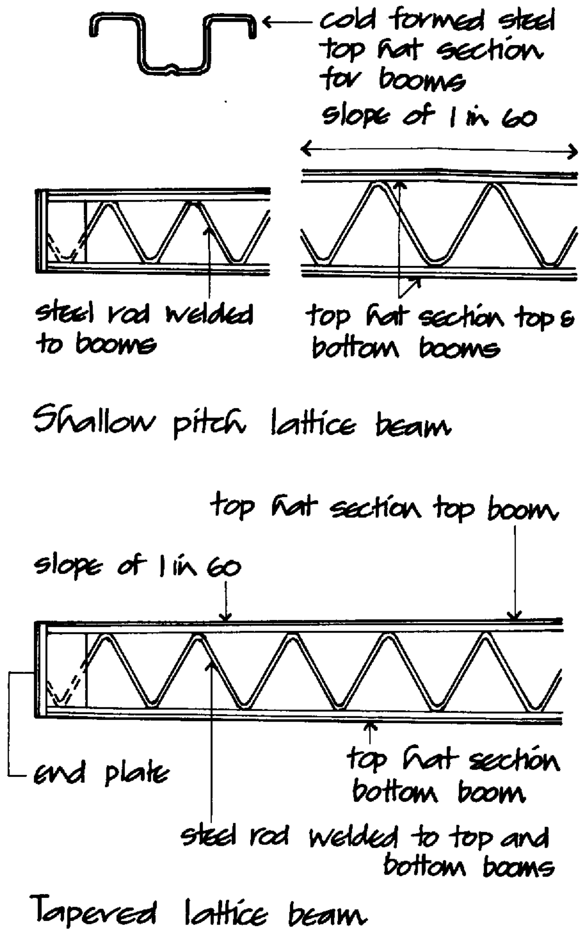


Fig. 45

V-beam flat roof construction

A system of V-section standard grid lattice beam is supported by end lattice beams supported on steel columns. The V-section or prismatic beams are fabricated from tubular steel sections welded together. The V-beams are spaced to support metal decking across the whole of the roof or the V-beams can be spaced apart to suit continuous or separate rooflights. Figure 47 is an illustration of a single-bay, single-storey lattice V-beam structure. With standard section, standard span lattice V-beams, a reasonably economic single- or multi-span flat roof structure can be built.

Space grid flat roof construction

A two-layer space deck constructed of a grid of standard units is one of the commonly used flat roof

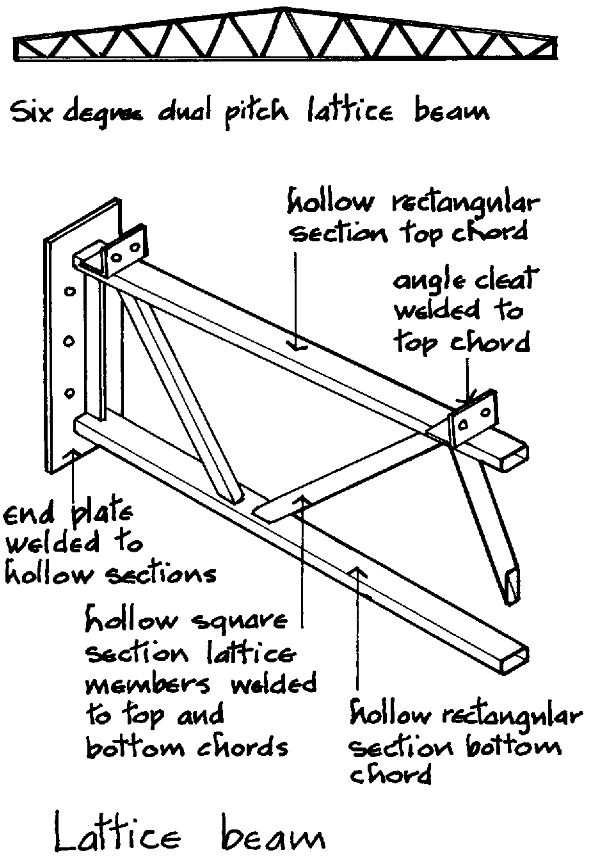


Fig. 46

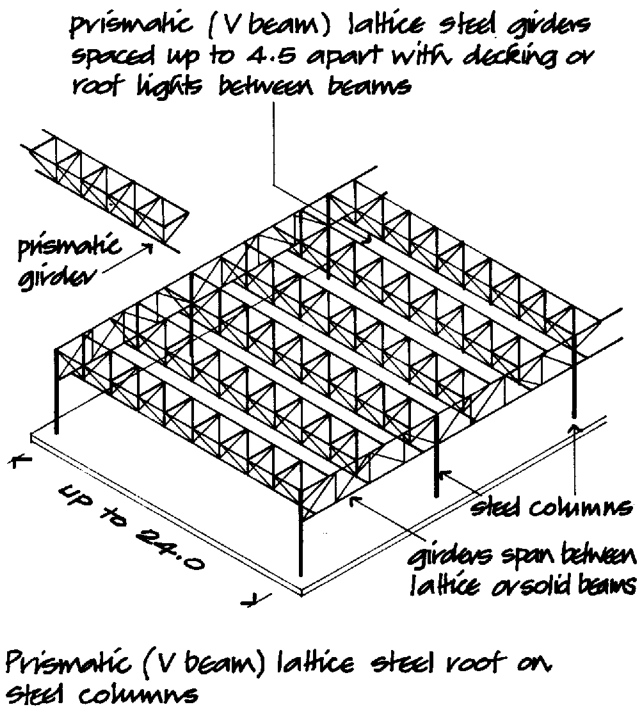


Fig. 47

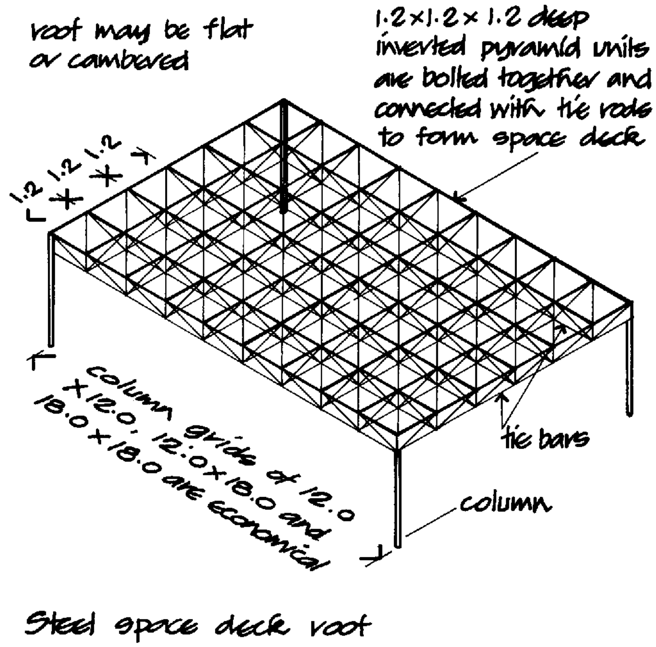


Fig. 48

structures for single-storey buildings such as sports halls, shopping centres, leisure halls, factories and other buildings where it is convenient to have the whole floor area free of obstructing columns. Figure 48 is an illustration of a single-storey structure with a space deck flat roof supported on steel columns.

The space deck is assembled on site from standard space deck units, each in the form of an inverted pyramid with a steel angle tray base, tubular diagonals welded to the tray and a coupling boss as illustrated in Fig. 49. The space deck units are bolted together through the angle trays and connected with tie bars through the coupling bosses. The tie bars which have right- and left-hand threads can be adjusted to give an upward camber to the top of the deck to allow for deflection under load and to provide a positive fall to the roof to encourage the run-off of rainwater and so avoid ponding.

Space deck roofs may be designed as either two-way spanning structures with a square column grid or as one-way spanning structures with a rectangular column grid. Economic column grids are 12.0 × 12.0, 18.0 × 18.0 and 12.0 × 18.0. Various arrangements of the column grid are feasible with also a variety of roof levels, canopies and overhangs.

The advantages of the space deck roof are the comparatively wide spacing of the supporting columns, economy of structure in the use of standard units and

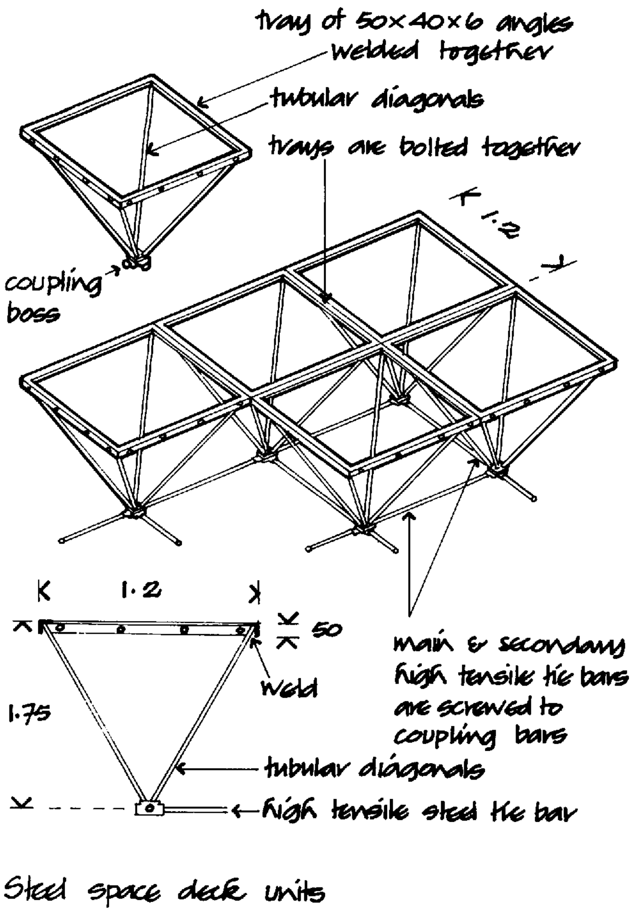


Fig. 49

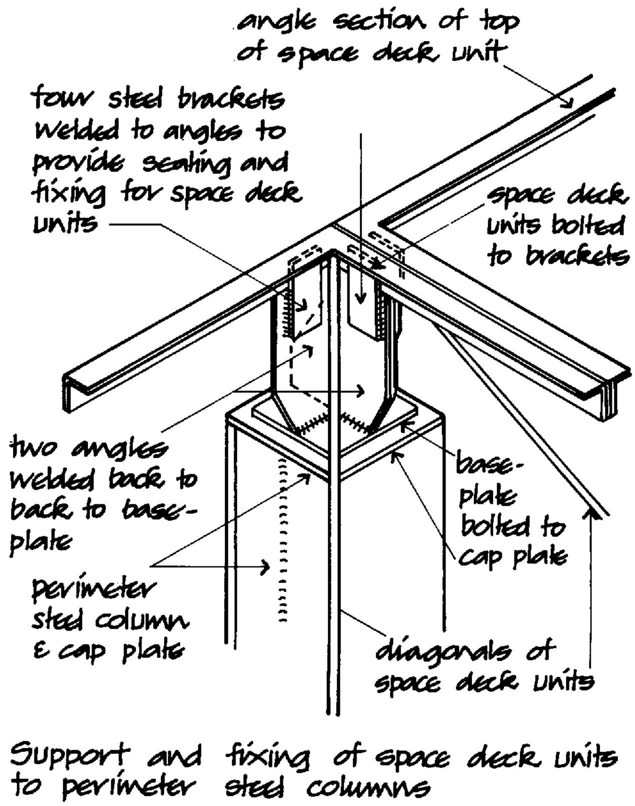


Fig. 50

speed of erection. The disadvantage of the space deck is the great number of lattice members that will collect dust and require careful maintenance to inhibit rust.

The roof of the structural space deck may be covered with steel decking, insulation and one of the flat roof weatherings. Rooflights can be accommodated within one or more of the standard space deck units.

Steel columns supporting the space deck are usually connected to the units at the junction of the trays of the units. Figure 50 is an illustration of the junction of a column at the perimeter of the structure. A steel cap plate is welded to the cap of the column to which a seating is bolted. This seating of steel angles has brackets welded to it into which the flanges of the trays fit and to which the trays are bolted. Likewise a seating is bolted to a cap plate of internal columns with brackets into which the flanges of the angles of four trays fit, as shown in Fig. 51.

The space deck can be finished with either flat or sloping eaves at perimeter columns or the deck can be

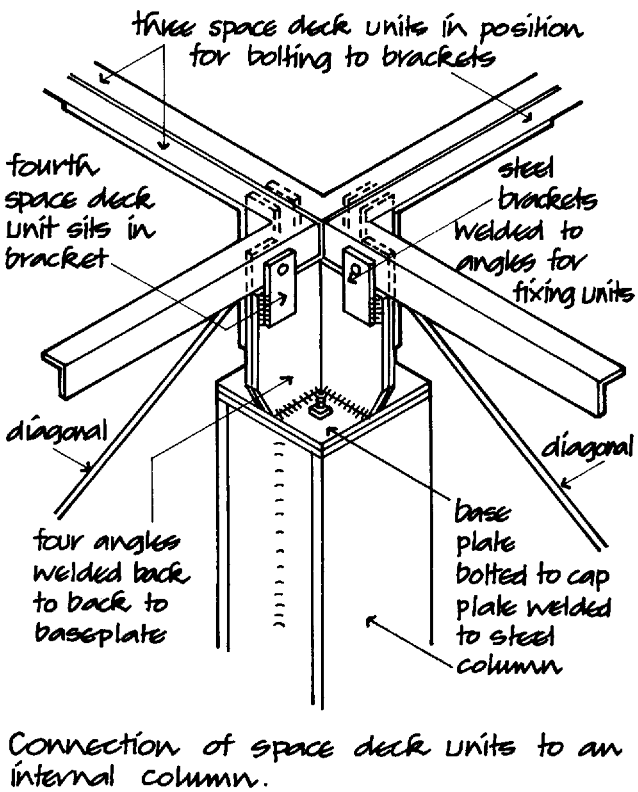


Fig. 51

cantilevered beyond the columns as an overhang. Figure 52 illustrates a two-deck unit overhang and a fixed base with the columns bolted to a concrete pad foundation.

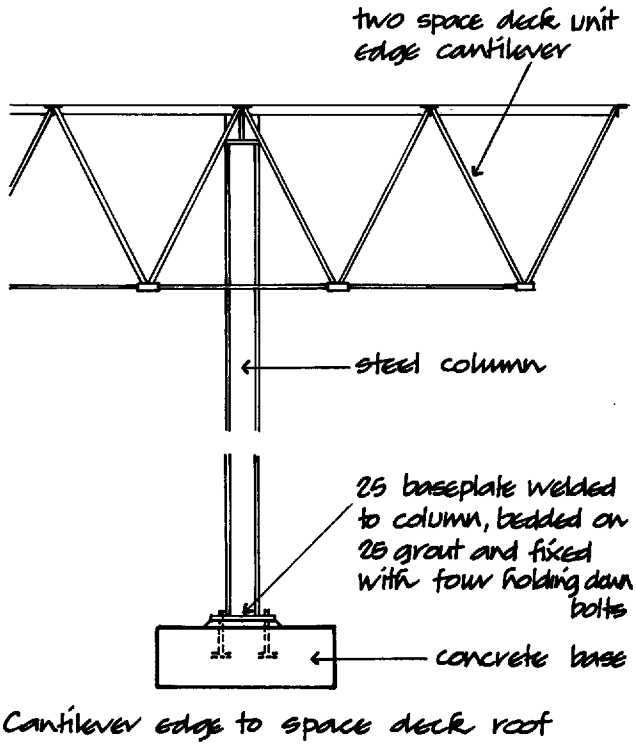


Fig. 52

COMPOSITE FRAME CONSTRUCTION

For many years in the second half of the twentieth century the majority of structural frames were constructed with reinforced concrete, in part due to an initial shortage of steel and in part due to the fashion for the newer material concrete. The somewhat better resistance to damage by fire of reinforced concrete, as compared to steel alone, also played some part in the preference for concrete.

Most reinforced concrete structural frames are constructed as concrete cast in-situ inside temporary falsework of timber or steel as a mould and as temporary support for the initially wet concrete. Complex and labour-intensive systems of falsework and support have to be erected and maintained in place until the concrete gains sufficient strength to be self-supporting and then dismantled (struck) and erected again and then struck at each floor level. This is a costly and somewhat illogical way of building.

With changes in Building Regulations which accepted lightweight dry linings and mineral fibre and cement coatings to steel as fire protection, and a change from requirements for protection of the building to requirements for safety in escape from buildings in case of fire, reinforced concrete no longer enjoyed an advantage over steel. In consequence, steel is now as much used for structural frameworks as reinforced concrete and is more generally used for single-storey buildings.

During recent years manufacturers equipped to precast a range of reinforced concrete structural beams and columns, under carefully controlled factory conditions, have successfully offered a comprehensive design, manufacture and erection service for both single- and multi-storey frames of pre-cast reinforced concrete frames and lattice steel roof beams, at prices competitive with structural steel frames. The advantages of these composite frames are that the reinforced concrete columns and beams will require little maintenance other than occasional washing for appearance and will provide better resistance to damage by fire than steel alone, where good sense or insurance requirements seek protection of valuable contents. Lattice steel beams are used for roofs, in this composite form of construction, where there is now no requirement for fire resistance.

The pre-cast reinforced concrete columns and beams are cast and compacted under closely controlled conditions in the factory. Frame joints and base fixings are cast in as necessary, and the exposed faces of the frame can be smooth and dense, so that no maintenance is required during the useful life of the building, or finished with a variety of finishes.

A variety of shapes for columns, beams and structural frames is practical and reasonably economic where repetitive casting of several like-members is called for.

Figure 53 is an illustration of a typical two-bay, single-storey composite frame structure. The pre-cast reinforced concrete columns, which have fixed bases, serve as vertical cantilevers to take the major part of the loads from wind pressure. Steel brackets, cast into the column head, support concrete and lattice steel roof beams. Concrete or lattic steel spine beams under the roof valley provide intermediate support for every other roof beam.

The top of the lattice steel roof beams, which are pitched at 6° to the horizontal, support low pitch, profiled steel roof sheeting. Fixing slots or brackets cast into the columns provide a fixing and support for sheeting rails for profiled steel cladding.

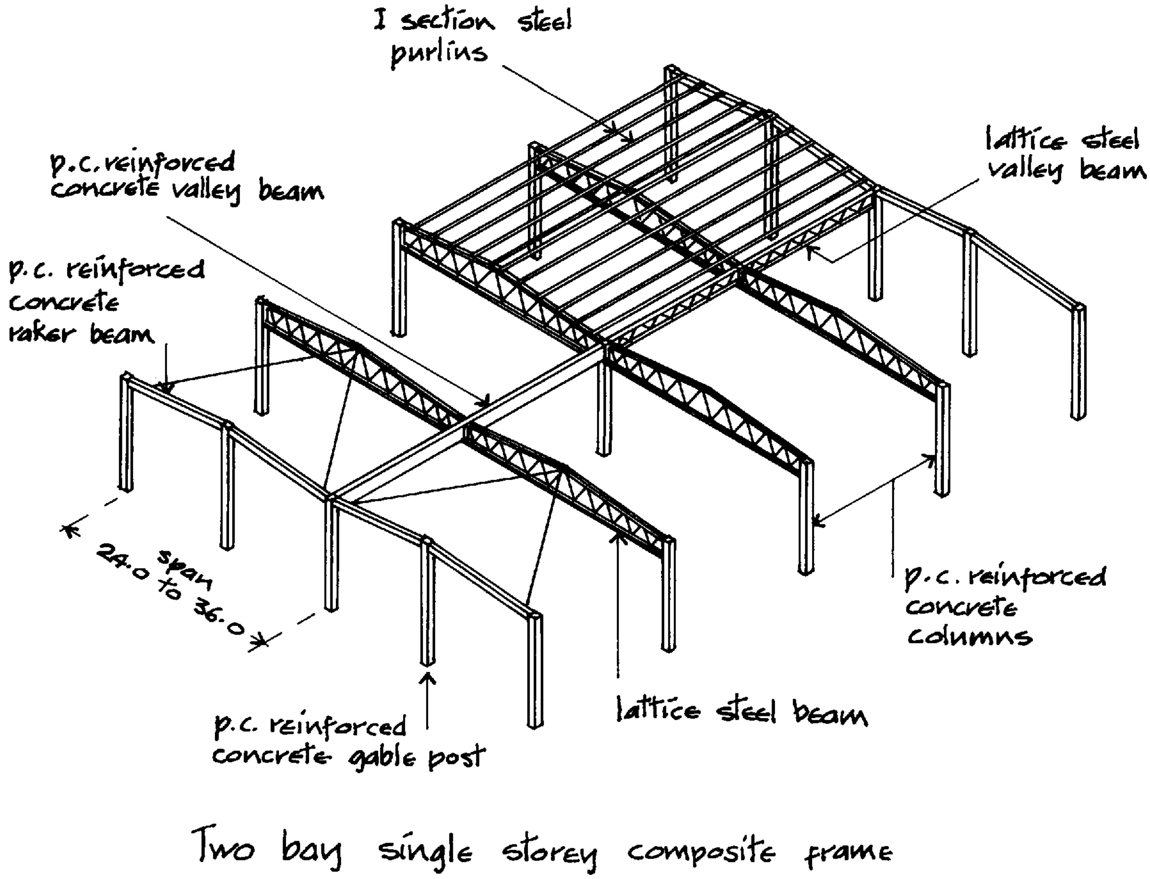

I section steel
purlins
lattice steel
valley beam
p.c. reinforced
concrete valley beam
p.c. reinforced
concrete
raker beam
span
24.0 to 36.0
p.c. reinforced
concrete
columns
lattice steel beam
p.c. reinforced
concrete gable post
Two bay single storey composite frame

Fig. 53

CHAPTER TWO

ROOF AND WALL CLADDING, DECKING AND FLAT ROOF WEATHERING

FUNCTIONAL REQUIREMENTS

The functional requirements of roofs and walls comprise:

Strength and stability
Resistance to weather
Durability and freedom from maintenance
Fire safety
Resistance to the passage of heat
Resistance to the passage of sound
Security.

Strength and stability

The strength of roof and wall cladding and roof decking depends on the properties of the materials used and their ability to support the self-weight of the cladding plus the anticipated wind and snow loads, between supporting purlins, rails, bearers and beams.

The stability of cladding and decking depends on the:

(1) Depth and spacing of the profiles of sheeting and decking
(2) Composition of the materials and thickness of the boards and slabs used for decking
(3) Ability of the materials to resist distortion due to the:
  (a) Wind pressure
  (b) Wind uplift
  (c) Snow loads
  (d) Weight of personnel engaged in fixing and maintaining the roofs.

The strength and stability of the comparatively thin sheets of steel or aluminium used for profiled sheeting derive principally from the depth and spacing of the profiles, from the shallow depth of corrugated sheet for small spans to the considerable depth of deep trapezoidal profiles and standing seams for medium to large spans between supports. Longitudinal and transverse ribs, to deep profile sheeting and decking, provide additional rigidity against buckling due to the distortion caused by point loads and the sometimes very considerable wind pressure and uplift.

Steel roof cladding sheets fixed across a structural frame act as a diaphragm which contributes to the stability of the frames in resisting the racking effect of the considerable lateral wind forces that act on the sides and roofs of large buildings. The extent of the contribution of the sheet covering to the stability of the frames depends on the thickness of the sheets, the strength of the fasteners used to fix the sheets and the strength of the sheets in resisting the tearing effect of the fasteners fixed through it. From a calculation of the likely maximum wind forces acting on a building, cladding sheets of adequate thickness to resist tearing away from fasteners, adequate profile to resist buckling and the required section and spacing of fasteners can be selected so that the sheeting will act in whole or part as a diaphragm to resist wind pressure on the building.

The comparatively thick corrugated and profiled fibre cement cladding sheets, used for short- and medium-span support between purlins, rails and beams, have adequate strength in the depth of the profiles for the anticipated loads and rigidity in the thickness of the material to resist distortion and loss of stability over the moderate spans between supports.

Resistance to weather

The traditional roofing materials, tile and slate, effectively resist the penetration of rainwater to the interior by the run-off of rainwater down the slope over at least two thicknessses of tile or slate. The great advantage of these traditional materials is that the small units of slate or tile will accommodate the range of moisture and thermal and structural movements common to exposed roofs, without damage for the life of the majority of buildings and without suffering damage or deterioration, providing the slope of the roof is adequate and sound tiles and slates are securely fixed.

Large sheets of profiled steel and aluminium serve to resist the penetration of rainwater, through the impermeability of these metals to water, which runs down the slope of the roof over the necessary end and side laps of the sheets. The least slope of the roof is dictated by the end lap of the sheets necessary to prevent water finding its way up the slope and between closely fitting sheets. Thermal and structural movements across the roof are accommodated by the profiles that will allow for normal contraction and expansion and accommodated down the slope by some movement at fixings at end laps. Where long sheets are used, the secret fixings of standing seams will allow adequate movement.

Profiled metal sheets are usually fixed with screws driven through the troughs of the profiles to steel purlins and sheeting rails. Integral steel and neoprene washers on the screw head effectively seal the perforation of the sheet against penetration of rain. Recently it has become practice to fix profiled metal sheeting through the ridge of the troughs. This requires some care in driving the screw home to find a secure fixing without driving the screw so firmly that it distorts the profile. The advantage of this method of fixing is that the perforation of the sheet is less exposed to rainwater that will tend to run down the troughs. Standing seams to the long edges of sheets provide a deep upstand as protection against rain penetration at vulnerable long edges, particularly with very low pitch roofs. Secret fixings that do not require perforation of sheets accommodate thermal movements and are not visible for appearance sake.

Profiled cladding for walling is usually fixed through the troughs of the profile for ease of fixing and where the screw heads will be least visible.

The more solid, thicker profiled fibre cement sheets will resist the penetration of rainwater through the density of the sheet material, the slope of the roof and the end and side laps. These sheets, which will absorb some rainwater, should be laid at a pitch of not less than 10° to avoid the possibility of frost damage. The cladding will accommodate moisture, thermal and structural movement through the end and side laps and the comparatively large fixing holes for screws or hook bolts. Because of the thickness of these sheets they do not make a close fit at end laps through which there will be considerable penetration of wind under pressure. Flat roof weathering membranes which resist the penetration of rainwater through the impermeability of the two-, three- or single-ply membranes and the sealed joints or continuity of the membrane will, in time, harden and no longer retain sufficient elasticity or tensile strength to resist the very considerable thermal movements common to flat roof coverings laid over effective insulation materials.

Durability and freedom from maintenance

The durability of coated, profiled steel sheeting depends initially on some care in handling and fixing. The thin sheets may be distorted and damaged by careless handling and subject to damage through careless fixing that may lead to corrosion of exposed steel around fixing holes and distortion of sheets by fixings driven home too tightly. The edges of sheets should be painted or coated to provide protection of the steel exposed at edges of sheets.

For roofing and side wall cladding, the durability of profiled steel sheets depends on climate and the colour of the coating material. Sheeting on buildings close or near to the coast and buildings in heavily polluted industrial areas will deteriorate more rapidly than those inland. Sheeting with light coloured coatings is more durable than that with dark coloured coatings due to the effect of ultraviolet light on dark hues and the increased heat released from solar radiation on absorptive dark coatings.

The early deterioration of coated sheets is due to the formation of a white layer on the exposed surfaces of the organic coating that takes the form of an irregular, chalk-like coating that may become apparent, particularly with dark colours, some 10 to 25 years after fixing. This coating, which is termed chalking, does not adversely affect the protective properties of the coating. It may, however, so affect appearance as to be unacceptable, particularly on darker shades of colour. The coat of chalking can be removed by washing and lightly brushing the whole surface of the sheeting, which can then be overpainted with a primer and silicone, alkyd paint to improve appearance. After some years the coating may craze in the form of irregular, interconnected cracks and lose adhesion to the steel sheet. Dark coloured sheets are likely to suffer this type of defect sooner than light coloured sheets. A remedy for this defect is to strip affected areas of coating, clean and prime exposed steel surfaces and paint the whole of the cladding. At this stage of deterioration of the surface of the sheets it is probably more economical and certainly far more satisfactory to strip the whole of the sheeting and replace it with new. Because of the need for regular inspection and comparatively early remedial maintenance, organic coated steel sheeting is, at best, a short- to medium-term material with a useful life of 25 years in the most favourable conditions and as little as ten years before costly maintenance is necessary.

Asbestos cement and fibre cement sheeting does not corrode or deteriorate for many years providing it is laid at a sufficiently steep pitch to shed water. Because of the brittle nature of the material it is liable to damage by knocks or undue pressure from those walking carelessly over the surface. The coarse texture of the material readily collects dirt which is not washed away by rain and the irregular dirt staining of this sheet is not generally accepted as an attractive feature.

Flat roof weathering membranes, laid directly over insulation, suffer very considerable temperature variations between day and night due to the texture and colour of the materials that absorb solar radiation. The heat released is retained due to the insulation below. In consequence there is considerable expansion and contraction of the membrane between day and night which in time may cause the weathering layer or layers to tear. Solar radiation also causes oxidation and brittle hardening of bitumen saturated or coated materials which in time will no longer be impermeable to water.

Single skin membranes of synthetic rubber-like materials will, for some years, accommodate thermal movements by the inate elasticity of the material. In time, due to brittle hardening and gradual loss of elasticity, these materials will fail.

The durability of a weathering membrane in an inverted or upside down roof is much improved by the layer of insulation which is laid over the membrane protecting it from the destructive effects of solar radiation to a considerable extent.

The useful life of bitumen impregnated felt membranes is from 10 years, for organic fibre felts up to 20 years and for high performance felts up to 25 years. The useful life of the latter materials used in an inverted or upside down roof can reasonably be doubled.

Over the years, mastic asphalt as a weathering membrane will oxidise and suffer brittle hardening which, combined with thermal movements, will give this material a useful life of up to 20 years.

Fire safety

The requirements from Part B of Schedule 1 to the Building Regulations, 1991 are concerned to:

(a) Provide adequate means of escape
(b) Limit internal fire spread (linings)
(c) Limit internal fire spread (structure)
(d) Limit external fire spread
(e) Provide access and facilities for the Fire Services.

Fire safety regulations are concerned to ensure a reasonable standard of safety in case of fire. The application of the regulations, as set out in the practical guidance given in Approved Document B, is directed to the safe escape of people from buildings in case of fire rather than the protection of the building and its contents. Insurance companies that provide cover against the risks of damage to the buildings and contents by fire will generally require additional fire protection.

Means of escape The requirement from the Building Regulations is that the building shall be designed and constructed so that there are means of escape from the building in case of fire to a place of safety outside the building. The main danger to people in buildings, in the early stages of a fire, is the smoke and noxious gases produced which cause most of the casualties and may also obscure the way to escape routes and exits. The Regulations are concerned to:

(a) Provide a sufficient number and capacity of escape routes to a place of safety
(b) Protect escape routes from the effects of fire by enclosure, where necessary, and to limit the ingress of smoke
(c) Ensure the escape routes are adequately lit and exits suitably indicated.

The general principle of means of escape is that any person in a building confronted by an outbreak of fire can turn away from it and make a safe escape.

The number of escape routes and exits depends on the number of occupants in the room or storey, and the limits on travel distance to the nearest exit depend on the type of occupancy. The number of occupants in a room or storey is determined by the maximum number of people they are designed to hold, or calculated by using a floor space factor related to the type of accommodation which is used to determine occupancy related to floor area as set out in Approved Document B. The maximum number of occupants determines the number of escape routes and exits; where there are no more than 50 people one escape route is acceptable. Above that number, a minimum of 2 escape routes is necessary for up to 500 and up to 8 for 16000 occupants. Maximum travel distances to the nearest exit are related to purpose-group types of occupation and whether one or more escape routes are available. Distances for one direction escape are from 9.0 to 18.0 and for more than one direction escape from 18.0 to

45.0, depending on the purpose groups defined in Approved Document B.

Internal fire spread (linings) Fire may spread within a building over the surface of materials covering walls and ceilings. The Regulations prohibit the use of materials that encourage spread of flame across their surface when subject to intense radiant heat and those which give off appreciable heat when burning. Limits are set on the use of thermoplastic materials used in rooflights and lighting diffusers.

Internal fire spread (structure) As a measure of ability to withstand the effects of fire, the elements of a structure are given notional fire resistance times, in minutes, based on tests. Elements are tested for the ability to withstand the effects of fire in relation to:

(a) Resistance to collapse (loadbearing capacity) which applies to loadbearing elements
(b) Resistance to fire penetration (integrity) which applies to fire separating elements
(c) Resistance to the transfer of excessive heat (insulation) which applies to fire separating elements.

The notional fire resistance times, which depend on the size, height and use of the building, are chosen as being sufficient for the escape of occupants in the event of fire.

The requirements for the fire resistance of elements of a structure do not apply to:

(1) A structure that only supports a roof unless
  (a) the roof acts as a floor, e.g. car parking, or as a means of escape
  (b) the structure is essential for the stability of an external wall which needs to have fire resistance
(2) The lowest floor of the building.

Compartments To prevent rapid fire spread which could trap occupants, and to reduce the chances of fires growing large, it is necessary to subdivide buildings into compartments separated by walls and/or floors of fire-resisting construction. The degree of subdivision into compartments depends on:

(a) The use and fire load (contents) of the building
(b) The height of the floor of the top storey as a measure of ease of escape and the ability of fire services to be effective
(c) The availability of a sprinkler system which can slow the rate of growth of fire.

The necessary compartment walls and/or floors should be of solid construction sufficient to resist the penetration of fire for the stated notional period of time in minutes. The requirements for compartment walls and floors do not apply to single-storey buildings.

Concealed spaces Smoke and flame may spread through concealed spaces, such as voids above suspended ceilings, roof spaces and enclosed ducts and wall cavities in the construction of a building. To restrict the unseen spread of smoke and flames through such spaces, cavity barriers and stops should be fixed as a tight fitting barrier to the spread of smoke and flames.

External fire spread To limit the spread of fire between buildings, limits to the size of 'unprotected areas' of walls and also finishes to roofs, close to boundaries, are imposed by the Building Regulations. The term 'unprotected area' is used to include those parts of external walls that may contribute to the spread of fire between buildings. Windows are unprotected areas as glass offers negligible resistance to the spread of fire. The Regulations also limit the use of materials of roof coverings near a boundary that will not provide adequate protection against the spread of fire over their surfaces.

Access and facilities for the Fire Services Buildings should be designed and constructed so that:

- Internal firefighting facilities are easily accessible
- Access to the building is simple
- Vehicular access is straightforward
- The provision of fire mains is adequate.

Resistance to the passage of heat

The interior of buildings is heated by the transfer of heat from heaters and radiators to air (conduction), the circulation of heated air (convection) and the radiation of energy from heaters and radiators to surrounding colder surfaces (radiation). This internal heat is transferred to and through colder enclosing walls, roof and floors by conduction, convection and radiation to colder outside air. As long as the interior of buildings is heated to a temperature above that of outside air, transfer of heat from heat sources to outside air will continue. For the sake of economy in the use of expensive fuel and power sources, and to conserve limited supplies of fuel, it is sensible to seek to limit the rate of transfer of heat from inside to outside. Because of the variable complex of the modes of transfer of heat it is convenient to distinguish three separate modes of heat transfer as conduction, convection and radiation.

Conduction is the direct transmission of heat by contact between particles of matter, convection the transmission of heat by the motion (circulation) of heated gases and fluids, and radiation the transfer of heat from one body of radiant energy through space to another by a motion of vibration in space which radiates equally in all directions.

Conduction

The speed or rate at which heat is conducted through a material depends mainly on the density of the material. Dense metals conduct heat more rapidly than less dense gases. Metals have high and gases have low conductivity. Conductivity (k) is the rate of heat per unit area conducted through a slab of unit thickness per degree of temperature difference. It is expressed in watts per metre thickness of material per degree kelvin (W/mK) where W (watt) is the unit of power which is equivalent to joules (the unit of heat) per second (J/s) and the temperature is expressed in kelvin (K).

Convection

The density of air that is heated falls and the heated air rises and is replaced by cooler air. This, in turn, is heated and rises so that there is a continuing movement of air as heated air loses heat to surrounding cooler air and cooler surfaces of ceilings, walls and floors. Because the rate of transfer of heat from air to cooler surfaces varies from rapid transfer through thin sheets of glass in windows to an appreciably slower rate of transfer to insulated walls by conduction, and because of the variability of the exchange of cold outside air with warm inside air by ventilation, it is not possible to quantify heat transfer by convection. Usual practice is to make an assumption of likely total air changes per hour or volume (litres) per second depending on categories of activity in rooms and then to calculate the heat required to raise the temperature of the fresh, cooler air introduced by natural or mechanical ventilation, making an assumption of the temperature of inside and outside air.

Radiation

Energy from a heated body radiating equally in all directions is partly reflected and partly absorbed by another cooler body (with the absorbed energy converted to heat). The rate of emission and absorption of radiant energy depends on the temperature and the nature of the surface of the radiating and receiving bodies. The heat transfer by low temperature radiation from heaters and radiators is small whereas the very considerable radiant energy from the sun that may penetrate glass and that from high levels of artificial illumination is converted to appreciable heat inside buildings. An estimate of the solar heat gain and heat gain from artificial illumination may be assumed as part of the heat input to buildings and used in the calculation of heat input and loss.

Transmission of heat

The practical guidance in Approved Document L to meeting the requirements from Part L of Schedule 1 to the Building Regulations 1991, for the conservation of fuel and power, is mainly directed to limiting the loss of heat through the fabric (walls, floors and roofs) of buildings by establishing maximum values for the overall transmission of heat, the '*U*' value, through walls, roofs and floors and to limiting the size of glazed areas.

Because of the complexity of the combined modes of transfer of heat through the fabric of buildings it is convenient to use a coefficient of heat transmission, the *U* value. This air-to-air heat transmittance coefficient, the *U* value, takes account of the transfer of heat by conduction through solid materials and gases, convection of air in cavities and across inside and outside surfaces and radiation to and from surfaces. The *U* value is expressed as W/m^2K. A high *U* value indicates comparatively high rates of overall transmission and a low *U* value indicates low rates.

The maximum *U* values given in Approved Document L are 0.45 W/m^2K for exposed walls, floors, ground floors and roofs for buildings other than dwellings.

The loss of heat through windows and rooflights is limited by setting maximum sizes related to floor and roof areas as:

Windows
35% of exposed wall area for places of assembly, offices and shops
15% of exposed wall area for industrial and storage.
Rooflights
20% of roof area for places of assembly, offices, shops, industrial and storage.

The methods of making an estimate of rates of heat transfer that are suggested in Approved Document L are the elemental approach and calculation procedures discussed below.

Elemental approach The elemental approach method is used to select the components of the construction of elements of the fabric of buildings that will not exceed stated maximum U values for walls, floors and roofs. Two methods of calculating what thickness of insulation may be required for an element of structure are set out in Approved Document L.

The first method depends on the use of tables giving basic thickness of a range of insulation materials required to achieve the maximum U values and allowable reduction in the basic thickness of insulation where a small range of conventional components are used in the construction, e.g. 100 brick outer skin, a cavity and 100 concrete block inner skin to a wall.

The second method takes account of the insulating properties of the whole construction of an element by calculating the thermal resistance of each component of the element and the standard values for the resistance of air spaces and surfaces to transmission of heat. It may be used to make a more accurate calculation of U values, particularly where the materials of the components are not included in the tables used in the first method.

Resistivity, which is the reciprocal of conductivity, expresses the resistance of a material to the transfer of heat. Resistivity multiplied by the thickness of a material is defined as resistance which may be determined by dividing the thickness of a material, in metres, by its thermal conductivity.

Calculation procedures There are two calculation procedures. The first calculation procedure is an alternative to the elemental approach by allowing variations in the level of insulation of elements and the areas of windows and rooflights to facilitate the use of other areas of glass and rooflights than those set out above, as long as the rate of heat loss would be no greater than that determined by the elemental approach. The second calculation procedure allows greater freedom of selection of components of the elements of structure by reference to an energy target that can take account of notional internal temperatures, internal heat gains from people, cooking, hot water systems, lighting and solar heat gain. The energy use calculated by this procedure should be no greater than it would be for a similar building that complies with the elemental approach.

Condensation

During recent years increased expectation of thermal comfort in buildings and the need to conserve limited supplies of fuel and power has led to improved levels of insulation in the fabric of buildings and the common use of weatherseals to opening windows that has restricted natural ventilation. These changes have led to the likelihood of increased levels of humid conditions that cause condensation on the inner faces of cold surfaces such as glass in windows and the inside of thin metal sheet weathering.

The limited capacity of air to take up water in the form of water vapour increases with temperature so that the warmer the air, the greater the amount of water vapour it can hold. The amount of water vapour held in air is expressed as a ratio of the actual amount of water vapour in the air to the maximum which the air could contain at a given temperature. This relative humidity (rh) is given as a percentage. Air is saturated at 100% relative humidity and the temperature at which this occurs is defined as the dew point temperature. When the temperature of warm moist air falls to a temperature at which its moisture vapour content exceeds the saturation point, the excess moisture vapour will be deposited as water. This will occur, for example, where warm moist air comes into contact with cold window glass, its temperature at the point of contact with the glass falls below that of its saturation point and the excess moisture vapour forms as droplets of water on the inside window surface as condensation. Thus, the greater the amount of moisture vapour held in the air and the greater the temperature difference between the warm inside air and the cold window surface, the more the condensation.

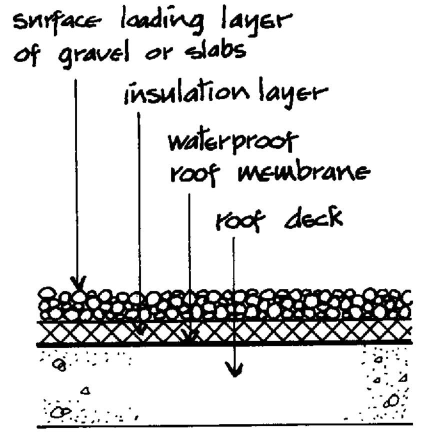
The main sources of moisture vapour in air in buildings are moisture given off by occupants, moisture given off from cooking and flueless heaters, bathing, clothes washing and drying, moisture generating processes and the drying out from a new building.

Internal temperatures which are high relative to cold outside air will tend to produce high levels of condensation on cold surfaces from high levels of moisture vapour. An atmosphere that contains high levels of moisture vapour is said to be humid. The level of humidity that is acceptable for comfort in buildings varies from about 30% to 70% relative humidity. Low levels of humidity, below about 20%, may cause complaints of dry throats and cause woodwork to shrink and crack. High levels of humidity, e.g. above 70%, may cause discomfort and lead to condensation on cold surfaces, mould growth and excess heat. For comfort in buildings and to limit the build-up of humidity it is necessary to provide a degree of ventilation for an adequate supply of oxygen and to limit fumes, body odour and smells and to exchange drier fresh air from outside with humid, stale inside air. The level of ventilation required depends on the activity and number of people in a given space and sources of heat and water that will contribute to increased humidity.

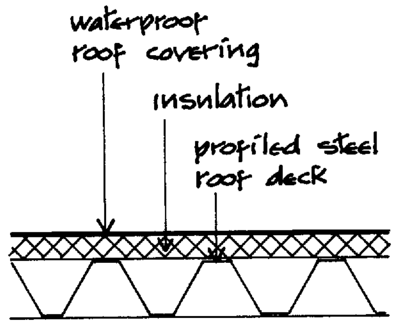
The position of the layer of insulation in the thickness of roof and wall construction is determined mainly by convenience in fixing the material as, e.g. over and across purlins and sheeting rails in single-storey framed structures. The position of the insulation will affect the temperature of those parts of the construction relative to inside and outside temperatures and the possibility of condensation of warm moist air on cold surfaces. To minimise the possibility of condensation the construction, where practical, should be on the inside of the insulation where it will be maintained at inside air temperature. This arrangement, which is sometimes referred to as warm construction, is illustrated in Fig. 54 where the whole of the construction including the weathering membrane is below the insulation in a roof. This unusual arrangement is adopted to protect the weathering membrane from the extremes of temperature variations that can occur between day and night.

More usually the insulation is laid under the weathering layer on the deck of both solid concrete and profiled steel decking, as illustrated in Fig. 54, showing typical warm construction or warm roofs. Where the insulation is on or towards the inside face, as for example with ceiling insulation, the construction will be cold or cold roof construction.

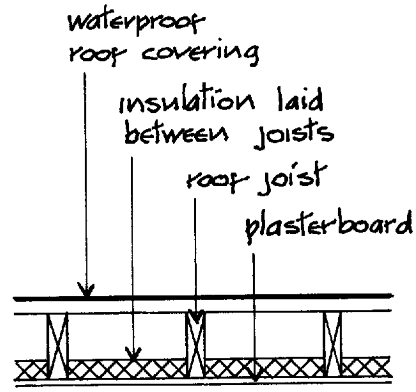
With profiled metal and fibre cement sheeting it is usual practice to lay the insulation across the purlins and sheeting rails under the roof and wall covering. The



Warm construction - Warm roof
Inverted roof



Warm construction - Warm roof



Cold construction - Cold roof

Fig. 54

covering will, therefore, be at outside air temperature and, as such, will be a cold construction component of roofs and walls and be liable to suffer condensation of warm moist inside air that penetrates the insulation and lining. The likelihood of condensation on the cold under surface of sheeting depends on the humidity and temperature of the inside air, the extent to which warm moist air can penetrate the insulation and lining sheets and the relative temperature of inside and outside air. The humidity of the inside air depends on temperature and the activities inside the building. The air inside a laundry will be much more humid than that inside a dry heated store and much more likely to cause condensation on cold sheeting.

Heavy condensation on the underside of steel sheeting may, in time, cause corrosion of steel and saturation of porous insulating materials which will lose their effectiveness as insulation. Condensation on the underside of cold fibre cement sheets will have no adverse effect on the material.

With comparatively dry inside air it is generally sufficient to accept that the insulation and any supporting lining sheets will serve as an adequate check against appreciable volumes of inside air causing condensation on the underside of cladding.

With medium and high levels of internal humidity it is generally necessary to provide some form of check or barrier to the penetration and build-up of warm moist air that might otherwise condense on cold cladding. The two ways of minimising the build-up of warm moist air under sheeting are by ventilating the space between the sheeting and the top of the insulation or by making some form of check or barrier to the penetration of warm moist air.

Ventilation

Ventilation of the space between sheeting and insulation combined with the check to penetration of inside air provided by the insulation itself and any under lining sheets used, is the most straightforward way of minimising condensation. The space between the sheeting and the insulation is ventilated by providing spacers laid over the insulation, under the troughs of the profiled sheeting and over the purlins and sheeting rails to provide a space of 100 which is ventilated through the open, unsealed joints between sheets to outside air. This passive ventilation is generally sufficient to prevent an excessive build-up of warm moist air under the sheeting.

With medium and high levels of humidity in buildings there is a pressure drive of internal moisture vapour towards colder outside air. Because of the vapour pressure drive, moisture vapour may penetrate joints between insulation and lining panels and also, to an extent, penetrate the insulation itself. With low to medium levels of internal humidity, foamed insulation boards closely butted together and any internal lining panels will generally serve as a check to moisture vapour penetration. Where open textured insulation such as mineral fibre quilt or mat is used, there may be appreciable penetration of moisture vapour through the insulation. A ventilated space between the top of the insulation and the cladding will generally minimise the build-up of moisture vapour. Some moisture may, however, condense to water on the cold underside of the metal sheeting. To prevent condensation water falling on the insulation and saturing it, a breather paper membrane is stretched over the insulation and spacer bars. The micro porous holes in the breather paper allow moisture vapour to penetrate from below whilst retaining condensation water that will either evaporate or run down to eaves. The breather paper will, in addition, prevent cold ventilation air penetrating the open textured insulation thus reducing its insulating properties.

Glass fibre tissue faced foamed insulation boards laid over purlins, with the joints between the insulation boards taped on the top surface of the boards, will provide a sufficient check to the penetration of moisture vapour where there are low to medium levels of internal humidity.

Site-assembled and factory-made composite panels of profiled foamed or high density rock wool insulation that fits closely between profiled sheeting and profiled inner lining sheets with end and side laps between panels sealed will act as an effective check to the penetration of all but the highest levels of internal humidity.

Composite panels of insulation, closely fitting between sheeting and inner lining panels effectively sealed, and other forms of over purlin insulation to buildings with low levels of humidity may well not require ventilation of roof spaces.

The requirements for ventilation are illustrated in Fig. 55.

Resistance to the passage of sound

Where it is a requirement that the fabric of a building resists the pentration of sound it is necessary to ensure that there are as few openings as practical through which airborne sound may penetrate. Open windows, ventilators and small construction gaps will allow appreciable transfer of sound. Effective air seals

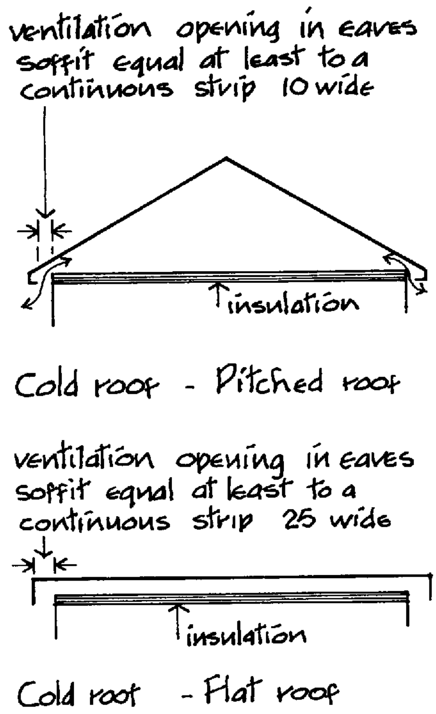


Fig. 55

around the opening parts of windows and doors, dampers to ventilators and careful sealing of construction gaps will appreciably reduce sound penetration. The thin metal skin of profiled steel sheeting affords no appreciable resistance to sound penetration, whereas a 60 or 80 thickness of mineral wool thermal insulation with a 20 air gap will provide appreciable reduction of low levels of sound.

Where effective resistance to high levels of sound is necessary as, for example, in buildings close to airports and where the sound from noisy industrial processes inside buildings has to be contained, it may be advantageous to adopt some form of solid enclosure such as brick or concrete to provide the required sound reduction.

Security

Many single-storey framed buildings which are occupied during working hours and days are vulnerable to damage by vandalism or forced entry, unless adequately guarded at night and weekends. Apart from the obvious risk of forced entry through windows, doors and rooflights there is a risk of entry by prising thin profiled sheeting from its fixing and so making an opening large enough for entry.

PROFILED SHEET COVERINGS FOR ROOFS AND WALLS

Corrugated iron sheets were first produced about 1830 from wrought or puddled iron which was either pressed or rolled to the corrugated profile. Because of the purity of the iron and the thickness of the sheets, the original corrugated iron sheets had a useful life of more than 50 years in all but the most corrosive atmospheres.

After steel making became a commercial proposition in about 1860, thin corrugated steel sheets were first used in Britain about 1880. These thin corrugated steel sheets were considerably cheaper and thinner than the original iron sheets but had a useful life of only about a quarter of that of the heavier iron sheets because the 'impurities' in the steel promoted more rapid corrosion even when the sheets were zinc coated. The comparatively rapid destructive corrosion of steel sheets led to the use of the non-corrosive alternative, asbestos sheets, early in the twentieth century.

In the early days of the use of corrugated steel sheets it was common practice to protect the sheets against corrosion by coating them with tar, pitch or paint. As long as these coatings adhered strongly to the whole of the surface and edges of the sheets, corrosion did not occur. Once the coating was broken, rust spread rapidly between the steel and the coating and frequent chipping and wire brushing of the exposed steel was necessary, followed by the application of protective coatings.

In 1883 zinc-galvanised corrugated steel sheets were imported into this country from Scandinavia and shortly afterwards similar sheets were produced here.

Galvanised, corrugated sheets are coated all over with a thin film of zinc, applied by dipping or spraying. Providing the zinc coating is sufficiently thick and adheres strongly to the steel below, it will inhibit rust for some years. On exposure the zinc coating first oxidises and then is converted to basic zinc carbonate which is largely insoluble in clean atmospheres and protects the zinc from further corrosion. In time, however, this surface film is worn away by the scouring action of wind and rain and progressive corrosion occurs until there is no further protection of the steel which rapidly corrodes.

The principal disadvantage of corrugated steel sheets is the difficulty of preventing corrosion of the steel for more than a few years. Other disadvantages are low thermal resistance, poor fire resistance and the poor appearance of the sheets due to the shallow corrugations.

Corrugated steel sheets coated with bitumen were first used in this country in 1923. During manufacture these sheets were immersed in hot bitumen which adhered strongly to the sheets and was effective in preventing corrosion of the sheets for some time. However, the bitumen coating by itself was highly inflammable and some spectacular fires, during which the bitumen burnt fiercely and the sheeting collapsed, caused this early type of protected sheeting to be withdrawn. A later, improved protective coating consisted of hot bitumen covered with a coating of asbestos felt bonded to the bitumen, which was in turn coated with bitumen. The combination of bitumen and asbestos felt protected the steel sheets from corrosion, improved thermal resistance and provided a fair degree of resistance to damage by fire. These sheets had a singularly unattractive appearance.

With improvements in the techniques of cold roll forming steel strip, a range of trapezoidal section profiled steel sheets was introduced about 1960. The improved strength and rigidity of these profiles allowed the use of thinner strip and wider spacing of supports than is possible with the shallow depth of corrugated sheet, and the bold angular trapezoidal profile contrasted favourably with the small, somewhat indeterminate profile of corrugated sheets. These trapezoidal profile sheets were at first coated with zinc, asbestos felt and bitumen and later with organic plastic coatings.

Plastic-coated profiled steel sheeting is the principal sheet material used for weather protection of single-storey framed buildings today. These sheets are made in a wide range of trapezoidal profiles and colours. Trapezoidal profile steel sheets are also the principal material used for roof decking where the sheets serve as support for insulation and a weather coat of built-up bitumen felt and thin membrane coatings for roofing.

Corrugated asbestos cement sheets were first used as an alternative to steel sheets because they are corrosion free and are comparable in cost to steel sheeting. The disadvantages of asbestos cement as a roof covering are its dull, cement grey colour, the thickness of the sheet which makes it impossible to form a close joint at overlaps of sheets for low pitched roofs and the brittle nature of the material which is readily fractured during handling, fixing and in use. Due to the hazards to health in the manufacture of asbestos products, these sheets are now made as fibre cement sheets.

PROFILED STEEL SHEETING

The advantages of steel as a material for roof and wall sheeting are that its favourable strength-to-weight ratio and ductility make it both practical and economic to use comparatively thin, lightweight sheets that can be cold roll formed to profiles with adequate strength and stiffness for handling and to support the loads normal to roof and wall coverings. The disadvantage of steel as a sheeting material is that it suffers rapid, progressive, destructive corrosion.

Protective coatings for profiled steel sheets

Corrosion of steel When exposed to air and water or salt solutions, steel undergoes a complex electrochemical change which is essentially a process of oxidation, termed corrosion, where the metal tends to return to an oxidised condition similar in composition to an iron ore from which it was produced. The corrosive oxidation of steel produces a reddish deposit on the surface of the steel, known as rust. The initial deposit of rust does not generally prevent further corrosion of the steel below so that progressive corrosion of the metal occurs. Because rust has poor strength and negligible ductility, the characteristics for which steel is used, corrosion reduces the usefulness of steel.

The corrosive process is a complex electrochemical action that depends on the characteristics of the metal, atmosphere and temperature. Corrosion of steel is most destructive in conditions of persistent moisture, atmospheric pollution and where different metals are in contact.

Zinc coating The most economic and effective way of protecting steel against corrosion is by coating it with zinc which corrodes more slowly than steel. The zinc coating acts as a barrier against contact of steel with the atmosphere and acts sacrificially to protect the steel at cut edges by galvanic action where two dissimilar metals are in contact in the presence of moisture and corrosion of only one takes place. The most reactive of the two will become the anode in a natural electric cell and will oxidise to protect the cathode from corrosion. Thus the zinc coat protects the steel as it is anodic to steel in a galvanic action and corrodes sacrificially to the benefit of the steel.

Hot-dip galvanising This is the most commonly used method of applying a zinc coating to steel. There are three stages to the process. The steel is first degreased and cleaned in cold, dilute hydrochloric acid, the cleaned steel is given a prefluxing treatment and then fully immersed in molten zinc at a temperature of about 450°C. The thickness of the coating depends on the time of immersion, withdrawal rate and the temperature of the molten zinc. The usual coatings of zinc are a minimum of 275 g/m^2 including both sides for cladding. The zinc coating adheres strongly to the steel through the formation of a very thin alloy layer, between the steel and the zinc, which bonds strongly to both metals. The protection afforded by the zinc coating depends on the thickness of the coating and atmospheric conditions. The products of the corrosion of zinc in rural areas are of low solubility that tend to inhibit corrosion of the zinc below for periods of up to 30 years, whereas the products of corrosion in industrial areas are soluble and afford less protection for periods of about 7 years. The life expectancy of a protective coating in a particular atmosphere is proportional to the weight of the zinc coating.

In rural, dry sub-tropical and marine tropical areas where the rate of atmospheric corrosion is low, hot-dip galvanised zinc coating will provide by itself adequate protection of steel sheets where the metallic grey colour of the sheets provides an acceptable finish to buildings.

Zalutite Zalutite is a protective coating of an alloy of zinc, aluminium and silicon which is about twice as durable as a zinc coating. It is used as a protective coating by itself as a low cost form of protection where the appearance of the surface is not important. The usual thickness of this coating is 185 g/m^2 including both sides.

Organically (plastic) coated profiled steel sheets The majority of profiled steel sheets used today are organically coated with one of the plastic coatings available for the protection afforded by the plastic finish and the range of colours available. Plastic coatings to galvanised zinc coated steel sheets serve as a barrier to atmospheric corrosion of zinc, the erosive effect of wind and rain and protection from damage during handling, fixing and in use. Also they serve as a means of applying a colour to the surface of the sheets. The principal advantage of the extra cost of the plastic coating is in the application of a colour to what is otherwise a drab metallic grey zinc coating.

Colour is applied to organically coated steel sheets by the addition of pigment to the coating material. The effect of ultraviolet radiation and the weathering effect of wind and rain is to gradually bleach the colour pigment in the coating. Loss of colour is not uniform over the whole surface of profiled sheets, it being most pronounced on south-facing slopes and sides of buildings and irregular on the ridges and flanges of the sheets. This varied loss of colour over a number of years spoils the appearance of buildings.

Organically coated steel sheets are used principally for the benefit of the colours available so that the inevitable loss of colour may in time become unacceptable from the point of view of appearance. The term 'life expectancy to first maintenance' used in relation to coloured, organically coated steel sheets, expresses the term in years that a particular coating will adequately retain its colour to a comparatively stringent standard of appearance before overpainting is deemed necessary. The term 'life expectancy' to first maintenance is not generally used to define the useful life of the coating as protection against corrosion and damage, which may be considerably longer than that of colour retention.

Organic coatings for profiled steel sheets

uPVC-polyvinyl chloride This is the cheapest and most used of the organic plastic coatings and is known as 'Plastisol'. The comparatively thick (200 microns) coating that is applied over a zinc coating provides good resistance to damage in handling, fixing and in use and good resistance to normal weathering agents. The material is ultraviolet stabilised to retard degradation by ultraviolet light and the consequent chalking and loss of colour. The durability of the coating is good as a protection for the zinc coating below but the life expectancy to first maintenance of acceptable colour retention is only of the order of 10 to 20 years.

Polyvinyl chloride is an economic, tough, durable, scratch-resistant coating that will provide good protection of the zinc coating and steel below for many years but has poor colour retention.

Acrylic-polymethyl methacrylate – PMMA This organic plastic, which is about twice the price of uPVC, is applied with heat under pressure as a laminate to galvanised zinc steel strip to a thickness of 75 microns. It forms a tough finish with high strength, good impact resistance and good resistance to damage by handling, fixing and in use. It has excellent chemical resistance and its good resistance to ultraviolet radiation gives a life expectancy of acceptable colour retention to first maintenance of up to 20 years. The hard smooth finish of this coating is particularly free from dirt staining.

PVF-polyvinylidene fluoride A comparatively expensive organic plastic coating for profiled steel sheets which is used as a thin (25 microns) coating to zinc coated steel strip for its excellent resistance to weathering, excellent chemical resistance, durability and resistance to all high energy radiation. Because this coating is thin it may be damaged by careless handling and fixing. The durability of this coating is good as protection for the zinc coating and the steel sheet and its life expectancy to first maintenance in relation to colour retention is better than 15 years and up to 30 years.

Silicone polyester This is the cheapest of the organic coatings used for galvanised steel sheet. It is suitable for use in temperate climates where life expectancy to first maintenance is from five to seven years. It is not suitable for use in marine and hot humid atmospheres or where there is aggressive industrial pollution of the atmosphere. The galvanised steel sheets are primed and coated with stoved silicone polyester to a thickness of 25 microns. The coating provides reasonable protection against damage in handling, fixing and use, good resistance to ultraviolet radiation and a life expectancy to first maintenance of five to seven years.

Bitumen and fibre mineral coatings Galvanised steel strip is coated with hot bitumen, a second layer of a composite of mineral fibre and bitumen, finished with a coloured alkyd resin. This coating provides good protection against corrosion, moderate protection against damage by handling, fixing and in use and a life expectancy of 10 to 15 years to first maintenance.

Insulation materials

Materials used as insulation may be grouped as inorganic and organic insulants. Inorganic insulants are made from naturally occurring materials that are formed into fibre, powder or cellular structures that have a high void content, e.g. glass fibre and mineral wool (rockwool). Inorganic insulants are generally incombustible, do not support spread of flame, are rot and vermin proof, are permeable to moisture vapour and generally have a higher *U* value than organic insulants.

The inorganic insulants most used as insulation to steel sheeting are glass fibre and rockwool in the form of loose fibres, mats and rolls of felted fibres and semi-rigid boards, batts and slabs of compressed fibres.

Organic insulants are based on hydrocarbon polymers in the form of thermosetting or thermoplastic resins to form structures with a high void content, e.g. polystyrene, polyurethane, isocyanurate and phenolic. Organic insulants generally have a lower *U* value than inorganic insulants, are combustible, and support the spread of flames more readily than inorganic insulants. Thermoplastic insulants have comparatively low softening points.

The organic insulants most used as insulation to steel sheeting are expanded polystyrene in the form of boards, extruded polystyrene in the form of boards and polyurethane and isocyanurate in the form of preformed rigid boards.

The cheapest materials used for insulation are glass fibre, rockwool and polystyrene.

Table 1 gives *U* values for insulating materials.

Table 1. Insulating materials

Material	*U* value W/m²K
Glass fibre	0.04
Rockwool	0.037
EPS	0.04
XPS	0.025
PIR	0.02
PUR	0.022

EPS = expanded polystyrene
XPS = extruded polystyrene
PIR = rigid polyisocyanurate
PUR = rigid polyurethane.

Where there is appreciable internal humidity in buildings it is necessary to prevent warm, moist air condensing to water on cold metal surfaces such as sheeting and spacers and so causing corrosion. Condensation may be prevented or minimised by ventilation of roof and wall cavities under sheeting or by the use of a vapour check or barrier on the warm side of the construction. Steel inner lining panels and preformed organic insulants serve as checks to the penetration of medium levels of internal humidity.

The practical guidance in Approved Document L to meeting the requirement from Part L of Schedule 1 to the Building Regulations 1991, for the conservation of fuel and power, gives a maximum *U* value for the walls and roofs of buildings, other than dwellings, of 0.45 W/m²K.. As thin steel sheets provide negligible resistance to the passage of heat, insulation is used to provide the major part of resistance to the transfer of heat. An insulation thickness of 52 with a material of 0.025 conductivity and 73 with a material of 0.03

conductivity is necessary to achieve a U value of 0.45 W/m^2K.

Profiled steel cladding

The term cladding is a general description for materials used to clothe or clad the external faces of buildings to provide protection against wind and rain. Profiled steel sheeting is one form of cladding. Steel sheet cladding for roofs is known as roof sheeting or roof cladding, and cladding for walls as wall sheeting, walling or sidewalling. Because cladding serves as a weathering skin, insulation has to be laid or fixed under it as illustrated in Fig. 56.

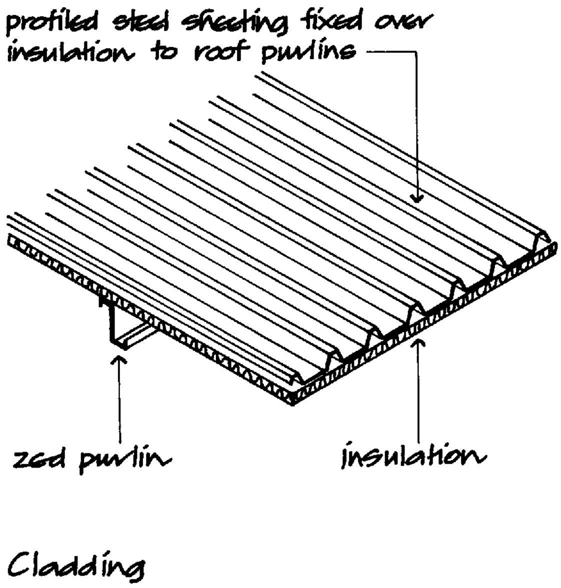


Fig. 56

Corrugated steel sheeting, illustrated in Fig. 57, has shallow corrugations 19 deep that provide longitudinal strength and rigidity sufficient for the limited centres of support common in small buildings and economy in the reduction of the steel strip by forming. The cover width of corrugated sheet is 914 as compared to 860 for a trapezoidal profiled sheet 48 deep.

The typical trapezoidal profile steel sheet is formed with trapezoidal section ridges with flat lower flanges as illustrated in Fig. 58. The depth of the ridges provides longitudinal strength and stiffness for support of dead and imposed loads. The thin flat bottom flange of the sheet between ridges is subject to buckling in handling, fixing and local loading, such as wind uplift, to the extent that it may be necessary to improve stiffness with shallow longitudinal ribs in both the wide lower flanges and the top of ribs as illustrated in Figs. 57 and 58.

During recent years standing seam profiled sheets

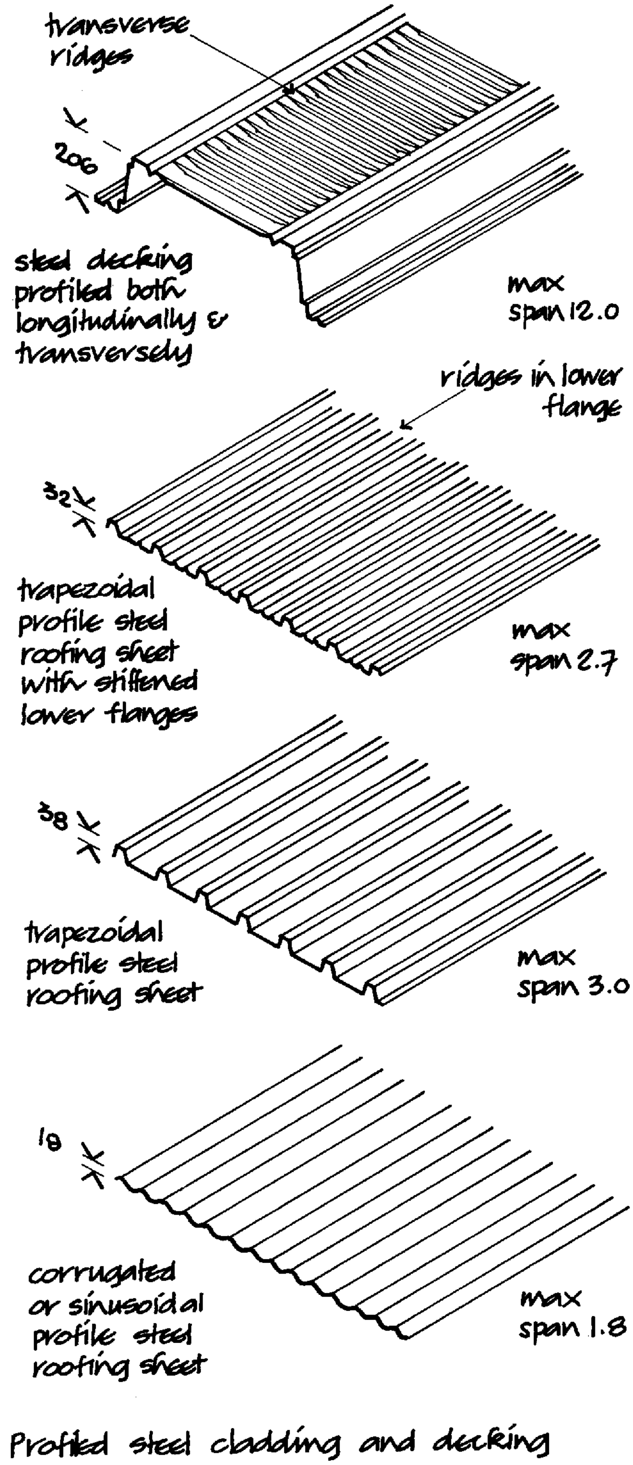


Fig. 57

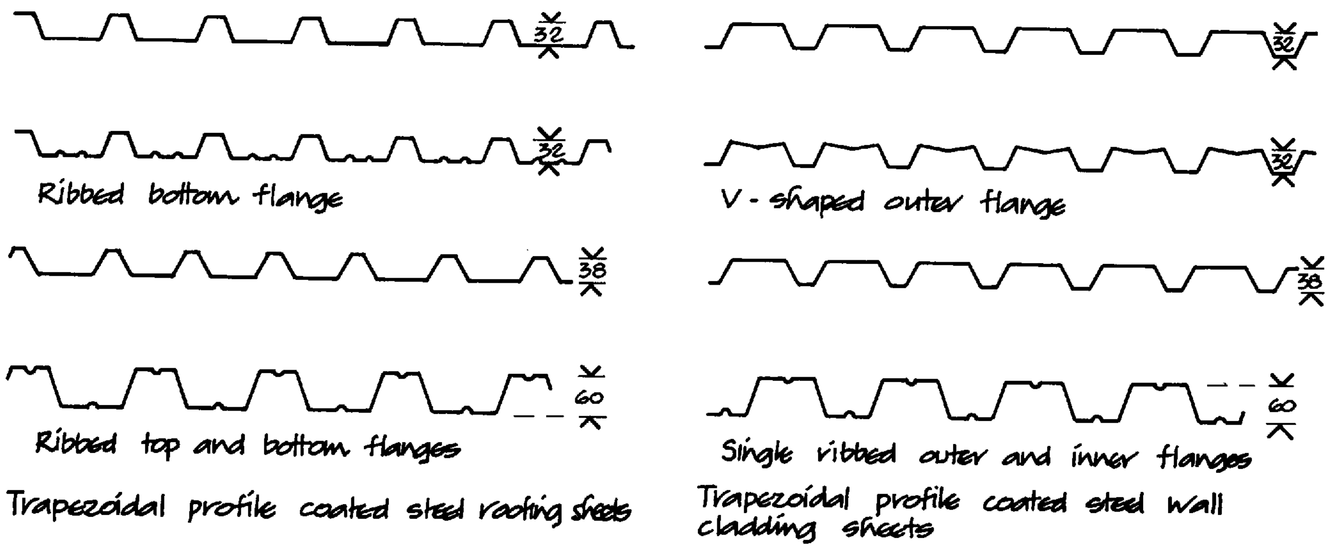


Fig. 58

have been produced for use as low pitch roof coverings. The two long edges of the sheets have deep upstands that are secured with secret fixings and weathered by overlapping or with a capping.

Roof and sidewall cladding systems

Single skin cladding The simplest system of cladding consists of a single skin of profiled steel sheeting fixed

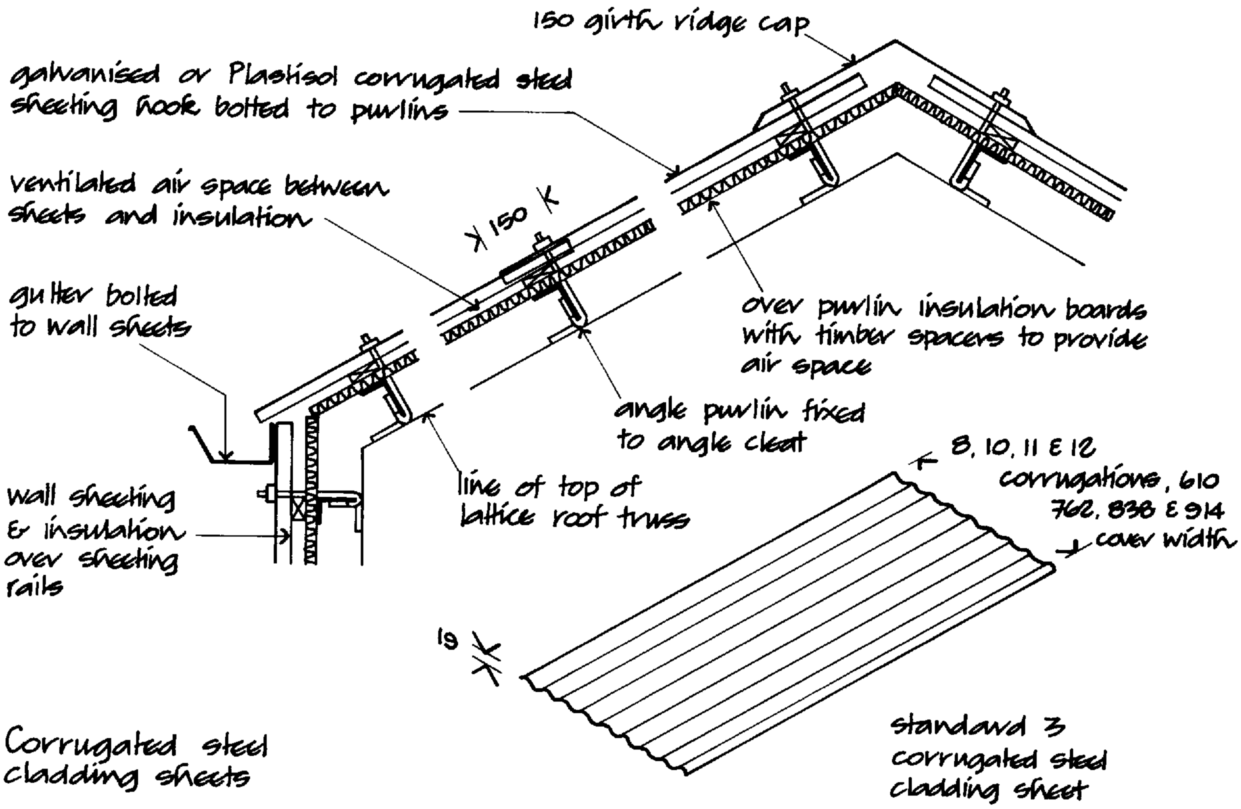


Fig. 59

directly to purlins and sheeting rails without insulation or inner lining. This, the cheapest form of cladding, is used for buildings that do not require heating such as stores, warehouses, sheds and buildings heated by their own processes, e.g. foundries. Corrugated or trapezoidal sheeting is fixed directly to roof purlins and sheeting rails.

Over purlin insulation without lining The most straightforward and economic system of supporting insulation under cladding is to use semi-rigid or rigid preformed boards laid across roof purlins and sheeting rails as illustrated in Fig. 59. Where corrugated or shallow depth trapezoidal sheeting is used the necessarily closely spaced purlins and sheeting rails will provide adequate support for the insulation boards without the need for inner lining sheets. Where the purlins and sheeting rails are more widely spaced the insulation boards are supported by T-section bars laid across the purlins at intervals suited to the support of the boards. To provide an air space for passive ventilation between cladding and insulation, to minimise condensation, timber spacers are used as illustrated. Corrugated cladding is secured with galvanised hook bolts that are bolted through the ridges of the cladding and hooked to angle purlin, sheeting rails and trapezoidal sheeting by screws. This system of cladding is suitable for buildings with low to medium levels of internal humidity where the appearance of insulation boards as a soffit and inner finish to walls is acceptable.

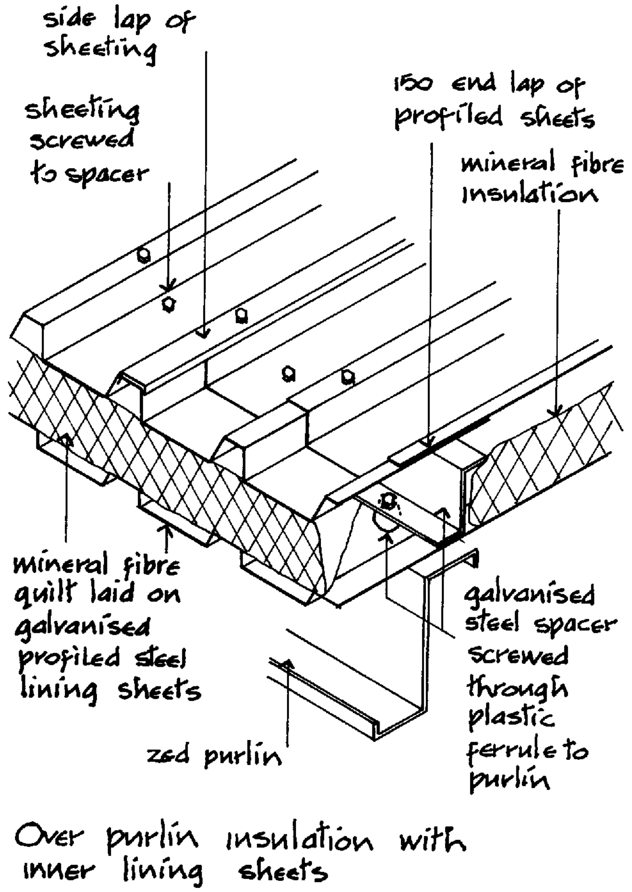


Fig. 60

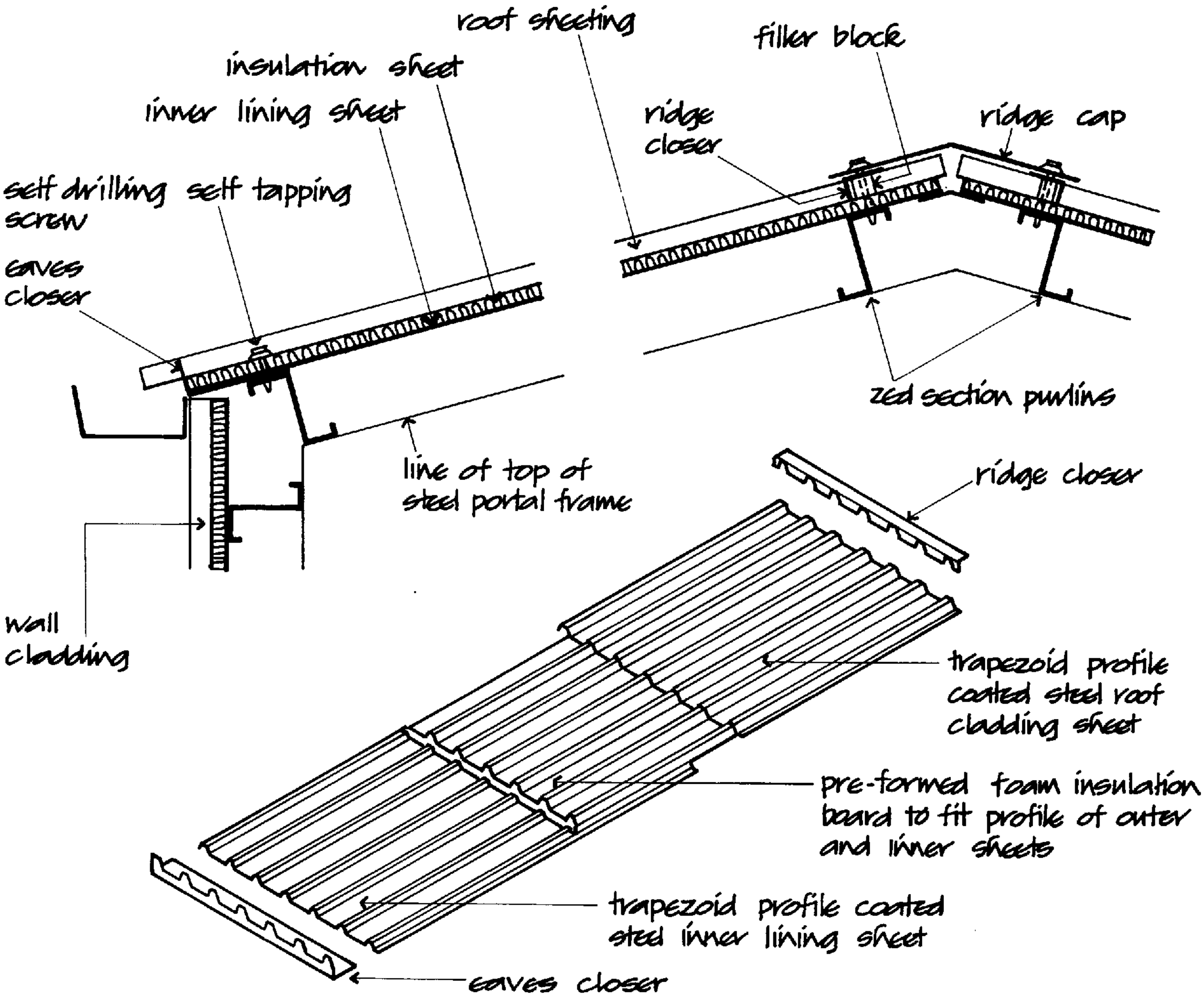
Over purlin insulation with inner lining Where mineral fibre mat insulation is used and where more rigid forms of insulation will not be self-supporting between widely spaced purlins, it is necessary to use profiled inner lining sheets or panels to provide support for insulation.

Lining sheets or panels are cold, roll formed, steel strips with shallow depth profiles adequate to support the weight of insulation. The sheets of panels are hot dip galvanised and may be coated on the exposed side with a heat cured, polyester coating or lining enamel as a protective and decorative coating.

The most commonly used system of over purlin insulation with lining panels consists of cladding sheets over mineral fibre mat or quilt laid on lining panels. To prevent compression of the loose mat or quilt, its thickness is maintained by spacers fixed between cladding and lining panels as illustrated in Fig. 60. The spacers are usually of Zed section cold formed steel of the same or greater depth than the insulation. The spacers are screwed through ferrules, through the troughs of the lining panels to the roof purlins and sheeting rails. The roof and walling sheets are then fixed by screwing through the crown or troughs of the sheeting, to the spacers, with self-tapping screws with neoprene washers. In this system the plastic ferrules serve as a thermal break. The space between the top of the sheeting and the insulation is passively ventilated to minimise condensation, through the open ends and side laps of the sheeting, where there are low or medium levels of humidity in the building. Where the internal humidity is high, with low pitch roofs and in exposed positions, a breather paper is often spread over the insulation and the top of spacers under sheeting which has sealed end and side laps to exclude rain, and with the roof and wall cavity below the sheets sealed. The breather paper, which is impermeable to water, protects the insulation from any rain or water condensation yet allows moisture vapour to penetrate it.

Over purlin composite insulation and sheeting (site assembled) This system comprises a core of rigid preformed lightweight insulation shaped to match the profile of both the roof sheeting and the inner lining sheets. The advantages of this system are that the insulation is sufficiently rigid for use without spacers between the roof, wall and lining sheets, the insulation fills and seals the space between the sheets and that insulants with a low *U* value such as PUR and EPS can be used. The separate roof and wall sheeting, preformed insulation and inner lining sheets are assembled on site and fixed directly to the purlins and rails with self-tapping screws, driven through the troughs or crowns of the profiles as illustrated in Fig. 61. The side and end laps between lining sheets are sealed against the penetration of moisture vapour. Coated steel eaves and ridge filler pieces are used to seal the insulation cavity. This system of cladding, which is somewhat more expensive than the fibre quilt and spacers system, has the advantage of no thermal bridge due to spacers, continuity of insulation and the use of efficient insulants for cladding buildings with medium to high levels of internal humidity. The disadvantage is that the intimate contact of the insulation with the underside of the sheeting may lead to a considerable build-up of heating of sheets due to solar radiation and so reduce the useful life of coated sheeting.

Over purlin composite (factory formed) A more expensive system of composite panels consists of



Profiled steel cladding, insulation and inner lining sheets

Fig. 61

factory-formed panels with a foamed insulation core enclosed and sealed by profiled sheeting and either flat or profiled inner lining panels made for batten capping for low pitch roofs. The advantages of the composite panels are that the two panels and their insulating core act together structurally to improve loading characteristics and that the panels have secret fixings for appearance. A particular disadvantage of these panels is that the sealed edges of the sheets may act as a very narrow thermal bridge. Because the insulation is sealed in the panels there is no need for ventilation of roof spaces.

The insulating core is usually of foamed insulation such as PUR. Figure 62 is an illustration of factory-formed panels.

Standing seams Standing seams are principally used for low and very low pitch roofs to provide a deep upstand as weathering to the side joints of sheeting and also for the benefit of secret fixings for appearance. To avoid the complication of detail at end laps with standing seams, these sheets are usually provided in lengths that can span from ridge to eaves. The standing seams for sheets that are assembled on site over insulation and inner lining panels are made as interlocking standing seams. With this system the roof and wall sheeting may be the same. Figure 63 is an illustration of standing seam cladding with secret fixings between panels, screwed to spacers and hooked to upstands of the standing seams. The spacers serve to maintain the space between roof sheeting and lining sheets for mineral fibre quilt insulation.

An advantage of the secret fixings used with standing seams is that the clip on fixing allows some freedom for the thermal movement of long sheets that might otherwise be deformed if thermal movement were restrained by screwed fixings.

Because of the considerable stiffening effect of the depth of the standing seams, the depth of the profiles of the sheet can be reduced.

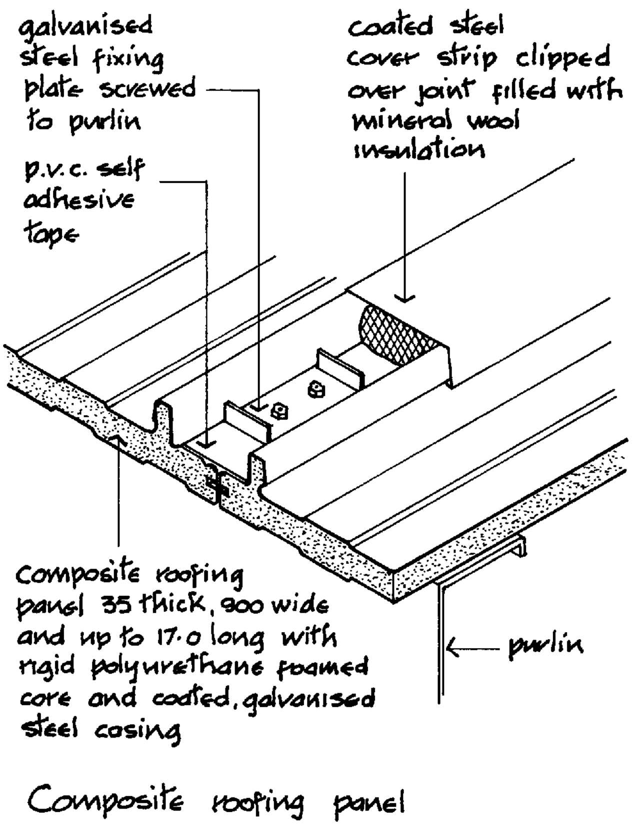


Fig. 62

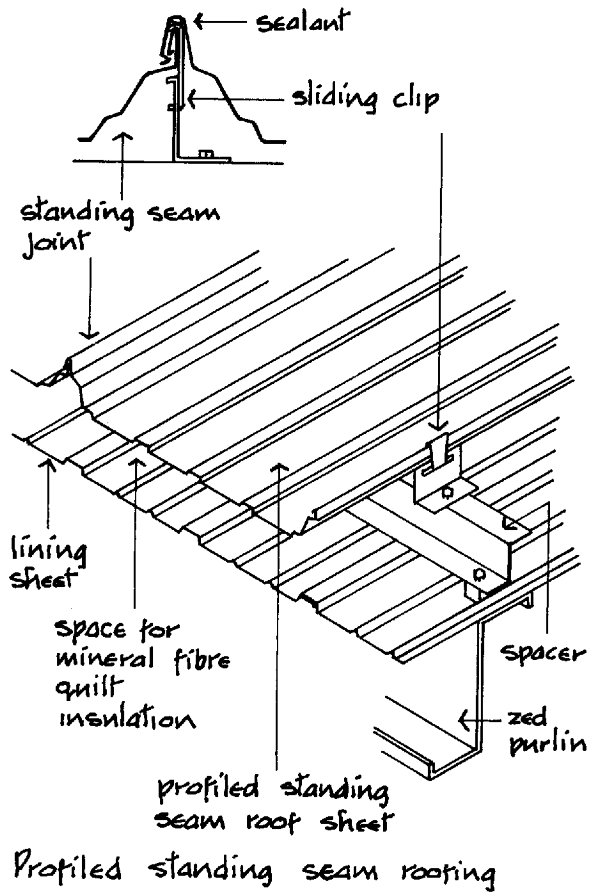


Fig. 63

Fasteners Steel cladding, lining sheets and spacers are usually fixed with coated steel or stainless steel self-tapping screws illustrated in Fig. 64. The screws are *mechanically* driven through the sheets into purlins or spacers. These primary fasteners for roof and wall sheeting may have heads coloured to match the colour of the sheeting.

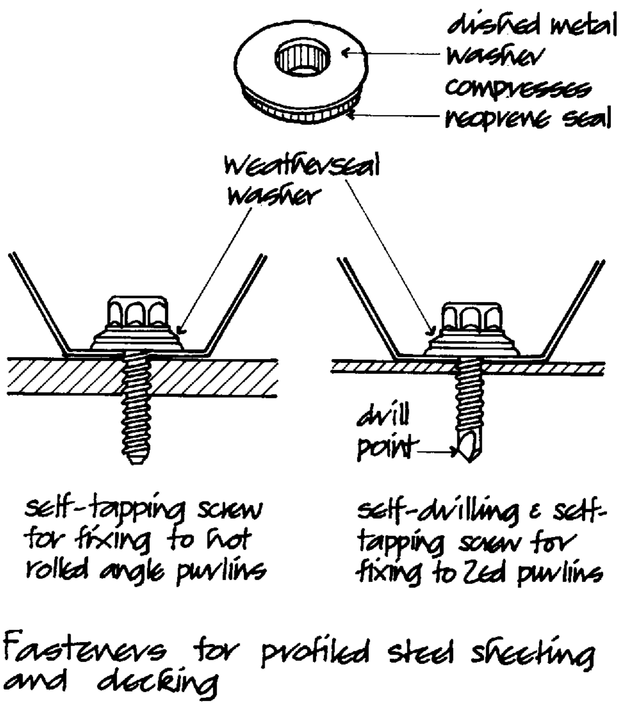


Fig. 64

For appearance the roof and wall sheeting screws are fixed in the trough of the sheets, where they are least visible. Correctly driven home, the neoprene washer under the head of the screws should make a watertight joint. Recently it has become common to fix roof sheeting through the crown of the profile, particularly with low and very low pitch roofs, to minimise the potential for damage and penetration of water through poorly fixed trough fasteners. Some care in crown fixing is necessary to ensure that at sheet overlaps the two sheets fit closely and also that the fasteners are not driven home so tightly as to deform the profile of the sheet.

Secondary fasteners, which have a shorter tail than primary fasteners, are used for fixing sheet to sheet and flashing to sheet.

Wall cladding, walling and wall sheeting Profiled steel wall sheeting is usually fixed with the profile vertical for the convenience in fixing to horizontal sheeting rails fixed across columns. The sheeting may be fixed horizontally for appearance. Horizontal fixed sheeting will be just as effective as a weather-resistant cladding as vertically fixed sheet because the overlap of the sheets and the slope of the profiles will shed water running down the face of the walling. There is usually some additional steel support required to provide a fixing for horizontally fixed wall sheeting to give support particularly between widely spaced columns.

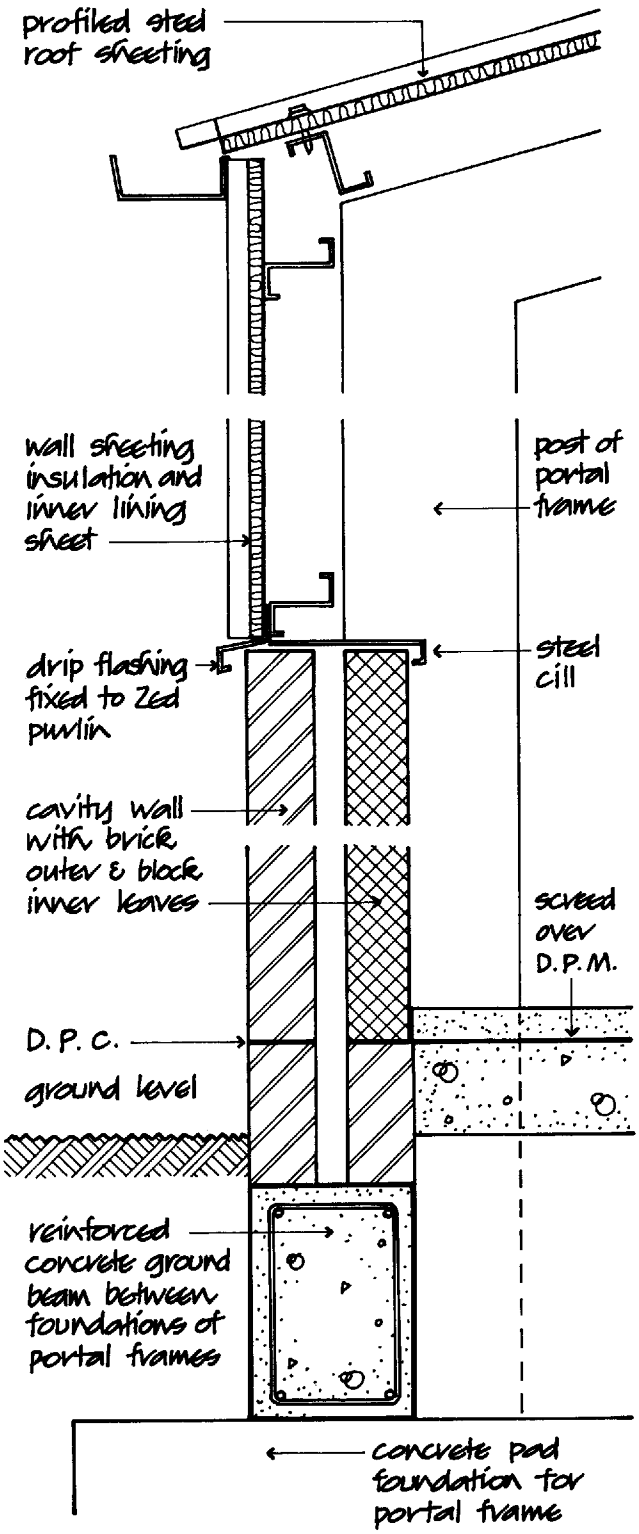
Because wall sheeting or cladding does not have to support the weight of snow or loads from those fixing or repairing roofs, it may have a less deep profile than roof sheets of similar unsupported span. A typical trapezoidal wall sheeting profile is illustrated in Fig. 58. The pitch of profiles, i.e. the distance between the centre lines of profiles, does not have to be the same for wall sheeting as that for roofing.

Mineral wool insulation, in the form of mat or quilt, for wall sheeting will be given support by spacer bars fixed between the wall sheeting and inner lining panels at sufficiently close centres to ensure that the insulant does not sag and make a break in the insulation.

Wall cladding is usually of the same system as that for roof cladding.

Either for appearance or to provide a robust type of lower walling to withstand knocks, a solid wall upstand to the lower part of walls may be constructed as illustrated in Fig. 65. The cavity wall is raised on reinforced concrete ground beams up to the sill level of side wall windows.

Gutters For appearance and as a protection against corrosion, cold formed organically coated steel eaves gutters are used. The gutters which may be laid level or more usually at a slight fall to rainwater pipes are supported by steel brackets screwed to eaves purlins under steel eaves closers, fixed under roof cladding and over wall cladding as illustrated in Figure 59. A separate steel eaves closer is fixed under roof sheeting as shown in Fig. 61. Valley gutters and parapet wall gutters may be of galvanised steep strip, cold formed to shape, with the inside of the gutter painted with bitumen as protection against corrosion. These gutters are supported on steel brackets fixed over purlins. Valley and parapet wall gutters should have an underlining of insulation which may be half the thickness of insulation for roof cladding.



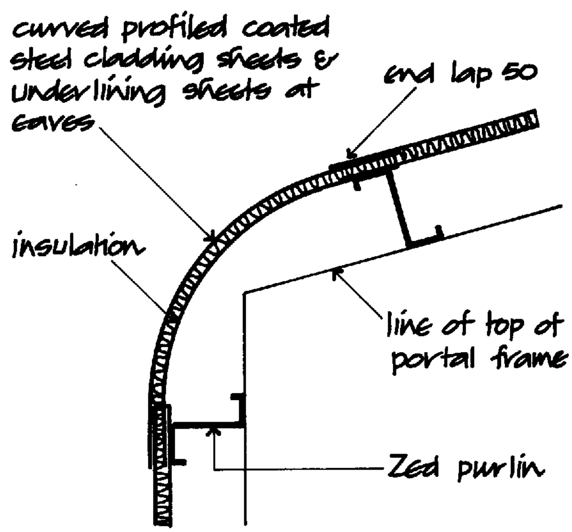
Profiled steel wall sheeting for portal frame building

Fig. 65

Ridges Ridges are covered with cold formed steel strip organically coated. The ridge may be formed to match the profile of the roof sheeting or be flat with a shaped filler to seal the spaces between the underside of the ridge and the profile of the sheeting as illustrated in Fig. 61. Wall cladding is commonly finished with a preformed steel strip closer and drip above finished external surfaces over a low concrete or brick curb upstand for appearance.

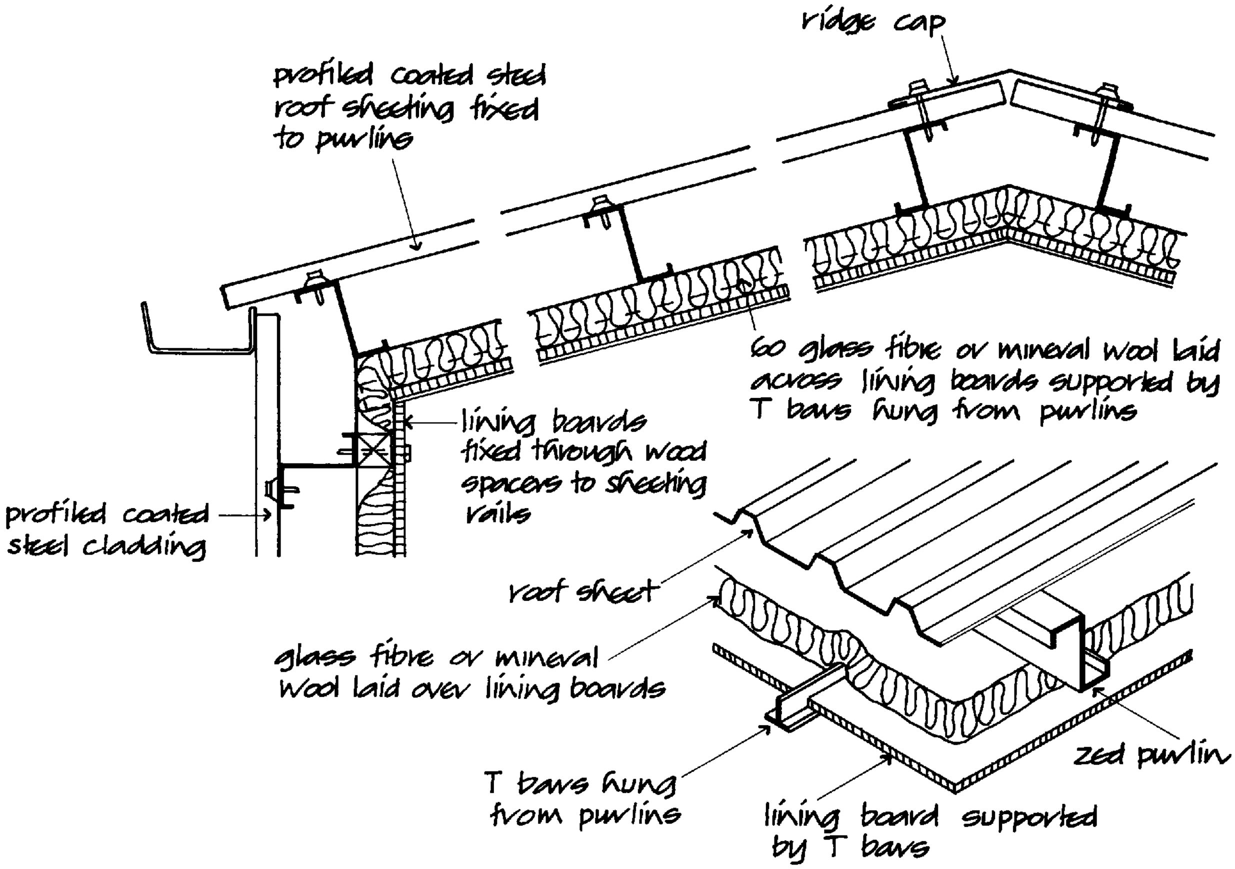
Curved sheets For appearance curved, profiled, organically coated steel sheets are used at eaves, ridges and external angles of wall cladding. The profile of the curved sheets must match the profile of the sheeting to roof and wall cladding that it is to fit to at eaves. The usual internal radius of curve is from 400 to 1200. Either plain curved sheets or laterally embossed sheets are produced. The shallow embossing of the sheets with regularly spaced sinkings and protrusions between profiles tends to assist and regularise the curving process. To an extent the shallow embossing detracts from the smooth transition between adjacent surfaces that the curvature is designed to emphasise. Figure 66 is an illustration of curved sheets to eaves. Where curved eaves sheets are used it is often practice to form a secret gutter.

Under purlin lining system To provide a flush soffit to roof cladding for appearance, it is usual to fix the inner lining and insulation under the purlins between roof



Curved profiled steel cladding

Fig. 66



Steel roof sheeting with under purlin insulation

Fig. 67

frames. The roof sheeting is screwed directly to the top of the purlins. The soffit lining of preformed boards, such as plasterboard, is supported by metal T-section supports at centres to suit the boards. The T-section supports are fixed to brackets screwed to the underside of purlins. Mineral wool insulation is laid over the lining boards as illustrated in Fig. 67.

Profiled aluminium roof and wall cladding In common with other metals aluminium, on exposure to atmosphere, corrodes to form a thin coating of oxide on its surface. This oxide coating, which is integral with the aluminium, adheres strongly and being insoluble, protects the metal below from further corrosion so that the useful life of aluminium is 40 years or more.

Aluminium is a lightweight, malleable metal with poor mechanical strength, which can be cold formed without damage. Aluminium alloy strip is cold rolled as corrugated and trapezoidal profile sheets for roof and wall cladding. The sheets are supplied as metal mill finish, metal stucco embossed finish, pre-painted or organically coated.

Mill finish is the natural untreated surface of the metal from the rolling mill. It has a smooth, highly reflective metallic silver grey finish which dulls and darkens with time. Variations in the flat surfaces of the mill finish sheet will be emphasised by the reflective surface. A stucco embossed finish to sheets is produced by embossing the sheets with rollers to form a shallow, irregular raised patterned finish that reduces direct reflection and sun glare and so masks variations in the level of the surface of the sheets.

A painted finish is provided by coating the surface of the sheet with a passivity primer and a semi-gloss acrylic or alkyd-amino coating in a wide range of colours.

A two coat PVF acrylic finish to the sheet is applied by roller to produce a low-gloss coating in a wide range of colours.

Figure 68 is an illustration of profiled aluminium roof and wall sheeting, fixed over rigid insulation boards bonded to steel lining trays, to a portal steel frame.

Aluminium sheeting, which is more expensive as roof and wall cladding, is used for its greater durability particularly where humid internal atmospheres might cause early deterioration of coated steel sheeting.

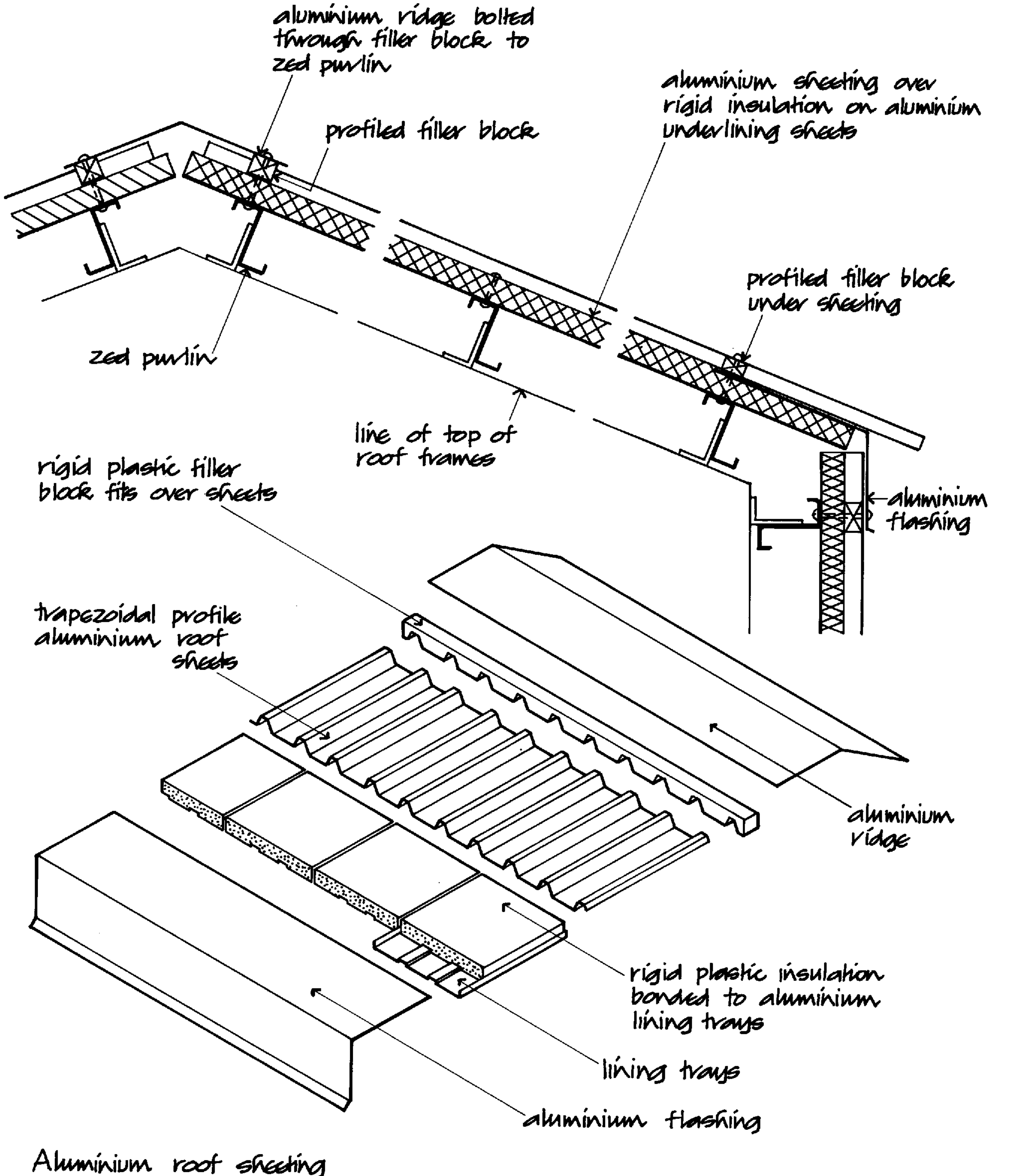


Fig. 68

FIBRE CEMENT PROFILED CLADDING

Asbestos cement sheets

The original fibre cement corrugated sheets were manufactured by felting asbestos fibres with alternate layers of cement and water. The wet mix of asbestos and cement was pressed into corrugated sheets which were steam cured to accelerate hardening of cement. The earliest corrugated asbestos cement sheets, which were first imported into this country in 1910, were manufactured here soon afterwards. For the following 50 years these sheets were extensively used for roof and side wall cladding for a variety of single-storey buildings used in agriculture, manufacturing and for storage.

The advantage of asbestos cement is that it is, unlike steel, non-corrosive, unaffected by atmospheric pollution, maintenance free and has a useful life of 40 years or more. The natural drab, light grey cement colour of the sheets does not make an attractive finish to buildings. Corrugated sheets tend to weather with irregular dirt staining on the sides of the corrugations and algae and lichen growth may flourish on the surface of the sheets in persistently damp conditions.

Because of the necessary thickness of the material it is not possible to make a close fitting at end laps, which will allow wind penetration and the fittings at ridge and eaves look somewhat lumpy and ugly as compared to the neat finish possible with thinner metal strip. Nonetheless corrugated asbestos cement sheets continued to be used for many years for the considerable advantage of low initial cost, durability and freedom from maintenance.

For appearance a range of coloured asbestos cement sheets is produced through the application of acrylic coating.

Some years ago it was established that the continuing inhalation of airborne asbestos fibres could, over time, become a serious health hazard particularly to those employed in the manufacture and use of asbestos fibre-based materials. The facts are that blue asbestos fibre, principally from South Africa, is a much more serious hazard than white asbestos fibre. A much publicised, hysterical outcry has since condemned all asbestos fibre for any use whatsoever and in all conditions regardless of good sense and statistical evidence.

In consequence asbestos fibre reinforced cement sheets are no longer used in this country. As a substitute, fibre reinforced cement sheets are produced in a range of corrugated and profiled sheets both for replacement for damaged asbestos cement sheets and also for new work. These fibre cement sheets are manufactured from cellulose and polymeric fibres, Portland cement and are water pressed to profiles the same or very similar to the original asbestos cement sheets. A range of acrylic coated coloured sheets is produced.

Corrugated fibre cement sheets

These sheets are pressed to a sinusoidal or corrugated profile with a 73 or a 146 pitch of corrugations which coincides with the original 3 inch and 6 inch imperial measure. These two corrugated profiles are still fairly extensively used for replacement and repair work, and

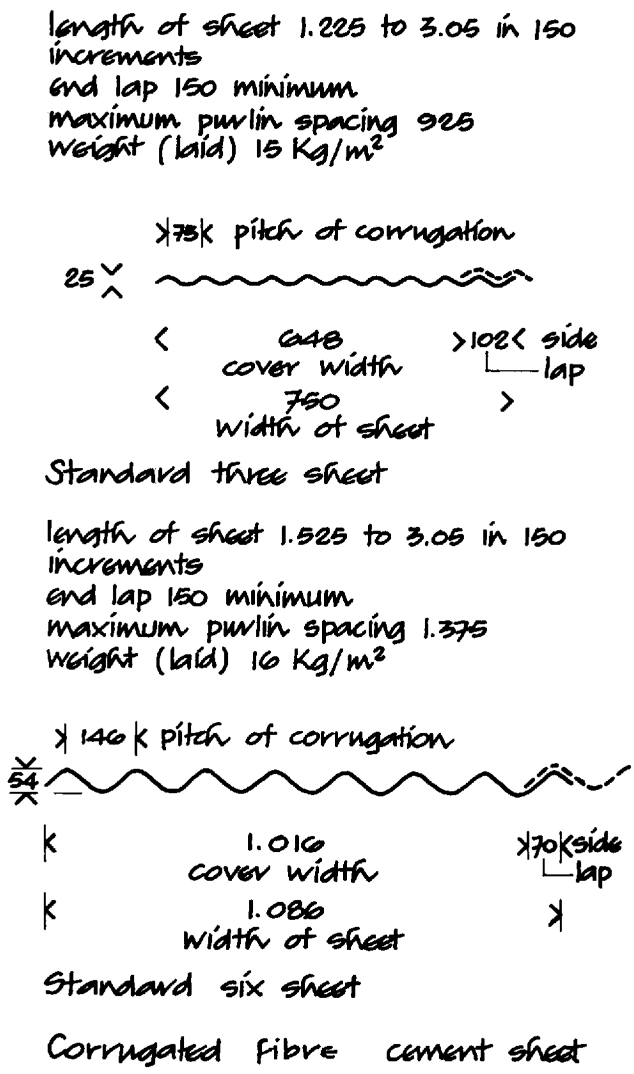


Fig. 69

for new cladding to single-storey buildings for the advantage of freedom from maintenance and freedom from corrosion both from moisture externally and condensation moisture from warm inside air. These sheets are heavier and require closer centres of support from purlins and rails than the deeper profile steel sheets.

Figure 69 illustrates the principal dimensions of profile 3 and profile 6 corrugated fibre cement sheets.

A range of fittings is made for finishes at ridge and eaves as illustrated in Fig. 70. The ridge is covered with a two piece fitting, each half of which fits over the corrugations of the two slopes. Eaves closer and eaves filler pieces fit under the corrugations of the eaves sheets.

Corrugated fibre cement sheet is usually at a pitch or slope of at least 10° to the horizontal but can be fixed at a pitch of not less than 5° in sheltered positions. Figure 71 is an illustration of corrugated fibre cement sheets fixed as roof and side walling to a single-storey, single-bay framed building which does not require heating. The sheeting is fixed with galvanised hook bolts to angle purlins with end lap between sheets of 150. The two piece ridge is hook bolted through the sheeting and the eaves filler is bolted to the ends of the sheeting.

Where the interior of the building is to be heated a system of over purlin insulation with under lining sheets, similar to that used for profiled steel sheeting, is used.

A variety of fixings is available to suit the various purlins used to support the sheets as illustrated in Fig. 72.

Figure 73 is an illustration of the use of profiled fibre cement sheets with mineral wool quilt insulation laid over steel underlining sheets with galvanised steel spacers on cold formed purlins.

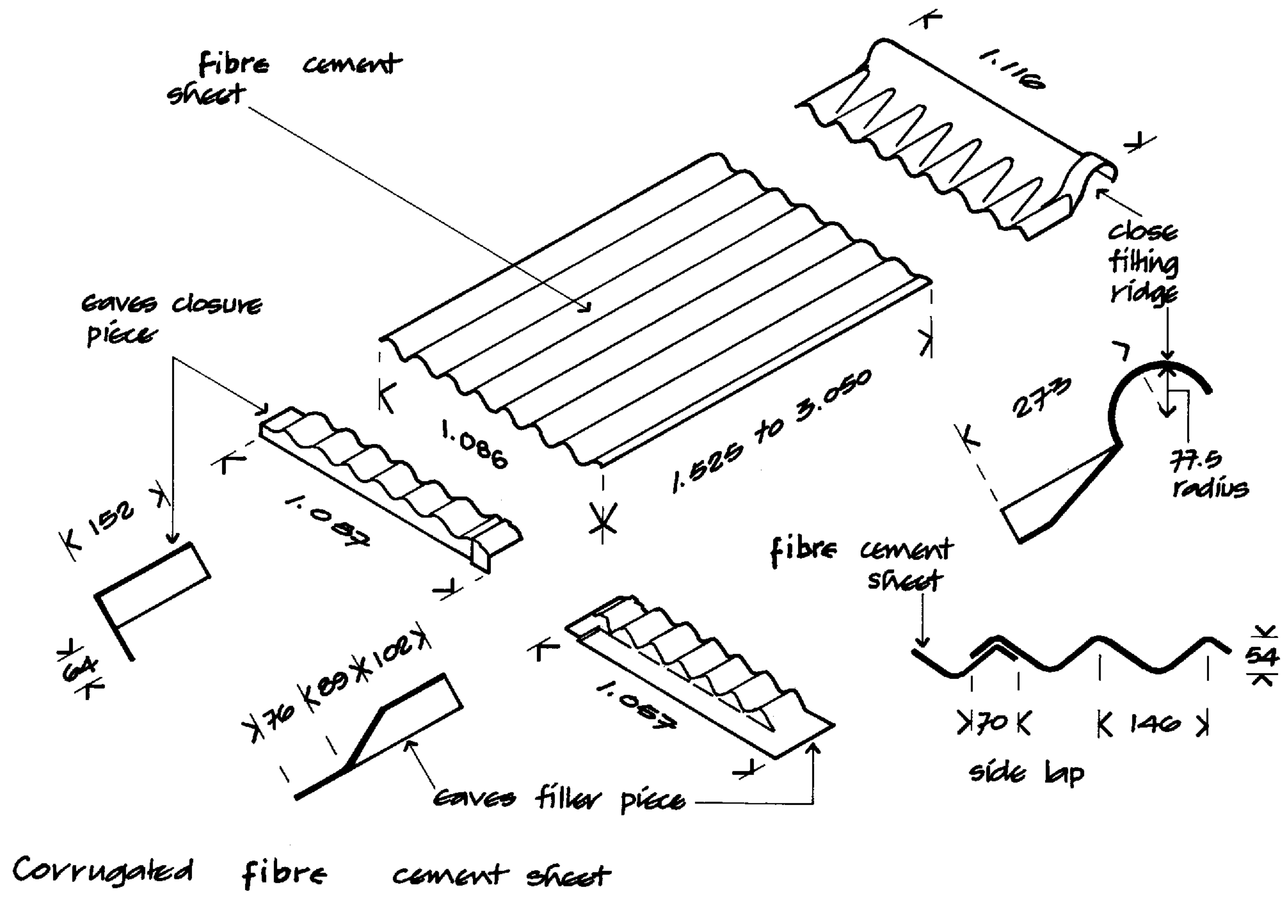


Fig. 70

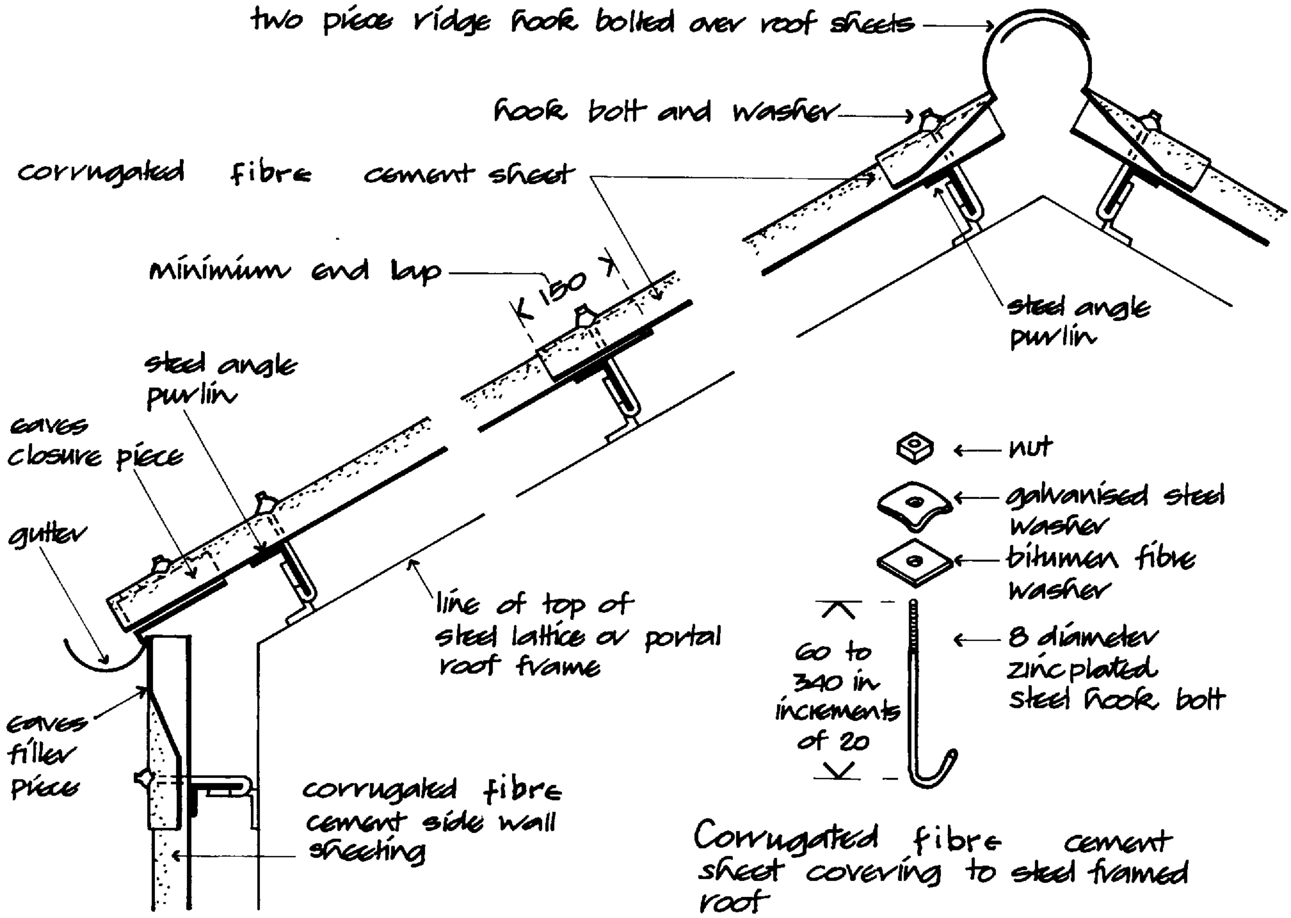


Fig. 71

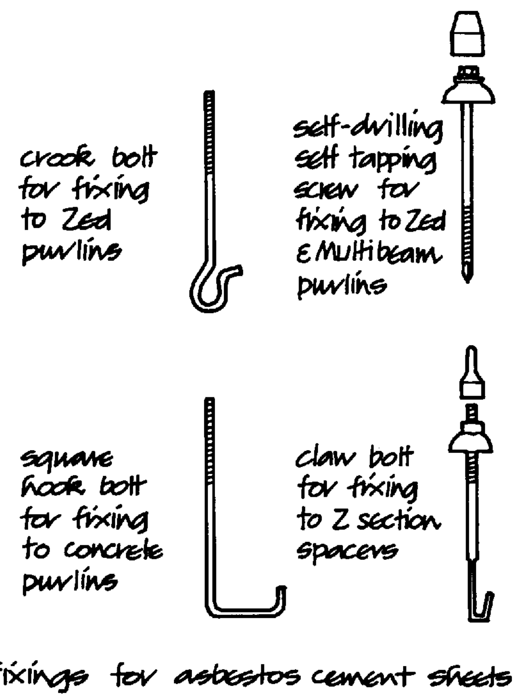


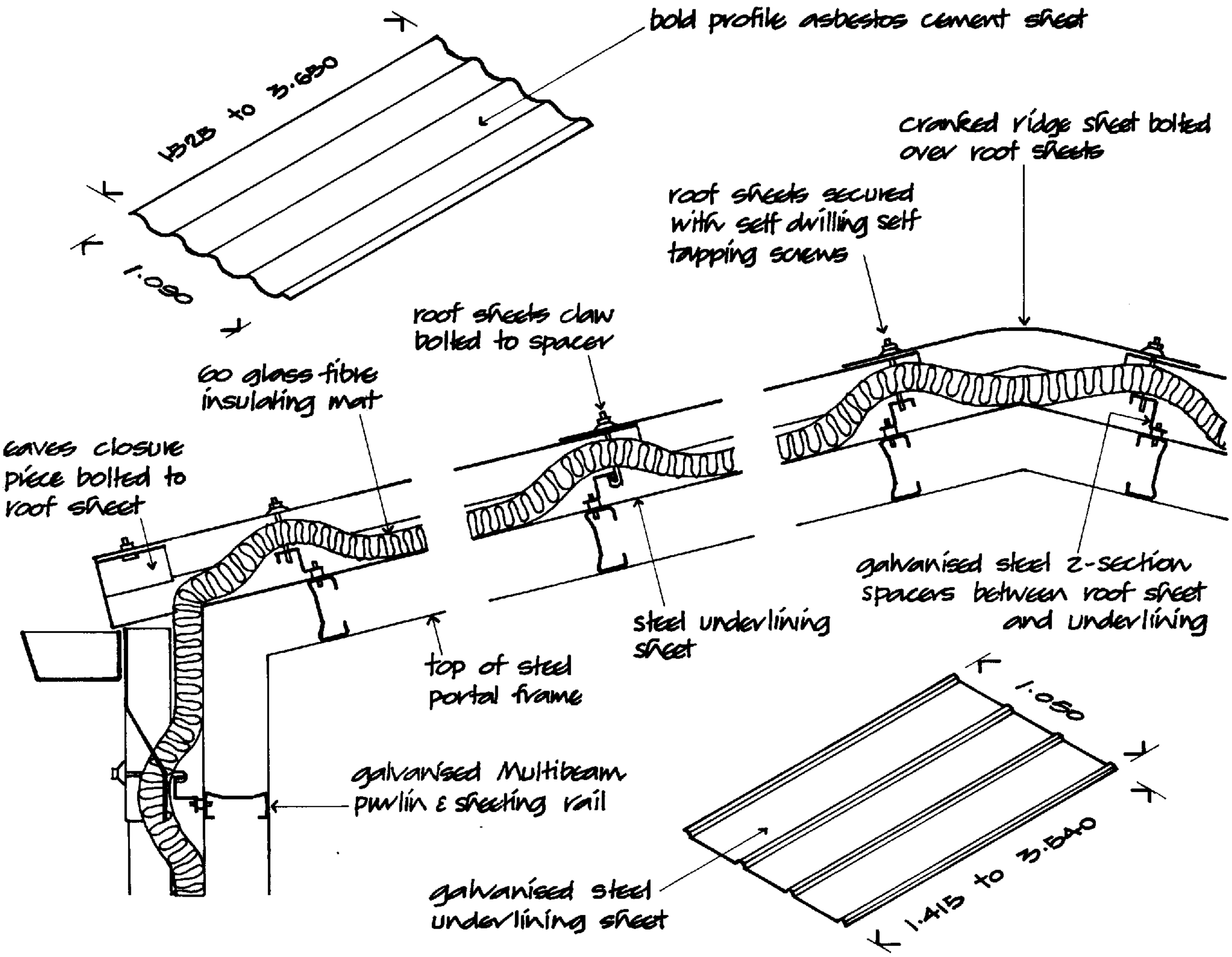
Fig. 72

DECKING

Decking is the general term used for the material or materials used and fixed across roofs to serve as a flat surface onto which one of the flat roof weathering membranes is laid. Decking is designed to support the weight of the materials of the roof and imposed loads of wind and snow. Decking, which is commonly used for flat roof coverings laid to a shallow fall or slope sufficient to encourage run off of rainwater, may also be laid across low pitch lattice beam and portal frames.

Profiled steel decking

The most commonly used form of decking at present is galvanised profiled steel sheeting fixed across beams or purlins. The zinc coating provides adequate protection and is the usual finish where the metallic grey of the zinc coat is an acceptable finish to the exposed underside of



Asbestos-cement sheeting with insulation and steel sheet underlining

Fig. 73

the decking. As an alternative, the underside of the decking may be primed ready for painting or be coated with a paint finish.

Trapezoidal profile steel decking with depths of up to 200 are produced as decking for spans of up to 12.0 between structural frames or beams. As stiffening against buckling, ribs are pressed in the ridges, troughs and sides of the profiles as illustrated in Fig. 74. The decking is secured with screws driven through cold formed purlins or by self-tapping screws to holes in beams and roof frames.

The steel decking provides support for rigid insulation boards which are either bedded in bitumen on the ridges of the decking or secured with self-drilling screws, depending on the anticipated wind uplift. The weathering membrane is then bonded to the insulation boards as illustrated in Fig. 75. This is a form of warm roof or warm construction as the roof frame, intermediate supports and the steel decking are below the insulation and, as such, will be maintained at inside air temperature. Where there is likely to be appreciable moisture vapour pressure drive from warm inside air towards colder outside air, it is practice to bond a layer of some material such as bitumen felt or polythene sheet across the steel decking below the insulation to act as a vapour check.

Profiled steel decking is used as the support for insulation and a weather finish of built-up bitumen felt,

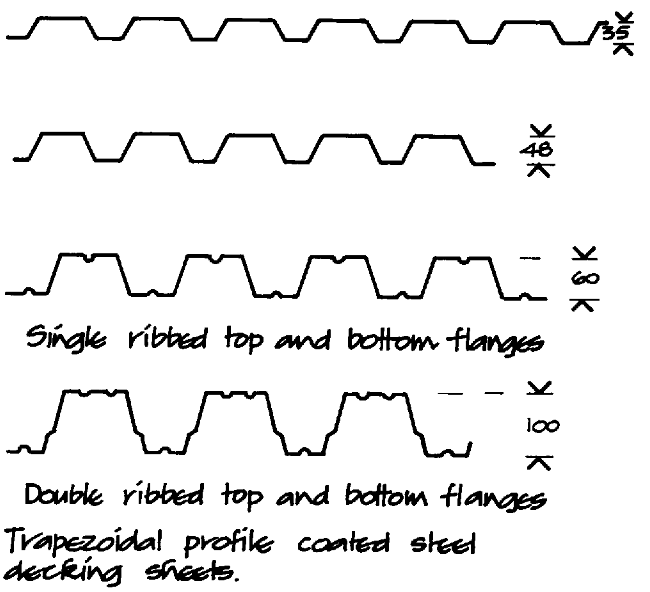


Fig. 74

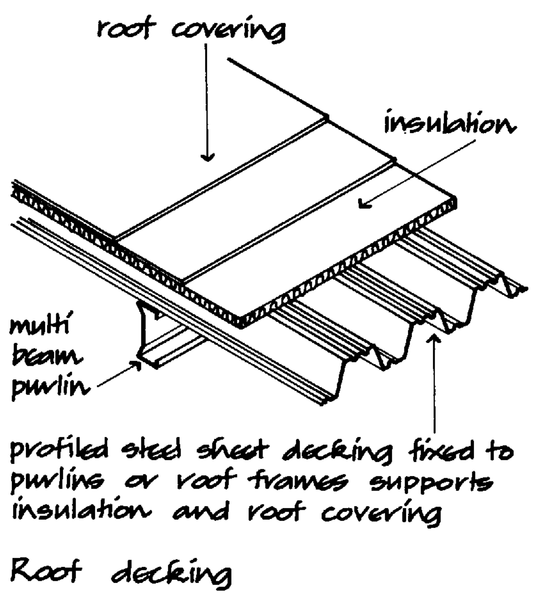


Fig. 75

high performance felt or a single ply membrane for flat or low pitch roofs for the advantage of widely spaced supports that is possible with deep profile decking.

The trapezoidal profile steel decking illustrated in Fig. 76 is fixed across the secondary beams of a steel framed flat roof structure with self-tapping fasteners. A felt vapour check is bonded to the decking with bitumen. Rigid insulation boards are bonded to the vapour check either with bitumen or self-drilling self-tapping screws and flat washers as necessary to resist wind suction uplift. The roof is finished with built-up bitumen felt as a weathering surface.

The requisite fall or slope for rainwater run off is provided by taper section insulation boards.

Composite steel decking and cladding

The system of steel decking and mineral fibre insulation illustrated in Fig. 77 combines the long span advantage of steel decking, a high degree of insulation and profiled steel cladding for low pitch roofs. The profiled steel decking has deep web stiffening longitudinally for spans of up to 12.0, for fixing between widely spaced beams or roof frames without intermediate support. Lattic steel spacer bars are fixed to the decking over a polythene vapour check to maintain the thickness of a thick layer of fibre insulation. The profiled PVC or acrylic coated steel cladding sheets are supported by the spacer bars, under the longitudinal ridges of the cladding, which has shallow transverse stiffening ribs to strengthen the wide troughs of the profile.

This roofing system is designed specifically for the high insulation that is possible due to the spacer bars and the life expectancy to first maintenance of the PVC or acrylic coating. Fibre insulation thicknesses of 160, 220 and 270 are available with this system.

Wood wool slab decking

Wood wool slabs are made from seasoned wood fibres bound together under pressure with Portland cement. The finished slabs which have coarse, open textured surfaces, moderate compressive strength and thermal resistance and good resistance to rot and fungal growth, are used as roof deck for flat roofs to support the roof covering and provide some degree of insulation. Wood wool slabs are made in thicknesses of 50, 75, 100 and 125, widths of 600 either as plain slabs or channel interlocking slabs. The material of the slabs is combustible but not readily ignited and the spread of flames is low. Plain slabs are used as a deck to timber-framed roofs with the slabs supported at up to 600 centres. Channel interlocking slabs are manufactured with steel channels in the long edges of the slabs as reinforcement for spans of up to 4.0 for normal roof

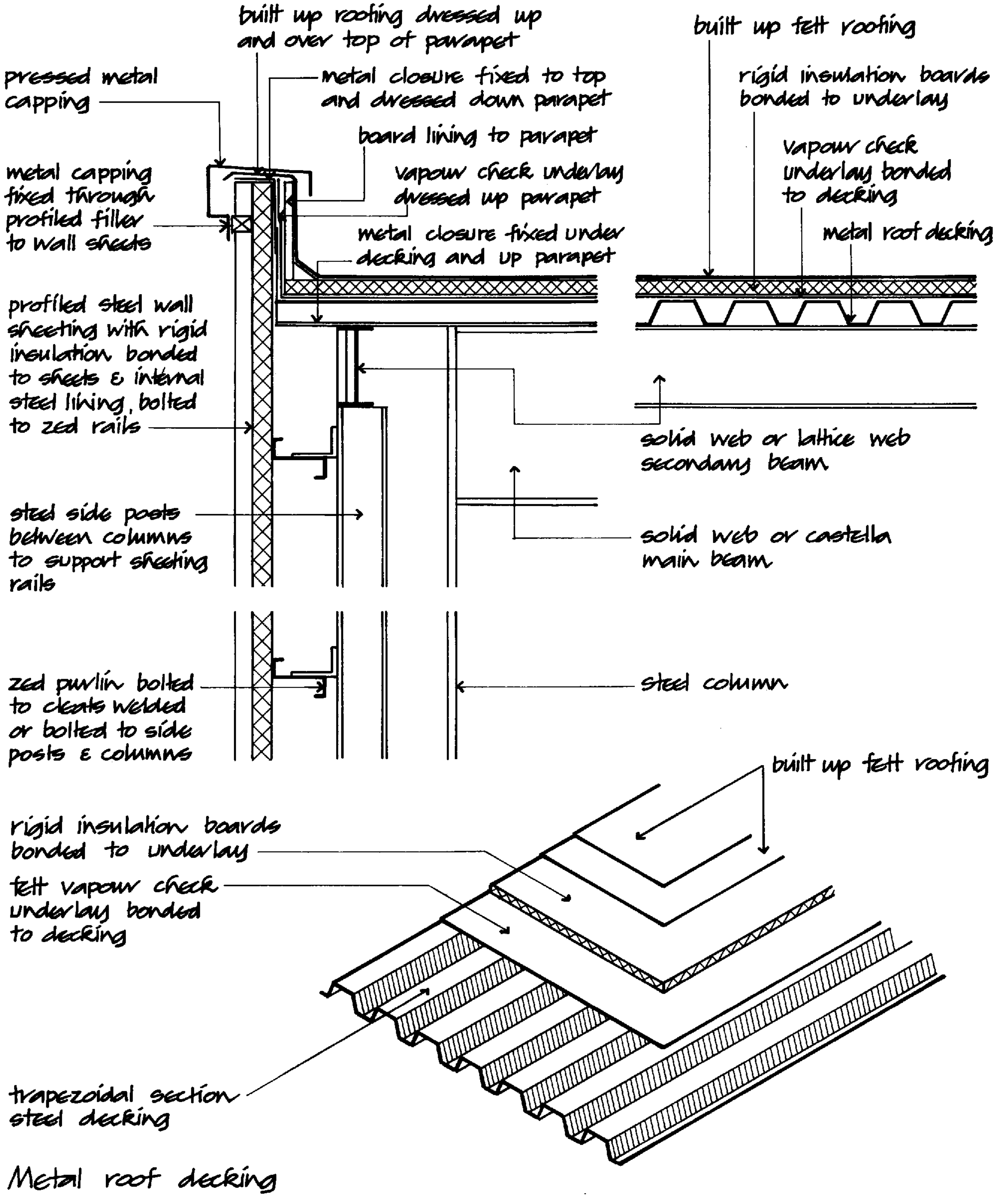
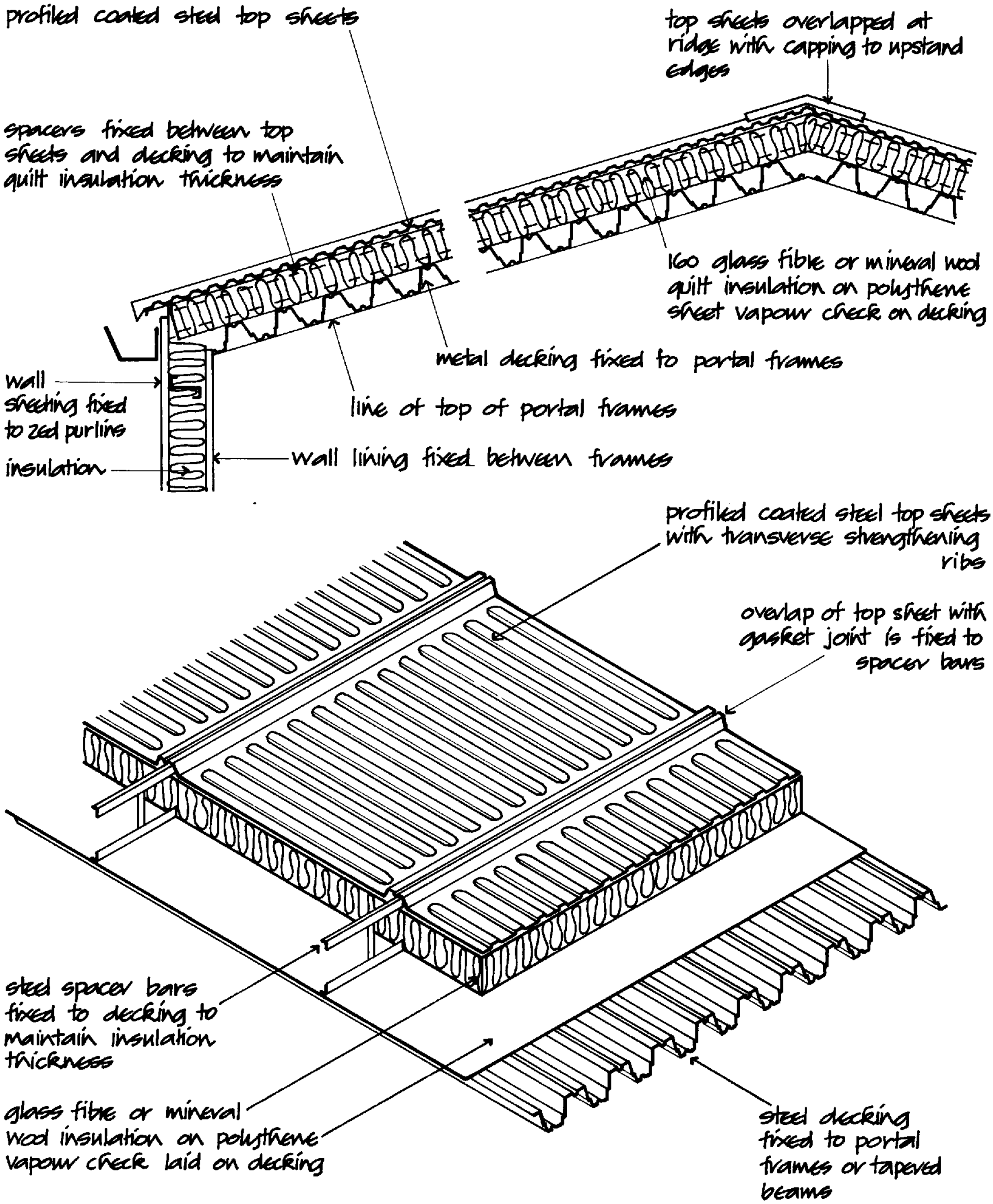

built up roofing dressed up and over top of parapet
pressed metal capping
metal closure fixed to top and dressed down parapet
board lining to parapet
metal capping fixed through profiled filler to wall sheets
vapour check underlay dressed up parapet
metal closure fixed under decking and up parapet
built up felt roofing
rigid insulation boards bonded to underlay
vapour check underlay bonded to decking
metal roof decking
profiled steel wall sheeting with rigid insulation bonded to sheets & internal steel lining, bolted to zed rails
solid web or lattice web secondary beam
steel side posts between columns to support sheeting rails
solid web or castella main beam
zed purlin bolted to cleats welded or bolted to side posts & columns
steel column
built up felt roofing
rigid insulation boards bonded to underlay
felt vapour check underlay bonded to decking
trapezoidal section steel decking
Metal roof decking

Fig. 76



Steel decking insulation and steel sheeting

Fig. 77

loads. Another system of wood wool slabs employs either 'T' plates or I-section supports as reinforcement. Tee section cold formed steel supports are fixed with clips and plates that are screwed, welded or shot fired into purlins or secondary beams and the wood wool slabs are laid between the T-sections as illustrated in Fig. 78. The joints between the slabs are covered with hessian scrim in a slurry of cement and sand. Insulation boards can be bonded or screwed to the slabs to provide additional insulation and as a base for the roof covering.

The I-section cold formed steel supports for slabs fit to grooves cut in the long edges of the slabs. The I-section supports are fixed to each supporting beam by screwing, welding or shot firing. The joints between the slabs are covered with hessian scrim in a sand and cement slurry as shown in Fig. 79.

A disadvantage of the steel channel reinforcement and the cold formed T- and I-section supports is that they will act as cold bridges to the transfer of heat and may encourage condensation and dirt staining on the soffit of plastered slabs.

To provide a fall for roof drainage the slabs can be laid across taper or sloping beams, a screed to falls can be spread over the surface of the slabs, or taper section insulation boards can be laid across the slabs.

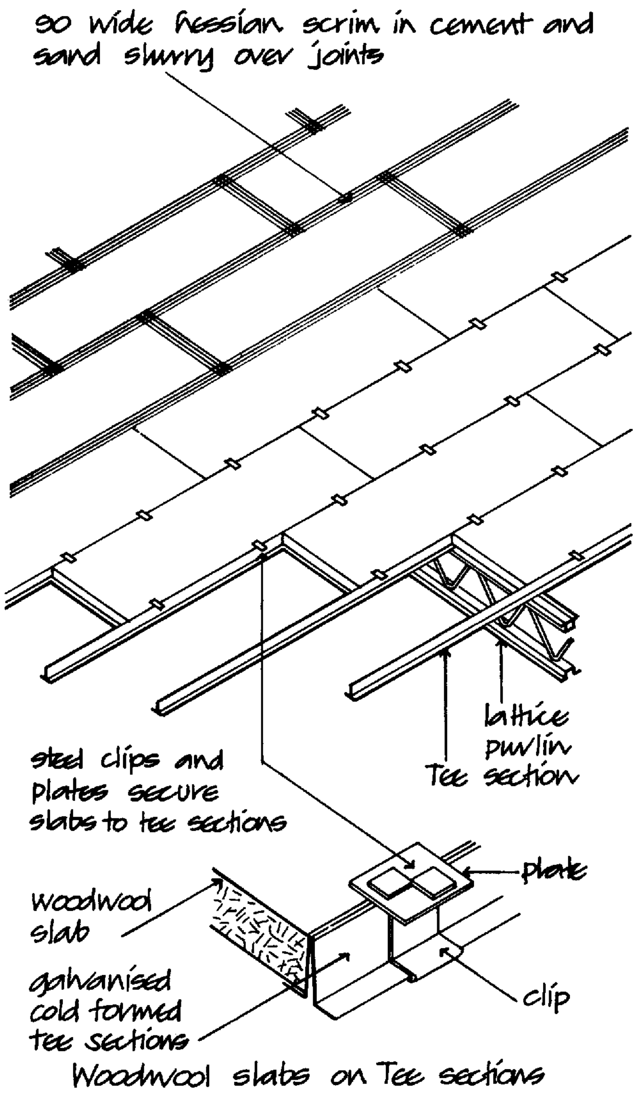


Fig. 78

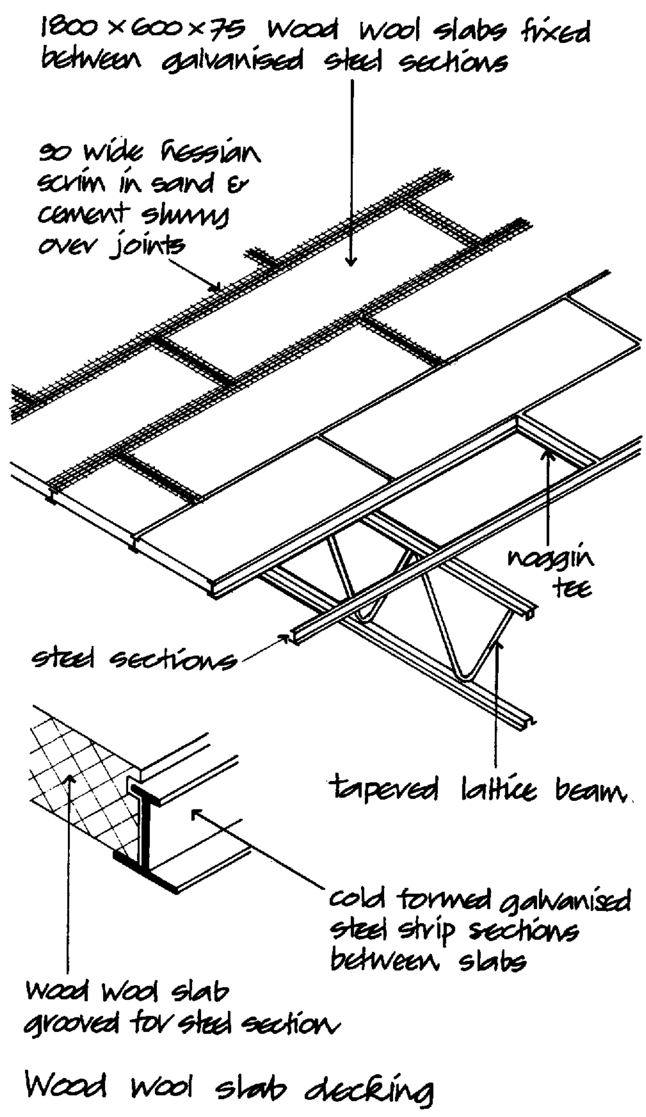


Fig. 79

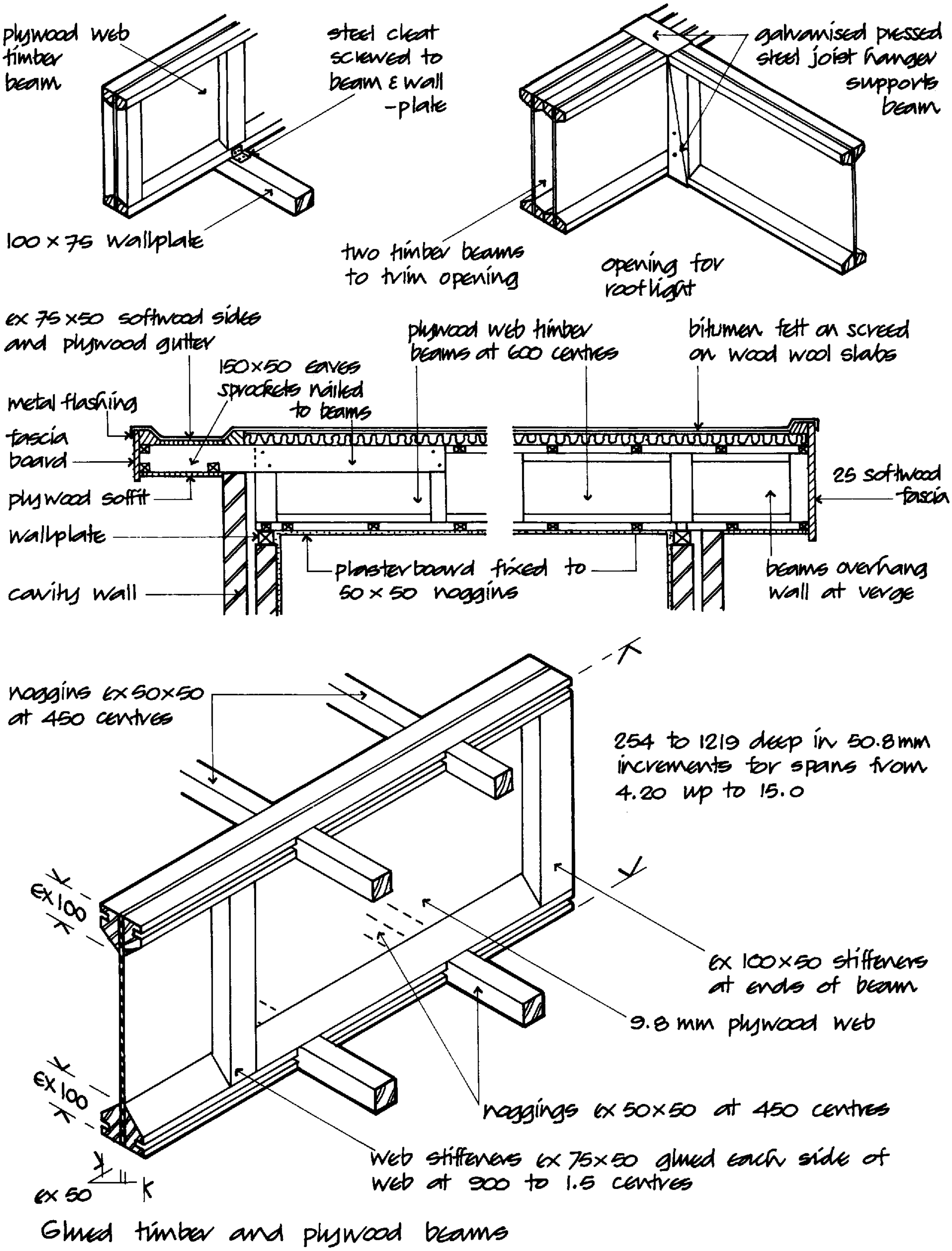

plywood web timber beam
steel cleat screwed to beam & wall-plate
100 × 75 wallplate
galvanised pressed steel joist hanger supports beam
two timber beams to trim opening
opening for roof light
ex 75 × 50 softwood sides and plywood gutter
150 × 50 eaves sprockets nailed to beams
plywood web timber beams at 600 centres
bitumen felt on screed on wood wool slabs
metal flashing
fascia board
plywood soffit
wallplate
cavity wall
plasterboard fixed to 50 × 50 noggins
25 softwood fascia
beams overhang wall at verge
noggins ex 50 × 50 at 450 centres
254 to 1219 deep in 50.8 mm increments for spans from 4.20 up to 15.0
ex 100
ex 100
ex 50
ex 100 × 50 stiffeners at ends of beam
9.8 mm plywood web
noggings ex 50 × 50 at 450 centres
web stiffeners ex 75 × 50 glued each side of web at 900 to 1.5 centres
Glued timber and plywood beams

Fig. 80

Wood wool slabs are less used than they were since the advent of profiled steel as decking.

Timber decking

The advantage of the use of timber beams as the structural deck for flat roofs is that the timber requires no maintenance and does not suffer corrosion in humid atmospheres, e.g. in swimming pools. Because the maximum span of timber beams is about 15.0 and the beams are more expensive than comparable standard lattice steel beams, the use of timber beams is generally limited to medium span roofs where conditions such as humid atmospheres justify their use.

The timber beam deck illustrated in Fig. 80 consists of timber beams fabricated with plywood webs and softwood section top and bottom booms, glued together with timber web stiffeners and noggin pieces. The beams are fixed at centres to suit wood wool slabs that serve as surface to the deck and insulation. To provide additional insulation, a layer of taper insulation board is bonded to the slabs to provide drainage falls. The beams may be exposed or covered with a soffit of plasterboard.

Lightweight concrete slab decking

Lightweight reinforced concrete slabs are made from a mix of Portland cement, finely ground sand and lime. The materials are mixed with water and a trace of aluminium powder is added. The mix is cast in moulds around reinforcing bars and auto claved to cure and harden the slabs. The effect of the trace of aluminium powder is to entrain minute bubbles of gas in the concrete which is lightweight and has better resistance to the transfer of heat than dense concrete. The lightweight slabs are designed specifically for use as deck material for roofs where the resistance to damage by fire is an advantage.

The slabs are laid across steel or concrete flat or low pitch structures as a deck as illustrated in Fig. 81. The slabs are secured with steel straps cast into or fixed to the structure and reinforced with continuity steel bars bedded to the joints. The slabs can be used by themselves as a deck for flat roof covering or with a layer of insulation under the covering.

FLAT ROOF WEATHERING

With the now common use of profiled sheeting to roofs, with a slope or pitch of as little as $2\frac{1}{2}°$ to the horizontal, the terms 'flat roof' and 'pitched roof' are no longer clearly defined. A flat roof has been used to describe a roof with a finished weathering surface of up to 5° to the horizontal and a pitched roof as a roof with a slope of over 5° to the horizontal. In current roof terminology a pitched roof has a weathering surface of more than 10° to the horizontal, a low pitched roof from 5° to 10° to the horizontal and a very low pitch or flat roof a slope of up to 5° to the horizontal.

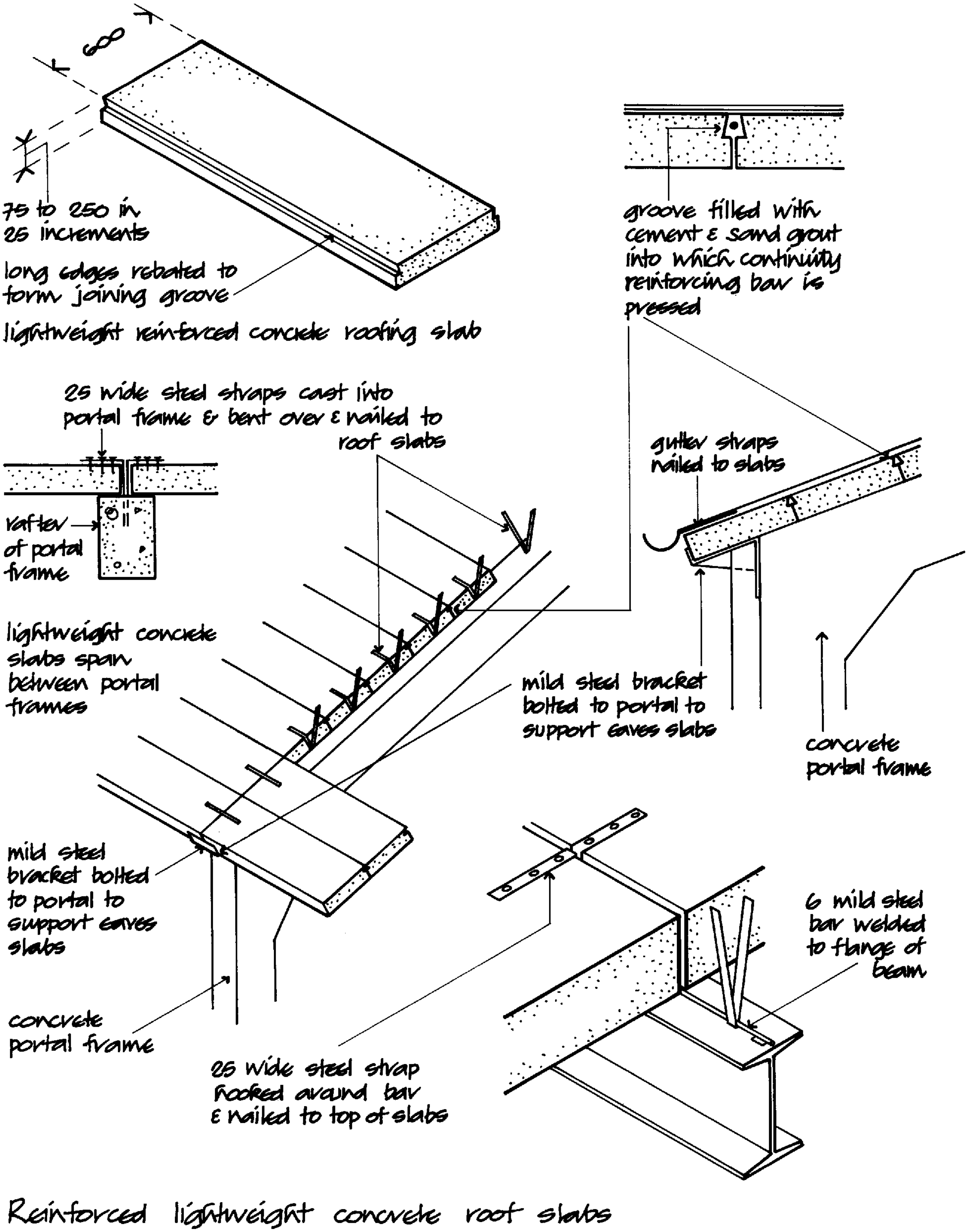
There is no economic or practical advantage in the use of a flat roof structure unless the roof is used as a deck for leisure, recreation or storage purposes. A flat roof structure is less efficient structurally than a pitched roof structure and there is often little, if any, saving in unused roof space as compared to a low pitch frame structure. The inevitable deflection of horizontal beams that would cause ponding of rainwater on flat roofs requires the construction of falls on the roof to clear rainwater to outlets. The many failures of flat roofs that have occurred over the years have not tended to recommend the use of flat roofs.

Nonetheless it has been fashionable for many years to construct large buildings with flat roofs for the sake of the horizontal line that was in favour and to avoid too large an expanse of visible roof.

Recent improvements in flat roof weathering membranes and careful detailing have made flat roof coverings a viable alternative to sheet metal profiled sheets.

It is generally accepted practice for flat roofs to be constructed with a finished weathering surface that has a fall or slope of at least 1 in 80 to rainwater outlets so that rainwater will run off towards outlets. This fall is often increased to 1 in 40 to make allowance for deflection of beams under load and inaccuracies in construction.

Due to the self-weight of a roof structure and the imposed loads of wind and snow, every horizontal structure will deflect or sag at mid-span between points of support. It would, therefore, seem logical to accept this inevitable deflection as a means of providing the shallow fall or slope necessary to drain rainwater to outlets at mid-span. This sensible approach to design in the utilisation of an inevitable structural effect, to drain a roof surface, is not generally accepted because it is usually inconvenient to have rainwater down pipes



Reinforced lightweight concrete roof slabs

Fig. 81

running down inside a building at the middle of a clear span of structures, as the pipes will probably constrain freedom of layout of activities on floors and are unsightly. Rainwater pipes could be run with a shallow fall under roofs to down pipes fixed to columns or walls. Rainwater pipes run to shallow falls need sealed joints and are more subject to blockages than vertical pipes. The most convenient place to run rainwater down pipes is at points of support, such as columns and walls, just where the deflection of a roof is least and natural run-off of water will not occur.

Drainage and falls

For the reasons given above, horizontal, flat roof structures must have some form of construction to provide a fall or slope to the roof surface to drain water to the necessary outlets to rainwater down pipes fixed to points of support. The choice of a means of construction to provide a fall will depend on whether the roof surface is to fall to eaves or parapet gutters or to have a fall in two directions to central outlets as illustrated in Fig. 82. The junction of falls in two directions that form a shallow valley is termed a current. The more straightforward one-direction fall can be constructed with some form of tapered lattice beam with the top boom sloping at 1 in 40 or with tapered firring pieces of wood or tapered insulation boards laid over the structure to provide the necessary falls. The two direction fall is more complicated to construct because of the need to mitre the ends of tapered firring pieces or tapered boards to form the junction of falls running at right angles to each other. A wet screed can be laid and finished with cross falls without difficulty.

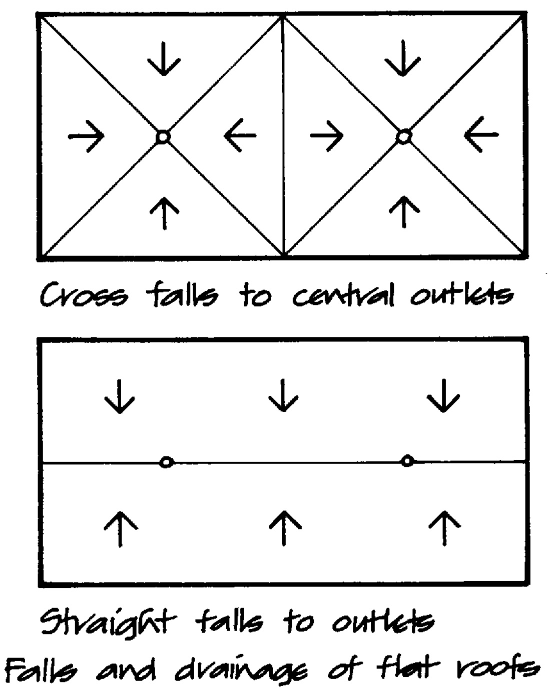


Fig. 82

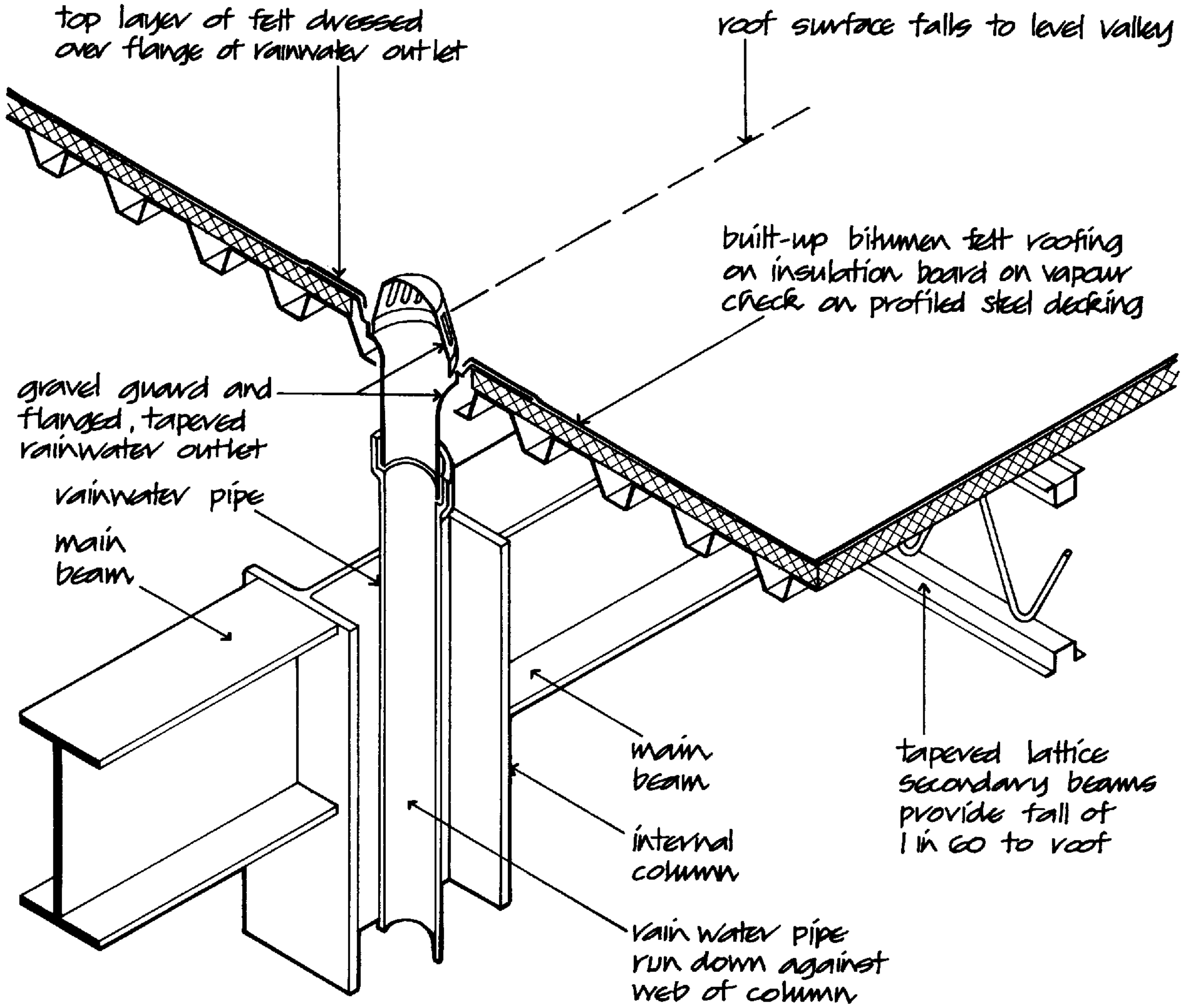
Flat roof coverings are usually designed to fall directly to rainwater outlets without the use of gutters or sumps formed below the surface of the roof. The run-off of water from a flat roof is comparatively slow and regular and there is no advantage in the use of gutters or sumps to accelerate the flow of water and considerable disadvantage in the construction of gutters and sumps and the additional cost of joints necessary in the finishing of a roof covering around the edges of gutters and sumps.

A typical straight-fall rainwater outlet is illustrated in Fig. 83 where the roof falls in two directions to a level valley that is drained by internal outlets above points of support of the structure with the down pipes run against columns. The falls are provided by tapered lattice, secondary beams spanning between main beams.

The area of roof to be drained to rainwater outlets and the flow of water is determined by reference to maps of England showing areas of peak rainfall. The area of roof to be drained is usually based on the need to drain rainwater in periods of maximum rainfall. Calculations are commonly based on a fall of 75 mm per hour for two minutes which occurs with a frequency on average once every year in most of the more densely populated parts of the Midlands and South of England.

Insulating flat roofs

Warm roof The majority of flat roofs are constructed as a deck, laid across the members of the structural roof. The deck acts as support for the flat roof covering, below which a layer of some insulating material is laid. Because the insulation is above the deck, this form of roof construction is described as a 'warm roof' as the deck is insulated from the outside and will, therefore, tend to be maintained at the same temperature as the heated inside of buildings and be much less vulnerable to condensation than it would be were the insulation below the deck. The warm roof form of construction is



Rain water outlet in built-up bitumen felt roof

Fig. 83

of particular advantage where profiled steel decking is used as the support for the roof surface, as the insulation above the deck greatly reduces the likelihood of warm moist air from the inside condensing on the surface of the metal deck. The disadvantage of the warm roof is that the insulation under the roof covering will increase the temperature differences of the covering between day and night and so increases elongation stress and fatigue of the covering.

Ventilation Approved Document F, which gives practical guidance to meeting the requirements from Part F of Schedule 1 to the Building Regulations 1991, states that the requirements will be met if condensation in a roof and in the space above insulated ceilings is limited so that under normal conditions:

(a) The thermal performance of the insulating materials and
(b) The structural performance of the roof construction will not be substantially and permanently reduced.

The Approved Document states that it is not necessary to ventilate warm deck roofs or inverted roofs where the moisture from the building cannot permeate the insulation, and the requirements will be met by ventilation of cold deck roofs where the moisture from the building can permeate the insulation.

The effect of this guidance is that warm deck roofs may need a vapour check below the insulation layer where the vapour pressure drive from inside warm air to outside colder air may cause moisture vapour to penetrate the insulation. Cold deck roofs require cross-ventilation of the space above insulation and below the roof covering as illustrated in Fig. 55.

Insulation materials The materials most used as insulation to flat roofs are in the form of rigid boards that are laid over the structural deck of warm roofs as support for the roof covering. Mineral fibre materials in the form of wood wool and glass fibre quilts and mats are used at ceiling level laid over and supported by the ceiling finish in cold roof forms of construction.

The board materials most used are vegetable wood fibre softboards for economy and cork boards, plastic foam, polystyrene bead and extruded boards, rigid urethane (PUR) and phenolc (PIR) boards.

Materials for flat roof coverings

Mastic asphalt Asphalt is one of the traditional materials used as a waterproof surface covering for flat roofs. The original mastic asphalt was a mixture of natural rock asphalt and natural lake asphalt.

Natural rock asphalt is mined from beds of limestone which were saturated or impregnated with asphaltic bitumen thousands of years ago. The rock, which is chocolate brown in colour, is mined in France, Switzerland, Italy and Germany. The rock is hard, and because of the bitumen with which it is impregnated, it does not as readily absorb water as ordinary limestone.

Natural lake asphalt is dredged from the bed of a dried-up lake in Trinidad. It contains a high percentage of bitumen with some water and about 36%, by weight, of finely divided clay.

Asphalt is manufactured either by crushing natural rock asphalt and mixing it with natural lake asphalt or, more usually today, by crushing natural limestone and mixing it with bitumen, or a mixture of bitumen and lake asphalt, while the two materials are sufficiently hot to run together. The heated mixture of asphalt is run into moulds in which it cools and solidifies. The British Standard specification for mastic asphalt using natural rock asphalt is BS 6577 and that for limestone aggregates is BS 6925.

The solid blocks of asphalt are heated on the building site and the hot plastic material is spread and worked into position and levelled with a wood float in two coats, breaking joint, to a finished thickness of 20. The first 10 coat is spread on a separating layer of sheathing felt that is laid on the surface of the roof without a bond to the roof deck. The purpose of this layer is to isolate the asphalt from movements that will occur in the roof structure below and also to reduce blowing of asphalt by allowing lateral escape of entrapped air and moisture that would otherwise expand and cause blow holes or blisters in the surface of the asphalt. When the top surface of the asphalt has been finished level with a wood float and the asphalt is still hot, the surface is dressed with fine sand that is spread and lightly rubbed into the surface with the float. The purpose of the sand dressing is to break up the bitumen-rich top surface and so avoid unsightly crazing of the top surface that would occur as the rich bitumen surface oxidised and crazed.

As the asphalt roof covering cools it gradually hardens to a hard, impermeable, continuous waterproof surface that will have a useful life of 20 years or more. In time the bitumen in the asphalt will become hard and brittle and will no longer be capable of resisting the inevitable movements that occur in any roof covering. It is practice to renew an asphalt roof covering about every 20 years if a watertight covering is to be maintained.

An asphalt roof covering is usually laid to a fall of at least 1 in 40 so that, allowing for deflection under load and constructional errors, there will be a minimum fall of at least 1 in 80 at any point on the roof for rainwater run-off.

There will be considerable fluctuations in the temperature of an asphalt roof surface that is dark coloured and absorbs radiant heat from the sun during the day and cools at night. To reduce temperature change it is practice to dress asphalt with light coloured stone chippings that reflect radiant heat, reduce heat loss at night and ageing fatigue. Stone chippings are bonded to asphalt with a cold applied bitumen solution.

Where an asphalt covered roof is used as balcony, terrace, promenade deck or roof garden, it is practice to add 5% to 10% of grit to the top layer of asphalt to provide a more resistant surface and to use paving grade asphalt to a thickness of 25. For roof gardens three-coat asphalt to a thickness of 30 is used where the surface is not accessible for inspection and repair.

Asphalt is most used as a roof covering on solid decks of concrete and wood wool slabs and less on lightweight decks because of the weight advantage of built-up bitumen and single ply coverings.

At upstands, parapets and curbs to rooflights an upstand skirting at least 150 high is formed in two coats of asphalt 13 thick, with a reinforcing angle fillet of asphalt as illustrated in Fig. 84. The top of the asphalt skirting is turned into a groove cut in a brick joint which is finished with mortar pointing. As an additional weathering, a non-ferrous metal flashing of lead can be dressed down over the skirting from the level of the d.p.c., built into the brick wall. Upstand skirtings to concrete are turned into a groove formed or cut in the concrete and the joint finished with a mortar pointing.

At verges of timber or concrete roofs the asphalt covering is reinforced with expanded metal lathing and run over the edge as a drip with 20 thick asphalt as illustrated in Fig. 84. Curbs to rooflights are either formed in concrete up to which an asphalt skirting is run, or a curb is formed with a pressed metal upstand with timber facing to which an asphalt skirting is formed and reinforced with expanded metal.

Rainwater outlets are usually formed over points of

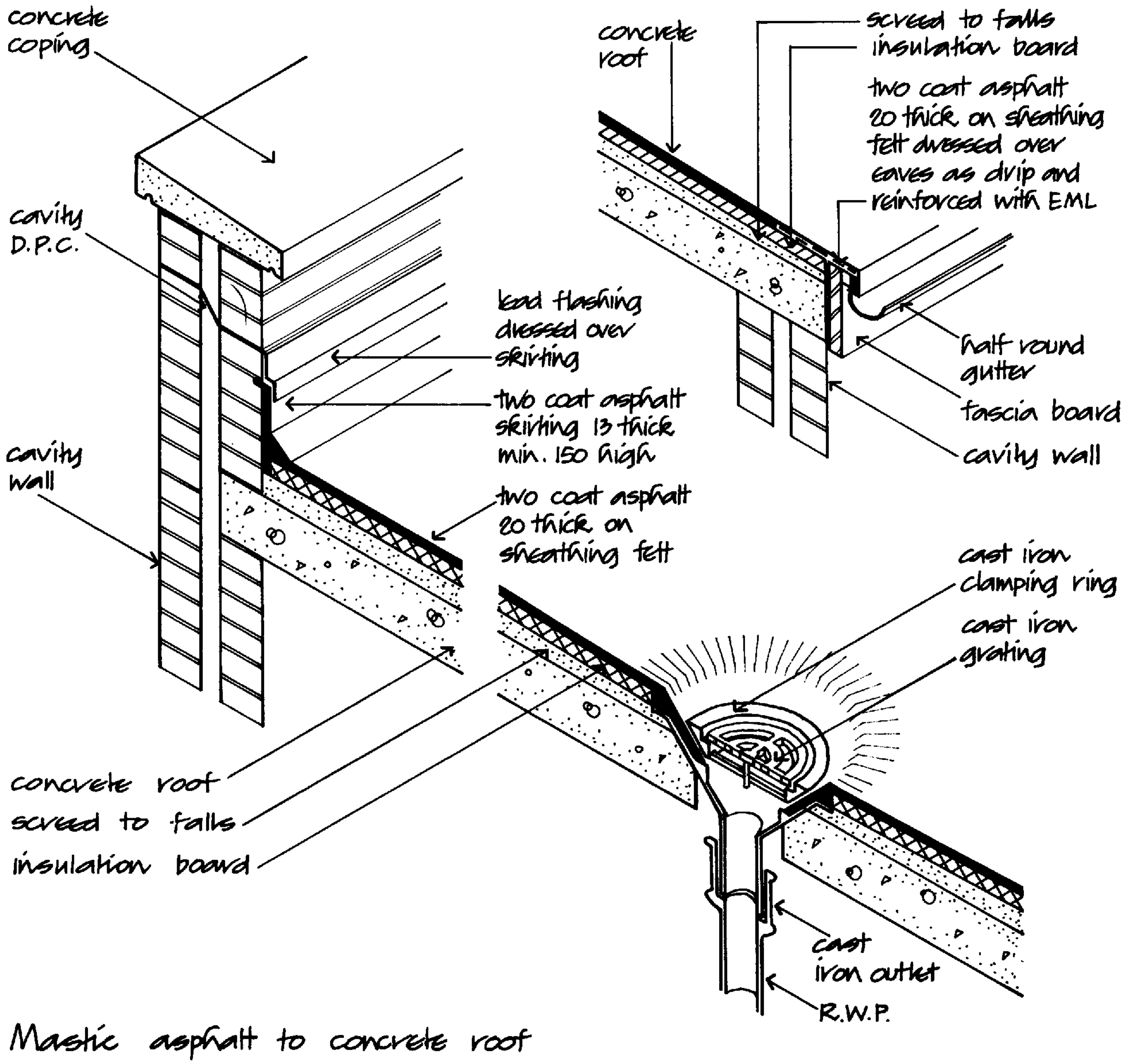


Fig. 84

support of the roof structure so that internal down pipes can be run either against or inside internal columns. The outlets may be constructed in level valleys formed by the fall of the roof. The asphalt is dressed into the rainwater outlet as illustrated in Fig. 84.

Sheet metal coverings The traditional materials that have been used as a weather covering to flat roofs are sheets of lead, copper, aluminium or zinc, laid over flat roof decks. These comparatively small sheets of thin, non-ferrous metal are lapped over and fixed to timber battens fixed to the deck down the slope or fall as illustrated in Volume 1.

The advantage of these materials, particularly lead and copper, is their durability to the extent that they may well have a useful life in excess of that of the majority of buildings. The disadvantage of these materials is that the very considerable labour required in fixing and jointing makes them a comparatively expensive roof covering.

Built-up roof coverings Built-up roof coverings of bitumen impregnated felt have been used for many years as an economic form of flat roof covering. The materials used for built-up roofing are:

Organic fibre-based felts The original felt roofing was made of sheets with a base of felted animal or vegetable fibres satured with bitumen, laid overlapping in two or three layers bonded to the roof deck and together with hot bitumen. The disadvantages of this short life roof covering are that the material is subject to rot due to the absorption of moisture, it may rupture after a few years due to the continuous strain of extension and contraction with temperature changes that are normal to exposed roofs and it has high surface spread of flame characteristics. The use of fibre-based bitumen felt as a roof covering is now confined to use as a shortlife covering for sheds and other temporary buildings.

As a substitute for organic fibre-based felt, asbestos fibre-based felt was used for its better resistance to loss of strength by water absorption and its improved resistance to damage by fire. Because of the hazards to health in the use of asbestos fibre and because of the greater tensile strength of glass fibre-based felts, asbestos fibre felt is no longer used.

Glass fibre-based felt This roof sheeting was first introduced in the 1950s. The glass tissue of this felt is composed of insoluble glass fibres held together with an adhesive. Glass fibre-based felt built-up roofing is the cheapest of the felt roofing materials used. The glass fibre-based felts, which have poor tensile strength and low fatigue endurance in resisting the strain of extension and contraction due to temperature changes, are vulnerable to mechanical and impact damage. This comparatively cheap type of roofing may be used as the first layer in built-up roofing.

High performance roofing

Polyester base roofing Since the 1960s a range of 'high performance polyester roofing' has been produced comprising a polyester fabric with bitumen coating. The high tensile strength and tear resistance of the polyester fabric gives good resistance to the strains of extension and contraction, rupturing and damage.

Two types of bitumen coating are used, oxidised bitumen (SBS) and modified bitumen (APP). The latter coating provides improved fatigue resistance and flexibility. High performance polyester-based roofing, which is more expensive than glass fibre felt, is much used as the under and top coatings to built-up roofing.

The surface of the bitumen coated sheets is coated with fine granules of mineral to prevent the sheets sticking together in the roll. The top surface of the top layer is supplied with mineral granules as a weathering finish.

Attaching built-up roofing to roof decks

Full bonding, partial bonding The first layer of built-up roof sheeting has to be attached to the roof deck surface to resist wind uplift. The method of attachment chosen depends on the nature of the surface of the roof deck. The conventional method of attaching built-up sheet coverings to a roof is by the pour and roll technique, in which hot bitumen is poured onto the deck in front of the roll of sheeting which is then continuously rolled out onto the bitumen. The two methods of bonding that are used are full bonding, where the whole of the bottom layer of sheeting is attached to the deck, and partial bonding.

Partial bonding is used on roof deck surfaces with high laminar strength, e.g. wood wool, polyurethane and polyisocyanuate which will provide adequate attachment by partial adhesion and allow some movement of the sheeting independent of the deck. Full bonding is used on surfaces of low laminar strength such as mineral fibre and expanded polystyrene.

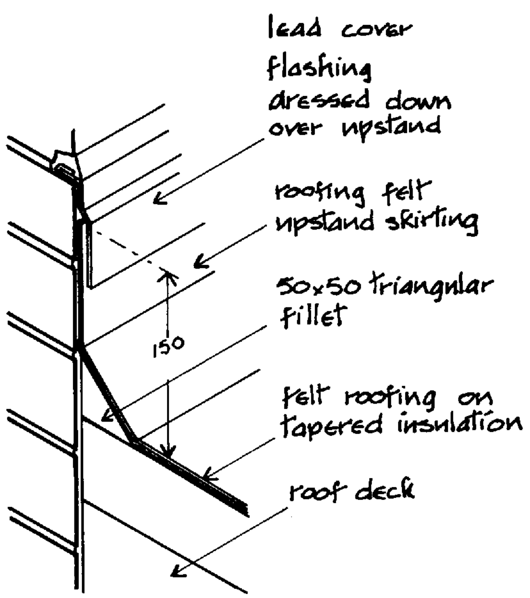
For partial bonding a first layer of perforated glass fibre underlay is laid on the deck. This layer is fully bonded to the deck around the perimeter of the roof and around openings for a width of 500 to prevent wind uplift of edges. The next layer of polyester base roofing is then fully bonded to the first layer by the pour and roll method and the third layer of polyester base sheeting is fully bonded to the second layer.

Where the fully bonded method of attachment is followed, two layers of polyester base sheeting are generally used.

Joints The joints between the sheets of roofing used in built-up roofing are overlapped 50 along the long edges of the sheets, down the slope or fall of the roof and 75 at end laps. The joints of sheets in successive layers are staggered so that there is not too great a build-up of thickness of material on the roof. The overlap joints are fully bonded in hot bitumen.

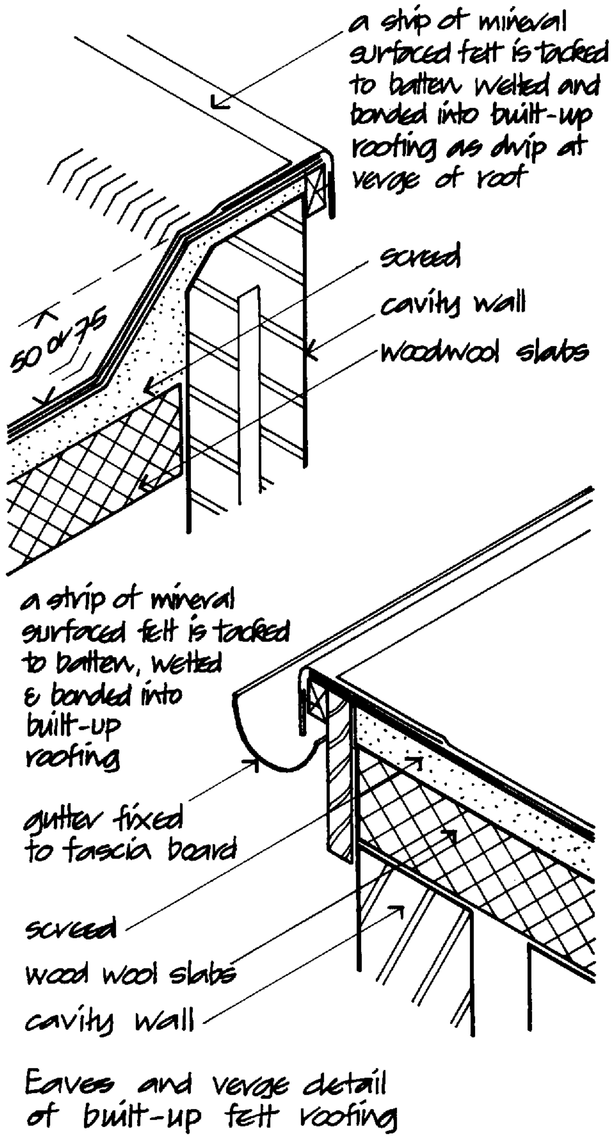
Skirtings and upstands At upstands to parapets, abutments and curbs to rooflights an upstand skirting at least 150 high is formed. To take out the sharp right-angled junction of the roof and upstand, a timber, wood fibre board or polyurethane angle fillet, 50 × 50, is fixed so that the covering is not damaged by being turned up at a right angle. The first layer of three-ply roofing is finished at the angle fillet, the next two layers in three-ply work and both layers in two-ply work are dressed up as a skirting as illustrated in Fig. 85. The top edge of the skirting is covered with a lead flashing, the top edge of which is wedged into a groove in a brick joint.

Eaves and verges At eaves and verges a welted drip is formed with a strip of mineral faced roofing. The strip of roofing is nailed to a batten or fascia board, bent to form a 75 deep drip edge and then turned onto the roof and bonded between the two top layers of sheeting as illustrated in Fig. 86. At verges an edge upstand is



Upstand skirting to abutment

Fig. 85



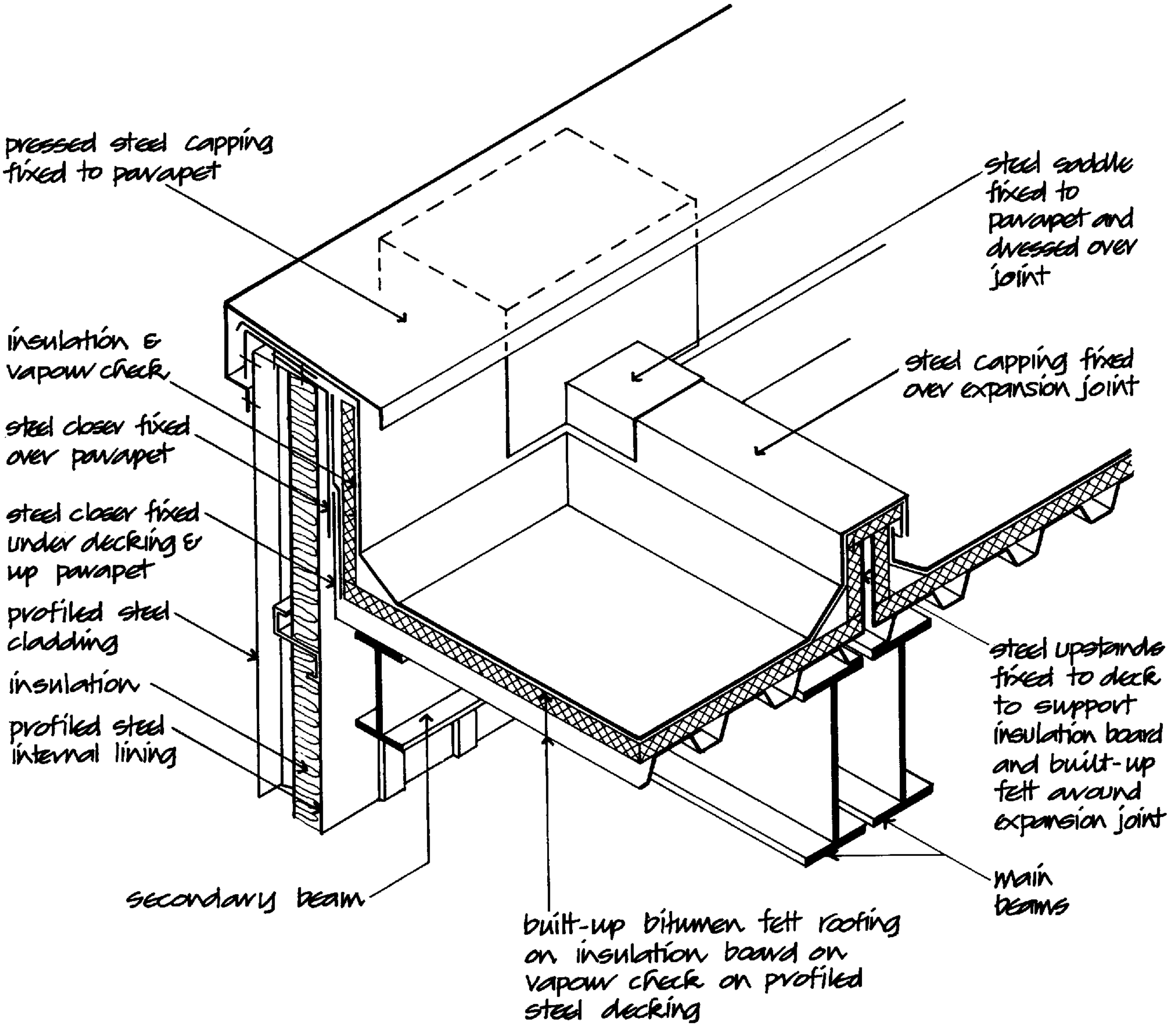
Eaves and verge detail of built-up felt roofing

Fig. 86

formed with timber or in the roof surface to prevent water running off the roof. A strip of mineral surfaced roofing is nailed to a batten or fascia board, turned up to form a welt and bonded into the two top layers of roofing as illustrated in Fig. 86.

Expansion joint Where there is an expansion joint formed in the structure to accommodate anticipated thermal, structural or moisture movements, it is necessary to make some form of upstand in the roof each side of the joint. The roofing is dressed up each side of the joint as a skirting to the upstands. A plastic coated metal capping secured with secret fixings is used as weather capping to the joint as illustrated in Fig. 87.

Torching On roofs where access is difficult for equipment for heating bitumen and also for surfacing existing coverings, it is convenient to use a felt coated with additional bitumen on one side which can be heated by a torch for adhesion to the roof surface onto which the felt is rolled either as built-up roofing on new roofs or as one layer on old roof coverings. Polyester



Parapet and Expansion joint to profiled steel decking covered with built-up bitumen felt roofing

Fig. 87

base sheeting is used for torched attached sheeting. The face of the sheeting is heated by the flame of a gas torch causing the bitumen to soften and bond to the roof as the sheet is progressively unrolled onto the roof.

Nailing The first layer of roofing of polyester or glass polyester-based sheeting is nailed to timber boarded decks with galvanised nails at 200 centres. The second and third layers are then attached by full bonding by the pour and roll method with 50 overlaps at long edges and 75 at end laps.

Single ply roofing

Since the mid 1960s a range of polymeric single ply roofing materials has been produced. Single ply roofing materials are very extensively used for flat roofing in the US and to a considerable extent in Northern Europe. These materials provide a tough, flexible, durable lightweight weathering membrane which is able to accommodate thermal movements without fatigue. To take the maximum advantage of the flexibility and elasticity of these membranes the material should be loose laid over roofs so that it is free to expand and contract independently of the roof deck. To resist wind uplift the membrane is held down either by loose ballast, a system of mechanical fasteners or adhesives.

The materials used in the manufacture of single ply membranes may be grouped as thermoplastic, plastic elastic and elastomeric.

Thermoplastic These materials include:

PVC Polyvinylchloride is a tough material with good flexibility, resistance to fire and oil damage that can be solvent or heat welded.

CPE Chlorinated polyethylene is a tough material with good flexibility and resistance to fire and oil that can be solvent or heat welded.

CSM Chlorosulphonated polyethylene is similar to CPE except that the material on exposure to solar radiation stiffens to produce greater toughness and elasticity. It can be solvent or heat welded.

VET Vinyl ethylene terpolymer is a mixture of ethyl vinyl acetate, terpolymer and PVC which has long term flexibility, good flame and spread resistance and can be solvent or heat welded.

Plastic elastic These materials include:

PIB Polyisobutylene has good resistance to chemicals and oxidation, flexibility and can be solvent or heat welded.

IIR Butyl rubber is highly elastic, does not heat soften but is susceptible to exposure to ozone. It cannot be heat welded and is jointed with adhesive.

Elastomeric EPDM – Ethylene propylene diene monomer – materials are flexible and elastic with good resistance to oxidation, ozone and ultraviolet degradation. Such materials are jointed with adhesives.

These single-ply materials are impermeable to water, moderately permeable to moisture vapour, flexible and maintain their useful characteristics over a wider range of temperatures than the materials used for built-up roofing. To enhance tear resistance and strength, these materials may be reinforced with polyester or glass fibre fabric.

The cheapest and most used material, PVC, is made in sheet thicknesses of 1.2 mm to 1.5 mm.

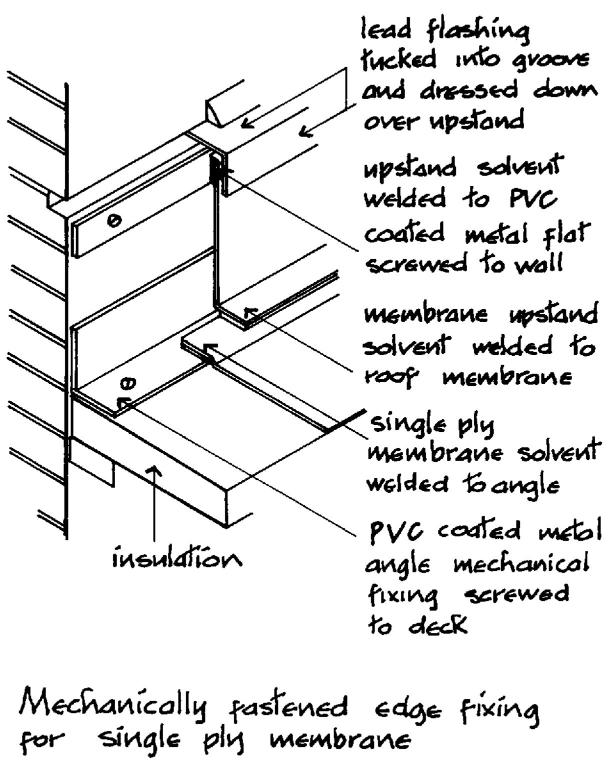


Fig. 88

Jointing single-ply membranes The joints between the sheets of the membrane are sealed either by solvent or hot air welding the 50 minimum overlap between thermoplastic sheets or by adhesive for elastomeric sheets. Solvent welding is the method most used for thermoplastic sheets. As the solvent is spread between the sheets, pressure is applied to the joint by dragging a sand-filled bag over the top of the joint. As the solvent evaporates to air, the edges of the two sheets at the overlap become welded together to make a watertight joint.

Hot air welding is mainly used to make joints at corners and upstands where a solvent welded joint might be difficult to make. The heated nozzle of the welding machine is inserted into and run along the joint. As the material softens, pressure is applied over the seam with a silicon rubber roller to make firm contact of the two sheet edges to form a watertight joint. The 50 overlap joint between elastomeric sheet membrane is made watertight by the application of adhesive and tapes that bond and seal the joints.

Laying single-ply membranes The three systems of laying single-ply membranes are:

(1) loose laid membrane
(2) loose laid ballasted
(3) adhered.

Loose laid membranes, which allow maximum

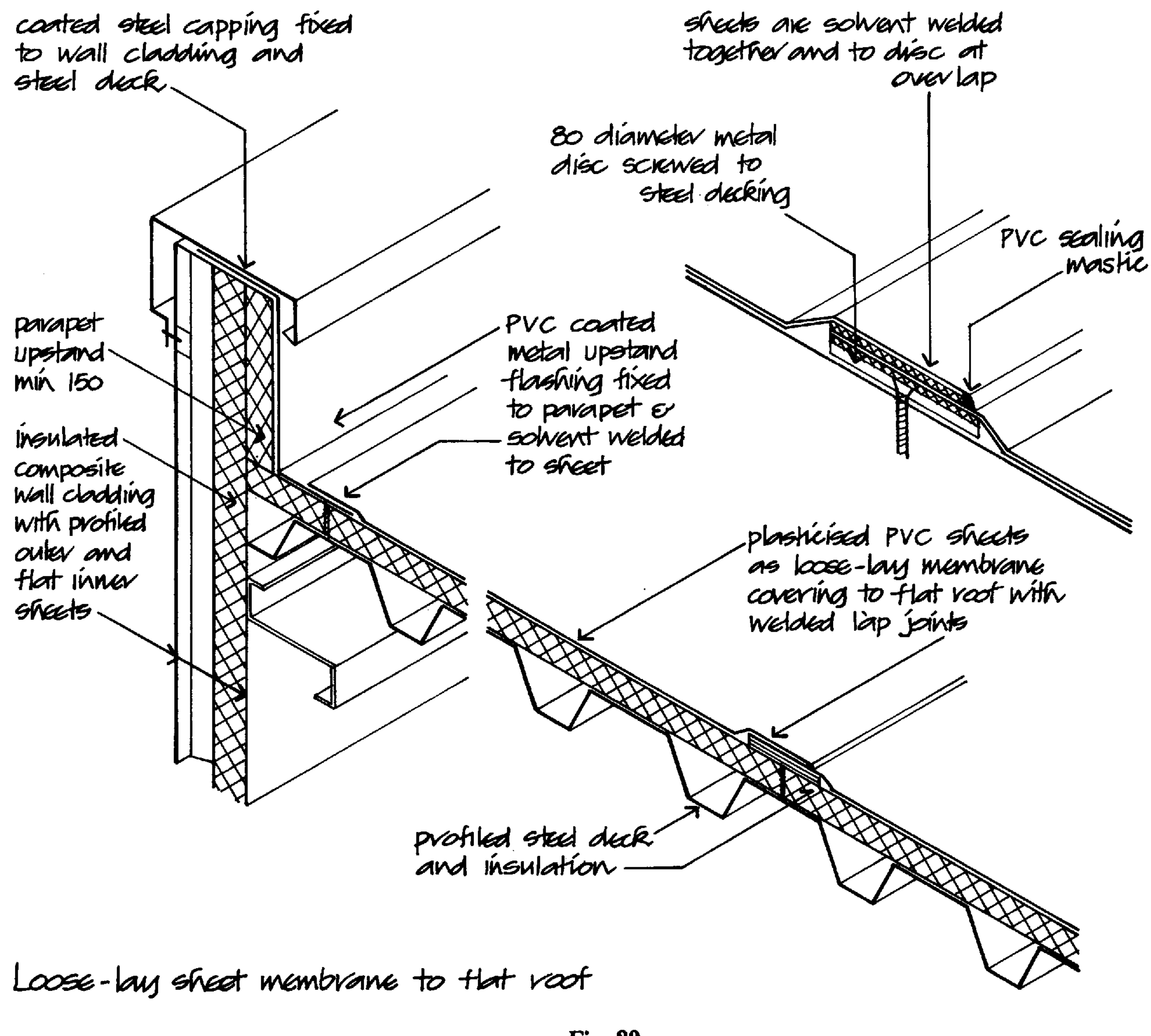


Fig. 89

freedom of movement of the membrane independent of the roof deck, have to be mechanically fastened, both with edge fasteners and fasteners at joints between sheets to provide restraint against wind uplift of this comparatively lightweight material.

Loose laid ballasted membranes employ ballast to weight down the membrane against wind uplift.

Membranes are adhered to the deck or roof against wind uplift where a system of fasteners or ballasting cannot be used.

Mechanical fasteners Both loose laid and loose laid ballasted systems of laying single-ply membranes employ mechanical fasteners to the periphery of the roof and around penetrations of roof covering against wind suction uplift. These fasteners are formed from PVC coated metal angles and flats that are screwed to the deck and upstands. The single-ply membrane is solvent-welded to the fasteners to mechanically secure the membrane against wind uplift as illustrated in Fig. 88. Where single-ply membranes are not ballasted against wind uplift as, for example, on lightweight metal decking that is not designed to carry the load of ballast, it is generally necessary to secure the membrane to the deck by a system of mechanical fasteners. These fasteners take the form of PVC coated metal strips screwed to the deck below the joints between the sheets or a series of flat or round disc washers. One edge of the membrane is fixed under and the other over the flats or washers and the joint between the sheets is solvent-welded or one sheet is solvent-welded to the washers and the other solvent-welded over it as illustrated in Fig. 89.

Loose laid ballasted system The loose laid membrane, which is mechanically secured at the perimeter and penetrations, is weighted with a topping of clean, round, screen size 16 to 32 ballast spread over the membrane to a thickness of at least 50, on a layer of protective fleece that is laid over the membrane. Where pedestrian traffic to the roof is allowed for, paving slabs are laid on a protective fleece over the membrane with a margin of ballast around the roof to allow for movement. With inverted roof systems the ballast or paviors are laid on a filter layer on the insulation that is laid over the single play membrane.

Figure 90 is an illustration of a ballasted membrane to an inverted roof.

Adhered system On sloping and curved roof structures where ballasted or mechanically fastened membranes may not be either practical or effective, it is necessary to secure the single-ply membrane with partial or full bonding to the roof surface depending on the anticipated extent of wind uplift. The membrane is secured with adhesive to the roof surface and the joints are made with either solvent or heat welding.

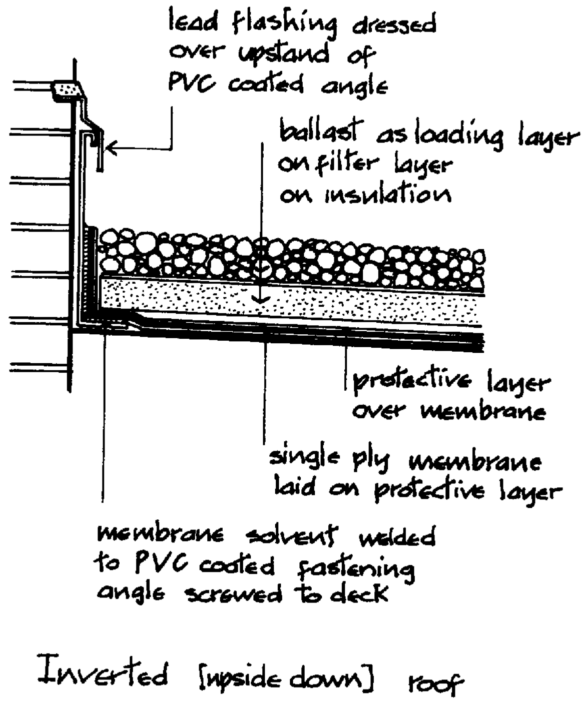


Fig. 90

CHAPTER THREE

ROOFLIGHTS

The useful penetration of daylight through windows in the walls of buildings is some 6.0 to 9.0 inside the building, depending on the level of the head of windows above floor level. It is plain, therefore, that inside a building in excess of 12.0 to 18.0 in width or length there will be areas to which a useful degree of daylight will not penetrate through windows in walls. The traditional means of providing daylight penetration to the working surfaces of large single-storey buildings is through rooflights either fixed in the slope of roofs or as upstand lights in flat roofs. Usual practice was to cover the middle third of each slope of symmetrical pitch roofs and the whole of north facing slopes of north light roofs with rooflights and about a third of flat roofs with upstand rooflights. The penetration of daylight through these rooflights provided adequate natural light on working surfaces in factories and workshops for bench level, hand-operated activities.

With the very considerable increase in automated processes of manufacturing not dependent on bench level hand-controlled operations, the provision of daylight through roofs is often a disadvantage due to the variability of natural daylight and shadows cast by heavy overhead moving machinery, to the extent that artificial illumination by itself has become common in many modern factories and workshops.

The advantage of economy and convenience in the use of natural lighting from rooflights has to be balanced against the disadvantages of poor thermal and sound insulation, discomfort from glare, solar heat gain and the hazards of fire from the materials used for rooflights.

FUNCTIONAL REQUIREMENTS

The primary function of rooflights is:

Admission of daylight.

The functional requirements of rooflights as a component part of roofs are:

Strength and stability
Resistance to weather
Durability and freedom from maintenance
Fire safety
Resistance to the passage of heat
Resistance to the passage of sound
Security.

Daylight

The prime function of rooflights is to admit an adequate quantity of daylight with minimum diversity and without excessive direct view of the sky or penetration of direct sunlight. The area of rooflights chosen for single-storey buildings is a compromise between the provision of adequate daylight and the need to limit loss of heat through the lights. The ratio of the area of rooflights to floor area is up to 1 to 6 for most factory buildings with pitched roofs and up to 1 to 3 for roofs with vertical monitor lights.

The quantity of daylight that is admitted through a window or rooflight is expressed as a daylight factor. This is defined as the ratio of the daylight illumination at a point on a plane due to the light received directly or indirectly from a sky of assumed or known luminance distribution, to the illuminance on a horizontal plane due to an unobstructed hemisphere of this sky.

It has been practice for some time to determine the required area of window or rooflight from the minimum daylight factor, which is the daylight at the worst lit point on the working plane assuming that if there is adequate daylight at the worst lit point there will be adequate light at all other points. This assumption is reasonable where specific critical judgements in daylight alone, which depend on colour, contrast and detail, such as clinical judgements in a hospital, have to be made. Even though daylight at the worst lit point may be satisfactory for a specific task, the daylight in the room or area as a whole may not be entirely satisfactory. The minimum daylight factor that has been in use, which gives an indication of daylight requirements at a given point for the performance of critical tasks, does not provide a wholly satisfactory indication of the distribution of daylight in a particular room or area for a variety of activities.

In DD73.1982, which is a draft for development as a preliminary to the publication of a new Code for Daylighting, it is proposed that an average daylight factor and the uniformity ratio be adopted as a better indication of the daylight requirements more closely matching the specific requirements of distribution of illuminance and luminance in a specific room than that given by a minimum daylight factor alone. It is likely that this proposal will be accepted for inclusion in a new Code for Daylighting.

The average daylight factor may be calculated from the formula:

average daylight factor =

$$\frac{\text{total incident light flux on working plane}}{\text{outdoor illuminance} \times \text{area of working plane}}$$

The uniformity ratio, which is an indication of the diversity of daylight, is the ratio of

$$\frac{\text{minimum daylight factor}}{\text{average daylight factor}}$$

The lower the uniformity ratio the greater the diversity of illuminance, and the higher the uniformity ratio, the better the lighting.

The recommendations for average daylight factors and minimum uniformity ratios of daylight for working places given in DD73.1982 are:

- Average daylight factors on reference plane, 5 for full daylight and 2 for supplemented daylight
- Uniformity ratio, 0.7 for top lit, 0.3 for side lit with full daylight and supplemented daylight.

Glare, discomfort and disability Glare is the word used to describe the effect of excessive contrast, in a fixed direction of view, between a very bright light source and a relatively dark background light, such as the contrast of a window at the end of a dark corridor which may cause discomfort without reducing vision, or the contrast of a very bright skylight at the top of a stair which can cause disability to vision.

Both discomfort and disability glare are caused by excessive contrast and unfavourable distribution of luminance in the visual field. Discomfort glare, which is directly related to the absolute luminance irrespective of whether there is unfavourable contrast present, may occur on a bright day in a room that is comfortable on a dull day.

The discomfort glare index is an expression of subjective discomfort in relation to the luminance of windows, average luminance of interiors and the direction of the source of glare related to the normal direction of viewing. A table of glare constants is set out in DD73.1982 to limit the degree of discomfort due to glare which is generally acceptable to occupants of rooms. Rooflights should be of sufficient area to provide satisfactory daylight and be spaced to give reasonable uniformity of lighting on the working surface without excessive direct view of the sky, to minimise glare or penetration of direct sunlight and to avoid excessive solar heat gain. In pitched roofs, rooflights are usually formed in the slopes of the roof to give an area of up to one sixth of the floor area and spaced as indicated in Fig. 91 to give good uniformity and distribution of light. Rooflights in flat roofs are constructed with upstand curbs to provide an upstand to which the roof covering can be finished. The area of the lights should be up to one sixth of the floor area and spaced similar to lights in pitched roofs. Monitor rooflights with either vertical or sloping sides give reasonable uniformity and distribution of light with the spacing shown in Fig. 91. Vertical monitor lights should have an area of up to one third of the floor area to provide adequate daylight to the working plane. North light roofs, with the whole or a large part of the north facing slopes glazed, are adopted to avoid or minimise sun glare and solar heat gain. In consequence the daylight is from one direction only with less uniformity of distribution and stronger modelling than with lights in symmetrical pitch or flat roofs. The area of glazing of north lights should be up to one third of the floor area and the spacing of lights is shown in Fig. 91.

Strength and stability

The materials used for rooflights, glass and flat or profiled, transparent or translucent sheets, are used in the form of thin sheets to obtain the maximum transmission of light and for economy. Glass which has poor tensile strength requires support at the comparatively close centres of about 600 to provide adequate strength and stiffness as part of the roof covering. Plastic sheets that are profiled to match sheet metal and fibre cement roof coverings, for the sake of weathering at end and side laps, have less strength in the material of the sheets and stiffness in the depth of the profiles than steel sheets and generally require support at closer

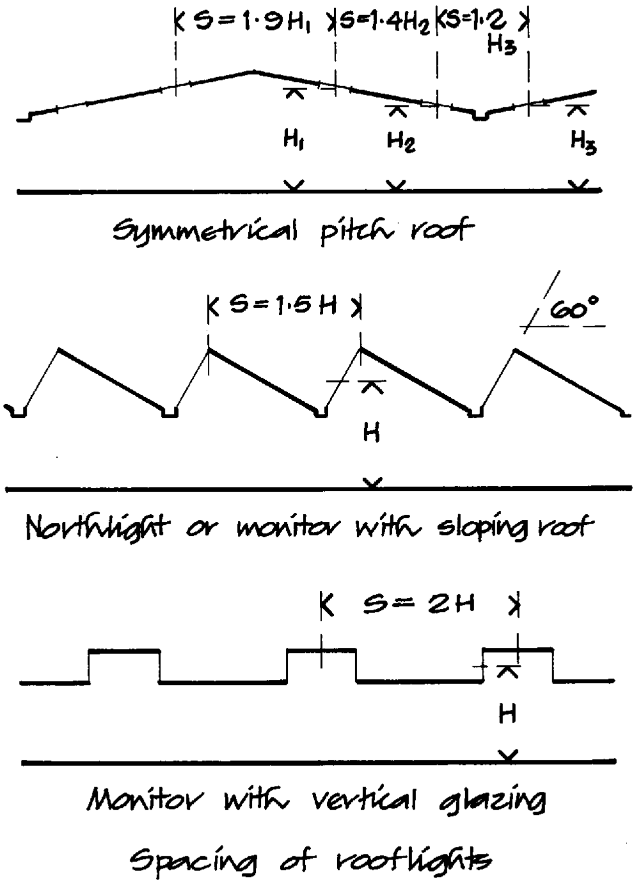


Fig. 91

centres. Plastic sheets that are extruded in the form of double and treble skin cellular flat sheets have good strength and stiffness in the nature of the material and the cellular form in which they are used.

Resistance to weather

The metal glazing bars used to provide support for glass are made with either non-ferrous flashings or plastic cappings and gaskets that fit over the glass to exclude wind and rain, together with top and bottom non-ferrous flashings to overlap and underlap profiled sheet coverings pitched at least 15° to the horizontal.

Profiled plastic sheets fixed in the slopes of pitched roofs are designed to provide an adequate side lap and sufficient end lap to give the same resistance to the penetration of wind and rain as the profiled metal cladding in which they are fixed at a pitch or slope of not less than 10° to the horizontal.

Where profiled plastic sheets are fixed as rooflights in roof slopes of less than 10° to the horizontal it is necessary to seal both side and end laps to profiled metal sheeting with either double-sided tape or a silicone sealant to exclude wind and rain.

Profiled plastic sheets fixed as rooflights in roof slopes covered with fibre cement sheets do not make a close fit to either the side or end laps to the fibre cement sheets. Because of the considerable gaps between the sheets it is difficult to form a seal to exclude wind and rain.

Cellular flat plastic sheets are fitted with metal or plastic gaskets to weather the joints between the sheets fixed down the slope of roofs and non-ferrous metal flashings at overlaps at the top and bottom of sheets.

Rooflights in flat roofs and low pitch roofs are fixed on a curb to which an upstand skirting of the roof covering is dressed to exclude wind and rain with the rooflights overlapping the curb to weather rain, with wind stops as necessary between the light and the curb.

Durability and freedom from maintenance

Unlike the plastic materials that are used in rooflights, glass does not suffer discoloration and yellowing with age and maintains its bright, lustrous, fire-glazed finish for the useful life of buildings. Because of its smooth, hard finish glass is easily cleaned by washing to maintain its bright lustrous finish. Plastic materials more readily dirt stain than glass due to the surface of these materials and cannot effectively be cleaned to return the material to its initial clean finish.

Fire safety

The requirements from Part B of Schedule 1 to the Building Regulations 1991, Fire Safety, that are relevant to rooflights are those that limit internal fire spread (linings) and those that limit external fire spread.

To limit the spread of fire over the surface of materials, the guidance to Approved Document B limits the use of materials that encourage the spread of flames across their surfaces when subject to intense radiant heat and those that give off appreciable heat when burning. The use of thermoplastic materials in rooflights and lighting diffusers is limited by reference to the classification of the lower surface of the material related to its spread of flame characteristics and by limitations to the size and disposition of rooflights and lighting diffusers related to roof or ceiling areas.

To limit the spread of fire between buildings the guidance in Approved Document B sets limits on the use of materials used in roof coverings and rooflights that may encourage the spread of fire. A minimum distance from boundaries is related to the spread of flame characteristics of materials used in roof coverings which limits the use of thermoplastic materials in rooflights. The separate limitations in the use of plastic in rooflights relates to the classification of surface spread of flame of the material to distances from boundaries and sets limits on the spacing and size of plastic rooflights.

Resistance to the passage of heat

Because the thin sheets of glass or plastic used on rooflights offer little resistance to the transfer of heat, the area of rooflights is limited. Some reduction in the transfer of heat is effected by the use of double-glazing in the form of two skins of glass or plastic sheeting and the double or triple skin, cellular flat sheets of plastic. It is plainly impractical to clean the surfaces of glass or plastic sheets inside the air space of double-glazing which may in time suffer a reduction in light transmission due to the accumulations of dust and condensation on surfaces inside the air space. Sealed double-glazing units of glass or plastic sheets will prevent this loss of light transmission.

The practical guidance given in Approved Document L to meeting the requirements of Part L of Schedule 1 to the Buildings Regulations 1991, for the conservation of fuel and power, sets limits to the maximum U value of roofs at 0.45 W/m^{2}K, and maximum areas of single-glazed areas of rooflights for all buildings other than dwellings, at 20% of roof area. In the notes of guidance to the maximum area of rooflights is a statement that where double-glazing is used, the maximum glazed area may be doubled and where double glazing is coated with low emissivity coating, and where triple-glazing is used, the maximum glazed area may be trebled.

Resistance to the passage of sound

The thin sheets of glass and plastic used in rooflights offer little resistance to the transfer of sound. Double skin glass and plastic sheet will result in minimal reduction in sound transfer. Where sound reduction is a critical requirement of a roof it is necessary to use the mass of a material such as concrete for the roof without any rooflights or with concrete lens lights.

Security

Single-storey buildings clad with lightweight metal cladding to roofs and walls are as vulnerable to forced entry through windows, doors, thin wall and roof cladding and both glass and plastic rooflights. There is little point, therefore, in seeking to secure windows and doors when the surrounding wall can as easily be broken through. Unattended buildings in isolated situations are just as likely to suffer damage by vandalism to any one of the flimsy or brittle materials of the fabric. Security against forced entry and vandalism is best achieved by reasonably secured perimeter fencing and effective day and night surveillance.

MATERIALS USED FOR ROOFLIGHTS

Before fibre cement and metal sheeting came into use the traditional material for rooflights was glass laid in continuous bays across the slopes of roofs and lapped under and over the traditional roofing materials, slate and tile, down the slope. The majority of rooflights today are of translucent profiled sheets of plastic formed to the same profile as the roof sheeting. For economy in material and simplicity of fixing, profiled translucent sheeting is extensively used instead of glass.

Glass

Glass is used in the form of flat sheets supported by metal glazing bars fixed in the slope of roofs of buildings, used as flat sheets fixed in metal frames for deck and lantern lights and shaped for use as domelights.

The types of glass used for rooflights today are float glass (see Volume 2) that is transparent and has flat, parallel, bright, fire-polished surfaces with little distortion, solar control glass to limit the admission of solar radiation, patterned glass which is textured or patterned and is translucent, and wired glass which is used to minimise the danger from broken glass during fires.

Glass has poor mechanical strength and requires the support of metal glazing bars at comparatively close centres of about 600 for use as patent glazing in the slope of roofs and as side wall glazing. The need for glazing bars to provide support for glass and the necessary flashings of caps and gaskets for weathering adds considerably to the cost of glass for rooflights. Glass affords little resistance to the transfer of heat, the U value of single-glazing being 5.7 W/m^{2}K for 6 glass. A comparatively small increase in the resistance to the transfer of heat is effected by the use of double-glazing, the U value of double-glazing being 2.8 W/m^{2}K. The thin solid material of glass offers poor resistance to the transfer of sound.

When subjected to the heat generated by fires in buildings ordinary glass quickly cracks, falls away from its support and presents a hazard to those below. It is also a poor barrier to the spread of fire within and between buildings. The wire mesh that is embedded in wired glass will hold together glass that cracks when subjected to the heat of fires and so minimise the danger from broken glass. It will also maintain the glass as a barrier to the spread of fire for a period of from a half to one hour. For these reasons wired glass is often used in rooflights. The principal advantage of glass is that as it is transparent it provides a clear undistorted view and also because it has a bright, fire-glazed finish it is easily cleaned by washing and maintains its clear lustrous finish without discolouring and yellowing with age. Glass is still used for roof and wall lights in the form of patent glazing for the sake of a clear view and its lustrous finish, compared to the translucent, dull opaque finish of the cheaper material, plastic.

Profiled, cellular and flat plastic sheets

Plastic sheet material which is transparent or translucent and can be shaped to match the profiles of metal and fibre cement sheets is extensively used as rooflights in the slopes of roofs and on flat roofs in the form of lay lights and domelights.

The materials most used for profiled sheeting are:

(1) uPVC-polyvinyl chloride – rigid PVC
uPVC is the cheapest of the translucent plastic materials used for rooflights. It has reasonable light transmittance (77%), reasonable impact and scratch resistance, adequate strength for use as a profiled sheet for roofing and good resistance to damage in handling, fixing and use. It is resistant to attack from most chemicals and has a useful life of 20 years or more. On exposure to solar radiation the material discolours to the extent that there is appreciable yellowing and reduction of light transmission after some 10 years. Due to its low softening point the material, when subjected to the temperatures generated by fires, softens but does not readily burn.

(2) GRP – glass reinforced polyester
GRP has very good impact resistance, rigidity, dimensional stability and fairly good scratch resistance. The material is translucent and has moderate to reasonable light transmittance of from 50% to 70%. GRP has very good durability and resistance to damage in handling, fixing and use. When subjected to the temperatures generated by fires GRP is usually inflammable.

The materials most used for flat sheet rooflights, laylights and domelights are:

(1) PC – polycarbonate
This material is used as extruded sheet in single, double and triple skin rooflights both in the flat sheet and the cellular forms. It has good light transmittance (up to 88%), good resistance to weathering, reasonable durability and extremely good impact resistance (for this characteristic it is sometimes referred to as 'shatterproof'). Polycarbonate is the most expensive of the plastic materials used for rooflights and is used principally for its impact resistance in situations where glass and other plastics would be damaged and for the improved resistance to transfer of heat of the double and triple skin forms.

(2) PMMA – polymethyl methacrylate
This plastic is used for shaped rooflights. It has a hard smooth finish that is particularly free from dirt staining, has excellent chemical resistance, good impact resistance and good resistance to ultraviolet radiation. The material softens and burns readily when subject to the heat generated by fires.

ROOFLIGHTS

Rooflights in pitched roofs covered with slate or tile take the form of continuous bays of glass fixed in the slope, and rooflights in pitched roofs covered with profiled sheeting take the form of bays of profiled sheeting to match the profile of the roofing. The whole or major part of north light roofs and the upstands of monitor rooflights are generally finished with glass or flat polycarbonate sheets as illustrated in Fig. 92.

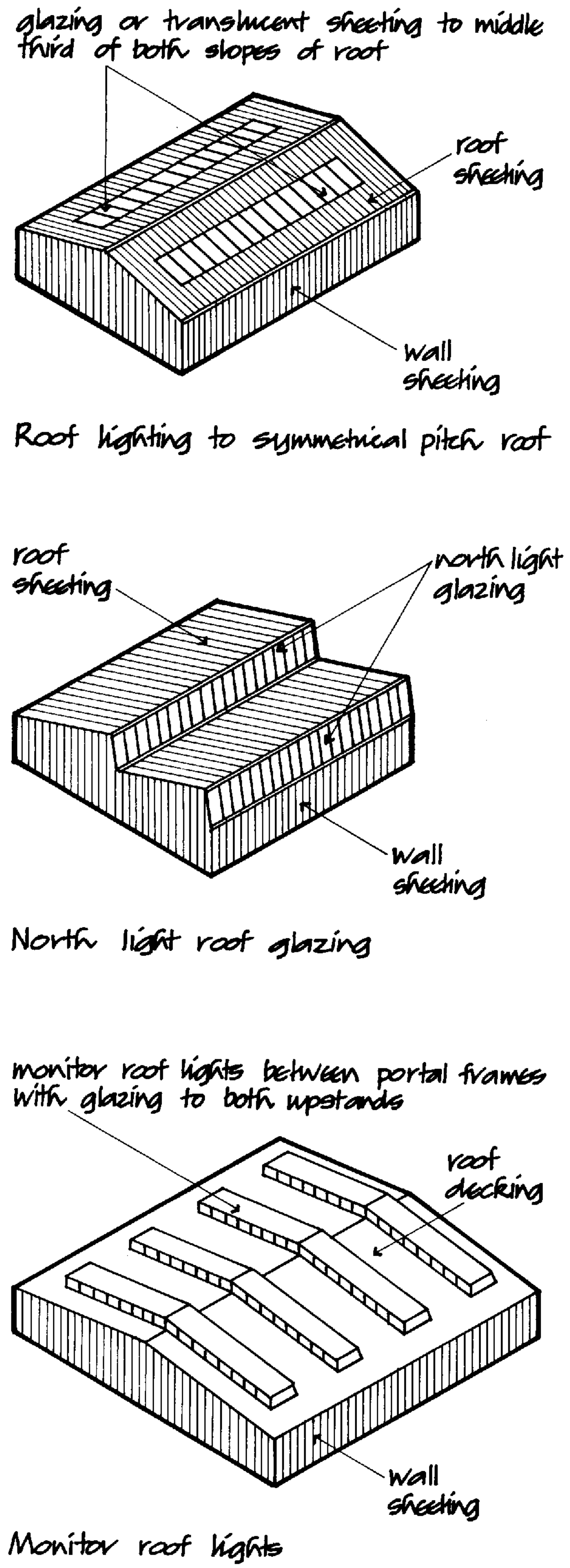
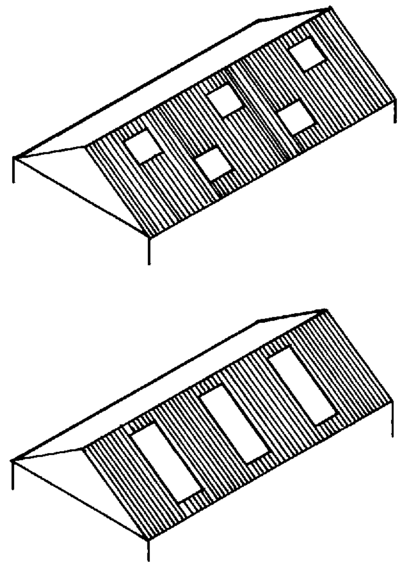


Fig. 92

The most straightforward way of constructing rooflights in pitched roofs covered with profiled sheeting is by the use of sheets of uPVC or GRP formed to match the profiles of the roof sheeting. The profile of translucent sheeting does not generally closely match the profile of metal roof sheeting so that it is impossible to achieve a close fit between the translucent and metal sheeting over wide bays of rooflights. To minimise the mismatch of profiles it is necessary to limit the width of rooflights to comparatively narrow widths, particularly on low pitch roofs where sealed end laps are required to exclude wind and rain as illustrated in Fig. 93.



Translucent sheeting fixed in narrow bays to profiled steel sheets

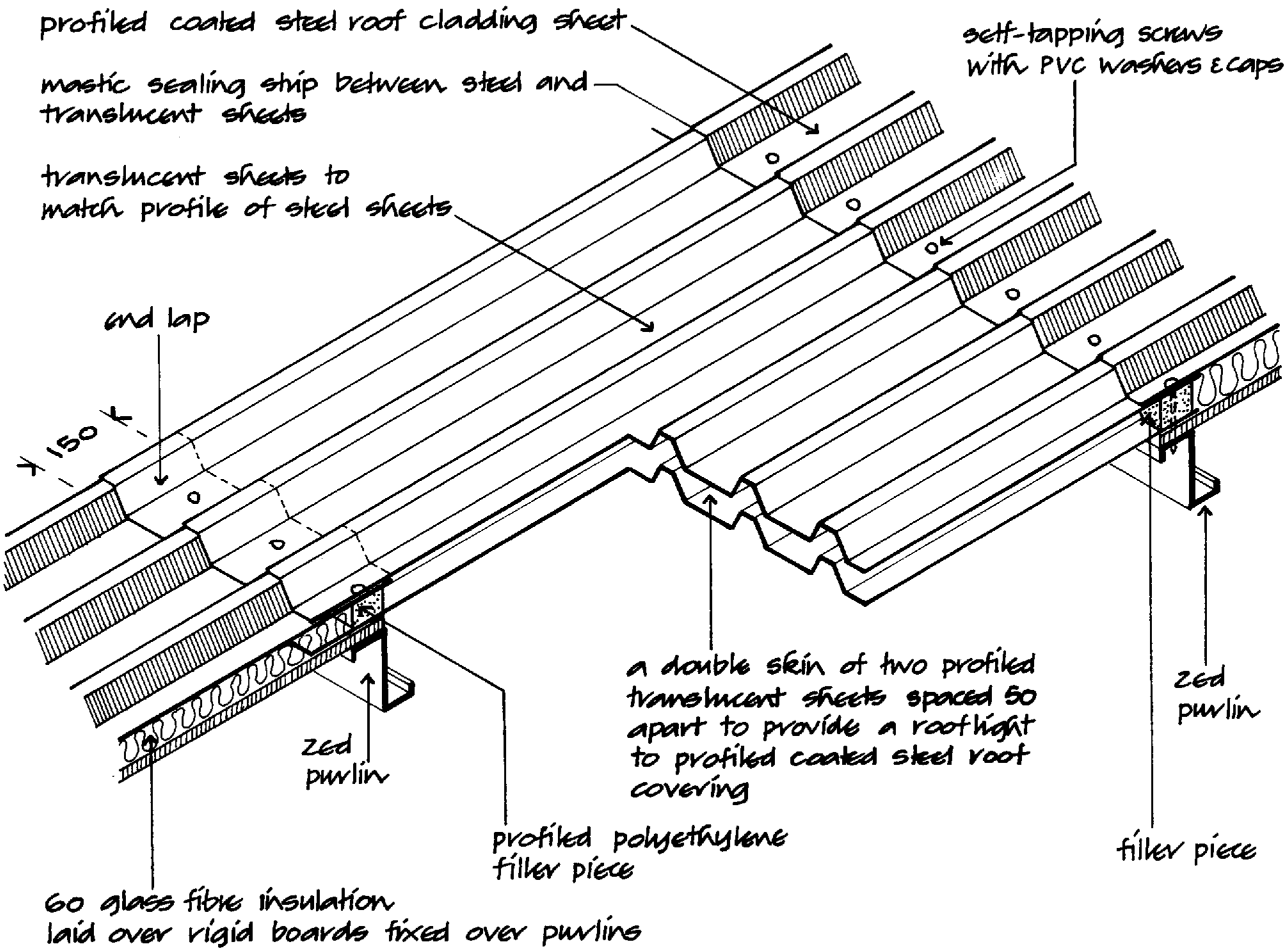
Fig. 93

Translucent glass-reinforced polyester sheets composed of thermosetting polyester resins, curing agents, light stabilisers, flame retardants and reinforcing glass fibres are roll formed in a range of profiles to match most profiled metal and fibre cement sheets. The light transmission of the clear sheets is 70%. Three grades of GRP sheet are produced to satisfy the conditions for external fire exposure and the surface spread of fires set out in the Building Regulations. The material has good strength and stability, is lightweight and shatterproof and has a life expectancy of 20 to 30 years. The sheets offer poor resistance to the transfer of heat, single skin sheets having a U value of 5.7 W/m^{2}K and double skin sheets 2.8 W/m^{2}K.

The sheets are laid to match the abutting metal or fibre cement cladding sheets with side overlaps of profiles to adjacent sheets and under and over end laps to match those of the surrounding sheeting. Sheets with a profile that is less than 35 deep should not be used on a roof pitched at less than 10° and those with profiles 35 or more deep can be laid on roofs pitched as low as 6° to the horizontal provided all laps are sealed.

All side laps between translucent sheets and between translucent sheets and metal and fibre cement sheets should be sealed with self-adhesive closed cell PVC sealing tape to make a weathertight joint. End laps between translucent sheets and between translucent sheets and metal and fibre cement sheets to roofs pitched below 20° should be sealed with beads of silicone sealant. In common with other lightweight sheeting material used for roofing, the fixing of these sheets is critical to resist uplift from wind suction which dictates the necessary centres for the fixing of fasteners. The sheets are fixed with the same type of fasteners that are used for metal or fibre cement sheeting, self-drilling and self-tapping fasteners to metal purlins or spacers and hook bolts to steel purlins with PVC washers and neoprene gaskets to make a weathertight seal. Usual practice is to secure the sheets by fasteners driven through the trough of corrugations or profiles into purlins or spacers. Stitching fasteners are driven through the crown of sheets at side and end laps.

Double skin rooflights are constructed with two skins of GRP as illustrated in Fig. 94, with two sheets of the same profile as the metal or fibre cement sheet roof covering or one to match the cladding and the lower to match the profile of lining sheets. Profiled, high density foam spacers, bedded top and bottom in silicone mastic



Roof Lights
Translucent sheets in profiled steel covered pitched roof

Fig. 94

are fitted between the sheets to maintain the air space and seal the cavity. Double-sided adhesive tape is fixed to all side laps of both top and bottom sheets as a seal. The double skin rooflight is secured with fasteners driven through the sheets and foam spacers to purlins. Stitching screws are driven through the crown of profiles at side and end laps.

Factory-formed sealed double skin GRP rooflight units are made from a profiled top sheet and a flat undersheet with a spacer and sealer.

Translucent polyvinyl chloride (uPVC) sheets are produced in a range of profiles to match most metal and fibre cement sheeting. The material has good impact resistance, reasonable strength and stability and is lightweight and shatterproof. It has a life expectancy of ten years or more because, even though the material is ultraviolet stabilised, it will gradually discolour and lose transparency to an appreciable extent. The sheets provide poor thermal insulation; the U value of single skin sheeting is 5.7 W/m^{2}K and double skin 2.7 W/m^{2}K. Because of the low softening point of the material, uPVC sheets soften but do not readily burn when subjected to the heat generated by fires.

These sheets are laid to match metal and fibre cement

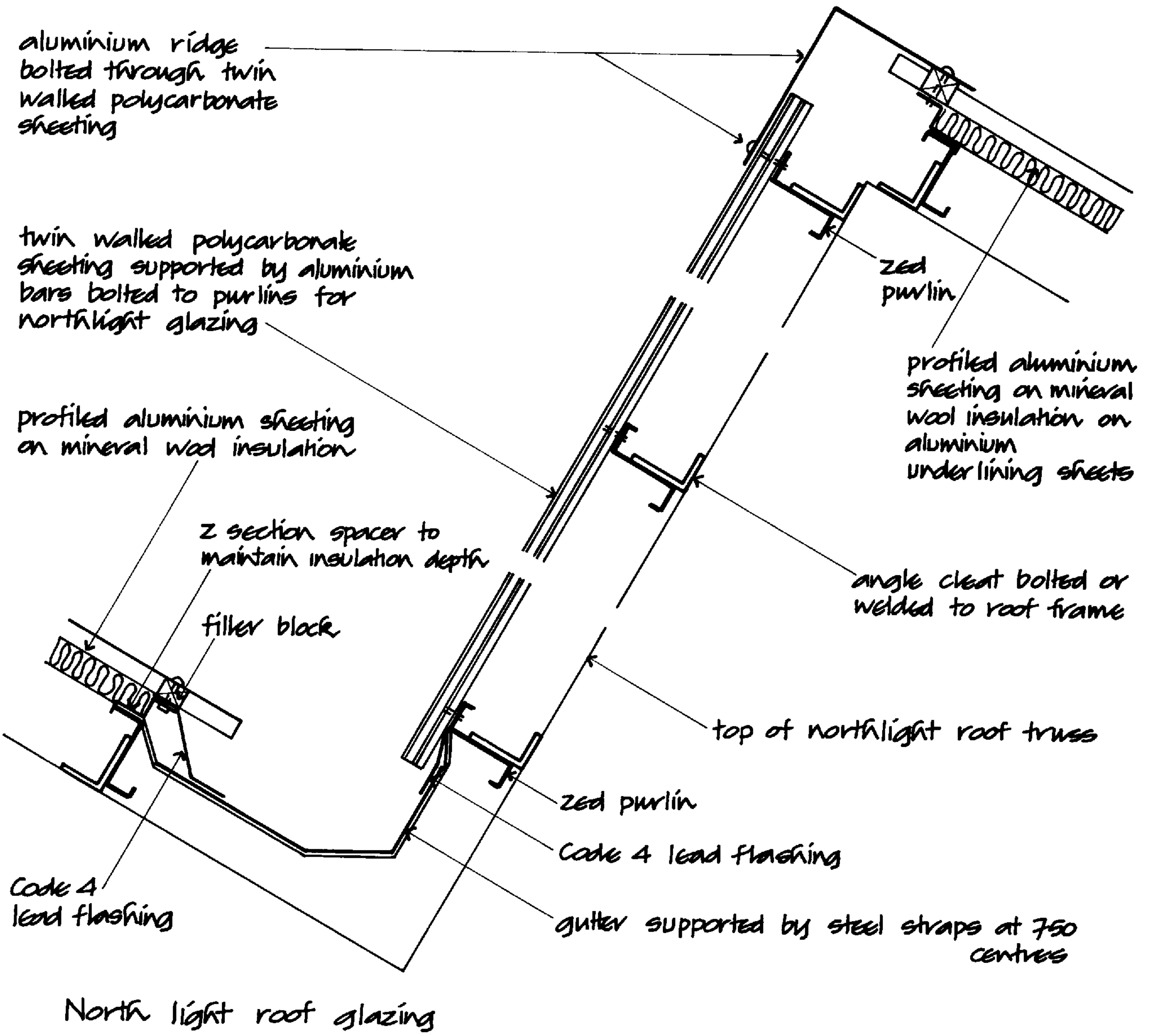


Fig. 95

roofing sheets with side laps of profiles and under and over end laps to match the laps for the abutting roof sheeting. For roof pitches of 15° and less, side and end laps should be sealed with sealing strips and all laps between uPVC sheets should be sealed.

Uplift due to wind suction dictates the necessary centres of fixing for fasteners that should be fitted to holes in the sheets that are 3 larger than the fastener to allow for the considerable thermal expansion of the material. Fasteners similar to those used for roofing sheets are used. Double skin rooflights are formed with two sheets of profiled uPVC with plastic spacers or as sealed double skin rooflights with a profiled top sheet and a flat undersheet. The details shown in Fig. 94 apply both to GRP and uPVC rooflights.

Transparent double or triple skin cellular flat sheets of polycarbonate are used for rooflights because of the extremely good impact resistance of the material. The light transmission of the clear sheet is about 80%. Because of the cellular structure, these flat sheets have good strength and stability and a U value for the double skin of 2.8 W/m^{2}K. In common with other plastic materials polycarbonate softens when subjected to the heat generated by fires. Polycarbonate sheeting is more expensive than either uPVC or GRP.

The flat cellular sheets of polycarbonate are supported by aluminium glazing bars fixed to purlins. The capping of the glazing bars compresses a neoprene gasket to the sheets to make a weathertight seal. Figure 95 is an illustration of polycarbonate sheeting used as a rooflight to the north facing slope of a roof.

Patent glazing

The traditional method of fixing glass in the slopes of roofs as rooflights is by means of wood or metal glazing bars that provide support for the glass and form weather flashings or cappings to exclude rain. The word 'patent' refers to the patents taken out by the original makers of glazing bars for rooflights. The original wood, iron and steel glazing bars have been replaced by aluminium and lead or plastic coated steel bars. The disadvantage of patent glazing is the considerable labour and expense in the provision and fixing of glazing bars at comparatively close centres and the necessary top and bottom flashings to weather the overlap with roof sheeting. The advantage of patent glazing is that glass maintains its hard, lustrous, fire-glazed finish which is easy to clean and does not discolour and so reduce light transmission during the useful life of buildings. For this reason glass is sometimes preferred as a glazing material for the roofs and walls of buildings.

Glass has poor resistance to the transfer of heat, the U value of single 6 thick glass being 5.7 W/m^{2}K and that of double-glazing 2.8 W/m^{2}K. Glass is a comparatively heavy glazing material being 15 kg/m^2 for 6 thick glass.

When subjected to the heat generated by fires, ordinary glass shatters and falls. Wired glass is used in rooflights because the wire embedded in the glass keeps it in place for some time once the glass shatters in the heat of fires, thus reducing the hazard from falling glass and maintaining the glass as a barrier to the spread of fire.

The most commonly used glazing bars are of extruded aluminium with seatings for glass, condensation channels and a deep web top flange for strength and stiffness in supporting the weight of glass. Glass is secured with clips, beads or screwed or snap-on cappings.

Figure 96 is an illustration of aluminium glazing bars used to support single sheet wired glass as rooflights in the slope of a symmetrical pitch roof. The glazing bars are secured in fixing shoes screwed or bolted to angles fixed to purlins and fitted with aluminium stops to prevent glass slipping down the slope of the roof. Aluminium spring clips, fitted to grooves in the bars, keep the glass in place and serve as weathering between the glass and the bar.

A system of steel battens and angles and an angle and a purlin provide a fixing for glass and sheeting at the overlap of the rooflight and the sheeting as illustrated in Fig. 96. Lead flashings are fixed as weathering at the overlap of glass and sheeting.

Figure 97 is an illustration of an aluminium glazing bar for single-glazing and an aluminium glazing bar for sealed double-glazing units that are secured with aluminium beads bolted to the bar and weathered with butyl strips.

Figures 98 and 99 are illustrations of aluminium glazing bars with bolted aluminium capping and snap-on aluminium to the bars. Cappings are used to secure glass in position on steep slopes and for vertical glazing as they afford a more secure fixing than spring clips and also for appearance to give more emphasis to the bars which would otherwise look somewhat insignificant.

Figures 100 and 101 are illustrations of steel bars covered with lead and PVC sheathing as a protection against corrosion. Steel bars are used for the mechanical strength of the material and the advantage of more

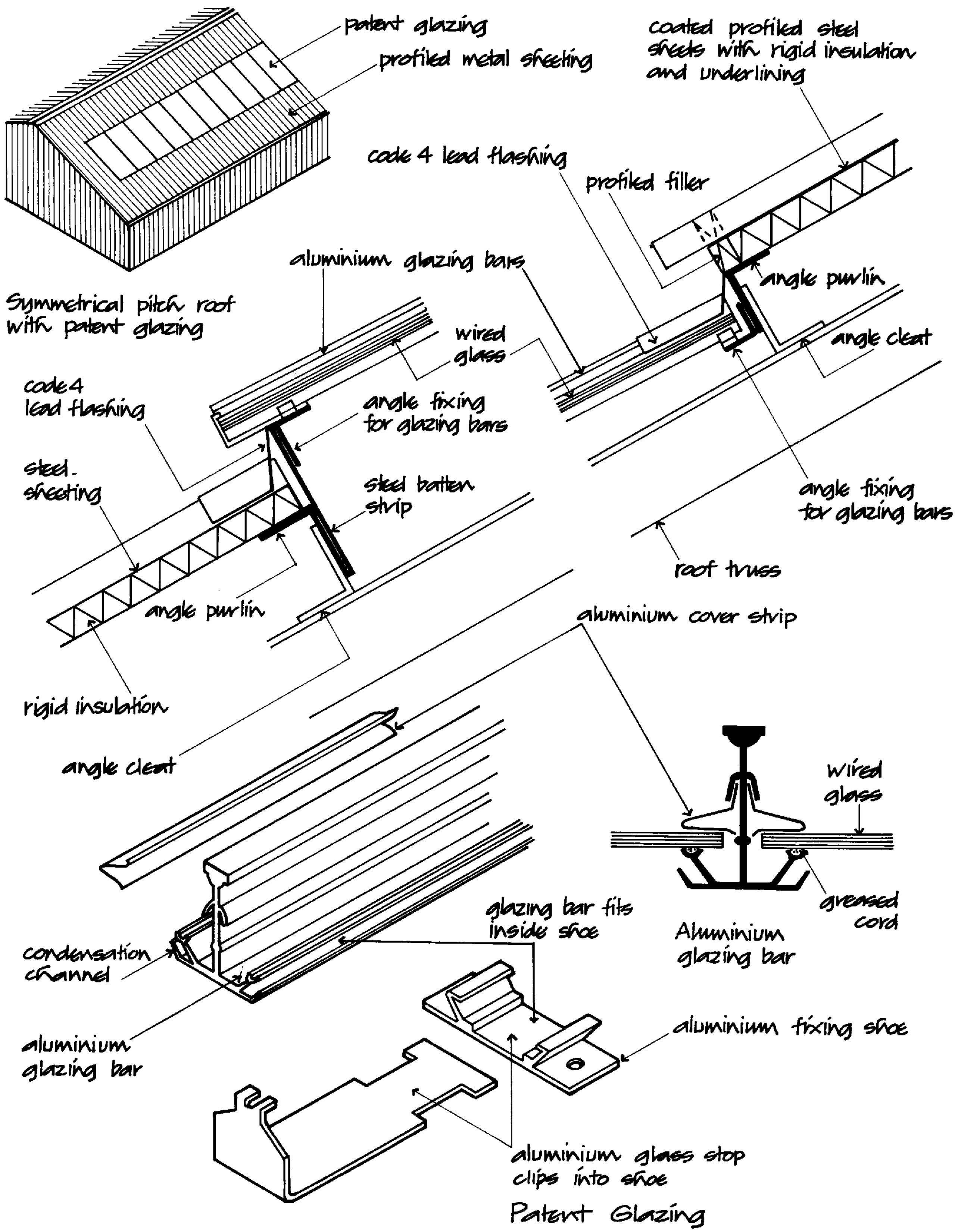

patent glazing
profiled metal sheeting
coated profiled steel sheets with rigid insulation and underlining
Symmetrical pitch roof with patent glazing
code 4 lead flashing
profiled filler
angle purlin
aluminium glazing bars
wired glass
angle cleat
code 4 lead flashing
angle fixing for glazing bars
steel sheeting
steel batten strip
angle fixing for glazing bars
roof truss
angle purlin
rigid insulation
aluminium cover strip
angle cleat
wired glass
greased cord
Aluminium glazing bar
glazing bar fits inside shoe
condensation channel
aluminium glazing bar
aluminium fixing shoe
aluminium glass stop clips into shoe
Patent Glazing

Fig. 96

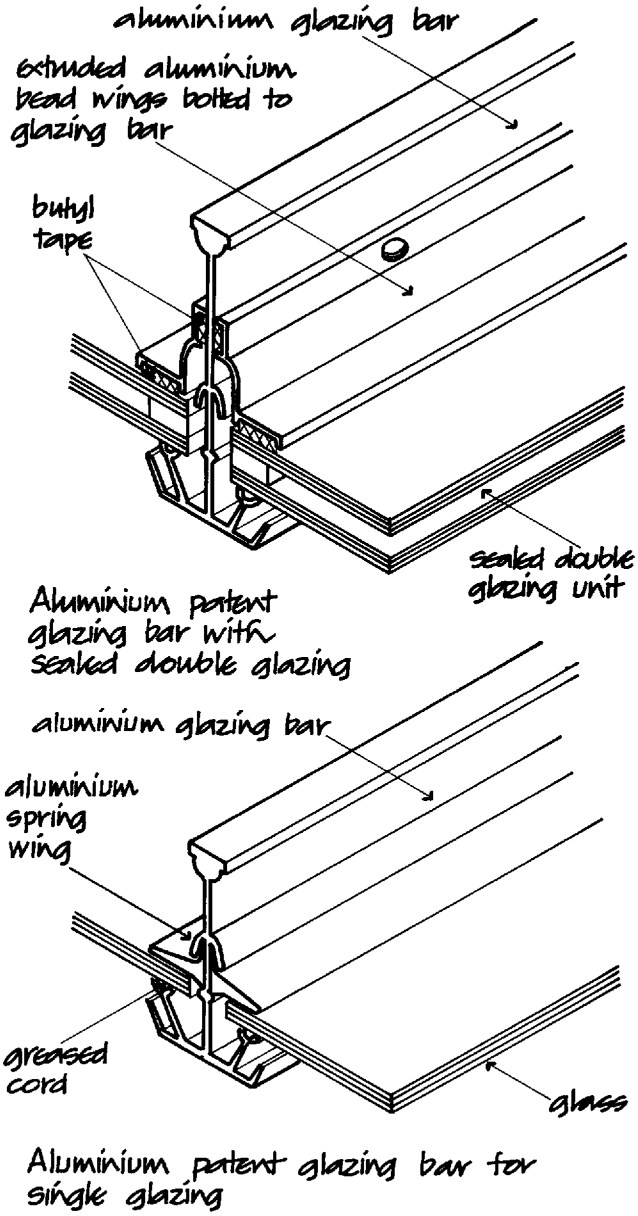


Fig. 97

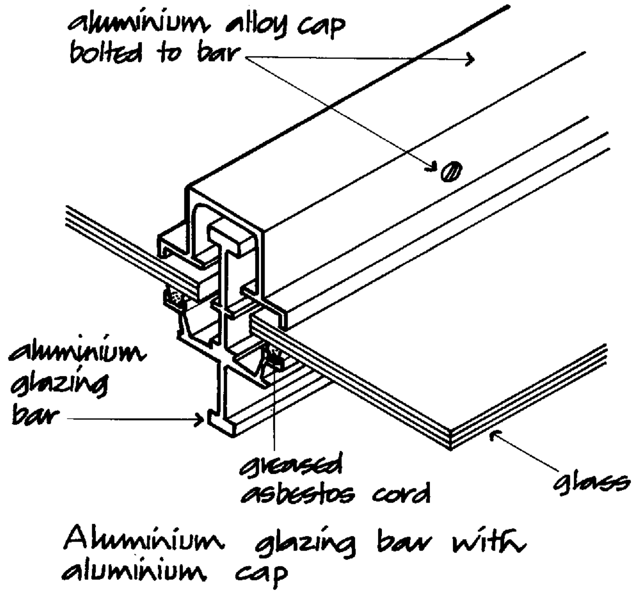


Fig. 98

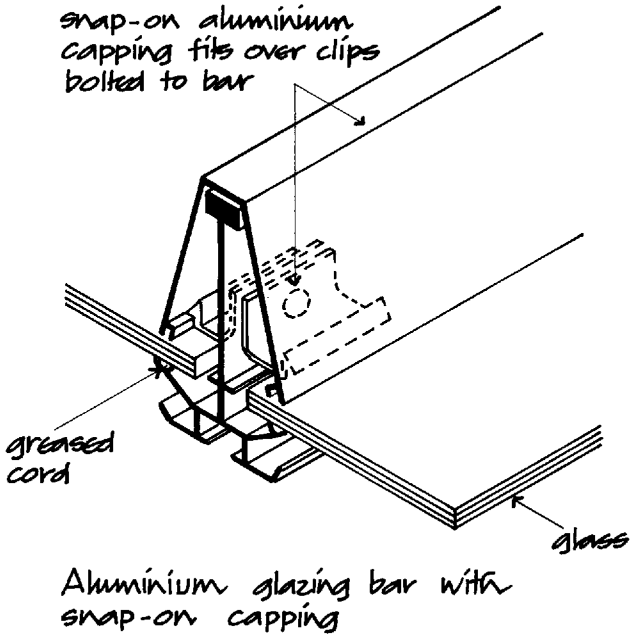


Fig. 99

widely spaced supports than is possible with aluminium bars of similar depth.

Rooflights in flat and low pitch roofs

Before the introduction of plastic and fibre glass as material for rooflights, the majority of rooflights to flat roofs were constructed as lantern lights or deck lights which were framed in timber or steel and covered with glass.

A lantern light is constructed with glazed vertical sides and a hipped or gable-ended glazed roof. The vertical sides of the lantern light are used as opening lights for ventilation as illustrated in Fig. 102. Lantern lights were often used to cover considerable areas, the light being framed with substantial timbers of iron or

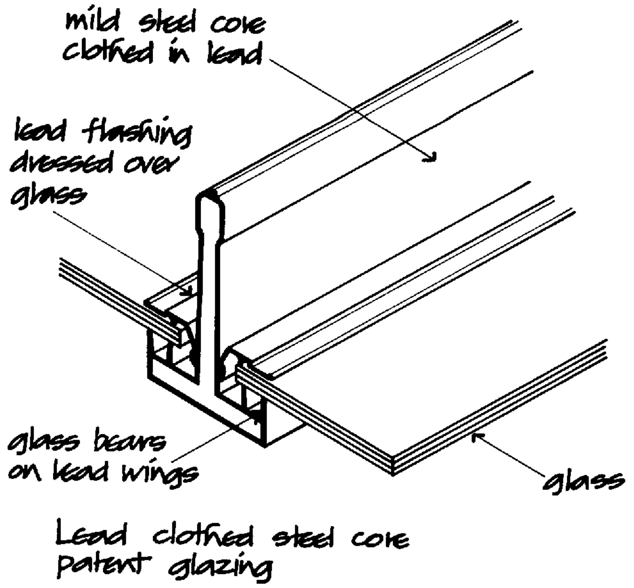


Fig. 100

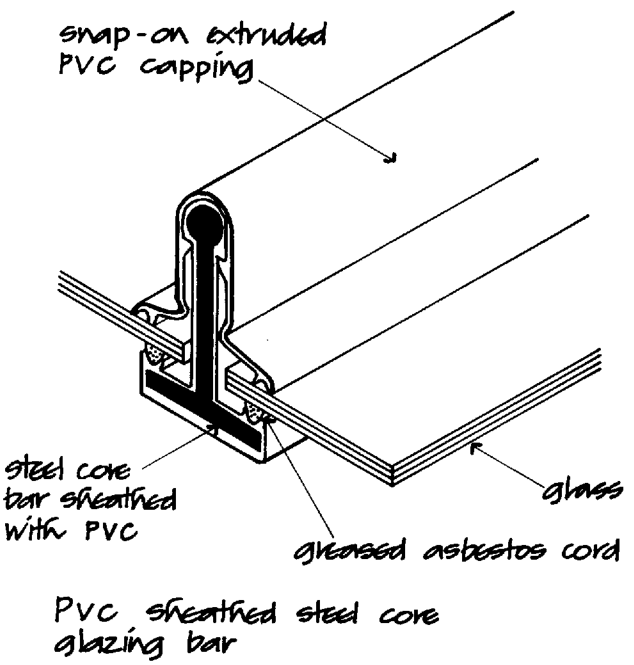


Fig. 101

steel and frames in the form of a glazed roof to provide top light to large stair-wells and large internal rooms. The traditional lantern light of timber or steel requires frequent and careful maintenance if it is to remain sound and watertight. Lantern lights have largely been

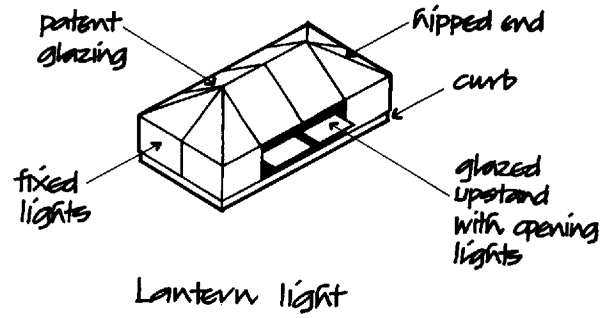


Fig. 102

replaced by domelights for economy in first cost and freedom from maintenance. The advantage of the lantern light is the facility of ventilation from the opening upstand sides that can be controlled by cord or winding gear from below to suit the occupants of the room or space.

Figure 103 is an illustration of an aluminium lantern light constructed with standard aluminium window frame and sash sections, aluminium corner posts and aluminium patent glazing to the pitched roof with an aluminium ridge section. The aluminium sections require no maintenance other than occasional washing. In common with all rooflights fixed in flat roofs, the lantern light illustrated in Fig. 103 is bolted to an upstand curb against wind uplift, to which the upstand skirting of the roof covering is dressed to a height of at least 150.

Deck lights are constructed as a hipped or gable-ended glazed roof with no upstand sides. The deck light does not provide a means of ventilation and serves solely as a rooflight as shown in Fig. 104. The deck light illustrated in Fig. 105 is constructed with lead sheathed steel glazing bars pitched and fixed to a ridge and bolted to a steel tee fixed to the upstand curb. The monopitch light, illustrated in Fig. 106, combines the simplicity of construction of a single slope for roof lighting with the advantage of one glazed upstand side for ventilation from one direction only.

The nature of the materials, glass, reinforced plastic (GRP), uPVC, acrylic and polycarbonate, facilitates the production of a range of shaped rooflights for use in flat and low pitched roofs. The disadvantage of some of the plastic materials is that they discolour and may require replacement after some ten years to restore daylight penetration.

The advantage of the square and rectangular base rooflights, illustrated in Fig. 107, is that they require

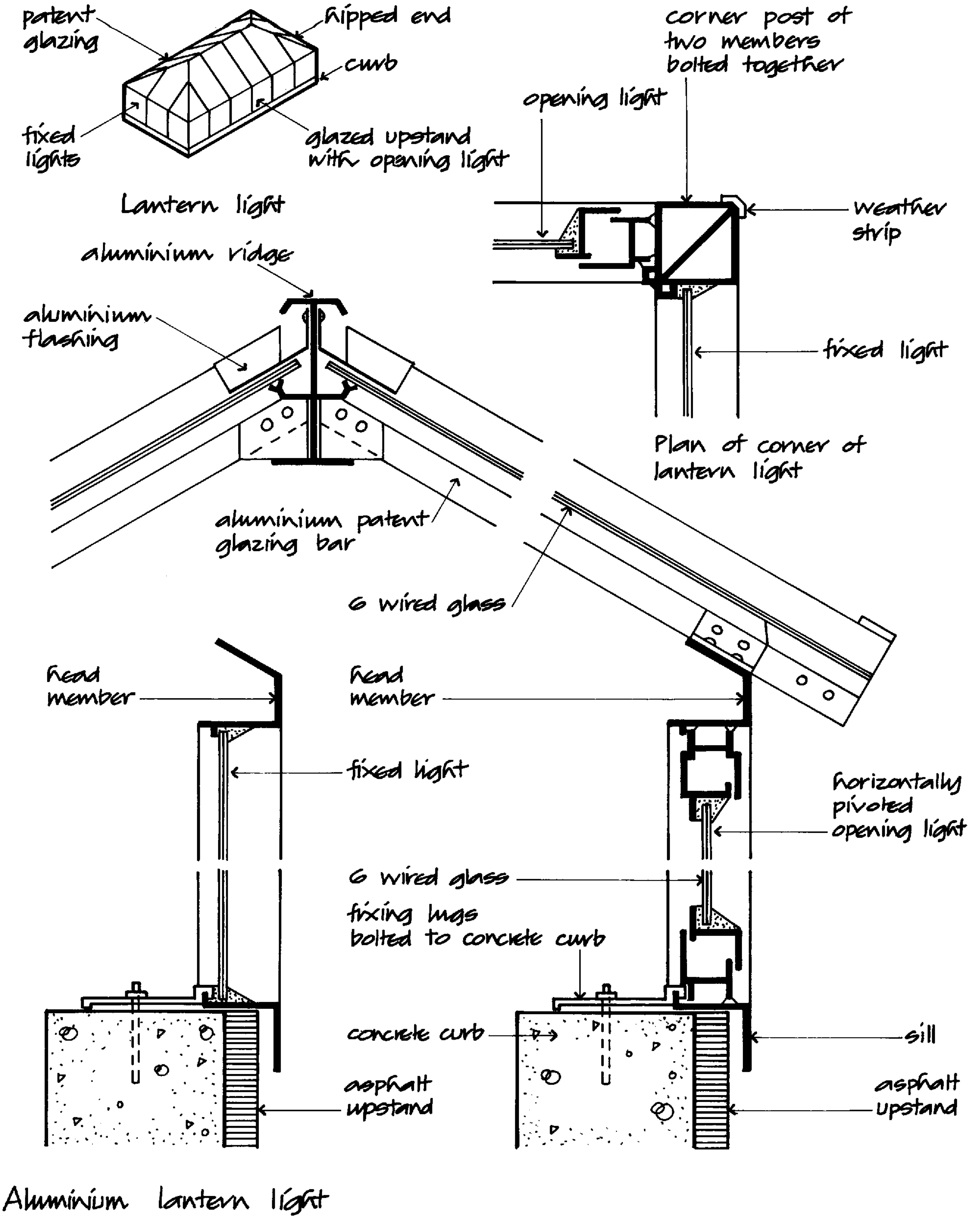

patent glazing
hipped end
curb
fixed lights
glazed upstand with opening light
Lantern light
corner post of two members bolted together
opening light
weather strip
fixed light
Plan of corner of lantern light
aluminium ridge
aluminium flashing
aluminium patent glazing bar
6 wired glass
head member
head member
fixed light
horizontally pivoted opening light
6 wired glass
fixing lugs bolted to concrete curb
concrete curb
sill
asphalt upstand
asphalt upstand
Aluminium lantern light

Fig. 103

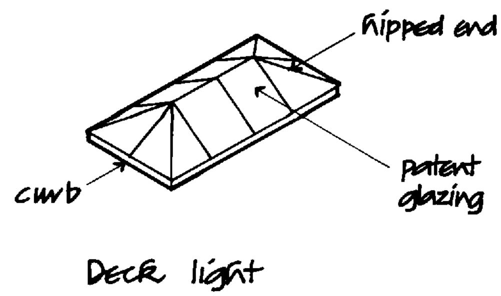


Fig. 104

straightforward trimming of the roof structure around openings and upstands and flashings to curbs as compared to the more complicated trimming and flashings required around the circular base of domelights. One of the commonly used rooflights is the rectangular base domelight illustrated in Fig. 107 which can be formed in one piece or made up in sections and joined with glazing bars to cover larger openings. The advantages of these lights are that they are economical to manufacture and fix, are lightweight and have

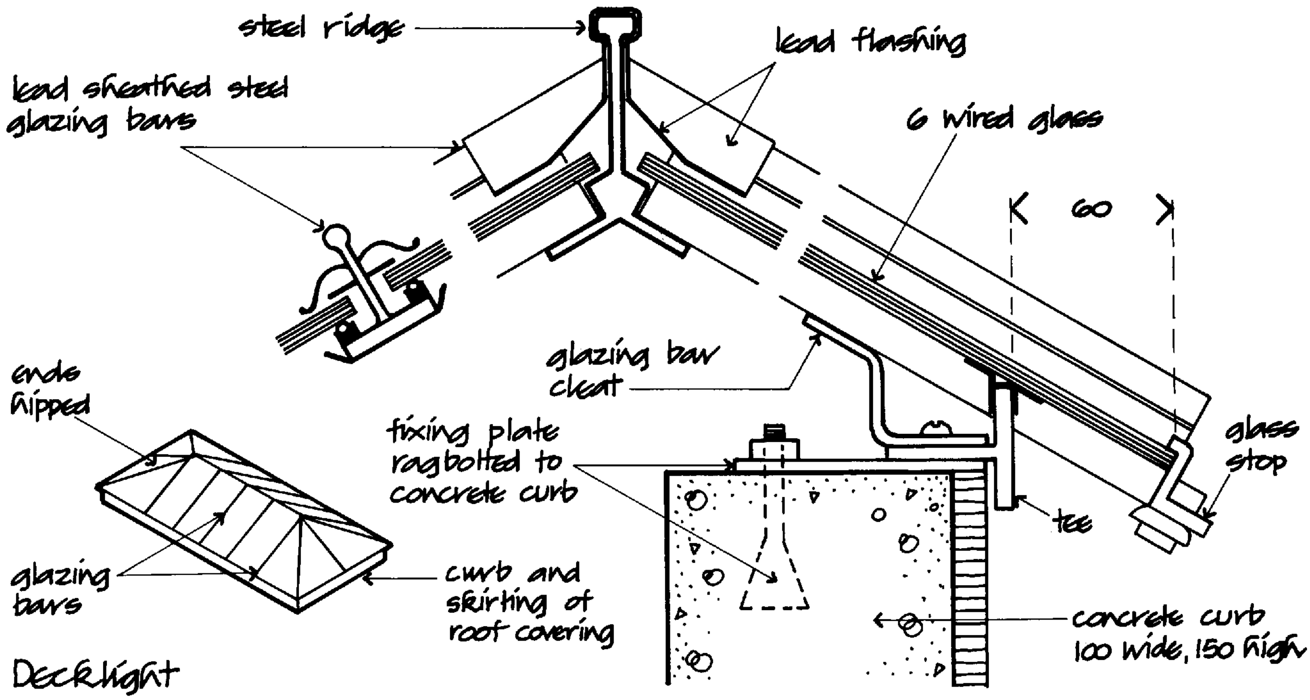


Fig. 105

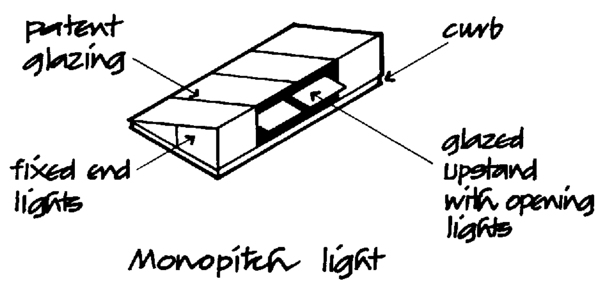


Fig. 106

adequate strength and stiffness from the curved shape of the light.

The round base domelight, shown in Fig. 107, is more expensive to construct than a square base light because of the additional labour involved in trimming a round opening in a roof.

The pyramid light, illustrated in Fig. 107, is used for appearance as the steeply pitched glazed sides afford no increase in light penetration through the opening in the roof.

Plastic rooflights are made as either single skin lights

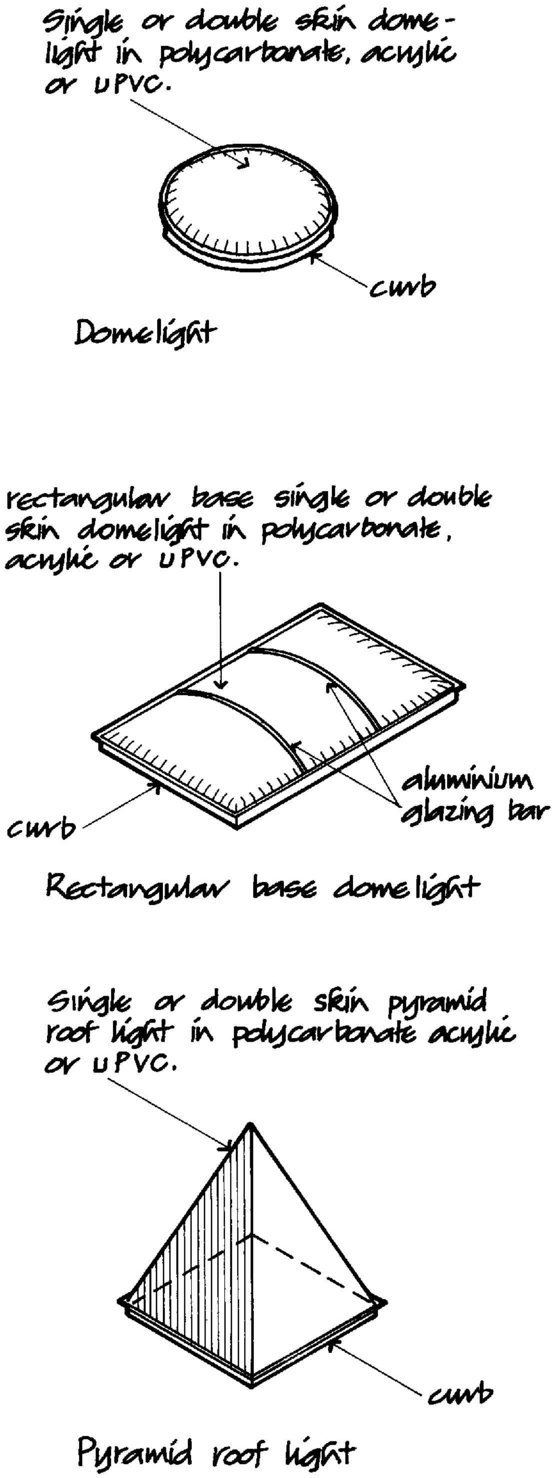


Fig. 107

or as sealed double skin lights which improves their resistance to the transfer of heat. Plastic rooflights are bolted or screwed to upstand curbs against wind uplift, formed on the roof to which an upstand skirting of the roof covering is dressed as illustrated in Fig. 108.

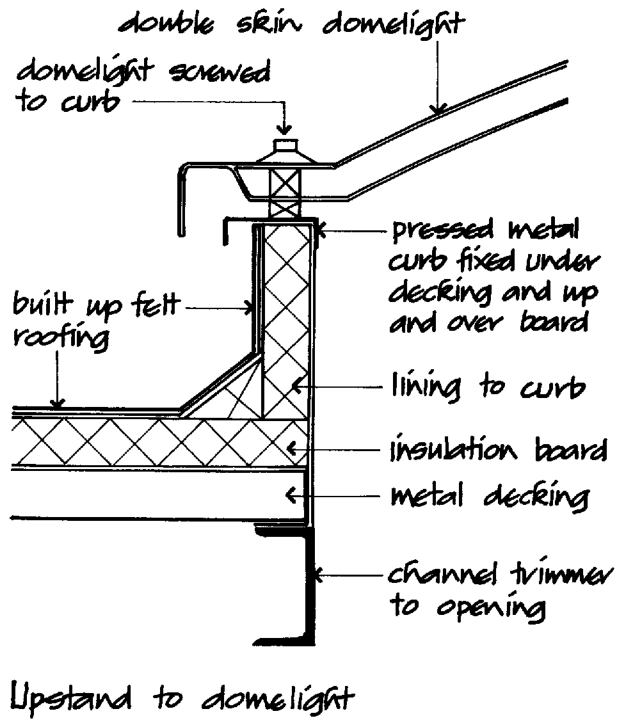


Fig. 108

Lens lights

Lens lights consist of square or round glass blocks or lenses that are cast into reinforced concrete ribs, as illustrated in Fig. 109, to provide diffused daylight through concrete roofs. The lens lights can be pre-cast and bedded in place on site or in-situ cast in a concrete roof. The daylight transmission of these lights is poor compared to other forms of rooflight. Lens lights are used in a concrete roof as rooflights to provide resistance to fire, for reasons of security and to reduce sound transmission.

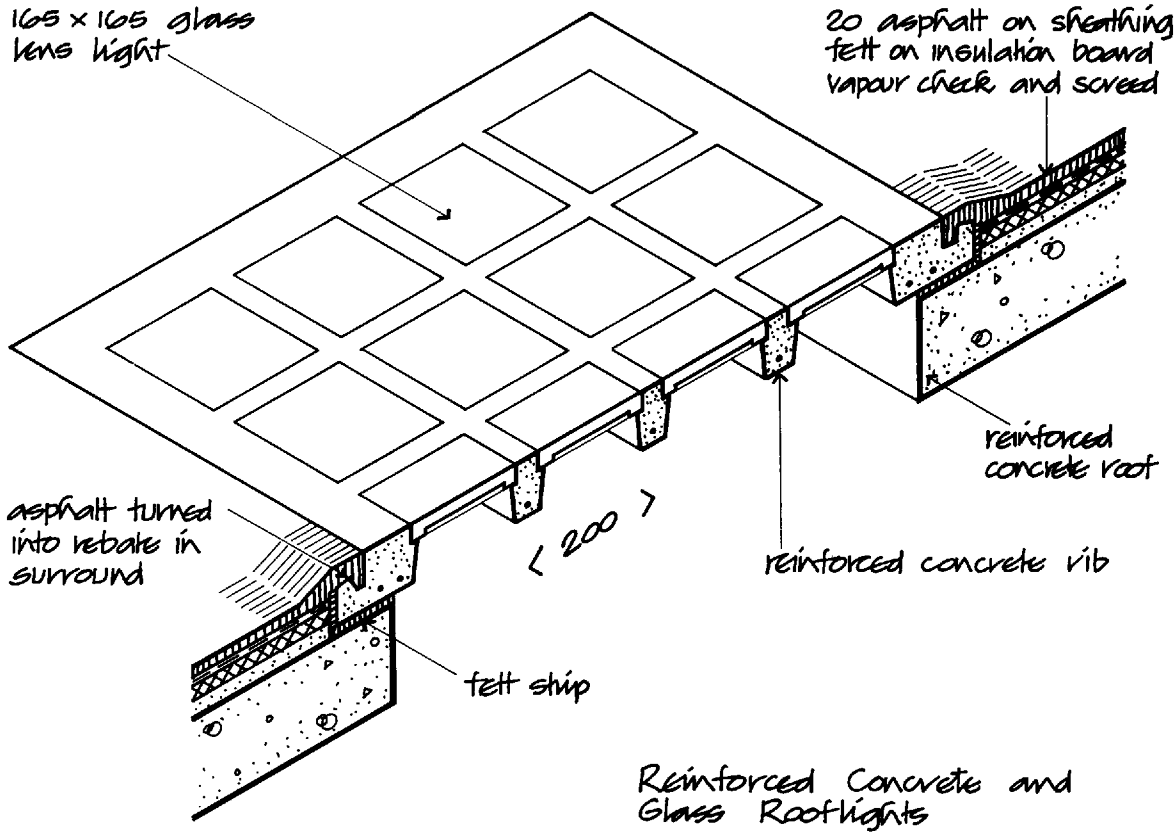

165 × 165 glass lens light
20 asphalt on sheathing felt on insulation board vapour check and screed
reinforced concrete roof
asphalt turned into rebate in surround
‹ 200 ›
reinforced concrete rib
felt strip
Reinforced Concrete and Glass Rooflights

Fig. 109

CHAPTER FOUR

DIAPHRAGM, FIN WALL AND TILT-UP CONSTRUCTION

Brickwork has for centuries been the traditional material for the walls of houses and other small buildings. A one brick thick wall of well burned bricks, bonded and laid in a mortar of the same density and porosity as the bricks, has more than adequate strength to support the comparatively small loads from the floors and roof of a house, and sufficient stability in resisting the lateral pressure of wind. The wall, either solid or more usually as a cavity wall, will resist penetration of rain, have good resistance to damage by fire, require very little maintenance and have a useful life in excess of more than 100 years.

Brickwork has good compressive strength in supporting vertical loads but poor tensile strength in resisting lateral pressure from the lateral loads of floors and roof and wind pressure. The minimum thickness of walls is prescribed in the Building Regulations by reference to the height and length of walls so that the greater the height of wall the greater the thickness the wall has to be at its base, to resist the lateral forces that tend to overturn it (see Volume 1).

A brick wall acts structurally as a vertical cantilever, rising vertically from its fixed base on the foundation so that lateral forces, such as wind, tend to cause the wall to bend. This bending is resisted by the small tensile strength of the brickwork, lateral restraint by floors and roof built into the wall and by buttressing walls and piers built into the wall (see Volume 1). The higher the wall, the greater the vertical cantilever arm of the wall and the thicker the wall needs to be at its base to resist overturning caused by lateral forces.

The majority of tall, single-storey buildings, enclosing large open areas, such as sports halls, warehouses, supermarkets and factories with walls of more than 5.0 in height were until recently built with a frame of lattice steel or a portal frame covered with steel or fibre cement sheeting, insulation and a protective inner lining. Of recent years brick diaphragm or fin walls have been increasingly used for this type of building for the economy, durability, resistance to fire and penetration of rain and thermal and sound insulation advantages of such structures.

A diaphragm wall is built with two leaves of brickwork bonded to brick cross ribs or diaphragms inside a wide cavity between the leaves so that the wall is formed of a series of stiff box or I-sections structurally as illustrated in Fig. 110.

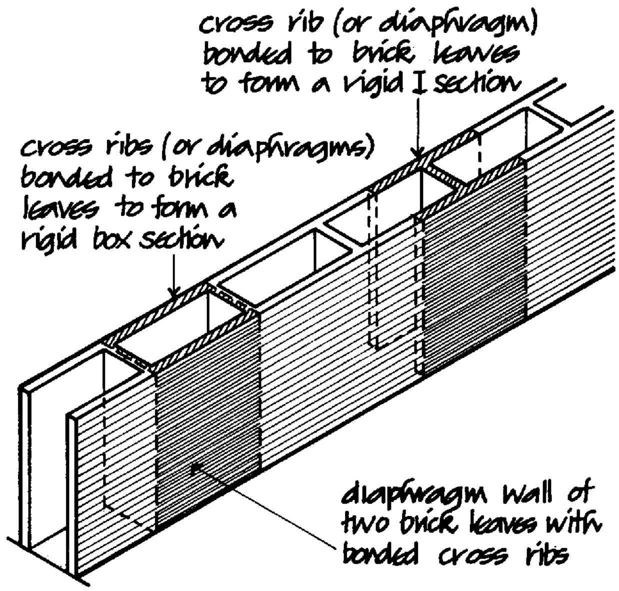


Fig. 110

A fin wall is built as a conventional cavity wall buttressed with piers or fins bonded to the external leaf of the cavity wall to buttress or stiffen the wall against overturning. A fin wall acts structurally as a series of T-sections, as illustrated in Fig. 111. The effective width of the flange of the T-section, that is the outer leaf, may be less than the centres of the fins for design calculations.

BRICK DIAPHRAGM WALLS

The economic advantage of a diaphragm wall, in comparison to a portal frame structure, increases with the height of the wall. For wall heights of up to about 5.0 there is no cost benefit in using a diaphragm wall instead of a portal frame. For wall heights of over 5.0 the diaphragm wall is an economic alternative to a

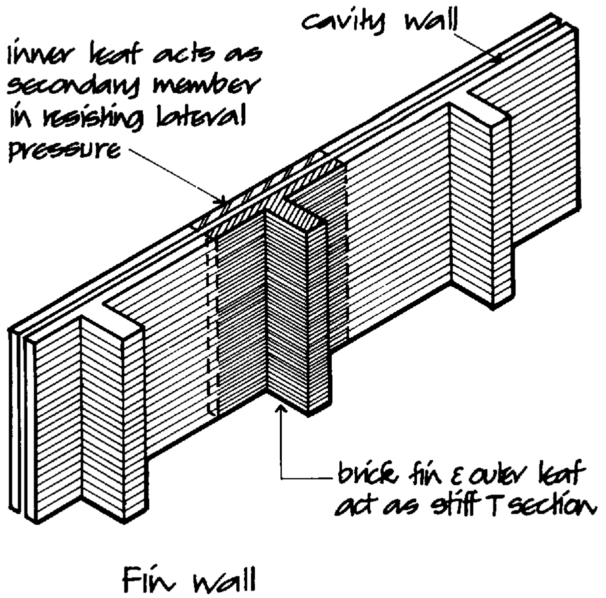


Fig. 111

portal frame structure for tall, single-storey, single-cell buildings.

Strength

The compressive strength of the bricks and mortar of a diaphragm wall is considerable in relation to the comparatively small dead load of the wall, roof and imposed loads of wind and snow.

Stability

A diaphragm wall is designed for stability through the width of the cavity and the spacing of the cross ribs to act as a series of stiff box or I-sections and by the roof which is tied to the top of the wall to act as a horizontal plate to resist lateral forces.

Construction

The width of the cavity and the spacing of the cross ribs is determined by the box or I-section required for stability and the need for economy in the use of materials by using whole bricks whenever possible. Cross ribs are usually spaced four or five whole brick lengths (with mortar joints) apart and the cavity one-and-a-half or two-and-a-half whole bricks (with mortar joints) apart so that the cross ribs can be bonded in alternate courses to the outer and inner leaves. Figure 112 is an illustration of the bonding of typical diaphragm walls. It will be seen that the stretcher bond of the leaves is broken by header faces where the cross ribs are bonded in alternate courses. The colour of the header faces of many bricks is noticeably different from that of the stretcher faces so that in a diaphragm wall where the cross ribs are bonded to the leaves there is a distinct pattern on the wall faces. This pattern can be avoided, for appearance, by bonding the cross ribs to either one or both of the leaves with metal shear ties built into the cross ribs and the leaves.

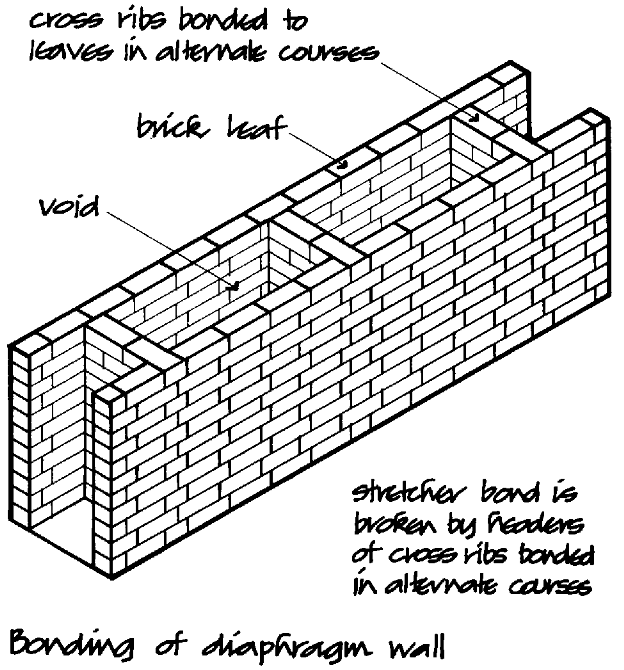
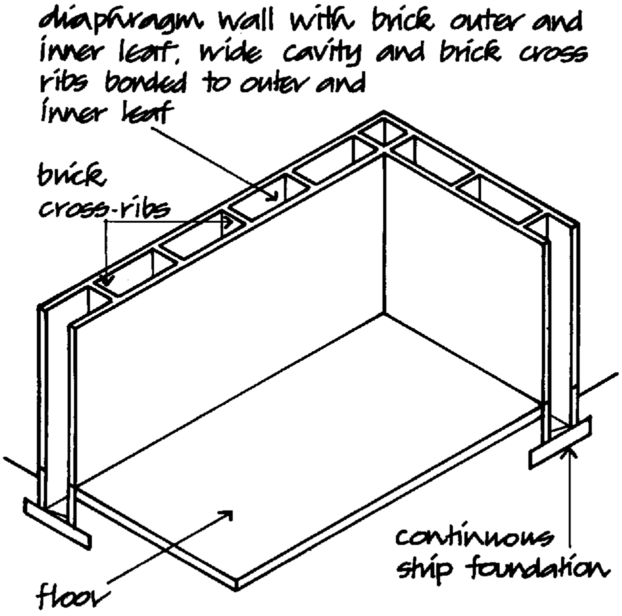


Fig. 112

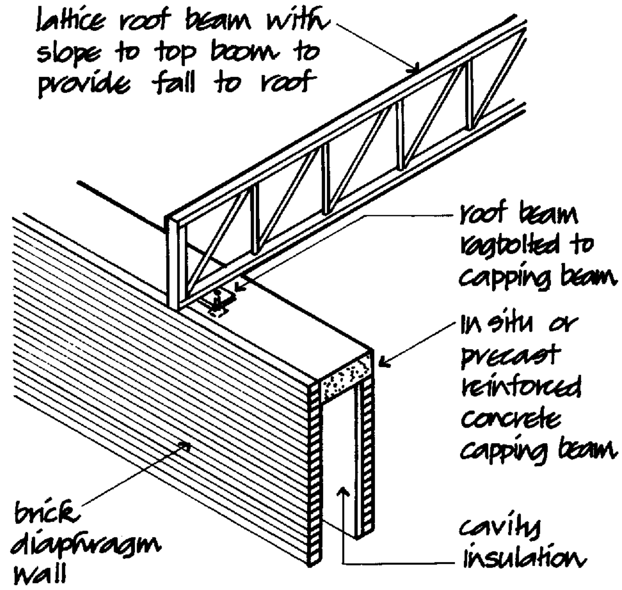
The loads on the foundation of a diaphragm wall are so slight that a continuous concrete foundation is used for walls built on most natural undisturbed subsoils. A concrete strip foundation to a diaphragm wall is illustrated in Fig. 113. The width of the foundation is determined from the load on the foundation and the safe bearing capacity of the subsoil (see Volume 1).

The roof of a diaphragm wall is tied to the top of the wall to act as a prop in resisting the overturning action



Diaphragm wall construction

Fig. 113



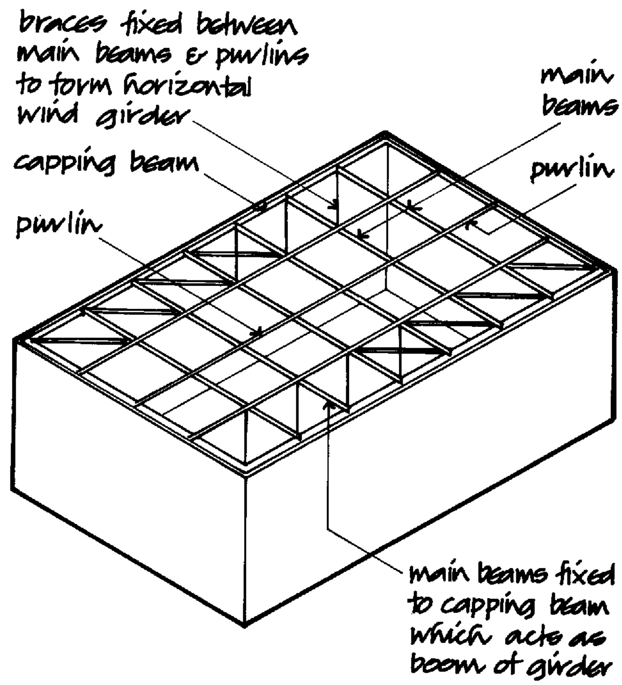
Connection of roof beams to diaphragm wall

Fig. 114

of lateral wind pressure, by transferring the horizontal forces on the long walls to the end walls of the building that act as shear walls. To ensure that the roof structure is tied to the whole of the length of the top of walls, a reinforced concrete capping beam is cast or bedded on the top of the wall and the roof beams are bolted to the capping beam as illustrated in Fig. 114. It will be seen from Fig. 114 that the reinforced concrete capping does not project to the external face of the wall. This is solely for the sake of appearance.

The capping beam can be of reinforced, in-situ cast, concrete on a support of fibre cement sheet. The disadvantage of this method of construction is the near impossibility of preventing wet cement stains disfiguring fairface brick surfaces below. To avoid unsightly stains on brickwork a system of pre-cast reinforced concrete capping beams is used. The beam is cast in lengths suited to the convenience of transport and handling and to span between cross ribs. The sections are tied with end ties or anchor bolts cast into the ends of sections and the joint is made with cement grout. Roof beams are tied to the capping beam with studs cast in the beam to which the beam is bolted as illustrated in Fig. 114.

The roof is tied to the capping beam to act as a horizontal prop to the top of the wall by transferring loads to the end walls. So that roof beams act together as a stiff plate they are braced by horizontal lattice steel wind girders connected to the roof beams, as illustrated in Fig. 115.



Wind girder to beam roof

Fig. 115

Door and window openings in diaphragm walls should preferably be designed to fit between the cross ribs so that the ribs can form the jamb of the opening. Large door and window openings will cause large local loading at the jambs from beam end bearings over the openings. Double ribs or thicker ribs are built at the jambs of large openings, to take the additional load, as illustrated in Fig. 116. Reinforced concrete lintels, the full thickness of the wall, are cast or bedded over openings.

Vertical movement joints are necessary in long walls to accommodate thermal movement. These joints are formed through the thickness of the wall by building double ribs to form a joint which is sealed with a non-hardening mastic as illustrated in Fig. 117.

A long, high diaphragm wall with flat parallel brick leaves may have a somewhat dull appearance. The flat surfaces of the wall can be broken by the use of projecting brick piers and a brick plinth, as illustrated in Fig. 118, where selected cross ribs project from the

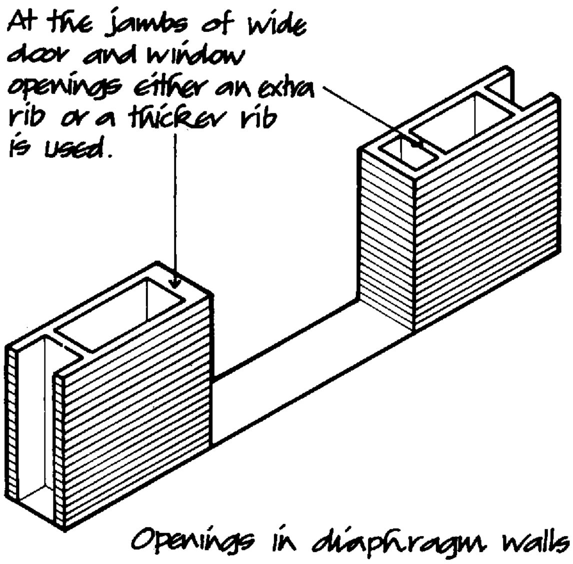


Fig. 116

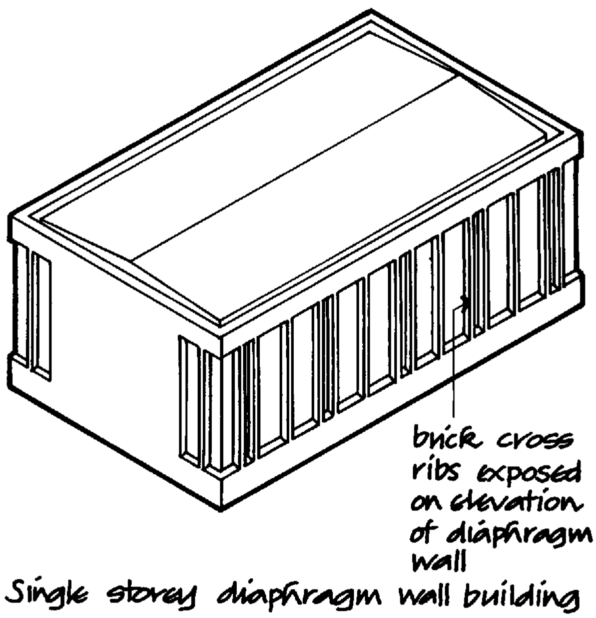


Fig. 118

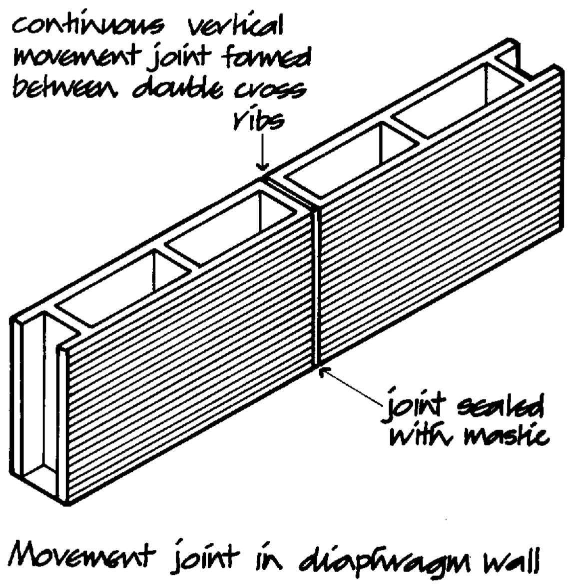


Fig. 117

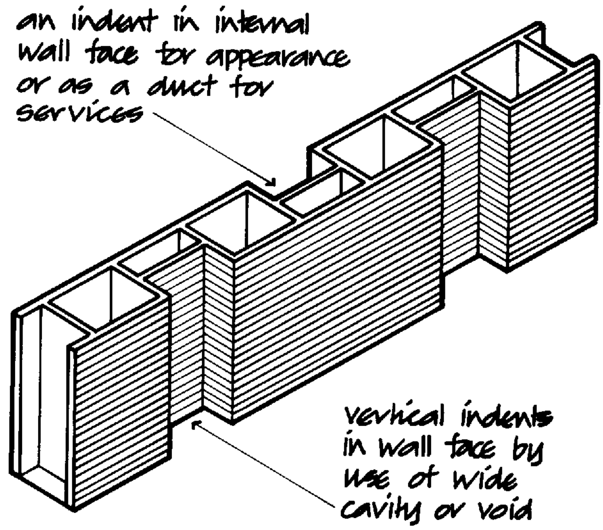


Fig. 119

face of the wall, purely for appearance. As an alternative the external face of the wall can be indented by variations in the width of the cavity as illustrated in Fig. 119. The width and the depth of the breaks in the wall face are chosen for appearance.

Resistance to weather

Experience of diaphragm walls built in positions of severe exposure, and recent tests carried out, show that a diaphragm wall will satisfactorily resist penetration of rainwater to the inner face of the wall. In positions of severe exposure there may be some penetration of rain into the brick cross ribs. To assist drying out of the cross ribs, by evaporation, it may be wise to ventilate the voids in the wall.

A continuous horizontal damp proof course (d.p.c.) should be built into a diaphragm wall for both leaves and cross ribs at floor level and at least 150 above ground level. Bitumen felt d.p.c.s, which have poor resistance to compression, may squeeze out under heavy loads, whereas the more expensive brick d.p.c. of three courses of engineering bricks will provide good resistance to tensile stress at the base of the wall.

At the jambs of openings it is practice to build in a vertical d.p.c. of bitumen felt.

Resistance to the passage of heat

The thermal insulation of a diaphragm wall is some 10% less than that of a conventional cavity wall due to the circulation of air in the voids in the wall. The common method of improving the thermal insulation of a diaphragm wall is by fixing insulating boards, 75 or 100 thick, inside the voids against the inner leaf. The insulating boards are secured in position behind wall ties built into the cross ribs or with galvanised nails driven into the inner leaf.

The roof of diaphragm wall structures should act as a horizontal plate to prop the top of the wall against lateral forces. Some form of flat roof construction of main beams with or without secondary beams is most suited to act as a plate. Solid-web castellated or lattice main beams spanning the least width of the building, with horizontal wind girders, is the usual roof construction, with metal decking, insulation and built-up bitumen felt roof covering. Laminated timber main beams are used for the appearance of the natural material of the beams which are exposed.

Where pitched roof construction is used the frames of the roof structure should be braced to act as horizontal or near horizontal wind girders to prop the walls.

BRICK FIN WALLS

A fin wall is a conventional cavity wall buttressed by brick fins bonded to the outer leaf and projecting from the external face of the wall to stiffen high walls against horizontal pressures. Fig. 120 is an illustration of part of a fin wall. The minimum dimensions and spacing of the fins are determined by the cross-sectional area of the T-section of the wall required to resist the tensile stress from lateral pressure and by considerations of the appearance of the building. The spacing and dimensions of the fins can be varied to suit a chosen external appearance.

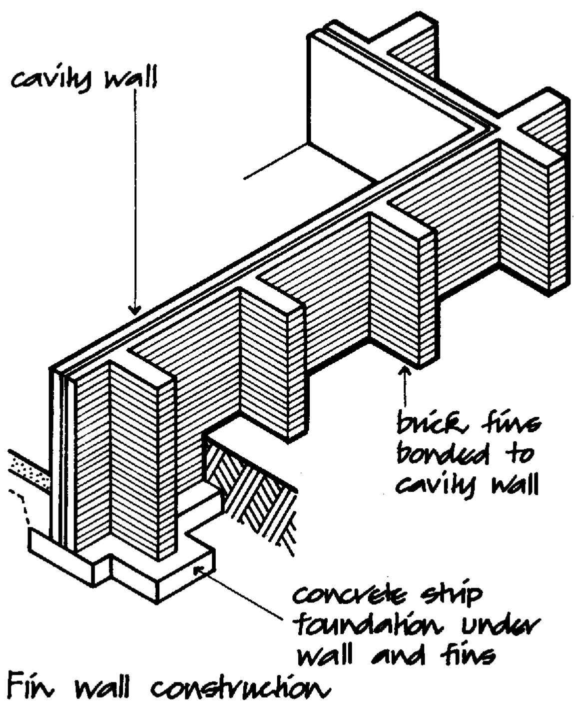


Fig. 120

For walls over about 5.0, a fin wall is used instead of a diaphragm wall because of the effect of the protruding vertical fins illustrated in Fig. 121 which can be built in a variety of ways for appearance. Some typical profiles for brick fins are illustrated in Fig. 122. For best effect, special bricks are used. These special bricks can

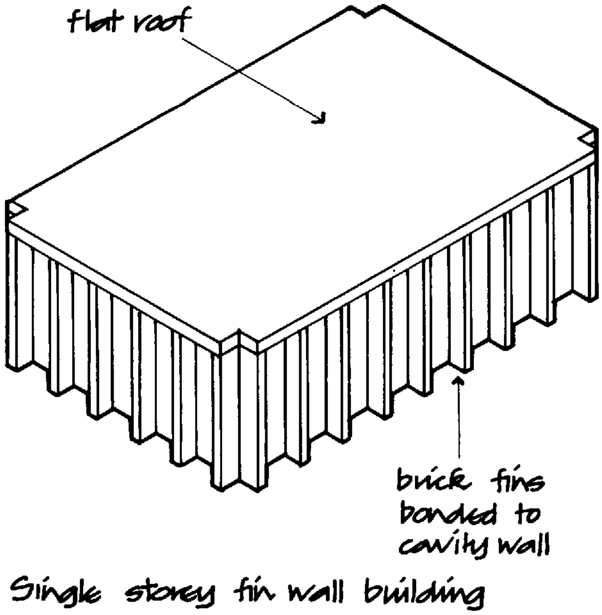


Fig. 121

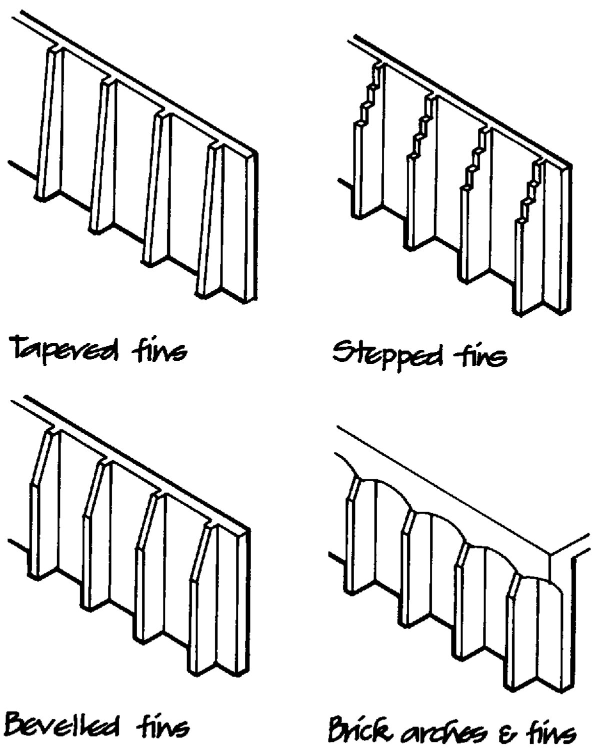


Fig. 122

be selected from the range of 'specials' produced by brickmakers or they can be specially made to order. The use of 'specials' will provide a better finish to brickwork than is possible by cutting standard bricks to the required shape. The use of special bricks does considerably increase the cost of brickwork.

Strength

The strength of the brickwork of a fin wall is considerable in relation to the comparatively small dead load of the wall and roof and imposed loads of wind and snow.

Stability

Stability against lateral forces from wind pressure is provided by the T-section of the fins and the prop effect of the roof, which is usually tied to the top of the wall to act as a horizontal plate to transfer moments to the end walls.

Construction

The wall is constructed as a conventional cavity wall with a 50 cavity and inner and outer leaves of brick tied with wall ties. The fins, which are bonded to the outer leaf in alternate courses, are usually one brick thick

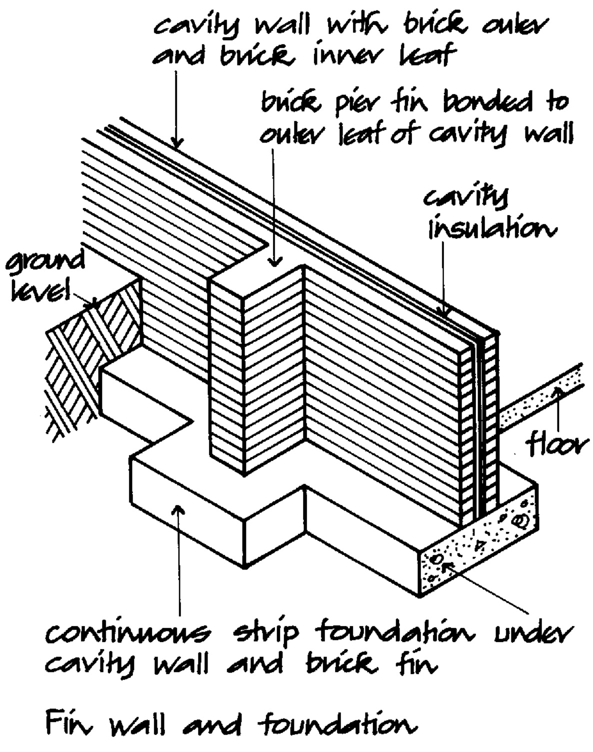


Fig. 123

with a projection of four or more brick lengths. The fins should be spaced a number of whole bricks apart to minimise cutting of bricks and at centres necessary for stability and for appearance.

The loads on the foundation of a fin wall are so slight that a continuous concrete strip foundation will provide support and stability for the wall on most natural subsoils. A continuous strip foundation to a fin wall is illustrated in Fig. 123 from which it will be seen that the foundation is spread under the wall and extended under the fins.

The roof of a fin wall is usually designed as a horizontal plate which props the top of the wall to transfer lateral pressures and so achieve an economy in the required wall section. Roof beams generally coincide with the centres of the fins, the roof beams being tied either to a continuous reinforced concrete capping beam cast or bedded on the wall or to concrete padstones cast or bedded on the fins as illustrated in

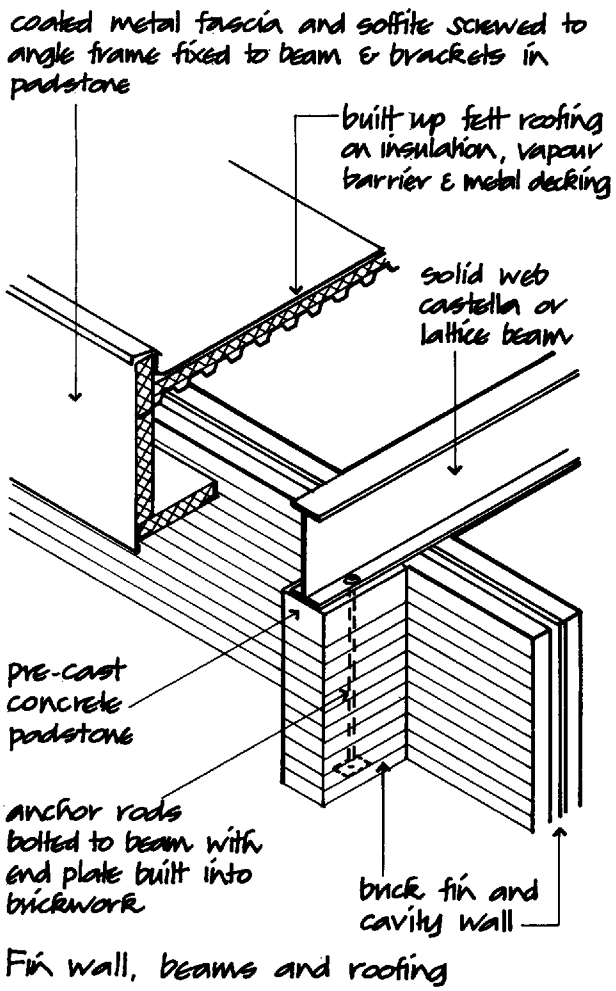


Fig. 124

Fig. 124. To resist wind uplift on lightweight roofs the beams are anchored to the brick fins through bolts built into the fins, cast or threaded through the padstones and bolted to the beams (Fig. 124).

Horizontal bracing to the roof beams is provided by lattice wind girders fixed to the beams to act as a plate in propping the top of the wall. These wind girders are usually combined with a capping plate to the top of fin walls.

Door and window openings in fin walls should be the same as the width between fins for simplicity of construction. To allow sufficient cross-section of brickwork at the jambs of wide openings either a thicker fin or a double fin is built, as illustrated in Fig. 125.

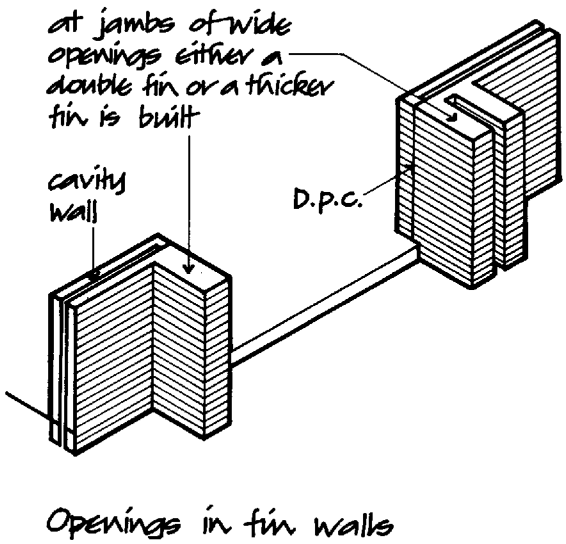


Fig. 125

Movement joints, which are necessary in long walls, are formed between double brick fins as illustrated in Fig. 126.

Resistance to weather

The cavity wall serves as a barrier to the penetration of rain to the inside face of the wall in all but positions of severe exposure. To an extent the projecting fins serve to disperse driving rain and thus give some protection to the cavity wall.

A continuous horizontal damp-proof course must be built into the wall and the fins at floor level and at least 150 above ground. The considerations of the choice of materials are the same as that for diaphragm walls.

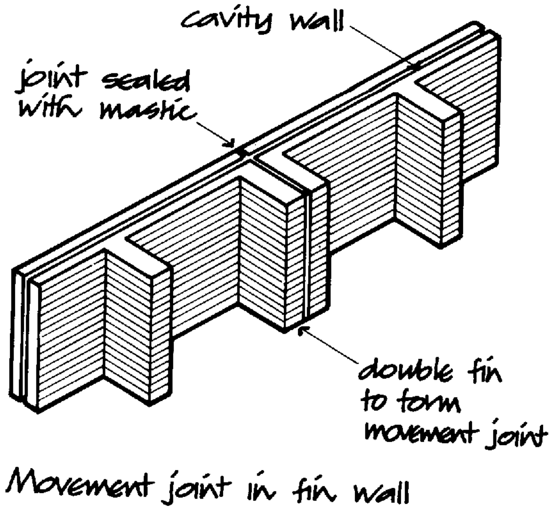


Fig. 126

Resistance to the passage of heat

The insulation of the cavity wall is usually improved by the use of insulation bats fixed in the cavity against the inner leaf of the wall or by the use of cavity fill.

BLOCKWORK WALLS

The majority of diaphragm and fin walls are built of brick because the small unit of the brick facilitates bonding and the construction of fins, recesses and cross ribs. Both diaphragm and fin walls can be built of concrete blocks, where the spacing of cross ribs and fins and width of voids is adapted to the block dimensions to minimise wasteful cutting of blocks. Because of the larger size of blocks, a wall of blocks will tend to have a more massive appearance than a similar wall of bricks.

TILT-UP CONSTRUCTION

Introduction

The term tilt-up construction is used to describe a technique of precasting large, slender reinforced concrete wall panels on site on the floor slab or on a temporary casting bed which, when cured (hardened), are tilted by crane into position as the enclosing wall envelope and structure. This technique or system of building has been used principally for the construction of single-storey commercial and industrial buildings on open sites where there is room for casting and the necessary lifting equipment.

This system of building, which has been much used in the US and Australia for the speed of casting and erecting the panels in a matter of days and for the security, durability and freedom from maintenance of the concrete walls, has more recently been adopted for the construction of multi-storey buildings.

To gain the maximum advantage of speed of casting and erecting that is possible with this system of construction, the individual reinforced concrete wall panels should be cast on the accurately levelled floor slab as close as is practical to their final position.

The site slab of concrete is cast over the completed foundations, drainage and service pipe work and accurately levelled with a wide, travelling screeding machine to provide a level surface onto which the wall panels can be cast. The panels are then cast around reinforcement inside steel edge shuttering on a bond breaker applied to the surface of the site slab. The wall panels may be cast as individual panels, as a continuous strip which is cut to panel size or stack cast one on the other, separated by a bond breaker. After a few days the cured, hardened panels are then lifted into position and propped ready for the roof deck. The sequence of operations is illustrated diagrammatically in Fig. 127.

Panel size is limited by the strength of the reinforced concrete panel necessary to suffer the stresses induced in the panel as it is lifted into the vertical and by the lifting capacity of the cranes. The wall panels may vary in design from plain, flat slabs to frames with wide openings for glazing providing there is adequate reinforced concrete to carry the anticipated loads. A variety of shapes and features is practical and economic by the repetitive use of formwork in the casting bed. A variety of external finishes can be produced from smooth, hard surfaces to a number of textured finishes.

The typical thickness of these reinforced concrete panels is 160.

Strength and stability

Depending on the bearing capacity of the subsoil and the anticipated loads on the foundations, strip, pad or pile and beam foundations may be used. The panels are tilted up and positioned on the levelled foundations against a rebate in the concrete, up to timber runners or onto a seating angle and set level on shims. A

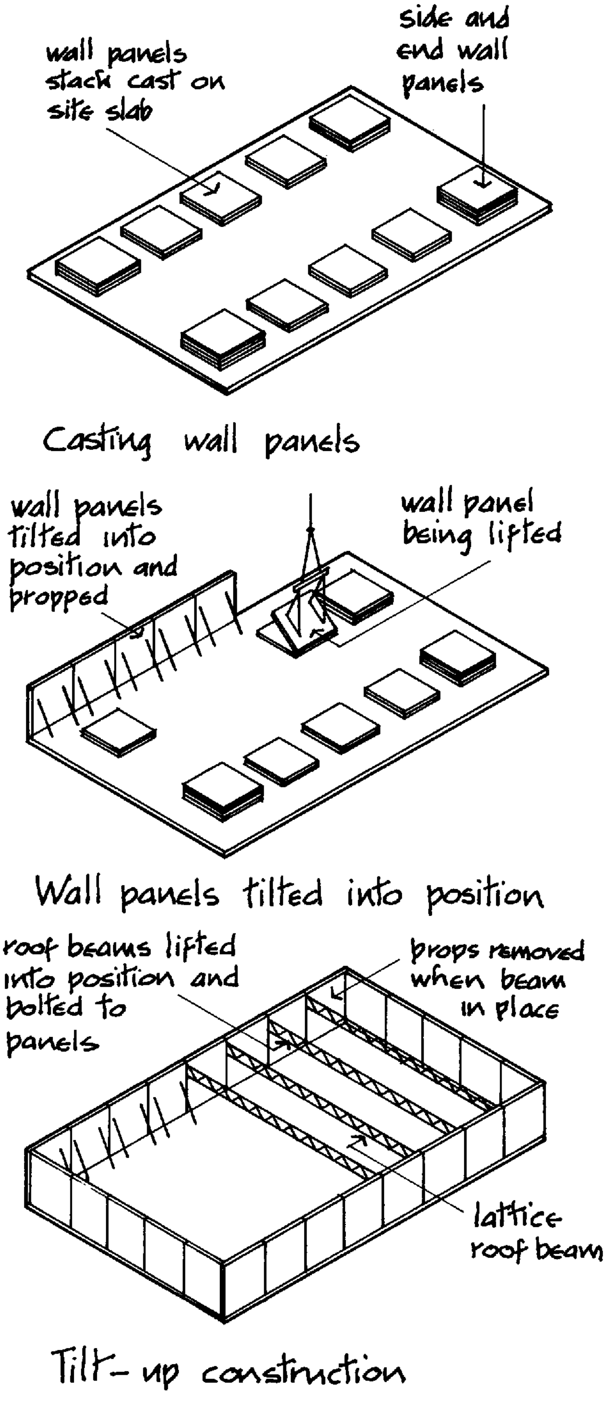


Fig. 127

mechanical connection of the foot of the panels to the foundation or the floor slab is often used. Cast in metal, dowels projecting from the foot of the panels are set into slots or holes in the foundations and grouted in position, or a plate, welded to studs, or bar anchors, cast into the foot of the panel, provide a means of welded connection to rods cast into the site slab as illustrated in Fig. 128.

The roof deck serves as a diaphragm to give support to the top of the wall panels and to transmit lateral wind forces back to the foundation. Lattice beam roof decks are welded to seat angles, welded to a plate and cast in studs as illustrated in Fig. 128. A continuous chord angle is welded to the top of the lattice beams and to bolts cast or fixed in the panel. The chord angle, which serves as a transverse tie across the panels, is secured to the panels with bolts set into slots in the angle to allow for shrinkage movements of the panels.

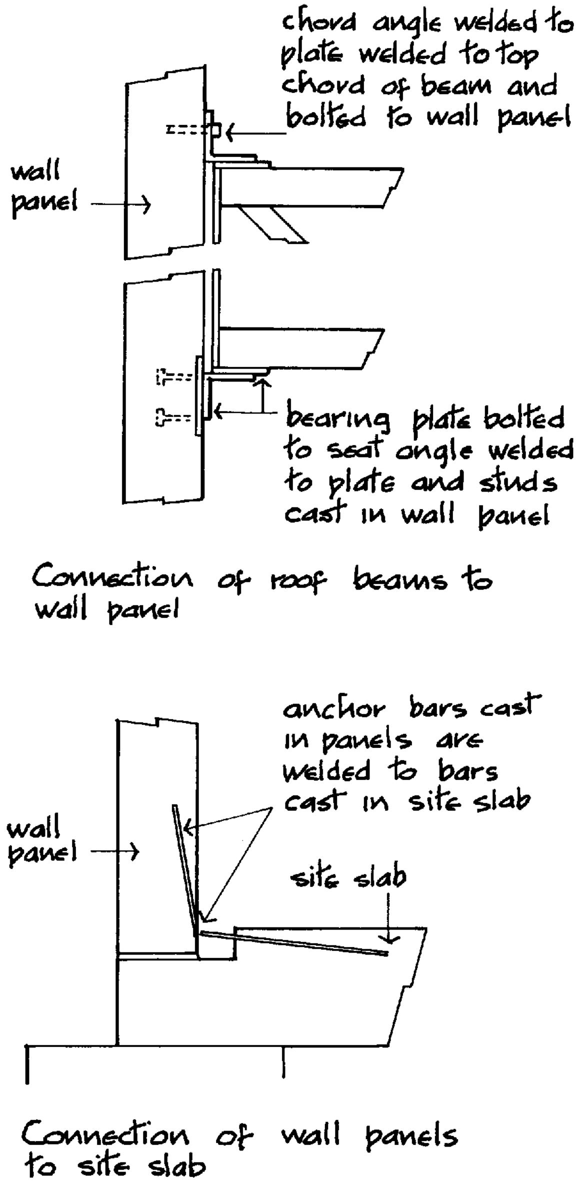


Fig. 128

Resistance to weather

The high density of the concrete panels is adequate to resist the penetration of rainwater to the inside face of the panels. The open vertical joint between panels, which will act as a drainage channel for rainwater falling on the outside face, is sealed against rain and wind penetration with a polysulphide sealant run inside the joint over a polyethylene backing strip.

Durability and freedom from maintenance

A smooth, dense finish to concrete panels should require little if any work of maintenance for many years. This type of finish can be cleaned by washing from time to time or overpainted to enhance appearance.

Fire safety

The reinforced concrete wall panels provide good resistance to damage by fire and will serve as an effective barrier to the spread of fire between buildings.

Resistance to the passage of heat

The usual 160 thickness of the reinforced concrete panels is not sufficient, by itself, to provide the *U* value for walls required by the Building Regulations for buildings which require internal heating. The most straightforward way of enhancing the thermal resistance of the panels is to apply one of the proprietary lining systems to the inner face of the wall to provide an insulating lining and an interior wall finish. Lining panels with a core of foamed PIR or PUR to a plasterboard facing and a polythene moisture vapour check on the inner face are fixed by shot-fired connectors direct to the panels or fixed to timber battens which are shot-fire fixed to the panel.

Resistance to the passage of sound

Solid concrete wall panels without openings provide good resistance to airborne sound either from outside or from inside to outside.

Security

Solid wall panels provide good security against forced entry, damage by vandalism and substantial protection against damage by accidental knocks.

CHAPTER FIVE

SHELL STRUCTURES

For some years from the middle of the twentieth century it was fashionable to construct single-storey buildings as reinforced concrete shells. The majority of shell structures were built in the warm, dry climates of South America and the Middle East where cheap labour made the construction of this form of building reasonably economic. Those buildings that were constructed as shell forms in colder, wetter northern climates were designed as shell forms principally for the sake of the elegant and unusual form that such buildings can take rather than considerations of economy or utility as a weathershield. One of the latest and probably the best known form of shell structure is the Sydney Opera House in Australia.

One of the factors that led to the use of reinforced concrete shell forms was the worldwide shortage of steel that followed the end of World War 2 in the middle of the twentieth century. Reinforced concrete became the principal structural material for framed structures for some years as a substitute for the previously used steel frame. It was a logical development and use of the initially plastic nature of concrete to construct thin shells combining the compressive strength of concrete with the minimum of steel in the form of a shell.

With the current worldwide surplus of steel it is no longer either necessary or economic to use reinforced concrete as a structural material.

A shell structure is a thin, curved membrane or slab, usually of reinforced concrete, that functions both as structure and covering, the structure deriving its strength and rigidity from the curved shell form. The term 'shell' is used to describe these structures by reference to the very considerable strength and rigidity of thin, natural, curved forms such as the shell of an egg, a nut and crustaceans such as the tortoise. The strength and rigidity of curved shell structures makes it possible to construct single curved barrel vaults 60 thick and double curved hyperbolic paraboloids 40 thick in reinforced concrete for spans of 30.0.

The attraction of shell structures lies in the elegant simplicity of curved shell forms that utilise the natural strength and stiffness of shell forms with great economy in the use of material. The disadvantage of shell structures is their cost. A shell structure is more expensive than a portal framed structure covering the same floor area because of the considerable labour required to construct the centering on which the shell is cast.

The material most suited to the construction of a shell structure is concrete, which is a highly plastic material when first mixed with water that can take up any shape on centering or inside formwork. Small section reinforcing bars can readily be bent to follow the curvature of shells. Once the cement has set and the concrete hardened the reinforced concrete membrane or slab acts as a strong, rigid shell which serves as both structure and covering to the building.

Shell structures are sometime described as single or double curvature shells. Single curvature shells, curved on one linear axis, are part of a cylinder or cone in the form of barrel vaults and conoid shells, as illustrated in Fig. 129. Double curvature shells are either part of a sphere, as a dome, or a hyperboloid of revolution, as illustrated in Fig. 129. The terms 'single curvature' and 'double curvature' do not provide a precise geometric distinction between the form of shell structures as a barrel vault is a single curvature shell but so is a dome. These terms are used to differentiate the comparative rigidity of the two forms and the complexity of the centering necessary to construct the shell form. Double curvature of a shell adds considerably to its stiffness, resistance to deformation under load and reduction in the need for restraint against deformation.

Centering is the term used to describe the necessary temporary support on which a curved reinforced concrete shell structure is cast. The centering for a single curvature barrel vault is less complex than that for a dome which is curved from a centre point.

The most straightforward shell construction is the barrel vault, which is part of a cylinder or barrel with the same curvature along its length, as shown in Fig. 130. The short-span barrel vault, illustrated in Fig. 130, is used for the width of the arch ribs between which the barrel vaults span. It is cast on similar arch ribs supporting straight timber or metal centering which is comparatively simple and economic to erect and which can, without waste, be taken down and used again for

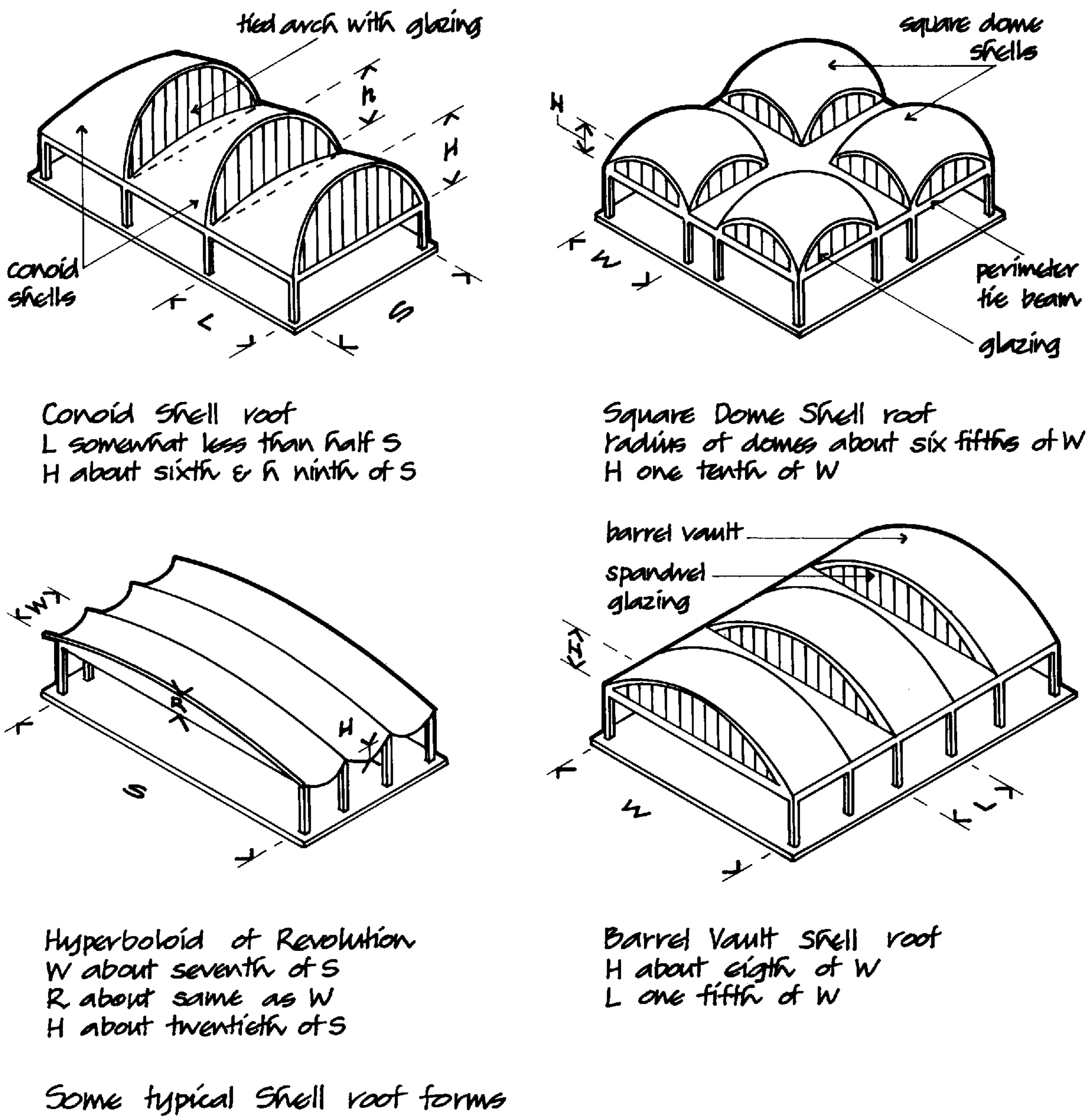


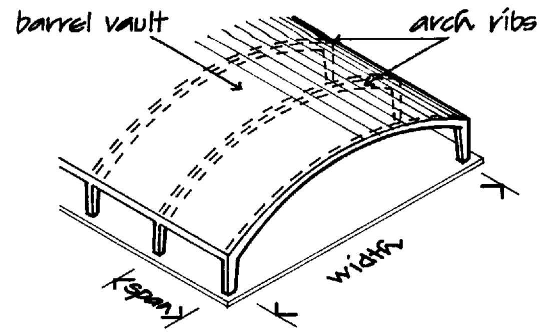
Fig. 129

similar vaults. The centering for the conoid, dome and hyperboloid of revolution shells, illustrated in Fig. 129, is considerably more complex and therefore more expensive than that for a barrel vault because of the necessary additional labour and wasteful cutting of material to form support for shapes that are not of a linear uniform curvature.

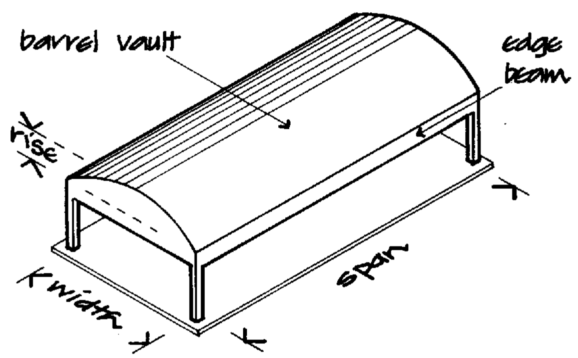
BARREL VAULT SHELL ROOFS

Reinforced concrete barrel vaults

These consist of a thin membrane of reinforced concrete positively curved in one direction so that the vault acts as structure and roof surface. The concrete



Short Span Barrel Vault



Long Span Barrel Vault

Fig. 130

shell is from 57 to 75 thick for spans of 12.0 to 30.0, respectively. This thickness of concrete provides sufficient cover of concrete to protect the reinforcement against damage by fire and protection against corrosion. The wet concrete is spread over the centering around the reinforcement and compacted by hand to the required thickness. The stiffness of the concrete mix and the reinforcement prevent the concrete from running down the slope of the curvature of the shell while the concrete is wet.

The usual form of barrel vault is the long span vault illustrated in Fig. 130 where the strength and stiffness of the shell lie at right angles to the curvature so that the span is longitudinal to the curvature. The usual span of a long-span barrel vault is from 12.0 to 30.0, with the width being about half the span and the rise about one fifth of the width. To cover large areas, multi-span, multi-bay barrel vault roofs can be used where the roof is extended across the width of the vaults as a multi-bay roof as illustrated in Fig. 131 or as a multi-bay, multi-span roof.

Stiffening beams and arches

Under local loads the thin shell of the barrel vault will tend to distort and lose shape and, if this distortion were of sufficient magnitude, the resultant increase in local stress would cause the shell to progressively collapse. To strengthen the shell against this possibility, stiffening beams or arches are cast integrally with the shell.

Figure 132 illustrates the four types of stiffening members generally used, common practice being to provide a stiffening member between the columns supporting the shell, that is at the limits of the span of the barrel vault. The downstand reinforced concrete beam, which is usually 150 or 225 thick, is the most efficient of the four because of its depth. To avoid the interruption of the line of the soffit of the vaults caused by a downstand beam, an upstand beam is sometimes used. The disadvantage of an upstand beam is that it breaks up the line of the roof and needs protection against weather.

Arch ribs for stiffening barrel vaults, which are less efficient structurally because they usually have less depth than beams, are sometimes preferred for appearance as they follow the curve of the shell and therefore do not appear to interrupt the line of the vault as do beams. The spacing of arch ribs is the same as for beams.

Edge and valley beams

Due to self-weight and imposed loads the thin shell will tend to spread and its curvature flatten out. To resist this, reinforced concrete edge beams are cast between columns as an integral part of the shell. Edge beams may be cast as dropped beams or upstand beams or partly upstand and partly dropped beams, as illustrated in Fig. 133. The advantage of the dropped beam, illustrated in Fig. 130, is that it exposes the whole of the outside of the vault to view. This effect would be spoiled if a rainwater gutter were to be fixed. In hot climates, where rainwater rapidly evaporates and it is not practice to use gutters, the dropped beam edge finish is used. In temperate climates an upstand beam is usual to form a drainage channel for rainwater (Fig. 133).

Similarly between multi-bay vaults a downstand or

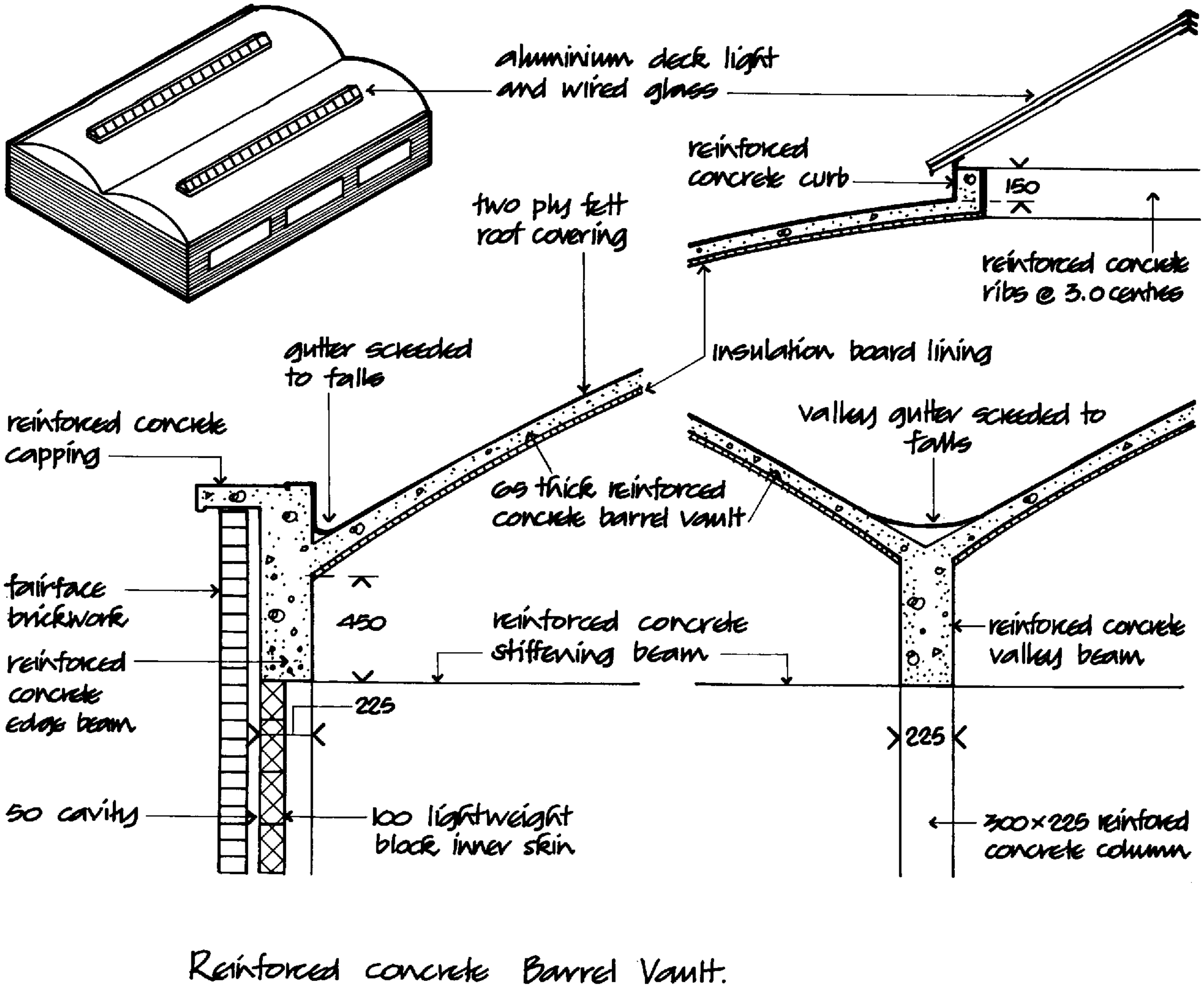


Fig. 131

feather edge valley beam is cast as illustrated in Fig. 131. Spreading of the vaults is largely transmitted to adjacent shells and thence to edge beams on the boundary of roofs, so that comparatively slender feather edge or downstand valley beams are practical.

Rooflights

Top light through the barrel vault can be provided by decklights formed in the crown of the vault, as illustrated in Fig. 131 or by dome lights. The decklight can be continuous along the crown or formed as individual lights. The rooflights are fixed to an upstand curb cast integrally with the shell as illustrated in Fig. 131. One of the advantages of these shells is that their concave soffit reflects and helps to disperse light over the area below. The disadvantage of these top lights is that they may cause overheating and glare in summer months.

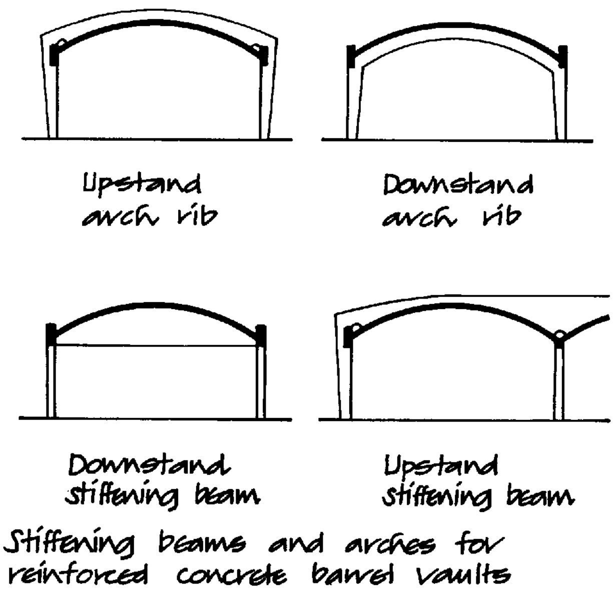


Fig. 132

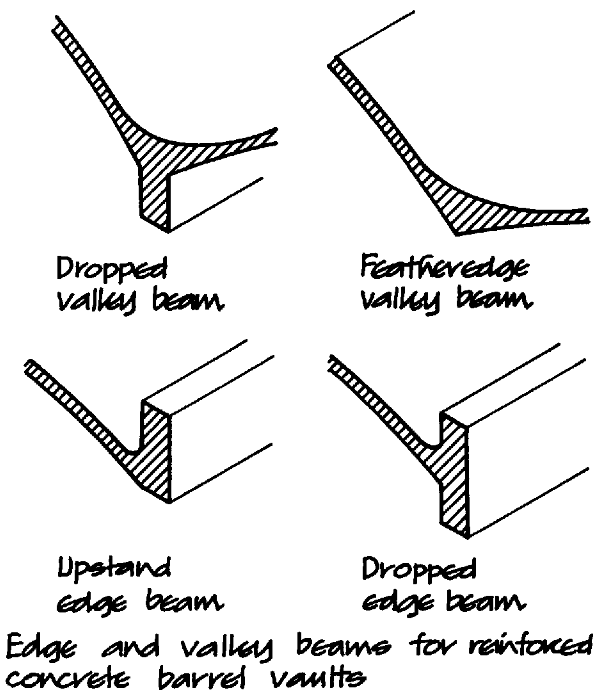


Fig. 133

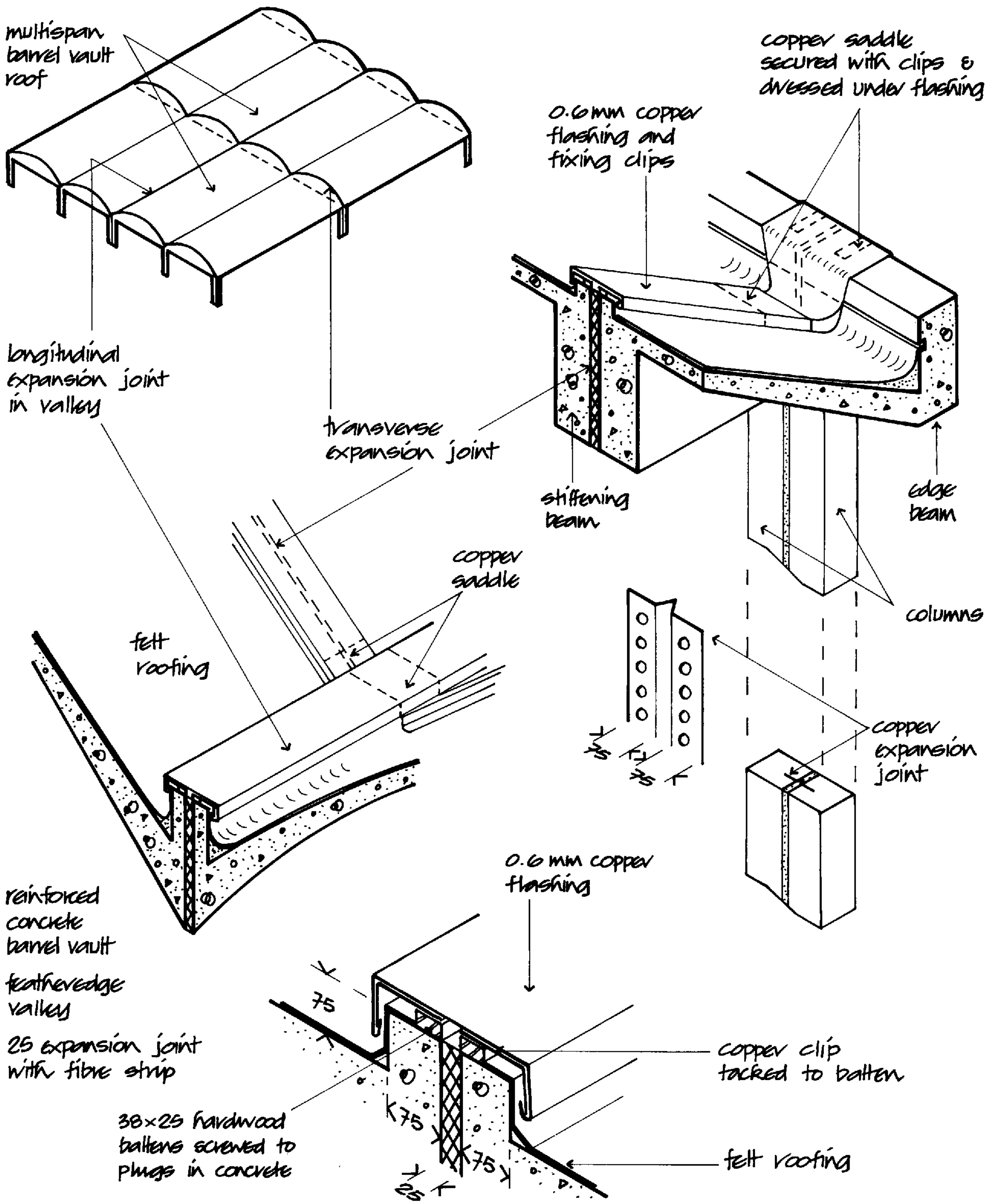
Thermal insulation

The thin concrete shell offers poor resistance to transfer of heat so that some form of insulating soffit lining or a lightweight aggregate screed on the shell may be necessary. The need to add some form of insulating lining to improve insulation adds considerably to the cost of the shell. Pliable insulating boards which can be laid on the centering and take up the curve of the vault will adhere sufficiently to the concrete of the shell to provide adequate fixing. The possibility of condensation forming on the underside of the cold concrete shell and so saturating the insulation makes this an unsatisfactory finish to the soffit of the vault. To fix preformed insulating lining under the vault with a ventilated air space between the shell and the lining would be grossly expensive. The most satisfactory method of providing insulation is to spread a lightweight screed over the shell.

The difficulties of improving the insulation of shells, controlling condensation and at the same time maintaining the elegance of the curved shape of the shell makes these structures largely unsuited to heated buildings in temperate climates.

Expansion joints

With changes in temperature, lineal expansion or contraction of these rigid concrete shells occurs. If there were excessive contraction or expansion the stresses so caused might deform the shell and cause gradual collapse. To limit expansion and contraction, continuous expansion joints are formed at intervals of about 30.0 both along the span and across the width of multi-bay, multi-span barrel vault roofs. In effect the expansion joint is formed by erecting separate shell structures each with its own supports and with compressible and expandable joint material between adjacent structures as illustrated in Fig. 134. The expansion joint transverse to the span of the vaults is formed by casting an upstand to adjacent stiffening beams with a non-ferrous flashing to weather the joint as shown in Fig. 134. The expansion joint is made continuous to the ground with double columns each side of a vertical expansion joint. Longitudinal expansion joints are formed in a valley with upstands weathered with non-ferrous capping over the joint (Fig. 134). This joint is continuous to the ground with a vertical expansion joint between a pair of columns.



Expansion joints and flashings in reinforced concrete Barrel Vaults
Expansion joints at intervals of not more than 30 metres

Fig. 134

Roof covering

Concrete shells may be covered with non-ferrous sheet metal, asphalt, bitumen felt, a plastic membrane or a liquid rubber-based coating consisting of a neoprene (synthetic rubber) undercoat and chlorosulphonated polyethylene finishing coat applied by brush or spray with reinforcing tape bedded in the material over construction joints in the concrete. This elastomeric coating is supplied in six different colours and being extremely light in weight, that is 0.97 kg/m^2 and resilient, is ideal as a covering for concrete shells. Built-up bituminous felt is often used because it is comparatively light in weight and cheap. Mastic asphalt roofing is a comparatively heavy covering (44 kg/m^2) and is not much used for shell roofs. Non-ferrous sheet metal coverings are fixed to concrete shells in the same way that they are fixed to concrete roofs as described in Volume 1.

Walls

The walls of shell structures take the form of non-loadbearing panel walls of brick, block or timber built between or across columns to exclude wind and rain and an insulation against transfer of heat.

North light reinforced concrete barrel vault

To avoid the possibility of overheating and glare from toplights in the summer months a system of north light barrel vaults is used. The roof consists of a thin reinforced concrete shell on the south-facing side of the roof, with a reinforced concrete framed north-facing slope, pitched at from 60° to 80° as illustrated in Fig. 135.

The rigidity of a barrel vault depends on its continuous curvature, which in this type of roof is interrupted by the north light opening. In consequence a north light shell is less efficient structurally than a barrel vault shell. The economic span of a north light shell is 12.0 to 15.0 as compared to the 30.0 or more of the barrel vault.

The reinforced concrete beam and post framing in the north light slope serves as a deep open web beam supporting the crown of the vaulted slope. The north light framing may be open between supporting columns, as illustrated in Fig. 135, or stiffened with intermediate posts as illustrated in Fig. 136. Obviously an increase in the spacing of the posts of the north light

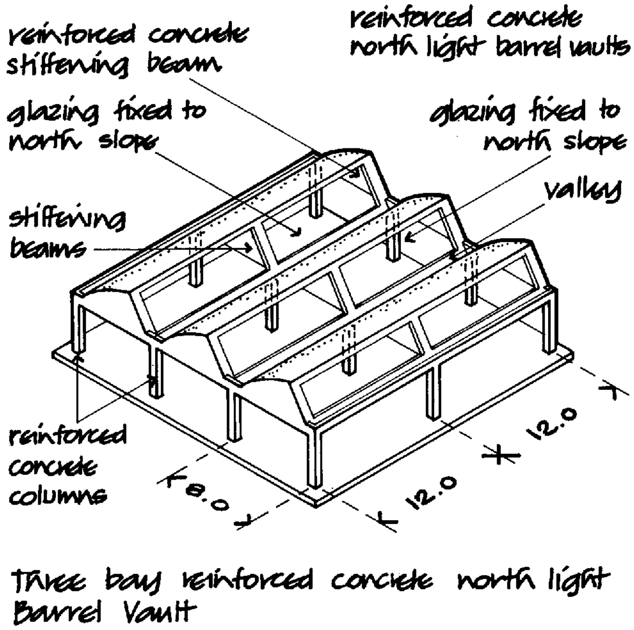


Fig. 135

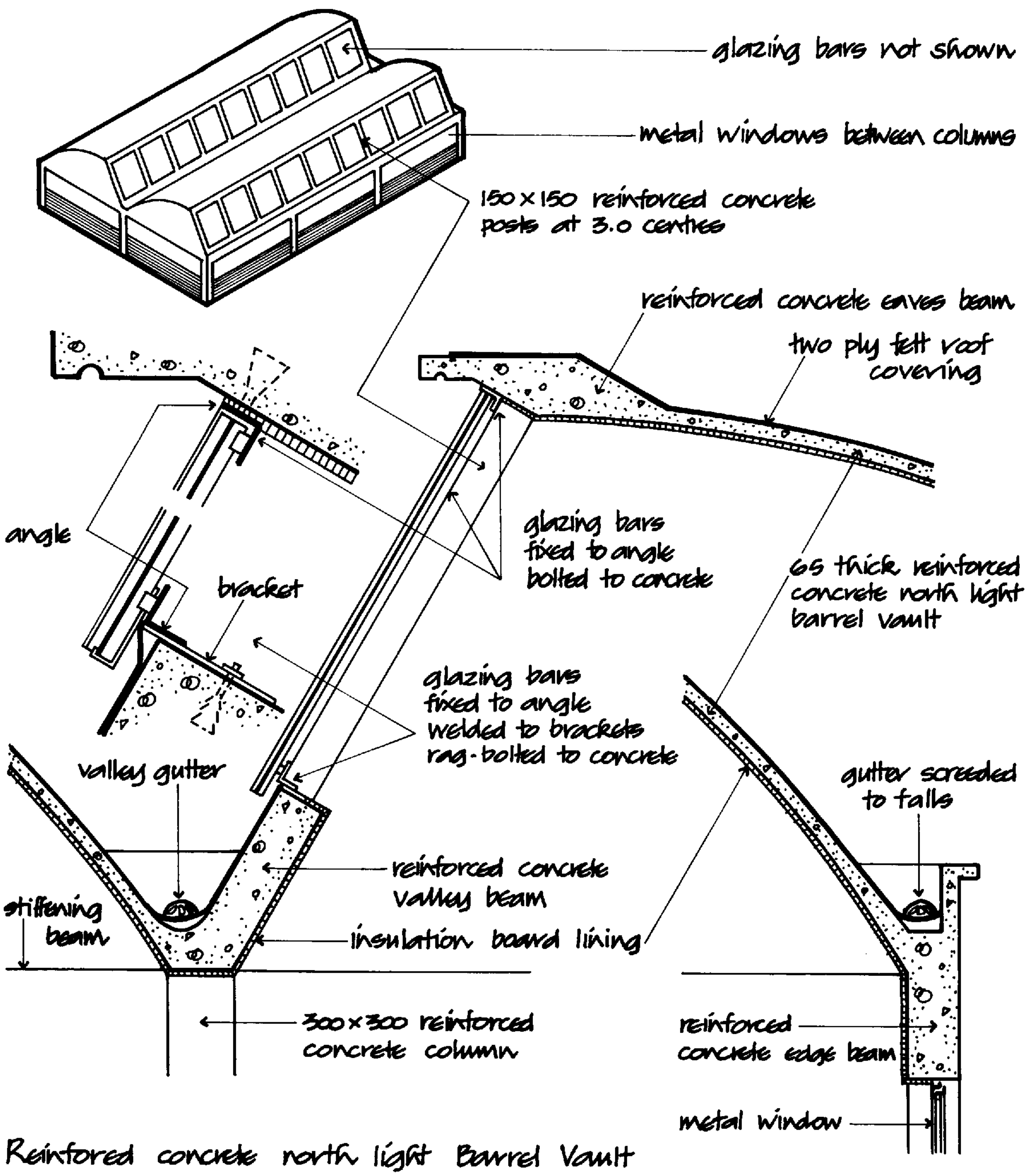
frame will require an increase in the section of the eaves and valley beams shown in Fig. 136.

The description of stiffening beams and arches, edge beams, insulation, expansion joints and roof covering given under the heading of barrel vaults applies equally to north light vaults. The north light slope is glazed with patent metal glazing or profiled plastic sheeting fixed to timber grounds or metal angles screwed to the concrete as illustrated in Fig. 136.

Timber barrel vaults

Single- and multi-bay barrel vaults can be constructed from small section timber with spans and widths similar to reinforced concrete barrel vaults. The vault is formed of three layers of boards glued and nailed together and stiffened with ribs at close centres, as shown in Fig. 137. The ribs serve both to stiffen the shell and to maintain the boards' curvature over the vault. Glued laminated edge and valley beams are formed to resist spreading of the vault.

There is no appreciable difference in cost between similar concrete and timber barrel vaults.



glazing bars not shown
metal windows between columns
150 x 150 reinforced concrete posts at 3.0 centres
reinforced concrete eaves beam
two ply felt roof covering
angle
bracket
glazing bars fixed to angle bolted to concrete
65 thick reinforced concrete north light barrel vault
glazing bars fixed to angle welded to brackets rag-bolted to concrete
valley gutter
gutter screeded to falls
reinforced concrete valley beam
stiffening beam
insulation board lining
300 x 300 reinforced concrete column
reinforced concrete edge beam
metal window
Reinfored concrete north light Barrel Vault

Fig. 136

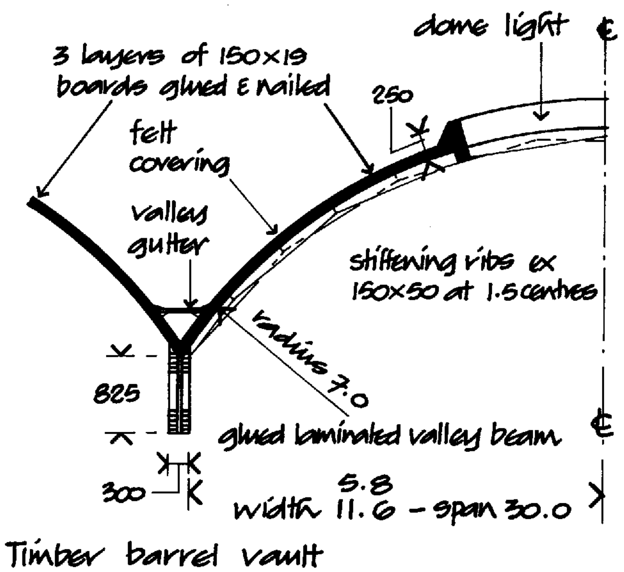


Fig. 137

CONOID AND HYPERBOLOID SHELL ROOFS

Reinforced concrete conoid shell roofs

In this shell form the curvature and rise of the shell increases from a shallow curve to a steeply curved end in which north light spandrel glazing is fixed as illustrated in Fig. 129. The glazed end of each shell consists of a reinforced concrete or steel lattice which serves as a stiffening beam to resist deformation of the shell. Edge beams resist spreading of the shell as previously described.

It will be seen from the illustration of this form in Fig. 129 that, because of the sharply curved glazed end, there is a considerable volume of space inside the shell which cannot be used for production or storage. This particular arrangement of conoid shells is not suitable for use over heated factories and warehouses but is used over long-span enclosures such as railway stations and covered markets where the enclosed space is not heated and a high roof is no disadvantage.

A system of in-situ or pre-cast unit concrete conoid shells with tied lattice steel arches in a range of standard sizes has been used with spans of up to 63.0 and in bays of 7.5, with north light glazing incorporated in the steel arch framing, as illustrated in Fig. 138. This roof system is reasonable in first cost, requires little maintenance and is suited to unheated long-span enclosures.

Hyperbolic paraboloid shells

The hyberbolic paraboloid concrete shells designed and constructed by Felix Candella in Mexico demonstrated the dramatic shapes and structural possibilities of doubly curved shells. This shape is formed when a parabolic generator moves along a parabolic directrix with the plane of the generator remaining vertical as it moves along the directrix (Fig. 139). The resulting surface is described as a hyperbolic paraboloid because horizontal sections through the surface are hyperbolas and vertical sections parabolas.

The structural significance of this shape is that at every point on the surface, straight lines, which lie in the surface, intersect so that in effect the surface is made up of a network of intersecting straight lines. In consequence the centering for a reinforced concrete hyperbolic paraboloid can consist of thin straight sections of timber which are simple to fix and support.

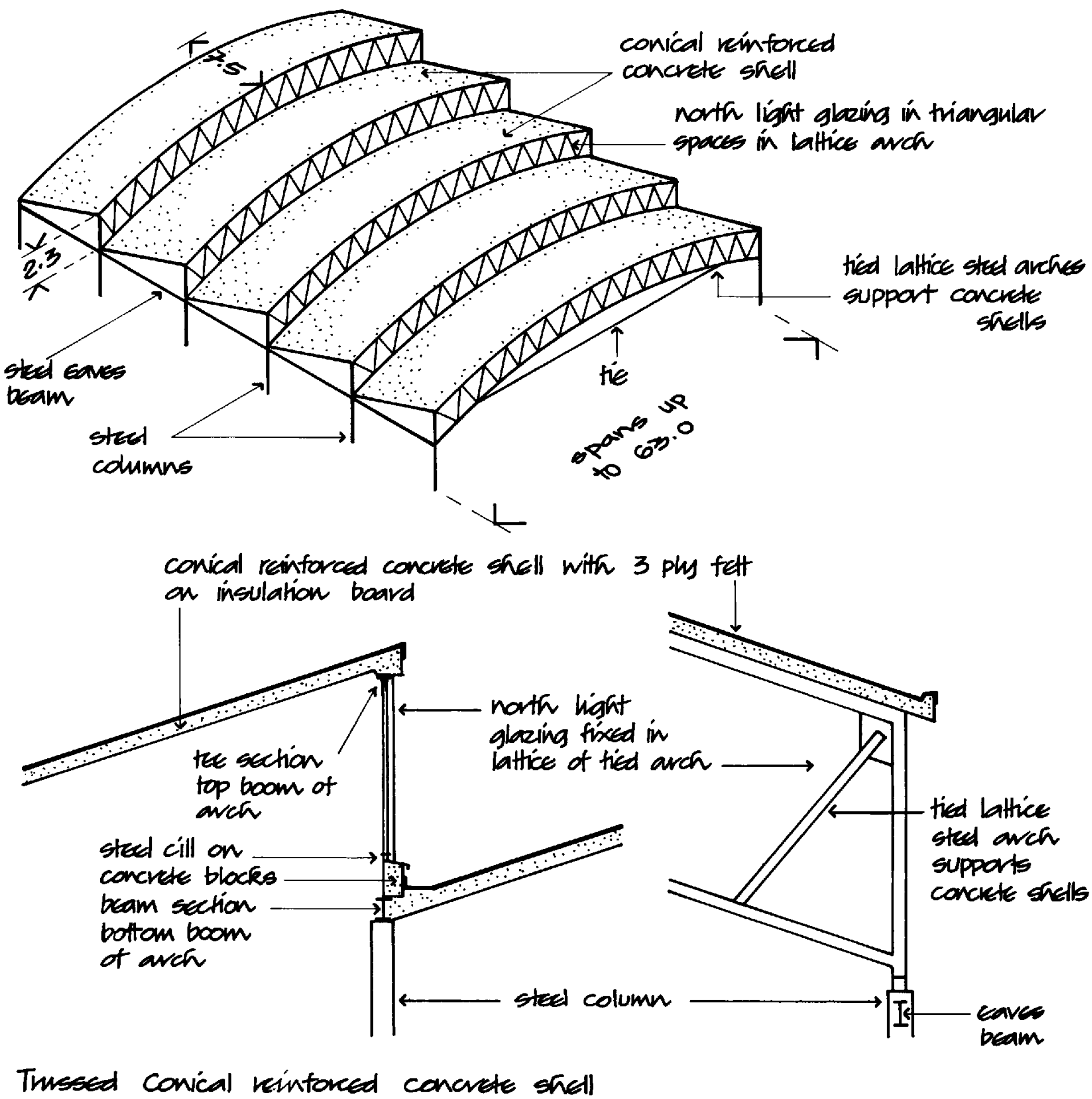
The most usual form of hyperbolic paraboloid roof is a straight line limited section of the shape illustrated in Fig. 140, the form being limited by straight lines for convenience in covering square plan shapes.

To set out stright line limited hyperbolic paraboloid surfaces it is only necesssary to draw horizontal plane squares ABCD and lift one or more corners as illustrated in Fig. 140. The straight lines joining corresponding points on opposite sides set out the surface. The number of lines used to set out the surface is not material except that the more lines used the more clearly the surface will be revealed.

It will be seen from Fig. 140 that this surface is formed by concave downward parabolas running between high points 'a' and 'c' and concave upward parabolas between low points 'B' and 'D'. The amount by which the corners are raised will affect the curvature, shape and strength of the roof. The rise of a straight line limited hyperbolic paraboloid is the difference in height between the high and low points. If three corners are lifted differing heights, then the rise is the mean of the difference between the high and low points.

Obviously if the rise is small there will be little curvature of the shell which will then behave like a plane surface or plate and will need considerable thickness to resist deflection under load. The economic limit of least rise of this shell form is a rise of not less than one fifteenth of the diagonal span, that is the horizontal distance 'AC' in Fig. 140. The greater the rise the less the required thickness of shell.

Straight line limited hyperbolic paraboloids can be combined to provide a structure with rooflights fixed in



conical reinforced concrete shell
north light glazing in triangular spaces in lattice arch
7.5
2.3
tied lattice steel arches support concrete shells
tie
spans up to 63.0
steel eaves beam
steel columns
conical reinforced concrete shell with 3 ply felt on insulation board
north light glazing fixed in lattice of tied arch
tee section top boom of arch
steel cill on
concrete blocks
beam section bottom boom of arch
tied lattice steel arch supports concrete shells
steel column
eaves beam
Trussed Conical reinforced concrete shell

Fig. 138

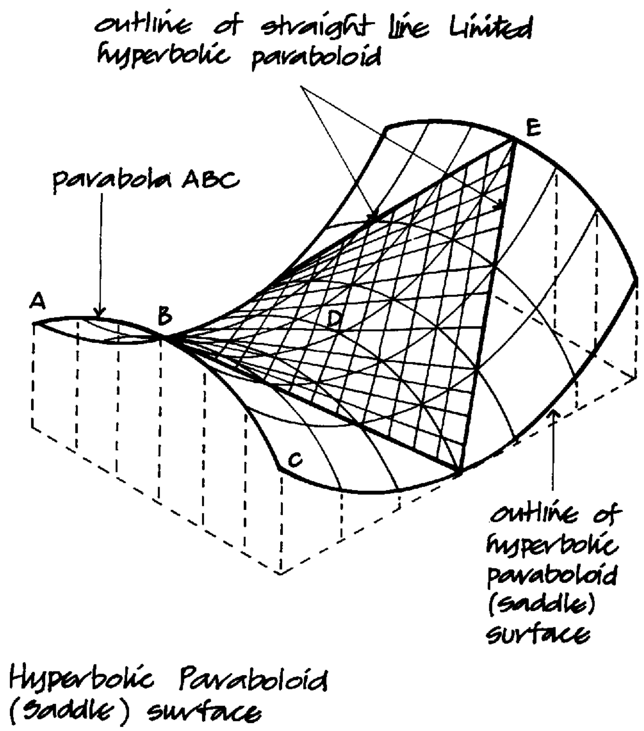


Fig. 139

the spandrel between adjacent shells (Fig. 141), where a number of similar separate hyperbolic paraboloid surfaces are combined to form a roof with spandrel glazing.

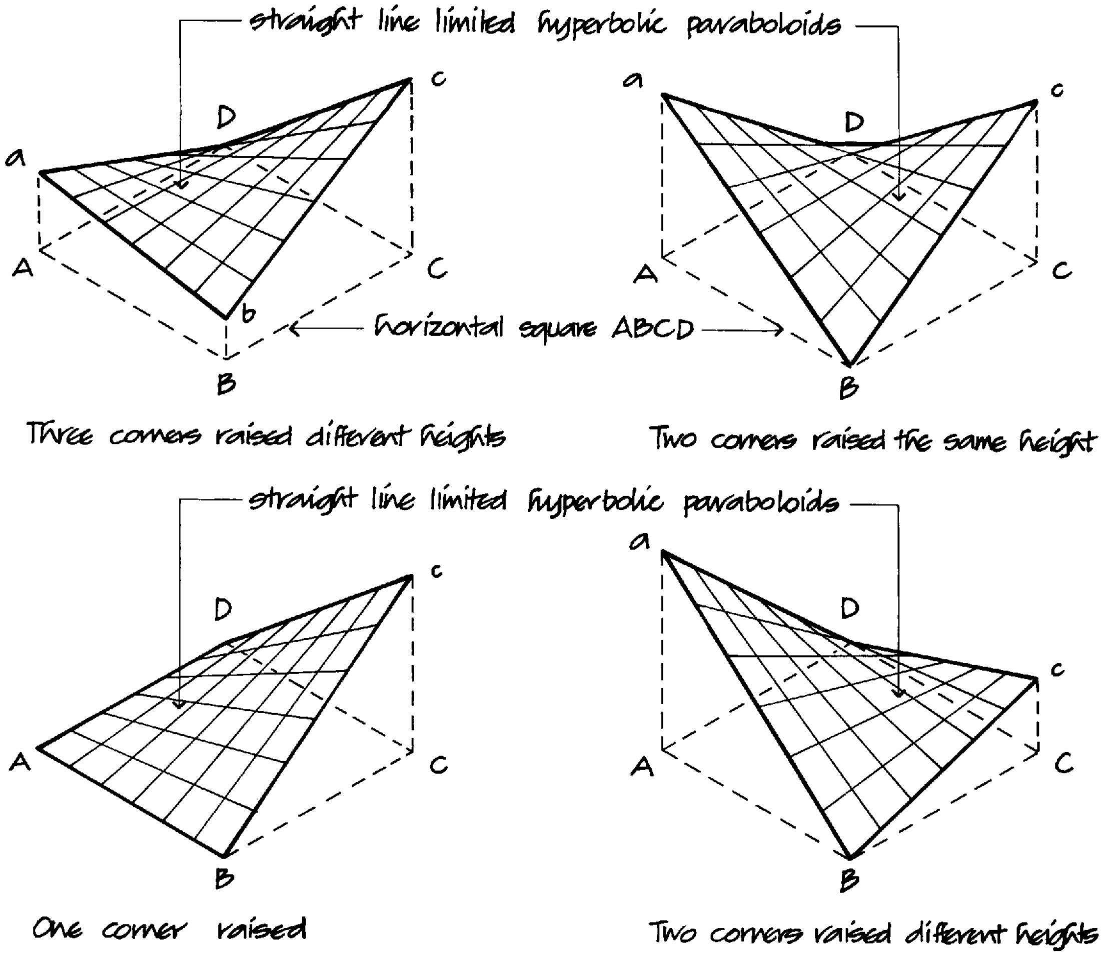
Reinforced concrete hyperbolic paraboloid shell

Figure 142 is an illustration of an umbrella roof formed from four hyperbolic paraboloid surfaces supported on one column. The small section reinforcing mesh in the surface of the shell resists tensile and compressive stress and the heavier reinforcement around the edges and between the four hyperbolic paraboloid surfaces resists shear forces developed by the tensile and compressive stress in the shell. A series of these umbrella roofs are combined, with roof glazing between them, to give cover to the floor area below.

Timber hyperbolic paraboloid shell

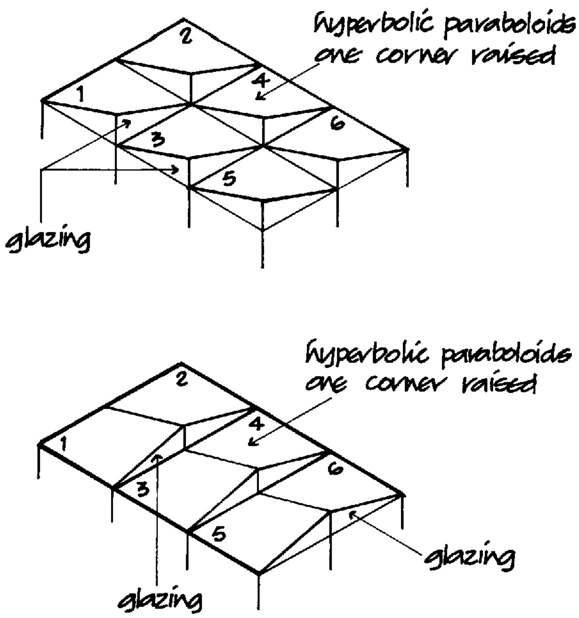
A hyperbolic paraboloid shell can be formed with three layers of boards nailed together and glued around the edges with laminated edge beams, as illustrated in Fig. 143. It will be seen that the boards do not follow the straight lines lying in the surface of the shell. If they did they would have to be bent along their length and twisted across their width. As it is difficult to twist a board across its width and maintain it in that position, the boards are fixed as shown where they have to be bent only along their length. The timber edge beams, formed by glueing and screwing boards together, resist shear. Low points of the shell are anchored to concrete abutments to prevent the shell spreading under load.

The advantage of a timber shell is its low density of 25 kg/m^2 as compared to the density of 150 kg/m^2 for a similar concrete shell, and the better insulation of the timber.



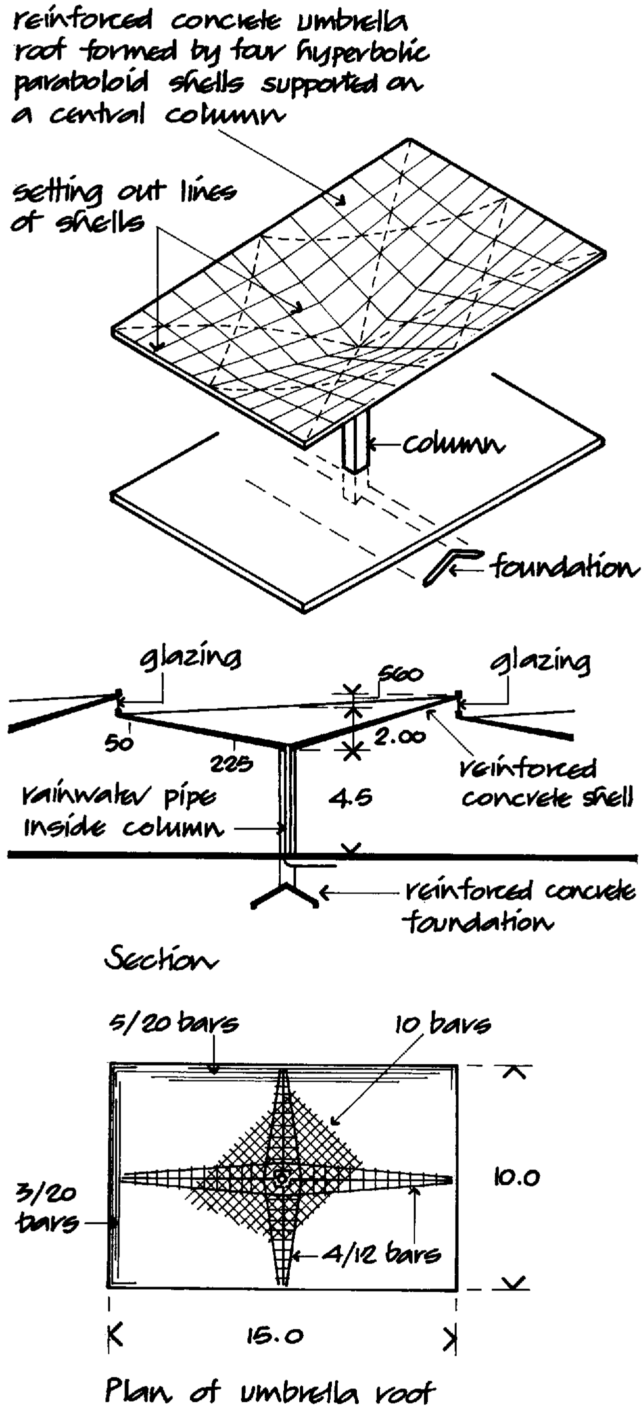
Setting out straight line limited hyperbolic paraboloid surfaces
on a square base

Fig. 140



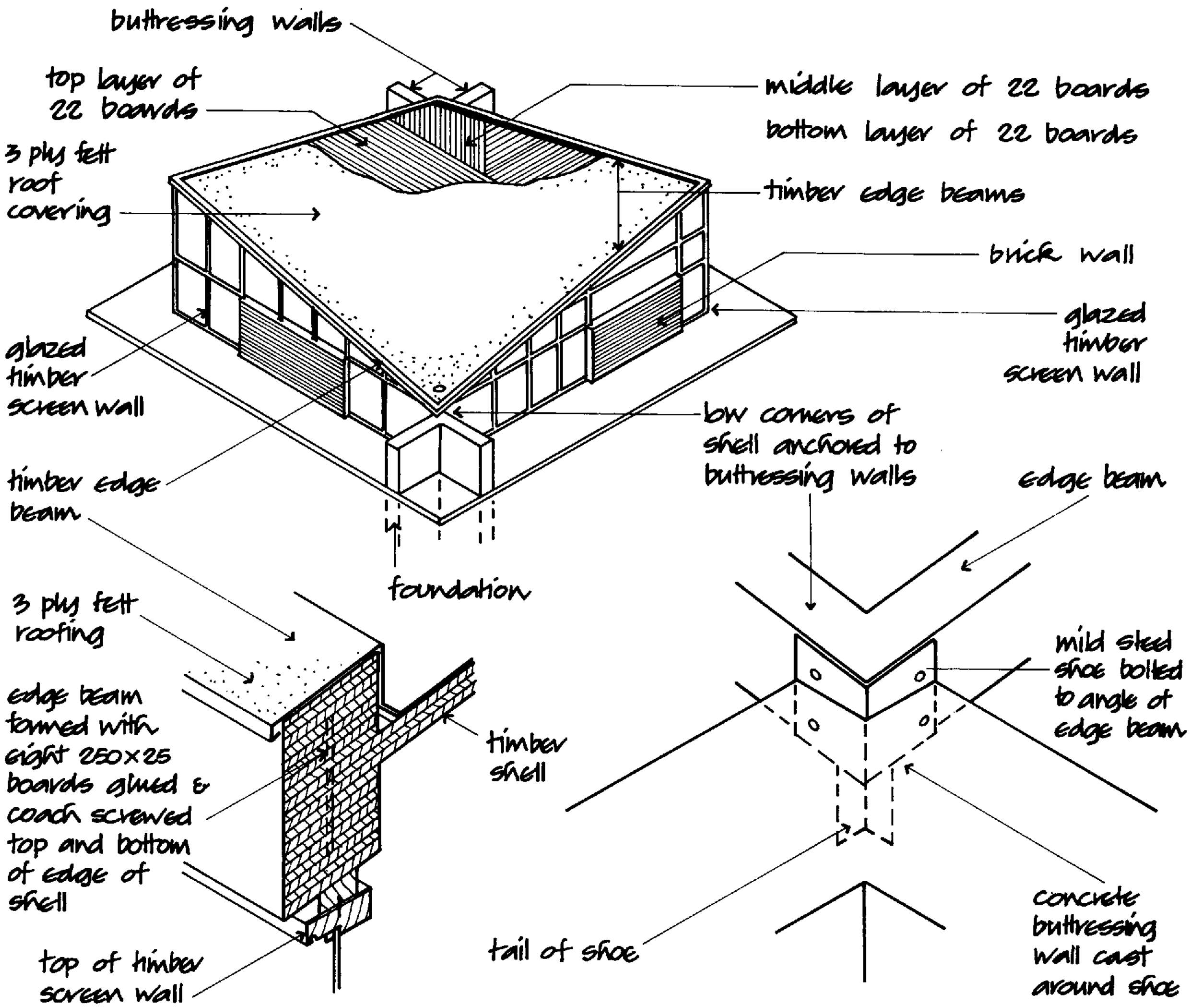
Hyperbolic paraboloid surfaces combined to form a roof

Fig. 141



Reinforced concrete hyperbolic paraboloid

Fig. 142



Hyperbolic paraboloid Timber Shell roof

Fig. 143

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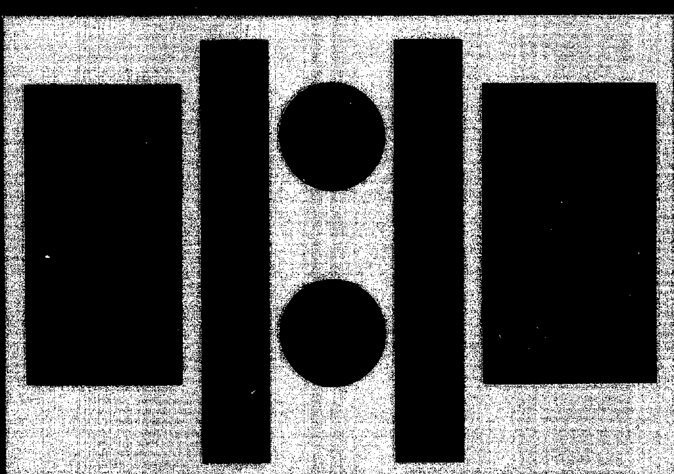

FOURTH EDITION

THE CONSTRUCTION OF BUILDINGS

VOLUME 4

FOURTH EDITION

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THE CONSTRUCTION OF BUILDINGS

VOLUME 4

MULTI-STOREY BUILDINGS,
FOUNDATIONS AND SUBSTRUCTURES,
STRUCTURAL STEEL FRAMES, FLOORS AND ROOFS,
CONCRETE, CONCRETE STRUCTURAL FRAMES,
EXTERNAL WALLS AND CLADDING OF
FRAMED BUILDINGS

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Architect

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CONTENTS

INTRODUCTION

There have been few changes in the basic form of the structural steel, skeleton frame since the first frame was erected in Chicago in 1883. Recent innovations such as the slimfloor and the parallel beam frame, described in this edition, have been adopted to accommodate services in the depth of the floor rather than as a fundamental change in the form of the frame.

The reinforced concrete structural frame, which came into general use in the middle of the twentieth century and was initially used as a substitute for the steel frame, because of the shortage of steel, is to this day much used as a skeleton structural frame. There is little to choose between the reinforced concrete and the skeleton steel frame as regards cost, speed of erection and convenience.

Because of its initial, wet plastic form that facilitates moulding to any shape, reinforced concrete has been, and still is, widely used for precast frames and precast wall frames particularly in those countries where air temperature is, for some months, below freezing.

The use of the initial plasticity of concrete in the construction of unconventional forms has been little exploited other than in such signal buildings as the Sydney Opera House and the shell forms designed by F. Candella in South America.

The appearance of multi-storey buildings has been, and still is, subject to change in the choice and use of materials as wall cladding. Buildings may have the appearance of solid loadbearing structures by the use of natural stone or brick facings fixed to and supported by the frame, be faced with panels of concrete, GRC, GRP, sheet metal or glass fixed to and supported by the frame in a variety of forms.

The so-called high technology buildings of recent years may have some real or false structural members exposed, services such as lifts and pipework exposed on the face of the building and large areas of glass. This artifice is no more high technology than another more conventionally faced building where the services are concealed within the envelope.

What has undergone little change in form is the foundations to multi-storey buildings except that the increasingly conservative approach to loads on foundation bases has meant that the mass of the foundation alone often exceeds that of the structure it supports.

In this edition such innovations as flowdrill jointing to hollow rectangular sections, parallel beam, top hat sections and slimfloor construction have been included. Details of fixings for stone and brick cladding have been revised and expanded and the provisions in The Building Regulations (Amendment) Regulations 1994 have been included.

AUTHOR'S NOTE

For linear measure all measurements are shown in either metres or millimetres. A decimal point is used to distinguish metres and millimetres, the figures to the left of the decimal point being metres and those to the right millimetres. To save needless repetition, the abbreviations 'm' and 'mm' are not used, with one exception. The exception to this system is where there are at present only metric equivalents in decimal fractions of a millimetre. Here the decimal point is used to distinguish millimetres from fractions of a millimetre, the figures to the left of the decimal point being millimetres and those to the right being fractions of a millimetre. In such cases the abbreviations 'mm' will follow the figures e.g. 302.2 mm.

CHAPTER ONE

FOUNDATIONS AND SUBSTRUCTURES

The foundation of a building is that part of the substructure which is in direct contact with and transmits loads to the ground. The substructure is that part of a building or structure which is below natural or artificial ground level and which supports the superstructure. In practice the concrete base of walls, piers and columns and raft and pile foundations are described as the foundation.

The foundation of a building is designed to transmit loads to the ground so that any movements of the foundation are limited and will not adversely affect the functional requirements of the building. Movement of the foundations may be caused either by the load of the building on the ground or by movements of the ground independent of the load.

Ground movements, due to the applied load of buildings on foundations, cause settlement by the compression of soil below foundations or because of shear failure due to overloading.

Settlement movements on non-cohesive soils, such as gravel and sand, take place as the building is erected and this settlement is described as 'immediate settlement'. On cohesive soils such as clay, the settlement is gradual as water or water and air are expelled from pores in the soil. This settlement, which is described as 'consolidation settlement', may continue for several years after completion of the building.

Movement of the foundation by settlement is limited, by the design of the foundation, to avoid damage to connected services and drains and to limit relative movement between different parts of the foundation which otherwise might cause distortion of the structure and damage to finishes, cladding or structural members.

Movements of the foundation that are independent of the applied loads of buildings are due to seasonal changes or the effects of vegetation that lead to shrinking or swelling of clay soils, frost heave, changes in ground water level and changes in the ground due to natural or artificial causes.

FUNCTIONAL REQUIREMENTS

The functional requirements of foundations are:

Strength and stability

The requirements from Part A of Schedule 1 to the Building Regulations 1991, as amended 1994, relevant to foundations are, under the heading 'Loading', that 'the combined dead, imposed and wind loads of the building be safely transmitted to the ground without causing such movement of the ground as will impair the stability of any part of another building' and under the heading 'Ground movement', that 'the building shall be constructed so that ground movement caused by swelling, shrinking or freezing of the subsoil or landslip or subsidence (other than subsidence arising from shrinkage) in so far as the risk can be reasonably foreseen, will not impair the stability of any part of the building'.

The first requirement, under the heading 'Loading', is concerned with the bearing strength of the ground relative to the loads imposed on it by the building. The foundation or foundations should be designed so that the combined loads from the building are spread over an area of the ground capable of sustaining the loads without undue movement. The reference to movement of the ground that might impair the stability of another building is presumably to the pressure on the ground from the foundations of a new building increasing the load on the ground under the foundations of an adjoining building and so increasing the possibility of instability. The swelling, shrinkage or freezing of subsoil is described in Volume 1 and later in this chapter relative to the general classification of soils.

Land instability

The term 'Ground movement', used in the requirements from the Building Regulations relevant to foundations, is more usually expressed as land instability.

Land which is unstable, or may become unstable, is widespread in Great Britain. The extent of unstable land varies from the comparatively large areas affected by coal mining to small areas affected by local quarries. Instability which is caused by natural processes, such as landslip of sloping strata, may be accelerated by human activities such as mining and earth excavation.

Landslip may be broadly grouped under the headings:

- Landslip
- Surface flooding and soil erosion
- Natural caves and fissures
- Mining and quarrying
- Landfill

Landslip

Landslip may occur under natural slopes where weak strata of clay, clay over sand or weak rock strata may slip down the slope, particularly under steep slopes and where water acts as a lubricant to the slip movement. Landslides of superficial strata nearest to the surface, which will be most noticeable and therefore recorded, are those that will in the main cause land instability that may affect the foundations of buildings. Landslides of deeper strata that have occurred or may occur, generally go unnoticed and will only affect deep excavations and foundations.

The most noticeable landslides occur in cliff faces where the continuous erosion of the base of the cliff face by tidal movements of the sea undermines the cliff and causes collapse of the cliff face and subsidence of the supported ground. Similar landslip and subsidence may occur where an excavation is cut into a slope or hillside. The previously supported sloping strata are effectively undermined and may slip towards the excavation. Landslip is also common around excavations for deep coal mining which may break through sloping strata and so encourage landslides.

The Department of the Environment has commissioned studies and prepared reports of areas liable to land instability in and around the coal mining areas of Great Britain. Similar studies have led to reports of areas liable to land instability due to landslip around areas of metal, stone, chalk and limestone quarrying.

Surface flooding

Surface flooding may affect the stability of surface ground and the seasonal movement of water through permeable strata below the surface may cause gradual erosion of soils and permeable rocks that may lead to land instability. The persistent flow of water from fractured water mains and drains may cause gradual erosion of soil and lead to land instability. The incidence of surface flooding and erosion by below surface water is, by and large, known and recorded by the regional water authorities.

Natural caves and fissures

Natural caves and fissures occur generally in areas of Great Britain where soluble rock strata, such as limestone and chalk, have been eroded over time by the natural movement of subterranean water. Where there are caves or small cavities in these areas near the surface, land instability and subsidence may occur. The Department of the Environment has prepared a review of information on the incidence of such cavities in the form of regional reports and maps showing the location and nature of known cavities and the likelihood of land instability due to the cavities.

Mining and quarrying

Mining and quarrying of mineral resources has been carried out for centuries over much of England and parts of Wales and Scotland. The majority of the mines and quarries have by now been abandoned and covered over. From time to time mining shafts collapse and ground, filled over quarries, may subside. There is potential for land instability and subsidence over those areas of Great Britain where mineral extraction has taken place. The Department of the Environment has commissioned surveys and produced reports of those areas known or likely to be subject to land instability due to mining and quarrying activities. There are ten regional reports and atlases indicating the location of areas that may be subject to land instability subsidence. Coal mining areas have been comprehensively surveyed and mapped and reported. Other areas where comparatively extensive quarrying for stone, limestone, chalk and flint has taken place have been surveyed, mapped and reported. Less extensive quarrying, for chalk for example in Norwich, has been included. The reports indicate those areas where subsidence is most likely to occur and the necessary action that should be taken preparatory to building works.

Landfill

Landfill is a general term to include the ground surface which has been raised artificially by the deposit of soil from excavations, backfilling, tipping, refuse disposal and any form of fill which may be poorly compacted, of uncertain composition and density and thus have indeterminate bearing capacity and be classified as unstable land.

Of recent years regional and local authorities have had some control and reasonably comprehensive details of landfill which may give indication of the age, nature and depth of recent fill. The land over much of the area of the older cities and towns in this country, particularly on low lying land, has been raised by excavation, demolition and fill. This overfill may extend some metres below the surface in and around older settlements and where soil excavated to form docks has been tipped to raise ground levels above flood water levels. Because of the variable and largely unknown nature of this fill, the surface is in effect unstable land and should be considered as such for foundations. There are no records of the extent and nature of this type of fill that has taken place over some considerable time. The only satisfactory method of assessing the suitability of such ground for foundations is by means of trial pits or boreholes to explore and identify the nature and depth of the fill.

Site exploration

As a preliminary to the design of foundations for buildings it is necessary to determine the nature and variability of the soil strata that underlie the building site and assess those properties of the subsoil that may affect the performance of the building.

An inspection of the site, the natural surface of the ground and natural vegetation, evidence of marshy ground, signs of ground water and flooding, irregularities in topography, ground erosion and ditches and flat land near streams and ditches, where there may be soft alluvial soil, will provide an overall indication of the nature of the subsoil. Information on subsoil conditions from county and local authorities, geological surveys, aerial photography, Ordnance Survey maps and works for buildings and services adjacent to the site will provide further reliable information.

To obtain a more precise knowledge of the nature and variability of the subsoil it is necessary to determine the thickness, depth, properties and any major changes in the subsoil strata that are likely to be significantly affected by structural loads.

Trial pits and boreholes

For exploration to shallow depths of up to about two metres, trial pits are excavated by hand over the area of the site likely to be affected by the foundations. The advantage of trial pits is that the sides of the pit can be inspected at all levels.

Where it is necessary to explore to depths greater than two metres, samples of soil are taken from boreholes that are drilled by hand or by means of power operated drills that take out samples of soil at regular intervals. The samples are collected and a note is made of the depth at which the sample was taken and sections of the subsoil strata are prepared. Selected samples of soil are then tested to determine grading of particle size, shear strength, moisture/density relationship, permeability and compressibility.

Rocks, soils, made-up ground and fill

Ground is the term used for the earth's surface which varies in the composition within the following five groups:

- Rocks
- Non-cohesive soils
- Cohesive soils
- Peat and organic soils
- Made-up ground and fill

Rocks include the hard, rigid, strongly cemented geological deposits such as granite, sandstone and limestone, and soils include the comparatively soft, loose, uncemented geological deposits such as gravel, sand and clay. Unlike rocks, soils and made up ground and fill are compacted under the compression of the loads of buildings on foundations.

Rocks

Rocks may be classified as sedimentary, metamorphic and igneous according to their geological formation as shown in Table 2, Volume 1, or in the five groups set out in Table 1, Volume 1, by reference to their presumed bearing value, which is the net loading intensity considered appropriate to the particular type of ground for preliminary design purposes. The presumed bearing values are based on the assumption that foundations are carried down to unweathered rock.

Hard igneous and gneissic rocks in sound condition have so high an allowable bearing pressure that there is little likelihood of foundation failure.

Hard limestones and hard sandstones are, when massively bedded, stronger than good quality concrete and it is rare that their full bearing capacity is utilised. Limestones are liable to solution by ground water containing dissolved carbon dioxide flowing along joints in the stone which may become enlarged and reduce the soundness of the rock as a foundation.

Schists and slates are rocks with pronounced cleavage. If the beds are shattered or steeply inclined a reduction in bearing values is made.

Hard shales and hard mudstones, formed from clayey or silty deposits by intense natural compaction, have a fairly high allowable bearing pressure.

Soft sandstones have a very variable allowable bearing pressure depending on the cementing material.

Soft shales and soft mudstones are intermediate between hard cohesive soils and rocks. They are liable to swell on exposure to water and soften.

Chalk and soft limestone include a variety of materials composed mainly of calcium carbonate and the allowable bearing pressure may vary widely. When exposed to water or frost these rocks deteriorate and should, therefore, be protected with a layer of concrete as soon as the final excavation level is reached.

Thinly bedded limestones and sandstones which are stratified rocks, often separated by clays or soft shales, have a variable allowable bearing pressure depending on the nature of the separating material.

Heavily shattered rocks have been cracked and broken up by natural processes. The allowable bearing pressure is determined by examination of loading tests.

Soils

The characteristics of a soil that affect its behaviour as a foundation are compressibility, cohesion of particles, internal friction and permeability. It is convenient to compare the characteristics and behaviour of clean sand, which is a coarse grained non-cohesive soil, with clay which is a fine grained cohesive soil, as foundations to buildings.

Compressibility

Under load sand is only slightly compressed due to the expulsion of water and some rearrangement of the particles. Because of its high permeability sand is rapidly compressed due to quick expulsion of water, and compression of sand subsoils keeps pace with the erection of buildings so that once the building is completed no further compression takes place.

Clay is very compressible, but due to its impermeability compression takes place slowly because of the very gradual expulsion of water through the narrow capillary channels in the clay. The compression of a clay subsoil under the foundation of a building may continue for some years after the building is completed, with consequent gradual settlement.

Cohesion of particles (plasticity)

There is negligible cohesion between the particles of sand and in consequence it is not plastic. There is marked cohesion between the particles of clay, which is plastic and can be moulded, particularly when wet. The different properties of compressibility and plasticity of sand and clay are commonly illustrated

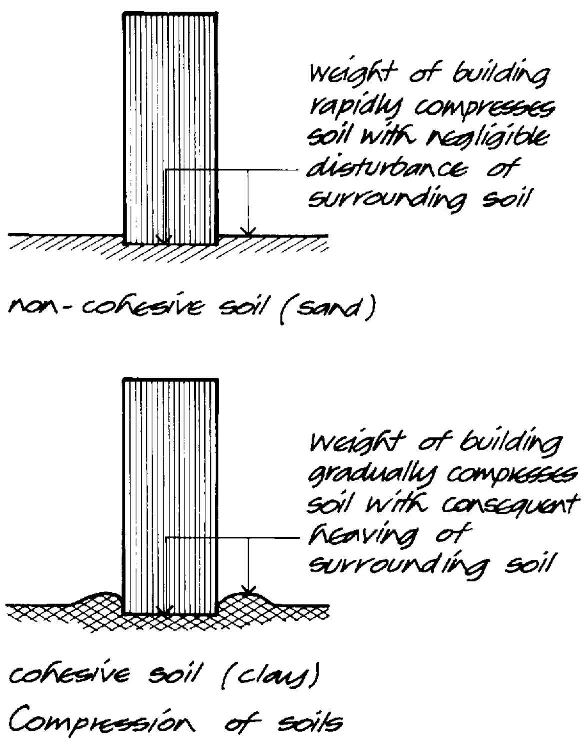


Fig. 1

when walking over these soils. A foot makes a quick indent in sand with little disturbance of the soil around the imprint, whereas a foot sinks gradually into clay with appreciable heaving of the soil around the imprint. In like manner, the weight of a building on sand causes rapid compression with little disturbance of the surrounding soil, whereas on clay compression is slow and often accompanied by surrounding surface heave as illustrated in Fig. 1. The surface heave may be pronounced if the shear resistance of the clay is overcome as explained later.

Internal friction

There is considerable friction between the coarse particles of sand which strongly resists displacement or rearrangement of the particles. When this internal friction is overcome, for example by too great a load from the foundations of a building, the soil shears and suddenly gives way.

There is little friction between the fine particles of clay. Owing to the plastic nature of clay, shear failure, under the load of a building may take place along several strata simultaneously with consequent heaving of the soil as illustrated in Fig. 2. The shaded wedge of soil below the building is pressed down and displaces soil at both sides which moves along the slip surfaces indicated. In practice the load on a foundation may not be uniform over its area and the internal friction of the subsoil under the building may vary so that shear of the soil may occur on one side only as

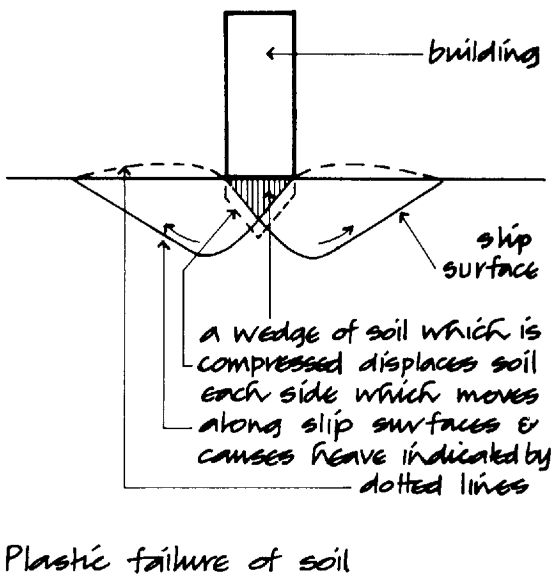


Fig. 2

illustrated in Fig. 3. This is an extreme, theoretical type of failure of a clay subsoil which is commonly used by engineers to calculate the resistance to shear of clay subsoils and presumes that the half cylinder of soil ABC rotates about centre O on slip plane ABC.

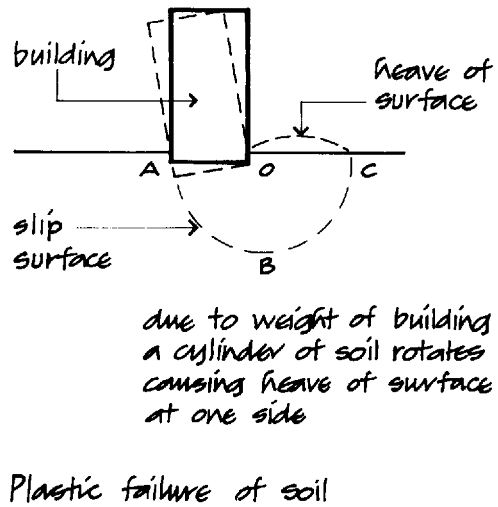


Fig. 3

Permeability

When water can pass rapidly through the pores or voids of a soil, the soil is said to be permeable. Coarse grained soils such as gravel and sand are permeable, and because water can drain rapidly through them they consolidate rapidly under load.

Fine grained soils such as clay have low permeability and because water passes very slowly through the pores they consolidate slowly.

Frost heave

The expansion of water in soils due to freezing atmospheric conditions was described in Volume 1. The expansion and consequent heaving of the soil occurs at the surface and for a depth of some 600 particularly in silty soils. The foundations of large buildings are generally some metres below the surface, at which level frost heave will have no effect in this country.

Non-cohesive coarse grained soils

Non-cohesive coarse grained soils such as gravels and sands consist of coarse grained, largely siliceous unaltered products of rock weathering. Gravels and sands composed of hard mineral particles have no plasticity and tend to lack cohesion especially when dry. Under pressure from the loads on foundations the soils in this group compress and consolidate rapidly by some rearrangement of the particles and the expulsion of water.

The three factors that principally affect the allowable bearing pressures on gravels and sands are density of packing of particles, grading of particles and size of particles. The denser the packing, the more widely graded the particles of different sizes and the larger the particles the greater the allowable bearing pressure.

Ground water level and the flow of water will adversely affect allowable bearing pressures in non-cohesive soils where ground water level is near to the foundation level and so affect the density of packing and where flow of water may wash out finer particles and so affect grading.

Non-cohesive soils must be laterally confined to prevent spread of the soil under pressure.

Cohesive fine grained soils

Cohesive fine grained soils such as clays and silts are a natural deposit of the finer siliceous and aluminous products of rock weathering. Clay is smooth and greasy to the touch, shows high plasticity, dries slowly and shrinks appreciably on drying. The principal characteristic of cohesive soils as a foundation is their susceptibility to slow volume changes. Under the pressure of the load on foundations, clay soils are very gradually compressed by the expulsion of water or water and air through the very many fine capillary paths so that buildings settle gradually during erection and this settlement will continue for some years after the building is completed.

Seasonal variations in ground water and vigorous growth of trees and shrubs will cause appreciable shrinkage, drying and wetting expansion of cohesive soils. Shrinkage and expansion due to seasonal variations will extend to one metre or more in periods of severe drought below the surface in Great Britain and up to four metres or more below large trees. When shrubs and trees are removed to clear a site for building on cohesive soils, for some years after the clearance there will be ground recovery as the soil gradually recovers water previously taken out by trees and shrubs. This gradual recovery of water by cohesive soils and consequent expansion may take several years.

Volume changes in cohesive soils under or around foundations close to the external faces of exposed buildings will be greater due to seasonal variations than under buildings which give protection from the effects of seasonal variations.

Peat and organic soils

Peat and organic soils have a high proportion of fibrous or spongy vegetable matter from the decay of plants mixed with varying proportions of fine sand, silt or clay. These soils are highly compressible and will not serve as a stable foundation for buildings.

Made-up ground and fill

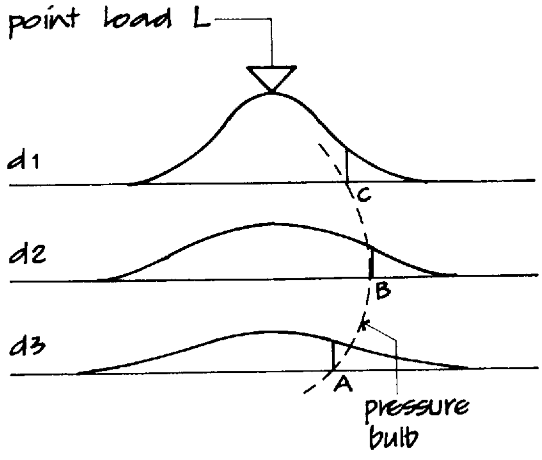
Made-up ground and fill will not usually serve as a stable foundation for buildings due to the extreme variability of the materials used to make up ground and the variability of the compaction or natural settlement of these materials.

Foundation design

Failure of the foundation of a building may be due to excessive settlement by compaction of subsoil, collapse of subsoil by failure in shear or differential settlement of different parts of the foundation. The allowable bearing pressure intensity at the base of foundations is the maximum allowable net loading taking into account the ultimate bearing capacity of the subsoil, the amount and type of settlement expected and the ability of the structure to take up the settlement. It is a combined function of both the site conditions and the characteristics of the particular structure.

Bearing pressures

The intensity of pressure on a subsoil is not uniform across the width or length of a foundation and decreases with depth below the foundation. In order to determine the probable behaviour of a soil under foundations the engineer needs to know the intensity of pressure on the subsoil at various depths. This is determined by Boussinesq's equation for the stress at any point below the surface of an elastic body and in practice is a reasonable approximation to the actual stress in soil. By applying the equation, the vertical stress on planes at various depths below a point can be calculated and plotted as shown in Fig. 4. The

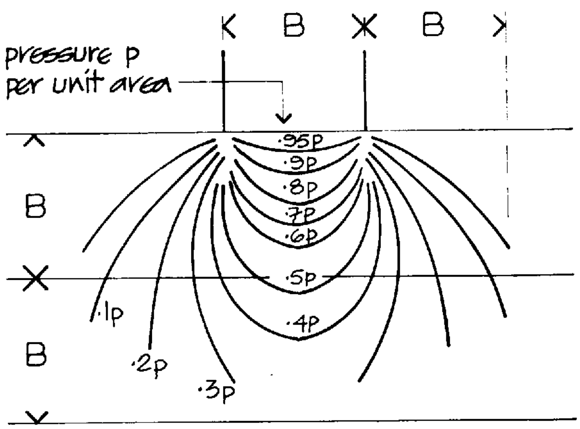


Vertical stress distribution

Fig. 4

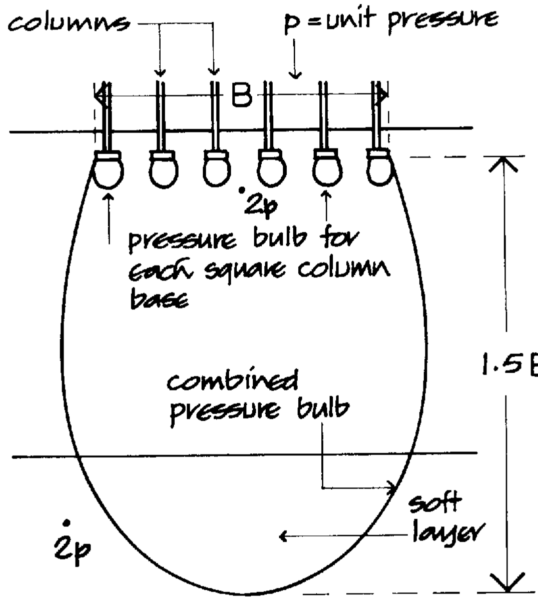
vertical ordinates at each level d_1, d_2, etc., represent graphically unit stress at points at that level. If points of equal stress, A, B, and C are joined the result is a bulb of unit pressure extending down from L. If this operation is repeated for unit area under a foundation the result is a series of bulbs of equal unit pressure as illustrated in Fig. 5.

Thus the bulb of pressure gives an indication of likely stress in subsoils at various points below a foundation. If there are separate foundations close together, as for example where there is a group of columns, then the bulbs of pressure can be combined to form one large pressure bulb diagram as illustrated in Fig. 6. Where bulbs of pressure of adjacent foundations intersect an increased intensity of pressure occurs.



Bulbs of vertical pressure under a strip foundation

Fig. 5



Combined pressure bulb

Fig. 6

It is because there are often strata of different soils below the surface that some knowledge of the intensity of pressure is necessary. For example, the soft layer in Fig. 6 is intersected by the combined pressure bulb; that may indicate that unit pressure is so great that the soft layer may fail. In practice it would be tedious to construct a bulb of pressure diagram each time a foundation were to be designed and engineers today generally employ ready prepared diagrams or charts to determine pressure intensities below foundations.

Contact pressure

A perfectly flexible foundation uniformly loaded will cause uniform contact pressure with all types of soil. A perfectly flexible foundation supposes a perfectly flexible structure supporting flexible floors, roof and cladding. The CLASP system of building commonly employed for schools uses a flexible frame (see Chapter 2) and was originally designed to accommodate movement in the foundation of buildings on land subject to mining subsidence. Most large buildings, however, have rigid foundations designed to support a rigid or semi-rigid frame.

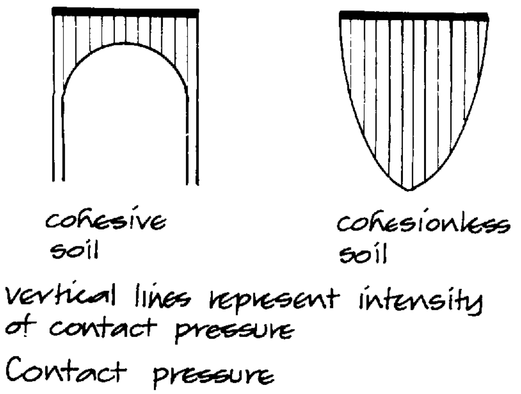


Fig. 7

The theoretical contact pressures between a perfectly rigid foundation and a cohesive and a cohesionless soil are illustrated in Fig. 7, the vertical ordinate representing intensity of contact pressure at points below the foundation. In practice the contact pressure on a cohesive soil such as clay is reduced at the edges of the foundation by yielding of the clay and as the load on the foundation increases more yielding of the clay takes place so that the stresses at the edges decrease and those at the centre of the foundation increase as illustrated in Fig. 8.

The contact pressure on a cohesionless soil such as dry sand remains parabolic as illustrated in Fig. 8 and the maximum intensity of pressure increases with increased load. If the foundation is below ground the edges stresses are no longer zero as illustrated in Fig. 8 and increase with increase of depth below ground.

For footings the assumption is made that contact pressure is distributed uniformly over the effective area of the foundation as differences in contact pressure are usually covered by the margin of safety used in design.

For large spread foundations and raft foundations

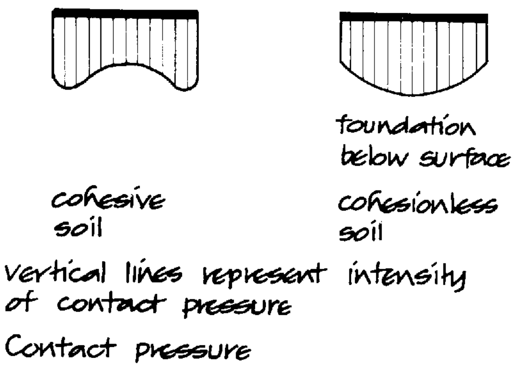


Fig. 8

it may be necessary to calculate the intensity of pressure at various depths.

An understanding of the distribution of contact pressures between foundation and soil will guide the engineer in his choice of foundation. For example, the foundation of a building on a cohesionless soil such as sand could be designed so that the more heavily loaded columns would be towards the edge of the foundation where contact pressure is least and the lightly loaded columns towards the centre to allow uniformity of settlement over the whole area of the building as illustrated in Fig. 9. Conversely a foundation on a cohesive soil such as clay would be arranged with the major loads towards the centre of the foundation where pressure intensity is least as illustrated in Fig. 10.

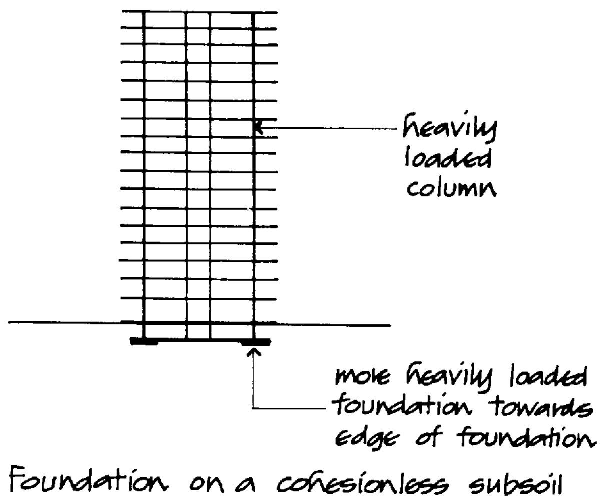


Fig. 9

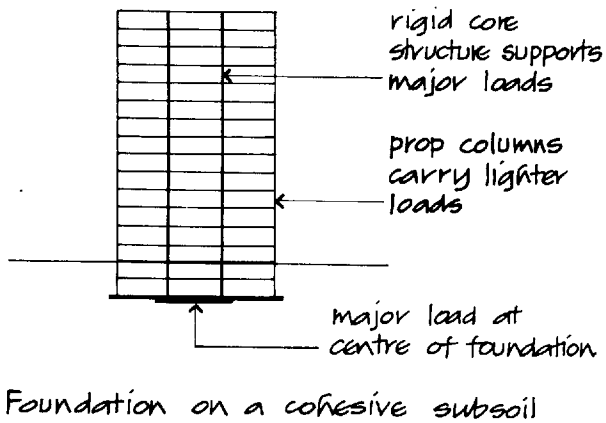


Fig. 10

Differential settlement (relative settlement)

Parts of the foundation of a building may suffer different magnitudes of settlement due to variations in load on the foundations or variations in the subsoil and different rates of settlement due to variations in the subsoil. These variations may cause distortion of a rigid or semi-rigid frame and consequent damage to rigid infill panels and cracking of loadbearing walls, rigid floors and finishes. Some degree of differential settlement is inevitable in the foundation of most buildings but so long as this is not pronounced or can be accommodated in the design of the building the performance of the building will not suffer.

The degree to which differential settlement will adversely affect a building depends on the structural system employed. Solid load bearing brick and masonry walls can accommodate small differential settlement through small hair cracks opening in mortar joints between the small units of brick or stone. These cracks, which are not visible, do not weaken the structure nor encourage the penetration of rain. More pronounced differential settlement such as is common between the main walls of a house and the less heavily loaded bay window bonded to it, may cause visible cracks in the brickwork at the junction of the bay window and the wall. Such cracks will allow rain to penetrate the thickness of the wall. To avoid this, either the foundation should be strengthened or some form of slip joint be formed at the junction of the bay and the main wall.

High, framed buildings are generally designed as rigid or semi-rigid structures and any appreciable differential settlement should be avoided. Differential settlement of more than 25 between adjacent columns of a rigid or semi-rigid framed structure may cause such serious racking of the frame that local stress at the junction of vertical and horizontal members of the frame may endanger the stability of the structure and also crack solid panels within the frame. An empirical rule employed by engineers in the design of foundations is to limit differential settlement between adjacent columns to $\frac{1}{500}$th of the distance between them.

Differential settlement can be reduced by a stiff structure or substructure or a combination of both. A deep hollow box raft (see later in Fig. 17) has the advantage of reducing net loading intensity and producing more uniform settlement.

A common settlement problem occurs in modern buildings where a tower or slab block is linked to a low podium. Plainly there will tend to be a more pronounced settlement of the foundations of the tower or slab block than the podium and at the junction of the two structures there must be structural discontinuity and some form of flexible joint that will accommodate the differences in settlement. Figure 11 illustrates two examples of this arrangement.

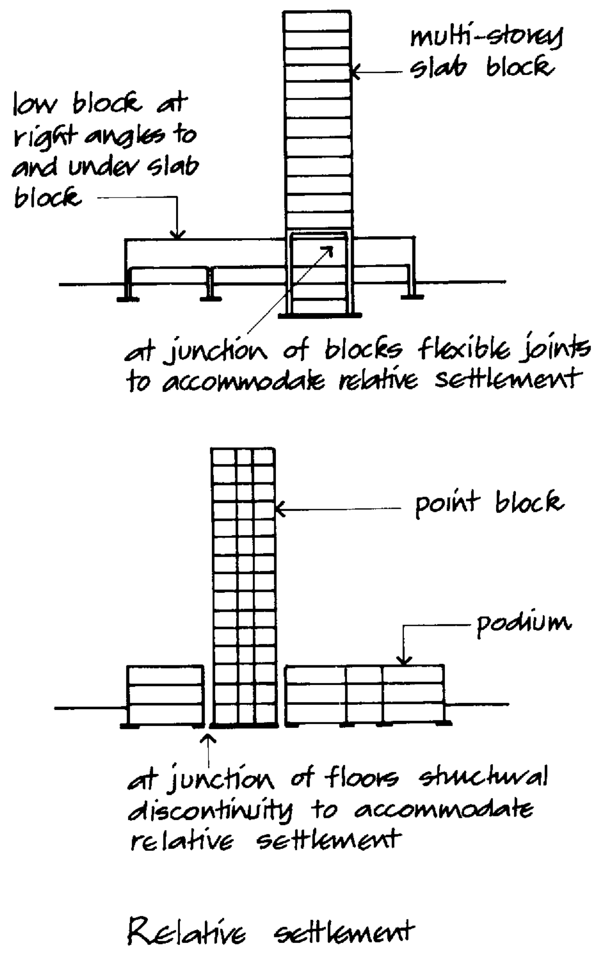


Fig. 11

FOUNDATIONS

Foundations may be classified as:

- Strip foundations
- Pad foundations
- Raft foundations
- Pile foundations

and these are illustrated in Fig. 12.

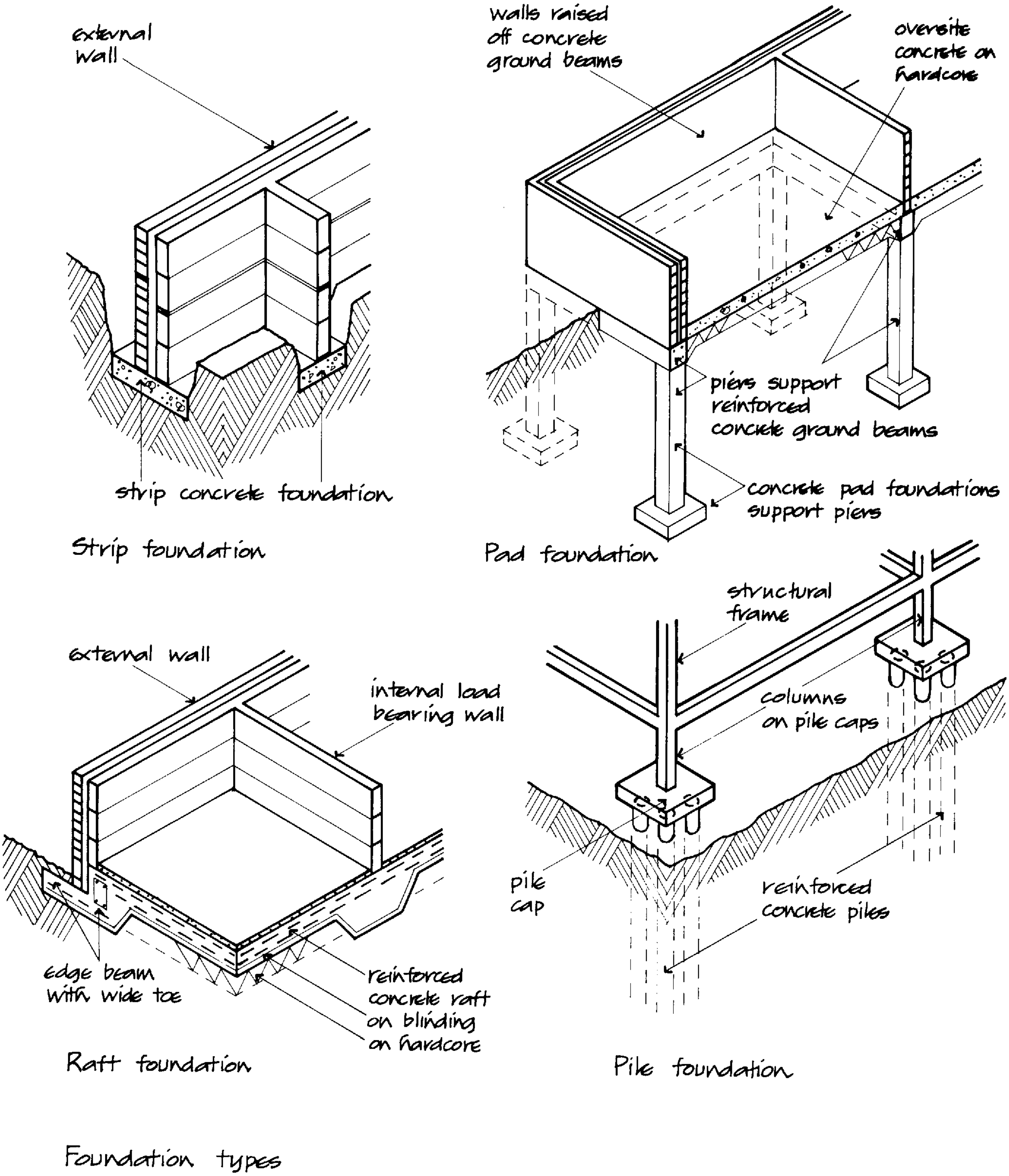

external wall
strip concrete foundation
Strip foundation
walls raised off concrete ground beams
oversite concrete on hardcore
piers support reinforced concrete ground beams
concrete pad foundations support piers
Pad foundation
external wall
internal load bearing wall
edge beam with wide toe
reinforced concrete raft on blinding on hardcore
Raft foundation
structural frame
columns on pile caps
pile cap
reinforced concrete piles
Pile foundation
Foundation types

Fig. 12

Strip foundations

Strip foundations (see Volume 1, Chapter 1) consist of a continuous, longitudinal strip of concrete designed to spread the load from uniformly loaded walls of brick, masonry or concrete to a sufficient area of subsoil. The spread of the strip depends on foundation loads and the bearing capacity and shear strength of the subsoil. The thickness of the foundation depends on the strength of the foundation material. Strip foundations with a wide spread are commonly of reinforced concrete, as illustrated in Fig. 13.

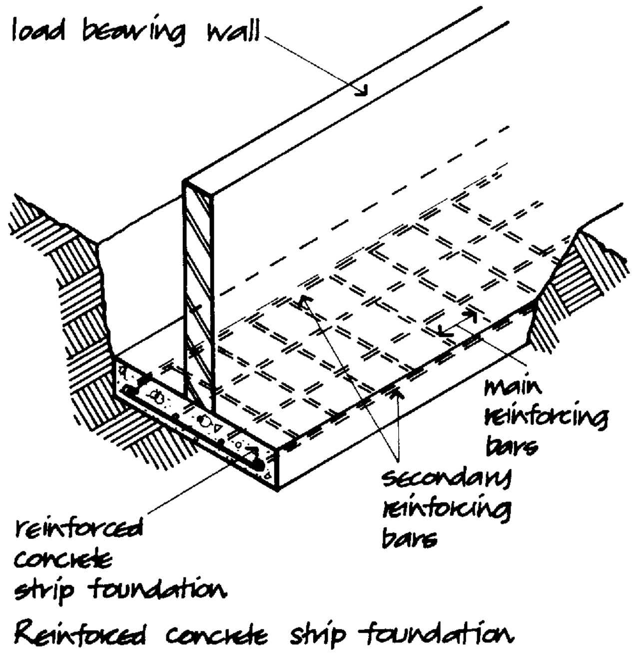


Fig. 13

Pad foundations

The foundation to piers of brick, masonry and reinforced concrete and steel columns is often in the form of a square or rectangular isolated pad of concrete to spread a concentrated load. The area of this type of foundation depends on the load on the foundation and the bearing and shear strength of the subsoil and its thickness on the strength of the foundation material. The simplest form of pad foundation consists of a pad of mass concrete as illustrated in Volume 1, illustrating a pier and foundation beam base for a small building. Heavily loaded pad foundations supporting columns of framed buildings are generally of reinforced concrete as illustrated in Fig. 14 showing the base of a reinforced concrete column. The area of the pad foundation is determined by the load of the foundation and the allowable bearing pressure on the subsoil and the thickness and reinforcement from a calculation of bending and shear stresses.

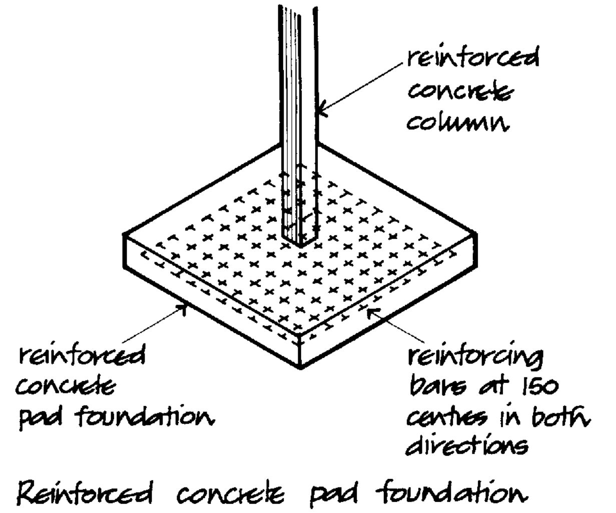


Fig. 14

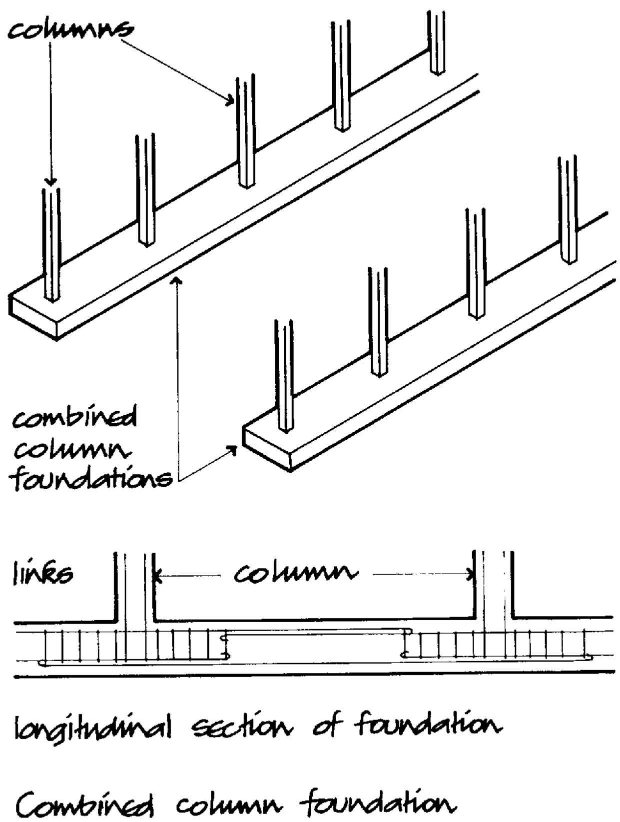
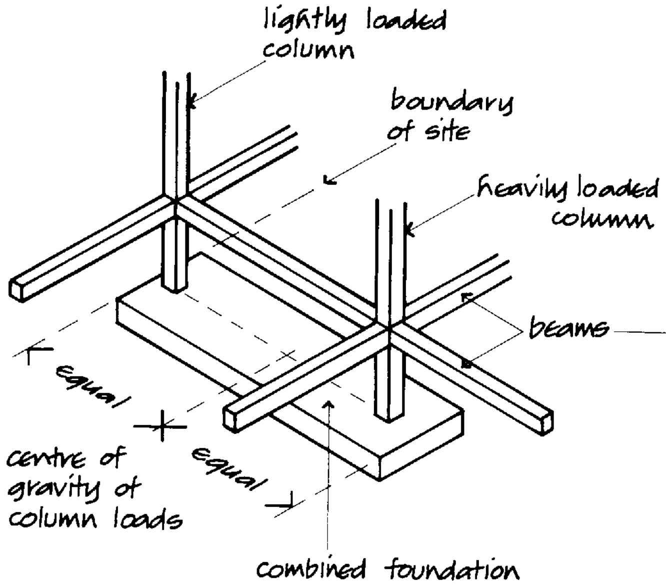
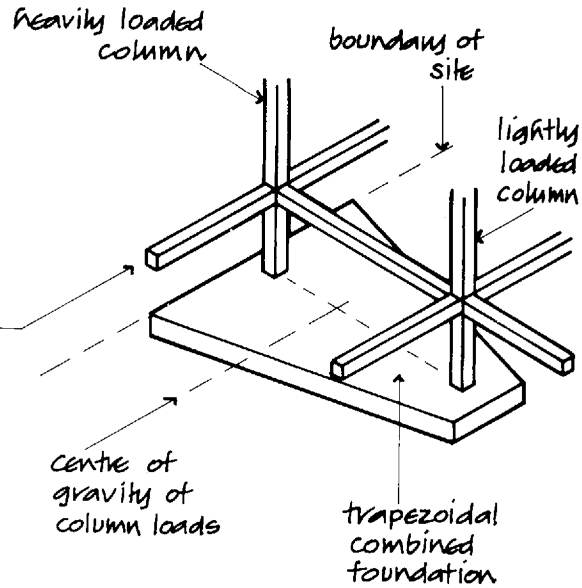


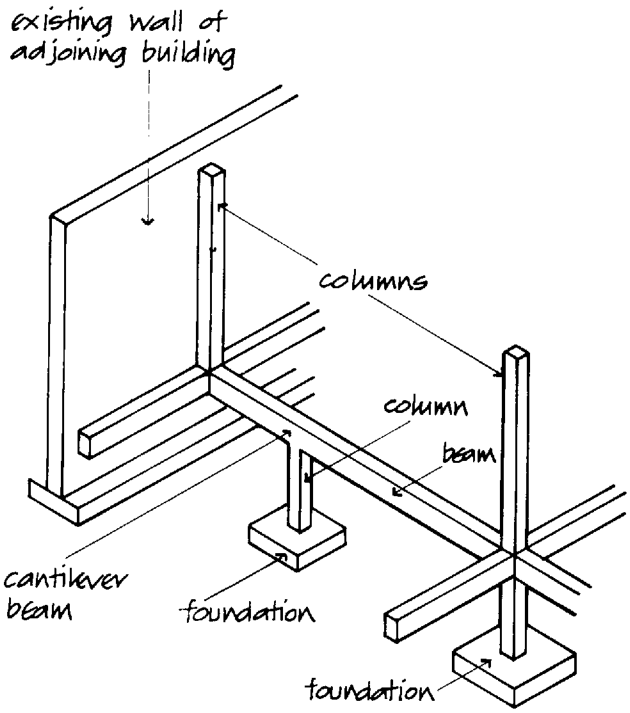
Fig. 15



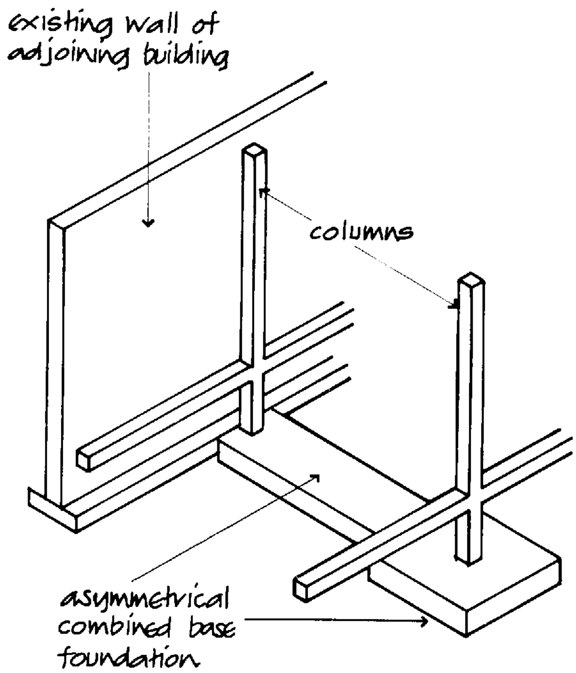
Rectangular combined base foundation



Trapezoidal combined base foundation



Cantilever beam foundation



Asymmetrical combined base foundation

Fig. 16

Where there is a wide spread of pad foundations to a framed building due to the low bearing capacity of the subsoil or the close spacing of columns, such that the edge of adjacent separate foundations would be close together, it may be economical and convenient to form one continuous column foundation, as illustrated in Fig. 15. This in effect is a reinforced concrete strip foundation supporting concentrated loads.

Combined foundations

The foundations of adjacent columns are combined (1) when a column is so close to the boundary of the site that a separate foundation would be eccentrically loaded and (2) where foundations of adjacent columns are linked to resist uplift, overturning or opposing forces.

Because the base of the column adjacent to the site boundary cannot spread uniformly around the column, it is combined with the base of an adjacent column to form a combined or balanced base foundation as illustrated in Fig. 16.

Where a framed building is to be erected alongside an existing building it is often necessary to use a cantilever or asymmetrical combined base founda-

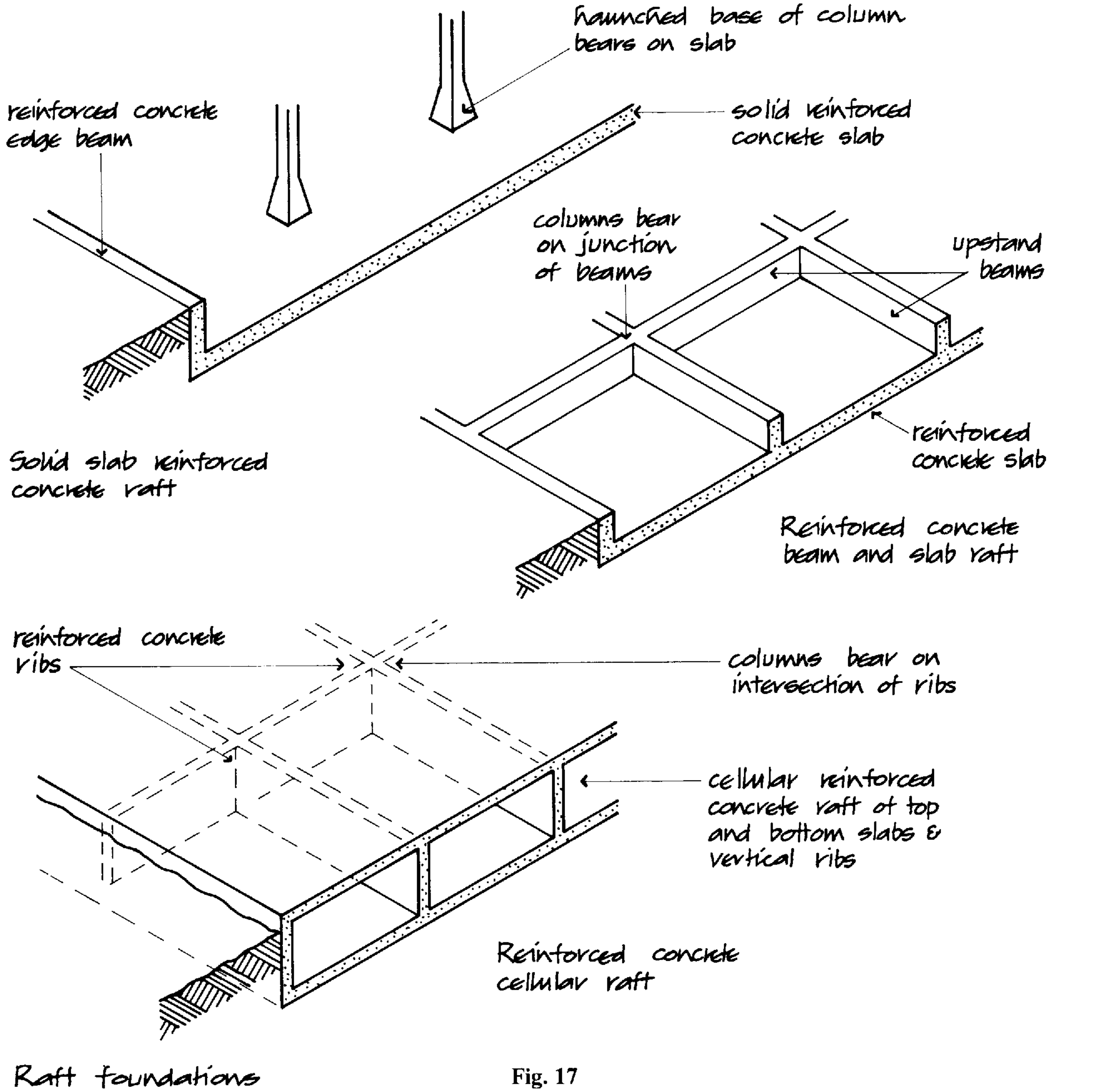


Fig. 17

tion for columns next to the existing building, so that pressure on the subsoil due to the base may not so heavily surcharge the subsoil under the foundation of the existing building as to cause it to settle appreciably. Cantilever and asymmetrical combined foundations are illustrated in Fig. 16.

Raft foundations

A raft foundation is continuous in two directions, usually covering an area equal to or greater than the base of a building or structure. Raft foundations are used for lightly loaded structures on soils with poor bearing capacity or where variations in soil conditions necessitate a considerable spread of the load, for heavier loads in place of isolated foundations, where differential settlements are significant and where mining subsidence is likely.

The three types of reinforced concrete raft foundations are:

- Solid slab raft
- Beam and slab raft
- Cellular raft

and these are illustrated in Fig. 17.

Solid slab raft foundation

Solid slab raft foundation is a solid reinforced concrete slab generally of uniform thickness, cast on subsoils of poor or variable bearing capacity, so that the loads from walls or columns of lightly loaded structures are spread over the whole area of the building. A solid slab raft of uniform thickness to support walls and a variant, a solid slab raft with stiffening edge beams are illustrated in Volume 1.

The solid slab raft foundation illustrated in Fig. 17 supports reinforced concrete columns. The columns have haunched bases to spread the point load and resist punching shear. The solid slab raft is cast below ground level with an upstand edge beam. The lower floor will take the form of a suspended timber floor.

Beam and slab raft foundation

As a foundation to support the heavier loads of walls or columns a solid slab raft would require considerable thickness. To make the most economical use of reinforced concrete in a raft foundation supporting heavier loads it is practice to form a beam and slab raft. This raft consists of upstand or downstand beams that take the loads of walls or columns and spread them to the monolithically cast slab which bears on natural subsoil.

On compact soils which can be excavated without the necessity of timbering to trenches it is economical to use downstand beams, illustrated in Fig. 18, and where the subsoil is granular, upstand beams may be necessary, also illustrated in Fig. 18.

Cellular raft foundation

Where differential settlements are likely to be significant and the foundations have to support considerable loads the great rigidity of the monolithically cast reinforced concrete cellular raft is an advantage. This type of raft consists of top and bottom slabs separated by and reinforced with vertical cross ribs in both directions, as illustrated in Fig. 17. The monolithically cast reinforced concrete cellular raft has great rigidity and spreads foundation loads over the whole area of the substructure to reduce consolidation settlement and avoid differential settlement.

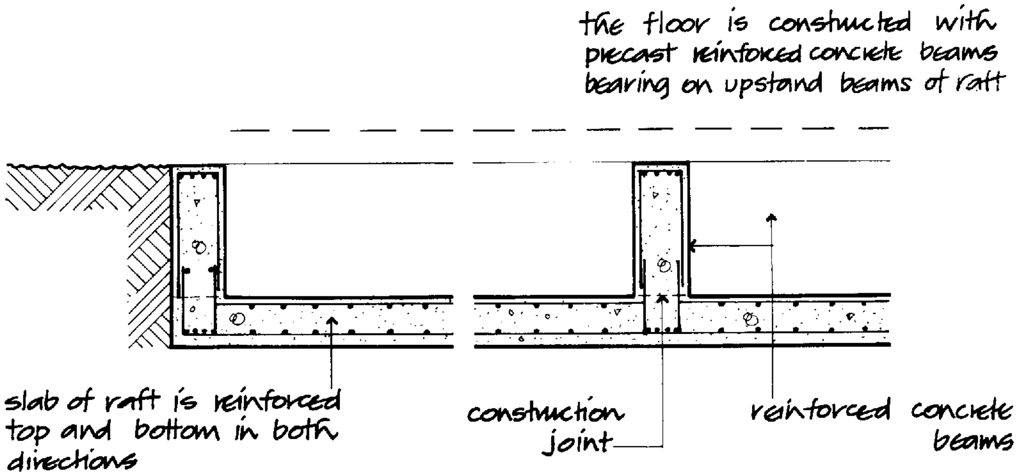
A cellular raft may be the full depth of a basement storey and the cells of the raft may be used for mechanical plant and storage.

A cellular raft is also used when deep basements are constructed to reduce settlement by utilising the overburden pressure that occurs in deep excavations. This negative or upward pressure occurs in the bed of deep excavations in the form of an upward heave of the subsoil caused by the removal of the overburden, which is taken out by excavation. This often quite considerable upward heave can be utilised to counteract consolidation settlement caused by the load of the building and so reduce overall settlement.

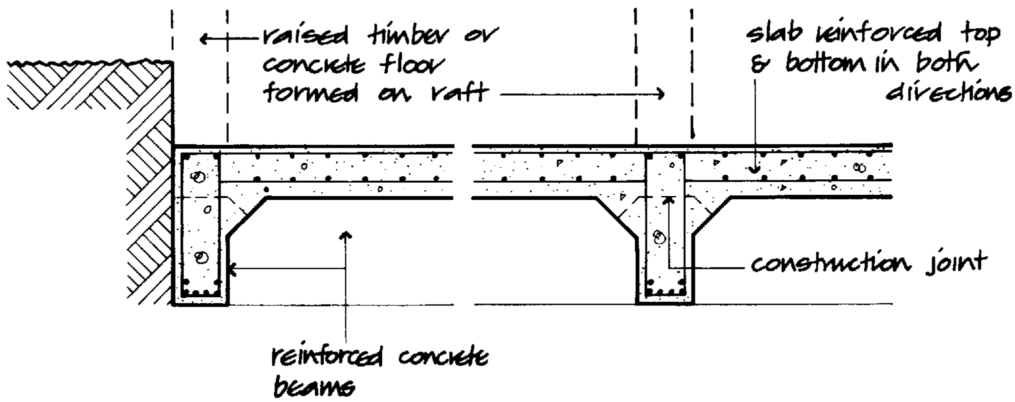
Pile foundations

The word pile is used to describe columns, usually of reinforced concrete, driven or cast in the ground in order to carry foundation loads to some deep underlying firm stratum or to transmit loads to the subsoil by the friction of their surfaces in contact with the subsoil.

The main function of a pile is to transmit loads to lower levels of ground by a combination of friction along their sides and end bearing at the pile point or base. Piles that transfer loads mainly by friction to clays and silts are termed *friction piles* and those that mainly transfer loads by end bearing to compact gravel, hard clay or rock are termed *end-bearing piles.*



Beam and slab raft with upstand beams



Beam and slab raft with downstand beams

Reinforced concrete beam and slab rafts

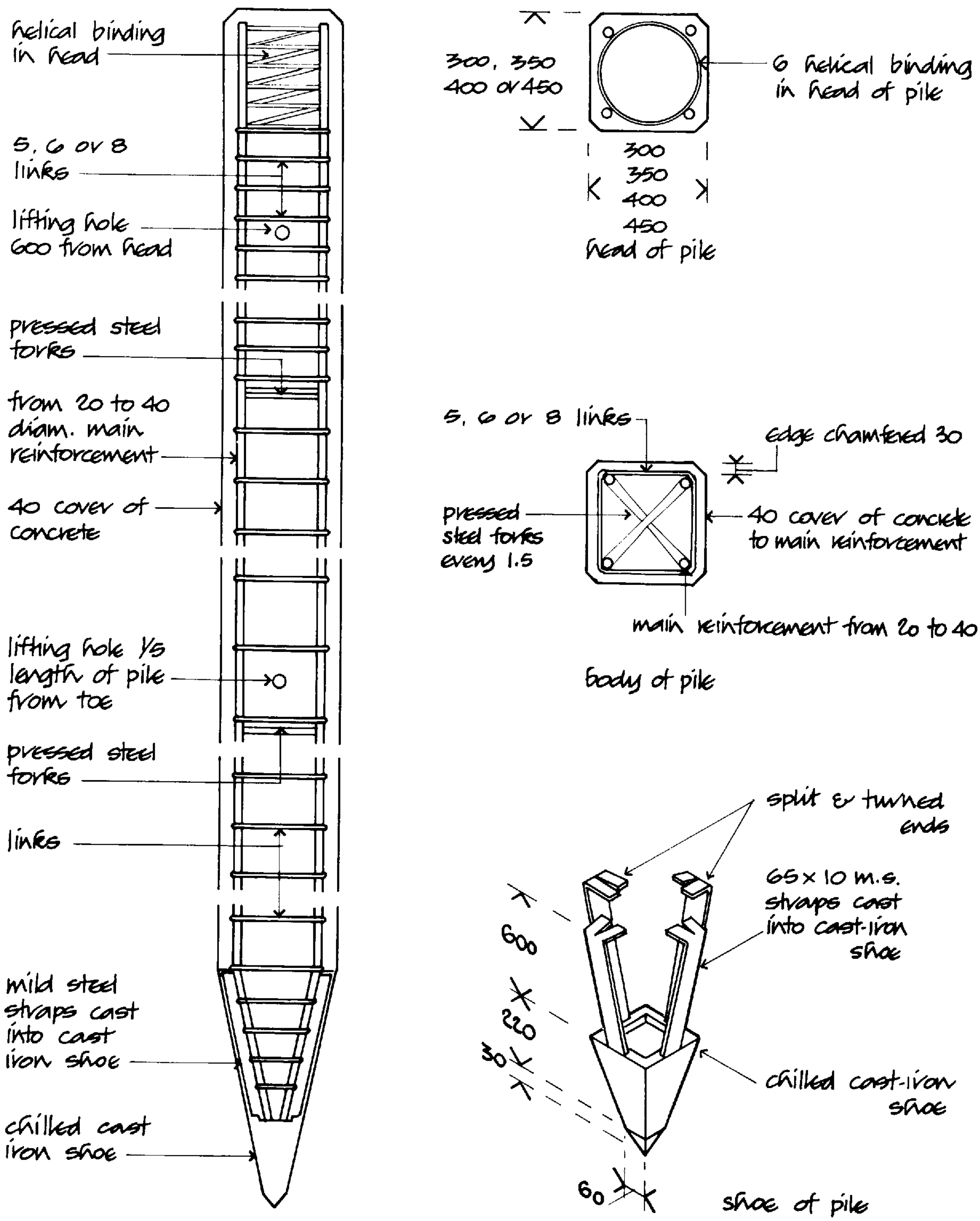
Fig. 18

Piles may be classified by their effect on the subsoil as *displacement piles* or *non-displacement piles. Displacement piles* are driven or otherwise forced into the ground to displace subsoil, such as solid piles and piles formed inside tubes which are driven into the ground and which are closed at their lower end by a shoe or plug which may either be left in place or extruded to form an enlarged toe. *Non-displacement piles* are formed by boring or other methods of excavation that do not substantially displace subsoil and where the borehole is lined with a casing or tube that is either left in place or extracted as the hole is filled.

Driven piles are those formed by driving a precast pile and those made by casting concrete in a hole formed by driving. *Bored piles* are those formed by casting concrete in a hole previously bored or drilled in the subsoil.

Driven piles

Square, polygonal or round section reinforced concrete piles are cast in moulds in the manufacturer's yard and are cured to develop maximum strength. The placing of the reinforcement and the mixing, placing compaction and curing of the concrete can be



Precast reinforced concrete piles

Fig. 19

accurately controlled to produce piles of uniform strength and cross-section. The piles are lifted into position and driven into the ground by means of a mechanically operated drop hammer attached to a mobile piling rig. Figure 19 is an illustration of a typical pile.

The pile is driven in until a predetermined 'set' is reached. The word set is used to describe the distance that a pile is driven into the ground by the force of the hammer falling a measurable distance. From the weight of the hammer and the distance it falls the resistance of the ground can be calculated and the bearing capacity of the pile calculated.

To connect the top of the precast pile to the reinforced concrete foundation the top 300 of the length of the pile is broken to expose reinforcement to which the reinforcement of the foundation is connected. Precast driven piles are not in general used on sites in built-up areas due firstly to difficulties in moving them through narrow streets and secondly to the nuisance caused by the noise of driving and the vibration caused by driving which might damage adjacent buildings. Driven piles are used as end-bearing piles in weak subsoils where they are driven to a firm underlying stratum. Driven piles give little strength in bearing due to friction of their sides in contact with soil, particularly when the surrounding soil is clay. This is due to the fact that the operation of driving moulds the clay around the pile and so reduces frictional resistance between the pile and the surrounding clay.

In coarse grained cohesionless soils where the piles do not reach a firm stratum, driven piles act as friction bearing piles due to the action of pile driving, which compacts the coarse particles around the sides of the pile and so increases frictional resistance and in compacting the soil increases its strength. This type of piled foundation is sometimes described as a floating foundation, as is a cast-in-place piled foundation, as bearing is mainly by friction and in effect the piles are floating in the subsoil rather than bearing on firm soil.

Prestressed concrete piles may be used in place of cast concrete piles. The advantages of a prestressed concrete pile are that, due to the prestress of the concrete the pile will have a smaller cross-sectional area than a comparable cast pile and the prestress will reduce tensile cracking of the pile and so give greater durability, particularly in water bearing soils.

Timber piles are little used for the foundations of buildings because of the difficulty of obtaining sufficiently large sections and lengths and because of the possibility of timber rotting underground.

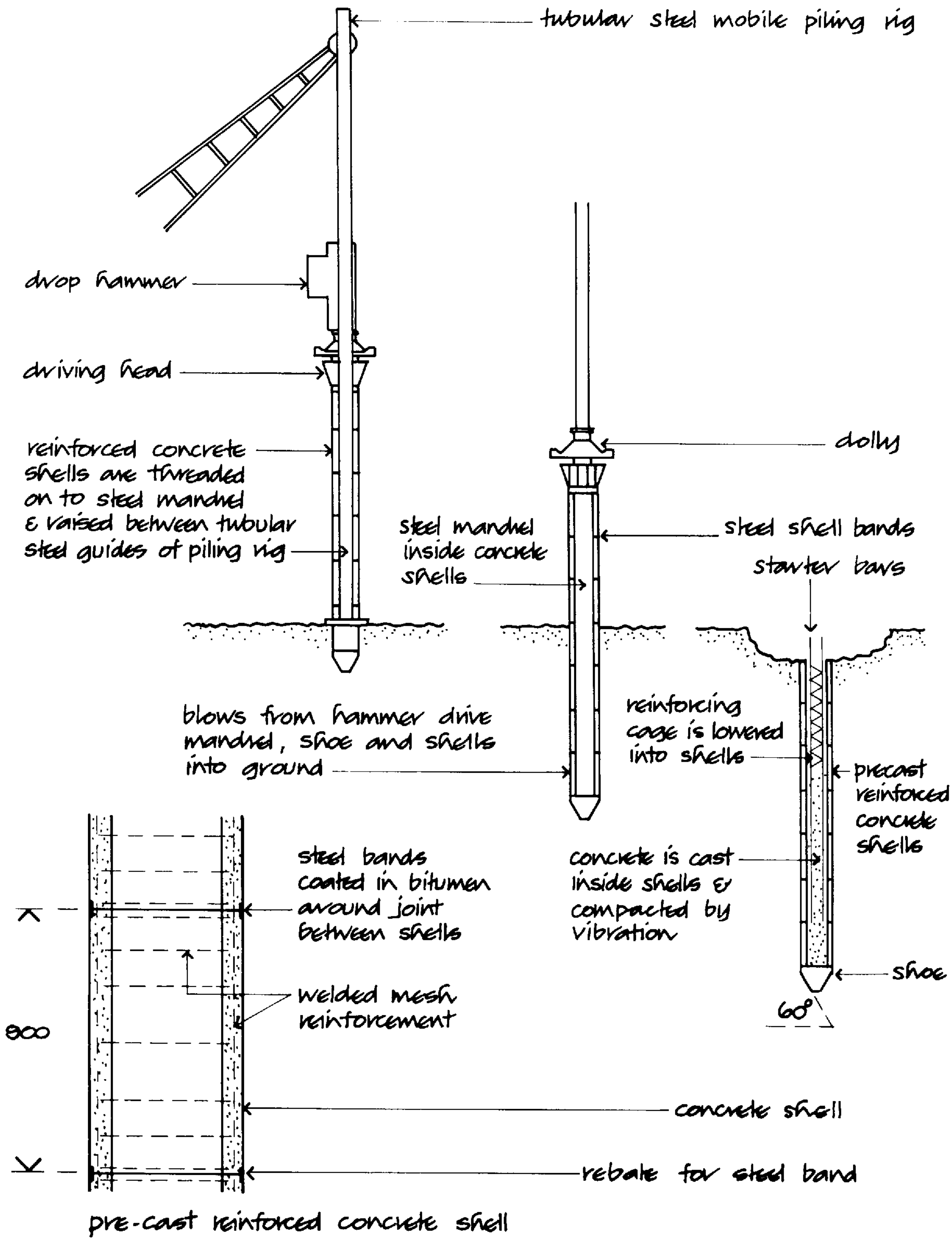
Driven cast-in-place piles

Driven cast-in-place piles are of two types, the first has a permanent steel or concrete casing and the second is without permanent casing. The purpose of driving and maintaining a permanent casing is to consolidate the subsoil around the pile casing by the action of driving, and the lining is left in place to protect the concrete cast inside the lining against weak strata of subsoil that might otherwise fall into the pile excavation and to protect the green concrete of the pile against static or running water.

Figure 20 is an illustration of a driven cast-in-place pile with a permanent reinforced concrete casing. Precast reinforced concrete shells are threaded on a steel mandrel. Metal bands and bitumen seal joints between shells. The mandrel and shells are lifted on to the piling rig and then driving into the ground. At the required depth the mandrel is removed, a reinforcing cage is lowered into the shells and the pile completed by casting concrete inside the shells. This type of pile is used principally in soils of poor bearing capacity and saturated soils where the concrete shells protect the green concrete cast inside them, from static or running water.

A driven cast-in-place pile without permanent casing is illustrated in Fig. 21. The base of a steel lining tube, supported on a piling rig, is filled with ballast. A drop hammer rams the ballast and the tube into the ground and at the required depth the tube is restrained and the ballast is hammered in to form an enlarged toe as shown. Concrete is placed by hammering it inside the lining tube which is gradually withdrawn. The effect of driving the tube and the ballast into the ground is to compact the soil around the pile and the subsequent hammering of the concrete consolidates it into pockets and weak strata. The enlarged toe provides additional bearing area at the base of the pile. This type of pile acts mainly as a friction pile.

Another type of driven cast-in-place pile without permanent casing is formed by driving a lining tube with cast iron shoe into the ground with a piling hammer operating in a piling rig as illustrated in Fig. 22. Concrete is placed by hammering the lining tube as it is withdrawn. The particular application of this type of pile is for piles formed through a substratum so compact as to be incapable of being taken out by



Driven cast-in-place pile

Fig. 20

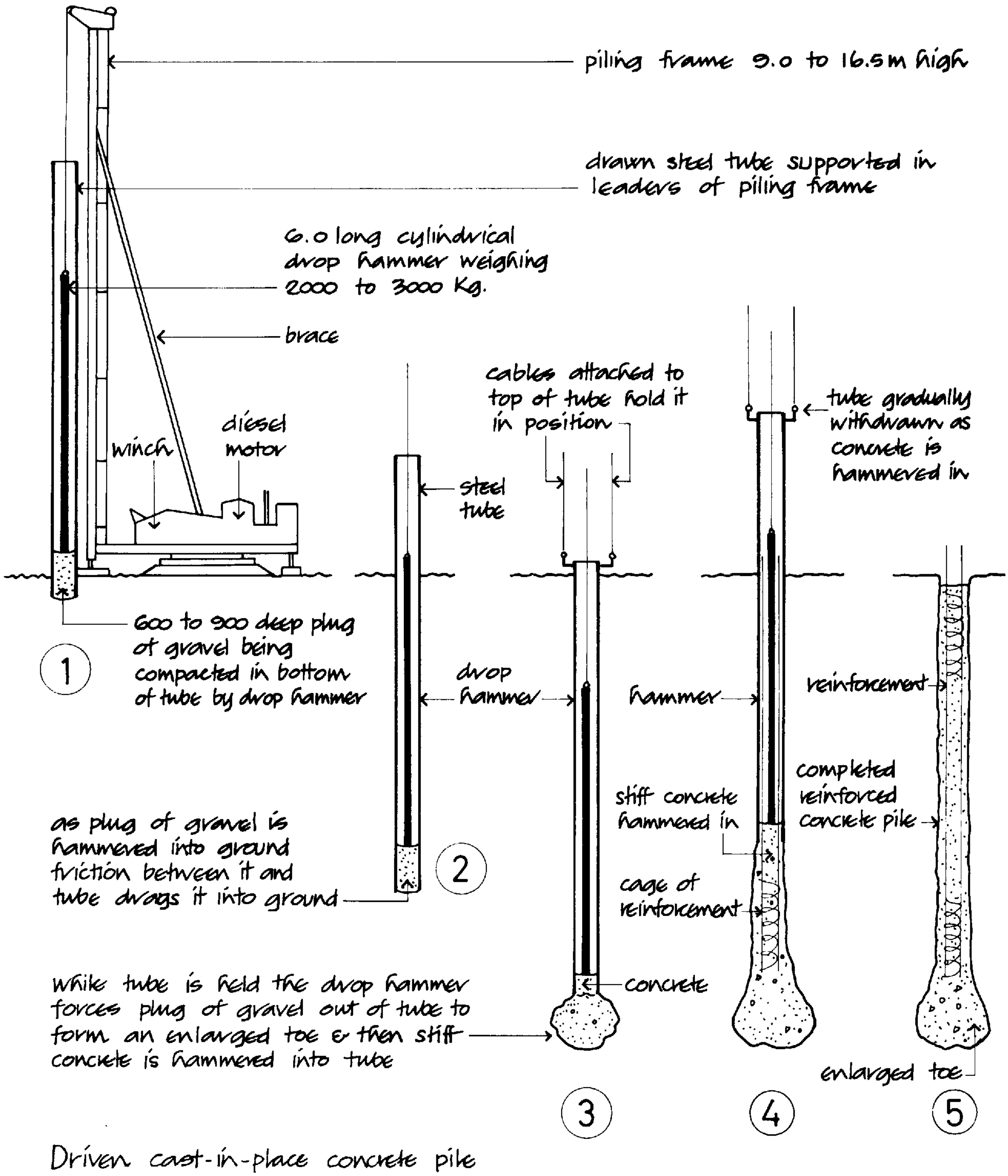

piling frame 9.0 to 16.5m high
drawn steel tube supported in leaders of piling frame
6.0 long cylindrical drop hammer weighing 2000 to 3000 Kg.
brace
winch
diesel motor
600 to 900 deep plug of gravel being compacted in bottom of tube by drop hammer
1
steel tube
as plug of gravel is hammered into ground friction between it and tube drags it into ground
2
drop hammer
cables attached to top of tube hold it in position
concrete
while tube is held the drop hammer forces plug of gravel out of tube to form an enlarged toe & then stiff concrete is hammered into tube
3
tube gradually withdrawn as concrete is hammered in
hammer
stiff concrete hammered in
cage of reinforcement
4
reinforcement
completed reinforced concrete pile
enlarged toe
5
Driven cast-in-place concrete pile

Fig. 21

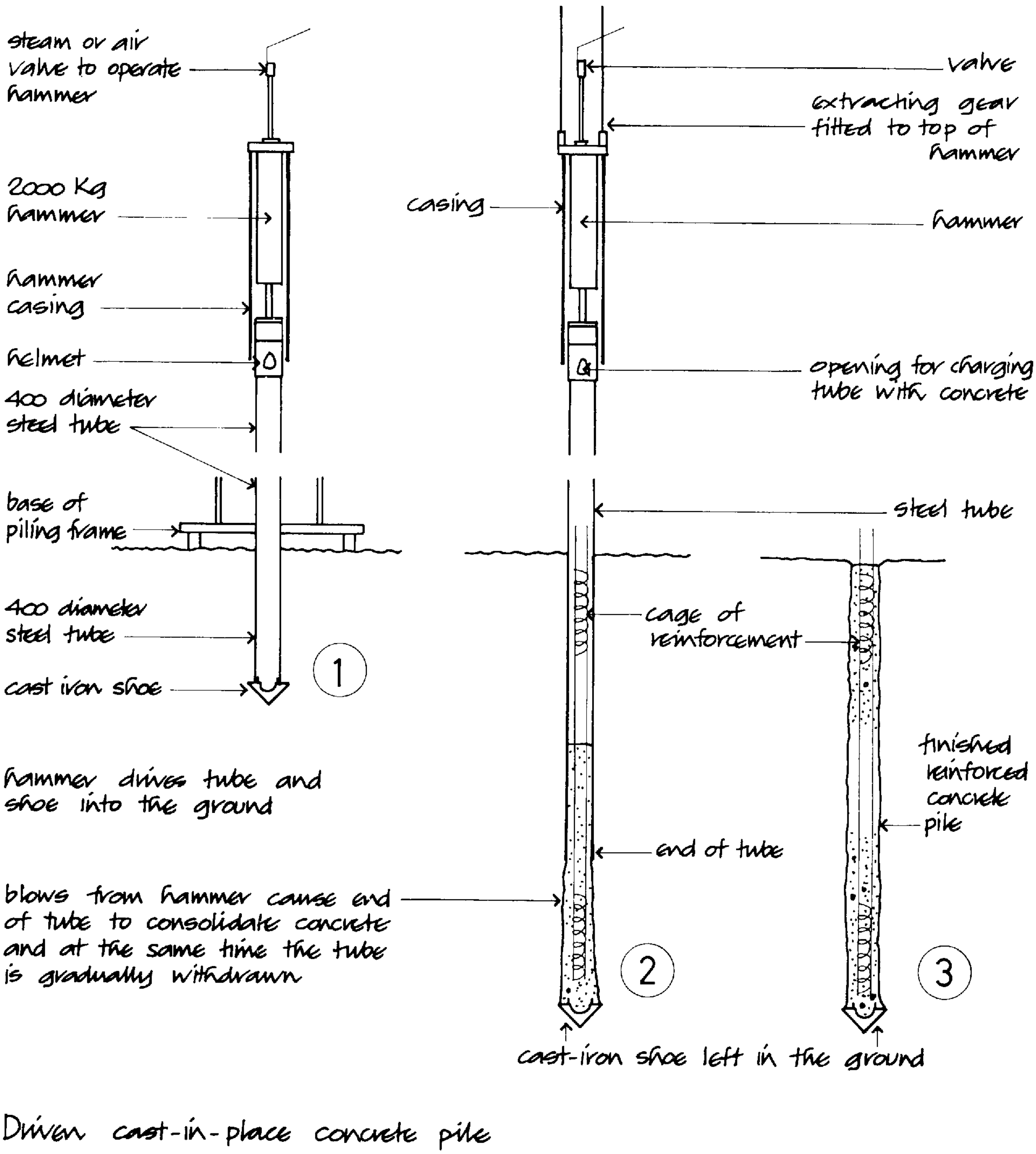


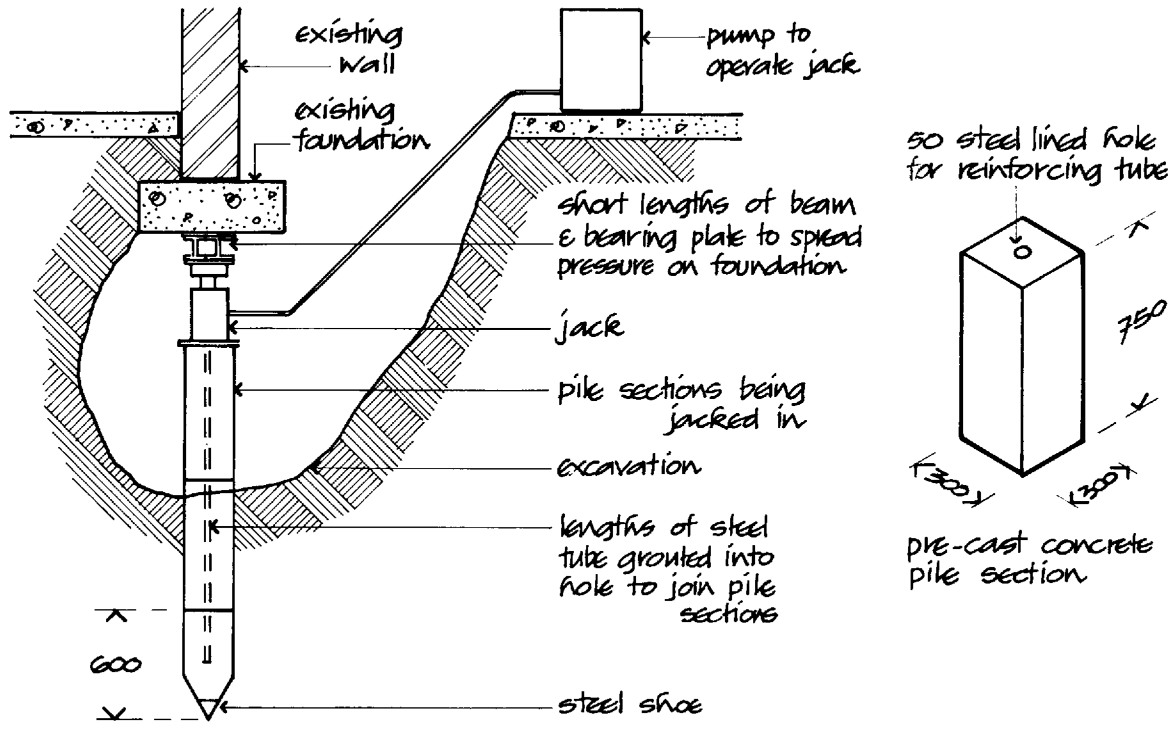
Fig. 22

drilling. The purpose of the cast iron shoe, which is left in the ground, is to penetrate the compact stratum through which the pile is formed.

Jacked piles

Figure 23 illustrates a system of jacked piles that are designed for use in cramped working conditions, as for example where an existing wall is to be underpinned and headroom is restricted by floors and in situations where the vibration caused by pile driving might damage existing buildings.

Where the wall to be underpinned has a sound concrete base the pile sections are jacked into the ground under the base, as illustrated in Fig. 23, and a concrete cap is cast on top of the pile and up to the



Pre-cast concrete jacked pile for underpinning

Fig. 23

underside of the concrete base. When the wall to be underpinned has a poor base and the wall might be disturbed by jacking piles under it, then pairs of piles are jacked in each side of the wall to support steel or reinforced concrete needles that in turn support the weight of the wall.

The precast concrete sections are jacked into the ground, as illustrated, and lengths of tube are grouted inside the steel lined hole in each section to make a strong connection between sections.

Piles formed on both sides of the wall are jacked in against units loaded with kentledge.

Bored piles

A hole is bored or drilled by means of earth drills or mechanically operated augers which withdraw soil from the hole into which the pile is to be cast. Usually steel lining tubes are lowered or knocked in, as the soil is taken out, to maintain the sides of the drilling. As the pile is cast the lining tubes are gradually withdrawn.

The principal advantages of bored piles are that light, easily manipulated equipment may be used for the work and that a precise analysis of the subsoil strata is obtained from the soil withdrawn during drilling. Disadvantages are that it is not possible to check that the concrete is adequately compacted and that there is adequate cover of concrete to reinforcement.

Figure 24 illustrates the drilling and casting of a bored cast-in-place pile. Soil is withdrawn from inside the lining tubes with a cylindrical clay cutter that is dropped into the hole, bites into the cohesive soil, is withdrawn and the soil knocked out of it. Coarse grained soil is withdrawn by dropping a shell cutter (or bucket) into the hole. Soil, retained on the upward hinged flap, is emptied when the cutter is withdrawn. The operation of boring the hole is more rapid than might be supposed and a pile can be bored and cast in a matter of hours.

Concrete is cast under pressure through a steel helmet which is screwed to the top of the lining tubes. The application of air pressure at once compacts the concrete and simultaneously lifts the helmet and lining tubes as the concrete is compacted. As the

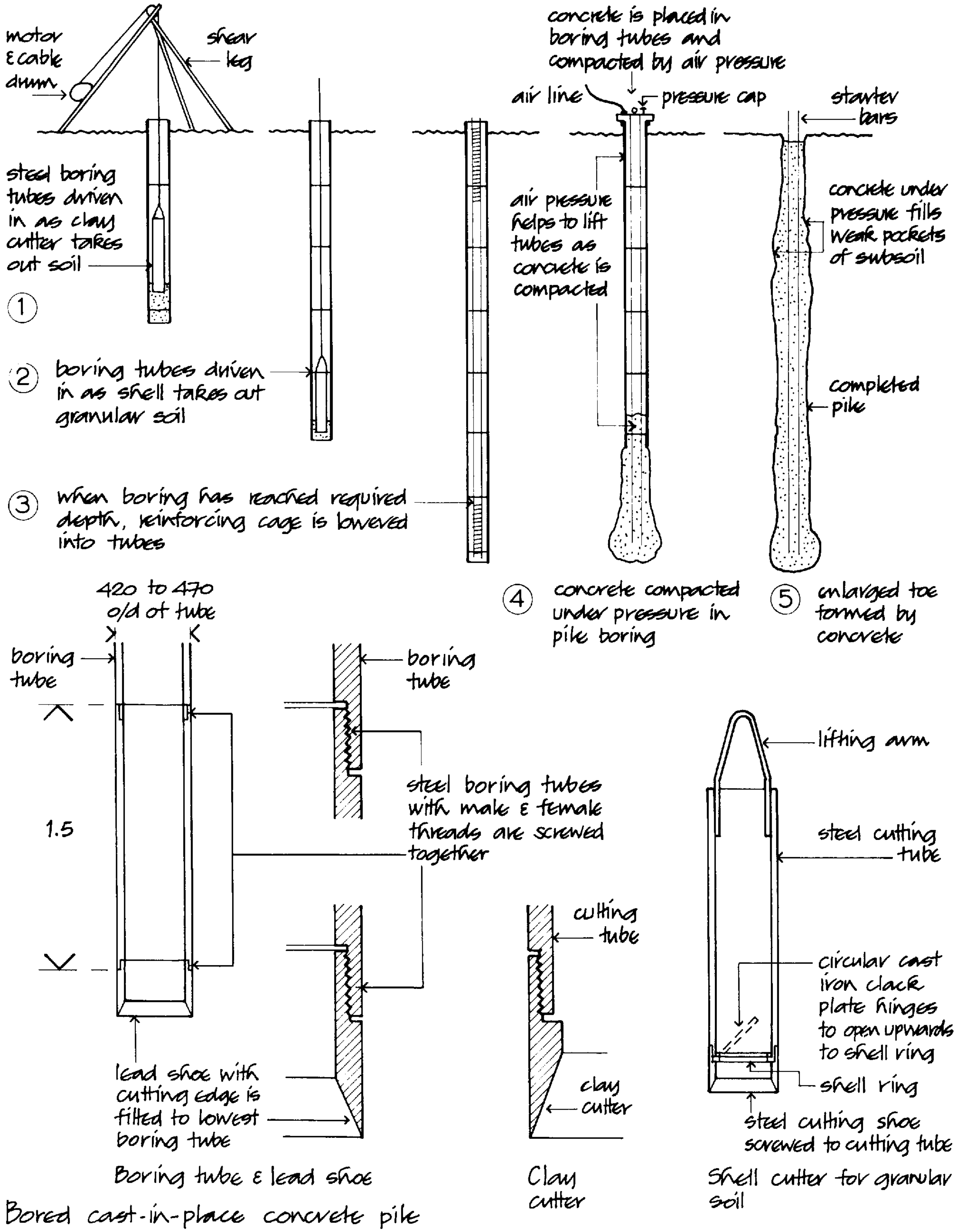

motor & cable drum
shear leg
steel boring tubes driven in as clay cutter takes out soil
1
2 boring tubes driven in as shell takes out granular soil
3 when boring has reached required depth, reinforcing cage is lowered into tubes
concrete is placed in boring tubes and compacted by air pressure
air line
pressure cap
air pressure helps to lift tubes as concrete is compacted
4 concrete compacted under pressure in pile boring
starter bars
concrete under pressure fills weak pockets of subsoil
completed pile
5 enlarged toe formed by concrete
420 to 470 o/d of tube
boring tube
1.5
steel boring tubes with male & female threads are screwed together
lead shoe with cutting edge is fitted to lowest boring tube
Boring tube & lead shoe
cutting tube
clay cutter
Clay cutter
lifting arm
steel cutting tube
circular cast iron clack plate hinges to open upwards to shell ring
shell ring
steel cutting shoe screwed to cutting tube
Shell cutter for granular soil
Bored cast-in-place concrete pile

Fig. 24

lining tubes are withdrawn, protruding sections are unscrewed and the helmet refixed until the pile is completed.

As the concrete is cast under pressure it extends beyond the circumference of the original drilling to fill and compact weak strata and pockets in the subsoil, as illustrated in Fig. 24. Because of the irregular shape of the surface of the finished pile it acts mainly as a friction pile to form what is sometimes called a floating foundation.

Figure 25 illustrates the formation and casting of a large diameter bored pile. A tracked crane supports hydraulic rams and a diesel engine which operates a Kelly bar and rotary bucket drill. The diesel engine rotates the Kelly bar and bucket in the bottom in which angled blades excavate and fill the bucket with soil. The hydraulic rams force the bucket into the ground. The filled bucket is raised and emptied and drilling proceeds. In non-cohesive soils the excavation is lined with steel lining tubes. To provide increased end bearing the drill can be belled out to twice the diameter of the pile.

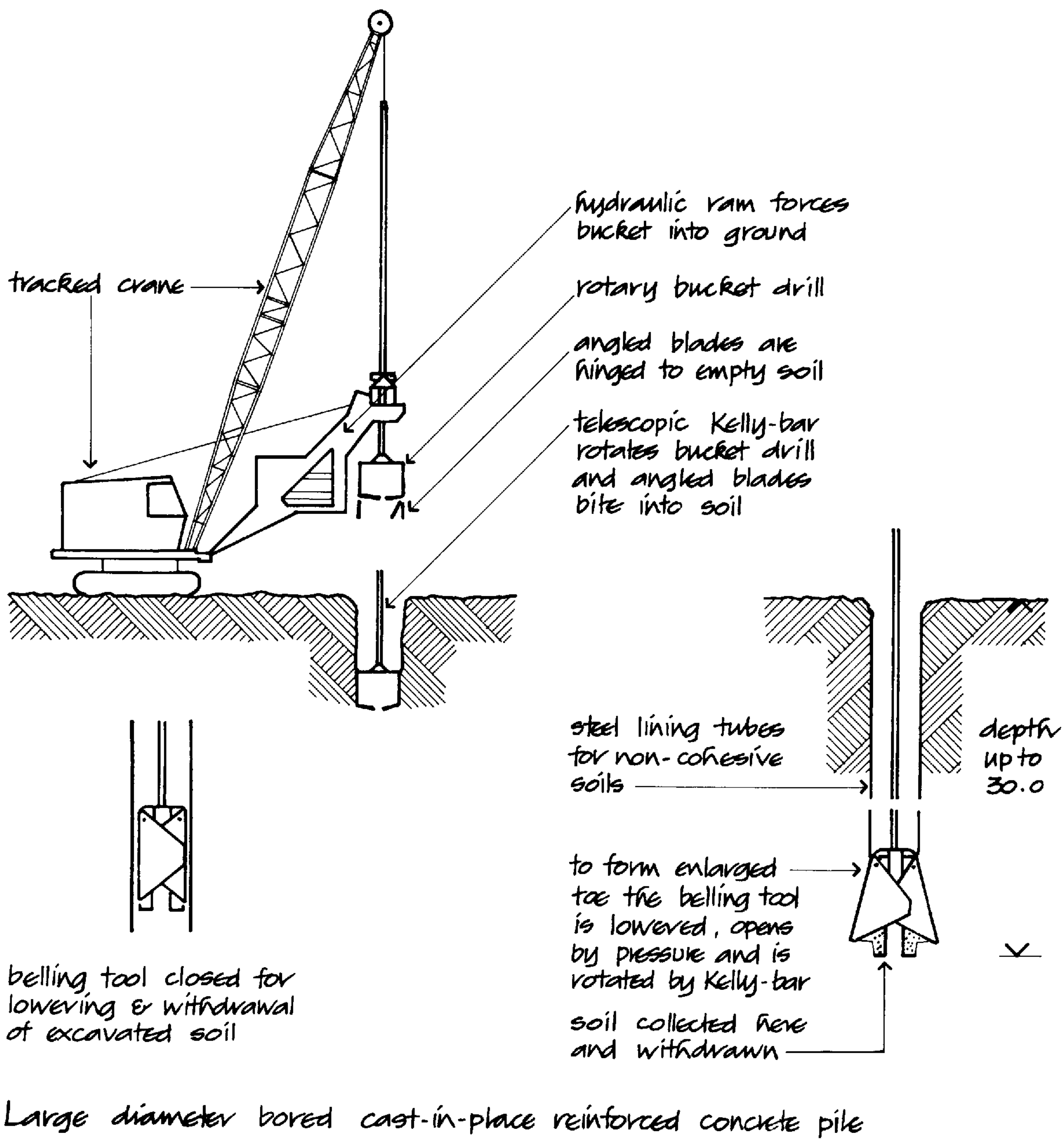


Fig. 25

Spacing of piles

The spacing of piles should be wide enough to allow for the necessary number of piles to be driven or bored to the required depth of penetration without damage to adjacent construction or to other piles in the group. Piles are generally formed in comparatively close groups for economy in the size of the pile caps to which they are connected.

As a general rule the spacing, centre to centre of friction piles, should be not less than the perimeter of the pile and the spacing of end-bearing piles not less than twice the least width of the pile.

Pile caps

Piles may be used to support pad, strip or raft foundations. Commonly a group of piles is used to support a column or pier base. The load from the column or pier is transmitted to the piles through a reinforced concrete pile cap which is cast over the piles. To provide structural continuity the reinforcement of the piles is linked to the reinforcement of the pile caps through starter bars protruding from the top of the cast-in-place piles or through reinforcement exposed by breaking off the top concrete from precast piles. Figure 26 illustrates typical arrangements of pile caps.

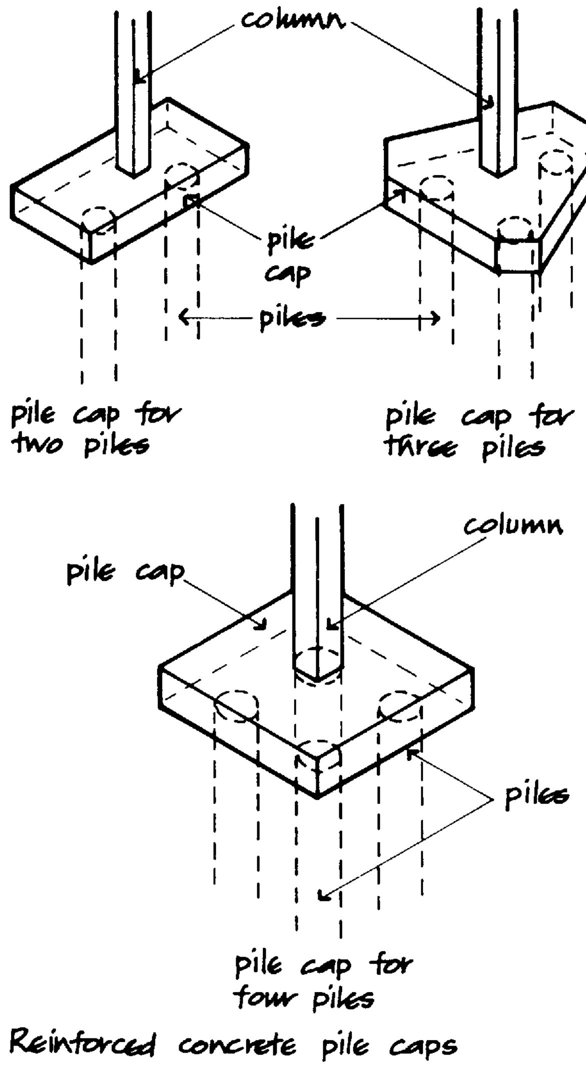


Fig. 26

SUBSTRUCTURES

The substructure of multi-storey buildings is often constructed below natural or artificial ground level.

In towns and cities the ground for some metres below ground level has often been filled, over the centuries, to an artificial level. Filled ground is generally of poor and variable bearing capacity which is not improved by building operations to form a foundation at a lower level. It is generally necessary and expedient, therefore, to remove the artificial ground and construct a substructure or basement of one or more floors below ground. Similarly, where there is a top layer of natural ground of poor and variable bearing capacity, it is often removed and a substructure formed. Where there are appreciable differences of level on a building site a part or the whole of the building may be below ground level as a substructure.

The natural or artificial ground around the substructure is often permeable to water and may retain water to a level above that of the lower level or floor of a substructure. Ground water in soil around a substructure will impose pressure on both the walls and floor of a substructure. This, often considerable pressure of water, may well penetrate small shrinkage and movement cracks in dense concrete walls and floors and dense solidly built brick walls.

To limit the penetration of ground water under pressure it is practice to build in water stops across construction and movement joints in concrete walls and floors and to line brick walls and concrete floors with a layer of impermeable material in the form of a waterproof lining like a tank, hence the term 'tanking to basements'.

Another approach is to accept that there will be some penetration of ground water and construct an enclosing wall of dense concrete with water stops, separate from and around the substructure, so that water penetrating the outer walls drains to a sump outside the substructure enclosing walls.

Waterstops to concrete walls and floors

Dense concrete, which is practically impermeable to water, would by itself effectively exclude ground water were it possible to prevent shrinkage, constructional, structural, thermal and moisture movement cracks. As concrete dries out after placing it shrinks and this inevitable drying shrinkage causes cracks particularly at construction joints, through which ground water will penetrate. To minimise shrinkage cracks it is practice to cast adjacent bays or areas of concrete in floors and walls with a gap of 450 or 600 between them. When the bays of concrete have dried out for some days and much of the drying shrinkage has taken place, concrete is then cast into the spaces

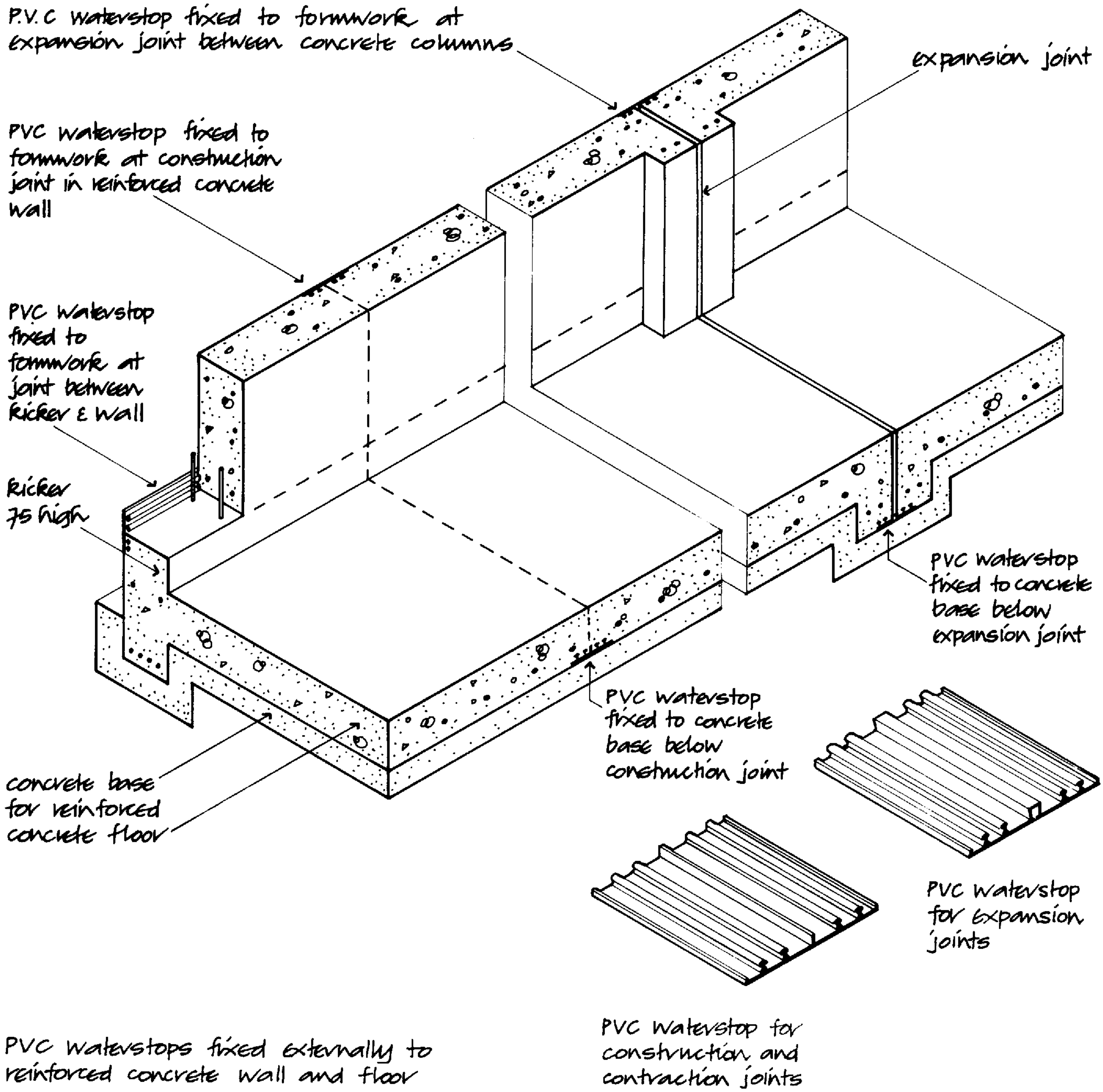


Fig. 27

between the bays. This procedure reduces overall shrinkage at the expense of an increase in construction joints which are in themselves a source of weakness.

Waterstops

As a barrier to penetration of water through construction joints and expansion joints in concrete, waterstops are fixed and cast against or cast into the thickness of concrete floors and walls.

PVC waterstops are cast into the underside of floors and the outside face of concrete walls across construction joints and expansion joints, as illustrated in Fig. 27. These flat faced waterstops are bonded to the concrete base under floors and fixed to the face of formwork for walls so that concrete is placed and compacted around the dumbell projections on the stops each side of the joint. The waterstop for expansion joints has a centre bulb that protrudes into the expansion joint to provide flexibility against movement. At the junction of joints, preformed cross-over sections of stop are heat welded to straight lengths of waterstop.

Rubber waterstops are cast into the thickness of concrete walls and floors as illustrated in Fig. 28. Plain web stops are cast in at construction joints and

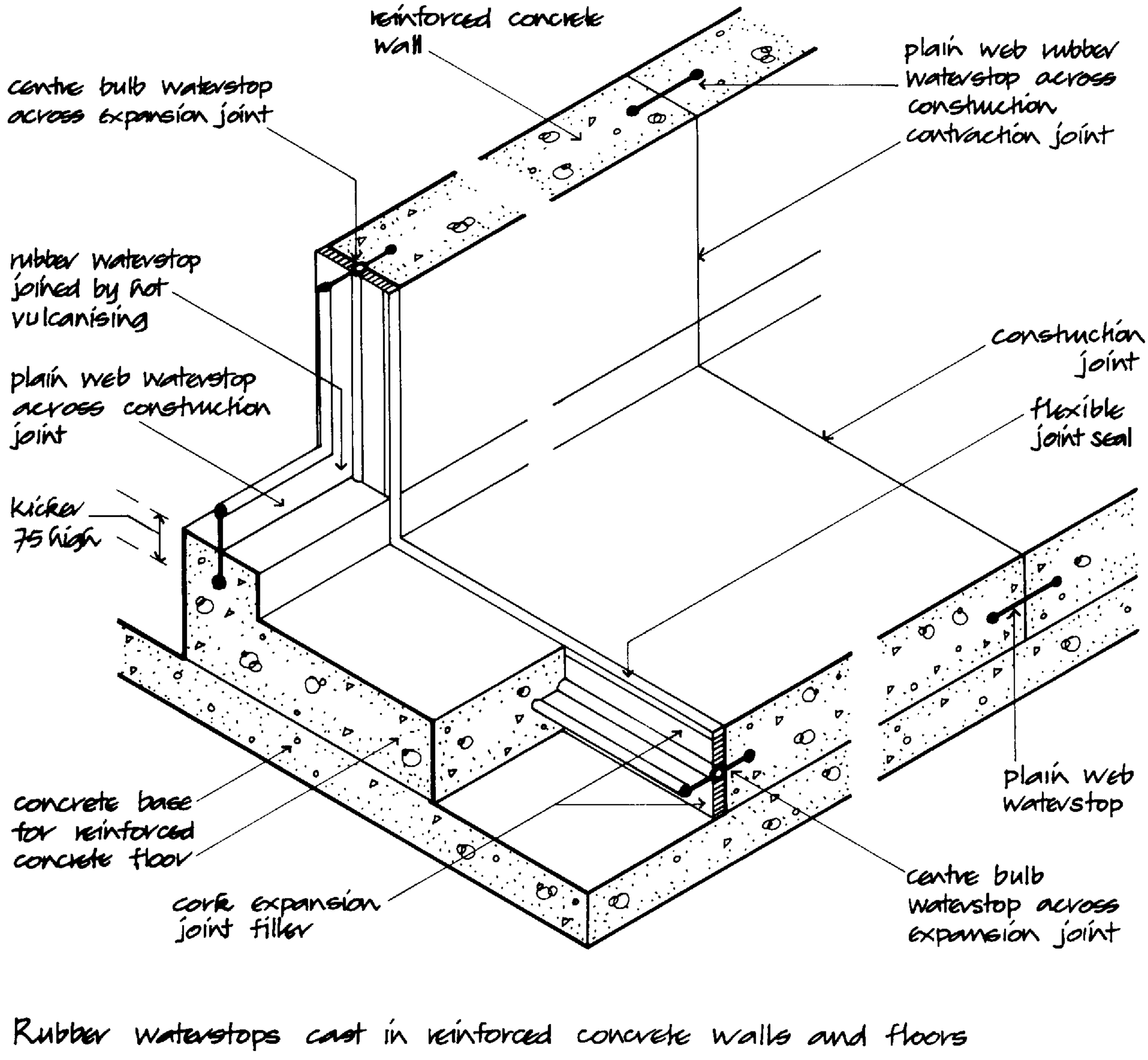


Fig. 28

centre bulb stops at expansion joints. These stops must be firmly fixed in place and supported with timber edging to one side of the stop so that concrete can be placed and compacted around the other half of the stop without moving it out of place. At the junction of joints the stops are joined by hot vulcanising.

For waterstops to be effective concrete must be placed and firmly compacted up to the stops and the stops must be secured in place to avoid them being displaced during placing and compacting of concrete. Waterstops will be effective in preventing penetration of water through joints providing they are solidly cast up to or inside sound concrete and there is no gross contraction at construction joints or movement at expansion joints.

Tanking

The term tanking is used to describe a continuous waterproof lining to the walls and floors of substructures to act as a tank to exclude water.

Mastic asphalt

The traditional material for tanking is mastic asphalt (see Chapter 4, Volume 1) which is applied and spread hot in three coats to a thickness of 20 for vertical and 30 for horizontal work. Joints between each laying of asphalt in each coat should be staggered at least 75 for vertical and 150 for horizontal work with the joints in succeeding coats. Angles are reinforced with a two coat fillet of asphalt.

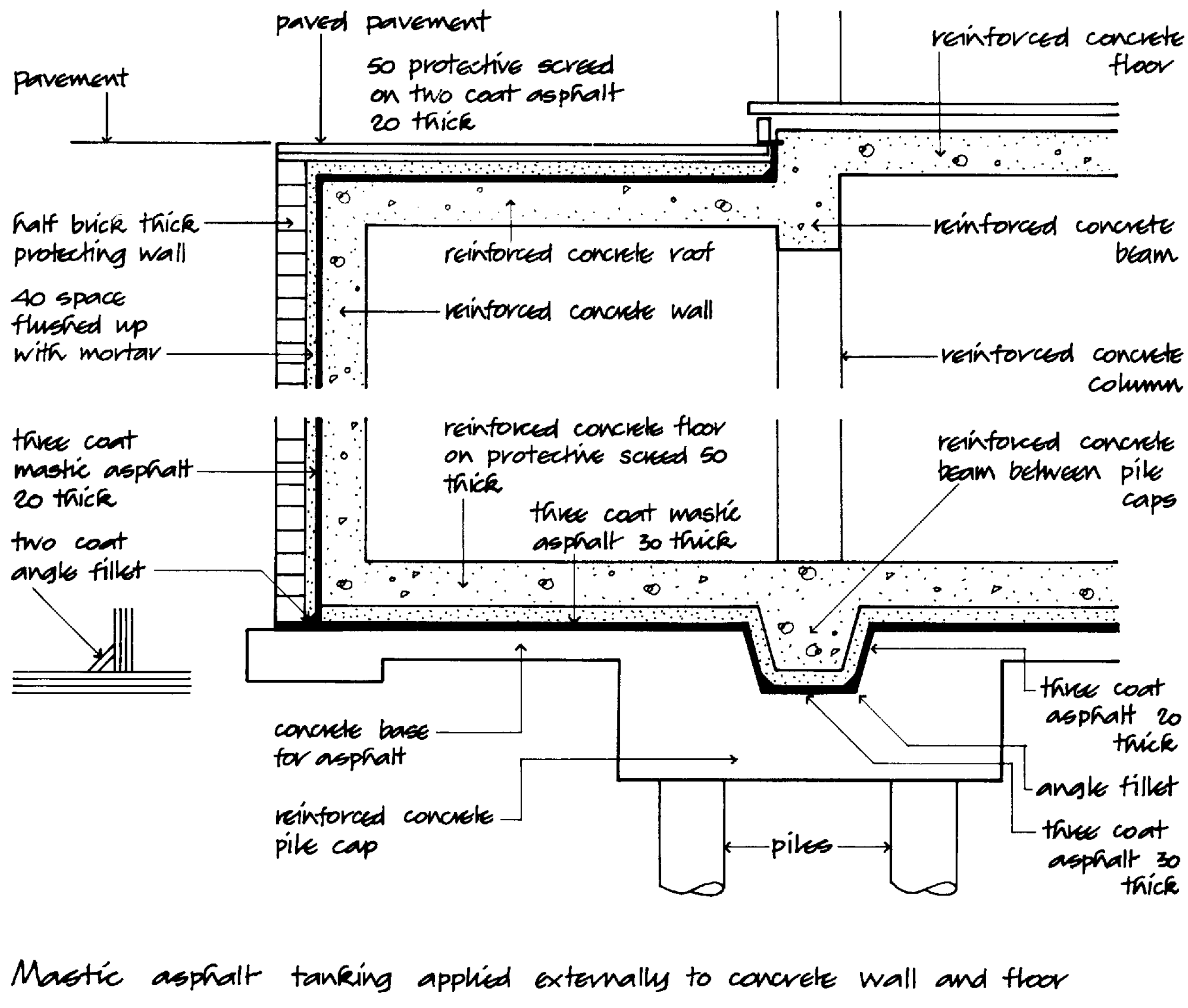


Fig. 29

Asphalt tanking should be applied to the outside face of structural walls and under structural floors so that the walls and floors provide resistance against water pressure on the asphalt and the asphalt keeps water from the structure.

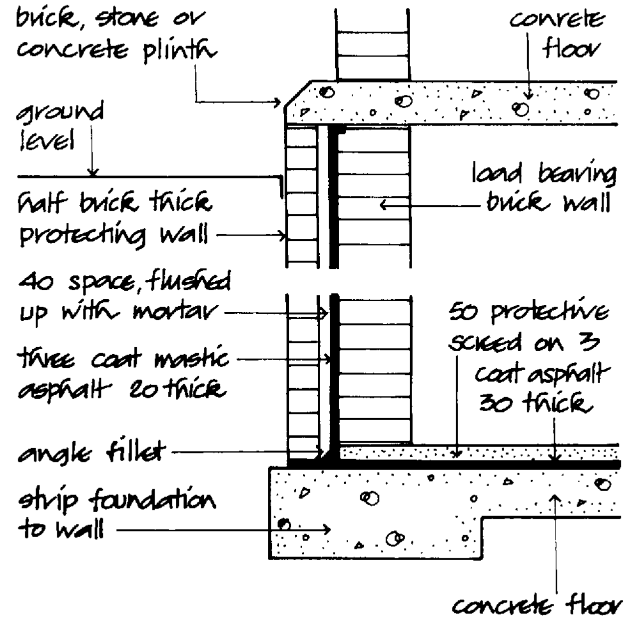
Figure 29 is an illustration of asphalt tanking applied externally to the reinforced concrete walls and floor of a substructure or basement. The horizontal asphalt is spread in three coats on the concrete base and over pile caps and extended 150 outside for the junction of the horizontal and vertical asphalt and the angle fillet. The horizontal asphalt is then covered with a protective screed of cement and sand 50 thick. The reinforced concrete floor should be cast on the protective screed as soon as possible to act as a loading coat against water pressure under the asphalt below.

When the reinforced concrete walls have been cast in place and have dried, the vertical asphalt is spread in three coats and fused to the projection of the horizontal asphalt with an angle fillet. A half brick protective skin of brickwork is then built leaving a 40 gap between the wall and the asphalt. The gap is filled solidly with mortar, course by course, as the wall is built. The half brick wall provides protection against damage from backfilling and the mortar filled gap ensures that the asphalt is firmly sandwiched up to the structural wall.

In Fig. 29 the asphalt tanking is continued under a paved forecourt. Where vertical asphalt is carried up on the outside of external walls it should be carried up at least 150 above ground to join a damp proof course.

Figure 30 is an illustration of mastic asphalt tanking to a concrete floor and load bearing brick wall to a substructure. The protective screed to the horizontal asphalt and protecting outer wall and mortar filled gap to the vertical asphalt serve the same functions as they do for a concrete substructure. As a key for the vertical asphalt the horizontal joints in the external face of the load bearing wall should be lightly raked out and well brushed when the mortar has hardened sufficiently.

Where the walls of substructures are on site boundaries and it is not possible to excavate to provide adequate working space to apply asphalt externally, a system of internal tanking may be used. The concrete base and structural walls are built and the horizontal asphalt is spread on the concrete base and a 50 protective screed spread over the asphalt. Asphalt is then spread up the inside of the structural



Mastic asphalt tanking applied externally to brick wall and concrete floor.

Fig. 30

walls and joined to the angle fillet reinforcement at the junction of horizontal and vertical asphalt. A loading and protective wall, usually of brick, is then built with a 40 mortar filled gap up to the internal vertical asphalt. The internal protective and loading wall, which has to be sufficiently thick to resist the pressure of water on the asphalt, is usually one brick thick. A concrete loading slab is then cast on the protective screed to act against water pressure on the horizontal asphalt.

An internal asphalt lining is rarely used for new buildings because of the additional floor and wall construction necessary to resist water pressure on the asphalt. Internal asphalt is sometimes used where a substructure to an existing building is to be waterproofed.

Service pipes for water, gas and electricity and drain connections that are run through the walls of a substructure that is lined with asphalt tanking are run through a sleeve that provides a watertight seal to the perforation of the asphalt tanking and allows for some movement between the service pipe or drain and the sleeve. The sleeve is coated with asphalt which is joined to the vertical asphalt with a collar of asphalt, run around the sleeve, as illustrated in Fig. 31.

Asphalt which is sandwiched in floors as tanking

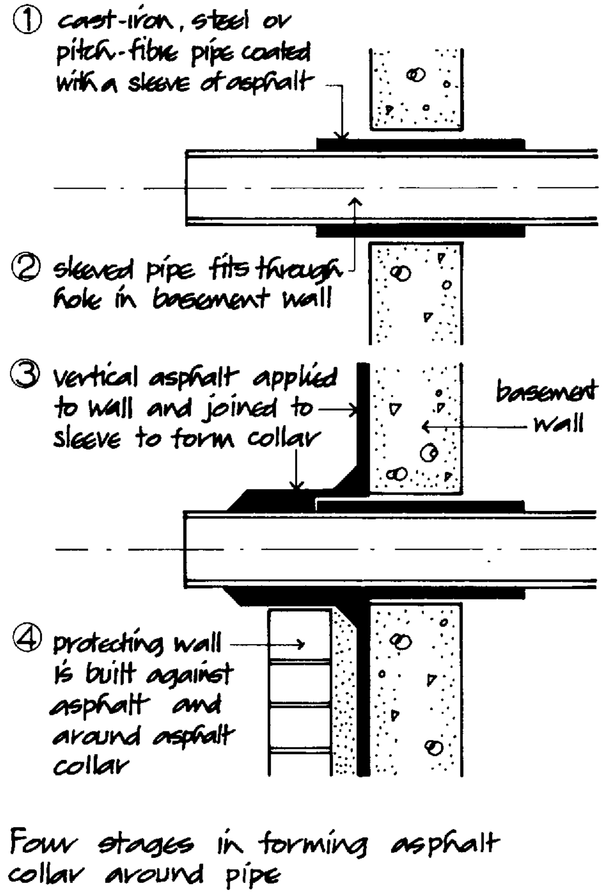


Fig. 31

has adequate compressive strength to sustain the loads normal to buildings. The disadvantages of asphalt are that asphalting is a comparatively expensive labour intensive operation and that asphalt is a brittle material that will readily crack and let in water if there is differential settlement or appreciable movements of the substructure. In general the use of asphalt tanking is limited to substructures with a length or width of not more than about seven and a half metres to minimise the possibility of settlement or movement cracks fracturing the asphalt.

Bituminous membranes

As an alternative to asphalt, bituminous membranes are commonly used for waterproofing and tanking to substructures. The membrane is supplied as a sheet of polythene or polyester film or sheet bonded to a self-adhesive rubber/bitumen compound or a polymer modified bitumen. The heavier grades of these membranes are reinforced with a meshed fabric sandwiched in the self-adhesive bitumen. The membrane is supplied in rolls about one metre wide and twelve to eighteen metres long, with the self-adhesive surface protected with a release paper backing.

The particular advantage of these membranes is that their flexibility can accommodate small shrinkage, structural, thermal and moisture movements without damage to the membrane. Used in conjunction with waterstops to concrete substructures these membranes are generally preferable to asphalt as tanking.

The surface to which the membrane is applied by adhesion of the bitumen coating must be dry, clean and free from any visible projections that would puncture the membrane. The membrane is applied to a dry, clean float finished screed for floors and to level concrete wall surfaces on which all projecting

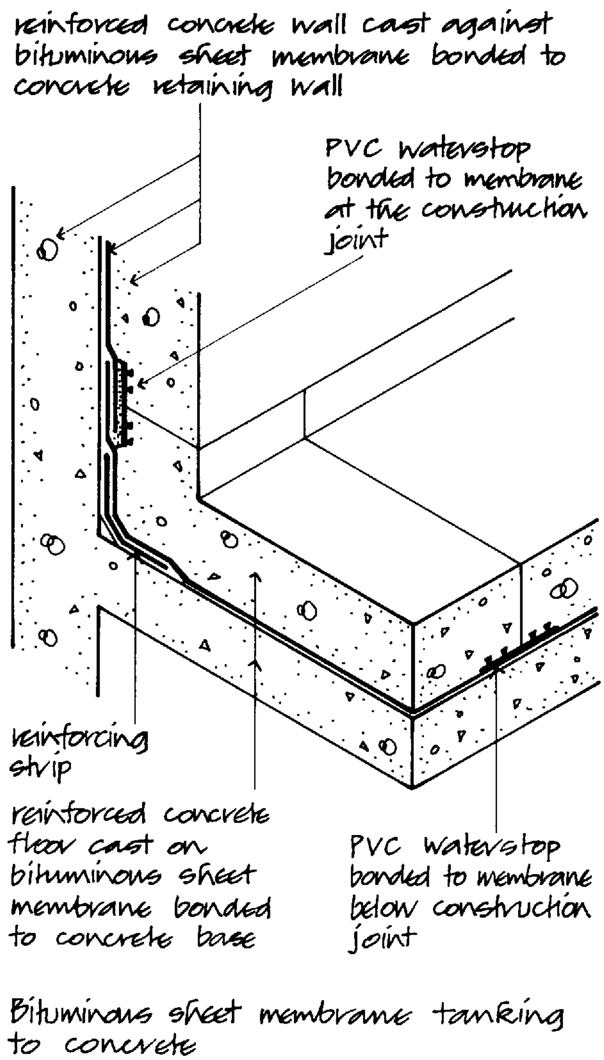


Fig. 32

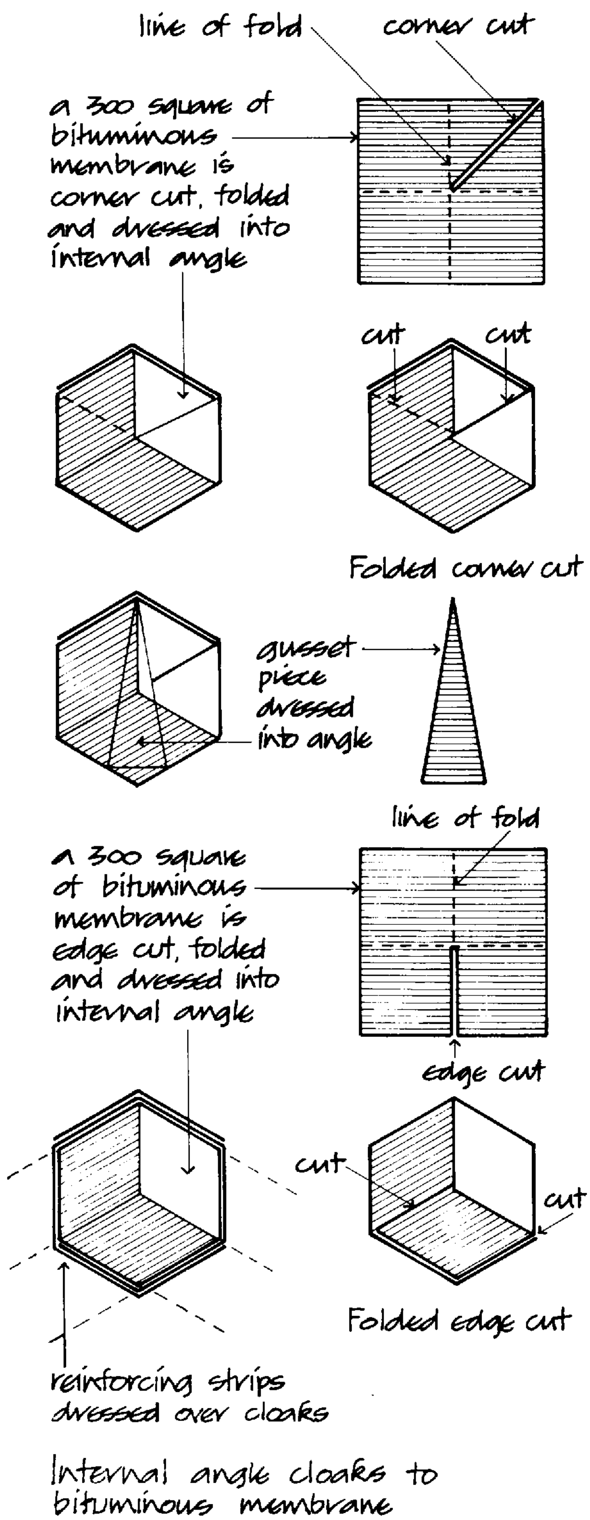


Fig. 33

nibs from formwork have been removed and cavities filled.

The vertical surface to which the membrane is to be applied is first primed. The rolls of sheet are laid out, the paper backing removed and the membrane laid with the adhesive bitumen face down or against walls and spread out and firmly pressed on to the surface with a roller. Joints between long edges of the membrane are overlapped 75 and end joints 150 and the overlap joints are firmly rolled in to compact the join. Laps on vertical wall surfaces are overlapped so that the sheet above overlaps the sheet below.

At construction and movement joints the membrane is spread over the joint with a PVC or rubber waterstop cast against or in the concrete.

Bitumen membranes are formed outside structural walls and under structural floors, as illustrated in Fig. 32, with an overlap and fillet at the junction of vertical and horizontal membranes. To protect the vertical membrane from damage by backfilling, a protective half brick skin should be built up to the membrane.

At angles and edges a system of purposely cut and shaped cloaks and gussets of the membrane material is used over which the membrane is lapped, as illustrated in Fig. 33. To be effective as a seal to the vulnerable angle joints, these overlapping cloaks and gusset must be carefully shaped and applied.

The effectiveness of these membranes as waterproof tanking depends on dry, clean surfaces free from protrusions or cavities and careful workmanship in spreading and lapping the sheets, cloaks and gussets.

CHAPTER TWO

STRUCTURAL STEEL FRAMES, FLOORS AND ROOFS

During the eighteenth century the application of steam power to large cast iron machinery, particularly in the textile grade, made it possible to gather large groups of labour together under one roof.

The earliest textile mills and warehouses were constructed with loadbearing brick or stone walls supporting timber floors and roofs. Heating was by open coal fires and lighting by oil lamps. Following a series of disastrous fires in mills, William Strutt designed and built in Derby the first fireproof mill in the years 1792–3. This six-storey mill consisted of loadbearing external walls and internal cast iron columns supporting timber beams at 3.0 centres between which brick arches were sprung. The arched brick floors were covered with sand on which tiles were laid.

A later development was the use of cast iron beams in place of timber. Up to the middle of the nineteenth century the majority of mills, factories and warehouses were constructed in this way and it was then that wrought iron began to replace cast iron as the material for beams. The failure of cast iron beams prompted the change. Following the invention in 1856 by Bessemer and in 1865 by Siemens and Martin of processes of converting iron into steel, mild steel began to compete with wrought iron and cast iron as a structural material. For many years, however, the Board of Trade limited the allowable stress in mild steel to that of wrought iron, that is 5 T/sq. in. (78 N/mm^2), in tension and 4 T/sq. in. (63 N/mm^2) in compression. Due to this it was generally cheaper to use wrought iron than steel up to 1897 when the Board of Trade relaxed its regulations to allow steel to be stressed at 8 T/sq. in. (125 N/mm^2), the figure recommended by the British Association.

The first structural steel framed building to be erected in this country was the Ritz Hotel in London (1904–5) in which the whole of the weight of the masonry walls and floors and roofs was carried by the steel frame. A year later (1906) the east wing of Selfridges store was erected with a structural steel frame.

Up to the beginning of the Second World War (1939) the majority of tall buildings in this country were constructed with structural steel frames generally clad with brick or masonry to give the simulation of a large brick or masonry loadbearing structure.

The shortage of steel that followed the Second World War encouraged the use of reinforced concrete frames for buildings up to about 1980. Since 1980, due to considerable overproduction of steel and resulting competition, structural steel frames may be cheaper than comparable reinforced concrete frames.

The advantages of the structural steel frame are the speed of erection of the ready prepared steel members and the accuracy of setting out and connections that is a tradition in engineering works which facilitates accuracy in the fixing of cladding materials. With the use of sprayed on or dry lining materials to encase steel members to provide protection against damage by fire, a structural steel frame may be cheaper than a reinforced concrete structural frame because of speed of erection and economy in material and construction labour costs.

FUNCTIONAL REQUIREMENTS

The functional requirements of a structural frame are:

Strength and stability
Durability and freedom from maintenance
Fire safety

Strength and stability

The requirements from Part A of Schedule 1 to the Building Regulations 1991, as amended 1994, are that buildings be constructed so that the loadbearing elements, foundations, walls, floors and roofs have adequate strength and stability to support the dead loads of the construction and anticipated imposed loads on roofs, floors and walls without such undue deflection or deformation as might adversely affect the strength and stability of parts or the whole of the building. The strength of the loadbearing elements of the structure is assumed either from knowledge of the behaviour of similar traditional elements, such as walls and floors under load, or by calculations of the behaviour of parts or the whole of a structure under load, based on data from experimental tests, with various factors of safety to make allowance for unforeseen construction or design errors.

The strength of individual elements of a structure may be reasonably accurately assessed taking account of tests on materials and making allowance for variations of strength in both natural and man-made materials.

The strength of combinations of elements such as columns and beams depends on the rigidity of the connection and the consequent interaction of the elements. Here calculations make assumptions, based on tests, of the likely behaviour of the joined elements as a simple calculation or a more complex calculation of the behaviour of the parts of the whole of the structure. Various factors of safety are included in calculations to allow for unforeseen circumstances. Calculations of structural strength and stability provide a mathematical justification for an assumption of a minimum strength and stability of structures in use.

Imposed loads are those loads that it is assumed the building or structure is designed to support taking account of the expected occupation or use of the building or structure. Assumptions are made of the likely maximum loads that the floors of a category of building uses and may be expected to support. The load of the occupants and their furniture on the floors of residential buildings will generally be less than that of goods stored on a warehouse floor.

The loads imposed on roofs by snow are determined by taking account of expected snow loads in the geographical location of the building. Loads imposed on walls and roofs by wind (wind loads) are determined by reference to the situation of the building on a map of the United Kingdom on which basic wind speeds have been plotted. These basic wind speeds are the maximum gust speeds averaged over 3 second periods, which are likely to be exceeded on average only once in 50 years. In the calculation of the wind pressure on buildings a correction factor is used to take account of the shelter from wind afforded by obstructions and ground roughness (see Volume 2).

The stability of a building depends initially on a reasonably firm, stable foundation. The stability of a structure depends on the strength of the materials of the loadbearing elements in supporting, without undue deflection or deformation, both concentric and eccentric loads on vertical elements and the ability of the structure to resist lateral pressure of wind on walls and roofs.

The very considerable dead weight of walls of traditional masonry or brick construction is generally sufficient, by itself, to support concentric and eccentric loads and the lateral pressure of wind. The dead weight of skeleton framed multi-storey buildings is not generally, by itself, capable of resisting lateral wind pressure without undue deflection and deformation without some form of bracing to enhance stability. Unlike the joints in a reinforced concrete structural frame, the normal joints between vertical and horizontal members of a structural steel frame do not provide much stiffness in resisting lateral wind pressure.

Disproportionate collapse

A requirement from Part A of Schedule 1 to the Building Regulations 1991, as amended 1994, is that a building shall be constructed so that in the event of an accident, the building will not suffer collapse to an extent disproportionate to the cause. This requirement applies only to a building having five or more storeys (each basement level being counted as one storey) excluding a storey within the roof space where the slope of the roof does not exceed 70° to the horizontal.

The requirement to reduce the sensitivity of a building to disproportionate collapse in the event of an accident was included after the partial collapse of a multi-storey block of flats known as Ronan Point. This block of flats was constructed of precast reinforced concrete loadbearing, storey height panels supporting reinforced concrete floors. It appears that the occupant of a flat, on an intermediate floor, put a lighted match to her gas stove without realising that, due to an escape of gas, there had been a very considerable build-up of gas in her kitchen. There was an explosion that blew out wall panels and caused the partial collapse of floors above and below. On inspection it was determined that there was not sufficient horizontal tying of the floors to the wall panels to resist the unexpected and very considerable pressure of the explosion. Subsequently the building was demolished. Hence the new requirement to provide resistance to collapse disproportionate to the cause. The requirement is for the provision of horizontal tying adequate to a cause such as an explosion of this kind.

Durability and freedom from maintenance

The members of a structural steel frame are usually inside the wall fabric of buildings so that in usual circumstances the steel is in a comparatively dry atmosphere which is unlikely to cause progressive, destructive corrosion of steel. Structural steel will, therefore, provide reasonable durability for the expected life of the majority of buildings and require no maintenance.

Where the structural steel frame is partially or wholly built into the enclosing masonry or brick walls the external wall thickness is generally adequate to prevent such penetration of moisture as is likely to cause corrosion of steel. Where there is some likelihood of penetration of moisture to the structural steel, it is practice to provide protection by the application of paint or bitumen coatings or the application of a damp-proof layer. Where it is anticipated that moisture may cause corrosion of the steel, either externally or from a moisture laden interior, one of the weathering steels, that are much less subject to corrosion, is used.

Fire safety

The requirements from Part B of Schedule 1 to the Building Regulations 1991, as amended 1994, are concerned to ensure a reasonable standard of safety in case of fire. The application of the Regulations, as set out in the practical guidance given in Approved Document B, is directed to the safe escape of people from buildings in case of fire rather than the protection of the building and its contents. Insurance companies that provide cover against the risks of damage to the building and contents by fire may require additional fire protection such as sprinklers.

Internal fire spread (structures)

The requirement from the Regulations relevant to structure is to limit internal fire spread (structure).

As a measure of ability to withstand the effects of fire, the elements of a structure are given notional fire resistance times, in minutes, based on tests. Elements are tested for their ability to withstand the effects of fire in relation to:

(a) resistance to collapse (loadbearing capacity) which applies to loadbearing elements
(b) resistance to fire penetration (integrity) which applies to fire separating elements
(c) resistance to the transfer of excessive heat (insulation) which applies to fire separating elements.

The notional fire resisting times, which depend on the size, height and use of buildings, are chosen as being sufficient for the escape of occupants in the event of fire.

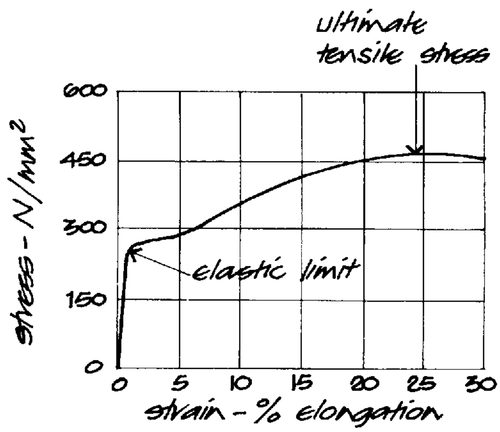
The requirements for the fire resistance of elements of a structure do not apply to:

(1) A structure that only supports a roof unless:
   (a) the roof acts as a floor, e.g. car parking, or as a means of escape and
   (b) the structure is essential for the stability of an external wall which needs to have fire resistance.
(2) The lowest floor of the building.

METHODS OF DESIGN

Permissible stress design method

With the introduction of steel as a structural material in the late nineteenth and early years of the twentieth century, the permissible stress method of design was accepted as a basis for the calculation of the sizes of structural members. Having established and agreed a yield stress for mild steel the permissible tensile stress



Stress/strain curve for mild steel

Fig. 34

was taken as the yield stress divided by a factor of safety to allow for unforeseen overloading, defective workmanship and variations in steel. The yield stress in steel is that stress at which the steel no longer behaves elastically and suffers irrecoverable elongation as shown in Fig. 34, which is a typical stress/strain curve for mild steel.

The loads to be carried by a structural steel frame are dead, imposed and wind loads. Dead loads comprise the weight of the structure including walls, floors, roof and all permanent fixtures. Imposed loads include all moveable items that are stored on or usually supported by floors, such as goods, people, furniture and moveable equipment. Wind loads are those applied by wind pressure or suction on the building. Dead loads can be accurately calculated. Imposed loads are assumed from the usual use of the building to give reasonable maximum loads that are likely to occur. Wind loads are derived from the maximum wind speeds.

Having determined the combination of loads that are likely to cause the worst working conditions the structure is to support, the forces acting on the structural members are calculated by the elastic method of analysis to predict the maximum elastic working stresses in the members of the structural frame. Beam sections are then selected so that the maximum predicted stress does not exceed the permissible stress.

In this calculation a factor of safety is applied to the stress in the material of the structural frame. The permissible compressive stress depends on whether a column fails due to buckling or yielding and is determined from the slenderness ratio of the column, Young's modulus and the yield stress divided by a factor of safety. The permissible stress method of design provides a safe and reasonably economic method of design for simply connected frames and is the most commonly used method of design for structural steel frames.

A simply connected frame is a frame in which the beams are assumed to be simply supported by columns to the extent that whilst the columns support beam ends, the beam is not fixed to the column and in consequence when the beam bends (deflects) under load, bending is not restrained by the column. Where a beam bears on a shelf angle fixed to a column and the top of the beam is fixed to the column by means of a small top cleat designed to maintain the beam in a vertical position, as illustrated later in Fig. 52, it is reasonable to assume that the beam is simply supported and will largely behave as if it had a pin jointed connection to the column.

Collapse or load factor method of design

Where beams are rigidly fixed to columns and where the horizontal or near horizontal members of a frame, such as the portal frame (see Volume 3), are rigidly fixed to posts or columns then beams do not suffer the same bending under load that they would if simply supported by columns or posts. The effect of the rigid connection of beam ends to columns is to restrain simple bending, as illustrated in Fig. 35. The fixed and beam bends in two directions, upwards near fixed ends and downwards at the centre. The upward bending is termed negative bending and the downward positive bending. It will be seen that bending at the ends of the beam is prevented by the rigid connections that take some of the stress due to loading and transfer it to the supporting columns. Just as the rigid connection of beam to column causes negative or upward bending of the beam at ends so a comparable, but smaller, deformation of the column will occur.

Using the elastic method of analysis to determine working stress in a fixed end beam to select a beam section adequate for the permissible stress design method, produces a section greater than is needed to

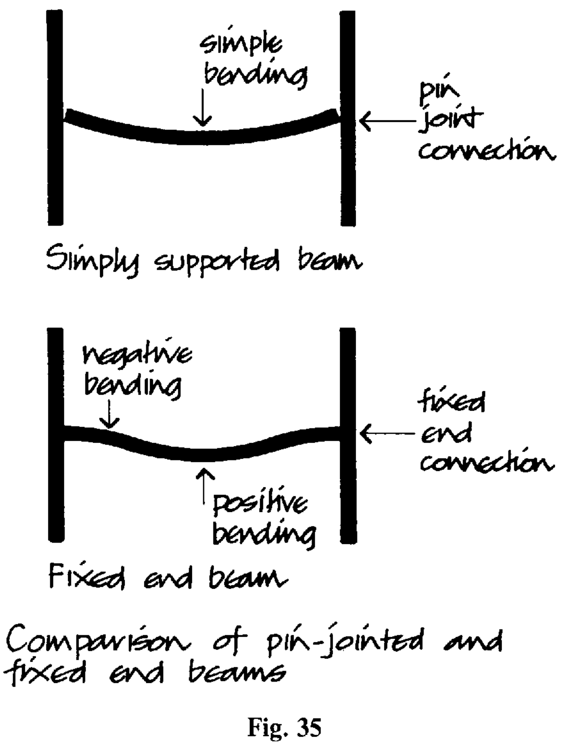


Fig. 35

provide a reasonable factor of safety against collapse, because in practice the permissible stress is not reached and in consequence the beam could safely support a greater load.

The collapse or load factor method of design seeks to provide a load factor, that is a safety factor, against collapse applied to particular types of structural frame for economy in the use of materials by using the load factor which is applied to the loads instead of stress in materials.

The load factor method was developed principally for use in the design of reinforced concrete and welded connection steel frames with rigid connections as an alternative to the permissible stress method, as a means to economy in the selection of structural sections.

In the use of the load factor method of design plastic analysis is used. In this method of analysis of the forces acting in members it is presumed that extreme fibre stress will reach or exceed yield stress and the fibres behave plastically. This is a valid assumption as in practice the fibres of the whole section play a part in sustaining stress and under working loads extreme fibre stress would not reach yield point.

Limit state method of design

The purpose of structural analysis is to predict the conditions applicable to a structure that would cause it to become either unserviceable in use or unable to support loads to the extent that members might fail.

In the permissible stress method a limit is set on the predicted working stress in the members of the frame by the use of a factor of safety applied to the predicted yield stress of the materials used. In the load factor method of design a limit is set on the working loads to ensure that they do not exceed a limit determined by the application of a factor of safety to the loads that would cause collapse of the structure.

The limit state method of design seeks to determine the limiting states of both materials and loads that would cause a particular structure to become unserviceable in use or unsafe due to excessive load. The limiting conditions that are considered are serviceability during the useful life of the building and the ultimate limit state of strength.

Serviceability limit states set limits to the behaviour of the structure to limit excessive deflection, excessive vibration and irreparable damage due to material fatigue or corrosion that would otherwise make the building unserviceable in use.

Ultimate limit states of strength set limits to strength in resisting yielding, rupture, buckling and transformation into a mechanism and stability against overturning and fracture due to fatigue or low temperature brittleness.

In use the limit state method of design sets characteristic loads and characteristic strengths which are those loads and strengths that have an acceptable chance of not being exceeded during the life of the building. To take account of the variability of loads and strength of materials in actual use a number of partial safety factors may be applied to the characteristic loads and strengths, to determine safe working loads and strengths.

The limit state method of design has not been accepted wholeheartedly by structural engineers because, they say, it is academic, highly mathematical, increases design time and does not lead to economic structures. The opponents of limit state design prefer and use permissible stress design for simplicity in execution and the knowledge that the use of the more complex limit state design method may be rewarded with little significant reduction in frame sections.

Structural engineers profess to predict the likely behaviour of a structure from an acceptance of working loads and yield stresses in materials so as to design a structure that will be both safe and serviceable during the life of a building. There is often little reward in employing other than the permissible stress method of design for the majority of buildings so that the use of the limit state method is confined in the main to larger and more complex structures where the additional design time is justified by more adventurous and economic design.

STEEL SECTIONS

Mild steel

Mild steel is the material generally used for constructional steelwork. It is produced in several basic strength grades of which those designated as 43, 50 and 55 are most commonly used. The strength grades 43, 50 and 55 indicate minimum ultimate tensile strengths of 430, 500 and 550 N/mm^2 respectively.

Each strength grade has several subgrades indicated by a letter between A and E, the grades that are normally available are 43A, 43B, 43C, 43D, 43E, 50A, 50B, 50C, 50D and 55C. In each strength grade the subgrades have similar ultimate tensile strengths and as the subgrades change from A to E the specification becomes more stringent, the chemical composition changes and the notch ductility improves. The improvement in notch ductility (reduction in brittleness), particularly at low temperatures, assists in the design of welded connections and reduces the risk of brittle and fatigue failure which is of particular concern in structures subject to low temperatures.

Properties of mild steel

Strength

Steel is strong in both tension and compression with permitted working stresses of 165, 230 and 280 N/mm^2 for grades 43, 50 and 55 respectively. The strength to weight ratio of mild steel is good so that mild steel is able to sustain heavy loads with comparatively small self weight.

Elasticity

Under stress, induced by loads, a structural material will stretch or contract by elastic deformation and return to its former state once the load is removed. The ratio of stress to strain, which is known as Young's modulus (the modulus of elasticity), gives an indication of the resistance of the material to elastic deformation. If the modulus of elasticity is high the deformation under stress will be low. Steel has a high modulus of elasticity, 200 kN/mm^2, and is therefore a comparatively stiff material, which will suffer less elastic deformation than aluminium which has a modulus of elasticity of 69 kN/mm^2. Under stress, induced by loads, beams bend or deflect and in practice this deflection under load is limited to avoid cracking of materials fixed to beams. The sectional area of a mild steel beam can be less than that of other structural materials for given load, span and limit of deflection.

Ductility

Mild steel is a ductile material which is not brittle and can suffer strain beyond the elastic limit through what is known as plastic flow, which transfers stress to surrounding material so that at no point will stress failure in the material be reached. Because of the ductility of steel the plastic method of analysis can be used for structures with rigid connections, which makes allowance for transfer of stress by plastic flow and so results in a section less than would be determined by the elastic method of analysis, which does not make allowance for the ductility of steel.

Resistance to corrosion

Corrosion of steel occurs as a chemical reaction between iron, water and oxygen to form hydrated iron oxide, commonly known as rust. Because rust is open grained and porous a continuing reaction will cause progressive corrosion of steel. The chemical reaction that starts the process of corrosion of iron is affected by an electrical process through electrons liberated in the reaction, whereby small currents flow from the area of corrosion to unaffected areas and so spread the process of corrosion. In addition, pollutants in air accelerate corrosion as sulphur dioxides from industrial atmospheres and salt in marine atmospheres increase the electrical conductivity of water and so encourage corrosion. The continuing process of corrosion may eventually, over the course of several years, affect the strength of steel. Mild steel should therefore be given protection against corrosion in atmospheres likely to cause corrosion.

Fire protection

Although steel is non-combustible and does not contribute to fire it may lose strength when its temperature reaches a critical point in a fire in a building. A temperature of 550°C is generally accepted as the critical temperature for steel, which temperature will generally be reached in the early stages of a fire. To give protection against damage by fire, building regulations require fire protection of structural steelwork in certain situations.

Weathering steels

The addition of small quantities of certain elements modifies the structure of the rust layer that forms. The alloys encourage the formation of a dense fine grained rust film and also react chemically with sulphur in atmospheres to form insoluble basic sulphate salts which block the pores on the film and so prevent further rusting. The thin tightly adherent film that forms on this low alloy steel is of such low

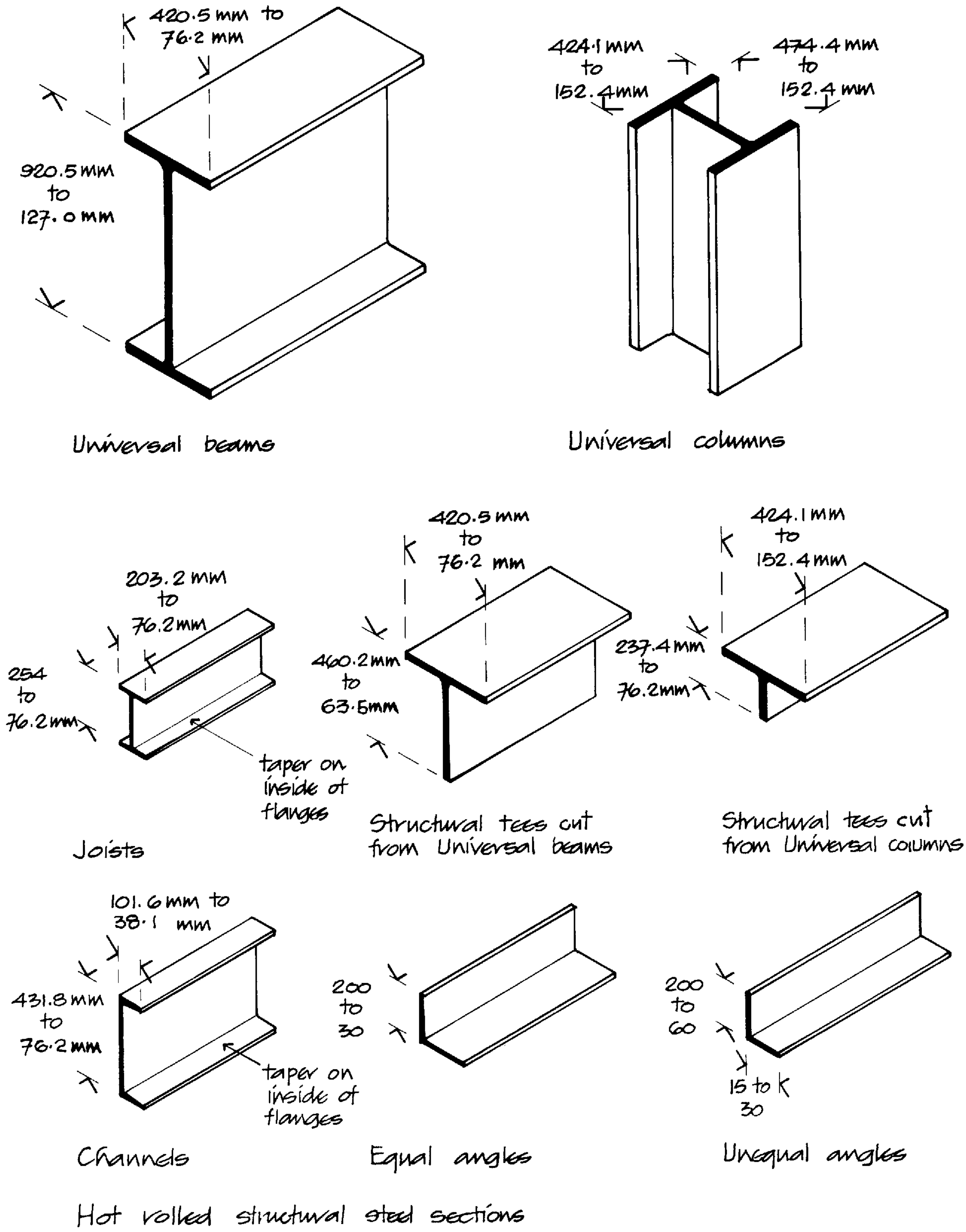

420.5 mm to
76.2 mm
920.5 mm
to
127.0 mm
Universal beams
424.1 mm
to
152.4 mm
474.4 mm
to
152.4 mm
Universal columns
203.2 mm
to
76.2 mm
254
to
76.2 mm
taper on
inside of
flanges
Joists
420.5 mm
to
76.2 mm
460.2 mm
to
63.5 mm
Structural tees cut
from Universal beams
424.1 mm
to
152.4 mm
237.4 mm
to
76.2 mm
Structural tees cut
from Universal columns
101.6 mm to
38.1 mm
431.8 mm
to
76.2 mm
taper on
inside of
flanges
Channels
200
to
30
Equal angles
200
to
60
15 to
30
Unequal angles
Hot rolled structural steel sections

Fig. 36

permeability that the rate of corrosion is reduced almost to zero. The film forms a patina of a deep brown colour on the surface of steel.

The low permeability rust film forms under normal wet/dry cyclical conditions. In conditions approaching constant wetness and in conditions exposed to severe marine or salt spray conditions the rust film may remain porous and not prevent further corrosion. Weathering steels are produced under the brand names 'Cor-Ten' for rolled sections and 'Stalcrest' for hollow sections.

Standard rolled steel sections

The steel sections most used in structural steelwork are standard hot rolled steel universal beams and columns together with a range of tees, channels and angles illustrated in Fig. 36.

Universal beams and columns are produced in a range of standard sizes and weights designated by serial sizes. Within each serial size the inside dimensions between flanges and flange edge and web remain constant and the overall dimensions and weights vary as illustrated in Fig. 37. This grouping of sections in serial sizes is convenient for production within a range of rolling sizes and for the selection of a suitable size and weight by the designer. The deep web to flange dimensions of beams and the near similar flange to web dimensions of columns are chosen to suit the functions of the structural elements. Because of the close similarity of the width of the flange to the web of column sections, they are sometimes known as 'broad flange sections'.

A range of comparatively small section 'joists' is also available, which have shallowly tapered flanges and are produced for use as beams for small to medium spans. The series of structural tees is produced from cuts that are half the web depth of standard universal beams and columns. The range of standard hot rolled structural steel angles and channels has tapered flanges. The standard rolled steel sections are usually supplied in strength grade 43A material with strength grades 50 and 55 available for all sections at an additional cost per tonne. All of the standard sections are available in Cor-Ten B weathering steel.

Castella beam

This open web beam section is made by cutting the web of a beam along a castellated line. The two halves are then welded together to form the castellated beam illustrated in Fig. 38.

The castella beam is one and a half times the depth of the beam section from which it was cut and

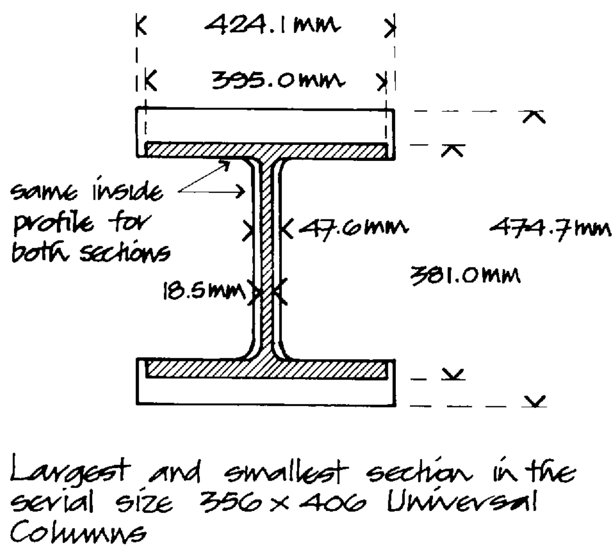


Fig. 37

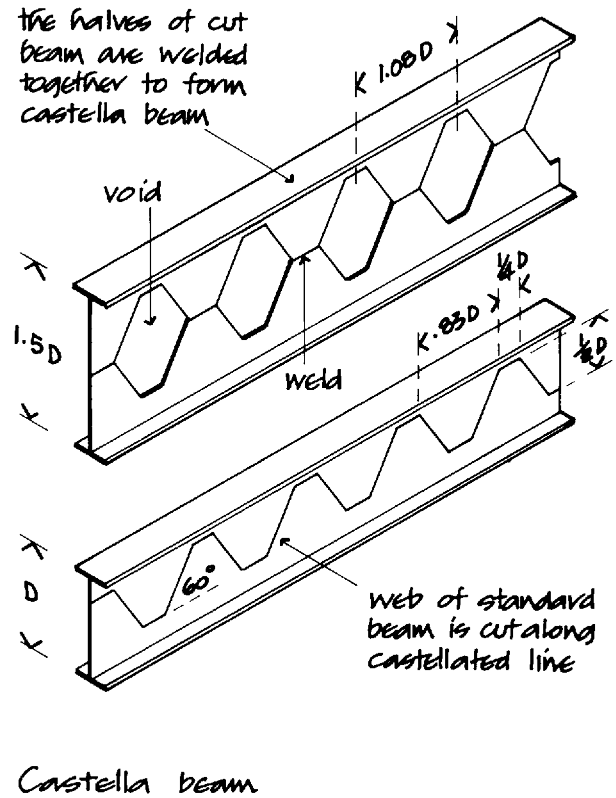


Fig. 38

therefore suffers less deflection under load. This section is economical for lightly loaded floors and long span roofs and the openings in the web are convenient for electrical and heating services.

Steel tubes

A range of seamless and welded seam steel tubes is manufactured for use as columns, struts and ties. The use of these tubes as columns is limited by the difficulty of making beam connections to a round section column. These round sections are the most efficient and compact structural sections available and are extensively used in the fabrication of lattice girders, columns, frames, roof decks and trusses for economy, appearance and comparative freedom from dust traps. Connections are generally made by scribing the ends of the tube to fit around the round sections to which they are welded. For long span members such as roof trusses, bolted plate connections are made at mid span for convenience in transporting and erecting long span members in sections.

Hollow rectangular and square sections

Hollow rectangular and square sections are made from round tube which, after heating, is passed through a series of rolls which progressively change the shape of the tube from a round to a square or rectangular section. To provide different wall thicknesses the tube can be reduced by stretching. The range of these sections is illustrated in Fig. 39. These sections are ideal for use as columns as the material is uniformly disposed around the axis and the rectangular section facilitates beam connections.

These hollow sections are used for lattice roof trusses and frames for the economy in material, particularly where the frame is exposed, and for the neat appearance of these sections which with welded connections have a more elegant appearance than angle sections. These sections are also much used in the fabrication of railings, balustrades, gates and fences.

Cold roll-formed steel sections

As long ago as 1936 a seven-storey block of flats was erected at Quarry Hill, Leeds, with a steel frame of cold rolled sections for both columns and beams. These sections are made from thin strips of steel

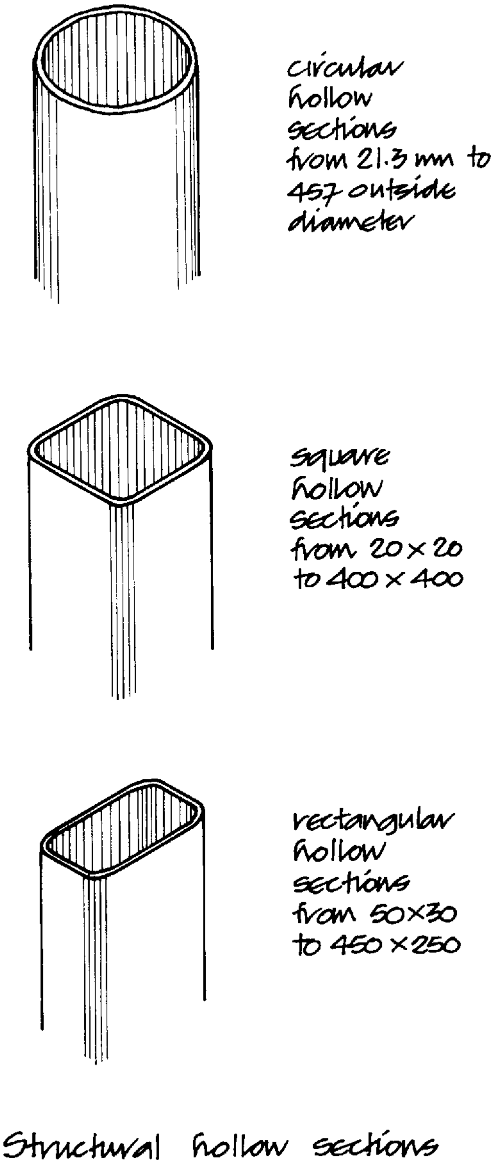


Fig. 39

rolled to shape as illustrated in Fig. 40, which shows some of the common sections used. The advantage of cold rolling is that any shape can be produced to the exact dimensions to suit a particular use. Structural beam and column sections can be produced by welding sections together as illustrated in Fig. 41.

Cold rolled sections are extensively used in motor vehicles and domestic equipment, such as cookers, and as trim to a variety of cupboard fittings. In buildings, these sections are used for purlins, sheeting rails and cladding (see Volume 3). These sections are usually given a protective coating, such as galvanising or plastic coating, to inhibit corrosion.

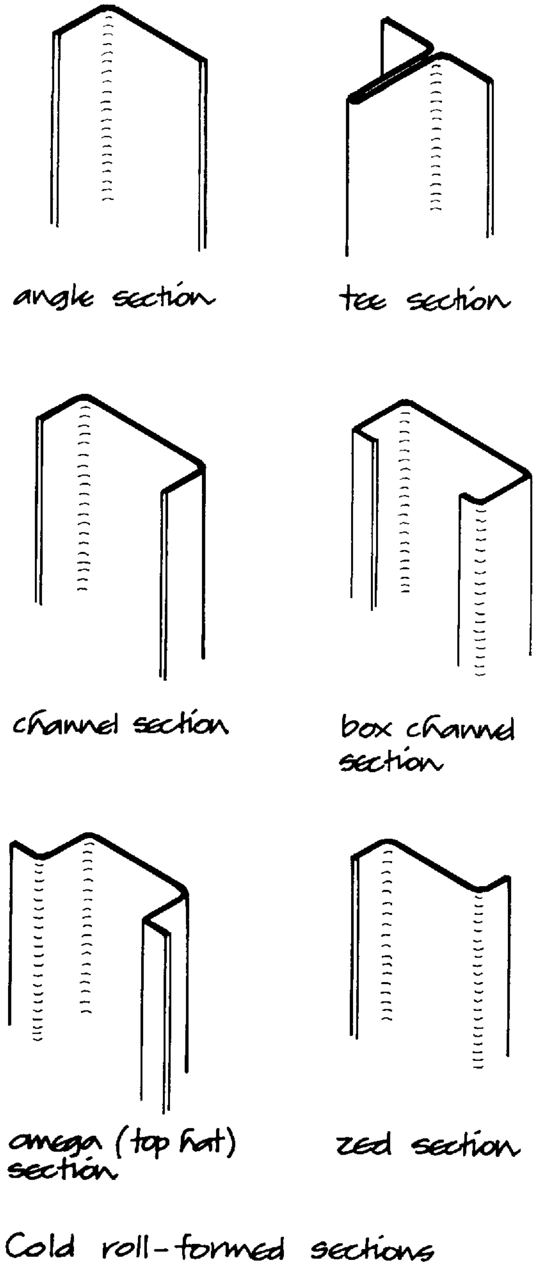


Fig. 40

The advantage of these sections as a structural material is that the engineer can design the exact section he requires using the least material to achieve desired strength, so that with repetitive use of a few sections considerable economy of material is effected.

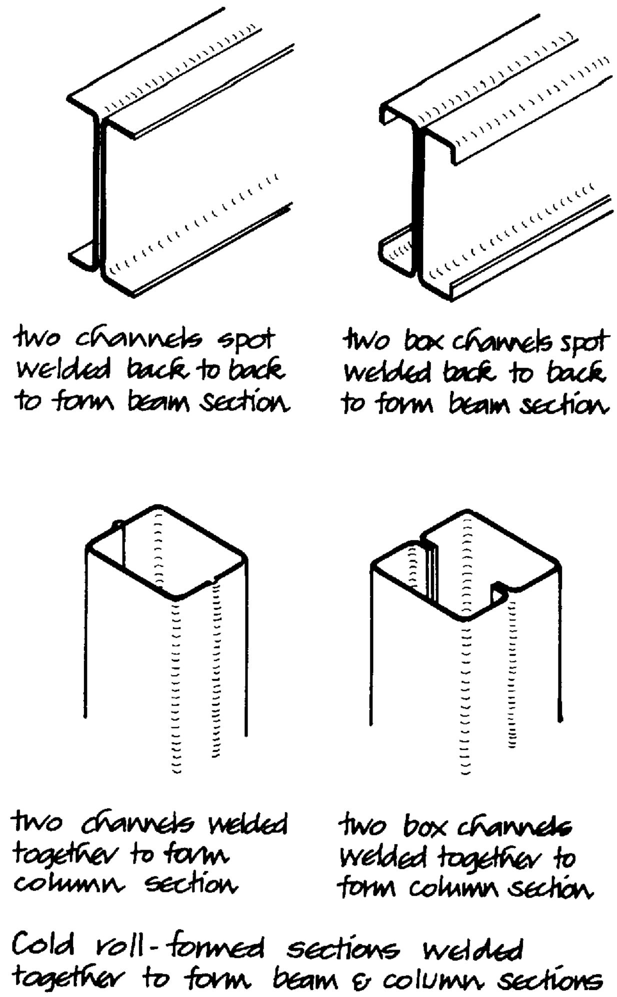


Fig. 41

STRUCTURAL STEEL FRAMES

The earliest structural steel frame was erected in Chicago in the year 1883 for the Home Insurance building. At that time there were no limitations to the height of buildings, and the introduction of the passenger lift provided access to multi-storey buildings. Property taxes at that time were levied on site area so that developers were encouraged to obtain the maximum lettable floor area.

At the time the traditional method of building was solid load bearing walls of stone or brick. To use this system of building for multi-storey buildings would have necessitated walls of such thickness that there would have been an appreciable loss of floor area. The skeleton steel frame was introduced to reduce the thickness of external walls and so gain valuable floor space. A skeleton of steel columns and beams carried the whole of the load of floors and the solid masonry or brick walls, the least thickness of which was dictated by weather resistance rather than load bearing requirements. Since then the steel frame has been one of the principal methods of constructing multi-storey buildings.

Skeleton frame

The conventional steel frame is constructed with hot rolled section beams and columns in the form of a skeleton designed to support the whole of the imposed and dead loads of floors, external walling or cladding and wind pressure. The arrangement of the columns is determined by the floor plans, horizontal and vertical circulation spaces and the requirements for natural light to penetrate the interior of the building.

Figure 42 is an illustration of a typical rectangular grid skeleton steel frame. In general the most economic arrangement of columns is on a regular rectangular grid with columns spaced at 3.0 to 4.0 apart parallel to the span of floors which bear on floor beams spanning up to 7.5, with floors designed to span one way between main beams. This arrangement provides the smallest economic thickness of floor slab and least depth of floor beams, and therefore least height of building for a given clear height at each floor level.

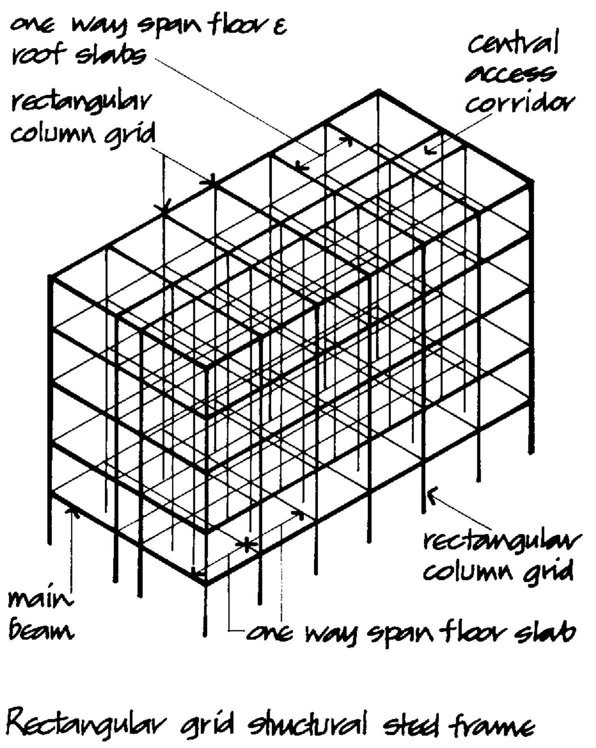


Fig. 42

Figure 43 is an illustration of a typical small skeleton steel frame designed to support one-way span floors on main beams and beams to support solid walls at each floor level on the external faces of the building. This rectangular grid can be extended in both directions to provide the required floor area.

Where it is inconvenient to have closely spaced internal columns, a larger rectangular or square grid is used as illustrated in Fig. 44, where each bay is divided by secondary beams spaced at up to 4.5 apart to carry one-way span floor slabs with the main floor beams which are supported by columns in turn supporting the secondary beams. This arrangement allows for the least thickness of floor slab, that is the least weight of construction. However, with increase in span of main floor beams goes increase in their depth and for a given minimum clear floor height between floor and soffit of beam this larger grid frame makes for greater overall height of building than does a smaller column grid.

Large floor areas unobstructed by columns can be framed by using deep long span solid web beams or by the use of deep lattice beams or a Vierendeel girder as illustrated in Fig. 45. The advantage of using a lattice or Vierendeel girder is that the girders may be designed so that their depth occupies the height of a floor and so does not increase the overall height of construction.

The conventional steel frame comprises continuous columns which support short beam lengths. This frame arrangement inhibits the use of projections from the rectangular frame because of the discontinuity of the beams which cannot be extended as cantilevers other than by the use of double columns. A solution is the use of continuous beams and short column lengths as illustrated in Fig. 46. This non-typical frame arrangement is practical and economic, particularly where welded built up beams and welded connections are used.

Wind bracing

The connections of beams to columns in multi-storey skeleton steel frames do not generally provide a sufficiently rigid connection to resist the considerable lateral wind forces that tend to cause the frame to rack. The word rack is used to describe the tendency

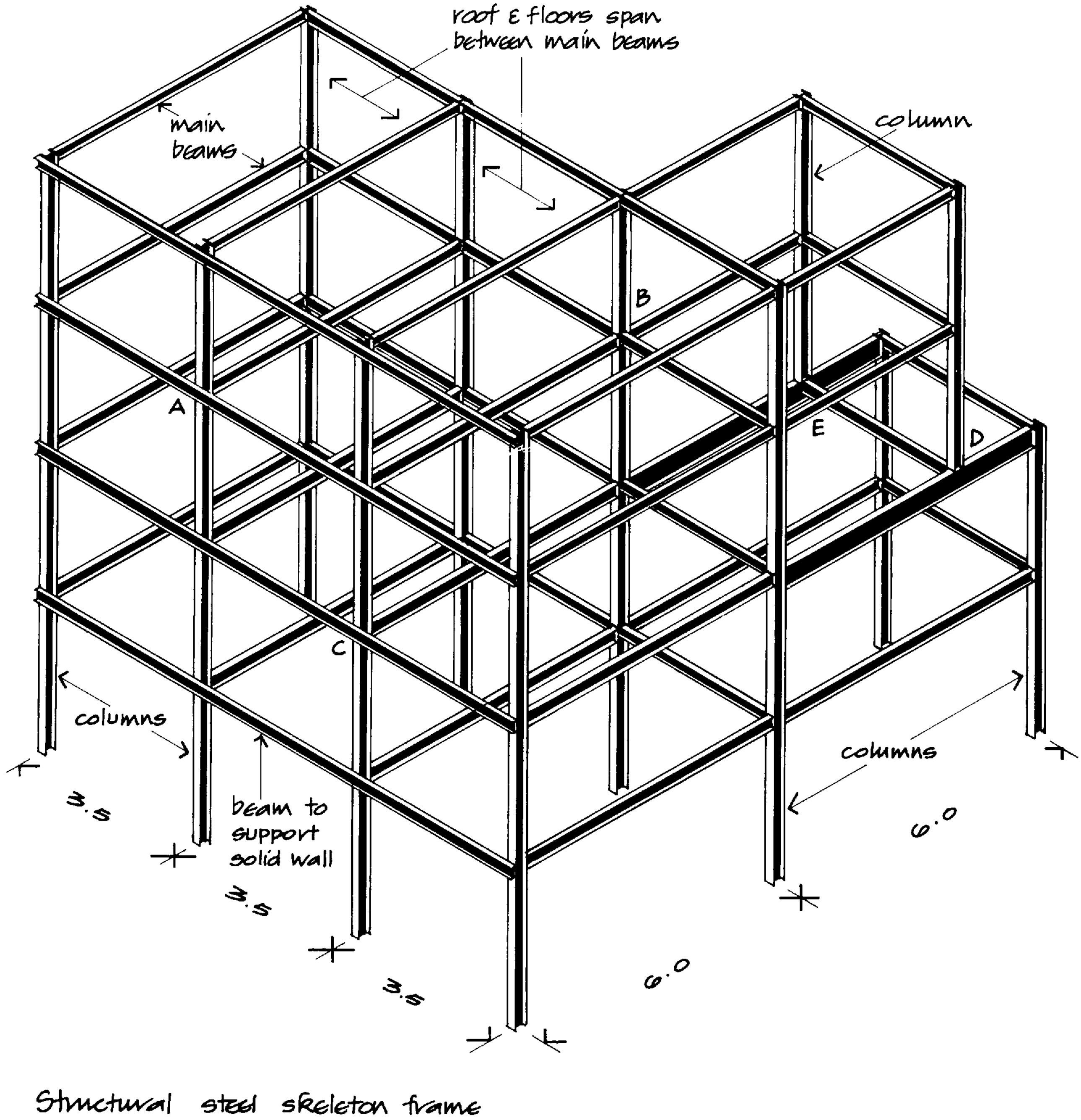


Fig. 43

of a frame to be distorted by lateral forces that cause right-angled connections to close up against the direction of the force in the same way that books on a shelf will tend to fall over if not firmly packed in place.

To resist racking caused by the very considerable wind forces acting on the faces of a multi-storey building it is necessary to include some system of bracing between the members of the frame to maintain the right-angled connection of members. The system of bracing used will depend on the rigidity of the connections, the exposure, height, shape and construction of the building.

The frame for a 'point block' building, where the access and service core is in the centre of the building and the plan is square or near square, is commonly

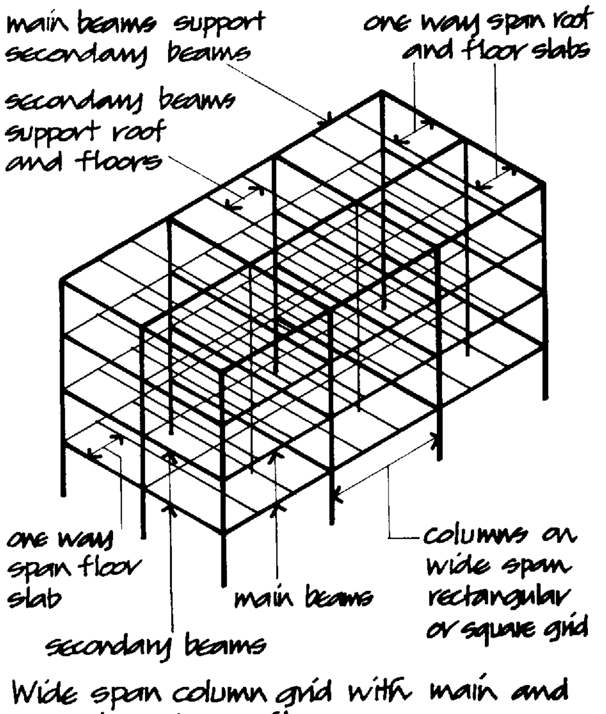


Fig. 44

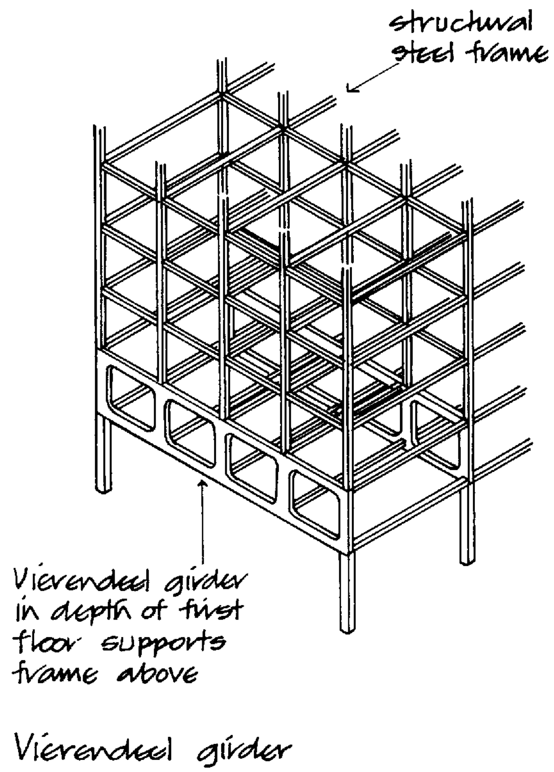


Fig. 45

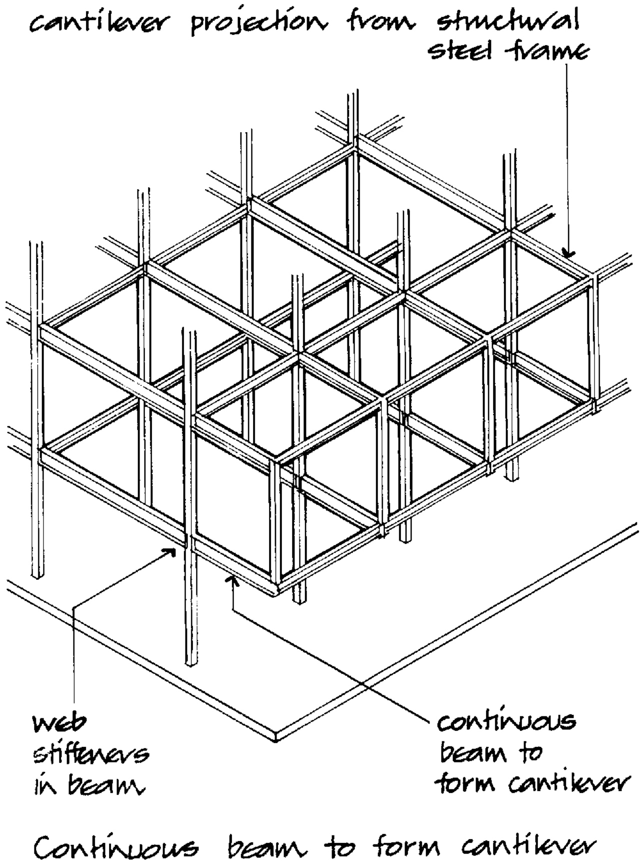


Fig. 46

braced against lateral forces by connecting cross braces in the two sides of the steel frame around the centre core which are not required for access as illustrated in Fig. 47. Wind loads are transferred to the braced centre core through solid concrete floors acting as plates or by bracing steel framed floors.

With the access and service core on one face of the frame as illustrated in Fig. 48, the wind bracing can be connected in two opposite sides of the service core frame, leaving the other two sides for access and natural lighting. Wind forces are transferred to the braced service core by horizontal bracing to one or more of the framed floors.

With the skeleton steel frame to a 'slab block' which is rectangular on plan and has main facades much wider than end walls, it is common to connect cross braces to the end wall frames as illustrated in Fig. 49, to resist the racking effect of wind on the larger wall areas. Here it may be reasonable to accept that the wind forces acting on the smaller end walls will be resisted by the many connections of the two main wall frames and the horizontal plate floors.

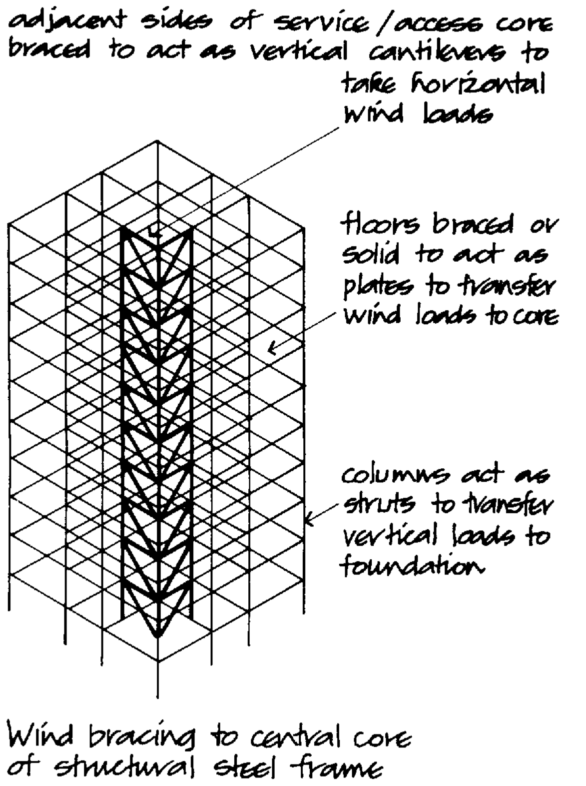


Fig. 47

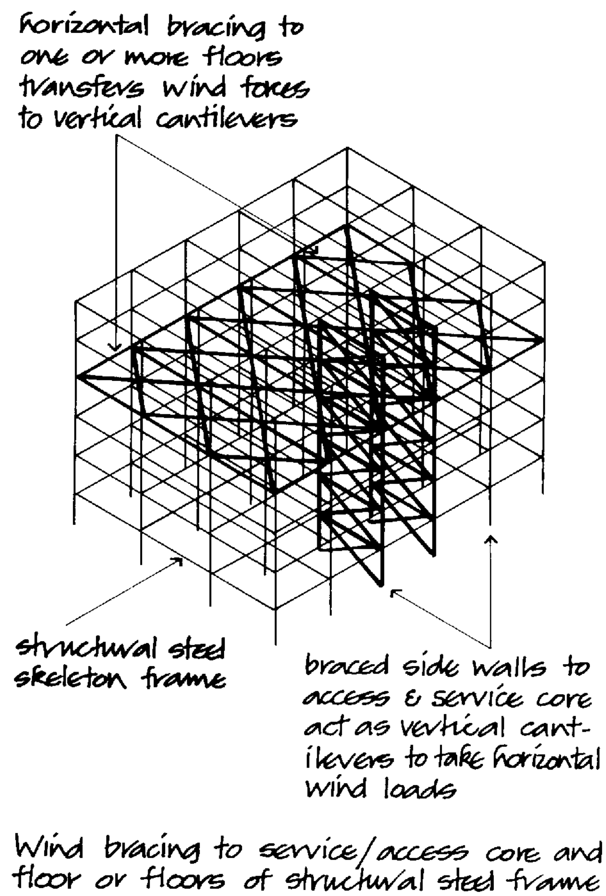


Fig. 48

To provide fire protection to means of escape access and service cores to multi-storey buildings it is common to construct a solid reinforced concrete service core that by its construction and foundation acts as a stiff vertical cantilever capable of taking wind forces. Here wind forces are transferred to the core by solid plate floors, braced floors or by cantilever steel hangers that also serve to support floor beams as illustrated in Fig. 50.

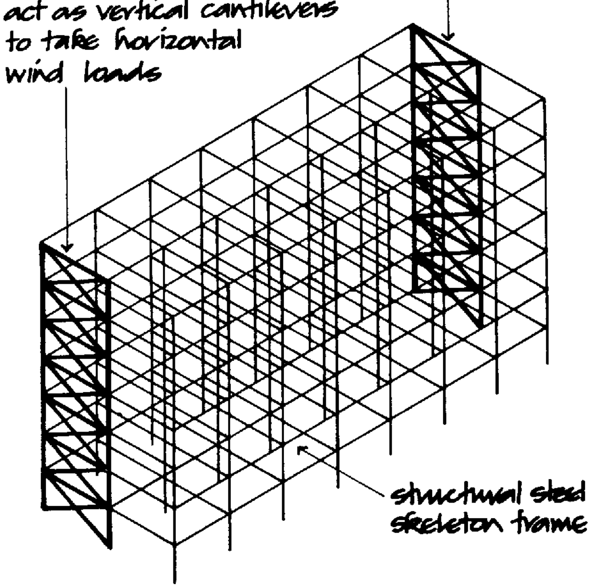
Pin jointed structural steel frames

The shortage of materials and skilled craftsmen that followed the Second World War encouraged local authorities in this country to develop systems of building employing standardised components that culminated in the CLASP system of building.

The early development was carried out by the Hertfordshire County Council in 1945 in order to fulfil their school building programme. A system of prefabricated building components based on a square grid was developed, to utilise light engineering prefabrication techniques, aimed at economy by mass production and the reduction of site labour. Some ten years later the Nottinghamshire County Council, faced with a similar problem and in addition the problem of designing a structure to accommodate subsidence due to mining operations, developed a system of building based on a pin jointed steel frame and prefabricated components. The pin jointed frame, with spring loaded diagonal braces, was designed to accommodate earth movements.

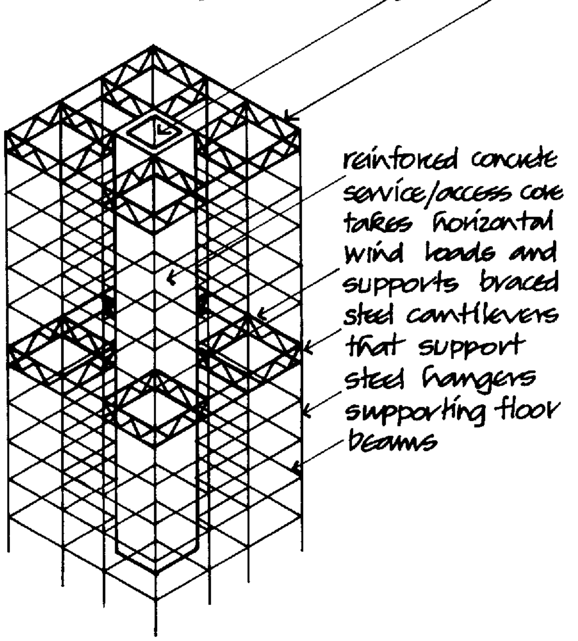
In order to gain the benefits of economy in mass production of component parts, the Nottinghamshire County Council joined with other local authorities to form CLASP (Consortium of Local Authorities Special Programme) which was able to order, well in advance, considerable quantities of standard components at reasonable cost. The CLASP system of building has since been used for schools, offices, housing and industrial buildings of up to four storeys. The system retained the pin jointed frame, originally designed for mining subsidence areas, as being the cheapest light structural steel frame.

The CLASP system is remarkable in that it was designed by architects for architects and allows a



Wind bracing to end walls of structural steel frame

Fig. 49



Reinforced concrete core supporting cantilever beams & steel hangers

Fig. 50

degree of freedom of design, within standard modules and using a variety of standard components, that no other system of prefabrication has yet to achieve. The CLASP building system is illustrated in Fig. 51.

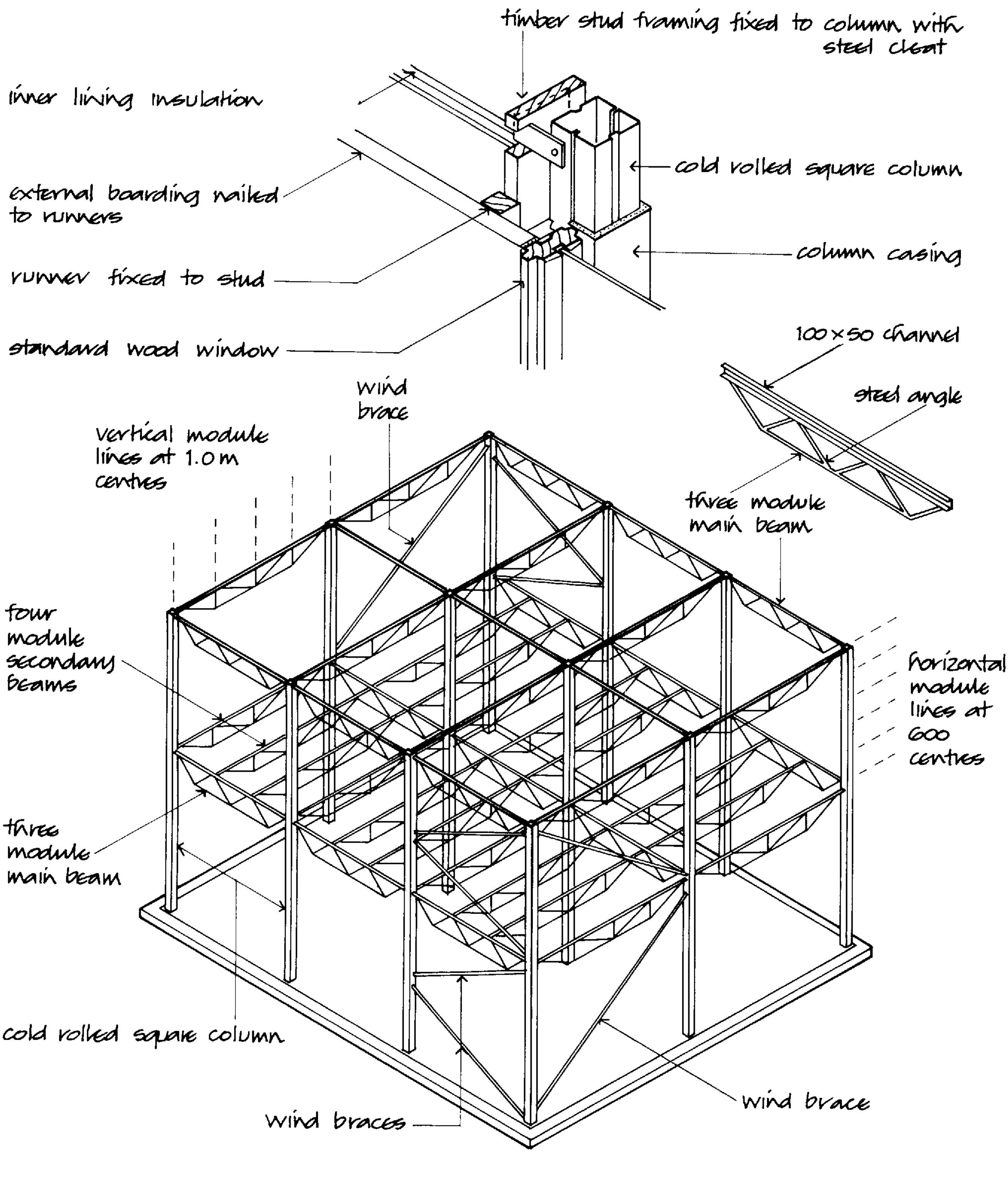
Steel frame connections and fasteners

Connections between the members of a steel frame are made with angle section seating or shelf cleats to support beam end bearings on columns with top angle cleats, side cleats for beam to beam connections and splice connections between column lengths as illustrated in Fig. 52. These connections are made from short lengths of angle or tee section and plate that are fixed with bolt fasteners or by welding. To reduce on-site labour to a minimum, connecting cleats are fixed to columns and beams in the fabricator's shop as far as practicable for site assembly connections to be completed on site.

These simple cleat connections can be accurately and quickly made to provide support and connection between beams and columns. Cleat connections of beams to columns are generally assumed to provide a simple connection in structural analysis and calculation as there is little restraint to simple bending by the end connection of beams. This simply supported, that is unrestrained, connection is the usual basis for the design calculation for structural steel frames. Where the connection is made with high strength bolts or by welding it may be assumed that the connection is semi-rigid or rigid for design calculation purposes.

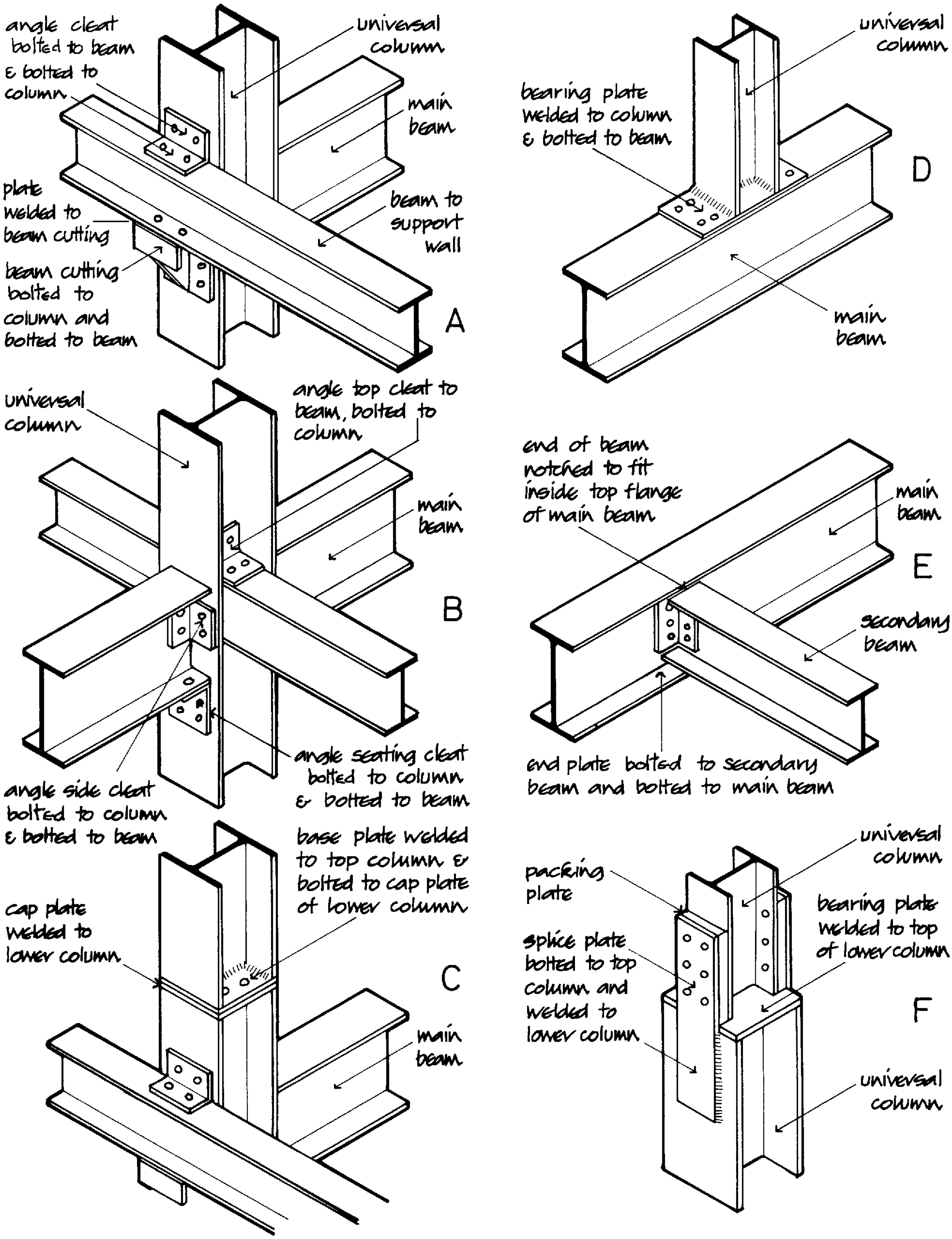
The connection of four beams to a column illustrated in Fig. 52, part B, shows a seating cleat shop bolted to the column to support the main beam and a side cleat bolted to the column to maintain the beam with its long axis vertical with the beam bolted to the cleats. The secondary beams bear on seating cleats bolted to the column with top angle cleats bolted to the beam and the column. This arrangement of connections of beams to columns was used where black bolts were used for site connections. Of recent years the use of shop welding has largely been abandoned in favour of the use of site bolted connections, using high strength friction bolts.

The connection of column lengths may be through plates to columns of similar section shown in Fig. 52, part C, or with a bearing plate, splice plates and packing pieces to connect columns of different section shown in Fig. 52, part F. In each case the



Pin jointed steel frame

Fig. 51



Structural steelwork connections

Fig. 52

column connection is made above floor level for convenience in fixing.

The beam to beam connection shown in Fig. 52, part E, is made with angle cleats bolted to the webs of the two beams. The beam illustrated in Fig. 52, part A, is fixed to the face of the column on a beam cutting and bearing plate for convenience in supporting an external wall that will be built across the face of the columns. The column connection to a supporting beam shown in Fig. 52, part D, may be made with angle cleats bolted to the flanges of the column and beam as an alternative connection.

Fasteners

In the early days of the use of structural steel for buildings, connections were made with angle cleats riveted to cleats and members. Wrought iron rivets were used as fasteners, the rivets being either dome or countersunk headed. The rivets were heated until red hot, fitted to holes in the connecting metals and closed by hammering the shank end to a dome head. As the rivet cooled it shrank in length and drew the connecting plates together. Rivets were used as both shop and field (site) fasteners for structural steelwork up to the early 1950s. Today rivet fasteners are rarely used and bolts are used as fasteners for site connections with welding for some shop connections. Site bolting requires less site labour than riveting, requires less skill, is quieter and eliminates fire risk.

Hexagon headed black bolts

Hexagon headed black bolts (Fig. 53) and nuts were used for connections made on site. The bolts are fitted to holes 2 larger in diameter than the bolt shank and secured with a nut. The protruding end of the bolt shank is then burred over the nut by hammering, to prevent the nut working loose. Because these bolts are not a tight fit there is the possibility of some slight movement in the connection. For this reason black bolts are presumed to have less strength than fitted bolts and their strength is taken as 80 N/mm^2.

Turned and fitted bolts

To obtain more strength from a bolted connection it may be economical to use steel bolts that have been accurately turned. These bolts are fitted to holes the same diameter as their shank and the bolt is driven home by hammering and then secured with a nut.

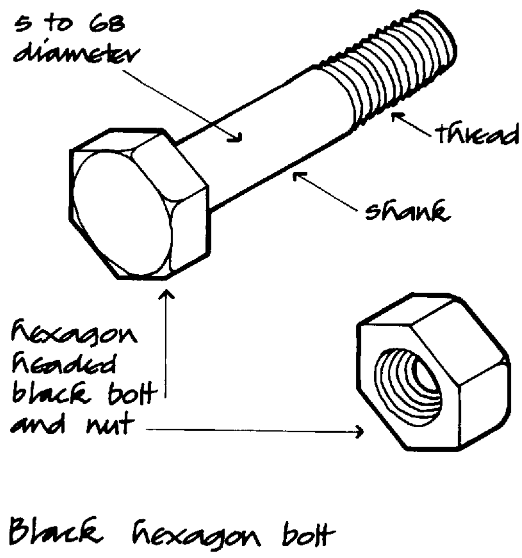


Fig. 53

Because of their tight fit the strength of these bolts is taken as 95 N/mm^2. These bolts are more expensive than black bolts and have largely been superseded by the high strength bolts described below.

High strength friction grip bolts

These bolts are made from high strength steel which enables them to suffer greater stress due to tightening than ordinary bolts. The combined effect of the greater strength of the bolt itself and the increased friction due to the firm clamping together of the plates being joined makes these bolts capable of taking greater loads than ordinary bolts. These bolts are tightened with a torque wrench which measures the tightness of the bolt by reference to the torque applied, which in turn gives an accurate indication of the strength of the connection, whereas hand tightening would give no measure of strength. Though more expensive that ordinary bolts these bolts and their associated washers are commonly used.

Strength of bolted connections

Single shear, double shear

Bolted connections may fail under load for one of two reasons. Firstly they may fail by the shearing of their shank. Shear is caused by the action of two opposite and equal forces acting on a material. The simplest analogy is the action of the blades of a pair of scissors or shears on a sheet of paper. As the blades close they exert equal and opposite forces which tear through the fibres of the paper forcing one part up and the other down. In the same way if the two plates joined by a bolt move with sufficient force in opposite directions than the bolt will fail in single shear as illustrated in Fig. 54. The strength of a bolt is determined by its resistance to shear in accordance with the strengths previously noted.

Where a bolt joins three plates it is liable to failure by the movement of adjacent plates in opposite directions as illustrated in Fig. 54. It will be seen that the failure is caused by the shank failing in shear at two points simultaneously, hence the term double shear. It is presumed that a bolt is twice as strong in double as in single shear.

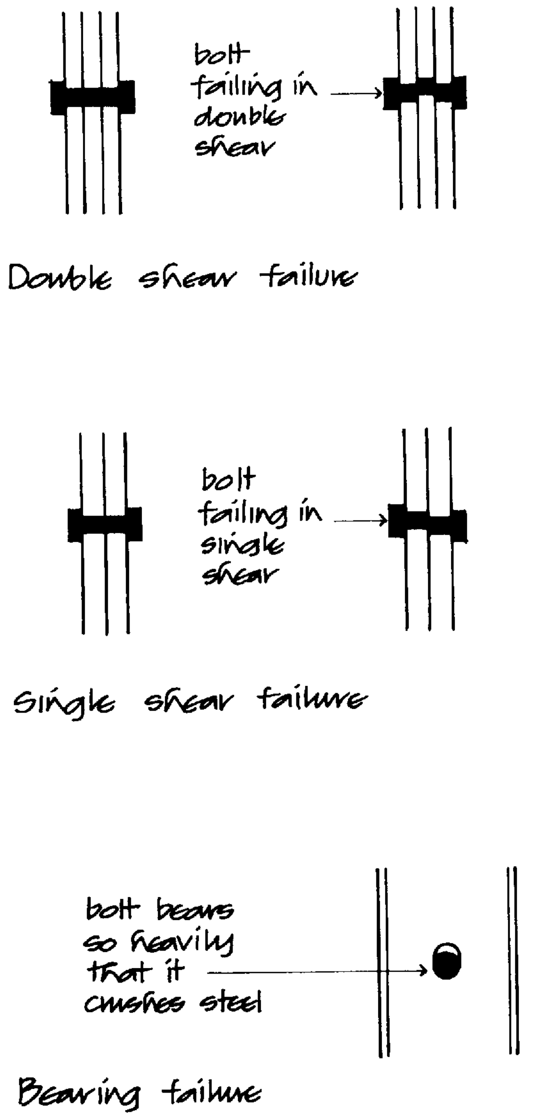


Fig. 54

Bearing strength

The other type of failure that may occur at a connection is caused by the shank of the bolt bearing so heavily on the metal of the member or members it is joining that the metal becomes crushed as illustrated in Fig. 54. The strength of mild steel in resisting crushing due to the bearing of bolts is taken as 200 N/mm^2. The bearing area of a particular bolted connection is the product of the diameter of the bolt and the thickness of the thinnest member at the joint.

Bolt pitch (spacing)

If bolts are too closely spaced they may bear so heavily on the section of the members around them that they tear through the metal with the result that instead of the load being borne by all it may be transferred to a few bolts which may then fail in shear. To prevent the possibility of this type of failure it is usual to space bolts not less far apart than two and a half times their diameter, measured centre to centre and no bolt less than one and three quarter times its diameter from the edge of a member.

Welding

The word welding describes the operation of running molten weld metal into the heated junction of steel plates or members so that when the weld metal has cooled and solidified it strongly binds them together. The edges of the members to be joined are cleaned and also shaped for certain types of weld. For a short period the weld metal is molten as it runs into the joint, and for this reason it is obvious that a weld can be formed more readily with the operator working above the joint than in any other position. It will be seen that welding can be carried out more quickly and accurately in a workshop where the members can be manipulated more conveniently for welding than they can be on site.

Welding is most used in the prefabrication of built-up beams, trusses and lattice frames. The use of shop welded connections for angle cleats to conventional skeleton frames is less used than it was due to the possibility of damage to the protruding cleats during transport, lifting and handling of members.

In the design of welded structures it is practice to prefabricate as far as practical in the workshop and make site connections either by bolting or by designing joints that can readily be welded on site. The advantage of welding as applied to structural steel frames is that members can be built up to give the required strength for minimum weight of steel, whereas standard members do not always provide the most economical section. The labour cost in fabricating welded sections is such that it can only be justified in the main for long span and non-traditional frames. The reduction in weight of steel in welded frames may often justify higher labour costs in large heavily loaded structures. In buildings where the structural frame is partly or wholly exposed the neat appearance of the welded joints and connections is an advantage.

It is difficult to tell from a visual examination whether a weld has made a secure connection, and X-ray or sonic equipment is the only exact way of testing a weld for adequate bond between weld and parent metal. This equipment is somewhat bulky to use on site and this is one of the reasons why site welding is not favoured.

Surfaces to be welded must be clean and dry if the weld metal is to bond to the parent metal. These conditions are difficult to achieve in our wet climate out on site. The process of welding used in structural steelwork is 'fusion welding', in which the surface of the metal to be joined is raised to a plastic or liquid condition so that the molten weld metal fuses with the plastic or molten parent metal to form a solid weld or join.

For fusion welding the requirements are a heat source, usually electrical, to melt the metal, a consumable electrode to provide the weld metal to fill the gap between the members to be joined and some form of protection against the entry of atmospheric gases which can adversely affect the strength of the weld.

The metal of the members to be joined is described as the parent or base metal and the metal deposited from the consumable electrode, the weld metal. The fusion zone is the area of fusion of weld metal to parent metal.

The method of welding most used for structural steelwork is the arc welding process where an electric current is passed from a consumable electrode to the parent metals and back to the power source. The electric arc from the electrode to the parent metals generates sufficient heat to melt the weld metal and the parent metal to form a fusion weld.

The processes of welding most used are described in the following sections.

Manual metal-arc (MMA) welding

This manually operated process is the oldest and the most widely used process of arc welding. The equipment for MMA welding is simple and relatively inexpensive and the process is fully positional in that welding can be carried out vertically and even overhead due to the force with which the arc propels drops of weld metal on to the parent metal. Because of its adaptability this process is suitable for complex shapes, welds where access is difficult and on-site welding.

The equipment consists of a power supply and a hand held, flux covered, consumable electrode as illustrated in Fig. 55. As the electrode is held by hand the soundness of the weld depends largely on the skill of the operator in controlling the arc length and speed of movement of the electrode.

The purpose of the flux coating to the electrode is

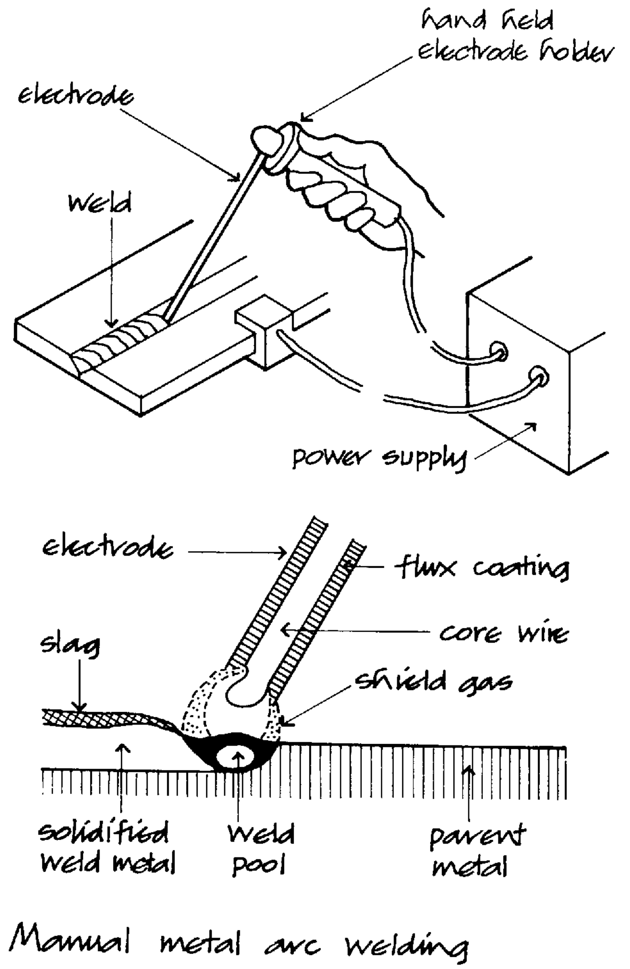


Fig. 55

to stabilise the arc, provide a gas envelope or shield around the weld to inhibit pick up of atmospheric gases and produce a slag over the weld metal to protect it from atmosphere.

Because this weld process depends on the skill of the operator there is a high potential for defects.

Metal inert-gas (MIG) and metal active-gas (MAG) welding

These processes use the same equipment, which is more complicated and expensive than that needed for MMA welding.

In this process the electrode is continuously fed with a bare wire electrode to provide weld metal and a cylinder to provide gas through an annulus to the electrode tip to form a gas shield around the weld as illustrated in Fig. 56. The advantage of the continuous electrode wire feed is that there is no break in welding to replace electrodes as there is with MMA welding, which can cause weakness in the weld run, and the continuous gas supply ensures a constant gas shield protection against the entry of atmospheric gases which could weaken the weld.

The manually operated electrode of this type of welding equipment can be used by less highly trained welders than the MMA electrode. The bulk of the

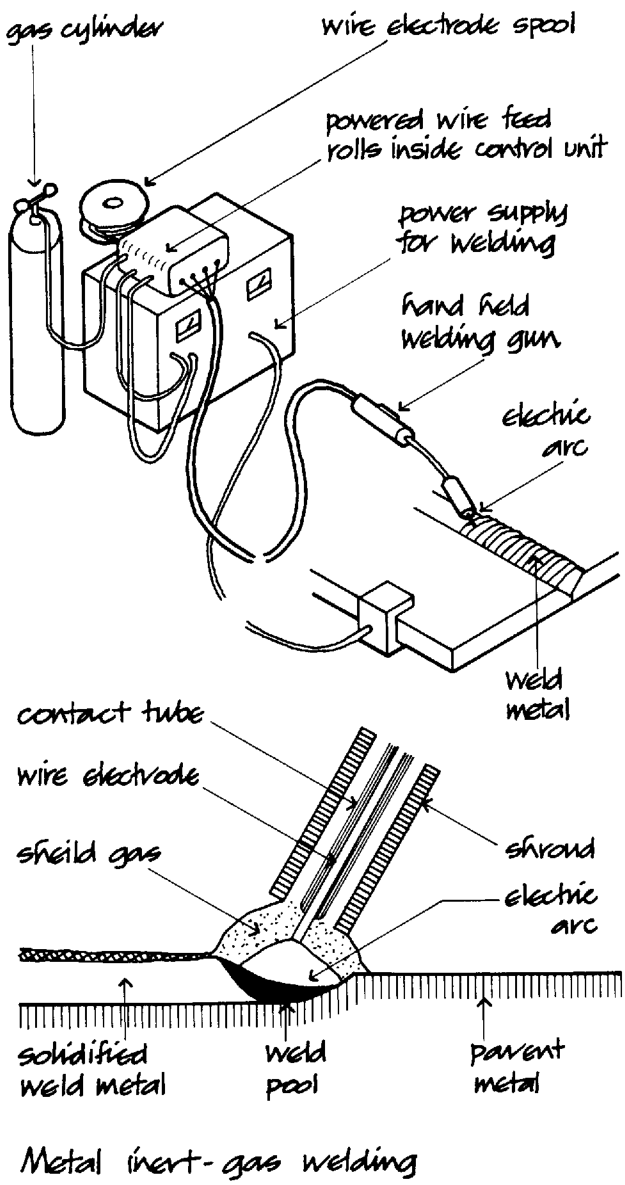


Fig. 56

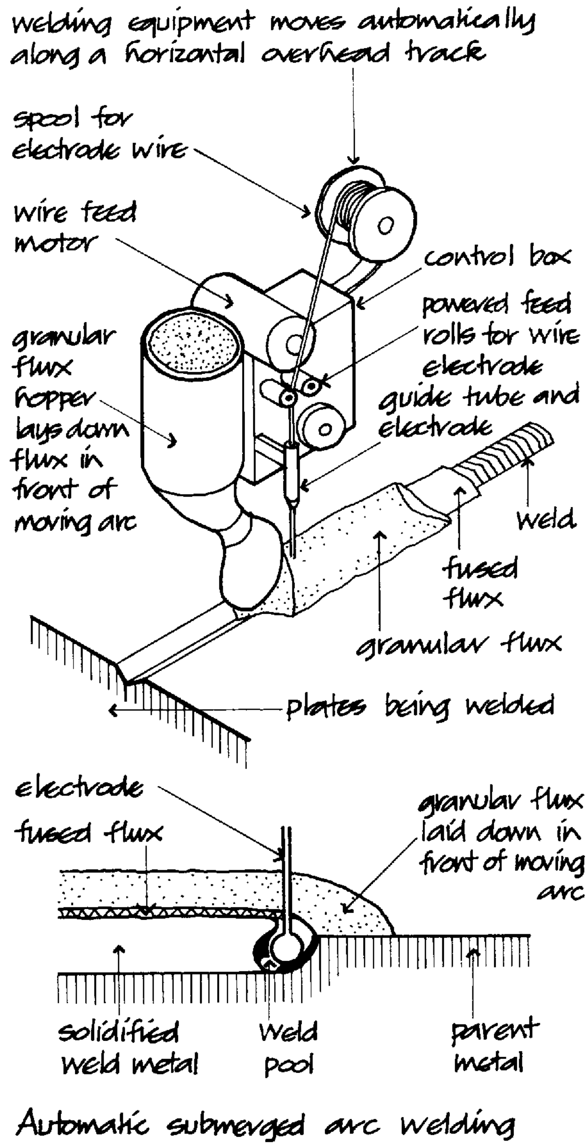


Fig. 57

equipment and the need for shelter to protect the gas envelope limit the use of this process to shop welding.

Submerged arc (SA) welding

Submerged arc (SA) welding is a fully automatic bare wire process of welding where the arc is shielded by a blanket of flux that is continuously fed from a hopper around the weld, as illustrated in Fig. 57. The equipment is mounted on a gantry that travels over the weld bench to lay down flux over the continuous weld run. The equipment, which is bulky and expensive, is used for long continuous shop weld runs of high quality that can be formed by welders with little skill.

Types of weld

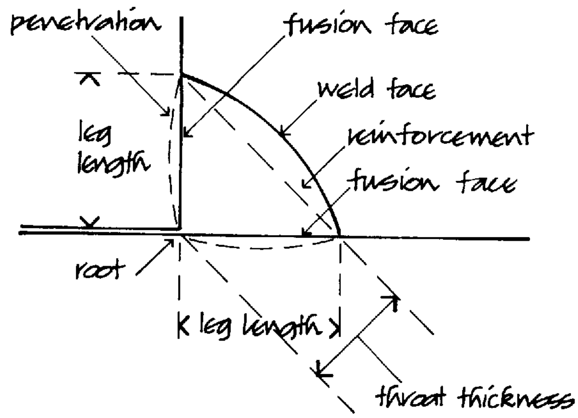
Fillet weld

This weld takes the form of a fillet of weld metal deposited at the junction of two parent metal membranes to be joined at an angle, the angle usually being a right angle in structural steelwork. The surfaces of the members to be joined are cleaned and the members fixed in position. The parent metals to be joined are connected to one electrode of the supply and the filler rod to the other. When the filler rod electrode is brought up to the join, the resulting arc causes the weld metal to run in to form the typical fillet weld illustrated in Fig. 58.

The strength of a fillet weld is determined by the throat thickness multiplied by the length of the weld to give the cross-sectional area of the weld, the strength of which is taken as 115 N/mm^2. The throat thickness is used to determine the strength of the weld as it is along a line bisecting the angle of the join that a weld usually fails. The throat thickness does not extend to the convex surface of the weld over the reinforcement weld metal because this reinforcement metal contains the slag of minerals other than iron that form on the surface of the molten weld metal, which are of uncertain strength.

The dotted lines in Fig. 58 represent the depth of penetration of the weld metal into the parent metal and enclose that part of the parent metal that becomes molten during welding and fuses with the molten weld metal.

The leg lengths of fillet weld used in structural steelwork are 3, 4, 5, 6, 8, 10, 12, 15, 18, 20, 22, and 25, see Fig. 58. Throat thickness is leg length by 0.7.



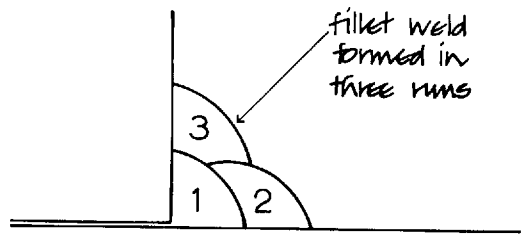


Fig. 58

Fillet welds 5 to 22 are those most commonly used in structural steelwork, the larger sizes being used at heavily loaded connections. Fillet welds of up to 10 are formed by one run of the filler rod in the arc welding process and the larger welds by two or more runs, as illustrated in Fig. 58.

When fillet welds are specified by leg length the steel fabricator has to calculate the gauge of the filler rod and the current to be used to form the weld. An alternative method is to specify the weld as, for example, a 1–10/225 weld, which signifies that it is a one run weld with a 10 gauge filler rod to form 225 of weld for each filler rod. As filler rods are of standard length this specifies the volume of the weld metal used for specified length of weld and therefore determines the size of the weld.

Intermittent fillet welds are generally used in structural steelwork, common lengths being 150, 225 and 300.

Butt welds

These welds are used to join plates at their edges and the weld metal fills the gap between them. The section of the butt weld employed depends on the thickness of the plates to be joined and whether welding can be executed from one side only or from both sides.

The edges of the plates to be joined are cleaned and shaped as necessary, the plates are fixed in position and the weld metal run in from the filler rod. Thin plates up to 5 thick require no shaping of their edges and the weld is formed as illustrated in Fig. 59. Plates up to 12 thick have their edges shaped to form a single V weld as illustrated in Fig. 60. The purpose of the V section is to allow the filler rod to be manipulated inside the V to deposit weld metal throughout the depth of the weld without difficulty.

Plates up to 24 thick are joined together either with a double V weld, where welding can be carried out from both sides, or by a single U where welding can only be carried out from one side. Figure 61 is an illustration of a double V and a single U weld. The U-shaped weld section provides room to manipulate the filler rod in the root of the weld but uses less of the expensive weld metal than would a single V weld of similar depth. It is more costly to form the edges of plates to the U-shaped weld than it is to form the V-shaped weld and the U-shaped weld uses less weld

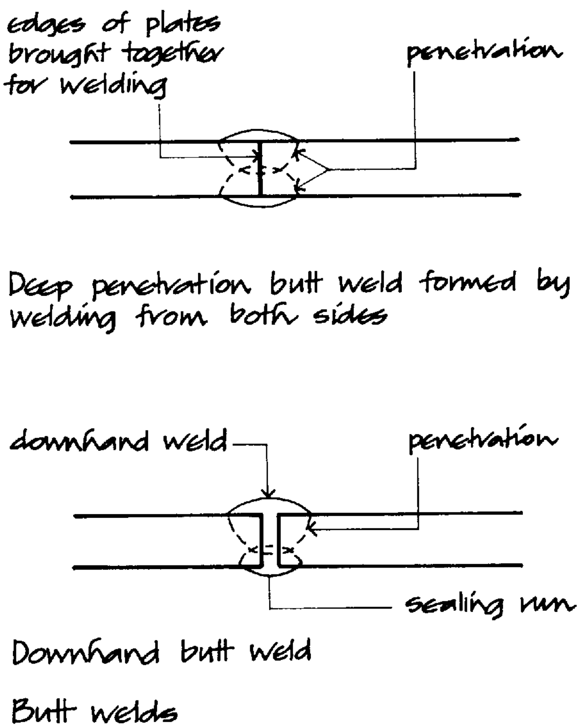


Fig. 59

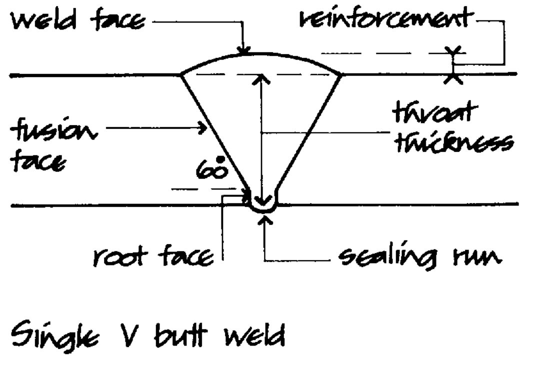


Fig. 60

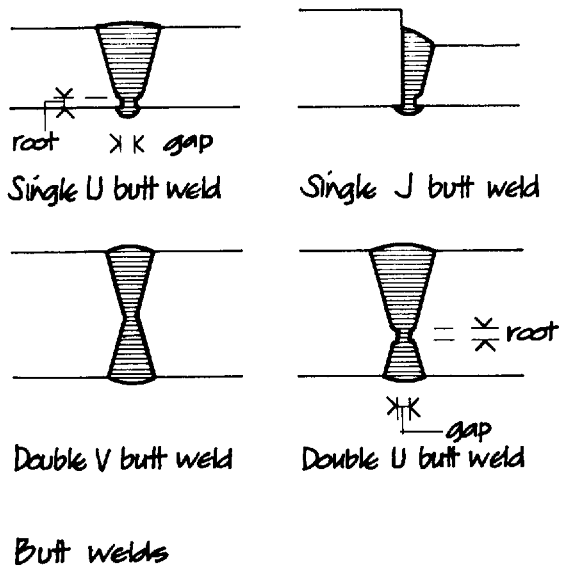
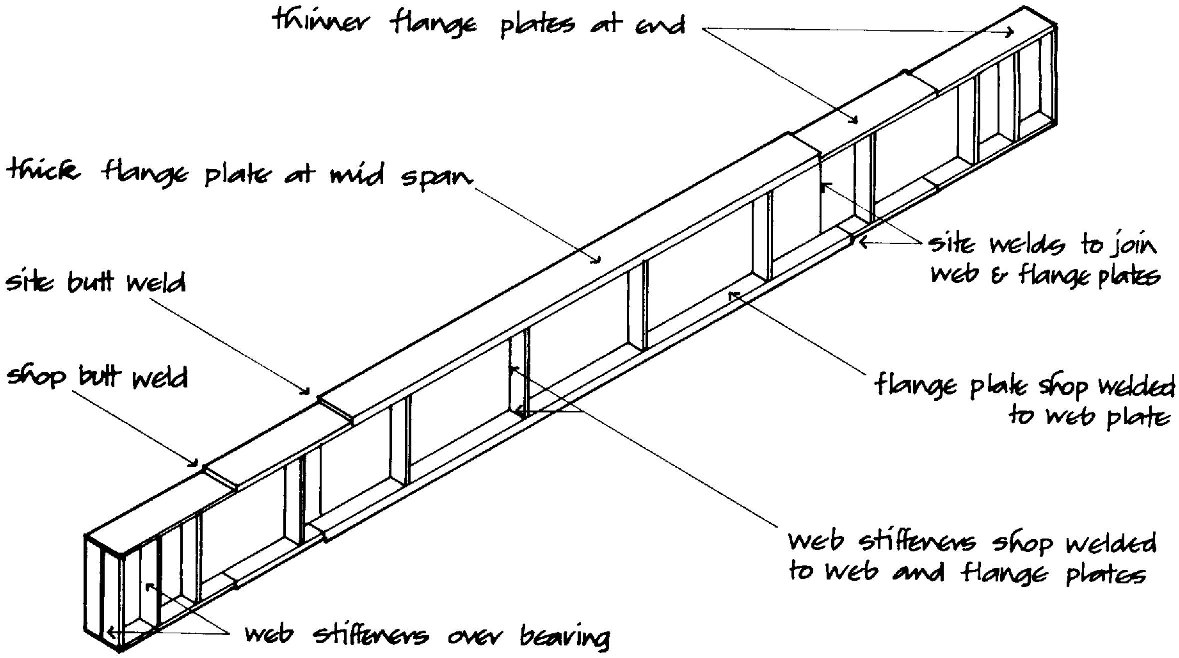


Fig. 61

metal than does a V weld of similar depth. Here the designer has to choose the weld that will be the cheapest.

Plates over 24 thick are joined with a double U weld as illustrated in Fig. 61. Butt welds between plates of dissimilar thickness are illustrated in Fig. 61.

The throat thickness of a butt weld is equal to the thickness of the thinnest plate joined by the weld and the strength of the weld is determined by the throat thickness multiplied by the length of the weld to give the cross-sectional area of throat. The size of a butt weld is specified by the throat thickness, that is the thickness of the thinnest plate joined by the weld. The shape of the weld may be described in words as, for example, a double V butt weld or by symbols.



Welded built up long span beam

Fig. 62

Uses of welding in structural frames

Built-up beams

As has been stated, welding can often be used economically in fabricating large span beams whereas it is generally cheaper to use standard beam sections for medium and small spans.

Figure 62 is an illustration of a built-up beam section fabricated from mild steel strip and plates, fillet and butt welded together. It will be seen that the material can be disposed to give maximum thickness of flange plates at mid span where it is needed.

Figure 63 illustrates a welded beam end connection where strength is provided by increasing the size of the plates which are shaped for welding to the column.

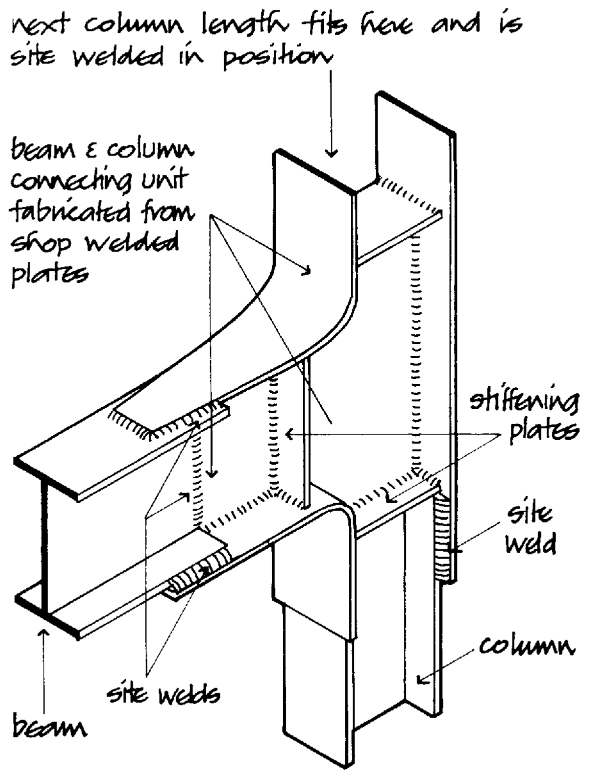
Built-up columns

Columns particularly lend themselves to fabrication by welding where a fabricated column may be preferable to standard rolled steel sections. Columns can be fabricated by welding two standard channel or angle sections together, or by welding plates or beams as illustrated in Fig. 64. A disadvantage of the closed box section columns illustrated is that site connections to the column are usually made with long bolts passing right through the columns, which adds to the cost of the connection. This can be overcome by welding seat angles to the column and using a web cleat welded to the column in lieu of the conventional top angle cleat.

Welded connections

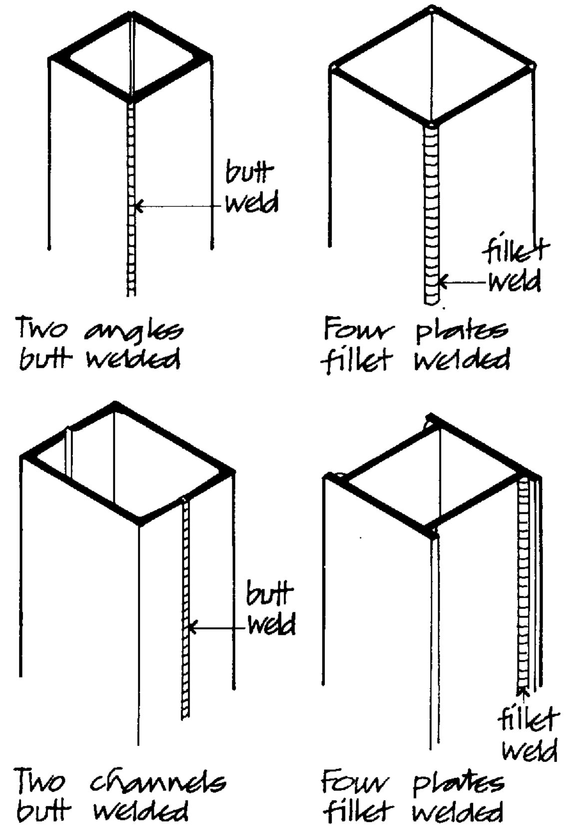
Figure 52 illustrates typical shop welded and site bolted connections. Angle seating cleats are fillet welded to columns and bolted to beams and angle side cleats are fillet welded to columns and bolted to beams as illustrated.

The column splice connection illustrated in Fig. 52 is made by fillet welding the splice plates to the lower column length and bolting the top of the splice plates through packing pieces.



Welded beam to column connection

Fig. 63



Welded built-up columns

Fig. 64

Figure 65 illustrates a welded column connection directly to a slab base plate.

Column bases and foundations

Steel columns in framed buildings are used to support heavy loads and it is necessary to spread these loads from the comparatively small section of the columns to concrete, steel or reinforced concrete bases, which in turn spread the loads to the subsoil. The size of the foundation depends on the loads it supports and the bearing capacity of the subsoil. Where the subsoil for some depth below the surface has poor bearing capacity it is practice to use piles to transmit the loads from foundations down to a firm underlying stratum.

Column base plates

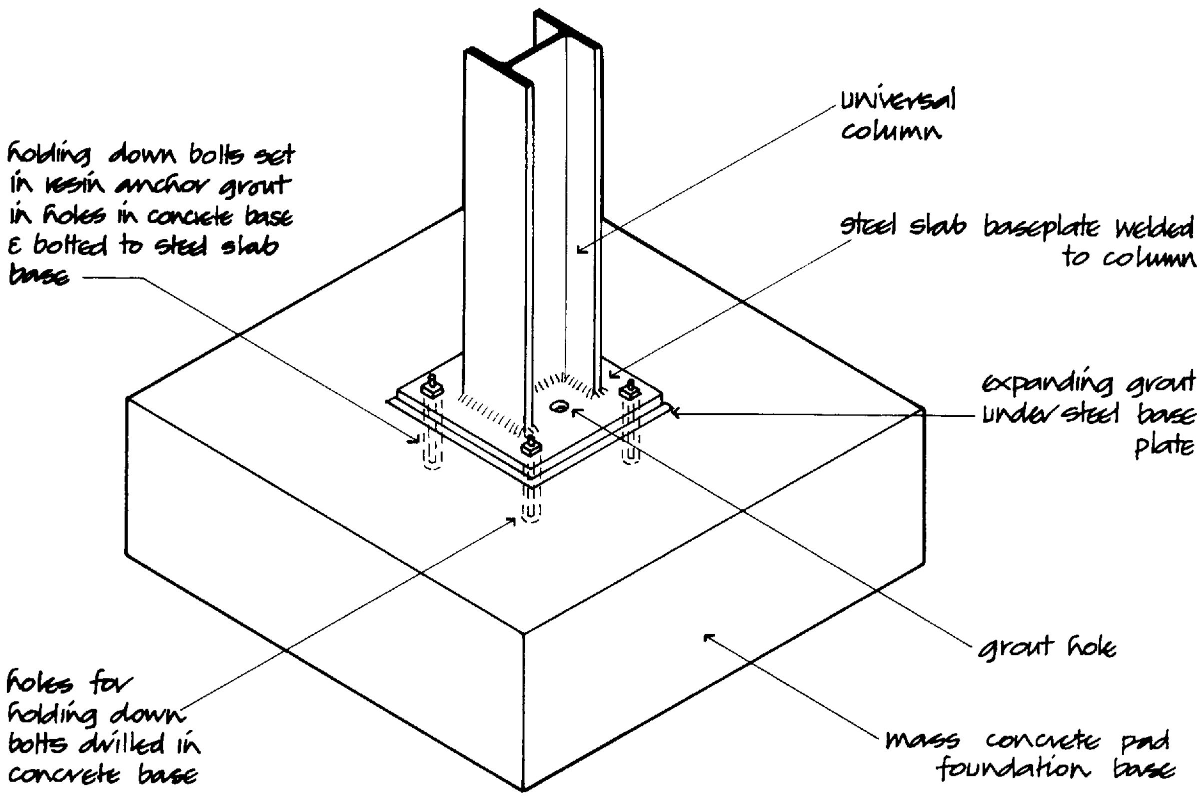
The bases of steel columns are accurately machined so that they bear truly on the steel base plates to which they are secured by welding. The purpose of the base plate is to provide a sufficient area at the base of the column bearing on the concrete foundation that will not crush the concrete and to enable the base to be bolted to the concrete base. The two types of plate used are a comparatively thin plate 12 thick and the thicker bloom or slab illustrated in Fig. 65.

The base plate is either welded to the column or secured to it by means of gusset plates, as illustrated in Fig. 66.

Mass concrete foundation to columns

The base of columns carrying moderate loads of up to say 400 kN bearing on soils of good bearing capacity can be economically of mass concrete. The size of the base depends on the bearing capacity of the soil and load on the column base and the depth of the concrete is equal to the projection of the concrete beyond the base plate, assuming an angle of dispersion of load in concrete of 45 degrees. Figure 65 is an illustration of a mass concrete base.

Holding down bolts are either cast into the



Steel slab base on concrete pad foundation

Fig. 65

concrete base or collars are cast in. When bolts are cast in concrete they are held in place whilst the concrete is being poured by means of a wood or metal template suspended over the concrete. It is often difficult to ensure that bolts are accurately cast in position on site and it is not uncommon for cast in bolts to be cut out and reset in position when the steel columns are being erected.

Collars are made of a sleeve of expanded steel as illustrated in Fig. 67 and the collars are cast into the concrete. The steel column is raised into position with holding down bolts in the collars. When the column has been levelled the holding down bolts are grouted into the collars. The advantages of these collars is that they allow room for the steel erector to manoeuvre the bolts until the column is in its correct position.

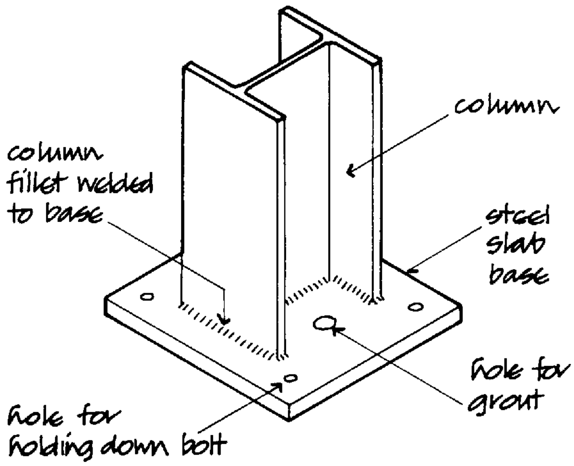
Columns are levelled in position on concrete bases by inserting steel wedges between the steel base plate and the concrete and these are adjusted until the column is level and plumb. Stiff concrete is then hammered in between the steel plate and the concrete base to complete the foundation.

Reinforced concrete base

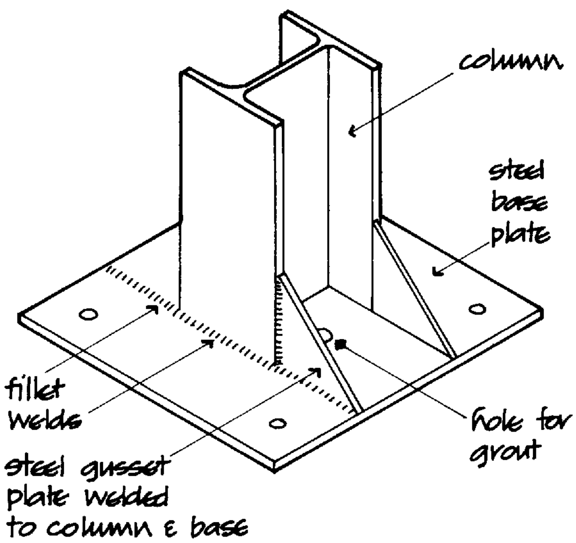
The area of the base required to spread the load from heavily loaded columns on subsoils of poor to moderate bearing capacity is such that it is generally more economical to use a reinforced concrete base than a mass concrete one. The steel column base plate is fixed as it is to a mass concrete base. Where column bases are large and closely spaced it is often economical to combine them in a continuous base or raft, as described in Chapter 1.

Steel grillage foundation

Steel grillage foundation is a base in which a grillage of steel beams transmits the column load to the subsoil. The base consists of two layers of steel beams, two or three in the top layer under the foot of

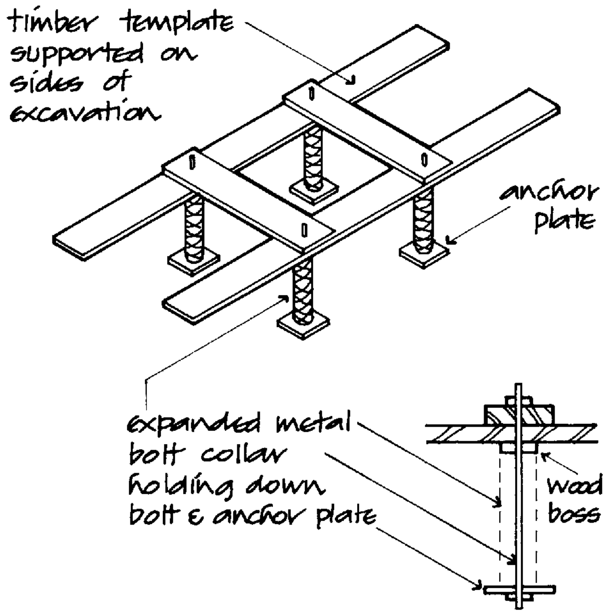


Column welded to slab base



Column welded to plate base

Fig. 66



Expanded metal foundation bolt boxes

Fig. 67

the column and a lower cross layer of several beams so that the area covered by the lower layer is sufficient to spread column loads to the requisite area of subsoil. The whole of the steel beam grillage is encased in concrete. This type of base is rarely used as a reinforced concrete base is much cheaper.

Hollow rectangular sections

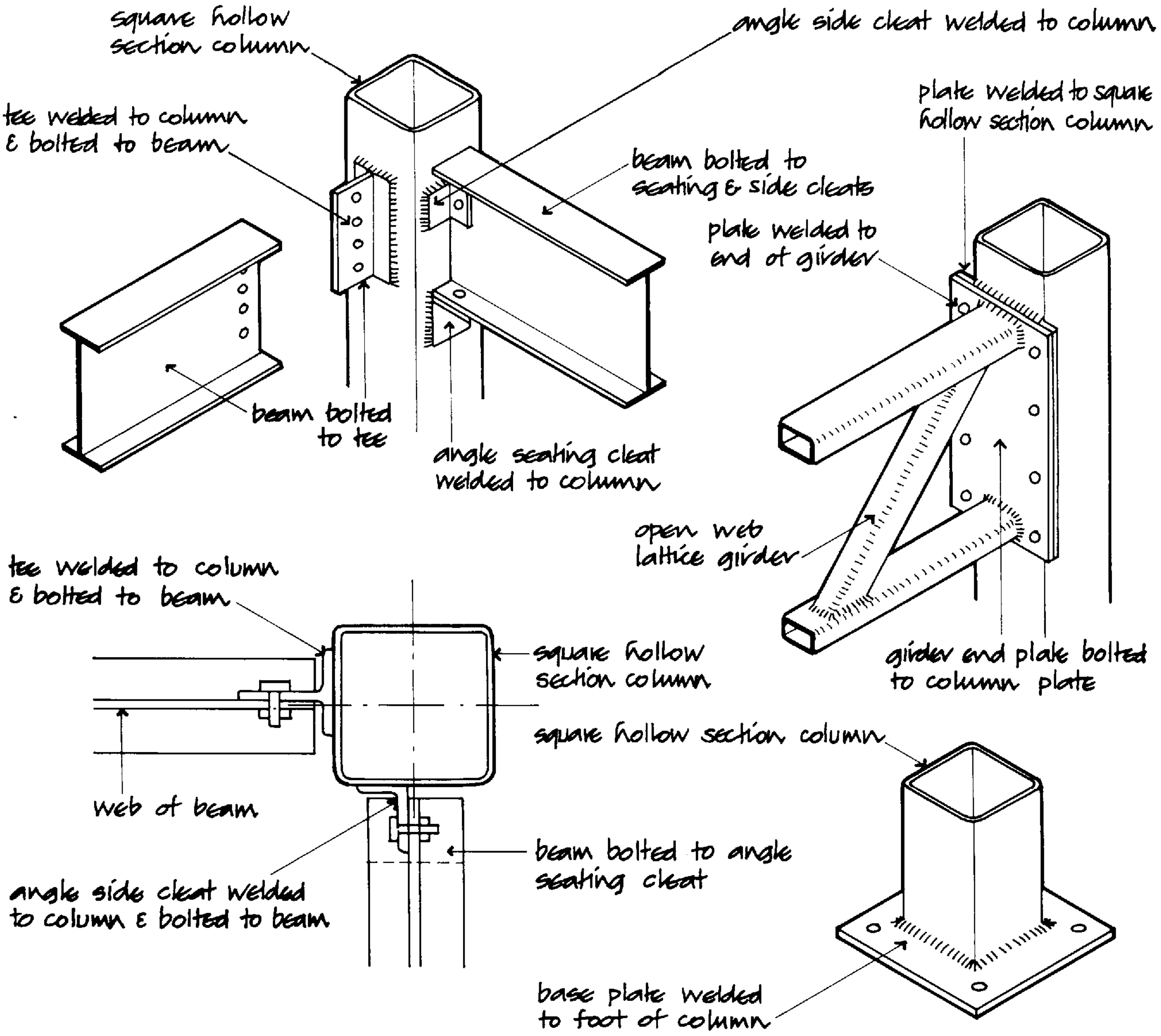
Beam to column connections

Bolted connections to closed box section columns may be made with long bolts passing through the section. Long bolts are expensive and difficult to use as they necessitate raising beams on opposite sides of the column at the same time in order to position the bolts. Beam connections to hollow rectangular and square section columns may be made through plates, angles or tees welded to the columns. Standard beam sections are bolted to tee section cleats welded to columns and lattice beams by bolting end plates welded to beams to plates welded to columns, as illustrated in Fig. 68.

Flowdrill jointing

A recent innovation in making joints to hollow rectangular steel sections (HRS) is the use of the flowdrill technique as an alternative to the use of either long bolting through the section or site welding.

The flowdrill technique depends on the use of a tungsten carbide bit which can be used in a conventional drilling machine. As the tungsten carbide bit rotates on the surface of the HRS it generates sufficient heat to soften the steel so that the bit penetrates the steel wall of the HRS and redistributes the metal to form an internal bush as illustrated in



Connections to hollow section columns

Fig. 68

Fig. 69. Once the metal has cooled, the formed bush is threaded with a coldform flowtap to provide a threaded hole for a bolt. The beam connection to the HRS column is then completed by bolting end plates or web cleats to the beam and the ready drilled holes in the HRS column as illustrated in Fig. 69.

The flowdrill method of jointing is the preferred method of jointing for the benefit of economy in materials and site labour.

Cold strip sections

Beam to column connections

These connections are made by means of protruding studs or tees welded to the columns and bolted to the beams. Studs welded to columns are bolted to small section beams and ties and larger section beams to tee section cleats welded to columns, as illustrated in

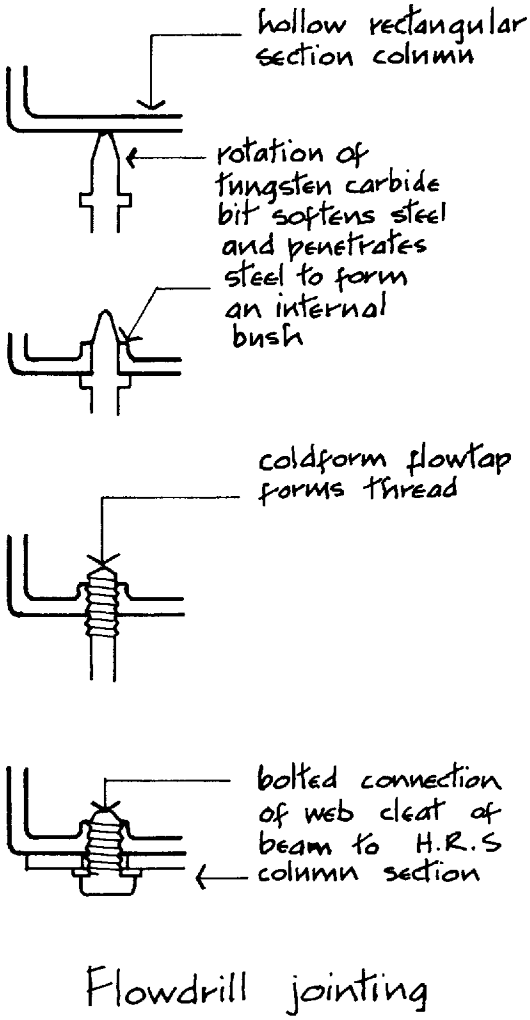


Fig. 69

Fig. 70. The tee section cleat is required for larger beams to spread the bearing area over a sufficient area of thin column wall to resist buckling.

Parallel beam structural steel frame

This type of structural steel frame uses double main or spine beams fixed each side of internal columns to support secondary rib beams that support the floor. The principal advantage of this form of structure is improved flexibility for the services, which can be located in both directions within the grid between the spine beams in one direction and the rib beams in the other. The advantage of using two parallel main spine beams is simplicity of connections to columns and the use of continuous long lengths of beam independent of column grid, which reduces fabrication and erection complexities and the overall weight of steel by the use of continuity of beams.

The most economical arrangement of the frame is a rectangular grid with the more lightly loaded rib beams spanning the greater distance between the more heavily loaded spine or main beams. Where long span ribs are used, for reasons of convenience in internal layout or for convenience in running services or both, a square grid may be most suitable.

The square grid illustrated in Fig. 71 uses double spine or main beams to internal columns with pairs of rib beams fixed to each side of columns with profiled steel decking and composite construction structural concrete topping fixed across the top of the rib beams. The spine beams are site bolted to end plates welded to short lengths of channel section steel that are shop welded to the columns. At the perimeter of the building a single spine beam is bolted to the end plate of channel sections welded to the column.

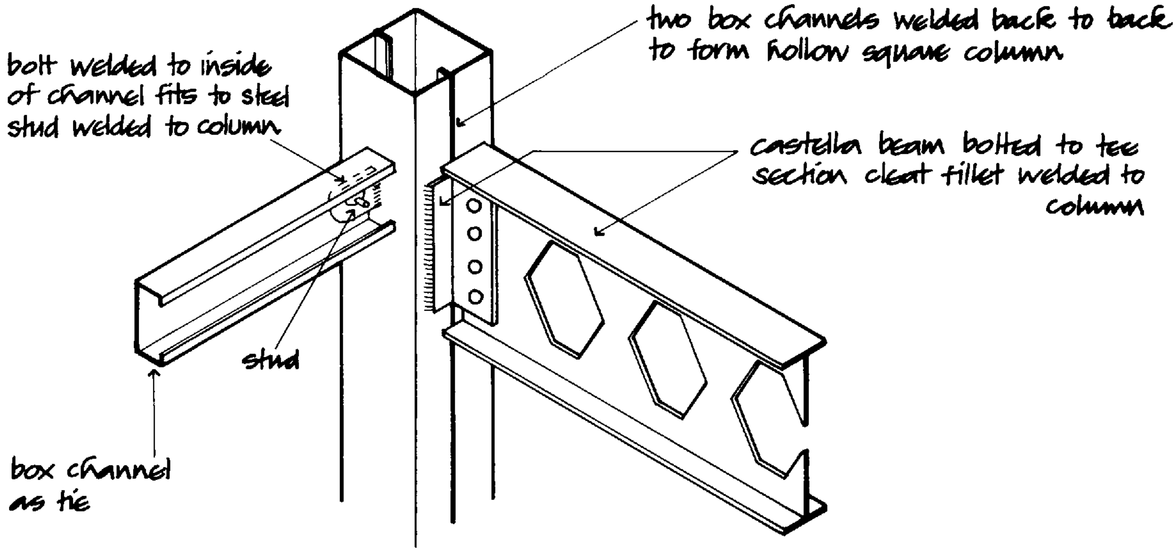
The parallel beam structural frame may be used, with standard I section beams and columns or with hollow rectangular section columns and light section rolled steel sections or cold formed strip steel beams and ribs, for smaller buildings supporting moderate floor loads in which there is need for provision for the full range of electric and electronic cables and air conditioning. Although the number of steel sections used for each grid of the framework in this system is greater than that needed for the conventional steel frame, there is generally some appreciable saving in the total weight and, therefore, the cost of the frame and appreciable saving in the erection time due to the simplicity of connections. The overall depth of the structural floor is greater than that of a similar conventional structural steel frame. As all the services common to modern buildings may be housed within the structural depth, rather than being slung below the structural floor of a conventional frame above a suspended ceiling, there may well be less overall height of building for given clear height between finished floor and ceiling level.

FLOORS AND ROOFS TO STRUCTURAL STEEL FRAMES

FUNCTIONAL REQUIREMENTS

The functional requirements of floors and roofs are:

Strength and stability
Resistance to weather



Cold roll-formed sections - connections

Fig. 70

Durability and freedom from maintenance
Fire safety
Resistance to the passage of heat
Resistance to the passage of sound

Strength and stability

The requirements from Part A of Schedule 1 to the Building Regulations 1991, as amended 1994, are that buildings be constructed so that the loadbearing elements, foundations, walls, floors and roofs have adequate strength and stability to support the dead loads of the construction and anticipated loads on roofs, floors and walls without such undue deflection or deformation as might adversely affect the strength and stability of parts or the whole of the building.

The strength and stability of floors and roofs depend on the nature of the materials used in the floor and roof elements and the section of the materials used in resisting deflection (bending) under the dead and imposed loads. Under load any horizontal element will deflect (bend) to an extent. Deflection under load is limited to about $\frac{1}{300}$ of span to minimise cracking of rigid finishes to floors and ceilings and to limit the sense of insecurity the occupants might have, were the floor to deflect too obviously. In general the strength and stability of a floor or roof is a product of the depth of the supporting members, the greater the depth the greater the strength and stability.

Resistance to weather (roofs)

The requirements for resistance to the penetration of wind, rain and snow and the construction and finishes necessary for both traditional and more recently used roof coverings is described in Volumes 1 and 3.

Durability and freedom from maintenance

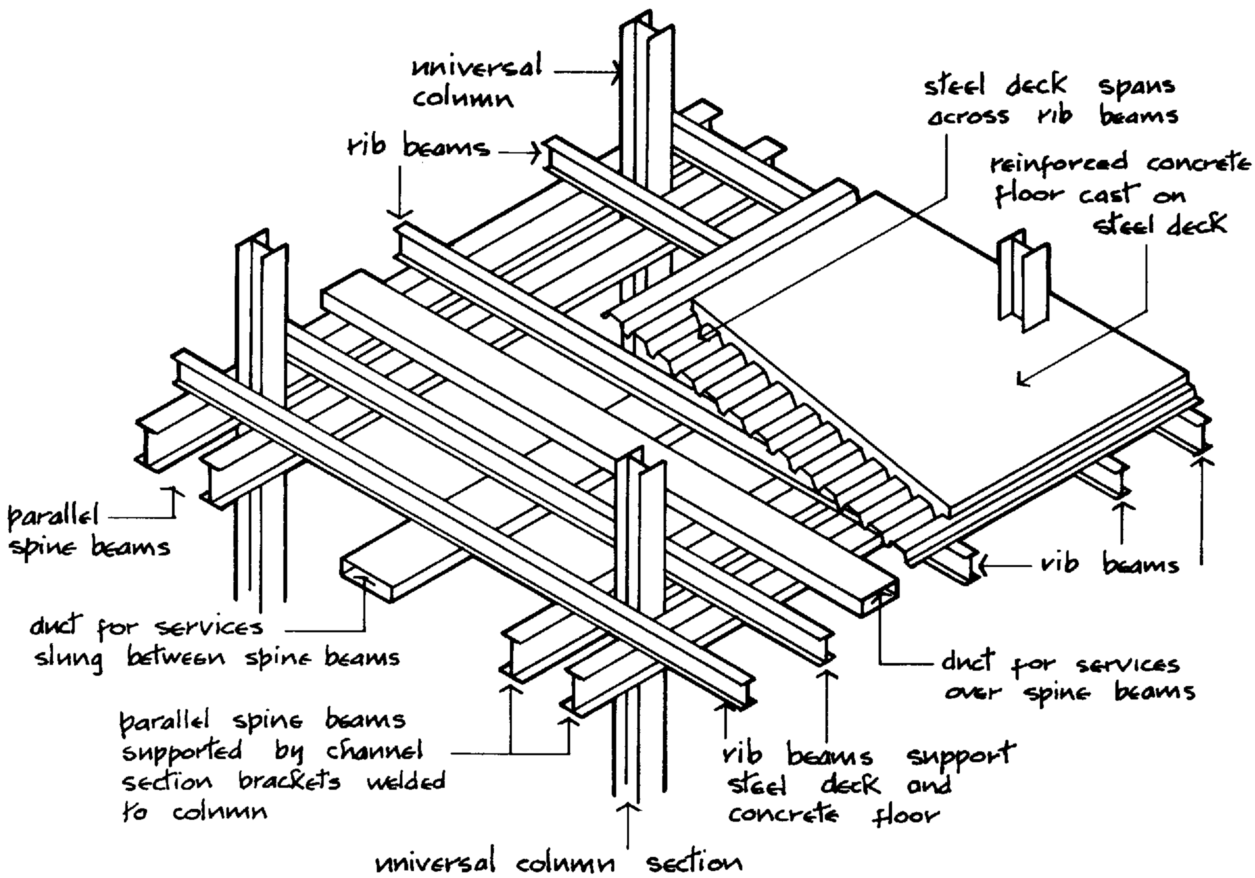
The durability and freedom from maintenance of both traditional and the more recently used roof coverings is described in Volumes 1 and 3.

The durability and freedom from maintenance of floors constructed with steel beams, profiled steel decking and reinforced concrete depends on the internal conditions of the building. The majority of multi-storey framed buildings today are heated, so that there is little likelihood of moist internal conditions occurring, such as to cause progressive, destructive corrosion of steel during the useful life of the building.

Fire safety

The requirements from Part B of Schedule 1 to the Building Regulations 1991, as amended 1994, are concerned to:

(a) provide adequate means of escape
(b) limit internal fire spread (linings)



Parallel beam structural steel frame

Fig. 71

(c) limit internal fire spread (structure)
(d) limit external fire spread
(e) provide access and facilities for the Fire Services

Fire safety regulations are concerned to ensure a reasonable standard of safety in case of fire. The application of the regulations, as set out in the practical guidance given in Approved Document B, is directed to the safe escape of people from buildings in case of fire rather than the protection of the building and its contents. Insurance companies that provide cover against the risks of damage to the buildings and contents by fire will generally require additional fire protection such as sprinklers.

Means of escape

The requirement from the Building Regulations is that the building shall be designed and constructed so that there are means of escape from the building in case of fire to a place of safety outside the building. The main danger to people in buildings, in the early stages of a fire, is the smoke and noxious gases produced which cause most of the casualties and may also obscure the way to escape routes and exits. The Regulations are concerned to:

(a) provide a sufficient number and capacity of escape routes to a place of safety
(b) protect escape routes from the effects of fire by enclosure, where necessary, and to limit the ingress of smoke
(c) ensure the escape routes are adequately lit and exits suitably indicated

The general principle of means of escape is that any person in a building confronted by an outbreak of fire can turn away from it and make a safe escape.

The number of escape routes and exits depends on the number of occupants in the room or storey, and the limits on travel distance to the nearest exit depend on the type of occupancy. The number of occupants in a room or storey is determined by the maximum number of people they are designed to hold, or calculated by using a floor space factor related to the type of accommodation which is used to determine occupancy related to floor area as set out in Approved Document B. The maximum number of occupants determines the number of escape routes and exits; where there are no more than 50 people one escape route is acceptable. Above that number, a minimum of 2 escape routes is necessary for up to 500 and up to 8 for 16000 occupants. Maximum travel distances to the nearest exit are related to purpose-group types of occupation and whether one or more escape routes are available. Distances for one direction escape are from 9.0 to 18.0 and for more than one direction escape from 18.0 to 45.0, depending on the purpose groups defined in Approved Document B.

Internal fire spread (linings)

Fire may spread within a building over the surface of materials covering walls and ceilings. The Regulations prohibit the use of materials that encourage spread of flame across their surface when subject to intense radiant heat and those which give off appreciable heat when burning. Limits are set on the use of thermoplastic materials used in rooflights and lighting diffusers.

Internal fire spread (structure)

As a measure of ability to withstand the effects of fire, the elements of a structure are given notional fire resistance times, in minutes, based on tests. Elements are tested for the ability to withstand the effects of fire in relation to:

(a) resistance to collapse (loadbearing capacity) which applies to loadbearing elements
(b) resistance to fire penetration (integrity) which applies to fire separating elements
(c) resistance to the transfer of excessive heat (insulation) which applies to fire separating elements

The notional fire resistance times, which depend on the size, height and use of the building, are chosen as being sufficient for the escape of occupants in the event of fire.

The requirements for the fire resistance of elements of a structure do not apply to:

(1) A structure that only supports a roof unless:
  (a) the roof acts as a floor, e.g. car parking, or as a means of escape
  (b) the structure is essential for the stability of an external wall which needs to have fire resistance.
(2) The lowest floor of the building.

Compartments

To prevent rapid fire spread which could trap occupants, and to reduce the chances of fires growing large, it is necessary to subdivide buildings into compartments separated by walls and/or floors of fire-resisting construction. The degree of subdivision into compartments depends on:

(a) the use and fire load (contents) of the building
(b) the height of the floor of the top storey as a measure of ease of escape and the ability of fire services to be effective
(c) the availability of a sprinkler system which can slow the rate of growth of fire.

The necessary compartment walls and/or floors should be of solid construction sufficient to resist the penetration of fire for the stated notional period of time in minutes. The requirements for compartment walls and floors do not apply to single-storey buildings.

Concealed spaces

Smoke and flame may spread through concealed spaces, such as voids above suspended ceilings, roof spaces and enclosed ducts and wall cavities in the construction of a building. To restrict the unseen spread of smoke and flames through such spaces, cavity barriers and stops should be fixed as a tight fitting barrier to the spread of smoke and flames.

External fire spread

To limit the spread of fire between buildings, limits to the size of 'unprotected areas' of walls and also finishes to roofs, close to boundaries, are imposed by the Building Regulations. The term 'unprotected area' is used to include those parts of external walls that may contribute to the spread of fire between buildings. Windows are unprotected areas as glass offers negligible resistance to the spread of fire. The Regulations also limit the use of materials of roof coverings near a boundary that will not provide adequate protection against the spread of fire over their surfaces.

Access and facilities for the Fire Services

Buildings should be designed and constructed so that:

- Internal firefighting facilities are easily accessible
- Access to the building is simple
- Vehicular access is straightforward
- The provision of fire mains is adequate

Resistance to the passage of heat

The requirements for the conservation of power and fuel by the provision of adequate insulation of roofs are described in Volumes 1 and 3.

Resistance to the passage of sound

A description of the transmission and perception of sound is given in Volume 2. In multi-storey buildings the structural frame may provide a ready path for the transmission of impact sound over some considerable distance. The heavy slamming of a door, for example, can cause a sudden disturbing sound clearly heard some distance from the source of the sound by transmission through the frame members. Such unexpected sounds are often more disturbing than continuous background sounds such as eternal traffic noise. To provide resistance to the passage of such sounds it is necessary to provide a break in the path between potential sources of impact and continuous solid transmitters.

FLOOR AND ROOF CONSTRUCTION

In the early days of iron and steel framed construction, floors were constructed with comparatively closely spaced iron or steel filler beams, between main beams, giving support to shallow brick arches built between them on which concrete was spread to provide a level floor. This type of 'fire resisting' floor was in general use before the advent of reinforced concrete. The filler beam and brick arched floor gave way to the hollow clay block and in situ cast reinforced concrete floor described in Volume 1. This labour intensive form of construction was used for the advantage of the fire resisting property of the clay blocks and the reduction in dead weight afforded by the hollow blocks.

With the development of the technique of mass production of precast reinforced concrete units, systems of precast reinforced concrete slabs, beams and infill concrete block floors became common for steel framed buildings. The advantage of these floor systems was a considerable reduction in site labour and speed of erection because the slabs and beams were 'self-centering', that is they required no support from below once in place whereas previous floor systems required some support from below during construction.

Precast hollow floor beams

The precast, hollow, reinforced concrete floor units illustrated later in Fig. 111, Chapter 4, are from 400 to 1200 wide, 110 to 300 thick for spans of up to 10 metres for floors and 13½ metres for the less heavily loaded roofs. The purpose of the voids in the units is to reduce deadweight without affecting strength. The reinforcement is cast into the webs between the hollows. The wide floor units are used where there is powered lifting equipment which can swing the units into place. These hollow floor units can be used by themselves as floor slabs with a non-structural levelling floor screed or they may be used with a structural reinforced concrete topping with tie bars over beams for composite action with the concrete casing to beams. End bearing of these units is a minimum of 75 on steel shelf angles or beams and 100 on masonry and brick walls.

The ends of these floor units are usually supported by steel shelf angles either welded or bolted to steel beams so that a part of the depth of the beam is inside the depth of the floor as illustrated later in Fig. 111. The ends of the floor units are splayed to fit under the top flange of the beams. A disadvantage of the construction shown later in Fig. 111 is that the deep I section beam projects some distance below the floor units and increases the overall height of construction for a given minimum clear height between floor and underside of beam. To minimise the overall height of

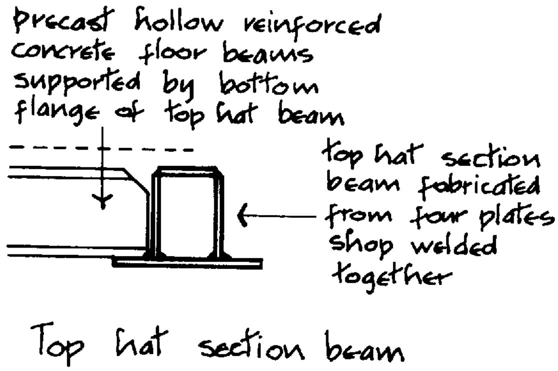


Fig. 72

construction it is recent practice in Sweden to use welded top hat profile beams with the floor units supported by the bottom flange as illustrated in Fig. 72. The top hat section is preferred because of the difficulty of lowering and manoeuvring the units into the web of broad flange I section beams. This Swedish construction is particularly suited to multi-storey residential flats where the comparatively small imposed loads on floors facilitates a combination of overall beam depth and floor units to minimise construction depth. A screed is spread over the floor for lightly loaded floors and roofs and a reinforced concrete constructional topping for more heavily loaded floors.

Precast prestressed concrete floor units

These comparatively thin, prestressed solid plank, concrete floor units are designed as permanent centering (shuttering) for composite action with structural reinforced concrete topping as illustrated later in Fig. 112, Chapter 4.

The units are 400 and 1200 wide, 65, 75, or 100 thick and up to 9½ metres long for floors and 10 metres for roofs. It may be necessary to provide some temporary propping to the underside of these planks until the concrete topping has gained sufficient strength. A disadvantage of this construction is that as the planks are laid on top of the beams so that the floor spans continuously over beams, there is increase in overall depth of construction from top of floor to underside of beams.

Precast concrete tee beams

Precast concrete tee beam floors are mostly used for long span floors and particularly roofs of such buildings as stores, supermarkets, swimming pools and multi-storey car parks where there is a need for wide span floors and roofs and the depth of the floor is no disadvantage. The floor units are cast in the form of a double tee as illustrated later in Fig. 113, Chapter 4. The strength of these units is in the depth of the tail of the tee which supports and acts with the comparatively thin top web. A structural reinforced concrete topping is cast on top of the floor units.

Precast beam and filler block floor

This floor system of precast reinforced concrete beams or planks to support precast hollow concrete filler blocks is illustrated later in Fig. 114, Chapter 4, for use with concrete beams. For use with steel beams the floor beams are laid between supports such as steel shelf angles fixed to the web of the beams or laid on the top flange of beams and the filler blocks are then laid between the floor beams. The reinforcement protruding from the top of the planks acts with the concrete topping to form a continuous floor system spanning across the structural beams. These small beams or planks and filler blocks can be manhandled into place without the need for heavy lifting equipment. This type of floor is most used in smaller scale buildings supporting the lighter imposed floor loads common in residential buildings for example.

Hollow clay block and concrete floor

This floor system, illustrated in Volume 1, consists of hollow clay blocks and in situ cast concrete reinforced as ribs between the blocks. This floor has to be laid on temporary centering to provide support until the in situ concrete has gained sufficient strength.

This floor system is much less used than it was due to the considerable labour required for setting up the temporary support and laying out the blocks and reinforcement.

Cold rolled steel deck and concrete floor

The traditional concrete floor to a structural steel frame consisted of reinforced concrete, cast in situ with the concrete casing to beams, cast on timber centering and falsework supported at each floor level until the concrete has sufficient strength to be self-supporting. The very considerable material and labour costs in erecting and striking the support for the concrete floor led to the adoption of the precast concrete self-centering systems such as the hollow beam and plank and beam and infill block floors. The term 'self-centering' derives from the word centering used to describe the temporary platform of wood or steel on which in situ cast concrete is formed. The precast concrete beam, plank and beam and block floors do not require temporary support, hence the term self-centering.

A disadvantage of the precast concrete beam and plank floors for use with a structural steel frame is that it is practice to erect the steel frame in one operation. Raising the heavy, long precast concrete floor units and moving them into position is to an extent impeded by the skeleton steel frame.

Of recent years profiled cold rolled steel decking, as permanent formwork acting as the whole or a part of the reinforcement to concrete, has become the principal floor system for structural steel frames. The profiled steel deck is easily handled and fixed in place as formwork (centering) for concrete.

The profiled cold roll-formed steel sheet decking, illustrated in Fig. 73, is galvanised both sides as a protection against corrosion. The profile is shaped for bond to concrete with projections that taper in from the top of the deck. Another profile is of trapezoidal section with chevron embossing for key to concrete.

The steel deck may be laid on the top flange of beams, as illustrated in Fig. 73, or supported by shelf

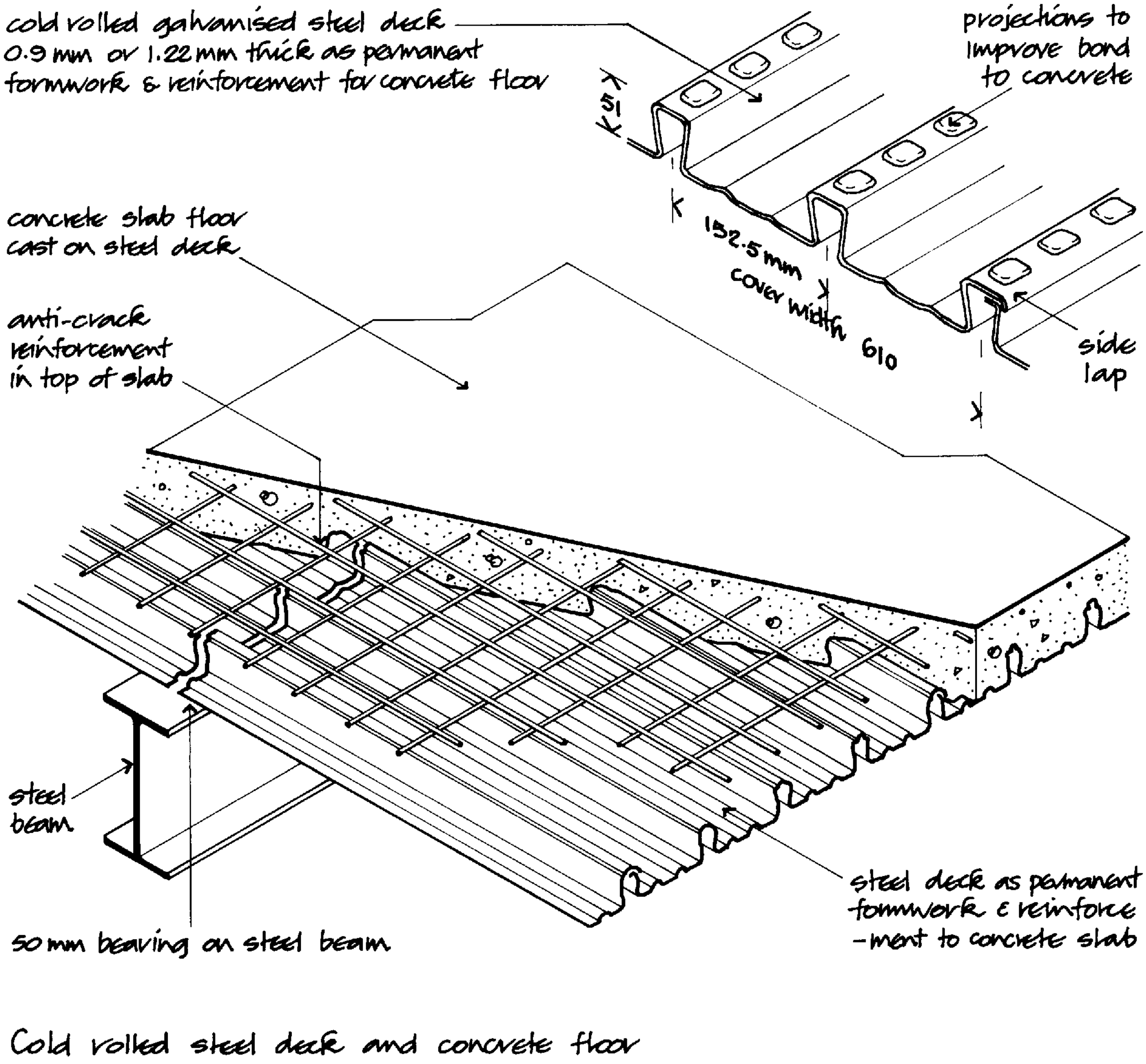


Fig. 73

angles bolted to the web of the beam to reduce overall height and fixed in position on the steelwork with shot fired pins, self-tapping screws or by welding, with two fixings to each sheet. Side laps of deck are fixed at intervals of not more than one metre with self-tapping screws or welding.

For medium spans between structural steel beams the profiled steel deck acts as both permanent formwork and as reinforcement for the concrete slab that is cast in situ on the deck. A mesh of anti-crack reinforcement is cast into the upper section of the slab, as illustrated in Fig. 73.

For long spans and heavy loads the steel deck can be used with additional reinforcement cast into the bottom of the concrete between the upstanding profiles and, for composite action between the floor and the beams, shear studs are welded to the beams and cast into the concrete.

The steel mesh reinforcement cast into the concrete slab floor is sufficient to provide protection against damage by fire in most situations. For high fire rating the underside of the deck can be coated with sprayed on protection or an intumescent coating.

Where there is to be a flush ceiling for appearance and as a housing for services, a suspended ceiling is hung from hangers slotted into the profile or hangers bolted to the underside of the deck.

Slimfloor floor construction

'Slimfloor' is the name adopted by British Steel for a form of floor construction for skeleton steel framed buildings. This form of construction is an adaptation of a form of construction developed in Sweden where restrictions on the overall height of buildings dictated the development of a floor system with the least depth of floor construction to gain the maximum number of storeys within the height limitations.

Slimfloor construction comprises beams fabricated from universal column sections to which flange plates are welded as illustrated in Fig. 74. The flange plates, which are wider overall than the flanges of the beams, provide support to profiled steel decking that acts in part as reinforcement and provides support for the reinforced concrete constructional topping.

The galvanised, profiled steel deck units are 210 deep with ribs at 600 centres. The ribs and the top of the decking are ribbed to stiffen the plates and provide some bond to concrete. To seal the ends of the ribs in the decking to contain the concrete that

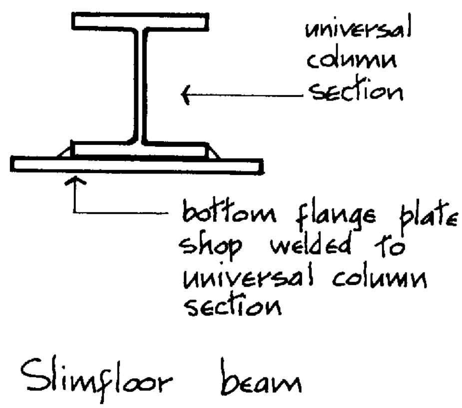


Fig. 74

will be cast around beams, sheet steel stop ends are fixed through the decking to the flange plates as illustrated in Fig. 75. Constructional concrete topping is spread over the decking and into the ribs around reinforcement in the base of the ribs and anti-crack reinforcement in the floor slab.

The galvanised pressed steel deck units are designed for spans of 6 metres for use with the typical grid of 9 metre beam spans at 6 metre centres. For spans of over 6 and up to $7\frac{1}{2}$ metres the decking will need temporary propping at mid-span until the concrete has developed adequate strength.

The slimfloor may be designed as a non-composite form of construction where the floor is assumed to have no composite action with the beams as illustrated in Fig. 75. This non-composite type of floor construction is usual where the imposed floor loads are low, as in residential buildings, and the floor does not act as a form of bracing to the structural frame. Where buildings are in excess of four storeys in height and the imposed floor loads are relatively high, a composite form of construction may be used. Composite action between the concrete floor and the steel beams is achieved through 19 diameter studs which are shop-welded to the top flange of beams and transverse reinforcement cast in over the beams as illustrated in Fig. 76.

The reason for using a composite action form of floor construction is to provide the least constructional thickness of floor design and to utilise the lateral bracing effect of the floor on the structural frame.

A particular advantage of the slimfloor is that all or some of the various services, common to some modern buildings, may be accommodated within the deck depth rather than being slung below the

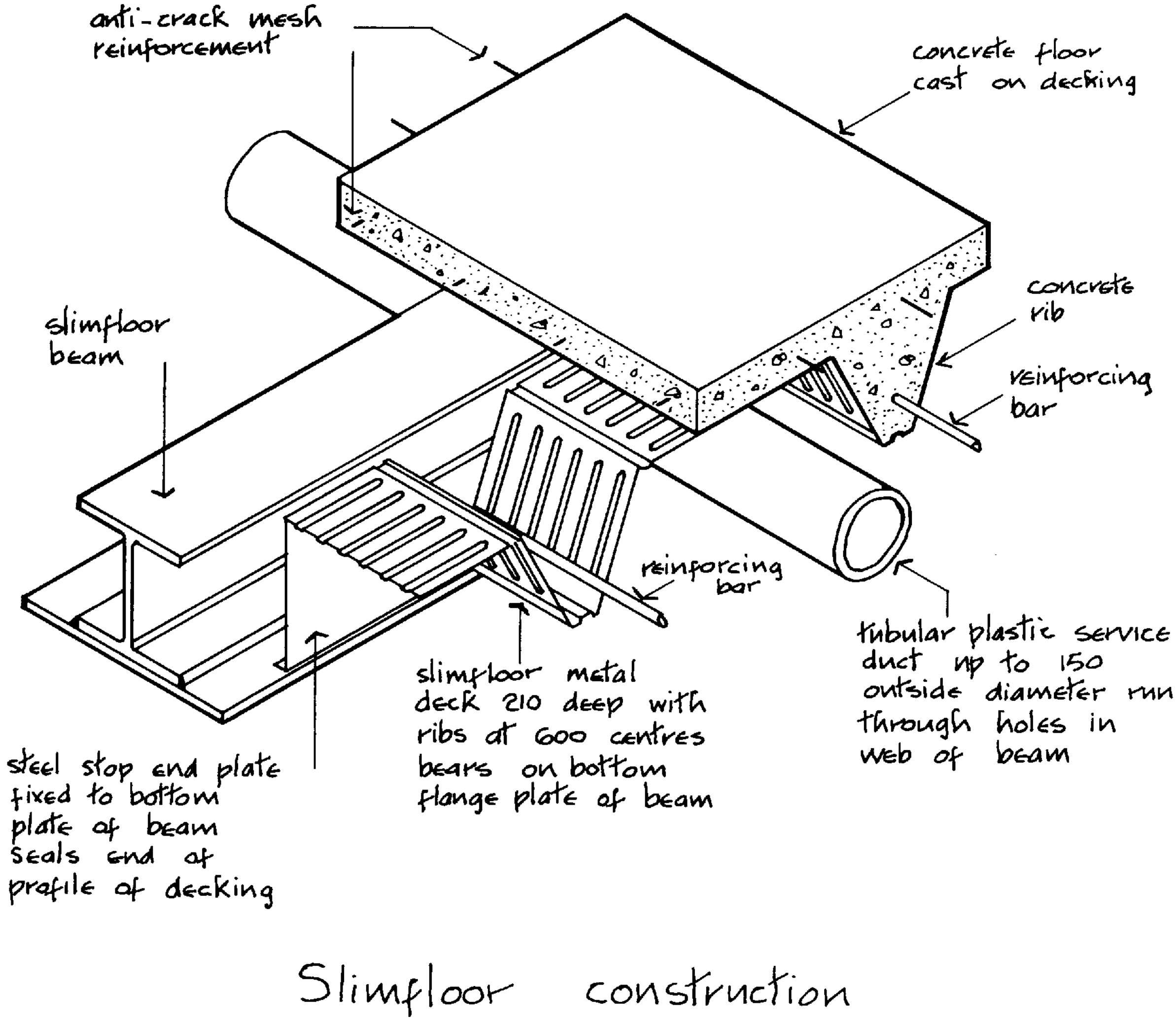


Fig. 75

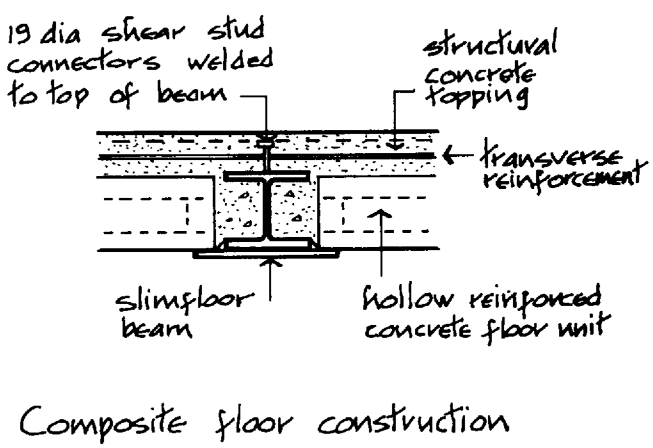


Fig. 76

structural floor over a false ceiling. Calculations and tests have shown that 150 diameter holes may be cut centrally through the web of the beams at 600 spacing along the middle third of the length of the beam without significantly affecting the load carrying capacity of the beam. Figure 75 is an illustration of the floor system showing a plastic tube sleeve run through the web of a beam for service pipes and cables.

The ceiling finish may be fixed to the underside of the decking or hung from the decking to provide space for services such as ducting.

Because of the concrete encasement to the beams, most slimfloor constructions achieve 1 hour's fire resistance rating without the need for applied fire protection to the underside of the beam. Where fire resistance requirement is over 60 minutes it is necessary to apply fire protection to the underside of the bottom flange plate.

The advantages of the slimfloor construction are:

(a) speed of construction through ease of man-handling and ease of fixing the lightweight deck units which provide a safe working platform
(b) pumping of concrete obviates the need for mechanical lifting equipment
(c) the floor slab is lightweight as compared to in situ or precast concrete floors
(d) the deck profile provides space for both horizontal services in the depth of the floor and vertical services through the wide top flange of the profile
(e) least overall depth of floor to provide minimum constructional depth consistent with robustness requirements dictated by design codes

FIRE SAFETY

Fire protection of structural steelwork

Fires in buildings generally start from a small source of ignition, the 'outbreak of fire', which leads to the 'spread of fire' followed by a steady state during which all combustible material burns steadily up to a final 'decay stage'.

Building regulations are mainly concerned with controlling the spread of fire to ensure the safety of those in the building and their safe escape in a notional period of time that varies from a half to six hours, depending on the use of the building, its construction and size.

To limit the growth and spread of fires in buildings the Regulations classify materials in accordance with the tendency of the materials to support spread of flame over their surface which is also an indication of the combustibility of the materials. Regulations also impose conditions to contain fires inside compartments to limit the spread of flame.

To provide safe means of escape, the Regulations set standards for the containment of fires and the associated smoke and fumes from escape routes for notional periods of time deemed adequate for escape from buildings.

One aspect of fire regulations is to specify notional periods of fire resistance for the loadbearing elements of a building so that they will maintain their strength and stability for a stated period during fires in buildings for the safety of those in the building.

Steel, which is non-combustible and makes no contribution to fire, loses so much of its strength at a temperature of 550°C that a loaded steel member would begin to deform, twist and sag and no longer support its load. Because a temperature of 550°C may be reached early in the development of fires in buildings, regulations may require a casing to structural steel members to reduce the amount of heat getting to the steel.

The larger the section of a structural steel member the less it will be affected by heat from fires by absorbing heat before it loses strength. The greater the mass and the smaller the perimeter of a steel section, the longer it will be before it reaches a temperature at which it will fail. This is due to the fact that larger sections will absorb more heat than smaller ones before reaching a critical temperature.

By applying a P/A factor, in which P is the perimeter in metres and A the cross-sectional area in square metres, to steel sections it is possible to use a reduced thickness of fire protection around heavy sections.

The traditional method of protecting structural steelwork from damage by fire is to cast concrete around beams and columns or to build brick or blockwork around columns with concrete casing to beams. These heavy, bulky and comparatively expensive casings have by and large been replaced by lightweight systems of fire protection employing sprays, boards, preformed casing and intumescent coatings.

The materials used for fire protection of structural steelwork may be grouped as:

- Sprayed coatings
- Board casings
- Preformed casings
- Plaster and lath
- Concrete, brick or block casings

Spray coatings

A wide range of products are available for application by spraying on the surface of structural steel sections to provide fire protection. The materials are

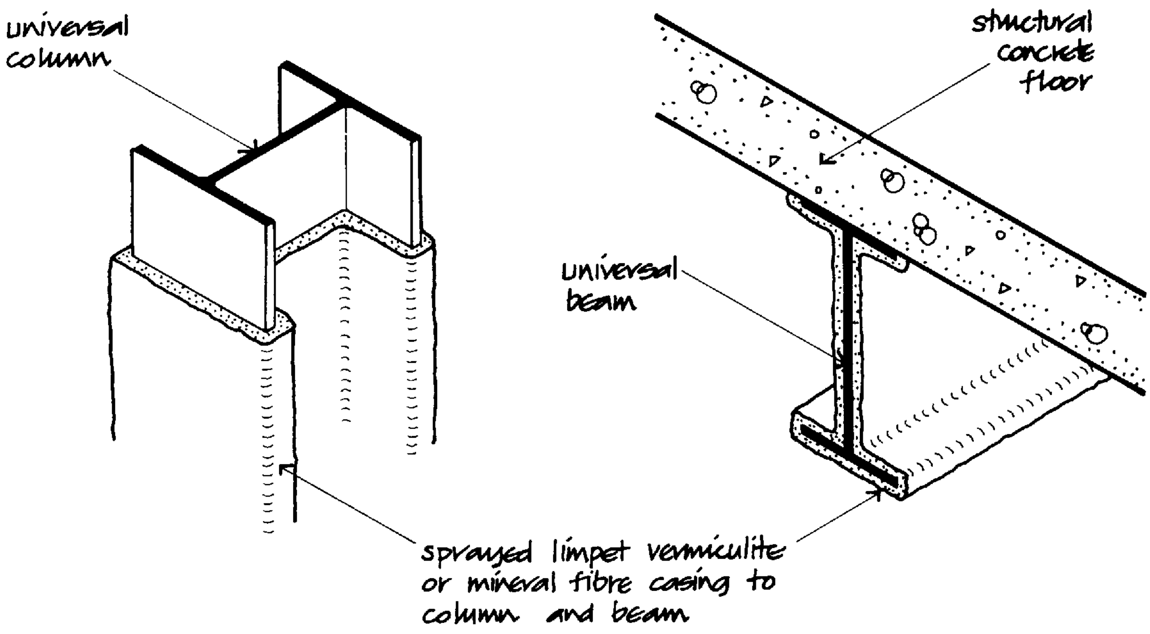


Fig. 77

sprayed on to the surface of the steel sections so that the finished result is a lightweight coating that takes the profile of the coated steel, as illustrated in Fig. 77.

This is one of the cheapest methods of providing a fire protection coating or casing to steel for protection of up to four hours, depending on the thickness of the coating. The finished surface of these materials is generally coarse textured and because of the lightweight nature of the materials these coatings are easily damaged by knocks and abrasions. They provide some protection against corrosion of steel and, being lightweight, assist in controlling condensation.

These sprayed systems of protection are suitable for use where appearance is not a prime consideration and for beams in floors above suspended ceilings. Being lightweight and porous, spray coatings are not generally suited to external use.

Spray coatings may be divided into two broad groups as:

- Mineral fibre spray coatings
- Vermiculite/gypsum/cement spray coatings

Mineral fibre coatings

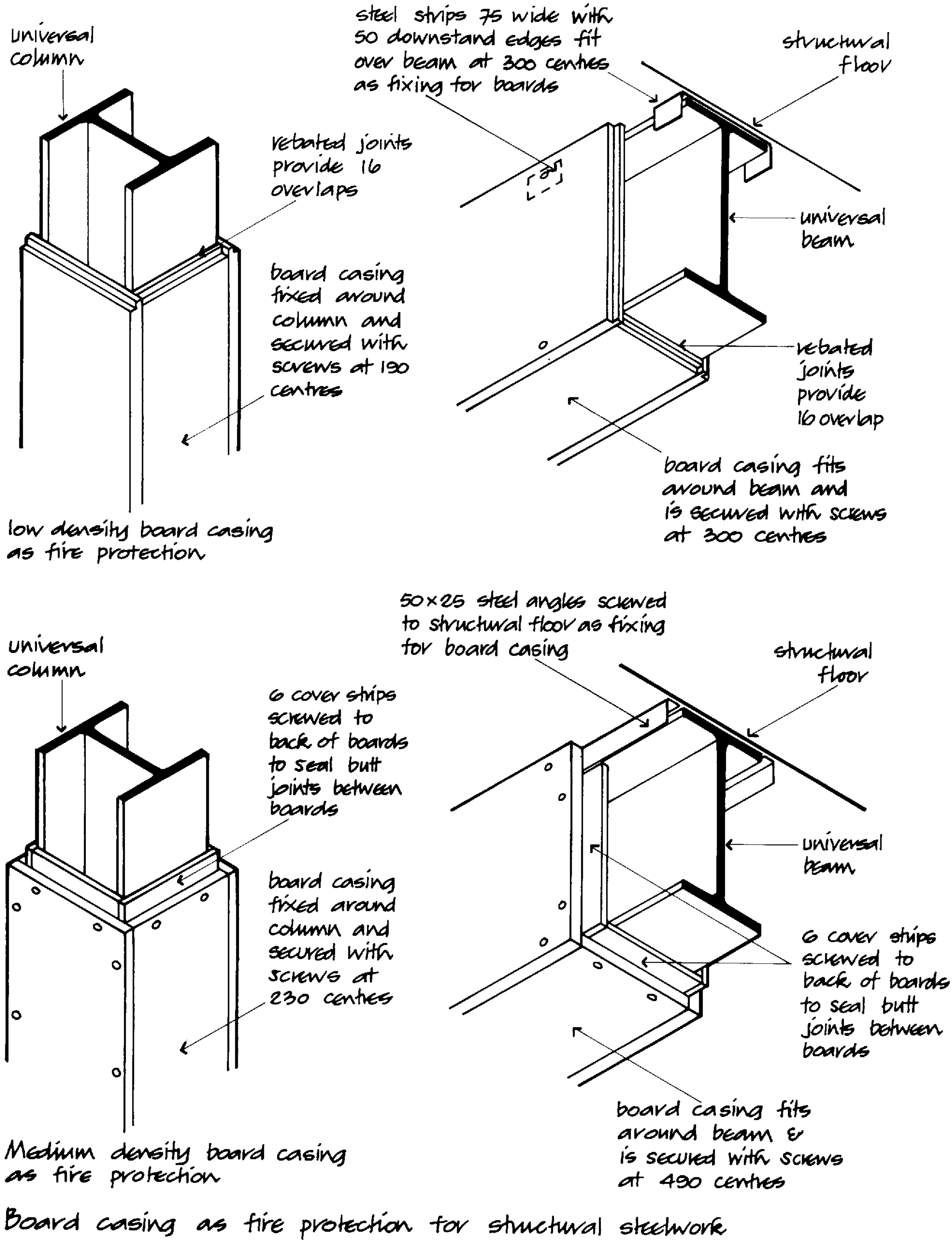
Mineral fibre coatings consist of mineral fibres that are mixed with inorganic binders, the wet mix being sprayed directly on to the clean, dry surface of the steel. The material dries to form a permanent, homogenous insulation that can be applied to any steel profile.

Vermiculite/gypsum/cement coatings

Vermiculite/gypsum/cement coatings consist of mixes of vermiculite or aerated magnesium oxychloride with cement or vermiculite with gypsum plaster. The materials are premixed and water is added on site for spray application directly to the clean, dry surface of steel. The mix dries to a hard, homogenous insulation that can be left rough textured from spraying or trowelled to a smooth finish. These materials are somewhat more robust than mineral spray coatings but will not withstand knocks.

Intumescent coatings

These coatings include mastics and paints which swell when heated to form an insulating protective coat which acts as a heat shield. The materials are applied by spray or trowel to form a thin coating over the profile of the steel section. They provide a hard finish which can be left textured from spraying or trowelled smooth, and provide protection of up to two hours.



universal column
rebated joints provide 16 overlaps
board casing fixed around column and secured with screws at 190 centres
low density board casing as fire protection
steel strips 75 wide with 50 downstand edges fit over beam at 300 centres as fixing for boards
structural floor
universal beam
rebated joints provide 16 overlap
board casing fits around beam and is secured with screws at 300 centres
universal column
6 cover strips screwed to back of boards to seal butt joints between boards
board casing fixed around column and secured with screws at 230 centres
Medium density board casing as fire protection
50×25 steel angles screwed to structural floor as fixing for board casing
structural floor
universal beam
6 cover strips screwed to back of boards to seal butt joints between boards
board casing fits around beam & is secured with screws at 490 centres
Board casing as fire protection for structural steelwork

Fig. 78

Board casings

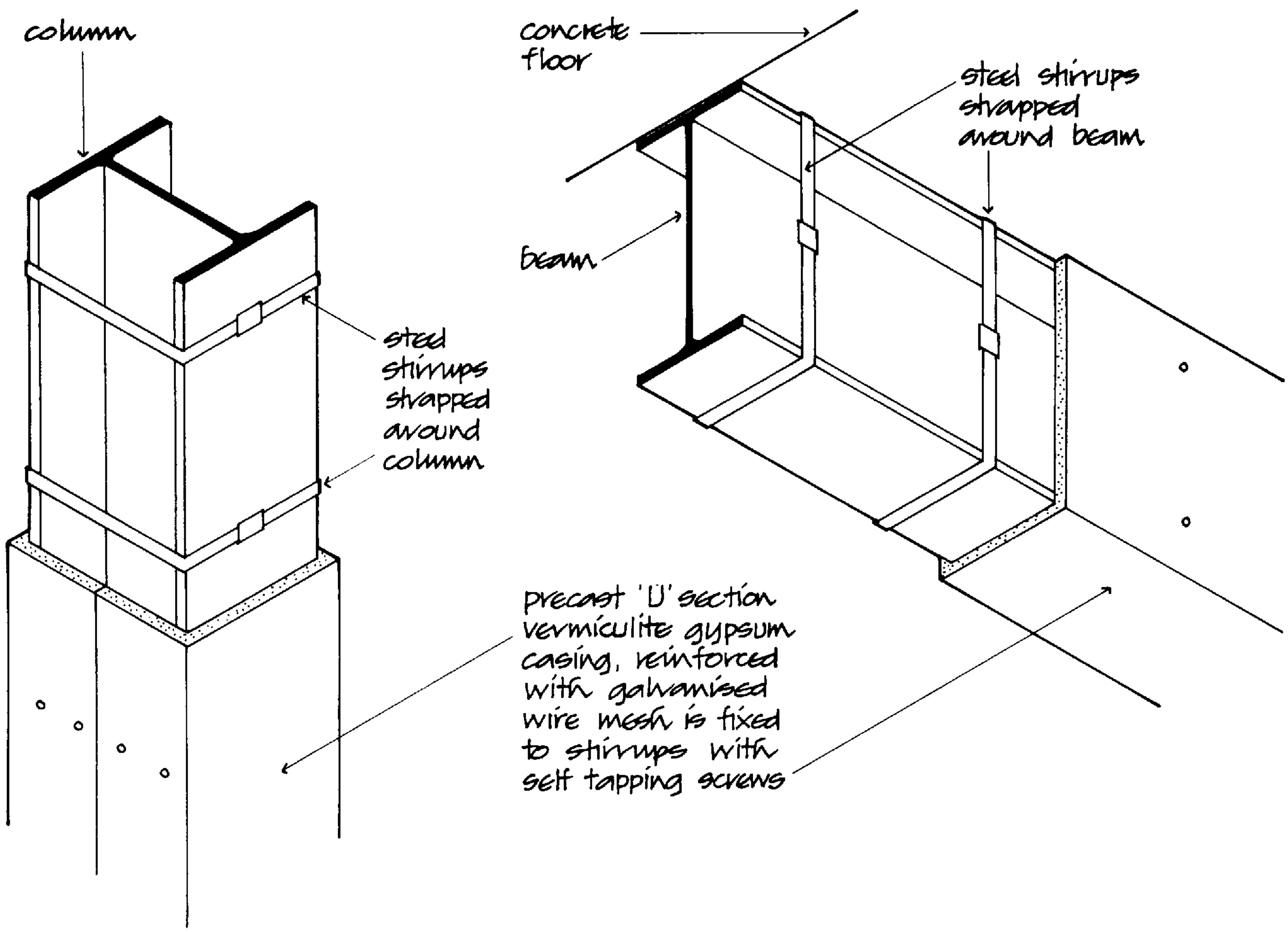
There is a wide choice of systems based on the use of various preformed boards that are cut to size and fixed around steel sections as a hollow, insulating fire protection. Board casings may be grouped in relation to the materials that are used in the manufacture of the boards that are used as:

- Mineral fibre boards or batts
- Vermiculite/gypsum boards
- Plasterboard

For these board casings to be effective as fire protection they must be securely fixed around the steel sections, and joints between boards must be covered, lapped or filled to provide an effective seal to the joints in the board casing. These board casings, which are only moderately robust, can suffer abrasion but are readily damaged by moderate knocks and are not suitable for external use. Board casings are particularly suitable for use in conjunction with ceiling and wall finishes of the same or like materials.

Mineral fibre boards and batts

Mineral fibre boards and batts are made of mineral fibres bound with calcium silicate or cement. The surface of the boards and batts, which is coarse textured, can be plastered. These comparatively thick boards are screwed to light steel framing around the steel sections. Mineral fibre batts are semi-rigid slabs which are fixed by means of spot-welded pins and lock washers. Mineral fibre boards



Fire protection of structural steelwork using precast vermiculite gypsum 'U' section casing

Fig. 79

are moderately robust and are used where appearance is not a prime consideration.

Vermiculite/gypsum boards

Vermiculite/gypsum boards are manufactured from exfoliated vermiculite and gypsum or non-combustible binders. The boards are cut to size and fixed around steelwork, either to timber noggins wedged inside the webs of beams and columns or screwed together and secured to steel angles or strips as illustrated in Fig. 78.

The edges of the boards may be square edged or rebated. The boards, which form a rigid, fairly robust casing to steelwork, can be self-finished or plastered.

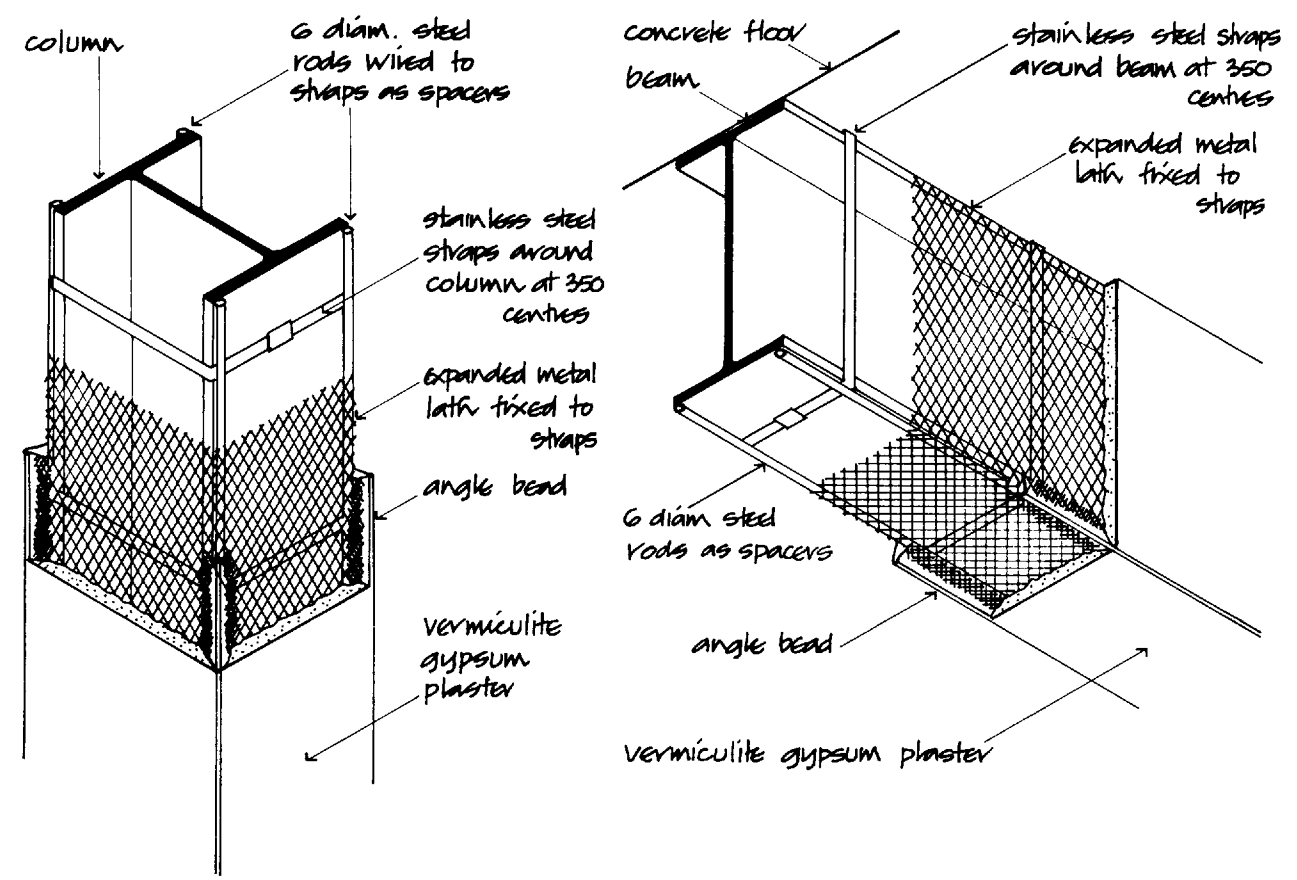
Plasterboard casings

Plasterboard casings can be formed from standard thickness plasterboard or from a board with a gypsum/vermiculite core for improved fire resistance. The boards are cut to size and fixed to metal straps around steel sections. The boards may be self-finished or plastered. This is a moderately robust casing.

Preformed casings

These casings are made in preformed 'L' or 'U' shapes ready for fixing around the range of standard column or beam sections respectively. The boards are made of vermiculite and gypsum, or with a sheet steel finish on a fire resisting lining, as illustrated in Fig. 79. The vermiculite and gypsum boards are screwed to steel straps fixed around the steel sections and the sheet metal faced casings by interlocking joints and screws or by screwing.

These preformed casings provide a neat, ready finished surface with good resistance to knocks and abrasions in the case of the metal faced casings.



Fire protection of structural steelwork using metal lath and plaster casing

Fig. 80

Plaster and lath

Plaster on metal lath casing is one of the traditional methods of fire protection for structural steelwork. Expanded metal lath is stretched and fixed to stainless steel straps fixed around steel sections with metal angle beads at arrises, as illustrated in Fig. 80. The lath is covered with vermiculite gypsum plaster to provide an insulating fire protective casing that is trowelled smooth ready for decoration. This rigid, robust casing can suffer abrasion and knocks and is particularly suitable for use where a similar finish is used for ceilings and walls.

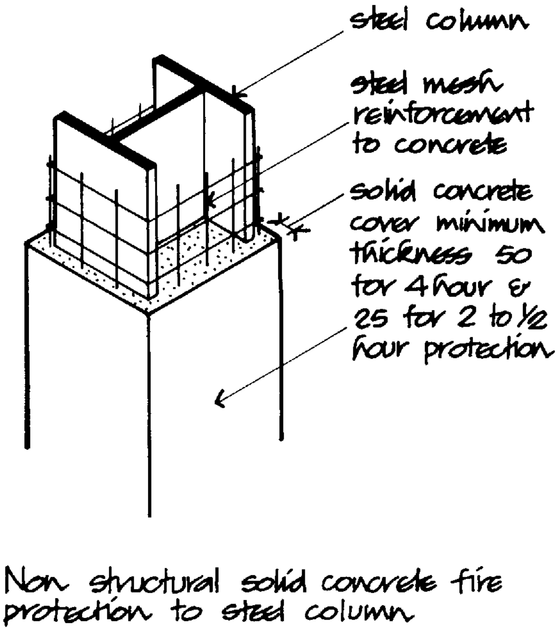


Fig. 81

Concrete, brick or block casing

An in situ cast concrete casing is the traditional method of providing fire protection to structural steelwork and protection against corrosion. This solid casing is highly resistant to damage by knocks. To prevent the concrete spalling away from the steelwork during fires it is lightly reinforced, as illustrated in Fig. 81.

The disadvantages of a concrete casing to steelwork are its mass, which considerably increases the dead weight of the frame, and the cost of on site labour and materials in the formwork and falsework necessary to form and support the wet concrete.

Brick casings to steelwork may be used where brickwork cladding or brick division or compartment walls are a permanent part of the building, or where a brick casing is used for appearance sake to match surrounding fairface brick. Otherwise a brick casing is an expensive, labour intensive operation in the necessary cutting and bonding of brick around columns.

Blockwork may be used as an economic means of casing columns, particularly where blockwork divisions or walls are built up to structural steelwork. The labour in cutting and bonding these larger units is considerably less than with bricks. The blocks encasing steelwork are reinforced in every horizontal joint with steel mesh or expanded metal lath.

CHAPTER THREE

CONCRETE

A description of the materials used in and the proportioning of concrete was given in Chapter 1, Volume 1. The following notes are additional to those in Volume 1.

CEMENT

The cement used today was first developed by Joseph Aspdin, a Leeds builder, who took out a patent in 1824 for the manufacture of Portland cement. Aspdin developed the material for the production of artificial stone and named it Portland cement because, in its hardened state, it resembled natural Portland limestone in texture and colour. The materials of Aspdin's cement, limestone and clay, were later burned at a high temperature by Isaac Johnson in 1845 to produce a clinker which, ground to a fine powder, is what we now term Portland cement.

The characteristics of a cement depend on the proportions of the compounds of the raw materials used and the fineness of the grinding of the clinker, produced by burning the raw materials. A variety of Portland cements is produced, each with characteristics suited to a particular use.

The more commonly used Portland cements are:

- Ordinary Portland cement
- Rapid hardening Portland cement
- Sulphate resisting Portland cement
- White Portland cement
- Low heat Portland cement
- Portland blastfurnace cement
- Water repellent cement

Ordinary Portland cement

Ordinary Portland cement is the cheapest and most commonly used cement, accounting for about 90% of all cement production. It is made by heating limestone and clay to a temperature of about 1300°C to form a clinker, rich in calcium silicates. The clinker is ground to a fine powder with a small proportion of gypsum, which regulates the rate of setting when the cement is mixed with water. This type of cement is affected by sulphates such as those present in ground water in some clay soils. The sulphates have a disintegrating effect on ordinary Portland cement. For this reason sulphate-resisting cements are produced for use in concrete in sulphate-bearing soils, marine works, sewage installations and manufacturing processes where soluble salts are present.

Rapid hardening Portland cement

Rapid hardening Portland cement is similar to ordinary Portland except that the cement powder is more finely ground. The effect of the finer grinding is that the constituents of the cement powder react more quickly with water and the cement develops strength more rapidly.

Rapid hardening cement develops in three days, a strength which is similar to that developed by ordinary Portland in seven days. The advantage of the early strength developed by this cement is the possibility of speeding up construction by, for example, early removal of formwork. Although rapid hardening is more expensive than ordinary Portland cement, it is often used because of its early strength advantage. Rapid hardening Portland cement is not a quick setting cement. Several months after mixing there is little difference in the characteristics of ordinary and rapid hardening cements.

Sulphate resisting Portland cement

The proportions of the constituents of the cement that are affected by sulphates, that is aluminates, are reduced to provide increased resistance to the effect of sulphates. The effect of sulphates on ordinary cement is to combine with the constituents of the cement and the consequent increase in volume on crystallisation causes cement, and therefore concrete, to disintegrate. This disintegration is severe where the concrete is alternately wet and dry, as in marine works.

Because it is necessary to control, with some care, the composition of the raw materials of this cement it is more expensive than ordinary cement. High alumina cement described later is also a sulphate-resisting cement.

White Portland cement

White Portland cement is manufactured from china clay and pure chalk or limestone and is used to produce white concrete finishes. Due to the comparatively expensive raw material used (that is china clay) and the process of manufacture, it is considerably more expensive than ordinary cement and is used in the main for the surface of exposed concrete and for cement renderings. Pigments may be added to the cement to produce pastel colours.

Low heat Portland cement

Low heat Portland cement is used mainly for mass concrete works in dams and other constructions where the heat developed by hydration of other cements would cause serious shrinkage cracking. The heat developed by the hydration of cement in concrete in construction works is dissipated to the surrounding air, whereas in large mass concrete works it dissipates slowly. Control of the constituents of low heat Portland causes it to harden more slowly and therefore develop less rapidly than other cements. The slow rate of hardening does not affect the ultimate strength of the cement yet allows the low heat of hydration to dissipate through the mass of concrete to the surrounding air.

Portland blastfurnace cement

Portland blastfurnace cement is manufactured by grinding Portland cement clinker with blast furnace slag, the proportion of slag being up to 65% by weight and the percentage of cement clinker no less than 35%. This cement develops heat more slowly than ordinary cement and is used in mass concrete works as a low heat cement. It has good resistance to the destructive effects of sulphates and is commonly used in marine works.

Water repellent cement

Water repellent cement is made by mixing a metallic soap with ordinary or white Portland cement. Concrete made with this cement is more water repellent and therefore absorbs less rain water than concrete made with other cements and is thus less liable to dirt staining. This cement is used for cast concrete and cast stone for its water repellent property.

High alumina (aluminous) cement

High alumina (aluminous) cement is not one of the Portland cements. It is manufactured from bauxite and limestone or chalk in equal proportions. Bauxite is a mineral containing a higher proportion of alumina (aluminium oxide) than the clays used in the manufacture of Portland cements, hence the name given to this cement.

The disadvantages of this cement are that there is a serious falling off in strength in hot moist atmospheres, and it is attacked by alkalis. This cement is no longer used for concrete.

AGGREGATES

Concrete is a mix of particles of hard material, the aggregate, bound with a paste of cement and water with at least three quarters of the volume of concrete being occupied by aggregate. Volume for volume, cement is generally more costly than aggregate and it is advantageous, therefore, to use as little cement as necessary to produce a dense, durable concrete.

A wet concrete mix is spread in the form of foundation bases, slabs or inside formwork for beams and columns and compacted into a dense mass. There is a direct relation between the density and strength of finished concrete and the ease with which concrete can be compacted. The characteristics of the aggregate play a considerable part in the ease with which concrete can be compacted. The measure of the ease with which concrete can be compacted is described as the workability of the mix. Workability is affected by the characteristics of the particles of aggregate such as size and shape, so that for a given mix workability can be improved by careful selection of aggregate.

The grading of the size and the shape of the particles of aggregate affects the amount of cement and water required to produce a mix of concrete that is sufficiently workable to be compacted to a dense mass. The more cement and water that are needed for the sake of workability, the greater the drying shrinkage there will be by loss of water as the concrete dries and hardens.

Characteristics of aggregate

Aggregate for concrete should be hard, durable and contain no materials that are likely to decompose or change in volume or affect reinforcement. Clay, coal or pyrites in aggregate may soften, swell, decompose and cause stains in concrete.

Aggregate should be clean and free from organic impurities and coatings of dust or clay that would prevent the particles of aggregate from being adequately coated with cement and so lower the strength of the concrete.

Types of aggregate

Natural aggregates

Sand and gravel are the cheapest and most commonly used aggregate in this country and consist of particles of broken stone deposited by the action of rivers and streams or from glacial action. Sand and gravel deposited by rivers and streams are generally more satisfactory than glacial deposits because the former comprise rounded particles in a wide range of sizes and weaker materials have been eroded by the washing and abrasive action of moving water. Glacial deposits tend to have angular particles of a wide variety of sizes, poorly graded, which adversely affect the workability of a concrete in which they are used.

Crushed rock aggregates are generally more expensive than sand and gravel, owing to the cost of quarrying and crushing the stone. Providing the stone is hard, inert and well graded it serves as an admirable aggregate for concrete. The term 'granite aggregate' is used commercially to describe a wide range of crushed natural stones, some of which are not true igneous rocks. Natural granite is hard and dense and serves as an excellent aggregate.

Hard sandstone and close grained crystalline limestone when crushed and graded are commonly used as aggregate in areas where sand and gravel are not readily available.

Because of the depletion of inland deposits of sand and gravel, marine aggregates are used. They are obtained by dredging deposits of broken stone from the bed of the sea. Most of these deposits contain shells and salt. Though not normally harmful in reinforced concrete, limits should be set to the proportion of shells and salt in marine aggregates used for concrete. One of the disadvantages of marine fine aggregate is that it has a preponderance of one size of particle which can make design mix difficult. Sand from the beach is often of mainly single sized particles and contains an accumulation of salts. Beach sands to be used as fine aggregate in concrete should be carefully washed to reduce the concentration of salts.

Artificial aggregates

Blastfurnace slag is the by-product of the conversion of iron ore to pig iron and consists of the non-ferrous constituents of iron ore. The molten slag is tapped from the blastfurnace and is cooled and crushed. In areas where there is a plentiful supply of blastfurnace slag it is an economical and satisfactory aggregate for concrete.

Clean broken brick is used as an aggregate for concrete required to have a good resistance to damage by fire. The strength of the concrete produced with this aggregate depends on the strength and density of the bricks from which the aggregate is produced. Crushed engineering brick aggregate will produce a concrete of medium crushing strength. Porous brick aggregate should not be used for reinforced concrete work in exposed positions as the aggregate will absorb moisture and encourage the corrosion of the reinforcement.

Fine and coarse aggregate

Fine aggregate is the term used to describe natural sand, crushed rock and gravel, most of which passes through a 5 BS sieve and coarse aggregate the term used to describe natural gravel, crushed gravel or crushed rock, most of which is retained on a 5 BS sieve. The differentiation of fine and coarse aggregate is made because in practice the fine and coarse aggregate are ordered separately for mixing to produce a determined mix for particular uses and strengths of concrete.

Grading of aggregate

The word grading is used to describe the percentage of particles of a particular range of sizes in a given aggregate from fines (sand) to the largest particle size. A sound concrete is produced from a mix that can be readily placed and compacted in position, that is a mix that has good workability and after compaction is reasonably free of voids. This is affected by the grading of the aggregate and the water/cement ratio.

The grading of aggregate is usually given by the percentage by weight passing the various sieves used for grading. Continuously graded aggregate should contain particles graded in size from the largest to the smallest to produce a dense concrete. Sieve sizes from 75 to 5 (3 to $\frac{3}{16}$ inches) are used for coarse aggregate.

An aggregate containing a large proportion of large particles is referred to as being 'coarsely' graded and one having a large proportion of small particles as 'finely' graded.

Particle shape and surface texture

The shape and surface texture of the particles of an aggregate affect the workability of a concrete mix. An aggregate with angular edges and a rough surface, such as crushed stone, requires more water in the mix to act as a lubricant to facilitate compaction than does one with rounded smooth faces to produce a concrete of the same workability. It is often necessary to increase the cement content of a mix made with crushed aggregate or irregularly shaped gravels to provide the optimum water/cement ratio to produce concrete of the necessary strength. This additional water, on evaporation, tends to leave void spaces in the concrete which will be less dense than concrete made with rounded particle aggregate.

The nature of the surface of the particles of an aggregate will affect workability. Gravel dredged from a river will have smooth surfaced particles which will afford little frictional resistance to the arrangement of particles that takes place during compaction of concrete. A crushed granite aggregate will have coarse surfaced particles that will offer some resistance during compaction.

The shape of particles of aggregate is measured by an angularity index and the surface by a surface coefficient. Engineers use these to determine the true workability of a concrete mix which cannot be judged solely from the grading of particles.

Water

Water for concrete should be reasonably free from such impurities as suspended solids, organic matter and dissolved salts which may adversely affect the properties of concrete. Water that is fit for drinking is accepted as being satisfactory for mixing water for concrete.

CONCRETE MIXES

The strength and durability of concrete are affected by the voids in concrete caused by poor grading of aggregate, incomplete compaction or excessive water in the mix.

Water/cement ratio

Workability

The materials used in concrete are mixed with water for two reasons, firstly to enable the reaction with the cement which causes setting and hardening to take place and secondly to act as a lubricant to render the mix sufficiently plastic for placing and compaction.

About a quarter part by weight of water to one part by weight of cement is required for the completion of the setting and hardening process. This proportion of water to cement would result in a concrete mix far too stiff (dry) to be adequately placed and compacted. About a half by weight of water to one part by weight of cement is required to make a concrete mix workable.

It has been established that the greater the proportion of water to cement used in a concrete mix, the weaker will be the ultimate strength of the concrete. The principal reason for this is that the water, in excess of that required to complete the hardening of the cement, evaporates and leaves voids in the concrete which reduce its strength. It is practice, therefore, to define a ratio of water to cement in concrete mixes to achieve a dense concrete. The water/cement ratio is expressed as the ratio of water to cement by weight and the limits of this ratio for most concrete lie between 0.4 and 0.65. Outside these limits there is a great loss of workability below the lower figure and a loss of strength of concrete above the upper figure.

Water reducing admixtures

The addition of 0.2% by weight of calcium lignosulphonate, commonly known as 'lignin', to cement will reduce the amount of water required in concrete by 10% without loss of workability. This allows the cement content of a concrete mix to be reduced for a given water/cement ratio. Calcium lignosulphonate acts as a surface active additive that disperses the cement particles which then need less water to lubricate and disperse them in concrete.

Water reducing admixtures such as lignin are promoted by suppliers as densifiers, hardeners, water proofers and plasticisers on the basis that the reduction of water content leads to a more dense concrete due to there being fewer voids after the evaporation of water.

To ensure that the use of these admixtures does not adversely affect the durability of a concrete, it is practice to specify a minimum cement content.

Nominal mixes

Volume batching

The constituents of concrete may be measured by volume in batch boxes in which a nominal volume of aggregate and a nominal volume of cement are measured for a nominal mix, as for example in a mix of 1:2:4 of cement:fine:course aggregate. A batch box usually takes the form of an open top wooden box in which volumes of cement, fine and coarse aggregate are measured separately for the selected nominal volume mix. For a mix such as 1:2:4 one batch box will suffice, the mix proportions being gauged by the number of fillings of the box with each of the constituents of the mix.

Measuring the materials of concrete by volume is not an accurate way of proportioning and cannot be relied on to produce concrete with a uniformly high strength. Cement powder cannot be accurately proportioned by volume because while it may be poured into and fill a box, it can be readily compressed to occupy considerably less space. Proportioning aggregates by volume takes no account of the amount of water retained in the aggregate which may affect the water/cement ratio of the mix and affect the proportioning, because wet sand occupies a greater volume than does the same amount of sand when dry.

Volume batch mixing is mostly used for the concrete for the foundations and oversite concrete of small buildings such as houses. In these cases, the concrete is not required to suffer any large stresses and the strength and uniformity of the mix is relatively unimportant. The scale of the building operation does not justify more exact methods of batching.

Weight batching

A more accurate method of proportioning the materials of concrete is by weight batching, by proportioning the fine and coarse aggregate by weight by reference to the weight of a standard bag of cement. Where nominal mixes are weight batched it is best to take samples of the aggregate and dry them to ascertain the weight of water retained in the aggregate and so adjust the proportion of water added to the mix to allow for the water retained in the aggregate.

Water is incompressible and it is immaterial, therefore, whether it is proportioned by volume or by weight.

Designed mixes

Designed mixes of concrete are those where strength is the main criterion of the specified mix, which is judged on the basis of strength tests. The position in which concrete is to be placed, the means used and the ease of compacting it, the nature of the aggregate and the water/cement ratio all affect the ultimate strength of concrete.

A designed concrete mix is one where the variable factors are adjusted by the engineer to produce a concrete with the desired minimum compressive strength at the lowest possible cost. If, for example, the cheapest available local aggregate in a particular district will not produce a very workable mix it would be necessary to use a wet mix to facilitate placing and compaction, and this in turn would necessitate the use of a cement-rich mix to maintain a reasonable water/cement ratio. In this example it might be cheaper to import a different aggregate, more expensive than the local one, which would produce a comparatively dry but workable mix requiring less cement. These are the considerations the engineer and the contractor have in designing a concrete mix.

Prescribed mixes and standard mixes

Prescribed mixes and standard mixes are mixes of concrete where the constituents are of fixed proportion by weight to produce a 'grade' of concrete with minimum characteristics strength.

Mixing concrete

Concrete may be mixed by hand when the volume to be used does not warrant the use of mechanical mixing plant. The materials are measured out by volume in timber gauge boxes, turned over on a clean surface several times dry and then water is added as the mix is turned over several times until it has a suitable consistency and uniform colour. It is obviously difficult to produce mixes of uniform quality by hand mixing.

A small hand tilting mixer is often used. The mixing drum is rotated by a petrol or electric motor, the drum being tilted by hand to fill and empty it. This type of mixer takes over a deal of the back breaking work of mixing but does not control the quality of mixes as materials are measured by volume.

A concrete batch mixed mechanically feeds the materials into the drum where they are mixed and from which the wet concrete is poured. The materials may be either weight or volume batched.

For extensive works, plant is installed on site which stores cement delivered in bulk, measures the materials by weight and mechanically mixes them. Concrete for high strength reinforced concrete work can only be produced from batches (mixes) of uniform quality such as are produced by plant capable of accurately measuring and thoroughly mixing the materials.

Ready-mixed concrete is extensively used today. It is prepared in mechanical, concrete mixing depots where the materials are stored, weight batched and mixed and the wet concrete is transported to site on lorries on which rotating drums are mounted. The action of the rotating drum prevents the concrete from setting and hardening for an hour or more. Once delivered it must be placed and compacted quickly as it rapidly hardens. On cramped urban sites and where there is a nearby source of ready-mixed concrete this material is much used.

Placing and compacting concrete

The initial set of Portland cement takes place from half an hour to one hour after it is mixed with water. If a concrete mix is disturbed after the initial set has occurred the strength of the concrete may be adversely affected. It is usual to specify that concrete be placed as soon after mixing as possible and not more than half an hour after mixing.

A concrete mix consists of particles varying in size from powder to coarse aggregate graded to, say, 40. If a wet mix of concrete is poured from some height and allowed to fall freely the larger particles tend to separate from the smaller. This action is termed segregation of particles. Concrete should not, therefore, be tipped or poured into place from too great a height. It is usual to specify that concrete be placed from a height not greater than one metre.

Once in place concrete should be thoroughly consolidated or compacted. The purpose of compaction is to cause entrapped bubbles of air to rise to the surface in order to produce as dense and void-free concrete as possible. Compaction may be effected by agitating the mix with a spade or heavy iron bar. If the mix is dry and stiff this is a very laborious process and not very effective. A more satisfactory method is to employ a pneumatically operated poker vibrator which is inserted into the concrete and, by vibration, liberates air bubbles and compacts the concrete. As an alternative the formwork of reinforced concrete may be vibrated by means of a motor attached to it.

Construction joints

Because it is not possible, on most building sites, to place concrete continuously it is necessary to form construction joints. A construction joint is the junction of freshly placed concrete with concrete that has been previously placed, for example on the previous day. These construction joints are a potential source of weakness because there may not be a good bond between the two placings of concrete.

Practice is to brush the surface of concrete at construction joints soon after it has been placed to clean the surface to provide a bond to concrete subsequently placed. There should be as few construction joints as practical and joints should be either vertical or horizontal. Joints in columns are made as near as possible to beam haunching and those in beams at the centre or within the middle third of the span. Vertical joints are formed against a strip board.

Water bars are fixed across or cast into construction joints where there is a need to provide a barrier to the movement of water through the joint (see Chapter 1).

Curing concrete

Concrete gradually hardens and gains strength after its initial set. For this hardening process to proceed and the concrete to develop its maximum strength there must be water present in the mix. If, during the early days after the initial set, there is too rapid a loss of water the concrete will not develop its maximum strength. The process of preventing a rapid loss of water is termed curing concrete. Large exposed areas of concrete such as road surfaces are cured by covering the surface for at least a week after placing, with building paper, plastic sheets or wet sacks to retard evaporation of water. In very dry weather the surface of concrete may have to be sprayed with water in addition to covering it.

The formwork around reinforced concrete is often kept in position for some days after the concrete is placed in order to give support until the concrete has gained sufficient strength to be self-supporting. This formwork also serves to prevent too rapid a loss of water and so helps to cure the concrete. In very dry weather it may be necessary to spray the formwork to compensate for too rapid a loss of water.

Deformation of concrete

Hardened concrete will suffer deformation due to:

(1) Elastic deformation which occurs instantaneously and is dependent on applied stress
(2) Drying shrinkage that occurs over a long period and is independent of the stress in concrete
(3) Creep, which occurs over a long period and is dependent on stress in concrete
(4) Expansion and contraction due to changes in temperature and moisture
(5) ASR (alkali–silica reaction)

Elastic deformation

Under the stress of dead and applied loads of a building, hardened concrete deforms elastically. Vertical elements such as columns and walls are compressed and shorten in height and horizontal elements such as beams and floors lengthen due to bending. These comparatively small deformations which are related to the strength of the concrete are predictable and allowance is made in design.

Drying shrinkage

The drying shrinkage of concrete is affected principally by the amount of water in concrete at the time of mixing and to a lesser extent by the cement content of the concrete. It can also be affected by a porous aggregate losing water. Drying shrinkage is restrained by the amount of reinforcement in concrete.

The rate of shrinkage is affected by the humidity and temperature of the surrounding air, the rate of air flow over the surface and the proportion of surface area to volume of concrete.

Where concrete dries in the open air in summer, small masses of concrete will suffer about a half of the total drying shrinkage a month after placing and large masses about a half of the total shrinkage a year after placing. Shrinkage will not generally affect the strength or stability of a concrete structure, but is sufficient to require the need for movement joints where solid materials such as brick and block are built up to the concrete frame.

Creep

Under sustained load concrete deforms as a result of the mobility of absorbed water within the cement gel under the action of sustained stress. From the point of view of design, creep may be considered as an irrecoverable deformation that occurs with time at an ever decreasing rate under the action of sustained load. Creep deformation continues over very long periods of time to the extent that measurable deformation can occur thirty years after concrete has been placed. The factors that affect creep of concrete are the concrete mix, relative humidity and temperature, size of member and applied stress.

Concrete is a mix of aggregate, water and cement. Most aggregates used in dense concrete are inert and do not suffer creep deformation under load. The hardened cement water paste surrounding the particles of aggregate is subject to creep deformation under stress due to movements of absorbed water. The relative volume of cement gel to aggregate therefore affects deformation due to creep. Changing from a 1:1:2 to a 1:2:4 mix increases the volume of aggregate from 60 to 75% yet causes a reduction in creep by as much as 50%.

Temperature, relative humidity and the size of members have an effect on the hydration of cement and migration of water around the cement gel towards the surface of concrete. In general, creep is greater the lower the relative humidity and increases with a rise in temperature caused, for example, by solar heating. Small section members of concrete will lose water more rapidly than large members and will suffer greater creep deformation during the period of initial drying.

The effect of creep deformation has the most serious effect through stress loss in prestressed concrete, deflection increase in large span beams, buckling of slender columns and buckling of cladding in tall buildings.

ASR (alkali–silica reaction)

The chemical reaction of high silica-content aggregate with alkaline cement causes a gel to form, which expands and causes concrete to crack. The expansion, cracking and damage to concrete is often most severe where there is an external source of water in large quantities. Foundations, motorway bridges and concrete subject to heavy condensation have suffered severe damage through ASR.

The destructive effect of alkali–silica reaction has been known for some time. The damage caused by this reaction became apparent in this country with the report in 1980 of damage caused to a viaduct at Plymouth.

The expansion caused by the gel formed by the reaction is not uniform in time or location. The reaction may develop slowly in some structures yet very rapidly in others and may affect one part of a structure but not another. Changes in the method of manufacture of cement, that have produced a cement with higher alkalinity, are thought to be one of the causes of some noted failures. To minimise the effect of ASR it is recommended that cement rich mixes and high silica content aggregates be avoided.

REINFORCEMENT

In 1849 a French engineer, Joseph Monier, made some concrete flower tubs reinforced by casting wire mesh into the concrete and later, in 1867, he took out a patent for the process of strengthening concrete by embedding steel in concrete. Some years later François Hennebique applied Monier's idea to building and engineering when he developed reinforced concrete piles and later reinforced concrete structures. Today reinforced concrete is one of the two structural materials used in engineering and building works.

Concrete is strong in resisting compressive stress but comparatively weak in resisting tensile stress. The tensile strength of concrete is between one tenth and one twentieth of its compressive strength. Steel, which has good tensile strength, is cast into reinforced concrete members in the position or positions where maximum tensile stress occurs.

To determine where tensile and compressive stresses occur in a structural member it is convenient to consider the behaviour of an elastic material such as India rubber under stress. A bar of rubber laid across, and not fixed to, two supports bends under load and the top surface shortens and becomes compressed under stress and the bottom surface stretched under tensile stress, as illustrated in Fig. 82. A member that is supported so that the supports do not restrain bending under load is said to be simply supported. From Fig. 82 it will be seen that maximum stretching due to tension occurs at the outwardly curved underside of the rubber bar. If the bar were of concrete it would seem logical to cast steel reinforcement in the underside of the bar. In that position the steel would be exposed to the surrounding air and it would rust and gradually lose strength. Further if a fire occurred in the building near the beam the steel might lose so much strength as to impair its reinforcing effect and the beam would collapse. It is practice, therefore, to cast the steel reinforcement into concrete so that there is at least 15 of concrete cover between the reinforcement and the surface of the concrete.

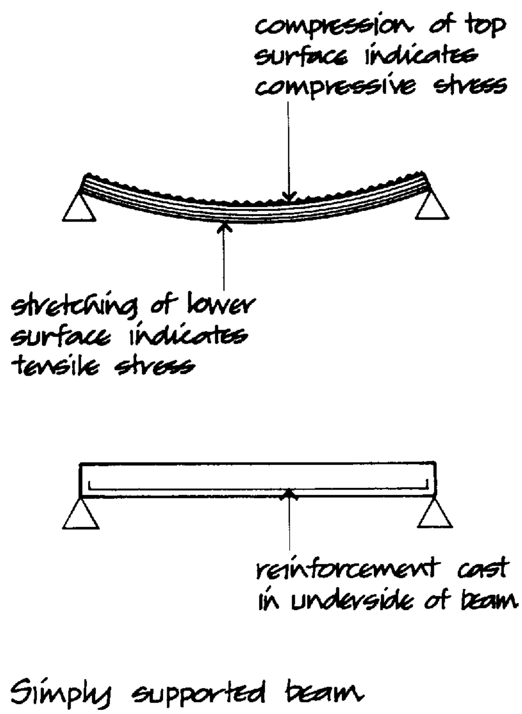


Fig. 82

Concrete cover

A 15 cover of concrete is sufficient to protect steel reinforcement from corrosion inside the majority of buildings and up to 60 where reinforced concrete is exposed to sea water and abrasion.

From laboratory tests and experience of damage caused by fires in buildings it has been established that various thicknesses of concrete cover will prevent an excessive loss of strength in steel reinforcement for particular periods of time. The presumption is that the concrete cover will protect the reinforcement for a period of time for the occupants to escape from the particular building during a fire. The statutory period of time that the concrete cover is to provide protection against damage by fire varies with the size and type of building from half an hour to four hours.

Bond and anchorage of reinforcement

The cement in concrete cast around steel reinforcement adheres to the steel just as it does to the particles of the aggregate and this adhesion plays its part in the transfer of tensile stress from the concrete to the steel. It is of importance, therefore, that the steel reinforcement be clean and free from scale, rust and oily or greasy coatings.

Under load, tensile stress tends to cause the reinforcement to slip out of bond with the surrounding concrete due to the elongation of the member. This slip is partly resisted by the adhesion of the cement to the steel and partly by the frictional resistance between steel and concrete. To secure a firm anchorage of reinforcement to concrete and to prevent slip it is usual practice to hook or bend the ends of bars as illustrated in Fig. 83.

Deformed bars, illustrated in Fig. 84, offer a greater surface of frictional resistance than do plain

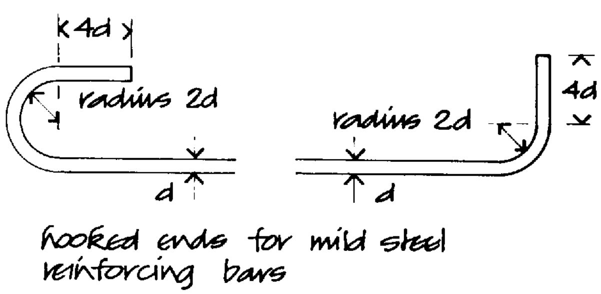


Fig. 83

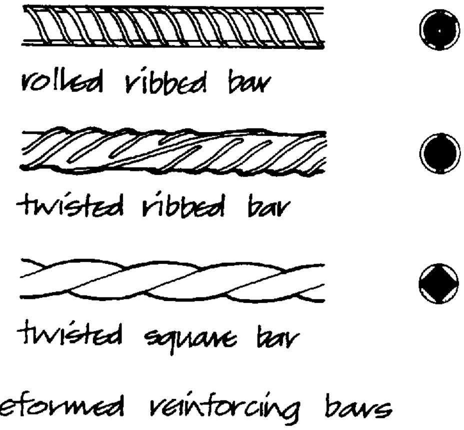


Fig. 84

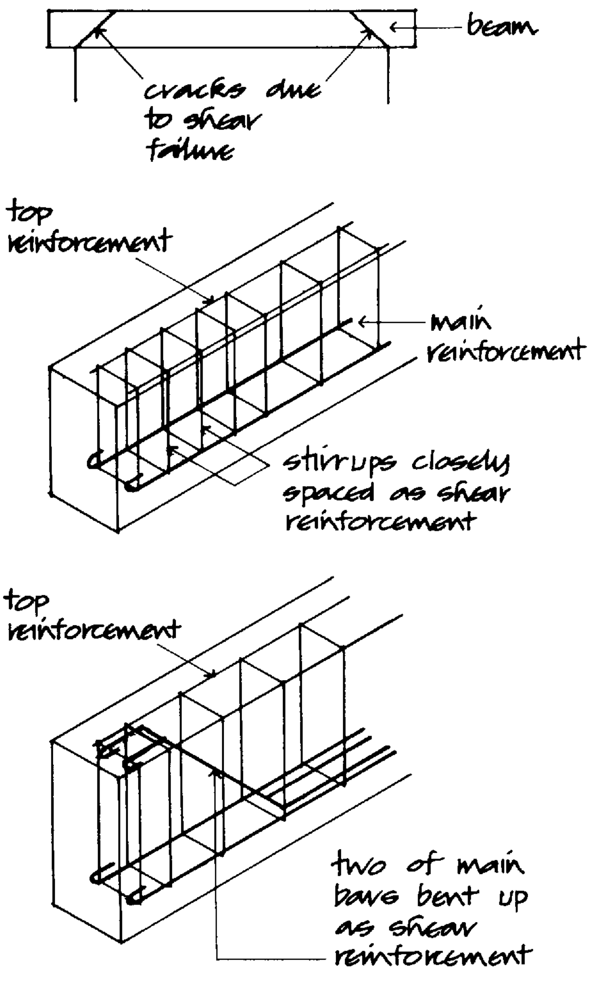
bars and this can obviate the necessity to use hooked or bent ends for anchorage to prevent slip.

Shear

Beams are subjected to shear stresses due to the shearing action of the supports and the self-weight and imposed loads of beams. A pair of scissors does not cut paper, it shears it. The action of the blades, as they meet, is to force one side of the paper up and the other down and shear it into two pieces. The supports and the weight of the beam and its load act to shear a beam in the same way. Shear stress is greatest at the points of support and nil at mid-span in uniformly loaded beams. Shear failure occurs at an angle of 45° as illustrated in Fig. 85. Due to its poor tensile strength, concrete does not have great shear resistance and it is usual to introduce steel shear reinforcement in most beams of over, say, 2.5 span. The shear reinforcement may take the form of bars bent up at 45° near supports, or as steel stirrups or links more closely spaced at the point of support where maximum shear stress is developed, as illustrated in Fig. 85.

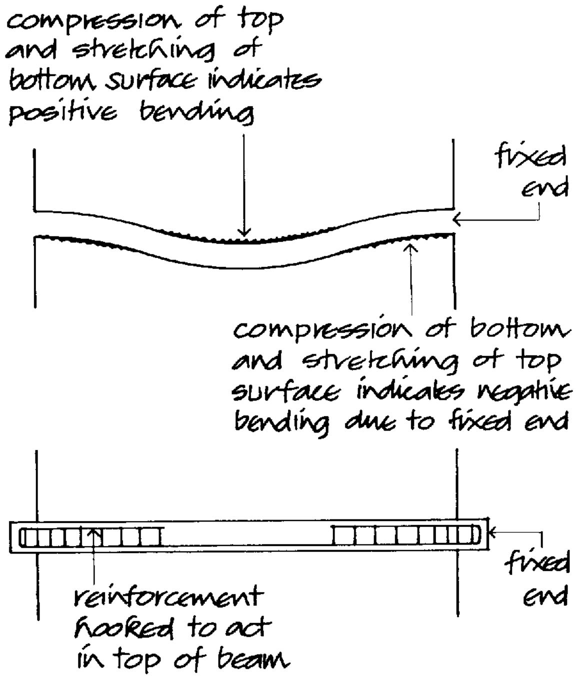
Fixed end support

A beam with fixed end support is restrained from simple bending by the fixed ends as illustrated in Fig. 35. Because of the upward, negative, bending close to the fixed ends the top of the beam is in tension while the underside is in tension at mid-span due to positive bending. In a concrete beam with fixed ends it is not sufficient to cast reinforcement in to the lower face of the beam only, as the concrete will not have sufficient tensile strength to resist tensile stresses in the top of



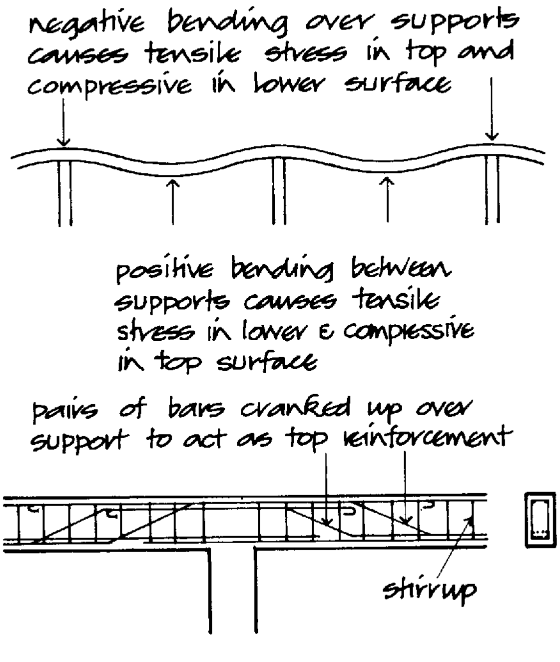
Shear reinforcement

Fig. 85



Beams with fixed ends

Fig. 86



Reinforced concrete beam to span continuously over supports

Fig. 87

the beam near points of support. Both top and bottom reinforcement are necessary, as illustrated in Fig. 86.

Similarly, a beam over several supports will bend as illustrated in Fig. 87, indicating normal or positive bending between supports and reverse or negative bending over supports. This indicates the stresses in a beam spanning continuously over supports, the reinforcement in such a beam being disposed as illustrated in Fig. 87.

Cantilever beams

A bar of rubber with one end fixed will bend under load as illustrated in Fig. 88, corrugation of the underside indicating compression and stretching of the top tensile stress. A comparable concrete canti-

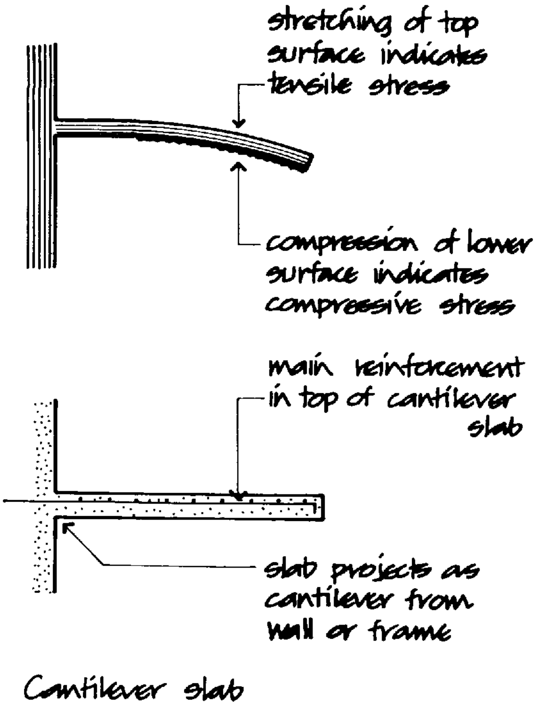


Fig. 88

lever will plainly require reinforcement in the top as illustrated in Fig. 88.

Columns

Columns are designed to support the loads of roofs, floors and walls. If all these loads acted concentrically on the section of the column then it would suffer only compressive stress and it would be sufficient to construct the column of either concrete by itself or of reinforced concrete to reduce the required section area. In practice, the loads of floor and roof beams and walls and wind pressure act eccentrically, that is off the centre of the section of columns and so cause some bending and tensile stress in columns. The steel reinforcement in columns is designed primarily to sustain compressive stress to reinforce the compressive strength of concrete, but also to reinforce the poor tensile strength of concrete against tensile stress due to bending from fixed end beams, eccentric loading and wind pressure.

Mild steel reinforcement

The cheapest and most commonly used reinforcement is round section mild steel rods of diameter from 6 to 40. These rods are manufactured in long lengths and can be quickly cut and easily bent without damage. The disadvantages of ordinary mild steel reinforcement are that if the steel is stressed up to its yield point it suffers permanent elongation, exposed to moisture it progressively corrodes and on exposure to the heat generated by fires it loses strength.

In tension, mild steel suffers elastic elongation which is proportional to stress up to the yield stress and it returns to its former length once stress is removed. At yield stress point mild steel suffers permanent elongation and then with further increase in stress again suffers elastic elongation.

If the permanent elongation of mild steel which occurs at yield stress were to occur in reinforcement in reinforced concrete, the loss of bond between the steel and the concrete and consequent cracking of concrete around reinforcement would be so pronounced as to seriously affect the strength of the member. For this reason maximum likely stresses in mild steel reinforcement are kept to a figure some two-thirds below yield stress. In consequence the mild steel reinforcement is working at the most at stresses well below its ultimate strength.

Cold worked steel reinforcement

If mild steel bars are stressed up to yield point and permanent plastic elongation takes place and the stress is then released, subsequent stressing up to and beyond the former yield stress will not cause a repetition of the initial permanent elongation at yield stress. This change of behaviour is said to be due to a reorientation of the steel crystals during the initial stress at yield point. In the design of reinforced concrete members, using this type of reinforcement, maximum stress need not be limited to a figure below yield stress, to avoid loss of bond between concrete and reinforcement, and the calculated design stresses may be considerably higher than with ordinary mild steel.

In practice it is convenient to simultaneously stress cold drawn steel bars up to yield point and to twist them axially to produce cold worked deformed bars with improved bond to concrete.

Deformed bars

To limit the cracks that may develop in reinforced concrete around mild steel bars, due to the stretching of the bars and some loss of bond under load, it is common to use deformed bars that have projecting ribs or are twisted to improve the bond to concrete.

The type of deformed reinforcing bars generally used are ribbed bars that are rolled from mild steel and ribbed along their length, ribbed mild steel bars that are cold drawn as high yield ribbed bars, ribbed, cold drawn and twisted bars, high tensile steel bars that are rolled with projecting ribs and cold twisted square bars. Figure 84 is an illustration of some typical deformed bars.

Galvanised steel reinforcing bars

Where reinforced concrete is exposed externally or is exposed to corrosive industrial atmospheres it is sound practice to use galvanised reinforcement as a protection against corrosion of the steel to prevent rust staining of fairface finishes and inhibit rusting of reinforcement that might weaken the structure. The steel reinforcing bars are cut to length, bent and then coated with zinc by the hot dip galvanising process. The considerable increase in cost of the reinforcement is well worth while.

Stainless steel reinforcement

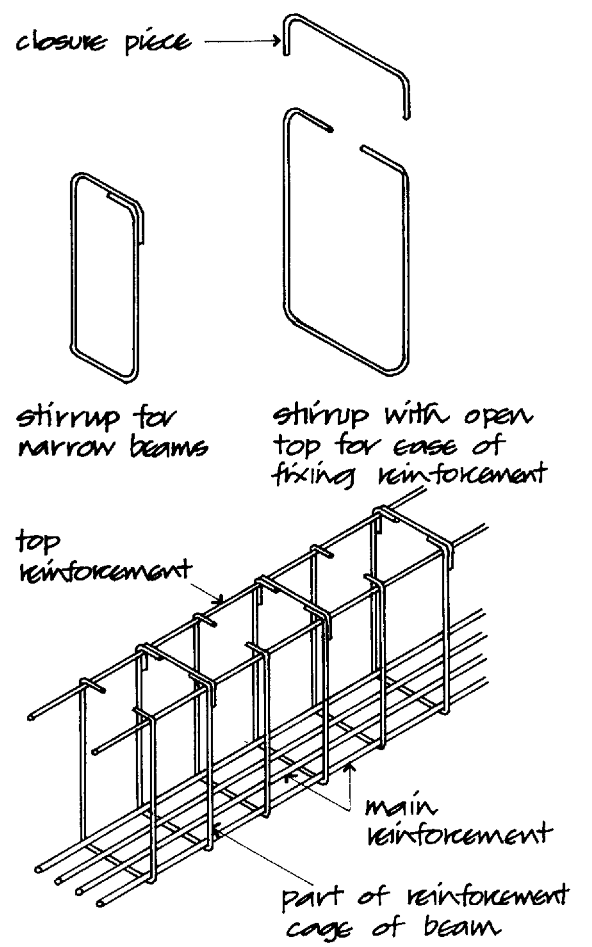
Stainless steel is an alloy of iron, chromium and nickel on which an invisible corrosion resistant film forms on exposure to air. Stainless steel is about ten times the cost of ordinary mild steel. It is used for reinforcing bars in concrete where the cover of concrete for corrosion protection would be much greater than that required for fire protection and the least section of reinforced concrete is a critical consideration.

Assembling and fixing reinforcement

Reinforcing steel for concrete is used in the main to provide resistance to tensile stresses in structural members. The steel reinforcing bars must therefore be placed and secured in the positions inside formwork where they will be most effective in reinforcing concrete that will be poured and compacted inside the formwork around the reinforcement. It is of importance, therefore, that the reinforcement is rigidly fixed in position so that it is not displaced when wet concrete is placed and compacted.

Reinforcement for structural beams and columns is usually assembled in the form of a cage with the main and secondary reinforcement being fixed to links or stirrups that hold it in position. The principal purpose of these links is to secure the longitudinal reinforcing bars in position when concrete is being placed and compacted. They also serve to some extent in anchoring reinforcement in concrete and in addition provide some resistance to shear with closely spaced links at points of support in beams.

Links are formed from small section reinforcing bars that are cut and bent to contain the longitudinal reinforcement. Stirrup or links are usually cold bent to contain top and bottom longitudinal reinforcement to beams and the main reinforcement to columns with the ends of each link overlapping, as illustrated in Fig. 89. As an alternative, links may be formed from two lengths of bar, the main 'U' shaped part of the link and a top section, as illustrated in Fig. 89. The advantage of this arrangement of links is that



Stirrups to form reinforcement cage of beams

Fig. 89

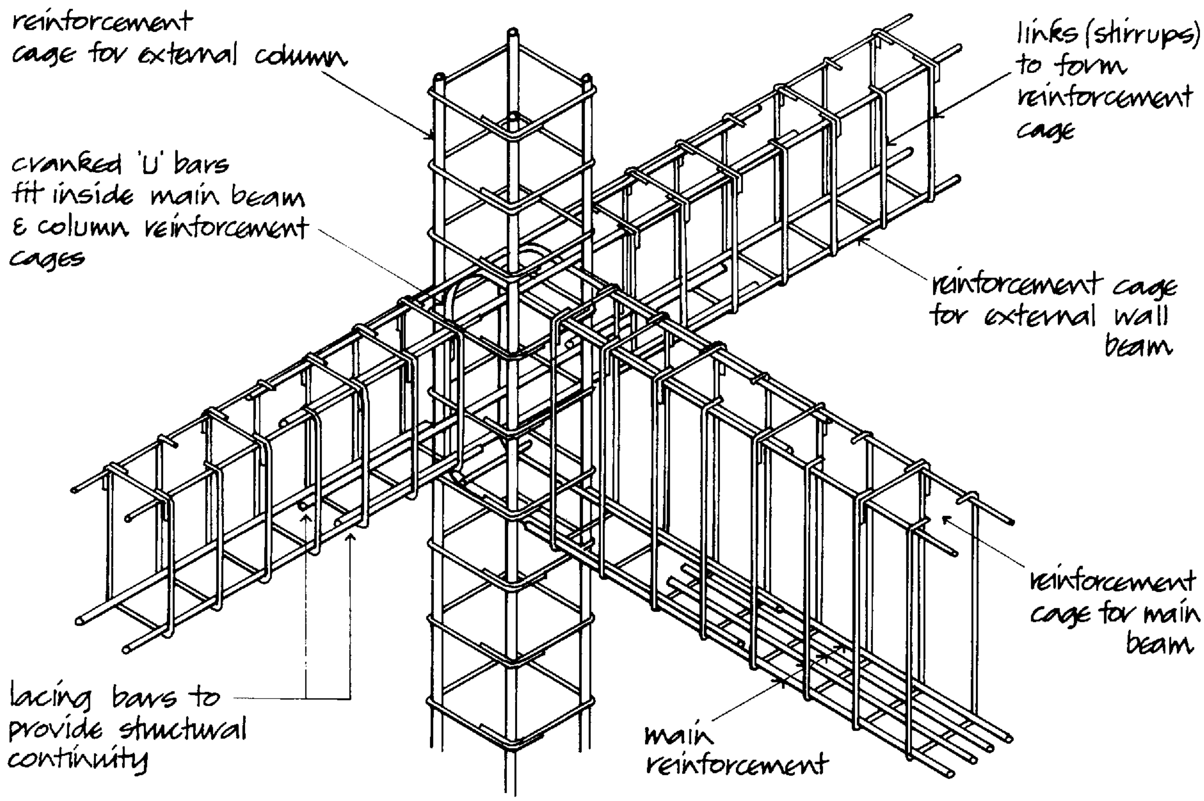
where there are several longitudinal reinforcing bars in a cage they can be dropped in from the top of the links rather than being threaded through the links as the cage is wired up, thus saving time. Figure 89 is an illustration of part of a reinforcement cage for a reinforced concrete beam.

The separate cages of reinforcement for individual beams and column lengths are made up on site with the longitudinal reinforcement wired to the links with 1.6 mm soft iron binding wire that is cut to short lengths, bent in the form of a hair pin and looped and twisted around all intersections to secure reinforcing bars to links. The ends of binding wire must be flattened so that they do not protrude into the cover of concrete, where they might cause rust staining. Considerable skill, care and labour are required in accurately making up the reinforcing cages and assembling them in the formwork. This is one of the disadvantages of reinforced concrete where unit labour costs are high.

At the junction of beams and columns there is a considerable confusion of reinforcement, compounded by large bars to provide structural continuity at the points of support and cranked bars for shear resistance and as ties between members.

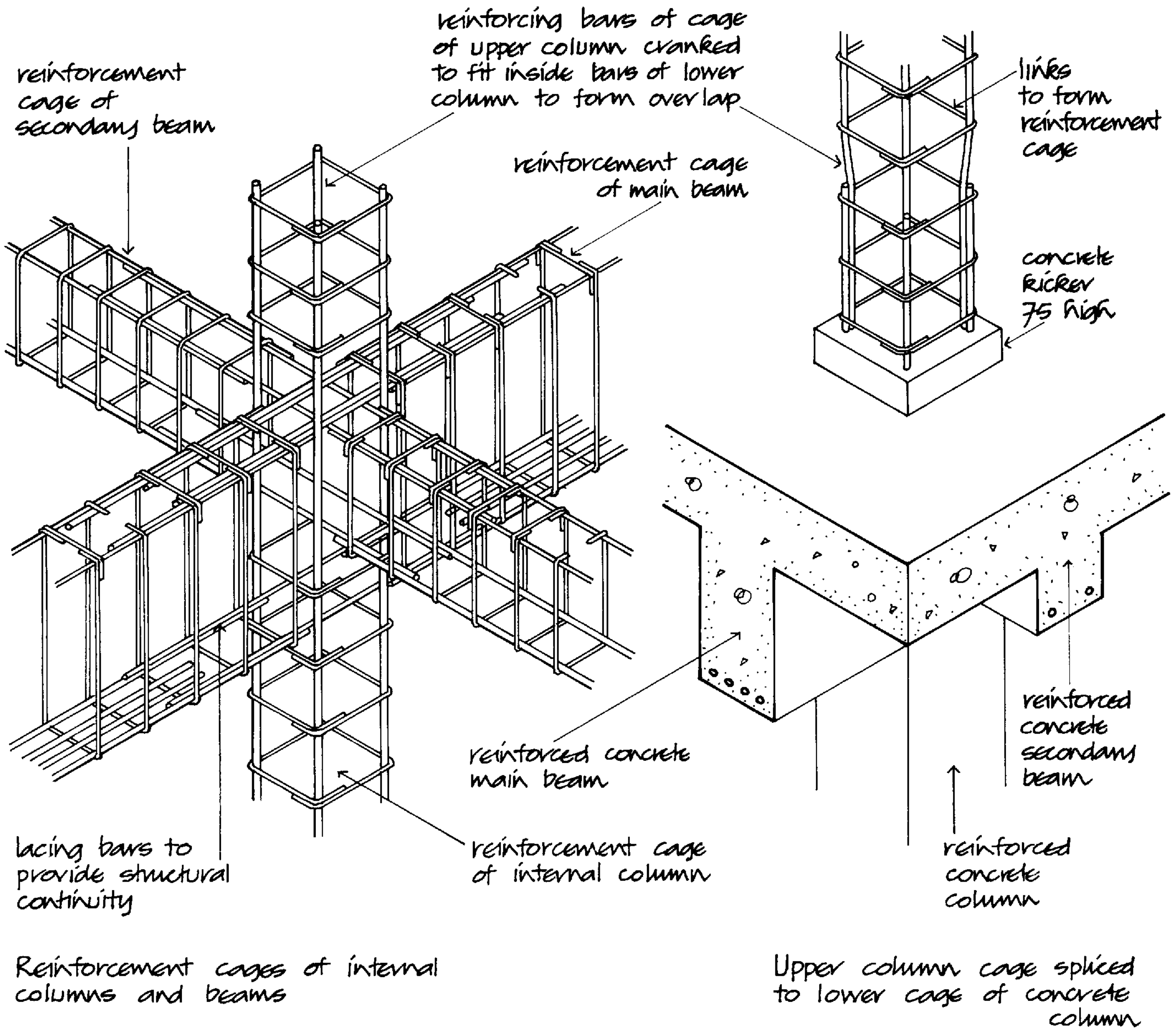
Figure 90 is an illustration of the junction of the reinforcement for a main beam with an external beam and an external column. It will be seen that the longitudinal bars for the beams finish just short of the column reinforcement for ease of positioning the beam cages and that continuity bars are fixed through the column and wired to beam reinforcement. The cranked 'U' bars fixed inside the column and wired to the main beam serve to anchor beam to column against lateral forces.

Figure 91 is an illustration of the reinforcement for the junction of four beams with a column. It will be seen that the reinforcement for intersecting beams is arranged to cross over at the intersection inside columns. Figure 91 is an illustration of a column splice made in vertical cages for convenience in erecting formwork floor by floor and handling cages.



Reinforcement cages for reinforced concrete beam and external column connection

Fig. 90



Reinforcement cages for reinforced concrete internal columns and beams

Fig. 91

In the reinforcement illustrated in Figs 90 and 91, the reinforcing bars are deformed to improve anchorage and obviate the necessity for hooked or bent ends of bars that considerably increase the labour of assembling reinforcing cages.

Spacers for reinforcement

To ensure that there is the correct cover of concrete around reinforcement to protect the steel from corrosion and to provide adequate fire protection, it is necessary to fix spacers to reinforcing bars between the bars and the formwork. These spacers must be securely fixed so that they are not displaced during placing and compacting of concrete and are strong enough to maintain the required cover of concrete. Concrete spacer blocks, the thickness of the required cover, can be cast on site from sand and cement with a loop of binding wire protruding for binding to reinforcement or one of the ready prepared concrete

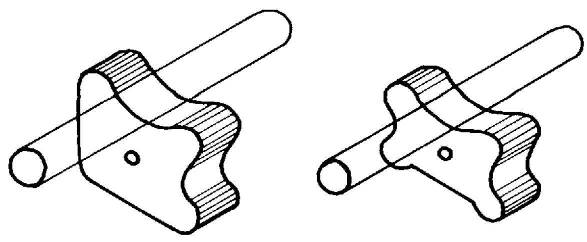


Fig. 92

spacers illustrated in Fig. 92 may be used. The holes in the spacers are for binding wire.

A range of ready prepared plastic wheel spacers and pylon spacers is available for fixing to reinforcement to provide a variety of thicknesses of concrete cover. These spacers, illustrated in Figs 93 and 94, are designed to clip firmly around various diameters of bar for both vertically and horizontally fixed reinforcement. These spacers, which are not affected by concrete, are sufficiently rigid to provide accurate spacing and will not cause surface staining of concrete, are commonly used in reinforced concrete work.

To provide support for top reinforcement in layers of concrete in slabs, steel chairs are used. The chairs are made from round section steel rods welded

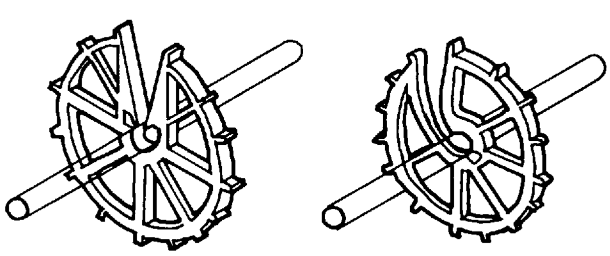


Fig. 93

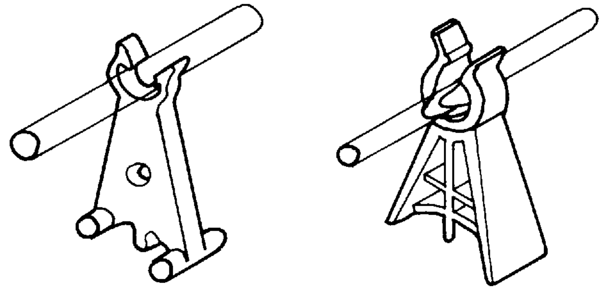


Fig. 94

together and galvanised. The chair spacer, illustrated in Fig. 95, sits on the lower layer of reinforcement and provides support for the upper layer. These chairs are robust enough to support the weights usually associated with placing and compacting concrete.

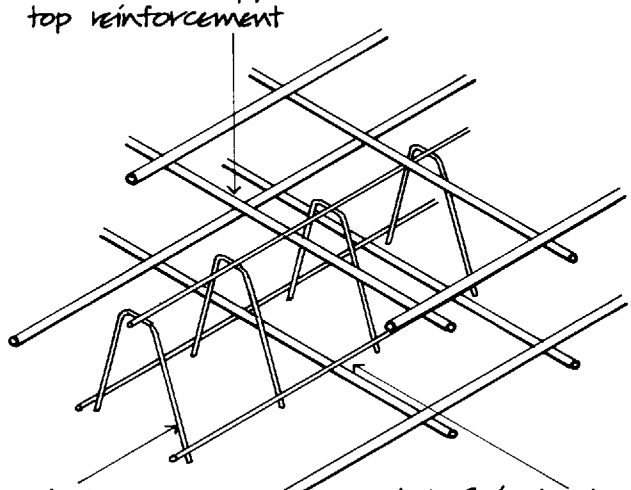


Fig. 95

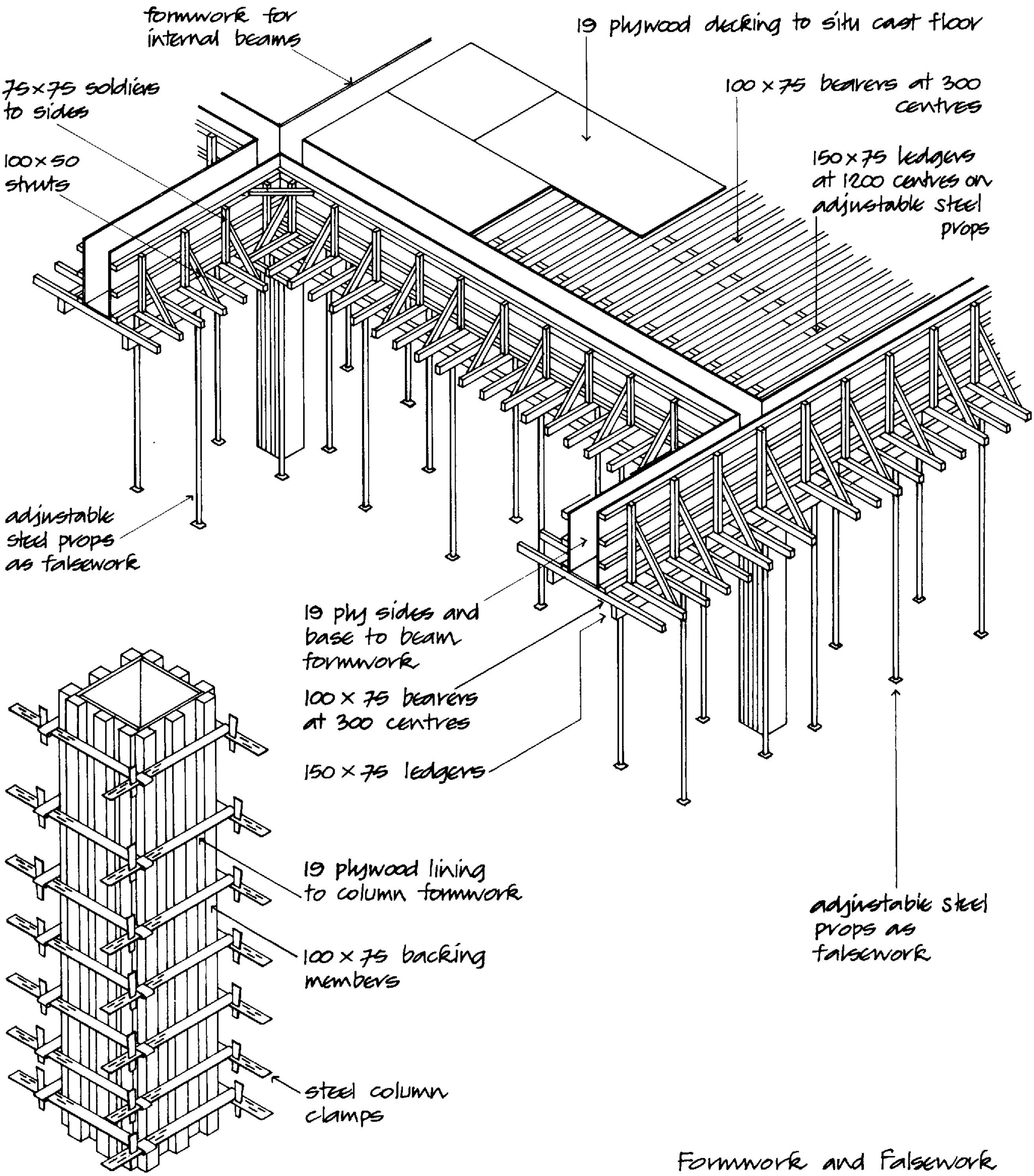

formwork for internal beams
19 plywood decking to situ cast floor
75×75 soldiers to sides
100×75 bearers at 300 centres
100×50 struts
150×75 ledgers at 1200 centres on adjustable steel props
adjustable steel props as falsework
19 ply sides and base to beam formwork
100×75 bearers at 300 centres
150×75 ledgers
19 plywood lining to column formwork
100×75 backing members
steel column clamps
adjustable steel props as falsework
Formwork and Falsework

Fig. 96

FORMWORK AND FALSEWORK

Formwork is the term used for the temporary timber, plywood, metal or other material used to contain, support and form wet concrete until it has gained sufficient strength to be self-supporting. Falsework is the term used to describe the temporary system or systems of support for formwork.

Formwork and falsework should be strong enough to support the weight of wet concrete and pressure from placing and compacting the concrete inside the forms. Formwork should be sufficiently rigid to prevent any undue deflection of the forms out of true line and level and be sufficiently tight to prevent excessive loss of water and mortar from the concrete. The size and arrangement of the units of formwork should permit ease of handling, erection and striking. Striking is the term used for dismantling formwork once concrete is sufficiently hard.

The traditional material for formwork was timber in the form of sawn, square edged boarding that is comparatively cheap and can be readily cut to size, fixed and struck. The material most used for lining formwork today is plywood which provides a more watertight lining than sawn boards and a smoother finish. Joints between plywood are sealed with foamed plastic strips. Other materials used as facing for formwork are steel sheet, glass reinforced plastics and hardboard. Where concrete is to be exposed as a finished surface the texture of timber boards, carefully selected to provide a pattern from the joints between the boards and the texture of wood, may be used or any one of a variety of surface linings such as steel, rubber, thermoplastics or other material may be used to provide a finished textured surface to concrete.

Formwork should be reasonably watertight to prevent small leaks causing unsightly stains on exposed concrete surfaces and large leaks causing honeycombing. Honeycombing is caused by the loss of water, fine aggregate and cement from concrete through large cracks, which results in a very coarse textured concrete finish which will reduce bond and encourage corrosion of reinforcement. To control leaks from formwork it is common to use foamed plastic strips in joints.

To facilitate the removal of formwork and avoid damage to concrete as forms are struck, the surface of forms in contact with concrete should be coated with a release agent that prevents wet concrete adhering strongly to the forms. The more commonly used release agents are neat oils with surfactants, mould cream emulsions and chemical release agents which are applied as a thin film to the inside faces of formwork before it is fixed in position.

The support for formwork is usually of timber in the form of bearers, ledgers, soldiers and struts. For beams, formwork usually comprises bearers at fairly close centres, with soldiers and struts to the sides and falsework ledgers and adjustable steel props as illustrated in Fig. 96. Formwork for columns is formed with plywood facings, vertical backing members and adjustable steel clamps as illustrated in Fig. 96. Falsework consists of adjustable steel props fixed as struts to the sides.

Temporary falsework and formwork are struck and removed once the concrete they support and contain has developed sufficient strength to be self-supporting. In normal weather conditions the minimum period after placing ordinary Portland cement concrete that formwork can be struck is from 9 to 12 hours for columns, walls and sides of large beams, 11 to 14 days for the soffit of slabs and 15 to 21 days for the soffit of beams.

PRESTRESSED CONCRETE

Because concrete has poor tensile strength, a large part of the area of an ordinary reinforced concrete beam plays little part in the flexural strength of the beam under load. In the calculation of stresses in a simply supported beam the strength of the concrete in the lower part of the beam is usually ignored.

When reinforcement is stretched before or after the concrete is cast and the stretched reinforcement is anchored to the concrete, it causes a compressive prestress in the concrete as it resists the tendency of the reinforcement to return to its original length. This compressive prestress makes more economical use of the concrete by allowing all of the section of concrete to play some part in supporting load. In prestressed concrete the whole or part of the concrete section is compressed before the load is applied, so that when the load is applied the compressive prestress is reduced by flexural tension.

In ordinary reinforced concrete, the concrete around reinforcement is bonded to it and must, therefore, take some part in resisting tensile stress. Because the tensile strength of concrete is low it will crack around the reinforcement under load and when the load is removed the cracks will remain. The hair cracks on the surface of concrete are not only unsightly, they also reduce the protection against fire and corrosion the concrete cover is intended to give. In designing reinforced concrete members it is usual to limit the anticipated tensile stress in order to limit deflection and the extent of cracking of concrete around reinforcement. This is a serious limitation in the most efficient use of reinforced concrete, particularly in long span beams.

When reinforcement is stretched by prestressing and anchored to concrete and the prestress is released, the tendency of the reinforcement to return to its original length induces a compressive prestress in concrete. The stretching of reinforcement before it is cast into concrete is described as pre-tensioning and stretching after the concrete has been cast as post-tensioning. The advantage of the induced compressive prestress caused either by pre- or post-tensioning is that under load the tensile stress developed by bending is acting against the compressive stress induced in the concrete and in consequence cracking is minimised. If cracking of the concrete surface does occur and the load is reduced or removed, then the cracks close up due to the compressive prestress. Another advantage of the prestress is that the compressive strength of the whole of the section of concrete is utilised and the resistance to shear is considerably improved, so obviating the necessity for shear reinforcement.

Plainly, if the prestress is to be maintained the steel reinforcement must not suffer permanent elongation or creep under load as does mild steel. High tensile wire is used in prestressed concrete to maintain the prestress under load. Under load, a prestressed concrete member will bend or deflect and compressive and tensile stresses will be developed in opposite faces, as previously explained. Concrete in parts of the member will therefore have to resist compressive stress induced by the prestress as well as compressive stress developed during bending. For this reason high compressive strength concrete is used in prestressed work to gain the maximum advantage of the prestress. A consequence of the need to use high strength concrete is that prestressed members are generally smaller in section than comparable reinforced concrete ones.

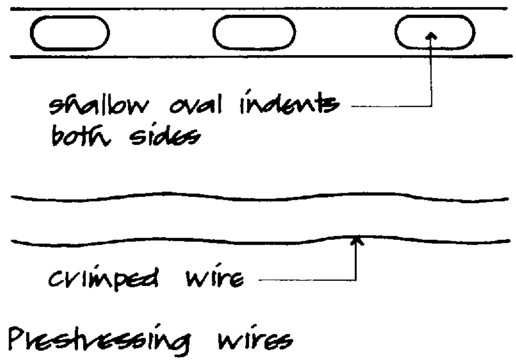


Fig. 97

Pre-tensioning

High tensile steel reinforcing wires are stretched between anchorages at each end of a casting bed and concrete is cast around the wires inside timber or steel moulds. The tension in the wires is maintained until the concrete around them has attained sufficient strength to take up the prestress caused by releasing the wires from the anchorages. The bond between the stretched wires and the concrete is maintained by the adhesion of the cement to the wires, by frictional resistance and the tendency of the wires to shorten on release and wedge into the concrete. To improve frictional resistance the wires may be crimped or indented, as illustrated in Fig. 97. When stressing wires are cut and released from the anchorages in the stressing frame the wires tend to shorten, and this shortening is accompanied by an increase in diameter of the wires which wedge into the ends of the member, as illustrated in Fig. 98.

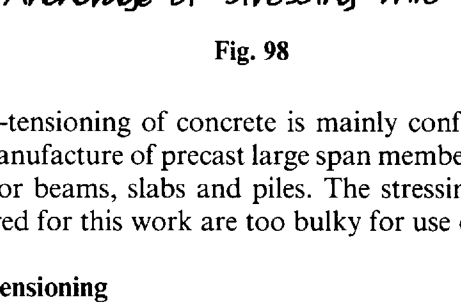


Fig. 98

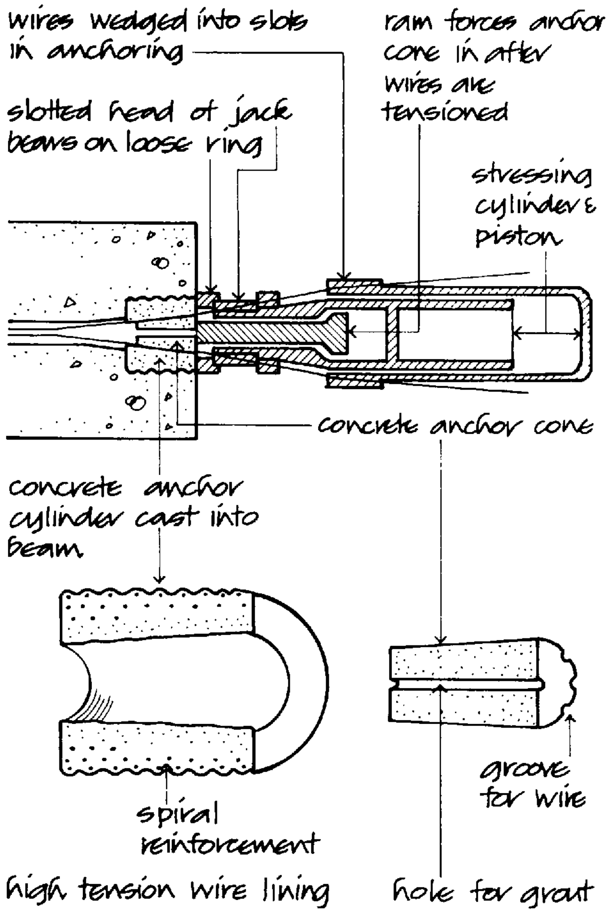
Pre-tensioning of concrete is mainly confined to the manufacture of precast large span members such as floor beams, slabs and piles. The stressing beds required for this work are too bulky for use on site.

Post-tensioning

After the concrete has been cast inside moulds or formwork and has developed sufficient strength to resist the prestress, stressing wires are threaded through ducts or sheaths cast in along the length of the member. These prestressing wires are anchored at one end of the member and are then stretched and anchored at the opposite end to induce the compressive prestress.

The advantage of post-tensioning is that the stressing wires or rod are stressed against the concrete and there is no loss of stress as there is in pretensioning due to the shortening of the wires when they are cut from the stressing bed. The major part of the drying shrinkage of concrete will have taken place before it is post-tensioned and this minimises loss of stress due to shrinkage of concrete.

The systems of post-tensioning used are: Freyssinet, Gifford–Udall-CCL, Lee-McCall, Magnel–Blaton and the PSC one wire system.



Post-tensioned prestressed concrete Freyssinet system

Fig. 99

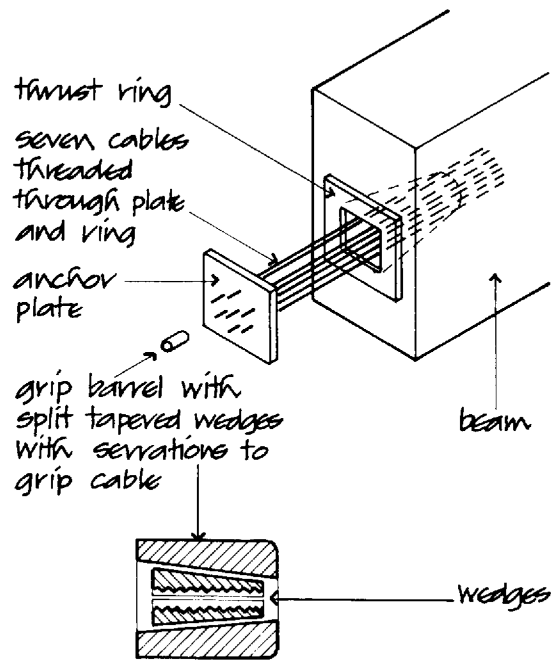
The Freyssinet system

A number of high tensile steel wires, of diameter 7, are arranged around a core of fine coiled wire and threaded through a duct formed in the precast member. The duct is formed by casting an inflatable tube or greased rod into the concrete and withdrawing it when the concrete has set. The wires are held between a concrete cone cast into the concrete and a loose cone, as illustrated in Fig. 99. The wires are stressed by means of a jack and are then anchored by hammering the grooved cone into the cast-in cone and the wires are then released from the jack.

Cement and water grout is then forced under pressure into the cable duct to protect the wires from corrosion.

The Gifford–Udall-CCL system

High tensile wires, diameter 7, are threaded into a duct in the concrete member and are anchored to steel plates by means of barrels and wedges, as illustrated in Fig. 100. This system is designed to use from one to twelve wires, and each wire is separately



Post-tensioned pre-stressed concrete C.C.L. system

Fig. 100

stressed and anchored either at one or both ends of the member. When the wires have been stressed the duct through which they pass is filled with cement grout as before.

The advantage of this system is that the precise stress in each wire is controlled, whereas in the Freyssinet system all wires are jacked together and if one wire were to break the remaining wires would take up their share of the total stress and might be overstressed.

The Lee–McCall system

An alloy bar is threaded through a duct in the concrete member and stressed by locking a nut to one end and stressing the rod the other end with a jack and anchoring it with a nut. The simplicity of this system is self-evident.

The Magnel–Blaton system

High tensile wires are arranged in layers of four wires each and are held in position by metal spacers. The layers of wire are threaded through a duct in the concrete member. One end of the wires is fixed in metal sandwich plates against an anchor plate cast

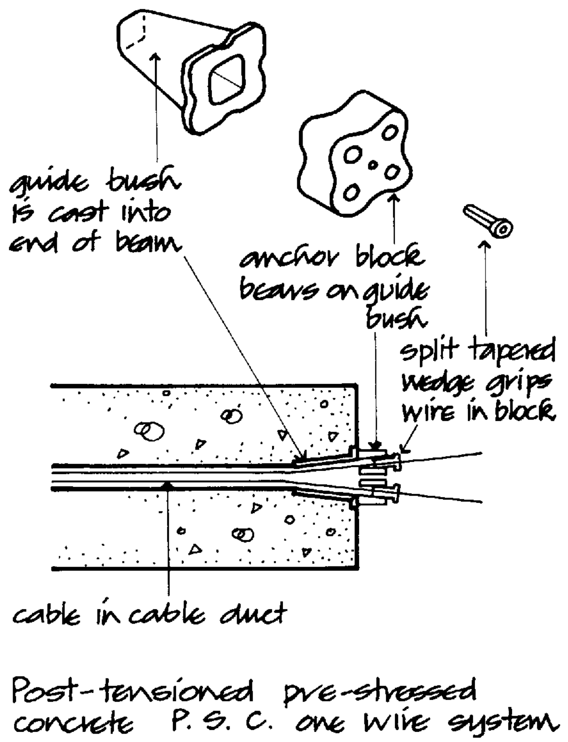


Fig. 101

into the concrete. Pairs of wires are stressed in turn and wedged in position. The stressed wires are grouted in position in the duct by introducing cement grout through a hole in the top of the member leading to the duct.

The PSC one wire system

One, two or four high tensile wires are cast inside a sheath in the concrete member. The wires are stressed one at a time and anchored in taper sleeves which fit inside an anchor block, as illustrated in Fig. 101. After stressing the duct is grouted as previously described.

LIGHTWEIGHT CONCRETE

It is advantageous to employ lightweight concrete, such as no fines concrete, for the monolithic load-bearing walls of buildings and aerated concrete for structural members, such as roof slabs, supporting comparatively light loads, to combine the advantage of reduced deadweight and improved thermal insulation.

The various methods of producing lightweight concrete depend on:

(1) The presence of voids in the aggregate
(2) Air voids in the concrete
(3) Omitting fine aggregate or
(4) The formation of air voids by the addition of a foaming agent to the concrete mix

Lightweight aggregates containing voids were described in Chapter 6, Volume 2. The aggregates described for use in lightweight concrete building blocks are also used for mass concrete or reinforced concrete structural members, where improved thermal insulation is necessary and where the members, such as roof slabs, do not sustain large loads.

No fines concrete

No fines concrete consists of concrete made from a mix containing only coarse aggregate, cement and water. The coarse aggregate may be gravel, crushed brick or one of the lightweight aggregates. The coarse aggregate used in no fines concrete should be as near one size as practicable to produce a uniform distribution of voids throughout the concrete. To ensure a uniform coating of the aggregate particles with cement/water paste it is important that the aggregate be wetted before mixing and the maximum possible water/cement ratio, consistent with strength, be used to prevent separation of the aggregate and cement paste.

Construction joints should be as few as possible and vertical construction joints are to be avoided if practicable because successive placings of no fines concrete do not bond together firmly as do those of ordinary concrete.

Because of the porous nature of this concrete it must be rendered externally or covered with some protective coating or cladding material and the no fines concrete plastered or covered internally. A no fines concrete wall provides similar insulation to a sealed brick cavity wall of similar thickness. In Scandinavian countries no fines concrete walls, without reinforcement, have been used for multi-storey blocks of flats.

Aerated and foamed concretes

An addition of one part of powdered zinc or aluminium to every thousand parts of cement causes hydrogen to evolve when mixed with water. As the cement hardens a great number of small sealed voids form in the cement to produce aerated concrete, which usually consists of a mix of sand, cement and water.

Foamed concrete is produced by adding a foaming agent, such as resin soap, to the concrete mix. The foam is produced by mixing in a high speed mixer or by passing compressed air through the mix to encourage foaming. As the concrete hardens many sealed voids are entrained.

Aerated and foamed concretes are used for building blocks and lightweight roofing slabs, as described in Volume 3.

SURFACE FINISHES OF CONCRETE

It is only during the last fifty years that concrete has been accepted as a finish to buildings. Today a variety of concrete finishes is commonplace. The principal finishes employed are surfaces left untreated and either smooth or textured from the formwork, finishes textured by hammering and surfaces with an aggregate exposed.

Plain concrete finishes

Concrete is generally placed inside formwork in stages and when the formwork is removed variations in colour and texture and fine hair cracks usually clearly indicate the different placings of concrete. On drying, concrete shrinks and fine irregular shrinkage cracks appear in the surface in addition to the cracks and variations due to successive placings. One school of thought is to accept the cracks and variations in texture and colour as a fundamental of the material and make no attempt to control or mask them. Another school of thought is at pains to mask cracks and variations by means of designed joints and profiles on the surface.

Board marked concrete finishes are produced by compacting concrete by vibration against the surface of the timber formwork so that the finish is a mirror of the grain of the timber boards and the joints between them. This type of finish varies from the regular shallow profile of planed boards to the irregular marks of rough sawn boards and the deeper profile of boards that have been sand blasted to pronounce the grain of the wood. A necessary requirement of this type of finish is that the formwork be absolutely rigid to allow dense compaction of concrete to it and that the boards be non-absorbent.

One method of making construction joints is to form a horizontal indentation or protrusion in the surface of the concrete where construction joints occur by nailing a fillet of wood to the inside face of the timber forms or by making a groove in the boards so that the groove or protrusion in the concrete masks the construction joint.

Various plain concrete finishes can be produced by casting against plywood, hardboard or sheet metal to produce a flat finish or against corrugated sheets or crepe rubber to produce a profiled finish.

Tooled surface finishes

One way of masking construction joints, surface crazing of concrete and variations in colour is to tool the surface with hand or power operated tools. The action of tooling the surface is to break up the fine particles of cement and fine aggregate which find their way to the surface when wet concrete is compacted inside formwork and also to expose the coarse texture of aggregate.

Bush hammering

A round headed hammer with several hammer points on it is vibrated by a power driven tool which is held against the surface and moved successively over small areas of the surface of the concrete. The hammer crushes and breaks off the smooth cement film to expose a coarse surface. This coarse texture effectively masks the less obvious construction joints and shrinkage cracks.

Point tooling

A sharp pointed power vibrated tool is held on the surface and causes irregular indentations and at the same time spalls off the fine cement paste finish. By moving the tool over the surface a coarse pitted finish is obtained, the depth of pitting and the pattern of the pits being controlled by the pressure exerted and the movement of the tool over the surface. For best effect with this finish as large an aggregate size as possible should be used to maintain an adequate cover of concrete to reinforcement. The depth of the pitting should be allowed for in determining the cover required.

Dragged finish

A series of parallel furrows is tooled across the surface by means of a power operated chisel pointed tool. The depth and spacing of the furrows depend on the type of aggregate used in the concrete and the size of the member to be treated. This highly skilled operation should be performed by an experienced mason.

Margins to tooled finishes

Bush hammered and point tooled finishes should not extend to the edges or arrises of members as the hammering operation required would cause irregular and unsightly spalling at angles. A margin of at least 50 should be left untreated at all angles. As an alternative a dragged finish margin may be used with the furrows of the dragging at right angles to the angle.

Exposed aggregate finish

This type of finish is produced by exposing the aggregate of the concrete used in the member or by exposing a specially selected aggregate applied to the face or faces of the member. In order to expose the aggregate it is necessary either to wash or brush away the cement paste on the face of the concrete or to ensure that the cement paste does not find its way to the face of the aggregate to be exposed. Because of the difficulties of achieving this with in situ cast concrete, exposed aggregate finishes are confined in the main to precast concrete members and cladding panels.

One method of exposing the aggregate in concrete is to spray the surface with water, while the concrete is still green, to remove cement paste on the surface. The same effect can be achieved by brushing and washing the surface of green concrete. The pattern and disposition of the aggregate exposed this way is dictated by the proportioning of the mix and placing and compaction of the concrete, and the finish cannot be closely controlled.

To produce a distinct pattern or texture of exposed aggregate particles it is necessary to select and place the particles of aggregate in the bed of a mould or alternatively to press them into the surface of green concrete. This is carried out by precasting concrete.

Members cast face down are prepared by covering the bed of the mould with selected aggregate placed at random or in some pattern. Concrete is then carefully cast and compacted on top of the aggregate so as not to disturb the face aggregate in the bed of the mould. If the aggregate is to be exposed in some definite pattern it is necessary to bed it in water-soluble glue in the bed of the mould on sheets of brown paper that are washed off later. Once the concrete member has gained sufficient strength it is lifted from the mould and the face is washed to remove cement paste.

Large aggregate particles which are to be exposed are pressed into a bed of sand in the bed of the mould and the concrete is then cast on the large aggregate. When the member is removed from the mould after curing, the sand around the exposed aggregate is washed off. Alternatively, large particles may be pressed into the surface of green concrete and rolled, to bed them firmly and evenly.

CHAPTER FOUR

CONCRETE STRUCTURAL FRAMES

IN SITU CAST FRAMES

Joseph Aspdin produced the earliest Portland cement in order to manufacture artificial stone. A French gardener, Joseph Monier, who was making concrete flower boxes found that they cracked and to strengthen them he cast a wire mesh in the concrete. This was the birth of reinforced concrete and Monier took out a patent in 1867 for the manufacture of reinforced concrete flower pots. Some years later another Frenchman, François Hennebique, was chiefly responsible for the development of reinforced concrete for use in buildings, firstly as reinforced concrete piles and later as reinforced concrete beams and columns. In 1930, Freyssinet began development work that led to the use of prestressed concrete in building.

The first reinforced concrete framed building to be built in this country was the General Post Office building in London which was completed in 1910. Subsequently comparatively little use was made of reinforced concrete in this country until the end of the Second World War. Steel had been the traditional material used for structural frames and engineers regarded the newfangled reinforced concrete with some suspicion. The great shortage of steel that followed the end of the Second World War prompted engineers to use reinforced concrete as a substitute for steel in structural building frames.

The shortage of steel continued for some years after the end of the war. At the time the conventional method of providing fire protection to structural steel frames was to encase beams and columns in concrete that was cast in situ in formwork around the steel. This concrete casing added nothing to the strength of the steel members, added considerably to the dead weight of the frame and was costly in the formwork and falsework necessary for casting concrete.

With firstly a shortage and later the comparatively high cost of steel it was common to use a reinforced concrete structural frame with the concrete providing compressive strength and fire protection with the small section steel rods cast in to provide tensile strength where it was most needed. Up to the early 1980s the majority of framed buildings in this country were constructed with reinforced concrete frames. Recently a steel frame may be somewhat cheaper than a reinforced concrete frame for multi-storey framed structures and wide span single storey shed buildings.

The reinforced concrete frames that were constructed after the Second World War were treated as a substitute for steel frames and were designed as though they were of steel, with columns on a rectangular grid supporting main floor beams supporting one way spanning floor slabs. This design procedure ignored the inherent differences between a steel and a concrete frame.

The conventional steel frame consists of 'I' section columns and beams that have greater strength on the axis parallel to the web of the section than at right angles to it. It is logical, therefore, to connect the main beams to the flanges of columns and span one way slabs between main beams with ties at right angles to main beams. The floor slabs bear on the beams in simple bending and do not act monolithically with the beams supporting them. In these conditions the rectangular column grid is the most economical arrangement.

The members of a reinforced concrete frame can be moulded to any required shape so that they can be designed to use concrete where compressive strength is required and steel reinforcement where tensile strength is required, and the members do not need to be of uniform section along their length or height.

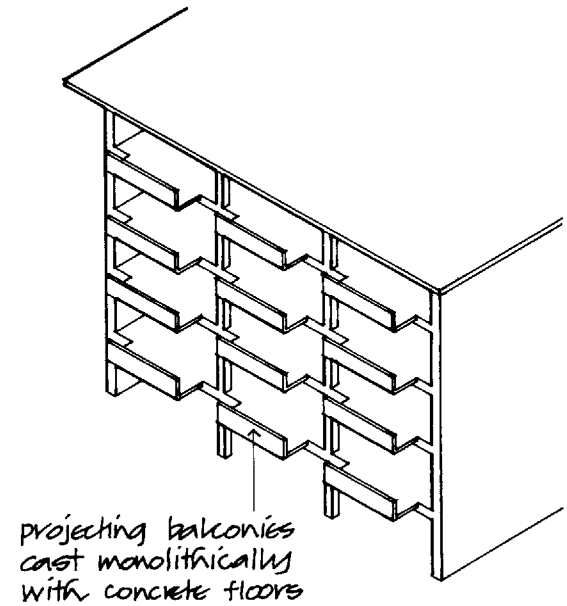
The singular characteristics of concrete are that it is initially a wet plastic material that can be formed to any shape inside formwork for economy in section as a structural material, or for reasons of appearance, and when it is cast in situ will act monolithically as a rigid structure.

These characteristics are at once an advantage and a disadvantage. Unlimited choice of shape is an advantage structurally and aesthetically, but may well be a disadvantage economically in the complication of formwork and falsework necessary to form irregular shapes. A monolithically cast reinforced concrete frame has advantageous rigidity of connections in a frame and in a solid wall or shell structure, but this rigidity is a disadvantage in that it is less able to accommodate to movements due to settlement, wind pressure and temperature and moisture changes than is a more flexible structure.

The cost of formwork for concrete can be considerably reduced by repetitive casting in the same mould in the production of precast concrete cladding and structural frames, and the rigidity of the concrete frame can be of advantage on subsoils of poor or irregular bearing capacity and where severe earth movements occur as in areas subject to earthquakes.

The form of buildings, such as the shell forms illustrated in Volume 3, the Sydney Opera House, the Alvarado Palace Brazilia and precast cladding demonstrate the application of the initial plasticity of concrete and the structural rigidity and strength of reinforced concrete to advantage.

In spite of considerable publicity emphasising the advantages of steel as a structural frame material, the in situ cast reinforced concrete frame is still extensively used for both single and multi-storey buildings as a convenient and economic skeleton frame within which or on which a variety of wall envelopes may be supported or hung to provide the appearance of traditional loadbearing walling, panel cladding, infill framing and thin sheet finishes.



In-situ cast reinforced concrete frame

Fig. 102

Structural frame construction

The principal use of reinforced in situ cast concrete as a structural material for building is as a skeleton frame of columns and beams with reinforced concrete floors and roof. In this use reinforced concrete differs little from structural steel skeleton frames cased in concrete. In those countries where unit labour costs are low and structural steel is comparatively expensive, a reinforced concrete frame is widely used as a frame for both single and multi-storey buildings such as the small framed building, with solid end walls and projecting balconies with upstands, illustrated in Fig. 102.

The in situ cast, reinforced concrete structural frame is much used for multi-storey buildings such as flats and offices. Repetitive floor plans can be formed inside a skeleton frame of continuous columns and floors. To use the same formwork and falsework, floor by floor, variations in the reinforcement and/or mix of concrete in columns, to support variations in loads, can provide a uniform column section. The uniformity of column section and formwork makes for a speedily erected and economic structural frame.

An advantage of the reinforced concrete structural frame is that the columns, beams and floor slabs provide a level, solid surface on which walls and partitions can be built and between which walls, partitions and framing may be built and secured by bolting directly to a solid concrete backing.

A reinforced concrete structural frame with one way spanning floors is generally designed on a rectangular grid for economy in the use of materials in the same way as a structural steel frame. Where floors are cast monolithically with a reinforced concrete frame, the tie beams that are a necessary part of a structural steel frame may be omitted as the monolithically cast floors will act as ties. The flush floor slab soffit between main beams, illustrated in Fig. 103, may be of advantage in running services below ceilings and the disposition of demountable divisions.

The main beams in the external walls of a reinforced concrete frame may be cast as upstand beams, as illustrated in Fig. 103, which can serve as the apron below windows and the flush soffit below these beams will allow the head of windows to be in line with the ceiling and so obtain maximum penetration of light to the interior.

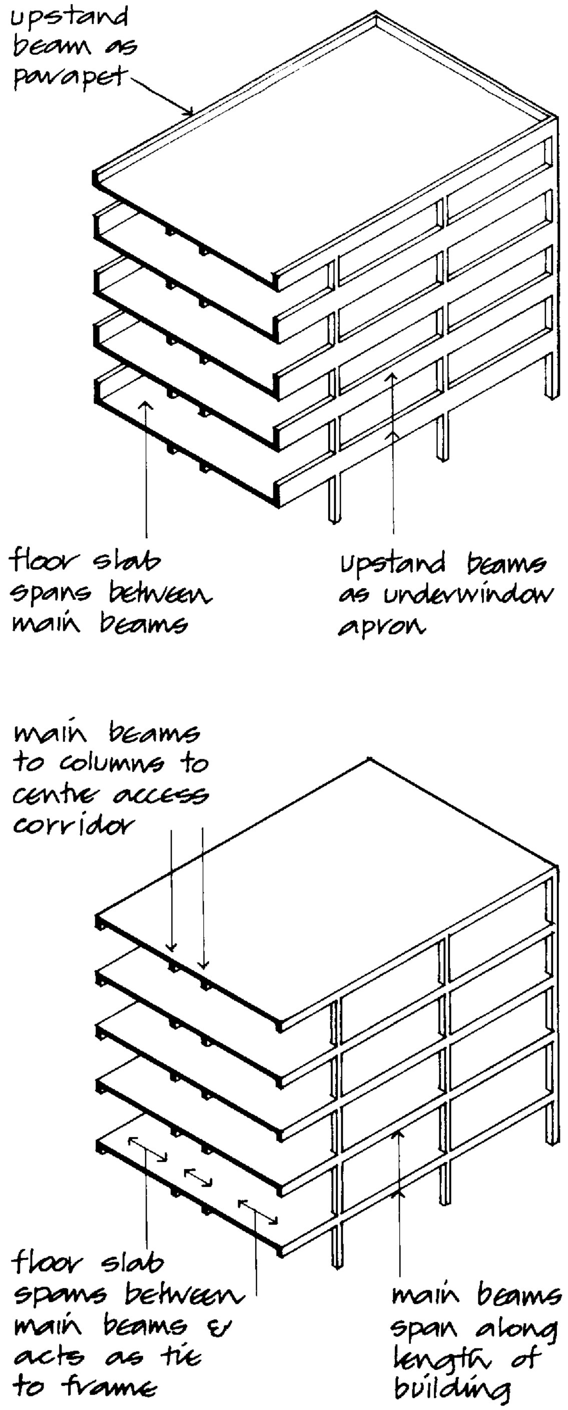


Fig. 103

Cross wall and box frame construction

Multi-storey structures, such as blocks of flats and hotels with identical compartments planned on successive floors one above the other, require permanent solid vertical divisions between compartments for privacy and sound and fire resistance.

In this type of building it is illogical to construct a frame and then build solid heavy walls within the frame to provide horizontal separation, with the walls taking no part in load bearing. A system of reinforced concrete cross walls at once provides sound and fire separation and acts as a structural frame supporting floors, as illustrated in Fig. 104. Between the internal cross walls reinforced concrete beam and slab or plate floors may be used. Where flats are planned on two floors as maisonettes the intermediate floor of the maisonette may be of timber joist and concrete beam construction to reduce cost and dead weight. The intermediate timber floor inside maisonettes is possible where building regulations require vertical and horizontal separation between adjacent maisonettes.

Where a system of cross walls and flat slab floors is employed the structure takes the form of a series of adjacent boxes, and this system is sometimes described as cross wall or box frame construction. A box frame form of construction may be used for external walls where the inherent strength and stability of a reinforced concrete wall are used, both for structural support and as an external wall perforated for

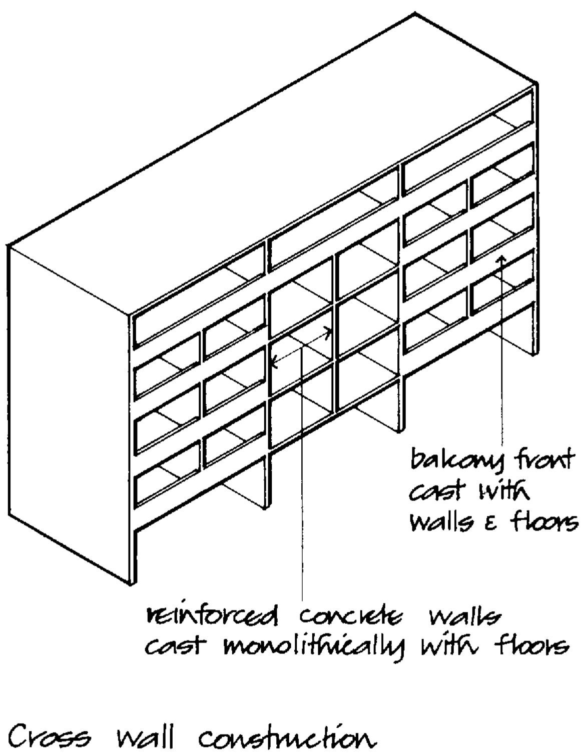


Fig. 104

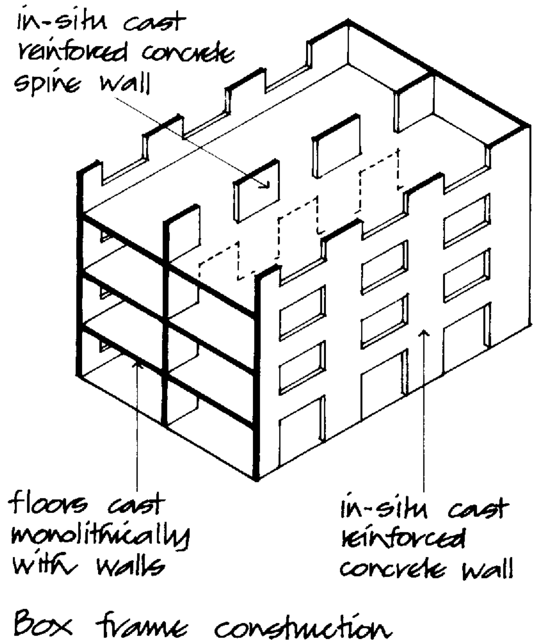


Fig. 105

window openings as illustrated in Fig. 105. Here the wall frame may be used for external walls with an internal frame or as both external and internal walls.

Wind bracing

A steel frame depends on the use of continuously rolled, comparatively slender steel sections that are put together in the form of a skeleton frame. Where a part or parts of a building have to be enclosed, as for example lift shafts, stairs and lavatories, it is usual to construct the steel frame around these parts and then enclose them with brickwork carried at each floor by the frame. Initially concrete is a wet, plastic material that can be moulded to any desired shape and the shape is not dependent on the reinforcement which can be disposed to suit the shape of the concrete.

In a reinforced concrete structure it is not logical to cast beams and columns to support permanent brick walls when a monolithically cast concrete wall will serve the dual function of frame and enclosing wall. In multi-storey reinforced concrete framed buildings it is usual to contain the lifts, stairs and lavatories within a service core, contained in reinforced concrete walls, as part of the frame. The hollow reinforced concrete column containing the services and stairs is immensely stiff and will strengthen the attached skeleton frame against wind pressure.

In addition to stiffening the whole building, such a service core will also carry a considerable part of floor loads by cantilevering floors from the core and using props in the form of slender columns on the face of the building. Similarly monolithically cast reinforced concrete flank end walls of slab blocks may be used to stiffen a skeleton frame structure against wind pressure on its long façade.

FLOOR CONSTRUCTION

In situ cast concrete floors

The principal types of reinforced in situ cast concrete floor construction are:

- Beam and slab
- Waffle grid slab
- Drop beam and slab
- Flat slab

Beam and slab floor

A beam and slab floor is generally the most economic and therefore most usual form of floor construction for reinforced concrete frames.

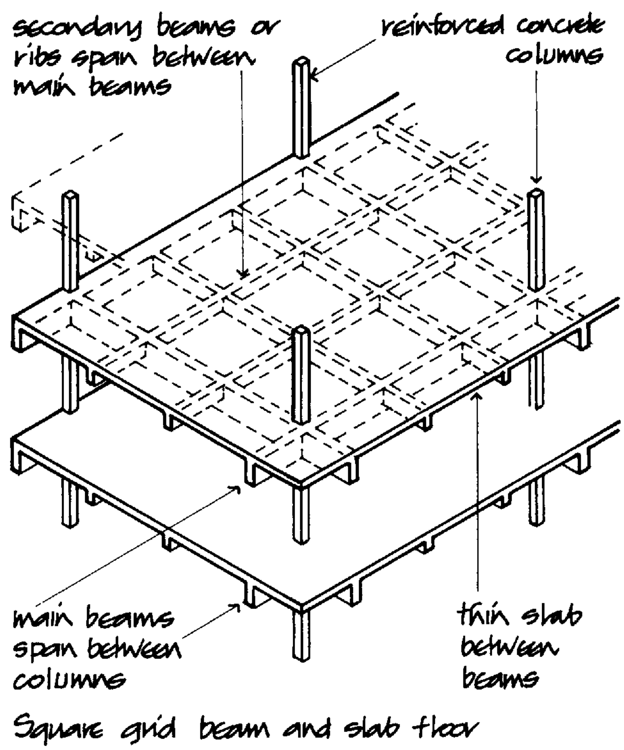
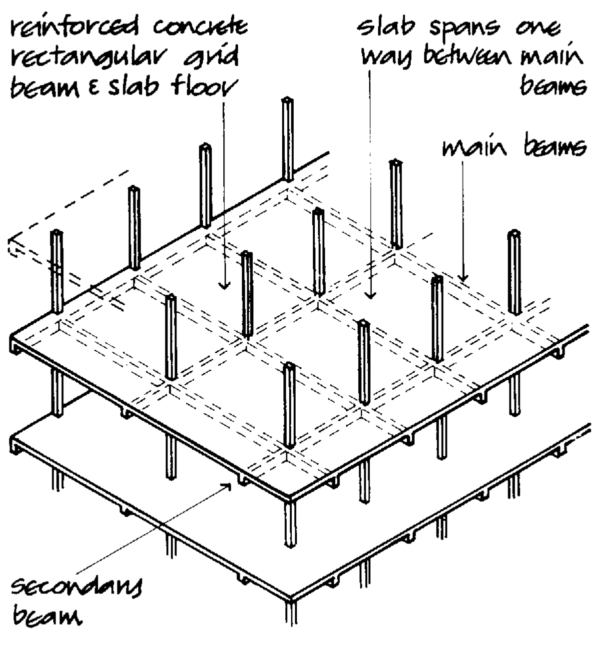


Fig. 106

When a reinforced concrete frame is cast monolithically with reinforced concrete floors it is logical to design the floor slabs to span in both directions so that all the beams around a floor slab can bear part of the load. This two-way span of floor slabs effects some reduction in the overall depth of floors as compared to a one-way spanning floor slab construction. Since the most economical shape for a two-way spanning slab is square, the best column grid for a reinforced concrete frame with monolithically cast floors is a square one as illustrated in Fig. 106. The in situ cast reinforced concrete floor illustrated in Fig. 107 combines main and secondary beams as a grid to provide the least thickness of slab for economy in the mass of concrete used in construction. This square grid results in the minimum thickness of floor slab and minimum depth of beams and therefore the minimum dead weight of construction. Departure from the square column grid, because of user requirements and circulation needs in a building, will increase the overall depth, weight and therefore cost of construction of a reinforced concrete frame.

A rectangular column grid supports beams and a one-way span floor as illustrated in Fig. 107. The floor can be cast in situ on centering and falsework.

In a steel frame the skeleton of columns and beams is designed to carry the total weight and loads of the building, and the floor slabs, which span between beams, act independently of the frame. In in situ cast reinforced concrete frame and floor construction, columns, beams and floors are cast and act monolithically. The floor construction, therefore, acts with and affects the frame and should be considered as part of it.



Rectangular grid beam and slab floor

Fig. 107

Waffle grid slab floor

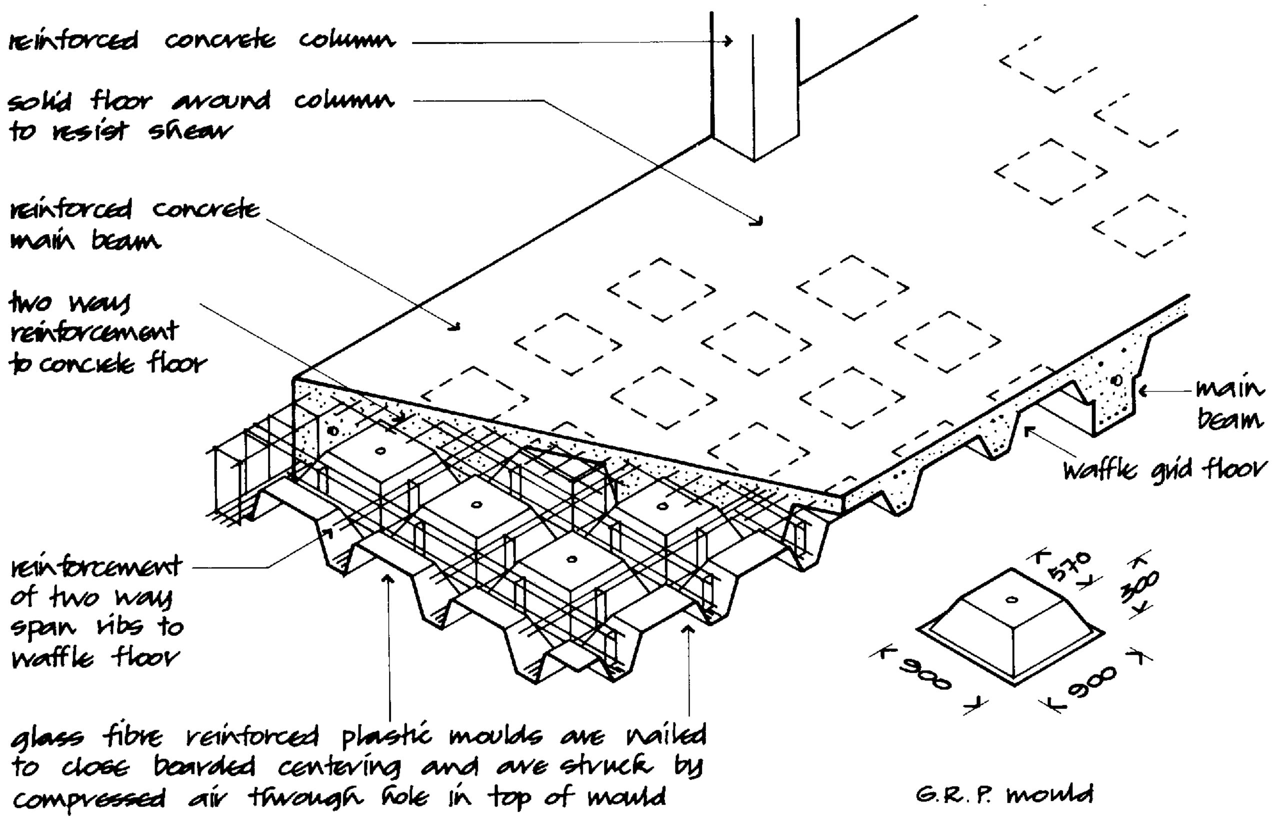
If the column grid is increased from about 6.0 to about 12.0 square or near square it becomes economical to use a floor with intermediate cross beams supporting thin floor slabs, as illustrated in Fig. 108. The intermediate cross beams are cast on a regular square grid that gives the underside of the floor the appearance of a waffle, hence the name. The advantage of the intermediate beams of the waffle is that they support a thin floor slab and so reduce the dead weight of the floor as compared to a flush slab of similar span. This type of floor is used where a widely spaced square column grid is necessary and floors support comparatively heavy loads. The economic span of floor slabs between intermediate beams lies between 900 and 3.5. The waffle grid form of the floor may be cast around plastic or metal formers laid on timber centering as illustrated in Fig. 108, so that the smooth finish of the soffit may be left exposed.

Drop slab floor

This floor construction consists of a floor slab which is thickened between columns in the form of a shallow but wide beam, as illustrated in Fig. 109. A drop slab floor is of about the same dead weight and cost as a comparable slab and beam floor and will have up to half the depth of floor construction from top of slab to soffit of beams. On a 12.0 square column grid the overall depth of a slab and beam floor would be about 1.2 where the depth of a drop slab floor would be about 600. This difference would cause a significant reduction in overall height of construction of a multi-storey building with appreciable saving in cost.

Flat slab (plate) floor

In this floor construction the slab is of uniform thickness throughout, without downstand beams and with the reinforcement more closely spaced



Waffle grid in-situ cast reinforced concrete floor

Fig. 108

between the points of support from columns. To provide sufficient resistance to shear at the junction of columns and floor, haunched or square headed columns are often formed, as illustrated in Fig. 110. The dead weight of this floor and its cost are greater than the floor systems previously described but its depth is less and this latter advantage provides the least overall depth of construction in multi-storey buildings.

The floor slabs in the floor systems described above may be of solid reinforced construction or constructed with one of the hollow, or beam or plank floor systems.

In modern buildings it is common to run air conditioning, heating, lighting and fire fighting services on the soffit of floors above a false ceiling and these services occupy some depth below which minimum floor heights have to be provided. Even though the beam and slab or waffle grid floors are the most economic forms of construction in themselves, they may well not be the most advantageous where the services have to be fixed below and so increase the overall depth of the floor from the top of the slab to the soffit of the false ceiling below, because the services will have to be run below beams and so increase the depth between false ceiling and soffit of slab. Here it may be economic to bear the cost of a flat slab or drop slab floor in order to achieve the least overall height of construction and its attendant saving in cost.

Up to about a third of the cost of an in situ cast reinforced concrete frame goes to providing, erecting and striking the formwork and falsework for the frame and the centering for the floors. It is important, therefore, to maintain a uniform section of column up the height of the building and repetitive floor and beam design as far as possible, so that the same formwork may be used at each succeeding floor. Alteration of floor design and column section involves extravagant use of formwork. Uniformity of

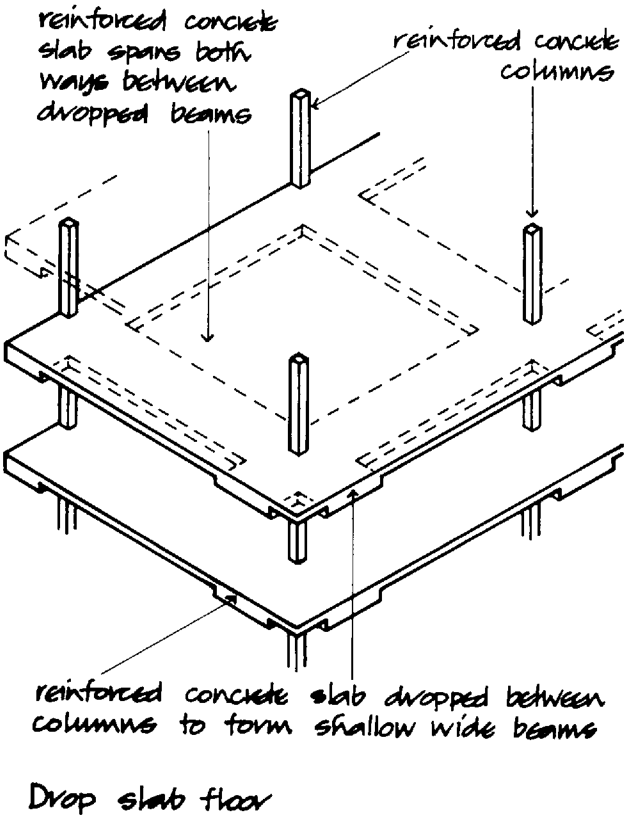


Fig. 109

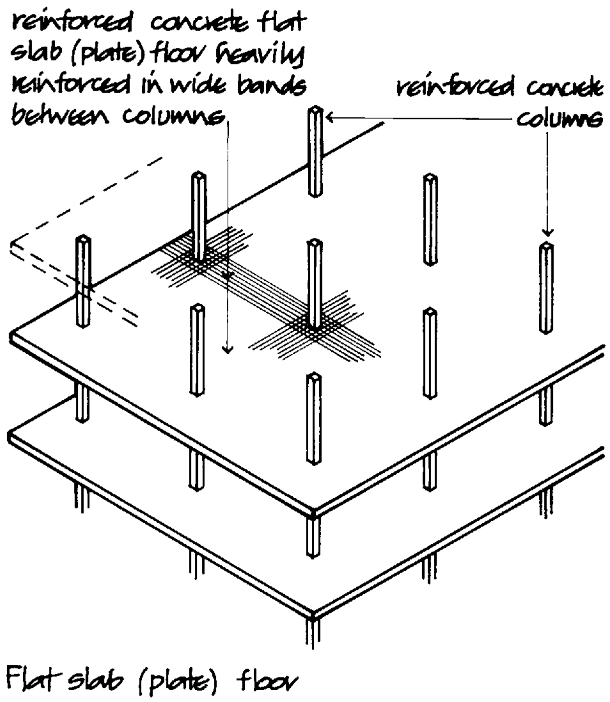


Fig. 110

column section is maintained by using high strength concrete with a comparatively large percentage of reinforcement in the lower, more heavily loaded storey heights of the columns and progressively less strong concrete and less reinforcement up the height of the building.

Precast reinforced concrete floor systems

Precast reinforced concrete floor beams, planks, tee beams or beam and infill blocks that require little or no temporary support and on which a screed or structural concrete topping is spread are commonly used with structural steel frames and may be used for in situ cast concrete frames instead of in situ cast floors.

Precast beams and plank floors that require no temporary support in the form of centering are sometimes referred to as self-centering floors.

The advantage of these precast floor systems is that there is a saving in site labour in erecting and striking centering and falsework for floors and that there is no falsework in the form of props to obstruct work. Of the types of precast floor described the precast hollow unit and plank floor are the most commonly used.

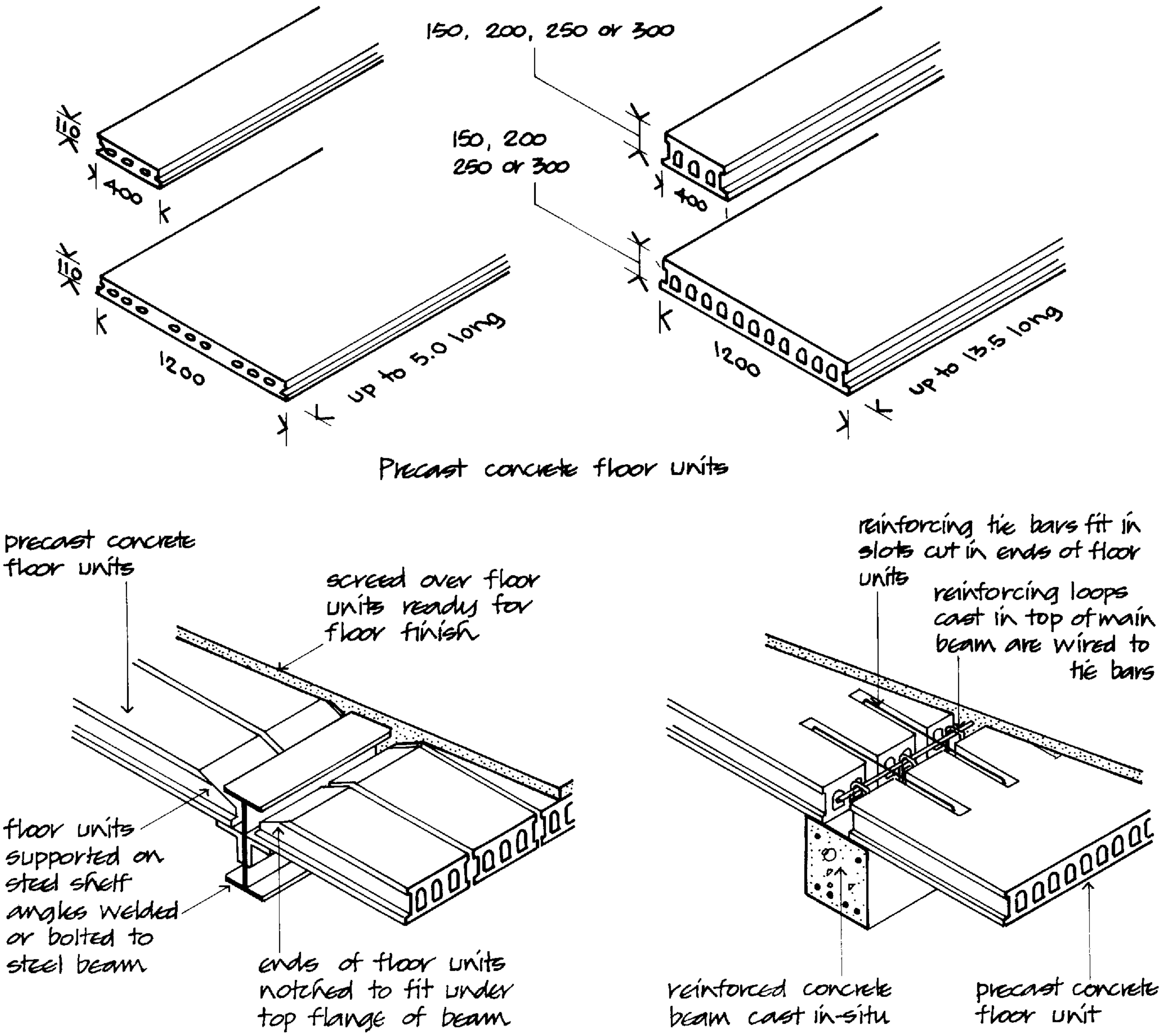
Precast hollow floor units

These large precast reinforced concrete, hollow floor units are usually 400 or 1200 wide, 110, 150, 200, 250 or 300 thick and up to ten metres long for floors and thirteen and a half metres long for roofs. The purpose of the voids or hollows in the floor units is to reduce dead weight without affecting strength. The reinforcement is cast into the webs between hollows.

The hollow floor units can be used by themselves as floor slab with a floor screed or they may be used with a structural reinforced concrete topping with tie bars over beams for composite action with the beams. End bearing of these units is a minimum of 75 on steel and concrete beams and 100 on masonry and brick walls. Figure 111 is an illustration of precast hollow floor units.

Precast concrete plank floor units

These comparatively thin, prestressed solid plank, concrete floor units are designed as permanent shuttering and for composite action with structural reinforced concrete topping, as illustrated in Fig.



Precast concrete floor units supported by shelf angles and steel beam

Precast concrete floor units bearing on reinforced concrete beam

Hollow precast reinforced concrete floor units

Fig. 111

112. The units are 400 or 1200 wide, 65, 75 or 100 thick and up to $9\frac{1}{2}$ metres long for floors and 10 metres for roofs. It may be necessary to provide some temporary propping to the underside of these planks until the concrete topping has gained sufficient strength.

Precast concrete tee beams

Precast prestressed concrete tee beam floors are mostly used for long span floors in such buildings as stores, supermarkets, swimming pools and multi-storey car parks where there is a need for wide span

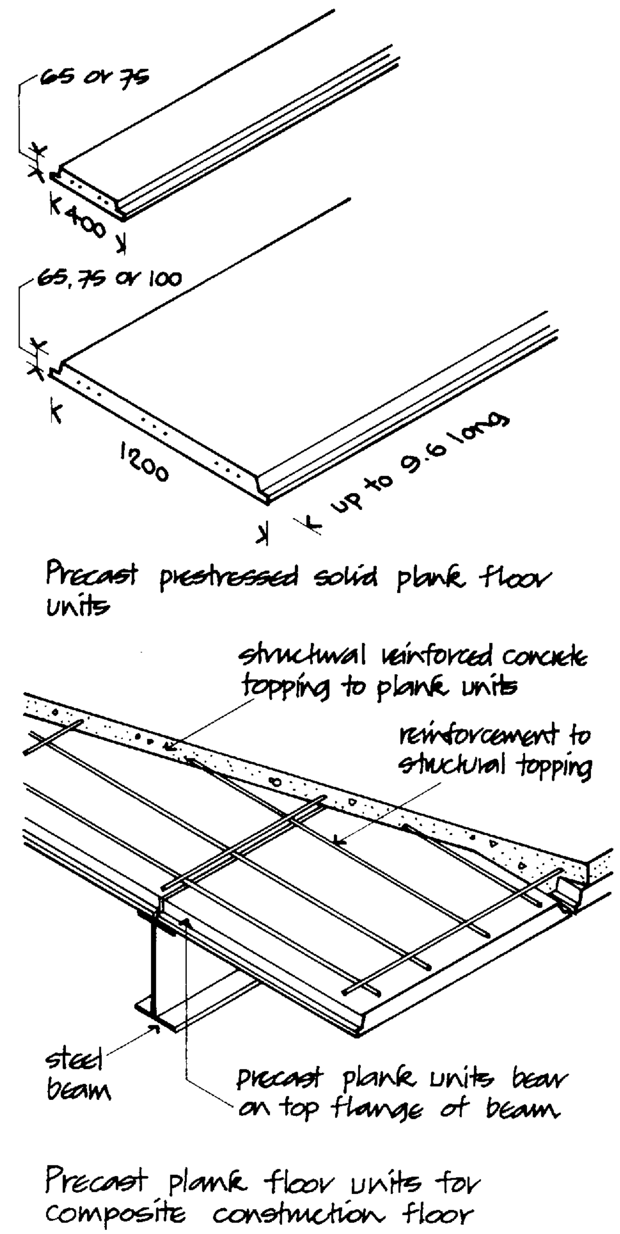


Fig. 112

floors and the depth of this type of floor is not a disadvantage. The floor units are cast in the form of a double tee, as illustrated in Fig. 113. The strength of these units is in the depth of the ribs which support and act with the comparatively thin top web. A structural reinforced concrete topping is cast on top of the floor units.

Precast beam and filler block floor

This floor system consists of precast reinforced concrete planks or beams that support precast hollow concrete filler blocks, as illustrated in Fig. 114. The planks or beams are laid between supports with the filler blocks between them and a concrete topping is spread over the planks and filler blocks. The reinforcement protruding from the top of the plank acts with the concrete topping to form a reinforced concrete beam.

The advantage of this system is that the light-weight planks or beams and filler blocks can be lifted much more easily and placed in position than the much larger hollow concrete floor units.

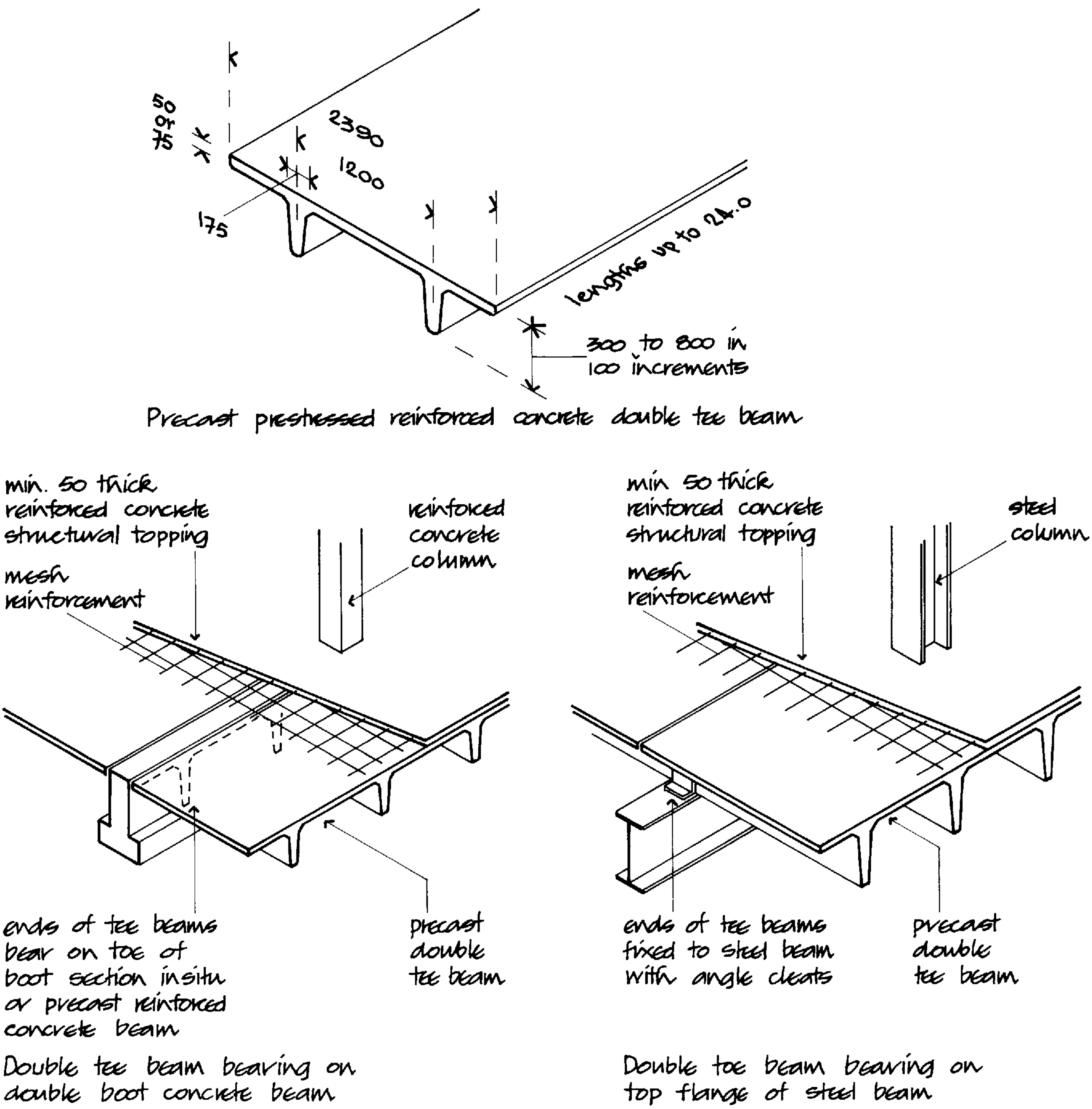
Hollow clay block and concrete floor

A floor system of hollow clay blocks and in situ cast reinforced concrete beams between the blocks and concrete topping, cast on centering and falsework, was for many years extensively used for the fire resisting properties of the blocks. This floor system is much less used because of the very considerable labour in laying the floor.

PRECAST REINFORCED CONCRETE FRAMES

The development of the structural building frame depended on the use of steel and, later, reinforced concrete as a skeleton frame to support floors and walls of the traditional materials, stone and brick. This form of construction was facilitated by a plentiful supply of cheap labour to construct the frame and build walls using the traditional skills of masonry and bricklaying developed over the centuries. The supply of skilled and unskilled labour was adequate at the time for the construction of the comparatively few large buildings in cities and towns.

The extensive programmes of rebuilding and rehousing that followed the end of the Second World War coincided with a shortage of the traditional building materials, i.e. brick, stone, timber and steel, and a depleted labour force wholly inadequate to the scale of the projected work. In the event, a substantial part of the building programmes was met by the use of concrete in the form of precast frames, cladding units and wall frames. The combination of the use of precast concrete units and the introduction of the tower crane made it possible to produce standard components and assemble them on site with the minimum of skilled labour.



Precast prestressed concrete double tee beam

Fig. 113

The advantage of precast concrete was that the materials cement, sand, gravel and crushed rock were readily available and could be combined with the least amount of steel to produce a material that was structurally sound and could serve both as a frame and as a wall material for buildings. Mechanisation of the production of standard, repetitively cast units off the site and their assembly on site required the least amount of labour, either skilled or unskilled.

The two basic forms of precast concrete frames are (a) the frame members precast either as separate

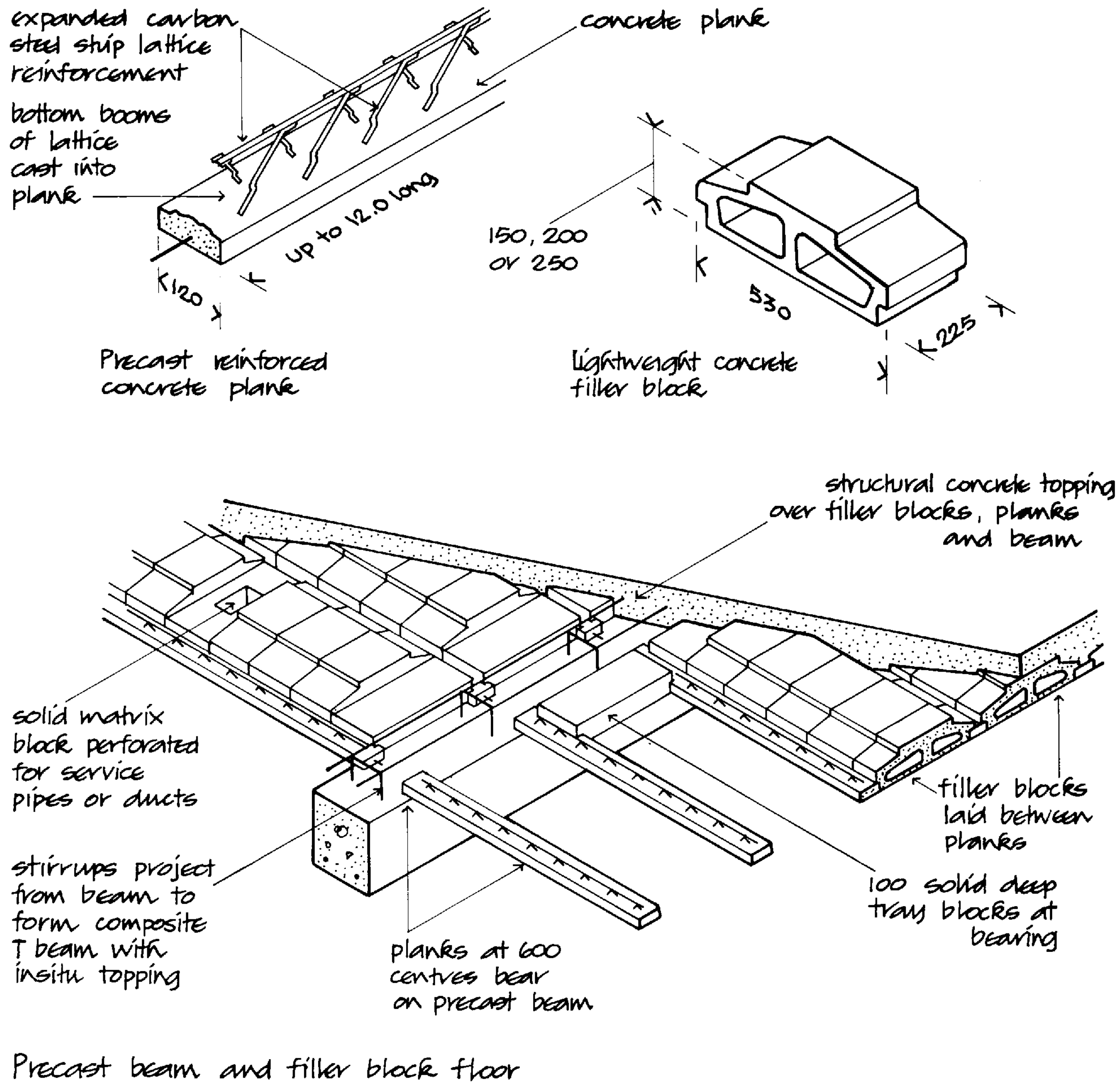


Fig. 114

lengths of column and beam or combined as beam and column units, which are assembled and joined on site ready for infill panels or a cladding of brick or precast concrete units and (b) the wall frame units which serve both as structure and walling combined in large wall units, usually storey height, assembled and joined on site to precast concrete floor units.

The advantage of the precast frame is that it allows the use of various wall and cladding finishes, either as infill panels fixed inside the frame or as a covering of cladding. The wall frame, however, is a large, solid, storey height panel of concrete that can be varied only in the surface finish of concrete and the size and disposition of windows.

In the years from 1950 to 1970 precast concrete frames, wall frames and cladding were extensively used as an accepted form of construction for multi-storey housing and other large buildings where standard units of construction could be used to advantage. Since the early 1970s, precast concrete has lost favour as a material for framing and cladding buildings. This loss of favour is principally a change of fashion as glass reinforced cement, then plastics and more recently sheet metal cladding panels were used instead of precast concrete, and for reasons of economy steel was used for structural frames in place of concrete. Publicised failures of precast concrete wall units, such as that at Ronan Point, have done much to add to the disfavour of concrete as a building material. These failures were not failures of the material itself but failures of the systems of jointing due to poor design or faulty workmanship or a combination of both.

Precast concrete has been established as a sound, durable material for framing and cladding buildings where repetitive casting of units is an acceptable and economic form of construction. Fashions change and it is likely that precast concrete will once again find favour as a building material.

The chief problem in precast concrete framework is joining the members on site, particularly if the frame is to be exposed, to provide a solid, rigid bearing in column joints and a strong, rigid bearing of beams to columns that adequately ties beams to columns for structural rigidity.

Where the frame is made up of separate precast column and beam units there is a proliferation of joints to be made on site. The number of site joints is reduced by the use of precast units that combine two or more column lengths with beams, as illustrated in Fig. 115. The number of columns and beams that can be combined in one precast unit depends on the particular design of the building and the facilities for casting, transporting, hoisting, and fixing units on site.

The general arrangement of precast structural units is as separate columns, often two storey height and as cruciform, 'H' or 'M' frames. The 'H' frame unit is often combined with under window walling, as illustrated in Fig. 116.

The two basic systems of jointing used for connections of column to column are by direct end bearing or by connection to a bearing plate welded to protruding studs. Direct bearing of ends is effected through a locating dowel which can also be used as a post tensioning connection, as illustrated in Fig. 117. A coupling plate connection is made by welding a plate to studs protruding from the end of one column and bolting studs protruding from the other to the plate, as illustrated in Fig. 116. Plainly the studs and plate must be accurately located else there will be an excessive amount of site labour in making this connection. The completed joint is usually finished by casting concrete around the joint. Alternatively the joint may be made with bronze studs and plate and left exposed as a feature of an externally exposed frame.

Beams are joined to columns by bearing on a haunch cast on the column or by connecting a steel box or plate, cast in the ends of beams at an angle or plate set in a housing in columns, as illustrated in Fig. 118.

Precast floor units bear either directly on beams or, more usually, on supporting nibs cast for the purpose. Ends of floor units are tied to beams through protruding studs or dowels so that the floor units serve to transfer wind pressure back to an in situ cast service and access core.

The precast frame illustrated in Fig. 115 is the structural external wall system for a 22 storey block of flats. The precast structural framework was built around a central in situ cast reinforced concrete access and service core containing lifts and stairs. The precast framework is tied to the central core through the precast concrete floor units at each floor level which are dowel fixed to the precast frame and tied with reinforcement to the in situ core. The precast framework is vertically tensioned by couplers through columns, as illustrated in Fig. 117, so that column ends are compressed to the dry mortar bed. The storey height frames are linked by short lengths of beam that are dropped in and tied to frames.

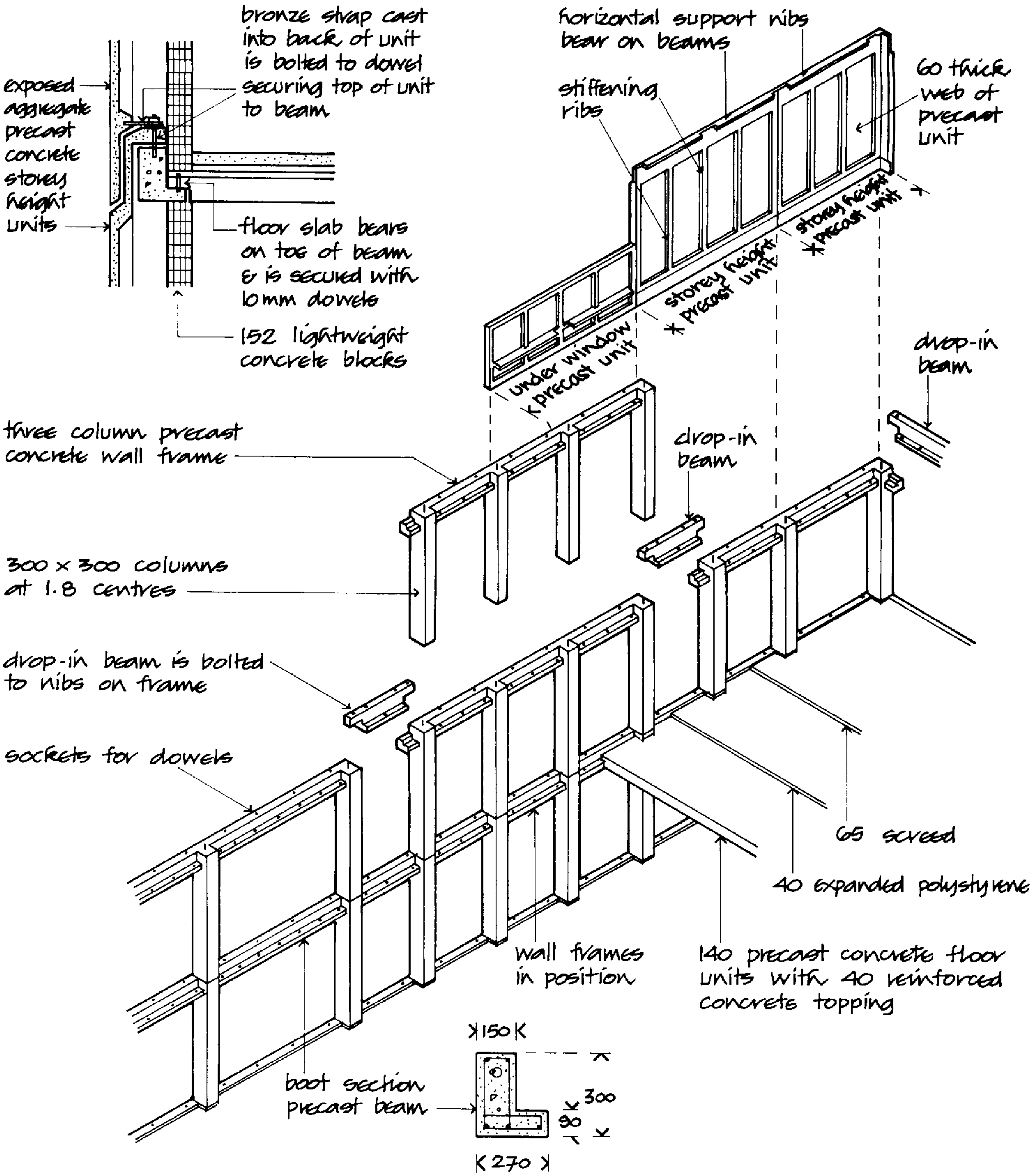
The precast framework was designed for rapid assembly through precasting and direct bearing of beams on columns and end bearing of columns, to avoid the use of in situ cast joints that are laborious to make and which necessitate support of beams while the in situ concrete hardens.

The top hung, exposed aggregate, precast concrete cladding panels have deep rebate horizontal joints and open vertical joints with mastic seals to columns, as illustrated in Fig. 119.

The precast reinforced concrete frame illustrated in Fig. 118 is a proprietary frame system for use in framing low rise slab blocks where the frame serves as the structural walls that are tied through the hollow precast concrete floor units that are tied to the frame. These standard frame sections can be used for various systems of solid and panel wall cladding systems.

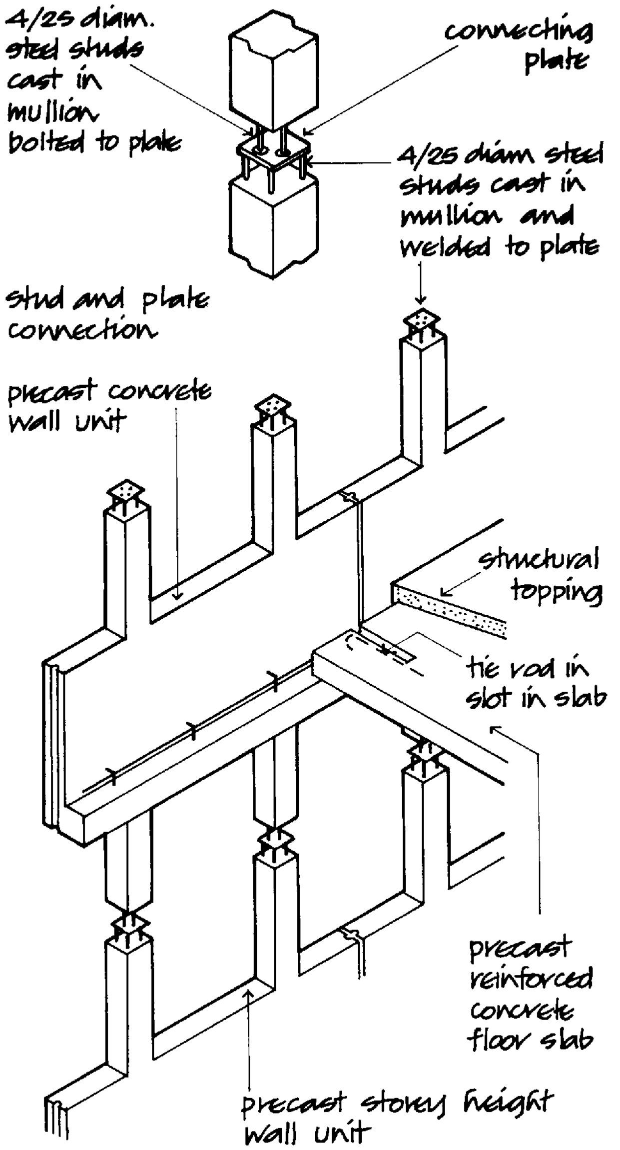
Precast concrete wall frames

Precast concrete wall frames were used extensively in



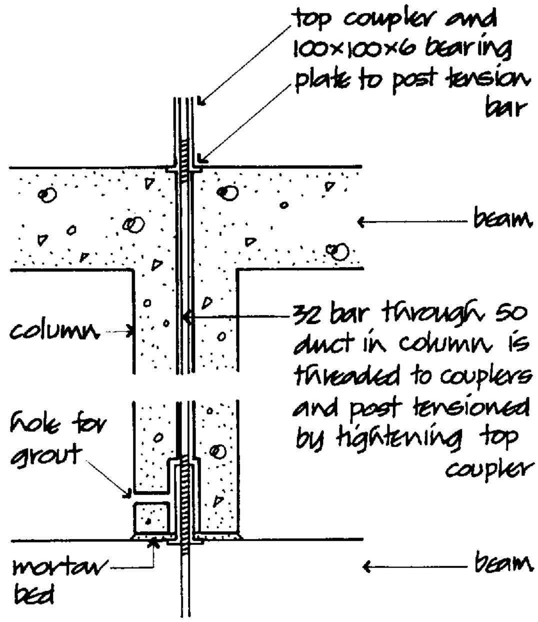
Precast reinforced concrete wall frames and precast concrete cladding units

Fig. 115



Precast concrete wall units

Fig. 116



Precast concrete frame to frame joint

Fig. 117

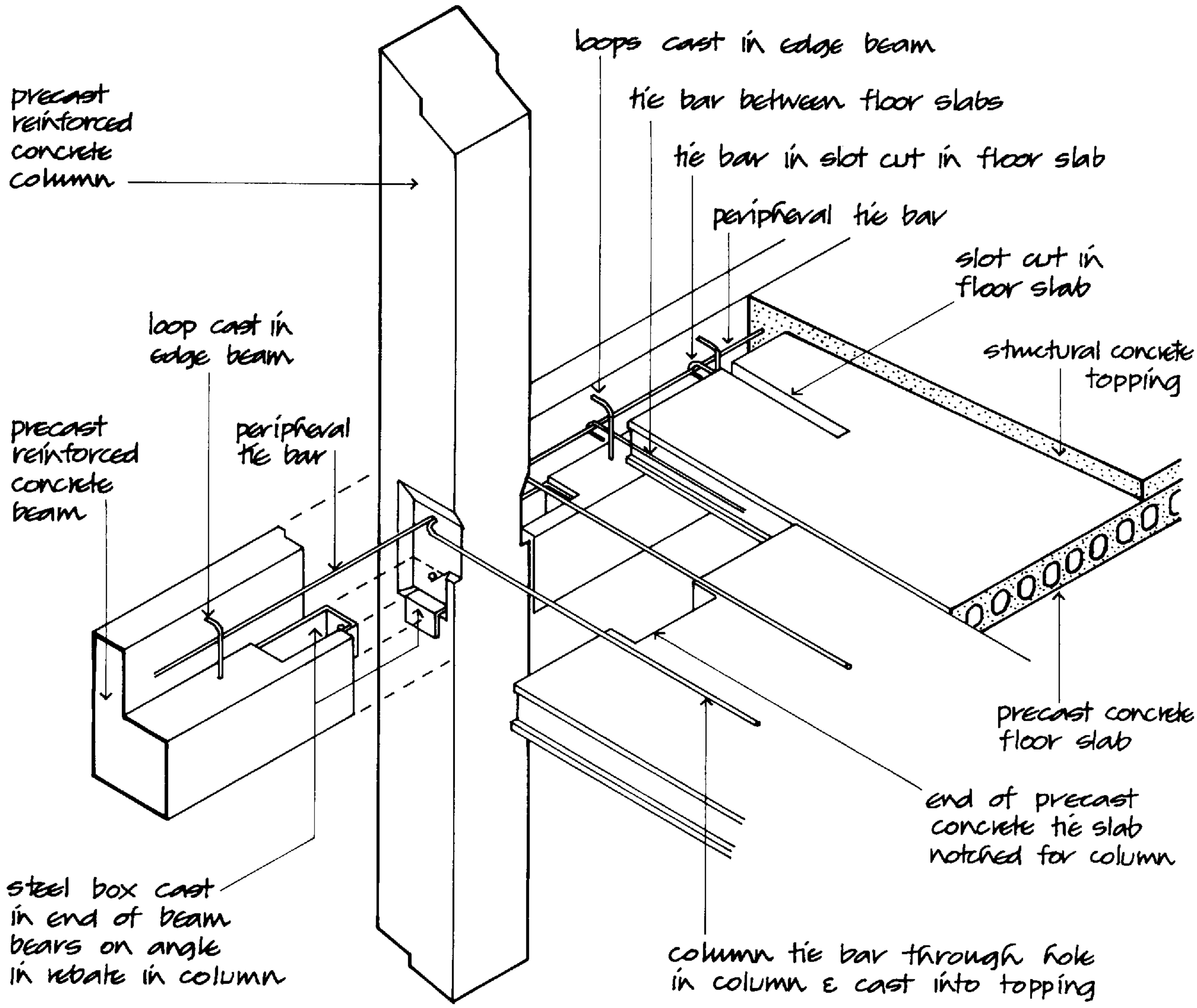
Russia and northern European countries in the construction of multi-storey housing where repetitive units of accommodation were framed and enclosed by large precast reinforced concrete wall panels that served as both external and internal walls and as a structural frame. The advantages of this system of building are that large, standard, precast concrete wall units can be cast off site and rapidly assembled on site largely independent of weather conditions, a prime consideration in countries where temperatures are below freezing for many months of the year.

Reinforced concrete wall frames can support the loads of a multi-storey building, can be given an external finish of exposed aggregate or textured finish that requires no maintenance, can incorporate insulation either as a sandwich or lining and have an internal finish ready for decoration. Window and door openings are incorporated in the panels which can be delivered to site with windows and doors fixed in position.

In this system of construction the prime consideration is the mass production of complete wall units off the site, under cover, by unskilled or semi-skilled labour assisted by mechanisation as far as practical towards the most efficient and speedy erection of a building. The appearance of the building is a consequence of the chosen system of production and erection rather than a prime consideration.

The concrete wall units will give adequate protection against wind and rain by the use of rebated horizontal joints and open drained vertical joints with back-up air seals similar to the joints used with precast concrete cladding panels.

Some systems of wall frame incorporate a sandwich of insulation in the thickness of the panel with the two skins of concrete tied together across the insulation with non-ferrous ties. This is not a very satisfactory method of providing insulation as a



Precast reinforced concrete structural frame

Fig. 118

sufficient thickness of insulation for present day standards will require substantial ties between the two concrete skins and the insulation may well absorb water from drying out of concrete and rain penetration, and so be less effective as an insulant. For best effect the insulation should be applied to the inside face of the wall as an inner lining to panels, or as a site fixed or built inner lining or skin.

The wall frame system of construction depends, for the structural stability of the building, on the solid, secure bearing of frames on each other and the firm bearing and anchorage of floor units to the wall frames and back to some rigid component of the structure, such as in situ cast service and access cores.

Figure 120 is an illustration of a typical precast concrete wall frame.

LIFT SLAB CONSTRUCTION

In this system of construction the flat roof and floor slabs are cast one on the other at ground level around columns or in situ cast service, stair and lift cores. Jacks operating from the columns or cores pull the roof and floor slabs up into position.

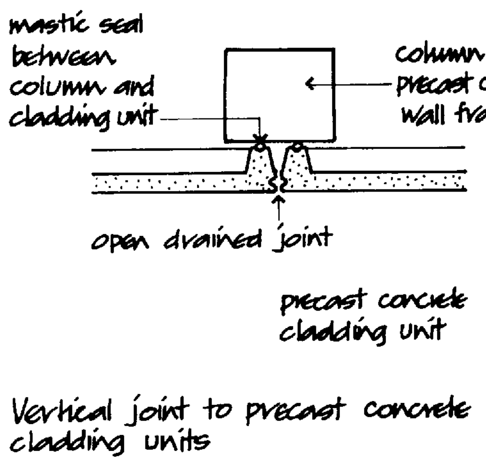


Fig. 119

This system of construction was first employed in America in 1950. Since then many buildings in America, Europe and Australia have been constructed by this method. The advantage of the system is that the only formwork required is to the edges of the slabs and no centering whatever is required to the soffit of roof or floors. The slabs are cast monolithically and can be designed to span continuously between and across points of support, and so employ the least thickness of slab. Where it is convenient to cantilever slabs beyond the edge columns and where cantilevers for balconies, for example, are required they can, without difficulty, be arranged as part of the slab.

The advantages of this system are employed most fully in simple, isolated point block buildings of up to five storeys where the floor plans are the same throughout the height of the building and a flush slab floor may be an advantage. The system can be employed for beam and slab and waffle grid floors, but the forms necessary between the floors to give the required soffit take most of the advantage of simplicity of casting on the ground.

Steel or concrete columns are first fixed in position and rigidly connected to the foundation and the ground floor slab is then cast. When it has matured it is sprayed with two or three coats of a separating medium consisting of wax dissolved in a volatile spirit. As an alternative, polythene sheet or building paper may be used as a separating medium. The first floor slab is cast inside edge formwork on top of the ground floor slab and when it is mature it is in turn coated or covered with the separating medium and the next floor slab is cast on top of it. The casting of successive slabs continues until all the floors and roof have been cast one on the other on the ground. Lifting collars are cast into each slab around each column.

The slabs are lifted by jacks, operating on the top of each column, which lift a pair of steel rods attached to each lifting collar in the slab being raised. A central control synchronises the operation of the hydraulically operated reciprocating ram type jacks to ensure a uniform and regular lift.

The sequence of lifting the slabs depends on the height of the building, the weight of the slabs and extension columns, the lifting capacity of the jacks and the cross-sectional area of the columns during the initial lifting. The bases of the columns are rigidly fixed to the foundations so that when lifting commences the columns act as vertical cantilevers. The load that the columns can safely support at the beginning of the lift limits the length of the lower column height and the number of slabs that can be raised at one time. As the slabs are raised they serve as horizontal props to the vertical cantilever of the columns and so increasingly stiffen the columns, the higher the slabs are raised. The sequence of lifting illustrated in Fig. 121 is adopted so that the roof slab, which is raised first, stiffens the columns which are then capable of taking the load of the two slabs subsequently lifted, as illustrated. The lifting sequence for a three-storey building is illustrated in Fig. 121 where the roof is raised on the lower column lengths, followed by the upper floor slabs. The steel lifting collars which are cast into each slab around each column provide a means of lifting the slabs and also act as shear reinforcement to the slabs around columns, and so may obviate the necessity for shear reinforcement to the slabs. Figure 122 is an illustration of a typical lifting collar fabricated from mild steel angle sections welded together and stiffened with plates welded in the angle of the sections.

The lifting collars are fixed to steel columns by welding shear blocks to plates welded between column flanges and to the collar after the slab has been raised into position, as illustrated in Fig. 123. Connections to concrete columns are made by welding shear blocks to the ends of steel channels cast into the column and by welding the collar to the wedges, as illustrated in Fig. 123. With this connection it is necessary to cast concrete around the exposed steel wedges for fire protection.

The connection of steel extension columns is made by welding, bolting or riveting splice plates to the flanges of columns at their junction. Concrete exten-

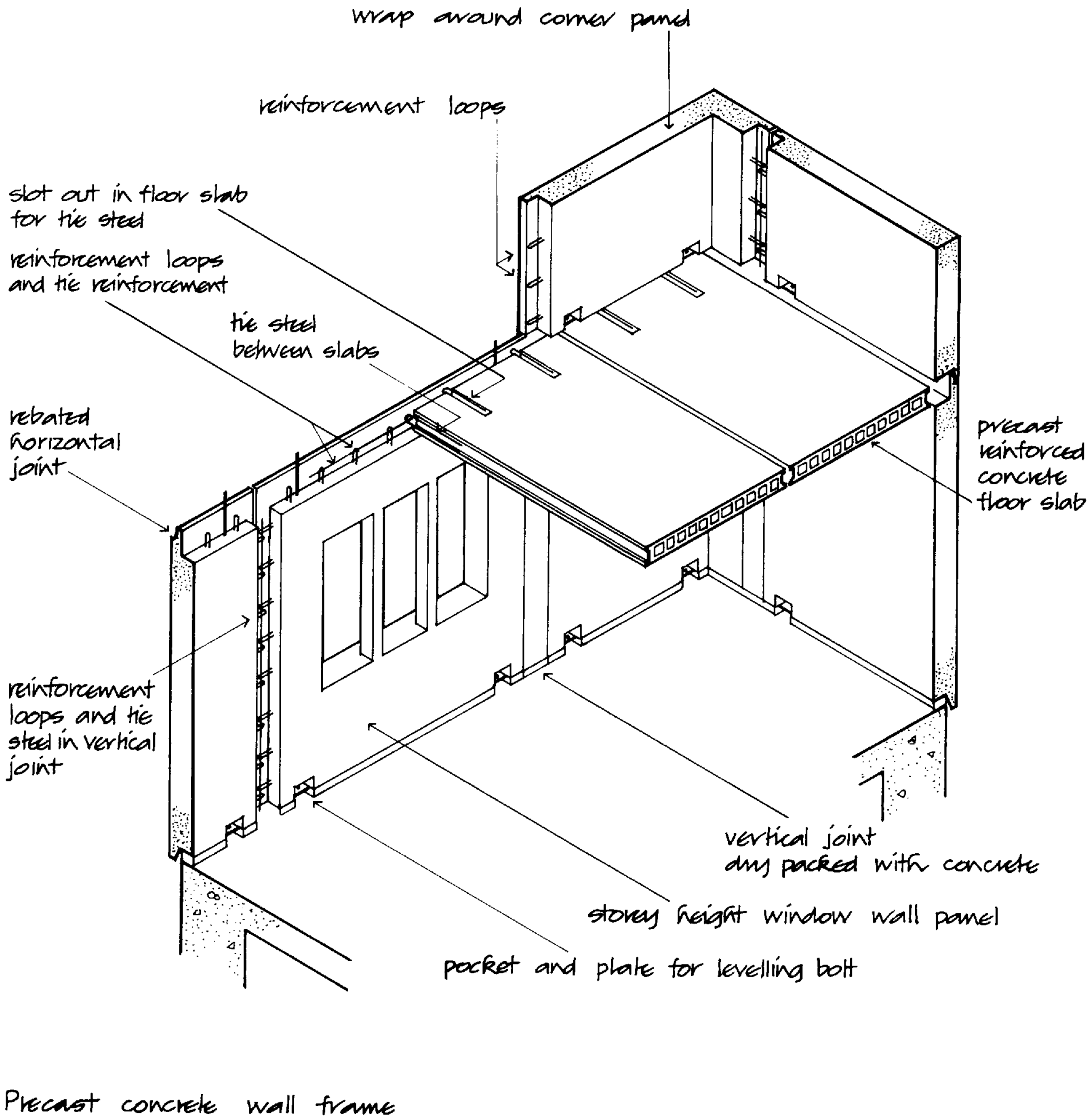


Fig. 120

sion columns are connected either with studs protruding from column ends and bolted to a connection plate, or by means of a joggle connection.

Composite construction

Composite construction is the name given to structural systems in which the separate structural characteristics and advantages of structural steel sections and reinforced concrete are combined as, for example, in the inverted 'T' beam system described below.

A steel frame, cased in concrete, and designed to allow for the strength of the concrete in addition to that of the steel is a form of composite construction. It has been accepted for some time now that it is reasonable to allow for the stiffening and strengthen-

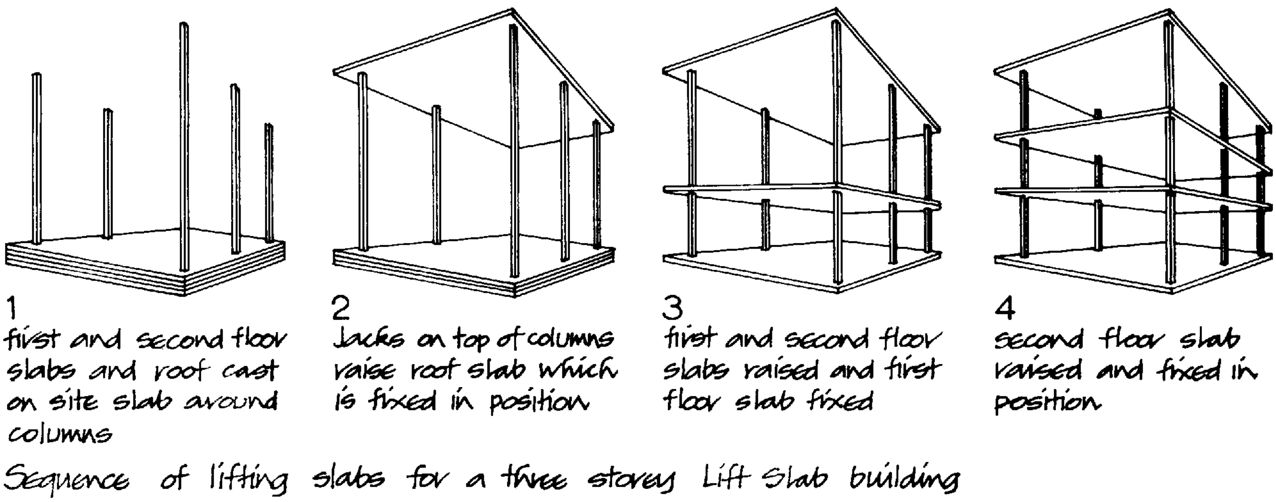


Fig. 121

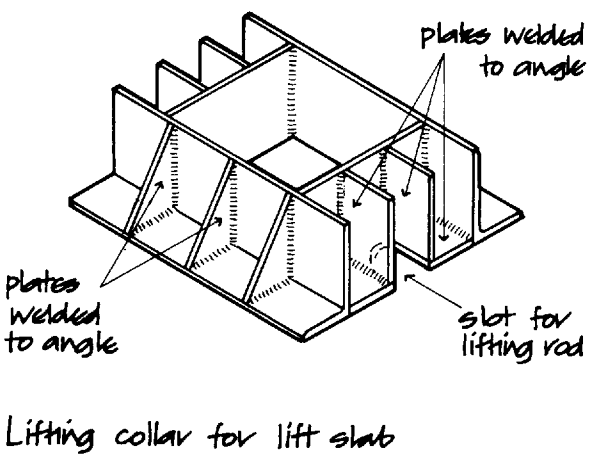


Fig. 122

ing effect of a solid concrete casing to structural steel beams and columns and it is usual practice for engineers to allow for this effect in their calculations. By reinforcing the concrete casing and allowing for its composite effect with the steel frame, a saving in steel and a reduction in the overall size of members can be effected.

Shear studs and connectors

A concrete floor slab bearing on a steel beam may be considered to act with the beam and serve as the beam's compressive flange, as a form of composite construction. This composite construction effect will only work if there is a sufficiently strong bond between the concrete and the steel, to make them act together in resisting shear stresses developed under load. The adhesion bond between the concrete and the top flange of the beam is not generally sufficient and it is usually necessary to fix shear studs or connectors, to the top flange of the beam, which are then cast in the floor slab. The purpose of these studs and connectors is to provide a positive resistance to shear.

Figure 124 is an illustration of typical shear studs and connectors and composite floor and beam construction.

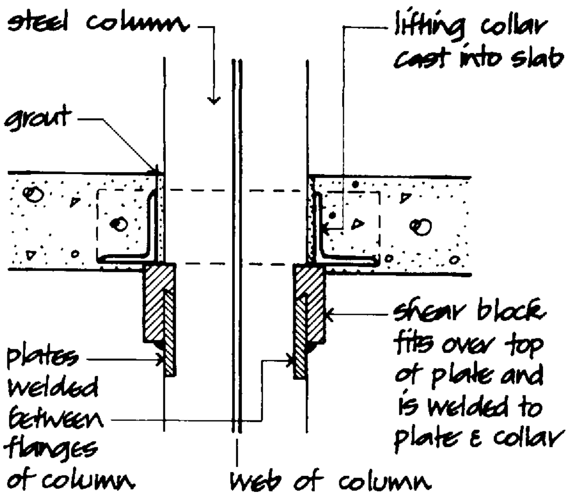
Inverted 'T' beam composite construction

The composite beam and floor construction described above employs the standard 'I' section beams. The top flange of the beam is not a necessary part of the construction, as the concrete floor slab can be designed to carry the whole of the compressive stress, so that the steel in the top flange of the beam is wastefully deployed. By using an inverted 'T' section member, steel is placed in the tension area and concrete in the compression area, where their characteristics are most useful.

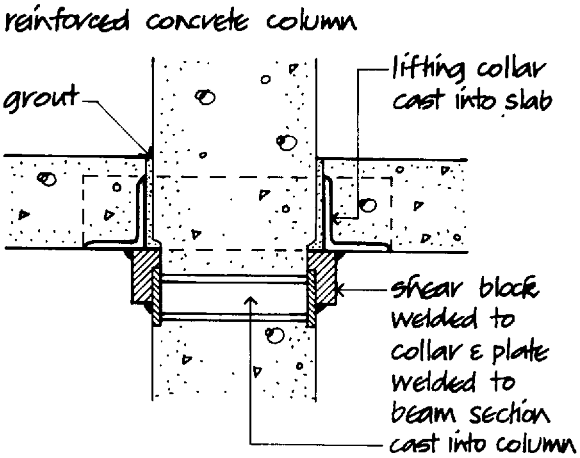
A cage of mild steel binders, cast into the beam casing and linked to the reinforcement in the floor slab, serves to make the slab and beam act as a form of composite construction by the adhesion bond of the concrete to the whole of the 'T' section.

Preflex beams

The use of high tensile steel sections for long span beams has been limited owing to the deflection of the



Connection of slab to steel column



Connection of slab to concrete column

Lift slab - Connection of slab to columns

Fig. 123

beams under load, which causes cracking of concrete casing, and possible damage to partitions and finishes. Preflex beams are made by applying and maintaining loads, which are greater than working loads, to pairs of beams. In this deflected position, reinforced concrete is cast around the tension flanges of the beams. When the concrete has developed sufficient strength the load is released and the beams tend to return to their former position. In so doing the beams induce a compressive stress in the concrete around the tension flange which prevents the beams wholly regaining their original shape. The beams now have a slight upward camber. Under loads the deflection of these beams will be resisted by the compressive stress in the concrete around the bottom flange which will also prevent cracking of concrete. Further stiffening of the beam to reduce deflection is gained by the concrete casing to the web of the beam. By linking the reinforcement in the concrete web casing to the floor slab, the concrete and steel can be made to act as a composite form of construction.

These beams may be connected to steel columns, with end plates welded to beam ends and bolted to column flanges, or may be cast into reinforced concrete columns.

Prefix beams are considerably more expensive than standard mild steel beams and are designed, in the main, for use in long span heavily loaded floors.

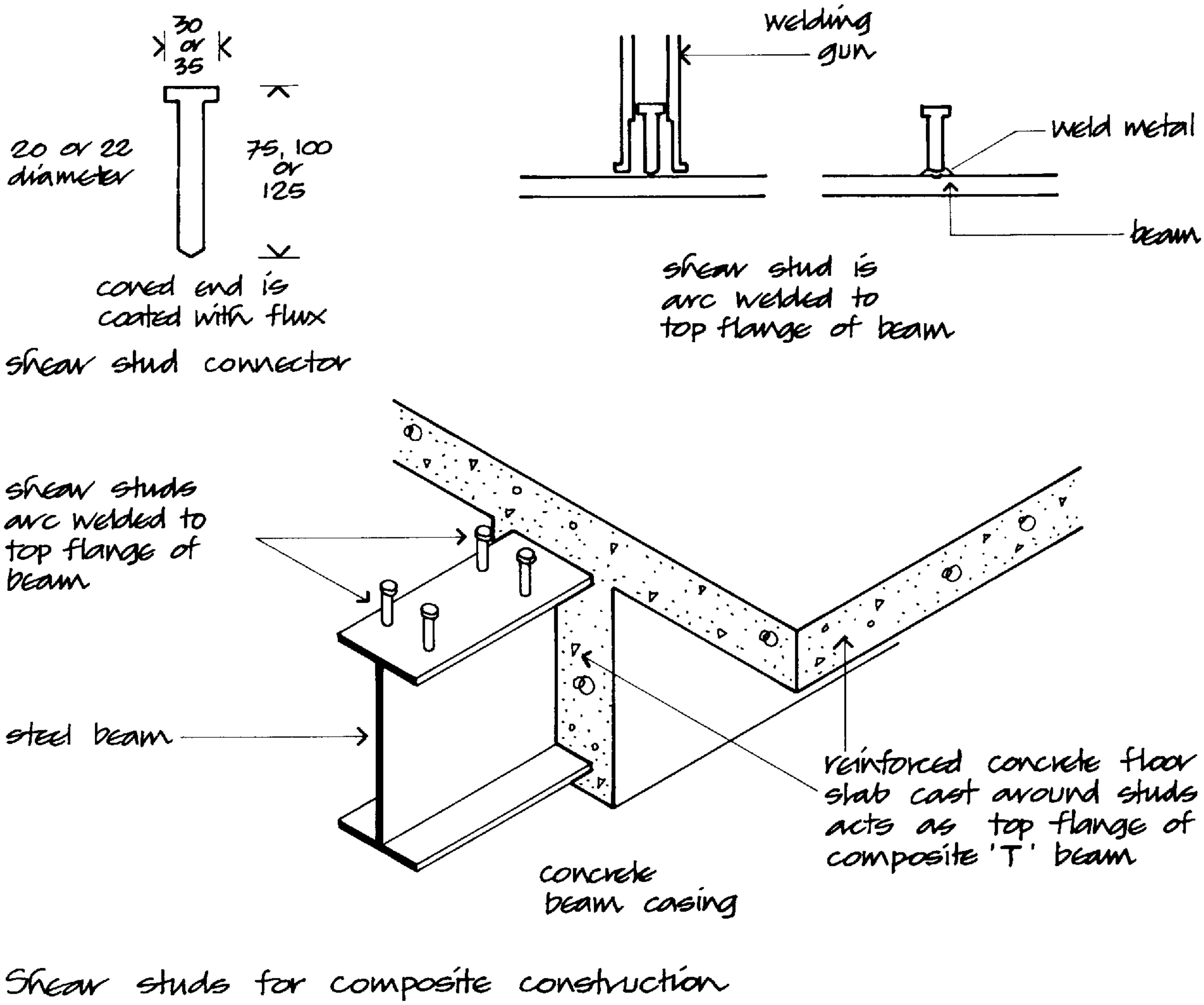

30
or
35
20 or 22
diameter
75, 100
or
125
coned end is
coated with flux
shear stud connector
welding
gun
weld metal
beam
shear stud is
arc welded to
top flange of beam
shear studs
arc welded to
top flange of
beam
steel beam
reinforced concrete floor
slab cast around studs
acts as top flange of
composite 'T' beam
concrete
beam casing
Shear studs for composite construction

Fig. 124

CHAPTER FIVE

EXTERNAL WALLS AND CLADDING OF FRAMED BUILDINGS

The earliest structural frames for multi-storey buildings were used to support floors and walls using traditional masonry or brick wall construction. The steel frame was built into the external walls, which it supported at each floor level, so that these buildings had the appearance of large traditional loadbearing wall structures.

Brick and stone had been used for centuries as a walling material, their use and behaviour were well understood and their appearance gave the impression of permanence and solidity. For many years the walls of the majority of multi-storey framed buildings were built in stone and brick. The main disadvantage of stone and brick as wall materials to framed buildings is the very considerable weight of wall material that the frame has to support in addition to that of floors.

Many of the early multi-storey framed buildings were built in the form of large loadbearing wall structures with comparatively small windows between large areas of solid walling, as if the walls had to support the whole of the loads of walls and floors for the full height of the building. At the time the need for daylight penetration to interiors was subordinate to considerations of appearance. The move towards an increase in the relative area of glass to solid walling to framed structures was gradual and erratic. The acceptance of a radical change of style that has come to be known as the 'modern movement', vigorously promoted in Germany in the 1930s, together with the adoption of the reinforced concrete frame was the cause of a fundamental change in the concept of both the function and appearance of walls.

There was a very gradual and reluctant abandonment of the concept of a wall as a solid enclosure perforated with windows, in favour of the acceptance of the logic of a structural frame supporting a lightweight enclosing weathershield. It was affected by fashion in the form of changes and variations in styles of architecture – the adoption of the concept of what is known as 'building science' and of expediency.

Since the end of the Second World War there has been a confusion of change in the form of walls to framed buildings. The exposed reinforced concrete frame with infill panels, that was in vogue in the 1950s, was in part an expression of 'honesty' in design in exposing the frame and expediency in using readily available materials as lightweight infill panels in multi-storey housing development. The 'curtain wall' of glass that was widely used for office and commercial development from the mid 1950s through the 1960s was a style adopted from pre-war Germany and vigorously promoted by glass producers.

The very considerable movement of people to towns, particularly in former Russia, during the 1950s and 1960s, together with the adoption of minimum standards of housing and the shortages of steel, prompted the use of precast concrete frames, wall panels and wall frames. These could be mass produced and fixed largely independent of weather conditions, to complete extensive state organised housing programmes in most northern European countries. The new wonder material of the petrochemical industry, plastics, reinforced with glass fibre and also, cement, reinforced with glass fibre have to an extent been used as lightweight panels in place of precast concrete.

In the last twenty years, brick has again gained popularity as a material for the walls of framed buildings. The many virtues of this traditional material have been successfully promoted by the Brick Development Association. Many recently completed buildings are clad in brickwork supported by or attached to structural frames, with the brick walling simulating traditional loadbearing forms of piers and arches. Others have employed brick as a facing to such features as projecting canopies in the 'look no hands' abandonment of sense and reality.

More recently, thin sheet metal wall panels have come into vogue, used by themselves as a wall finish or with the frame and services exposed in what is often referred to as 'high tech' architecture. The advantage of a 'rain screen' is being promoted in the use of an outer skin, usually of sheet metal, as an outer protective skin to a backing of weather seal and insulating panels.

The structural frame has provided the possibility of endless variation in the form and appearance of buildings that no longer need be contained inside a loadbearing envelope. Any one of the wall materials that have been used with some degree of success are available to meet the changing needs of use, economy and fashion.

An external wall is the continuous, usually vertical structure that encloses a building to provide privacy, security and equable conditions for comfort, storage and operation for the occupants, goods or machinery housed in the building.

The external walls of framed buildings differ from traditional loadbearing walls because the structural frame has an effect on and influences the design of the wall structure that it supports. To the extent that the structural frame may affect the functional requirements of an external wall, it should be considered as part of the wall structure. The use of the various materials that may be used for the external walls of framed buildings is to an extent influenced by the relative behaviour of the structural frame and the wall to accommodate differential structural, thermal and moisture movements that affect the functional requirements of a wall.

Movements of structural frames

Under load, both steel and concrete structural frames suffer elastic strain and consequent deflection (bending) of beams and floors and shortening of columns. Deflection of beams and floors is generally limited to about one three hundredth of span, to avoid damage to supported facings and finishes. Shortening of columns by elastic strain under load is of the order of 2.5 mm for each storey height of about 4 metres. Elastic shortening of steel columns may be of the order of 1.5 mm per storey height.

The comparatively small deflection of beams and shortening of columns under load can, by and large, be accommodated by the joints in materials such as brick, stone and block and the joints between panels, without adversely affecting the function of most wall structures.

Unlike steel, concrete suffers drying shrinkage and creep in addition to elastic strain. Drying shrinkage occurs as water, necessary for the placing of concrete and setting of cement, migrates to the surface of concrete members. The rate of loss of water and consequent shrinkage depend on the moisture content of the mix, the size of the concrete members and atmospheric conditions. Drying shrinkage of concrete will continue for some weeks after placing. For the small members of a structural frame, drying out of doors in summer, about half of the total shrinkage takes place in about one month and about three quarters in six months. For larger masses of concrete, about half the total shrinkage takes place one year after placing.

Drying shrinkage of concrete is restrained by the bond between concrete and reinforcement to the extent that concrete in heavily reinforced members shrinks less than that in lightly reinforced sections. Drying shrinkage of the order of 1.2 mm for each 4 metres of column length may well occur.

Creep of concrete is dependent on stress and is affected by humidity and by the cement content and the nature of the aggregate in concrete. The gradual creep of concrete may continue for some time and result in a shortening of columns of the order of up to 2.5 mm for each storey height of column over the long term. Like drying, shrinkage creep is restrained by reinforcement.

The combined effect of elastic strain, drying shrinkage and creep in concrete may well amount to a total reduction of up to 6 mm for each storey height of building. Because of these effects, it is necessary to make greater allowance for shortening in the design of wall structures supported by an in situ cast concrete frame than it is for a steel frame. Solid wall structures, such as brick, which are built within or supported by a concrete structural frame should be built with a 12 to 15 mm compression joint at each floor level to avoid damage to the wall by shortening of the frame and expansion of the wall materials due to thermal and moisture movements.

Experience shows that there are generally considerably greater inaccuracies in line and level with in situ cast concrete frames than there are with steel frames. There is an engineering tradition of accuracy of cutting and assembling steel that is not matched by the usual assembly of formwork for in situ cast concrete. Deflection of formwork under the load of wet concrete and some movement of formwork during the placing and compaction of concrete combine to create inaccuracies of line and level of both beams and columns in concrete frames that may be magnified up the height of multi-storey buildings. Allowances for these inaccuracies can be made where fixings for cladding are made by drilling for bolt fixings rather than relying on cast on or cast in supports and fixings. The advantage of the precast concrete frame is in the greater accuracy of casting of concrete in controlled factory conditions than on site.

FUNCTIONAL REQUIREMENTS

The functional requirements of a wall are:

Strength and stability
Resistance to weather
Durability and freedom from maintenance
Fire safety
Resistance to the passage of heat
Resistance to the passage of sound

Strength and stability

A wall structure should have adequate strength to support its own weight between points of support or fixing to the structural frame, and sufficient stability against lateral wind pressures.

To allow for differential movements between the structural frame and the wall structure there has to be adequate support to carry the weight of the wall structure, and also restraint fixings that will maintain the wall in position and at the same time allow differential movements without damage to either the fixings or the wall material.

Brick and precast concrete cladding do not suffer the rapid changes of temperature between day and night that thin wall materials do, because they act to store heat and lose and gain heat slowly. Thin sheet wall materials such as GRP, metal and glass suffer rapid changes in temperature and consequent expansion and contraction which may cause distortion and damage to fixings or the thin panel material or both.

In the design of wall structures faced with thin panel or sheet material the ideal arrangement is to provide only one rigid support fixing to each panel or sheet with one other flexible support fixing and two flexible restraint fixings. The need to provide support and restraint fixings with adequate flexibility to allow for thermal movement and at the same time adequately restrain the facing in place and maintain a weathertight joint, has been the principal difficulty in the use of thin panel and sheet facings.

Resistance to weather

The traditional walling materials, brick, stone and block, serve to exclude rain from the inside of buildings by absorbing rain water that evaporates to outside air during dry periods. The least thickness of solid wall material necessary to prevent penetration of rain water to the inner face depends on the degree of exposure to driving rain (see Volume 1). Common practice is to construct walls as a cavity wall with an outer leaf of brick as rain screen, a cavity and an inner leaf of some lightweight block as thermal barrier and solid inside wall surface.

Individual precast concrete wall panels act in much the same way as brick by absorbing rain water. Because of the considerable size of these panels there have to be comparatively wide joints between panels to accommodate structural, thermal and moisture movements. The joints are designed with a generous overlap to horizontal and an open drained joint to vertical joints to exclude rain.

Non-absorbent sheet materials, such as metal and glass, cause driven rain to flow under pressure in sheets across the face of the wall so making the necessary joints between panels of the material highly vulnerable to penetration by rain. These joints should at once be sufficiently wide to accommodate structural, thermal and moisture movements and serve as an effective seal against rain penetration. The materials that are used to seal joints are mostly short-lived as they harden on exposure to atmosphere and sun and lose resilience in accommodating movement.

The 'rain screen' principle is designed to provide a separate outer skin, to screen wall panels from scouring by wind and rain and deterioration by sunlight and to improve the life and efficiency of joint seals.

Durability and freedom from maintenance

The durability of a wall structure is a measure of the frequency and extent of the work necessary to maintain minimum functional requirements and acceptable appearance.

Walls of brick and natural stone will very gradually change colour over the years. This slow change of colour, termed weathering, is generally accepted as one of the attractive features of these traditional wall materials. Walls of brick and stone facing require very little maintenance over the expected life of most buildings. Precast concrete wall panels which weather gradually may become dirt stained due to slow run off of water from open horizontal joints. This irregular and often unsightly staining, particularly around top edges of panels, is a consequence of the panel form of this type of cladding.

Panels of glass will maintain their lustrous fire glazed finish over the expected life of buildings, but will require frequent cleaning of the surface, if they are to maintain their initial appearance, and periodic attention to and renewal of seals.

Of the sheet metal facings that can be used for wall structures, bronze and stainless steel, both expensive materials, will weather by the formation of a thin film of oxide that is impermeable and prevents further oxidation. Aluminium which weathers with a light coloured, coarse textured oxide film that considerably alters the appearance of the surface can be anodised to inhibit the formation of an oxide film or coated with a plastic film for the sake of appearance. Steel, which progressively corrodes to form a porous oxide, is coated with zinc to inhibit the rust formation and a plastic film as decoration.

None of the plastic film coatings are durable (see Volume 3) as they lose colour over the course of a few years on exposure to sunlight and this irregular colour bleaching may well not be acceptable from the point of view of appearance to the extent that painting or replacement may be necessary in 10 to 25 years. In common with other thin panel materials there will be a need for periodic maintenance and renewal of seals to joints between metal faced panels.

Fire safety

The requirements from Part B of Schedule 1 to the Building Regulations 1991, as amended 1994, are concerned to:

(a) provide adequate means of escape
(b) limit internal fire spread (linings)
(c) limit internal fire spread (structure)
(d) limit external fire spread
(e) provide access and facilities for the Fire Services

Fire safety regulations are concerned to ensure a reasonable standard of safety in case of fire. The application of the regulations, as set out in the practical guidance given in Approved Document B, is directed to the safe escape of people from buildings in case of fire rather than the protection of the building and its contents. Insurance companies that provide cover against the risks of damage to the buildings and contents by fire will generally require additional fire protection such as sprinklers.

Means of escape

The requirement from the Building Regulations is that the building shall be designed and constructed so that there are means of escape from the building in case of fire to a place of safety outside the building. The main dangers to people in buildings, in the early stages of a fire, are the smoke and noxious gases produced which cause most of the casualties and may also obscure the way to escape routes and exits. The Regulations are concerned to:

(a) provide a sufficient number and capacity of escape routes to a place of safety
(b) protect escape routes from the effects of fire by enclosure, where necessary, and to limit the ingress of smoke
(c) ensure the escape routes are adequately lit and exits suitably indicated

The general principle of means of escape is that any person in a building confronted by an outbreak of fire can turn away from it and make a safe escape.

The number of escape routes and exits depends on the number of occupants in the room or storey, and the limits on travel distance to the nearest exit depend on the type of occupancy. The number of occupants in a room or storey is determined by the maximum number of people it is designed to hold, or calculated by using a floor space factor related to the type of accommodation, which is used to determine occupancy related to floor area as set out in Approved Document B. The maximum number of occupants determines the number of escape routes and exits; where there are no more than 50 people 1 escape route is acceptable. Above that number, a minimum of 2 escape routes is necessary for up to 500 and up to 8 for 16 000 occupants. Maximum travel distances to the nearest exit are related to purpose-group types of occupation and whether one or more escape routes are available. Distances for one direction escape are from 9.0 to 18.0 and for more than one direction escape from 18.0 to 45.0, depending on the purpose groups defined in Approved Document B.

Internal fire spread (linings)

Fire may spread within a building over the surface of materials covering walls and ceilings. The Regulations prohibit the use of materials that encourage spread of flame across their surface when subject to intense radiant heat and those which give off appreciable heat when burning. Limits are set on the use of thermoplastic materials used in rooflights and lighting diffusers.

Internal fire spread (structure)

As a measure of ability to withstand the effects of fire, the elements of a structure are given notional fire resistance times, in minutes, based on tests. Elements are tested for the ability to withstand the effects of fire in relation to:

(a) resistance to collapse (loadbearing capacity) which applies to loadbearing elements
(b) resistance to fire penetration (integrity) which applies to fire separating elements
(c) resistance to the transfer of excessive heat (insulation) which applies to fire separating elements

The notional fire resistance times, which depend on the size, height and use of the building, are chosen as being sufficient for the escape of occupants in the event of fire.

The requirements for the fire resistance of elements of a structure do not apply to:

(1) A structure that only supports a roof unless
  (a) the roof acts as a floor, e.g. car parking, or as a means of escape
  (b) the structure is essential for the stability of an external wall which needs to have fire resistance.
(2) The lowest floor of the building.

Compartments

To prevent rapid fire spread which could trap occupants, and to reduce the chances of fires growing large, it is necessary to subdivide large buildings into compartments separated by walls and/or floors of fire-resisting construction. The degree of subdivision into compartments depends on:

(a) the use and fire load (contents) of the building
(b) the height of the floor of the top storey as a measure of ease of escape and the ability of fire services to be effective
(c) the availability of a sprinkler system which can slow the rate of growth of fire

The necessary compartment walls and/or floors should be of solid construction sufficient to resist the penetration of fire for the stated notional period of time in minutes. The requirements for compartment walls and floors do not apply to single storey buildings.

Concealed spaces

Smoke and flames may spread through concealed spaces, such as voids above suspended ceilings, roof spaces and enclosed ducts and wall cavities in the construction of a building. To restrict the unseen spread of smoke and flames through such spaces, cavity barriers and stops should be fixed as a tight fitting barrier to the spread of smoke and flames.

External fire spread

To limit the spread of fire between buildings, limits to the size of 'unprotected areas' of walls and also finishes to roofs, close to boundaries, are imposed by the Building Regulations. The term 'unprotected area' is used to include those parts of external walls that may contribute to the spread of fire between buildings. Windows are unprotected areas as glass offers negligible resistance to the spread of fire. The Regulations also limit the use of materials of roof coverings near a boundary that will not provide adequate protection against the spread of fire over their surfaces.

Access and facilities for the Fire Services

Buildings should be designed and constructed so that:

- Internal firefighting facilities are easily accessible
- Access to the building is simple
- Vehicular access is straightforward
- The provision of fire mains is adequate

Resistance to the passage of heat

The interior of buildings built with insulated solid masonry walling and those clad with insulated panels of concrete, GRC, GRP, glass and metal, is heated by the transfer of heat from heaters and radiators to air (conduction), the circulation of heated air (convection) and the radiation of energy from heaters and radiators to surrounding colder surfaces (radiation). This internal heat is transferred to and through colder enclosing walls, roof and floors by conduction, convection and radiation to colder outside air.

The interior of buildings clad with large areas of glass may gain a large part or the whole of their internal heat from a combination of solar heat gain through glass cladding and from internal artificial lighting to the extent that there may be little need for supplementary internal heating. As long as the interior of buildings is heated to a temperature above that of outside air, transfer of heat from heat sources to outside air will continue. For the sake of economy in the use of expensive fuel and power sources, and to conserve limited supplies of fuel, it is sensible to seek to limit the rate of transfer of heat from inside to outside. Because of the variable complex of the modes of transfer of heat it is convenient to distinguish three separate modes of heat transfer as conduction, convection and radiation.

Conduction is the direct transmission of heat by contact between particles of matter, convection the transmission of heat by the motion (circulation) of heated gases and fluids, and radiation the transfer of heat from one body of radiant energy through space to another by a motion of vibration in space which radiates equally in all directions.

Conduction

The speed or rate at which heat is conducted through a material depends mainly on the density of the material. Dense metals conduct heat more rapidly than less dense gases. Metals have high and gases have low conductivity. Thermal conductivity (λ-value) is the rate of heat per unit area conducted per unit time through a slab of unit thickness per degree of temperature difference. It is expressed in watts per metre thickness of material per kelvin (W/mK) where W (watt) is the unit of power which is equivalent to joules (the unit of heat) per second (J/s) and the temperature is expressed in kelvin (K).

Convection

The density of air that is heated falls and the heated air rises and is replaced by cooler air. This, in turn, is heated and rises so that there is a continuing movement of air as heated air loses heat to surrounding cooler air and cooler surfaces of ceilings, walls and floors. Because the rate of transfer of heat from air to cooler surfaces varies from rapid transfer through thin sheets of glass in windows to an appreciably slower rate of transfer to insulated walls by conduction, and because of the variability of the exchange of cold outside air with warm inside air by ventilation, it is not possible to quantify heat transfer by convection. Usual practice is to make an assumption of likely total air changes per hour or volume (litres) per second depending on categories of activity in rooms and then to calculate the heat required to raise the temperature of the fresh, cooler air introduced by natural or mechanical ventilation, making an assumption of the temperature of inside and outside air.

Radiation

Energy from a heated body radiating equally in all directions is partly reflected and partly absorbed by another cooler body (with the absorbed energy converted to heat). The rate of emission and absorption of radiant energy depends on the temperature and the nature of the surface of the radiating and receiving bodies. The heat transfer by low temperature radiation from heaters and radiators is small whereas the very considerable radiant energy from the sun that may penetrate glass and that from high levels of artificial illumination is converted to appreciable heat inside buildings. An estimate of the solar heat gain and heat gain from artificial illumination may be assumed as part of the heat input to buildings and used in the calculation of heat input and loss.

Transmission of heat

The practical guidance in Approved Document L to meeting the requirements from Part L of Schedule 1 to the Building Regulations 1991, as amended 1994, for the conservation of fuel and power, is mainly directed to limiting the loss of heat through the fabric (walls, floors and roofs) of buildings, other than dwellings, by establishing maximum values for the overall transmission of heat, the '*U*' value, through walls, roofs and floors and to limiting the size of glazed areas.

Because of the complexity of the combined modes of transfer of heat through the fabric of buildings it is convenient to use a coefficient of heat transmission, the *U* value. This air-to-air thermal transmittance coefficient, the *U* value, takes account of the transfer of heat by conduction through solid materials and gases, convection of air in cavities and across inside and outside surfaces and radiation to and from surfaces. The *U* value expressed as W/m^2K is a measure of how much heat will pass through one square metre of a structure when the combined radiant and air temperature on each side of the structure differ by 1 K. A high *U* value indicates comparatively high rates of overall transmission and a low *U* value indicates low rates.

The three methods of showing compliance with the regulation for conservation of fuel and power for all other buildings than dwellings, which are set out in Approved Document L, are:

- an elemental method
- a calculation method
- an energy use method

The *elemental method* relates thermal performance to a table of standard *U* values for the envelope of buildings and a basic allowance for windows, doors and rooflights as a percentage of exposed wall area, and as a percentage of roof area for rooflights.

The standard *U* values given in Approved Document L are 0.45 W/m^2K for exposed walls, floors, ground floors and 0.25 W/m^2K for roofs of buildings other than dwellings.

The loss of heat through windows, doors and rooflights is limited by setting maximum sizes related to floor and roof areas as:

Windows
40% of exposed wall areas for places of assembly, offices and shops
15% of exposed wall area for industrial and storage.
Rooflights
20% of roof area for all buildings.

A modification of the basic allowance for windows, doors and rooflights, which is based on a *U* value of 3.3 W/m^2K may be made where the *U* value is other than that used in the basic allowance.

Appendix A of Approved Document L provides a series of tables setting out the base thickness of insulation required in typical roof, floor and wall construction necessary to meet the requirements for thermal performance.

The *calculation method* allows, within certain limits, greater flexibility in selecting areas of windows, doors and rooflights and/or the level of insulation of individual elements of the building envelope than the elemental method does, providing the calculated rate of heat loss through the envelope is not greater than that of a building of the same size and shape designed to comply with the elemental method.

The *energy use method* allows completely free design using any valid conservation measure and takes account of useful solar and internal heat gains, providing the calculated annual energy use of the proposed building is less than the calculated annual energy use of a similar building designed to comply with the elemental method.

In the calculation and energy use methods maximum *U* values are set at 0.45 W/m^2K for the roof and 0.7 W/m^2K for the walls and floors of residential buildings and 0.7 W/m^2K for the roof, walls and floors of non-residential buildings.

In the calculation and energy use methods for buildings other than dwellings there is no requirement to use the standard assessment procedure for calculating the rate of heat loss or calculation of annual energy use.

Buildings which are clad with large areas of glass as a wall envelope can meet the requirements for the conservation of energy by taking account of solar heat gain through surface modified or surface coated solar control glass. The effect of this type of glass is that the surface coating reflects back into the building the long wave energy generated by heating, lighting and occupants, while permitting the transmission of short wave energy from outside (see Volume 2).

Condensation

During recent years increased expectation of thermal comfort in buildings and the need to conserve limited supplies of fuel and power has led to improved levels of insulation in the fabric of buildings and the common use of weatherseals to opening windows that has restricted natural ventilation. These changes have led to the likelihood of increased levels of humid conditions that cause condensation on the inner faces of cold surfaces such as glass in windows and the inside of thin metal sheet weathering.

The limited capacity of air to take up water in the form of water vapour increases with temperature so that the warmer the air, the greater the amount of water vapour it can hold. The amount of water vapour held in air is expressed as a ratio of the actual amount of water vapour in the air to the maximum which the air could contain at a given temperature. This relative humidity (rh) is given as a percentage. Air is saturated at 100% relative humidity and the temperature at which this occurs is defined as the dew point temperature. When the temperature of warm moist air falls to a temperature at which its moisture vapour content exceeds the saturation point, the excess moisture vapour will be deposited as water. This will occur, for example, where warm moist air comes into contact with cold window glass, its temperature at the point of contact with the glass falls below that of its saturation point and the excess moisture vapour forms as droplets of water on the inside window surface as condensation. Thus, the greater the amount of moisture vapour held in the air and the greater the temperature difference between the warm inside air and the cold window surface, the more the condensation.

The main sources of moisture vapour in air in buildings are moisture given off by occupants, moisture given off from cooking and flueless heaters, bathing, clothes washing and drying, moisture generating processes and the drying out from a new building.

Internal temperatures which are high relative to cold outside air will tend to produce high levels of condensation on cold surfaces from high levels of moisture vapour. An atmosphere that contains high levels of moisture vapour is said to be humid. The level of humidity that is acceptable for comfort in buildings varies from about 30% to 70% relative humidity. Low levels of humidity, below about 20%, may cause complaints of dry throats and cause woodwork to shrink and crack. High levels of humidity, e.g. above 70%, may cause discomfort and lead to condensation on cold surfaces, mould growth and excess heat. For comfort in buildings and to limit the build-up of humidity it is necessary to provide a degree of ventilation for an adequate supply of oxygen and to limit fumes, body odour and smells and to exchange drier fresh air from outside with humid, stale inside air. The level of ventilation required depends on the activity and number of people in a given space and sources of heat and water that will contribute to increased humidity.

Ventilation

The use of sealed glazing and effective weatherseals to the joints of cladding panels and windows in the envelope of modern buildings has restricted the natural exchange of outside and inside air to provide ventilation of buildings. For comfort there should be a continuous change of air inside buildings to provide an adequate supply of oxygen, to limit the build-up of humidity, fumes, body odour and smells and provide a regular movement of air that is necessary for bodily comfort. The necessary movement of air inside sealed buildings may be induced artificially by mechanical systems of air conditioning which filter, dry and humidify air through a complex of inlet and extract ducting, connected to one or more air treatment plants. The pumps necessary to force air through the ducts may cause an unacceptable level of noise and the air handling system is costly to instal, maintain and run. To economise, it is often practice to install individual air conditioning heaters which filter, dry and heat air that is recirculated from individual rooms with the effect that stale air is constantly circulated so causing conditions of discomfort.

As an alternative, buildings may be constructed and finished with mainly open plan floor areas largely free of enclosed spaces, set around one or more central areas open from ground to roof level to provide facility for the natural movement of heated air to rise and so cause natural ventilation. This stack system of ventilation, so called by reference to the upward movement of air up a chimney stack, can be utilised by itself or with some small mechanical ventilation to provide comfort conditions with the least initial and running costs.

Thermal bridge (cold bridge)

Thermal bridge is the term used to describe a material of high conductivity, that is a poor thermal insulator, in a wall structure that offers little resistance, or appreciably less resistance, to the transfer of heat than the surrounding material or materials. The prime example of a thermal bridge is the thin glass in windows which offers negligible resistance to transfer of heat and serves as a bridge to the transfer of cold from outside (cold bridge) or heat from outside (hot bridge) to the inside of buildings.

The members of a structural frame act as a thermal bridge where the wall is built up to or between the frame as is common with solid wall structures, as illustrated later in Fig. 126 where the resistance to the thermal transfer through the brick slips and beam is appreciably less than through the rest of the wall. Similarly there is a thermal bridge across a precast wall panel and a beam and column as illustrated later in Fig. 149.

A thermal bridge will also encourage condensation of warm moist air on its cold surfaces as, for example, where there is a cold bridge in the external wall of a bathroom or kitchen, on which water vapour will condense from the warm moisture laden inside air and cause staining and possible damage to finishes.

There is no single or several wholly effective ways of preventing the thermal bridge formed by the supporting structural frame. The effect of the bridge may be modified by the use of floor insulation and a suspended ceiling or by setting frame members, where possible, back from the outer face of the wall, as illustrated later in Fig. 127.

Wall panels of precast concrete, GRP and GRC have been used with a sandwich or inner lining of an insulating material. This arrangement is not entirely effective because the insulating material, if open pored as are many insulating materials, may absorb condensate water which will reduce its thermal properties and the edge finish to panels, necessary for rigidity and jointing, will act as a thermal bridge, as illustrated later in Fig. 155.

Thin metal wall panel materials which are supported by a metal carrier system fixed across the face of the structural frame can provide thermal insulation more effectively by a sandwich, inner lining or inner skin of insulating material with the edge jointing material acting as a thermal break in the narrow thermal bridge of the edge metal, as illustrated later in Fig. 180.

Resistance to the passage of sound (see also Volume 2)

Sound is the effect of air disturbances that radiate from a source as 'airborne sound' or by a vibration in solid material as 'impact sound'. The awareness of sound depends on the background level to the extent that where the background level is high, as in cities, only comparatively loud sounds are intrusive, whereas in rural areas where background sound levels are low, a small sound may be intrusive.

Sound from a source such as a radio is generated by a cyclical disturbance of air that radiates from the source. The most effective barrier to airborne sound is an intervening mass such as a solid wall. The more dense and thick the material, the more effective it is as a barrier to airborne sound as the dense mass absorbs the energy generated by the sound source.

Impact sound is generated when a solid material transfers the energy by vibration. The continuous solid material of a structural frame is a prime conductor of impact sound. The sound of a door slammed shut may be transferred audibly through several floors of a structural frame where background levels of sound are low. Unexpected impact sounds can be most disturbing.

The most effective way of reducing impact sound is to isolate the potential source of impact from continuous solid transmitters such as structural frames. Resilient fixings to door frames and resilient bushes to supports for hard floor finishes effectively isolate the source of common impact sounds.

EXTERNAL WALLS AND CLADDING

The words wall, walling, cladding, facings and wall facings are variously used relative to the usually vertical envelope of buildings.

By definition a wall is a continuous, usually vertical structure of brick, stone, block, concrete, timber or metal, thin in proportion to its height and length. The traditional wall of stone or brick, which is built off a foundation, is self-supporting to the extent that the whole of the weight of the wall, and such floors and roofs as it supports, is carried by the foundation.

The word cladding came into general use as a description of the external envelope of framed buildings, which clothed or clad the building in a protective coating that was hung, supported by or secured to the skeleton or structural frame as a jacket or coat is hung from the shoulders as a protective cladding.

The word facings has been used to describe materials used as a thin, non-structural, decorative, external finish such as the thin, natural stone facings applied to brick or concrete backing.

The words wall or walling will be used to describe the use of those materials such as stone, brick, concrete and blocks that are used as the external envelope of framed buildings where the appearance is of a continuous wall to the whole or part of several storeys or as walling between exposed, supporting beams and columns of the frame.

The word cladding will be used to describe panels of concrete, GRC, GRP, glass and metal fixed to and generally hung from the frame by supporting beams or inside light framing as a continuous outer skin to the frame.

The external walls and cladding of framed buildings are broadly grouped as:

- Solid and cavity walling of stone, block and brick
- Facings applied to solid and cavity background walls
- Cladding panels of precast concrete, GRC and GRP
- Infill wall framing to a structural grid
- Thin sheet cladding of glass and metal

SOLID AND CAVITY WALLING

Natural and reconstructed stone walling

The traditional use of ashlar stone walling (see Volume 1), of accurately squared stones for the external face of large buildings, continued in the construction of many of the earliest framed buildings, such as the Ritz Hotel in London, for the sense of solidity and permanence that such a finish provided. The solid walls faced with ashlar natural stone with a backing of squared stone or brick were built around the supporting steel columns and supported at each floor level by steel beams built in to support some two-thirds of the wall thickness at each floor level. Large projecting cornice stones were supported by cantilevered steel beams around which the stones were cut to fit at vertical joints.

The advantage of the supporting steel frame was a reduction in the thickness of the walling, particularly in the lower storeys of multi-storey buildings, as compared to a fully self-supporting wall of similar height and the improved resistance to damage by fire of the steel frame by virtue of the enclosing walls. Many of the earlier multi-storey buildings in the USA were constructed this way for the increase in floor area as compared to traditional construction and thus increased rental value of the building, where taxes were levied on site area.

In London and other cities in England, terra cotta (burnt earth) blocks were much used in the walls of large buildings built in the Victorian period. Fired blocks of terra cotta, with a semi-glaze finish, were moulded in the form of natural stone blocks, both plain and heavily ornamented, to replicate the form and detail of the stonework buildings of the time. The plain and ornamented blocks were made hollow to reduce and control shrinkage of wet clay during firing. In use the hollows in these blocks were filled with concrete and the blocks then laid as if they were natural stone. Well-burnt blocks of terra cotta are durable even in heavily polluted atmospheres where natural limestone and sandstone facings deteriorate.

The massive form of construction of stone or terra cotta walling to framed buildings, which imposed very considerable loads on the supporting frame and foundations and was needlessly extravagant in the use of costly materials, provided adequate resistance to weather, poor resistance to the passage of heat and allowance for such structural, thermal and moisture movements as might occur, in the many joints in the walling material and the massive construction. To economise in the use of limited supplies of expensive stone it was practice to bond ashlar facing stones to a backing of roughly squared stone or brickwork.

More recently to improve thermal resistance and to provide a cavity as a barrier to the penetration of water to the inner face, it became practice to construct stone faced walling as a cavity wall with the outer leaf of stone bonded to a backing of brick, a cavity and an inner leaf of lightweight block similar to the loadbearing wall illustrated in Volume 1. The frame provided support for the outer leaf through beams built in at each floor level to support two-thirds of the thickness of the outer leaf. This form of construction provided appreciable resistance to the transfer of heat and improvement to the resistance to the penetration of water to the inner face and some little reduction in loads on the frame and foundations. For reasons of economy in labour and the use of the limited supply of native natural stone solid or cavity stone faced buildings are rarely constructed with solid stone walling today.

Reconstructed stone

Reconstructed stone is one of the several terms that have been used to describe a wall material that is made with aggregate and cement to resemble in appearance and be used in a similar way to natural stone. When the material first came into use some fifty years ago it was called artificial stone. To avoid the use of the word artificial, the material is generally referred to as reconstructed stone. The British Standard refers to the material as cast stone, which is a fair description of the method of manufacture. The majority of manufacturers of the material prefer the description reconstructed stone.

The material is made by casting a mix of natural stone aggregate, cement and water inside timber moulds by either the moist earth or the plastic or wet mix method. The moist earth method of mixing and casting is used principally for both plain and ornamental stones similar in size to natural stone ashlar blocks, where the fine natural stone aggregate and the comparatively dry mix produces a finish that very closely resembles that of the natural stone from which the aggregate is crushed, to the extent that it is often difficult to distinguish reconstructed from natural stone. Natural stone, such as Portland or Bath, crushed to a maximum size of 6 or less, is mixed with cement and just sufficient water that the material has the consistency and feel of moist earth in the hand. This mix is spread in the bed of the mould to a thickness of about 30 and compacted to a thickness of about 20 by electric or air-powered hammering. Ordinary backing concrete is then placed and compacted over the drier mix, in layers of about 50, to the required depth. Where necessary, reinforcement is cast into the backing concrete with the reinforcement at least 30 from the finished face.

The advantage of the moist earth method of casting is that the finished surface closely resembles that of the natural stone from which the face aggregate is produced and the finished surface requires little if any surface finishing. Because of its fine texture the facing material can be carved. More usually today ornamental carved finishes to reconstructed stone blocks are produced by casting on to GRP or rubber formers.

The majority of reconstructed stone blocks used for ashlar and ornamental stone facings that resemble natural limestone and sandstone finishes, are cast by the moist earth method. The main limitation of this method of casting is that return faces are generally limited to about 200.

The plastic or wet mix method of casting reconstructed stone is used for the larger blocks and for cladding panels where deep return faces and ornamentation cannot successfully be cast by the moist earth method. With the plastic method of casting a comparatively wet mix of crushed natural stone aggregate, graded up to 14, is mixed with ordinary or white cement and poured into the mould inside which it will, because of the wet mix, find its own level during consolidation. The mix, which is consolidated by vibrating tables, will tend to be more dense on the lower faces of the mould. Surface voids on upper faces are filled with the same fine material once the block is taken from the mould. The wet mix is consolidated around the necessary reinforcement, suspended inside the mould. Because of the wet mix that is used it is essential that the moulds be watertight to avoid leakages of grout that might otherwise stain exposed faces.

Because of the consolidation of the wet mix in the mould there is a surface of fine particles of aggregate and cement on finished faces. This fine surface, of what is called laitance, is removed to expose the underlying aggregate cement mix by sand blasting or by wet grinding. Well-made reconstructed stone is generally indistinguishable from the natural stone it is made from and will often be as durable and weather just like the natural material. In the early years when this material was extensively used a number of inferior products were produced which rapidly lost colour, became dirt stained and gave the material, then known as artificial stone, a bad name which it has only recently lost.

Solid and cavity brick walling

The durable, economic, familiar, traditional wall material, brick, has for many years been one of the principal materials used as walling to framed buildings.

In the early days of the multi-storey structural frame, brick walling was built as a large solid loadbearing brick structure with traditional windows and the frame members built in to the walling on each floor level as illustrated in Fig. 125. Beams built into the walling at each floor level provided support

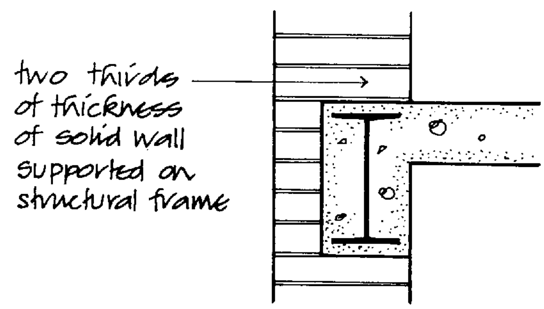
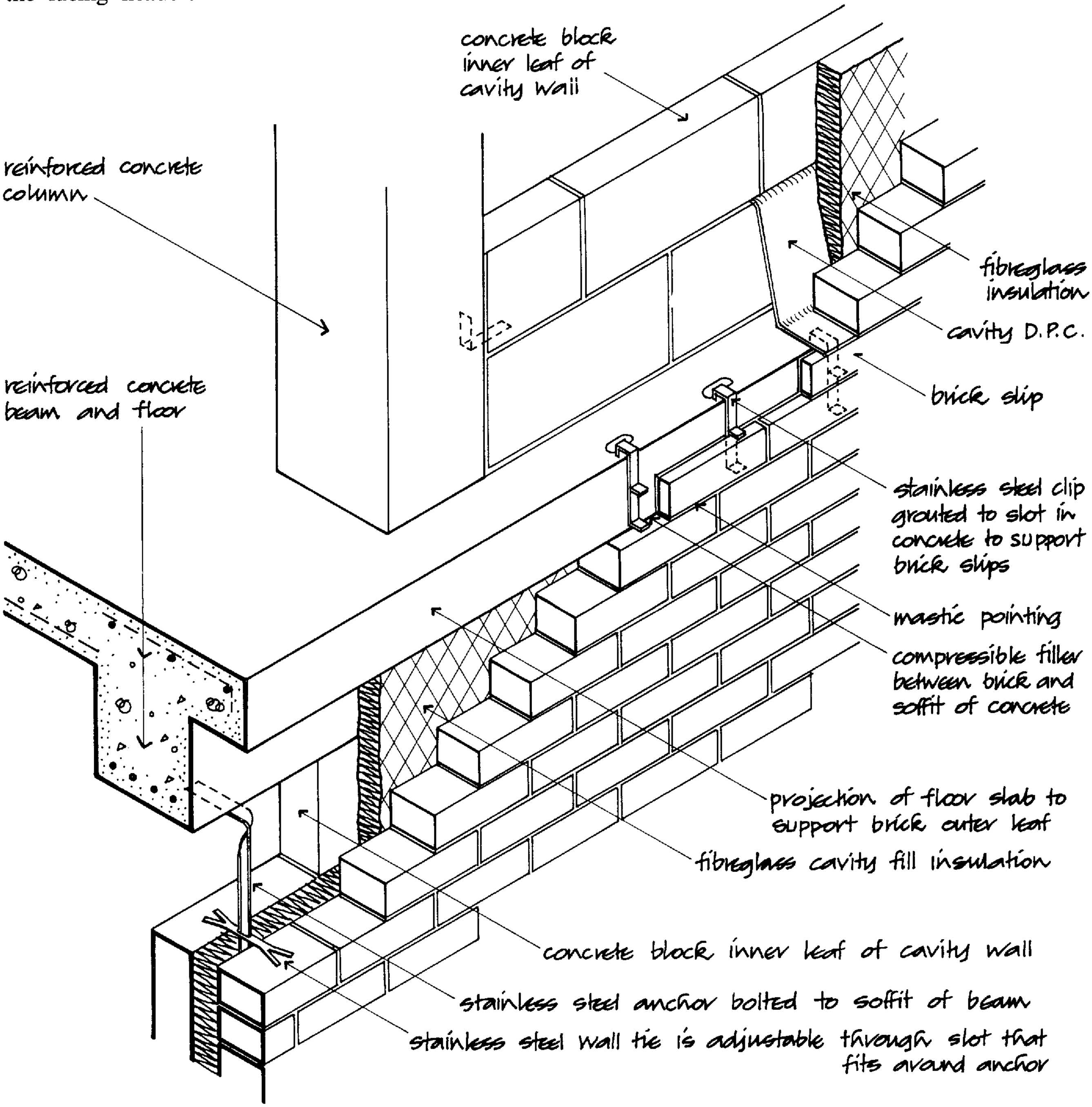


Fig. 125

for two-thirds of the thickness of the wall. The horizontal beams provided adequate support and the massive construction of the wall adequate resistance to lateral wind pressure and suction. At each supporting beam, bats of half a brick were used to mimic the facing headers in the rest of the wall. The considerable thickness of the wall was generally sufficient to resist penetration of rainwater to the inside face. As there was at the time no requirement for the conservation of fuel, the comparatively poor resistance of the wall to the passage of heat was not a consideration. The disadvantages of this form of



Brick cladding to reinforced concrete frame

Fig. 126

construction were the gross mass of the walling and the cost of the necessary framing to support it and the poor thermal resistance of the wall.

With the introduction of the cavity wall, changing fashion and increasing expectation of thermal comfort in buildings, solid walling to framed buildings was, by and large, abandoned in favour of cavity walling. With the use of cavity walling to framed buildings it was considered necessary to provide support of at least two-thirds of the thickness of the outer leaf of the wall and the whole of the inner leaf at each floor level. This posed difficulties where the external face was to have the appearance of a traditional loadbearing wall. The solution was to fix special brick slips to mask the horizontal frame members at each floor level as illustrated in Fig. 126. A disadvantage of these brick slips is that even though they are cut or made from the same clay as the surrounding whole bricks, they may tend to weather to a somewhat different colour than that of the whole bricks and so form a distinct horizontal band that defeats the original objective.

An alternative to the use of brick slips at each floor level is to build the external leaf of the cavity walling directly off a projection of the floor slab with the floor slab exposed as a horizontal band at each floor level or to build the walling between floor beams and columns and so admit the frame as part of the facade.

The strength and stability of solid and cavity walling constructed as cladding to framed structures depend on the support afforded by the frame and the resistance of the wall itself to lateral wind pressure and suction. As a general principle the slenderness ratio of walling is limited to 27 where the slenderness ratio is the ratio of the effective height or length to effective thickness. The effective thickness of a cavity wall may be taken as the combined thickness of the two leaves.

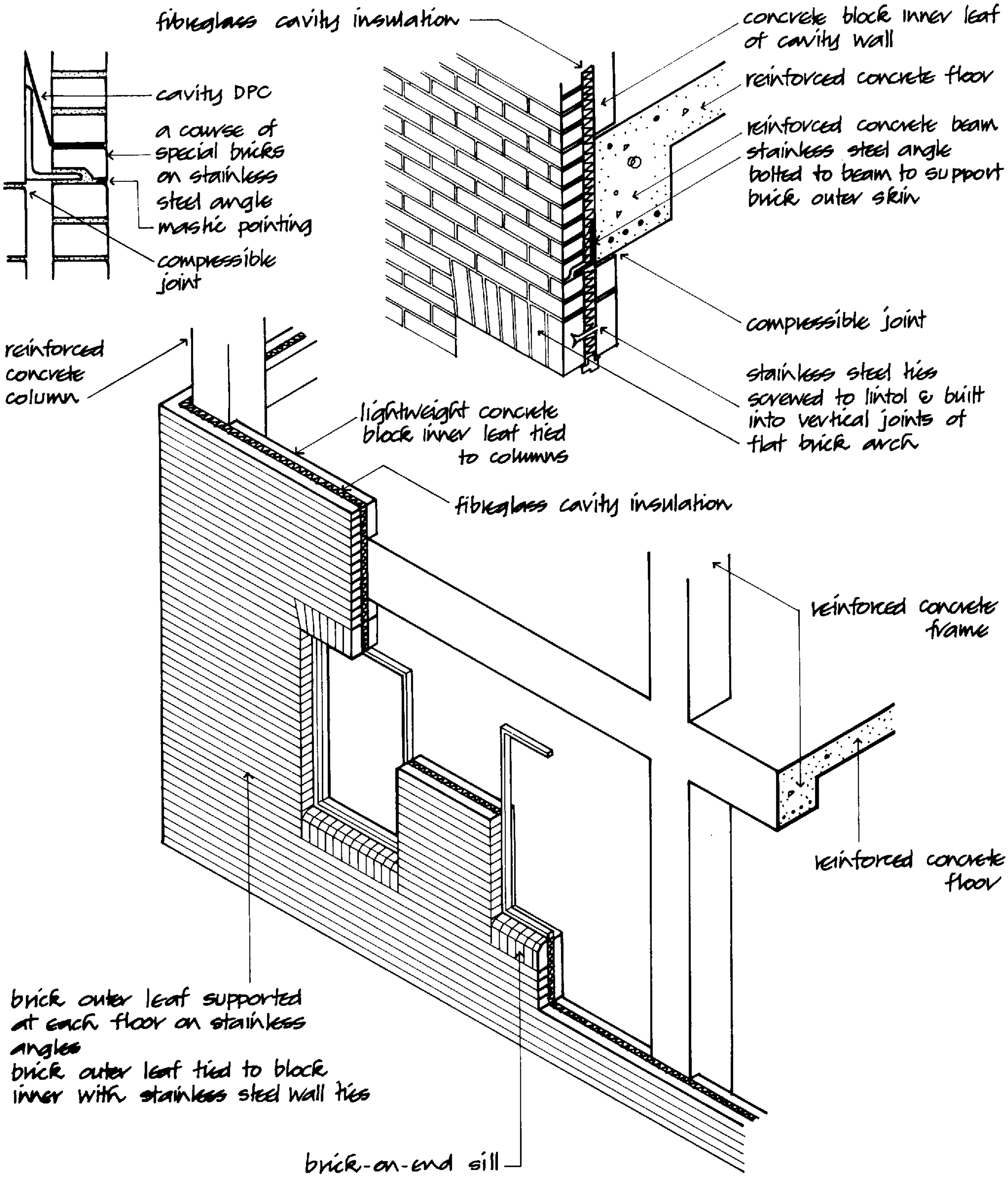
To provide the appearance of a loadbearing wall to framed structures, without the use of brick slips, it is usual practice to provide support for the outer leaf by stainless steel brackets or angles built into horizontal brick joints as illustrated in Fig. 127.

A common support for the brick outer leaf of a cavity wall is a stainless steel angle secured with expanding bolts to a concrete beam as illustrated in Fig. 127. Depending on the relative thickness of the supporting flange of the angle and the thickness of the mortar joints, the angle may be bedded in the mortar joint or the bricks bearing on the angle may be cut to fit over the angle. To allow for relative movement between walling and the frame it is usual practice to form a horizontal movement joint at the level of the support angle by building in a compressible strip which is pointed on the face with mastic to exclude water.

As an alternative to a continuous angle support a system of support brackets may be used. These stainless steel brackets fit to a channel cast into the concrete. An adjusting bolt in each bracket allows some vertical adjustment and the slotted channel some horizontal adjustment so that the supporting brackets may be accurately set in position to support brickwork as it is raised. The brackets are bolted to the channel to support the ends of abutting bricks as illustrated in Fig. 128. A horizontal movement joint is formed at the level of the bracket support. Supporting angles or brackets may be used at intervals of not more than every third storey height of building or not more than 9 metres whichever is the less, except for four storey buildings where the wall may be unsupported for its full height or 12 metres whichever is the less. Where support is provided at every third storey height the necessary depth of the compressible movement joint may well be deeper than normal brick joints and be apparent on the face of the wall.

To provide support for the wall against lateral forces it is necessary to provide some vertical anchorage at intervals so that the slenderness ratio does not exceed 27. Fishtailed or flat anchors fitted to channels cast into columns are bedded in the face brickwork at the same intervals as wall ties as illustrated in Fig. 129, to provide lateral, vertical restraint. To provide horizontal lateral restraint, anchors are fitted to slots in cast-in channels in beams or floor slabs at intervals of up to 450. To provide anchorage to the top of the wall at each floor level where brick slips are used, it is usual to provide anchors that are bolted to the underside of the beam or slab and to fit stainless steel ties that are built into brickwork at 900 centres as illustrated in Fig. 126.

Where solid or cavity walling is supported on and built between the structural frame grid, some allowance should be made for movements of the frame relative to that of the walling due to elastic shortening and creep of concrete, flexural movement of the frame and thermal and moisture movements. Practice is to build in some form of compressible filler at the junction of the top of the walling and the frame members and the wall and columns as movement joints, with metal anchors set into cast-in channels in



Brick cladding to reinforced concrete structural frame

Fig. 127

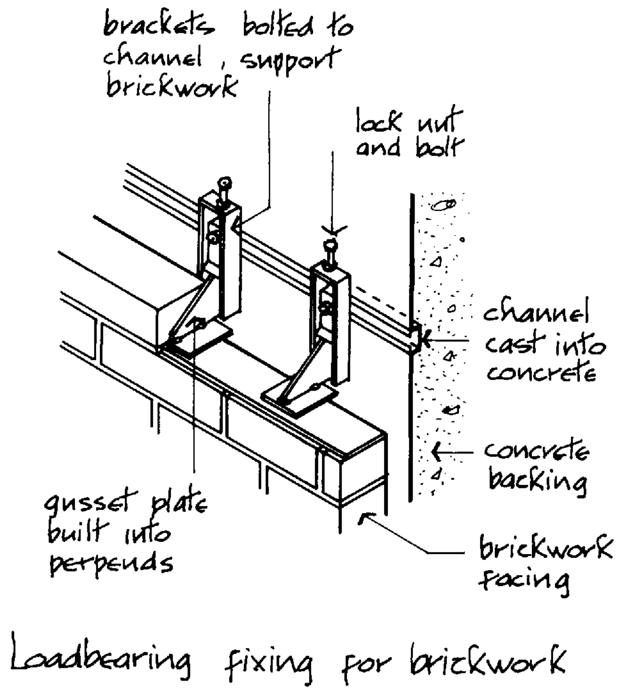


Fig. 128

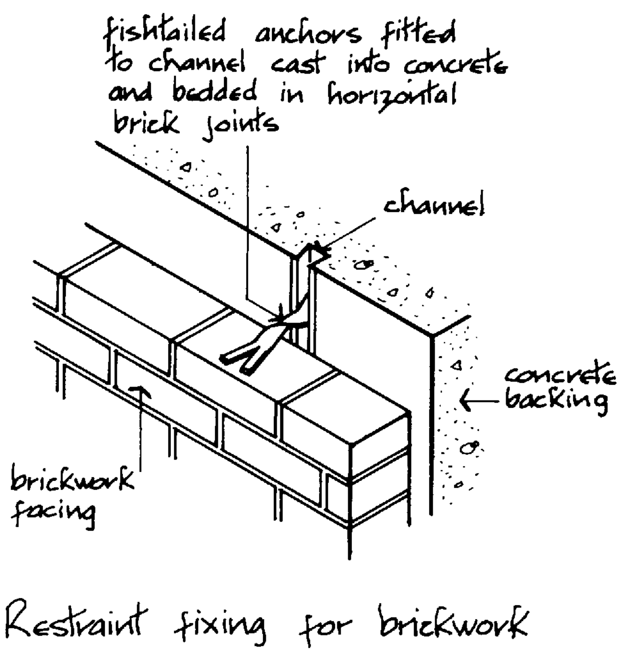


Fig. 129

columns and bedded in brickwork and to both leaves of cavity walls at intervals similar to cavity wall ties.

Where cavity walling is built up to the face of columns of the structural frame and supported at every third storey, support and restraint against lateral forces is provided by anchors fitted to cast-in channels and bedded in horizontal brick joints at intervals similar to cavity ties.

To provide for movement along the length of walling it is usual to form continuous vertical movement joints to coincide with vertical movement joints in the structural frame and at intervals of not more than 15 metres along the length of continuous walling and at 7.5 metres from bonded corners, with the joints filled with compressible strip and pointed with mastic. A wall of sound, well-burnt clay bricks should require no maintenance during the useful life of a building other than renewal of mastic pointing of movement joints at intervals of about 20 to 25 years.

Resistance to the penetration of wind-driven rain depends on the degree of exposure and the necessary thickness of the outer leaf of cavity walling and the cavity. In all but the most exposed positions a normal cavity wall of a single brick outer leaf, a 50 cavity and inner block leaf, will provide adequate resistance to penetration of moisture to the inner face of the wall.

The use of cavity trays and a dpc at all horizontal stops to cavities is accepted practice. The purpose of these trays, illustrated in Fig. 126, is to direct water that may collect inside the cavity away from the inner face of the wall. If the thickness of the outer leaf and the cavity is sufficient to resist penetration of water, there seems little logic in the use of these trays.

To prevent water soluble salts from the concrete of concrete frames finding their way to the face of brickwork and so causing unsightly efflorescence of salts, the face of concrete columns and beams that will be in contact with brickwork is painted with bitumen.

The requirements for resistance to the passage of heat usually necessitate the use of some material with comparatively good resistance to the transfer of heat, either in the cavity as cavity fill or partial fill with a lightweight block inner leaf, as illustrated in Fig. 127.

Where the cavity runs continuously across the face of the structural frame, as illustrated in Fig. 127, the resistance to the transfer of heat of the wall is uninterrupted. Where a floor slab supports the outer leaf, as illustrated in Fig. 126, there will be to an extent a cold bridge as the brick slips and the dense concrete of the floor slab will afford less resistance to the transfer of heat than the main cavity wall. The very small area of floor and ceiling that may well be colder is generally of little consequence and unlikely to encourage damp staining.

FACINGS APPLIED TO SOLID AND CAVITY WALL BACKING

The word facings is used to describe comparatively thin, non-structural slabs of natural or reconstructed stone, faience, ceramic and glass tiles or mosaic which are fixed to the face of and supported by solid background walls or to structural frames as a decorative finish. Common to the use of these non-structural facings is the need for the background wall or frame to support the whole of the weight of the facing at each storey height of the building or at vertical intervals of about three metres, by means of angles or dowels. In addition to the support fixings, restraint fixings are necessary to locate the facing units in true alignment and to resist wind pressure and suction forces.

To allow for elastic and flexural movements of the structural frame and differential thermal and moisture movements, there must be flexible horizontal joints below support fixings and vertical movement joints at intervals along the length of the facings. Both horizontal and vertical movement joints must be sufficiently flexible to accommodate anticipated movements and be water resistant to prevent penetration of rainwater.

Natural and reconstructed stone facings

Natural and reconstructed stone facings are applied to the face of buildings to provide a decorative finish to simulate the effect of solidity and permanence traditionally associated with solid masonry. Because of the very considerable cost of preparation and fixing, this type of facing is mostly used for prestige buildings such as banks and offices in city centres.

Granite is the natural stone much favoured for use as facing slabs for the hard, durable finish provided by polished granite and the wide range of colours and textures available from both native and imported stone. Polished granite slabs are used for the fine gloss surface that is maintained throughout the useful life of a building. To provide a more rugged appearance the surface of granite may be honed to provide a semi-polish, flame textured to provide random pitting of the surface or surface tooled to provide a more regular rough finish. Granite facing slabs are generally 40 thick for work more than 3.7 above ground and 30 thick for work less than 3.7 above ground.

Limestone, such as the native Portland, Bath or Clipsham, is used as facings, by and large, to resemble solid ashlar masonry work, the slabs having a smooth finish to reveal the grain and texture of the material. These comparatively soft limestones suffer a gradual change of colour over the course of years and this weathering is said to be an attractive feature of these limestones. Limestone facing slabs are 75 thick for work more than 3.7 above ground and 50 thick for work less than 3.7 above ground.

Hard limestones, including Roman stone and a number of very dense stones from France and Germany, are much used as facings for the hardness and durability of the materials. This type of stone is generally used as flat, level finished, facing slabs in thicknesses of 40 for work more than 3.7 above ground and 30 for work less than 3.7 above ground.

Sandstones, such as York stone, Darley Dale, Blaxter and Hollington, are used as facing slabs. Some care and experience are necessary in the selection of these native sandstones as the quality, and therefore the durability, of the stone may vary between stones taken from the same quarry. This type of stone is chosen for the colour and grain of the natural material whose colour will gradually change over some years of exposure. Because of the coarse grain of the material it may stain due to irregular run-off of water down the face. As with limestone, sandstone facing slabs are usually 75 thick for work 3.7 above ground and 50 thick for work less than 3.7 above ground.

Marble is less used for external facings in northern European climates, as polished marble finishes soon lose their shine. Coarser surfaces, such as honed or eggshell finishes, will generally maintain their finish, providing white or travertine marble is used. Marble facing slabs are 40 thick for work 3.7 above ground and 30 thick for work below that level. Reconstructed stone made with an aggregate of crushed natural stone is used as facing slabs as if it were the natural material, in thicknesses the same as that for the natural stone.

Fixing natural and reconstructed stone facings

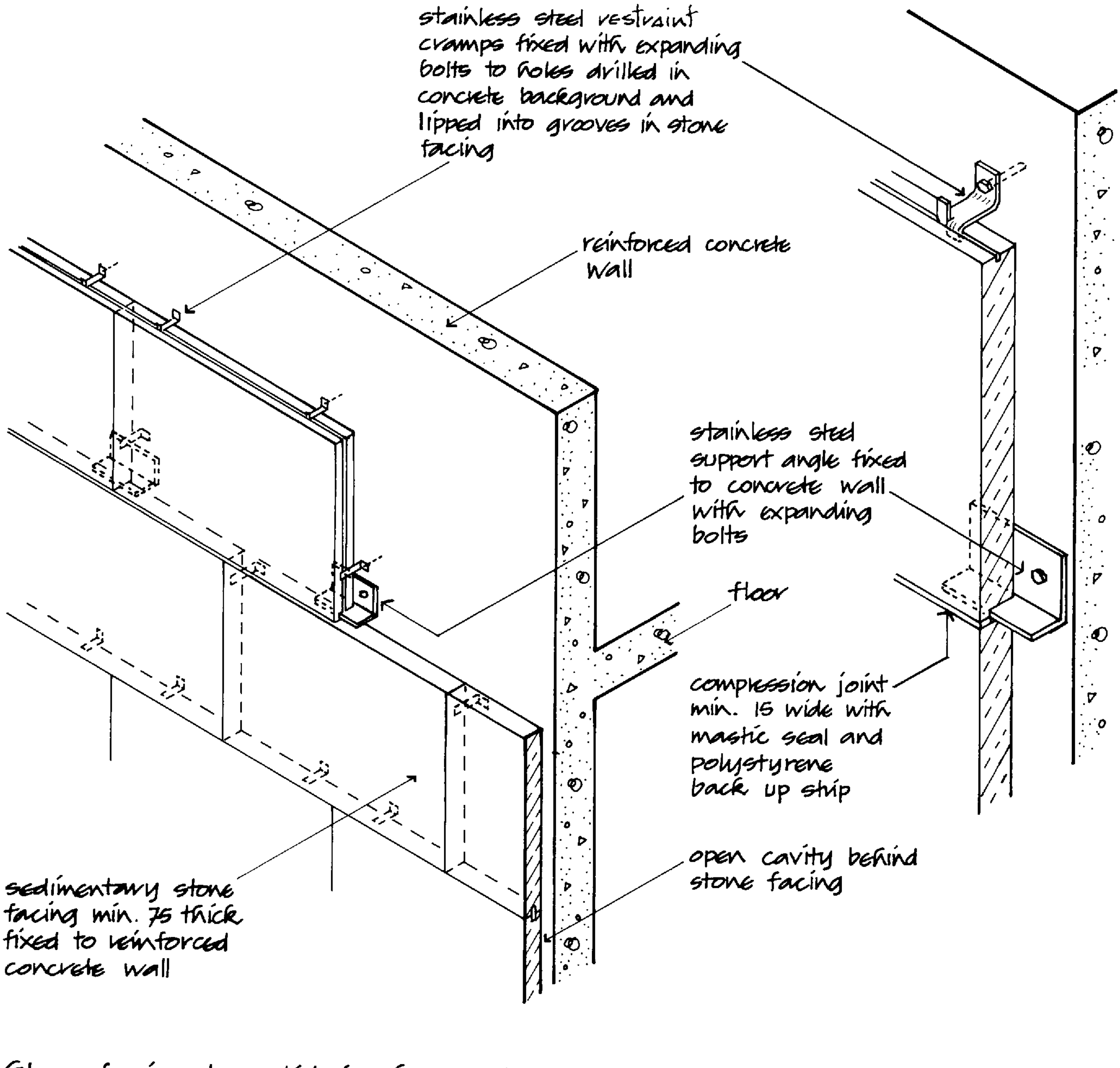
The size of natural and reconstructed stone facing slabs is generally limited to about 1.5 in any one or both of the face dimensions or such less size as is practical to win from the quarry. Facing slabs are fixed so that there is a cavity between the back of the slabs and the background wall or frame to allow for fixings, tolerances in sawn thickness of slabs and to provide a cavity to minimise penetration of water to the backing. Where water might be trapped in the cavity behind the facing slabs on cavity trays weep holes should be provided.

The type of fixings used to support and secure facing slabs in position are:

- Loadbearing fixings
- Restraint fixings
- Combined loadbearing and restraint fixings
- Face fixings
- Soffit fixings

Loadbearing fixings

These support fixings are made from one of the corrosion resistant metals such as stainless steel, aluminium bronze or phosphor bronze. Stainless steel is the general description for a group of steel



Stone facing to solid background concrete wall

Fig. 130

alloys containing chromium and other elements. The type of stainless steel commonly used for structural fixings is austenitic stainless steel.

Loadbearing fixings take the form of either stainless steel angle supports to the lower edge of each slab or stainless steel corbel plates set in slots cut in the back of stones as illustrated in Figs 130 and 131. The size of the angle or corbel plate supports depends on the weight of the slabs to be supported. Common practice is to support each facing slab on two supports with the angle or corbel supports fixed centrally on vertical joints between slabs so that each supports two slabs. Angle or corbel plate supports should be at least 75 wide. At vertical movement joints two supports are used, one each side of the joint, to the lower edge or lower part of the two stone slabs each side of the joint. These supports should be at least 50 wide. The usual method of fixing angle supports to the supporting background is with expanding bolts fitted to holes drilled in the concrete or solid brick backing as illustrated in Fig. 132. Where the background is sound and solid this form of fixing, made by the stone fixer, can be accurately located whereas preformed pockets or holes in the background may not coincide with the required fixing position. As an alternative bolts may be fitted to a metal channel cast into concrete as illustrated in Fig. 133. Where support fixings are to be built into a brick or block wall backing it is usual to build the background wall at the same time that the stone slabs are fixed, so that the stone slabs may be set in position and fishtailed ended corbel plates can be solidly bedded in brick or block horizontal courses two-thirds of the thickness of the background wall or not less than 100.

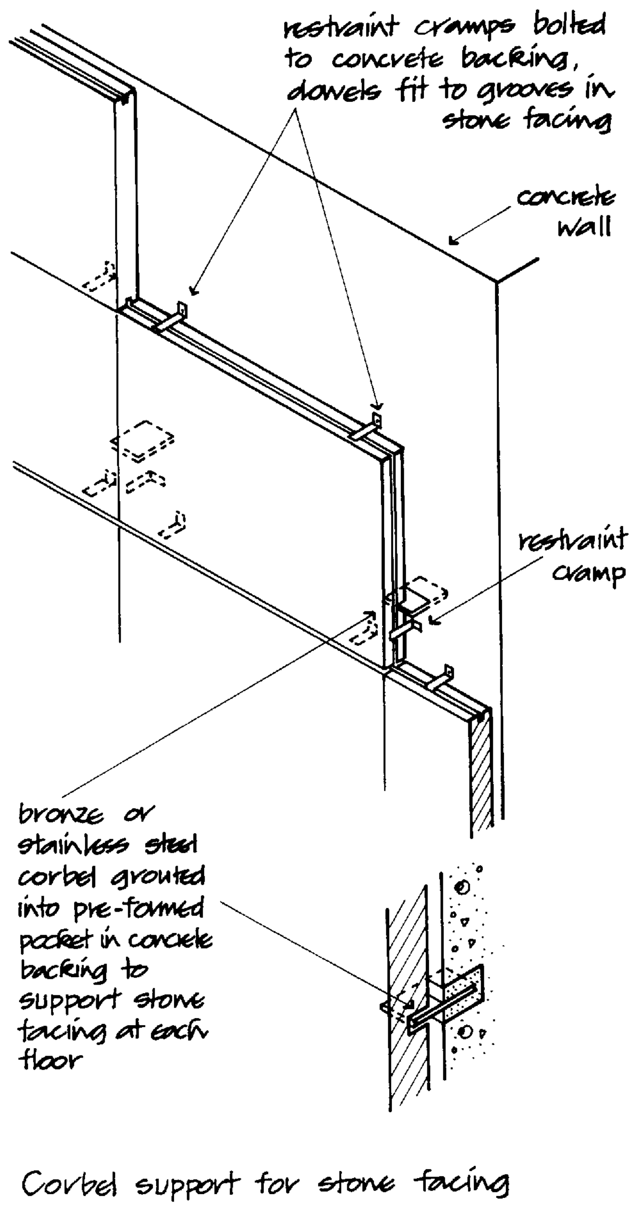


Fig. 131

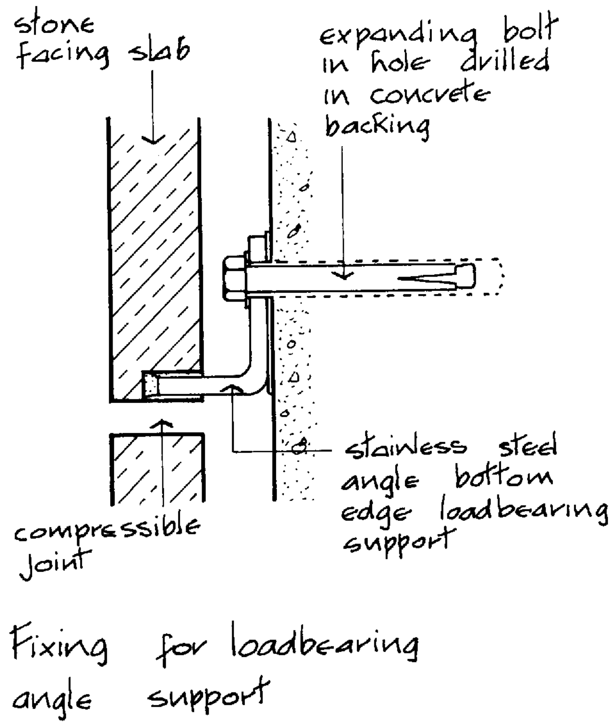
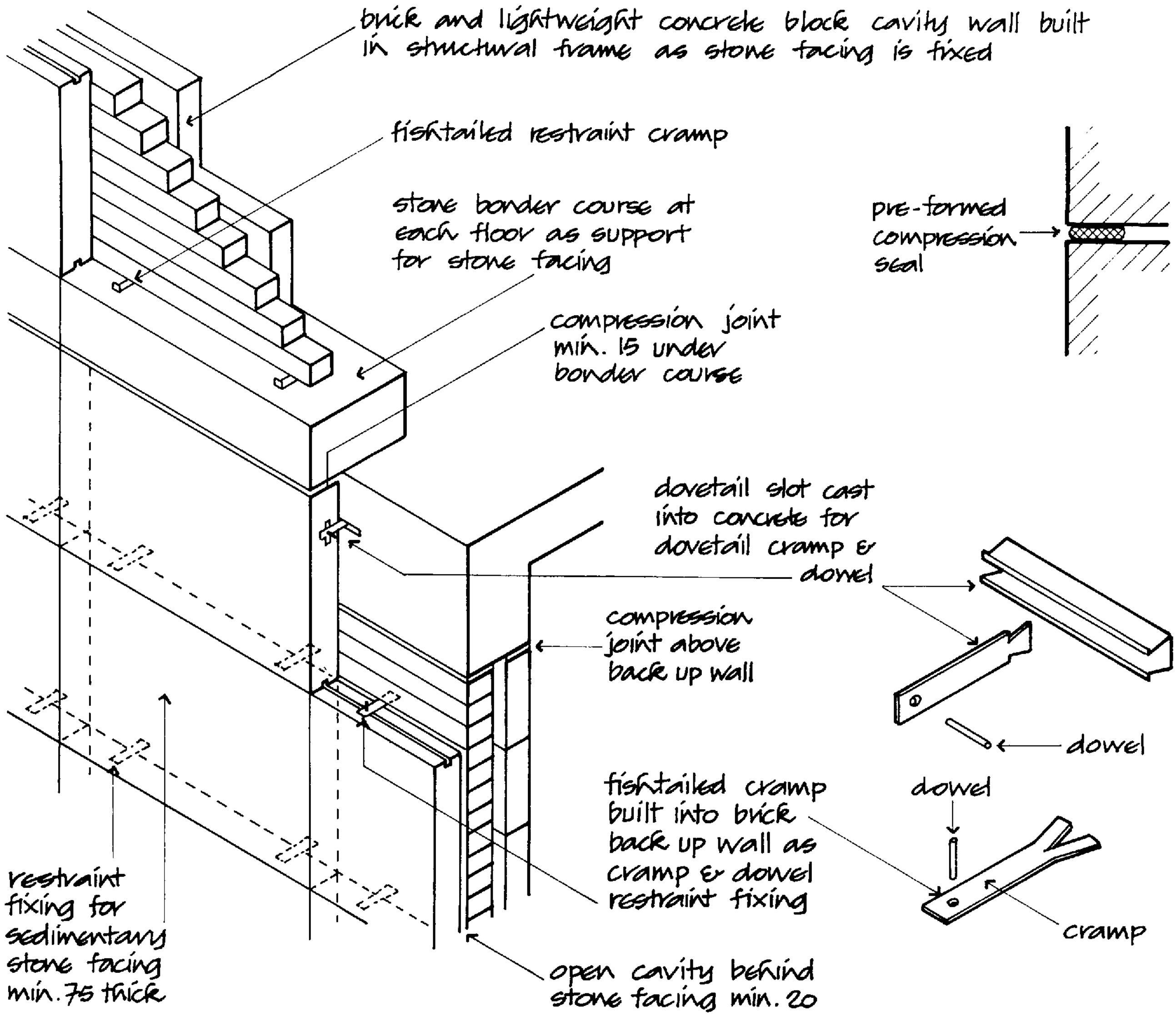


Fig. 132



Stone facing to solid background of brickwork

Fig. 133

Restraint fixings

Restraint fixings are used to maintain the stone slabs in their correct position and alignment and to resist the very considerable wind pressure and suction that may act on the face of the stone slabs.

These restraint fixings take the form of stainless steel hook plates or wire fixings fitted to pockets in the edges of slabs and secured to the background by cast-in channels or by bolting to the background or by dowels fitted to plates secured in cast-in channels as illustrated in Fig. 134. Hook plate, wire and dowel restraint fixings may be used to join two adjacent stones. For the majority of stone facing slabs there should be two restraint fixings to the top and two to the bottom of each slab, located at approximately one-fifth of the length of the side measured from the corner and not more than 1200 apart. Small slabs may be secured with one top and one bottom restraint fixing. Figure 130 is an illustration of stone facing slabs supported by angle loadbearing fixings and restrained by hooked plate restraint fixings.

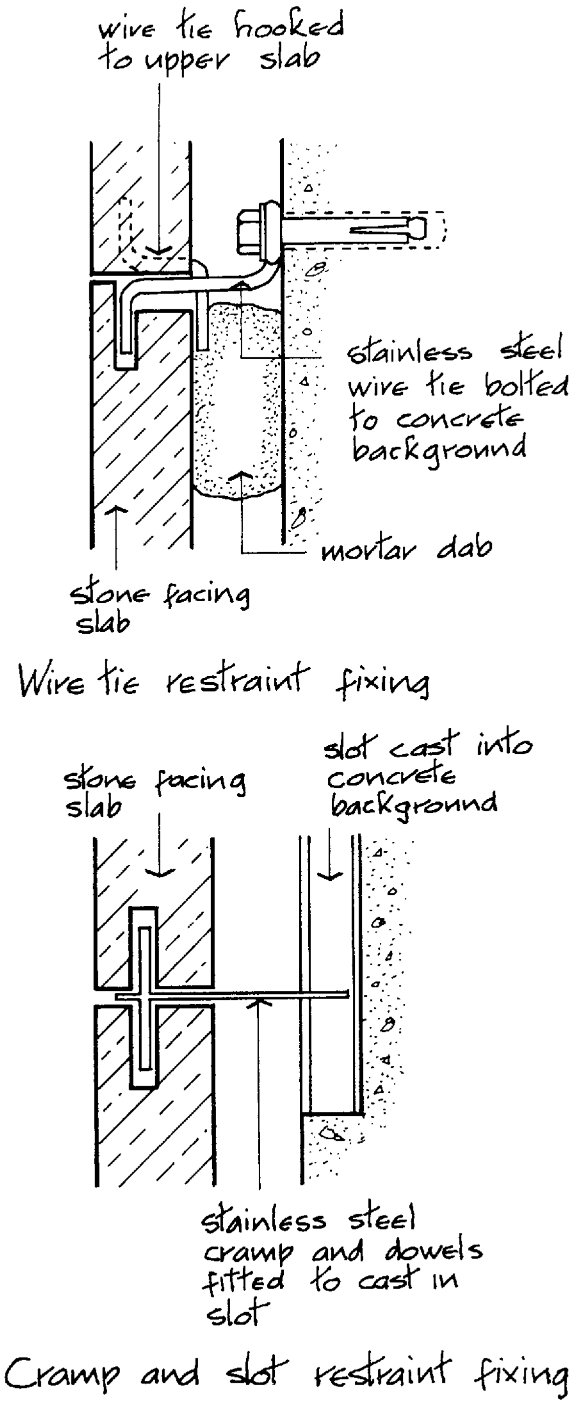


Fig. 134

Combined loadbearing and restraint fixings

Loadbearing fixings may be designed and used as restraint fixings, as illustrated in Fig. 133, where angle fixings have a loose or welded on dowel pin to act as restraint or the protruding flange of a corbel plate is inclined upwards at 15° and thus acts as restraint.

Face fixings

As an alternative to support and restraint fixing of stone facing slabs, face fixing may be used for thin slabs. Each stone facing slab is drilled for and fixed to a solid background with at least four stainless steel or non-ferrous bolts. The stone slabs are bedded in position on dabs of lime putty or weak mortar which is spread on the back of the slabs and the slabs are secured with expanding bolts and washers as illustrated in Fig. 135. The holes drilled in the stone for the bolts are then filled with pellets of stone to match the stone of the slabs. Joints between stones are filled with gunned-in mastic sealant to provide a weathertight joint and to accommodate differential thermal and structural movement. The whole of the weight of the stone slabs is supported by the bolts that must have a sufficient section to support the weight in shear and the bolts must be accurately set in place and strongly secured to the solid backing if the not uncommon failure of this method of fixing is to be avoided.

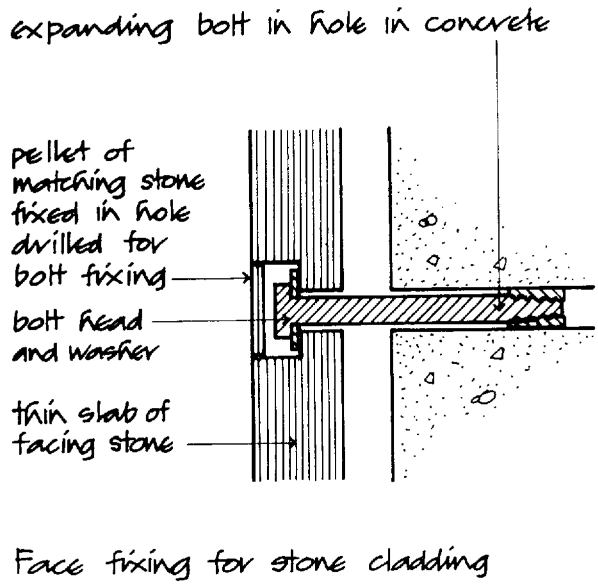


Fig. 135

Soffit fixings

Support and fixing of stone facings to soffits is effected by the use of hangers and plates, cramps or dowels that are suspended in slot hangers cast in the

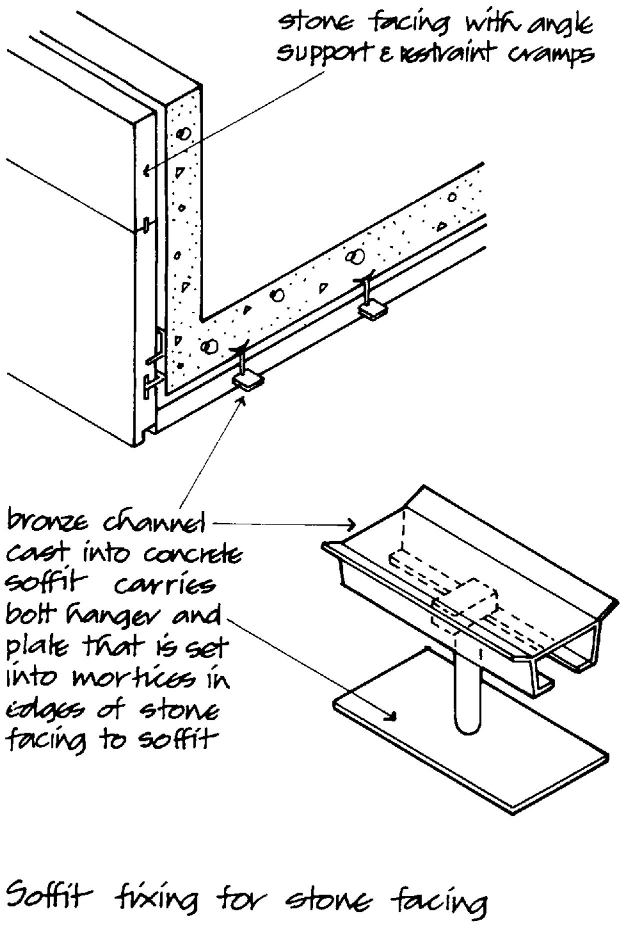


Fig. 136

structural soffit. The system illustrated in Fig. 136 consists of slot anchors that are cast into the concrete soffit to support hangers and plates that fit to slots in joints between stones to take the whole of the weight of the stone lining to the soffit.

Joints between stone slabs

Joints between stone facing slabs should be sealed as a barrier to the penetration of rainwater running off the face of the slabs. Where rainwater penetrates the joints between stone slabs it will be trapped in the cavity between the slabs and the background wall and will not evaporate to air during dry spells and may cause conditions of persistent damp. Open or butt joints between slabs should be avoided in external face work.

The joints between sedimentary stone slabs, such as limestone and sandstone, may be filled with a mortar of cement, lime and sand (or crushed natural stone) mix 1:1:6 and finished with either flush or slightly recessed pointing to a minimum depth of 5. Joints between granite and hard limestone slabs are filled with a mortar of 1:2:8 cement, lime and sand (or stone dust) or 4:1 cement and sand to a minimum thickness of 3. As an alternative to mortar filling the joints between stones a sealant may be used. Sealants such as one part polysulphide, one part polyurethane, two parts polysulphide or two parts polyurethane are recommended for the majority of stones. These sealant joints should be not less than 5 wide.

The jointing sealants will accommodate a degree of movement between stones without failing as a water seal for up to 15 to 20 years, when they may well need to be reformed. Mortar joints will take up some slight movement between stones but may in time not serve as an effective water seal as wind driven rain may penetrate the fine cracks that open up.

Some penetration of rainwater through joints between stones may well occur as sealants age and mortar cracks. There will generally be no large penetration of water into the cavity behind the stones so that unless obvious damp stains appear on the inside face of the background walling it is unlikely that anyone will be concerned to go to the considerable expense of hacking out and reforming the joints.

Movement joints

As a building is erected and loads increase there is an early measurable elastic shortening of columns of the order of about 2.5 mm per 4 metre storey height of a reinforced concrete frame and a later gradual shortening due to creep of the same magnitude. A less pronounced shortening takes place as a steel frame is erected. Much of the early elastic shortening of the columns of a structure will have taken place before a wall cladding is fixed. The long-term shortening of reinforced concrete columns, through creep, has to be allowed for in horizontal movement joints. Differential temperature and moisture movements of a wall facing relative to the supporting structure will generally dictate the need to allow some movement of joints and fixings. There will be, for example, very considerable temperature differences between facing slabs on an exposed south facing wall and the structure behind so that differential thermal movement has to be allowed for both in joints and support and restraint fixings.

A general recommendation in the fixing of stone facing slabs is that there should be horizontal movement joints at each storey height below loadbearing support fixings or not more than 3 metres. These joints are usually 10 to 15 deep and filled with one of the elastic sealants. Where so wide a joint would not be acceptable in facework finished with narrow joints it is usual to accommodate movement in narrower sealant filled horizontal joints to all the facework. Vertical movement joints are formed in facework where these joints occur in the structure to allow for longitudinal structural, thermal and moisture movements. A continuous vertical joint is formed between stone facings and filled with sealant.

Faience slabwork

Faience is the term used to describe fire glazed stoneware in the form of slabs that are used as a facing to a solid background wall. The best quality slabs are made from stoneware which shrinks and deforms less on firing than does earthenware. The fired slab is glazed and then refired to produce a fire glazed finish. The slabs are usually 300 × 200, 450 × 300 or 610 × 450 and 25 to 32 thick. They form a durable, decorative facing to solid walls. The glazed finish, which will retain its lustre and colour indefinitely, needs periodic cleaning, especially in polluted atmospheres.

Faience slabwork was much used as a facing in the 1930s in this country, as a facing to large buildings such as cinemas. This excellent facing material has since then lost favour. When first used the slabs were fixed with cement mortar dabs to a keyed brick background. This unsatisfactory method of fixing made no allowance for differential movements and has been abandoned in favour of support fixings to each slab and restraint fixings and movement joints in the same way that stone facings are fixed.

Terra cotta

Terra cotta (burnt earth) was much used in Victorian buildings as a facing because it is less affected by polluted atmospheres than natural limestone and sandstone facings. Fired blocks of terra cotta, with a semi-glaze self finish, were moulded in the form of natural stone blocks to replicate the form and detail of the stonework buildings of the time. The plain and ornamental blocks were made hollow to reduce and control shrinkage of the clay during firing. In use the hollows in the blocks were filled with concrete and the blocks were then laid as if they were natural stone. Well burned blocks of terra cotta are durable even in heavily polluted atmospheres. This labour intensive system of facing is little used today.

Tiles and mosaic

Tile is the term used to describe comparatively thin, small slabs of burnt clay or cast concrete up to about 300 square and 12 thick. These small units of fired clay and cast concrete are used as a facing to structural frames and solid background walls. For many years practice has been to bond tiles directly to frames and walls with cement mortar dabs which by themselves provide sufficient adhesion to maintain individual tiles in place. This system of adhesion does not make any allowance for differential movements between the frame, background walls and tiles, other than in the joints between tiles, which can be considerable, particularly with in situ cast concrete work. To make allowance for movements in the structure and the facing, tiles should be supported and restrained by cramps that provide a degree of flexibility between the facing and the background. Plainly it would be both tedious and expensive to fix individual tiles in this way. For economy and ease of fixing, the tiles can be cast on to a slab of plain or reinforced concrete which is then fixed in the same way as stone facing slabs.

Mosaic is the term used to describe small squares of natural stone, tile or glass set out in some decorative pattern. The units of mosaic are usually no larger than 25 square. A mosaic finish as an external facing should be used as a facing to a cast concrete slab in the same way as tiles.

CLADDING PANELS

Precast concrete cladding panels

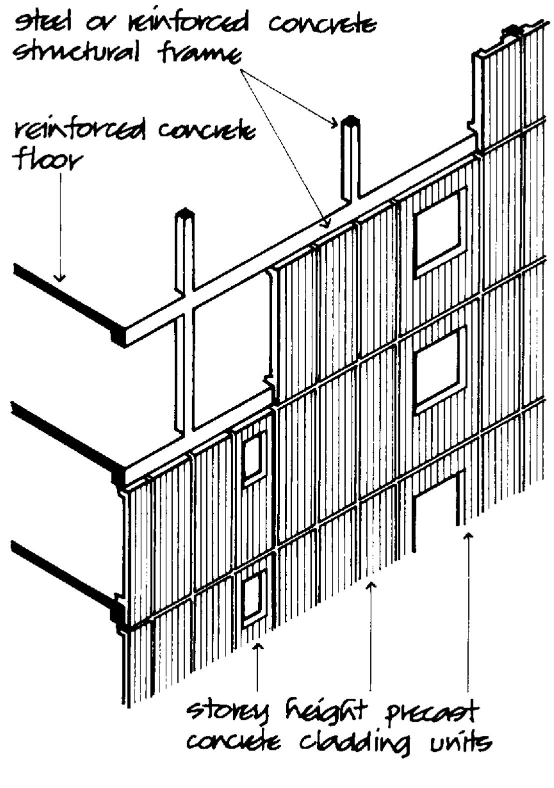
The aesthetic, economic and constructional advantages of the use of precast concrete cladding slabs or units as a facing and walling to framed structures were demonstrated by Le Corbusier in the multistorey housing development, the Unité at Marseilles, which was completed in 1952.

The use of precast concrete and the design of this one building had a profound influence on the use of precast concrete for many years. The advantages of repetitive casting, speed of erection largely independent of weather and the rugged appearance of the material that was a vogue of the 1950s and 1960s led to the extensive use of this system of wall cladding.

Precast concrete cladding panels or units are usually storey height as illustrated in Fig. 137 or column spacing wide as spandrel or undersill units for support and fixing to the structural frame. Precast concrete cladding units are hung on and attached to frames as a self-supporting facing and wall element which may combine all of the functional requirements of a wall element.

Precast concrete cladding units are cast with either the external face up or down in the moulds, depending on convenience in moulding and the type of finish. Where a finish of specially selected aggregate is to be exposed on the face, the face up method of casting is generally used for the convenience and accuracy in applying the special finish to the core concrete of the panel. Cladding units that are flat or profiled are generally cast face down for convenience in compacting concrete into the face of the mould bed.

Strongly constructed moulds of timber, steel or glass fibre reinforced plastic are laid horizontal, the reinforcing cage and mesh is positioned in the mould and concrete is placed and compacted. For economy in the use of the comparatively expensive moulds it is essential that there be a limited number of sizes, shapes and finishes to cladding units to obtain the economic advantage of repetitive casting.



Storey height precast concrete cladding

Fig. 137

There is no theoretical limit to the size of precast units, providing they are sufficiently robust to be handled, lifted and fixed in place, other than limitations of the length of a unit that can be transported and lifted. In practice cladding units are usually storey height for convenience in transport and lifting and fixing in place. Cladding units two or more storeys in height have to be designed, hung and fixed to accommodate differential movements between the frame and the units, which are multiplied by the number of storeys they cover.

The initial wet plastic nature of concrete facilitates the casting of a wide variety of shapes and profiles from flat solid web enclosing panels to the comparatively slender solid sections of precast concrete frames for windows.

The limitation of width of cladding units is determined by facilities for casting and size for transport and lifting. The width of the units cast face up is limited by ease of access to placing the face material in the moulds. The usual width of storey height panels is from 1200 to 1500, or the width of one or two structural bays.

For strength and rigidity in handling, transport, lifting and support and fixing, and to resist lateral wind pressures, cladding units are reinforced with a mesh of reinforcement to the solid web of units and a cage of reinforcement to vertical stiffening ribs and horizontal support ribs. Figure 138 is an illustration of a storey height cladding unit.

The vertical stiffening ribs are designed for strength in resisting lateral wind pressures on the units between horizontal supports and strength in supporting the weight of the units that are either hung from or supported on the horizontal support ribs. The least thickness of concrete necessary for the web and the ribs is dictated largely by the cover of concrete necessary to protect reinforcement from corrosion, for which a minimum web thickness of 85 or 100 is usual. The necessary cover of concrete to reinforcement makes this system of walling heavy, cumbersome to handle and fix and bulky looking.

Storey height precast concrete cladding is supported by the structural frame, either by a horizontal

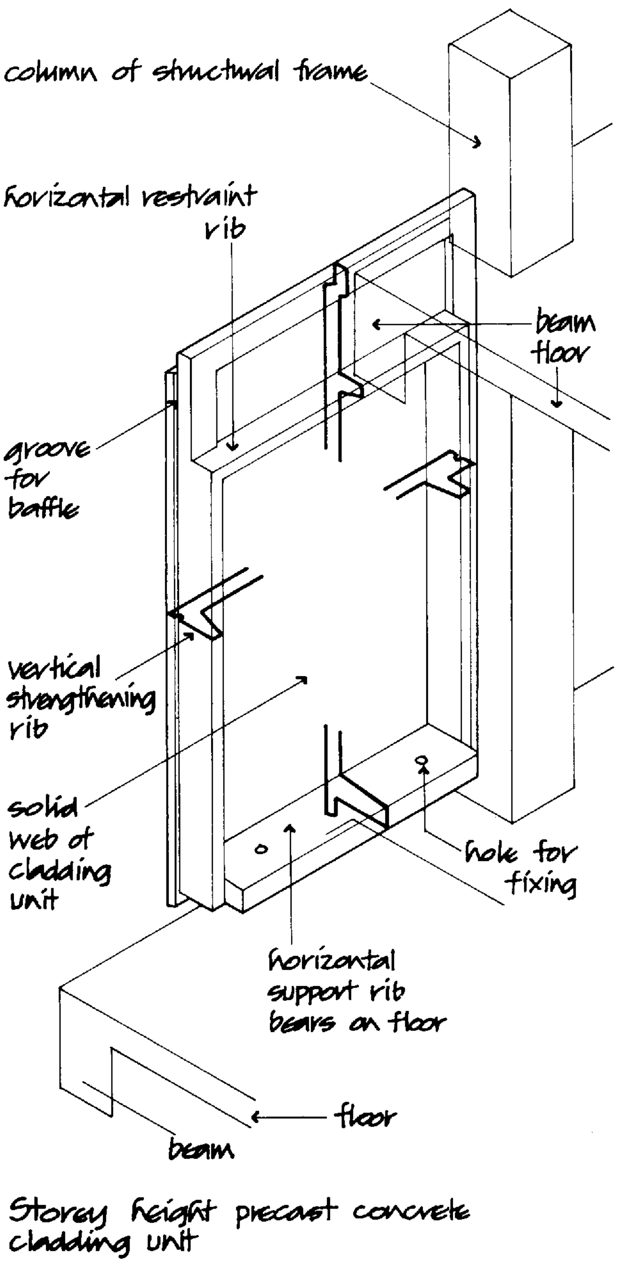


Fig. 138

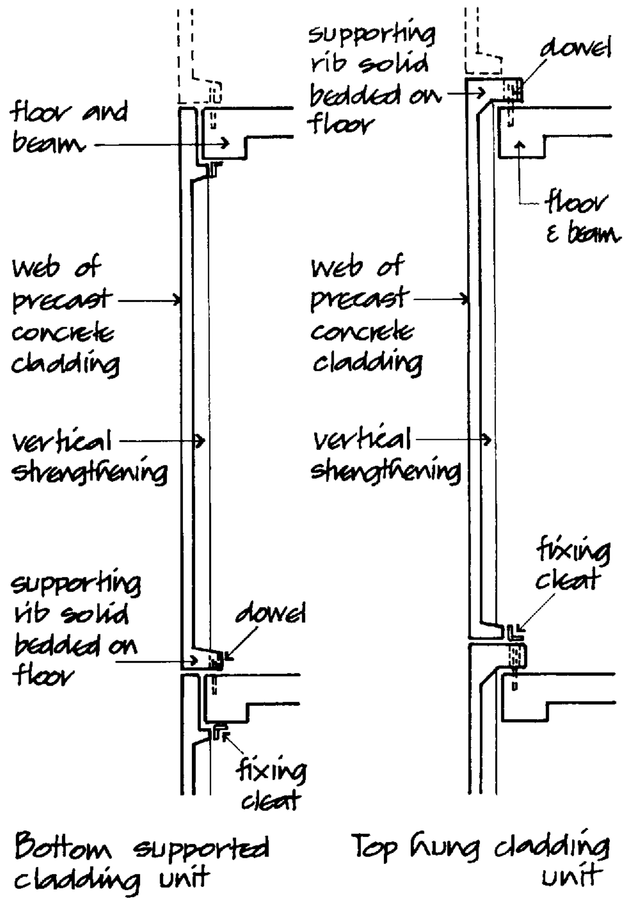
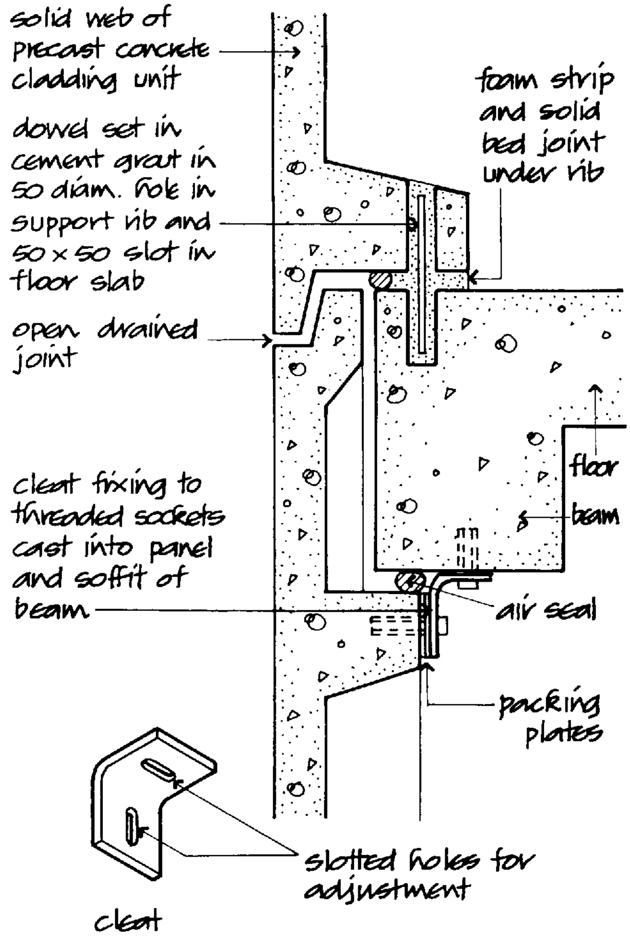


Fig. 139

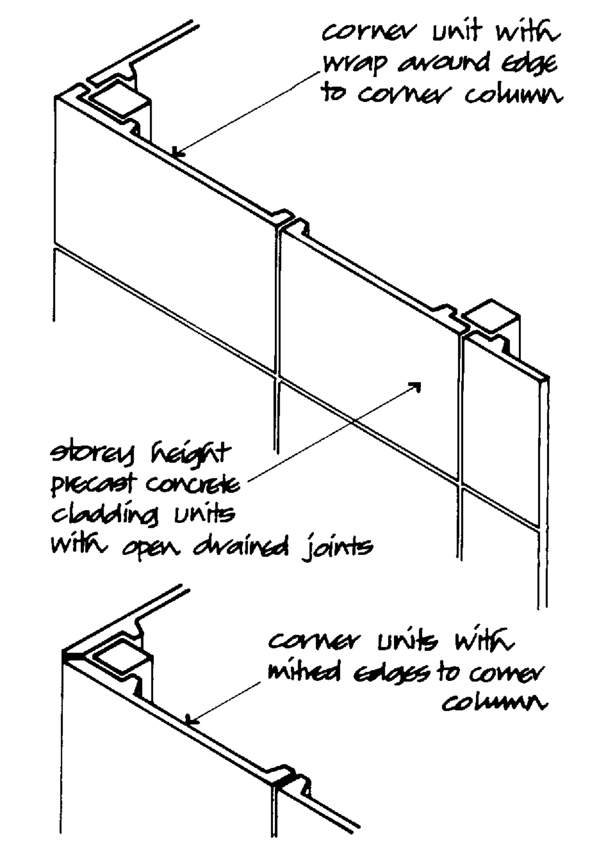
support rib at the bottom of the units or hung on a horizontal support rib at the top of the units, as illustrated in Fig. 139. Bottom support is preferred as the concrete of the unit is in compression and less likely to develop visible cracks and crazing than it is when top hung. Whichever system of support is used, the horizontal support rib must have an adequate projection for bearing on structural floor slabs or beams and for the fixings used to secure the units to the frame. At least two mechanical support and two restraint fixings are used for each unit. The usual method of fixing at supports is by the use of steel or non-ferrous dowels that are grouted into 50 square pockets in the floor slab. The dowel is then grouted into a 50 diameter hole in the support rib, as illustrated in Fig. 140. The advantage of this dowel fixing is that it can readily be adjusted to inaccuracies in the structure and the panel. Dowel fixings serve to locate the units in position and act as restraint fixings against lateral wind pressures.

Restraint fixings to the upper or lower horizontal ribs of cladding units, depending on whether they are top or bottom supported, must restrain the unit in place against movements and lateral wind pressure. The restraint fixing most used is a non-ferrous or stainless steel angle cleat that is either fixed to a slotted channel cast in the soffit of beams or slabs or more usually by expanding bolts fitted to holes drilled in the concrete. The cleat is bolted to a cast-in stud protruding from the horizontal rib of the unit as illustrated in Fig. 140. The slotted hole in the



Fixing for bottom supported precast concrete cladding units

Fig. 140



Corner units to precast concrete cladding

Fig. 141

downstand flange of the cleat allows some vertical movement between the frame and the cladding.

Another system of fixing combines support fixing by dowels with restraint fixing by non-ferrous flexible straps that are cast into the units and fit over the dowel fixing. Support and restraint fixing may be provided by casting loops or hooked ends of reinforcement, protruding from the back of cladding units, into a small part of or the whole of an in situ cast concrete member of the structural frame. The disadvantage of this method is the site labour required in making a satisfactory joint and the rigidity of the fixing that makes no allowance for differential movements between structure and cladding.

At external angles on elevations cladding units may be joined by a mitre joint or as a wrap around corner unit specially cast for the purpose, as illustrated in Fig. 141.

A very common use for precast concrete cladding units is as undersill cladding to continuous horizontal windows or as a spandrel unit to balcony fronts. A typical undersill unit, illustrated in Fig. 142, is designed for bottom rib support and top edge restraint at columns.

The web, horizontal support and restraint ribs and the vertical stiffening ribs are similar in construction to storey height panels. Support and restraint fixing is through the bottom horizontal rib bearing on the floor slab with dowel fixing and restraint fixing by cleats fixed to columns and ribs, as illustrated in Fig. 143. As an alternative to bottom support these units can be top supported on an in situ cast concrete beam at sill level so that several undersill cladding units may be used between widely spaced columns. Joints are made as either sealed or open drained joints, similar to those for storey height panels.

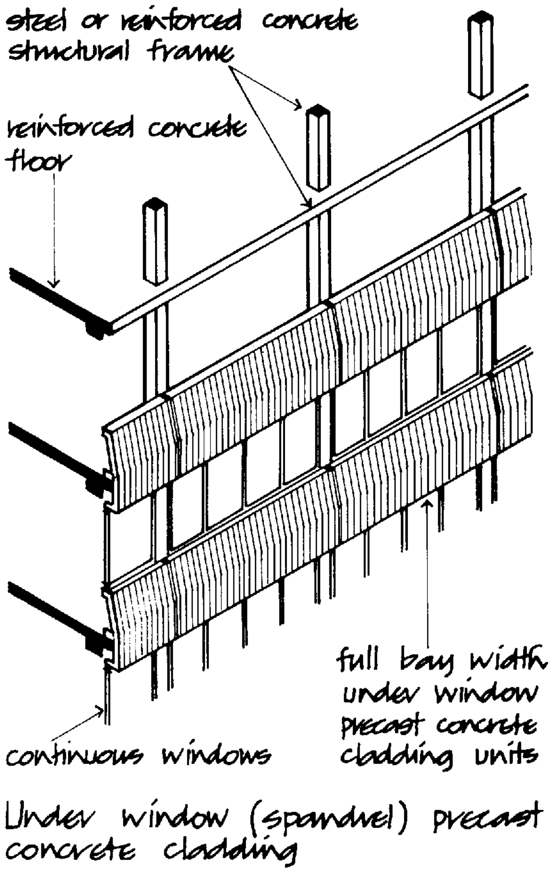


Fig. 142

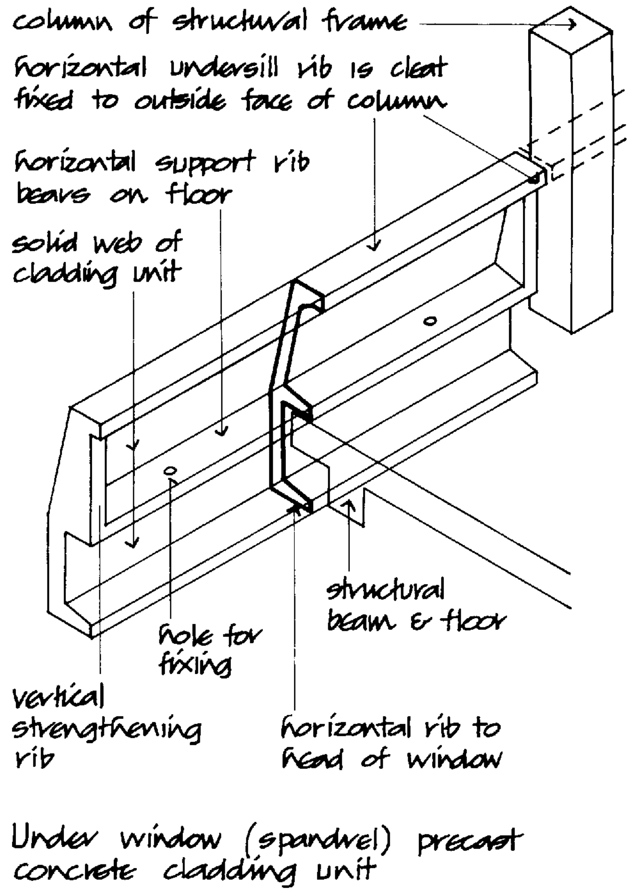


Fig. 143

At parapet level of buildings faced with precast concrete cladding panels either a special cladding unit is used or a special parapet unit is cast, as illustrated in Fig. 144.

Because of the plastic nature of wet concrete it is possible to cast cladding units in a variety of profiled and textured finishes and to include openings for windows in individual cladding units, within the need for repetitive casting for economy. The limitations to the complexity and fineness of detail of the textures and profiles that can be achieved are the need for reinforcement and cover of concrete for stiffening ribs at edges and around openings and the size of the aggregate in concrete that limits fine detail. Figure 145 is an illustration of a profiled window unit.

Surface finishes

Due to compaction of wet concrete in the mould, the lower face of the concrete consists of a water rich mix of the fine particles of cement and aggregate. On drying this thin layer of cement rich material shrinks and forms a surface of irregular fine cracks and the surface may show marked colour differences due to variations in placing, compacting and mixing of the concrete. Because such a surface is not generally an acceptable finish the exposed faces of precast concrete are usually treated to reveal the underlying aggregate.

To provide an acceptable finish to the exposed faces of precast concrete panels it is practice to provide what is sometimes called an 'indirect finish' by abrasive blasting, surface grinding, acid washing or tooling to remove the fine surface layer and expose the aggregate and cement below. This surface treatment has the general effect of exposing a surface of reasonably uniform colour and texture. This form of surface treatment can produce a fine smooth finish by light abrasive sand or grit blasting or grinding or a more coarse texture by heavy surface treatment.

It was the fashion for some years to use coarse finishes to precast concrete panels by exposing the surface aggregate by heavy abrasive blasting or tooling the surface to produce bush hammered,

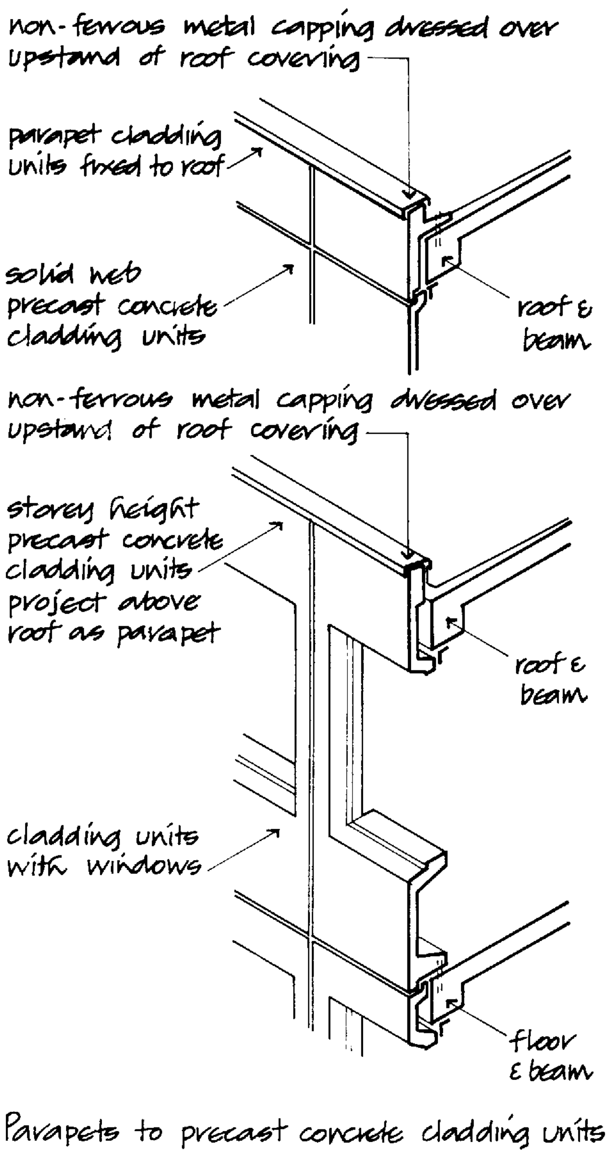


Fig. 144

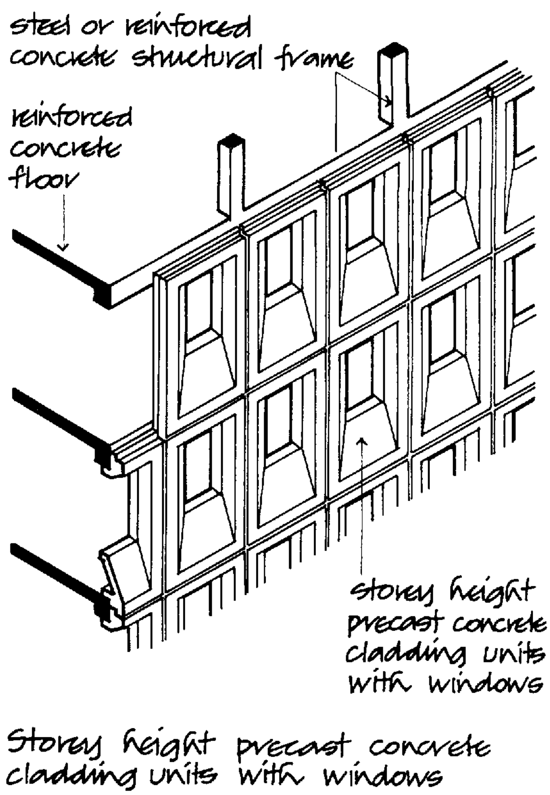


Fig. 145

chisel or pointed tool finishes to emphasise the rugged, heavy nature of the panels.

A variety of profiled finishes is produced by casting the panels face down in moulds against timber, etched metal or glass fibre formers to produce a distinct profiled finished face. The finished face of the panels is acid washed or abrasive blasted to remove the surface of fine particles of cement and expose the aggregate. Much favoured at one time was a board marked finish produced by casting on to the surface of boards which had been grit blasted so that the finished concrete surface displayed the grain of the wood.

Of recent years profiled finishes to precast concrete panels have lost favour partly by change of fashion and particularly because the dull, grim effect of these finishes, accentuated by surface staining, is not particularly attractive in the dull light of northern climates.

Exposed aggregate finishes are produced by casting the panels face up so that a selected aggregate of comparatively large stones may be spread over the wet compacted concrete and lightly compacted in place so that the aggregate is exposed. Once the concrete has hardened the surface is washed or blasted to remove traces of cement to expose the colour and texture of the aggregate. This form of rugged finish, which at one time was highly fashionable, has since lost favour.

Applied finishes

It is common today, where precast concrete cladding panels are used, to provide facing materials of brick or stone to the panels for the advantage of casting and fixing such traditional finishes to precast panels to minimise site labour.

Any sound, well-burnt type of brick that is reasonably frost resistant may be used as a facing material and fixed to the precast concrete panels using the mould to produce the full range of brick construction features such as corbels, string courses, piers and arches.

The facing brickwork is bonded to the concrete panel either with a mechanical key or by stainless steel or nylon filament ties. A mechanical key can be provided where bricks with holes in them are used and cut along the length of the brick, so that the resulting semicircular grooves may provide a bond to the concrete. To ensure a good bond to the bricks it is essential to thoroughly saturate the bricks before the backing concrete is placed. Where ties are used to retain the face bricks in place the nylon filament, stainless steel wire or bars are threaded through holes in the brickwork and turned up between bricks as loops to bond with the backing concrete.

The face brickwork may be pre-pointed or post-pointed. For pre-pointing, fillets are suspended between the joints in brickwork which is laid in the bed of the mould and the pointing material of cement, lime and sand is then pumped into the space below the fillets. The face of the brickwork is protected from mortar by a cloth or paper impregnated with a retarder laid in the bed of the mould. The fillets are removed and the backing concrete placed and compacted over the bricks and around the tie loops. The face pointing, which is usually up to 25 deep, is allowed to harden before the concrete is placed. For post-pointing the bricks are laid in the bed of the mould between neoprene strips to provide the necessary recess of about 20 for pointing and the concrete backing is then cast on the bricks and consolidated. Pointing is carried out on site when the cast panels are in place.

This is a labour intensive way of providing a brick facing to concrete panels that at best will provide a simulation of traditional brickwork. Because there have to be both horizontal and vertical movement joints between the concrete panels, which will interrupt any attempt to copy loadbearing brickwork, it provides the possibility of setting the bricks in any pattern, other than the traditional bonded horizontal bonded pattern, for purely decorative purposes.

Natural and reconstructed stone facing slabs are used as a decorative finish to precast concrete panels. Any of the natural or reconstructed stones used for stone facework to solid backgrounds may be used for facings to precast concrete panels. For ease of placing the stone facing slabs in the bed of the mould, it is usual to limit the size of the panels to not more than 1.5 metres in any one dimension. Granite and hard limestone slabs not less than 30 thick and limestone, sandstone and reconstructed stone slabs not less than 50 thick are used.

The facing slabs are secured to and supported by the precast panel through stainless steel corbel dowels at least 4.7 mm in diameter, that are set into holes in the back of the slabs and cast into the concrete panels at the rate of at least 11 per metre square of panel and inclined at 45° or 60° to the face of the panel. Normal practice is that about half of the dowels are inclined up and half down, relative to the vertical position of the slab when in position on site. The dowels are set in epoxy resin in holes drilled in the back of the slabs. Flexible grommets are fitted around the dowels where they protrude from the back of the slab. These grommets, which are cast into the concrete of the panel, together with the epoxy resin bond of the dowel in the stone slab, provide a degree of flexibility to accommodate thermal and moisture movement of the slab relative to that of the supporting precast concrete cladding panel. All joints between the stone facing slabs are packed with closed cell foam backing or dry sand and all joints in the back of the stone slabs are sealed with plastic tape to prevent cement grout running in. When the precast panel is taken from the mould the jointing material is removed for mortar or sealant jointing.

To prevent the concrete of the precast panel bonding to the back of the stone slabs either polythene sheeting or a brushed on coating of clear silicone waterproofing liquid is applied to the whole of the back of the slabs. The purpose of this debonding layer is to allow the facing slabs free movement relative to the precast panel due to differential movements of the facing and the backing.

The necessary joints between precast concrete cladding panels faced with stone facing slabs are usually sealed with a sealant to match those between the facing slabs.

Joints between precast concrete cladding panels

The joints between cladding panels must be sufficiently wide to allow for inaccuracies in both the structural frame and the cladding units, to allow unrestrained movements due to shortening of the frame and thermal and moisture movements and at the same time exclude rain.

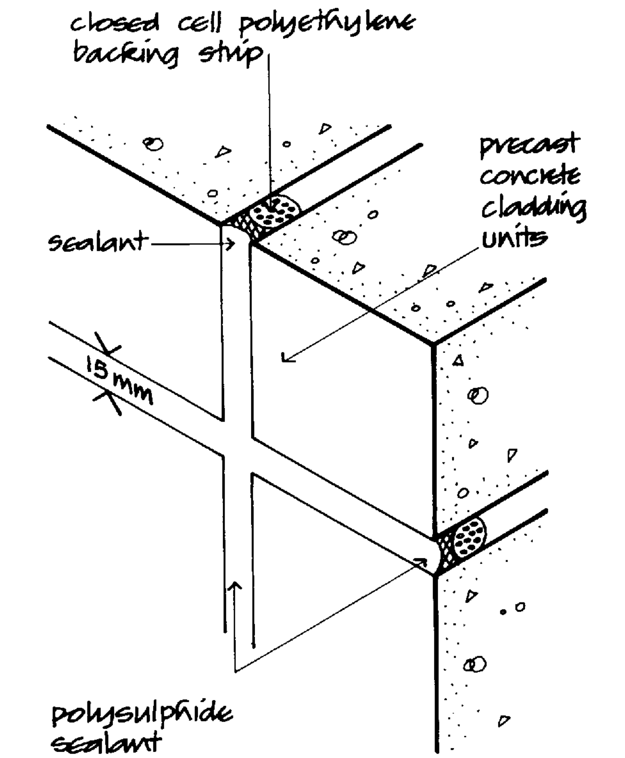
The two systems of making joints between units are the face sealed joint and the open drained and rebated joint.

Sealed joints are made watertight with a sealant that is formed inside the joint over a backing strip of closed cell polyethylene, at or close to the face of the units as illustrated in Fig. 146. The purpose of the backing strip is to ensure a correct depth of sealant. Too great a depth or width of sealant will cause the plastic material of the sealant to move gradually out of the joint, due to its own weight. Sealant material is applied by a gun and compacted and shaped by hand. The disadvantage of sealant joints is that there is a limitation to the width of joint in which the sealant material can successfully be retained and that the useful life of the material is from 15 to 20 years, as it oxidises and hardens with exposure to sunlight and has to be raked out and renewed. Sealed joints are used in the main for the smaller cladding units.

The sealants most used for joints between precast concrete cladding panels are two part polysulphide, one part polyurethane, epoxy modified two part polyurethane and low modulus silicone. Which of these sealants is used depends to an extent on experience in the use of a particular material and ease of application on site. The two part sealants require more skill in mixing the two components to make a successful seal than the one part material which is generally reflected in the relative cost of the sealants.

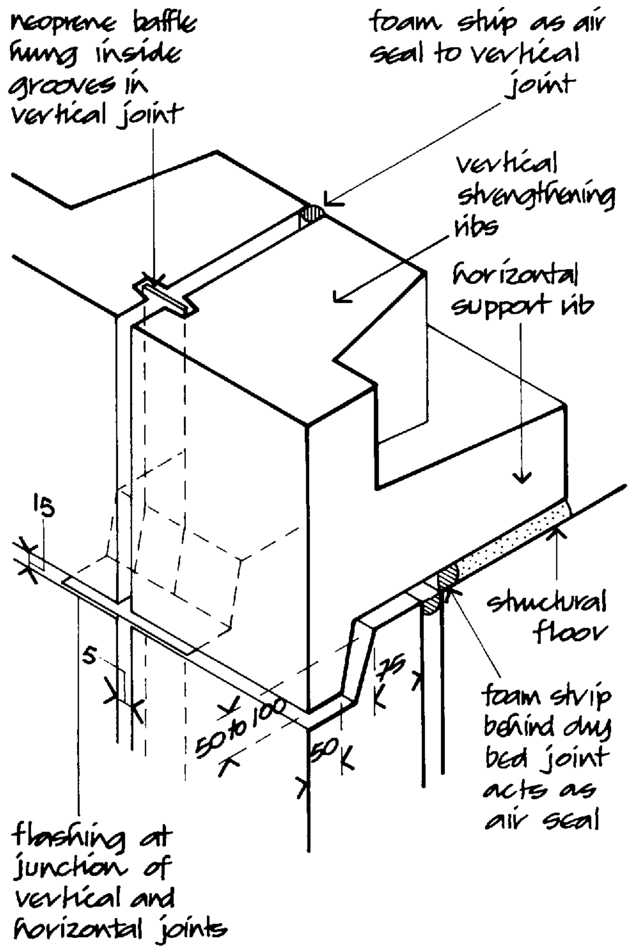
A closed cell polyethylene backing strip is rammed into the joint and the sealant applied by power or hand pump gun and compacted and levelled with a jointing tool.

Open drained joints between precast concrete cladding panels are more laborious to form than sealed joints and are mostly used for the larger precast panels where the width of the joint may be too wide to seal and where the visible open joint is



Sealed joints to precast concrete cladding units

Fig. 146



Open drained joints between storey height precast concrete cladding units

Fig. 147

used to emphasise the rugged, coarse textured finish to the panels.

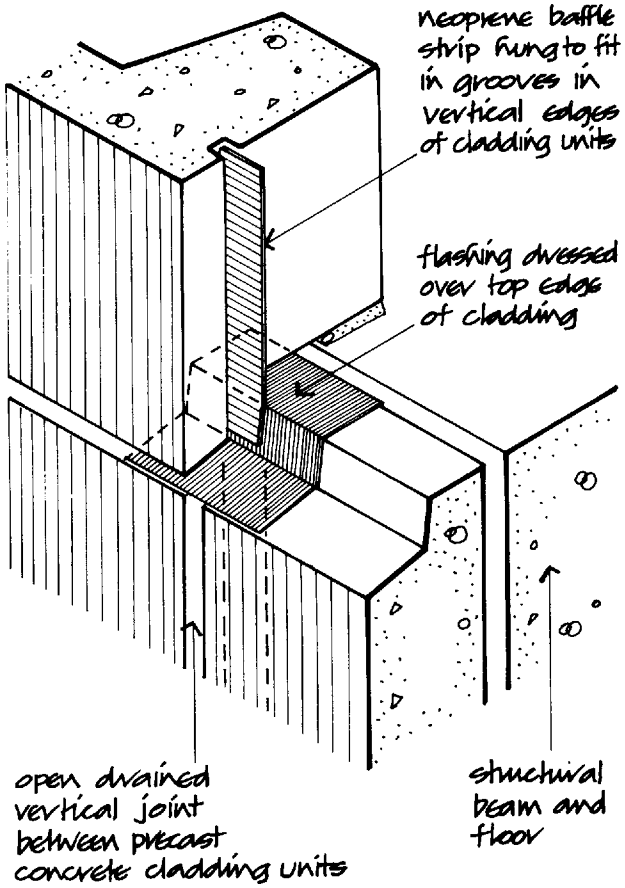
Open joints are the most effective system of making allowance for inaccuracies and differential movements and serving as a bar to rain penetration without the use of joint filling material.

Horizontal joints are formed as open overlapping joints with a sufficiently deep rebate as a bar to rain penetration, as illustrated in Fig. 147. The rebate at the joint should be of sufficient section to avoid damage in transport, lifting and fixing in place. The thickness necessary for these rebates is provided by the depth of the horizontal ribs. The air seal formed at the back of horizontal joints is continuous in both horizontal and vertical joints as a seal against outside wind pressure and driving rain.

Vertical joints are designed as open drained joints in which a neoprene baffle is suspended inside grooves formed in the edges of adjacent units, as illustrated in Fig. 148. The open drained joint is designed to collect most of the rain in the outer zone of the joint in front of the baffle, which acts as a barrier to rain that may run or be forced into the joint by wind pressure. The baffle is hung in the joint so that to an extent there is a degree of air pressure equalisation each side of the baffle due to the air seal at the back of the joint. This air pressure equalisation acts as a check to wind driven rain that would otherwise be forced past the baffle if it were a close fit and there were no air seal at the back of the joint. At the base of each open drained joint there is a lead flashing, illustrated in Figs 147 and 148, that serves as a barrier to rain at the most vulnerable point of the intersection of horizontal and vertical joints. As cladding panels are fixed, the baffle in the upper joints is overlapped outside the baffle of the lower units.

Where there is a cavity between the back of the cladding units and an inner system of solid block walls or framing for insulation, air seals can be fitted between the frame and the cladding units.

It is accepted that the system of open joints between units is not a complete barrier to rain. The effectiveness of the joint depends on the degree of exposure to driving rain, the degree of accuracy in the manufacture and assembly of the system of walling and the surface finish of the cladding units. Smooth faced units will tend to encourage driven rain to sheet across and up the face of the units, and so cause a greater pressure of rain in joints than there would be with a coarse textured finished which will disperse



Open drained vertical joint between precast concrete cladding units.

Fig. 148

driven rain and wind and so reduce pressure on joints.

The backs of cladding panels will tend to collect moisture by possible penetration of rain through joints and from condensation of moisture laden air from outside and warm moist air from inside by vapour pressure, which will condense on the inner face of panels. Condensation can be reduced by the use of a moisture vapour check on the warm side of insulation as a protection against interstitial condensation in the insulation and as a check to warm moist air penetrating to the cold inner face of panels.

Precast concrete cladding panels are sometimes cast with narrow weepholes, from the top edge of the lower horizontal ribs out to the face, in the anticipation that condensate water from the back of the units will drain down and outside. The near certainty of these small holes becoming blocked by windblown debris makes their use questionable.

Attempts have been made to include insulating material in the construction of precast cladding, either as a sandwich with the insulation cast between two skins of concrete or as an inner lining fixed to the back of the cladding. These methods of improving the very poor thermal properties of concrete are not successful because of the considerable section of the thermal bridge of the dense concrete horizontal and vertical ribs that are unavoidable and the likelihood of condensate water adversely affecting some insulating materials.

It has to be accepted that there will be a thermal bridge across the horizontal support rib of each cladding panel that has to be in contact with the structural frame.

The most straightforward and effective method of improving the thermal properties of a wall structure clad with precast concrete panels is to accept the precast cladding as a solid, strong, durable barrier to rain with good acoustic and fire resistance properties and to build a separate system of inside finish with good thermal properties. Lightweight concrete blocks by themselves, or with the addition of an insulating lining, at once provide an acceptable internal finish and thermal properties. Block wall inner linings should be constructed independent of the cladding panels and structural members, as far as practical, to reduce interruption of the inner lining as illustrated in Fig. 149.

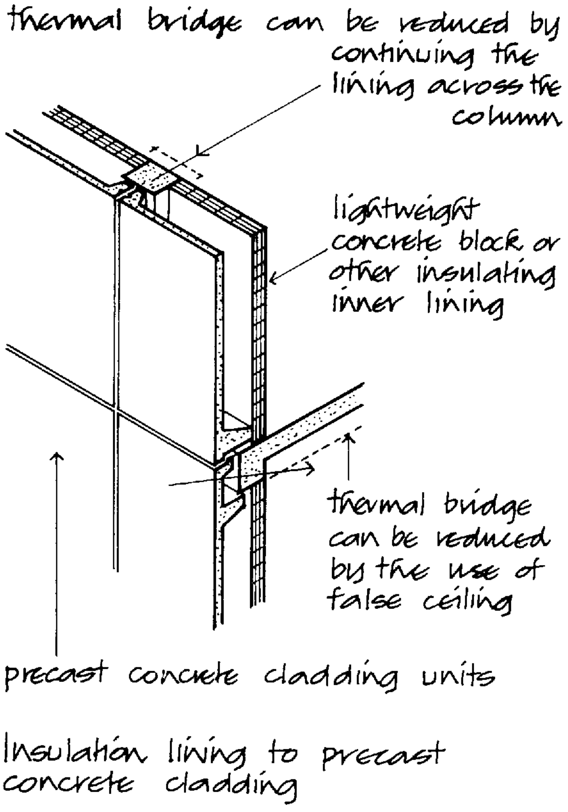


Fig. 149

GLASS FIBRE REINFORCED CEMENT CLADDING PANELS (GRC)

Glass fibre reinforced cement as a wall panel material was first used in the early 1970s after studies at the Building Research Establishment and the production of an alkali resisting glass fibre. The material has since been used as a lightweight substitute for precast concrete in wall cladding in the UK, in America, the Middle East and Japan.

The principal advantage of GRC as a wall panel material is weight saving as compared to similar precast concrete panels. Much of the mass of concrete used in panels is required as protection of the steel reinforcement against atmospheric chemical attack, whereas alkali resisting glass fibre, which is not subject to attack, can be used in panels with a skin thickness of 10 to 15 and a weight saving of about 80% of that of a comparable concrete panel. This weight reduction will afford substantial savings in transport, handling and erection costs and some small saving in structural frame members.

Because of the fine grain of the material that can be used in the manufacture of GRC and the freedom from the constraint of the need for steel reinforcement and its necessary cover against corrosion, this material can be formed in a wide variety of shapes, profiles and accurately finished mouldings. The material has inherently good durability and chemical resistance, is non-combustible, not susceptible to rot and will not corrode or rust stain. The limiting factors in the use of this material arise from relatively large thermal and moisture movements and the restricted ductility of the material.

The material is a composite of cement, sand and alkali resistant (AR) glass fibre in proportions of 40–60% cement, 20% water, up to 25% sand and 3.5–5% glass fibre by weight. The glass fibre is chopped to lengths of about 35 before mixing. It is formed in moulds by spray application of the wet mix, which is built up gradually to the required thickness and compacted by roller. After the initial 3 thickness has been built up it is compacted by roller to ensure a compact surface finish. For effective hand spraying the maximum width of panel is about 2 metres. For mass production runs of panel, a mechanised system is used with dual spray heads which spray fibre and cement, sand and water separately in the mould which moves under the fixed spray heads. The mechanised spray results in a greater consistency of the mix and a more uniform thickness of panel than is usually possible with hand spraying.

The moulds for GRC are either timber or the more durable GRP lined, timber framed types. Spray moulded GRC panels have developed sufficient strength 24 hours after moulding to be taken from moulds for curing.

The size of GRC cladding panels is limited by the method of production as to width and to the storey height length for strength, transport and lifting purposes. It is also limited by the very considerable moisture movement of the cement rich material, that may fail if moisture movement is restrained by fixings. The usual thickness of GRC single skin panels is 10 to 15.

As a consequence of moulding, the surface of a GRC panel is a cement rich layer which is liable to crazing due to drying shrinkage and to patchiness of the colour of the material due to curing. To remove the cement rich layer on the surface and provide a more uniform surface, texture and colour, the surface can be acid etched, grit blasted or smooth ground. Alternatively the panels can be formed in textured moulds so that the finished texture masks surface crazing and patchiness.

Using ordinary or rapid hardening Portland cement the natural colour of these panels is a light, dull grey. White or pigmented white cement can be used instead of Portland cement to produce a white or colour finish, which may well not be uniform, panel to panel. For a uniform colour finish that can be restored by repainting on site, coloured permeable coatings are used which have microscopic pores in their surface that allow a degree of penetration and evaporation of moisture that prevents blistering or flaking of the coating. Textured permeable finishes such as those used for external renderings and microporous matt and glass finish paints are used.

The thin single skin of GRC does not have sufficient strength or rigidity by itself to be used as a wall facing other than as a panel material of up to about 1 metre square, supported by a metal carrier system or bonded to an insulation core for larger panels, as illustrated in Fig. 150.

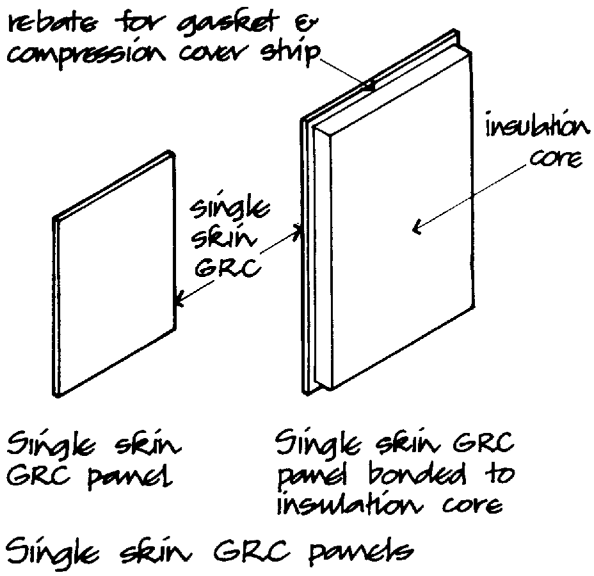


Fig. 150

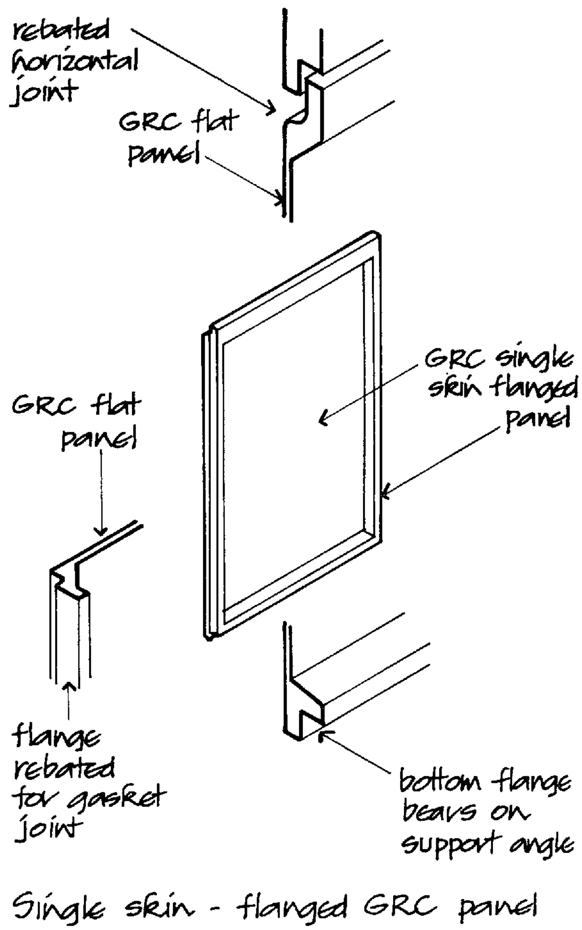


Fig. 151

Storey height, spandrel and undersill panels are made with either flanged or ribbed edges as illustrated in Figs 151 and 152, which serve as stiffeners and provide an edge surface for jointing. The ribs are formed by spraying over preformed hollow or foam plastic formers.

The considerable moisture movement of the cement rich material of GRC panels in variable climates imposes limitations to the size of panel and complexities in fixings that must allow for moisture movement and at the same time support and restrain panels to avoid damage to the panel or fixings. To provide a flexible system of restraint and support fixings for single skin GRC panels and adequate support and stiffness for the comparatively thin material, a stud frame system is much used today for storey height panels. Stud frames are fabricated from cold formed steel sections with welded joints. The galvanised frame is attached to the back of the single skin panel during manufacture, with GRC strips that are rolled into the back of the panel over bent bars welded to the steel frame, as illustrated in Fig. 153. Two gravity anchors secure the GRC panel to the stud frame next to the two support fixings close to the lower edge of the panel. The bent bar restraint fixings to the back of the panel at once provide adequate fixing and accommodate moisture and thermal movements of the panel relative to the stud frame.

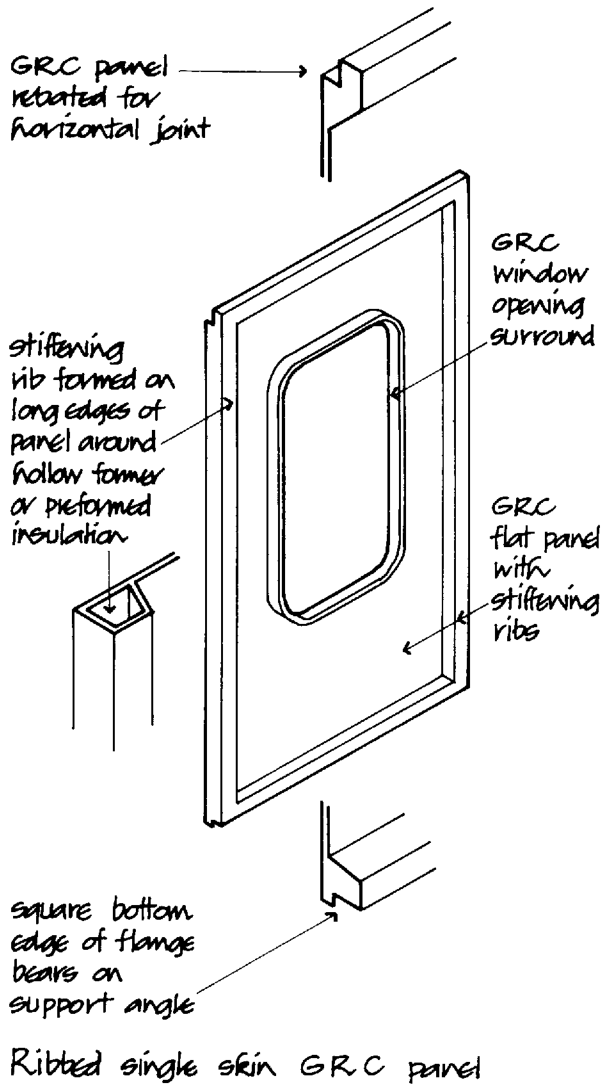


Fig. 152

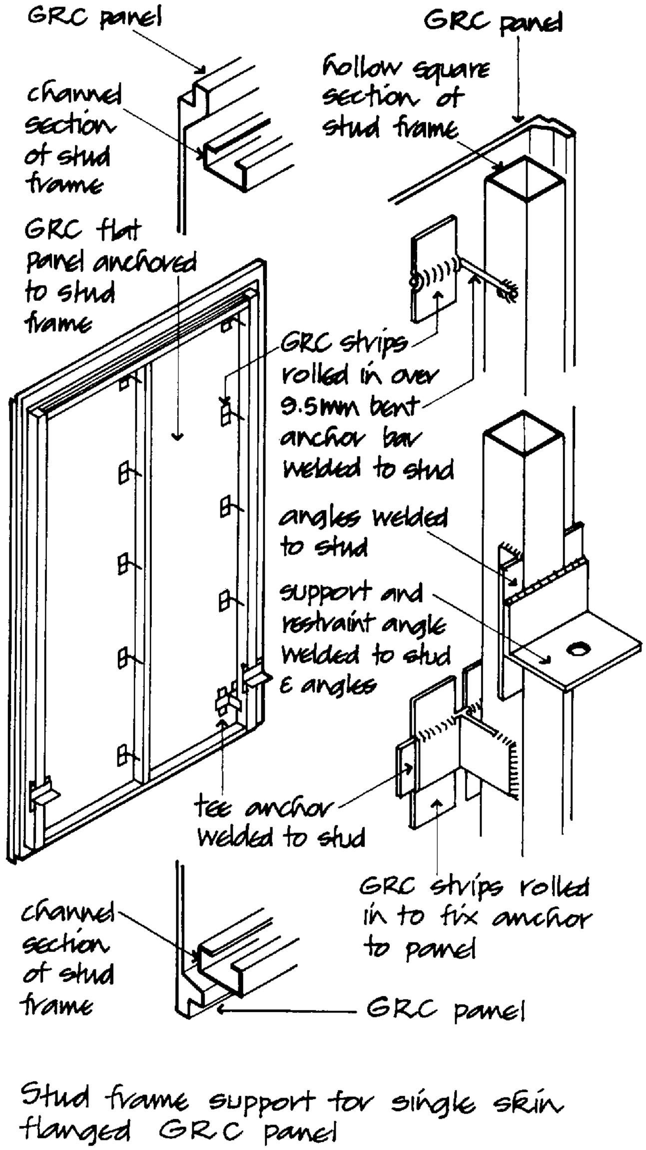
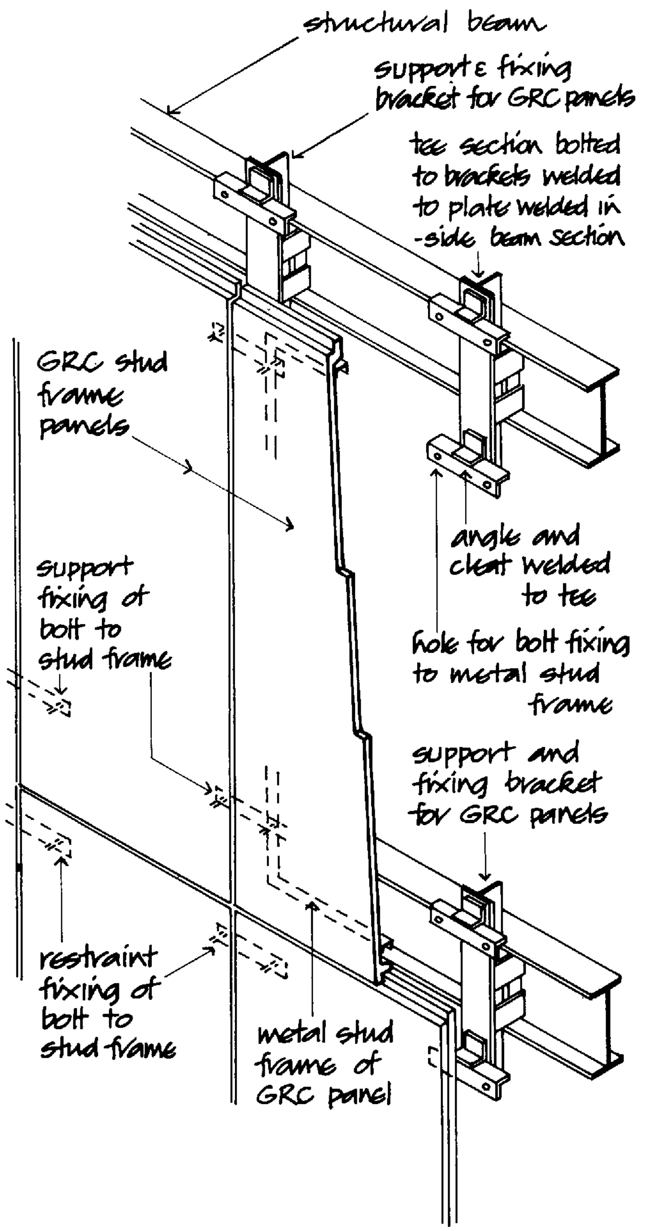


Fig. 153

Figure 154 is an illustration of the fixings for a stud frame to a structural steel frame. This stud frame system of support and restraint for single skin panels which has been used for double storey height panels with success, is the preferred system of construction for GRC panels. A single skin of GRC has poor thermal properties, poor integrity against damage by fire and has to be stiffened for use as large panels.

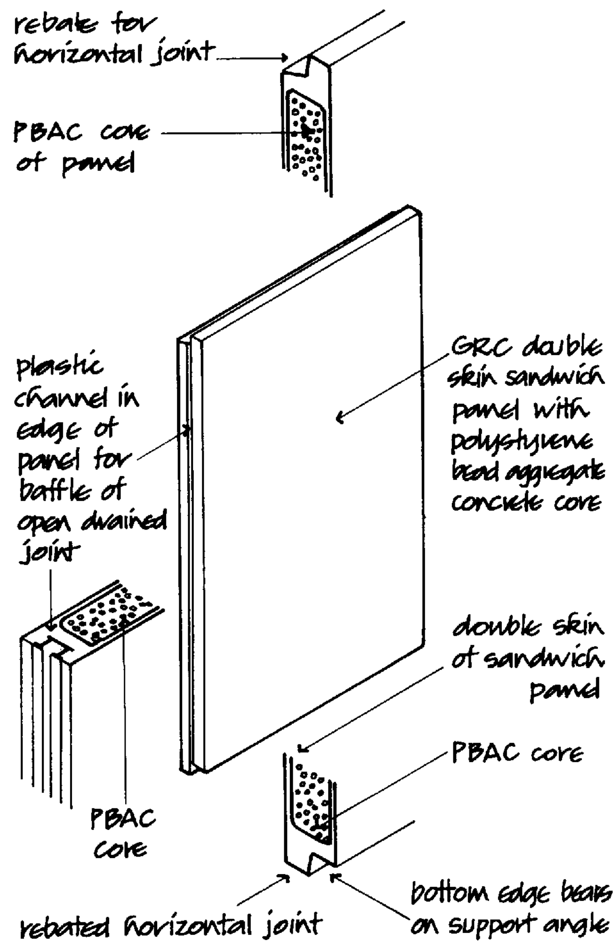
Sandwich panels of GRC, made as a sandwich of two skins of GRC enclosing a core of insulation, have been used to combine the advantages of good thermal properties with the stiffness and strength gained from the sandwich construction. Figure 155 is an illustration of a typical sandwich panel of two skins of GRC formed around a core of insulation. Usual practice is to form ribs of GRC between the two skins across the core as stiffeners to the thin skins.

These composite panels, which in one unit fulfil the functional requirements of a wall, have to a large extent been abandoned in favour of stud frames. The disadvantages of a sandwich panel are the differences in both moisture and thermal movement between the inner and outer skins, which may at the least cause distortion of the panel face and at the most fracture



GRC stud frame panels supported and fixed to structural steel frame

Fig. 154



Double skin GRC sandwich panel with (PBAC) polystyrene bead aggregate concrete core

Fig. 155

of the junction of the skins, interstitial condensation in the core that may cause delamination and distortion of panel faces, the sometimes obvious surface rippling of the outer skin over the core ribs and the inevitable thermal bridge of the solid edge GRC material.

The advantages of GRC as a surface material are that it can be used as a thin, lightweight skin with adequate strength and durability for use as a wall facing material for storey height panels and as undersill or spandrel panels to continuous horizontal windows. Both the tensile and impact strength of GRC diminish with time and allowance is made for this loss of strength in design calculations.

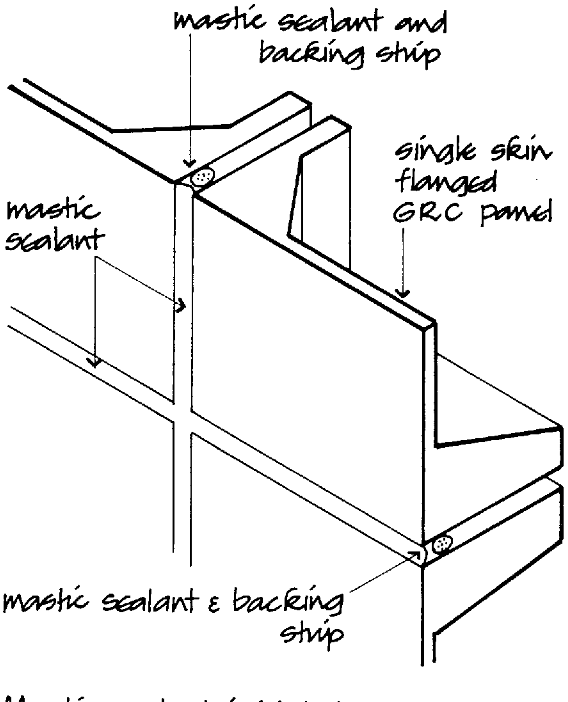
The principal disadvantage of GRC as a material is the considerable moisture movement with changing conditions of atmospheric humidity which impose restraints on its use in climates of varying humidity. This is one of the reasons the material has lost favour in the UK and for its continued use in Middle Eastern countries. There is little moisture movement in the drier climates, and the contrast of light and shade in those countries, enhances the smooth white finish of the great variety of forms possible with this material.

Jointing

The three types of joint used are sealant filled, compression gasket and open drained joint. As with other wall panel materials the sealant filled joint illustrated in Fig. 156 is mostly used for smaller panels with joints of uniform width. The face filled joint will require renewal after some years as the mastic oxidises and hardens.

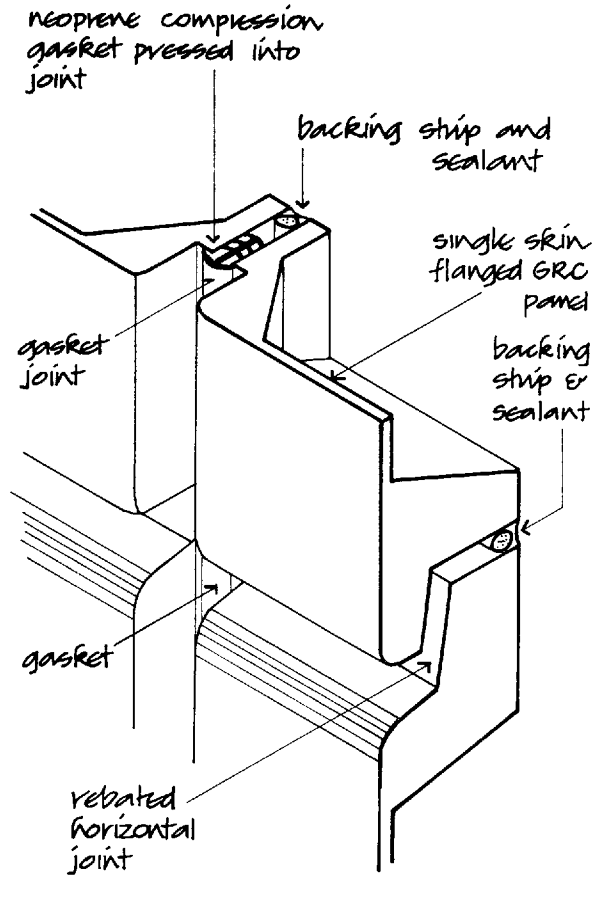
The gasket joint, adopted from glazing techniques, illustrated in Fig. 157, is effective where accuracy in the manufacture and fixing of the panels will ensure a tight fit for the gasket to exclude rain. Preformed cross-over gaskets are heat welded to straight lengths of gasket on site. These compression or push fit gaskets may be recessed for protection or exposed as a feature of the wall face.

The open drained joint illustrated in Fig. 158 requires a considerable edge depth of GRC to



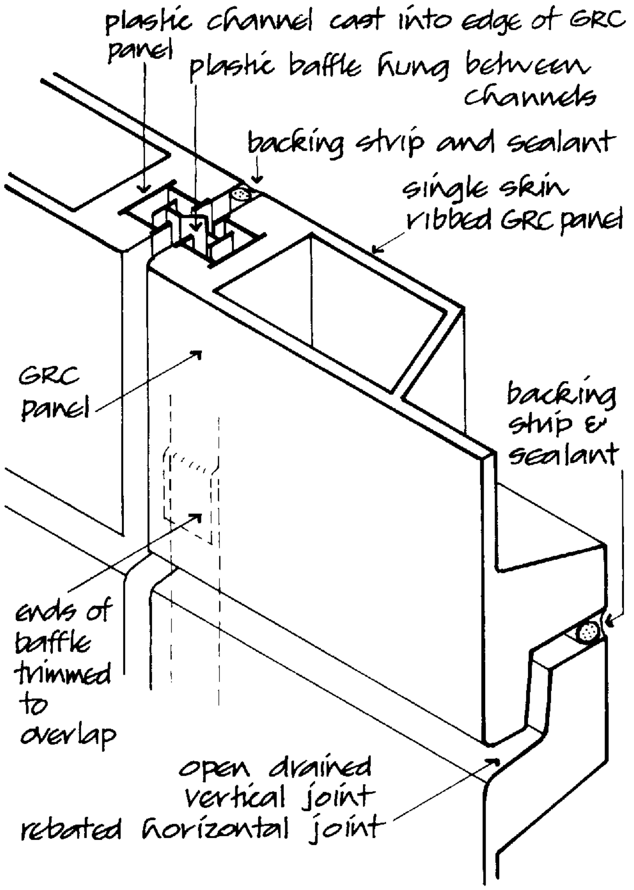
Mastic sealant joint between GRC panels

Fig. 156



Gasket joint between GRC panels

Fig. 157



Open drained joint between GRC panels

Fig. 158

accommodate the channels which are moulded into edges of panels for the baffle. This deep, thick edge which can be moulded as either a flange, a thickened rib or an edge to sandwich panels acts as a comparatively wide thermal bridge. Open drained vertical joints are used with rebated horizontal joints.

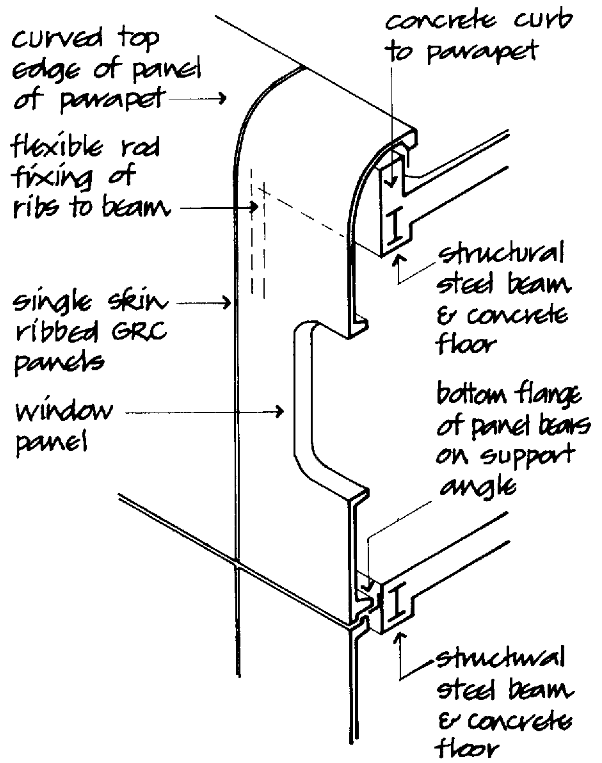
None of these joints will be effective unless there is adequate dimensional accuracy in GRC panels and accuracy in fixing to ensure reasonable uniformity of joint width and a smooth finish to the edges of panels.

Support and restraint fixing of panels

GRC panels should be supported at or near the base of the panel so that the material is in compression to minimise visible shrinkage and movement cracks on the face. The support fixing should either allow some horizontal movement of the panel by the use of low friction pads or, where two support fixings are used, one should allow movement. There should be as few fixings to the carrier system or structural frame as necessary to support and restrain the panel in position and resist lateral wind pressure. For single skin flanged, ribbed and stud frame panels and sandwich panels there should preferably be two lower edge support and restraint fixings and two top restraint fixings to accommodate vertical, horizontal and rotational movements of the panel relative to the frame or carrier system.

The weight of panels is supported on galvanised steel, stainless steel or non-ferrous angles under a GRC flange in the lower edge of panels, as illustrated in Fig. 159, on metal levelling shims or low friction pads or both. The angle is fixed with expanding bolts back to the structure or bolted to carrier systems. Restraint is provided by a dowel, welded to the angle, that fits into a hole or slot in the panel inside a resilient bush or sleeve that allows for movement of the panel.

Restraint fixings are made by threading studs to



GRC panels fixed to structural steel frame

Fig. 159

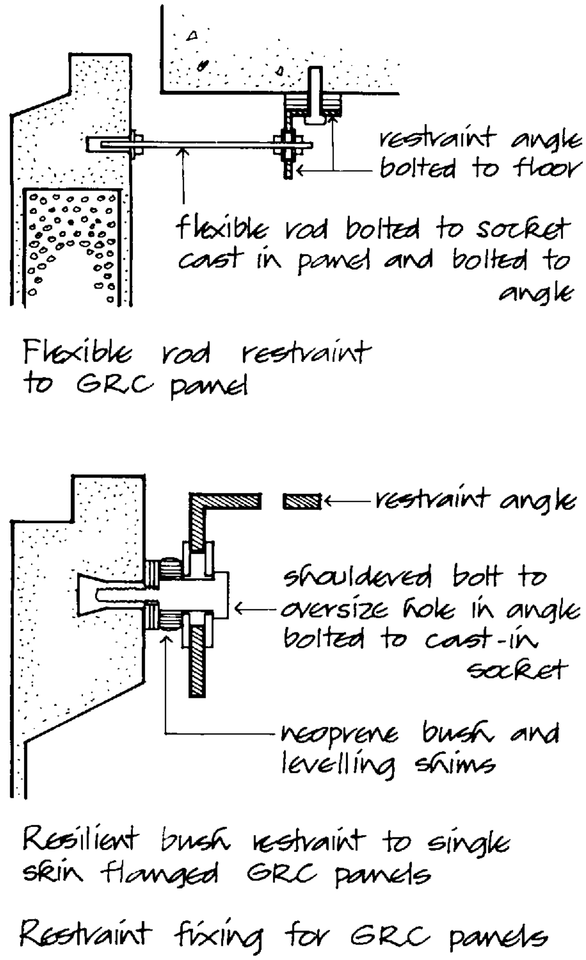


Fig. 160

sockets cast in flanges or ribs at the back of panels, which are bolted to restraint angles, bolted to cleats fixed to the structure or carrier system. Movement of the panel relative to the fixing is provided for by oversize holes or slots in the angle and rubber or neoprene bushes or by flexible rods, as illustrated in Fig. 160.

GLASS FIBRE REINFORCED POLYESTER CLADDING (GRP)

Glass fibre reinforced polyester laminate was first used as a thin skin wall cladding material in the mid 1950s and subsequently up to the late 1970s as a lightweight skin panel material for wall systems. This material has never been used as extensively as precast concrete and of recent years its use has declined.

GRP is a composite of a durable, thermosetting polyester resin, reinforced with glass fibre, that is used as a thin laminate with high strength, low density, good corrosion and weather resistance but a low modulus of elasticity. It can be moulded without pressure or high temperature with comparatively simple, inexpensive equipment to produce an unlimited variety of shape and detail. The polyester resin is supplied as a viscous syrup-like material which is polymerised by the addition of chemical catalysts, under controlled heat, into a hard solid material. Glass fibre is made by drawing molten glass to a filament of glass fibre which has high tensile strength.

GRP cladding panels are made by 'laying up' or spraying the viscous GRP material in moulds lined with GRP. The surface of the mould is first waxed and polished and then coated with a release agent. In the 'laying up' process the materials are laid in the mould by hand in layers of glass fibre mat and resin mixed with catalyst in successive layers, and consolidated by hand. In the spray process the materials are sprayed into the mould and consolidated by hand in layers.

As a preliminary to laying up or spraying the GRP material in the mould, a thin gel coat of resin is spread on to the surface of the mould. The primary purpose of the gel coat is as a protection against moisture which might otherwise penetrate the surface of the GRP to the glass fibre and cause swelling, rupture and breakdown of the GRP laminate.

Once the gel coat has hardened sufficiently to be tacky, the first layer of resin, catalyst and glass mat is spread in the mould and consolidated by roller, followed by successive layers up to the required thickness of the laminate. The moulded panel is then taken from the mould and cured in a box or chamber under controlled conditions of temperature and humidity to develop structural and dimensional stability.

Control of the process of manufacturing GRP panels has a most significant effect on the finished product in use as a wall panel material. Selection of the resin, catalyst, fillers and pigment for a particular purpose, the careful mixing of the materials, skill in application of the materials to form a sound laminate, control of curing and control of the conditions of temperature and humidity in the workshop all have a significant effect on the dimensional accuracy, stability, strength and durability of the finished product.

One of the main reasons for the comparatively limited use of this material is the difficulty of control in manufacture and the failures that have been caused by faulty control and poor workmanship.

The natural colour of GRP is not generally accepted as an attractive finish for wall panels and it is usual to make panels that are coloured with a pigment added to the gel coat or the resin binder. The addition of pigment and the selection of colour can appreciably affect the weathering characteristics of GRP panels. Strong colours such as oranges and reds tend to fade through the effect of ultraviolet light, which causes the surface to chalk, and colour fastness may well be irregular between panels. Dark colours encourage high surface temperatures that increase the risk of separation of the laminae of the skin, a failure that is known as lamination. Variations in the surface of flat smooth faced panels, caused by mechanical and thermal distortion, may be obvious in surfaces more than about a metre wide. A matt texture or shallow ribbed finish will effectively mask distortions of the surface without noticeably affecting the smooth sleek surface of this finish.

To enhance the poor resistance to damage and spread of flame characteristics of GRP it is practice to add fillers or chemical additives to the resin or to coat the surface. The addition of fillers to improve the fire retardancy of the material has the effect of weakening its capacity to resist weathering agents and affects pigments which are added. The addition of fillers and pigment to improve fire resistance and colour appreciably reduces the weathering characteristics of this material. One method that has been used to provide protection against weathering and to improve fire resistance is to coat the surface with polyurethane to improve weathering and to modify the gel coat to improve fire resistance.

Because GRP is an expensive material, it is used as a thin skin for all panels in thicknesses of from 3 to 6, and has to be stiffened with edge flanges, shaped profiles, stiffening ribs or a sandwich construction. To be effective as stiffening, shaped profiles must be deep in relation to the thickness of the skin. Because GRP is used for the dramatic effect of the level face of panels, the usual method of stiffening is to bond stiffening ribs to the back of the panel skin. These stiffening ribs are usually made of hollow sections of GRP that are overlaid with GRP as the laminate is built up. Figure 161 is an illustration of a ribbed panel stiffened with top hat and box section hollow ribs.

In common with the other thin skin panel material, metal, GRP can be formed with ease around a

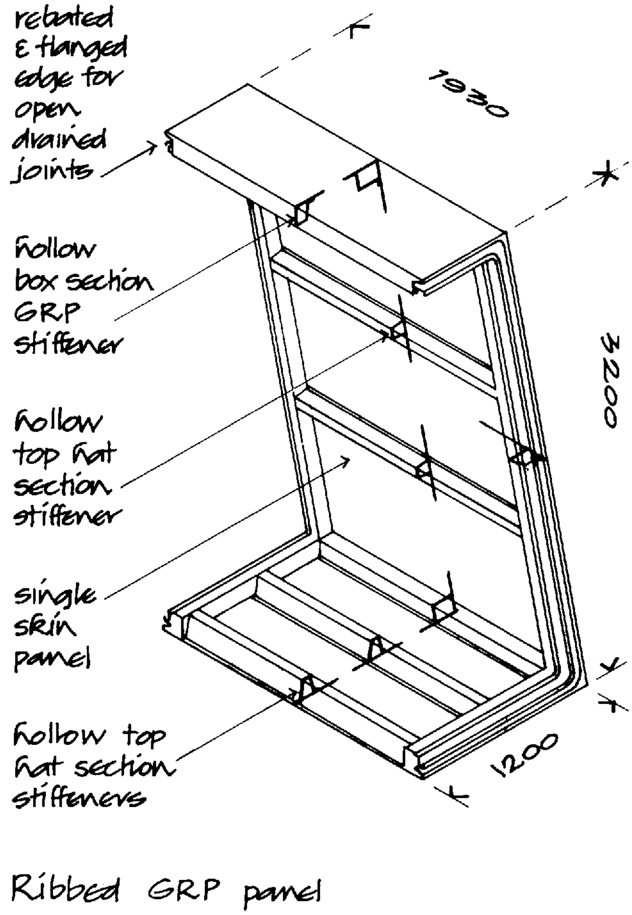


Fig. 161

core of insulating material as a sandwich panel. The sandwich of GRP at once provides stiffening and insulation. These sandwich panels are made with two laminate skins of GRP moulded around the insulating core with the GRP skins joined around the edges of the panel to seal the sandwich and for fixing. Figure 162 is an illustration of a sandwich panel. The size of these panels should be limited to avoid too great a distortion of the finished panel face through differential expansion of core and skin material.

Jointing

As with any other facing panel wall structure the joints between the panels of GRP have to allow for differential structural, thermal and moisture movements between the supporting frame and the wall and must serve as an effective barrier to penetration of rain. The three types of joint that have been used are mastic sealant, gasket and open drained joint.

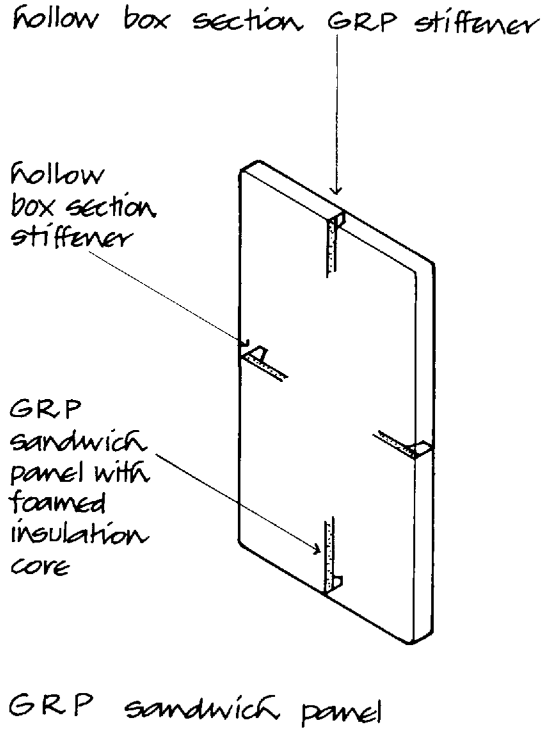


Fig. 162

There have been a number of failures of sealant joints due to overwide joints or poor workmanship or both, which resulted in unsightly mastic failure, and which have given this method of jointing a bad name. Providing the joint is reasonably tight and adequate to the anticipated movements, a skilfully applied sealant joint will give satisfactory performance for the life of the sealant material, which will need periodic attention.

Gasket jointing techniques, adopted from glazing, have been successfully used for GRP panels. Preformed gaskets of neoprene or ethylene propylene diamine monomer (EPDM) fit around and seal the edges of adjacent panels with the gasket compressed to the panels with adjustable clamps bolted to the carrier system, as illustrated in Fig. 163. These gaskets have preformed cross-over intersections at the junction of horizontal and vertical joints that are heat welded on site to straight lengths of gasket. Both neoprene and EPDM gaskets oxidise, harden and lose resilience on exposure and may need replacement every 10 to 20 years.

Open drained joints have the advantage that the jointing material is not visible and that the open drain serves as a check to driving rain. The open drained joint illustrated in Fig. 164 has outer and inner drain channels and a baffle.

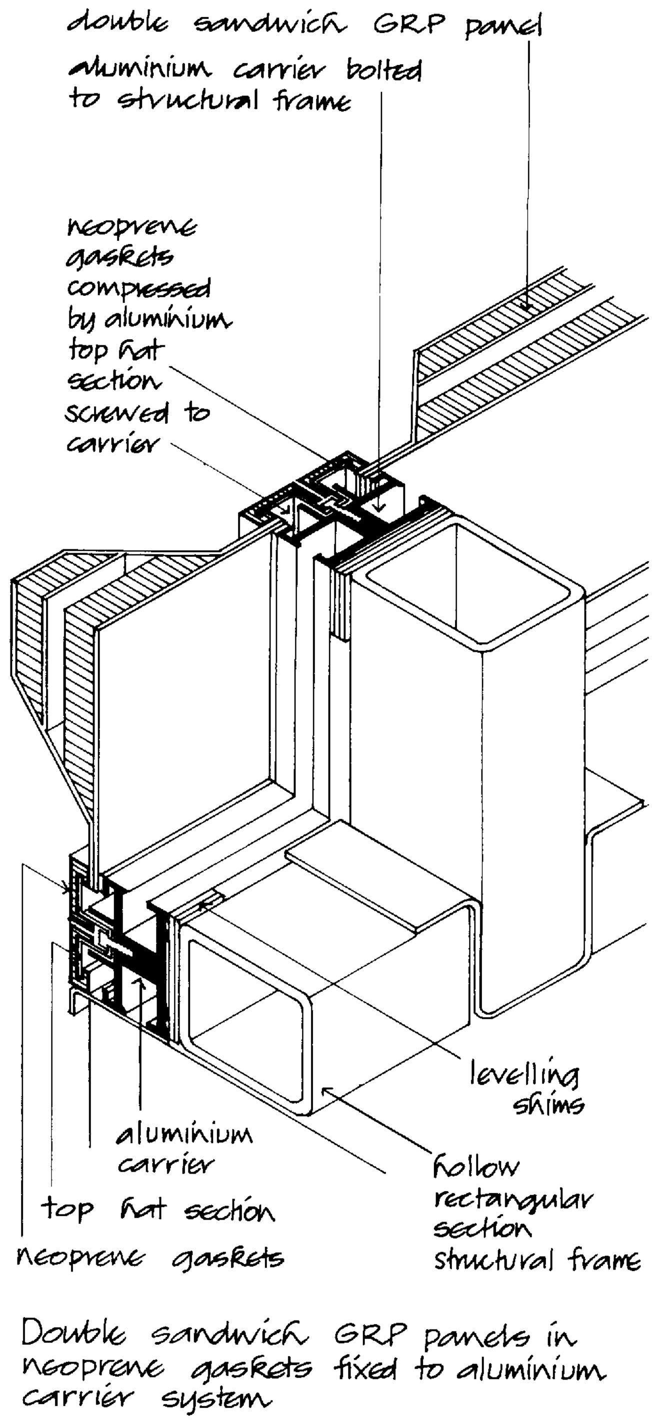


Fig. 163

Support and fixing

Because GRP is a comparatively expensive material it is used as a thin skin and in consequence GRP panels are lightweight and do not by themselves require substantial support fixings. Because of the

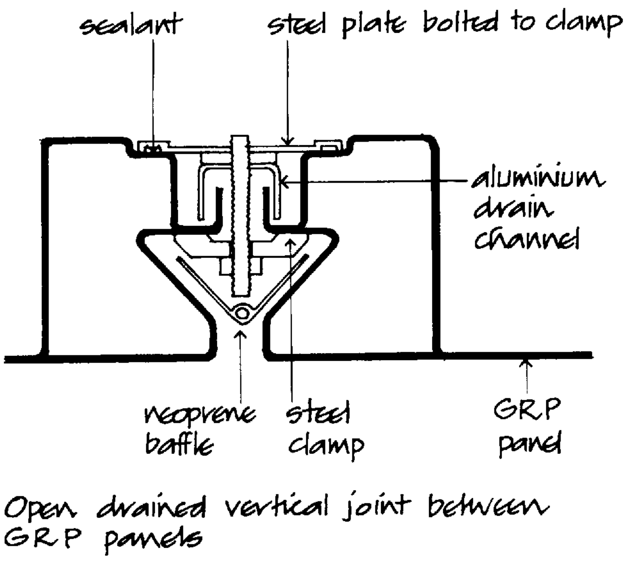


Fig. 164

considerable thermal movement of GRP and the thin skin form of its use, it is essential to support and restrain panels to or in fixings that will allow for thermal movement and restrain the lightweight panels in position. Usual practice is to clamp panels back to the structure or to the carrier system inside neoprene or EPDM gaskets that hold the panels in place and act as weather seal. The neoprene gasket illustrated in Fig. 163 is clamped in place by a top hat metal section screwed to the aluminium carrier.

Another method of support and fixing is to incorporate timber battens or framing in either single skin or sandwich panels. The timber battens can be enclosed in the GRP laminate as stiffening ribs and used as a means of fixing the panel by screwing back to the carrier system or structure and as a means of fixing for windows.

GRP as a material for wall panels lost favour principally because of failure due to poor manufacturing techniques and lack of colour fastness to expose surfaces. Since the introduction of this material for use as wall panels there have been considerable improvements in the mixing manufacture and use of thermosetting materials which, applied to this type of panel, could make it wholly acceptable as a wall panel material.

INFILL WALL FRAMING TO A STRUCTURAL GRID

Infill wall frames are fixed within the enclosing members of the structural frame or between projections of the frame, such as floors and roof slabs, which are exposed as illustrated in Fig. 165. The infill wall may be framed with timber or metal sections with panels of glass in the form of a window wall, framed around solid panels of any one of the thin sheet materials, framed above a brick or block riser

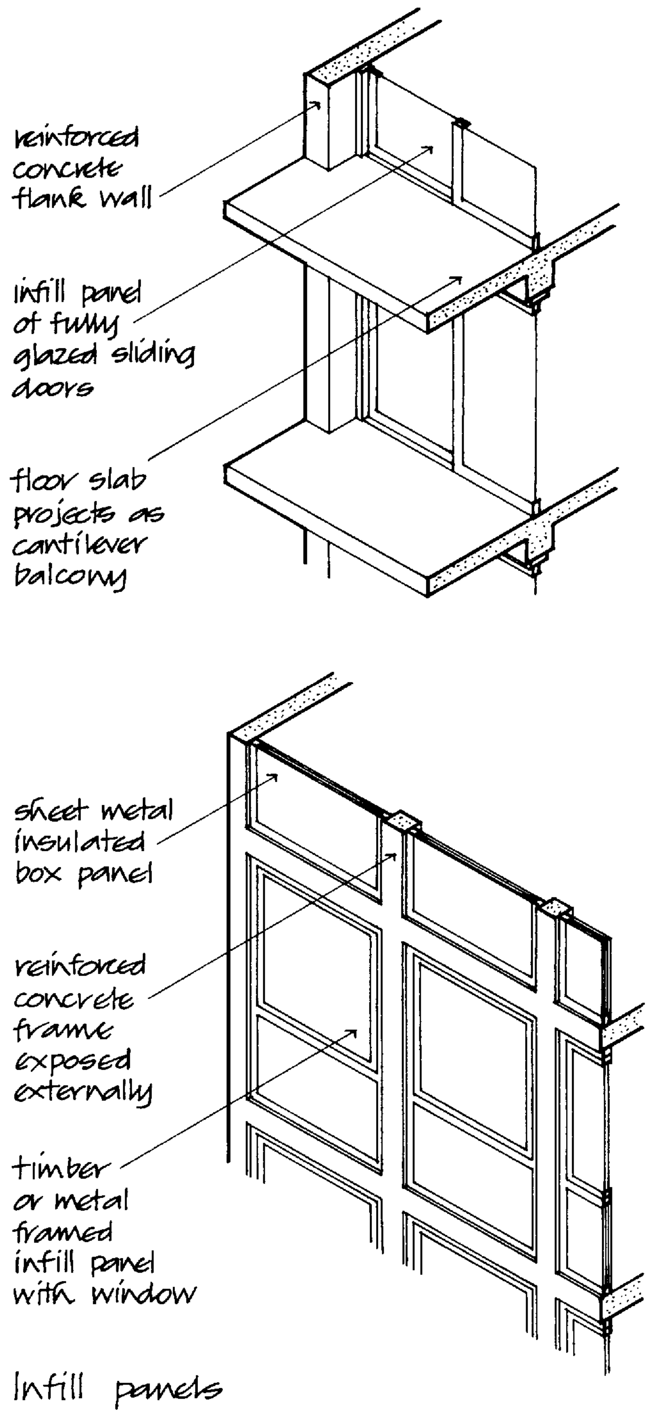


Fig. 165

below sill level or framed as support for wood, metal or GRP sheeting with or without windows. Any one or more of the thin sheet materials may be used as panel framing or covering to the supporting frame to serve as a wall element to satisfy the functional requirements of strength and stability, resistance to weather, durability, fire safety and resistance to the passage of heat and sound.

The framing with its panels or sheet covering should have adequate strength and stability in itself to be self-supporting within the framing members and resist wind pressure and suction acting on it, in the position of exposure it is fixed. There should be sufficient support and restraint fixings between the frame and the surrounding structural members. The framing and its panels and sheet covering must adequately resist the penetration of water to the inside face by a system of resilient mastic or drained and sealed joints between framing and panels, of the type used for windows (see Volume 2) and overlap, drained and sealed joints of the type used for sheet metal or GRP sheeting. The joints between the framing and the structure should be filled with a resilient filler and weathersealed with mastic to accommodate structural, moisture and thermal movements.

To enhance the thermal resistance of the lightweight framing and covering materials double glazing and/or solar control glass should be used with double skin insulated panels, insulation between framing members or behind sheet covering materials.

In the 1950s and 1960s, following the end of the Second World War, the infill wall frame system was much used in framed buildings, particularly for multi-storey housing, as an expedient to utilise readily available materials that could be used in the mass production and rapid fixing of wall elements, in extensive programmes of housing that occurred in many northern European countries.

Many of the early infill wall frame systems suffered deterioration due to the use of steel framing poorly protected against corrosion, panel materials that absorbed water and poor jointing materials that gave inadequate protection against rain penetration. These failures, coupled with the introduction of alternative walling materials such as concrete, GRC and GRP panels and glazed walls, led to loss of favour of wall infill framing.

There is some logic in the use of lightweight wall framing as an apparent cladding element within the load carrying structural frame, as compared to the current fashion for covering the whole of the outside of a structural frame with what appears to be a loadbearing wall with all the features of brickwork such as piers, arches and decorative string courses provided by an outer skin of brick attached to the structural frame, where a loadbearing wall by itself could often support floors by itself.

In many countries where summer temperatures are high and shade from the sun is a necessity, and concrete is the most economic and readily available material, many buildings both large and small are constructed with a reinforced concrete frame with projecting floors and roof for sun shade and as shaded outdoor balcony areas in summer as illustrated in Fig. 165. Because of the protection afforded by the projecting floor slabs and roof against wind driven rain and the diminuition of daylight penetration caused by these projections, in winter months, it is common practice to form fully glazed infill panels in this form of construction.

With the variety of solid walling materials, such as brick, stone and block, and lightweight panels and wall sheeting available extensive combinations of these materials are possible as infill walling to framed structures.

Infill wall framing, which is currently out of fashion may well, as fashions do, have a new lease of life as a sensible form of enclosure to buildings.

GLAZED WALL SYSTEMS

Up to the beginning of the twentieth century glass was a comparatively expensive material. Window glass was made by hand in the spun, crown glass process and later the blown cylinder process. Window glass made by these processes was cut into comparatively small squares (panes) for use in the windows of traditional loadbearing walls. Plate glass was made by casting, rolling and grinding and polishing sheets of glass both sides. These laborious methods of production severely limited the use of glass in buildings.

With the development of a continuous process of drawing window glass in 1914 and a process of continuously rolling, grinding and polishing plate glass in the 1920s and 1930s, there was a plentiful supply of cheap window glass and rolled and polished plate glass.

In the 1920s and 1930s window glass was extensively used in large areas of windows framed in slender steel sections as continuous horizontal features between under sill panels and as large metal framed windows. During the same period rolled plate glass was extensively used in rooflights to factories, the glass being supported by glazing bars fixed down the slope of roofs. Many of the sections of glazing bar that were developed for use in rooflights were covered by patents so that roof glazing came to be known as 'patent glazing' or 'patent roof glazing'.

The early uses of glass as a wall facing and cladding material were developed from metal window glazing techniques or by the adaptation of patent roof glazing to vertical surfaces, so that the origins of what came to be known as 'curtain walling' were metal windows and patent roof glazing.

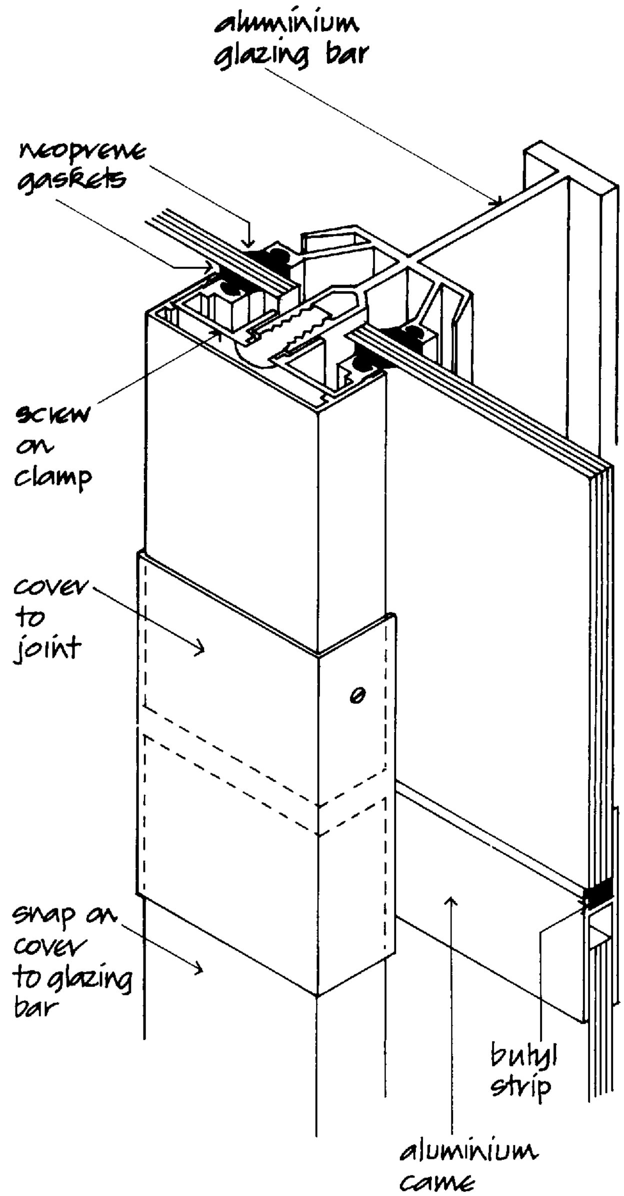
The early window wall systems, based on steel window construction, lost favour principally because of the rapid and progressive rusting of the unprotected steel sections that in a few years made this system unserviceable. The considerable buckling and distortion of frames and fracture of glass that was due to rusting, rigid putty fixing of glass and rigid fixing of framing gave steel window wall systems a bad name.

With the introduction of zinc coated steel window sections and the use of aluminium window sections there was renewed interest in metal window glazing techniques. Cold formed and pressed metal box section subframes, which were used to provide a bold frame to the slender section of metal windows, were adapted for use as mullions to glazed wall systems based on metal window glazing techniques. These hollow box sections were used either as mullions for mastic and bead glazing of glass and metal windows or as clip on or screw on cover sections to the metal glazing.

Hollow box section mullions were either formed in one section as a continuous vertical member, to which metal window sections and glass were fixed, or as split section mullions and transomes in the form of metal windows with hollow metal subframes that were connected on site to form split mullions and transomes. The complication of joining the many sections necessary for this form of window panel wall system and the attendant difficulties of making weathertight seals to the many joints has, by and large, led to the abandonment of window wall glazing systems.

Glass for rooflights fixed in the slope of roofs is to a large extent held in place by its weight on the glazing bars and secured with end stops and clips, beads or cappings against wind uplift. The bearing of glass on the glazing bars and the overlap of bays down the slope act as an adequate weather seal.

To adapt patent roof glazing systems to vertical glazed walls it was necessary to provide a positive seal to the glass to keep it in place and against wind suction, to support the weight of the glass by means of end stops or horizontal transomes and sills and to make a weathertight seal at horizontal joints.



Aluminium glazing bar used for vertical glazing

Fig. 166

The traditional metal roof glazing bar generally took the form of an inverted 'T' section with the tail of the T vertical for strength in carrying loads between points of support with the two wings of the T supporting glass. For use in vertical wall glazing it was often practice to fix the glazing bars with the tail of the T inside with a compression seal on the outside holding the glass in place, as illustrated in Fig. 166.

The usual section of metal glazing bar, which is well suited to roof glazing, does not provide a simple, positive fixing for the horizontal transomes and sills necessary for vertical glazing systems. The solution was to use continuous horizontal flashings or cames on to which the upper bays of glass bore and up to which the lower bays were fitted, as illustrated in Fig. 166. Patent roof glazing techniques, adapted for use as vertical glazing, are still in use but have by and large been superseded by extruded hollow box section mullion systems.

Hollow box section mullions were designed specifically for glass curtain walling. These mullion sections provided the strong vertical emphasis to the framing of curtain walling that was in vogue in the 1950s and 1960s and the hollow or open section transomes with a ready means of jointing and support for glass. The pattern of what came to be known as curtain walling was set by the United Nations Secretariat Building and Lever House in New York, in which the framing elements of slender vertical mullions supporting glass and smooth panels were emphasised by mullions as continuous verticals up the height of the building.

Hollow box section mullions, transomes and sills were generally of extruded aluminium with the section of the mullion exposed for appearance sake and the transome and sill and head joined to mullions with spigot and socket joints, as illustrated in Fig. 167. A range of mullion sections was available to cater for various spans between supporting floors and various wind loads. The mullions, usually fixed at about 1 to 1½ metre centres, were secured to the structure at each floor level and mullion lengths joined with spigot joints as illustrated in Fig. 167. The spigot joints between mullions and mullions and between mullions and transomes, head and sill, made allowance for thermal movement and the fixing of mullion to frame allowance for differential structural, thermal and moisture movements. Screw on or clip on beads with mastic or gasket sealants held the glass in place and acted as a weather seal. This form of curtain walling with exposed mullions was the fashion during the 1950s, 1960s and early 1970s.

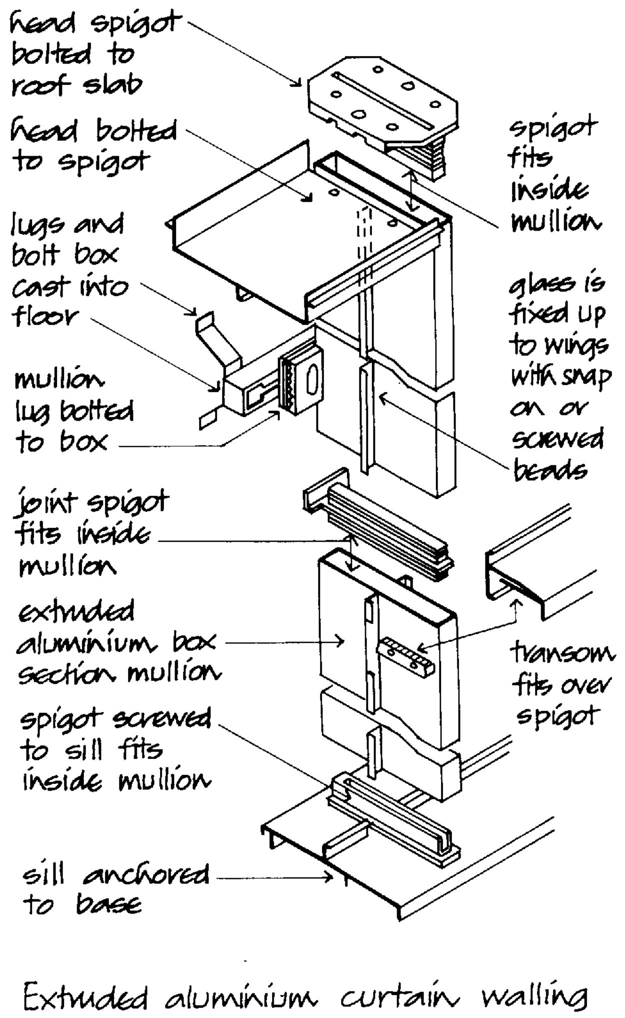
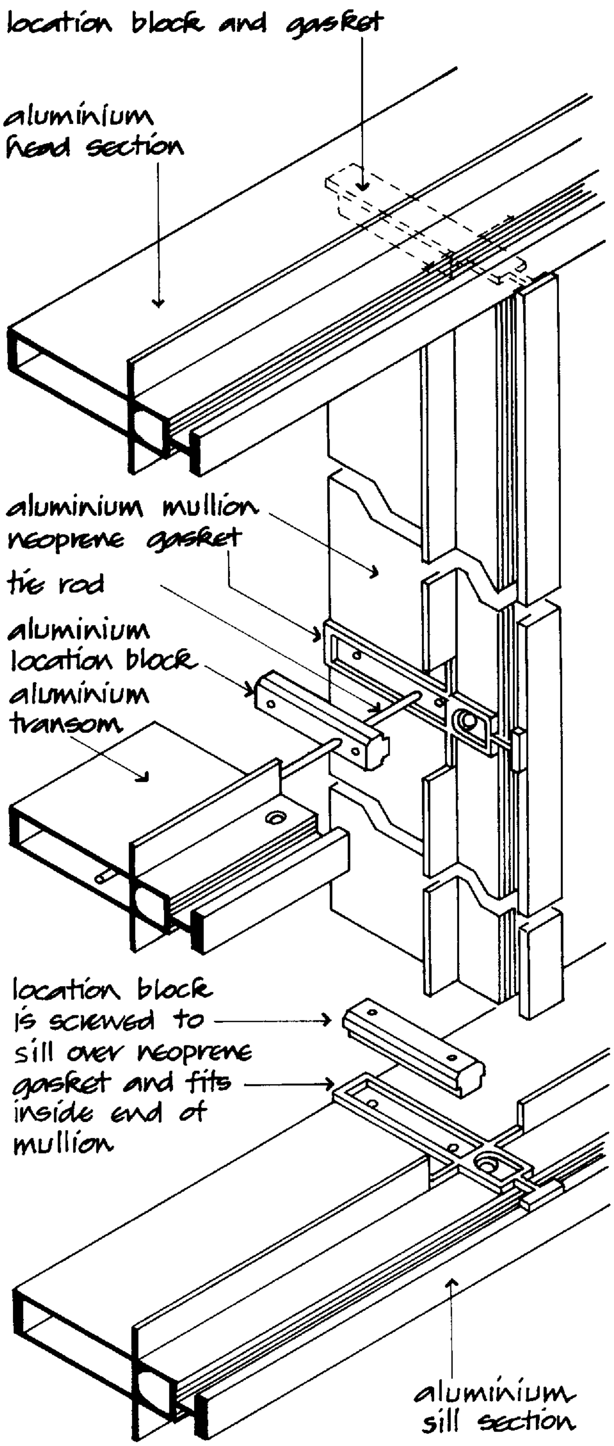


Fig. 167

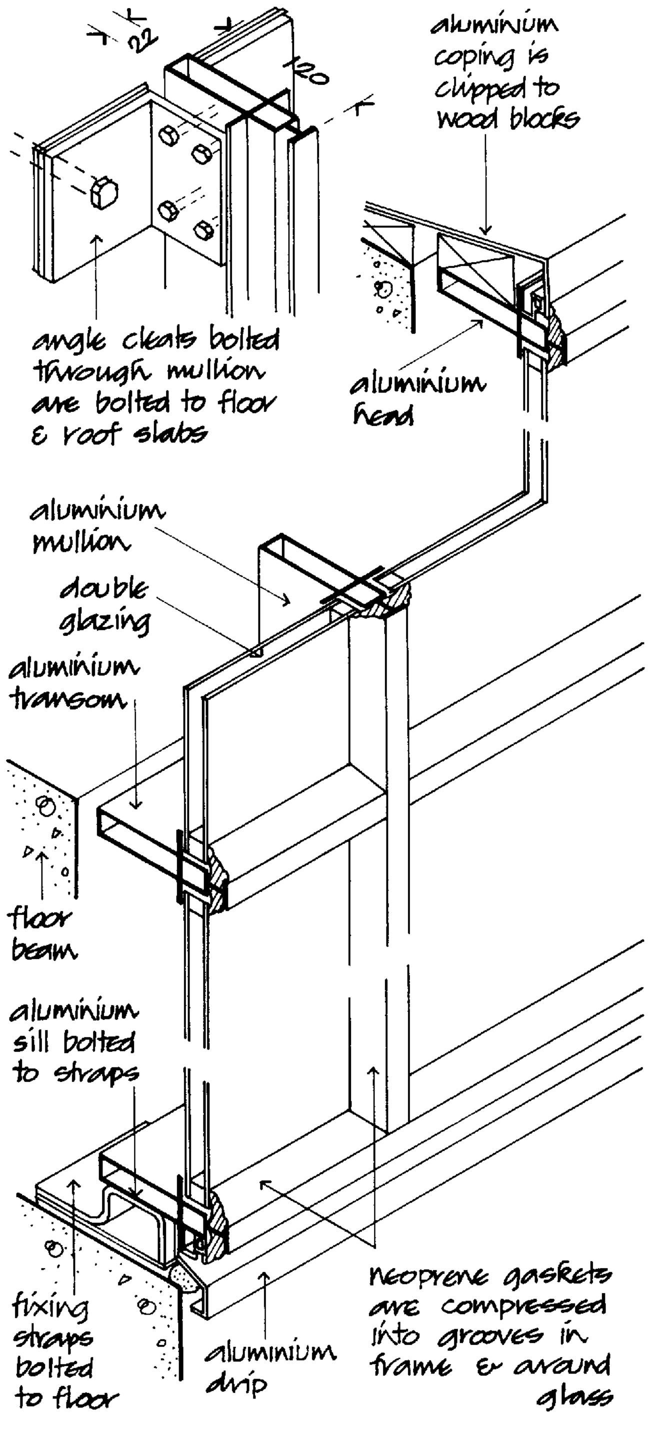
Since then fashion has changed. The introduction of tinted solar control glass and the use of gaskets to provide a more positive rain and wind weather seal around glass has facilitated a move to systems of glass walls where the hollow box section framing members are fixed behind the glass, which is held in slender gaskets, to give the appearance of a glass wall, as illustrated in Figs 168 and 169.

More recently the use of toughened glass, hung from brackets fixed to the structure, has provided the means of effecting what is truly a curtain wall of glass. The large squares of toughened glass are hung from the top by metal studs anchored to the frame with additional restraint fixings, as illustrated in Fig. 170. The joints between the glass are sealed with a silicone based sealant.



Aluminium carrier frame for glazed and panel wall cladding

Fig. 168



Glazed wall cladding in aluminium carrier

Fig. 169

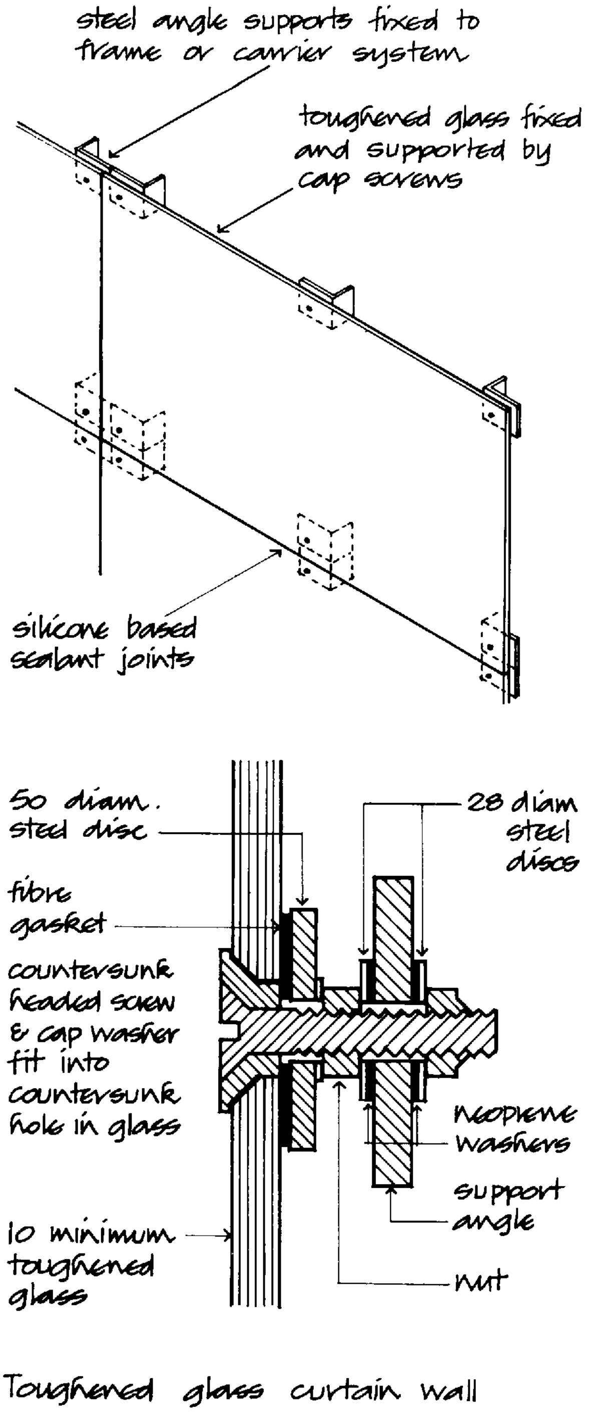


Fig. 170

GLASS

Float glass

Most of the flat glass used in building today in the UK is produced by the float method of production that was first introduced in 1959.

In the float process, molten glass from the melting furnace runs on to and floats across the surface of an enclosed bath of molten tin. The glass is maintained in a chemically controlled atmosphere at a high enough temperature for the surfaces to become flat and parallel. The glass is cooled as it moves across the molten tin, until it is hard enough to be taken out. A continuous sheet of glass, uniform in thickness and with bright fire polished surfaces, is produced. The thickness of the finished glass is controlled by speeding the flow of molten glass across the surface of molten tin to make it thinner and slowing down the flow to make it thicker. The range of glass thickness produced is from 3 to 15. This flat glass has the fire polished finish of drawn glass and the freedom from distortion of plate glass.

Solar control glass

Solar heat gain through clear sheet glass, in the early days of the use of large window areas and curtain walling, did produce uncomfortable conditions of heat inside buildings by the transmission of solar energy directly through glass.

Most buildings that have more recently been constructed with large areas of glass exposed to solar radiation, use one of the solar control glasses to reduce solar heat gain. These solar control glasses reduce the transmission of solar energy by absorbing or reflecting some of the energy of the sun. The heat absorptive glasses are produced with a colour tint throughout the thickness of the glass or a colour to one surface. The effect of the colour tint of green, grey or bronze is to absorb some solar radiation.

Heat reflective glasses are produced by coating one surface of the glass with a thin reflective film which gives the glass a colour by reflection, such as silver, bronze and a wide choice of other colours. Solar control glass absorbs more solar energy and becomes hotter and expands more than clear glass. It is often used as much for the effect of the colour of the glass as for its solar control property.

Toughened glass

Toughened glass is made by a process of heating and cooling which causes compressive stresses in the surface of the glass which are balanced by tensile stresses in the centre thickness of the glass. These counterbalancing stresses give toughened glass its increased strength. This glass will only break under extreme loads which bend the glass sufficiently to overcome the stresses, or by severe impact with a sharp object that may penetrate the surface and so release the stresses and cause the glass to fracture. Toughened glass is up to five times stronger than ordinary glass of the same thickness.

The proprietary names 'Armourplate', 'Armourcast' and 'Armourclad' are used for toughened glass.

A glazed wall system should satisfy the functional requirements of a wall where it serves as the building envelope, and the requirements of a window where it serves to admit daylight and provide ventilation.

Strength and stability

The strength and stability of a glazed wall depend on the size, thickness and nature of the glass in resisting lateral wind pressure, the section of the mullions between support and restraint fixings to the structure, the section of the transomes and sills in supporting glass and the arrangement of joints between framing members and between glass and framing member, to allow for thermal movement of the glass wall and structural movements.

For economy in the use of glass and framing, the usual spacing of proprietary mullion sections is from 760 to 1200 for 6 thick float glass. Mullion spacing of up to 2400 has been used with mullions specifically engineered for the purpose. Mullions should have adequate section to withstand lateral wind pressures acting on the glass they support between fixings at each floor level without undue deflection and they should have sufficient strength to support the weight of glass and framing between support fixings without undue lengthening by elastic strain. The system of support fixings for mullions depends on the arrangement of panels of glass, both fixed and for opening lights and opaque panels of glass or sheet metal between floors. Usual practice is to use one support fixing with one restraint fixing for each storey height or one support fixing and two restraint fixings for every two storey height lengths of wall so that the mullions are hung from a rigid fixing and restrained by lower fixings to allow for differential movements between structure and glass wall framing.

Support fixings take the form of lugs or brackets fixed to the back of mullions that are bolted to the structure, as illustrated in Fig. 169, with expanding bolts fixed to holes drilled in concrete or directly to steel. Each support fixing must be firmly attached to the structure to support the necessary weight of glass and framing. No provision for movement is made at support fixings.

Restraint fixings are designed to retain the framing and allow for differential movements between the glass wall system and the structure. Restraint fixings take the form of lugs or brackets fixed to the back of mullions and bolted to the structure, through slotted holes to allow some differential movement, with low friction plastic washers that allow movement and at the same time restrain the fixing. Where there are support fixings at each floor level for storey height lengths of mullion, the spigot joint between mullions illustrated in Fig. 167 serves as a restraint fixing. Another form of restraint fixing is a bracket fixed to the structure where the back of the mullion is restrained in a channel in which the mullion has some freedom of vertical movement.

Movement joints between frame members are formed by spigot joints between lengths of mullion and spigot joints of transomes and sills to mullions, such as those illustrated in Fig. 167. These joints, which are weather-sealed with mastic or with neoprene gaskets (Fig. 167), allow for thermal movements of glass and framing and some differential movement between glazed wall and structure.

Glass is secured in place on spacer blocks under the lower edge of the glass and with neoprene gaskets that are compressed to the glass by a compression fit, as illustrated in Fig. 169, or by a compression strip on the gasket, as illustrated in Fig. 166. The edge clearance of the glass in the framing and the resilience of the gasket allow for thermal movement of the glass in the metal framing.

Exclusion of wind and rain

The smooth, hard impermeable surface of glass in curtain walls allows wind-driven rain to flow in sheets both across and up and down the face of the wall. Rain, under pressure of wind, will penetrate the smallest gap at joints between glass and framing. The joints between glass and framing have to be wide enough to accommodate movements and at the same time serve as a weather seal to both wind and rain.

Many of the earlier curtain wall systems relied on cover beads to keep the glass in place and mastic seals to exclude rain, with a drainage channel behind the glass to collect rain that penetrated joints. The most vulnerable points in these systems were the junctions of horizontal to vertical framing members, where the joints between beads and frame members generally allowed some penetration of rain and wind. Current practice is to employ neoprene or EPDM gaskets preformed to fit around each individual square of glass that is fixed close to the outside face of the mullion. These gaskets effectively seal the junction of glass and framing. The neoprene gasket illustrated in Fig. 169 is a push fit compression seal that is compressed into a rebate in the frame and fits tightly around the edges of the glass. The seal illustrated in Fig. 166 is a compression seal that fits around the glass and is compressed into a frame with a screwed on compression strip. Neoprene gaskets have better resilience but become hard and brittle more quickly than EPDM seals. On exposure to sunlight, both types of seal oxidise, harden and lose resilience and may need replacing every twenty years or so. Compression gaskets preformed as a continuous joint around each square of glass are the most effective weatherseal.

Thermal properties

A thin sheet of glass provides negligible resistance to the transfer of heat. Systems of double or triple glazing can be used to improve thermal properties of glass. The transfer of heat of single glazing is assumed as 5.7 Wm^2K, double glazing as 2.8 W/m^2K and triple glazing as 2.0 W/m^2K. The improvement in insulation by using double glazing is plainly worthwhile. Building regulations concerned with conservation of energy require a minimum level of insulation against transfer of heat through walls and permit a percentage of the area of the wall to be glazed. The requirements for offices is that a maximum of 35% of the area of a wall may be single glazed. A proportionally larger area may be double glazed. The effect of this regulation is that the rest of the wall requires an insulation value of 0.45 W/m^2K. The consequence is that either nearly two-thirds of a glass wall have to have some form of insulating lining or backing to comply with the regulations, or some system of heat recovery has to be used to satisfy the energy conservation requirement. As an alternative the calculation procedure may be used to certify that the energy consumption in a fully glazed building would be no more than it would be for a similar building, calculated by the elemental approach.

For the purposes of insulation, most glass wall systems use double glazing with composite metal panels between sill and head levels of windows or inner linings of insulting panels or back up walls or combinations of these. Many glazed wall systems use tinted solar control glass either as single or double glazing.

Thermal bridge

The metal framing members of glazed wall systems are good conductors of heat and act as a thermal bridge. Where double glazing and insulated panels are used the thermal bridge effect of the supporting metal frame is such that it is worth considering the use of some form of thermal break. The simplest form of thermal break is made by extending the neoprene gasket system over the face of the metal frame. This provides some little reduction in transmittance. A more sophisticated and more effective thermal break is to interpose some material with low transmittance in the framing as a break in the thermal bridge. The plastic thermal break in the carrier system illustrated later, in Fig. 177, is effective as a break in the thermal bridge of the frame, which itself has an insulated core. Plainly the complication of this form of construction is only worthwhile in framing members around panels with moderate or good insulating values.

Acoustic properties

A thin sheet of glass offers little resistance to the transmission of airborne sound because of its small mass per unit area. Double or triple glazing will effect some reduction in sound transmission (see Volume 2).

Fire resistance

A glass wall system is an 'unprotected area' as defined in the Building Regulations and as such is limited in area for buildings over 15 metres high. In multi-storey glazed wall systems it is necessary to use some form of fire resistant panel, lining or back up wall to a part of glazed walls. This requirement for fire resistance is usually combined with the requirement for thermal insulation.

SHEET METAL WALL CLADDING

Sheet metal has for many years been used as wall cladding principally in the form of profiled sheets of steel or aluminium that are used both as a roof covering and wall cladding to factories and other single storey buildings. The original sinusoidal section corrugated iron has largely been replaced by trapezoidal section sheets, for their improved span and appearance. Both galvanised steel and aluminium profiled sheets can be coated with an inorganic plastic coating as a protection and for the range of colours possible with these coatings. The properties, sections and uses of these profiled sheets were described in Volume 3.

Because of the very poor thermal properties of a thin sheet of metal and current requirements for energy conservation, a range of composite metal sheets is produced in which an insulating core is sandwiched between two sheets of metal that are profiled to provide stiffness. These composite sheets are used for roof and wall cladding to single storey buildings, for both the advantage of the insulation core and the internal lining of sheet metal.

Sheet metal in the form of panels has been in limited use for some 50 years, principally in France, Germany and America, both as wall cladding and more commonly as opaque panels to curtain wall framing. Of recent years sheet metal cladding panels have been more extensively used, in the vogue for 'high technology' applied to buildings, for the smooth, flat and curved surfaces associated with the modern rolled or pressed metal sheet, machine age image.

Sheet metal cladding can be broadly grouped as:

- Single skin and composite sheets
- Flat and profiled single skin panels
- Flat and profiled composite panels

Single skin profiled sheets

Single skin profiled sheets are made from a steel or aluminium strip that is cold rolled in one direction to a standard range of sinusoidal and trapezoidal profiles. The strength of these sheets depends on the depth of the one-way profile in supporting the loads common to roofs and walls. Because the strength of these sheets lies in the direction of the profile, they are supported by and fixed to sheeting rails at right angles to the profile. As roof and wall covering, the sheets are fixed with end laps of sheets and side laps of the profile to exclude rain. For insulation, an underlining of insulating material or a sandwich of insulating material with an underlining sheet is used. The use of these sheets as roof and wall cladding was described in Volume 3.

Profiled sheeting has traditionally been used as roof and wall cladding to single storey buildings in what is sometimes referred to as the 'shed form' of building common to factories, warehouses and other such buildings with large areas of roof and walls, often without windows. A limited range of flashings is available for weathering and to provide a finish at sills, eaves, ridges and around openings.

Of recent years profiled sheets have been used in non-traditional ways in what has come to be known as the 'super shed' form, principally for single storey buildings. Profiled sheets have been used with the profile fixed horizontally or diagonally across walls as a continuous wall covering, often with curved sheets to eaves and corners, or in panels with purpose made angles both of metal and other sheet material, with the structural frame either inside the enclosing cladding or exposed outside for effect.

Composite sheets

A range of standard, flat and profiled composite sheets is available with an insulating core between two sheets of steel or aluminium to combine an acceptable internal finish with adequate insulation. The advantage of profiled composite sheets is in the economy of continuous rolling for mass production. These sheets which are produced in lengths of up to 10 metres, are designed for face fixing to sheeting rails fixed to the structure. The difficulty of making a neat, weathertight and attractive finish to the end of the one way profile of these sheets at corners and around openings has limited their use to simple, wide span shed forms of buildings. The profiled, composite steel sheeting, illustrated in Fig. 171, is designed for use as side wall sheeting to single storey buildings where the sheet can be used in single lengths without horizontal joints and with a side lap formed by the profile.

Flat composite sheets with secret fixings are designed to combine the economic advantages of continuous rolling and the stiffness provided by lamination of the insulating core to the two skins, with the appearance of flat panels for use as walling. The flat steel sheets illustrated in Fig. 172 are made in widths of 900, lengths of up to 10 metres and thickness of 50. The long edges of the sheets are formed to provide an interlocking joint in which the fixings to the sheeting rails are hidden. Sheeting rails are required at up to 3 metre intervals. These sheets are galvanised and coated with coloured inorganic

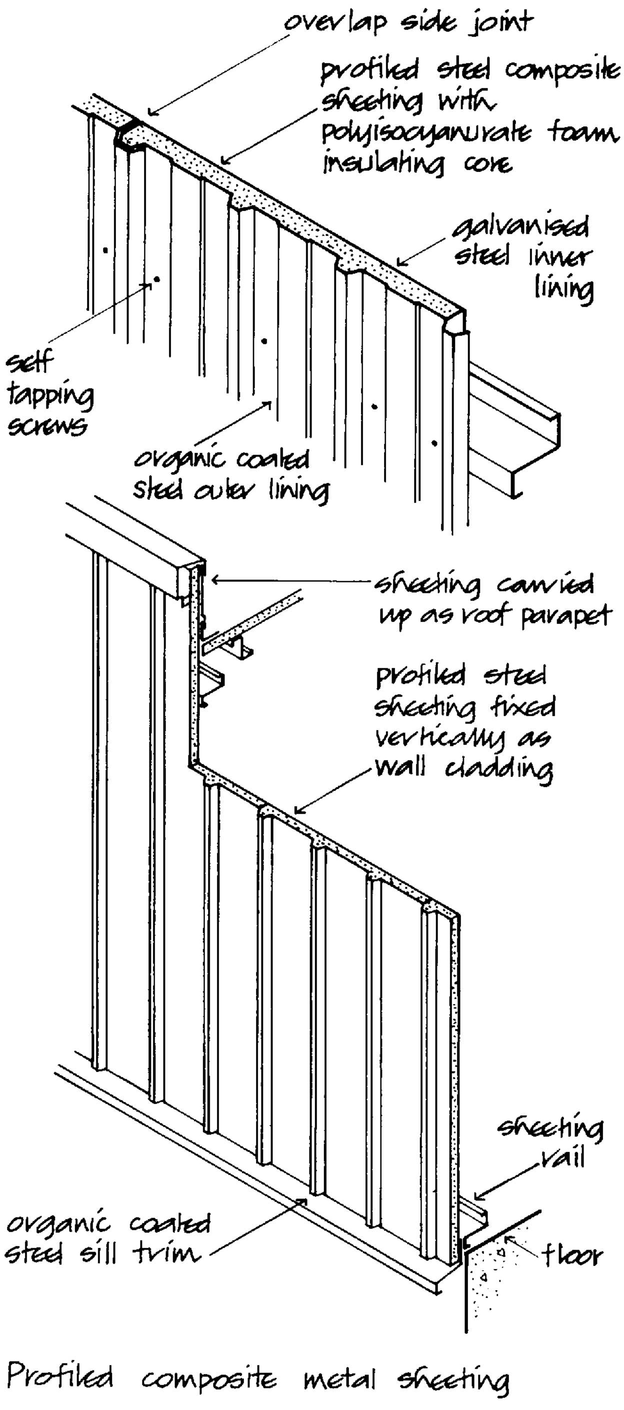


Fig. 171

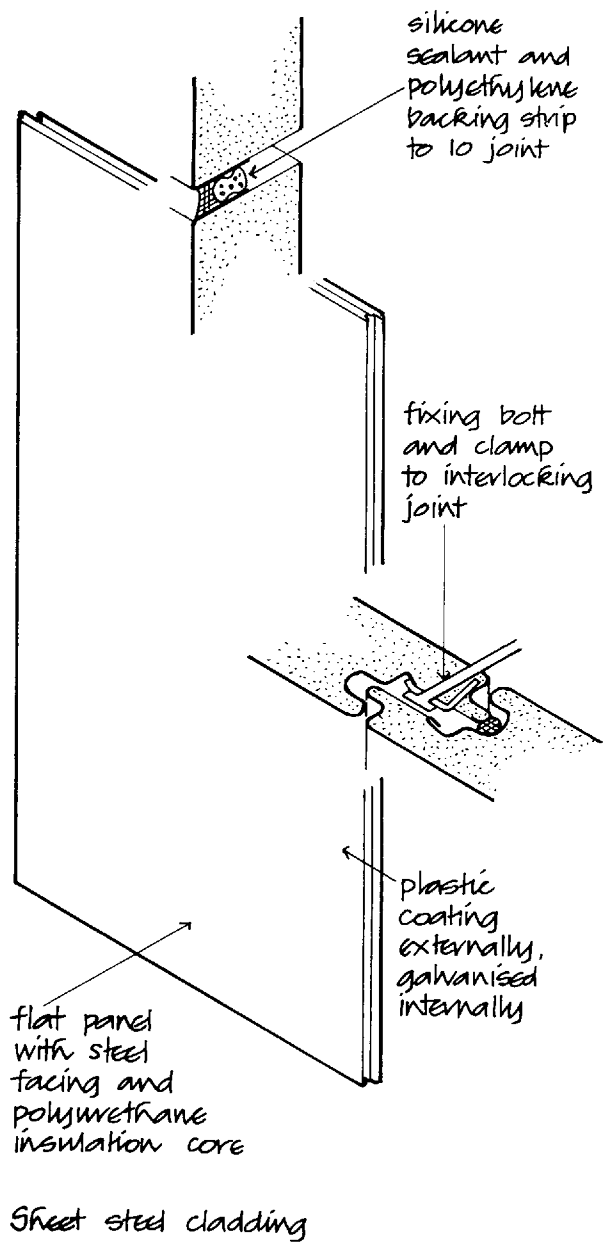


Fig. 172

coating externally and painted internally. End joints are sealed with mastic as illustrated. These sheets can be made with openings for windows with square or rounded corners. The principal use of these flat sheets is for continuous undersill panels between continuous horizontal windows and as flat cladding to walls of single storey buildings.

The aluminium faced composite sheet illustrated in Fig. 173 is made in widths of 600, lengths of up to 10 metres and thickness of 50. Horizontal and vertical joints are made with an insulated plastic insert that is fixed in the edge of one sheet and fits to the adjacent sheet as a male and female joint. The joint is sealed with a neoprene gasket as illustrated. Window panels and square and rounded corner fittings are supplied. The exterior face of these sheets is finished with an oven dried paint finish in a range of colours.

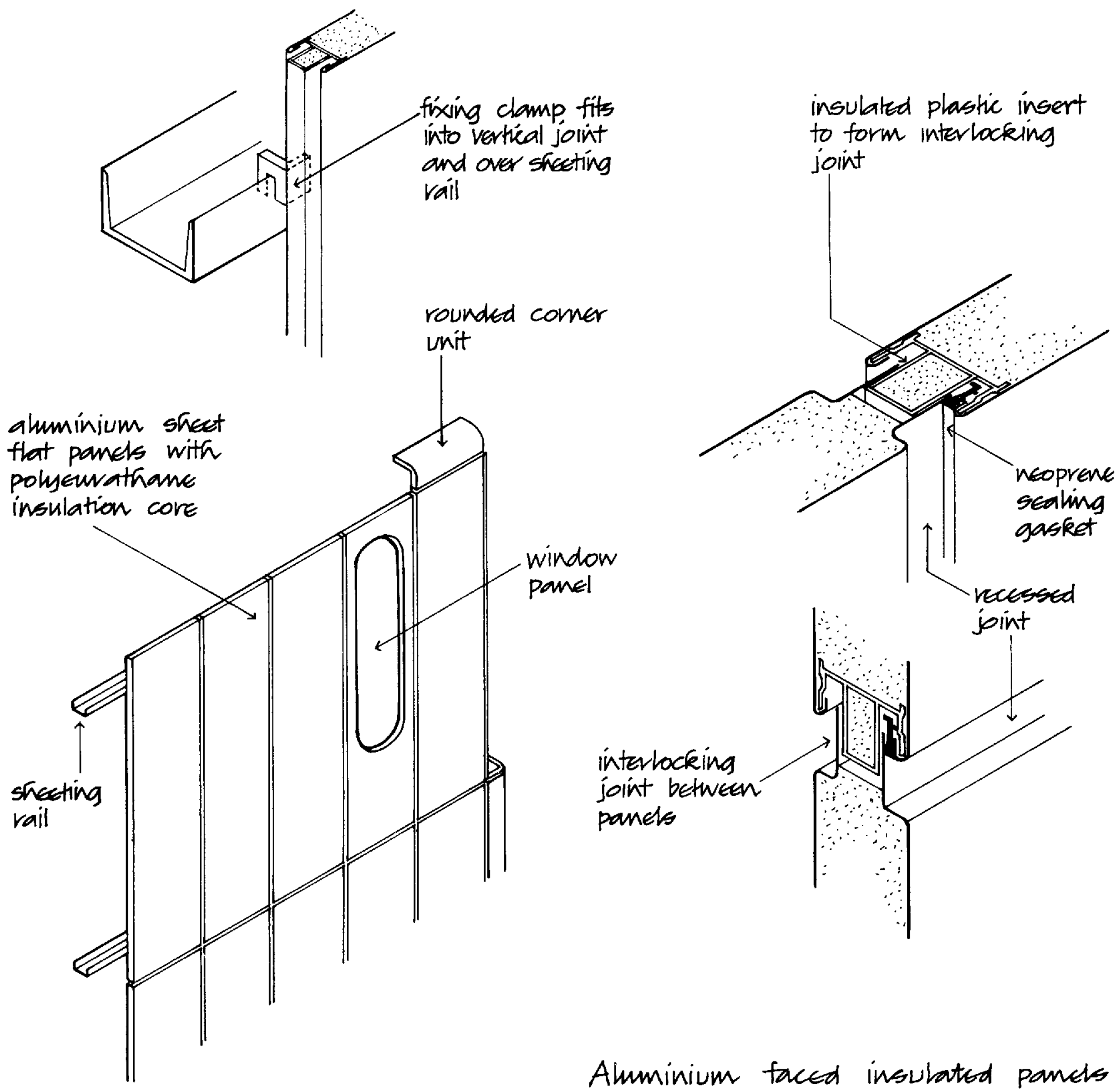


Fig. 173

SHEET METAL WALL PANELS

Sheet metal is used in the form of separate flat or profiled panels supported by a metal carrier system which is fixed to the structure or the panels are fixed to rails fixed to the structure. These panels are separated either by visible joints between panels or separated by the visible members of their supporting frame.

The materials used for metal panels are steel sheet, aluminium sheet and stainless steel sheet. Galvanised steel sheet is usually coated on the exposed face with one of the inorganic plastic coatings described in Volume 3.

Aluminium sheet is the most used material for sheet metal panels because the metal is not liable to progressive corrosion. On exposure to atmosphere a thin, stable oxide forms as a coarse textured coating that inhibits further corrosion. Because the natural oxide film has a dull colour and texture it is common to use sheet aluminium with an anodised, acrylic or polyester powder finish.

Anodising is an electrochemical process which increases the thickness of the oxide film. During the process of anodising the oxide film is porous and allows colours to be introduced. The anodised finish can be silver, coloured with organic dye or pigment or integral in which proprietary acids are used. A range of colours can be produced with organic dye but the colour retention is not particularly good. A few colours can be produced with inorganic pigments to provide a finish with reasonable colour retention. Integral anodising produces a tough, resistant film with good colour retention. Colours produced by integral anodising are black and shades of bronze.

Acrylic finish is an applied stoved coating with a semi-gloss finish that can be produced in a variety of colours. The coating is tough and durable but acceptable colour retention is of the order of 15 years.

Polyester powder finish is applied to the surface and cured in a gas fired oven to produce a smooth, hard finish with good colour retention and durability.

Stainless steel sheet, which is more expensive than steel or aluminium sheet, has the advantage that it does not progressively corrode, and will retain its natural colour. The exposed surface can be left as a matt finish or given a bright, highly polished finish. A dull polished finish is generally used, which is not highly reflective, is easily cleaned and maintains its appearance.

Single skin panels

Single skin panels of sheet metal are used as flat or profiled panels as an outer facing to lightweight wall cladding systems. The thin sheet material is stiffened by forming it as a shallow pan, by pressing or drawing to a profiled finish or by fixing or suspending flat panels on a carrier frame.

The process of forming sheet metal as a shallow pan is a comparatively simple and inexpensive process. The corners of the sheet are cut, the edges cold bent using a brake press and the corners are then welded. A wide variety of edge profiles can be produced by brake pressing. The advantages of forming sheet metal panels as a shallow pan are that the flanged pan edges provide a degree of stiffness to the panel and provide a means of fixing and making joints between panels.

The process of forming a profiled surface to individual sheet metal panels in one operation is carried out by pressing or drawing. To keep the cost of this operation within reasonable limits it is essential that a considerable number of identical panels be produced. The advantages of a profiled face to sheet metal panels are that the profile provides stiffness to the thin sheet material and masks any thermal or structural distortion of the face of the panel. Profiled panels are usually formed with flanged edges as a shallow pan.

Flat sheet panels can be formed as a shallow pan and fixed to a supporting aluminium frame to stiffen the thin sheet as illustrated in Fig. 174. When the flat sheet is fixed to the stiffening frame by welding or through studs welded to the back of the sheet and bolted to the frame, there is usually a degree of apparent distortion of the flat surface of the sheet due to differences in thermal movement of the sheet that is directly exposed to sunlight and the frame that is protected.

To minimise apparent distortion of the flat sheet it is practice to hang the flat sheets on to a supporting frame with cleats, studs or pins that fit to supporting

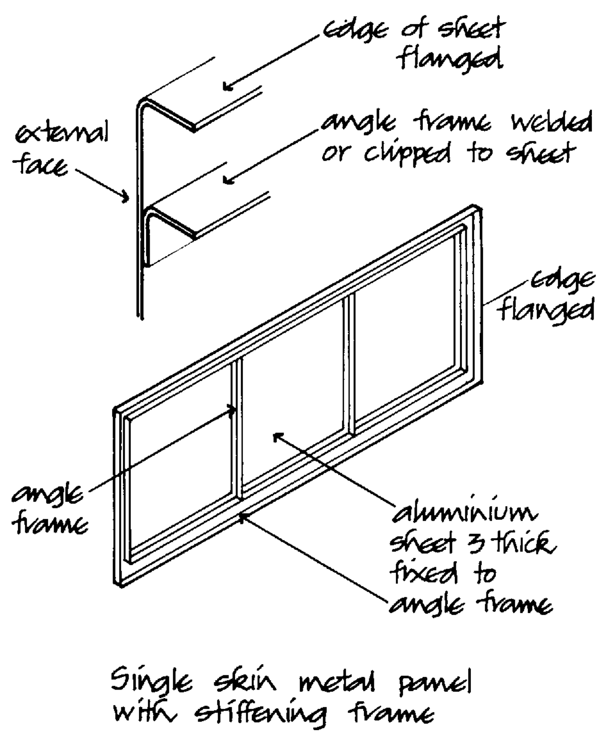


Fig. 174

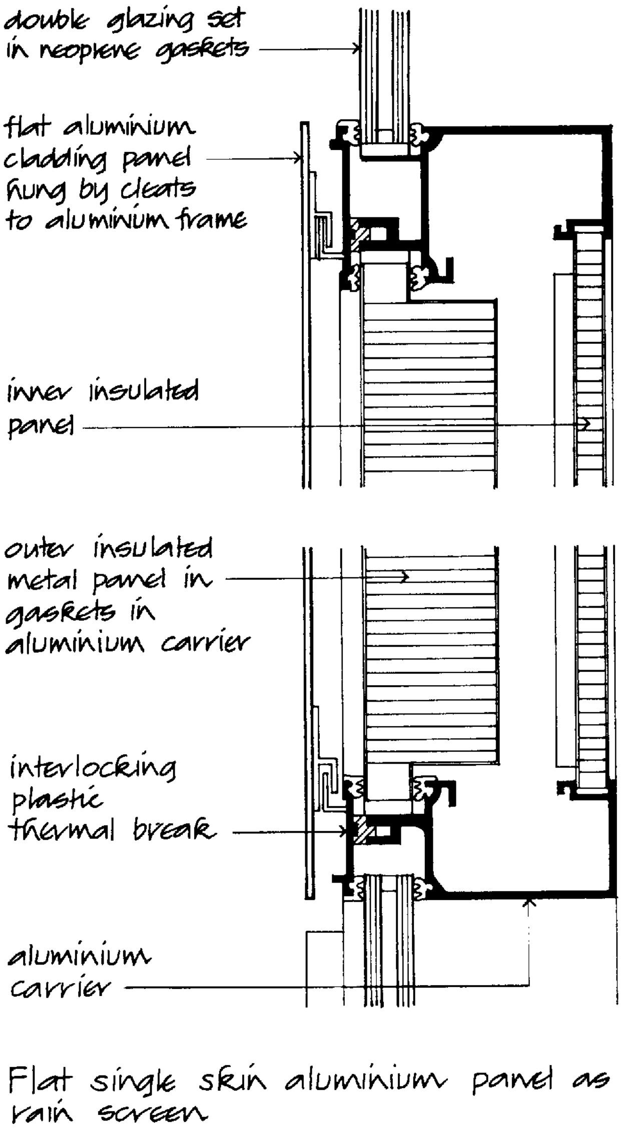


Fig. 175

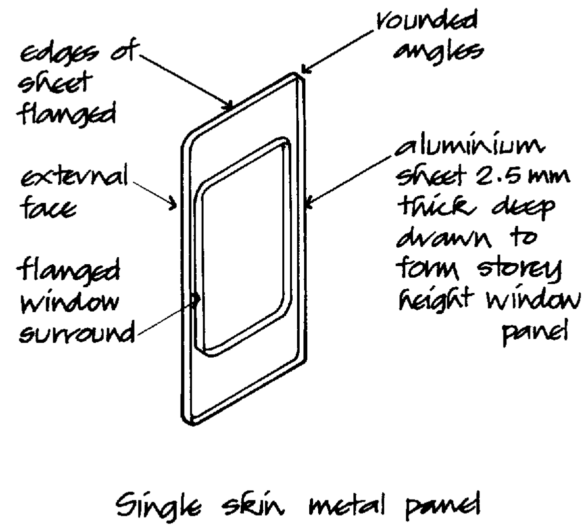


Fig. 176

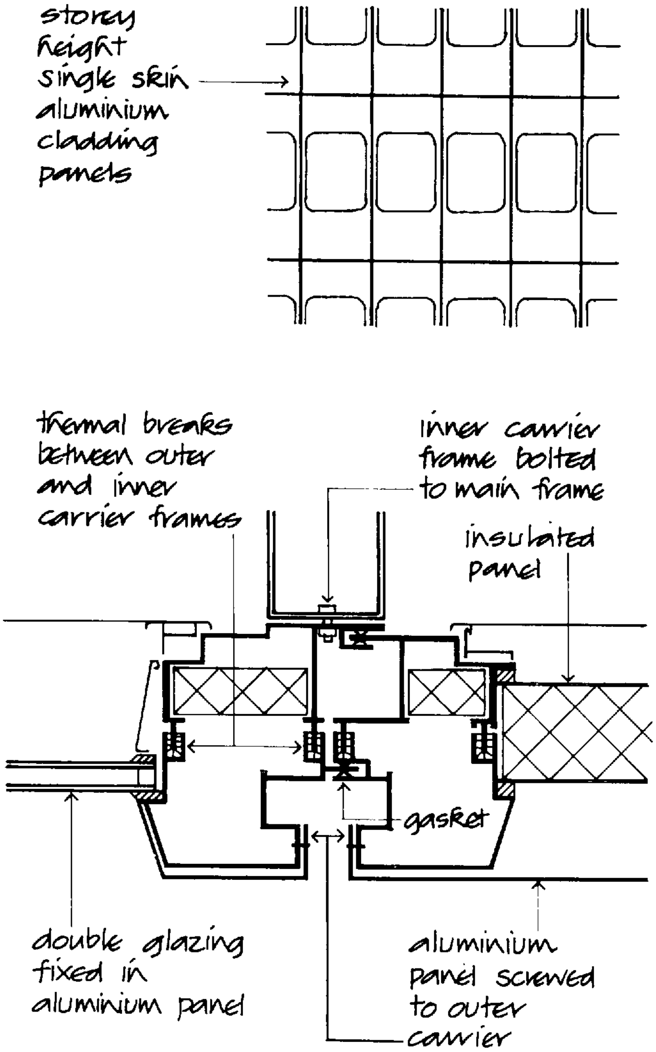
brackets as illustrated in Fig. 175. The flat sheet hangs from two or more supporting cleats, studs or pins near to the top edge of the sheet and is restrained by similar fixings that hold the sheet in position but do not restrain thermal movement. To be effective this arrangement requires accuracy in setting out and fixing to ensure adequate top support and reasonably close fitting restraint fixings that will not impede expansion and contraction of the sheet.

The flat sheet panels, illustrated in Fig. 175, are hung in front of the outer insulated metal panels as rain screens to provide an outer protection against wind, rain and solar heat. Flat sheet panels can be formed by drawing as window panels, as illustrated in Fig. 176, with drawn flanged edges to the panel and around the window opening for stiffening and fixing. The deep drawn aluminium panels illustrated in Fig. 177 are screwed to separate outer aluminium carrier frames that are fixed to inner carrier frames through plastic thermal breaks. The aluminium carrier systems that support the single skin outer panels and the insulated panels behind are supported by a metal frame which is fixed back to the structure. Neoprene gaskets serve as weather and air seals. The complication of outer and inner carrier systems, thermal breaks, gaskets and insulated linings requires an accuracy in engineering skill that is not common to most building projects.

The single skin, deep drawn, profiled aluminium panels illustrated in Fig. 178 form spandrel rain screen panels. The panels are supported by lugs hung on pins fixed to lugs that are supported by the aluminium carrier system and the carrier system is similarly hung on lugs fixed to the structure so that there is freedom from restraint to allow for differential thermal and structural movements between the panels, the carrier system and the structure.

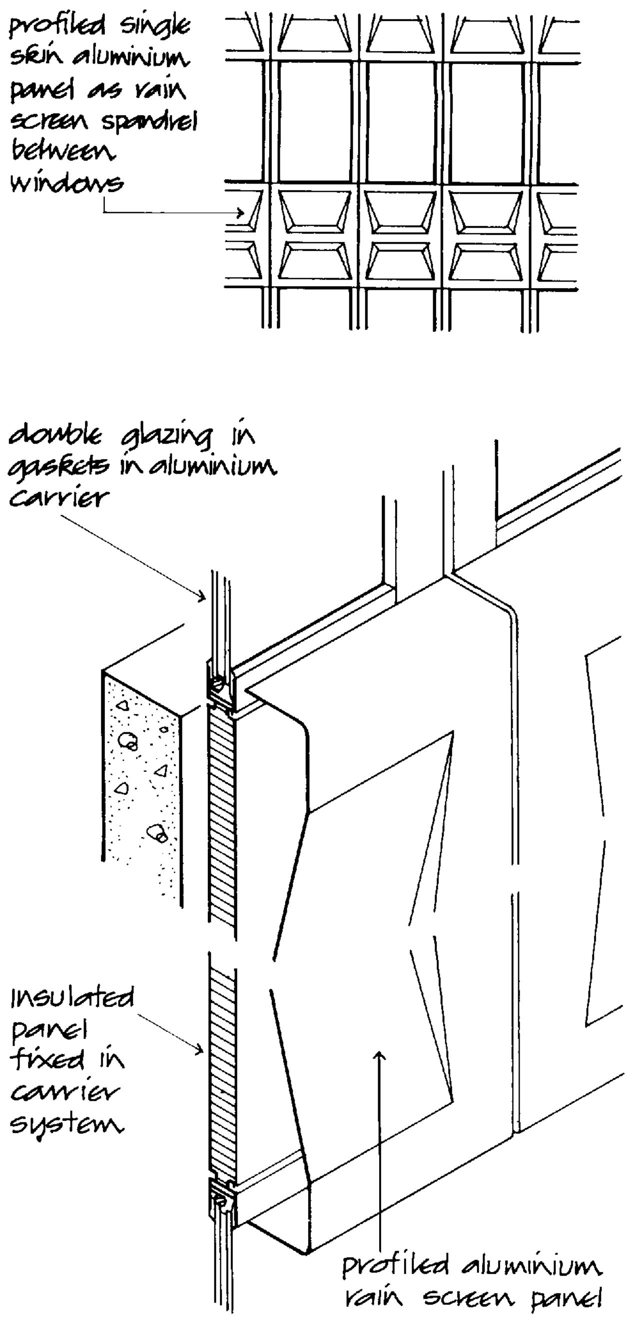
Rain screens

The term rain screen has been used to describe the use of an outer panel as a screen to an inner system of insulation and lining so arranged that there is a space between the screen and the outer lining for ventila-



Single skin aluminium cladding panels

Fig. 177



Profiled aluminium panel as rain screen

Fig. 178

tion and pressure equalisation. The open joints around the rain screen allow some equalisation of air pressure between the outer and inner surfaces of the rain screen, which provides relief of pressure of wind driven rain on the joints of the outer lining behind the rain screen. Another advantage of the rain screen is that it will protect the outer lining system from excessive heating by solar radiation and protect gaskets from the hardening effect of direct sunlight.

All wall panel systems are vulnerable to penetration by rain which is blown by the considerable force of wind on the face of the building. The joints between smooth faced panel materials are most vulnerable from the sheets of rainwater that are blown across impermeable surfaces. The concept of pressure equalisation is to provide some open joint or aperture that will allow wind pressure to act each side of the joint and so make it less vulnerable to wind driven rain. Plainly it is not possible to ensure complete pressure equalisation because of the variability of gusting winds that will cause unpredictable, irregular, rapid changes in pressure. Providing there is an adequate open joint or aperture there will be some appreciable degree of pressure equalisation which will reduce the pressure of wind-driven rain on the outer lining behind the rain screen. A fundamental part of the rain screen is air tight seals to the joints of the panels of the outer lining system to prevent wind pressure penetrating the lining.

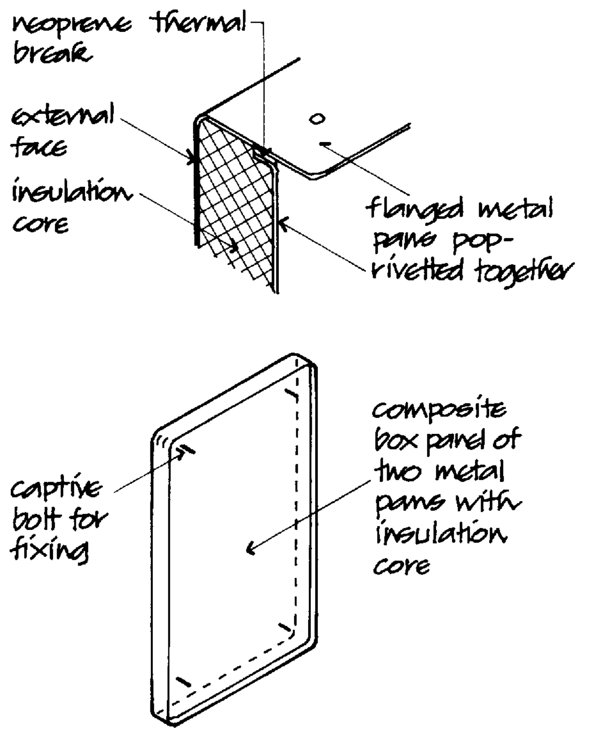
Because of the unpredictable nature of wind-blown rain and the effect of the shape, size and groupings of buildings on wind, it is practice to provide limited air space compartments behind rain screens with limited openings to control air movements.

The single skin panels hung in front of insulated metal panels illustrated in Figs 175 and 178 serve as rain screens to the outer insulated metal panels and carrier systems.

Composite sheet metal panels

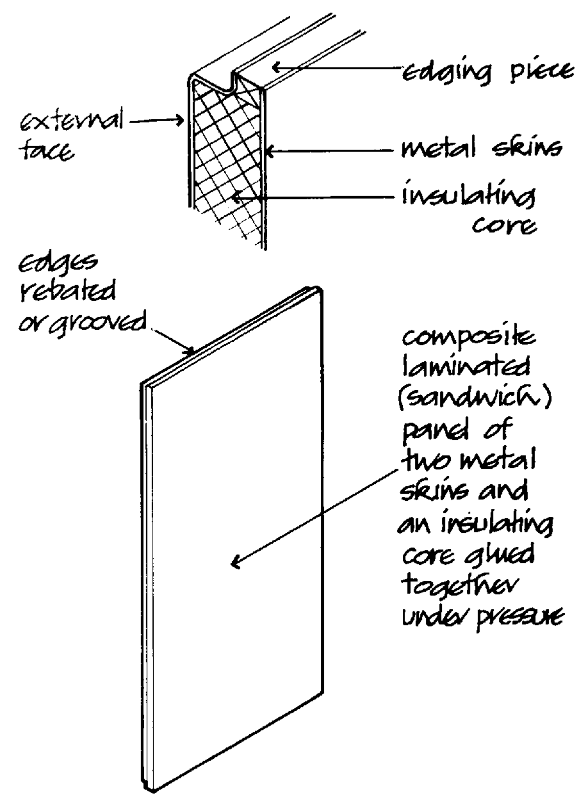
A thin sheet of metal provides negligible resistance to the transfer of heat and the thin sheet by itself has to be stiffened. The advantage of the combination of two thin skins of metal sheet with a core of insulating material is that the core provides insulation and the two skins some stiffness.

There are two forms of composite sheet metal panel, the box panel and the laminated panel. Box panels derive their stiffness from the two sheets of metal that are formed as shallow pans that are joined around an insulating core as illustrated in Fig. 179. Laminated sheet metal panels are formed from two skins of sheet metal that are glued to an insulating core, under pressure. The adhesion of the sheets of metal to the core provides a rigid panel that derives its stiffness from the sandwich of skins and core and that maintains its flat surface by virtue of the laminated form. Laminated panels are usually sealed with an edging of plastic or wood as illustrated in Fig. 180.



Composite metal box cladding panel

Fig. 179

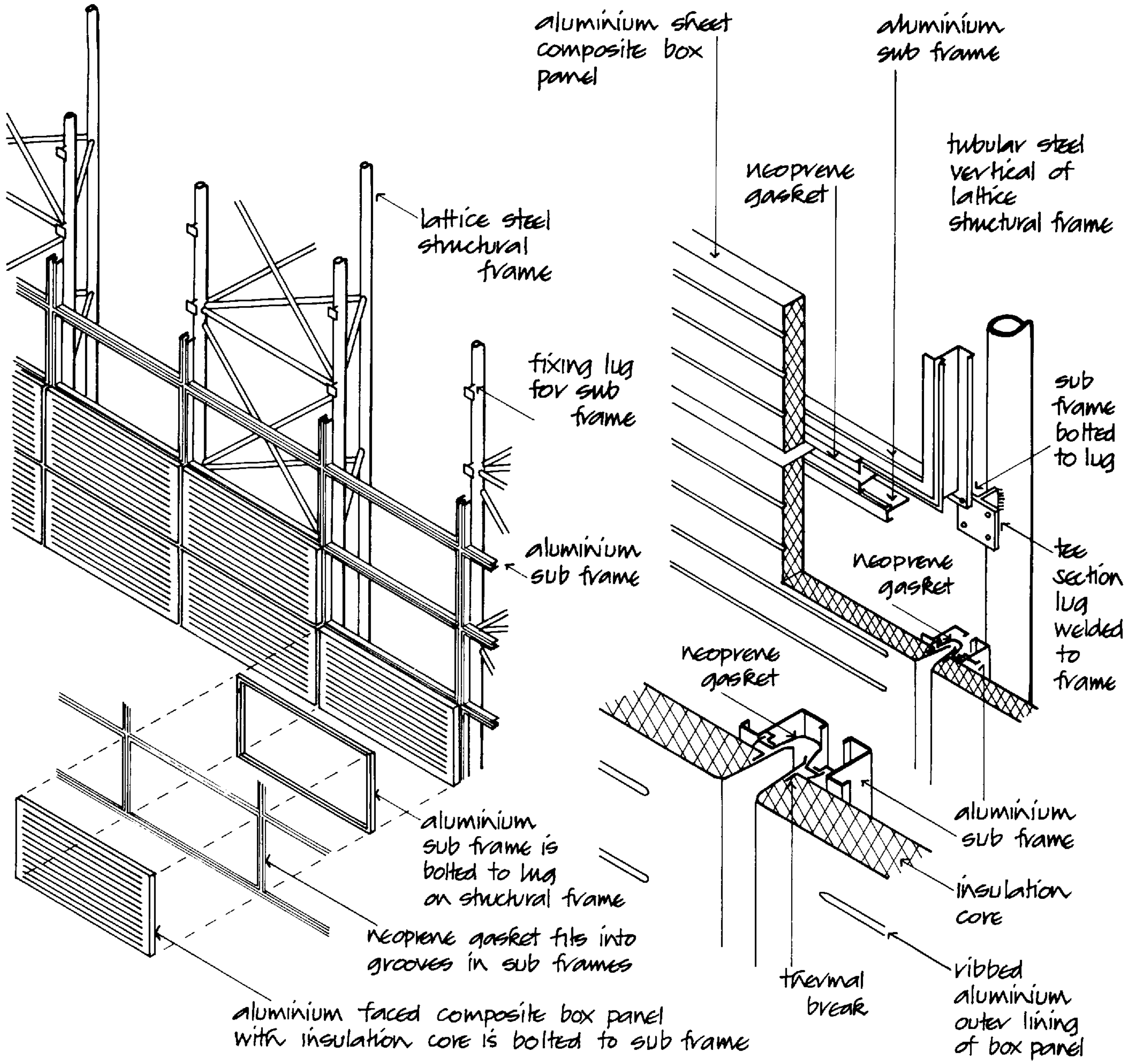


Composite laminated (sandwich) metal cladding panel

Fig. 180

The disadvantage of composite panels is that the insulated core causes the outer skin of the panel to expand and contract more than the inner skin due to changes in air temperature and solar radiation so that the outer skin may bow out as it expands. This may cause apparent distortion of flat faced panels and delamination of laminated panels, which will lose some rigidity from loss of bond between the outer skin and the insulating core. To minimise distortion caused by delamination, the size of the panels should be limited, light or reflective colours should be used on the outer face to reduce solar heat gain and panels should not be rigidly fixed inside a carrier system that will restrain movement and so accentuate distortion of the outer skin.

The aluminium sheet, box panels illustrated in Fig. 181 were specifically designed for this building which is a notable example of the integration of the



Sheet metal and insulation composite box panel cladding

Fig. 181

components of a building. The ribbed, anodised aluminium, box panels are made by vacuum forming. The outer tray is filled with phenelux foam and the inner skin then fitted and pop rivetted to the outer tray through a thermal break. Separate aluminium subframes for each panel are bolted to lugs on the structural frame. Continuous neoprene gaskets seal the open drained joints between panels which are screwed to subframes with stainless steel screws.

Jointing and fixing

Composite sheet metal panels have been in use as spandrel panels to curtain wall systems for many years and the jointing and fixing of these panels for use as external cladding has developed from the early use in curtain walling. The use of preformed gasket seals in aluminium carrier systems has developed with changes in curtain wall techniques so that today the majority of composite panels are fixed and sealed in neoprene gaskets fitted to aluminium carrier systems fixed to the structural frame, as illustrated in Figs 177, 178 and 181, in which the carrier system supports the panels and the gaskets serve as a weather seal and accommodate differential thermal movements between the panels and the carrier system, whether the carrier system is exposed on the face of the building or hidden by open joints.

To reduce the effect of the thermal bridges made by the metal carrier at joints, systems of plastic thermal breaks and insulated cores to carrier frames are used.

Where open horizontal joints are used to emphasise the individual panels there is a flat or sloping horizontal surface at the top edge of each panel from which rain will drain down the face of panels and in a short time cause irregular and unsightly dirt stains, particularly around the top corners of the panels.

Single skin panels hung as rain screens in front of insulated panels will provide some protection from rain and wind and extreme changes of temperature and the hardening effect of sunlight on gaskets.

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Volume 5

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Preface

Since publication of the first volume of *The Construction of Buildings* in 1958, the five volume series has been used by both lecturers and students of architecture, building and surveying, and by those seeking guidance for self-build housing and works of alteration and addition.

The layout of all volumes has remained the same until this latest revision to Volume 5. A wide right hand column of text has now been adopted to facilitate the inclusion of small diagrams in the left hand column, and larger diagrams within the text column so that, wherever possible, the diagram is adjacent to the relevant text for ease of reference. Bold subheadings in the left hand column provide a quick reference to the reader. Other volumes in the series will be revised to include the new layout.

Volume 5 deals with building services, water, electricity and gas supplies, foul water discharge and refuse storage. It does not attempt to cover heating, ventilating, air-conditioning, lifts or electronic or fire services.

The new Third Edition, the first revision to the volume in ten years, has been updated and includes changes to the 16th Edition of the Wiring Regulations and the current regulations on gas supply that concern safety.

1: Water Supply and Distribution

WATER SOURCES

History

Following the destruction of the Roman engineering works in Britain, there remained no organised piped supplies of water up to the twelfth century. In Saxon and Norman times the sole sources of water were streams, rivers, natural springs and man-made wells, on which the small population depended and around which it settled.

Monastic supplies

During the twelfth and thirteenth centuries the monasteries organised supplies of water usually from springs on high ground, from which water flowed by gravity, through wood, earthenware or lead pipes. Many of these monastic water systems were extended to supply neighbouring settlements. At the time water was less used by the general population outside the monasteries for either washing or drinking, than it is today.

With the dissolution of the monasteries in the sixteenth century the monastic water supplies were taken over by the civic authorities. The supply of water was generally in the hands of a local contractor who levied a charge for drawing water from the conduits and public fountains.

Water wheel

This rudimentary system of water supply was in existence until the end of the sixteenth century when the water wheel was first used to raise water to a cistern from which it flowed by gravity through wood or earthenware pipes to fountains, wash houses and buildings. The large wooden water wheels were driven by the river or stream from which they drew water. The wheel scooped up water, which was discharged at a high level, or drove air pumps which forced the water up.

Newcomen engine

From the middle of the eighteenth century the Newcomen steam engine gradually replaced the water wheel as the motive power to raise water. Water was piped under the head pressure from cisterns to communal conduits or fountains from which the populace drew their supply and from which water carriers collected water to retail for a small charge. A few town houses had a piped supply of water, the charge for which was beyond the means of the majority. The supply of water was, by and large, in the hands of commercial suppliers for profit, and this arrangement continued up to the middle of the nineteenth century.

The rapid increase in the urban population that followed the Industrial Revolution, culminated in the spread of cholera epidemics during the first half of the nineteenth century. The prime cause of cholera was gross pollution of water supplies by untreated sewage discharged directly into streams and rivers from which water supplies were drawn. Following investigations of the cause of cholera and reports of the total inadequacy of clean water supplies for the urban population, principally by Edwin Chadwick, the Waterworks Clauses Act was passed in 1847.

Waterworks Clauses Act

The Waterworks Clauses Act was the first comprehensive Act that standardised water work practice throughout the country. The Act controlled the construction of waterworks, laying of pipes, supply of water, fouling of water and obliged the water undertakers to supply water constantly, in sufficient quantity and at a reasonable pressure to all houses demanding water.

Prior to this Act the intermittent supply of water was a gravity supply, so that a storage cistern in each building was necessary to maintain a constant supply and those buildings above the level of the supply had no piped water. With a constant supply there was in theory no longer need for a storage cistern in each building and with reasonable pressure piped water could be provided to each floor level.

During the 130 years following the Waterworks Clauses Act municipalities largely took over the supply of water. The control of water pollution improved dramatically and water undertakings expanded the supply to the increasing urban population. The development of the supply and control of water supplies led to the Water Act 1973, which set up ten regional water authorities charged with the collection and supply of water in their area and the control of sewage treatment works and the pollution of water.

Quantity of water

There is no overall shortage of water in this country. In an average year rainfall over England and Wales is 900 mm, half of which is lost to evaporation and transpiration, leaving an average of 190 billion litres per day from which the public water supplies and industry take about 17 billion litres. Thus the direct supply consumption, including industry and agriculture, is about 10% of the potential supply available from rainwater.

The organisation of public water supply is not concerned, therefore, with the quantity of water available but with the collection and storage in order to cover seasonal variations and requirements, the movement of water from areas of surplus to areas of shortage and the overall control and treatment of effluents to avoid pollution and maintain the quality of water supplies.

Surface water

Surface rainwater that drains across lowland ground to rivers will contain various impurities from field drainage and factory and sewage effluents, whereas surface water that drains to upland rivers and lakes will be comparatively free of impurities.

Lowland surface water is stored in reservoirs in which some purification occurs naturally on exposure to air. Further purification is generally necessary by sedimentation and chemical additives.

In England and Wales a high proportion of water supplies is drawn from surface water.

Ground water

Rainwater that has percolated through permeable strata to a sub-surface level will generally contain few impurities due to the filtration effect and may need little purification. Ground water that is drawn from deep wells and borings is usually free from impurities.

Storage

In lowland areas water is mainly drawn from rivers and stored in reservoirs against seasonal variations in supply and demand and in which the chemical and biological content of the water may be controlled. In upland areas, water is usually stored in natural or man-made lakes fed by run-off from the surrounding higher ground and in reservoirs fed by wells and boreholes.

Most urban and rural areas of this country are served by a supply of water piped from the water supplier's main. Water authorities are required by statute to provide a supply of wholesome water for which they may require a capital contribution towards the cost of running the supply pipe from their nearest main. In outlying areas it may be more economical to draw supply from a well or borehole than pay the capital contribution.

Wells, boreholes and springs

A well is a shaft sunk or excavated below the level of ground water or into permeable subsoil, water bearing strata. The shaft, usually circular, is lined with brick, stone or precast concrete sections to maintain the sides of the well.

A borehole is a steel-lined shaft driven or drilled into the ground to a water bearing stratum.

Springs break where the water level in a permeable stratum is above the level of the junction of permeable and impermeable strata as illustrated in Fig. 1.

Wells are defined as shallow and deep wells. A shallow well is one that is sunk to collect ground water and a deep well is one that is sunk to collect water from below the first impermeable stratum.

The distinction is made between shallow and deep wells in relation to the quality or purity of the water drawn from each. The shallow well may draw surface and ground water that could be contaminated whereas water from a deep well is less likely to be contaminated as the water has percolated to a permeable stratum and has been purified by

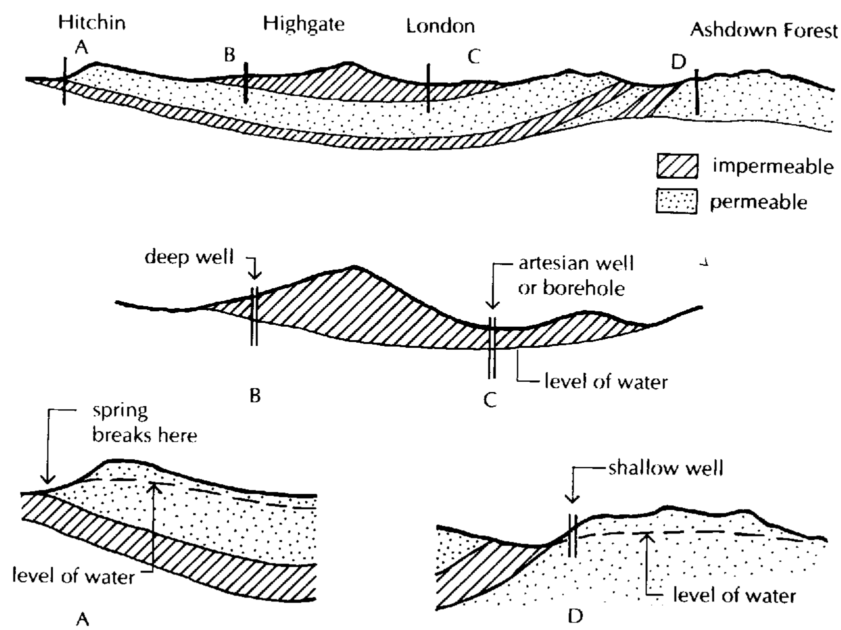


Fig. 1 Section across London Basin and Weald.

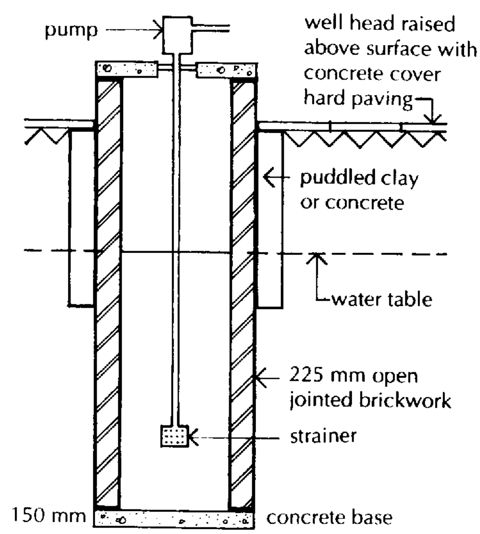


Fig. 2 Section through well.

filtration through the over lying strata. Fig. 1 illustrates the difference between deep and shallow wells.

Wells are generally excavated by hand and the smallest diameter of the well is dictated by the space required by the excavator to work in the shaft. The well hole is lined with stone, brick or precast concrete rings. The lining of a shallow well should be rendered impermeable for some distance down from the surface with a surround of puddled clay or concrete to exclude surface water, that may be polluted, as illustrated in Fig. 2. The lining of a deep well should likewise be made impermeable down to the first impermeable stratum to exclude surface and ground water. Water is raised from wells by a pump (see Fig. 2). Shallow wells may dry up during summer months.

An artesian well is sunk, in a valley, to a permeable stratum from which water rises with force from the folded permeable layer sandwiched between impermeable layers as illustrated in Fig. 1.

A borehole is sunk by driving or drilling steel lining tubes down to a water bearing permeable stratum. Water enters the perforated or slotted end of the tube and is raised by a force pump.

Consumption

Over the last 40 years the consumption of water in this country has doubled and is still rising. The water companies, the electricity generating industry and fish farming are the biggest users.

An average household uses about 380 litres every day of which 3% is used for drinking and cooking. A toilet flush takes about 7, a bath

80, a shower 35 and a washing machine 80 litres every cycle. A hosepipe or sprinkler can use 540 litres per hour, as much as the average person uses every four days.

Domestic water to most of the established urban settlements in this country is drawn from mains laid down some hundred or more years ago which by now, due to deterioration of old pipework, suffer considerable loss of water by leaks.

The combination of a naturally variable climate and periods of low rainfall have caused some recent water shortages. The remedy for this is a combination of more economical use of water, renewal of existing mains and works of feeder mains to move water from areas of high rainfall and low population to areas of drought and high consumption.

Water quality, purity and wholesomeness

The measure of the purity or wholesomeness of water is its freedom from pathogens which may be the cause of waterborne diseases in man. The waterborne diseases are often caused by the pollution of water by untreated or partly treated sewage.

It is not practical to test all the water that is used for traces of pathogens. Instead samples are taken for evidence of pollution by sewage as an indication of the likelihood of disease-carrying pathogens.

Water is purified by sedimentation and by filtration and by the addition of very small doses of chlorine to the water. The action of chlorine in water is disinfection whereby the chlorine reduces the infectious organisms to extremely low levels.

Acidity, alkalinity

Rainwater and water that contains decomposing organic matter such as peat, is acid water. Acid water is corrosive to iron and steel and will take lead into solution. As acid water is plumbo solvent, lead pipes should not be used in distributing acid water as lead is a cumulative poison.

Alkaline water contains calcium bicarbonate which is the constituent of temporary hardness. Pure water consists of hydrogen and oxygen and a small number of positive and negative ions. The measure of the acidity or alkalinity of water is pH, the letters used to denote the concentration of hydrogen ions. An acid water has a pH value of less than 7.0 and alkaline water a pH above 7.0.

Hard water, soft water

Much of the water drawn from underground sources such as chalk and limestone beds and from surface water on and in clay deposits, is said to be hard. Free carbon dioxide in underground water combines with chalk and limestone to form calcium bicarbonate, which is soluble in water (temporary hardness) and calcium and magnesium sulphate and chloride (permanent hardness).

Temporary hardness, permanent hardness

Much of the water drawn from underground sources such as chalk and limestone beds and from surface water in clay deposits, is said to be hard. Free carbon dioxide in underground water combines with chalk or limestone to form calcium bicarbonate, which is soluble in water (temporary hardness) and calcium and magnesium sulphate and chloride (permanent hardness).

When soap is dissolved in hard water it reacts with the minerals in the water to form a scum on the surface before it combines with water to form a lather. The excessive rubbing required to form a lather together with the scum formed is the reason the water is described as hard. More soap is required to form a lather in hard water than in soft water. It is advantageous therefore to treat hard water to reduce the hardness for washing purposes.

Table 1 indicates the degree of hardness of water. Hardness is measured in mg/litre as $CaCO_3$ (calcium carbonate). The range of hardness acceptable for general washing purposes lies between 100 and 200 mg/litres.

Table 1 Water hardness.

0 to 50 mg/l	Soft
50 to 100 mg/l	Moderately soft
100 to 150 mg/l	Slightly soft
150 to 200 mg/l	Moderately hard
over 200 mg/l	Hard
over 300 mg/l	Very hard

Drinking water

For drinking many prefer the taste or palatability of soft water from deep wells and fast flowing streams, while others prefer the taste of a hard water. The temperature of the water affects the subjective judgement of taste: the colder the water the more palatable it is said to be. Most will agree that stagnant water and especially tepid stagnant water has an unpleasant taste. Obviously, there is no generally accepted measure of taste.

Water for washing

The constituents of soap disperse oil, grease and dirt in water to form a lather of minute bubbles that serve as a lubricant and assist in washing. The more readily soap combines with water to form a lather, the softer the water feels to the touch when washing. Water that readily forms a lather with soap is said to be soft and water that does not is said to be hard. The words soft and hard are used subjectively to express the common sense feel of water when used with soap for washing. The descriptions hard and soft have been adopted to define the mineral content of water.

Scale, limescale

When water is boiled the soluble mineral bicarbonates form a hard scale, limescale, inside kettles and pans, and inside hot water and heating boilers so that progressively more fuel is required to heat the water, thus wasting energy. In time, heating and hot water pipes may become blocked by the build-up of scale. The harder the water and the higher the temperature the greater the build-up of scale. There is, therefore, economic advantage in controlling the hardness of water.

Temporary hardness, hardness

Because the mineral bicarbonate hardness of water is converted to scale by heating, it is described as 'temporary hardness' or more accurately 'carbonate hardness'. The noncarbonate mineral content of water, that is unaffected by heating, is termed 'permanent hardness' or 'noncarbonate hardness'. Bicarbonates of calcium and magnesium dissolved in water cause temporary hardness, and sulphates and chlorides cause permanent hardness.

Water treatment

Water is usually treated to change a hard water to a soft or softer water to reduce scale formation and facilitate washing. Two methods are used: in the first, lime or lime with soda is added to the water, which brings about changes to the hardness compounds so that they become insoluble and precipitate by settlement or in filters, and in the second the nature of the hardness is changed in a base exchange softener. In the first method the hardness compounds are changed and removed, and in the second the hardness compounds are changed and remain in the water. In the second method of softening a natural or synthetic zeolite is used to convert compounds of calcium and magnesium to sodium carbonate-bicarbonate and sulphates that do not cause hardness. For domestic treatment small base exchange equipment is available.

Water purification

Water purification combines storage in reservoirs to allow suspended matter to settle, followed by filtration to remove both suspended and dissolved matter and a final treatment by chlorination.

WATER SUPPLY

Water mains

Water is supplied by the 'statutory water undertaker' required to supply a constant, potable (drinkable) supply of water for which service either a water rate is levied for domestic consumption or a charge by meter for most other users. The water rate is assessed on the rateable value of premises and charged as a percentage of the value either half-yearly or annually. This method of assessment for the use of water is currently under review.

Metered supplies are charged at the current rate of the consumption recorded.

Water meter

In many European countries the supply of water to all buildings is measured by meter and the cost charged by units of consumption. The advantage of making a charge through units of consumption is that it tends to encourage economy of consumption by the consumer who has a financial interest in maintaining his water installation. The disadvantage of metered supplies to the water authorities lies in the labour costs of periodic reading of meters and accounting for the actual consumption. It is open to any consumer in England to ask for a metered supply of water, providing the consumer bears the cost of fitting the meter.

Water is supplied, under pressure, through pipes laid under streets, roads or pavements. Cast iron, ductile iron, steel, concrete and more recently plastic pipes are used. In urban areas duplicate trunk mains feed street mains. By closing valves individual lengths of main may be isolated for repairs and renewals without interrupting the supply.

Connections to water main

Service pipe

Connections to the existing main are made by the water undertaker. The house or building service pipe connection is made to the main and the service pipe is run to a stop valve near to the site boundary of the building to be served. The stop valve is situated either immediately outside or inside the boundary. The purpose of the stop valve is to enable the water undertaker to disconnect the water supply where there is a waste of water in the building served, or non-payment of water rate or charge.

Supply pipe

The pipe that is run from the stop valve to and into the building is termed a supply pipe. The supply pipe is run underground and into the building as illustrated in Fig. 3. For convenience it is usual to run the supply pipe into the building through drain pipes to facilitate renewal of the pipe if need be.

It is the responsibility of the consumer to maintain so much of the incoming service pipe as is on his land. At the point that the supply pipe enters the building there should be a stop valve (see Fig. 3), to disconnect the supply for repair and maintenance purposes.

To reduce the risk of freezing, the supply pipe should be laid at least 750 mm below the finished ground surface and if the supply pipe enters the building and rises closer than 750 mm to the outside face of a wall, it should be insulated from where it enters the building and up to the level of the ground floor.

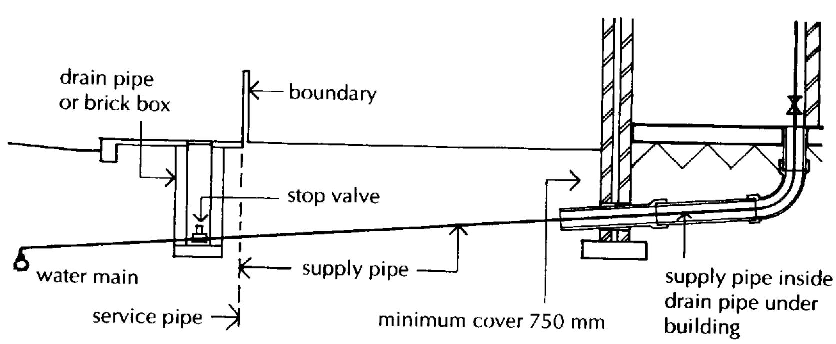


Fig. 3 Service pipe and supply pipe.

HOT AND COLD WATER SUPPLIES

Cold water supply

The intermittent supply of water that was common from the middle of the eighteenth to the middle of the twentieth century necessitated the use of a water storage cistern fixed at high level in each building to maintain a constant supply of cold water. These cisterns were designed to contain one or more days' use of water in the building, to allow for interruption in the supply.

Since those days, most water undertakers in England have required consumers to install a water storage cistern for the supply of cold water in each building, even though the water authority is obliged by statute to provide a constant supply. The cistern usually provides storage for twelve to twenty-four hours' consumption.

The principal reason for continuing the requirement for cistern-fed cold water supplies was that the airgap between the discharge of the supply pipe and the water level in the cistern acted as an effective break against backflow contamination of mains supply. In most European countries the use of cold water storage cisterns has long since been abandoned in favour of cold water supplied directly under pressure from the main supply on the grounds that roof level cisterns are 'expensive, unhygienic and unnecessary'. In 1988, for the first time in England, the new Water Supply Byelaws permitted the use of mains pressure supply of water as an alternative to the traditional cistern-fed supply.

Water Supply Byelaws

In the current byelaws there is a definition of the terms 'supply pipe' and 'distributing pipe'. A supply pipe is any pipe, maintained by the consumer, that is subject to water pressure from the authorities' mains, and a distributing pipe is any pipe (other than an overflow or flush pipe) that conveys water from a storage cistern or from hot water apparatus supplied from a feed cistern and under pressure from that cistern.

The Water Supply Byelaws set out requirements to prevent waste of water and contamination of mains supply water by backflow contamination.

Prevention of waste of water

Prevention of waste of water is mainly concerned with the overflow of roof level cisterns and cisterns to WCs and bidets and the unnecessary use of water through faulty taps and installations. The byelaws can exercise no control over the waste of water through taps carelessly left running, which is a cause of excessive consumption.

At present most consumers pay a charge for water through a water rate that is levied annually as a percentage of rateable value, taking no account of consumption. Where the charge for water is based on consumption measured by a meter, the consumer has a direct interest in the prevention of waste, through his pocket. A more sensible approach to prevention of waste would be through metered supplies as is the practice in most continental European countries.

Prevention of contamination

The principal concern of the byelaws is the prevention of contamination of mains supplied water by the flow of potentially polluted water from a supply or distributing system back into the mains water supply.

Flow of water from a supply or distributing system in a building, back into the mains supply, can occur when there is loss of pressure in the mains due to failure of pumps, or repair and maintenance on the mains, and also where a pumped supply in a building creates pressure greater than that in the mains.

Backflow

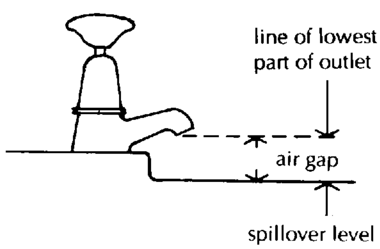


Fig. 4 Air gap to taps to fittings.

Loss or reduction of pressure in the mains supply could allow backflow from fittings, through draw-off taps, flushing cisterns and washing machines. The concern here is that if, for example, a bath were to be overfilled and the pressure in the mains supply pipe reduced, there would be a possibility that polluted water might find its way back into the mains pressure supply system.

As a guard against this, all draw-off taps to baths, wash basins and sinks must either be fixed so that there is an air gap between the spillover level of the fittings and the outlet of the tap, as illustrated in Fig. 4, or a double check valve assembly must be fitted to the supply pipe to each draw-off tap. These requirements apply equally to taps connected to mains pressure supply pipes and to distributing pipes from a cistern.

COLD WATER SUPPLY SYSTEMS

The two systems of cold water supply that are used are cistern feed and mains pressure.

Cistern feed (indirect)

The cistern feed supply is also termed the indirect system, because the cold water supply comes independent of the mains, from a cold water storage cistern.

Mains pressure (direct)

The mains pressure supply is also termed the direct system because the cold supply comes directly from the mains.

The advantages and disadvantages of the systems are:

Cistern feed – indirect supply

Advantages

(1) The reserve of water in the cistern that may be called on against interruption of supply to provide regular flow.

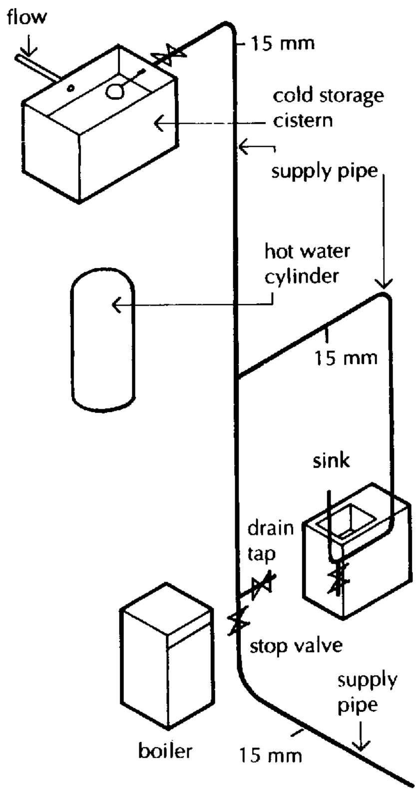


Fig. 5 Cistern feed cold water supply.

(2) The air gap between the supply pipe and the water level in the cistern acts as an effective barrier to backflow into the mains supply, that can cause contamination.

Disadvantages

(1) The considerable weight of a filled cistern to be supported at high level

(2) The inconvenience of access to the cistern for inspection and maintenance

(3) The possibility of the cistern overflowing

(4) The need to insulate effectively the cistern and its associated pipework against freezing

Mains pressure – direct supply

Advantages

(1) A uniformly high pressure supply to all hot and cold water outlets some distance below the pumped head of the supply

Disadvantages

(1) Discontinuity of supply to all hot and cold water outlets if mains supply is interrupted

(2) The need for comparatively frequent inspection, maintenance and repair of many valves and controls to the system

There is little, if any, difference in the necessary capital outlay between a cistern gravity feed and a mains pressure supply.

CISTERN FEED COLD WATER SUPPLY

Fig. 5 illustrates the cold water supply to a two storey house. The supply pipe rises through a stop valve and draw-off or drain tap to the ball valve that fills the cistern. A stop valve is fitted close to the cistern to shut off the supply for maintenance and repairs.

Prior to the implementation of the 1988 Water Supply Byelaws it was a requirement that only one supply pipe connection be made to the kitchen sink as a drinking water outlet. The rationale for this was that roof space storage cisterns were often left uncovered and the water in the cistern became somewhat fouled with dust and other debris to the extent that the water in it was made unpalatable. Today with the use of covered plastic cisterns the water drawn from them is generally considered fit for drinking.

Cisterns

Galvanised steel cisterns

A cistern is a liquid storage container which is open to the air and in which the liquid is at normal atmospheric pressure. The traditional cold water storage cistern is manufactured from mild steel plate or sheet, welded or riveted together and galvanised after manufacture. Today the majority of smaller cisterns are moulded from plastic.

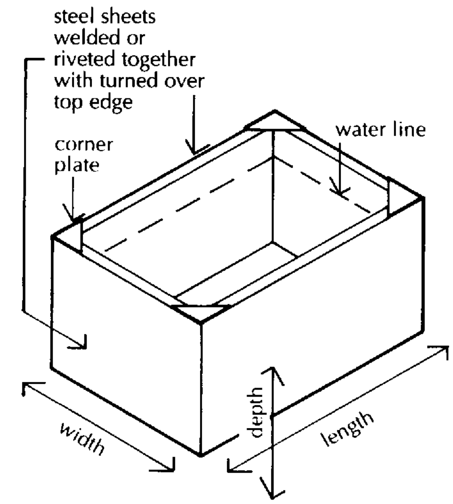


Fig. 6 Galvanised steel cistern.

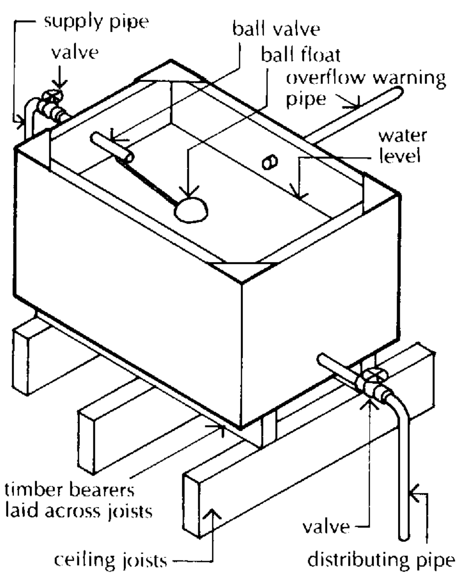


Fig. 7 Support for cistern.

Fig. 6 is an illustration of a typical galvanised steel cistern. The cistern has turn-over flanged or angle section stiffeners and corner plates to provide some rigidity to the sides. A loose steel cover can be supplied to give some protection from contamination by dust and dirt. Cisterns that serve to supply drinking water have a close fitting top with a screened air inlet.

The useful life of these cisterns depends on the thickness of the galvanising coating, which is applied after manufacture. Thinly coated cisterns may rust after twenty to thirty years and need replacement. Those more thickly coated may last for the normal life of a building.

When a galvanised steel cistern fails, due to rusting, it is usual practice to replace it with two smaller cisterns to avoid enlarging trap doors in ceilings for access to roof spaces.

Small capacity galvanised steel cisterns are used as header or feed tanks to provide the necessary head of cold water supply to boilers where an open vented pipework system is used. The header or feed cistern or tank is fixed in a roof space or in some position above the boiler to provide the necessary head of water. An expansion pipe runs up from the boiler, to discharge over the header tank, so that water under pressure from overheating may discharge into the header tank.

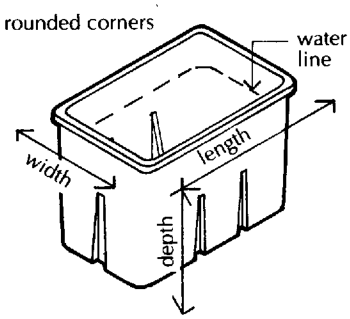
Because of the weight of water they are designed to contain, all cisterns must be adequately supported on timber or steel spreaders to transfer the load over a sufficient area of timber or concrete ceilings and roofs, as illustrated in Fig. 7.

Galvanised steel cisterns with a capacity of 18 to 3364 litres are available in sizes from 457 to 2438 mm long, 305 to 1524 mm wide and 305 to 1219 mm deep. The small cisterns are for use as header tanks and the larger for such buildings as multi-storey flats, where a gravity feed cold water supply is used.

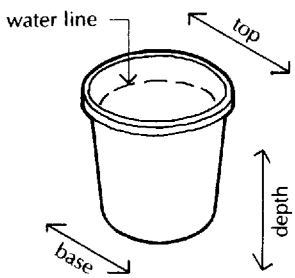
Stainless steel cisterns, manufactured from stainless steel sheets welded together, are used for drinking water storage where separate drinking water outlets are used. These expensive cisterns are used because of their freedom from rust and their durability.

Plastic cisterns

Of recent years plastic cold water storage cisterns have been used instead of the traditional galvanised steel cistern. The advantages of these cisterns are that they do not deteriorate by rusting, have smooth surfaces and are comparatively lightweight for handling. The disadvantage is that the thin plastic from which these cisterns are made has poor mechanical strength in supporting the weight of the water they contain. Square-sided plastic cisterns are moulded with ribbed sides, and round section cisterns with a flanged top and the support of



Polypropylene cistern



Circular glass reinforced polyester cistern

Fig. 8 Plastic cisterns.

a tightly fitting flanged cover as stiffening and support, as illustrated in Fig. 8.

An advantage of the round section plastic cisterns is that the material is sufficiently pliable to enable the empty cistern to be folded to an extent, to pass it through the small access trap door in ceilings as replacement for a defective cistern.

Rectangular section plastic cisterns are available with capacities from 18 to 227 litres, lengths of 430 to 1055 mm, widths of 305 to 635 mm and depths of 305 to 584 mm. Round section plastic cisterns are available with capacities from 18 to 227 litres, depths of 254 to 610 mm, base of 419 to 750 mm and tops of 464 to 845 mm.

The most convenient place for a cold water storage cistern is in a roof space below a pitched roof, or in a tank room on a flat roof or at some high level. In whichever position the cistern is fixed, there must be space around and over the cistern for maintenance or replacement of the ball valve.

The cold water storage cistern must be fixed not less than 2 m above the highest fitting it is to supply with water. This distance represents the least head of water necessary to provide an adequate flow.

The most convenient place for a cistern is therefore in the space below a pitched roof, or in a tank room or chamber above a flat roof or at some high level below the roof. Where a cistern is fitted inside a roof space it is necessary to spread the considerable weight of a full cistern across several ceiling joists.

The capacity of cold water storage cisterns is usually 114 litres per dwelling where the cistern supplies cold water outlets and WC cisterns, and 227 litres per dwelling where the cistern supplies both cold water to outlets and domestic hot water cylinders. The alternative is to calculate the capacity of the storage cistern at 90 litres per resident.

Cisterns are holed for the connection of the cold water supply, the distributing pipes to cold water outlets, and for the pipe to a hot water cylinder and the overflow pipe.

Ball valve, float valve

The water supply to the cistern is controlled by a ball valve that is fixed to the cistern, above the water line, and connected to the cold supply through a valve as illustrated in Fig. 7. A hollow copper or plastic ball, fixed to an arm, floats on the water in the cistern. As water is drawn from the cistern the ball falls and the arm activates the ball valve that opens to let water into the cistern. When the water has risen to the water line, marked on the cistern wall, the ball and arm rise to close the valve.

The two types of valve in use are the original Portsmouth valve and the diaphragm valve that is used for most new installations.

Portsmouth valve

The Portsmouth valve consists of a brass case and seating, as illustrated in Fig. 9. A brass piston, which is free to move inside the casing, is operated by a cam on the end of the ball arm that pivots to move the piston horizontally. To act as a water seal to the valve, a rubber or plastic washer is fitted to the end of the piston. As the water level in the cistern rises, the washer is pushed against the seating to shut off the water supply, which flows when the ball falls. An outlet allows water to discharge over the level of water in the cistern. The air space between the outlet and the water line of the cistern serves as a barrier to backflow contamination of the supply.

The original Portsmouth valve, which was noisy in operation, has been refined so that the piston is under equal water pressure at both ends, to reduce the noise of operation.

To reduce the noise of water falling from the valve outlet into an emptied cistern, it has been practice to fit a silencing tube to the outlet, to discharge water below the lowest level of water in the cistern. This is in contravention of Water Byelaw regulations as there is no longer an air gap as check to contamination.

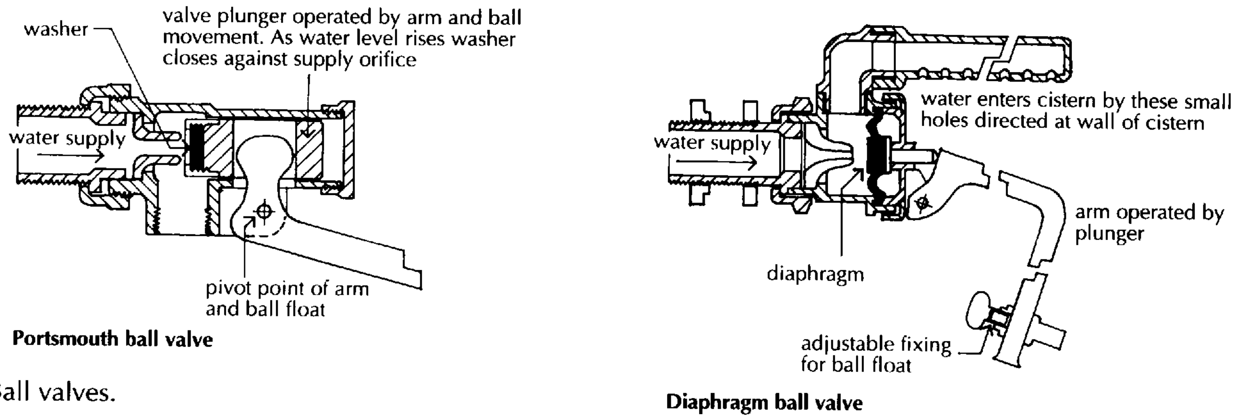


Fig. 9 Ball valves.

Diaphragm valve

The diaphragm ball valve, illustrated in Fig. 9, consists of a brass case with outlet attachment in which slots direct water towards the walls of the cistern to reduce the noise of filling. A ball float and arm operates through a pivot to move a rubber diaphragm up to and away from a nylon nozzle, to shut and open the water supply.

This valve, which operates quietly and efficiently, will need only occasional attention to clean the diaphragm of particles so it makes an effective seal with the nozzle.

In general, ball valves operate efficiently and require infrequent maintenance to renew the washer of the Portsmouth valve and clean the diaphragm. Against the possibility of the cistern overflowing due to a faulty valve, an overflow pipe is fitted to the cistern above the waterline and carried out of an external wall.

Air gap to ball valve

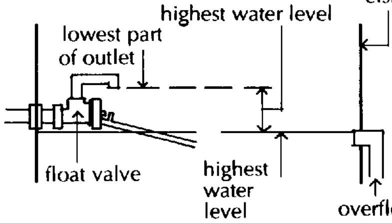


Fig. 10 Air gap to ball valve.

To prevent contamination of mains supply of water by back-siphonage, backflow or cross connection, the Water Supply Byelaws require an air gap between the outlet of float valves to cisterns and the highest water level in the cistern. This air gap is related to the bore of the supply pipe or the outlet and is taken as the minimum distance between the outlet of the float valve and the highest water level when the overflow pipe is passing the maximum rate of inflow to the cistern. Fig. 10 is an illustration of the air gap necessary to float valves to cisterns.

Overflow warning pipe

As a precaution against failure of the valve, and consequent overflow of the cistern, most water undertakers require an overflow warning pipe to be connected to the cistern above the water line and carried out of the building to discharge where the overflow of water will give obvious warning. The overflow pipe should be of larger bore than the supply pipe to the cistern and preferably twice the bore of the supply pipe and not less than 19 mm bore.

Insulation

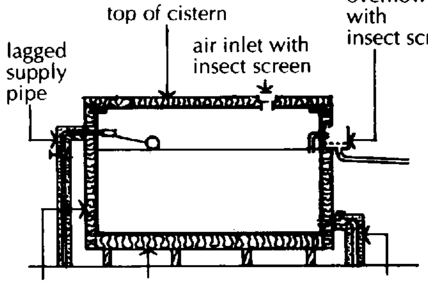


Fig. 11 Insulation to cisterns.

The Water Supply Byelaws include a requirement that water storage cisterns be insulated and fitted with a close fitting cover that excludes light and insects and is not airtight, and that the cistern shall be adequately supported to avoid distortion and be in a position where it may be readily inspected and cleaned, and valves readily installed, renewed or adjusted.

To meet these requirements it will be necessary to fit cisterns on a platform to support the cistern and spread its load to ceiling or roof rafters. The cistern should be surrounded with adequate insulation in the form of quilted or board insulation, strapped or otherwise securely fixed. The thickness of the insulation is not specified as it will depend on the position in which this cistern is fixed. Cisterns which are fixed inside the roof space under pitched roofs, where the insulation is at ceiling level and the roof space ventilated to minimise condensation, will require heavy, airtight insulation against freezing. The cover to the cistern will have to be insulated as will the base of the cistern where it is not in direct contact with some other insulation.

Fig. 11 is an illustration of a cistern with cover and insulation. The air inlet shown in the airtight cover has an insect screen, as does the overflow pipe.

Cistern feed cold water distributing pipe system

Fig. 12 illustrates the cold water distributing pipe system for a two-storey house. The distributing pipe is connected to the cistern some 50 mm above the bottom of the cistern to prevent any sediment that may have collected from entering the pipe. A stop valve is fitted to the

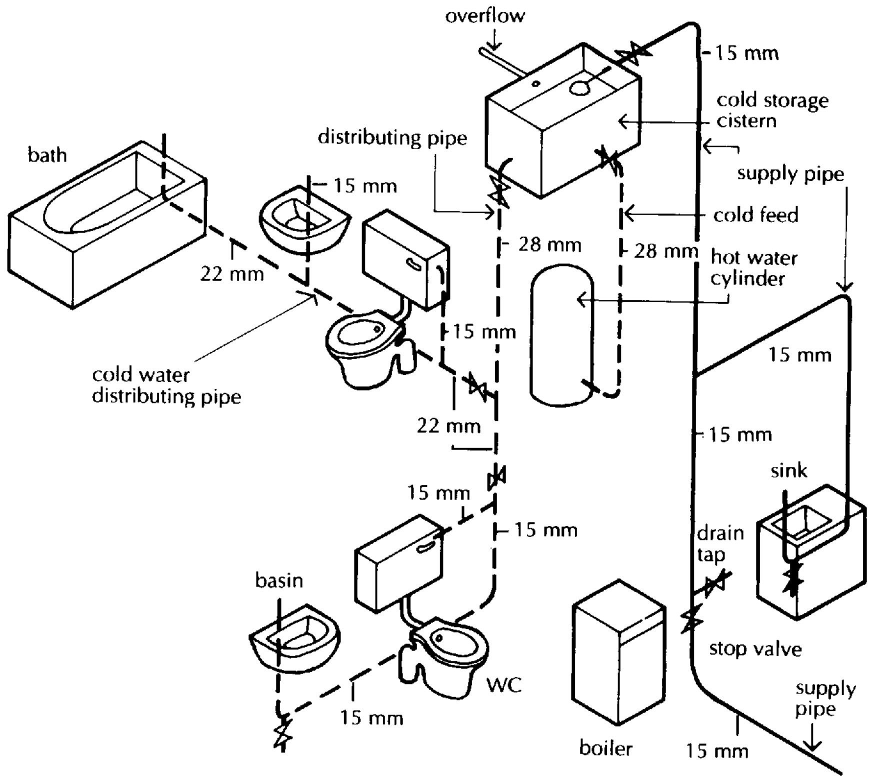


Fig. 12 Cold water distributing pipe system.

pipe adjacent to the cistern, isolating the whole system from the cistern in the event of repairs and renewals. The distributing pipe is carried down inside the building with horizontal branches to the first-floor and ground-floor fittings, as shown in Fig. 12.

The aim in the layout of the pipework is economy in the length of pipe runs, and on this depends a sensible layout of sanitary fittings. In Fig. 12 it will be seen that one horizontal branch serves both bath, basin and WC. For rewashering taps, stop valves are fitted to branches as shown. Where one branch serves three fittings as shown in Fig. 12, one stop valve will serve to isolate all three fittings.

Drain or draw-off taps should be provided where pipework cannot be drained to taps so that the whole distributing system may be drained for renewal or repair of pipework or when a building is left empty and the water in the system might otherwise freeze and fracture pipework or joints.

CISTERN FEED HOT WATER SUPPLY

Cistern feed hot water distributing pipe system

Fig. 13 illustrates the hot water distributing pipe system for a two-storey house. The hot water is drawn from a cylinder which is fed by cold water drawn from the cold water storage cistern in the roof.

The cold water in the hot water cylinder is heated by a heat exchanger in the cylinder through which hot water circulates from the boiler. The cold water feed to the cylinder is run through a stop valve to the bottom of the cylinder.

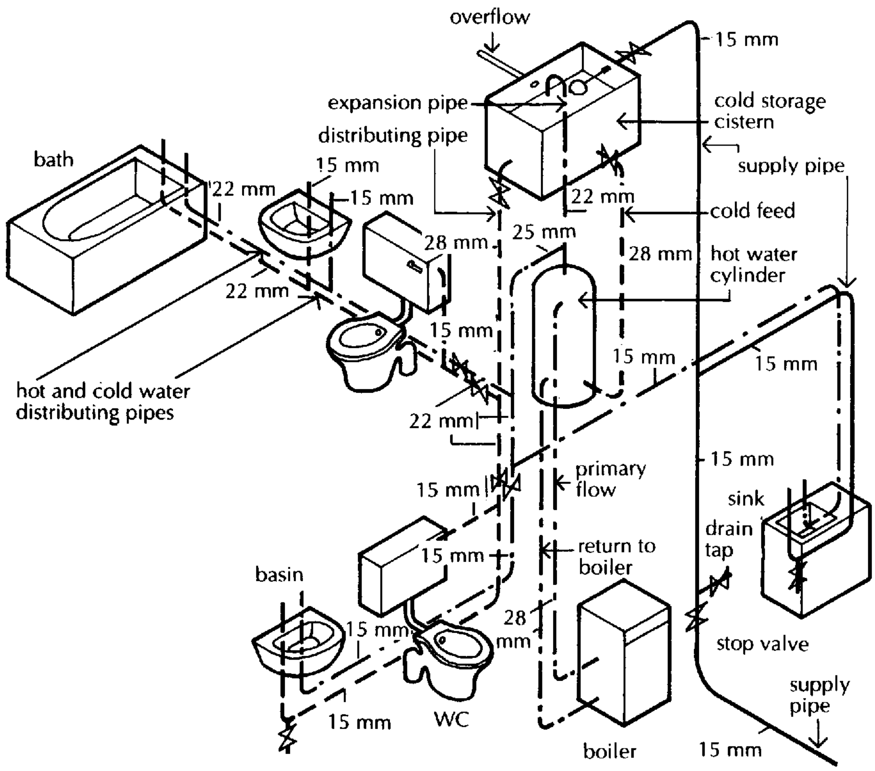


Fig. 13 Hot water distributing pipe system.

Hot water storage cylinder

Hot water storage cylinders are designed to contain water under pressure of the head of water from the cold water storage cistern. Most hot water storage containers are cylindrical and are fixed vertically to encourage cold water fed into the lower part of the cylinder to rise, as it is heated by the heat exchanger, to the top of the cylinder from which hot water is drawn, and so minimise mixing of cold and hot water.

The cold feed pipe to the cylinder is run from the cold water storage cistern and connected through an isolating stop valve to the base of the cylinder. The hot water distribution pipe is run from the top of the cylinder to the draw-off branches to sanitary appliances and is carried up to discharge over the cold cistern as an expansion pipe, in case of overheating, as illustrated in Fig. 13.

Vented hot water system

Because the expansion pipe discharges through the open end of the pipe, over the cold water storage cistern, in case of overheating and expansion of the hot water, this arrangement is described as a vented hot water system and the cylinder as a vented or open vented system. This is to distinguish it from the unvented system used with mains pressure system.

The required storage capacity of the cylinder depends on the number of sanitary appliances to be served and the estimated demand. A limited experiment by the Building Research Station suggests that the average consumption of domestic hot water is in the region of 50 litres per person per day. The interval between times of maximum demand on domestic hot water are longer than the recovery period required to reheat water in storage systems, and it is reasonable, therefore, to provide hot water storage capacity of 50 to 60 litres per person.

Storage cylinders are made either of galvanised sheet steel or copper sheet welded or riveted. Fig. 14 is an illustration of typical hot water storage cylinders. In course of time galvanised steel cylinders may rust and their average life is about 20 years, whereas a copper cylinder may have an unlimited life. Which of these two is used will depend on the pressure of the head of cold water, the nature of the water and the pipework used, and initial cost consideration. Most steel cylinders can support greater water pressure than copper cylinders, and steel cylinders are appreciably cheaper than copper cylinders.

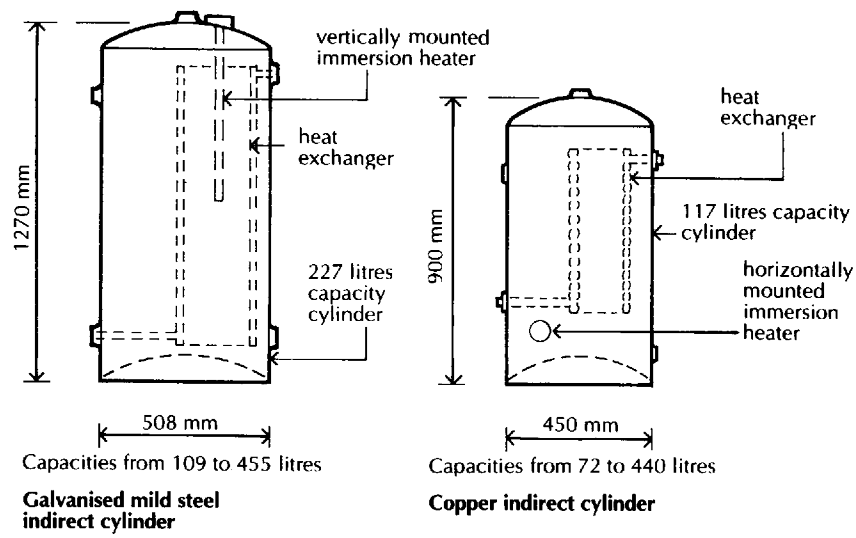


Fig. 14 Indirect hot water storage cylinders.

Indirect cylinder

The hot water storage cylinders illustrated in Fig. 14 are indirect cylinders, so called because the primary hot water from the boiler exchanges its heat indirectly through a heat exchanger to the hot water supply, there being no connection between the water from the boiler and the hot water supply. The purpose of this indirect transfer of heat is to avoid drawing hot water directly from the water system of the boiler. Where hot water is drawn directly from a boiler it has to be replaced and in hard water areas each fresh charge of water will deposit scale inside the boiler and its pipework and in time the build up of scale will reduce the efficiency of the boiler and the bore to its pipes. With an indirect cylinder there is no replacement of water to the boiler and its primary pipes and therefore no build up of scale.

Scale formation is proportional to water temperature. There is less build up of scale in the secondary hot water circulation because of the lower water temperature in the system. Indirect cylinders are in addition a protection against the possibility of drawing scalding water directly from the boiler. For these reasons indirect cylinders are used.

Heat exchanger

The heat exchanger which is fixed inside the cylinder and immersed in the water to be heated, takes the form of a coil of pipes or annulus designed to provide the maximum surface area for heat exchange.

Primary flow

The system of pipes that carries hot water from the boiler through the heat exchanger and back to the boiler, is described as a primary flow system.

Hot water boiler or heater

For a small building such as the two-storey house illustrated in Fig. 13 it is general practice to utilise one boiler for both space heating and hot water, to economise in the initial outlay on heating equipment and pipework and to make maximum use of floor space.

The boiler, whether combined space heating and hot water or separate, may be fired by solid fuel, gas, oil or electricity, in that order of current costs, solid fuel being the cheapest. Solid fuel suffers the disadvantage of being bulky to store, and residual ash and clinker are time-consuming and dirty to clear. Oil requires a bulky storage container and tends to smell, while gas is the most convenient of the fuels. Electricity is less used because of its cost.

The temperature of the water heated by the boiler is controlled by a thermostat, which can be set by hand to a range of water temperatures from 55°C to 85°C, the boiler firing and cutting out as the water temperature falls and then rises to the preselected temperature.

Water heated in the boiler rises in the primary flow pipe to the heat exchange coil or container inside the hot water storage cylinder and as it exchanges its heat through the exchanger to the water in the cylinder it cools and returns through the primary return pipe back to the boiler for reheating. There is a gravity circulation of water in the primary pipe system. The primary flow and return pipes should be as short as practicable, that is the cylinder should be near the boiler to minimise loss of heat from the pipes.

The circulating pipes from the boiler through the heat exchanger are termed primary flow and return as they convey the primary source of heat in the hot water system.

Small, compact, so-called, 'space saving' boilers require a forced flow of water around the primary circulation system by an electrically operated pump. A small feed cistern (not shown in Fig. 13) provides the head of water required for the boiler and its pipe system.

Immersion heater

An electric immersion heater is fitted to the hot water storage cylinder to provide hot water when the boiler is not used for space heating.

An electric immersion heater is both an inefficient and an expensive means of heating water. Because of the comparatively small surface area of the immersion heater, it requires some four hours to heat the water in the cylinder as compared to two hours for the heat exchange coil from the boiler. This slow recharge rate is an inconvenience added to the high cost of electricity.

MAINS PRESSURE COLD WATER SUPPLY

Fig. 15 illustrates the cold water, mains pressure pipe system to a two-storey house. Here the first line of defence against contamination of the mains supply is a double checkvalve assembly fitted upstream of the stop valve as the supply pipe enters the building.

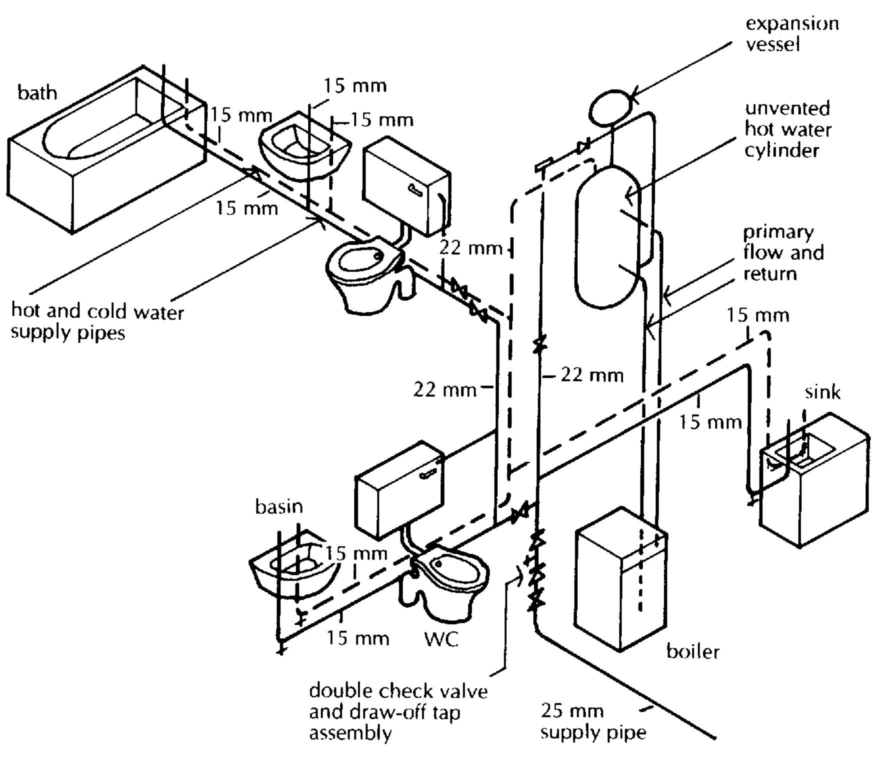


Fig. 15 Cold and hot water supply.

Check valve, non-return valve

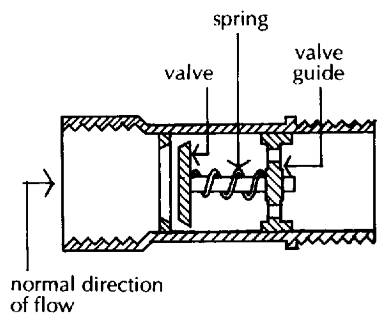


Fig. 16 Spring loaded check valve, non-return valve.

A check valve, more commonly known as a non-return valve, is a simple, spring-loaded valve that is designed to open one way to the pressure of water against the valve and to close when that pressure is reduced or stops. It therefore acts as a one way valve which closes against the direction of normal flow and prevents backflow from the supply pipe system into the mains. Fig. 16 is an illustration of a typical check valve.

A double check valve assembly is a combination of two check valves with a test cock between them. A test cock is a simple shut off device with a solid plug that, when rotated through 90°, either opens or closes.

In use, a check valve may become coated with sediment, particularly in hard water areas, and not operate as it should. To test that the check valves are working and acting as non-return valves, the stop valve is closed to test one check valve and opened to test the other with the test cock open.

Vacuum breaker

The new Water Supply Byelaws will accept a check valve and vacuum breaker, a pipe interrupter or other fittings or arrangement of fittings designed to prevent backflow, as an alternative to a double check valve assembly.

From the double check valve assembly the mains pressure supply pipe rises and branches horizontally to supply fittings on each floor level with stop valves to isolate sections for repair or maintenance and drain plugs, in an arrangement similar to that for the cistern-fed distribution pipe system. The supply pipe also supplies the unvented hot water storage cylinder.

MAINS PRESSURE HOT WATER SUPPLY

The hot water supply system for a small two storey house is illustrated in Fig. 17. From the double check valve assembly the supply pipe rises to fill the unvented hot water cylinder with cold water. The cold water in the cylinder is heated by a heat exchanger that exchanges heat from the boiler.

Unvented hot water cylinder

The difference between the traditional vented hot water system and the unvented system is that in the vented system the expansion of hot water is accommodated by the vented expansion pipe that will discharge an excess of expansion water to the cistern, and in the unvented system expansion of hot water is relieved by an expansion

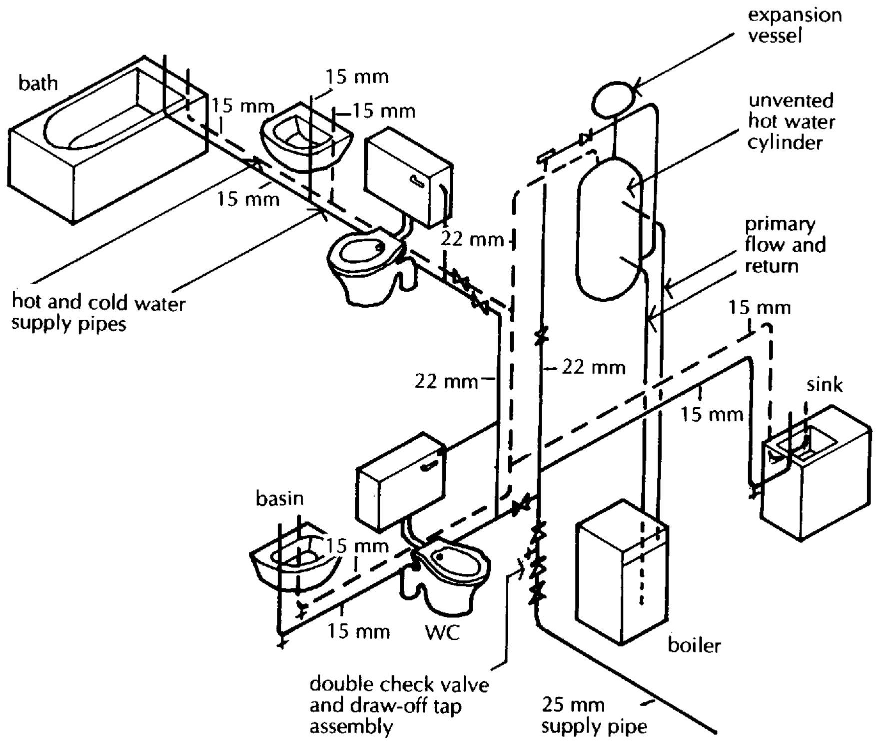


Fig. 17 Unvented hot water supply.

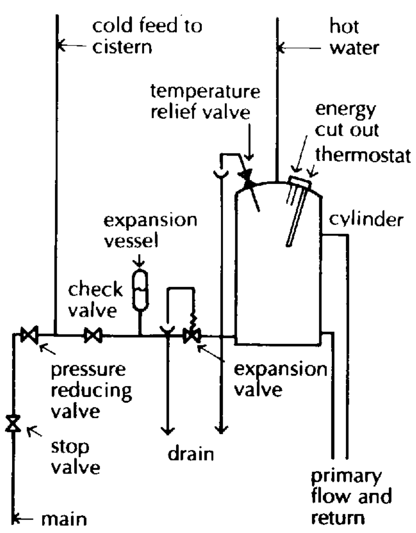


Fig. 18 Diagram of low pressure unvented hot water system.

vessel which contains a cushion of gas or air sufficient to take up the expansion by compression of the gas.

The advantages of the unvented over the vented hot water system, for the user, lie in the improved flow rates from showers and taps, reduction in noise caused by the filling of storage cisterns, and virtually no risk of frost damage. There is little if any economic advantage in the use of the unvented system. The saving in eliminating the cistern, feed and expansion pipes is offset by the additional cost of the expansion vessel and temperature and expansion control valves, and the necessary, comparatively frequent, maintenance of these controls.

Fig. 18 is a diagram of a low pressure unvented hot water cylinder. The pressure reducing valve is fitted to the feed pipe where low pressure systems are used and is provided to reduce mains pressure to a level that the cylinder can safely withstand. Where high pressure systems are used and the cylinder is designed to stand high pressure, the pressure relief valve is omitted.

Expansion vessel

An expansion vessel is a sealed container in which a flexible diaphragm separates water from the cylinder and the air or gas which the sealed vessel contains. As the water in the cylinder heats,

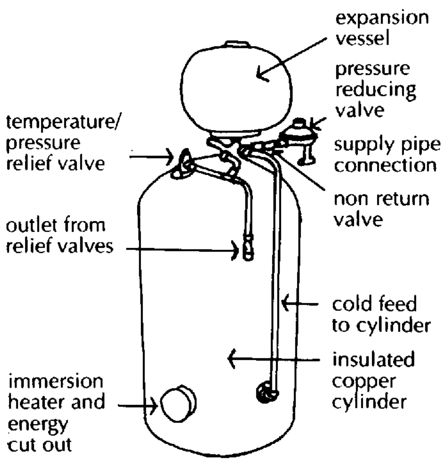


Fig. 19 Unvented hot water storage cylinder.

it will expand against the diaphragm, compress the air and gas and so relieve the water expansion. In this way the expansion vessel acts in the same way as a vented expansion pipe to indirect systems.

The pressure relief, or reducing valve, is a safety device against the expansion vessel being unable to take up the whole of the expansion of heated water. For control against overheating there is a thermostat on the immersion heater and also a temperature limiting cut-out that operates on the electricity supply, and a temperature operated relief valve to discharge if the other controls fail.

Fig. 19 is an illustration of an unvented copper indirect cylinder prepared ready for installation as a packaged unit complete with factory applied insulation, expansion vessel and the necessary valves and controls.

Hot water supply pipework

The hot water supply pipework is run from the top of the cylinder with horizontal branches to the hot water outlets to fittings on each floor. Stop valves and draw-off taps are fitted to control and drain the pipe system as necessary for maintenance and repair.

HOT WATER SUPPLY SYSTEMS

There are two hot water supply systems, the central and the local. In the former, water is heated and stored centrally for general distribution, and in the latter water is heated, or heated and stored locally for local use. The difference between these systems is that with the central system hot water is run to the site of the sanitary appliances from a central heat source, and with the local system the heat source, gas or electricity, is run to the local heater which is adjacent to the sanitary appliances. Fig. 20 illustrates the two systems diagrammatically.

The central system is suited, for example, to houses, hotels, offices and flats where a central boiler fired by solid fuel, oil, gas or electricity heats water in bulk for distribution through a straightforward vertical distributing pipe system with short draw-off branches leading to taps to sanitary appliances on each floor. In large buildings, one heat source may serve two or more hot water storage cylinders to avoid excessively long distribution pipe runs.

The local system is used for local washing facilities where the fuel – gas or electricity – is run to the local heater either to avoid extensive and therefore uneconomic supply or distributing pipe runs, or because local control is an advantage.

In some buildings it may be economic to use a combination of central and local hot-water systems.

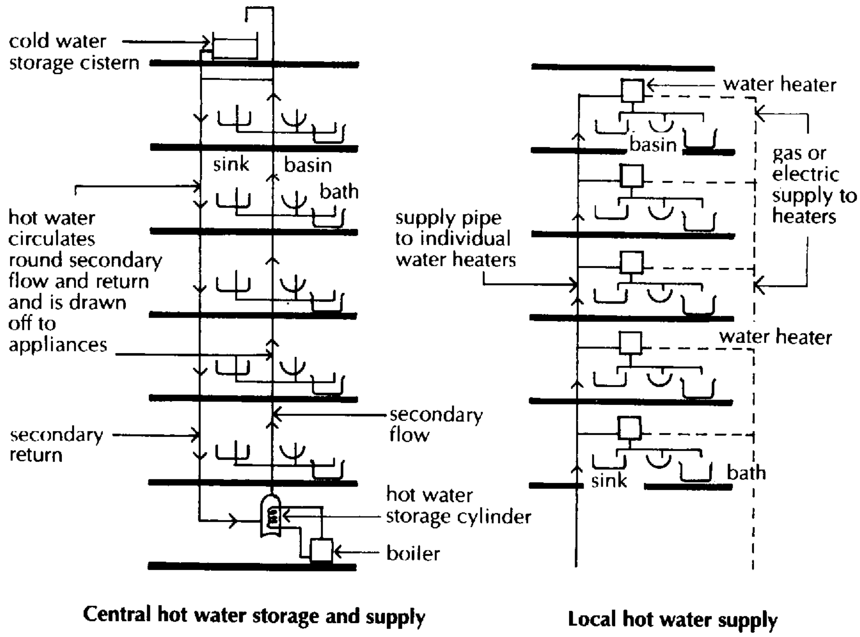


Fig. 20 Hot water supply systems.

Central hot water supply

From Fig. 20 it will be seen that water is heated and stored in a central cylinder from which a pump circulates it around a distributing pipe system from which hot water is drawn.

In the two-storey house used to illustrate hot water distribution or supply pipe systems, the hot water was drawn directly from single branches. In a small building, such as a house, where the sanitary fittings are compactly sited close to the cylinder, the slight inconvenience of running off the cooled water in the single branches before hot water is discharged is acceptable.

In larger buildings such as that illustrated in Fig. 20, the inconvenience of running off cooled water from long single branches is unacceptable as it is also wasteful of both water and energy.

Dead leg draw-off

Because the water in single pipe branches to draw-off taps cools, these branches are termed dead leg branches or pipes, or dead leg of pipe. To avoid too great an inconvenience and waste of water and energy, the length of these dead legs is limited to 20 m for 12 mm pipes ranging to 3 m for pipes more than 28 mm, unless the pipes are adequately insulated against loss of heat.

The storage cylinder contains hot water sufficient for both anticipated peak demand and demands during the recharge period. The system is therefore designed to supply hot water on demand at all times. The one disadvantage of the system is that there is some loss of heat from the distributing pipes no matter how adequately they are insulated. This is outweighed by the economy and convenience of one central heat source that can be fired by the cheapest fuel available, and one hot water source to install, supply and maintain – hot water being at hand constantly by simply turning a tap.

Where a mains pressure supply system is used the supply pipe connects to the unvented hot water storage cylinder from which supply pipes connect to the fittings and there is no roof level storage system.

Local hot water supply

A water heater, adjacent to the fittings to be supplied, is fired by gas or electricity run to the site of the heater. Fuel for local heaters is generally confined to gas or electricity. The water is either heated and stored locally or heated instantaneously as it flows through the heater. The advantages of this system are that there is a minimum of distributing pipework, initial outlay is comparatively low and the control and payment for fuel can be local, an advantage, for example, to the landlord of residential flats. The disadvantage is that local heaters are appreciably more expensive to run and maintain than one central system.

Hot water storage heaters

There are two types of local water heater, the hot water storage heater and the instantaneous water heater. The local hot water storage heater consists of a heat source and a storage cylinder or tank, and the instantaneous heater of a heat source through or around which cold water runs and is heated instantaneously as it is run off. The larger water storage heaters are used to supply hot water to ranges of fittings such as basins, showers and baths used in communal changing rooms of sports pavilions and washrooms of students' hostels.

The large, gas-fired, water storage heater illustrated in Fig. 21 consists of a water storage cylinder through which a heat exchanger rises to a flue from a combustion chamber. A thermostat in the water storage chamber controls the operation of the gas burners in the combustion chamber, cutting in to fire when the temperature of the water falls. A cold water supply pipe is connected to the base of the storage cylinder.

Hot water is drawn off either through a dead-leg draw-off pipe where pipe runs are short, or by a circulating secondary pipe system where runs are lengthy. The storage heater is heavily insulated to conserve energy. The size of the heater is determined by the anticipated use of hot water at times of peak use.

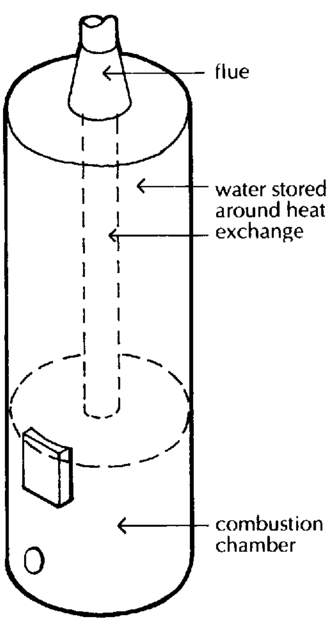


Fig. 21 Gas water storage heater.

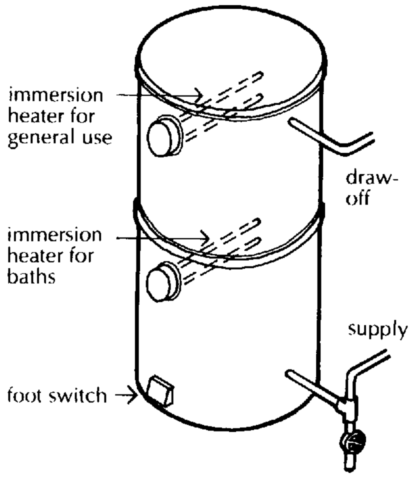


Fig. 22 Electric water storage heater.

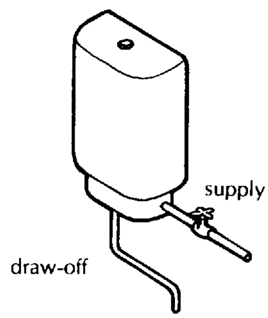


Fig. 23 Electric storage single point water heater.

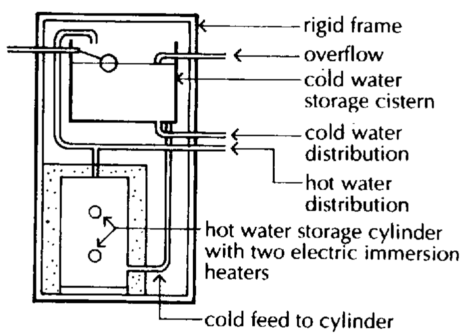


Fig. 24 Combined cold and hot water storage unit.

The electric water storage heater, illustrated in Fig. 22, is for use in communal washrooms of students' hostels and residential schools where peak demand for hot water in bulk is generally confined to mornings and evenings, between which times the heater automatically reheats the water. These heaters, which are heavily insulated to conserve energy, are housed in a separate enclosure away from the wet activities they serve, for safety reasons. Hot water for basins is drawn from the top of the cylinder, which is heated by an upper immersion heater. Hot water in bulk for baths is boosted by the operation of both the upper and lower immersion heaters. The lower immersion heater is operated by a foot switch, a thermostat or a timed switch.

An advantage of the electric storage heater is that it does not have to be fixed close to an outside wall, which the gas heater does because of its flue.

The small electric, single point water heater, illustrated in Fig. 23, is designed to heat and store a small volume of water for the supply to single basins. The hot water storage cylinder and electric immersion heater, which are heavily insulated to conserve energy, are housed in a glazed enamel metal casing for appearance sake. A thermostat controls the electric supply to the immersion heater, cutting-in to reheat the water as it is drawn off. These heaters are used for basins in single toilets where it is convenient to run water and an electrical supply for the occasional use of hot water.

A combined cold cistern and hot water storage heater that is designed to fit into a confined space is illustrated in Fig. 24. Inside a rigid frame a cold water storage cistern and an insulated hot water storage cylinder are combined with connections for water and electric supplies, and hot and cold water draw-off connections. These units are designed specifically for use in small flats where space is limited, and they can be fitted close to bathroom and kitchen.

A disadvantage of these units is that there is poor discharge of water from outlets because of the small head pressure of water from the cold water storage cistern. Because of the small capacity of the cold water cistern the frequent refilling of the cistern may be somewhat noisy in a confined space.

Instantaneous water heaters

These water heaters operate by running cold water around a heat exchanger so that water is heated as it flows. The heat exchanger only operates when water is flowing, hence the name instantaneous water heater.

Because the temperature of the water at the outlet is dependent on the rate of flow of water there is a limitation on the rate of flow from the outlet if the water is to be hot. Consequently the rate of flow from these heaters is limited.

Instantaneous gas water heater

Most instantaneous water heaters are fired by gas, which is ignited by a pilot light immediately water flows, to provide hot water instantaneously. Cold water running through a coil of pipework, wrapped around a combustion chamber and heat exchanger over a gas burner, is heated by the time it reaches the outlet. These heaters are controlled by the cold water supply valve; when the valve is opened the flow of water opens a gas valve to ignite the burners to heat water.

A single point, gas, instantaneous water heater is designed to supply hot water to single fittings such as a basin or sink. These heaters are usually fixed above the fitting to be supplied, and the hot water is delivered through a swivel outlet. A typical single point heater is illustrated in Fig. 25. Because of their small output and limited use the air intake from the room and the exhaust outlet to the room is acceptable. Where effective draught seals are fitted to windows to rooms in which these heaters are fired, there should be permanent ventilation to the open air.

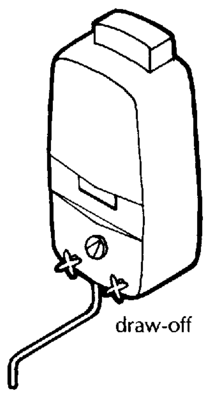


Fig. 25 Gas instantaneous single point water heater.

Multi-point instantaneous gas water heater

Multi-point gas water heaters were commonly used to supply domestic hot water to small houses and flats before combined space heating and hot water boilers became common. These heaters, illustrated in Fig. 26, can supply hot water to a sink, basin and bath through dead-leg draw-off pipes to fittings, hence the name multi-point.

When a tap over one of the fittings is opened, the flow of cold water through the coils of pipe around the heat exchanger is heated to deliver hot water. The initial flow of cold water opens a gas valve and the pilot light ignites the gas burners to provide heat. When all the taps to fittings are shut and there is no water flow, the gas valve shuts.

The rate of flow of hot water from these heaters is limited by the need for sufficient time to allow an adequate exchange of heat to the water coils in the heat exchanger. When more than one tap is opened there will be a restricted rate of flow of hot water, and filling a bath can be a somewhat lengthy process. For these reasons these heaters are much less used than they used to be.

The comparatively large output from these heaters necessitates a flue to open air to exhaust combustion gases and also an adequate intake of air for efficient and safe combustion of gases. A flue and permanent air vents or a balanced flue are necessary.

The gas valves in these heaters will only operate when there is comparatively high water pressure, such as that from a main supply,

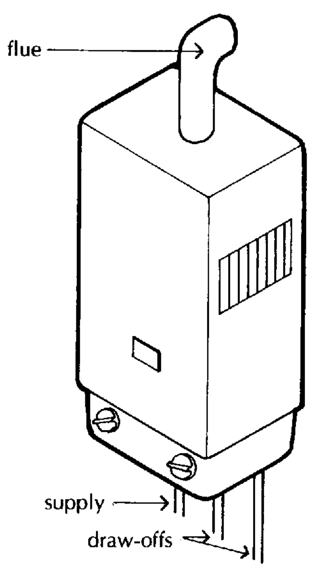


Fig. 26 Gas instantaneous multi-point water heater.

or a good head of water from a cistern. All gas fired heaters and boilers require regular maintenance if they are to operate efficiently and safely.

Instantaneous electric water heater

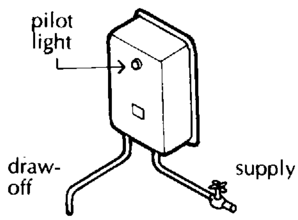


Fig. 27 Electric instantaneous single point water heater.

Water is heated as it flows through coiled heating elements immersed in a compact, sealed tank. The electric supply is operated by a flow switch in the cold water supply inlet. The control valve on the cold water supply pipe is used to adjust the temperature of the hot water outlet.

These heaters, illustrated in Fig. 27, are fixed over the single appliance to be supplied, with hot water delivered through a swivel outlet discharging over the appliance. The output of hot water from these heaters is limited by the rate of exchange of heat from the heating elements to cold water. In hard water areas limescale will coat the heating element and appreciably reduce the efficiency of these heaters. The heat exchange tank, which is heavily insulated, is housed in a glazed enamel casing for appearance sake.

The advantage of these heaters is that they are compact, require only one visible supply pipe and may be fixed in internal, unventilated toilets as they have no need for air intake or a flue.

WATER SERVICES TO MULTI-STOREY BUILDINGS

Mains water is supplied under pressure from the head of water from a reservoir, or pumped head of water or a combination of both. The level to which mains water will rise in a building depends on the level of the building relative to that of the reservoir from which the mains water is drawn, or relative to the artificial head of water created by pumps. Obviously mains pressure will rise less in a building on high ground than in one on lower ground.

In built-up areas there will, at times such as early morning, be a peak demand on the mains supply, resulting in reduced pressure available from the water main. It is the pressure available at peak demand times that will determine whether or not mains supply pressure is sufficient to feed cold water to upper water outlets. The pressure available varies from place to place depending on natural or artificial water pressure available, intensity of demand on the main at peak demand time and the relative level of the building to the supply pressure available.

Mains pressure supply

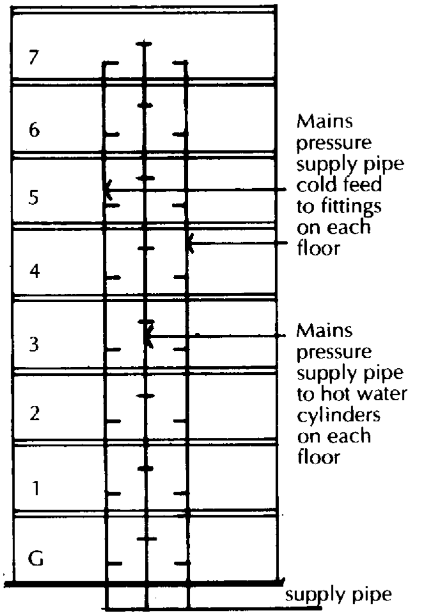


Fig. 28 Mains pressure supply.

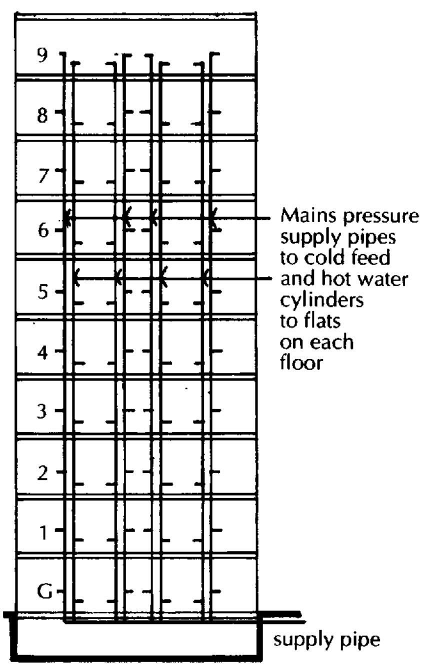


Fig. 29 Mains pressure supply.

Fig. 28 is a diagram of an eight-storey building where the mains pressure at peak demand times is sufficient to supply all cold and hot water outlets to all floors. Two supply pipe risers branch to provide cold water to ranges of sanitary fittings in male and female toilets on each floor and another riser branches to feed hot water storage cylinders on each floor for the toilets. This is the most economic arrangement of pipework where sanitary fittings are grouped on each floor, one above the other.

To provide reasonable equality of flow from outlets on each floor it is usual to reduce pipe sizes. In the arrangement shown in Fig. 28, the bore of the risers will be gradually reduced down the height of the building to provide a reasonable flow from all outlets to compensate for reduced flows as pumped head pressure increases down the height of the building.

Where the mains pressure is sufficient to provide a supply to a multi-storey building it is not always possible to provide a reasonable equality of flow to fittings on each floor by varying pipe sizes alone. An increase in pipe size will provide a little reduction in pressure loss from the frictional resistance to flow of larger bore pipes and fittings. There is a limit to the resistance to flow that can be effected, because of the limited range of pipe sizes, without using gross and uneconomic pipe sizes.

In the diagrammatic pipe layout illustrated in Fig. 29, of sanitary fittings in a ten-storey building with four flats to each floor, a pair of risers supplies the cold water outlets and hot water cylinder to each flat on each floor, with some reduction in pipe size down the building to provide reasonable equalisation of flow. Had a pair of risers been used to each pair of flats on each floor, it would not have been practical to provide reasonable equalisation of flow.

Another method of providing equalisation of rate of flow from outlets floor by floor in multi-storey buildings is by the use of pressure reducing valves at each flow level. This more sophisticated approach is used in modern buildings in Northern European countries.

Multiple risers

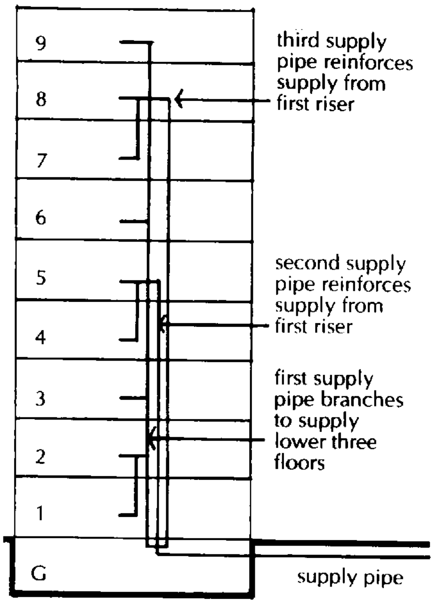


Fig. 30 Multiple risers.

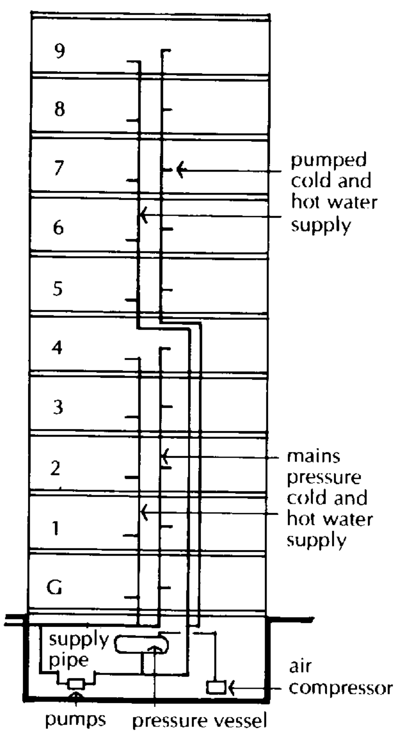


Fig. 31 Pumped and mains pressure supply.

Another method of equalising flow, being used experimentally, is the use of multiple rising pipes as illustrated in Fig. 30. One rising supply pipe branches to supply the three lower floors and then rises to supply the three floors above, where it is joined and its supply reinforced by the second rising supply and then up to the top three floors where it is joined and reinforced by the third rising supply pipe.

The logic in the use of this arrangement is that in multi-storey buildings in multiple occupation, such as a hotel, there will be unpredictable short periods of peak use, as for example when a tour party returns. During this short period there may be heavy call on water use on one floor, which may cause unacceptable starvation of water supply. By providing alternative reinforcing sources of supply and judicious arrangements of pipe sizes, a reduction of flow rate may be avoided or at least smoothed out.

It is good practice in the design of pipework layout to make an assumption of frequency of use of draw-off water to sanitary appliances. The assumption is based on an estimate of peak period use, such as first thing each morning, which does not allow for unpredictable heavy use. To provide for possible maximum use would involve gross and uneconomic pipework.

Where mains pressure is insufficient at peak demand times to raise water to the highest water outlet, it is necessary to install pumps in the building to raise water to the higher water outlets. In this situation it is usual to supply from the supply pipe those outlets that the mains pressure will reach, and those above by the pumped supply, to limit the load on the pumps as illustrated in Fig. 31.

Two mains pressure supply pipes rise to supply the lower five floors, one with branches to each floor level to cold water outlets and the other with branches at each floor level to hot water storage cylinders. The five upper floors are supplied by two rising supply pipes under the pressure of the pump in the basement. At each floor level branches supply cold water to sanitary fittings and there are branches to hot water cylinders.

There are two pumps, one operating and the other as standby in case of failure and to operate during maintenance. The pumps are supplied by the mains through a double check valve assembly to prevent contamination of the supply by backflow should the pumps fail.

Auto-pneumatic pressure vessel

The auto-pneumatic pressure vessel indicated in Figs. 31 and 32 is a sealed cylinder in which air in the upper part of the cylinder is under pressure from the water pumped into the lower part of the cylinder. The cushion of air under pressure serves to force water up the supply pipe to feed upper-level outlets as illustrated. Water is drawn from the auto-pneumatic pressure vessels as water is drawn from the upper-level outlets so that when the water level in the pressure vessel falls to a predetermined level, the float switch operates the pump to recharge the pressure vessel with water. Thus the cushion of air in the pressure vessel and its float switch control and limit the number of pump operations. In time, air inside the pressure vessel becomes mixed with water and is replaced automatically by the air compressor.

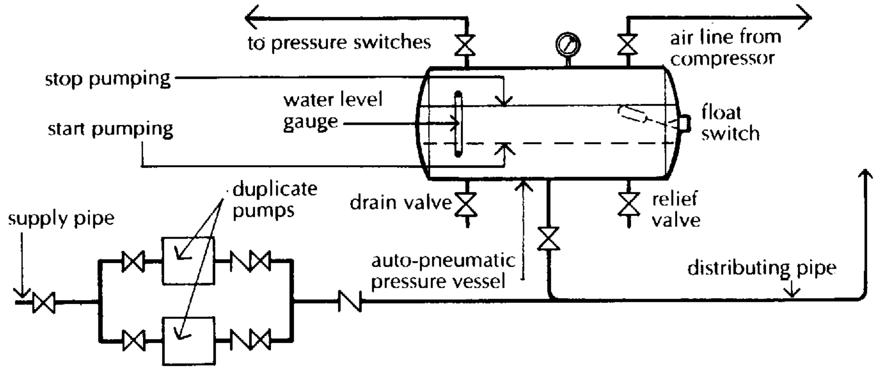


Fig. 32 Auto-pneumatic pressure vessel.

Gravity feed cold water supply

The traditional system of cold water supply was through a roof level cold water storage system to supply all cold water outlets except one mains pressure outlet to sinks for drinking water. The justification for this arrangement was that the air gaps between the mains supply and the water level in the system served as an effective and trouble free check against possible contamination of the mains supply. A separate drinking water supply was provided on the grounds that cistern water might not be palatable.

In multi-storey buildings, where mains pressure is insufficient to raise water to roof level, the comparatively trouble free, cistern feed to cold water outlets may be used with a covered drinking water storage vessel or cistern.

Fig. 33 is a diagram of a ten-storey building in which the drinking water outlets to the lower five floors are fed by mains supply. Because the mains pressure is insufficient to raise water to roof level the upper five floors are supplied with drinking water from a covered drinking water storage vessel or cistern. The roof level cold water storage cistern, the drinking water vessel or cistern and the drinking water outlets to the top five floors are fed by a pumped

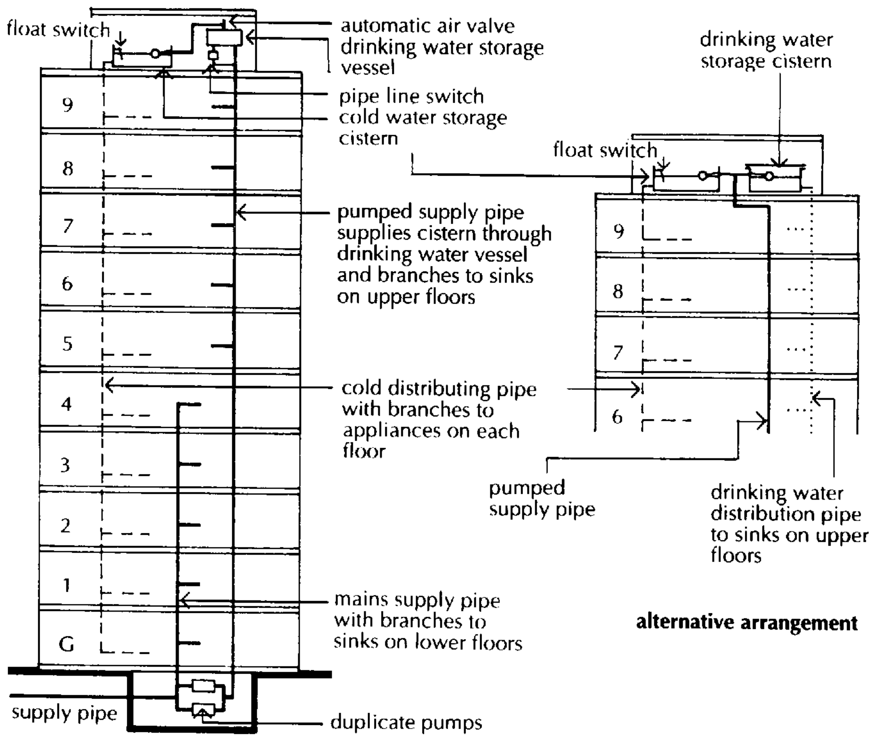


Fig. 33 Drinking water storage cistern.

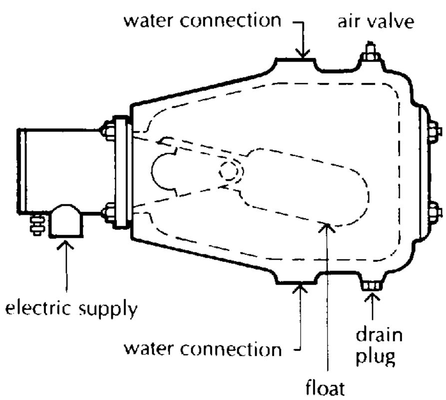


Fig. 34 Pipeline switch.

supply. The cold water storage cistern supplies cold water to all cold water outlets, other than the sink and to hot water cylinders on each floor.

There is a duplication of rising pipework to the five lower floors, which is considered a worthwhile outlay in reducing the load and wear on the pumps. The pumped supply feeds both the higher drinking water outlets and cold water storage cistern through a drinking water storage vessel.

The sealed drinking water storage vessel and the cold water storage cistern are filled through the pumped supply, in which a pipeline switch is fitted. A pipeline switch, illustrated in Fig. 34, is used to limit pump operations. As water is drawn from the drinking water vessel the water level falls until the float in the pipeline switch falls and starts the pump.

The cold water storage cistern is supplied through the drinking water vessel, from which it can draw water to limit pump operations. When the water level in the cold water storage cistern falls to a predetermined level, a float switch starts the pump to refill the cistern through the drinking water vessel.

Drinking water storage cistern

As an alternative a sealed drinking water storage vessel – a drinking water storage cistern – may be used, as illustrated in Fig. 33. The cistern has a sealed cover and filtered air vent and overflow to

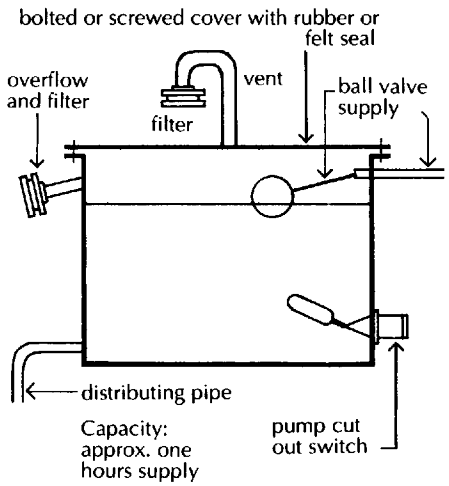


Fig. 35 Drinking water storage cistern.

exclude dirt and dust, as illustrated in Fig. 35. A pump cut out, or float switch, controls the pump operations at a predetermined level. As before, a float switch controls pump operations to fill the cold water storage cistern. The pumped service pipe feeds both cisterns so that whichever switch operates, the pump operates to fill both cisterns.

The advantage of the sealed drinking-water storage vessel is that it requires less maintenance than the drinking water cistern whose ball valve and filters require periodic maintenance. But the roof level switches have to be wired through a control box down to the basement level pumps and the switches will require regular maintenance in a position difficult to access.

As a check to the possibility of backflow from a pumped supply into the main, and as a reservoir against interruption of the mains supply, it has been practice to use a low level cistern as feed to the pumped supply to a roof level cistern, so that the air gap between the inlet and the water level in the cistern acts as a check to possible contamination of the mains supply.

Low level cistern

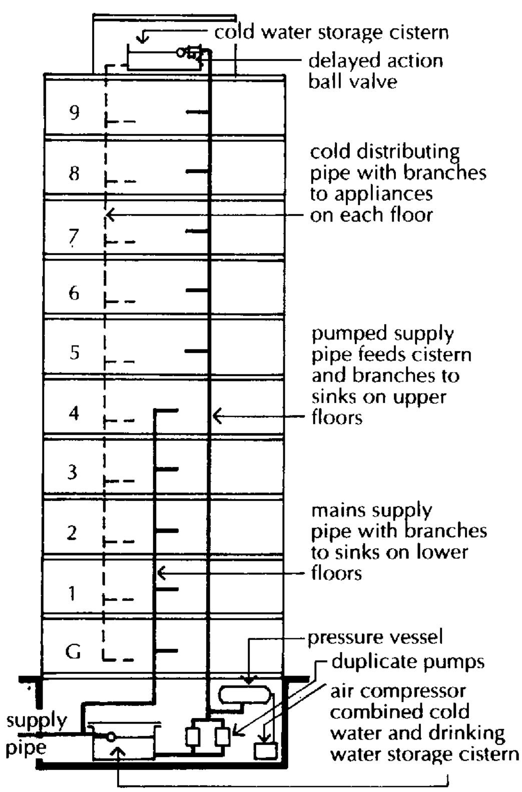


Fig. 36 Low level storage cistern.

Where the mains pressure is insufficient to supply cold water outlets on upper floors of multi-storey buildings, and a separate drinking water supply is required, a cistern feed supply to cold water outlets may be used in combination with a pumped supply to upper level drinking water outlets, as illustrated in Fig. 36.

Here a low level cistern is fitted as supply to the pumps. A low level cistern is used as a form of check against contamination of the supply and as a standby against interruption of the mains supply. The covered low level cistern serves to supply the upper level drinking water outlets and the roof level storage cistern. The operation of the pumps is controlled at low level through a pressure vessel similar to that illustrated in Fig. 32.

Drinking water outlets to the lower floors are connected to the mains supply pipe which in turn feeds a low level storage cistern from which a supply is pumped to the upper level drinking water outlets and the roof level storage cistern. Pump operations are limited by an auto-pneumatic pressure vessel, illustrated in Fig. 32, and a delayed action ball valve to the roof level cistern. As the low level cistern supplies both drinking and cold water outlets, it has to be sealed to maintain the purity of the drinking supply. A screened air inlet maintains the cistern at atmospheric pressure.

The pumped supply pipe shown in Fig. 36 feeds the roof-level cold water cistern, which is fitted with a delayed action ball valve.

Delayed action ball valve

A delayed action ball valve, illustrated in Fig. 37, is fitted to the roof level cistern to control and reduce pump operations. The delayed action ball valve consists of a metal cylinder (A) which fills with water when the cistern is full and in which a ball (B) floats to operate the valve (C) to shut off the supply. Water is drawn from the cistern and as the water level falls, float (E) falls and opens valve (D) to discharge the water from cylinder (A). The ball (B) falls and opens the valve (C) to refill the cistern through the pump, so limiting the number of pump operations.

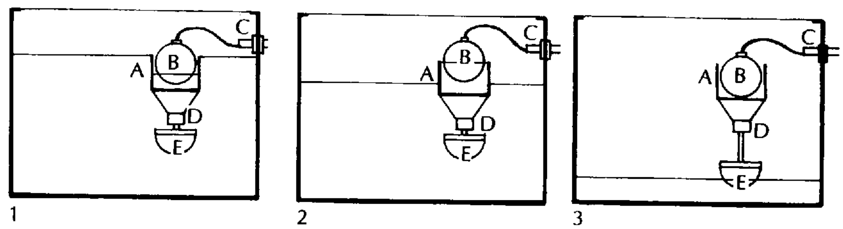


Fig. 37 Delayed action ball valve.

Intermediate water storage cistern

Current practice in multi-storey buildings of more than about ten storeys is to use a roof level and one or more intermediate water storage cisterns to supply outlets other than drinking water taps. The intermediate cisterns spread the very considerable load of water storage and also serve to reduce the pressure in distributing pipes, for which reason they are sometimes termed 'break pressure cisterns'.

Fig. 38 shows a ground-level storage cistern supplying a pumped supply to an intermediate and roof-level cistern from which distributing pipes supply sanitary appliances on the lower and upper floors respectively, thus spreading the weight of water storage and limiting pressure in distributing pipes. The pumped supply also feeds drinking water outlets to upper floors. A float switch in the pressure vessel and delayed-action ball valves in the cisterns limit pump operations. Intermediate cisterns are used at about every tenth floor.

Zoned supply system

The supply to the 22 storey building illustrated in Fig. 39 is divided into three zones in order to help equalise pressure and uniformity of flow from outlets on all floors. The supply to the lower nine floors is through two rising supply pipes taken directly from the mains supply.

The supply to the eight top floors is from a pumped supply through a roof level pump and pressure vessel, and the supply to the intermediate five floors is by gravity from a sealed drinking water cistern at roof level. In this way the loss of residual head to the lower

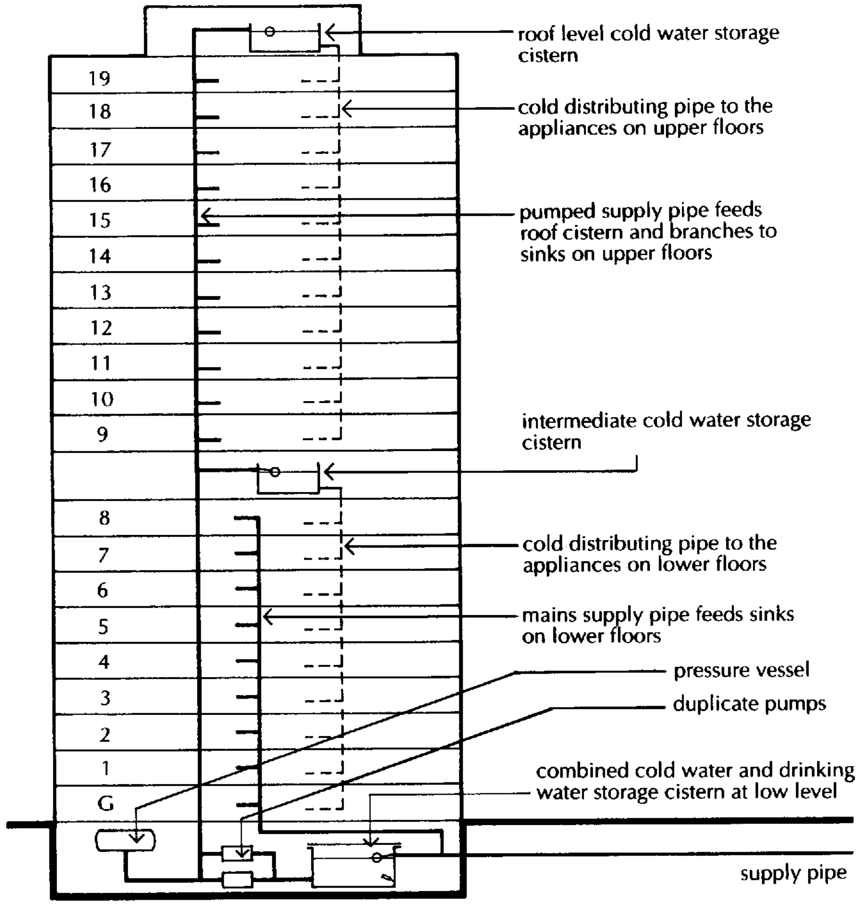


Fig. 38 Intermediate level storage cistern.

and upper floors is limited and the loss of head from the cistern is limited by feeding intermediate floors only. By dividing the building into three zones of supply, loss of head is limited in the main supply and distribution pipes, and by reduction in pipe diameter in each zone reasonable equalisation of flow from taps on each floor is possible.

PIPES (TUBULARS) FOR WATER SUPPLY

The materials used for pipework for water supplies are copper, galvanised mild steel and plastic. Up to the middle of this century lead was the material most used for water-supply pipework. The increase in the cost of lead after World War II led first to the use of galvanised mild steel tubes and later to light-gauge copper tubes instead of lead. Today, the light gauge copper tube is the material most used for water-supply pipework in buildings.

Minute quantities of lead may be leached from lead pipes used for water supplies. These small amounts of lead may in time be sufficiently toxic, particularly to the young, to be a serious hazard to health. The new Water Supply Byelaws prohibit the use of lead for

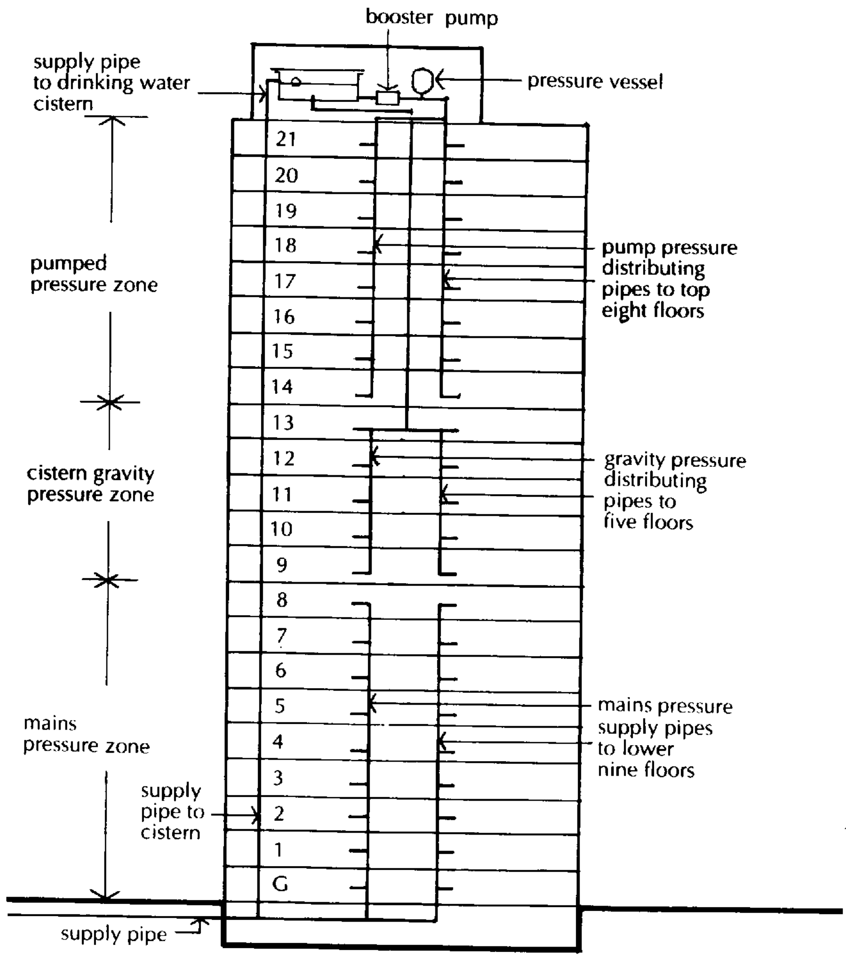


Fig. 39 Zoned supply system.

either new or replacement pipework for water supply. The byelaws also prohibit the use of lead solders for joining copper pipes, and so tin/silver solders are accepted.

Copper pipe (copper tubulars)

The comparatively high strength of copper facilitates the use of thin-walled light-gauge pipes or tubes for most hot and cold water services. The ductility of copper facilitates cold bending, the thin walls make for a lightweight material and the smooth surface of the pipe provides low resistance to the flow of water. Like lead, copper oxidises on exposure to air and the oxide film prevents further corrosion. Copper tube is the material most used for water services today.

Copper tubes are supplied as half-hard temper and dead soft temper, the former for use above ground for its rigidity and the latter principally for use in trenches or where its flexibility is an advantage, as in use in the underground service to buildings. Light gauge copper tube, size 6 to 159 mm (outside diameter) is manufactured; the sizes most used in buildings are 12, 15, 18, 22, 28, 35, 42 and 54 mm.

Jointing

Copper pipes are joined with capillary or compression joints – used for the majority of copper tubes in water services – and welding, for the larger bore pipe for drains above ground where the pipework is prefabricated in the plumbers' shop.

Capillary joint

A capillary joint is made by fitting plain ends of pipe into a shouldered brass socket. Molten solder is then run into the joint, or internal solder is melted by application of heat. Pipe ends and fittings must be clean, otherwise the solder will not adhere firmly to the pipe and socket. Fig. 40 illustrates typical capillary joints. This is a compact, neat joint.

Capillary joints, which afford the least labour and cost of material, are used for most small bore pipework particularly where there are a lot of joints.

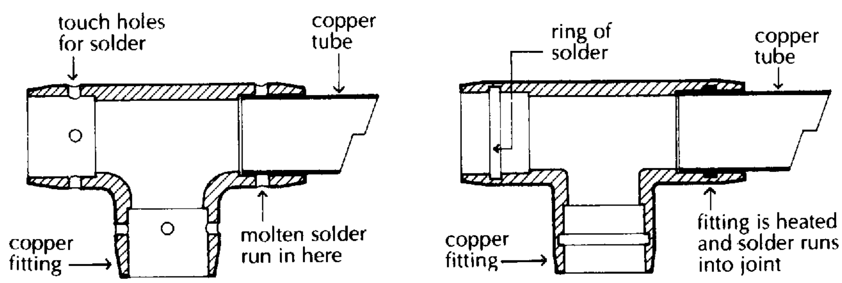


Fig. 40 Soft solder capillary fittings.

Compression joint

Compression fittings are either non-manipulative or manipulative. With the former, plain pipe ends are gripped by pressure from shaped copper rings; in the latter the ends of the pipes are shaped to the fitting, as illustrated in Fig. 41.

The manipulative fitting is used for long pipe runs and where pipework is not readily accessible, as the shaped pipe ends are more firmly secured than with the non-manipulative or capillary joint. The somewhat more expensive non-capillary joint is sometimes preferred to the cheaper capillary joint which is dependent on cleanliness of contact rather than friction.

Compression joints are often combined with capillary joints at the ends of pipe runs to facilitate repairs or alterations, because of the ease of disconnecting these joints.

The thin walled copper tubulars used for water services have poor mechanical strength in supporting the weight of a filled pipe. The pipework should, therefore, be supported at comparatively close

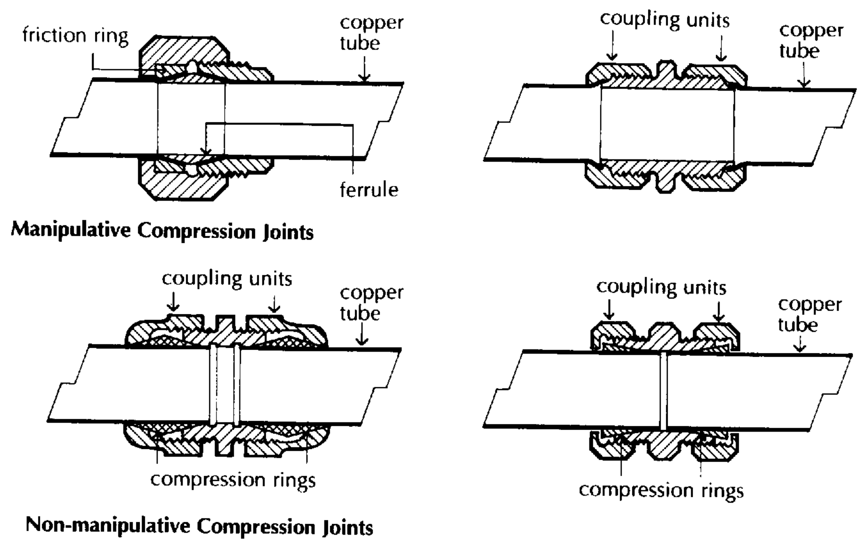


Fig. 41 Compression joints.

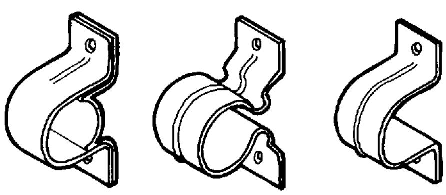


Fig. 42 Copper fixing clips.

intervals by pipe clips screwed to plugs in walls. The pipe clips, illustrated in Fig. 42, should be fixed at intervals of from 1.5 to 3 m horizontally and 2 to 3 m vertically, depending on the size of the pipe.

Galvanised mild steel (low carbon steel)

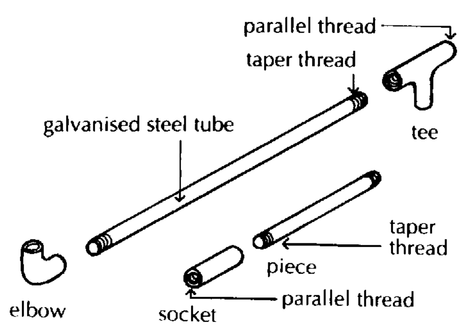


Fig. 43 Galvanised steel pipe.

Galvanised mild steel (low carbon steel) tubulars were commonly used for all water services during the middle of this century because of the low cost and availability of the material. Today, galvanised mild steel tubulars are used for service, supply and distributing pipework, 40 mm bore and over, particularly where there are long straight runs of pipework, because of the economy of material and labour in the use of this material. Galvanised mild steel tubulars are also used for fire prevention and fire fighting installations because of their greater resistance to damage by heat than other pipe materials.

Mild steel tubulars are manufactured with a nominal bore of 6 to 150 mm in three grades: light, banded brown; medium, banded blue; and heavy, banded red. In general, light is for gas services, medium for water services, and heavy for steam pressure services. For water services, tubulars should be galvanised to resist corrosion. Fig. 43 shows these tubulars.

Jointing

The pipe ends are threaded and the joint made with sockets, nipples or long screws, unions or fittings as illustrated in Fig. 43. Pipes are supported at intervals of from 2.5 to 3 m.

Plastic pipe or tube

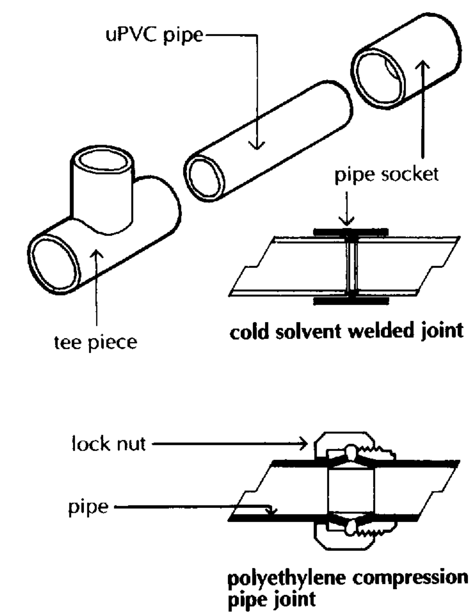


Fig. 44 PVC pipe.

Polythene and unplasticised PVC (poly vinyl chloride) tube is used respectively for use underground and above ground for water services.

Polythene (polyethylene) is flexible and used for water services underground, while the more rigid PVC is used for services above ground. Both materials are lightweight, cheap, tough, do not corrode and are easily joined. These materials soften at comparatively low temperatures and are used principally for cold water services and drains above and below ground. The pipes are manufactured in sizes from 17 to 609 mm, the sizes most used being 21.2, 26.6, 33.4, 42.1 and 60.2 mm (outside diameter).

uPVC and ABS (acrylonitrile butadine styrene) pipes are used primarily for waste pipes.

Polythene tube is jointed with gunmetal fittings as illustrated in Fig. 44. A copper compression ring is fitted into the pipe ends to prevent the wall of the pipe ends collapsing as the coupling is connected by tightening the nut. This type of joint is used to withstand high pressures, as in mains pressure supply pipework.

Solvent welded joint

A solvent weld cement is applied to the ends of the pipes to be joined and the ends of the pipes are fitted into the socket or other fitting (Fig. 44). The solvent cement dissolves the surfaces of the pipe end and fitting so that as the solvent hardens it welds the joined plastic surfaces together. The joint will set in 5 to 10 minutes and require 12 to 24 hours to become fully hardened.

This type of joint is commonly used with uPVC pipework, such as low pressure distribution pipework and more particularly waste branch pipes. Pipe runs in plastic are supported by clips at 225 to 500 mm horizontally and 350 to 900 mm vertically.

Insulation

Cold and hot water supply and distributing pipes should be fixed inside buildings, preferably away from external walls to avoid the possibility of water freezing, expanding and rupturing pipes and joints. Where pipes are run inside rooftop tank rooms and in unheated roof spaces, they should be insulated with one of the wrap-around or sectional insulation materials designed for the purpose. Similarly, roof-level and roof-space storage cisterns should be fitted with an insulation lining to all sides, the base, and to the top of the cisterns.

VALVES AND TAPS

Valves

The two general terms used to describe fittings designed to regulate or shut the flow of water along a pipeline, are valve and cock. A valve is a fitting that can be adjusted either to cause a gradual restriction in flow or a cessation of flow. For this reason valves are also known as stop valves.

Cock, plug cock, stop cock

A cock is a fitting that consists of a solid cylindrical plug, fixed with its long axis at right angles to flow. When shut the plug fills the pipe line. A 90° quarter turn of the plug brings a round port or hole in the plug into line with the flow, and so opens the plug. There is little control of flow with a plug that is designed to be either shut or open. Cocks are also described as plug cocks and stop cocks.

Globe valves

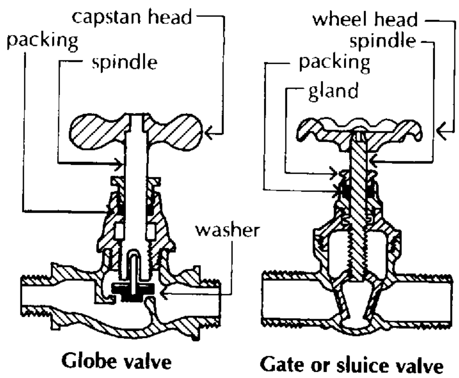


Fig. 45 Valves.

The two valves in common use are the globe valve and the gate valve.

Globe valves, so named for their rounded or globe shape, operate to control or shut flow, through a disc that is lowered slowly by turning a screwdown spindle to a seating. Because the operation to shut these valves is by screwing down, they are also described as screw down valves.

The design of these valves is such that they operate to close and open at right angles to the line of flow. In consequence there is a little restriction of flow when the valve is open as water flows up and down and then along the pipe line.

A globe valve is illustrated in Fig. 45. Globe valves are commonly used in high pressure and hot water pipework.

Gate valve, fullway gatevalve

A gate valve operates by raising or lowering a metal gate into or out of the line of the pipework as the spindle is screwed down or up. This valve is sometimes referred to as a fullway gate valve as when it is fully open it does not restrict flow along the pipeline, unlike the globe valve. For this reason the gate valve is used where there is low pressure flow in the pipeline, such as that from cistern feed systems. Fig. 45 is an illustration of a gate valve.

Taps

The word tap is used in the sense of drawing from or tapping into, as these fittings are designed to draw hot or cold water from the pipework. They are sometimes described as draw-off taps.

There are three types of draw-off tap: the bib tap, the pillar tap (including mixer taps which mix hot and cold water) and the draw-off tap which is used to draw off water to drain pipe systems.

Bib tap

The traditional bib tap, illustrated in Fig. 46, operates in the same way as a globe valve through a disc which is screwed down to close and up to open, except that the tap is at the end of a pipeline to open to discharge water. A washer fixed to the base of the disc seals the tap when shut. The supply to the bib tap is in line with the pipeline.

This type of tap is fixed above the bath, basin or sink to be served.

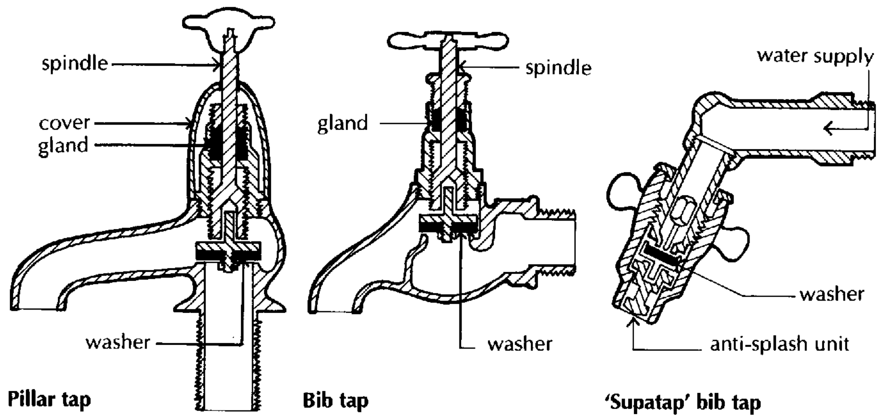


Fig. 46 Taps.

Pillar tap

This tap, illustrated in Fig. 46, is designed to be fitted to the bath, basin or sink it serves, with the supply pipe connected vertically to the base of the tap. This type of tap is usually covered by a metal or plastic cover for the sake of appearance. A wide variety of designs is available. The tap operates in the same way as a bib tap, through a screw down spindle which opens or closes a washer.

Supatap

The 'supatap', illustrated in Fig. 46, is designed so that the washer may be replaced without turning off the water supply, through an automatic closing valve that interrupts the supply.

Quarter turn taps

Many modern taps use a system of ceramic discs to open and close the supply. The lower disc is fixed and the top disc can be turned through 90°. When the two ports or holes in the top disc coincide with those in the bottom fixed disc, the water flows. A lever, when turned or depressed, operates a spindle to effect the necessary quarter turn to open the tap for water to flow.

Because of the quarter turn operation there is not the same control of flow as there is with bib and pillar taps and because of the small ports through which water flows there is not the same vigorous flow.

The advantage of these taps is that the polished ceramic discs will last as long as the tap itself without need of replacement. The simple operation of these taps makes it possible to design plain, elegant taps that consist of a plain steel cylinder on which a lever operates to open and shut the tap and can be used to operate a hot and cold water mixer.

Fig. 47 is an illustration of a quarter turn tap with ceramic disc washers.

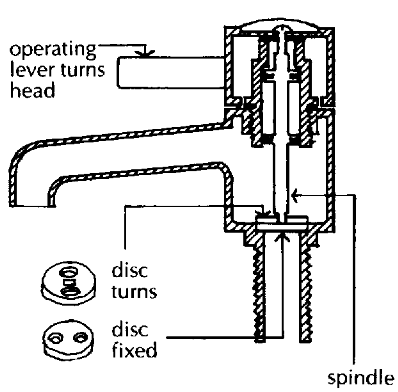


Fig. 47 Quarter turn tap.

Draw-off taps

A draw-off tap is similar to a bib tap except that it is operated by a loose wheel or capstan head and the outlet discharge is serrated to take a hose connection.

Contamination of supply

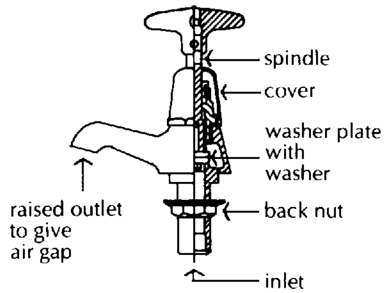


Fig. 48 Tap with raised outlet.

As one of several requirements to prevent contamination of the supply by backflow, the Water Supply Byelaws require an air gap between the lowest part of the outlet of water taps and the spill over level of sanitary appliances such as basins, baths and sinks. The rationale for this regulation is somewhat difficult to understand. It seems highly unlikely that a wash basin overflow, and overflow water rising above the rim of the basin, would coincide with the reduction or cessation of the supply and so cause contaminating backflow. Fig. 48 is an illustration of a tap to match this requirement.

The size of the gap is related to the bore of the pipe supplying the tap or the bore of the outlet. As an alternative to an air gap, a double check valve assembly or other suitable appliance may be used in the pipe supplying each tap.

ESTIMATION OF PIPE SIZES

Water storage capacity

British Standard 6700, 1987, recommends minimum storage for dwellings of 100–150 litres for small houses, for cold water only, and 100 litres per bedroom, total capacity, for larger houses.

Water storage capacity was determined by the regulations of water undertakings for dwellings at 114 and 227 litres for cold and domestic hot water respectively and for other uses from Table 2.

To provide a reasonable rate of flow from outlets, that is taps and valves, the required size of pipe depends on the static or pumped head of water pressure, the resistance to flow of the pipes, fittings and bends and the assumed frequency of use of outlets. For small pipe installations such as the average dwelling where there are 5 to 10 outlets, pipes of sufficient bore are used to allow simultaneous use of all outlets at peak use times. As only small bore pipes are required for this maximum rate of flow there is no point in making an estimate of pipe size for a more realistic usage.

With larger installations, such as the pipe system for a block of flats where there may be 100 or more outlets, it would be unrealistic and uneconomic in pipe size and cost to assume that all outlets will be in use simultaneously. It is usual therefore to make an assumption of the frequency of use of outlets, to estimate required pipe sizes that will give a reasonable rate of flow from outlets that it is assumed will be in use simultaneously at peak use times. If the actual simultaneous use is greater than the estimate then there will be reduced rate of flow from outlets. This 'failure' of the pipe system to meet actual in-use flow rates has to be accepted in any estimate of frequency of use of outlets.

Table 2 Cold water storage.

Recommended minimum storage of cold water for domestic purposes (hot and cold outlets)	
Type of building or occupation	**Minimum storage litres**
Hostel	90 per bedspace
Hotel	200 per bedspace
Office premises	
with canteen facilities	45 per employee
without canteen facilities	40 per employee
Restaurant	7 per meal
Day school nursery, primary	15 per pupil
secondary, technical	20 per pupil
Boarding school	90 per pupil
Children's home or residential nursery	135 per bedspace
Nurses' home	120 per bedspace
Nursing or convalescent home	135 per bedspace

Rate of flow

The rate of water flow at taps and outlets depends on the diameter of the outlet and the pressure of water at the tap or outlet. The size of the tap is fixed. The water pressure depends on the source water pressure from a cold water storage cistern or a pumped supply, and the loss of pressure to the frictional resistance of the pipework and its fittings such as elbows, tees, valves and taps. The design of pipework installation is concerned, therefore, with estimating the resistance to flow and the selection of pipes of sufficient size to allow a reasonable rate of flow at taps, where the source water pressure is known.

Water pressure hydraulic or static head

In the design of pipework for buildings it is convenient to express water pressure as hydraulic or static head, which is proportional to pressure. The static head is the vertical distance in metres between the source, the cold water storage cistern and the tap or outlet. This head represents the pressure or energy available to provide a flow of water from outlets against the frictional resistance of the pipework and its fittings. The frictional resistance to flow of pipes is expressed as loss of head (pressure) for unit length of pipe.

Loss of head

These loss of head values are tabulated against the various pipe diameters available and the various material in use. The frictional

Table 3 Equivalent pipe lengths.

Pipe fittings	**Equivalent length of pipe in pipe diameters**
90° Elbows	30
Tees	40
Gate valves	20
Globe valves and taps	300

resistance to flow of fittings such as elbows, tees, valves and taps is large in comparison to their length in the pipe run. To simplify calculation it is usual to express the frictional resistance of fittings as a length of pipe whose resistance to flow is equivalent to that of the fitting. Thus the resistance to flow of a tee is given as an equivalent pipe length.

The equivalent length of pipe is given in Table 3. From this the frictional resistance of a pipe and its fittings can be expressed as an equivalent length of pipe, that is the actual length plus an equivalent length for the resistance of the fittings. The head (pressure) in that pipe can then be distributed along the equivalent length of pipe to give a permissible rate of loss of head per metre run of equivalent pipe length, and the head remaining at any point along the pipe can be determined. From this, the pipe diameter required for a given rate of flow in pipework and at outlets can be calculated.

To select the required pipe sizes in an installation it may be useful to prepare an orthographic or isometric diagram of the pipe runs from the scale drawings of the building. This diagram need not be to scale as the pipe lengths and head available will, in any event, be scaled off the drawings of the building. The purpose of the diagram is for clarity in selecting pipe sizes and tabulating these calculations.

Fig. 49 is an isometric diagram, not to scale, of a cold distribution pipe installation for a small building. The source of supply – the cold water storage cistern – is shown. The head from the base of the cistern is measured and all pipe runs to sanitary appliances are indicated. Each pipe run is numbered between tees and tees and tees and taps.

A change of pipe diameter is most likely to be required at tees and it is convenient, therefore, to number pipes between these points and taps. There are various methods of numbering pipe runs. The method adopted in Fig. 49 is a box, one corner of which points to the pipe or one side of which is along the pipe run. The box contains the pipe number on the left hand side, the actual pipe length top right and the rate of flow in litres per second bottom right.

The rate of flow in a pipe is the rate of flow of the single sanitary appliance it serves, or the accumulation of all the rates of flow of all the sanitary appliances it serves. In Fig. 49 the head is measured from the base of the cistern to the taps or pipe runs. Some engineers measure from midway between the water line and the base of the cistern and others from some short distance below the cistern to allow a safety margin and to allow for furring of pipes. For most building installations it is usual to take head measurements from the base of the cistern.

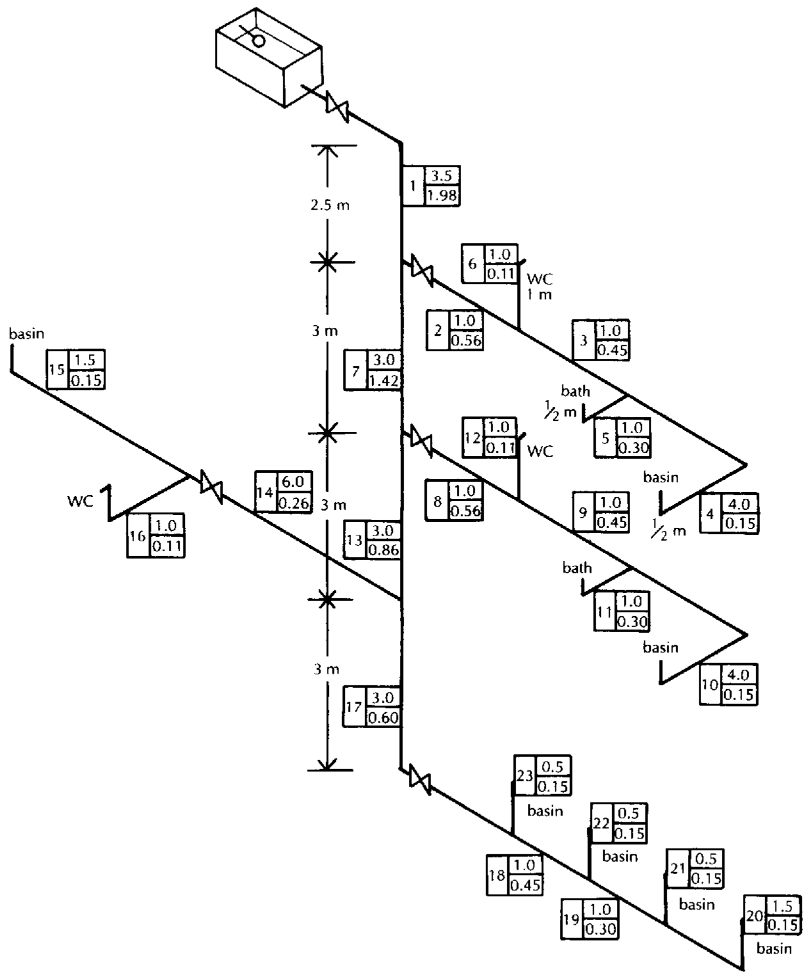


Fig. 49 Diagram of cold distribution pipe layout.

Frequency of use

In the following calculations to determine pipe sizes it is assumed that it is possible that all the taps served may be open simultaneously, and the pipes are sized accordingly. In large installations such as those of multi-storey blocks of flats, it is unlikely that all taps will be open at the same time and a frequency of use assumption, described later, is made to avoid the expense of over-large pipes.

Critical run of pipes

The procedure for selecting pipe sizes is firstly to determine the first index or critical run of pipes – that along which taps are most likely to be starved of water when all the taps are open. This starvation or loss of rate of flow is most likely to occur in the branch closest to the cistern, where head pressure is least. The first index run in Fig. 49 is pipe run 1, 2, 3, and 4. If pipes of adequate size for this run are selected to provide the required rates of flow at taps, then pipe run 1 will be large enough to supply all the other taps to the rest of the installation.

The head of water available in the fist index run 1, 2, 3, and 4 is 2 m, the vertical distance from the base of the cistern to the tap of the wash basin. The rate of flow from taps determines the cumulative rate of flow in the pipe runs. The unknown factors are the frictional resistance of the pipework and fittings and the size of pipes required for the given rates of flow. It is necessary, therefore, to make an initial assumption of one of these unknowns – the pipe sizes.

Assumption of pipe sizes

To make this initial assumption it is necessary to calculate a rate of loss of head in the index pipe run. The actual length of pipes is known and it is necessary to make an estimate of the likely length of pipe whose resistance to flow is equivalent to the resistance of the pipe fittings. This is usually taken as a percentage of the actual pipe length, and may vary from 25 to over 100. With experience in pipe sizing this assumed percentage will approach a fair degree of accuracy. In general, the greater the number of fittings to each unit length of pipe, the higher the percentage.

In Fig. 49, pipe run 1, 2, 3 and 4 has an actual length of 9.5 m. Assume an equivalent length of about 50% or say 5.5 m. Thus the total equivalent length of pipe is 9.5 + 5.5 = 15 m. The head is 2 m. The permissible rate of loss of head is therefore 2/15 = 0.13 per metre of equivalent length of pipe and this rate of loss of head should not be exceeded at any point along the pipe run.

The graph in Fig. 50 is used to select pipe sizes where the rate of flow is known and rate of loss of head has been assumed. In our example the rate of loss of head is 0.13. From that point on the base line read up to 1.98 litres per second, the flow required in pipe 1. These two intersect roughly midway between the heavy oblique lines indicating 35 and 42 mm pipe sizes. If the 35 mm pipe were selected then the rate of loss of head would be greater than the permissible loss of head figure of 0.13, so the next larger size, 42 mm, is selected for pipe run 1l.

Similarly, for pipe runs 2, 3 and 4, from the 0.13 rate of loss of head on the graph read up to 0.56, 0.45 and 0.15 rates of flow to select pipe sizes 28, 28 and 18 mm respectively, choosing as before the pipe size above the intersection of points.

These assumed pipe sizes may now be used to make a more exact calculation of friction losses in pipes and fittings and a more exact selection of pipe sizes. For this purpose it is usual to tabulate the calculations, as set out in Fig. 51.

The pipe numbers, design flow rates and actual pipe lengths of pipe runs 1, 2, 3 and 4 – the first index run – are entered in columns 1, 2, and 3 and the assumed diameters in column 7. The friction losses for

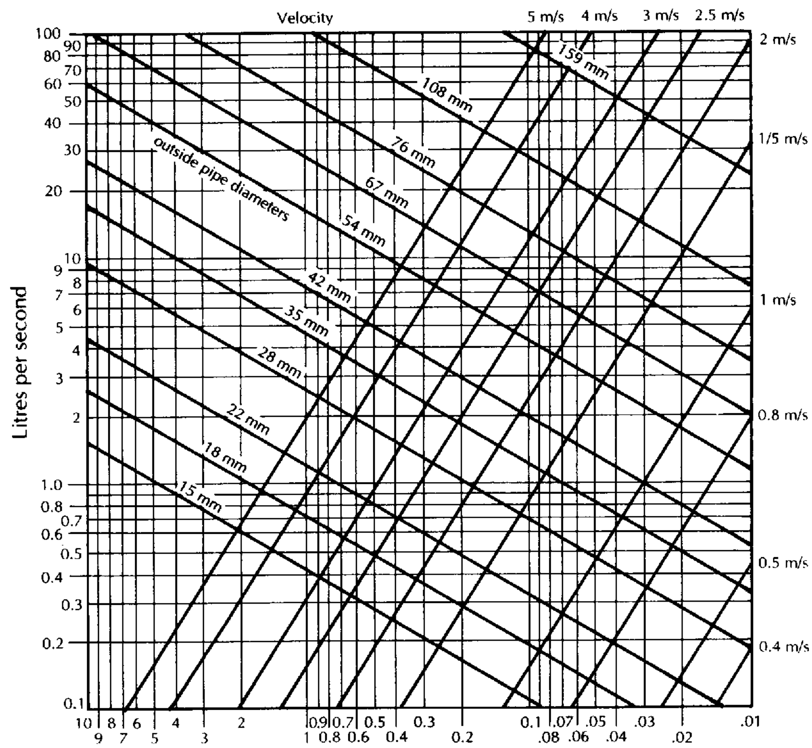


Fig. 50 Graph for selection of copper pipe sizes. Pipe sizes are outside diameters.

1	2	3	4	5	6	7	8	9	10	11	12
Pipe No.	**Design flow**	**Length**	**Equiv. length**	**Total eq. length**	**Head available**	**Assumed diam.**	**Permissible H/L value**	**Actual H/L value**	**Head used**	**Head remaining**	**Final diam.**
1	1.98	3.5	3.8	7.3	2.0	42	0.09	0.085	0.62	1.38	42
2	0.56	1.0	1.7	2.7	1.38	28	0.09	0.06	0.16	1.22	28
3	0.45	1.0	1.1	2.1	1.22	28	0.09	0.04	0.08	1.14	28
4	0.15	4.0	6.5	10.5	1.14	18	0.09	0.06	0.63	0.51	18
5	0.30	1.0	6.0	7.0	1.14	18	0.16	0.08			22
6	0.11	1.0	5.0	6.0	0.72	15	0.12	0.09			15
7	1.42	3.0	1.4	4.4	4.88	35	1.1	0.35	1.54	3.34	28
8	0.56	1.0			3.34						
9	0.45										
10	0.15										
11											

Fig. 51 Table for calculation of pipe size.

each pipe run due to elbows, tees, valves and taps are now calculated. These may be determined by a multiplier of the assumed pipe diameters to give an equivalent length of pipe from Table 3, or more accurately from tables published by the Chartered Institution of Building Services Engineers.

In pipe run 1 there is a gate valve, an elbow and a tee; the equivalent pipe sizes for these, from Table 3, are 20, 30 and 40 respectively. The sum of these, 90, multiplied by the assumed pipe diameter of 42 gives an equivalent pipe length of 90×42 or 3.8 m. Thus the total actual length of pipe 1, and equivalent length for fittings, is $3.5 + 3.8 = 7.3$ m, and this figure is entered in column 5. Similarly, for pipe run 2 where there is a valve and a tee, $20 + 40 = 60$, which multiplied by the assumed pipe diameter of 28 gives an equivalent length of 1.68 m, say 1.7 m, which is entered in column 4 to give a total length of 2.7 m in column 5. For pipe run 3 there is one tee, 40, which gives an equivalent length of $40 \times 28 = 1.12$ m, say 1.1 m, to give a total equivalent length of 2.1 m. In pipe run 4 there are two elbows, $30 + 30$, and one tap, 300, a total of 360 which multiplied by the assumed pipe diameter of 18 equals 6.48 m, say 6.5 m, to give a total equivalent length of 10.5 m.

With these more accurate totals of equivalent lengths in column 5 it is now possible to make a more accurate calculation of rate of loss of head. The head is 2 m and the total of equivalent lengths for pipe runs 1 to 4 in column 5 is 22.6. Thus the permissible rate of loss of head is $2 \div 22.6 = 0.09$, which is entered in column 8. With this more accurate rate of loss of head value, final pipe sizes are selected from Fig. 51.

For pipe run 1 the head loss and flow lines intersect just below the 42 mm pipe size line, confirming the assumed pipe size. The 42 mm pipe size line intersects the 1.98 flow line above a head loss value of 0.085 so that the actual head loss value in selecting the 42 mm pipe will be less than the permissible head loss value. The actual head loss in pipe run 1 will, therefore, be 0.085, which multiplied by the total equivalent length of 7.3 is 0.62, and this figure is entered in column 10 to give a figure of 1.38 head remaining in column 11.

This figure of 1.38 head remaining at the end of pipe 1 will therefore be the head available for pipe 2 and this figure is entered in column 6 for pipe 2. This head remaining at the end of pipe 1 will also be available for pipe 7.

Similarly, for pipe runs 2, 3 and 4, taking the permissible head loss value of 0.09 from Fig. 51, the required pipe sizes are 28, 28 and 18 mm respectively and the actual rate of head losses 0.06, 0.04 and 0.06. From these figures the head used and head remaining are calculated and tabulated. To calculate pipe sizes for pipe runs 5 and 6, tabulate pipe numbers, design flow and actual length. Assume pipe diameters of, say, 18 and 15 mm respectively, as these are common pipe sizes for branches to baths and WCs; then calculate equivalent lengths for fittings as before, based on these assumed pipe sizes, and tabulate total equivalent lengths. The head available for pipe 5 is taken from Fig. 51 as the head remaining at the end of the pipe run 3, that is 1.14. From the head available and the total equivalent length a permissible head loss value of 0.16 is calculated and a pipe size of 22 mm is taken from Fig. 51. The head available for pipe run 6 is the head remaining at the end of pipe run 2, that is 1.22, less half a metre, the height of the top of pipe run 6 above that of pipe run 4. The head available is therefore 0.72, the permissible head loss value is 0.12 and the pipe size is 15 mm.

To determine the pipe size for pipe run 7 tabulate in columns 1, 2 and 3 as before. Now assume a pipe size for pipe run 7. As the flow in 7 is less than in pipe 1 and the head will be greater, assume that pipe run 7 will be the next size smaller than 1, that is 35 mm. On this assumption calculate equivalent length for fittings of 1.4 and total equivalent length of 4.4. The head available at the function of pipe runs 1 and 7 is the head at that point: 2.5 less the head used in pipe 1, which from Fig. 51, column 10, is 0.62. Therefore the head available at the junction of pipes 1 and 7 is 2.5 − 0.62, which is 1.88.The head along the length of pipe 7 is 3.0 so the head available in pipe run 7 is 1.88 + 3.0, or 4.88. The permissible head loss value is the head available divided by the total equivalent length, that is 4.88 over 4.4 = 1.1. From Fig. 50, for a rate of flow of 1.42 and a permissible head loss value of 1.1, a 28 mm pipe is selected. The actual head loss is then as before and the head used and head remaining are calculated and tabulated. The head remaining will then be tabulated as available for pipe run 8.

The procedure outlined above is used in selecting pipe sizes for the rest of the pipe installation.

The table is a record which can be used to check the calculations leading to the selection of pipe sizes, to confirm that actual head losses do not exceed the permissible head losses, and therefore that pressure is available to provide the required rates of flow at taps and as a basis for subsequent calculations required by any change of plans.

The calculations shown illustrate the method used to determine pipe sizes required to provide a reasonable rate of flow of water from taps. To reduce the labour of manual calculation there are various computer programs that will undertake the necessary calculations once the basic information and assumptions have been supplied.

In the example of selection of pipe sizes for the installation shown in Fig. 49, a possibility was assumed that all the taps might be open at the same time and pipe sizes were selected for this. For small pipe installations, such as those for houses and other small buildings, and

Table 4 Loading units.

Appliances	Loading units
WC flushing cistern (9L)	2
Wash basin	$1\frac{1}{2}$ to 3
Bath tap of nom. size $\frac{3}{4}$	10
Bath tap of nom. size 1	22
Shower	3
Sink tap of nom. size $\frac{1}{2}$	3
Sink tap of nom. size $\frac{3}{4}$	5

for branches from main pipe runs in large installations, it is usual to assume pipe sizes sufficient for simultaneous use of all taps. In these situations only small pipe diameters will be required and there would be no appreciable economic advantage to reduction of pipe sizes by making another assumption.

In extensive pipe installations it is usual to assume a frequency of use for the taps to sanitary appliances so that smaller pipe sizes may be used than would be were it assumed that all taps were open simultaneously. Frequency-of-use values for individual sanitary appliances are expressed as loading or demand units, as set out in Table 4. The total of these units for sanitary appliances is used to determine notional rates of flow in pipes. The loading units of all the sanitary appliances shown in Fig. 49 are:

- 3 WCs, $3 \times 2 = 6$
- 7 basins, $7 \times 11/2 = 10/1/2$
- 2 baths, $2 \times 10 = 20$
- total of $36\frac{1}{2}$ loading units

This total of loading units would require a rate of flow of 0.68 litres per second in pipe run 1. Applying this figure to Fig. 50, with a permissible head loss figure of 0.09 in pipe run 1, a pipe size of 28 mm would be selected – compared with the 42 mm pipe based on an assumption of simultaneous use of all taps.

If the same loading units are then applied to the pipe runs 2, 3 and 4, the sum total of the units is so small as to make no significant difference in the selection of pipe sizes and the sizes previously selected will be used. From this example it will be seen that the use of loading units to determine rates of flow in pipes makes no significant economy in the selection of pipe sizes in pipe runs that serve a few sanitary appliances. As a general rule where pipe runs serve fewer than say ten sanitary appliances it is not worth using loading units to economise on pipe sizes.

2: Sanitary Appliances

Sanitary appliances, sometimes termed sanitary fittings, include all fixed appliances in which water is used either for flushing foul matter away or in which water is used for cleaning, culinary and drinking purposes. The former, termed soil appliances, include WCs and urinals, the discharge from which is described as soil, or soiled or foul water. The second type, termed waste appliances, includes wash-basins, baths, showers, sinks and bidets, the discharge from which is described as waste water.

The reason for the distinction between WCs and urinals as soiled water appliances and the others as waste water appliances, comes from the period before the construction of sewers in the mid nineteenth century. Before then, soiled or foul water appliances drained separately to cesspits or cesspools and waste water to soakaways. Cesspits and cesspools were at intervals cleared of the solid matter that had settled to the bottom and this decomposing matter was spread over land as a form of manure.

Today the soiled and waste water discharge from all sanitary appliances is discharged to a common sewer in most urban areas, and to cesspools or sewage treatment plant in outlying areas. There is no good reason today to differentiate between soiled and waste water fittings on the grounds of separation of discharges.

SOIL APPLIANCES

WC suite

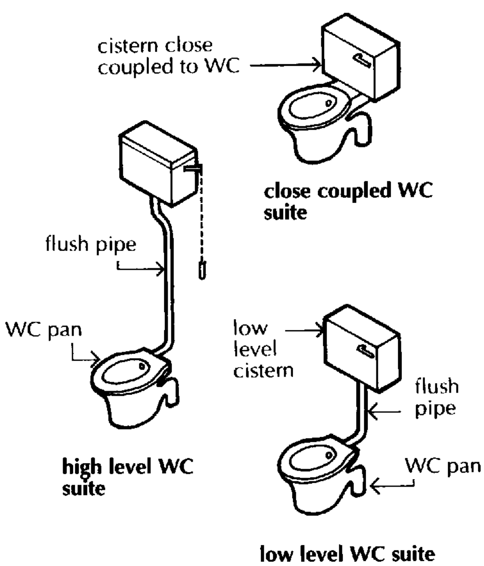


Fig. 52 WC Suites.

The majority of WCs today are sold as a matched set of WC pan, seat, flushing appliance and any necessary flush pipe, which together are described as a WC suite.

The letters WC stand for water closet, the word closet referring to the small room, enclosure or closet in which the early soiled water pans were enclosed when they replaced the original earth closets.

A WC pan is a ceramic or metal bowl to take solid and liquid excrement, with an inlet for flushing and a trapped outlet. The seat is usually a plastic ring secured to the back of the pan. The usual flushing appliance is a cistern designed to discharge water rapidly into the pan through a flush pipe, for cleaning and disposal of contents.

The flushing cistern may be fixed high above, near to or closely coupled to the pan, the three arrangements being described as high-level, low-level (low-down) or close-coupled WC suites, as illustrated in Fig. 52. The high-level suite is no longer popular because of the long unsightly flush pipe and the noisy operation of the flush. It has the advantage that the force of water from the long flush pipe effectively cleans the pan. The low-level or low-down suite is much used today for its appearance. The flush is less noisy than that of the high-level suite, but less effective in cleansing the pan.

The close-coupled suite is so called because the flushing cistern is fixed directly above the back of the pan for the sake of appearance. As the flush water does not discharge into the pan with force, it is at once comparatively quiet in operation and less effective in cleansing. A siphonic WC pan is generally part of a close-coupled suite for the sake of its comparatively quiet operation. Close-coupled suites are more expensive than low-level suites.

WC pans

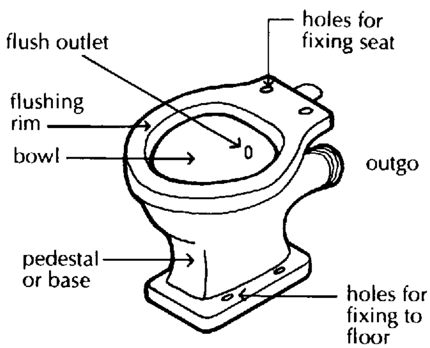


Fig. 53 Pedestal WC pan.

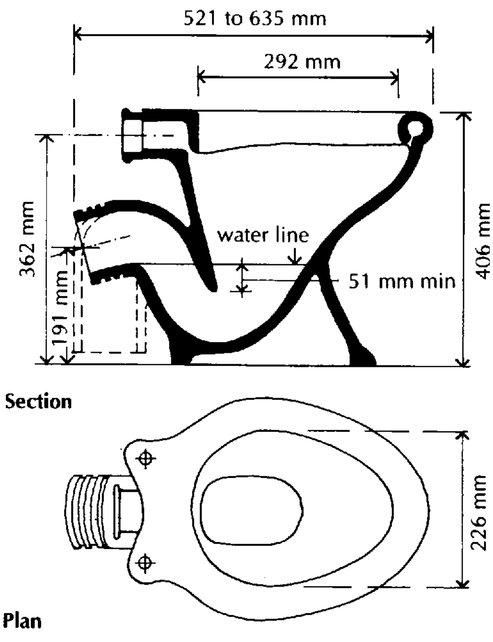


Fig. 54 Wash down WC pan.

Most WC pans are of the pedestal type, the base or pedestal being made integral with the pan. The pan is secured to the floor with screws through holes in the pedestal base to timber plugs in solid floors or directly to timber floors. Fig. 53 shows a typical pedestal WC pan.

The flushing rim is designed to spread the water, which discharges through the flush outlet, around the pan to wash down the sides of the bowl. In hard water areas the rim may become coated with lime scale and need fairly frequent cleansing. Spigot end connections for the flush pipe and for the waste pipe are moulded integrally with the pan.

Most WC pans are made of vitreous china which, after firing, has an impermeable body and a hard, smooth, glazed finish which is readily cleaned. The glazed finish to pans is generally white but may be finished in various pastel colour glazes for appearance sake.

The flushing cistern body and cover to close-coupled WC suites is also made of vitreous china for the sake of appearance. WC pans have integral traps to contain a water seal against odours from the drain pipes or drains.

The two types of pan in use today, the washdown and the siphonic, are distinguished by the operation of the flush water in cleansing and discharging the contents of the pan. In the washdown pan the flush water runs around the rim to wash down the bowl and then overturns the water seal to discharge the contents. In the siphonic pan the flush water washes the sides of the bowl and also causes a water trap or traps to overturn and create a siphonic action which discharges the contents. The purpose of this arrangement is to effect a comparatively quiet flush and discharge of contents.

The flush of water discharged from the old high level and the current low level flush cisterns is generally more effective in cleansing the sides of the WC bowl than is the discharge of flush water from a close-coupled WC suite.

Washdown WC pan

The flush water discharges into the washdown pan around the rim to cleanse the sides of the pan, and as the bowl fills the water in the trap overturns to discharge the contents and as the flush continues it refills the trap.

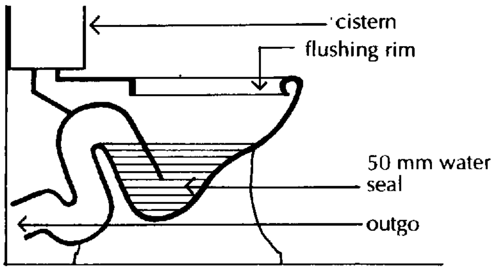


Fig. 55 Single seal siphon WC pan.

The trap is the 51 mm minimum projection of the pan into the water lying in the base of the pan. This acts as a seal against any foul smells that might otherwise rise from the drains. A minimum depth of water seal is set to allow for evaporation of water.

Fig. 54 is an illustration of a typical washdown pan. The back of the pan is near vertical and the sides slope steeply to minimise fouling. In the design of the pan the area of water in the pan should be as large as practical to receive foul matter.

The discharge of flush water down the flush pipe from the traditional high level WC suite is particularly noisy and as the flush water descends with some force there is a likelihood of some water spillage outside the pan. The discharge of flush water from the low level WC suite is both less noisy and less liable to spillage.

Siphonic WC pan

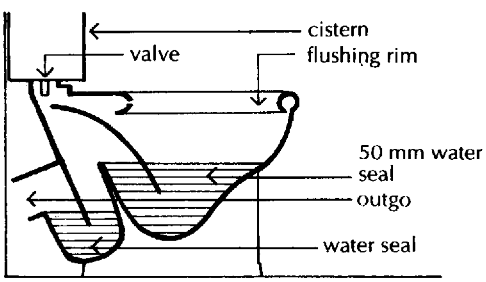


Fig. 56 Double seal siphonic WC pan.

These WC pans effect a discharge of the water in the bowl by the dual action of the flush water and a siphonic action caused by a momentary reduction in pressure that siphons out the liquid contents.

In the single seal pan illustrated in Fig. 55 the flush water causes a full bore flow in the outgo which creates a momentary reduction in pressure which assists the discharge by siphonic action. In the double seal pan illustrated in Fig. 56, some of the flush water enters the air space between the two water seals and this causes the lower water seal to overturn; the momentary reduction in pressure causes the upper water seal to be siphoned out and so discharge the contents of the WC bowl. In both the single seal and the double seal pans the continuing discharge of flush water refills the water seals that have been previously discharged.

It is because the flushing cistern is fixed close to the pan in close-coupled suites, that the discharge of flush water is not particularly vigorous, and the siphonic action pans are used to augment the normal flushing action. Because of the more complex construction of the discharge outgo of the siphonic pans they are more liable to fouling in use and more difficult to clean than a more straightforward washdown pan.

Discharge outgo

The majority of washdown WC pans are made with an outgo that is near horizontal, with a small slope down as illustrated in Fig. 54. This standard arrangement is used for simplicity in production and consequent economy. This type of outgo, described as a P trap outgo (Fig. 57), suits most situations as drain fittings are available to provide a connection to soil pipes relative to the position of the WC.

In some situations the WC pan may discharge to a drain below the floor level and it is convenient to have a vertical outgo. This type of

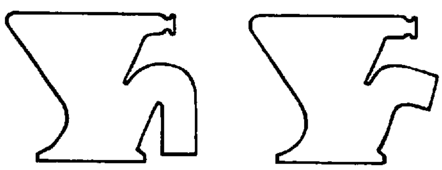


Fig. 57 WC pan outgoes.

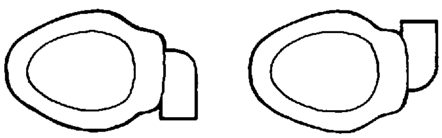


Fig. 58 WC pan outgoes.

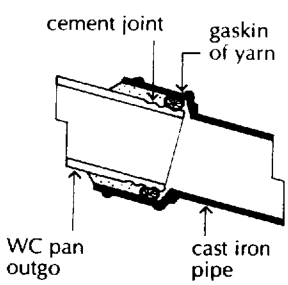


Fig. 59 WC to cast iron pipe.

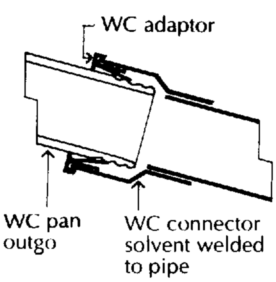


Fig. 60 WC to plastic pipe.

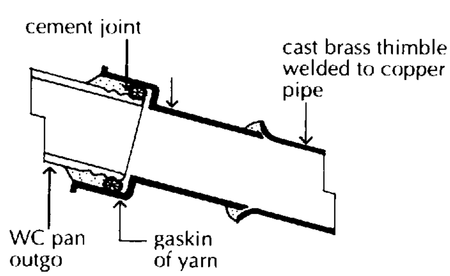


Fig. 61 WC to copper pipe.

outgo is described as an S trap (Fig. 57). P traps and S traps are so named for their sectional similarity to the letters.

Where a WC pan has to discharge to one side of its position, rather than straight back through a wall, it may be convenient to have a left hand or right hand outgo rather than several unsightly drain fittings. This somewhat exceptional arrangement is illustrated in Fig. 58. The hand, either right or left, is indicated by facing the front of the pan.

The connection of the outgo of a ceramic pan to the branch drain pipe is a common site of leaks because of the difficulty of maintaining a watertight joint and making some allowance for inevitable movement between the pan and the drain branch. In use the pan is designed to support the weight of the user with consequent inevitable movements of the pan which are more pronounced where the pan is fixed to a timber boarded floor.

The traditional joint between the spigot, open pipe, end of the WC outgo and a cast iron drain branch is a cement joint as illustrated in Fig. 59.

The junction of the spigot end of the outgo and the collar of the cast iron pipe is filled with a gaskin of yarn rammed firmly into place to prevent cement running into the pipe, and to align the spigot with the collar. Wet cement and sand is then rammed into the joint. The advantage of this joint is that it is comparatively simple to make. Its disadvantages are that as the cement dries it will shrink and may, if too wet a mix, crack, and this rigid joint may cause the spigot end of the outgo to crack due to movement.

An alternative to the cement joint has been a red lead putty joint. A mixture of linseed oil putty and red lead paint is rammed into the joint on to a gaskin of yarn. The advantage of this joint is that the red lead putty is sufficiently plastic to take up small movements. The disadvantage of the joint is that the material takes some time to harden.

The majority of soil pipes and branches now used are run in plastic pipe sections. The connection of the ceramic pan outgo to the plastic branch is effected by a plastic connector which is solvent welded to the soil pipe branch and whose socket end fits around the pan spigot. The seal is made with a tight fitting plastic adaptor that fits around the pan spigot outgo and adaptor as shown in Fig. 60.

The connection of a ceramic WC pan outgo to a copper branch pipe is made with a cast brass thimble. The thimble has a socket end to fit around the spigot end of the WC pan outgo. The plain end of the thimble is welded to the belled out end of the copper branch pipe. The joint between the socket end of the thimble and the spigot end of the WC pan outgo can be made with a cement and sand joint, a red lead putty joint or one of the proprietary jointing compounds packed into the joint against a gaskin of yarn. This joint is illustrated in Fig. 61.

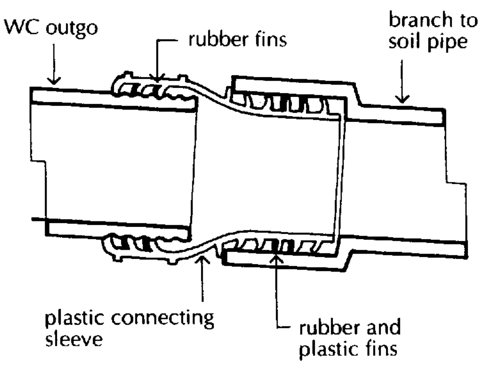


Fig. 62 Plastic sleeve connector for WC pan outgo.

Plastic connecting sleeves specifically made for the connection of the spigot end of a WC pan outgo and the socket ends of branch drain pipes are manufactured from plastic. The ends of the connector are formed with annular rubber and plastic fins to act as water seals as illustrated in Fig. 62.

The connecting sleeve is first forced into the socket end of the branch drain pipe so that the protruding rubber and plastic fins make a tight fit. The spigot end of the WC pan outgo is then worked into the other end of the connecting sleeve with such careful easing as is necessary for the protruding fins to make close contact with the outgo. Because these sleeve connectors are a necessarily tight fit, careful effort is required to fit them into place to make a watertight joint without deforming the connector. The advantage of these connectors is that they provide sufficient flexibility to accommodate any slight movement between the pan and the drain.

WC seats

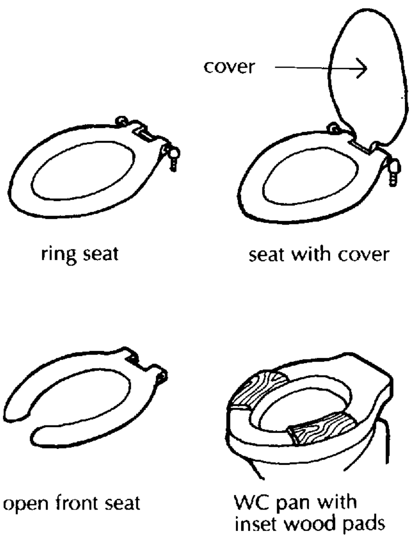


Fig. 63 WC seats.

The usual WC seat is in the form of a moulded plastic ring that fits the top of the WC pan. The back of the seat is bolted to pillars and a rod so that the seat is secured in position and can be lifted. Commonly a separate lift-up cover is fixed to the rod and pillars so that it can be raised or lowered to serve as a seat.

The ring seats and lift-up covers in Fig. 63 are moulded from plastic and finished in a small range of colours, some of which are chosen to match coloured ceramic WC suites.

The open fronted lift up seat illustrated in Fig. 63 has been used in male toilets to minimise fouling. As the effectiveness of this type of seat depends on sensible use – a rare commodity – it is less used than it was.

The inset wood pads fixed to one WC pan in Fig. 63 have been used in communal toilets to avoid the damage that occurs to lift-up seats in general use. Because of the careless use and the difficulty of thoroughly cleaning the wood pads, this arrangement is no longer much used.

Flushing cisterns

With the increasing consumption of domestic water and limited supplies, the water authorities have of recent years amended regulations set out in Water Byelaws to limit water use. In the average household up to 40% of total water consumption is by the use of WC flushing cisterns, which until recently discharged 9 litres of water with each flush.

Before the current byelaws were implemented, a dual-flush cistern was introduced. It was designed to discharge a 4.5 litres half flush by a partial press of the operating lever and a full flush through a full press of the flushing lever. It required some care in use to be effective due to the difficulty of distinguishing between a half and a full press on the flush lever, with the consequence that a full flush was normal.

The current Water Supply Byelaws, that came into effect in 1988, gradually phased out cisterns designed to give a 9 litre flush in favour of cisterns giving a 7.5 litre flush, effective from January 1991 in England and Wales and January 1993 in Scotland for all new installations. Replacement of cisterns of up to 9.5 litres will be permitted. Dual flush cisterns are no longer accepted.

Some water authorities in Europe accept the use of flushing valves that operate to discharge a predetermined volume of water by the operation of a lever or a push. With wear these valves may discharge more water than they were originally designed to discharge and with wear they may drip and waste water. Because of this the water authorities in this country insist on the use of flushing cisterns, which used to be called WWPs – water waste preventers.

Flushing cisterns are made of enamelled or galvanised pressed steel, of plastics or vitreous china. High-level and low-level cisterns are usually of pressed steel or plastic and close-coupled of vitreous china to match the material of the WC pan. Galvanised steel cisterns are used for fixing inside ducts behind the WC pan.

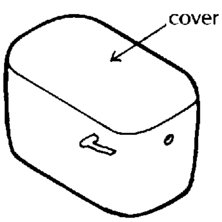


Fig. 64 WC cistern.

The WC flushing cistern illustrated in Fig. 64 is used for surface fixing for low level WC suites. The cistern body is either made from glazed ceramic, finished in white or a limited range of pastel colours to match coloured WC pans, or in plastic for economy. The cistern body is made in two pieces: the body and a lift-up cover or lid for access to the flush apparatus inside.

Perforations for water supply, overflow pipe, operating lever or push, and for a flush pipe, are provided. These cisterns, particularly the ceramic type, are somewhat bulky. The cistern is secured to a wall by two screws or bolts through the back of the body, above the water line, into plugs in the wall.

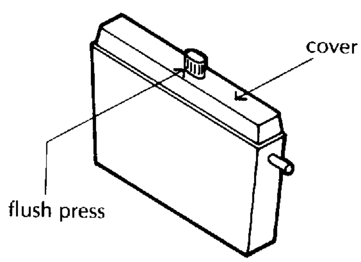


Fig. 65 Slimline cistern.

The so-called 'slimline' cistern, illustrated in Fig. 65, is designed for use with low level WC suites. It is wider and taller than the cistern in Fig. 64, so that it does not protrude from the wall too much. This is an advantage from the point of view of appearance and because the pan does not have to project so much into the room. A disadvantage of the bulky cistern in Fig. 64 is that the pan has to be fixed some distance forward, if the lift-up cover and seat are to remain in place when lifted.

The 7.5 litre slimline cisterns are usually made from rigid polystyrene plastic with a separate body and cover. The body is holed for the lever, water supply, overflow and flush pipe. The slimline cistern in Fig. 66 is designed for fixing in a duct or space behind WC pans, where it is concealed from sight with the operating lever protruding through a thin cover panel. As the cistern is out of

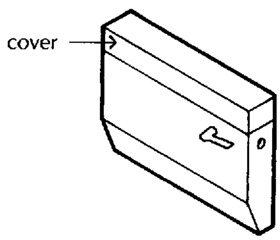


Fig. 66 7.5 litre 'Slimline' cistern.

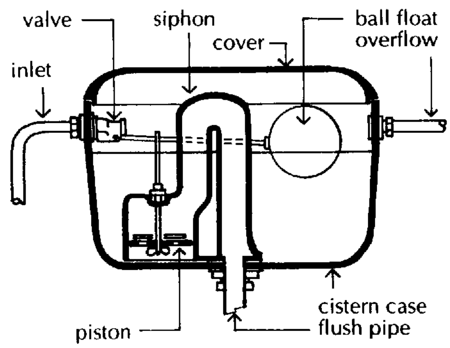


Fig. 67 7.5 litre WC flushing cistern.

sight it is usually made of galvanised steel or rigid plastic for economy. The water service and overflow pipes are out of sight and the flush pipe runs from behind the cover panel out to connect to the back of the pan.

Flushing cisterns discharge water in one operation through a flush pipe or directly to the pan by siphonic action. Fig. 67 is an illustration of a typical flushing cistern. It will be seen that the cistern is filled through a valve operated by a ball float and arm similar to that described for water storage cisterns. The Water Supply Byelaws require that there be an air gap between the highest level of water in the cistern and the outlet of the float valve. This air gap is related to the bore of the supply pipe and is the same as that for storage cisterns.

The plastic siphon is operated by a lever which raises a piston to force water over the siphon bend and the siphonic action causes the water in the cistern to follow, through perforations in the piston, up the siphon and down the flush pipes in one go. A distributing or cold water supply pipe is connected to the valve of the cistern and an overflow warning pipe is run outside the building or to discharge over the pan or onto the floor where the WC is fitted.

Small bore macerator sanitary system

The Building Regulations permit the use of small bore pipe discharges from WCs. They have been used in Europe for many years and their use depends on the macerator and pump fitted to the outlet of WC pans The electrically powered macerator and pump come into operation as the normal flush of a WC pan, by a conventional cistern, fills the pan. A macerator is a rotary shredder whose blades rotate at 300 rpm and reduce solid matter to pulp, which is, with the flush water, then pumped along a small (18 to 22 mm) pipe to the discharge stack.The macerator (shredder) and pump unit, which is about 340 x 270 x 165 mm, fits conveniently behind a WC pan (Fig. 68). The unit is connected to the horizontal outlet of a BS 5503 pan and a small bore outlet pipe. The macerator and pump are connected to a fixed, fused electrical outlet.

The particular advantage of the small bore system is in fitting a WC in either an existing or a new building some distance from the nearest foul water drainage stack, with a small bore (18 to 22 mm) pipe that can be run in floors or can be easily boxed in. In addition, because of the pumped discharge, the small bore branch discharge pipe can carry the discharge for up to 20 m with a minimum fall of 1 in 180 and can also pump the discharge vertically up to 4 m, with a reduced horizontal limit, which is of considerable advantage in fitting WCs in basements below drain levels. The macerator and pump unit can also be used to boost the discharge from other fittings such as baths, basins, sinks, bidets and urinals along small bore runs, with a

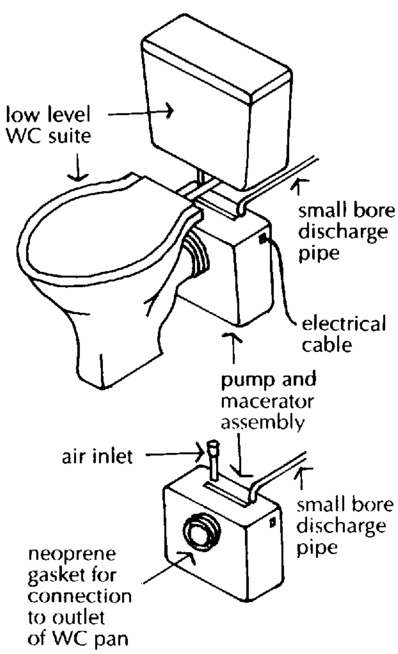


Fig. 68 Macerator unit for small bore discharge for WCs.

minimum fall, and over considerable runs not suited to normal gravity discharge.

The small bore discharge system is not a substitute for the normal short run branch discharge pipe system for fittings grouped closely around a vertical foul water drainage system, because of the additional cost of the macerator and pump unit and need for frequent periodic maintenance of the unit.

Urinals

The three types of urinal in general use are the stall urinal, slab urinal and bowl urinal.

Stall urinals

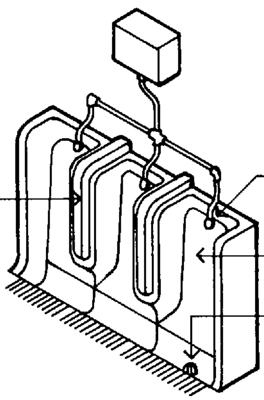


Fig. 69 Stall urinal.

The stall urinal consists of heavy, individual stoneware stalls with either a salt glazed or white glazed finish, each stall having its own integral channel. The stalls are set in place on a solid floor, against a wall. The junction between individuals stalls is covered with salt glazed or white glazed rolls or facing pieces, to serve as a finish to the joint between the stalls and also to afford some privacy to users.

The channel, at the foot of the stall, drains to a brass outlet to a branch drain pipe. The floor finish overlaps the edge of the channel. The three stall unit illustrated in Fig. 69 comprises two end stalls and one plain stall. An automatic flushing cistern, mounted on the wall, flushes through a horizontal pipe to spreaders to each stall. The stalls and the facing pieces are bedded in cement and sand, and joints are finished in cement.

This heavy, robust type of urinal was much used in Victorian times for the many public lavatories that were a feature of public utilities in towns. The sturdy materials were used for their resistance to vandalism, but this type of urinal, which takes up space and is laborious to clean, is less used than it was.

Slab urinals

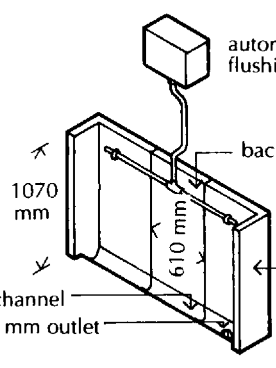


Fig. 70 Slab urinal.

Slab urinals, which are of less heavy construction, have largely taken over from stall urinals for use in public lavatories. These urinals consist of flat, white glazed ceramic slabs and white glazed ceramic channels that are bedded in cement and sand against a solid wall, with projecting end slabs to each range of urinals as illustrated in Fig. 70. The joints between the slabs and slabs and channels are pointed in cement. An automatic flushing cistern discharges water to a sparge pipe fixed over the slabs. The slabs are flushed by water from perforations in the sparge pipe. This straightforward, economical type of urinal is used for public lavatories and in schools as it is reasonably vandal proof, except for the sparge pipe which seems to be a favourite trophy for many.

The plain slab urinal, which is comparatively cramped when in full use, is avoided by some owing to lack of privacy because they prefer to

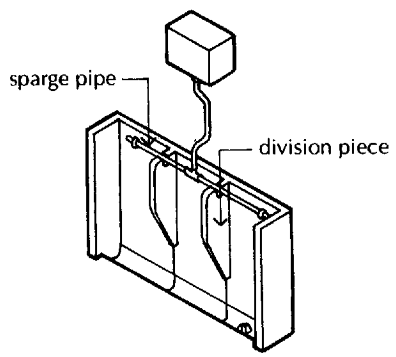


Fig. 71 Slab urinal with divisions.

use an enclosed WC closet if possible. To provide a degree of privacy, slab urinals with individual division pieces between the stalls are often installed; glazed division pieces are bedded in position between the slabs, as shown in Fig. 71. The division pieces, which may be damaged and become loose in time, to some extent add to the sense of being cramped when the urinal is in full use. An automatic flushing cistern flushes the stalls through a sparge pipe fixed to the range of stalls.

Slab and stall urinals are best finished with the floor finish run up to and over the edge of the channel to facilitate washing floors into the channel. On upper floors these urinals are formed with a step up to them to avoid the drain and gully protruding down through the ceiling below. Such step-ups can be a hazard to the unwary who step back without looking and may stumble or fall.

Bowl urinals

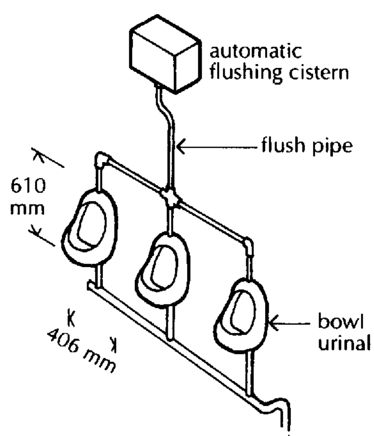


Fig. 72 Bowl urinal.

Individual white glazed ceramic bowl urinals fixed to a wall are used for ease of cleaning and the sense of space they give. For privacy these bowl urinals are separated by division pieces fixed to the wall between them. The disadvantage of these bowl urinals is that the floor over which they are fixed fairly readily becomes fouled by careless use of the bowl and needs frequent washing, and the bowls and flush pipes may be fairly readily damaged by careless use or vandalism.

The bowls, which should be bolted to a wall or support, are bedded in cement and sand and the joints finished with one of the silicone sealing compounds designed for the purpose. The automatic flushing cistern, flush pipe and waste, may be fixed into the wall as illustrated in Fig. 72, or fixed behind a partition or panel framing to which the bowl urinals are fixed.

Urinals are flushed by automatic flushing cisterns fixed above the urinal and discharging through a flush pipe, spreaders or sparge pipe. The automatic flushing cistern is of 4.5 litres capacity per slab, stall or bowl and the cisterns are adjusted to flush every 20 minutes.

The Water Supply Byelaws limit the flush of cisterns to two or more urinal bowls or stalls or two or more widths of slab each exceeding 700 mm in width, to 7.5 litres per hour for each unit and 10 litres per hour for a single urinal bowl or stall.

The cistern is filled directly from the distributing pipe, the rate of filling and therefore the frequency of flush being controlled by a valve. When full the siphon overturns and discharges the contents in one go. The flush from the cistern down the flush pipe is then distributed over the urinal by the individual spreaders to each slab, stall or bowl or by means of a perforated pipe, termed a sparge pipe to slab urinals only.

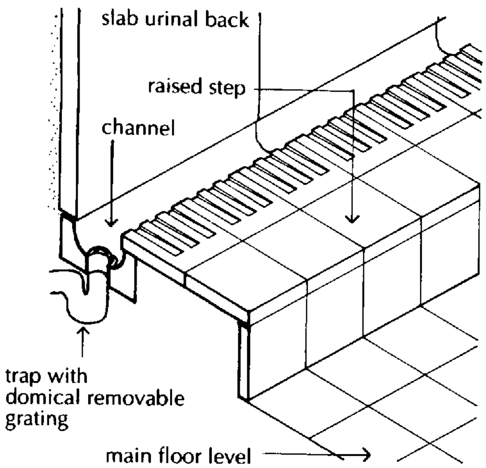


Fig. 73 Urinal step.

One outlet to trap and branch discharge pipe is used for up to six stalls or slab units, the outlet being in the channel to the slab or in the channel of one of the stall units. The outlet, 40 mm minimum diameter, is covered with a domed, gun metal grating and the outlet connected to a trap and waste. Deposits build up rapidly in the trap of urinals and traps of glazed ceramic, vitreous enamel or lead are often used to take the corrosive cleaning agents used.

To accommodate the channel of urinals in a floor, a step is often formed. Fig. 73 shows a typical urinal slab with channel, trap, and waste.

Bowl urinal outlets are often connected to a combined waste with a running trap.

WASTE WATER APPLIANCES

Waste or waste water appliances include basins, baths, sinks and bidets.

Wash basins

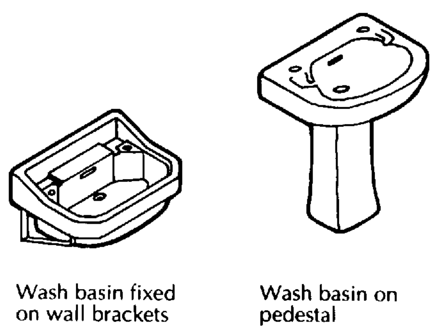


Fig. 74 Wash basins.

Wash basins, designed for washing the upper part of the body, are supported by wall brackets or by a pedestal secured to the floor, as shown in Fig. 74. The standard wash basin consists of a bowl, soap tray, outlet, water overflow connected to the outlet, and holes for fixing taps.

The usual wall-mounted basin is fixed on enamelled cast-iron brackets screwed to wood plugs in the wall. The more expensive pedestal basin consists of a basin and a separate vitreous china pedestal that is screwed to the floor and on which the basin is mounted. The purpose of the pedestal is to hide the trap, waste and hot and cold service pipes. Either the whole or a large part of the weight of the basin is supported by the pedestal which should preferably be fixed to a solid floor to provide solid support. A resilient pad is fitted between the bottom of the basin and the top of the pedestal as the two separately-made fittings rarely make a close fit.

The majority of wash basins are made of vitreous china. A wide range of sizes and designs is available, ranging from small corner basins and hand basins to basins large enough for bathing a small child. In recent years plastic basins have been made which are suited in particular to fitting to stands and working tops.

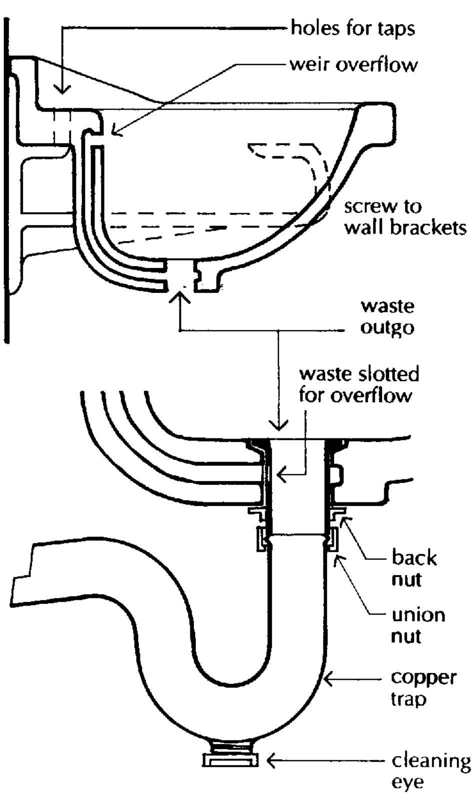


Fig. 75 Wash basin waste and trap.

Hot and cold pillar taps connected to 12 or 15 mm hot and cold distributing or supply pipes are fixed to or over wash basins. To prevent the possibility of foul water in the basin being back siphoned into the pipes, it is a requirement of the Water Supply Byelaws that there be an air gap between the outlet of the taps and the spill over or top edge of the basin, as described in Chapter 1.

To avoid an overflow of water from a basin, a weir overflow is usually formed during the manufacture of basins. This consists of a hole in the top of the basin, which can drain to the outlet, as shown in Fig. 75. These weir overflows will become fouled with soap and hairs in time and become blocked. As a blockage is difficult to clear it is wise to clean the overflow from time to time with soda and hot water.

A waste outgo, with slot to drain the weir overflow, is formed in the basin. A waste is fitted to the outgo, bedded in setting compound and secured with a back nut, as shown in Fig. 75. A copper or plastic P trap with 75 mm water seal is then connected to the waste outgo and the copper or plastic waste pipe.

When the basin is drained of water, the waste pipe may run full bore at the end of the discharge, cause self-siphonage and empty the water seal in the trap. Because of the shape of the basin there may not be sufficient tail-off water to refill the trap. To avoid this the waste pipe should be of limited length or an air-admittance valve should be fitted.

Baths

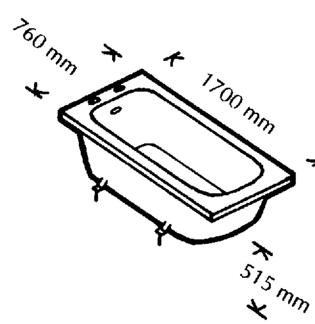


Fig. 76 Magna square.

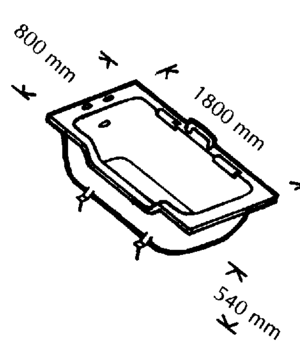


Fig. 77 Baths.

The type of bath most used is the standard Magna square ended bath, illustrated in Fig. 76. These baths are made of porcelain-enamelled cast iron, or enamelled pressed sheet steel or plastic. The enamel finish of the heavier and more rigid cast iron bath is less likely to be damaged than that on the lighter pressed steel bath. The plastic bath does not have the hard bright finish of the metal bath and is lightweight and not liable to rust, but it is fairly readily scratched. Baths are finished in white and a limited range of pastel colours.

The modified Magna bath has a drop edge side for ease of entry to the bath and a chromium plated handle for convenience of getting out of the bath, as shown in Fig. 77.

The Magna bath has a rectangular profile rim designed to accommodate end and side panels, and an outlet, overflow, holes for taps and adjustable feet, as shown in Fig. 77. The square ends are designed for fixing against a wall or partition, with one side and two end panels fitted to timber bearers under the rim of the bath, or for fitting into a purpose-made recess with one side panel only.

The traditional roll top or tub bath (Fig. 78), made of enamelled cast iron, was for years the usual form of bath. It was free sanding or set against a wall or partition. As the rounded end did not provide a ready means of fixing side and end panels, this type of bath was

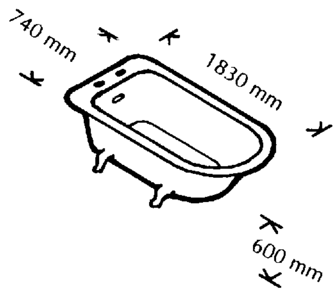


Fig. 78 Tub bath.

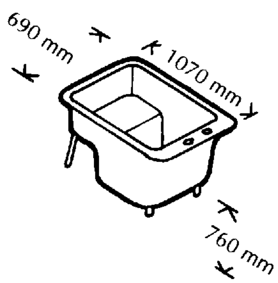


Fig. 79 Sitz bath.

sometimes totally enclosed in timber framed panelling with a removable top, in kitchens. Because of the cast iron body and heavy enamel finish these baths are very robust and durable.

This type of bath has regained favour and is often fitted into new and refurbished homes as a feature, often free standing as a centre piece to a large bathroom.

Sitz or sitting baths have a stepped bottom to form a seat, as illustrated in Fig. 79. These cast iron enamelled baths were originally made for the elderly or infirm who had difficulty in climbing into and out of a normal bath and could manage bathing in a sitting position. These baths, which have been used where space is restricted, have by and large been replaced by showers.

Baths are fixed on adjustable feet against a wall or in a recess with side and end panels of preformed board, plastic or metal secured to wood or metal brackets or frames. The plaster or tile wall finish is brought down to the top of the bath rim. In time, particularly on timber floors, the joint between the top of the bath and the plaster or tile will crack.

The discharge from a bath is unlikely to run full bore and cause self-siphonage and loss of water seal to the trap, and if the trap were to lose its seal by siphonage it would be filled by the tail-off water from the flat bottom of the bath. The length and slope of a bath waste is therefore not critical. A 75 mm seal trap is fitted to the bath waste and connected to the 40 mm waste.

An overflow pipe is connected to the bath and either run through an outside wall as an overflow warning pipe or connected to the bath outlet or trap, as illustrated in Fig. 80. Overflow warning pipes through an outside wall should have hinged flaps at the end, otherwise an appreciable cold draught may blow into the bath.

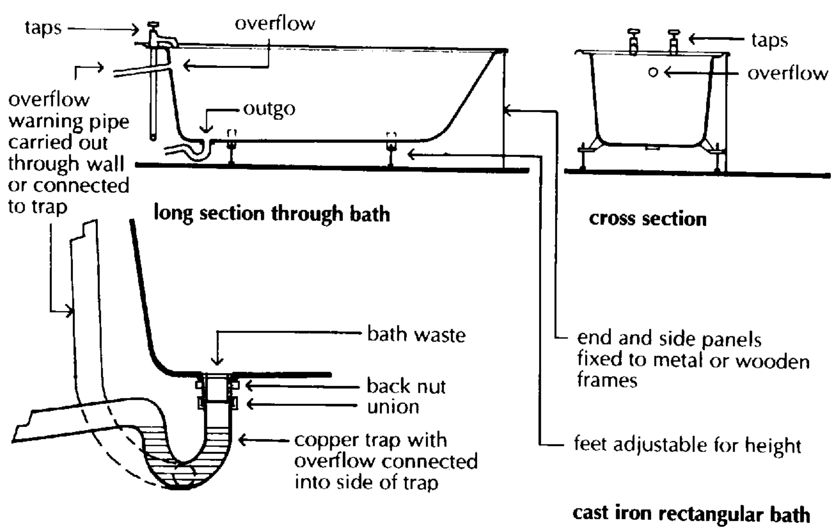
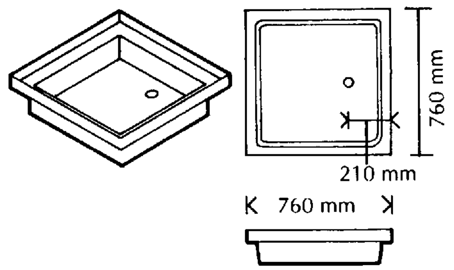


Fig. 80 Plumbing to bath.

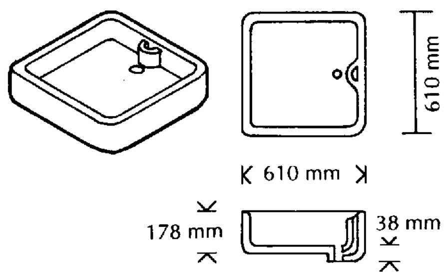
The 18 mm cold and hot distributing or supply pipes are connected to either individual pillar taps, a mixer with taps or a shower fitting, or both, with an air gap between the outlet and spillover level of the bath, similar to that for basins.

Where shower fittings are provided, the wall or walls over baths should be finished in some impermeable material such as tile, and a waterproof curtain be provided.

Showers



acrylic shower tray



glazed fireclay shower tray

Fig. 81 Shower trays.

The conventional shower or shower bath consists of a shower tray or receiver of glazed ceramic, enamelled cast iron or plastic to collect and discharge water, with a fixed or hand-held shower head or rose and mixing valves. The shower is either fixed in a wall recess or may be free standing with enamelled metal or plastic sides. The walls around fixed showers are lined with some impermeable material such as tile, and the open side is fitted with a waterproof curtain. Fig. 81 shows some shower trays. The tray with a waste and no overflow is for use as a shower only. The tray with a waste plug and an overflow is for use either as a shower or a foot bath.

A shower compartment is often surrounded with an upstand curb or may be sunk into the floor to contain the shower water that would otherwise spill over the surrounding floor. The shower tray may be fixed onto or recessed into the floor. A 75 mm seal trap is fitted to the tray and connected to a 40 mm waste. The discharge from a shower tray is unlikely to run full bore down the waste and as there is little likelihood of self-siphonage the length and slope of the waste are not critical.

The Water Supply Byelaws require a double check valve assembly to both hot and cold supply pipes to showers, where the head can be lowered below the spill over level of appliances.

Sinks

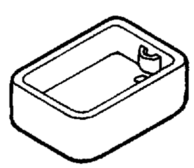


Fig. 82 Belfast sink.

The traditional sink was made of glazed stoneware, usually white glazed inside the bowl and salt glazed outside. They were heavy, durable sinks with a capacious bowl requiring substantial support. These highly practical sinks, commonly known as Belfast sinks (Fig. 82), which cannot conveniently be housed in the current kitchen units, lost favour until recently because of their appearance. They are back in fashion partly because the large bowl will accommodate such things as greasy pans that are impossible to clean in the tiny bowls of modern sinks. Fitted under natural teak draining boards these sinks are again in fashion as a feature to modern kitchens.

For many years the Belfast sink was replaced by cast iron enamelled sinks, often with an integrally cast drainer. The solidity of the cast iron base, together with the thick white enamel finish, provided a tough, durable sink that could withstand normal wear and tear

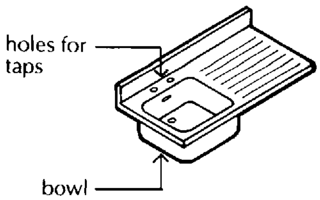


Fig. 83 Single bowl single drainer.

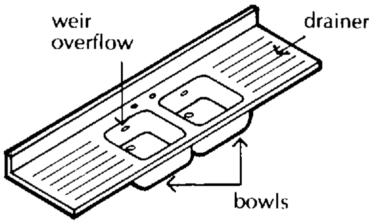


Fig. 84 Double bowl double drainer.

without damage for many years. The durable white enamel finish did tarnish with use but could be brought back to its original lustrous finish with a little effort. These large, practical sinks have lost favour to the stainless steel sink.

A range of stainless steel sinks, designed to fit into kitchen units, are made with single bowl and drainer (Fig. 83) and double bowl and double drainer (Fig. 84). The sinks are finished in the natural colour of the stainless steel from which they are pressed. The dull grey finish soon loses its initial sheen and is difficult to clean and burnish back to its original finish.

The majority of these sinks have so small a bowl that it is impossible to fully immerse anything larger than a plate for thorough cleaning, presumably on the basis that most people use dishwashing machines.

Most sinks have weir overflows connected to the waste outlet and are holed for fitting hot and cold taps or mixers. A 75 mm seal trap is connected to the sink waste which is connected to a 40 mm copper or plastic waste pipe. Because of the flat base of the bowl a sink waste is unlikely to run full bore and cause self-siphonage.

Bidets

Fig. 85 Bidet.

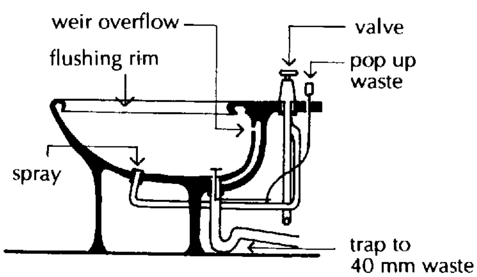


Fig. 86 Bidet.

Bidets, which are appliances for washing the excretory organs, have never been as popular in the UK as they are in the rest of Europe.

A bidet (Fig. 85) consists of a glazed ceramic pedestal bowl which is secured to the floor, usually backing on to a wall or partition. A bidet may be white glazed or finished in a limited range of pastel colours to match other bathroom appliances.

The shallow bowl has a flushing rim, a weir overflow connected to the waste and an inlet for a spray. An optional hand-held spray may be fitted to the hot and cold supply. The bidet operates through the discharge of water around the flushing rim, and a spray of water that rises from the bowl or a hand-held spray. The bowl may be filled with water and drained by the operation of a pop-up waste control. The temperature of the spray water is controlled by hot and cold water valves. Fig. 86 shows a bidet with a 75 mm trap from the waste outgo to a 40 mm waste pipe.

As a precaution against the possibility of contamination of the mains supply from a bidet, particularly through the submerged spray, the Water Supply Byelaws require a separate cistern feed to a bidet or other effective device to sprays and hand-held showers, such as double check valve assemblies. These requirements add considerably to the work and cost of fitting a bidet in this country. The discharge from a bidet is unlikely to run full bore in the waste and cause self siphonage.

TRAPS

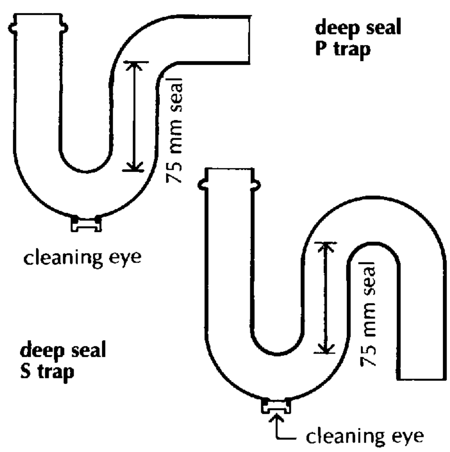


Fig. 87 Deep seal S and P traps.

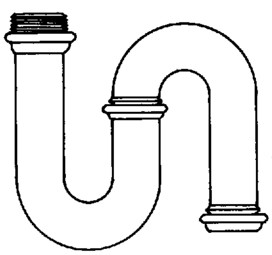


Fig. 88 Two piece copper S trap.

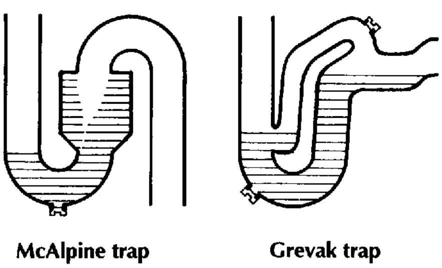


Fig. 89 Resealing traps.

A trap or waste trap is a copper or plastic fitting formed as a bend in pipework to contain a seal of water as a barrier to odours rising from sanitary pipework and drains into rooms. The traps are formed as P or S traps to accommodate the position of the waste pipe relative to the sanitary fitting outlet. At the bottom of the trap is a cleaning eye, which can be unscrewed to clear blockages. Fig. 87 shows P and S traps.

The depth of the water seal is measured from the top of the first bend and the bottom of the second. The traps shown in Fig. 87 are 75 mm deep seal traps – the depth of seal required for all sanitary fittings connected to single stack systems of drainage, except for WCs which have an integral 50 mm seal.

The two piece trap in Fig. 88 is used instead of the one piece trap because it can be adjusted to suit the position of the branch waste pipe relative to the appliance outgo, and can be uncoupled to clear blockages which are common with wash basins and sinks.

Before the single stack system of sanitary pipework was established as the optimum system to control siphonage of water seals, it was common to use resealing traps which contained a reservoir of water. These traps are designed to allow air through the trap or through an air tube to reseal the trap after the main seal has been cleaned by siphonage. The McAlpine trap and the Grevak trap in Fig. 89 work on this principle.

These traps, which are liable to blockages, are little used other than in older installations. Where siphonage may occur, an air admittance valve is used instead of a resealing trap.

3: Sanitary Pipework

PIPEWORK

History

Up to the middle of the nineteenth century few buildings had a supply of water piped above ground floor level. Water closets were either inside or outside at ground level and washing water was carried by jug to basins. From about the middle of the nineteenth century, due to improved pumping techniques, piped water increasingly extended above ground floor level, first to water closets and later to wash basins and baths. This improvement in sanitary and washing facilities was helped by the mass production of sanitary appliances.

The drainage above ground of water closets was usually separate from that of other sanitary appliances. The demands for hygienic arrangements, provoked by the typhus epidemics early in the century, were at first confined to the drainage of water closets. Waste water from basins and baths was not at that time thought to be foul and drains from waste water appliances were often connected to rainwater pipes and soakaways. To avoid drain smell, pipes from sanitary appliances were run directly out of buildings to vertical pipe systems termed stack or stack pipe, fixed to external walls.

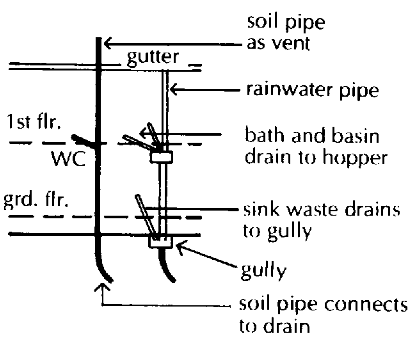


Fig. 90 Two pipe system.

A typical arrangement of the drainpipes of this period is shown in Fig. 90. The first-floor WC discharges to a separate, soiled-water pipe connected to the drains. The waste water from the first-floor bath and basin discharges into an open hopper head that also collects the rainwater from the roof, with the hopper head draining to a trapped gully connected to the drains. This was described as the two pipe system.

The advantage of this system is simplicity. The trapped gully taking the discharge of rainwater and waste water acts as an effective seal against odours rising from the drains. As the bath and basin wastes discharge over the hopper head they do not need a trap. By combining rain and waste water the discharge pipe is reasonably flushed.

The one disadvantage of the system is that with careless use the hopper head may become fouled, smelly and eventually blocked. It is a simple matter to clear a hopper head at first-floor level. The system of using hopper heads to collect waste water discharges was also used for buildings over two floors high and it was then that the smells from fouled hopper heads, floods from blocked heads, and the difficulty of clearing hopper heads above ground gave this system a bad name. The use of hopper heads for the collection of waste water has since been abandoned.

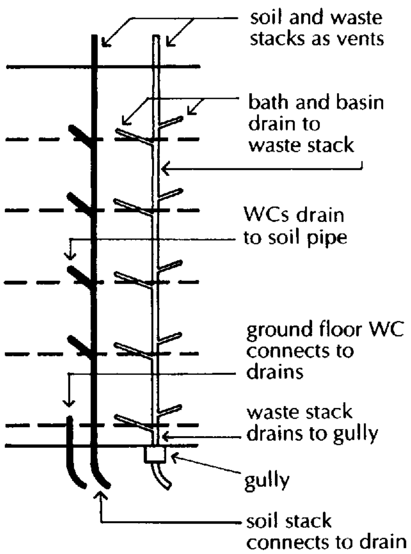


Fig. 91 Two pipe system.

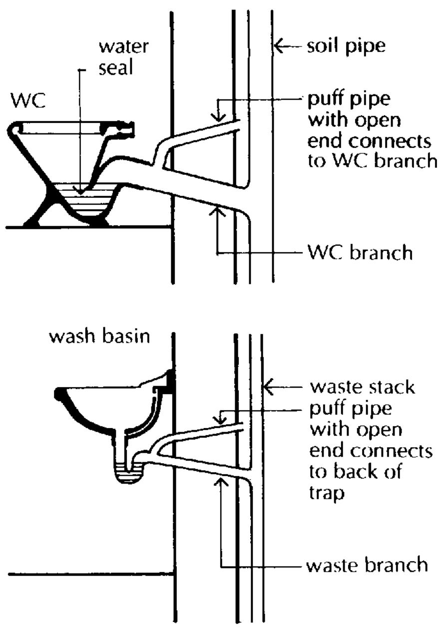


Fig. 92 Puff pipes.

When the use of open hopper heads lost favour, a two pipe system of separate sealed waste and soil stack systems was adopted, as shown in Fig. 91. There are two separate discharge stacks, one for the WCs and another for waste water discharges. Both pipe systems are sealed and each discharges separately to the drains, the soil stack directly and the waste stack through a trapped gully. In this modification of the original two pipe system, rainwater discharges were separated from the waste water as there were no longer hopper heads to collect the two discharges.

The discharge of water from sanitary appliances causes changes of air pressure in a sealed discharge pipe system. These changes or fluctuations are not in general large or of long duration and it is now known that pressure fluctuations sufficient to unseal water traps can be avoided by careful design of the discharge system. The single stack system in common use today is designed to that end.

When piped water and sanitary appliances were installed above ground, from the middle of the nineteenth century, it was known that there was a likelihood of siphonage of water from traps due to pressure fluctuations. To prevent drain smells, precautions were taken to prevent the siphonage of water from traps by the use of puff pipes and later anti-siphon pipes (vent pipes). The system of anti-siphon pipes became an intricate web of pipes festooned over buildings of the early twentieth century.

To prevent the siphonage or loss of the water seal in a trap it is only necessary to maintain equal air pressure on both sides of the trap to a sanitary appliance. The most straightforward way of doing this is to connect a short length of pipe from the outgo side of the trap to the open air. The short length of pipe was called a puff pipe, presumably because it drew in and expelled a puff of air to stabilise pressure. The use of a puff pipe to the trap of a WC and a basin is illustrated in Fig. 92.

The use of puff pipes to WC pan traps was abandoned for fear of drain smells rising up the soil pipe outside through the puff pipe and into an open window above. It would obviously need a singularly pungent smell propelled by considerable air pressure for this to happen. None the less, the fear of drain smells that has to this day beggared rationalisation of drains, caused the puff pipe to be abandoned. Recently puff pipes have been used to ventilate a discharge pipe system in a building with sealed windows, and the most recent regulations permit the use of air admittance valves, that are a form of puff pipe.

Having condemned the puff pipe, the then accepted means of preventing siphonage of the water seal of traps was the anti-siphon pipe (now called the vent pipe). A separate system of pipes was connected to the trap of all sanitary appliances to equalise air pres-

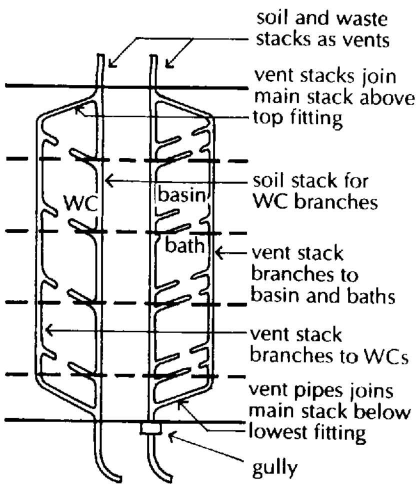


Fig. 93 Two pipe system fully vented.

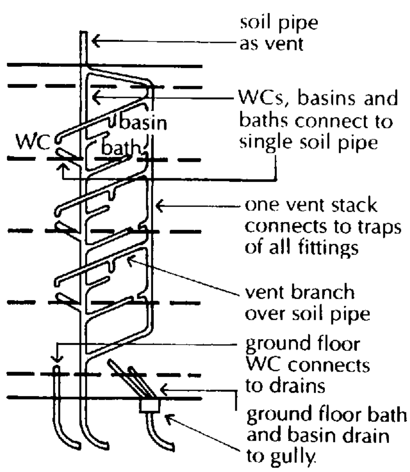


Fig. 94 One pipe system fully vented.

sure on both sides of the traps. Fig. 93 shows anti-siphon pipe systems applied to a two pipe system of pipework. There is a stack with branches from the vent pipes connected to the outlet side of each trap to each appliance. This fully vented two pipe system was commonly installed in buildings between the world wars, 1920 to 1939.

This unsightly and uneconomic web of pipes was later modified in the one pipe system which utilised a single discharge stack for the discharge from all appliances. Fig. 94 illustrates a fully vented one pipe system. The one pipe system gave a small economy in pipe runs but did little to improve the unsightly web of pipes on the external face of buildings.

In 1952 the Building Research Station, now the Building Research Establishment, published its first report on sanitary pipework. For some years the station had been carrying out tests in the laboratory and on site to determine the likelihood of siphonage of traps to appliances, with a view to effecting economy in sanitary pipework in housing. The report established that by careful arrangement of the branches to a soil pipe there would be no loss of seal to the traps of appliances and therefore no need for vent pipes.

The recommended single soil pipe with branches from sanitary appliances without vent pipes was called the single stack system (Fig. 95). Since then further work has shown that the single stack system can be used for multi-storey buildings without vent pipes by increasing the size of the stack or by the use of minimal vent pipes with a smaller stack.

From their study of pipe systems in use, the Research Station distinguished three conditions in which there could be loss of water seal to traps of appliances. These three conditions of air pressure fluctuations are:

(1) Induced siphonage
(2) Self-siphonage
(3) Back pressure

Induced siphonage

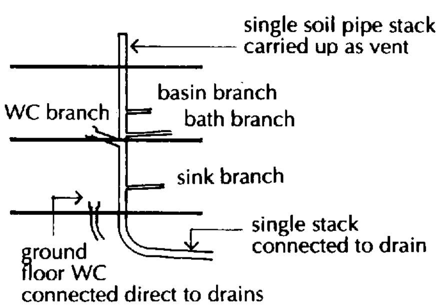


Fig. 95 Single stack system.

Induced siphonage may be caused by a discharge from a WC down a soil stack. As the discharge carries air with it there is a momentary reduction in pressure that may unseal the trap to a branch waste, as illustrated in Fig. 96. WC discharge branches to stacks should be swept in the direction of flow, as illustrated in Fig. 103, to reduce the likelihood of induced siphonage. Induced siphonage may also occur where waste pipes from two appliances connect to a common branch waste pipe.

Self-siphonage

Self-siphonage may occur where the discharge from an appliance runs full bore in the waste pipe at the end of the discharge, causing a reduction in pressure and possible loss of water seal to the trap, as illustrated in Fig. 97. Where loss of water seal to wash basin traps occurs, due to self-siphonage, the trap will not be filled because there is too little tail-off water from the funnel-shaped basin to fill the trap. To reduce the possibility of self-siphonage, wash basin wastes should not be more than 1.7 m long. If the water seal to the traps of baths and sinks is broken by self-siphonage, there is sufficient tail-off water from the flat bottom of these appliances to fill the trap and there is, therefore, less need to limit the length or slope of wastes against self-siphonage.

Back pressure occurs when a discharge reaches the base of a stack at the junction of a branch waste near the base of the stack. The increased pressure caused by the discharge may overturn the water seal in the trap to the branch waste, as illustrated in Fig. 98. To limit back pressure the bend at the base of the stack should have a large radius, shown in Fig. 103.

Similarly, where a branch waste is connected close to a WC branch, a discharge from the WC may cause back pressure in the branch waste. Branch wastes should not be connected to the stack for a depth of 200 mm below the centre line of the WC branch, as shown in Fig. 103.

For economy of sanitary pipework the single stack system, illustrated in Fig. 99, is used today in both domestic and public buildings.

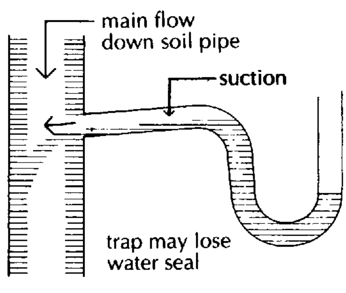


Fig. 96 Induced siphonage.

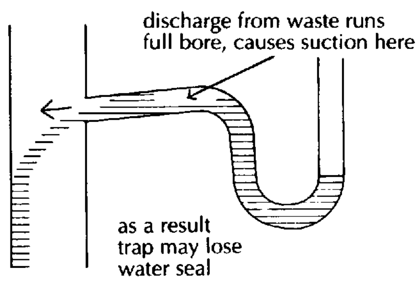


Fig. 97 Self-siphonage.

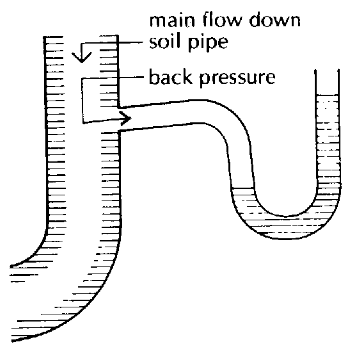


Fig. 98 Back pressure.

Ventilated stack system

Where pressure fluctuations in the stack may be so great as to cause induced siphonage or back pressure, for example in multi-storey buildings, a ventilation pipe connected to the stack is used. This arrangement is the ventilated stack system, shown in Fig. 99.

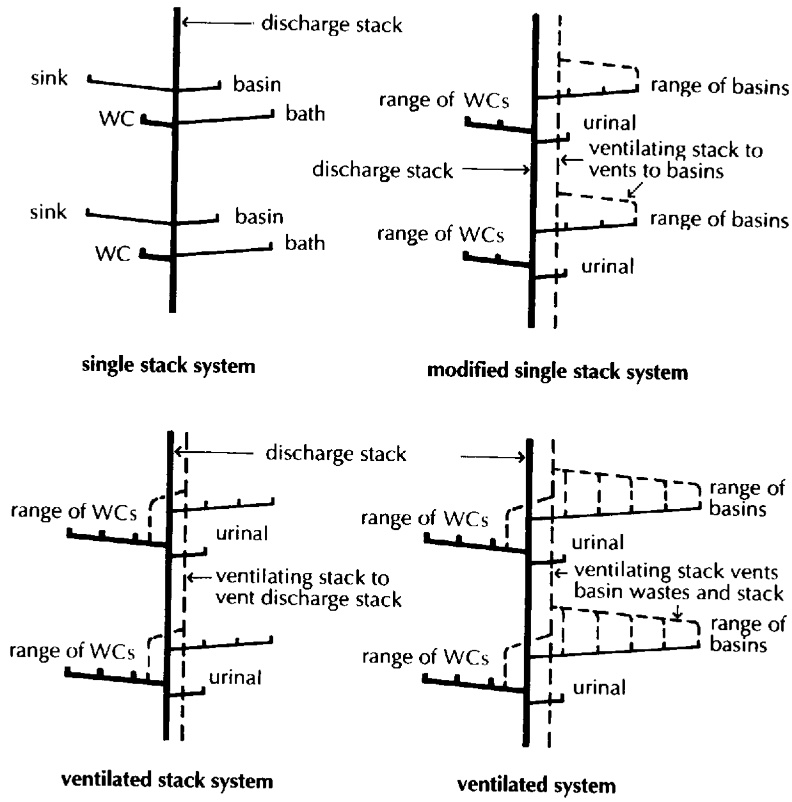


Fig. 99 Single stack systems.

Modified single stack system

Where pressure fluctuations in branch wastes to a single stack system may be sufficient to siphon the water seal from traps, a ventilation pipe system is connected to vent the traps. This is the modified single stack system, shown in Fig. 99.

Ventilated system

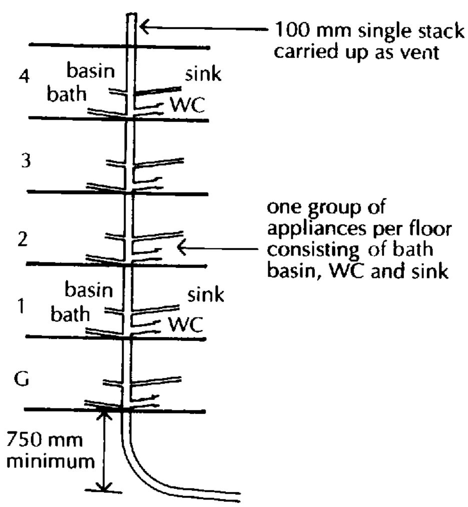


Fig. 100 Single stack for up to five floors.

Where pressure fluctuations in the stack and the branch wastes cannot be limited to prevent self-siphonage, induced siphonage and back pressure, for example in multi-storey buildings, a ventilated system is used, as shown in Fig. 99.

The single vertical pipe collecting discharges from all sanitary appliances is the discharge stack and the pipes from all appliances to the stack are discharge pipes. The single vertical ventilating pipe is the ventilating or vent stack and the branches from it to the discharge stack and discharge pipes are ventilating or vent pipes.

Fig. 100 illustrates the application of the single stack system to a five floor residential building with one group of appliances on each floor. The discharge pipes are arranged within the limitations set out in Fig. 103. The 100 mm single stack shown in Fig. 100 can also be used to take the discharge from two groups of appliances per floor for up to five floors.

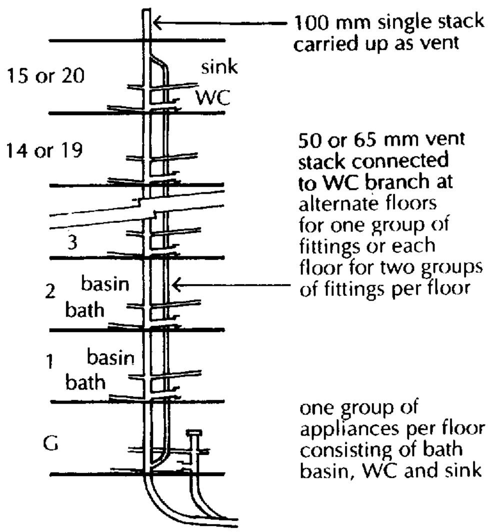


Fig. 101 Single stack for up to 20 floors.

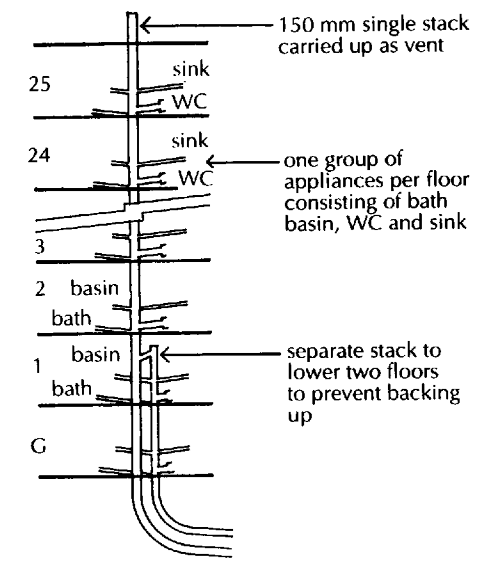


Fig. 102 Single stack for up to 25 floors.

The single stack system of sanitary pipework was originally developed for houses. It has since been developed for use in multi-storey buildings, such as flats, where sanitary fittings are closely grouped, floor over floor, so that short branch discharge pipes connect to a common single stack for economy in drain runs.

For blocks of flats of up to five floors, experience has shown that a single stack system of drainage is satisfactory for two groups of appliances on each floor where the fittings are grouped close to the stack. This arrangement may well work satisfactorily for blocks of flats up to say ten storeys providing the length of branches and their entry to the stack conform to the requirements set out.

For blocks of flats 15 to 20 floors high a modified system of the single stack with a ventilating stack can be used. The 50 or 65 mm stack is connected to WC branches on alternate floors for one group of appliances and to WC branches on each floor for two groups of appliances. This arrangement, which serves groups of sink, bath, basin and WC has been successfully used. Fig. 101 is an illustration of this arrangement, where the lowest group of appliances is connected directly to the drains through a substack.

As an alternative, a larger 150 mm single stack may be used without a ventilating stack for one group of appliances per floor. The larger stack limits pressure fluctuation for all but the lower two floors, where pressure is greatest. Fig. 102 is an illustration of this system applied to a 25 storey block of flats. The two lower floors are connected to a separate stack that drains directly to the drains underground.

A condition for the effective operation of the single stack system is that the stack enters the drains underground through a wide sweep bend to limit pressure of discharge as it enters the drain. The modifications of the single stack system have been effectively used where the conditions of close grouping of appliances, short branches and care in arranging the entries to the stack are carefully observed. Departure from these conditions may well result in siphonage or back siphonage.

Building Regulations

Section 1 of the approved document H1 gives practical guidance to meeting the requirements of the Building Regulations for sanitary pipework.

The approved documents give practical guidance to meeting the requirements of the Building Regulations, but there is no obligation to adopt any particular solution given in the documents if the requirements of the Regulations can be satisfactorily met in some other way.

Sanitary pipework includes all pipework used to carry the discharge of 'foul water' from sanitary appliances such as water closets, bidets, baths, wash basins and sinks, and ventilation of pipework as is necessary to prevent foul air from the drainage system entering the building under working conditions.

An acceptable level of performance of sanitary pipework and drainage will be met by any provision of section 1 of approved document H1. To reduce the risk to the health and safety of persons in buildings the foul water drainage system should:

(1) Convey the flow of foul water to a foul water outfall
(2) Minimise the risk of blockage or leakage
(3) Prevent foul air from the drainage system from entering the building under working conditions
(4) Be ventilated
(5) Be accessible for clearing blockages

In the document 'foul water' is defined as waste from a sanitary convenience or other soil appliance, and water which has been used for cooking or washing, but does not include waste containing any trade effluent. Foul outfall means a sewer, cesspool, septic tank or settlement tank. The capacity of the pipework, which depends on the size and gradient of the pipes, should be large enough to carry the expected flow, which depends on the type, number and grouping of appliances at any point.

Single stack system

The requirements of the Building Regulations for sanitary pipework can be met by the use of the single stack system of sanitary pipework, which is the system most in use for economy in layout and use of pipework. Fig. 103 is an illustration of a single stack system for a two-storey house, showing a single discharge stack pipe to which are connected branch discharge pipes from a sink, wash basin, WC, bath and ground floor WC.

Traps

Where sanitary appliances discharge foul water to the sanitary pipework system there should be a water seal, provided by means of a trap, to prevent foul air from entering the building under working conditions. There is a water seal trap to each of the appliances. The minimum size and depth of water seal for these traps are set out in Table 5.

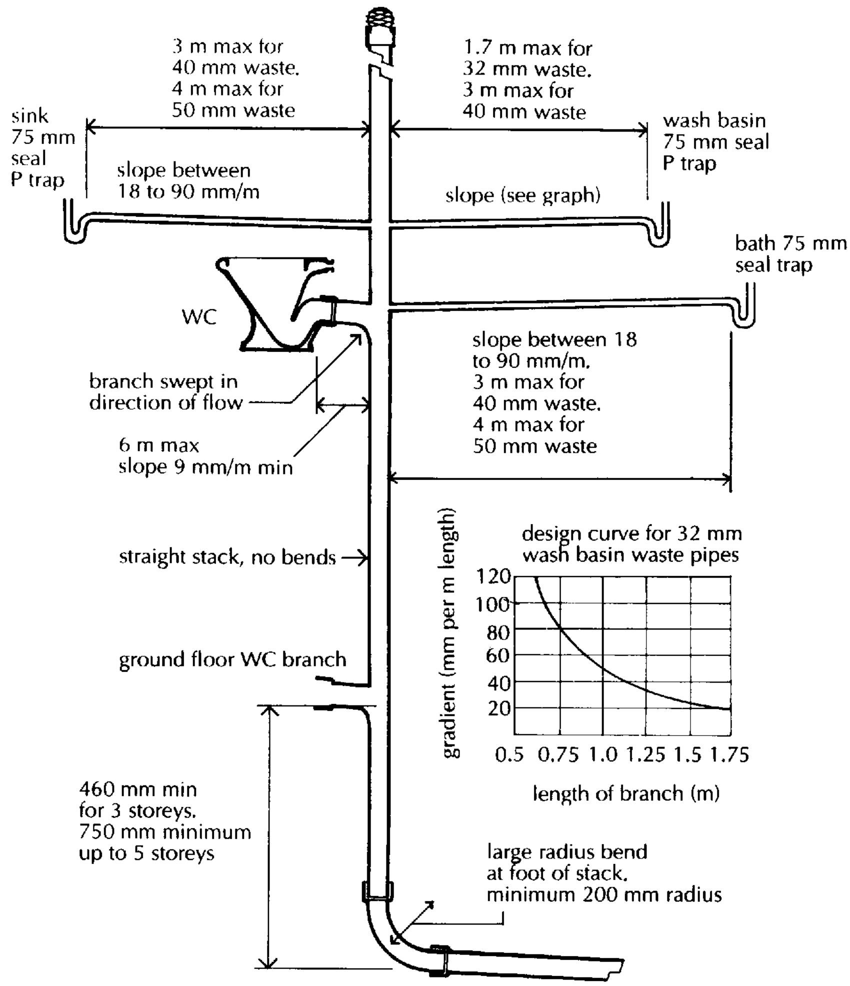


Fig. 103 Single stack system.

Table 5. Minimum trap sizes and seal depths.

Appliance	Diameter of trap [mm]	Depth of seal [mm]
washbasin bidet	32	75
sink bath shower food waste disposal unit urinal bowl	40	75
WC pan (siphonic only)	75	50

Water closet pans have a water seal trap that is integral with the pan in the form of a single or double water seal, as illustrated in Figs. 55 and 56. Baths, bidets, sinks and wash basins have a trap which is fitted to the appliance and connected to the branch discharge pipe. Single and double seal traps are illustrated in Figs 87 and 89. To facilitate clearing blockages there should be a clearing eye or the trap should be removable, as shown in Fig. 87.

To prevent the water seal in traps being broken by the pressures that can develop in a sanitary pipe system, the length and gradient of branch discharge pipes should be limited to those set out in Fig. 103, or a system of ventilating pipes should be used.

Branch pipes

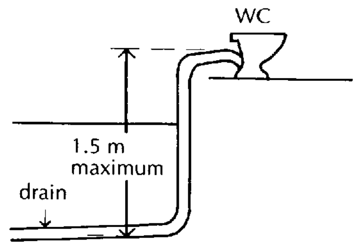


Fig. 104 Direct connection of ground floor WC to drain.

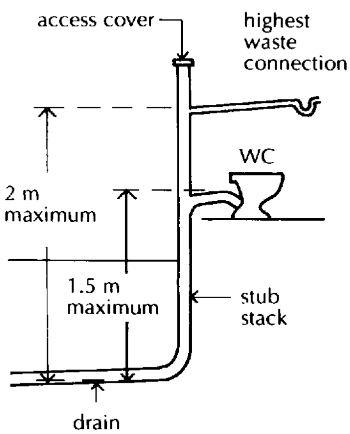


Fig. 105 Stub stack to ground floor appliances.

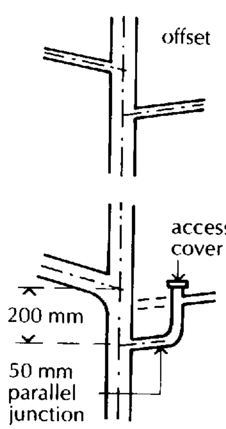


Fig. 106 Branch connections to stack.

The discharge of foul water from sanitary appliances is carried to the vertical discharge stack by branch pipes, as shown in Fig. 103. All branch discharge pipes should discharge into a discharge stack except those to appliances on the ground floor. Ground floor sinks, baths and wash basins may discharge to a gully, and WCs, bidets and urinals to a drain. A branch pipe from a ground floor WC should only discharge directly to a drain if the drop is less than 1.5 m, as shown in Fig. 104.

A branch pipe should not discharge into a stack lower than 450 mm above the invert of the tail of the bend at the foot of the stack for single dwellings up to three storeys, and 750 mm for buildings up to five storeys high.

The branch pipes from more than one ground floor appliance may discharge to an unvented stub stack, with the stub stack connected to a ventilated discharge stack or a drain, provided no branch is more than 2 m above the invert of the connection to the drain and branches from a closet more than 1.5 m from the crown of the closet trap, as shown in Fig. 105.

Branch pipes from waste water fittings such as sinks, baths and basins on the ground floor should discharge to a gully between the grating and the top level of the water seal. To avoid cross flow, small similar-sized connections not directly opposite should be offset by 110 mm on a 100 mm stack and 250 mm on a 150 mm stack as shown in Fig. 106. A waste water branch should not enter the stack within 200 mm below a WC connection as illustrated in Fig. 106.

Pipes serving single appliances should be at least the same diameter as the appliance trap and should be the diameter shown in Table 6 if the trap serves more than one appliance and is unventilated.

Bends in branch pipes, which should be avoided if possible, should have a radius as large as possible and a centre line radius of at least 75 mm for pipes of 65 mm or less in diameter. Junctions on branch pipes should be made with a sweep of 25 mm radius or at an angle of 45°, and connections to the stack of branch pipes of 75 mm diameter or more should be made with a sweep of 50 mm minimum radius or 45°.

Table 6 Common branch discharge pipes (unvented).

Appliance	Max. number to be connected	Max. length of branch (m)	Min. size of pipe (mm)	Gradient limits (fall per m) min (mm)	max (mm)
WCs	8	15	100	9	90
urinals: bowls	5	*	50	18	90
stalls	7	*	65	18	90
washbasins	4	4 (no bends)	50	18	45

* No limitation as regards venting but should be as short as possible.

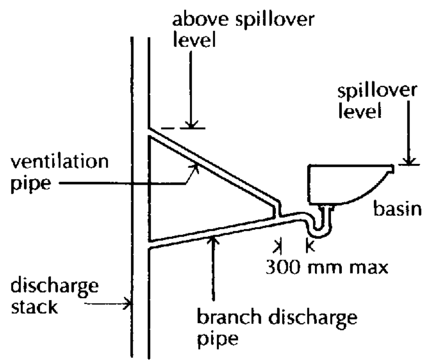


Fig. 107 Branch ventilation pipe.

It is not necessary to provide ventilation to branch pipes whose length and slope is limited to the figures given in Fig. 103, or to the common branch discharge pipes set out in Table 6. Where the length or slope is greater than these limits, the branch pipes should be ventilated by a branch ventilation pipe to external air, to a discharge stack or to a ventilating stack where the number of ventilating pipes and their distance to a discharge stack are large.

Branch ventilating pipes should be connected to the discharge pipe within 300 mm of the trap and should not connect to the stack below the spillover level of the highest appliance served, as illustrated in Fig. 107. Branch ventilating pipes to branch pipes serving one appliance should be 25 diameter or where the branch is longer than 15 m or has more than five bends, 32 in diameter.

Discharge pipes and stacks

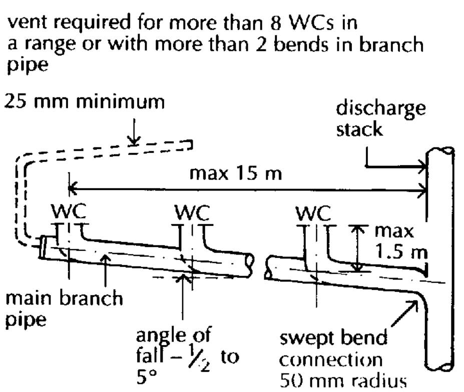


Fig. 108 Range of WCs branch discharge pipe.

Discharge pipes from ranges of WCs are usually 100 mm. The discharge pipes do not run full and there is little likelihood of self-siphonage of traps to appliances and, therefore, no need for venting. Ranges of eight or more WCs may be connected to a common discharge pipe. The shape and length of the common discharge pipe is not critical. The connection to the stack should be through a swept bend and the connections of the WCs to the common discharge pipe should likewise be through a swept bend as illustrated in Fig. 108. Where there are more than eight WCs in a range or more than two bends in the branch discharge pipe, a ventilating pipe may be necessary.

A range of up to four basins may be connected to a 50 mm common discharge pipe without venting, as illustrated in Fig. 109, and up to five with one 25 mm vent to the highest point of the discharge pipe. With ranges of more than five basins it is necessary to vent the trap to each appliance to limit pressure fluctuations that might otherwise

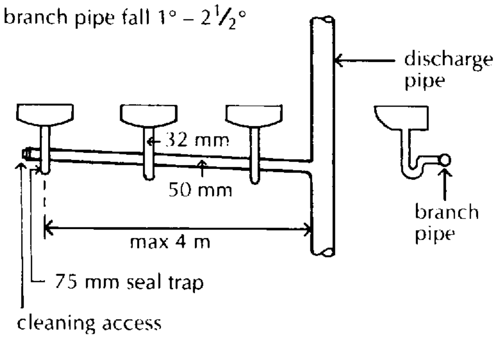


Fig. 109 Range of up to four wash basins with P traps.

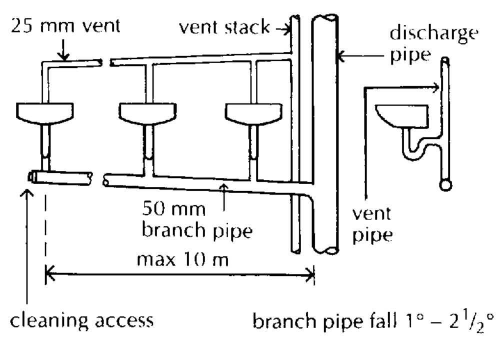


Fig. 110 Range of up to 10 wash basins with either P or S traps.

cause self-siphonage of the water seal to traps, as illustrated in Fig. 110. The vent stack and pipes are connected to the discharge pipes to each appliance and the vent stack may be run to outside air independent of the discharge stack.

The discharge pipes from basins fitted with spray taps do not run full and there is, therefore, no likelihood of self-siphonage. Ranges of up to eight basins fitted with spray taps do not require ventilation of traps.

The discharge pipe from urinals does not run full and there is no need for ventilation of traps. Discharge pipes to urinals should be as short as possible to minimise build up of deposits.

Ranges of WCs and basins and urinals on several floors may discharge to a common single stack without vent pipes when the estimated frequency of use of appliances and the consequent discharge loading of the pipe system is unlikely to cause gross pressure fluctuations.

Where the discharge loading of the stack is likely to cause pressure fluctuations sufficient to cause induced siphonage or back pressure, a vent stack connected to the discharge stack at each floor is used to limit pressure fluctuations. Where the traps of ranges of wash basins have to be vented to avoid self-siphonage, the vent stack may be run to outside air independent of the discharge.

Where both the discharge loading of the stack and the number of a range of wash basins require venting, the vent stack is connected both to the wash basin traps and the discharge stack as in the ventilated system. Fig. 99 illustrates these arrangements. Which one is used will depend on the estimated frequency of use, assumed discharge loading and the size of the discharge stack.

Alternatively, the vent stack may be connected to air independently of the discharge stack, as in the modified single stack system where the vent pipe system is used to limit pressure fluctuations in the discharge pipes to basins. Which system is used will depend on the estimated frequency of use, assumed discharge loading and the size of the discharge stack.

Discharge stacks should not have offsets in any part carrying foul water, should be run inside a building if it has more than three storeys and should discharge to a drain through a bend with as large a radius as possible and not less than 200 mm at the centre line, as illustrated in Fig. 103.

Discharge stacks should be ventilated to prevent water seals in traps being drawn by pressure that can develop in the system, by being continued up to outside air at least 900 mm above any opening in the building within 3 m and finished with a cage or cover that does not restrict flow of air.

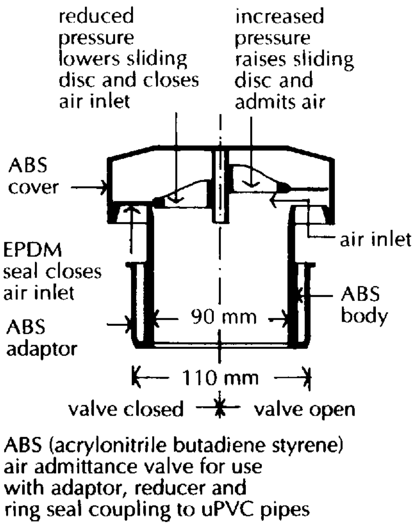


Fig. 111 Air admittance valve.

A discharge stack may terminate inside a building if it is fitted with an air admittance valve (Fig. 111) which has a British Board of Agreement Certificate. An air admittance valve operates through a disc which rises, due to increased pressure in the discharge stack, to release the air pressure and falls when the pressure is reduced to normal air pressure. An EPDM (ethylene-propylene diene monomer) seal serves to close the air inlet.

The dry part of a discharge stack above the highest branch, which serves only for ventilation, may be reduced to at least 75 mm diameter on one and two-storey houses.

The size of the discharge stack is determined by the anticipated flow from all the fittings discharging into it. Rodding points should be provided in the stack to give access to any length of pipe that cannot be reached from another part of the system.

PIPE MATERIALS

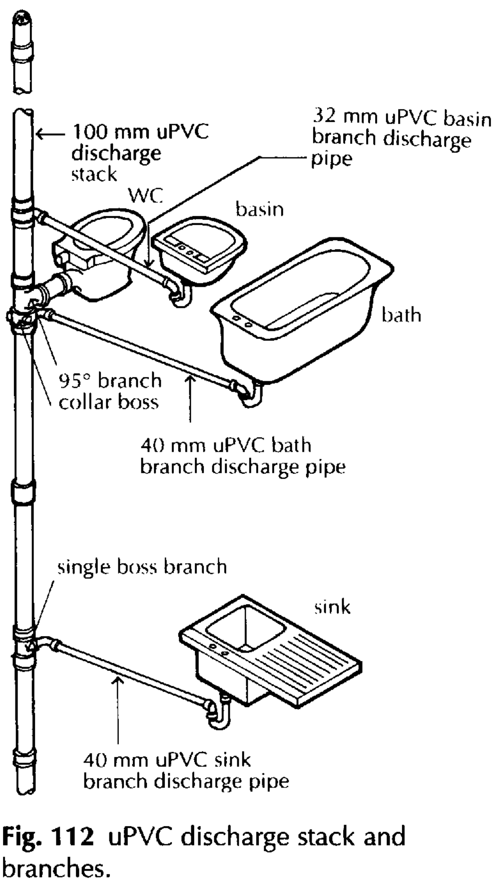


Fig. 112 uPVC discharge stack and branches.

The materials used for discharge pipework above ground are cast iron, copper and plastics. uPVC (unplasticised polyvinyl chloride) is the most commonly used material for discharge stack and branch pipe systems, because of its low cost, ease of cutting, speedily made joints and the range of fittings available. This smooth surface material is usually finished in black or grey, which requires no protective coating. The pipework is secured with loose brackets that are nailed or screwed to plugs in walls.

A variety of fittings is manufactured to suit the various branch waste connections for single stack systems of sanitary pipework. The plastic pipework is usually jointed by means of an elastomeric ring seal joint. The synthetic rubber ring forms an effective seal as it is compressed between the spigot and socket ends of the pipe as the spigot end is pushed into the socket.

Connections of uPVC branch pipes to outlets of appliances is made with a rubber compression ring that is hand tightened by a nut to a copper liner. Fig. 112 is an illustration of a uPVC discharge stack to a house.

Cast iron pipes

Cast iron pipes are used for discharge pipework where the strength and durability of the material and the wide range of fittings available justify the comparatively high initial cost. Where cast iron is used it is usual to run the discharge stack, WC discharge pipes and main branch pipes to ranges of fittings in cast iron, and discharge pipes from waste appliances in copper or plastic tube. In this way the strength and speed of fixing of cast iron is combined with the compact joints and ease of manipulation of copper or plastic pipe.

The pipes and fittings are sand cast or spun with socket and spigot ends, as illustrated in Fig. 113, and are given a protective coating of tar or bitumen. A range of socket and spigot fittings with or without bolted access doors is provided. Joints are made with molten lead which is caulked (rammed) into the joint that has been sealed with a gaskin of hemp, or with lead wool, caulked fibre or a rubber seal ring. Pipes and fittings are usually fixed by nailing through cast on ears to plugs in walls and floors.

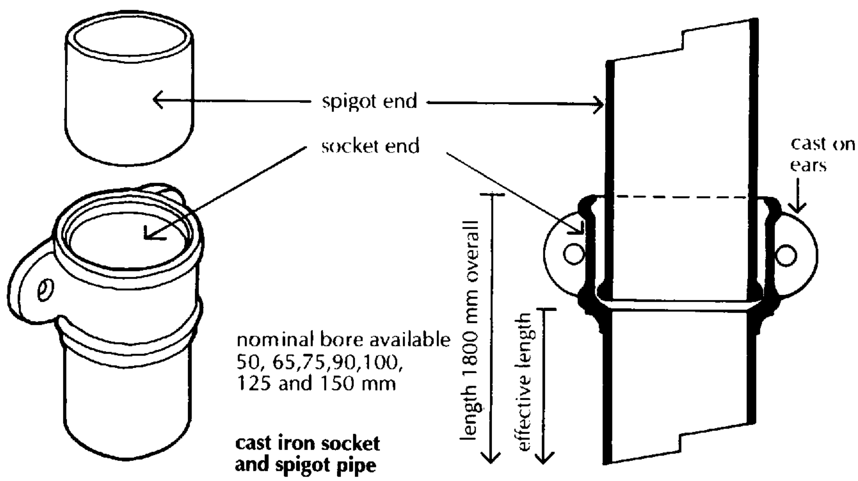


Fig. 113 Cast iron pipes.

Copper pipe (tubulars) with capillary or compression joints is used for discharge pipes to waste appliances because of the compact joints in this material, its ease of handling, and particularly for the facility of making bends in pipework run from appliances through walls to connect to discharge stacks.

With extensive discharge stack and branch pipework run internally in ducts, prefabricated systems of copper pipework may be used. The pipework is jointed with bronze welded joints (Fig. 114), so that complete sections of pipework may be prepared off site ready for fixing, to minimise site work. Here the high initial cost of pre-fabricated pipework is justified by appreciable reduction in on-site labour working in cramped conditions and also the durability of the pipework.

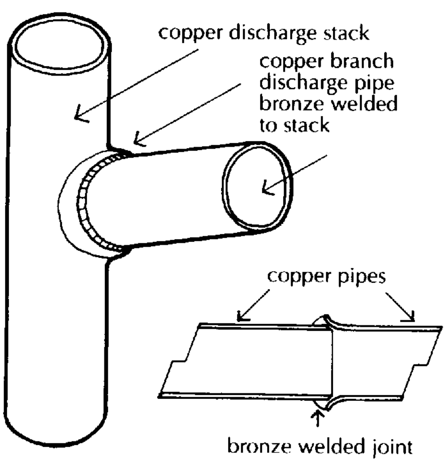


Fig. 114 Bronze welded joint.

TESTING

Soundness test (air test)

The accepted method of testing the soundness of discharge stacks and pipes above ground is the air test. A sound pipe system will contain air under pressure for a few minutes as an indication of its capacity to contain the flow of liquid in conditions normal to a discharge pipe system.

The air test is carried out to the whole discharge pipework above ground in one operation or, where the pipework is extensive, in two or more operations. The traps of all sanitary appliances are filled with water and the open ends of pipes are sealed with expanding drain plugs or bag stoppers. Air is pumped into the pipework through the WC pan trap and the air pressure is measured in a U tube water gauge or manometer. A pressure equal to 38 mm water gauge should be maintained for at least three minutes if the pipework is sound. Fig. 115 illustrates the equipment used for the air test.

If the air pressure is not maintained for three minutes, leaks may be traced by spreading a soap solution around joints, with the pipework under air pressure; bubbles in the soap solution will indicate leaks or, alternatively, smoke is pumped into the pipework from a smoke

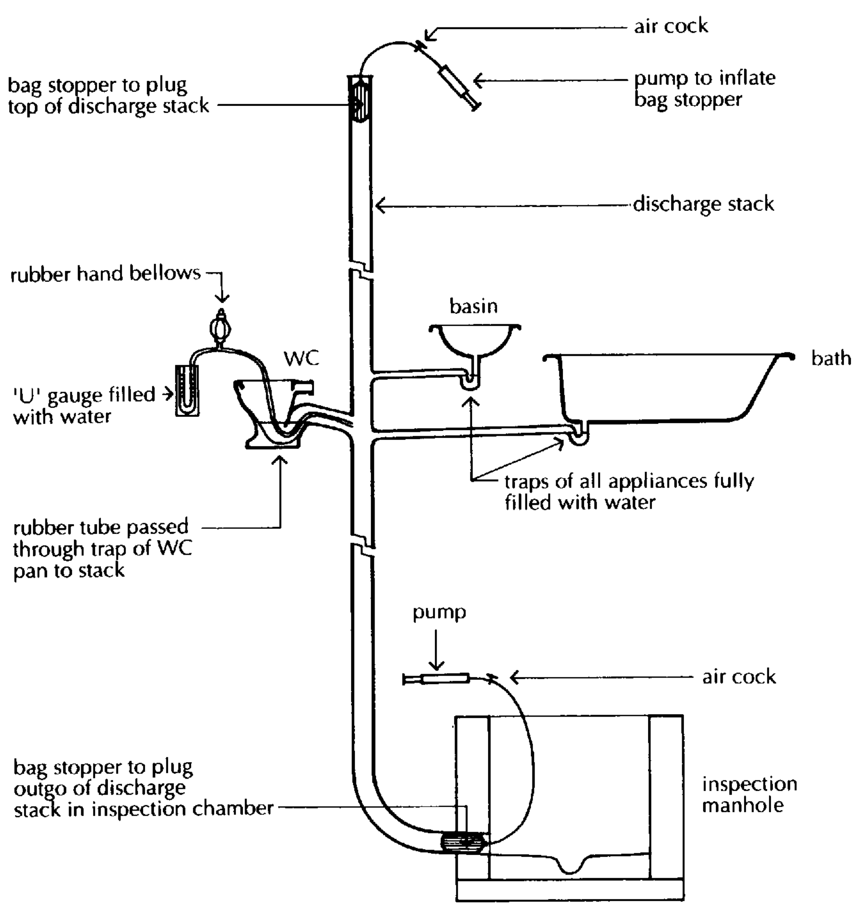


Fig. 115 Air test for sealed discharge stack and branches.

machine and the escape of smoke will indicate leaks. Leaking joints are made good and the air test applied to test for soundness.

In use test

To test the performance of a discharge pipe system in use, a group or groups of appliances are discharged simultaneously to cause conditions most likely to produce maximum pressure fluctuations. In buildings with up to nine appliances of each kind to a stack, the top-floor sink and wash basin are filled to overflowing and the plugs pulled simultaneous to a normal discharge of the top-floor WC. After this test a minimum of 25 mm water seal should be retained in every trap. With more than nine appliances of each kind to a stack, two or more WCs, basins and sinks are discharged simultaneously on the top floors for the performance in use test.

The discharge from fittings to the top of a stack provides conditions most likely to cause pressure fluctuations sufficient to induce siphonage and back pressure and loss of water seal. In the performance in use test, the discharge from baths, showers and urinals is ignored as their use does not generally add significantly to peak flow conditions.

PIPE DUCTS

For some years it was a requirement that discharge stacks be run internally to avoid the possibility of water in waste branches freezing and causing blockages. In the temperate climate of England it is unlikely that this will occur as waste branches rarely run full bore and running water does not readily freeze. The water from a slowly dripping tap may however gradually freeze and cause a blockage.

Because of the need to run internal discharge stacks inside pipe casing or ducts, for appearance sake and to avoid the inconvenience of unblocking drains internally, the requirement has by and large been abandoned, particularly for small buildings where there is access to discharge stacks run externally.

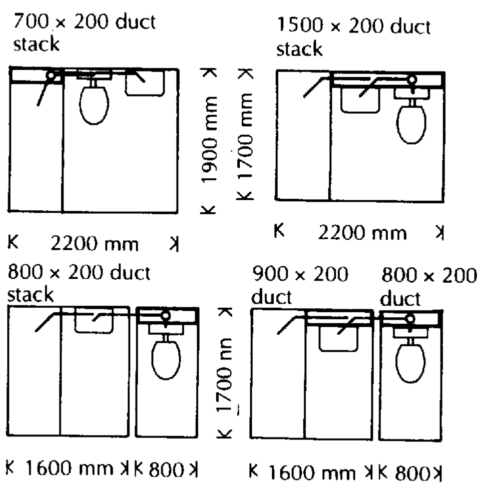


Fig. 116 Pipe ducts.

In large buildings all discharge pipework, together with hot and cold water services, are run internally in ducts for ease of access.

Where there are internal bathrooms and WCs to economise in pipework and to avoid over large ducts it is necessary to group sanitary appliances. Some compact groups of sanitary appliances and ducts and pipework are illustrated in Fig. 116, which illustrates ducts to bathroom with WC and a separate bathroom and WC.

Where there are two or more bathrooms and WCs on each floor of a multi-storey building, they will be grouped around a common duct: side by side where there are two, and back to back to a single duct where there are four.

Ventilation of internal WCs and bathrooms

Bathrooms and WCs are often sited internally in modern buildings, such as flats, so that external walls may be best used for the windows of other rooms. It is therefore necessary to provide means of extract

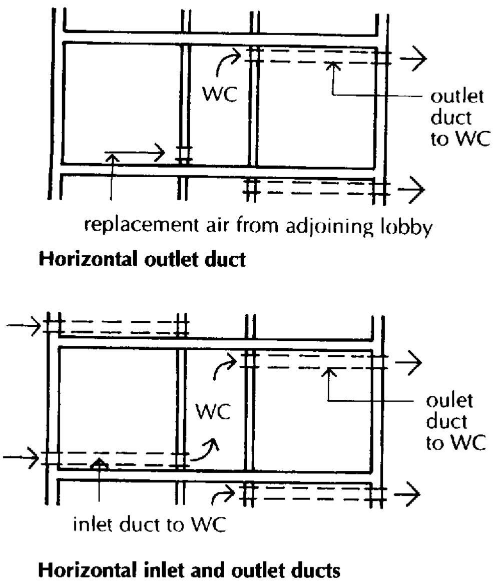


Fig. 117 Ducts.

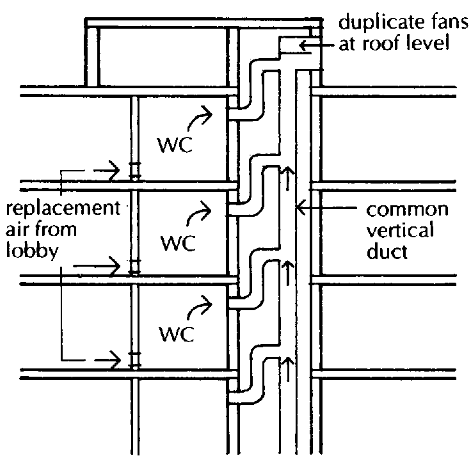


Fig. 118 Mechanical extract system.

ventilation to internal bathrooms and WCs, to rapidly dilute pollutants and moisture vapour in the air by air changes.

Extract ventilation may be provided either by mechanical extract of air or by passive stack ventilation. Passive stack ventilation is a ventilation system that uses ducts from the ceilings of rooms to terminals on the roof to operate through the natural stack effect of heated air rising, as in a chimney stack.

Mechanical ventilation is effected by an electrically operated extract fan designed to evacuate air rapidly through a duct to outside air. The Building Regulations recommend mechanical extract ventilation of 60 litres a second for bathrooms and sanitary accommodation located internally. The extract fan should be controlled by the operation of the light switch to the room and have a 15 minutes overrun after the light is turned off. To replace evacuated air there should be a 10 mm gap under the door to bathrooms and sanitary accommodation, through which replacement air can enter.

Air evacuated from internal bathrooms and sanitary accommodation is conducted through metal or plastic ducts run at high level or in hollow floors to outside air. Replacement air may enter at low level from an adjoining ventilated room either under a door or through a ventilation grille, as illustrated in Fig. 117. Where adjoining rooms or spaces afford poor ventilation for replacement air, it is necessary to provide ducts to supply replacement air from outside at low level, as illustrated in Fig. 117.

Mechanical ventilation through a vertical duct is used to provide steady air changes independent of wind direction and pressure. Air is drawn through a common vertical duct to the outside air with branches to individual internal rooms as illustrated in Fig. 118. A main fan and duplicate standby fan at roof level evacuate air through the vertical duct and shunt ducts from rooms. Replacement air enters the internal rooms from adjoining lobbies.

4: Foul Drainage

PIPE MATERIALS

Short, cylindrical, vitrified clay pipes have for centuries been used for drains underground. The joints between the pipes were made with puddled clay, either packed around the butt ends of adjacent pipes, packed into loose clay collars joining pipe lengths or packed into the socket end of one pipe around the spigot end of the next.

Puddled clay is plastic clay either in its natural wet state or to which water is added to make it plastic, so that it can be moulded around or packed tightly into collars or sockets of pipes. A gaskin of hemp, usually tarred or coated with tallow, was first rammed into the collars or sockets to align the pipes and prevent the puddled clay entering the pipeline. The clay pipeline was laid on the bed of the trench, then back filled with the excavated material.

Clay pipes with puddled clay joints

Well burnt (vitrified) clay or stoneware pipes were inert to sewage and impermeable to the intrusion of ground water and the puddled clay joints might remain watertight for many years, particularly in damp soil conditions. The plasticity of the clay joint would take up slight movements in the pipeline due to settlement, elongation or contraction of the pipeline, and slight displacement of the pipeline caused by backfilling the pipe trench and pressure on the ground from above.

The small movements that the puddled clay joints could accommodate might allow some seepage of sewage water through the joints to the pipeline, or intrusion of ground water into the pipe. The pipeline was buried underground, and unless considerable leaks from, or blockages of, the pipeline demanded attention, it remained so.

Up to the middle of the nineteenth century, standards of hygiene were appreciably poorer than those of today. The common practice in towns was to drain sewage into cesspits (pits dug into the ground, near to and sometimes under buildings) which retained solids and released liquids into open ditches and rivers, causing an all-pervading odour.

Following serious epidemics of typhus in the early nineteenth century, due to gross pollution of drinking water by sewage, there was a demand for drastic and rapid improvement in hygiene. During the latter part of the nineteenth century there was great activity in the building of new enclosed sewers to replace cesspits and an overall improvement in drain laying and maintenance.

Cement joints

By the beginning of the twentieth century the new wonder material, Portland cement, was being manufactured in quantity and the cement joint for drains, and later the concrete bed, were adopted as a 'cure-all' for all time, for blocked or leaking drains. The notion was to make a dense rigid joint of cement and sand between the brittle (rigid) clay pipes with a view to a rigid pipeline that would remain tight to seepage from inside and infiltration of ground water from without. To make doubly certain, the rigidly jointed clay pipeline that was initially laid on the bed of a drain trench was later laid on a rigid concrete base laid in the trench bottom. This combination of rigidly jointed clay pipes on a solid concrete bed was accepted as sound drain-laying practice from the beginning to the middle of the twentieth century.

A vitrified cylindrical drain pipe is brittle or rigid and will, under load, crack. The great advantage of the clay pipeline with puddled clay joints was that although the short lengths of pipe could not in themselves accommodate movement, the many plastic puddled clay joints could and did so without excessive seepage from or infiltration of ground water into the joints.

The movements that a pipeline underground may suffer are ground settlement, movement due to gain or loss of water in clay soils, disturbances during backfilling of the pipetrench and elongation or contraction due to temperature or moisture changes in the pipes and joints. After World War II (1939–45) the Building Research Station began an investigation of drain failures that culminated in Digests 124 and 125 (first series). The principal failures reported were due to blockage of the drain or excessive seepage from the drain requiring the attention of a builder.

At that time the two materials most in use for drain pipes were the traditional salt-glazed clay and the recently introduced pitch fibre. The investigations established that drain failures were due in clay pipelines to misalignment of the pipes, brittle fracture of the pipes or fracture of the rigid cement joint; and in pitch fibre lines they were due to flattening of the pipe or fracture of the joint coupling. These failures were caused by earth movement under or around the pipeline, or load stress on the pipeline from backfilling the trench, or surcharge loads on the ground above the trench, these causes often being made worse by supports placed under pipes during laying to facilitate alignment. Other causes of failure were temperature and moisture changes in the pipeline, often after laying and before backfilling the trench, and also damage to pipes during handling.

Rigid and flexible pipes

Clay pipes generally failed by brittle fracture either across or along the pipe or around sockets, whereas pitch fibre pipes generally failed by being flattened without fracture. The different behaviour of clay and pitch fibre pipes under load prompted the current classification of pipes as rigid and flexible.

Rigid pipes

Rigid pipes are those that fail by brittle fracture before they suffer appreciable deformation, and these include clay, concrete, cement and cast iron. Flexible pipes are those that suffer appreciable deformation before they fracture, and these include pitch fibre and uPVC.

Many of the failures of clay drainlines were a consequence of the rigidity of the pipes, the cement joints and the concrete bed in use at the time of the investigation. The rigidity of the pipeline and its bed were incapable of accommodating, without fracture, the soil movements and load stresses that a pipeline may suffer. From this understanding of failures there developed the discontinuous concrete or granular bed, and the flexible jointing system of clay drainlines. Thus practice had gone full circle from the flexible puddled clay joint, through rigid cement joints and bed, back to the flexible joint and granular bed of today. The deformation of flexible and rigid pipes has been controlled by the use of a granular bed, and limitations of load by the design of the trench and its backfilling.

DRAINAGE LAYOUT

The layout of foul drains depends on whether foul water and rainwater are discharged to a common drain system or to separate drain systems, which in turn depends on whether there is one sewer carrying both foul and rainwater or separate sewers for foul and rainwater.

Fig. 119 is an illustration of combined and separate drainage systems to a small two-floor house. As the drains for foul water and rainwater will generally run across each other at some point, it is necessary to adjust the level or gradient (slope) of the drains to accommodate this.

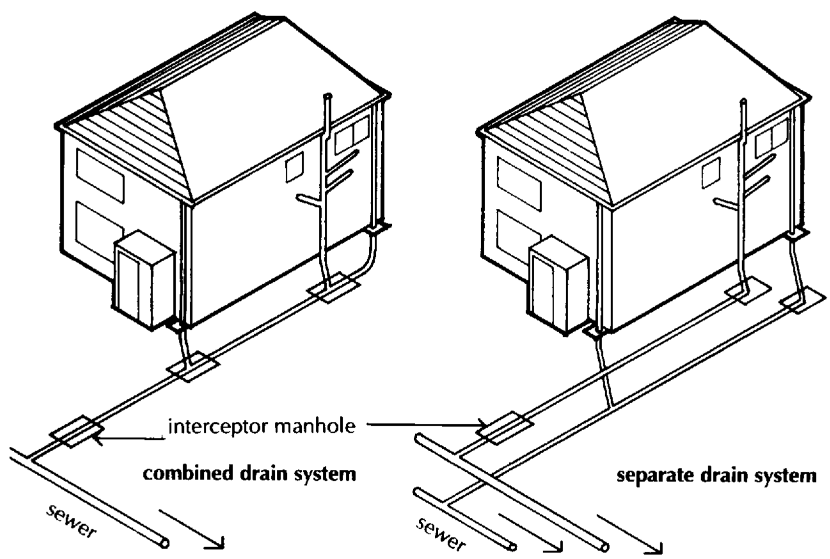


Fig. 119 Combined and separate drain systems.

Combined drains

In many of the older urban areas of England there is one sewer that takes the discharge of both foul water and rainwater from roofs and paved areas. Foul water is the discharge from WCs, bidets, baths, basins and sinks, and rainwater is the discharge of the run-off of rainwater from roofs and paved areas.

When the single, combined sewers of the older urban areas were laid out there was, at best, only rudimentary filtration and discharge from sewers to sea, river or inland soakaways. With later, more stringent controls for the purification of foul water, to minimise contamination of drinking water it became convenient and economic to separate foul and rainwater discharges to reduce the volume of water discharged to foul water sewers and the necessary size of water purification plants.

Separate drains

Outside the older urban areas it is usual for foul water and rainwater to drain to separate drainage and sewer discharge systems. It is general practice, therefore, to have combined drainage and sewer systems in the older urban areas and separate foul and rainwater systems in most other areas.

A combined drainage system which carries both foul and rainwater has to be ventilated throughout to conduct foul air discharge to the open air. In this system it is necessary, therefore, to fit trapped gullies with a water seal, to collect rainwater from roofs and paved areas. With separate systems of foul and rainwater drains it is necessary to fit trapped gullies only to the discharge of foul water fittings, where the discharge pipe does not serve as a ventilation pipe.

For economy in the use of labour and materials, the layout of a drain system should be kept simple. Fittings that discharge foul water should be grouped together on each floor to economise in water service pipe runs, discharge pipe branches should run to a common waste stack and groups of fittings on each floor should be positioned one over the other to avoid wasteful runs of pipework. Single fittings, such as basins or sinks fitted distant from other fittings, involve uneconomic and often unsightly lengths of water and discharge pipes.

Rainwater pipes from roof gutters and gullies to collect water from paved areas should be positioned to economise in and simplify drain runs. Wherever practicable, changes of direction and gradient should be as few and as easy as possible to minimise access points necessary to clear blockages.

Foul water drainage systems should be ventilated by a flow of air, with a ventilating pipe to the head of each main drain and any branch drain that is more than 6 m long serving a single appliance or 12 m long serving a group of appliances. Ventilated discharge pipes such as discharge stacks, discharging directly to the drain, are commonly used for ventilation of drains.

Drain runs should be laid in straight lines wherever possible to encourage the free flow of discharge water by gravity, with gentle curves in drain runs only where straight runs are not practicable. Bends in drain runs should be limited to positions close to or inside inspection chambers and to the foot of discharge pipes and should have as large a radius as practicable.

Where drain runs are near to or under a building, precautions should be taken to accommodate the effects of settlement without damage to the drain.

DRAIN PIPES

Clay pipes – materials, manufacture, sizes

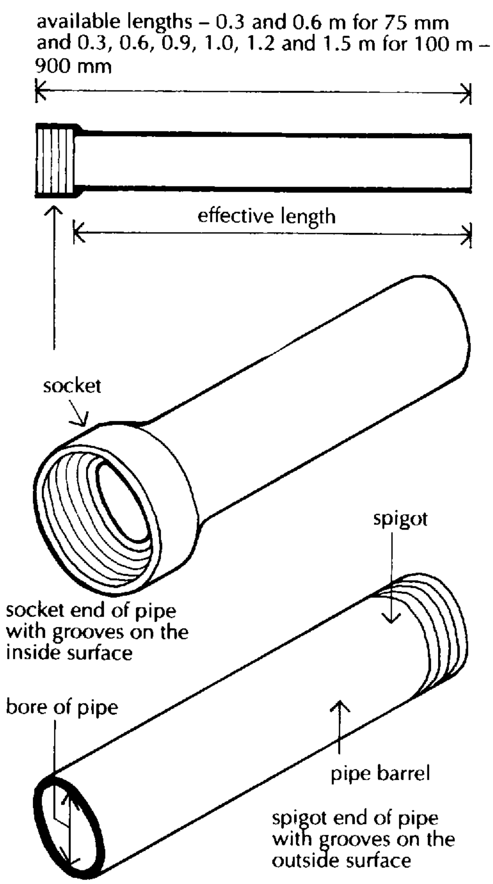


Fig. 120 Clay drain pipes.

Up to the middle of the nineteenth century clay pipes were made from local clays and fired in primitive kilns. Depending on the type of clay used, the skill in moulding and the control of the firing, pipes varied from well-formed dense pipes to soft, porous, badly-shaped pipes.

The increase in urban population that followed the Industrial Revolution, and the demand from the middle of the nineteenth century for improvement in hygiene, brought increases in the production and quality of clay pipes. About this time it became common practice to use salt-glazed clay drain pipes coated inside and out with a dense impermeable glaze. The fired-on salt glaze rendered both dense and porous pipes impermeable to both infiltration and exfiltration of water.

More recently, through quality control, preparation, moulding, drying and firing, clay pipes are produced which are sufficiently dense and impermeable in themselves so that they no longer require salt glaze against exfiltration and infiltration of water. Old habits die hard, however, and in spite of improved products and techniques the clay pipe manufacturers produce vitrified clay pipes glazed inside only or both inside and outside, to satisfy the demands of traditionalists who claim without justification that a glaze encourages flow in a pipe.

Today the majority of clay pipes are mass produced in a few highly automated plants. The selected clays are ground to a fine powder and just sufficient water is added for moulding. Pipes are formed by high-pressure extrusion – socketed pipes individually and plain pipes continuously – the cylinder of formed clay being cut to length. Straightforward fittings are formed by extrusion and the parts of junctions are extruded and then cut and joined by hand.

The moulded clay pipes and fittings are then dried in kilns to encourage regular, uniform loss of water to avoid loss of shape. Pipes and fittings are automatically fed through and fired in continuous tunnel kilns. Pipes and fittings which are to be glazed have a ceramic

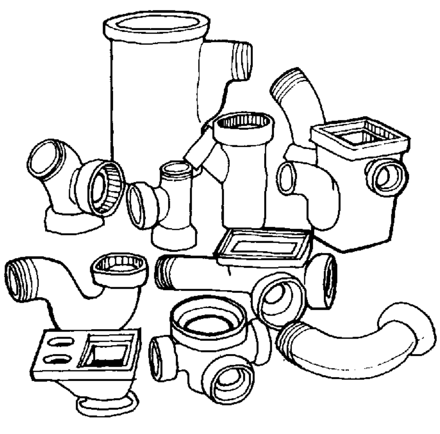


Fig. 121 Clay drain pipe fittings.

glaze or slip sprayed on, or they are dipped in the slip before they enter the kiln.

The nominal bore (inside diameter) of clay pipes for drains is from 75 to 900 mm in increments of 25 mm between 75 and 250 mm, one increment of 50 mm to 300 mm and then increments of 75 mm from 300 to 900 mm, as illustrated in Fig. 120.

A wide range of more than 250 fittings is made for clay drains such as bends, junctions, channels and gullies, some of which are shown in Fig. 121.

The advantage of the clay pipe for drains is that the comparatively short length of pipe and the wide range of fittings are adaptable both to the straightforward and the more complex drain layouts and the pipes themselves are inert to all normal effluents.

Jointing

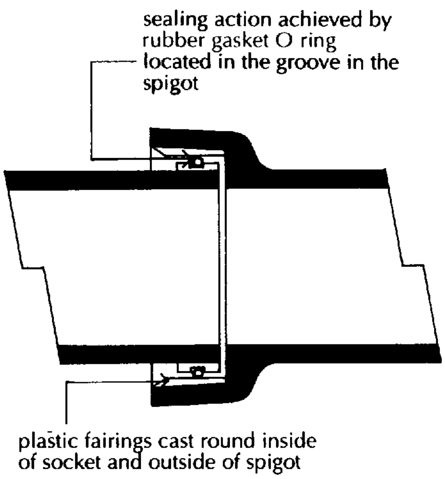


Fig. 122 Section at junction of socket and spigot clay pipes.

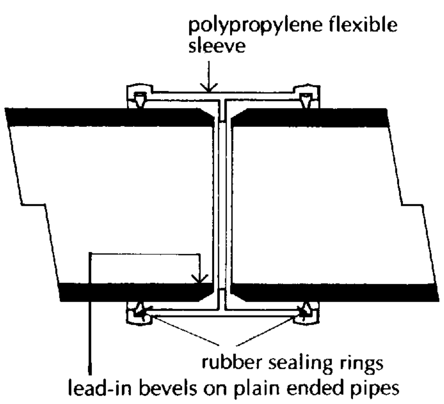


Fig. 123 Section at junction of plain ended clay pipes showing flexible coupling.

It is now generally accepted that flexible joints should be used with rigid clay drain pipes so that the drainlines are flexible in the many flexible joints. Flexible joints will accommodate earth movements under, around or over the pipeline. The flexible joint can be made in all weather conditions and, once made and tested, the trench can be backfilled to protect the pipeline from damage. There are two types of flexible joint in use: the socket joint for socket and spigot pipes and the sleeve joint for plain-ended clay pipes. Typical joints are shown in Figs. 122 and 123.

These flexible joint seals are made from either natural rubber, chloroprene rubber, butyl rubber or styrene-butadiene rubber. The flexible socket joint is made with plastic fairings cast on the spigot and socket ends of pipe to provide a simple push fit joint. It suffers the disadvantages that the joint may be damaged in handling and cut pipe lengths present difficulties on site.

The flexible coupling joint is made with a close fitting, flexible plastic sleeve with rubber sealing rings. The ends of the plain-ended pipes are bevelled to assist in forcing pipe ends into the sleeve to make a close watertight seal. Care is required to make these flexible joints in fitting pipe ends together and into sleeves to form a tight fit without damaging the seals.

The traditional cement and sand, rigid joint is still, to some extent, used by traditionalists on the grounds that it has been in use for a long time and is comparatively simple to make. A gaskin of hemp is first rammed into the joint between the spigot end of one pipe and the socket end of the other, and a mix of cement and sand is then rammed in to complete the rigid joint. Providing there is no undue settlement this joint may remain reasonably sound and watertight for some considerable time.

Cast iron pipes – materials, manufacture, sizes

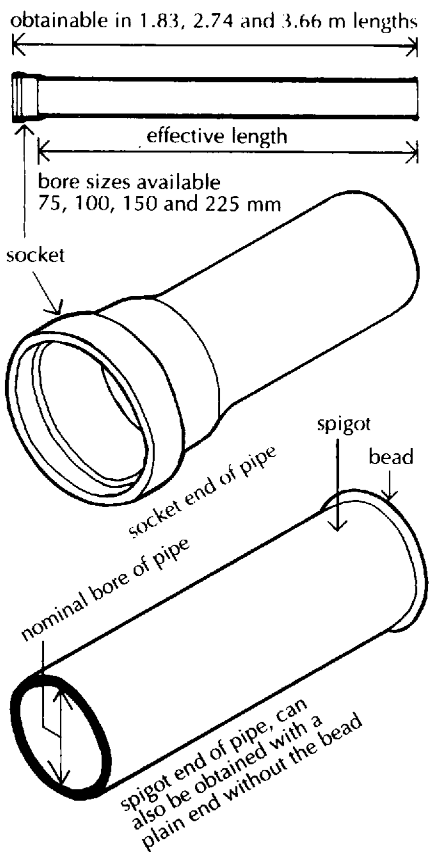


Fig. 124 Cast iron drain pipes.

For over 100 years cast iron pipes have been used for drains underground and for water and gas mains. A cast iron pipe is brittle or rigid and may suffer brittle fracture under heavy load or due to careless handling, but cast iron has better resistance to corrosion than either steel or wrought iron. In its molten state it runs freely into moulds, producing good, sharp, plain or intricate shapes. A cast iron pipe is stronger than the traditional clay pipe and has largely been used for drains under buildings and roads because of its superior strength. Cast iron pipes are coated inside and out with a hot dip solution of tar or bitumen to protect the iron from sewage and ground water.

Some years ago ductile iron pipes were first introduced. Molten grey iron (cast iron) is treated to change the micro-structure of the metal from the brittle graphite flake of cast iron to the ductile spheroidal graphite. The effect of this change is that the iron becomes ductile and can suffer deformation under load without fracture. The ductile iron pipe is thus a flexible pipe having high tensile strength, ductility and resistance to severe impact without fracture.

Cast iron pipes are used for drains because of their superior strength where there is unstable or made up ground, in shallow trenches, under buildings, for drains suspended under floors of buildings, in heavily waterlogged ground and where sewage is under pressure from pumping.

The traditional method of manufacturing cast iron pipes is to pour molten grey iron into vertically mounted sand moulds. More recently, cast iron pipes are made by spinning inside a mould. Molten grey iron is poured into a revolving water-cooled mould in which the molten metal forms on the inside of the mould by centrifugal force, producing a pipe of even thickness and smooth finish. Casting by this method is rapid and continuous. Ductile iron pipes are also made by the spin-moulding process. Cast iron and ductile iron pipes are made with socket and spigot ends or with plain ends, as shown in Fig. 124. All pipes are hot dip coated with either a bituminous or tar coating inside and out.

Pipes are manufactured with bore of 75, 100, 150 and 225 mm and in lengths of 1.83, 2.74 and 3.66 m, together with a wide range of fittings.

Jointing

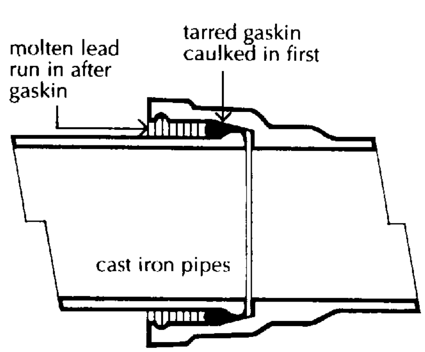


Fig. 125 Rigid joint made with run pig lead.

The traditional joint for socket and spigot cast iron pipes is the run lead or lead wool joint. A tarred jute gaskin is rammed (caulked) into the socket to align the pipes and prevent lead entering the pipeline. Molten lead is then run into the socket against an asbestos clip used to retain the molten lead joint, as shown in Fig. 125. This is a skilled laborious task that can only be carried out in dry weather, and

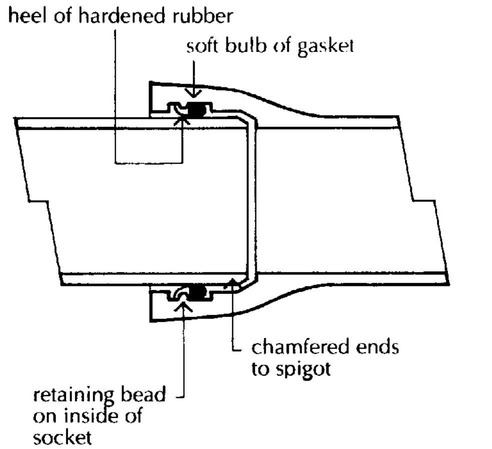


Fig. 126 Flexible push fit joint for cast iron.

requires room for working and clean conditions, all of which rarely combine in a drain trench. Lead wool – finely shredded lead – may be used instead of molten lead. The lead wool is hammered into the socket until it makes a watertight joint. This again is a laborious process.

A flexible push fit joint is commonly used today for cast iron and ductile iron pipes. A rubber gaskin, fitted inside the socket of pipes, comprises a heel of hardened rubber that aligns the pipes, and a bulb of softer rubber that makes the joint, as shown in Fig. 126. The pipe ends must be clean and are lubricated and joined by leverage from a crowbar for small pipes, or a fork tool for larger pipes. The joint is flexible and will accommodate longitudinal and axial movements. The joint is rapidly made in any conditions of weather, the pipeline may be tested right away and the trench can be backfilled to protect the pipeline.

The current recommended methods of laying rigid pipes on granular beds or on concrete, and the methods of protecting pipes from damage by settlement or from loads on the surface are described later in this chapter under the heading 'Drain laying'.

uPVC pipes – materials, sizes

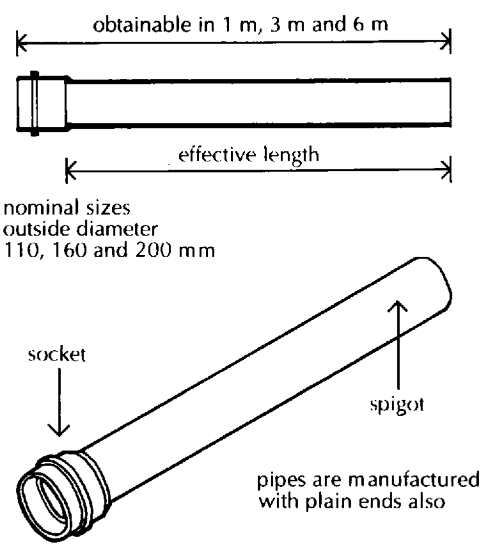


Fig. 127 PVC drain pipes.

uPVC pipes were first used for underground gas and water pressure pipes some 60 years ago. This pipe material was first used in the UK some 30 years ago and is now extensively used because of its ease of handling, cutting and jointing and the low cost. Polyvinyl chloride (PVC) is made by the electrolysis of coal and chalk to form carbide. Water is added to form acetylene. Hydrochloric acid is then added to form the monomer of vinyl chloride. The monomer is polymerised to a fine white powder of low density. To the PVC are added small quantities of lubricants, stabilisers and pigments. Heated uPVC material is extruded through a former and then 'frozen' by cooling to form a continuous pipe length.

The pipe is light in weight and flexible as it can to some extent deform under load without fracture. Deformation should be limited to an increase in horizontal diameter of not more than 5% to avoid blockages in pipelines or breaks to joints. Pipe sizes are described by the outside diameter of the pipe as 110, 160 and 200 mm, and lengths are 1.0, 3.0 and 6.0 m (Fig. 127).

Because of the comparatively long lengths in which this pipe material is made, with consequently few joints necessary, the material lends itself to assembly at ground level from where it can be lowered into narrow trenches. This is a distinct advantage on most building sites.

Jointing

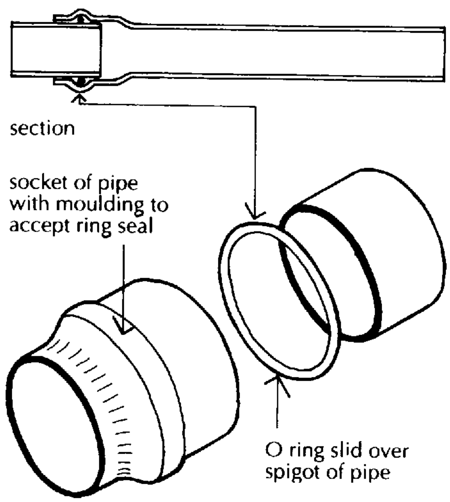


Fig. 128 PVC socket and spigot push fit joint.

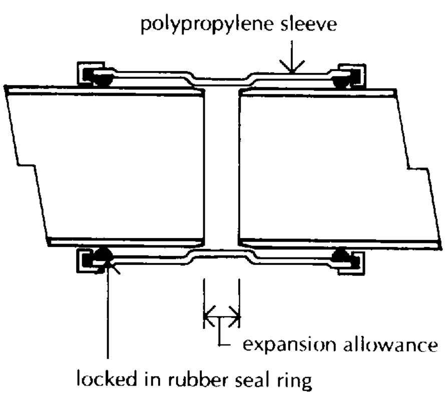


Fig. 129 PVC sleeve joint.

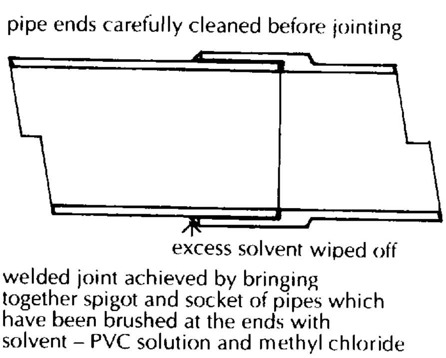


Fig. 130 PVC solvent welded joint.

Two jointing systems are used, as described here.

Socket and spigot push fit joints with rubber rings depend on a shaped socket end of pipe, as shown in Fig. 128, or a shaped coupling designed to fit around rubber sealing rings that fit between the socket or coupling and spigot end to make a watertight seal. Because the rubber ring seal has to be a tight fit between the pipes, it requires careful manipulation to fit the spigot end into the socket end of the pipe or coupling while making certain the rubber seal takes up the correct position in the joint.

Because of the considerable thermal expansion and contraction of this material it is necessary to provide for movement along the pipe lengths through the allowance between the spigot end of pipes and the shoulder on the socket end of the pipe or coupling, as illustrated in Fig. 128.

Several proprietary systems of push fit joints are available.

Sleeve joints of polypropylene with rubber sealing rings to plain-ended pipes depend on a separate plastic coupling sleeve that fits over the spigot ends of plain pipe lengths. Rubber seal rings in the ends of the sleeve compress on the spigot ends of the pipes being joined, as illustrated in Fig. 129. To provide a tight fit between the coupling sleeve and the pipe ends it is necessary to apply some force to push the pipe ends into the sleeve, for which cramps or jacks are available. The ends of the pipes being joined fit to shoulders in the sleeve to provide the expansion allowance illustrated in Fig. 129.

This sleeve jointing is generally favoured over the socket and spigot joint.

Solvent welded joints (Fig. 130) are available for short lengths of drain pipe. This type of joint is not used for long lengths of drain, as the rigid joint makes no allowance for expansion. The joint is made by bringing together the spigot and socket ends of the pipe after they have been brushed with a PVC solution and methyl chloride. The solvent dissolves the PVC, which fuses together after some time. A disadvantage of this joint is that it takes some time to fully harden.

uPVC drain pipes are commonly used with the proprietary drain systems such as the 'rodding eye' or the 'access bowl' drainage systems shown in Figs. 146 and 147. These systems comprise a package of plastic connections, clearing eyes and access bowls for inspection, to combine economy and speed of assembly and laying.

Because of the comparatively extensive range of fittings manufactured in clay, it is not uncommon for clay gullies, for example, to be used in conjunction with uPVC pipes.

Pitch-fibre pipes – materials, manufacture, sizes

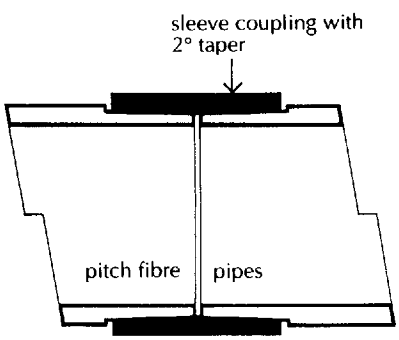


Fig. 131 2° taper coupling joint – long section through joint.

Pitch-fibre pipes have been successfully used on the Continent and America for many years. They were first manufactured and used in the UK from the middle of the twentieth century and were used for drains underground for both soil and surface water. The low cost, long length of pipe and ease of jointing, together with the flexibility of the material, recommended it as a drain pipe material.

Pitch fibre pipes are much less used for drainage than they were some years ago, principally because of the difficulty of making junctions and bends with the material and because of the very limited range of fittings. uPVC pipes have largely taken over as the principal flexible drain pipe material. Pitch fibre pipes are still used for long straight runs of surface water and land drainage and as conduits for small cable and pipe material.

The pipes are manufactured from a blend of wood cellulose products such as waste paper and other fibres. The fibres are mixed with water and woven into a felt of fibre-pipe size. The moulded fibre-felt pipe is dried and then immersed in hot pitch and later in water to give the pitch-fibre pipe a gloss finish. Pitch-fibre pipes consist of about 30% fibre and about 70% pitch. The pipes have a nominal bore of 50, 75, 100, 125, 150, 200 and 225 mm and are supplied in lengths of 1.7, 2.5 and 3 m.

Jointing

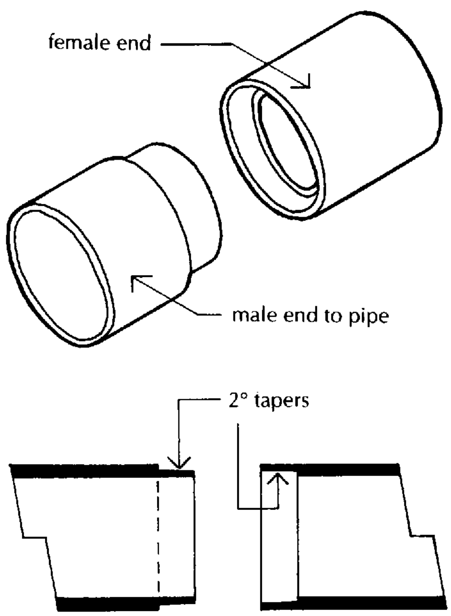


Fig. 132 Section through spigot and socket joint in pitch fibre pipes.

The joints in use are as follows.

The taper coupling joint was the original method of jointing when pipes were first produced. The ends of the pipe are machined to a 2° shallow taper and a pitch fibre coupling with 2° tapers acts as a joint. The joint is made by driving pipe ends into the coupling to form a watertight joint (Fig. 131).

Where it is necessary to make a joint to plain ends of pipe, as for example where a non standard length of pipe is used, the cut plain ends of pipe are jointed by a polyproplene coupling sleeve. Rubber D section snap rings are fitted around the plain ends of pipes to be joined. The pipe ends are pushed into the sleeve and the rubber rings roll along the pipe ends until they snap close with the flat of the D section rings bearing on the pipe. This joint requires some skill and care in the making if it is to be successful.

A spigot and socket joint is made between the tapered machined spigot end of one pipe and the tapered machined socket end of the next, by pushing the ends together. The components of this joint are shown in Fig. 132. The small end overlap of this joint may not provide an entirely watertight joint, but that is of little consequence as this joint is used to align perforated pipes used for land drainage, and plain pipes used as conduits for cables.

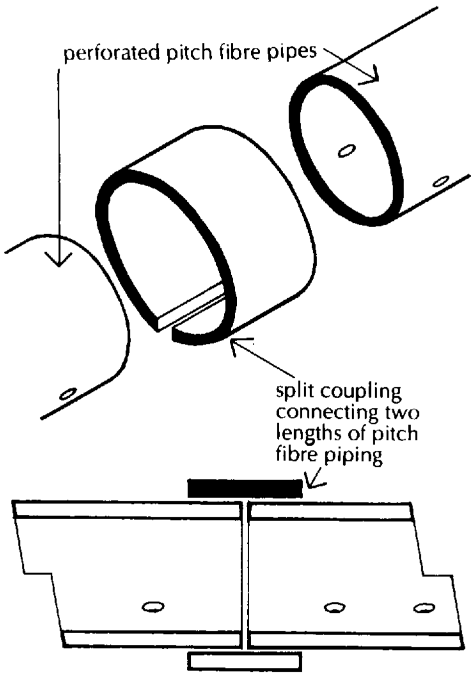


Fig. 133 Split coupling joint for pitch fibre pipes – long section through joint.

The split coupling joint (Fig. 133) is used for pipes perforated for land drainage and for pipes used as conduits. The advantage of this joint, which is used solely to align pipe lengths, is that it can be used to join non standard lengths.

Table 7 Recommended minimum gradients for foul drains.

Peak flow [litres/sec]	**Pipe size** [mm]	**Minimum gradient** [1:...]	**Maximum capacity** [litres/sec]
<1	75	1:40	4.1
	100	1:40	9.2
>1	75	1:80	2.8
	100	1:80*	6.0
	150	1:150†	15.0

* Minimum of 1 WC.
† Minimum of 5 WCs.

DRAIN LAYING

Drains laid underground should be of sufficient diameter to carry the anticipated flow, and should be laid to a regular fall or gradient to carry the foul water and its content to the outfall.

Pipe gradient or fall

Up to about 50 years ago traditional wisdom was to use a 4 in drain for up to four houses and a 6 in drain for more than four houses, the 4 in drain being laid at a uniform gradient of 1 : 40 and the 6 in drain at a gradient of 1 : 60. The gradient of the drain was related directly to the size of the pipe and bore little relation to the anticipated flow in the drain. The result was that drain pipes were often oversized and the gradient steeper than need be, resulting in excessive excavation.

Study of the flow load of drains in use has shown that the size of the drain pipe and its gradient should be related to the anticipated flow rate in litres per second, so that the discharge entering a drain will determine the necessary size and gradient of the drain. Where the sanitary appliances from a house or a few houses or flats discharge to a drain, the flow rate figure is so small as to require the smallest drain and it is not worth making a calculation of flow rate.

Drains are designed to collect and discharge foul and rainwater by the flow of water under gravity. Drains are, therefore, laid to a regular fall (slope) towards the sewer or outflow. The necessary least gradient or fall of a drain depends on the anticipated flow of water through it and the necessary size of drain to carry that flow. Table 7 gives recommended minimum gradients for foul drains.

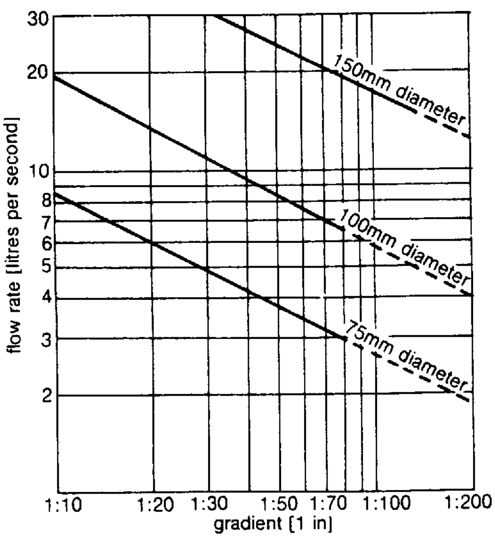


Table 8 Discharge capacities of foul drains running 0.75 proportional depth.

Approved Document H1 of the Building Regulations recommends that a drain carrying only waste water should have a diameter of at least 75 mm, and a drain carrying soil water at least 100 mm. The term waste water is generally used to include the discharge from baths, basins and sinks, and soil water includes the discharge from WCs.

Table 8, from Approved Document H1 of the Building Regulations, shows the relationship of flow rate to gradient for three pipe sizes with drains running three quarters of proportional depth. The rate of flow in drains with gradients as flat as 1:200 is given. Drains are not commonly run with gradients below 1:80 because the degree of accuracy necessary in setting out and laying drains required for shallow falls is beyond the skills of most building contractors.

Drains should be laid at a depth sufficient to provide cover for their protection and the excavation should be as narrow as practical for bedding and laying the drain lines. The greater the width of the trenches at the crown of the pipe, the greater the surcharge loads on the pipe. It is advantageous, therefore, to bed the drain in a narrow trench which may be increased in width above the level of the crown of the drain for ease of working. With modern excavating machinery, flexible joint pipelines may be assembled above ground and then lowered into and bedded in comparatively narrow trenches, so saving labour and cost in excavation and providing the best conditions for the least loads on the pipeline.

The depth of the cover to drain pipes depends on the depth at which connections are made to the drain, the gradient at which the pipes are laid and ground levels. Depth of cover is taken as the level of finished ground or paving above the top of a drain pipe. A minimum depth of cover is necessary to provide protection to the pipe against damage, and a maximum depth to avoid damage to the drain by the weight of the backfilling of the drain trenches. Minimum and maximum cover for rigid pipes are set out in Table 9.

Flexible pipes should have a minimum of 0.6 m of cover under fields and gardens and 0.9 m under roads.

Table 9 Limits of cover for standard strength rigid pipes in any width of trench.

		Fields and gardens		Light traffic roads		Heavy traffic roads	
Pipe bore	**Bedding class**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
	D or N	0.4	4.2	0.7	4.1	0.7	3.7
100	F	0.3	5.8	0.5	5.8	0.5	5.5
	B	0.3	7.4	0.4	7.4	0.4	7.2
	D or N	0.6	2.7	1.1	2.5	–	–
150	F	0.6	3.9	0.7	3.8	0.7	3.3
	B	0.6	5.0	0.6	5.0	0.6	4.6

Bedding flexible pipes

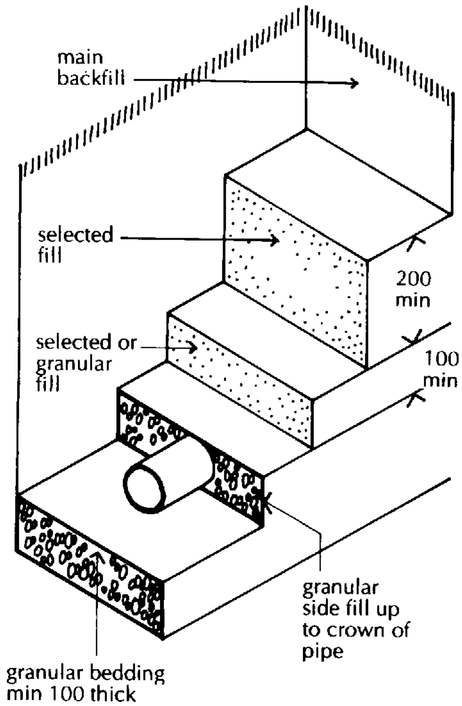


Fig. 134 Bedding for flexible pipes.

Flexible pipes should be laid in a narrow trench, on granular material such as clean, natural aggregate. This granular material is spread in the base of a trench that has been excavated and roughly levelled to the gradient or fall of the drains. The granular material is spread and finished to a thickness of 100 mm, to the drain gradient. Lengths of drain pipe are then lowered into the trench and set in position by scooping out the granular bed from under the collars of pipe ends, to set the pipe line in place in the centre of the trench. Further granular material is then spread and lightly packed each side of the pipe line, to support it against deformation under load, as illustrated in Fig. 134.

A layer of granular material or selected fill, taken from the excavated material, is then spread over the pipe line to a depth of 100 mm. A further layer of selected fill, free from stones, lumps of clay or other material larger than 40 mm, is spread in the trench to a thickness of 200 mm. The trench is then backfilled with excavated material up to ground level, and consolidated.

This drainlaying operation requires care and some skill to bed the drainline correctly, and further care in backfilling to avoid disturbing the drain. Where the bed of the trench is narrow, it may be necessary to cut the sides of the trench above the level of the bed of the drain, in the form of a V, sloping out from the centre for ease of access.

Bedding rigid pipes

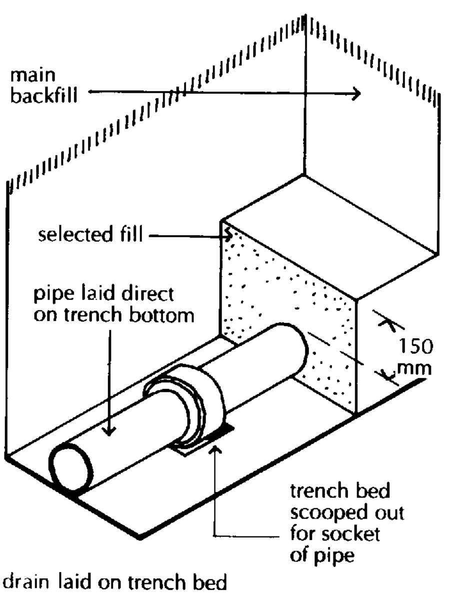


Fig. 135 Bedding for rigid pipes – Class D.

Where a drain trench is excavated in some cohesive soil such as clay for laying rigid pipelines of clayware, for example, it is possible to lay the pipes directly on the trench bottom which has been finished to the required pipe gradient by hand trimming by shovel. The pipe lengths are lowered into the trench and soil from the trench bottom is scooped out under each socket end of pipe so that the barrel of the pipes bears on the trench bottom and the collars keep the drainline in place. Fig. 135 illustrates this type of bedding.

For this operation to be successful the trench needs to be sufficiently wide for a man to stand in the trench astraddle the pipeline to scoop soil out from below the pipe collars. Once the pipeline is in place, a cover of selected fill from the excavation, free from large stones or lumps of clay, is spread in the trench to a depth of 150 mm above the crown of the pipes, and the trench is backfilled to surface level.

This bedding system is suited to the use of socket and spigot and clay pipes with one of the flexible joints that can be used in all weather conditions.

When the bed of drain trenches cannot be trimmed to the pipe gradient, a bed of granular material is spread in the bed of the trench and levelled to the pipe gradient to a thickness of 100 mm, as illustrated in Fig. 136. The rigid pipes are lowered into the trench and a layer of selected fill is carefully spread around the pipes and then filled up to a level 150 mm above the crown of the pipes. The trench is then back filled to surface level. This type of bedding is suited to plain clay pipes joined with flexible sleeves.

As an alternative, the granular bedding is spread 100 mm thick in the bed of the trench, the pipes are lowered into the trench and granular beddings is scooped out under the collar ends of pipes. The granular material is then spread around the pipes, up to half the outside diameter of pipe as shown in Fig. 137. Selected fill is then spread in the trench to a depth of 150 mm above the crown of pipes, and the trench is backfilled to the surface.

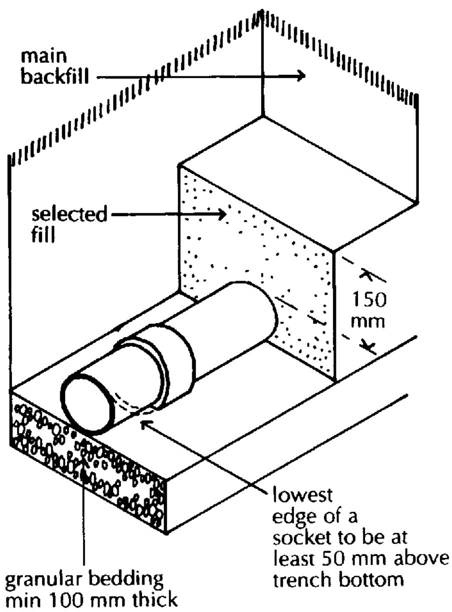


Fig. 136 Bedding for rigid pipes: granular bedding – Class N.

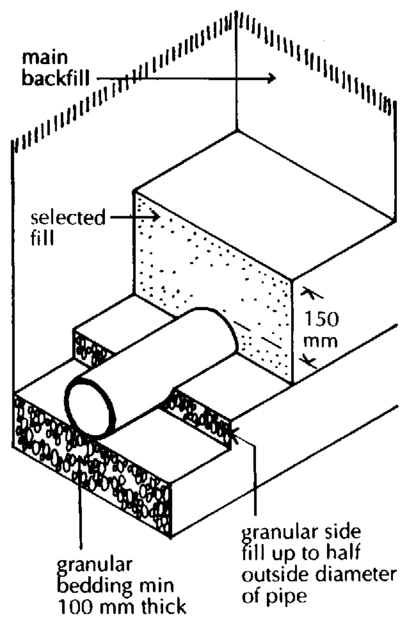


Fig. 137 Bedding for rigid pipes: Granular bedding – Class B.

This system of bedding has the advantage that the granular bedding each side of the pipes maintains them in position as the trench is filled.

It may well be that the most economical depth of flexible drain pipes below surface will provide less depth of cover than recommended. To avoid unnecessary excavation it is acceptable to lay flexible pipes with less cover when they are laid under fields or gardens. The pipes are laid on a bed of granular material 100 mm thick in the bed of the trench and then surrounded and covered with granular material up to a level of 75 mm above the crown of pipes, as illustrated in Fig. 138. Concrete paving slabs are then laid over the granular material, bearing on offsets in the trench walls. The trench is then backfilled up to surface level with selected fill from the excavation. The protection of concrete slabs and the granular material bed and surround of pipes will provide adequate protection against deformation of the pipes.

Rigid drain pipes that are laid at a depth that provides less than the recommended cover below surface, should be provided with protection from damage by an encasement of concrete, with flexible movement joints at each socket or sleeve joint of pipeline.

The drain trench is filled with concrete, to a depth of 100 mm, in sections along the length of the trench equal to pipe length. Between each section a 13 mm thick compressible board, holed for pipes, is set to the width of the trench. Before the concrete is hard it is scooped out for socket ends of pipe against one side of the board. A pipe is set in position up to the board and the next section of concrete is laid up to another flexible board in the trench. The concrete is scooped out for the next pipe, which is pushed into the flexible joint of the first pipe, and so on along the length of the trench, as illustrated in Fig. 139.

Once the drain line is laid it is tested and then concrete encasement is spread around the pipes, between the flexible boards, to provide a cover of 100 mm all round the drain. The trench is then backfilled to surface.

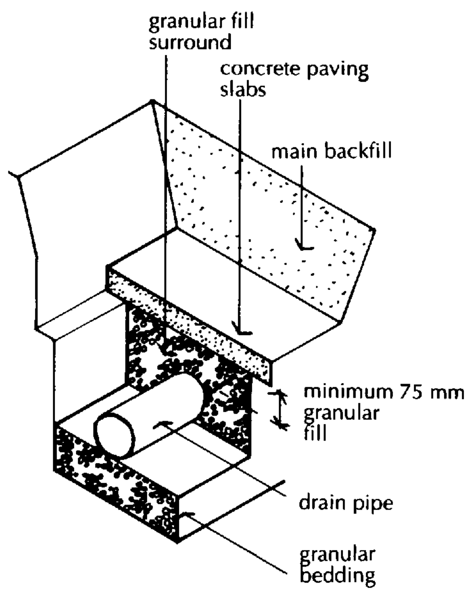


Fig. 138 Protection for flexible pipes under fields and gardens.

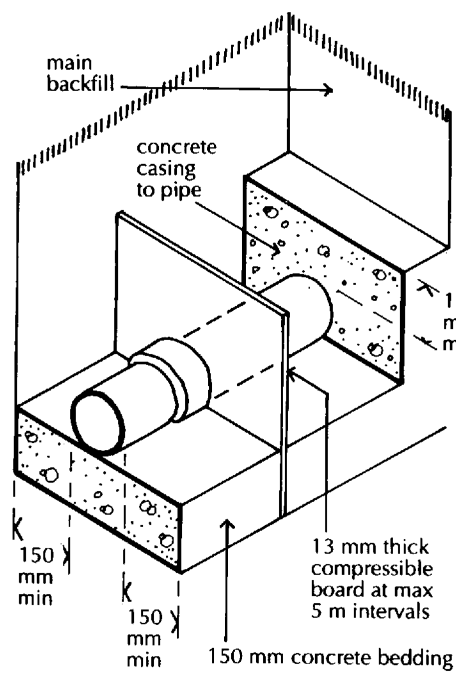


Fig. 139 Concrete casing to rigid pipes.

This complicated and expensive method of laying and protecting rigid drains is only used where no other method of laying would be possible.

Drains under buildings

When a drain is laid under a building and the crown of the pipes is at all points 300 mm or more below the underside of the ground floor slab, the drains should have flexible joints and be surrounded by granular material at least 100 mm thick all round the pipes. Where the crown of the drain is within 300 mm of the underside of the ground floor slab, it should be encased in concrete as an integral part of the slab.

Where a drain line is laid under a building there is a possibility that slight settlement of the wall might fracture the drain where it is laid to run through the wall. Drains under buildings are not uncommon in towns and cities where drains from the rear of buildings run under the buildings to sewers in the road.

There are two methods of avoiding the possibility of damage to drains running through walls.

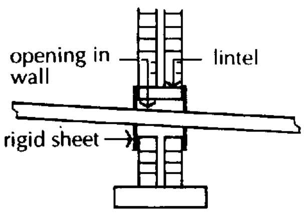


Fig. 140 Drain pipe through opening in wall.

The first method is by providing a minimum 50 mm clearance between the wall and the drain. The wall is built with a small lintel over the opening in the wall through which the pipe is to run, to provide at least 50 mm of clearance all round the drain. Where the drain is laid to run through the wall, two rigid sheets, holed for the pipe, are fitted to the pipe and secured in place by screws and plugs to the wall, as illustrated in Fig. 140, to exclude vermin or fill.

The disadvantage of this system is that it is difficult to provide a close fit of a rigid board to a pipe and to brickwork and to make a watertight joint between the external board and the wall.

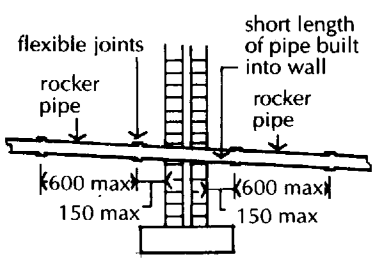


Fig. 141 Drain pipe built into wall.

The other method of providing protection to a drain run through a wall, is to provide for any slight settlement of the wall by means of rocker pipes. A short length of pipe is built into the wall, projecting no more than 150 mm each side of the wall. A length of pipe at most 600 mm long is connected to each end of the built-in pipe and connected to it with flexible joints. These rocker pipes are likewise connected to the drain line with flexible joints so that any slight movement of the pipe built into the wall is accommodated by the flexible joints of the rocker pipes.

This system, illustrated in Fig. 141, is best executed with plain clay pipes with flexible sleeve joints.

Drains close to buildings

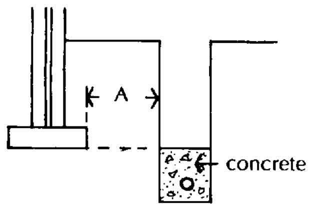


Fig. 142 Drains less than 1 m from foundations.

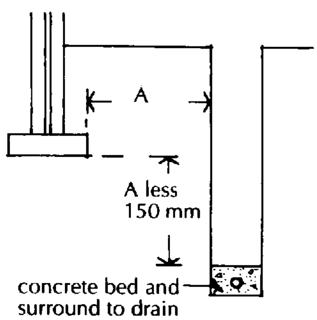


Fig. 143 Drains 1 m or more from foundations.

On narrow building sites, common to towns and cities, where there is only a narrow strip of land each side of a building, it may well be expedient to run a drain parallel to a flank wall of the building. To provide the necessary gradient or fall, the drain may be at or below the level of the wall foundation. To avoid the possibility of the loads on the wall foundation imposing undue pressure on the drain, it is often necessary to provide additional protection to the drain.

Where the drain trench bottom is less than 1 m from the foundation, indicated by the letter A in Fig. 142, the drain should be laid on a bed of concrete and then covered with concrete up to the level of the underside of the wall foundation.

A drain laid 1 m or more from the wall foundation, indicated by the letter 'A' in Fig. 143, and appreciably below the foundation of the adjacent wall, should be bedded on concrete and then covered with concrete up to a level equal to the distance from the wall of A less 150 mm.

This additional protection, which is expensive, may not be wholly satisfactory as it provides rigid encasement that makes no allowance for possible differential settlement along the length of the drain run, that might fracture the encasement and pipe run. It is plainly advisable to avoid drain runs close to walls where possible.

ACCESS POINTS TO DRAINS

There should be adequate access points to drains laid underground to provide means of clearing blockages by rodding through drains. Rodding is the operation of pushing flexible, sectional rods that can be screwed together, down drain lines to clear blockages. Drain rods may be of bamboo or other sufficiently flexible material capable of being bent to enter the drain line from an inspection chamber or manhole.

The four types of access point in use are:

(1) Rodding eyes, which are capped extensions of drain pipes
(2) Access fittings, which are small chambers in or as an extension of drain pipes with no open channel
(3) Inspection chambers, which are large chambers with an open channel but no working space at drain level
(4) Manholes, which are large chambers with an open channel and working space at drain level

The minimum dimensions for access fittings and chambers are given in Table 10.

Access points should be provided on long drain runs and at or near the head of each drain run, at a bend or change of gradient, a change of pipe size and at junctions where each drain run to the junction cannot be cleared from an access point.

The limits of the depth and minimum dimensions for access points are set out in Table 10 and the minimum spacing of access points in Table 11.

Table 10 Minimum dimensions for access fittings and chambers.

Type	Depth to invert [m]	Internal sizes length × width [mm × mm]	Internal sizes Circular [mm]	Cover sizes Length × width [mm × mm]	Cover sizes Circular [mm]
Rodding eye	—	As drain but min 100		—	
Access fitting		150 × 100	150	150 × 100	150
small	0.6 or less				
large		225 × 100	—	225 × 100	—
Inspection chamber	0.6 or less	—	190*	—	190*
	1.0 or less	450 × 450	450	450 × 450	450†
Manhole	1.5 or less	1200 × 750	1050	600 × 600	600
	over 1.5	1200 × 750	1200	600 × 600	600
	over 2.7	1200 × 840	1200	600 × 600	600
Shaft	over 2.7	900 × 840	900	600 × 600	600

* Drains up to 150 mm.

† For clayware or plastics may be reduced to 430 mm in order to provide support for cover and frame.

Table 11 Maximum spacing of access points in metres.

From	To	Access fitting Small	Access fitting Large	Junction	Inspection chamber	Manhole
Start of external drain*		12	12	—	22	45
Rodding eye		22	22	22	45	45
Access fitting						
small 150 diam		—	—	12	22	22
150 × 100		—	—	22	45	45
Inspection chamber		22	45	22	45	45
Manhole		22	45	45	45	90

* Connection from ground floor appliances or stack.

Inspection chamber – manhole

The traditional arrangement for inspecting, testing and clearing blockages in underground drains is the inspection chamber or manhole. This is a brick-lined pit at drain junctions and changes of direction or gradient in a drainline. The inspection chamber is located at those points where drain blockages are most likely to occur and from which blockages in drainlines can be cleared by rodding.

The inspection chamber provides access to inspect flow in the drain and, if necessary, means of testing drainlines. The traditional clay drain pipe was liable to blockages due to misalignment of the many joints or fracture of the pipes and their rigid cement joints, and there was therefore advantage in constructing inspection chambers at fairly frequent intervals when labour costs were low.

Today, inspection chambers are comparatively costly items and with the increased length of pipes available and flexible joints that closely align pipes and accommodate slight movement, it is possible to use fewer inspection chambers. The suppliers of uPVC drain pipes utilise systems of rodding points or access bowls instead of inspection chambers, for the purpose of clearing blockages. The rodding points cannot be used to inspect flow or for testing and it is usual to include one or more inspection chambers in this drain system.

The traditional inspection chamber or manhole – which is still much in use today where convenience outweighs cost and clay drain pipes are used – is a brick-lined pit at the junction of drain branches and at changes of direction and gradient, to facilitate inspection, testing and clearing obstructions. Their main purpose is access to clear blockages in any of the drain runs connecting inside the

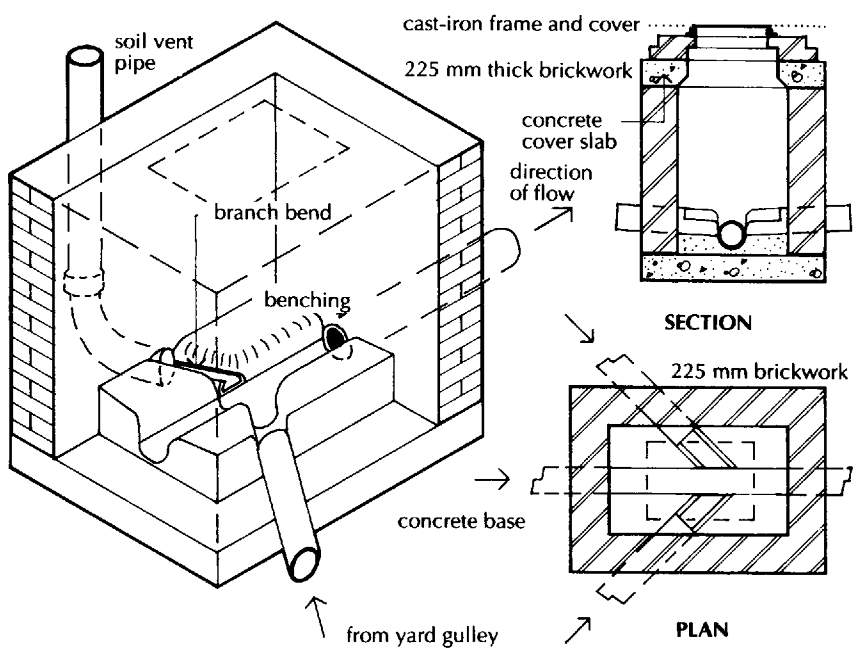


Fig. 144 Cut-away sectional view of inspection chamber.

chamber. An inspection chamber is a small, shallow chamber sufficient to clear blockages from above ground, and a manhole a deeper chamber large enough for a man to climb down to clear blockages.

An inspection chamber or manhole is formed on a 150 mm concrete bed, on which bricks walls are raised. In the bed of the chamber a half-round channel or invert takes the discharge from the branch drains, as illustrated in Fig. 144. The walls of the chamber may be of dense engineering bricks. If less dense bricks are used the chamber is lined with cement rendering to facilitate cleaning, and sometimes it is rendered outside to prevent the infiltration of groundwater. The chamber is completed with a cast iron cover and frame.

The word invert is used to describe the lowest level of the inside of a channel in an inspection chamber, or the lowest point of the inside of a drain pipe, and measurements to the invert of a drain are used to determine the gradient of that drain. In the bed of the chamber the three-quarter section branch drains discharge over the channel in the direction of flow, and fine concrete and cement rendering termed benching is formed around the branches to encourage flow in the direction of the fall of the drain, as shown in Fig. 144.

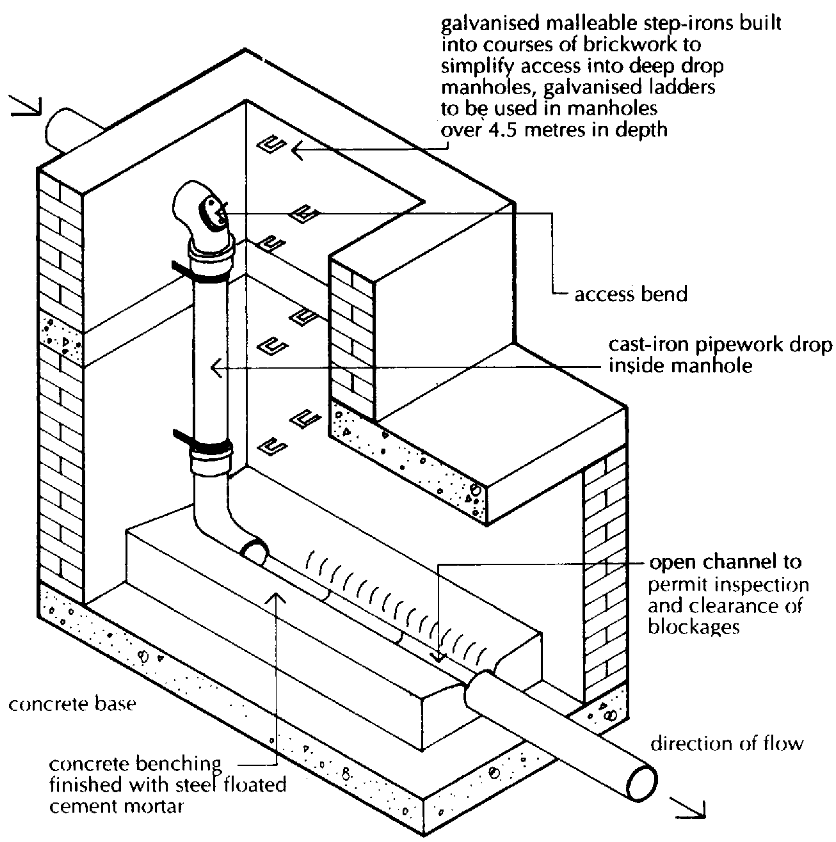


Fig. 145 Back drop manhole.

Backdrop manhole

Where a branch drain is to be connected to a main drain or a sewer at a lower level, it is often economical to construct a backdrop manhole to avoid deep excavation of a drainline. The backdrop chamber is constructed of brick on a concrete bed and the higher branch drain is connected to a vertical or drop drain that discharges to the channel in the backdrop chamber, as illustrated in Fig. 145 where the near side and end walls are omitted for illustration. This is a form of manhole adapted to suit the purpose. The drop drain is run in cast iron drains, supported by brackets screwed to plugs in the wall.

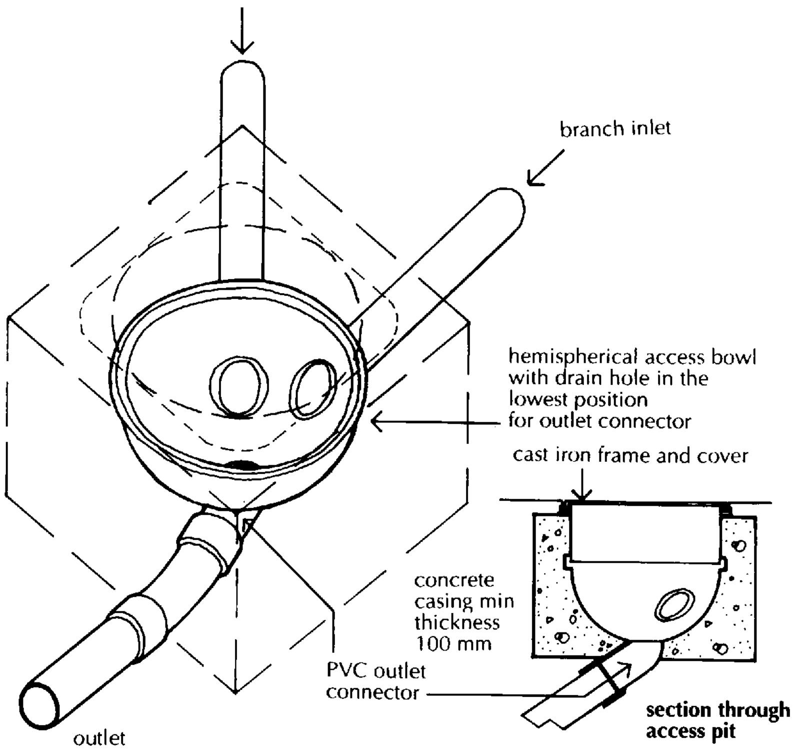


Fig. 146 Mascar access bowl drain system.

Access bowl drain system

As an alternative to the use of inspection chambers for access to drain junctions, where uPVC drains are used for small buildings such as houses, a system of PVC access bowls or chambers may be used.

The hemispherical access bowl (Fig. 146) is supplied with one hole for the outlet drain, and up to five additional holes can be cut on site to suit inlet branches. Purpose-made inlet and outlet PVC connectors are provided for solvent welding to the bowl for outlet and inlet connections to drains. One access bowl is sited close to the building for the discharge from the soil pipe and ground floor foul water and waste water fittings.

The access bowl is extended to ground level with PVC cylindrical extension sections, one of which is illustrated in Fig. 146. The access bowl is set on a concrete bed and after the drain runs have been connected it is surrounded with a minimum of 100 mm of concrete for protection and stability. A cast iron frame and cover is set on top of the access bowl at ground level.

These access bowls may be used at changes of direction in drain lines and at the boundary, before the connection to the sewer, for the purpose of rodding to clear blockages and inspection of flow. Access bowl access points, which are specifically designed for use with uPVC drain systems, can effect some cost saving compared to the traditional inspection chamber.

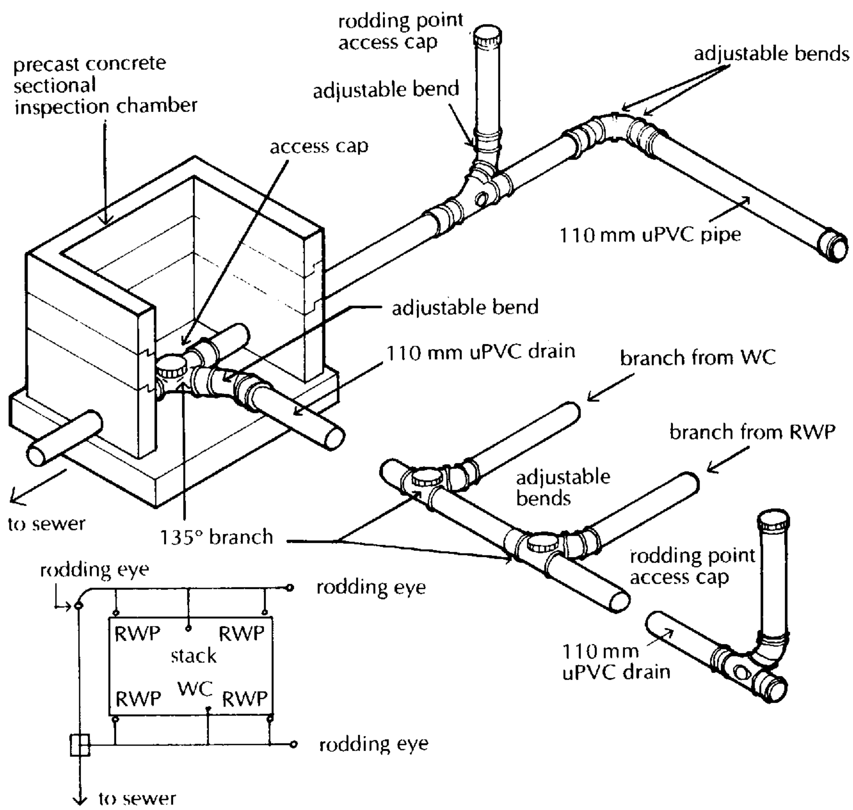


Fig. 147 Rodding point drain system.

Rodding point drain system

This sealed underground drain system combines the advantages of the long lengths of pipe and simplicity of jointing uPVC drain lines, with rodding points and one or more inspection chambers for access for inspection, testing and clearing blockages. Fig. 147 shows a typical layout. The rodding points are used as a continuation of straight drain runs extended to ground level with an access cap, as illustrated in Fig. 147. It is possible to rod through each drain run to clear a blockage and this arrangement dispenses with the need for inspection chambers at all junctions and bends with appreciable saving in cost. The drain runs are laid on granular bedding and backfilled as previously described.

Access fittings with access caps may be provided at all drain junctions, as shown in Fig. 147. These access caps are provided for blockages at junctions where rodding along the drain is not effective in clearing the blockage.

The drain pipes of the rodding points, which extend to finished ground level, should be protected inside a length of clay drain pipe of larger diameter than the rodding drain, set on a bed of concrete under the drain line with concrete casing around the clay pipe liner. As an alternative, precast concrete, sectional circular ring liners, 150 mm internal diameter, may be set on a concrete bed and extended to ground level as protection for the rodding point.

The access cap to the junction inside the inspection chamber at the connection to the sewer, may be used to check flow in the drain and for rodding if need be.

The short branch drain connections to rainwater gullies, ground floor WC and soil pipe can be cleared by ferrets or other flexible clearing equipment. Access caps to junctions are often covered by backfilling and can be exposed by excavation for access in the rare event of a stubborn blockage.

Soil stack pipe to connection drains

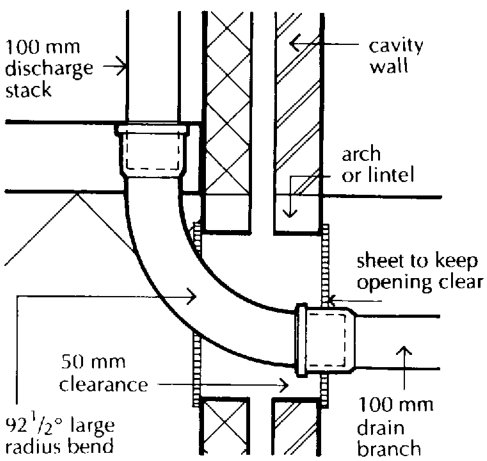


Fig. 148 Soil stack connection to drain.

In the single stack system, a single discharge stack pipe serves to carry both soil water and waste water discharges directly down to the drains, so that the soil pipe or stack may serve as a ventilation stack pipe to the drains. In this system the water trap seals to each of the sanitary appliances serve as a barrier to drain smells that might otherwise enter the building.

At the base of the soil pipe is a large radius or easy sweep bend to facilitate clearing blockages. In Fig. 148 the soil pipe is run inside the building – common practice in tall buildings. Whether the soil pipe is run inside or outside the building there should be a large radius bend at its connection to an inspection chamber.

Where the drain connection to a soil or waste pipe passes through the wall of the building, there should be at least 50 mm of clearance all round the drain to allow for any settlement of the wall that might otherwise fracture the pipe if it were built into the wall. The opening in the wall around the pipe is supported by small lintels or brick arches and covered with rigid sheet both sides, as illustrated in Fig. 148.

Gullies

Where there is a combined sewer that takes both soil and waste water discharges and also rainwater from roofs and paved areas, it is necessary to use a trapped gully at the foot of rainwater downpipes so

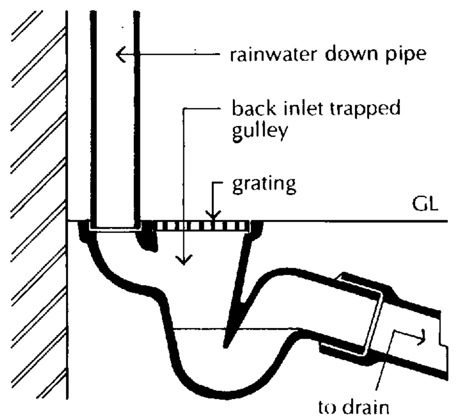


Fig. 149 Trapped gully.

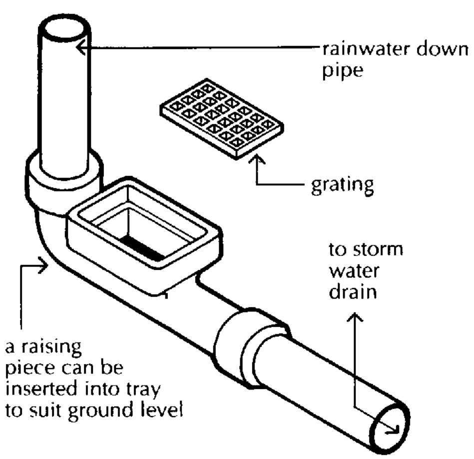


Fig. 150 Rainwater shoe.

that the water seal in the gully serves as a barrier to foul gases rising from the drains. The trapped gully illustrated in Fig. 149 has a back inlet connection for the rainwater pipe and a grating that serves as access to clear blockages and to take water running off paved areas. These gullies are made with either back or side inlet connections for rainwater pipes.

An alternative arrangement is to use a trapped gully without either back or side inlet and to fix the rainwater pipe so that it discharges, through a shoe, over the gully grating. The disadvantage of this is that the rainwater discharge may splash water around the gully and cause damp patches on walls. To drain paved areas to a drain discharging to a combined sewer, a trapped gully is used.

Where there are separate drain and sewer systems for foul water and rain and surface water, the gullies that collect rainwater and surface water can be connected directly to the surface or storm water drain, without trapped gullies, as there are no foul gases or air in the drain or sewer that may cause a smell.

The fitting used to collect rainwater (Fig. 150) is described as a rainwater shoe to differentiate it from gullies that have a water seal. The shoe has a grating that fits loosely into a tray to serve as access to clear blockages and collect water from paved areas.

As there is less likelihood of blockages in surface water drains than in soil water drains, it is not considered necessary to form inspection chambers at all junctions, bends and changes of gradient to the drain as is the case with foul-water drains. Rodding eyes at salient points to facilitate clearing drains are generally considered adequate for the purpose.

Because of the wide range of fittings available it is common to use clayware gullies and rainwater shoes for most drain pipe materials. Gullies and shoes are usually bedded on a small concrete base to provide a solid base for connection to stack pipes and drains.

Private sewers, common drain

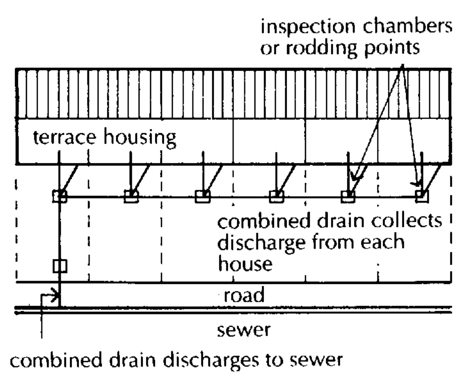


Fig. 151 Common drain.

Considerable economies in drainage costs may be effected by the use of combined drains or private sewers. There is no exact distinction between the words drain and sewer, but the most generally accepted definition is that pipelines under privately owned land, laid and maintained by the owner, are called drains, and pipelines laid and maintained by the local authority under roads are called sewers.

A private sewer, also termed a combined drain, is a system of drains laid for the use of two or more buildings, paid for and maintained by the owners of the buildings and making one connection to the public sewers. The reasons for laying a private sewer or combined drain are economy and convenience.

A common drain or sewer to a terrace of houses such as that illustrated in Fig. 151 requires one drain connection to the public sewer.

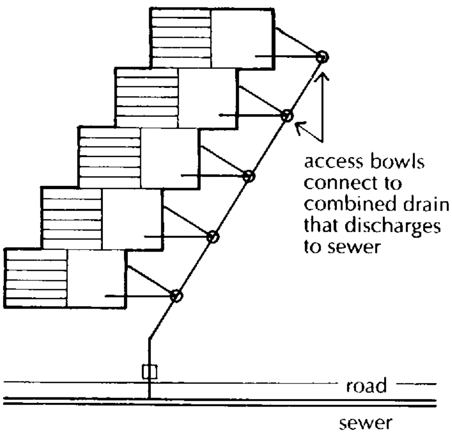


Fig. 152 Combined drains (private sewers).

The local authority makes a charge for a connection to its sewer, which not inconsiderable cost may be shared by several householders. This initial cost saving should be set against the cost and inconvenience of disputes over who should pay for subsequent repairs and maintenance.

Where properties do not directly front on to public roads and sewers, as is common in houses such as those shown in Fig. 152, it is plainly convenient to lay a private sewer by use of a combined drain, making one connection to the public sewer rather than separate connections from each house. Here economy and good sense combine. Having laid a private sewer or combined drain it is necessary to apportion the cost of maintenance work to it. Here lies the source of inevitable dispute over who should pay what.

If one householder were to damage the length of private sewer that ran under his land, should all pay a portion of the cost of repair or just the one owner? How to prove that the one owner caused the fault, and the 'falling out' of neighbours, is a possible consequence of the system.

Connections to sewers

Connections to public sewers are generally made by the local authority and paid for by the building owner or made by the building owner under the supervision of the local authority. In new developments with new sewers a branch connection is constructed in the sewer and where there is an existing sewer the old sewer is broken into and a new connection is made.

Intercepting traps

Until comparatively recent times, it has been practice, in the older urban areas, to build an intercepting or disconnecting trap into the drainline connection to combined foul and rainwater water sewers. An intercepting trap is a water-sealed trap incorporating a rodding eye which is built into an intercepting chamber near the boundary of buildings in the outfall drain to sewers, as illustrated in Fig. 153. The purpose of the trap is to provide a water seal between the sewer and the private drain against sewer gases rising into the private drains, and hopefully also as a bar against rats finding their way from the sewer into the private drain system.

Fresh air inlet (FAI)

Because of this water seal, a ventilation pipe, termed a fresh air inlet (FAI), is connected to the inspection chamber to ventilate the private drain, as illustrated in Fig. 153. An intercepting trap is a prime cause of blockages in foul drains. It is no longer considered necessary to provide a seal between sewer and drains, and modern practice is to

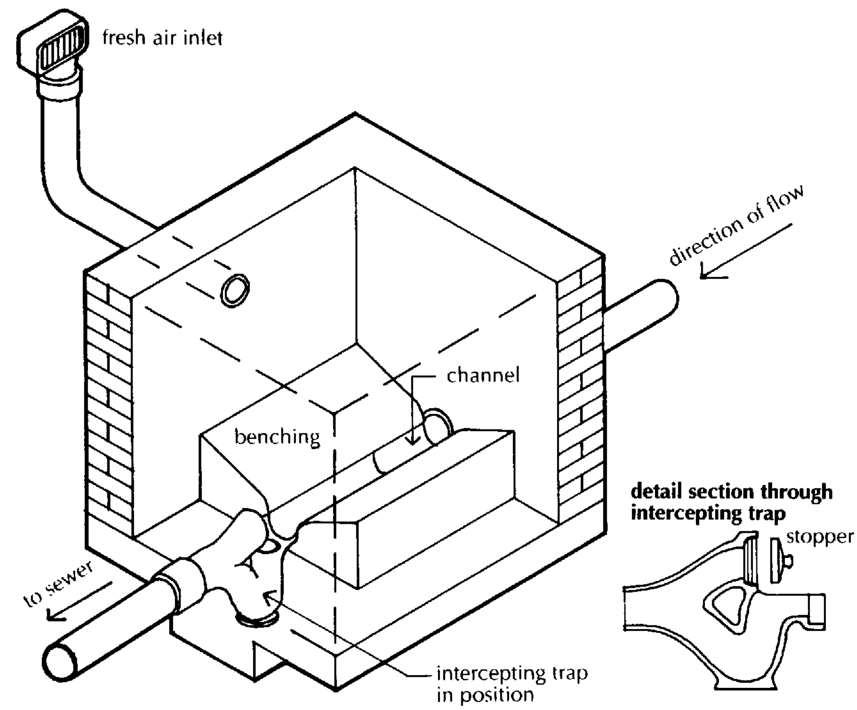


Fig. 153 Intercepting manhole.

dispense with the intercepting trap and discharge the drain directly into the sewer.

DRAIN TESTING

Water test

All newly laid drainlines should be tested for watertightness after jointing and laying and again after backfilling and consolidation of trenches. The drain is tested by water pressure applied by stopping the low end of the drain and filling it with water to a minimum head of water, as illustrated in Fig. 154. The head of water should be 1.5 m above the crown of the high end of the pipeline under test. Where long drainlines are to be tested, and the head of water would exceed 6 m due to the length and gradient of the drain, it is necessary to test in two or more sections along the line.

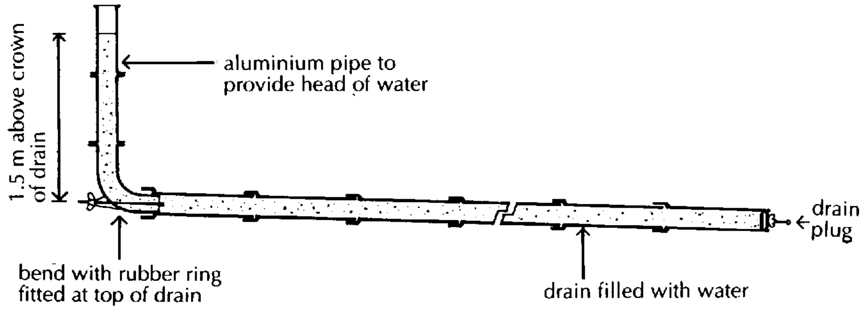


Fig. 154 Water test.

The loss of water over a period of 30 min should be measured by adding water from a measuring vessel at regular intervals of ten minutes, and noting the quantity required to maintain the original water level. The average quantity added should not exceed 1 litre per hour per linear metre, per metre of nominal internal diameter. The water test is a test of watertightness under pressure, a condition that a freely flowing drain will never suffer, and is thus a test of watertightness far more rigorous than the drainline is designed for.

Air test

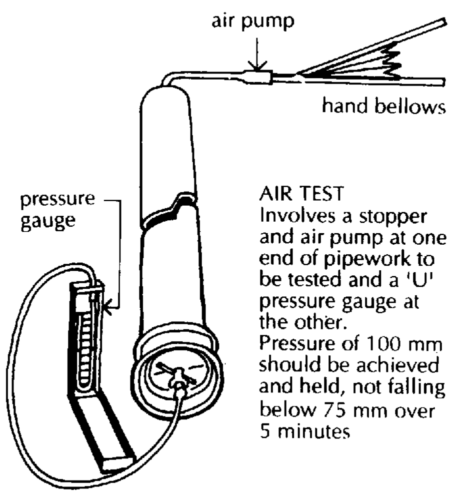


Fig. 155 Air test.

The air test is generally accepted as a less rigorous test than the water test. The drainline to be tested is stoppered at both ends and air pressure is provided by a pump, the pressure being measured by a graduated U tube or manometer, as shown in Fig. 155.

Expanding drain stoppers suited to take the tube from the pump at one end of the drainline and the tube to the pressure gauge or manometer at the other, are fitted to the ends of the drainline to be tested.

Air pressure is applied to the drain through the hand or foot operated pump until a pressure of 100 mm is recorded on the graduated U-section pressure gauge and the valve to the gauge is shut. An initial period of 5 min is allowed for temperature stabilisation and the pressure is then adjusted to 100 mm. The pressure recorded by the U gauge or manometer should then not fall below 75 mm over a further 5 min for a satisfactory test.

Where trapped gullies and ground floor appliances are connected to the drainline being tested, a pressure of 50 mm is adopted as the measure.

Smoke test

The smoke test has been used for old drains where the water or the air test is too rigorous for them. The drain to be tested is stoppered at suitable intervals and smoke is introduced under pressure from a smoke capsule or smoke machine. The purpose of the tests is to discover leaks by the escape of smoke, either when the line has been uncovered or is underground. An escape of smoke will find its way to the surface through a considerable depth of soil and all but the most dense concrete cover. Fig. 156 illustrates a smoke test machine.

The reason for using a smoke test, particularly on old drains, is to

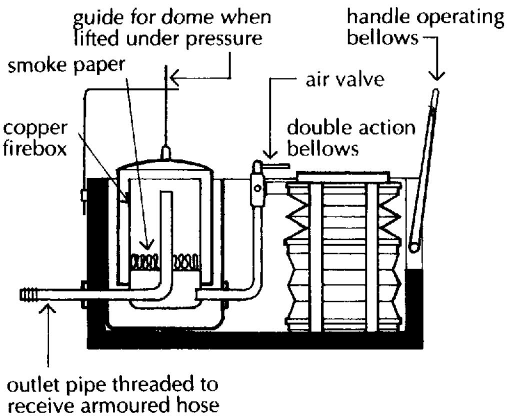


Fig. 156 Eclipse smoke testing machine.

give some indication of the whereabouts of likely leaks before any excavation to expose drains has been undertaken. This may be of use on long runs of drain and where drains run under buildings. The appearance and smell of smoke may give a useful indication as to where excavation to expose drains should take place.

Water, air and smoke tests act on the whole of the internal surface of drains. These tests may indicate leaks due to cracks in the crown of the drain. As drains never run full bore a crack in the crown of a drain may not cause any significant leakage and may not warrant repair.

CCT surveys

Modern technology provides a means of making visual inspection of the inside of drain runs by the use of a small camera that is inserted into and run down the line of a drain to provide a moving picture record on a monitor of the view of the inside of the drain. This is usually recorded on a cassette or disc. This somewhat expensive survey may well be a worthwhile alternative to excavation to expose drains.

SEWAGE COLLECTION AND TREATMENT

Cesspools

With the introduction of sanitary water closets (WCs), a cesspool was the traditional means of collecting the discharge from WCs. At the time and up to comparatively recently, it was considered that only the liquid outflow from WCs was insanitary. Water from washing and cooking was not deemed to be insanitary and was treated as dirty water.

In consequence waste water from baths, basins and sinks was drained to soakaways along with rainwater from roofs and paved areas, and later in the then developing urban areas, to combined sewers that collected all liquid discharges alike. At the time society was much less regulated than it is now and less fearful of infections from the natural cycle of life and decay.

A cesspool is an underground chamber or container used to collect and store all foul and waste water from buildings. They are emptied by pumping the contents to a tanker.

Today cesspools are only used in outlying areas where there is no ready access to a sewer and where ground is waterlogged or the slope of the site does not allow the use of a more compact and convenient septic tank.

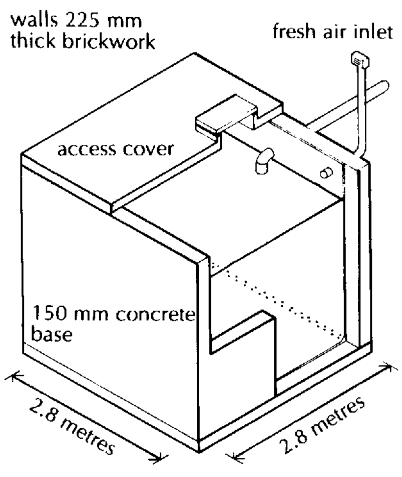


Fig. 157 Cesspool.

The size of the cesspool depends on an assumption of the amount of water used each day per person at 137 litres per head, and the number of days' storage capacity required before the cesspool can be drained. A minimum capacity of 18 000 litres capacity is recommended for an average household where the cesspool is drained every 45 days.

Many local authorities provide a service of emptying cesspools on a regular basis, weekly or monthly, free of charge, and more frequent collections on payment by the building owner. The authorities empty the cesspools by pumping to a tanker which then discharges the foul liquid to a sewage treatment works.

To comply with current regulations a cesspool should have no outlet and should effectively be watertight to loss of water from within and entry of ground water from without.

The traditional cesspool was a brick lined pit, such as that illustrated in Fig. 157, with engineering brick walls 220 mm thick or well burnt dense bricks lined inside with cement and sand rendering on a concrete base. A reinforced concrete cover over the cesspool would be formed at, or just above, ground level with some form of access cover for emptying and a fresh air inlet.

A range of prefabricated cesspools is available today. These are made from glass reinforced fibre plastic (GRP) in the form of sealed containers with capacities of 7500 to 54 000 litres. Larger capacities of up to 240 000 litres can be made.

The ribbed cylindrical cesspool, with access point, inlet and fresh air inlet (FAI), is delivered ready to lower into an excavated pit with the cylinder lying on its long axis. The cesspool is laid on a bed of concrete and surrounded with a lean mix of concrete, with the cover to the access point at or just above ground level.

Septic tank

A septic tank differs from a cesspool in that a cesspool is designed to contain and retain all the outflow of soil and water, whereas a septic tank is designed to take the outflow of soil and waste water, retain some solid organic matter for partial purification, and discharge the liquid sewage through a system of land drains to the surrounding ground to complete the process of purification.

A septic tank is an underground container whose function is to collect all the soil and waste water discharge, and inside the tank a series of baffles slow the flow of liquid waste from the inlet to the outlet and cause settlement of larger sewage particles to the base of the tank. The liquid content that is now partially purified then runs to a system of perforated or porous land drains from which it soaks into the ground for further purification. The extent of these so-called leaching drains depends on the nature of the soil, its porosity, the water table and the capacity of the septic tank.

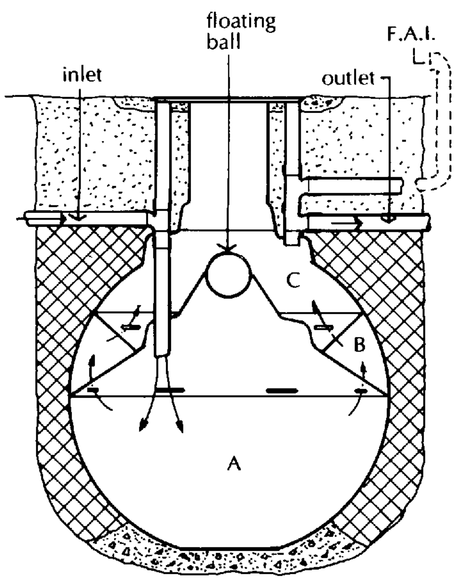


Fig. 158 Prefabricated septic tank.

The usual capacity of septic tanks is from 2800 to 6000 litres for from 4 to 22 people respectively. A range of moulded, high grade polyethalene, bulb-shaped tanks is manufactured, with access turret, inflow and outflow connections and a fresh air inlet (Fig. 158).

The tank is delivered ready to lower into an excavated pit. The tank is bedded on concrete and surrounded with lean mix concrete with the access cover at or just above ground level.

The septic tank is divided into three chambers. The outflow of the foul and waste water drains is discharged to the lower chamber (A in Fig. 158) in which the larger solid particles of sewage settle to the bottom of the chamber. As more sewage flows down the inlet, liquid rises through the slots in the bell shaped division over the lower chamber and enters the middle chamber (B). In this chamber fine particles of solid matter settle on top of the bell shaped division and settle through the slots into the lower chamber.

As the tank fills, liquid now comparatively free of solid sewage matter rises through the slots in the inverted bell shaped division to the third and upper chamber (C). As this upper chamber fills, the now partially purified liquid rises through the outflow to a system of perforated land drains.

The land or leaching drains, laid in trenches surrounded by granular material, spread the liquid sewage over an area sufficiently large to encourage further purification of the liquid sewage by aeration and the action of micro-organisms in sewage.

The accumulated sludge of solid sewage that settles in the base of the tank should be removed at intervals of not more than 12 months. This is effected by a tanker. A hose from the tanker first empties the upper chamber, by suction. As the liquid level falls, the ball that seals the division between the upper and middle chambers falls away. This provides access to remove the sludge from the lower chamber.

Sewage treatment plant

The preferred and more expensive system for sewage outflow, where no sewer is readily available, is the installation of a sewage treatment plant that will produce a purified liquid outflow that can be discharged to nearby ditches and streams without causing pollution of water supplies. A form of sedimentation tank, similar to a septic tank, causes solid sewage to settle. The resultant liquid outflow is further purified by exposure to air to accelerate the natural effect of micro-organisms, native to sewage, combining with oxygen to purify the sewage.

The three systems used to speed the exposure of the liquid sewage to air are:

(1) By spreading over a filter bed
(2) By spreading over rotating discs
(3) By pumping in air to combine with the liquid (aeration)

The traditional sewage treatment plant, such as that illustrated in Fig. 159, comprises a settlement tank which acts in the same way as a septic tank to allow solid matter to sink to the bed of the chamber either naturally or assisted by baffles. This first treatment generates a thin film of scum (biomass) on the surface of the liquid, which acts as a seal against air to encourage anaerobic micro-organisms to break down the solid particles.

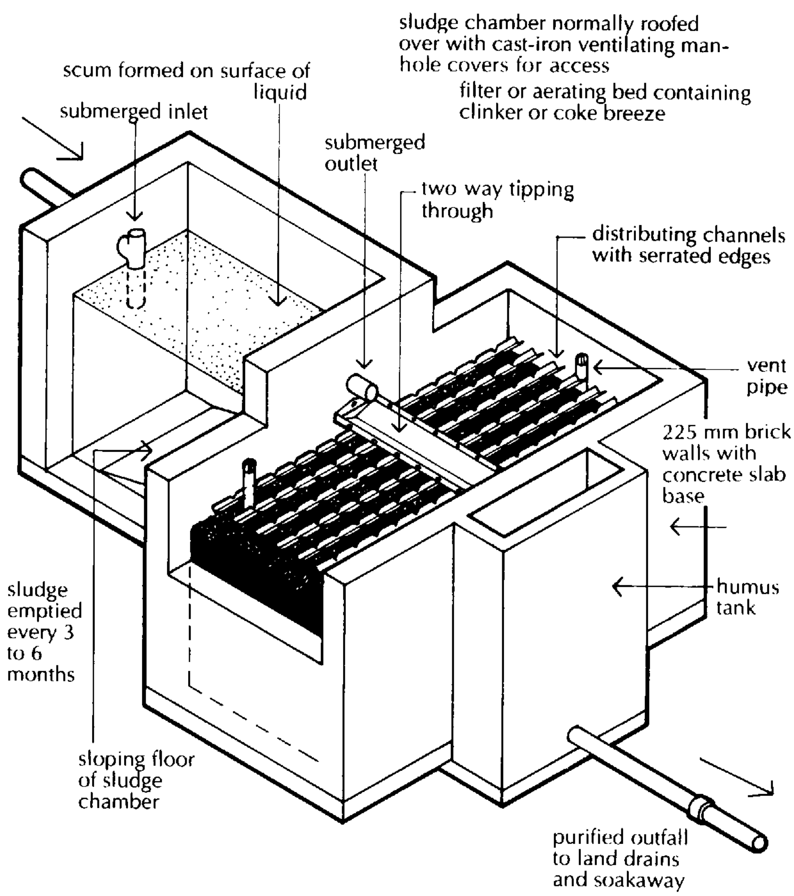


Fig. 159 Sewage treatment plant.

Liquid then flows from the settlement tank to a two-way tipping trough into distributing channels which spread the liquid over and through the filter medium. The filter medium is clinker or coke breeze chosen to expose the liquid to the maximum surface area of air. The then purified liquid runs through a humus tank to drains or a soakaway.

The small treatment plant shown in Fig. 159 is similar in operation to the larger filter beds used in municipal sewage works. It is built on a concrete base in an excavated pit, with brick walls lined inside with cement and sand rendering. The plant is roofed with reinforced concrete, with cast iron manhole covers inset for access for periodic cleaning.

The advantage of the small traditional sewage treatment plant is that there are no mechanically operated moving parts requiring attention. The disadvantages are that the plant is somewhat laborious to construct and the filter bed will need cleaning to remove sludge if it is to function efficiently.

Prefabricated sewage treatment plant

A variety of prefabricated sewage treatment units is available to service single and multiple groups of houses. These units are made from high grade moulded polyethalene. The units are delivered to site ready to be lowered into an excavated pit where they bear on a concrete bed and are surrounded with lean mix concrete. The standard units which are made for the treatment of sewage from 5 to 300 people have primary tank capacities of from 1100 to 40 000 litres.

The two systems used in these prefabricated units are the introduction of highly aerated water which is pumped into the treatment chamber by an electrically operated pump, or the use of several slowly rotating discs that expose the liquid sewage to air. The aim in both is to expose the liquid sewage to the maximum contact with air to accelerate treatment for purification.

Like the purpose-built sewage treatment plant in Fig. 159, the prefabricated treatment plant in Fig. 160 consists of three stages: a

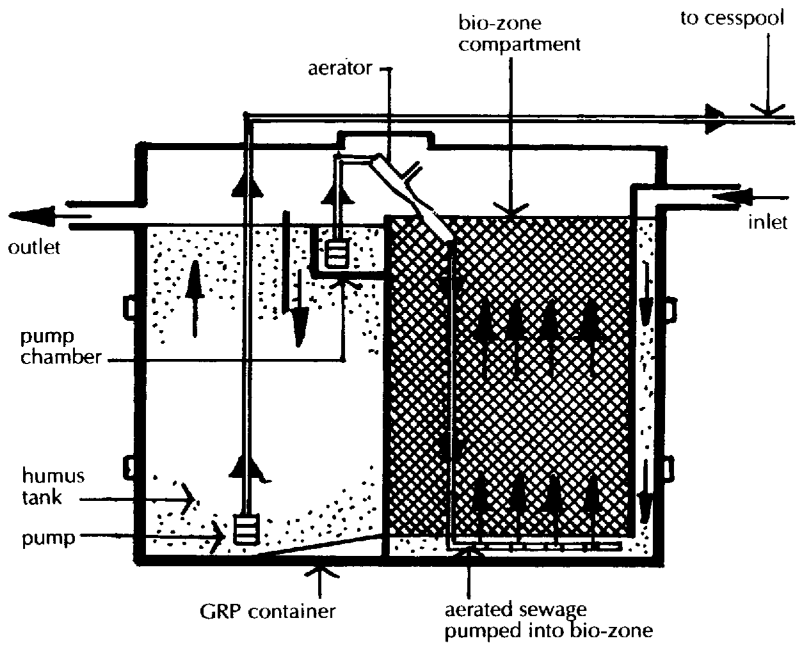


Fig. 160 Prefabricated sewage treatment plant.

settlement tank, a filter or Bio-zone and a humus tank. The settlement tank may be an existing brick-built septic tank or one of the bulb shaped GRP settlement tanks such as that in Fig. 158.

The filter or Bio-zone and humus tank are contained inside a ribbed GRP (glassfibre reinforced plastic) unit. In the filter or Bio-zone compartment, closely packed plastic coils or a honeycomb are supported and separated from the ends and base of the GRP unit. Liquid sewage from the settlement tank flows down a vertical channel to the base of the filter medium, through which it rises by natural gravity up to the liquid level of the filter and out over a weir to the pump chamber and humus tank. An electrically operated pump, submerged in the liquid sewage in the small pump chamber, forces liquid up a pipe, through an aerator and down to a perforated pipe below the filter. In this way the aerated liquid sewage rises through the filter to encourage and accelerate the action of aerobic micro-organisms in purifying the sewage.

A baffle in the humus tank encourages liquid to flow down to the bed of the tank and then up to the outlet. In so doing, bacterial cells group together to form larger particles, known as flocks, to sink more quickly to the base of the humus tank. An electrically operated recycling pump in the base of the humus tank returns the settled flocks back to the inlet of the settlement tank to cause further purification to take place.

The two electrically operated pumps in the pump chamber and the humus tank operate continuously to return the liquid sewage to the filter or Bio-zone and the settlement tank for further treatment. The now purified liquid flows from the humus tank to a drain which discharges it to a watercourse, as it meets the high standards of purity required by the National Rivers Authority.

The treatment plant is lowered into an excavated pit in the ground and bedded on and surrounded with concrete so that the cover of the plant is at, or just above, ground level. Metal access covers are set in place and an electricity supply run to the pumps from a control unit fixed in some convenient place, such as a garage. The inflow and outflow drains are connected.

The sludge that collects in the base of the settlement tank is pumped out two or three times a year. Regular maintenance of the pumps is necessary.

Pollution control

Before a cesspool, septic tank or sewage treatment plant is installed it is necessary to make sure that the installation conforms to the requirements of the National Rivers Authority (NRA) in England and Wales and the River Purification Boards (RPBs) in Scotland. The requirements of these and other water authorities are usually overseen by local authority environmental control officers who will advise on requirements best suited to the locality they oversee.

Pumps for sewage

Where sanitary fittings and their drains are below the level of the sewer, due to the slope of the ground, or in basements, it is necessary to raise the foul water by pumping. A sewage pump is an expensive piece of equipment and requires frequent maintenance if it is to function adequately. The need for pumping sewage should thus be avoided if at all possible.

The types of equipment used are the pneumatic ejector and the mechanical pump. The pneumatic ejector is used for small installations where the flow of sewage is small, as for one or a few houses, and where the sewage has to be raised comparatively small distances.

The pneumatic ejector

The pneumatic ejector is a relatively simple device with few moving parts to go wrong. The sewage enters the ejector cylinder through a non-return valve and raises a float that operates the air valves. Compressed air forces the sewage out through another non-return valve up to the sewer level and as the float falls the compressed air is evacuated. The ejector cylinder is fed by gravity from the drains. The air compressor and its air cylinder may be fitted adjacent to the ejector unit or at a higher level. The air compressor automatically operates to keep the air cylinder charged.

The operation of the pneumatic ejector is simple and straightforward and requires the least maintenance.

Where there is appreciable flow of sewage to be raised some distance to the sewer, a mechanical pump system is used. The two systems used are the submersible pump and the dry well suction pump.

Submersible pump

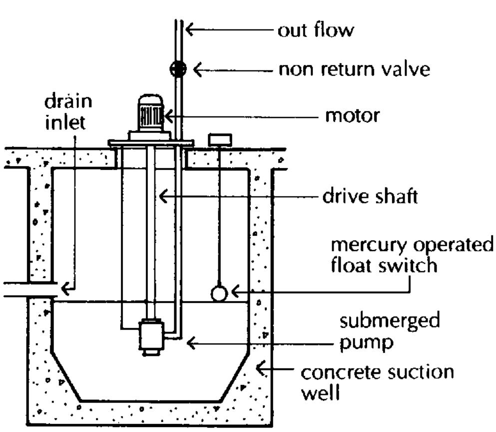


Fig. 161 Dry well suction pump.

The submersible pump and motor unit is submerged in the foul sewage to be raised, or the pump is submerged with the motor raised, as illustrated diagramatically in Fig. 161. In either case maintenance of the submerged parts is a disagreeable task.

The motor and pump assembly is suspended in a concrete sump into which the liquid sewage from the drains flows. The electrically operated pump is activated by a float switch through a ball that floats on the liquid sewage. As the liquid rises, the float operates the switch to start the motor and pump, which operate until the liquid level falls. The liquid sewage is pumped up the outflow, and through a non-return valve to sewer level.

This pumped sewage system requires fairly frequent maintenance and cleaning to ensure that the motor, pump, switch and non-return valve operate satisfactorily. The advantage of the submersible pump is that it operates more efficiently than a pump distant from the liquid to be pumped.

Dry well suction pump

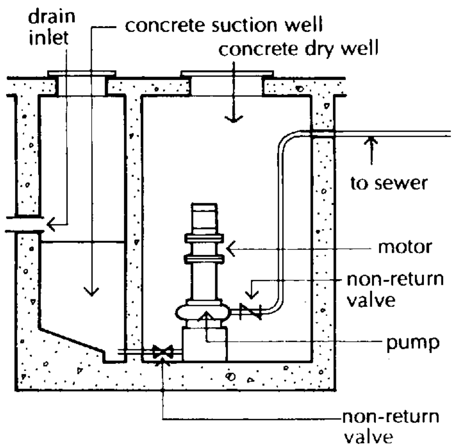


Fig. 162 Dry well sewage pump.

The dry well sewage pump is installed in a dry chamber or well adjacent to the chamber containing the sewage to be raised. An electrical motor and pump assembly is fixed in an underground chamber which is adjacent to a well into which the sewage outgo flows from the drains. The liquid sewage is pumped from the well, through non-return valves, up to the level of the sewer. Some form of float switch in the well controls the operation of the motor and pump to limit pumping operations.

The dry well is sufficiently large for an operative to climb down into the dry well for maintenance and repairs. Fig. 162 shows a typical layout. For continuous operation it is necessary to duplicate sewage pumping systems.

5: Roof and Surface Water Drainage

ROOF DRAINAGE

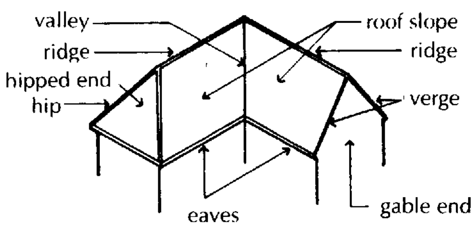


Fig. 163 Roof drainage.

Rainwater running off both pitched and flat roofs is usually collected by gutters and outlets and discharged by rainwater downpipes to drains, sewers or soakaways. The reason for collecting rainwater from pitched roofs is that unless the eaves have an appreciable overhang, the rainwater might saturate walls, particularly when the falling water is wind blown against wall surfaces.

Rainwater gutters and downpipes are a prime source of dampness in walls. Gutters that are blocked, cracked or have sunk may cause persistent saturation of isolated areas of wall, leading to damp staining and possible dry rot in timbers. Gutters are not readily visible to building owners and are generally difficult to access for regular clearing of leaves and other accumulated debris.

The terms used to describe the various parts of pitched roofs are given in Fig. 163. 'Eaves' is used to describe the general area of the lower edge of a pitched roof that drains to an eaves gutter. 'Verge' is that edge of a roof slope that finishes or verges over a gable end wall. Here the roof covering is raised somewhat to discourage wind blown rainwater from running down the gable end.

A valley is formed by the junction of two roof slopes at right angles where the rainwater running down the two slopes meets to run down to eaves. Valleys are particularly liable to blockages. They are difficult to inspect and difficult to access and are generally disregarded until a leak occurs.

The size of gutters and down pipes is determined by the estimated volume of rainwater that will fall directly on a roof during periods of intense rainfall. It is practice to use gutters and rainwater downpipes large enough to collect, contain and discharge water that falls during short periods of intense rainfall that occur during storms. Rainfall intensities of 75 mm/hour occur for 5 min once in every 4 years and for 20 min once in every 10 years. It is for such periods of intense rainfall that the drain system is designed.

To determine the amount of water that may fall on a pitched roof it is necessary to make allowance for the pitch or slope of the roof and for wind driven rain that may fall obliquely on a slope of roof facing the wind direction. A larger allowance for wind driven rain is made for rain falling on steeply sloping roofs than on roofs with a shallow slope. The effective area of roof to be drained is derived from the plan (horizontal) area of a roof multiplied by a factor allowing for the pitch or slope of the roof, as set out in Table 12.

Table 12 Calculation of area drained.

Type of surface	Design area [m^2]
flat roof	plan area of relevant portion
pitched roof at 30°	plan area of portion × 1.15
pitched roof at 45°	plan area of portion × 1.40
pitched roof at 60°	plan area of portion × 2.00
pitched roof over 70° or any wall	elevational area × 0.5

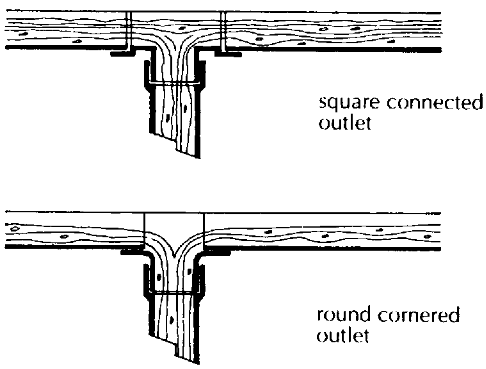


Fig. 164 Rainwater outlets.

Having determined the effective area of a roof slope to be drained it is necessary to select a size of gutter capable of collecting and discharging the volume of water assumed to fall during storms. For the purpose of choosing a gutter size it is assumed that the roof drains to a half round gutter up to 8 m long with a sharp edged outlet at one end only and laid level. This supposes an extreme condition as a run of eaves gutter 8 m long is unusual. This extreme condition is adopted on the grounds that if it can cope with rainwater collection all other less extreme conditions will operate successfully.

Most gutters are laid with a slight fall to encourage flow, and the majority of plastic eaves gutters have round cornered outlets to encourage discharge. Square cornered gutter outlets, such as those in cast iron, impede flow, whereas plastic gutters, which commonly have round edged outlets, cause less impedance to flow, as illustrated in Fig. 164. In the calculation of rainwater downpipe sizes some reduction of pipe size may be effected by the use of round edged gutter outlets.

To make the best use of the gutter it is practice to fix it to fall towards each side of an outlet to economise in gutter size and number of rainwater pipes, as illustrated in Fig. 165. Obviously to drain a given roof, a large gutter will require fewer outlets and pipes than a small gutter, as illustrated in Fig. 165. Which of the two arrangements shown is used will depend on economy in use of gutters and downpipes, economy of drain runs, position of windows and appearance. In the examples shown in Fig. 165 it would be possible to utilise two rainwater pipes, one at each end of the roof, with the gutter falling each way from the centre of the roof. Each half of the length of gutter would have to collect more rainwater than any one length of fall shown in Fig. 165, and a large gutter would be required.

The length of a gutter between outlets to rainwater downpipes will depend on the position and number of rainwater pipes related to economy and convenience in drain runs, which in turn will determine the area of roof that drains to a particular gutter length or lengths.

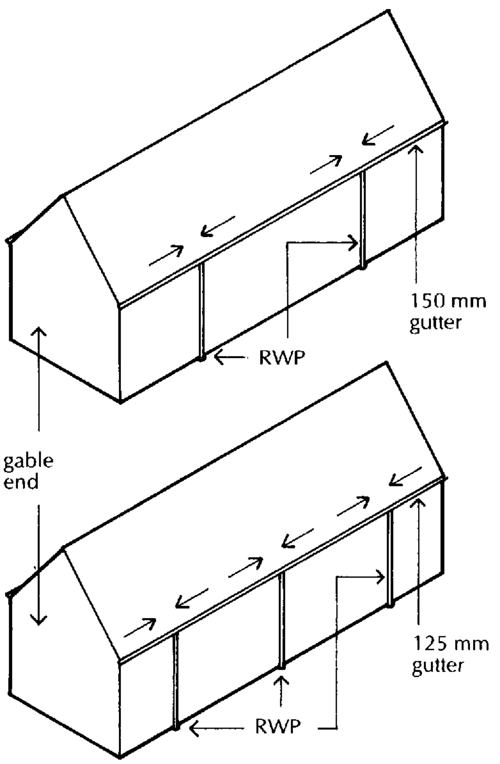


Fig. 165 Gutters and downpipes.

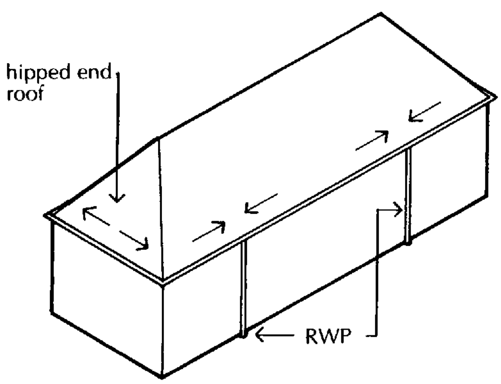


Fig. 166 Hipped end roof.

Table 13 gives an indication of the required diameter of half round gutter sizes related to the maximum effective area of roof that drains to that gutter, where the gutter is fixed level and the outlets are square edged.

Table 13 Gutter sizes and outlet sizes.

Max roof area [m^2]	**Gutter size** [mm dia]	**Outlet size** [mm dia]	**Flow capacity** [litres/sec]
6.0	—	—	—
18.0	75	50	0.38
37.0	100	63	0.78
53.0	115	63	1.11
65.0	125	75	1.37
103.0	150	89	2.16

Refers to half round eaves gutters laid level with outlet at one end sharp edged. Round edged outlets allow smaller downpipe sizes.

The figure given for flow capacity in gutters is given in litres per second, which is derived from rain falling on the relevant effective area of roof in millimetres per second where a cubic metre of water equals 1000 litres. This figure may be used to check gutter sizes chosen against manufacturers' recommended flow capacities of gutters.

The gutter outlet sizes will determine the size of rainwater downpipe to be used. For the majority of small buildings, such as single houses and small bungalows, a gutter with a diameter of 75 or 100 mm is adequate for the small flows between outlets.

Eaves gutters to hipped roofs are fixed to collect rainwater from all four slopes with angle fittings at corners, as shown in Fig. 166, to allow water to run from the hipped end slope to the outlets to main slopes. In Fig. 166 two downpipes are shown to each main roof slope, with the gutter to the hipped ends draining each way to the gutters to the main roof slopes. A square angle in a gutter, within 4 m of an outlet, somewhat impedes flow, and allowance is made for this in the calculation of flow in gutters.

Flooding and overflow of eaves gutters to hip ended roofs most commonly occur at angles where obstruction to the flow is greatest, blockages are most likely to occur and the angle gutter fittings may sink out of alignment.

The position of rainwater pipes will depend principally on economy and convenience in making connections to drains, rather than an ideal arrangement of gutters and their outlets. Running lengthy and complicated drain runs is more expensive that adjusting gutter outlets and rainwater drain pipes to suit economical drain runs.

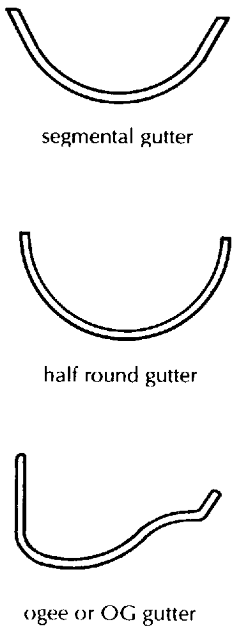


Fig. 167 Rainwater gutter cross-sections.

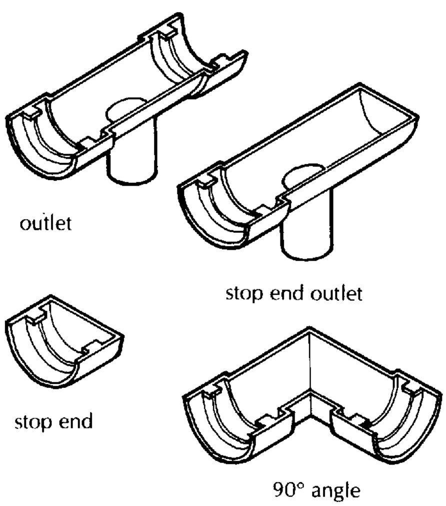


Fig. 168 Rainwater gutter fittings.

Eaves gutters to most roofs are fixed to a shallow fall of 1:360 towards outlets. This shallow fall avoids too large a gap between the edge of the roof covering and the low point of the gutter, yet is sufficient to encourage flow in the gutter and make allowance for any slight bow or settlement of the gutter.

The section of gutter most commonly used for the traditional pitched roof covered with slates or tiles is half round. This is the standard section of the generally used plastic and the traditional cast iron gutter. Other sections are available, such as the segmental and ogee or OG gutter illustrated in Fig. 167.

The segmental may be used to collect rainwater from small shallow pitched roofs. The ogee section was much used for cast iron gutters for its appearance as a feature to larger, more imposing houses and other buildings.

Gutter lengths and their associated fittings have spigot and socket ends so that the plain (spigot) end of gutter fits to the shaped (socket) end of gutter to provide a level bed of gutter. The necessary fittings to gutters are running outlets, stop end outlets, angles both internal and external, and stop ends. These fittings have socket ends to fit the spigot ends of the section of gutter.

Fig. 168 shows typical plastic gutter fittings for half round gutters. The angle fitting shown is an external angle fitting. Internal angle fittings are used where a wing or part of a building butts to another part at 90°.

Standard half round, uPVC gutter sections with spigot and socket ends and angles, outlet and stop end fittings, are commonly used to drain the majority of pitched roofs today. uPVC is a lightweight material that needs no protective coating, is moderately rigid and has a smooth surface that encourages flow. It is usually made with a black or pale grey finish. This material is particularly used for its comparatively low cost and freedom from maintenance.

Fig. 169 shows uPVC gutters. Flexible seals are bedded in the socket ends of both gutters and fittings. These seals are watertight and at the same time are sufficiently flexible to accommodate the appreciable thermal expansion and contraction that is characteristic of this material. Without the flexibility of the seals, long lengths of gutter might otherwise deform. The joint between spigot and socket ends is secured with a gutter strap clipped around the gutter.

uPVC gutter lengths are supported by plastic fascia brackets that are screwed to fascia boards. The gutter is pressed into the fascia brackets so that the lips of the bracket clip over the edges of the gutter to keep it in place. The spacing of the brackets is determined by the section of gutter used.

Rainwater downpipes are moulded with plain spigot and shaped socket ends. Socket ends are shaped to make the close fitting joint to

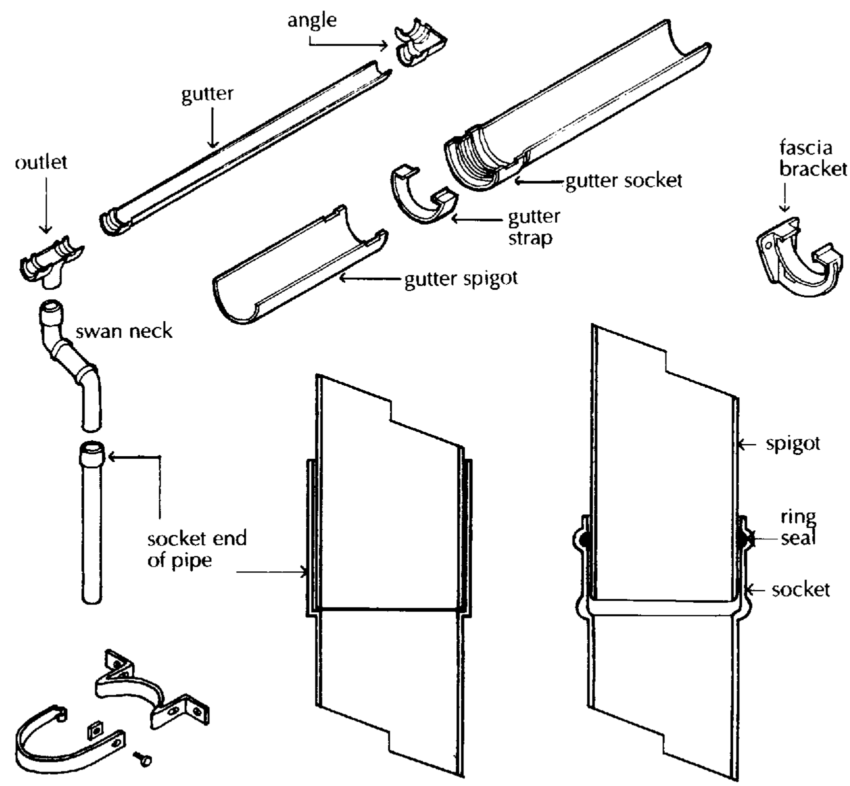


Fig. 169 uPVC rainwater gutters and downpipes.

spigot ends, or moulded to take a flexible ring seal as illustrated in Fig. 169. The former makes a reasonably close fit and the latter a more positive watertight fit. The shaped fitting or fittings from the gutter outlet to the downpipe are formed to make allowance for overhanging eaves so that water discharge is directed from the gutter towards the downpipe fixed to walls.

The swan neck fittings are either moulded in one piece to accommodate particular dimensions of eaves overhang, or consist of three fittings to allow for various eaves overhangs. The swan neck shown in Fig. 169 comprises three units: two bends and a short straight length used to allow for a particular eaves overhang.

Rainwater downpipes are secured to walls with plastic pipe clips screwed to walls. The two piece pipe clip illustrated in Fig. 169 facilitates fixing plugs and screws to walls.

Cast iron rainwater gutters and downpipes

Cast iron was the traditional material for gutters and downpipes for pitched roofs. It is heavy, rigid, brittle and durable as long as it is protected by paint. Standard gutters are of half-round or ogee section with socket and spigot ends with angle, outlet and stop end fittings.

The advantage of cast iron as a gutter material is that it is much less likely to sag than uPVC. Its disadvantage is that it is liable to rust and should be coated to inhibit rusting and for appearance sake.

The gutter joints are bedded in red lead putty or mastic and bolted together. Gutter lengths are supported by fascia or rafter brackets for half-round gutters and by screws or brackets for ogee gutters. Fig. 170 shows a cast iron gutter and downpipe.

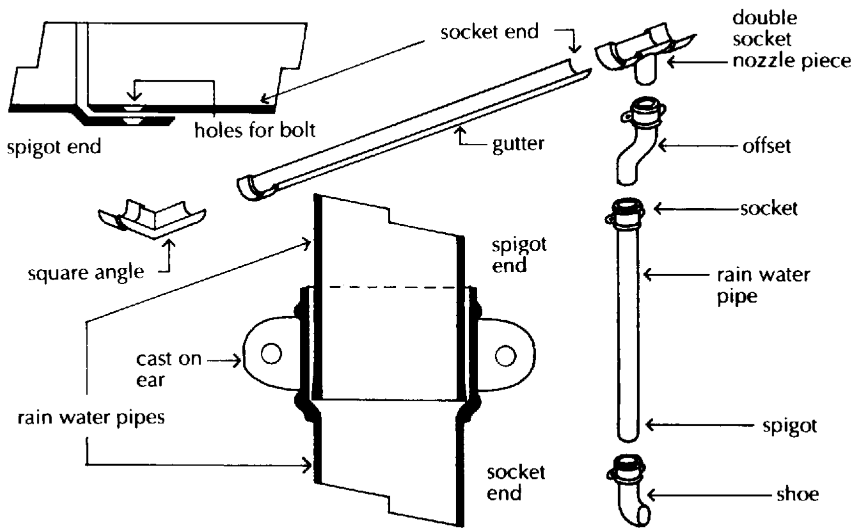


Fig. 170 Cast iron rain water gutter and pipe.

Standard round-section socket and spigot downpipes with cast-on ears for fixing are used with offset and shoe fittings. The downpipes are secured to walls with pipe nails driven into hardwood plugs through distance pieces to fix the pipes away from the wall for painting.

There have been two schools of thought as to whether the joints between downpipes should be left open or sealed. One claimed that open joints would give an indication of blockages in pipes by water overflowing from a particular joint, and so would indicate which pipe length to unblock. The second claimed that all joints should be sealed to prevent any seepage of water from them. Open joints are probably more useful with cast iron pipes whose coarse textured surface is more conducive to blockages than the smooth surface of uPVC pipes.

Aluminium, galvanised and enamelled finish pressed steel and zinc have been used for gutters and downpipes. None of these materials are now much used.

Gutters to wide span roofs

The considerable volume of rainwater that will fall on pitched roofs over extensive buildings such as factories, warehouses and sheds has to drain to gutters on one or more boundaries of the building, or to valley gutters between pitched roofs. Because of the considerable volume of rainwater that may fall on such roofs during periods of intense rainfall it is generally necessary to make an estimation of likely rainfall and gutter sizes needed to collect and discharge the water.

The estimation of water volume and gutter and downpipe sizes, described earlier in this chapter, is plainly more relevant to large roofed areas than to a small house where the standard 100 mm gutter will be adequate.

The section of gutter used is described as a boundary wall or box gutter because the gutter is bedded in or fixed to a boundary wall and is usually box-shaped. The material used for these gutters is pressed steel either galvanised or more usually galvanised and plastic coated to inhibit rust. Some typical sections are shown in Fig. 171. The socket and spigot ends of gutter are bedded in mastic and bolted together. Various outlet, stop end and angle fittings are made.

These gutters are either bedded on a boundary wall, supported by metal brackets as a verge gutter or used as a parapet gutter. The gutters are laid or fixed level with as few outlets as possible to discharge the estimated flow.

Valley gutter

Adjacent pitched roofs drain to a common valley gutter which either discharges to a rainwater outlet or a boundary gutter where there are hipped ends to roofs. These gutters are either galvanised pressed steel or plastic coated galvanised pressed steel. Some sections are shown in Fig. 171. A wide bed of gutter is convenient for access to clear blockages. The effective area of roof to be drained is determined as in Table 12.

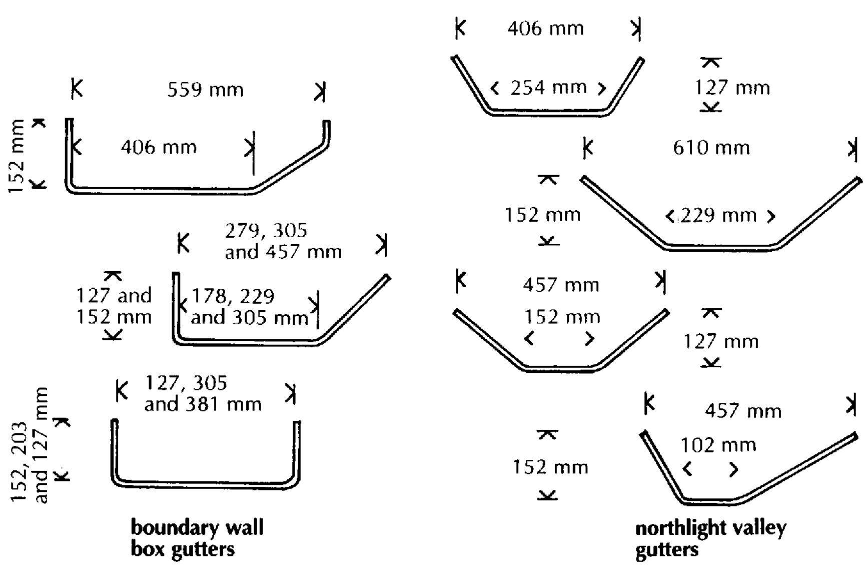


Fig. 171 Gutters.

Flat roofs

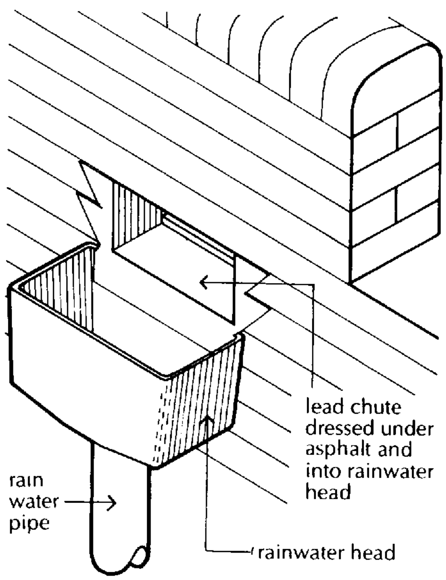


Fig. 172 Parapet rainwater outlet.

Flat roofs should be laid to a shallow fall towards outlets to avoid what is termed 'ponding'. Ponding is caused by too shallow a fall or the inevitable deflection under load of any horizontal structure that will cause water to lie on a flat roof in the form of a shallow pond. The static ponded water will accelerate deterioration of most flat roof coverings and will penetrate cracks caused by thermal and moisture movements of the structure.

For appearance sake flat roofs are often surrounded by parapet walls raised above the level of the roof finish. The run off of rainwater is encouraged by a fall or slope of the roof to outlets formed in the parapet wall. These outlets are lined with lead sheet shaped to fit in the bed and side of the outlet and are dressed down over a rainwater head, illustrated in Fig. 172. The lead chute is dressed under the flat roof covering. Because the run off of rainwater is comparatively slow, fairly close spacing of outlets is necessary for drainage.

Rainwater heads are usually of galvanised or galvanised plastic coated pressed steel with an outlet to the rainwater downpipe. The traditional cast iron rainwater head is little used because of its cost and the need for regular coating or painting to avoid unsightly rusting. Where a flat roof is carried over boundary walls it discharges rainwater to an eaves or boundary wall gutter.

Large expanses of flat roof should drain to outlets in the roof as well as boundary outlets to avoid extensive lengths of fall or slope to flat roofs. Outlets are formed in the roof in some position where the necessary rainwater downpipe may be fixed to part of the supporting structure, such as a column. These outlets are shaped so that the roof covering may finish to the outlet with a watertight joint. Fig. 173 is an illustration of an outlet to a flat roof covered with asphalt, with a lift-up grating to facilitate clearing blockages.

Connection to drains

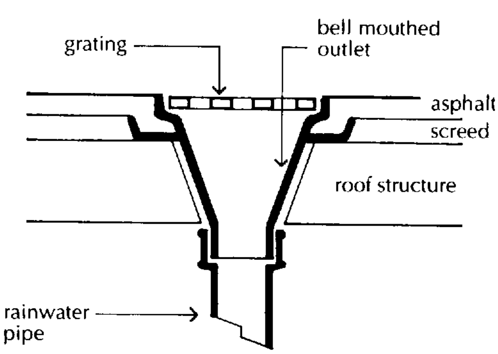


Fig. 173 Rainwater outlet.

It used to be practice to discharge rainwater from downpipes through a rainwater pipe shoe over a gully. This is not considered good practice today because water splashing from the shoe is liable to make the adjacent wall damp. Practice today is to connect down pipes to a back inlet gully, trapped gullies being used where the drainage is a combined drain system, and untrapped gullies where separate drain systems are used. Fig. 149 shows the connections of downpipes to gullies.

SURFACE WATER DRAINAGE

Paved areas

External surfaces that are paved with concrete, natural or artificial paving slabs, bricks or granite sets, should be laid with slight slopes or falls to gullies or channels. The purpose of the falls or slopes to drains is to discharge rainwater reasonably quickly for the convenience of people and to prevent ponding of water that would accelerate deterioration of paving materials by saturation and the effect of frost on water lying in fissures in the material.

The slope or fall of paved areas should be sufficient to drain water to outlets, yet not so steep as to make the surface slippery in wet or frosty weather. A minimum fall of 1:60 is generally recommended for paved areas on flat ground.

A fall or gradient of 1:30 to 1:20 is recommended along the length of access roads, with a crossfall of 1:40 across the width, usually formed as a camber or shallow curve to each side. As a general guide a paved area of 200 to 250 m^2 of paved area should drain to each gully at a slope, fall or gradient of 1:50. Paved areas abutting buildings should drain away from the building.

To economise in drain runs, paved areas should drain in two or more directions to yard gullies, with drainage channels between gullies in large paved areas to effect further economies. The drainage of the paved area in Fig. 174 is arranged by each way falls to channels that in turn drain to gullies. Where the fall or gradient is increased from 1:50 to 1:20 the effective area that can be drained to one gully can be increased to 500 m^2.

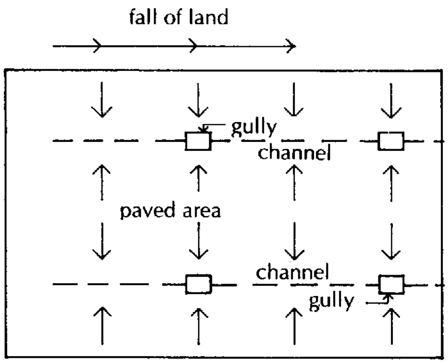


Fig. 174 Paved area drainage.

Channels

Channels between gullies may be level and depend on natural run off or may be laid to a slight fall by a gentle sinking towards a gully. A small square area of paving may be laid to fall to one central gully, with channels formed from each corner to the gully by the intersection of slopes. Forming this slope at intersections of falls, termed a current, may involve oblique cutting of paving slabs or bricks to provide a level surface.

Yard or surface water gullies are set on a concrete bed to finish just below the paved surface. The gullies generally have a 100 mm square inlet and are either trapped with a waterseal when they discharge to combined drains or are untrapped for discharge to a separate storm water drain.

Fig. 175 shows a trapped clay yard gully with loose cast iron grating for access to clear blockages. The graph in Fig. 176 indicates the area of paving that can be drained relative to estimated flow and size of drain relative to gradient or fall.

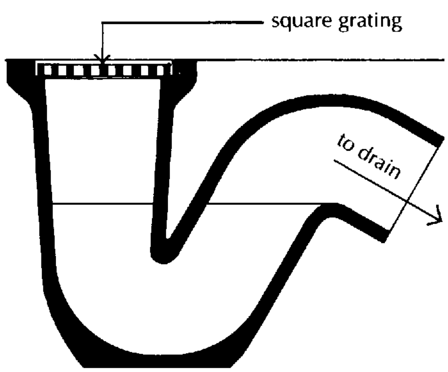


Fig. 175 Clay yard gully.

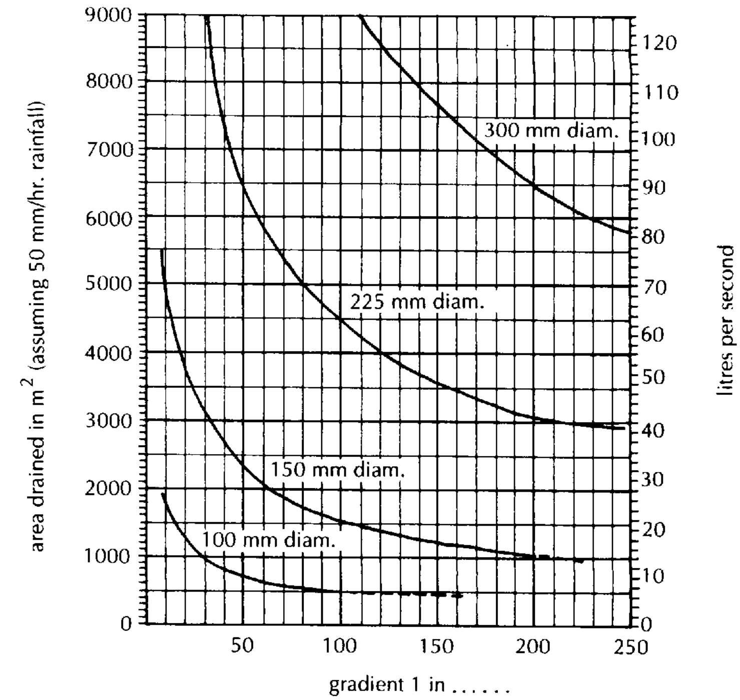


Fig. 176 Graph for determining diameter and gradient of surface water drains.

Drainage systems

Where there are separate drainage systems, roof and surface water drainage will connect to a separate system of underground drains discharging to the sewer. For the rain and surface water drains, it will generally be satisfactory to have a system of either clay or uPVC drains with rodding eye access fittings as necessary and an inspection chamber near the boundary. The description of pipe laying, bedding and gradient for foul water drains will apply equally to roof and surface water drains for which untrapped gullies are used, as there is no need for water seals and ventilation against foul odours.

Soakaways

Outside the more densely built-up urban areas there is often an adequate area of land as part of building sites to drain roof and surface water to soakaways.

A soakaway is a pit into which roof and surface water is drained and from which the water seeps into the surrounding ground. Soakaways are used where a combined sewer may not be capable of taking more water, where a separate rain and surface water sewer is distant and also as an alternative means of discharge.

Obviously if the soil is waterlogged and the water table or natural level of subsoil water is near the surface it is pointless to construct a soakaway. In this situation the surface water will have to be discharged by pipe to the nearest sewer, stream, river or pond.

In firm pervious ground such as chalk, it is generally sufficient to dig a pit into which the water is drained directly, and the pit is covered with a concrete slab as illustrated in Fig. 177.

In moderately compact soils such as clay, the pit may be filled with hardcore or clean broken stone to maintain the sides of the pit, as illustrated in Fig. 177.

In granular soils such as gravel and sand, the soakaway pit has to be lined with brick, stone or concrete to maintain the sides of the pit, and the lining of brick, stone or concrete must be porous or perforated to encourage the water to soak away into the surrounding soil, as illustrated in Fig. 177.

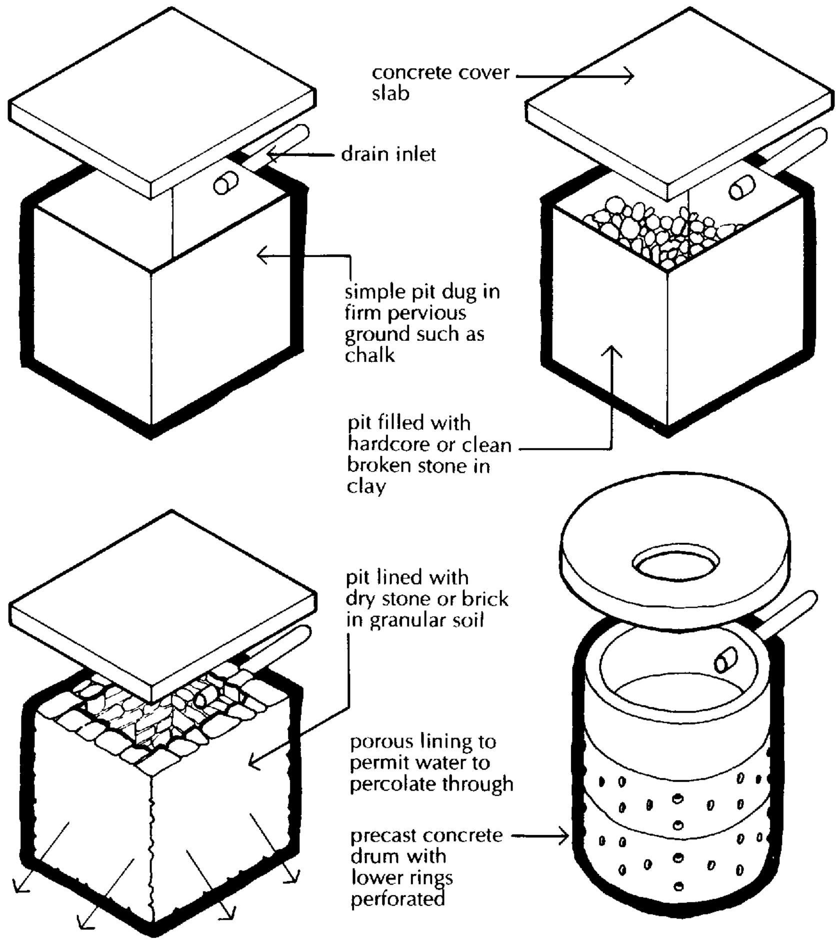


Fig. 177 Soakaways.

It may be cheaper to excavate two or more small soakaways rather than one large one, to reduce drain run lengths. Soakaways should be at least 3 m away from buildings so that the soakaway water does not affect the buildings' foundations, and they should also be on slopes down from buildings rather than towards buildings, to avoid overflowing and flooding.

6: Electrical Supply and Distribution

ELECTRICITY

The history of the development of a theory of electricity properly begins in the sixteenth century with William Gilbert, physician to Queen Elizabeth, who was first to use the word electric. He was studying the property of amber, after being rubbed, of attracting light objects, such as feathers. He named this power of attraction *electrica*, the Latin version of the Greek word for amber, a yellow, translucent, fossil resin much used in the manufacture of small ornaments.

Materials which have the property of attracting light objects, after being rubbed, were said to be electrified or charged with electricity. The energy used to overcome the frictional resistance between the two materials being rubbed together is converted to a charge of electrical energy in the amber. The more vigorously it is rubbed the greater the energy expended and the greater the charge of electricity in the amber.

Law of conservation of energy

Energy, which may neither be created nor destroyed (law of conservation of energy) is converted from one form – energy in rubbing to another, a charge of electrical energy in the amber.

Conductors, insulators

Early in the eighteenth century it was discovered that the electrical charge on amber could be transferred by contact with some materials and not with others. The materials through which the electrical charge could freely pass were called conductors and those through which the electrical charge could not pass were called insulators.

All metals are good conductors of electricity in that they offer small resistance to the transfer of electrical energy. Amber, sealing wax, hard rubber, dry glass and most plastics are good insulators in that they afford high resistance to the transfer of electrical energy.

The properties of copper and hard rubber or plastics as conductors and insulators respectively are used in electrical wire and cable. The plastic insulation around copper wire provides high resistance to the transfer of electrical energy from the conductive copper to another conductive material that touches the outside of the insulating plastic cover.

Earth, earthing

In the experiments to establish the properties of conductors and insulators, it was established that contact with an electrically charged material by hand had the effect of transferring the charge through the body to ground, as the human body is a fairly good conductor. The large mass of earth is said to be neutral electrically, so the human body conducts electrical charge by contact from the charged material to earth.

In the design of electrical installations, exposed metal, such as metal pipes, are connected to earth through a copper conductor as a path of least resistance to the discharge of electrical energy, rather than through the human body, as a safety device. This is described as the metal pipes being earthed.

Flow, current of electricity

In the middle of the eighteenth century it was suggested that electrical actions could be explained by supposing that electricity was a fluid. Electrically uncharged bodies contained a normal or equilibrium amount of the fluid and so showed no electrical effect.

When an electrically charged body was connected to a conductor some of the electric fluid flowed into the conductor, like a current of water flows in a stream. This analogy of the behaviour of water and electricity is expressed in the use of the word current, to define the sense of the transfer of electrical energy along a conductor. Some people still refer to 'turning on the juice', meaning turning on the electricity.

Amp

The unit of current, the ampere or amp, is the force of energy that one volt can move against one ohm of resistance in a conductor.

Resistance

All materials offer some resistance to the transmission or conduction of electricity by the conversion of electrical energy to heat. Some, like copper, have little resistance and others, such as plastics, have considerable resistance. In the design of electrical installations it is useful to know the measure of such resistance in order to choose the most suitable material for both conductors and insulators.

The unit measure of resistance to the transfer of electrical energy is the ohm, which is proportional to length and varies inversely to the cross sectional area of a conductor such as a copper wire.

For the most economical design of overhead cables for transmission of very high voltage electrical energy and the low voltage wiring in the home, the cross sectional area of a copper conductor relative to its resistance and cost per unit of length is a prime consideration.

Positive and negative electricity

Early in the eighteenth century two kinds of electricity were distinguished as vitreous and resinous electricity, the former generated by rubbing a glass rod and the latter by rubbing hard rubber. Bodies charged with vitreous electricity repelled one another and attracted those charged with resinous electricity, so establishing the rule that like repel and and unlike attract. Vitreous electricity is now called positive electricity and resinous electricity is called negative electricity.

In a body that is not electrically charged it is supposed that positive charges balance negative charges so that the body is said to be neutral electrically.

Voltage

Late in the eighteenth century Alessandro Volta (1745–1827) produced the first apparatus to provide a continuous current of electricity. His voltaic pile consisted of a pile of discs of copper and silver separated by discs of card or leather soaked in salt water. The reaction of the pile of copper, card, silver, card and so on, was to produce an electrical charge on the pile which caused a flow or current of electricity in a conductor connected to the two ends of the pile. This was the first battery capable of providing a stored charge of electricity that could be used to provide a continuous flow or current of electricity.

Volt

The charge of electrical energy stored in the pile may be given a numerical value in volts, which is the unit of potential electrical energy available. A volt is the unit of electrical energy or force necessary to cause one ampere of current to flow against one ohm of resistance.

Induced charges

Many experiments carried out in the eighteenth and early nineteenth centuries demonstrated that when an electrically charged conductor is brought near to, without touching, an uncharged insulated conductor, the insulated conductor acquires a charge that disappears when the charged conductor is removed. The action of causing a charge in a conductor by proximity is termed electrification by induction, and the charges are called induced charges.

The force between electric charges varies inversely to the square of the distance between them, so that the nearer the electrically charged wire is to the uncharged wire the greater the induced charge.

Magnetism

It had been known for many centuries that a particular mineral ore, lodestone, had the property of attracting iron and giving to the iron a like property of attracting other pieces of iron. The property of attracting is called magnetism, from the name of the district of Asia Minor where the lodestone was plentiful. This type of magnetism is described as ferro-magnetism.

Compass

During the twelfth and thirteenth centuries a property of iron, magnetised by being rubbed on lodestone, was first used as a compass. A thin rod or needle of ferro-magnetised iron, pivoted at its centre, will turn with one end towards the north pole of the earth no matter how often it is moved from that position. It is said that the magnetised needle is polarised, a term used in the later development of electro-magnetism.

Electro-magnetism

Up to the nineteenth century scientific enquiry into the nature of electricity, gravity, and ferro-magnetism continued largely as separate phenomena. Early in the nineteenth century, Oersted, a Danish scientist, demonstrated that an electric current flowing through a wire produced a magnetic effect on a compass needle by deflecting it to a position at right angles to the wire.

Michael Faraday, who had for some time been developing the theory that magnetism and electricity were of the same fundamental nature, began work on experiments to develop the idea. It was known that when an iron rod was moved in and out of a coil of electrically charged wire a charge was induced in the wire, and once the rod was still, the charge disappeared.

Faraday set a copper disc to rotate between the two poles of a horseshoe ferro-magnet, with one sliding contact in touch with the edge of the disc and another fixed to the pivot on which the disc rotated. As the disc rotated a measurable current of electricity flowed from the sliding contact to the fixed one. When the disc stopped rotating the electricity disappeared.

This was the first crude generator of electricity which over the subsequent 100 years was developed to what are now large complex generators that still depend on the principle of rotating a conductor through the field of force around a magnet, to generate electricity as an alternating current as the conductor rotates through the north and south polarity of the magnet.

ELECTRICAL SUPPLY

Supply generators

In England and Wales the bulk generation of electricity is carried out by PowerGen, National Power and Nuclear Electric who distribute power through the national grid to twelve regional electrical companies (RECs) and also directly to large consumers of electricity. In Scotland Scottish Hydro-Electric and Scottish Power generate and distribute electricity.

National grid

The national grid distributes electricity at 132 000 volts (132 kV), mainly by overhead conductors. A high voltage is used to minimise transmission losses in the great length of cable by the use of an economic section of copper conductor.

Supply from the national grid is converted by regional companies to lower voltages of 11 000 and 6600 volts, to supply districts within their areas, and this is further reduced to the standard 415 volts for local supply. The electricity supply to the majority of users is the standard 415 volt, three phase 50 Hz frequency alternating current, supplied through a cable consisting of three phase wires and a neutral conductor.

Over a period of some 100 years of development, a supply of electricity, alternating at a frequency of 50 Hz, has been accepted as the most efficient, economic and convenient. The windings of the generator are arranged so that the supply of alternating currents is phased, with three pulses of energy each revolution of the generator – the supply best suited to most electrically driven motors.

Low voltage supply

The regional electrical companies make a connection to the majority of buildings through a low voltage, 415 volt, three phase supply cable comprising three separate phase wires and one neutral conductor. The neutral conductor serves as a return path to complete the circuit for current flow back to the generator.

Where the anticipated load is low or moderate and where rotary equipment is used, connection to the consumer is made to any two of the three phase wires and the neutral to provide a 415 volt, three phase alternating supply. Where the anticipated load is low, as for a house, connection for the consumer is made to any one of the three phase wires and the neutral conductor to provide a 240 volt single phase supply.

High voltage supply

Low voltage is defined as exceeding 50 volts and not exceeding 1000 volts a.c., and high voltage as exceeding 1000 volts a.c.

Where the anticipated load on the supply is high, as for example to heavy industry or a common supply is made to a large building, it is necessary for the regional electricity company to provide a high voltage supply. This need is usually determined by the particular regional electricity company's policy on loading. The general division between low and high voltage intakes lies between 250 to 500 kVA.

The high voltage supply is connected to the REC's switch gear, from which a connection to the consumer's switch gear is made to the consumer's chosen supply system of one or more distribution centres.

Tariffs and metering

The majority of consumers are supplied by the RECs, who offer the option of three tariffs for the payment for supply:

(1) General purpose tariff
(2) Low voltage maximum demand tariff
(3) High voltage maximum demand tariff

General purpose tariff

This tariff is for relatively small consumers such as domestic premises. The tariff consists of a quarterly standing charge plus a charge per unit consumed, applicable to lighting, heating and power. In some regions a reduced charge for off-peak consumption, during night-time or weekends, may be available, which requires separate meters and circuits.

Low voltage maximum demand tariff

The purpose of maximum demand tariffs is to penalise consumers who exceed a maximum demand, agreed between the supplier and the consumer, in order to provide a reasonably uniform level of demand on the supply available and so avoid unpredictable demand.

Where the consumer exceeds the agreed maximum demand for any one month, they are required to pay a higher charge, based on consumption for that month, for the following 12 months. Were they to reduce consumption in any month after that year, they would not revert to the former lower payment until twelve months later. There is thus a two year period of higher payment for exceeding demand for one month.

Because it is very costly to shut down and start up generators to meet surges in demand, and it is impractical to reduce output, tariffs are designed to ensure steady demand as far as possible. To this end monthly tariffs generally vary monthly, being lowest from March to the end of October and higher from November to the end of February – the months when demand is highest. The charge consists of a monthly unit based on the actual kWh metered, with units metered during night-time being considerably lower than daytime, giving a reduction of up to 50%.

High voltage maximum demand tariff

This tariff is similar to the low voltage tariff in that it penalises consumers who exceed the agreed maximum demand and rewards those who take supplies in the summer months and during the night and at weekends.

Cost control

The penalties for exceeding agreed maximum demand of electrical supply may be considerable. It is a matter of economic good sense, therefore, for business to reduce peak demand where possible. Where electrically powered rotary machinery is used, there is a peak demand first thing in the morning when machinery is started up simultaneously. A phased starting, either organised for manual operation or by automatic means, can produce considerable financial reward with very little interruption to production.

Metering

The electricity supply authority has an obligation to provide a meter to record basic data, on which a tariff charge is based. The majority of small meters in use are of the induction type which record units consumed, to which a tariff is applied to calculate the charge to the consumer. The induction meter, which may be liable to electrical and mechanical failure, should be serviced and must be withdrawn at intervals for testing to comply with legal requirements.

Electronic meters are available and are being installed in some areas. It is likely that electronic meters will gradually replace induction meters. The advantage of the electronic meter is that remote reading of the meter is possible for computer recording at central points.

Electrical circuits

To effect the transfer of energy from a source of potential electrical power, such as a generator or transformer, a complete circuit of some conductive material is necessary to provide a path of low resistance back to the source, so that the maximum energy is available around the circuit for conversion to heat for lighting and heating and for motive power to rotary equipment. The material most used as a conductor is metal in the form of a copper or aluminium wire.

Phase conductors

With alternating current (a.c.) three phase supplies – the usual electrical source – there are three separate conductors, one to each of the three separate phase windings of the generator or voltage reduction transformer, and a fourth conductor serving as neutral back to the source to complete the circuit.

The three separate wires, which are termed phase or phase wires, are sometimes called live or live wires.

Neutral

The conductor which serves to complete the circuit is termed neutral.

Earth

In addition to the phase and neutral conductors, there is another separate conductor termed earth which may be a separate conductor in some cables or for economy may be combined in other cables with the neutral conductor. Fig. 178 shows the terms used.

The earth conductor serves as a protective and safety device by acting as part of a conductive circuit with earth, which is said to be neutral electrically. The earth conductor serves as a line of least resistance to the discharge of current in excess of that allowed for in the design of an electrical installation, which might otherwise damage equipment, cause a fire or endanger life.

The earth conductor to supply cables, which is for the benefit of the suppliers' equipment, may not be an effective earthing conductor for a consumer's installation. As the supplier is under no obligation to provide satisfactory earthing for the consumer, it is up to consumers to provide their own earthing provisions as necessary.

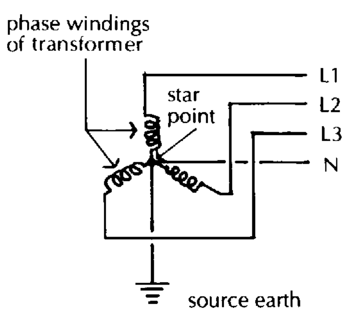


Fig. 178 Phase conductors (L1, L2, L3) and neutral for TN-C-S supply.

Where the three phase supply is used as a low voltage, low demand supply to, for example, a single house, a single phase connection is made to one of the three phases wires and the neutral of the supply cable for a 240 volt supply. If the incoming supply cable uses a combined neutral and earth conductor, as is usual, the consumer's single phase supply will need a separate earth conductor.

Main distribution

The electrical supply necessary for large buildings, groups of buildings and manufacturing industry is run to the site by the REC, through a transformer substation as necessary, to their main switch, circuit breaker equipment and meter. From the meter it is the responsibility of consumers to install their own main distribution system of cables to supply transformers and switch gear at load points on extensive sites, or some form of busbar distribution system for large buildings such as multi-storey buildings and factories.

A busbar is a round or rectangular copper or aluminium bar conductor, made in a range of standard lengths. The busbars are either of bare copper, which is supported at intervals by insulated carriers, or the copper bars can be totally insulated. The advantage of the bare copper busbar is that sub or final circuits can readily be connected through tee-offs, by clamping to rectangular bars at any point. The round section bar requires shaped connections.

Busbars are run inside solid enclosures or galvanised steel trunking in which there are insulating supports. Tap-off boxes, complete with miniature circuit breakers, can be fed to the trunking as necessary for sub or final circuits. For long runs, for example to supply fixed position lighting, the busbar will generally be PVC insulated single-core cable supported inside metal trunking fixed to the underside of a floor or roof, with socket outlets for individual lights. For heavier loads on horizontal runs, the insulated busbar will connect to terminals with plug-in units, complete with circuit breakers, to connecting machine cable feeds.

Vertical risers of busbar distribution systems are usually run as bare rods supported by insulated carriers inside metal trunking from which fused tap-off points are connected to each floor for connection to final circuits. Vertical risers that are not inside a fire compartment must be provided with insulated barriers at each floor as fire stops.

Fig. 179 shows busbar distribution to a block of flats, feeding distribution boards, circuit breakers and final circuits to floors.

Main distribution for high voltage supplies is run as either a radial or ring main system. Radial circuits run from main switchboard to an outlet and back to the main switchboard, with a circuit breaker for each radial feeder. This is the simplest and cheapest form of circuit for

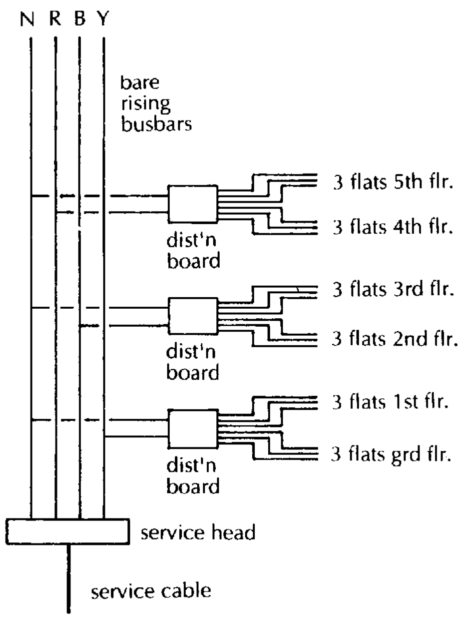


Fig. 179 Distribution to a block of flats.

high voltage main distribution, which is used for one or a few supply outlets. Ring main circuits run to a number of tap-off points and back to the main switchboard, with circuit breakers to each end of the ring system and switchgear for tapping-off to radial feeders or transformers.

The advantage of a ring circuit is that it supplies a number of outlets, additional outlets can be tapped-off without shutdowns, and maintenance on the feeder circuits is facilitated.

Final circuit distribution

Final circuits are those that feed directly to lighting or power fittings from the mains. In small buildings, such as houses and shops, the final circuits run from one mains distribution board fixed close to the entry point of the mains supply. In larger buildings the final circuits run from single tap-off points on radial or ring main circuits or from distribution boards connected to radial, ring or busbar mains distribution. The distinction between main and final circuits is in the anticipated loads, which are heavier on the main than final circuits and affect the size of the necessary cable, switchgear and circuit breakers for the circuits.

For the sake of economy in the size of cable, switchgear and circuit breakers, final circuits are divided into various circuits depending on the anticipated loads, and in larger installations are divided into nonessential and essential services.

Final circuits for houses, shops and small offices are run separately for:

(1) Lighting from fixed ceiling and wall fittings
(2) Portable fittings such as air heaters, kitchen equipment and portable lamps
(3) Fixed equipment such as cookers and water heaters.

For larger buildings, final circuits are run separately for nonessential services such as:

(1) Lighting, fixed light fittings
(2) Small power fittings such as heaters and other portable equipment
(3) Lifts
(4) Air conditioning
(5) General plant and fixed equipment

and for essential services such as:

(1) Critical processes such as computers
(2) Security systems
(3) Emergency lighting

(4) Fire alarms
(5) Communications

Low voltage supply

Low voltage three phase supplies by the RECs to consumers' premises are usually provided through cables that comprise three separate phase conductors. Each is insulated with a cross-linked polyethylene (XLPE) insulating covering around which a combined neutral and earth conductor, in the form of a metal sheath, is embedded in unvulcanised rubber surrounding the insulated phase conductors, and the whole is encased in a protective PVC sheath.

Earthing systems

TN–C–System

The earthing arrangement which is combined in a common neutral and earth conductor is referred to as the TN–C–S system. The letter T denotes the connection of the star point of the three phase supply. N denotes the connection of exposed conductive parts, such as metal pipes, with the source earth that is earthed neutral. C–S denotes the protective conductor combined in the supply cable and separate in the consumer installation. This system is also known as the pme system (protective multiple earthing).

TT system

Another earthing system used is the TT system where the second T denotes that the exposed conductive parts are connected by independent installation earth electrodes, by protective conductor to source earth. This system was used for overhead power supplies.

Another system, the TN–S, employs separate neutral and earthed protective conductors. This older system is less used.

Supply connections

The work of connecting the incoming 415 volt, three phase supply cable to the consumer's electrical installation is carried out by the REC's engineer after the electrical installation is completed and tested. For a 240 volt supply to small premises a connection is made to one of the three phase wires through the REC's main cut-out fuse housed in a sealed box. The combined neutral and earth metal sheath conductor of the supply cable is connected to an earth connection block provided by the consumer. From the REC's main cut-out fuse and earthing block, short lengths of single core insulated cable are connected to the REC's meter.

Meter tails

The consumer's electrical engineer will have installed a consumer unit in some position close to the anticipated entry point of the supply cable. Connected to the consumer's unit will be two short lengths of single wire – insulated cable ready for the REC's engineer to connect to their meter. These cables are commonly termed 'meter tails', and should be as short as practical – no more than 3 m long. Because the overcurrent protection of these tails is provided by the REC's main cut-out fuse, they require a minimum cross sectional area of the wire to these cables to be rated to the capacity of their fuse. For single phase supplies a minimum cross sectional area of conductor to each tail is specified – 10, 16 and 25 mm^2 for main cut-out fuses of 60, 80 and 100 amp rating respectively. For security it is good practice to use the largest cross section area of cable to allow for fuse replacement errors.

Fig. 180 shows connections from a supply cable to a single phase consumer unit.

It is common today for the supplier's meter and cut-out fuse to be installed inside a metal meter case fixed externally to facilitate meter reading. The meter and fuse are housed in a meter box that should preferably be set in a recess in an external wall to provide some protection from rain. Meter tails are run from the consumer's unit, fixed internally, to the meter.

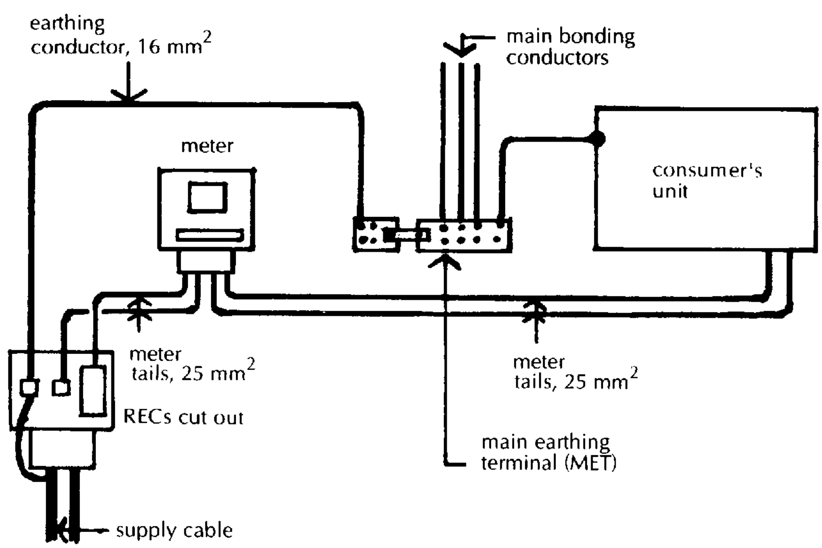


Fig. 180 Supply connections for a TN–C–S system.

ELECTRICAL DISTRIBUTION

Consumer's installation

A consumer's electrical installation for small premises, such as a house, begins at the connection of the meter tails to the REC's meter. From the meter a low voltage single phase, 240 volt supply is run to the consumer's installation, which includes a consumer's unit and the necessary separate circuits for lighting, heating and power.

A consumer's unit combines in one factory-made unit the necessary functions of a switch for isolation, circuit breaking devices (fuses) and distribution of supply to the various circuits. An earthing connection block is fixed adjacent to the consumer's unit. Fig. 181 shows the components of a consumer's unit.

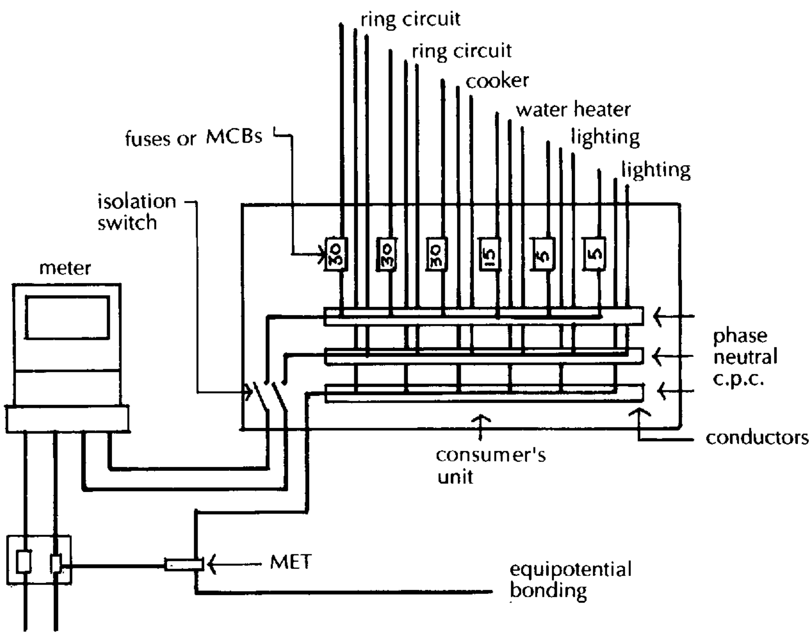


Fig. 181 Connections to consumer's unit and circuit distribution.

Isolation main switch

Isolation is the word used to describe the function of a device that effectively cuts off all voltages to the whole of an electrical installation or to a complete circuit, for the purpose of work to the installation, in case of fire and when premises are left unoccupied. For a single phase supply a double pole switch is included in the consumer's unit for safety, to make a break in both the phase (live) and neutral conductors by the operation of a manual switch.

Distribution

The three distribution conductors housed in the consumer's unit are connected separately to the phase and neutral of the supply and to the earth conductor made through the earth connection block. From the three distribution conductors the supply to each separate circuit is run from the phase conductor through an overcurrent protective device (fuse) and directly from the neutral and earth conductor to each circuit.

Main earthing terminal (MET)

To provide a means of connecting the earthing conductor of the TN–C–S supply cable to the means of earthing for the consumer's installation and to the main equipotential bonding, a main earthing terminal (MET) is included as part of the consumer's installation. The MET is made as two blocks of metal with a disconnectable link, as illustrated in Fig. 180. The disconnectable link is provided as a means of testing.

A conductor is run from the supplier's common earth and neutral conductor to the smaller MET block, and a conductor is run from the main MET block to the earth distribution in the consumer's unit. This provides the necessary earth connection to the various circuit protective conductors (cpcs), commonly called earth, to protect the installation against damage and danger of fire or shock to persons. Where there is a failure of insulation to a live conductor, and contact between the conductor and a conductive part of the installation, the circuit protective conductor provides an alternative path of least resistance for unpredicted currents to flow to earth.

One or more earth conductors are run from the main MET block to the extraneous conductors, such as metal water, gas, oil, and heating pipes, as main equipotential bonding. This bonding is shown as separate conductors in Fig. 186.

Overcurrent protective devices

In the phase (live) conductor to each circuit cable run from the distribution conductor, is a fuse or circuit breaker as protection against current greater than that which the circuit can tolerate. The purpose of these devices is to cause a break in a circuit as protection against damage to conductors and insulation by overheating caused by excessive currents.

Fuses

The fuse is the original form of overcurrent protective device which operates through a thin wire that is designed to overheat and rupture at a pre-determined maximum current, and so break the circuit. The three types of fuse in use are:

(1) Semi-enclosed rewirable fuse
(2) Cartridge fuse
(3) High breaking capacity (hbc) cartridge fuse

Semi-enclosed rewirable fuse

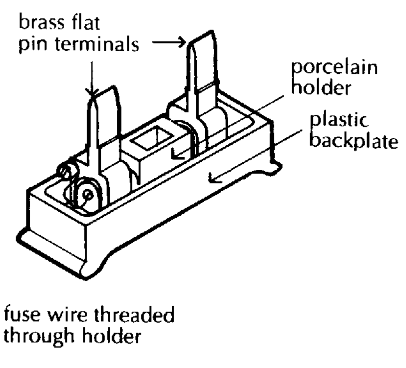


Fig. 182 Rewirable fuse.

The semi-enclosed, rewirable fuse (Fig. 182) consists of a porcelain fuse holder through which the fuse wire is threaded and connected to the two brass terminals. The fuse is pushed into position in the fuse block to make electrical contact. When the fuse wire has ruptured or blown, the holder is pulled out, a new fuse wire fitted and the fuse pushed back into place. This, the cheapest fuse available, has lost favour to the cartridge fuse and the circuit breaker which are easier to replace or reset.

The disadvantages of the semi-enclosed fuse is that the wrong type of wire may be fitted, and in time the wire may oxidise and not function as intended. Fuse wire is usually rated at 5, 10, 15 and 30 amp.

Cartridge fuse

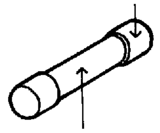


Fig. 183 Cartridge fuse.

A cartridge fuse consists of a fuse wire in a tube with metal end caps to which the wire is connected. The fuse wire is surrounded by closely-packed granular filler. When a circuit overcurrent occurs the wire heats, ruptures and breaks the circuit, the energy released being absorbed by the granular filler without damage to the fuse carrier. Fig. 183 shows a cartridge fuse.

These fuses are cheap, easy to replace by pressing into place between terminals and do not deteriorate over time. They are extensively used as circuit breakers in plug tops to provide protection to the flexible cable and moveable equipment connected to socket outlets. Cartridge fuses are made with ratings from 2 to 15 amps.

High breaking capacity fuse

The hbc (high breaking capacity) cartridge fuse consists of a ceramic tube with brass end caps and copper connecting tags to which the silver elements inside the tube are connected. The elements are surrounded by granulated silica filling to absorb the heat generated when the elements overheat, rupture and break circuit. These more sophisticated and expensive fuses are used for the more heavily loaded installations.

Circuit breakers

A circuit breaker is a thermal-magnetic, magnetic-hydraulic or assisted bi-metal tripping mechanism designed to operate on overload to break the connected circuit.

Miniature circuit breakers (MCBs)

Miniature circuit breakers (MCBs) are extensively used as protection against damage or danger resulting from current overload and short circuit in final circuits in buildings.

The simplest form of MCB consists of a sealed tube filled with silicon fluid in which is a closely fitting iron slug. When overload occurs the magnetic pull of the charged coil surrounding the tube causes the iron slug to move through the tube and trip the circuit breaker switch, which closes. To test or make the circuit it is only necessary to open the switch, which will remain open if the cause of the overload has been removed or will close if it has not.

The advantage of these circuit breakers is that there is no wire or cartridge to replace and the operation of a switch is all that is needed.

More sophisticated MCBs depend on thermo-magnetic trip operation. MCBs are factory moulded, sealed units available with terminals for plugging in or bolting to metal conductors in consumers' units. A range of ratings is provided to suit the necessary overload current ratings for particular final circuits.

The Wiring Regulations recommend disconnection times for overcurrent protective devices of 4 sec for connections to fixed equipment and 5 sec for portable and hand-held equipment.

Final circuits

Final circuits are the circuits of a consumer's installation that complete a circuit for the flow of current back to the supply neutral. For the low voltage, single phase alternating current usual for small premises, a small compact consumer's unit will provide distribution terminals for the number of separate final circuits used. Typical circuits for a house could be one or more ring main circuits and one cooker circuit, each with a 30 amp breaking capacity fuse or MCB and two or more lighting circuits each with a 5 amp fuse or MCB.

The purpose of segregating the various circuits is to afford economy in the cost of cables, the cross section of those with 5 amp fuses being smaller than those with a 30 amp rating. Fig. 181 shows a typical consumer's unit layout.

The length of each circuit is limited to provide an economical section of cable and to minimise the electrical resistance of the cable and the number of connections to each circuit, to limit overload current.

The two types of circuit that are used are the ring and the radial.

Ring circuit

Ring circuits are commonly used for socket outlets that provide electrical supply to portable equipment such as vacuum cleaners, electric fires, portable lamps and kitchen equipment, through a socket outlet and a plug top. The ring circuit (Fig. 184) makes a big loop or ring from one outlet to the next, round all the outlets and back to the consumer's unit, as the most economic and convenient cable layout.

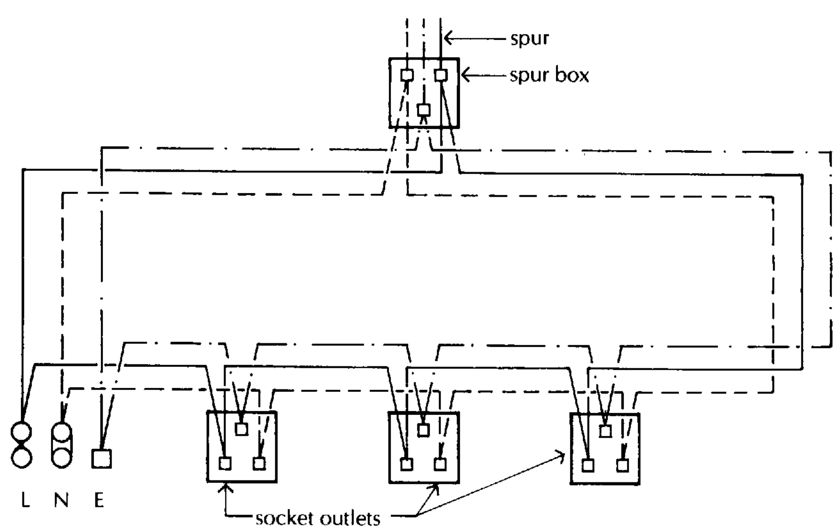


Fig. 184 Ring circuit.

The recommended maximum length of cable run depends on the cross section area of conductor chosen and the type of protective device used. While there is no recommended limit to the number of outlets served, it is recommended that a maximum of 100 m^2 of floor area be served by a ring circuit, protected by a 30 amp fuse or MCB in domestic premises.

The cable generally used for ring circuits is 2.5 m^2 conductor, twin and earth, PVC insulated and PVC sheathed cable.

Spur outlets

Where a socket outlet cannot be conveniently fed by a ring circuit a spur outlet may be run from the ring circuit. A spur outlet is connected through a joint box or spur box, as shown in Fig. 184. In effect the spur outlet is a radial circuit run off a ring circuit. There is no limit to the number of spurs which can be connected to a ring circuit other than a limit that there should be no more spur outlets than there are outlets fed directly off the ring. The cable to the spurs should be the same as that for the ring circuit.

Radial circuits

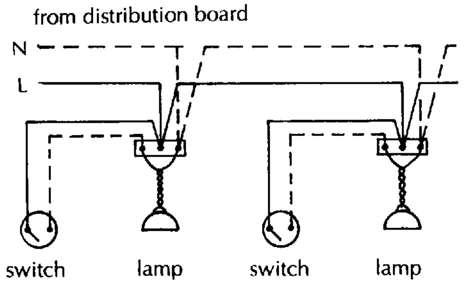


Fig. 185 Radial lighting circuit.

The circuit arrangement for lighting is generally in the form of radial circuits, each of which runs from the consumer's unit to its light fittings and back to the consumer's unit, as if radiating out. In each radial circuit the phase conductor runs in the form of a loop from the circuit through a switch back to the light fitting or fittings that the switch controls (Fig. 185). (For the sake of clarity the earth conductor is not shown in Fig 185.) By this arrangement the switch controls the fittings allocated to it without controlling the rest of the light fittings connected to the circuit.

The radial circuit is adopted for individually switch controlled light fittings as the most convenient and economical means of running cables. Where one switch is used to control several light fittings the circuit may be run as a ring circuit off a radial circuit, or as a ring circuit by itself, whichever is the most convenient.

A 5 amp fuse or MCB is connected as overcurrent protective device to the phase wire run out from the consumer's unit. The cables are run in 1.5 mm^2 conductor, twin and earth, PVC insulated and PVC sheathed cable.

To limit current flow to suit the fuse or MCB and cable size, there are usually two or more separate lighting circuits to most small installations such as those for a house.

Safety requirements

For safety the Wiring Regulations (BS 7671) recommend good workmanship in the running of cables to avoid damage to insulation and conductors, and the making of connections and sound judgement in the selection of materials to prevent danger from shock to persons and the possibility of fires from overheating of conductors due to current overload by short circuit.

Short circuit

A short circuit is, as the words imply, a fault in a circuit where a live conductor comes into contact with another, by breakdown of insulation to provide a path of least resistance to flow with consequent greater current than allowed for in the circuit design. A short circuit may cause overheating of conductors and breakdown of insulation and so damage the installation. It is to limit such occurrences that overcurrent protective devices, such as fuses and MCBs, are fitted.

Earthing

The Wiring Regulations (BS 7671) include recommendations for protection against the dangers of electric shock to persons or livestock, damage to installations and the danger of fire from overcurrents and earth faults. Earth faults occur when a live conductor makes contact with a conductive part of the installation, or extraneous conductive parts such as metal service pipes, and current flows to the neutral mass of earth. The earth conductor in cables and the earthing connections to conductive metals provide an alternative path for unplanned flows of electrical energy.

Electric shock

Electric shock to persons is differentiated as direct contact and indirect contact.

Direct contact

Shock from direct contact is caused when a person comes into contact with a live electrically charged part which causes a current to flow through them to earth. This is likely to cause injury which may be fatal.

It is generally accepted that a voltage over 50 may be fatal. Such heavy current flows, which are in effect short circuits, will, within 4 or 5 secs, cause protective devices to break circuit. Direct contact with a properly designed installation is unlikely.

Indirect contact

Indirect contact occurs when contact is made with an exposed conductive part of an electrical installation, such as the metal casing to an electric fire, which is not normally live but may have become so under earth fault conditions caused by contact of a live conductor with a metal casing due to insulation failure. The third conductor, the circuit protective conductor (cpc), is included in circuits and connected to metal casings to electric fires to serve as a conductor to earth for such unpredicted currents.

With the generally used TN–C–S system of supply cables, the earth (cpc) conductor of an installation is connected to the combined neutral earth of the supply cable, which may not provide a wholly satisfactory path to earth. It is generally necessary, therefore, to provide other earth paths through earth electrodes connected to the installation's earthing block.

It was practice for many years to make a connection to earth through a metal service pipe entering the building from underground. With the now common use of plastic pipework for service pipes, such as gas and water, this is no longer accepted as a satisfactory earthing arrangement.

Main equipotential bonding

The Wiring Regulations (BS 7671) require that all extraneous conductive metal parts, which are not part of an electrical installation, be connected to the main earthing terminal (MET). This earth bonding is provided as protection against the possibility of conductive metal outside (extraneous) the electrical installation becoming live due, for example, to failure of insulation of a cable run close to a heating pipe, making a live connection to the pipe. The conductive metals included are water, gas, oil, heating and hot water pipes, radiators, air conditioning and ventilation ducts, which should be earth bonded as illustrated in Fig. 186.

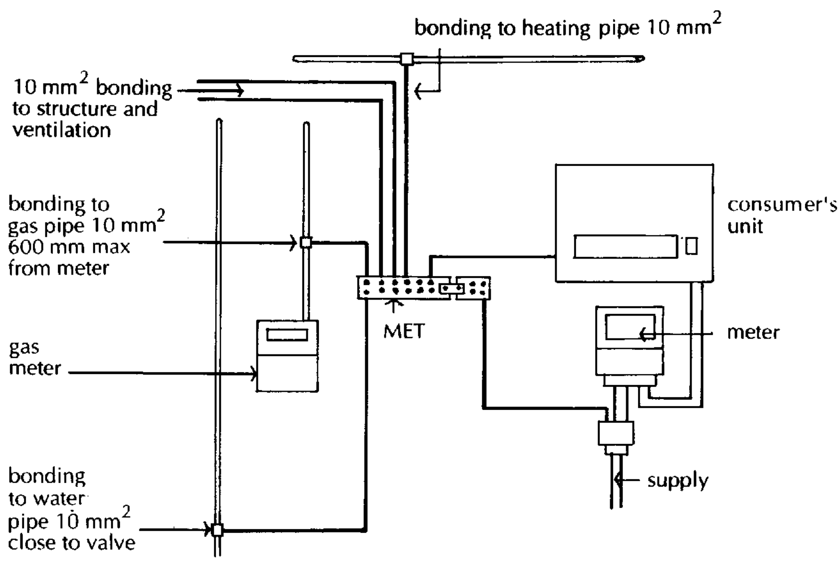


Fig. 186 Equipotential bonding.

Cross bonding

The purpose of equipotential bonding is to co-ordinate the characteristics of protective devices with earthing and the impedance (resistance) of the circuit to limit touch voltages until the circuit protective devices cause disconnection.

Because of the introduction of plastic pipes, connections and plastic coatings to metal, it may be necessary to provide earth bonding connections across plastic used as part of a whole system, where good sense indicates the possibility of indirect contact being made to metal that might become live.

Supplementary equipotential bonding

It is a requirement of the Wiring Regulations (BS 7671) that supplementary equipotential bonding be provided to all simultaneously accessible, exposed conductive parts in special conditions of wet activities and high humidity, such as bathrooms and swimming pools, where the moisture in such conditions provides additional risks due to the conductivity of water.

The term 'simultaneously accessible' in relation to exposed conductive parts means the possibility of someone, for example in a bath of water, reaching out to touch a heated, metal towel rail and so providing a conductive path from the metal bath to the towel rail, through their body. If the towel rail and its pipe connections had become electrically charged, due to a breakdown of insulation to a cable in contact with the pipes, there would be a possibility of shock to the individual. The purpose of supplementary bondings is to spread the voltage potential across and between other adjacent bonded metal parts to equalise and so limit the voltage potential to that least likely to cause injury or death in the few seconds before circuit breakers come into operation.

A bath, in which someone is immersed in water, is considered the appliance most requiring supplementary bonding between metal pipes and a metal waste pipe, as shown in Fig. 187. Bonding to a basin is required between metal hot and cold water pipes and a metal waste pipe. Similarly a metal supply pipe to the cistern of a WC should be bonded to a metal waste pipe.

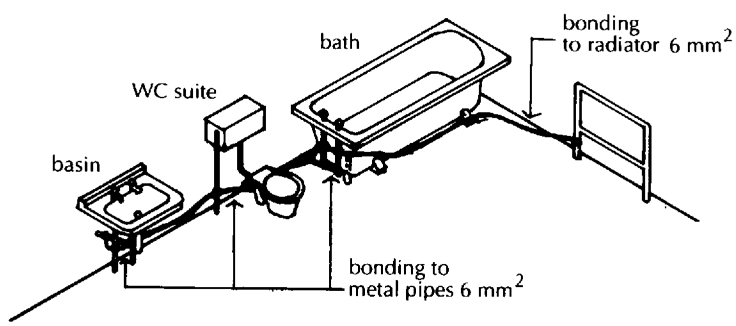


Fig. 187 Supplementary equipotential bonding.

To complete the supplementary bonding between all simultaneously accessible exposed conductive parts, there should be bonding between the cross bonding to a bath, basin, WC and a radiator. This connecting bonding may be effected by a conductive pipe that provides a link to sanitary fittings. Where there is no satisfactory conductive link by pipework, conductive bonding should be connected to all bonded fittings and connected to the radiator as a terminal.

To effect supplementary bonding a conductor, preferably of copper, should be connected between simultaneously accessible, exposed conductive parts by means of pipe clamps, through which the conductor should run continuously. The bonding conductor may be of bare copper or insulated copper, the lowest cross sectional area of which should be $4\,mm^2$.

Because it is a requirement that supplementary bonds be accessible for inspection and testing, there may well be some untidy exposed conductors and pipe clamps which cannot be behind removable bath panels or basin pedestals.

Supplementary bonding is only necessary where there are exposed and simultaneously accessible metal parts. It would be futile to bond to plastic pipework and covered metal pipework.

CABLES AND CONDUITS

Cable for final circuits

VIR cable

Vulcanised india rubber (VIR) cable was extensively used for final circuits before PVC cable was first produced. The VIR cable consists of an inner layer of rubber around tinned, copper wires with an outer coating of vulcanised rubber. The rubber outer coating of this cable becomes brittle with age and fails, requiring replacement after some 20 years. It was often run inside metal conduit from which old cable could be withdrawn and new cable pulled through. This type of cable has largely been replaced by PVC cable.

PVC cable

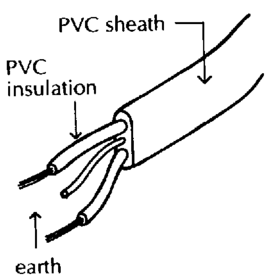


Fig. 188 PVC insulated, PVC sheathed cable.

The cable most used today for wiring to final circuits is PVC cable, either as PVC insulated, PVC sheathed cable or PVC insulated cable. In the former the phase and neutral copper wires are each separately covered with PVC as insulation and then all are surrounded with a PVC protective sheath in which the earth (cpc) copper conductor is enclosed, as shown in Fig. 188. The outer PVC sheath is for protection against damage during installation. PVC insulated cable comprises a copper conductor wire insulated with PVC. This is for use when the cable is protected by the conduit in which it is run.

PVC (polyvinyl chloride) is a tough, incombustible, chemically inert plastic which is an effective insulator that does not deteriorate during the useful life of most installations.

PVC twin and earth

The cable most used for final circuits to 240 volt, single phase supplies is PVC insulated, PVC sheathed cable commonly described as PVC twin and earth, describing the phase and neutral insulated conductors and the earth in the sheath. The size of the cable is defined by the cross sectional area of the copper wires – 1.5 mm^2 or 2.5 mm^2 for lighting and socket outlet circuits respectively.

For 415 volt, three phase supplies a three core PVC insulated and sheathed cable is used.

Protection

The Wiring Regulations (BS 7671) provide extensive recommendations on measures to be taken to minimise damage to cable during installation and in use. These may be broadly grouped under the headings mechanical damage, temperature, water and materials in contact including corrosive materials.

Mechanical damage includes precautions to avoid damage during installation, such as drilling holes in the centre of the depth of floor joist for cable runs rather than using notches in the top or bottom of joists where subsequent nailing might damage cable.

At comparatively high and low temperatures plastic may soften or become brittle respectively, and so weaken. At temperatures above 70°C plastic will appreciably soften, and below freezing will become noticeably brittle and crack.

Water, both as liquid and in vapour form, in contact particularly with terminals, may act as conductor between live and live and live and earth conductors.

To protect cables from damage by corrosive materials such as cement, cables run in plaster, concrete and floor screeds should be protected by channels or conduit.

Mineral insulated metal sheathed cable

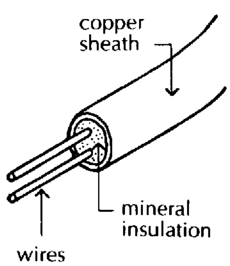


Fig. 189 Mineral insulated copper sheathed cable.

This type of cable consists of single-stranded wires tightly compressed in magnesium oxide granules, enclosed in a seamless metal sheath of copper or aluminium, as shown in Fig. 189. The combination of the excellent insulation of the magnesium oxide and the metal sheath gives this cable an indefinite life and reasonable resistance to mechanical damage. For added protection the metal sheath may be protected with a PVC sheath.

Because of the high initial cost of the cable and the various fittings and seals necessary at bends, junctions and terminations, the use of this cable is confined to commercial and industrial installations where the cost may be justified. The metal sheath may serve as the earth (cpc) conductor.

Channels

Channels of plastic or galvanised steel, generally in the form of a hat section, are used to provide PVC cable, which is to be buried in plaster, with protection and to secure the cable in position while the plaster is being spread. The brim of the hat section is tacked to the wall surface around the cable. These sections which are used solely as protection do not provide a ready means of pulling cable through when replacing cable.

Conduit

Round or oval section plastic or galvanised steel sections are used as protection where PVC cable is to be run in plaster, solid floors, walls and roofs. Conduit is used to provide all round protection, particularly where the cheaper PVC insulated cable is used, and to provide a means of renewing and replacing cable by drawing cable through the conduit. Because of the bulk of the conduit it is generally necessary to form or cut chases (grooves) in wall surfaces and solid floors and roofs where screeds are insufficiently thick to accommodate the conduits.

Plastic conduit

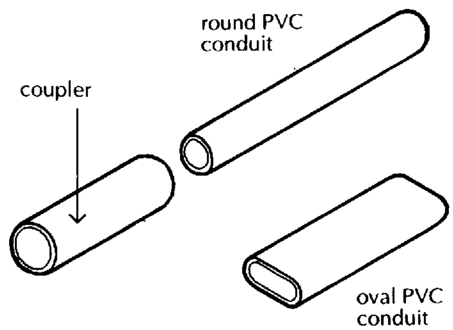


Fig. 190 PVC conduit.

Plastic conduit, which is considerably cheaper than metal conduit, is made in round or oval sections (Fig. 190). Round section conduit which can be buried in thick screeds has to be fixed in a chase or groove in walls. Oval section conduit can be buried in thick plaster finishes and thin screeds.

Lengths of conduit are joined by couplers, such as the one shown in Fig. 190, into which conduit ends fit. A limited range of elbows and junctions is made for solvent welding to conduit. The conduit is secured with clips that are tacked in position. There is some facility for pulling through replacement cable, but not as much as with metal conduit.

Because it is made from plastic, the conduit will not serve as earth conductor, as does metal conduit.

Metal conduit

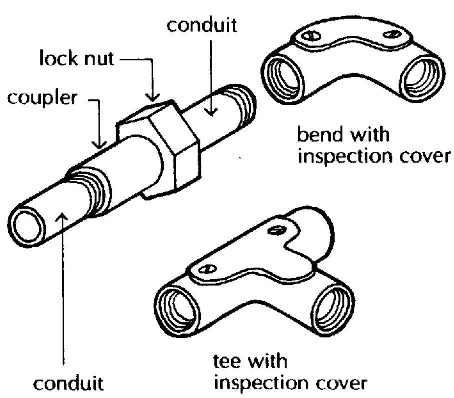


Fig. 191 Steel conduit.

Metal conduit is manufactured as steel tubes, couplings and bends which are either coated with black enamel or galvanised. The cheaper black enamel conduit is used for cables run in hollow floors and roofs and other dry situations. The more expensive galvanised conduit is used where it is buried in concrete floors, roofs and screeds and for chases in walls below plaster finishes where wet finishes might cause rusting if black enamel conduit were used.

Fig. 191 shows a steel conduit. The nominal bore of the conduit is its outside diameter, a range of sizes being produced.

Light and heavy gauge steel conduit is made, light gauge with push-fit connections and heavy gauge with screwed connections. The cheaper light gauge conduit does not provide as positive conductive connections as the heavy gauge, as earth conductor. Heavy gauge conduit is for use in concrete floors, walls, and roofs, where it provides protection against damage during the process of placing and compacting wet concrete.

Metal conduit is produced with a variety of fittings designed to facilitate pulling out old cable and replacing it with new. The access or inspection covers to the bend and tee, shown in Fig. 191, are for pulling through.

Because the conduit is of conductive metal it may serve as the earth (cpc) conductor, and single PVC insulated cable may be used as the conduit provides protection against damage.

Trunking

Where there are extensive electrical installations and several comparatively heavy cables follow similar routes, with standard conduit too small to provide protection, it is practice to run cables inside metal or plastic trunking to provide both protection and support for the cables.

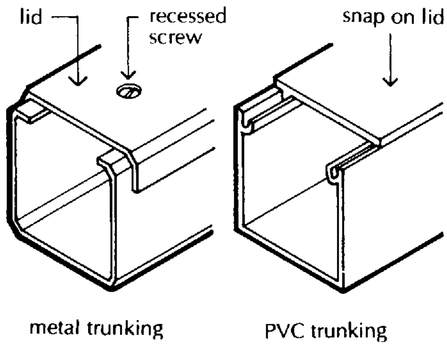


Fig. 192 Metal trunking.

Trunking is fixed and supported horizontally or vertically to wall, floor or ceiling structures, or above false suspended ceilings, with purpose-made straps secured to the structure. Trunking is run inside ducts for vertical runs and above false ceilings where appearance is a consideration or exposed in commercial premises. Trunking may be hollow, square, rectangular, circular or oval in section. Square or rectangular sections are usually preferred for convenience in fixing to walls or ceilings.

Fig. 192 is an illustration of square trunking with access for inspection and any necessary renewal or alterations. A range of square and rectangular trunking sizes is made, together with elbows, tees and gusset fittings. Large trunking systems are usually purpose-made from galvanised steel sheet to suit particular needs.

OUTLETS

Socket outlets

Socket outlets are so called because they comprise sockets in a wall-mounted front plate into which the terminals of a loose plug top fit to supply electricity to a wide range of moveable, portable and hand held electrical equipment.

Socket outlets are usually connected to a ring final circuit, there being no limit to the number of sockets connected to each ring circuit, which should not serve an area greater than $100\,m^2$ for domestic installations. A ring circuit is protected by a 30 amp fuse or MCB at the consumer unit.

A socket outlet consists of a galvanised steel box to which a front plate is screwed after the terminals of the front plate have been connected to the electric supply cable. The galvanised, pressed steel boxes are made with circular knockouts, which can be removed for cable entry, and lugs for screws to secure the plastic front plate. Steel boxes are usually made for recessing into a wall and plaster and others for surface fixings.

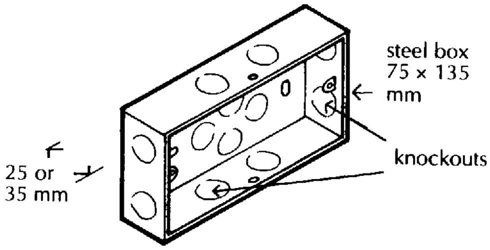


Fig. 193 2 gang steel box.

Fig. 193 shows a recessed steel box for a two gang, two plug top outlet. Steel boxes for surface fixing have a smooth faced finish with the knockouts for cable entry and holes for fixing screws in the back of the box. Fig. 194 shows a steel box for surface mounting.

Front plates to socket outlets are moulded from plastic to suit single, double or multi-gang plug top outlets, complete with sockets for square three pin plug tops. Brass terminals for the phase, neutral and earth conductor cables are fixed to the back of the front plate, and it is holed for two screws for fixing to the steel box. Socket outlets may be supplied with a switch and a pilot light to indicate the 'on' position. Fig. 195 shows a single outlet front plate, with optional switch and pilot light and a plug top.

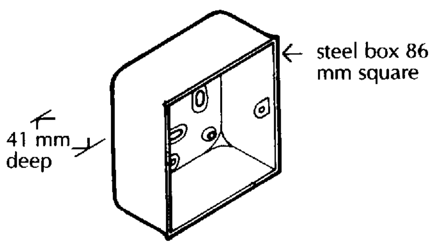


Fig. 194 Steel box for surface mounting.

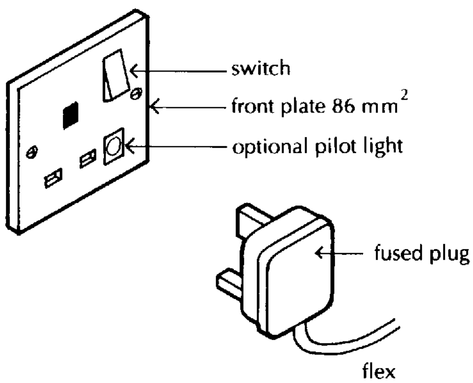


Fig. 195 13 amp outlet and plug.

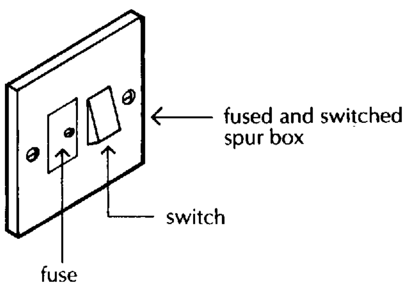


Fig. 196 Spur box.

Many socket outlets are connected to a ring circuit which is protected with a 30 amp fuse or MCB at the consumer unit. It is necessary to fit a cartridge fuse to the plug top to provide current overload protection to the flexible cord and appliance connected to the outlet. Fuses to plug tops to outlets vary from 2 or 4 amps for lighting to 13 amps for electric fires.

Where there is a spur branch to a ring circuit a spur box is fitted to provide a connection for the spur cables and to protect and control the spur outlet. A spur box consists of a steel box and plastic front plate in which is a fuse and a switch (Fig. 196). The terminals at the back of the front plate serve to make connection of the spur cables.

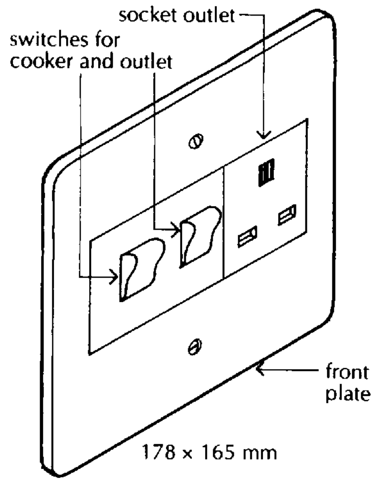


Fig. 197 Cooker control unit.

To suit the wide range of electrical equipment in use today, multi-gang socket outlets are common, particularly in kitchens and where electronic equipment is located. Multi-point socket outlet units with up to six outlets are available for fixing to kitchen worktops, test benches, laboratories and computer desks. These units, which are connected to a ring circuit outlet, can be fixed in position. They can be moved to another location if need be.

The electrical supply to a cooker with hobs, grill and oven requires a high fuse rating and cables. A separate radial circuit is run from the consumer's unit to the electric cooker, and protected by a 30 amp fuse or MCB in the consumer's unit. A wall mounted cooker control unit is fixed close to the cooker. This control unit consists of a recessed steel box and plastic front plate in which a single switch or two switches and a socket outlet are provided, as shown in Fig. 197. The socket outlet in the cooker control unit is for such portable equipment as an electric kettle. The two switches control the cooker and the socket outlet.

Lighting outlets

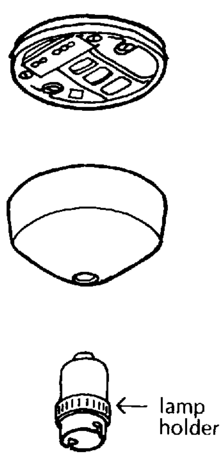


Fig. 198 Ceiling rose and lampholder.

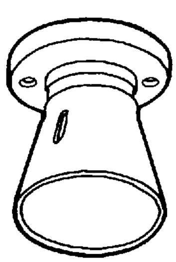


Fig. 199 Batten lampholder.

Lighting outlets may be connected to a radial circuit for ceiling and wall lights, where one or a few lighting fittings, recently termed luminaires, are controlled by a wall switch, or they may take the form of socket outlets for portable table lamps, connected to a ring circuit or one or more radial circuits depending on the number of outlets and convenience in wiring.

The traditional ceiling light, which was common for high ceilings, consisted of a ceiling rose screwed to the ceiling, from which a pendant cable dropped supporting a lamp holder fixed at some convenient height. The ceiling rose was connected to a radial circuit protected by a 5 amp fuse in the consumer unit, with a loop down to a wall switch which controlled the ceiling light. Fig. 198 shows traditional ceiling light with ceiling rose and lampholder.

Because a pendant lamp is unsuited to the lower ceiling height of most modern domestic buildings, a batten lampholder may be used for single ceiling lamps or one of the many lighting fittings designed to fit closely to ceilings.

The batten lampholder shown in Fig. 199 is assembled as a single unit with the lampholder close to the ceiling. The three cables, phase, neutral and earth, are connected to the terminals in the base, which is screwed to the ceiling. The lampholder is screwed to the base and the lampholder cover screwed around the lampholder.

Lighting outlets may be connected to a radial circuit for ceiling and wall lights where one or a few fittings are controlled by a wall switch, or a ring circuit where several portable lights, such as table lamps, are plugged into socket outlets and controlled by a common switch.

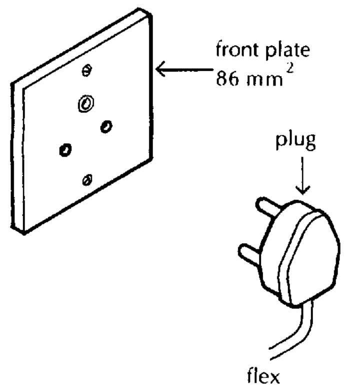


Fig. 200 2 amp outlet and plug.

Fig. 200 shows a front plate and plug top for a lighting outlet for portable lamps. The face plate is screwed to a steel box set in plaster finish just above floor level. The three pin plug top is connected to the flexible cable to a light fitting.

The conventional ceiling and table lamp illumination, by traditional incandescent filament lamps, is still much favoured as domestic lighting for the so called 'soft effect' of such shaded light, which does not show sharp contrast of light and shade.

Of recent years the more intense lighting systems used for display purposes in shops and showrooms have been used in the home for kitchen and general lighting. Systems of 'downlighting' have been used, consisting of a number of lights recessed into ceilings and systems of 'spotlighting', using lamps fixed to tracks in the ceiling, which may be adjusted to light a particular area.

Wall switch

A wall switch is generally recessed in a wall, partition or plaster depth for appearance sake. A galvanised, pressed steel box is set into a recess in the wall after knockouts have been removed for the cable entry. The three conductors, phase, neutral and earth, are connected to the terminals set into the back of the plastic front plate, which is then screwed to lugs in the steel box.

Fig. 201 shows a single gang switch, with steel box and plastic front plate.

For small rooms a single switch inside the access door or opening is generally sufficient for ceiling and wall lighting. For large area rooms it is often convenient and economical to use two or more circuits, each with its own wall switch, so that a part of, or the whole of, the room may be illuminated.

For staircases a system of two-way or three-way switching to a circuit is used to control the lighting on upper and lower floors as necessary. The system of two way or three way switching involves

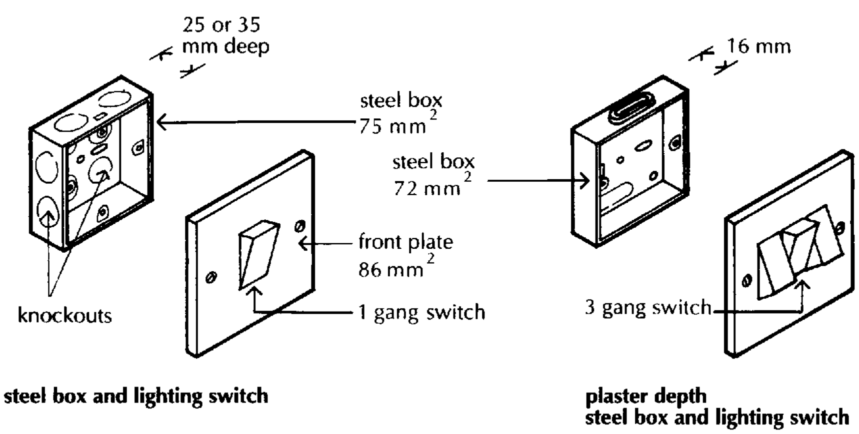


Fig. 201 Wall switches.

additional wiring to provide the means of switching from two places. Fig. 201 is an illustration of a steel box and plastic front plate for a three gang switch.

Clock connector box

Wall mounted electrically operated clocks which consume little electricity are usually connected to a radial lighting circuit which is protected by a 5 amp fuse or MCB at the consumer unit. The clock is connected through a fused connector box which comprises a steel box and plastic front plate. The connector and fuse are housed in a separate plate screwed to the front plate (Fig. 202).

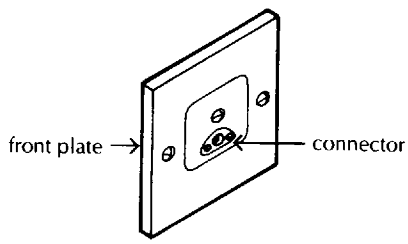


Fig. 202 Fused clock connector box.

7: Gas Supply

GAS AS A FUEL

Town gas

Town gas, first produced in 1812, is the combination of combustible gases from the carbonisation (heating) of coal. Each town had its own gasworks and gasholders supplying gas for lighting, cooking and heating – hence the name town gas. A byproduct of the heating or carbonisation of coal to produce town gas was coke, which was extensively used as a cheap fuel for heating.

With the introduction of electricity the demand for gas declined. During the first half of the twentieth century there was keen competition between the suppliers of gas and electricity to the advantage of the consumer. The advantage of a lighting and heating source at a competitive rate at the touch of a switch led to the changeover from gas to electricity, first for lighting and later for domestic heating. The manufacture of town gas required a large site, a ready source of high quality coal and a considerable labour force, all of which were becoming increasingly scarce and expensive.

Natural gas

Natural gas, first imported from North Africa in 1964 and supplied to consumers has since 1968 come from the North Sea fields which, it is estimated, have known reserves sufficient for current and future consumption well into the twenty-first century.

Natural gas, which is mainly methane, has twice the calorific value of town gas and is a high grade controllable fuel eminently suited to both domestic and commercial uses for heating. Since the introduction of natural gas, its use by industry and commerce has increased fourfold.

Unlike town gas, natural gas is nontoxic and as it is odourless, additives give warning of leaks by their distinctive smell. Natural gas is delivered to the consumer at pressures two to three times greater than town gas and in consequence pipes about half the bore of those needed for town gas can be used.

Since 1968 most town gas burning appliances have been converted to use natural gas and all new appliances are designed to burn natural gas. The conversion of appliances was effectively completed in 1976.

Combustion of gas

For the ignition and subsequent combustion of natural gas (methane), a supply of oxygen and a gas temperature of about 700°C is necessary.

In gas-fired cookers, fires and boilers the necessary oxygen is taken from an intake of air which is drawn into the combustion chamber or zone, mixes with gas, is ignited and burns to complete combustion.

By-products of combustion

The products of the complete combustion of gas are carbon dioxide and water vapour which are expelled, due to the pressure of combustion and the intake of air, to outside air by flues or by convection.

Lethal carbon monoxide

Where there is an insufficient intake of air to provide oxygen for the complete combustion of gas, the by-product will contain carbon monoxide, a gas that in very small quantities is lethal and can cause death in a few minutes.

Conditions for optimum combustion

The design of gas burning appliances is concerned primarily, therefore, to provide an optimum mix of gas (methane) and air for complete combustion for both efficiency in the use of fuel, safety, adequate convection currents for the intake of air and the evacuation of the by-products of combustion.

GAS SUPPLY

Service pipe

Gas is supplied under pressure through the gas main from which a branch service pipe is run underground to buildings. The service pipe is laid to fall towards the main so that condensate runs back to the main, where it is collected in buckets.

Where the consumption of gas is high, as in commercial and other large buildings, a valve is fitted to the service pipe just inside the boundary of the site to give the supplier control of the supply, for example in the case of fire. Domestic service pipes are run directly into the building without a valve at the boundary, and the meter valve or cock controls the supply.

The gas service pipe must not enter a building under the foundation of a wall or loadbearing partition, to avoid the possibility of damage to the pipe by settlement of the foundations. Gas service pipes running through walls and solid floors must pass through a sleeve so that settlement or movement does not damage the pipe. The sleeve is usually cut from a length of steel or plastic pipe larger than the service pipe which is bedded in mastic to make a watertight joint.

Gas meter installation

The service pipe connects to the supply pipe through a gas meter installation which comprises a cock or valve governor, filter and a meter, for domestic premises, with the addition of a thermal cut-out and non-return valve for larger installations.

Where possible, domestic meter installations are outside the premises in a position affording shelter, such as in a basement area under steps, or in a box or housing giving shelter. The advantage of fitting the meter outside is that it is naturally ventilated and in a position where the meter reader can gain access when the occupier is out.

Meter installations to large premises are often in a purpose-built meter house.

Gas cock (valve)

A gas cock to control the supply from the service pipe to the governor and meter consists of a solid plug that in the shut position fills the bore of the cock, and in the open position only partly obstructs the flow of gas. The gas cock is operated by a hand lever, as illustrated in Fig. 203. When the lever is in line with the service pipe the cock is open, and when it is at right angles to the pipe it is closed.

The connection of the gas cock to the pressure governor is made with a short length of semi-rigid stainless steel tube which can accommodate any movement between the service pipe and meter which might otherwise damage the meter. The semi-rigid tube is illustrated in Fig. 203.

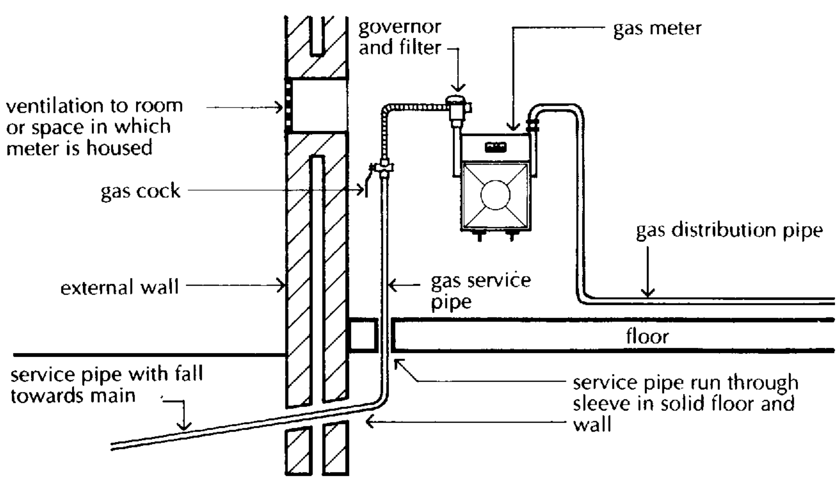


Fig. 203 Gas supply.

Pressure governor and filter

For domestic installations a combined pressure governor and filter is fitted at the connection of the service pipe to the meter, as illustrated in Fig. 203, and a separate governor and filter are used for larger installations. The fine mesh filter is fitted to collect pulverised particles of rust and metal which are carried along the main by gas. But for the filter these fine particles might clog gas jets to gas burning appliances.

The governor is a spring-loaded diaphragm valve, the function of which is to reduce the pressure of gas in the main to a pressure suited to gas burning appliances. The governor reduces mains gas pressure to 20 to 25 mbar standing pressure.

Gas meter

The meter illustrated in Fig. 204 is the traditional tin case gas meter. The light gauge tin case contains bellows that fill with gas through a valve and then discharge gas to the distribution pipe so that the movement of filling and emptying operates the meter that records the volume of gas supplied. As the meter records the volume of gas supplied it should not be near to a heat source otherwise the consumer will be paying for the heated and therefore greater volume of gas. Because of the flimsy construction of the tin case meter, it is practice to make connections of service and distribution pipes with either a semi-rigid stainless steel tube or a short length of lead pipe which can take up any movement and so prevent damage to the meter. Semi-rigid and lead pipe connections are illustrated in Fig. 204.

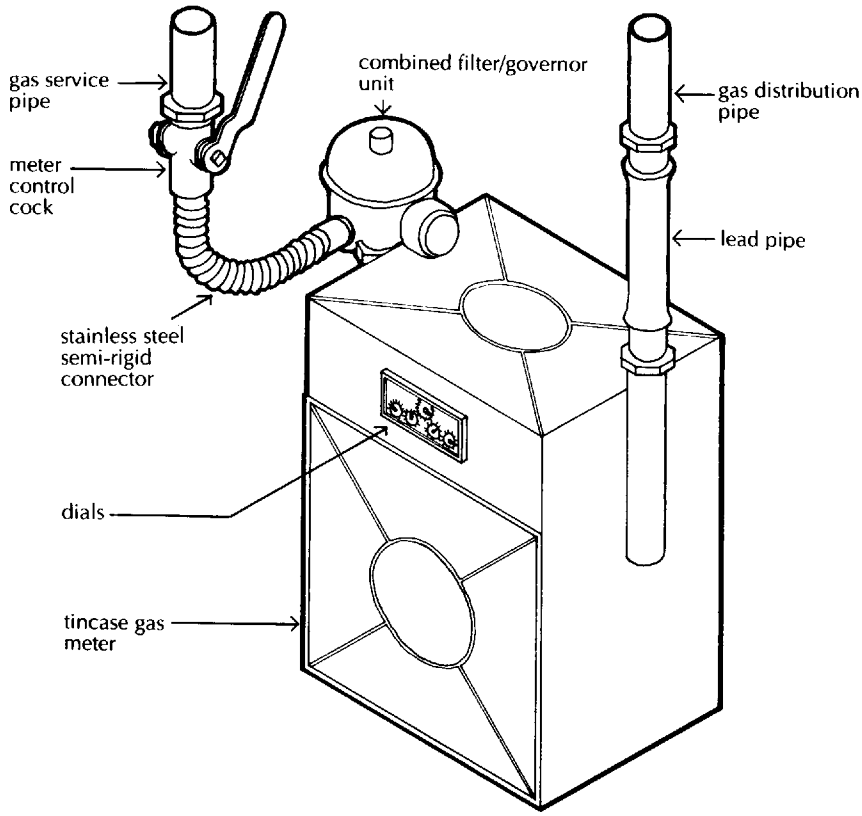


Fig. 204 Domestic gas meter installation.

Because both the pressure at which it is delivered and the calorific value of natural gas are higher than that of town gas, an appreciably smaller meter is used. These rigid steel case meters which contain compact bellows may be up to half the size of the old tin case meter illustrated in Fig. 204. Because of the greater rigidity of the steel case it is practice to make the service pipe connection with a semi-rigid tube and the distribution pipe with a rigid connection.

Where gas consumption is large a rotary displacement meter is used.

Meter box

It is practice today to fit gas meters in some position on an outside wall where there is access for meter reading. A metal meter box is fixed either on an external wall face or fitted to a recess in a wall to give some protection from weather. In this position the meter control cock or valve is more available for access in emergencies such as fire, than it is indoors.

Where interruption of the gas supply for maintenance, repair or replacement of the meter or governor is unacceptable, as in hospitals and some industries, it is usual to install a meter bypass. A bypass is a length of pipe connected directly between the service pipe and the distribution pipe to bypass the meter. There should be a separate gas cock, governor and filter in the bypass so that the meter cock may be closed for maintenance or repair work and the bypass cock opened meantime to continue the supply.

The room or space in which a gas meter is installed should be permanently ventilated to the open air against escape of gas and build up of heat. A small air brick or vent suffices for most domestic installations and ventilation equivalent to 4% of the floor area for larger installations.

PIPEWORK

The gas pipes which are run from the meter to supply the various appliances may be described as supply pipes. Commonly the system of pipes is described as a gas carcass and the work of running the pipes as gas carcassing.

The traditional pipework for gas carcassing for town gas was mild steel tubulars with a natural steel finish, as galvanised coatings are adversely affected by gas. Because of the lower calorific value of town gas and the larger volume of gas required, large bore pipes were used.

Today, because of the smaller bore of pipes required and labour saving convenience, copper tubulars are used for most small gas installations. Capillary or compression fittings at connections are used in the same way that water pipework is run.

Pipe sizes

For safety the size or bore of pipe used for gas carcassing should be adequate to deliver the necessary pressure of gas to each appliance. If the pipe is undersize, too low a pressure of gas at appliances may result in incomplete combustion and development of carbon monoxide, or there may be a flashback into pipework and an explosion may occur.

The required size of pipe from the meter and the branches to each fitting, such as cooker, boiler and gas fire, depends on the volume and pressure necessary and the frictional resistance of the pipes and fittings to flow.

The necessary sizing of pipework in a particular gas carcassing installation can be assisted by a simple line isometric diagram similar to that described for water pipe calculations, where dimensions of pipe lengths are shown and each identified by a letter. From this the actual length and additional length allowance for fittings is determined, to give an effective length and resistance to flow. A possible pipe size is assumed and checked against pressure loss, to provide adequate supply to appliances. The procedure for gas pipe sizing is similar to that for sizing water pipes.

Testing pipework for leaks

Newly installed gas carcassing may be tested for leaks before the pipework is connected to appliances. This involves capping off open ends of pipe. More usually pipework is tested after the gas burning appliances are connected and their supply shut off by closing gas cocks on each appliance. The pipework may be tested either before or after the meter has been installed.

The procedure for testing after the meter has been installed is to turn off the main gas cock and all gas appliances and pilot lights. The screw of the test nipple, on the outlet of the meter, is removed and a pressure gauge or manometer is connected to the nipple. The main gas cock is slowly opened to let gas into the pipework until a standing pressure of 20 to 25 mbar is indicated on the manometer. The gas is turned off at the main cock, and after a wait of one minute, over the next two minutes the pressure indicated on the manometer should show no drop in pressure greater than 4 mbar, for domestic installations.

If the pressure drops below the 4 mbar limit there is a leak, which can be indicated by leak detection liquid which, when sprayed around a leak, will bubble to indicate the position of the leak.

Purging

Purging is the operation of evacuating all air which has entered when the pipelines are first installed and when the gas is turned off for maintenance and repairs.

The purpose of purging gas pipelines of air is to avoid the possibility of gas mixing with air in the pipelines. Were this to occur and the jets to appliances ignited, the mixture of air and gas in the pipeline might also ignite and cause an explosion.

Air is purged by opening the main control cock and the cock to an appliance to cause the gas entering under pressure to force out all air. The gas is allowed to flow until there is a distinct smell of gas when the appliance or burner cock is closed. During this operation windows are opened and naked flames and electric sparks are avoided until the escaped gas is dispersed.

FLUES

Flues to gas burning appliances

The by-product of the combustion (burning) of gas and air is heated gases that will rise by natural convection. The purpose of a flue or ventilation system is to encourage the heated gases to rise, by convection or by force of a fan to outside air. Where the heated gases do not have a ready, adequate escape route to outside, they will mix with inside air.

On mixing with inside air the water vapour in the gases will cool to form condensation on cold surfaces, and the interruption to steady convection currents may cause incomplete combustion of gas and the mixing of small amounts of poisonous carbon monoxide gas with inside air.

Open flue appliances

Open flue appliances depend for their operation on an intake of air directly from the room or enclosure in which they are fixed. To this end there must be a permanent opening to outside air through which adequate air may be drawn to replace that drawn in by the appliance.

Ventilation

Where the permanent ventilation does not allow sufficient replacement air to enter the room, inefficient combustion may occur due to reduction of air pressure in the room and that may cause discomfort to the occupants and possible entry of poisonous carbon monoxide gas.

The inclusion of effective draught seals to windows and doors in modern buildings severely restricts the entry of adequate outside air to replace that required for combustion where there is insufficient positive permanent ventilation.

Natural convection flues

Natural convection flues depend for their operation on the natural draught or pull of heated gases rising from heating appliances. Heated gas expands and rises naturally to replace cooler more dense air. It is the function of flues to encourage heated gases to rise vertically from heating appliances to outside air. In general the higher a flue rises the greater the draught or pull of hot gases will be. Plainly a flue should rise directly with as little change of direction from the vertical as is practical.

Size of flue

There is an optimum size of flue to provide the best draught. The best cross sectional dimensions of a flue depend on the output from a heating appliance and the volume of air required for combustion of a particular appliance.

Draught diverter

A vigorous draught of gases up a flue is encouraged by draught plates and hoods over open flued boilers, gas fires and open fires. These draught diverting plates and hoods are designed to direct the heated combustion gases up the flue and to divert unwanted draughts of air away from the combustion chamber.

Existing brick or block built flues

Where gas burning appliances are fitted in existing buildings it is common to use an existing open fire brick flue as the flue to the new appliance. The flue is first swept to clear loose, friable material such as soot and broken brick or mortar, and the draught up the flue is tested with a burning oily rag or a smoke producing device to test the draught caused by the intake of naturally rising air. This will test for both the draught up the chimney flue and for an adequate intake of air by natural ventilation of air into the room.

Where flues are built into an external brick or block wall it may be necessary to line the flue to minimise condensation of flue gases inside the flue, caused by too rapid a cooling of the rising gases.

The condensation of moisture vapour from flue gases inside brick or block flues may cause unacceptable staining of wall surfaces and damage to chimneys, where the expansion of water soluble crystals in brick faces exposed to cold winds may adversely affect the structure.

Flue liners

To provide the best section of unobstructed flue inside an existing brick or block chimney it may be necessary to line the flue with a flexible stainless steel liner which is pulled up the flue and sealed to a flue terminal and the gas appliance at the base.

Flues built into new brick or block buildings are lined with clay pipes or purpose made flue blocks.

Flue pipes

Instead of flueways, flue pipes may be used. The flue pipe to a heating appliance may be independent of, or secured to, a wall. Stainless steel, enamelled steel or aluminium are used for both single walled and double walled pipes.

Double walled flue pipes consist of two concentric pipes separated by an insulating material. This insulating material maintains the heat and convection draught of flue gases and prevents the pipe becoming too hot, where it is exposed.

Flue terminal

Where a flue rises to open air it is finished with some form of terminal formed to deflect gusts of outside air that might otherwise blow down flues and temporarily block escape of flue gases.

If a flue is to be effective in discharging flue gases to open air it should rise above adjacent roofs and structures so that air currents blowing towards the flue terminal do not cause down draughts or suction currents as the blown wind gusts are deflected by surrounding buildings.

Room sealed appliances

Room sealed gas burning appliances are those that draw their combustion air intake directly from outside air instead of from inside air, as is the case with open flue appliances.

The majority of small capacity boilers used for space and water heating for domestic premises such as flats and houses are specifically designed to be small and compact to fit into kitchen or bathroom. These so called 'space-saving' boilers operate through a terminal fixed to the external face of a wall, into which air is drawn and from which combustion gases escape either by natural convection or fan assisted operation. With natural convection they rely on natural air movements and use a balanced flue to control intake and expulsion of gases. The other type use an electrically operated fan to assist extraction of combustion gases.

All these appliances are sealed so that no part of the intake air or exhaust gases enter the room in which the appliance is fixed. In operation both the balanced flue terminal and the smaller fan draught terminal will adequately disperse flue gases with extension to flues or flue pipes.

8: Refuse Storage

REFUSE COLLECTION

Refuse volume

The volume of loosely packed refuse from an average three person household is 0.09 m^2 per week, slightly less than the capacity of a standard 0.092 m^2 dustbin. The larger part of the volume of domestic refuse today is bulky lightweight paper and plastic wrapping and container material which, in our 'throw away' style of living, is increasing to the extent that it is estimated that the volume of refuse from an average three person household will increase to 0.12 m^2 before long.

This bulky refuse encourages the householder to compress as much as possible into his refuse bin, which makes it difficult to discharge the contents into the refuse collection vehicle. The bin is damaged by banging it against the vehicle to empty it and in a short time it too becomes refuse and the cycle of waste accelerates. The smaller part of domestic refuse is ash from solid fuel appliances, tins, bottles and kitchen waste. The latter, if not wrapped, may adhere to the side of the bin, putrefy and be the source of disagreeable odours and a breeding ground for flies.

The usual sequence in the storage of domestic refuse is the filling of a small bin or other small receptacle inside the dwelling, which is emptied into a refuse bin, a larger refuse storage container or into a refuse chute discharging to a refuse container.

Collection is usually once or twice a week. Refuse is collected from the premises or from the kerbside, depending on access and local arrangements, and larger containers are usually collected from the premises by vehicles designed for the purpose.

The required capacity of refuse containers depends on an assumption of about 0.3 m^2 refuse per person and the frequency of collection. It is sensible to provide a larger capacity than this average to cover interruption of collection during holiday periods and festivals when the volume of bulky, lightweight refuse increases considerably; otherwise refuse bins will be packed and difficult to empty or will have inadequate capacity with resulting spillage of refuse. An additional capacity of 10–25% is not unusual.

DUSTBINS (REFUSE BINS)

Refuse bins are still generally described as dustbins from the days when the solid fuel fire was the principal source of heat and the resultant volume of dust and ash that was discharged to bins gave them their name. At that time a more frugal style of living did not produce the volume of refuse common today.

Galvanised mild steel dustbin

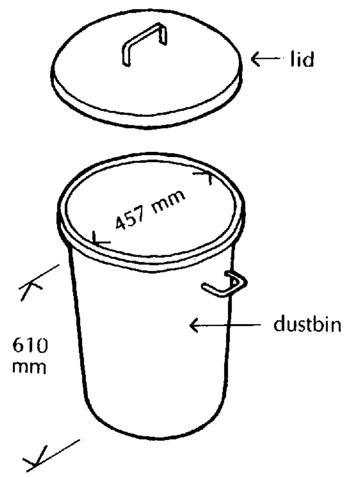


Fig. 205 Standard galvanised steel dustbin.

This is the traditional dust or refuse bin that has only recently been superseded by the plastic bin and the paper sack. A soundly made galvanised steel dustbin is robust and will give useful service for many years providing the zinc coating (galvanising) is not damaged by mishandling. Once the zinc coating wears, the mild steel rapidly rusts and the bin disintegrates.

The standard mild steel dustbin illustrated in Fig. 205 is round in section and tapers from top to bottom to facilitate emptying and also stacking. It has a reinforcing turnover rim, slightly dished bottom, lifting handles and a loose lid. The capacity of standard bins is $0.028\,m^2$ (1 ft), $0.056\,m^2$ (2 ft), $0.071\,m^2$ ($2\frac{1}{2}$ ft) and $0.092\,m^2$ ($3\frac{1}{4}$ ft). The $0.071\,m^2$ and $0.092\,m^2$ bins are those most used. A standard steel bin is heavy, about 12 kg, and when full it is near the limit in weight that can be lifted and emptied by an average person without strain.

Various non-standard light section galvanised steel bins are manufactured, mostly from corrugated or fluted sheet to reinforce the flimsy material. Because of the light section material from which they are made they have an appreciably shorter life than the heavier standard bin, and refuse that collects in the troughs of the corrugated or fluted sides is difficult to clean. These bins, though somewhat cheaper, are a false economy.

Rubber lids and rubber bases to steel bins are available to reduce the noise of handling the bins.

A specialised-steel bin, the dustless loading bin, is manufactured for the storage and emptying of ash and other dusty refuse. The lid is hinged to the bin and so designed that it does not open until the bin has been lifted by the special collection vehicle and sealed against a shutter for dustless emptying. This type of bin is too heavy for manhandling and has to be wheeled on a trolley to the collection vehicle.

Plastic refuse bins

Plastic refuse bins are about half the weight of a standard steel bin of the same capacity and if made of high density polyethylene or polypropylene are rigid, durable and may have a useful life of several years if reasonably handled. They do not deteriorate by oxidisation as do steel bins. There is no great difference in cost between the standard steel and the plastic bin. A good quality plastic bin, such as that illustrated in Fig. 206, has taper sides without flutes or corrugations, a reinforcing rim, lifting handles, and a loose lid. Usual capacities are $0.071\,m^2$ and $0.092\,m^2$.

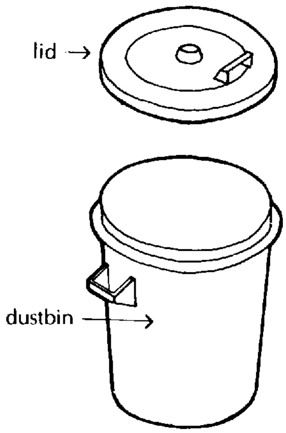


Fig. 206 Plastic dustbin.

These bins do tend to deteriorate fairly rapidly when manhandled in being emptied into collection vehicles. Being lightweight they are liable, if free standing, to be blown about in high winds when empty.

Lightweight, low density polythene plastic bins are manufactured with corrugated sides for reinforced. These flimsy bins are brittle and easily fractured, particularly at low temperatures, and do not have a reasonable useful life.

Square section plastic bins on wheels are supplied by some local authorities to reduce the labour of collection. These comparatively small, so-called 'wheelybins' are often overfilled and difficult to empty and so defeat the object of their design, which is to reduce labour.

Paper and plastic refuse sacks

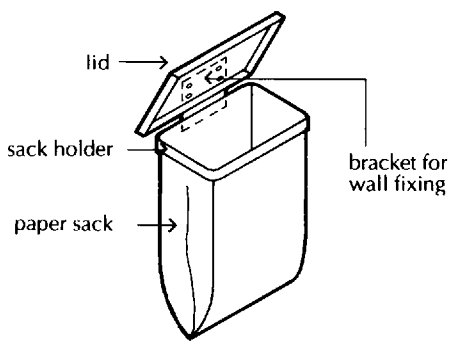


Fig. 207 Wall mounted holder and refuse paper sack.

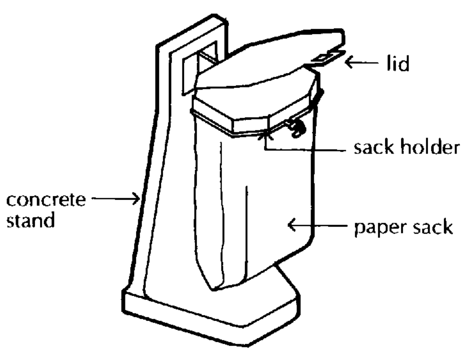


Fig. 208 Free standing holder and refuse paper sack.

First used in Scandinavia, the disposable paper refuse sack is an alternative to the steel or plastic bin for householders. The obvious advantage is that both the soiled container and its contents are collected and disposed of in one journey from and to the refuse collection vehicle. But the natural resource, wood, from which sacks are made is becoming increasingly scarce and expensive in our throw-away society and it seems unlikely, despite its advantages, that the paper sack will replace the steel and plastic bin.

Paper sacks for refuse are made from stout two ply wet strength paper or single ply waterproof kraft paper. These sacks are sufficiently robust to stand outside between normal collections and to store all but the most jagged of items of refuse without damage. Bags of capacity of $0.071\,m^2$ and $0.092\,m^2$ are generally used. The refuse sacks are supported by wall mounted or free standing holders, as shown in Figs. 207 and 208. Wall mounted holders are fixed to a wall with a back plate which supports the sack holder and its lid. Alternatively, free standing concrete or metal stands support sack holder and lid. For collection the full sack is unclipped and replaced with a fresh one. Free standing holders are heavy enough to stand in high wind and remain upright against knocks. Both wall mounted and free standing sack holders may be fitted with wire guards to protect against damage.

Plastic sacks have been used instead of paper sacks; they are cheaper than paper, require less space for storage of sacks and do not deteriorate in damp conditions. Plastic sacks are fixed to wall mounted or free standing holders similar to those for paper sacks.

To date the majority of paper and plastic refuse sacks have been supplied by local refuse collection authorities as a part of their refuse collection service, as a manpower saving device where the bulk of the refuse is collected from individual households.

This rational system of refuse storage depends on a degree of careful and sensible use by the householder. The all too frequent abuse of this system by overfilling and forcing in angular objects very soon reduces the efficiency of the system by causing needless spillage of refuse and consequent extra labour on the part of the collectors or the householder, or both.

REFUSE CHUTE

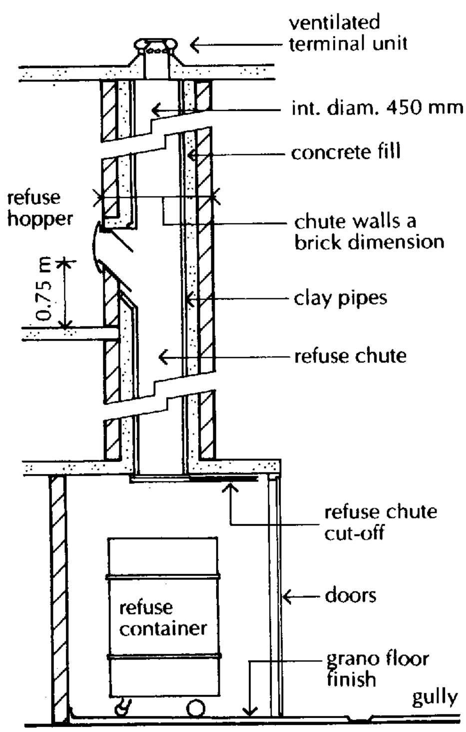


Fig. 209 Refuse chute and container chamber.

For domestic buildings of more than four floors, a system of refuse chutes is a sensible means of disposal and storage. A refuse chute is a vertical shaft into which refuse is tipped through hoppers, the refuse being collected and stored in a container at the foot of the chute. Refuse chutes are lined with cylindrical pipes of clay, concrete or fibre cement, internal diameter not less than 450 mm, the smooth impervious surface of the pipes providing the least impediment to the movement of the refuse down the chute and facilitating cleansing by periodic hosing down. The lining pipes are enclosed in a brick or concrete shaft for their support and as a protection against spread of fire.

Metal hoppers at each floor level provide entry points to the chute. The opening to these hoppers should not exceed 350 mm in width and 250 in depth. Hoppers to chutes should be located on open communal access balconies or well ventilated lobbies away from habitable rooms or in separate well ventilated lobbies of fire resisting construction, off main circulation lobbies.

At the foot of each chute there should be a container chamber as illustrated in Fig. 209. When the refuse container is full, the chute is closed by the steel shutter, the full container replaced with an empty one, and the shutter opened. Depending on the anticipated volume of refuse a variety of arrangements for containers is available, such as the single 0.95 m^2 wheeled container illustrated in Fig. 210, a range of single containers on a turntable, a range of refuse sacks on a turntable or a single large container.

Refuse chutes should be carried up to or above roof level with a ventilating terminal of the same diameter as the chute, or where this is not possible with a reduced ventilating pipe and terminal. Ventilation of the chute and lobbies in which the hoppers are located is essential.

With sensible use, reasonable periodic changes of container to avoid spillage, and cleansing of the chute and container chamber, the refuse chute is a satisfactory system for storage of refuse in multi-storey buildings.

The disadvantage of these chutes is that they can be somewhat noisy in use when heavy objects fall from higher hopper entries. Due to thoughtless use they become blocked with large cardboard boxes and such things as umbrellas which are difficult to clear.

WASTE DISPOSAL SYSTEMS

Refuse containers

Refuse containers are large metal containers in which refuse, both domestic and trade, is stored. The limit to the size of these containers is the capacity of a collection vehicle to lift and carry or tow away the container. The galvanised steel container shown in Fig. 210 is often described as a Paladin container.

These containers are wheeled for manhandling to the collection vehicle which is designed to lift, upturn and empty the contents into the rear of the collection vehicle. To this end there are various lifting attachments to the container such as the studs shown in Fig. 210, or angle iron rims to suit the various makes of collection vehicle. These standard $0.95\,m^2$ refuse containers are extensively used at the foot of chutes for communal and trade refuse. A wide variety of large, purpose-constructed, galvanised steel containers are available, principally for storage at the foot of chutes and for trade waste.

These heavy containers are somewhat difficult to manhandle towards the collection vehicle and are noisy in the operation of mechanically lifting them into the vehicle for emptying. They are rarely cleaned due to the difficulty of access to the inside of the container and are liable to become smelly in warm weather.

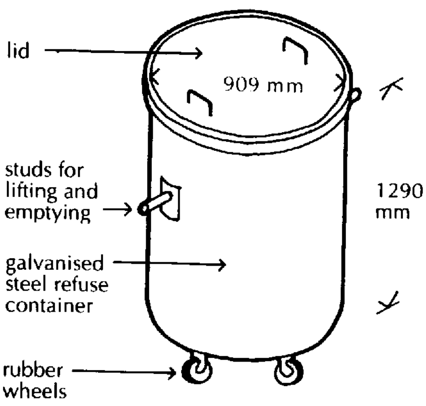


Fig. 2.10 Galvanised mild steel refuse storage container.

The Garchey system

The Garchey system is a method of waste disposal in which refuse is fed through an enlarged waste outlet in the sink into a waste tube housed inside a refuse receiver, fitted below the sink. Waste water from the sink runs into and fills the waste receiver, as illustrated in Fig. 211. When the waste tube is filled it is raised by the householder and its contents are washed down the waste to the 150 mm waste stack to the collection chamber. All waste water appliances are connected to the waste stack so that their discharges assist in washing down the refuse. Soil appliances are drained to a separate stack.

The Garchey refuse collection chamber is emptied once a week to a tanker which removes the waste from the refuse, and carts it away. Surplus water is drained to the sewer. Large material such as papers and contains has to be broken down before being fed into the system.

This refuse disposal system has not been extensively used because of its high initial cost and high maintenance due to careless usage. It was introduced some years ago for use in multi-storey blocks of flats, and is suited to the disposal of wet and damp waste such as that from kitchens. It is not, however, suited to the disposal of the increasing bulk of plastic containers, plastic film and paper wrapping that is common today.

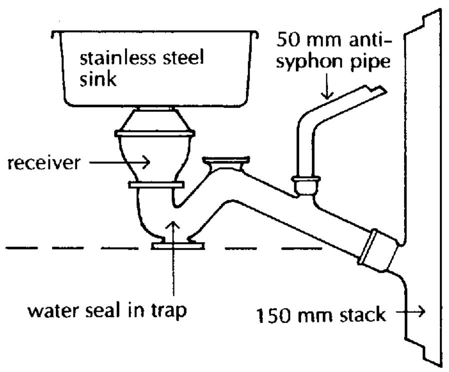


Fig. 211 Garchey refuse disposal unit.

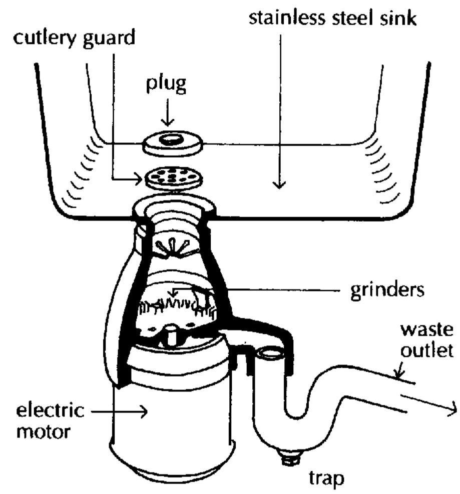


Fig. 212 Waste disposal unit.

Sink waste disposal units

Kitchen waste is fed through the sink waste to a disposal unit in which a grinder, powered by a small electric motor, reduces the refuse to small particles that are washed down with the waste water from the sink. These units are designed to dispose of such kitchen refuse as food remains which rot and cause disagreeable odours in bins. They are not suited to the disposal of larger bulky lightweight refuse. Fig. 212 is an illustration of one of these units.

In common with other seemingly sensible innovations in refuse disposal, this system has lost favour largely because of the impatience of users and the need for fairly frequent maintenance.

Bin liners

Of recent years plastic bin liners have become one of the most used ways of containing refuse for disposal. These cheap liners are convenient for both impatient, careless householders and for refuse collection operatives, but with the disadvantage of unsightly black bin liners littering the streets, and inevitable spillage.

Index

VOLUME 5 BUILDING SERVICES

Since publication of the first volume of *The Construction of Buildings* in 1958, the five volume series has been used by both lecturers and students of architecture, building and surveying, and by those seeking guidance for self-build housing and works of alteration and addition.

Volume 5, which deals with building services (water, electricity and gas supplies, foul water discharge and refuse storage), has been updated to include changes introduced by the 16th Edition of the Wiring Regulations and regulations on gas supply that concern safety.

A new presentation has been adopted for the Third Edition, with text and illustrations integrated to provide a reader-friendly layout and to aid accessibility of information.

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