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Guide to Residential Cast-in-Place Concrete Construction

Reported by ACI Committee 332

The quality of residential concrete is highly dependent on the quality of job construction practices. This guide presents good practices for the construction of foundations, footings, walls, and exterior and interior slabs-on-grade. The concrete materials and proportions must be selected with reference not only to design strength but workability and durability.

The principles and practices described here pertain to: site preparation; formwork erection; selection and placement of reinforcement in walls, slabs, and steps; joint design. location, construction, and sealing; use of insulation; wall concreting practices and safe form stripping; slab finishing practices; curing in all types of weather; and repairing of defects.

Keywords: admixtures; aggregates; air entrainment; compacting; concrete construction; **concrete slabs**; construction joints; control joints; cracking (fracturing); curing; discoloration; drainage; driveways; floors; **footings**; formwork (construction); **foundations**; heat transfer; isolation joints; joints (junctions); mixing; mix proportioning; patios; placing; reinforced concrete; repairs; residential buildings; sawed joints; scaling; sealing; sidewalks; site preparation; skid resistance; **slab-on-ground construction**; slump tests; spalling; standards; surface defects; thermal insulation; tolerances (mechanics); vapor barriers; **walls**; workability.

CONTENTS

CHAPTER I-INTRODUCTION

1.1-Scope

This guide covers cast-in-place residential concrete work for conventional one- or two-family dwellings.* Recommended practices for foundations, footings, walls, and slabs-on-grade (interior and exterior) are included. Earth-sheltered homes are beyond the scope of this report. Specific design provisions for reinforced concrete beams, columns, walls, and framed slabs are not included, because they should be designed by a registered professional engineer.

1.2-Objective

Recommended practices are provided in this guide for those people engaged in construction of residential concrete work. Also compiled are acceptable details, standards, and code provisions assembled in one document, which are intended to assist home builders, contractors, and others in providing quality concrete construction for one and two family dwelling units.

Implementation of the recommendations in this guide should result in acceptable quality concrete construction significantly free from scaling, spalling, and cracking of driveways, walks, and patios; leaking of basement walls; and dusting, cracking, and undue surface deviations of floor slabs.

*For any residence using concrete floors above the first story, see ACI 301. For building with concrete masonry, see ACI 531 for building code requirements. These are explained in detail in the commentary, ACI 531R, and specifications are given in ACI 531.1. For design and construction with precast concrete units, see ACI 512.2R.

1.3-Standard specifications and recommended practices

American Concrete Institute (ACI) standards are referenced in this guide by number, for example, as ACI 211.1. Specifications of other organizations such as the American Society for Testing and Materials (ASTM) and Federal agencies are also referred to by number only, for example, as ASTM C 94. Full titles of these referenced documents are provided in Chapter 12, References.

CHAPTER 2-REQUIREMENTS FOR CONCRETE FOR RESIDENTIAL CONSTRUCTION

2.1-General

Concrete for residential construction involves a balance between reasonable economy and the requirements for workability, finishing, durability, strength, and appearance. The required characteristics are governed by the intended use of the concrete, the conditions expected to be encountered at the time of placement, and the environmental factors affecting use of the product.

2.1.1 *Workability*

Workability includes placeability, consistency or "wetness," and finishing characteristics. Good workability means concrete can be placed, consolidated, and finished satisfactorily.

2.1.2 *Durability*

Durability is the capacity of the concrete to resist deterioration due to weathering and traffic. This may include exposure to freezing and thawing, wetting and drying, heating and cooling, seawater, soluble sulfates in the soil, and chemicals such as deicers and fertilizers.

2.1.3 *Strength*

Minimum compressive strength of concrete in pounds per square inch (megapascals) at 28 days is the property usually specified for most concrete work. It is easily measurable and indicates other desirable characteristics. Proportioning for and achievement of a proper specified level of compressive strength is usually assurance that such associated properties as tensile strength and low permeability will be satisfactory for the job.

When concrete must have a specialized design, it may be necessary to specify the strength that will be required at some particular early age. For example, for post-tensioned concrete, strength at seven days may have to be specified or else strength at the time of actual post-tensioning.

However, durability may be the controlling factor in determining quality of concrete. Specified design strength alone does not always assure adequate resistance to deterioration by freezing and thawing cycles, sulfate attack, or seawater exposure. A well-proportioned air-entrained mix is always essential to attain adequate durability.

2.2-Selecting concrete

Table 2.2 is a guide for use in selecting concrete strengths adequate for use in low-rise residential construction. The first consideration in using this table is to identify the design environmental exposure conditions to be resisted. Three exposures-severe, moderate, and mild-are described, together with the required strength of concrete and typical applications. Weathering areas are based on Fig. 2.2. Air-entrained concrete may be needed (Section 2.2.1), and for all slabs it is necessary for the concrete producer to supply concrete of adequate finishing characteristics (Section 2.2.3).

Table 2.2-Guidelines for selecting concrete strength

Minimum compressive strength f'_c at 28 days

	Regional Weathering Areas[a]			
	Mild[b,c]	Moderate[b]	Severe[b]	
Type or location of concrete construction	f'_c, psi (MPa)	f'_c, psi (MPa)	f'_c, psi (MPa)	Nominal slump,[b] in. (mm)
Basement walls and foundations not exposed to weather	2500 (17)	2500 (17)	2500 (17)[c]	6 ± 1(150 ± 25)[e,f]
Basement slabs and interior slabs on grade	2500 (17)	2500 (17)	2500 (17)[c]	5 ± 1(125 ± 25)[e,f]
Basement walls, foundations, exterior walls, and other concrete work exposed to weather	2500 (17)	3000 (21)[d]	3000 (21)[d]	6 ± 1(150 ± 25)[e]
Driveways, curbs, walks, patios, porches, steps and stairs, and unheated garage floors, exposed to weather	2500 (17)	3000 (21)[d]	3500 (24)[d,g]	5 ± 1(125 ± 25)[e,f]

[a]See Fig. 2.2 for weathering areas.

[b]Concrete should be proportioned to produce the design strength at the slump which will be used. Extra water, above the amount in the design proportions, should not be added, since it would reduce the strength.

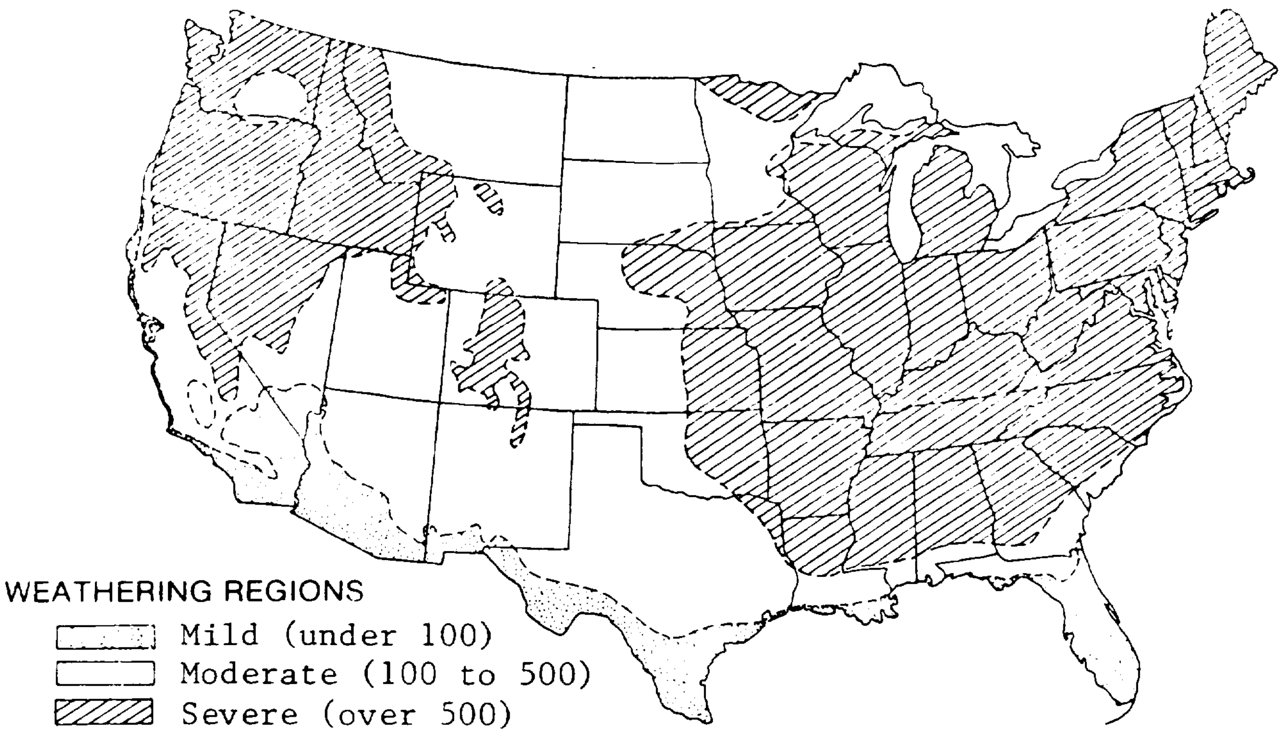
[c]Where local experience shows a history of satisfactory performance and where local codes permit, lower-strength concrete [f'_c = 2000 psi (14 MPa) but not less], may be used.

[d]Air-entrained concrete as recommended (Table 2.2.1).

[e]Standard Test ASTM C 143 should be used to measure slump. Slump for lightweight aggregate concrete should not exceed 3 in. (75 mm).

[f]When water-reducing, set-controlling admixtures are used to produce flowing [7 in. plus (175 mm plus) slump] concrete, all the required qualities of concrete expected should be maintained.

[g]Experience has shown that use of f'_c = 4000 psi (28 MPa) in areas subject to use of deicer salts, rather than the minimum f'_c shown, gives superior durability.



The weathering index for any locality is the product of the average annual number of *freezing-cycle days* and the average annual *winter rainfall* in inches, defined as follows:*

A *freezing-cycle day* is any day during which the air temperature passes either above or below 32 F (0 C). The average number of freezing-cycle days in a year may be taken to equal the difference between the mean number of days during which the minimum temperature was 32 F or below and the mean number of days during which the maximum temperature was 32 F or below.

Winter rainfall is the sum, in inches, of the mean monthly corrected precipitation (rainfall) occurring during the period between and including the normal date of the first killing frost in the fall and the normal date of the last killing frost in the spring. The winter rainfall for any period is equal to the total precipitation less one tenth of the total fall of snow, sleet, and hail. Rainfall for a portion of a month is prorated.

The map indicates general areas of the United States in which concrete is subject to severe, moderate, and mild weathering. The severe weathering region has a weathering index greater than 500. The moderate weathering region has a weathering index of 100 to 500. The mild weathering region has a weathering index of less than 100.

*Data needed to determine the weathering index for any locality may be found or estimated from the tables of Local Climatological Data, published by the Weather Bureau, U.S. Department of Commerce.

Fig. 2.2-Weathering indexes in the United States

Table 2.2.1 -Recommended air content for normal weight concretes for various exposures*

Nominal maximum size aggregate		Typical air contents of non-air-entrained concretes, percent	Recommended average air content, percent, for air-entrained concretes†‡		
in.	mm		Mild exposure§	Moderate exposure	Severe exposure
3/8	10	3.0	4.5	6.0	7.5
1/2	13	2.5	4.0	5.5	7.0
3/4	19	2.0	3.5	5.0	6.0
1	25	1.5	3.0	4.5	6.0
1 1/2	38	1.0	2.5	4.5	5.5

*See Fig. 2.2 and Table 2.2 for descriptions of exposures.

†Tolerance on air content ± 1.5 percent.

‡To prevent scaling or spalling, any concrete that is likely to be exposed to freezing in a saturated condition should have the air content indicated. This includes concrete that will remain uncovered, as in an open basement, during a winter season in a northern climate.

§Air entrainment used to improve workability and cohesiveness.

2.2.1 *Air-entrained concrete*

Concrete that will be subjected to severe or moderate exposures should contain entrained air in accordance with the values given in Table 2.2.1.

The values set forth in the table are necessary since an inadequate air content in outdoor flatwork in moderate or severe climates can lead to surface scaling, especially if deicers are used on the surface (Section 11.2.2). The table also gives air contents for mild exposures; entrained air is not required in concretes for mild exposures, but it is sometimes useful for improving workability and cohesiveness in mixes that might otherwise be too harsh.*

Air-entrained concrete can be achieved through the use of commercially available air-entraining agents or the use of air-entraining cement. It is recommended that concrete mixes be specifically proportioned for air entrainment because addition of air-entraining admixtures to mixes already having sufficient fines can lead to concrete finishing problems (Section 4.1.1).

*For additional information on the effect of air entrainment, refer to ACI 212.1R, Chapter 4, and ACI 212.2R, Chapter 3.

2.2.2 *Concrete for sulfate resistance*

Types of cement and water-cement ratios suitable for concrete resistant to sulfate attack are given in Table 2.2.2. Sulfate concentration can be determined by laboratory tests.

Table 2.2.2-Recommendations for normal weight concrete subject to sulfate attack

Exposure	Water soluble sulfate (SO_4) in soil, percent	Sulfate (SO_4) in water, ppm	Cement	Water-cement ratio, maximum[a]
Mild	0.00-0.10	0-150	—	—
Moderate[b]	0.10-0.20	150-1500	Type II, IP (MS), IS (MS)	0.50
Severe	0.20-2.00	1500-10,000	Type V	0.45
Very severe	Over 2.00	Over 10,000	Type V + Pozzolan[c]	0.45

[a]A lower water-cement ratio may be necessary to prevent corrosion of embedded items.
[b]Seawater also falls in this category.
[c]Use a pozzolan which has been determined by tests to improve sulfate resistance when used in concrete containing Type V cement.

2.2.3 *Finishing characteristics*

One of the keys to a good quality surface for a slab is concrete with good finishing characteristics. This means that there must be a good balance between the amount of coarse and fine materials so that the mix is neither too harsh nor too sticky. The mix should be proportioned to stiffen neither too rapidly nor too slowly at the temperature it will be used. For a discussion of proportioning, see Section 4.1.1.

2.2.4 *Testing concrete*

To verify that the delivered concrete meets the proper specifications, the purchaser may want to request a certified copy of the mix proportions.

Testing of concrete is not normally done on small residential work. On projects with a sufficient number of homes, the purchaser may want to employ a testing laboratory to test the slump, compressive strength, and (if applicable) air content.

CHAPTER 3 - CONCRETE MATERIALS

3.1 - Ingredients

Concrete consists of four basic ingredients. A fifth ingredient (admixture) may be added to modify the concrete as described in Sections 3.1.5 and 3.1.6. The materials* are

a. Portland cement
b. Sand (fine aggregate)
c. Gravel or crushed stone (coarse aggregate)
d. Water
e. Admixtures (chemical and/or mineral)

3.1.1- *Cement*

Cement with water acts as the paste that bonds together the aggregate particles to form concrete. Cement used in residential concrete is usually portland cement Type I or II, or air-entraining portland cement Type IA or IIA. Blended cements, if available, made by combining portland cement with pozzolan, or blast furnace slag, may also be used. These cements are designated Type IP or IS, or (if air entrained) IP-A or IS-A. In geographic areas where aggregate is reactive with alkalies, low-alkali cements should be used (see also Section 3.1.6).

For moderate sulfate exposure (150-1500 parts soluble sulfates per million) and seawater, Type II, IP-MS, or IS-MS is recommended. For severe exposures (over 1500 parts soluble sulfates per million), Type V cement may be required.

3.1.2 - *Sand (fine aggregate)*

Sand for use in concrete should meet the requirements of ASTM C 33. A clean sand, to be suitable, should not contain harmful quantities of organic matter, clay, coal, loam, twigs, branches, roots, weeds, or other deleterious materials. For aggregates that are reactive with cement, low-alkali cement should be used and, in some cases, a mineral admixture (Section 3.1.6) as well.

3.1.3 - *Gravel or crushed stone (coarse aggregate)*

Coarse aggregate for use in residential concrete should meet the requirements of ASTM C33. It may range in size from a ½ in. (13 mm) maximum size to a 1½ in. (38 mm) maximum size, depending on the application. Generally, the larger the aggregate size, the more economical the concrete mixture will be. However, concrete with smaller coarse aggregate is easier to handle and finish. For aggregates that are reactive with cement, low-alkali cement should be used and, in some cases, a mineral admixture (Section 3.1.6) as well.

3.1.4 - *Water*

Almost any water that is drinkable and has no pronounced taste or odor is satisfactory as mixing water for making concrete.

3.1.5- *Chemical admixtures*

Chemical admixtures, or air-entraining admixtures, may be added to concrete to achieve certain desirable effects such as

a. Reduction in the quantity of mixing water needed.
b. Increase in workability at the same water and cement content without loss of strength.
c. Acceleration of the set of the concrete.
d. Retardation of the set of the concrete.
e. Entrainment of proper quantities of air for both durability and workability.[+]

If an admixture containing chloride ion is used in concrete containing reinforcing steel or other embedded metal, or is used in concrete placed on metal deck, the amount of water-soluble chloride ion should conform to the limits set forth in Table 3.1.5.

*Specifications for ingredients are portland cement, ASTM C 150; blended cement, ASTM C 595; sand, gravel, and crushed stone or structural lightweight aggregate, ASTM C 33 or ASTM C 330; and admixture, ASTM C 260, ASTM C 494 and ASTM C 618.

[+]For additional information on chemical, mineral, and miscellaneous admixtures, refer to ACI 212.1R and ACI 212.2R.

Table 3.1.5—Maximum chloride ion content for corrosion protection

Category of concrete service	Maximum water-soluble chloride ion (Cl^-)* in concrete, percent (by wt) of cement
Prestressed concrete	0.06
Reinforced concrete that will be exposed to chlorides in service, such as sea-retaining walls	0.15
Reinforced concrete that will be dry or protected from moisture in service	1.00
Reinforced concrete that will not be exposed to chlorides but may be wet in service	0.30

*Test concrete at 28- to 42-day age.

3.1.6 - *Mineral admixtures*

Natural pozzolans, fly ash, and blast furnace slag are admixtures that may be used in concrete for such purposes as increasing strengths at later ages, reducing excessive expansion due to alkali-silica reaction, or as a source of additional fines when required in the mix to improve workability.

CHAPTER 4-PROPORTIONING, PRODUCTION, AND DELIVERY OF CONCRETE

4.1-Concrete

4.1.1 *Proportioning concrete*

Concrete proportioning is normally the responsibility of the ready-mixed concrete producer. Only the main considerations are outlined here. The objective in proportioning is to determine the most economical and practical combination of the materials available to produce a concrete that will perform satisfactorily under the usage conditions expected. This requires a good working knowledge of the basic functions and characteristics of the available concrete materials, the job requirements for placement and construction, and the long-term characteristics required of the concrete in place.

In the process of working out the proportions, the mix proportioner seeks to achieve the desired quality with respect to all of the following characteristics: designed strength, durability needed for the job, and adequate workability and proper consistency so that the concrete can be readily worked into the forms and around any reinforcement.

For the finishing qualities needed for concrete slabs, the mix designer will have to select the right amounts of whatever materials are being used, including cement, coarse and fine aggregates, water, and chemical and mineral admixtures. Too much cement plus mineral fines (Section 3.1.6) or too much sand passing the No. 50, No. 100, and No. 200 sieves can make the mix sticky.* Likewise, if an air-entraining admixture is added to a mix, it may be necessary to cut down on these fines to avoid stickiness in concrete finishing. If there is not enough fine material, the concrete may bleed excessively and cause a delay in finishing. A mix that contains too much coarse aggregate will be harsh and difficult to finish.

Unless job conditions demand an adjustment in mix proportions, it is usually best not to change the proportions after the job has started. Such changes can lead to trouble with deicer scaling from too low an air content (Section 11.2.2); discoloration from changes in cement content, changes in water content, or use of calcium chloride (Sections 11.1.8 and 11.1.8.1); or blistering that may be caused in part by excessive air or too many fines (Section 11.2.1).

Generally, a mix made with finely divided mineral admixture, color admixture, or color pigment requires a higher proportion of air-entraining agent to produce a given air content than a similar mix made without these materials.

When concrete made with such finely divided materials will be subjected to freezing and thawing conditions, the air content should be monitored for each delivered batch.

4.1.2 *Ready-mixed and other concrete mixtures*

Most concrete for residential construction is mixed and delivered in a revolving drum truck mixer. It is generally referred to as ready-mixed concrete. The proportioning, batching, mixing, and delivery are all done by the ready-mixed concrete supplier.[+] Some concrete producers now have truck- or trailer-mounted mobile continuous mixers in which the concrete is volumetrically batched and mixed at the job site.[‡]

The user should select concrete by strength (Section 2.2) for the intended use. To obtain the correct concrete for the job, it is advisable to order from a reputable and qualified ready-mixed concrete producer, and to specify the strength for the class selected, the exposure requirements, whether air entrainment is required,[§] and the intended use of the concrete.

4.1.3 *Placing and finishing*

It is not common for concrete slabs to blister, and workmen are often surprised that blistering occurs. Major contributing causes are sticky mixes, finishing practices that bring excessive amounts of fine material to the surface, any condition (such as a combination of warm weather and cold subgrade) that causes the surface to harden faster than the concrete below it, finishing the surface too soon, or handling of tools in ways that tend to close the surface too soon.** Finishers should be alert to these hazards and try to plan and carry out the work in ways that avoid them. For repair of blisters, see Section 11.2.1.

4.1.4 ***Job-mixed concrete***

Small jobs can be done with prepackaged mixe[++] or by mixing the separate ingredients.[‡‡]

*Ranges of aggregate gradings in ASTM C 33 and ASTM C 330 are usually satisfactory.

†Proportioning is done by weight, generally in accordance with ACI 211.1. Ready-mixed concrete should comply with ASTM C 94.

‡Concrete made in a mobile continuous mixer should comply with ASTM C 685.

§Concrete to be exposed to freezing and thawing should be air entrained.

**See ACI 302.1R for more information.

††Complying with ASTM C 387.

‡‡A good reference is the publication, "Concrete for Small Jobs," Reference

Table 4.1.4.1—Concrete proportions for job site mixing

Maximum size of coarse aggregate, in.	mm	Minimum cement content, 94-lb bags per cu yd	Maximum water content, gal. per bag of cement[a]	Approximate proportions by volume, ft^3 per bag of cement[b]		
				Cement	Fine aggregate	Coarse aggregate
3/8	9	6.4	5	1	2½	2⅝
½	13	6.3	5	1	2½	2½
¾	19	6.0	5	1	2½	2¾
1	25	5.8	5	1	2½	3
1½	38	5.4	5	1	2½	3½
2[c]	50	5.2	5	1	2½	4

[a]Includes moisture in aggregate.
[b]For concrete that will not be subject to freezing and thawing, these proportions may be varied to use up to 5 percent less cement and 10 percent more fine aggregate. One bag of cement weighs 94 lb (42.6 kg) and is counted as 1 ft^3 (0.0283 m^3).
[c]Not recommended for slabs or other thin sections.

4.1.4.1 *Mixing separate ingredients*- Field batching and mixing for small jobs in accordance with Table 4.1.4.1 will provide acceptable plain concrete. The amount of water used should not exceed 5 gal. per 94-lb bag (water-cement ratio = 0.44 by weight) or even less if freeze-thaw durability requires less. These mixes have been determined in accordance with recommended procedures, assuming conditions applicable to an average small job with common aggregates. Proportions in Table 4.1.4. I are for aggregates in a damp and loose condition. Mixing should be done in a batch mixer operated in accordance with the manufacturer's recommendations. For severe exposures, an air-entraining admixture should be added according to the manufacturer's instructions.

4.2-Concrete production

There is ample evidence that good concrete can be produced and placed as economically as poor concrete. The first requirement for producing good concrete of uniform quality is that the materials must be measured accurately for each batch.

Another requirement is that mixing be complete. Concrete should be mixed until it is uniform in appearance and all materials are evenly distributed. With truck-mixed concrete, this means 70 to 100 revolutions of the drum at mixing speed, with the drum not filled beyond its rated capacity. If the job is close to the concrete plant, the concrete should be mixed before leaving the plant. This is because during truck driving the mixer turns slowly, and its action is sufficient only to agitate already mixed concrete but not to thoroughly mix the previously unmixed materials. It may be desirable to add another 2 minute mixing cycle at the delivery site. Concrete that has an obviously non-uniform appearance or is obviously misbatched should be rejected.

CAUTION. In severe climate areas, concrete intended for outdoor exposure should have the entrained air content checked prior to the start of placement. This is particularly important for walks, driveways, curbs and gutters, and street work likely to receive applications of deicing salts. If air content cannot be checked, the ready-mixed concrete producer should be willing to verify the air content at the beginning of placement.

4.3-Concrete delivery

Fresh concrete undergoes slump loss to varying degrees depending on temperature, time en route, and other factors. Water should not be added after its initial introduction to the batch, except that if on arrival at the job site the slump of the concrete is less than that specified. When water is added under these conditions to regain lost slump, a minimum of 30 revolutions of the drum at mixing speed is necessary to uniformly disperse the water throughout the mix (but note the following limitation on drum revolutions).

4.3.1 *Limitation on delivery time*

After the water has been added to the concrete mix, the concrete should be delivered and discharged within 1½ hours and before the drum has revolved 300 times. If the concrete is still capable of being placed at a later time than this, without adding more water, the purchaser may waive the 1½ hour and 300-revolution maximums.

Slump decreases as time passes, and it is not allowable to compensate for the possibility of a slow delivery or of prolonged standby time at the job site by starting with a mix that is above the slump specified. The purchaser should require concrete to be delivered at a specified slump. If a delay in delivery or use is anticipated, use of a retarder in the mix might be considered.

In hot weather, or under other conditions that contribute to quick stiffening, the limitation of 1½ hours before discharge may have to be decreased. *

4.3.2 *Scheduling and planning*

To insure successful delivery and placement, attention must be given to scheduling ready-mixed concrete deliveries and providing satisfactory access to the site for truck mixers. The men and equipment required to properly place, finish, and cure the concrete should be on hand and ready at the job site when it is time to start placement.

*Requirements for delivery time are given in ASTM C 94. Proper procedures for batching, mixing, and transporting concrete to the job site are given in ACI 304.

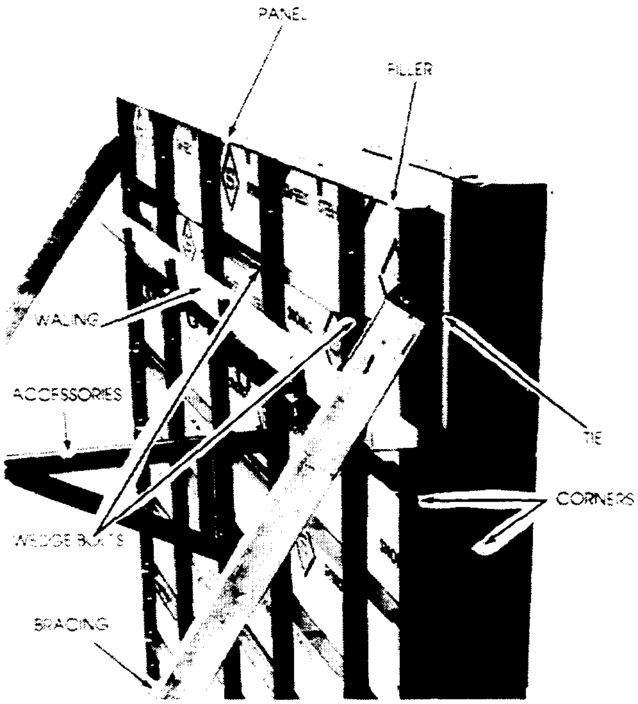


Fig. 5.1(a)--Manufactured plywood forms on steel frame

Fig. 5.1 (b)--Manufactured all-aluminum forms. This set produces brick texture

CHAPTER 5-FORMWORK

5.1-Introduction

Formwork is used to contain the freshly placed concrete in the shape, form, and location desired. Residential formwork may be job-fabricated of plywood or dimensional lumber, or it may be constructed of modular forms of wood, steel, aluminum, or fiberglass. Manufactured forms, rented or purchased, account for most of the residential formwork used today because of the precision of their dimensions, rapid assembly, rapid stripping, and the large number of possible reuses. The many proprietary systems available fall into five types:

plywood on steel frame,
all aluminum,
plywood, attached steel hardware,
plywood, and
all steel.

They are illustrated in Figs. 5.1(a) to 5.1(e).*

5.2-Economy in formwork

It is important for the builder to exercise sound judgment and planning when designing formwork. When dimensional lumber and plywood are used for job-fabricated forms, economy is achieved when pieces are of standard sizes. When commercial modular forms are used, economy comes with maximum use of standard form panel units. Embedments, inserts, and penetrations should be designed to minimize random penetration of the formed structure.

5.3-Formwork design and planning

The amount of planning required will depend on the size, complexity, importance, and possible number of reuses of the form. Complex building sites may necessitate formwork drawings and specifications. In addition to selecting types of materials, sizes, lengths, spacing, and connection details, formwork planning should provide for applicable details such as:

a. Erection procedures, plumbing, straightening, bracing, timing the removal of forms, shores, and breaking back of ties.

b. Anchors, form ties, shores, and braces.

c. Field adjustment of form during placing of concrete.

d. Waterstops, keyways, and inserts.

e. Working scaffolds and runways.

f. Joint-forming strips of wood or other material attached to inner faces of forms.

g. Pouring pockets, weep holes, or vibrator mountings where required.

h. Screeds and grade strips.

i. Removal of spreaders or temporary blocking.

j. Cleanout holes and inspection openings.

k. Sequence of concrete placement and minimizing time elapsed between adjacent concrete placements.

l. Form release agents and coatings.

m. Safety of personnel.

5.3.1 *Design and erection*

Formwork should be designed so that concrete slabs, walls, and other members will be of correct dimension, shape, alignment, and elevation, within reasonable tolerance. The following tolerances+ are suggested for variations from plumb and level.

*For a more detailed understanding of concrete formwork, see Reference 2.
+For other permissible tolerances, see ACI 117.

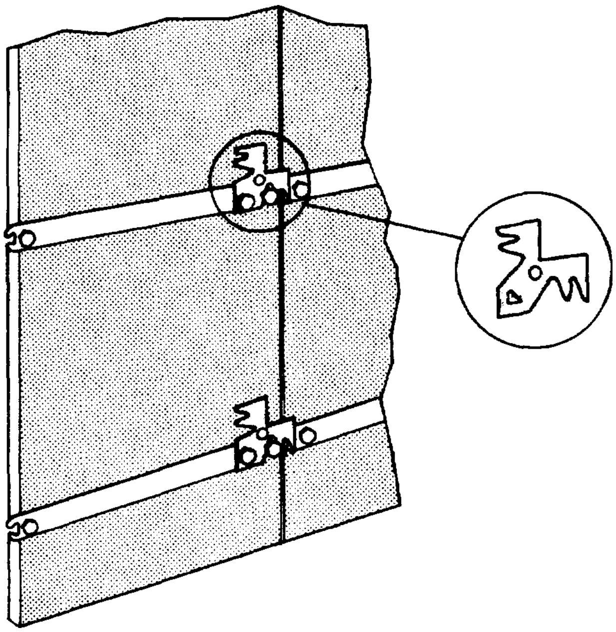


Fig. 5.1(c)-Manufactured plywood forms with attached steel hardware

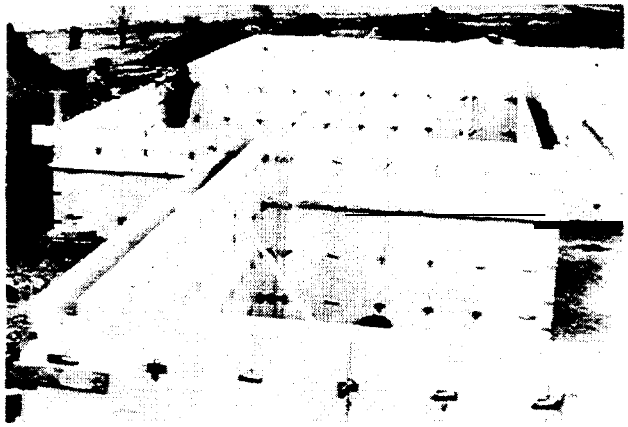


Fig. 5.1(d)-Manufactured plywood forms. Predrilled unframed plywood panels 1⅛ in. (2% mm) thick are aligned by base plates, using few wales or none. Locking and tying hardware is loose

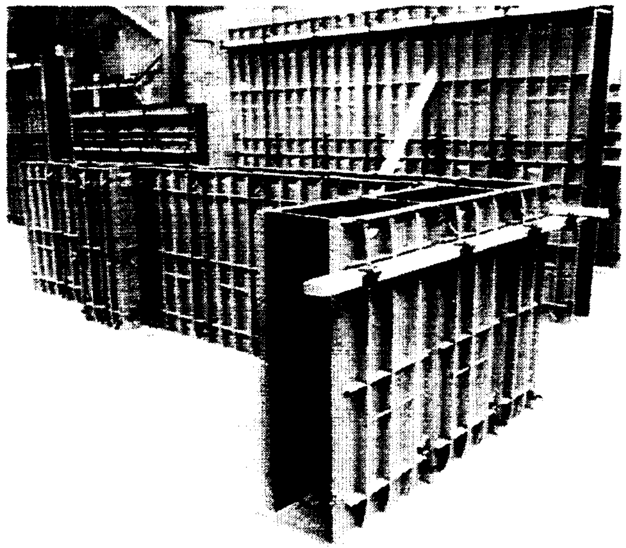


Fig. 5.1(e)-Manufactured all-steel forms

Variations from the plumb.

In the lines and surfaces of columns, piers, and walls and in arrises, contraction-joint grooves, and other conspicuous lines

in any bay or 20-ft maximum	± ½ in.
in conspicuous length in excess of 20 ft	± ¾ in.

Variation from the level or from the grades indicated on the drawings.

a. In slab soffits* ceilings, beam soffits, and in arrises in any 10 ft of length ± ½ in.

b. In exposed lintels, sills, parapets, horizontal grooves, and other conspicuous lines in any bay or any 20 feet of length ± ½ in.

These values are greater than provided in ACI 117.

Formwork should also be designed, erected, supported, braced, and maintained so that it will safely support all loads that might be applied until such loads can be safely supported by the hardened concrete.

When prefabricated formwork, shoring, or scaffolding units are used, manufacturers' recommendations for allowable loads should be followed. Erection of wall formwork on the footings can usually be started any time after the footing concrete is hard enough to permit forms to be stripped, to support the wall formwork, and to resist the construction activities associated with form setting.

5.3.2 *Loads to be supported by formwork during construction*

5.3.2.1 *Vertical loads-* vertical loads consist of dead load and live load. The weight of formwork plus the weight of freshly placed concrete is dead load. Live load includes the weight of workmen, equipment, material storage, and runways, as well as impact load.

5.3.2.2 *Horizontal loads--* Braces and shores should be designed to resist forseeable horizontal loads including those from wind, cable tensions, inclined supports, dumping of concrete, starting and stopping of equipment, and other shock loads such as impact.

5.3.2.3 *Lateral pressure on formwork-* Manufactured forms are designed to resist the lateral pressures normally exerted by the concrete against the sides of the forms in residential wall construction.+

5.3.3 *Form ties*

Form ties maintain the wall thickness and resist the lateral pressures exerted by the freshly placed concrete. As a rule, form ties should be adequate to withstand 1.5 times the computed lateral pressure for light formwork and walls not more than 8 ft (2.5 m) in height and 2 times the lateral pressure for walls greater than 8 ft

*Variations in slab soffits are to be measured before removal of supporting shores; the contractor is not responsible for variations due to deflection, except when the latter are corroboratory evidence of inferior concrete quality or curing, in which case only the net variation due to deflection can be considered.

+If loads must be calculated, refer to ACI 347.

(2.5 m) in height. The strength of individual form ties varies by manufacturer. Number and spacing of form ties may also vary with size and type of form used. Tie and form manufacturer's loading recommendations should be followed when planning tie spacing for formwork. The form ties used should be a kind that has outer ends that may be removed so as to be flush or slightly below the surface of the concrete wall. Tie holes on exposed exterior surfaces may require coating or patching to prevent rusting of the tie.

5.4-Form coatings or release agents

5.4.1 *Coatings*

Form coatings or sealers may be applied to the form contact surfaces, either during manufacture or in the field, to protect the form surfaces, facilitate the action of form release agents, and sometimes, prevent discoloration of the concrete surface.

5.4.2 *Release agents*

Prior to each use, form release agents are applied to the form contact surfaces to minimize concrete adhesion and facilitate stripping. Care must be exercised not to get any of the material on the reinforcing steel or surfaces where bond with future concrete placements is desired.

5.4.3 *Manufacturers' recommendations*

Manufacturers' recommendations should be followed in the use of form coatings, sealers, and release agents, but it is recommended that their performance be independently investigated before use. If color uniformity is a criterion for acceptance of concrete, a release agent that does not cause discoloration should be chosen. Where concrete surface treatments such as paint, tile adhesive, or other coatings are to be applied to formed concrete surfaces, it should be ascertained whether the form coating, sealer, or release agent will impair the adhesion or prevent the use of such concrete surface treatments.

5.5-Form erection practices

Before each use, forms should be cleaned of all dirt, mortar, and foreign matter, and they should be thoroughly coated with a release agent. Blockouts, inserts, and embedded items should be properly identified, positioned, and secured prior to placement of concrete.

When forms are erected, effective means should be applied to hold alignment and plumb during placement and hardening of the concrete. No movement to align forms after concrete has achieved initial set should be permitted. However, it is normal to make minor adjustments for alignment during and immediately after concrete placement.

When ribs, wales, braces, or shores need splicing, care should be taken to achieve the strength and safety equivalent to that of a nonspliced element. Joints or splices in sheathing, plywood panels, and bracing should be staggered. All ties and clamps should be properly installed and tightened.

5.6-Removal of forms and supports

The contractor is responsible for a safe formwork installation and should determine when it is safe to remove forms or shores. When forms are stripped, there must be no excessive deflection or distortion and no evidence of damage to the concrete, due either to removal of support or to the stripping operation. Adequate curing and thermal protection of the stripped concrete should be provided, as described in Sections 10.2 and 10.3. Supporting forms and shores must not be removed from beams, floors, and walls until these structural units are strong enough to carry their own weight and any anticipated superimposed load.* Forms and scaffolding should be designed so they can be easily and safely removed without impact or shock to the concrete and to permit the concrete to assume its share of the load gradually and uniformly.

Where building code or building official requires demonstrated strength before forms and shores are removed, it is necessary to employ a testing laboratory to make and break concrete test cylinders. When no tests are required, formwork and supports for walls, columns, and the sides of beams and girders may be stripped after 12 hours when the temperature surrounding the structural units is 50 F (10 C) or more; forms and supports for slabs may be removed after 14 days of temperatures of 50 F or more. However, if spans are greater than 20 ft (6 m), the supports for slabs must remain in place for 21 days at such temperatures. On basement walls the interior braces should be left in place until after backfilling.

When permitted by building codes, strengths may be confirmed by nondestructive testing procedures such as the rebound hammer, penetration resistance probe, or other appropriate equipment.+

CHAPTER 6-REINFORCEMENT

6.1 -General

Steel reinforcing is usually not required in one and two family residential construction. However, reinforcement may be needed to satisfy local acceptable practices and building code requirements.‡ Soil conditions in certain areas of the country warrant designs using conventional reinforcing steel systems or post-tensioned systems.

6.1.1 *Types of reinforcement*

Reinforcement for concrete construction is readily available as either deformed reinforcing bars or welded wire fabric,§ which comes in flat sheets or rolls.**

6.1.2 *Walls*

Basement walls should be constructed to meet the requirements of local codes.

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*See ACI 347 for specific, detailed information.

+Test methods for such equipment are given in ASTM C 803, ASTM C 805, ASTM C 873, and ASTM C 900.

‡See References 3, 4, 5, and 6.

§Steel reinforcing bars and welded wire fabric are covered by various ASTM specifications listed in the references.

**See Reference 7.

In the absence of local codes, basement walls may be constructed of unreinforced concrete [see Fig. 6.1.2(a)] where unstable soils or groundwater conditions do not exist and in Seismic Zones 0 and 1 [see Fig. 6.1.2(b), 6.1.2(c), and 6.1.2(d)]. Also in the absence of local codes, wall thickness should be in accordance with Table 6.1.2(a).

In the absence of local codes where unstable soil conditions exist or in Seismic Zones 2, 3, or 4, concrete basement walls should be reinforced as set forth in Table 6.1.2(b). Basement walls subject to unusual loading conditions, surcharge loads, or excessive water pressure should be designed in accordance with accepted engineering practices.

Separate concrete members such as porches, stoops, steps, or chimney supports should be connected to foundation walls or footings with reinforcing steel bars. These anchorages are recommended to prevent separation and to minimize differential settlement of the adjoining members.

6.1.3 *Footings*

Continuous wall footings and spread footings need only be reinforced to support unusual loads or where unstable soil conditions are encountered. Footings that span over pipe trenches or are placed over highly variable soils should be reinforced in accordance with local building code requirements.

6.1.4 *Slabs*

Reinforcement is generally not required in concrete slabs-on-ground used for single family residential construction. Reinforcement, however, can help limit cracking caused by drying shrinkage or large temperature changes. When it is desirable to extend the distance recommended between joints in outdoor slabs (Section 7.1.3.2), welded wire fabric can be used to reduce sizes of cracks and minimize infiltration of water, deterioration of concrete, or other effects that could be costly to repair. For such slabs and slabs in areas where there are expansive or compressible soils that change in volume in response to weather and affect the concrete, reinforcement is used as discussed in Section 6.2.3.1.2.

Floors to be covered with thinset tile or other inflexible covering should be jointless slabs in which any cracks that may form are held tightly closed by adequate amounts of welded wire fabric or other steel reinforcement.

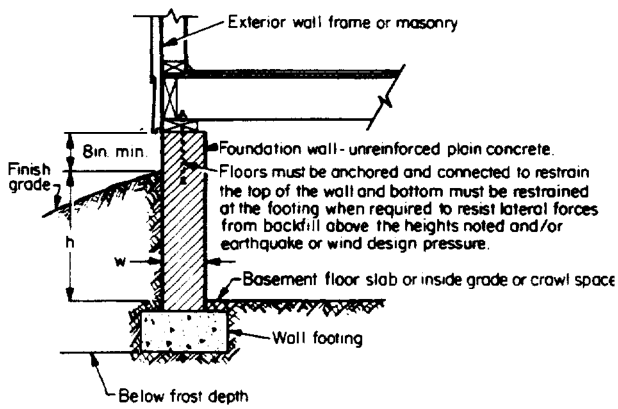

Fig. 6.1.2(a)—Unreinforced basement walls [see Table 6.1.2(a)]

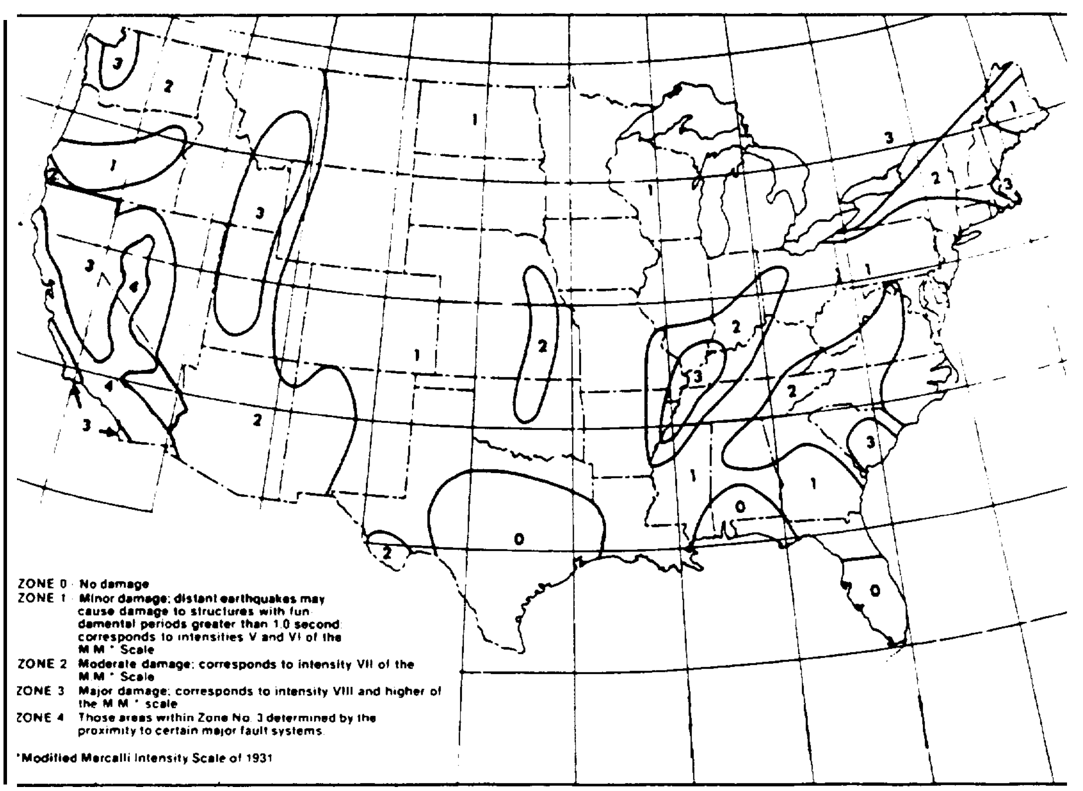

Fig. 6.1.2(b)—Seismic risk map, continental United States

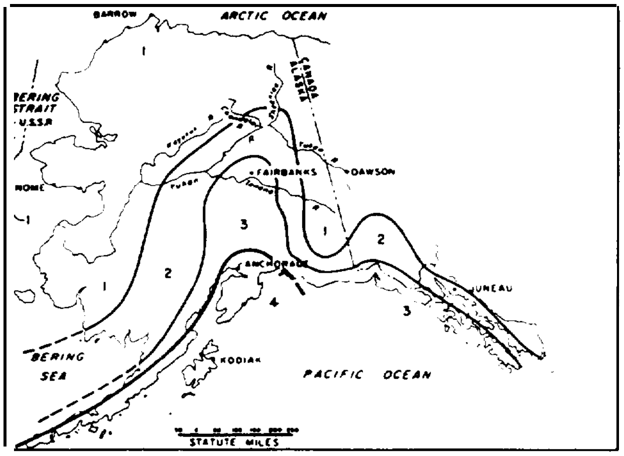

Fig. 6.1.2(c)—Seismic risk map, Alaska

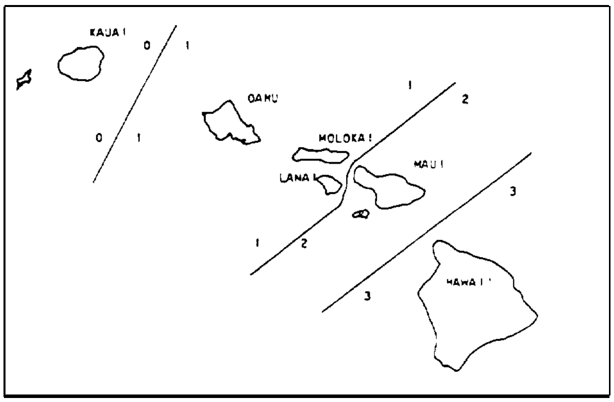

Fig. 6.1.2(d)—Seismic risk map, Hawaii

inforcement. Otherwise, cracks or joints are likely to reflect through the floor covering.

Recent developments in post-tensioning systems that may be useful in outdoor slabs on expansive or compressible soils provide an alternative to conventionally reinforced systems.*

6.2-Reinforcement requirements

6.2.1 *Walls*

Generally, reinforcement for walls is required only at joints between separately cast concrete elements and around openings. However, temperature steel can help to control thermal and shrinkage cracking (Section 7.1.4.2). Walls that retain soil or that will otherwise be excessively loaded may also require reinforcement (Section 6.1.2).

Adequate provisions should be made to assure that separate concrete components do not pull apart at the joints. When concrete porches or other concrete elements are placed after the concrete foundation walls, reinforcing steel bars and a support ledge or corbel should be provided at the connecting joint. No. 4 (12.77 mm diameter) bar dowels spaced not more than 24 in. (610 mm) on centers should be provided across the joint.

Where reinforcement is required in basement walls over 8 in. (200 mm) thick, bars should be located at

Table 6.1.2(a)-Minimum thickness and allowable depth of unbalanced fill for unreinforced concrete basement walls where unstable soil or ground water conditions do not exist in seismic zones No. 0 or 1*

See also Fig. 6.1.2(a)

These provisions apply to walls not covered by local codes

Nominal thickness,[a] w[b]		Maximum depth h of unbalanced fill,[c] h	
in.	mm	ft	m
6[d]	150[d]	4	1.2
8 to 12	200 to 300	7	2.1

[a]Unreinforced plain concrete walls should be designed in accordance with local building codes and standard engineering practices.
[b]Actual thickness is permitted to be ½ in. less than nominal thickness.
[c]Unbalanced fill is the height of outside finish grade above the basement floor or inside grade.
[d]Six in. (150 mm) plain concrete walls should be formed on both sides.

least 1 in. (25 mm) but not more than 2 in. (50 mm) from each face of the wall. If the thickness is 8 in., the steel should be placed at the centerline of the wall. In 6-in. (150-mm) walls, the steel should be placed at least 1 in. (25 mm) but not more than 2 in. (50 mm) from the face of the wall, that is, opposite (away from) the earth [Table 6.1.2(b), Footnote b]. Concrete cover for reinforcing steel adjacent to contraction joint grooves should be at least 1 in. (25 mm).

Lintels over wall openings should be reinforced, and precast units for this purpose are usually available from building material suppliers. However, lintels for large openings over 6 ft. (1.8 m) in width, or openings that have unusual loading conditions, should be designed by a registered professional engineer.

6.2.2 *Footings*

Deformed steel bars should be used in footings where reinforcement is required. Footings that cross over pipe trenches should be reinforced with at least two No. 5 (15.88-mm) bars, extending at least 1½ times the trench width. Footings spanning pipe trenches over 3 ft (0.9 m) in width should be designed by a registered professional engineer.

6.2.3 *Slabs*

6.2.3.1 *Slab types-* Concrete slabs-on-ground for single-family dwellings are classified in four types that cover almost all slabs encountered in practice. The slab appropriate to any given set of conditions should be adequate in terms of performance and economy.

6.2.3.1.1 Slab Type A. Slab Type A, the most commonly used type, is unreinforced except at special locations; all other slab types are reinforced. Slab Type A may contain reinforcement around depressions, openings, and heating ducts [Fig. 6.2.3.1. I(a) and Fig. 6.2.3.1.1(b)] and at pipe trenches.†

*Any such system should be designed by a registered professional engineer. It should be installed and inspected by competent personnel thoroughly familiar with such work and with the necessary safety procedures (Reference 8).

†It is a good idea to follow the provisions of Section 6.3 of ACI 318 regarding the use and amount of reinforcement because of the many requirements for type of pipe, prevention of corrosion, maximum allowable pressures, maximum allowable temperature of piped liquids, proper methods for putting pipe into service for the first time, and other matters.

Table 6.1.2(b)-Basement walls, reinforced: Reinforcement required for basement walls subjected to no more pressure than would be exerted by backfill having an equivalent fluid weight of 30 pcf (480 kg/m³) or located in seismic zone No. 2, 3, or 4.

These provisions apply to walls not covered by local codes
Walls must be designed by a registered professional engineer

Height of unbalanced fill[a]		Length of wall between supporting concrete walls		Minimum wall thickness[b]		Number and size of horizontal bars in upper 12 in. (300 mm) of wall		Size and spacing of vertical bars	
ft	m	ft	m	in.	mm	ASTM	SI equivalent	ASTM	SI equivalent
4 or less	1.2 or less	unlimited		8	200	not required		not required	
4	1.2	8	2.4	8	200	2 #3	2 9.52-mm dia.	#3 at 18 in. o.c.	9.52-mm dia., 460 mm o.c.
8 or less	2.4 or less	8 to 10	2.4 to 3	8	200	2 #4	2 12.70-mm-dia.	#3 at 18 in. o.c.	9.52-mm dia., 460 mm o.c.
8 or less	2.4 or less	10 to 12	3 to 3.7	8	200	2 #5	2 15.88-mm-dia.	#3 at 18 in. o.c.	9.52-mm dia., 460 mm o.c.
8	2.4	design required		design required		design required		design required	

[a]Unbalanced fill is the height of outside finish grade above the basement floor or inside grade. Backfilling should not be started until after the wall is anchored to the floor.
[b]Thickness of concrete walls may be 6 in. (150 mm) provided reinforcing is placed not less than 1 in. (25 mm) nor more than 2 in. (50 mm) from the face of the wall not against the earth.

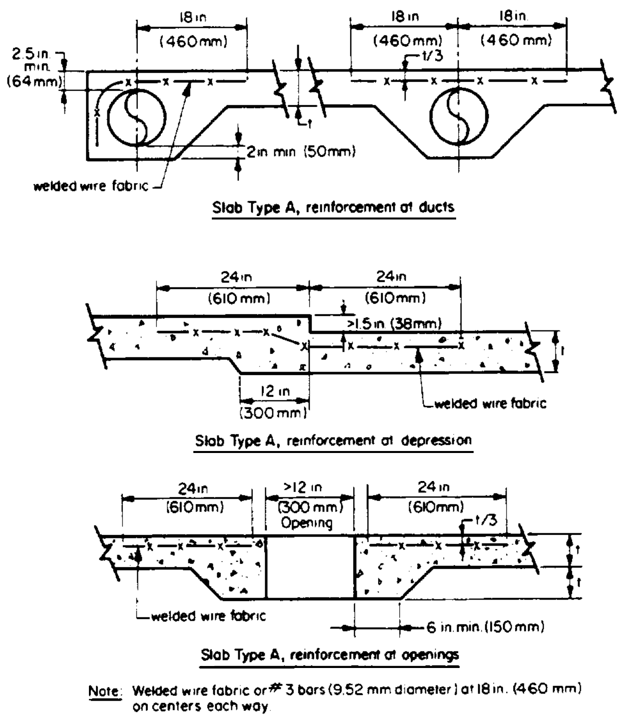

Fig. 6.2.3.1.1(a)-Details for Type A slabs

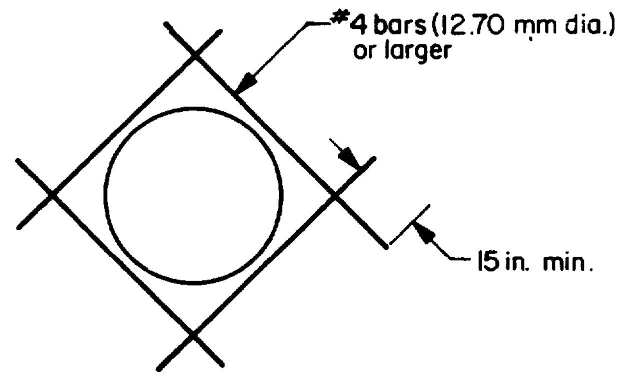

Fig. 6.2.3.1.1 (b) - Reinforcement around openings larger than 12 in. (300 mm) in slabs

Type A slabs are intended for use on firm ground where no soil volume change is expected. These are slabs of a 4 in. (100 mm) minimum thickness cast directly on a properly prepared gravel or sand base and unreinforced except at pipe trenches or the locations shown in Fig. 6.2.3.1.1(a). This type of slab serves basically as a separator between ground and living space for basements or slabs-on-ground.

Type A slabs may also be used for driveways or parking pads for passenger vehicles. If heavy vehicular loads are expected, however, a thicker slab may be required. This type of slab should have contraction joints spaced not more than 15 ft (4.6 m) on centers to control shrinkage cracking. When slabs are located outdoors, especially where subjected to extreme differences in temperature, the maximum distance between joints should be 10 to 12 ft (3 to 3.5 m). At isolation joints, such as at the intersection of driveway and curb, the pavement should be thickened and detailed to comply with the local building code.

6.2.3.1.2 *Slab Type B (lightly reinforced).* This 4-in. (100-mm) slab is normally used on ground that may undergo small movements (shrinkage or expansion) caused by changes in soil moisture from heavy rains or drought. It is also used when it is necessary to locate the joints farther apart than allowed in Type A slabs. To withstand these small movements as well as accommodate the stresses of drying shrinkage and thermal change without serious damage, the slab is provided with light reinforcement. This reinforcement will also minimize damage caused by minor soil movements. Welded wire fabric (or an equivalent amount of reinforcing steel bars) should be provided throughout the slab in accordance with Table 6.2.3.1.2, and details should comply with local building code provisions. Thicker slabs may be recommended for driveways and parking areas when vehicles larger than passenger cars are expected or where subsoil support is marginal. Pavement slabs should be thickened at isolation joints where vehicular traffic occurs.

6.2.3.1.3 *Slab Type C (heavily reinforced).* This type of slab transmits all superstructure loads to the

Table 6.2.3.1.2-Recommended reinforcement for slab Type B*

Maximum dimension or distance between contraction joints		Welded wire fabric wire spacing		Welded wire fabric wire size		Reinforcing bars as alternative
ft	m	in.	mm	Number	Diameter in mm	
15 to 25	4.5 to 7.5	6 × 6	150 × 150	W1.4 × W1.4 (10 gage)	3.43 × 3.43	#3 at 18 in. (45 mm) on centers each way
25 to 45	7.5 to 10.5	6 × 6	150 × 150	W2.0 × W2.0 (8 gage)	4.04 × 4.04	#3 at 18 in. (45 mm) on centers each way
45 to 65	10.5 to 17	6 × 6	150 × 150	W2.9 × W2.9 (6 gage)	4.88 × 4.88	#3 at 18 in. (45 mm) on centers each way

*Based on a coefficient of friction of 1.5, unit weight of concrete of 150 pcf (2400 kg/m³), and allowable working stress in steel of 45,000 psi (310 MPa).

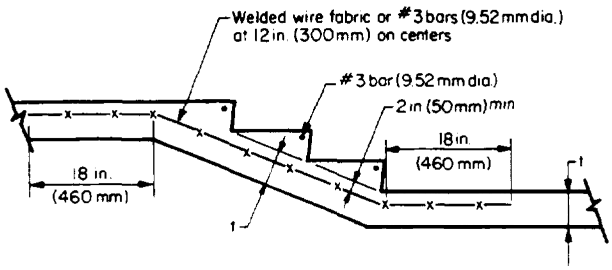

Fig. 6.2.3.4-Reinforcement for exterior steps

foundation soil. It is often used with soils that are expected to undergo substantial volume change over a period of time. Use of spread and continuous footings for the foundation is not advisable on such ground; therefore, loads are distributed by the slab over its entire area. This reduces the bearing stresses on the soil and also forces the foundation, slab, and superstructure to act as a monolithic structure.

The foundation slabs are designed with adequate stiffness and strength to resist severe soil movements, and designs are based on soil properties obtained by soil investigations. Slabs of this type need to be carefully analyzed and designed by a registered professional engineer in accordance with local building code provisions and appropriate standards.*

6.2.3.1.4 *Slab Type D.* This slab is appropriate for use with any soil including highly expansive soils because it does not rest on surface soil. It is designed in accordance with conventional engineering practices and is a structural slab supported on piles, piers, or footings that rest on unyielding stable soil or rock. Slabs should be designed and reinforced in accordance with local building codes and standard engineering practices. Soil contact should not be permitted with slab or grade beams; otherwise, pressure sufficient to damage the slab may result. It is also advisable to provide protection to reduce the effect of friction on piers or piles that pass through expansive soils.

6.2.3.2 *Placement of reinforcement-* Reinforcement in Type A slabs, if used, should be located as shown in Fig. 6.2.3.1.1(a). Reinforcement in Type B slabs should be placed in the middle of the slab, a minimum of 2 in. (50 mm) from the top surface. Sheet welded wire fabric (WWF) is better than roll WWF, since it is difficult to get the latter to lie flat. Deformed bars may also be used. Reinforcement should be adequately supported on metal, plastic, or 6000 psi (41 MPa) precast concrete chairs during concrete placement to prevent movement. Laying the fabric on the ground before placing the concrete and then pulling it up with hooks is not an acceptable method because the fabric seldom becomes located at the right height and dirt or stone is likely to be drawn up with it into the concrete. Deformed steel bars or welded wire fabric should not be continued through expansion joints but may extend through construction or contraction joints. Dowels may cross expansion joints. On at least one side of the joint the dowels should be lubricated, coated, or covered with caps.

Reinforcement should be continuous and lapped a minimum of 12 in. (300 mm) or 20 bar diameters, where required. Welded wire fabric should be lapped over adjacent sheets by one wire spacing plus 2 in. (50 mm).

6.2.3.3 *Reinforcement for embedded items, slab depressions, and openings* - Heating coils, pipes, or conduits embedded in the slab require special precautions. They should not be embedded in an unreinforced slab, because These items may cause excessive stresses in the concrete.+ Heating ducts can, however, be embedded if completely encased in at least 2 in. (50 mm) of concrete and if the slab over the duct is reinforced. Reinforcement should extend a minimum of 18 in. (450 mm) on each side of the duct or to the slab edge, whichever is closer [see Fig. 6.2.3.1.1(a) for typical details].

Reinforcement should be provided where the top surface of the slab is depressed more than 1½ in. (38 mm). Welded wire fabric should be placed in the middle of the slab and should extend 24 in. (610 mm) from edges of the depression, as shown in Fig. 6.2.3.1.1(a).

Openings in slabs should be kept to a minimum. Large openings can cause non-uniform stresses that will crack the concrete. Where 12-in. (300-mm) or larger openings are required, the slab should be reinforced as shown in Fig. 6.2.3.1.1(b).

6.2.3.4 *Reinforcement for exterior steps* - Reinforcement should be used in exterior steps as shown in Fig. 6.2.3.4. Welded wire fabric or #3 deformed bars

*Design and construction information on reinforced slabs is given in Reference 9 and on post-tensioned slabs in Reference 8.
+See footnote to Section 6.2.3.1.1.

are embedded 1/3 the thickness of the slab, measured from the bottom of the risers, but a minimum of 2 in. (50 mm) from the surface. As shown, #3 bars are also run parallel to the noses. Support for the steps should be provided by haunches as discussed in Section 8.4.1.1.

CHAPTER 7 -JOINTS AND EMBEDDED ITEMS

7.1- Joints

7.1.1 *Purpose of joints*

Concrete changes volume due to forces acting on it such as superimposed loads and changes in moisture content and temperature. These volume changes cause internal stresses if the free movement of the concrete mass is restrained. To reduce these restraining forces, concrete should not be cast directly against another part of the structure without providing adequate freedom and movement.

The intended function of joints is to

a. minimize undesirable cracking

b. accommodate differential movement of adjacent elements of construction, and

c. provide natural planes of weakness and prevent undesirable bonding to adjacent elements.

7.1.2 *Types of joints*

Three types of joints are used in concrete slabs and walls: isolation joints, contraction joints, and construction joints.

Isolation joints (also called expansion joints) are used at points of restraint including the junction between similar or dissimilar elements of a concrete structure. For example, they separate walls or columns from floors, or they separate two concrete structures such as a walk from a driveway or a patio from a wall.

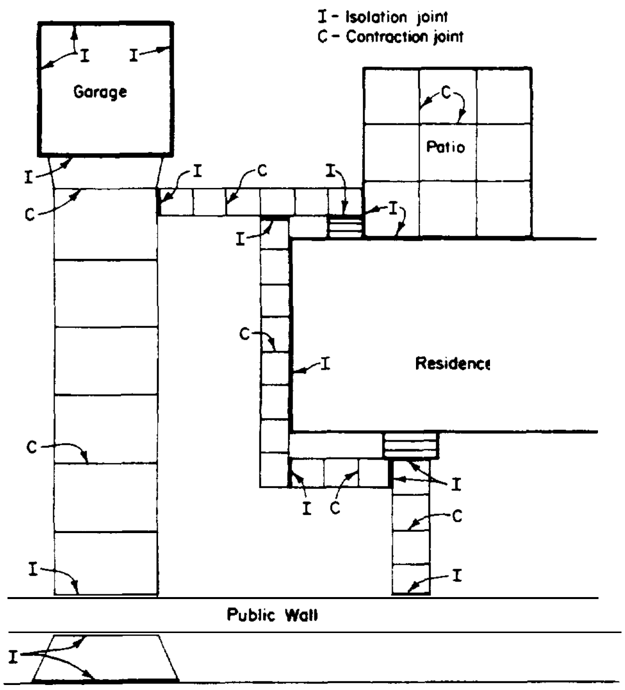

Fig. 7.1.3.1(a)--Recommended locations of isolation and contraction joints in flatwork around residences

Contraction joints (also called control joints) are made within a structural element to accommodate movements that are inevitably caused by temperature changes, drying shrinkage, and creep. The joint is sawed, formed, or tooled part way through the concrete. This forms a weakened plane so that later, when the concrete cracks, it will crack along this predetermined line and not at random locations.

Construction joints are joints that have been introduced for the convenience or needs of the construction process. This usually means that construction joints are located where one day's placement ends and the next day's placement begins-or where, for other reasons, concreting has been interrupted long enough so that the new concrete does not bond to the old. Usually only a keyway is used to keep the two adjoining parts in alignment, but sometimes it is necessary to place dowels or reinforcing steel across the joint to hold the concrete on both sides together.

7.1.3 *Slab joint location, size, and construction*

7.1.3.1 *Isolation joints for slabs* - The general method of locating isolation joints in slabs is shown in Fig. 7.1.3.1(a) and 7.1.3.1(b). Specific recommended locations for isolation joints are as follows.

a. Between slabs-on-ground and foundation walls.

b. Between slabs and inserts such as pipes, drains, hydrants, lamp posts, column footings, and other fixed structures or equipment.

c. Junctions of driveways with public walks, streets, curbs, and adjacent foundation walls.

d. At junction of garage slab (or apron) and driveway.

e. Where the garage slab abuts the garage wall.

f. Between driveway or sidewalk and steps, patio, planter, or other similar construction.

Isolation joints should extend the full depth of slabs. They should either run the full width of slabs or connect with contraction joints that do. The joints should be constructed so that the joint filler will be accurately aligned both vertically and horizontally.

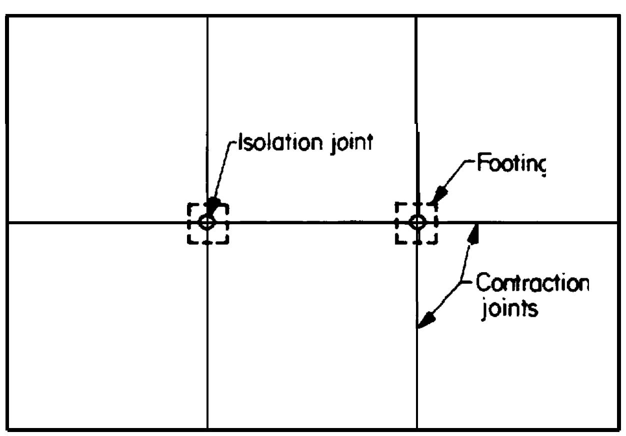

Fig. 7.1.3.1(b)-Isolation joints should be met by contraction joints. Panels should be as nearly square as possible

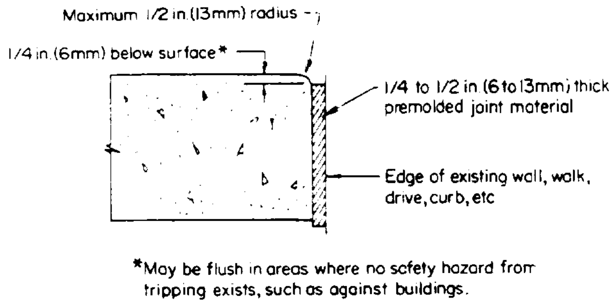

Fig. 7.1.3.1(c)-Details for a typical isolation joint

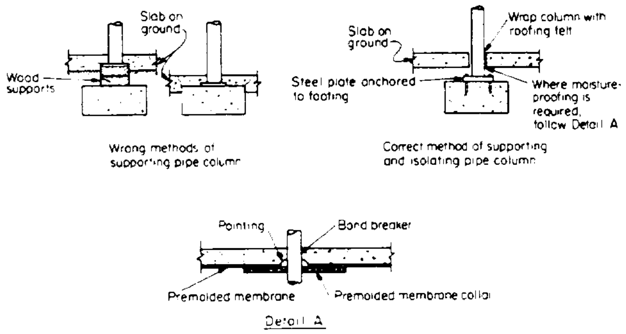

Fig. 7.1.3.1(d)-Column isolation joint design

A typical isolation joint for use between adjoining slabs-on-ground or between a slab and a building is shown in Fig. 7.1.3.1(c). There are various ways to form the joint around the perimeter of a floor. A piece of premolded filler, cut to the same depth as the floor slab, provides a convenient screed level for the floor slab. An alternative is a piece of the type of house siding that has a wedge-shaped cross section. This can later be withdrawn and the joint caulked with a sealant. Many builders simply use polyethylene film covering the top of the footing and extending up the side of the wall higher than the thickness of the floor slab.

Some right and wrong methods of isolating pipe columns are shown in Fig. 7.1.3.1(d). A convenient circular form for isolating columns from floors is shown in Fig. 7.1.3.1(e). Isolation joints around pipes, hydrants, pipe columns, and drains may be constructed of roofing felt, polyethylene sheet, or other suitable material placed in a vertical plane for the full depth of the slab. Joint fillers for isolation joints should be preformed materials that can be compressed without extruding significantly. They should preferably be materials that can recover their original thickness when compression ceases. Joint fillers should also be stiff enough to maintain alignment during concreting and durable enough to resist deterioration due to moisture and other service conditions. Acceptable filler materials include, but are not limited to, wood (cedar, redwood, pine, chipboard, fiberboard), cork, bituminous-impregnated vegetable and mineral fiber boards, solid or cellular rubber, and expanded plastic foams. The filler should be placed so that it does not protrude above the surface.

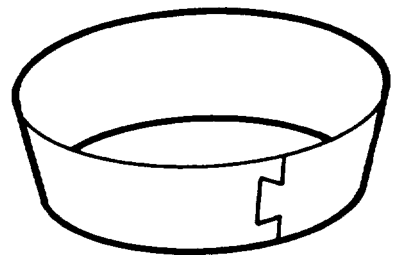

Fig. 7.1.3.1(e)-Circular form for isolating columns from floors. Form, which tapers slightly toward bottom, is left in place

7.1.3.2 *Contraction joints for slabs* - In continuous floor slabs on ground, contraction joints should be located not more than 15 ft (4.5 m) in both directions unless intermediate cracks are acceptable. A shorter interval should be used whenever there is reason to expect shrinkage to be high. If the slab is to be covered with carpet or flexible tile such as vinyl or asphalt (but not thin-set tile, Section 6.1.4), and minor shrinkage cracks are not objectionable, larger spacing of joints may be allowed. Transverse joints should be only 10 to 12 ft (3 to 3.5 m) apart in driveways and 4 to 5 ft (1.2 to 1.5 m) in sidewalks. If there is need to exceed these spacings, see Section 6.1.4 for the use of welded wire fabric. Double-width driveways should be provided with a longitudinal contraction joint.

Where forming of square panels is not economical, the ratio of panel dimensions should not be greater than 1:1.5. Since stress concentrations often cause cracks, joints should be located in such a way as to avoid buildup of stress concentrations at such points as A, B, C, D, and E in Fig. 7.1.3.2(a).

Contraction joints in sidewalks, patios, floors, and driveways may be made by tooling, sawing, or using 2 x 4 wood or plastic divider strips [Fig. 7.1.3.2(b)]. Hand-tooled joints can be formed by a metal tool to produce a vertical groove approximately ¼ the thickness of the slab but not less than 1 in. (25 mm) deep or by a hardboard insert strip approximately ¼ in. (6 mm) thick by 1 in. (25 mm) wide. Sawed joints also should be cut ¼ the thickness of the slab but not less than 1 in. (25 mm) deep to form a weakened plane below which a crack will form. Saw cutting should be done as soon as possible after hardening of the concrete. Wood divider strip contraction joints of the kind shown at the bottom of Fig. 7.1.3.2(b) can be used for decorative walks, driveways, and patios.

7.1.3.3 *Construction joints for slabs* - Construction joints are located where concreting operations are interrupted long enough for the previously placed concrete to harden. They are a convenient means of limiting the size of a placement to a manageable volume. Whenever possible, construction joint locations should be planned in advance so that bulkheads or formwork can be set in place and cold joints avoided. (Cold joints are locations where the concrete has bonded imperfectly or not at all to concrete already hardened). Some bulkhead details are shown in Fig. 7.1.3.3. Construc-

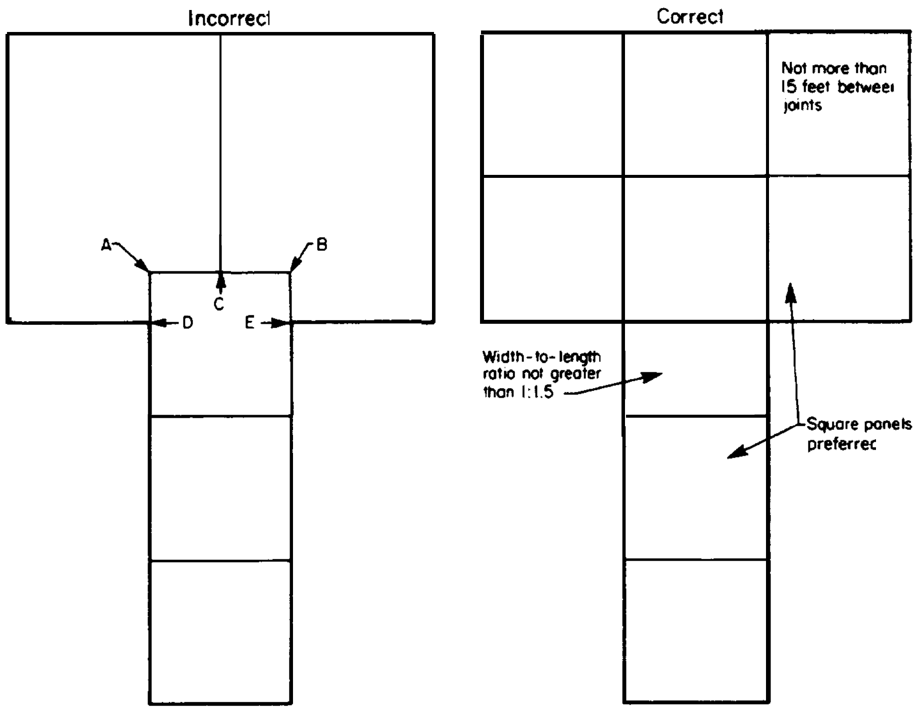

Fig. 7.1.3.2(a)-Joints should be located to avoid such stress concentrations as those of A, B, C, D, and E, which inevitably lead to cracking. Panels should be as nearly square as possible

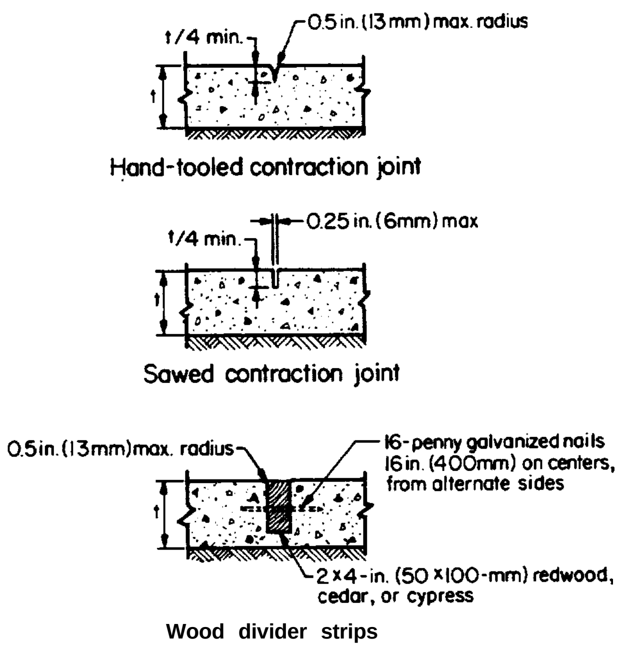

Fig. 7.1.3.2(b)-Contraction joints used in slabs-on-grade

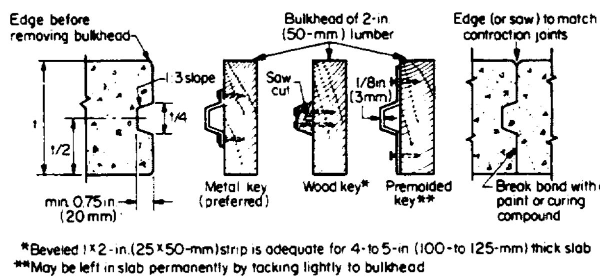

Fig. 7.1.3.3-Bulkhead details for construction joints

tion joints should not be located any closer than 5 ft. (1.5 m) to any other parallel joint. In planning the locations of construction joints, it is desirable to try to use them where they will actually function as isolation or contraction joints.

7.1.4 *Wall joint location, size, and construction*

7.1.4.1 *Isolation joints for walls* - An isolation joint should be used at any location where a wall meets a slab or an independent wall [Fig. 7.1.3.1(a) and Fig. 7.1.3.1(c)]. An isolation joint between the wall and the floor or exterior slab permits slight movement and helps prevent random cracking due to restraint of shrinkage, slight rotations, or settlement of the slab.

7.1.4.2 *Contraction joints for walls* - Contraction joints are recommended to eliminate random shrinkage cracking in walls while still providing structural stability and watertightness. As a rule of thumb, in residential concrete basement walls 8 ft (2.5 m) high and nominally 8 in. (200 mm) thick, vertical contraction joints should be located at spacings of 30 ft (9 m) along the wall. Fig. 7.1.4.2(a) illustrates location of contraction joints and shows reinforcing bars crossing them to keep the joints from opening wide. For walls of less height, the joint spacing should be reduced. Where available, the side of a window or door should be chosen as a joint location because this opening already constitutes a plane of weakness in the basement wall.

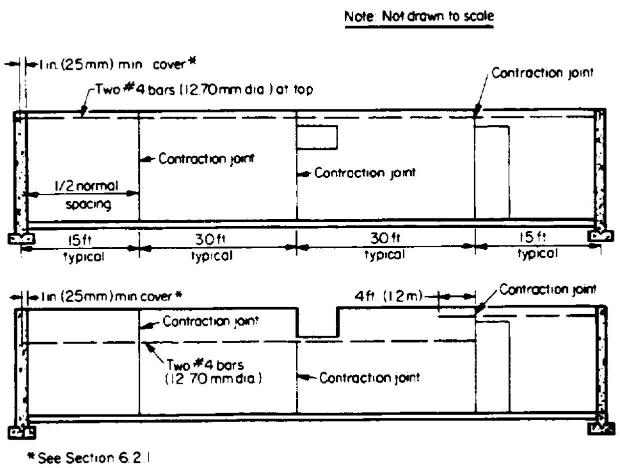

Fig. 7.1.4.2(a)-Contraction joint locations in walls and effect of window position on reinforcing bar location

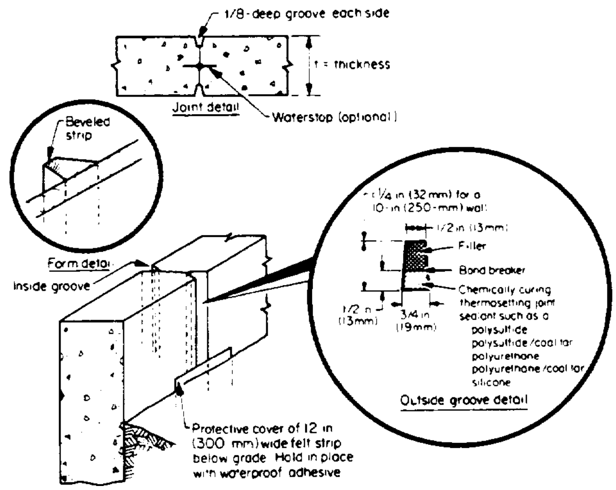

Fig. 7.1.4.2(b)-Method of making contraction joints in walls

Field experience has shown that, in addition to contraction joints, a small amount of reinforcement located as shown in Fig. 7.1.4.2(a) is effective in controlling shrinkage cracks.

Contraction joints are made in walls by attaching wood, metal, or plastic strips to the inside faces of the formwork. One method is shown in Fig. 7.1.4.2(b). The exterior side of the joint should be caulked with a chemically curing thermosetting joint sealant such as polysulfide, polyurethane, or silicone that will remain flexible after placement. After the groove has been carefully caulked, a protective cover such as a felt strip 12 in. (300 mm) wide should be placed over the joint below grade. Some builders install a waterstop at contraction joint locations for extra protection, as indicated in the detail in the figure.

Another method is to cut the contraction joints into the wall with a masonry saw. This should be done within a few hours after stripping the forms to prevent random cracking from occurring. With this method a waterstop should be used.

7.1.4.3 *Construction joints in walls* - Vertical construction joints are rarely necessary in one- and two-family houses. If needed they can nearly always be located at corners, edges of pilasters, or other places where they will be effectively concealed. At least three #4 dowel bars should be used at each vertical construction joint (top, bottom, and middle) to tie the sections of the wall together. A waterstop may also be required. If so, before the first concreting, the waterstop should be attached to the concrete side of the bulkhead. After the bulkhead has been stripped, the free edge of the waterstop should protrude into the space that remains to be concreted. In that way it will form a barrier across the cold joint.

7.2 -Embedded items

7.2.1 *Waterstops*

If waterstops are required in foundation walls or other subsurface construction, the waterstop should be securely positioned so that its center is in line with the joint and it will be properly embedded in the concrete [Fig. 7.1.4.2(b)].

7.2.2 *Radiant heating or snow melting systems*

Concrete used for any system containing pipes or wires for radiant heating or snow melting should not contain any added calcium chloride. Concrete in place should conform to the water-soluble chloride ion limitations set forth in Table 3.1.5.

Because of their outdoor exposure, concrete for slabs with snow melting systems must contain entrained air, and the slabs must have a slope (Section 2.2.1) of at least 1 in. per 4 ft (2 percent).

7.2.2.1 *Systems with piped liquids* - Piping is generally ferrous or copper pipe having 2 in. (50 mm) of concrete below and 2 to 3 in. (50 to 75 mm) of concrete over the top, placed at one time. Use of two separate layers has caused maintenance problems. Solid concrete cubes or blocking are recommended as supports for the piping. The pipe should not rest directly on any insulating subfloor or other subbase. Welded wire fabric should be placed over the piping, but if the piping is copper, the fabric must not be allowed to be in contact with it. Any contraction joint must allow for movement of the piping as well as provide protection against contact with any corrosive agents such as deicing salts. The pipe should be pressure tested prior to placing concrete. During placement of the concrete the pipe should contain air under pressure. To prevent cracking of the concrete, lukewarm water should be used initially to warm up the slab gradually.

7.2.2.2 *Systems with electric wire embedded* - When electric wires are used for radiant heating, they are laid out on freshly placed unhardened concrete and immediately covered with an additional 1 to 3 in. (25 to 75 mm) of top-course concrete to prevent a cold joint. Care should be taken to prevent abrasion of the wire insulation.

7.2.3 *Heating ducts*

Metal, rigid plastic, or wax-impregnated paper ducts may be embedded in concrete if necessary for the heating system. If metal ducts are used, the concrete should be checked to be sure if contains no more than 0.15 percent water-soluble chloride ion by weight of cement.

7.2.4 *Other embedded items*

All sleeves, inserts. anchors, and any items embedded to continue into adjoining work or to attach or support that work should be accurately positioned and secured before placing concrete. Anchor bolts for securing a wood sill to a foundation wall may be located after the concrete is placed and before it has set.

CHAPTER 8 - FOOTINGS AND WALLS

8.1- General

This chapter principally considers concrete basement or foundation walls. Much of what is included may also be applicable to retaining walls, non-load-bearing interior walls, and concrete walls above grade. Special attention may be required for the design and reinforcement of these walls when they are subject to loadings atypical for normal basement walls.

8.2 -Site conditions and drainage considerations for basement walls

Soil investigation should be thorough enough to insure design and construction of foundations suited to conditions at the building site. In many cases, no special soil investigations are needed for residential construction since local experience with the soils encountered at a site is often extensive.

The topography of a site, ground cover, or experience in the area sometimes indicates high groundwater, springs, or unusual soil conditions. If so, test borings should be taken or a pit dug to a point several feet below the proposed basement footing level. The height of standing water in the hole will indicate the elevation of the groundwater at the time observed. The borings or pit will also indicate the type of soil at the site.

Soils are classed broadly as either coarse or fine grained. Coarse-grained soils, such as gravel and sand, consist of relatively large particles. In fine-grained soils, such as silts and clay, the particles are relatively small. Fine-grained silts and clays may required long time periods to consolidate when subjected to foundation loads, while coarse-grained soils consolidate quickly. Residential foundation loads are usually small and will not cause significant settlement in most types of soil; but when organic soils, cohesive and sticky clays, or varying soil types are encountered, consideration should be given to long-term differential settlement. Usually, sites having coarse-grained granular soils are best, providing the water table is low.

Surface water must be made to drain away from the structure. Finished grade for the site should fall off ½ to 1 in. per ft (40 to 80 mm per m) for at least 8 to 10 ft (2.5 to 3.0 m) from the foundation wall. On hillside sites the construction of a cutoff drain on the high side of the building may be necessary to lead surface water away from the basement wall. On low sites, the building should be built high with fill added around the walls so that the water will flow away on all sides.

Rainwater runoff from downspouts must be diverted away from basement walls. Open gutters, underground tile, or splash blocks extending at least 3 ft (1 m) away from the house are acceptable means of diversion.

8.3 - Excavation and footings

8.3.1 *General excavation*

In good cohesive or clay soils, excavation is done with mechanical equipment at least to the level of the top of the footing. (The excavation should go deeper if a granular layer is to be used below the floor slab.) Porous noncohesive or sandy soils should be excavated to the level of the bottom of the footing.

Except where nominally 8-in. (200-mm) or thicker walls are to be formed only on one side [see Table 6.1.2(a)], the excavation should be 2 ft (0.6 m) larger on all sides than the outline of the basement walls to provide working room for basement construction operations. Banks in excess of 6 ft (2 m) high should be tapered back or stepped.

8.3.2 *Footing excavation and footing size*

Footings should be excavated by hand or by specialized equipment to the required width and at least 2 in. (50 mm) into natural undisturbed bearing soil. Footing excavation should be at least 6 in. (150 mm) below the zone of frost penetration, even though firm bearing soil is found at a shallower depth. The bottom of the excavation should be level so that the footing will bear evenly on the soil. Builders must consult the local building code and comply with its regulations.

In case the excavation is made too deep, backfill should not be placed below the footings because the nonuniform support might cause uneven settlement of the building. The excessive excavation should be filled with concrete as part of the footing.

Where footings might bear partially on rock, making uneven settlement a possibility, the rock should be removed to approximately 18 in. (450 mm) below the bottom of the proposed footing and replaced with a cushion of sand. An alternative method of construction is to increase footing depths so that the entire footing bears on rock.

In localities where controlled fill is permitted by local building codes and where the site has been compacted to the required density, the footing can be located directly on the controlled fill. Otherwise, it is recommended that the footings be made to extend down into the original undisturbed soil.

Footing widths should be based on the load and the soil bearing capacity. To accommodate wall forms, footings should project 4 in. (100 mm) on each side of the wall to be cast in place.

8.3.3 *Load distribution*

Where soil conditions are poor, wider footings are often used to distribute loads over a large area. This reduces the pressure on the supporting soil. These footings often require special reinforcement. When unusual soil conditions are encountered, the footings should be designed by a registered professional engineer.

8.3.4 *Frozen ground*

Concrete must not be placed on frozen ground. Builders should plan and coordinate the excavation so that the exposed earth is protected from freezing while footings are being formed. When fiberglass-filled blanket, straw, or other insulation has been placed over the ground ahead of time to protect it from freezing, the insulation should not be removed until immediately before casting the concrete in the footings and should then be promptly replaced to insure proper protection of the concrete during the curing period.

8.4 - Design of foundation walls

8.4.1

Except in seismically active areas and where unusual loading conditions exist, reinforcement of solid concrete basement walls or footings is generally not needed (Sections 6.1 and 6.1.2). Nominal wall thickness requirements for unreinforced concrete basement walls not covered by local codes are presented in Table 6.1.2(a).

8.4.1.1 Attachment of steps to foundation walls - Concrete slabs or steps that are to be used at an entrance to a residence should be supported by one or more haunches cantilevered from the main foundation wall. Haunches should be tied to the main wall with reinforcing bars and cast monolithically with the main wall (Fig. 8.4.1.1).

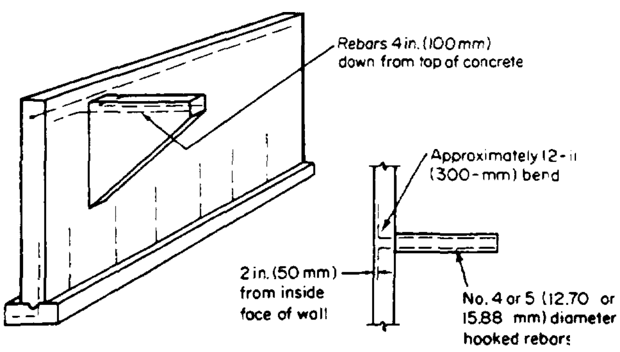

Fig. 8.4.1.1-Detail of haunch for entry slab or steps

8.4.2 *Structurally reinforced concrete basement walls*

Where unstable soil conditions exist, or in Seismic Zones 2, 3, and 4,* basement walls should be reinforced and should be designed by a registered professional engineer.

8.4.3 *Insulating foundation, basement, and other exterior walls*

In some areas insulation is required for the top 24 in. (600 mm) of basement walls. Insulation may be placed on the exterior or interior wall surface, or it may be cast into the middle of the wall as described next.

8.4.3.1 *Insulation on interior wall surface* - This has been the most common method in the past. See Fig. 8.4.3.1.

8.4.3.2 *Insulation sandwiched within the concrete wall* - One method is to use vertical plastic strips, inside the forms, between which panels of insulation are snapped into place. Another method is illustrated in Fig. 8.4.3.2.

8.4.3.3 *Insulation on exterior wall surface* - Keeping the concrete on the inside of the insulation provides an advantage in both summer and winter by using the

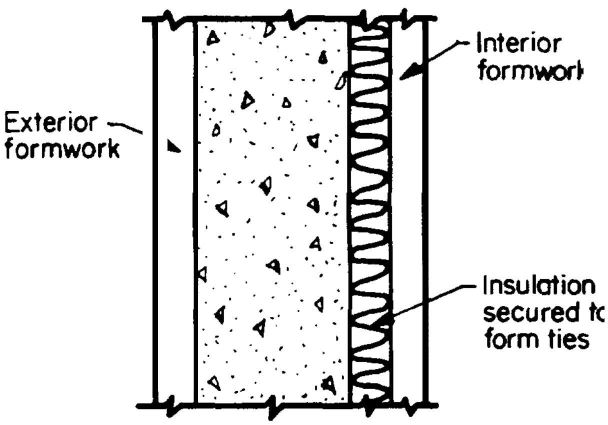

Fig. 8.4.3.1--Insulating board cast against interior face of wall

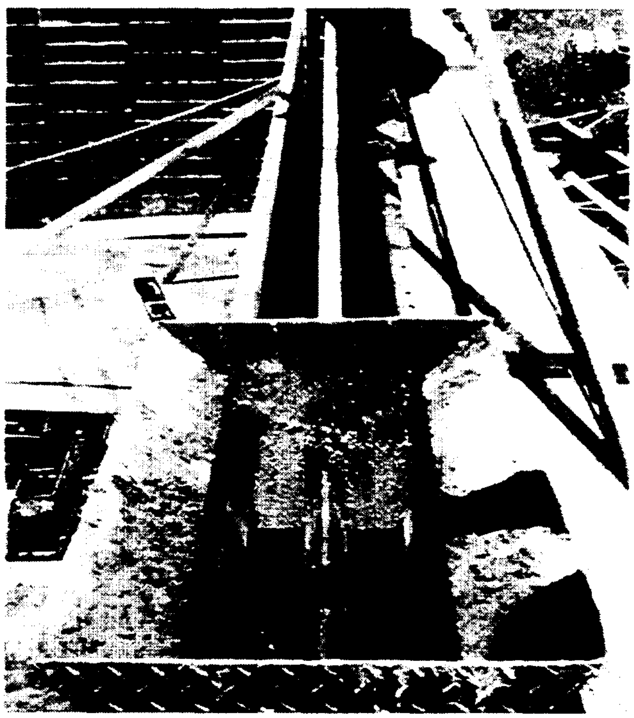

Fig. 8.4.3.2-Light reinforcing steel has been threaded through holes in the form ties while wall forms were being erected. These serve to securely position expanded polystyrene or other insulating panels within a wall. Concrete is placed by a splitting hopper to fill both sides at the same rate, thus avoiding differences of pressure on the two sides

*See Reference 3

heat capacity of the concrete as a heat sink. The insulation must, however, be protected from mechanical damage, for example, by a coat of portland cement plaster (Fig. 8.4.3.3).

8.4.3.4 *insulation on both exterior and interior surfaces* - In some proprietary systems insulation board is used initially as formwork within which to cast a concrete wall and is then left in place as insulation.

8.4.4 *Strength of concrete*

Concrete for walls should be chosen according to the exposure (Section 2.2 and Table 2.2).

8.5- Forming joints in walls

Joints are built into walls when the formwork is being erected. The purpose of joints is discussed in Section 7.1.1 and the types of joints in Section 7.1.2. The uses of joints in walls are discussed in Sections 7.1.4.1, 7.1.4.2, and 7.1.4.3.

8.6- Placing concrete in footings and walls

8.6.1 *Preparation of forms and subsoil*

Before concrete is placed in footings, the subsoil should be moistened. The insides of forms and the subsoil under footings must be moistened to prevent excessive absorption of mixing water from the concrete. Additional moisture does not have to be applied to oiled forms or damp subsoil. Pools of rainwater that have collected in footing forms must be pumped out, and all water that has collected in forms or on the grade should be removed before placing concrete. It is not always possible to get the surface completely dry, particularly where the water table is high. If so, the concrete should be placed in a manner that displaces the water without mixing it into the concrete.

Forms must be braced and aligned before concrete is placed in walls. Forms should be securely built. When forming systems are installed, they should be securely fastened together and braced in accordance with the instructions of the manufacturer. Form alignment should be checked before and after concrete placement to make certain that the wall is within required tolerances.

8.6.2 *Access for handling*

It is important to plan ahead for access of ready-mix concrete trucks to the walls. If it is not possible for trucks to have access to several locations around the forms, chutes, buggies, or wheelbarrows can be used to move the concrete. When steel or steel-lined chutes with rounded bottoms are used, the slope should not be greater than 1 vertical to 2 horizontal and not less than 1 vertical to 3 horizontal. Basement concrete can also be placed by a conveyor, mobile placer, or pump. The boom of a pump can usually distribute concrete to all areas of a basement from a single pump location.

8.6.3 *Avoiding segregation*

The concrete should be deposited into the wall forms as close as possible to its final position. Except for what has come to be known as "flowing concrete" (see next paragraph), lateral or fluid movement of concrete within the forms will produce flow lines and discoloration as well as segregation. Although these are sometimes acceptable and are not visually objectionable if covered with other materials, they do represent weakened planes. They may also offer an opening for water to come through. If flow lines do occur they can be eliminated by puddling the fresh concrete. They can be minimized by good workmanship and placement from several locations simultaneously. Construction practices should be followed that will reduce the possibility of segregation. Excessive slump (soupy mixes) will cause concrete to separate into aggregate and mortar, resulting in stone pockets, honeycomb, and permeable concrete, though so-called flowing concrete, described later, can be virtually free of these troubles.

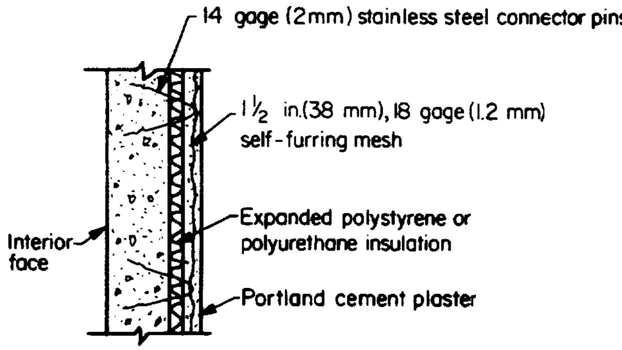

Fig. 8.4.3.3-Wall cast with insulation on exterior. Mesh on exterior serves as anchorage for portland cement plaster, which protects insulation against damage from impact or abrasion

8.6.4 *Slump*

Slumps of 6 ± 1 in. (150 ± 25 mm) (see Table 2.2 including Footnotes b, e, and f) are used for residential wall construction. The mix should be proportioned with enough cement for the water-cement ratio to produce the needed strength at such slumps. Segregation and excessive bleeding can easily occur at these slumps. The mix proportioner should be able to overcome these effects by increasing the proportion of sand, cement, or air-entraining admixture or by introducing a selected amount of materials such as fly ash or other mineral admixture and water-reducing, set-controlling admixtures, discussed next. If concrete is to be placed by pumping, the amount of coarse aggregate is generally decreased by amounts up to 10 percent, a practice that is better than increasing the slump.

Concrete with high flowability, sometimes called flowing concrete, is made by using various admixtures. The higher material cost may be offset by savings in labor through more efficient placement. To make flowing concrete, the following materials can be used in proportioning the mix:

a. high-range water reducer (HRWR), otherwise known as superplasticizer,

b. conventional water-reducing admixture Type A* used at very high dosage rates, or

c. an admixture system that includes a high dosage of normal setting, water-reducing admixture Type A* in conjunction with a set accelerating formulation, Type C or E,* to balance the retardation caused by the high dosage of normal setting admixture.

There are potential advantages with HRWRs as well as limitations. Advantages are improved workability, greater ease of placement, and more rapid strength development.[†] Major drawbacks are rapid loss of flowability (usually measured by a reduction in slump) and some uncertainty about whether concrete placed at 7 in. plus (175 mm plus) slump will have sufficient durability to cycles of freezing and thawing when saturated. The rapid loss of slump occurs with all HRWR admixtures; the way to accommodate the slump loss is to hold off dispersing the HRWR admixture in the mix until the concrete arrives at the job site. Job site dispensing may lessen the concrete producer's control over the quality of the concrete, possibly raising questions about whether responsibility for quality lies with the contractor or with the concrete producer. There are today on the market extended-slump-life HRWR's that may be added at the batch plant and thus reduce some of the above problems. If durability in freezing and thawing exposures is a concern, the durability of the mix at the slump range proposed should be investigated or documented beforehand.

8.6.5 *Placing concrete*

Residential walls are normally placed no more than one story at a time. Concrete should be placed in a continuous operation and in uniform lifts of no more than 4 ft (1.2 m). Concrete placement should be scheduled to completely fill the forms.

8.6.6 *Compacting concrete*

Hand tamping and spading provides adequate compaction. Residential concrete is generally compacted by puddling, moving a piece of lumber, or a steel rod, up and down vertically to consolidate the concrete and release pockets of entrapped (but not entrained) air. Care should be taken in this process not to hit or scrape the inside surfaces of the forms; such action could remove form release agent and create form stripping problems.

Vibrators are helpful in filling forms under window blockouts and around waterstops and other inserts; they are also recommended where the architectural appearance of the wall is important. When used, the vibrator should be inserted at close enough intervals so that its visible field of influence on each insertion slightly overlaps its field of influence on the previous insertion. It should be plunged into the freshly placed mass deeply enough to penetrate 6 in. (150 mm) into the previously placed lift and then removed slowly in a continuous motion. Vibrators should be kept moving up and down, never allowed to remain in one position in the concrete, and they should not be dragged.[‡]

CHAPTER 9 - CONCRETE SLAB CONSTRUCTION

In 1962, ACI Committee 332 published a guide for construction of residential slabs-on-grade.[§] More recently, a craftman's manual for slab-on-grade construction was published. Information on one method of constructing slabs over basements to provide fire resistance and improved heat capacity was recently published elsewhere.[††]

9.1 - Quality assurance

9.1.1 *General*

Requirements for concrete for residential construction are given in Chapter 2. It is particularly important that concrete for flatwork be proportioned for adequate strength and finishing and that, if subject to freezing and thawing, sulfate soils, or seawater, air entrainment be provided (Section 2.2.1).

Achieving a hard, wear-resistant, durable slab surface depends on three main factors: (a) proper concrete mix proportions, (b) good placing and finishing practices, and (c) proper and adequate curing. These factors are addressed in Chapters 2, 4, 9, and 10. Special attention should be paid to Sections 2.2, 2.2.1, 2.2.2, 2.2.3, 7.1.3 (including subsections), 9.3.3, 9.3.5, and 10.1.

9.1.2 *Cracking*

Cracks may be caused by settlement, soil expansion, concentrated loading, penetrations, uneven drying shrinkage between top and bottom, or restraint to drying shrinkage or temperature changes. Settlement cracks can often be prevented by proper preparation of the subgrade. Cracks from expanding soil can often be prevented by protecting the subgrade from absorbing water, including either water that can be drawn out of fresh concrete by the soil or rainwater that can collect beneath the slab and be absorbed by the soil. Cracking from concentrated loads may be avoided by transferring the loads to separate footings, isolating columns from floors by joints, and making slabs thick and strong enough to support the loads. Slab cracking caused by elements penetrating the slab can be prevented by isolation and contraction joints (Sections 7.1.3.1 and 7.1.3.2).

The contraction of slabs is primarily caused by the drying shrinkage that takes place after the concrete has begun to set, and this shrinkage depends largely on the amount of water the concrete still holds at the time. This amount of water will be less if a sand bed has been used, as described in Section 9.2.1. Shrinkage can also be affected by the cement content, type and amount of admixture, and type and source of aggregate.

*ASTM C 494 specifies the various types of admixtures.

†References 10 and 11 give more information on HRWRs, or superplasticizers.

‡For further details on consolidating concrete by vibration, see ACI 309, Chapters 4, 5, and 7.

§See Reference 12.

**See Reference 13.

††See Reference 14.

Drying shrinkage cracks can be minimized by controlling the concrete mix by using the proper aggregates combined with low water and slump requirements and by casting on a sand base. Along with such measures, the proper location of isolation joints and contraction joints (Sections 7.1.3.1 and 7.1.3.2) is necessary. Drying shrinkage cracks can be held tightly closed by using welded wire fabric, provided the right amount is used and properly located (Section 6.2.3.1.2).

As the concrete begins to harden, plastic shrinkage cracking can occur if the rate of moisture loss (evaporation) from the concrete exceeds the rate at which water rises to the surface (bleeding). If these cracks form during finishing, they can usually be closed with a float. However, the surface should be immediately protected from subsequent evaporation. Generally, these cracks do not penetrate the full depth of the slab and do not result in progressive deterioration.[*]

9.1.3 *Curling*

Because shrinkage in a slab occurs more rapidly at exposed upper surfaces, the slab may curl upward at edges. If the slab is restrained from curling, it may crack wherever stresses from restraint are greater than the tensile strength. There are three basic elements for reducing slab curling.

A. Locate joints at closer intervals so that the total movement of each slab will be less.

B. Use a concrete mix with low shrinkage characteristics.

C. Try to equalize the moisture content and temperature between the top and the bottom of a slab.

The following methods can be used to implement these principles:

A1. As an alternative to close spacing of contraction joints, place heavy amounts of reinforcing steel 2 in. (50 mm) down from the surface [½ in. (40 mm) down if the slab is only 4 in. (100 mm) thick]; conventional amounts of welded wire fabric will have little or no effect on curling.

B1. Select a higher strength concrete, 4000 psi (28 MPa) minimum, with low permeability.

2. Use a lower slump concrete, 2 to 3 in. (50 to 75 mm), struck off and compacted with a vibratory screed.

3. Avoid using any admixture that may increase drying shrinkage.

4. Use the highest proportion of maximum size aggregate and smallest proportion of sand that is consistent with good workability.

C1. Wait for bleed water to disappear from the surface before starting any finishing operation.

2. Give special attention to curing: cure 1 day wet and then apply a liquid-membrane curing compound so that enough moisture will be held in the slab to continue the curing process while moisture will leave slowly enough to minimize the moisture gradients that cause curling.

3. It has been reported[†] that curling can be reduced by casting the slab on a pervious bed such as sand without a vapor barrier (Section 9.2.1). Absorption of moisture by the sand more nearly equalizes the early loss of water from the bottom of the slab with the amount evaporating from the uncovered top surface. In addition to reducing drying shrinkage cracking (Section 9.2.2) and curling, this method is reported to minimize finishing problems.

Still another method that does not fall within the previous classification is to stiffen the slab by increasing its thickness at free joints and edges.

9.1.4 *Nonslip and nonskid surfaces*

Almost all indoor slabs are steel troweled, consequently very smooth, and tend to be slippery when wet. Even nontroweled outdoor surfaces may not have adequate skid or slip resistance. Slipperiness is prevented by various finishing techniques that provide both the degree of planeness and texture required.

If steel troweled surfaces are to be exposed to the weather or other wetting, they should be slightly roughened to produce a nonslip surface. This can be done by using a swirl finish or by brooming the freshly troweled surface. A soft-bristled broom is drawn over the troweled surface; if a coarser texture is desired, a stiffer bristled broom may be used.

Nonslip surfaces may also be produced by troweling in abrasive grains such as silicon carbide or aluminum oxide.:

9.1.5 *Scaling and spalling*

Scaling and spalling from exposure to alternate freezing and thawing and from the application of deicer chemicals are common problems in sidewalks, driveways, and floors of unheated garages built with non-air-entrained concrete. These problems may be virtually eliminated by insuring that there is an adequate amount of entrained air. Table 2.2.1 recommends requiring specific air contents on the basis of the maximum size of coarse aggregate. Success is dependent, however, on having a concrete of good mix proportions and low slump, observance of good placing and finishing procedures, providing adequate curing, and preventing application of deicers before the slab has had a chance to cure thoroughly and then to dry out (Section 10.3.1).[‡]

9.1.6 *Joint deterioration*

Joints may fail or deteriorate when the subgrade is not well compacted to uniform density (Section 9.2.1) or where water penetration through a joint washes away the subgrade. Spalling may be caused by intrusion of pebbles into an unsealed open joint, causing local fracturing when expansion of the slab causes the joint to close. Proper subgrade preparation (Section 9.2.1), joint design and spacing (Sections 7.1.3.1, 7.1.3.2, and 7.1.3.3), and joint sealing (Section 10.5) are necessary to prevent joint deterioration.

*A more complete discussion of plastic shrinkage cracks may be found in ACI 302.1R.

†See references 15 and 16.

‡Recommendations of ACI 302.1R should be followed

Table 9.2.3—Minimum R-values[a] of perimeter insulation for slabs-on-grade

Heating degree days[a] (65 F base) for one season	Minimum R-values[a,b]	
	Heated slab	Unheated slab
500 or less	2.8	—
1,000	3.5	—
2,000	4.0	—
2,500	4.4	2.5
3,000	4.8	2.8
4,000	5.5	3.5
5,000	6.3	4.2
6,000	7.0	4.8
7,000	7.8	5.5
8,000	8.5	6.2
9,000	9.2	6.8
10,000 or greater	10.0	7.5

[a]For definitions of heating degree days, R-value and U-value, and statements of the units of measurement, see Glossary (Appendix A).
[b]For increments between degree days shown, U-values' may be interpolated or the values shown in Fig. 2 of ASHRAE 90A-80 (published by American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., 1791 Tullie Circle NE, Atlanta, GA 30329) may be substituted.

9.2- Site preparation

9.2.1 *Subgrade and drainage*

The building site and subgrade must be well drained to prevent soil erosion, ponding of water, or saturation of soil at the foundations. Proper grading is required to drain all storm water away from the dwelling unit.

Grass, sod, roots, and other organic matter must be removed. Utility trenches and holes should be filled and uniformly compacted in 6-in. (150-mm) layers using fill material uniform in composition and free of organic matter, large stones, or large lumps of frozen soil.

Where the bearing or grade is not uniform, especially in clay or other cohesive soils, it is desirable to fill at least the top 4 in. (100 mm) with a gravel, crushed stone, or sand subbase. Fill coarse enough to be retained on a No. 4 sieve is widely used where it is desirable to interrupt capillarity between the slab and the soil. A vapor barrier may or may not be used over the fill, as described in Section 9.3.2. Sand fill only 2 or 3 in. (50 or 75 mm) thick, without a vapor barrier over it, is reported to minimize cracking (Section 9.2.2) and curling (Section 9.1.3) as well as finishing problems.*

In regions where shrinking or expansive soils, or soils of high moisture retention are common, the soil should be removed to a depth of 1 ft (0.3 m) below the foundation (local experience may justify more) and replaced with granular fill, unless the design of the foundation accounts for the adverse soil conditions. In the Far West, presaturation of expansive soils prior to placing the concrete slab has proved beneficial in preventing cracking of slabs.

The subgrade must be free of frost before concrete placement. If the subgrade temperature is below freezing, it must be raised and maintained above 50 F (10 C) long enough to remove all frost from the subgrade. The area may have to be covered with tarpaulins or polyethylene sheets and heated with steam from a portable steam generator.

The subgrade should be moist when concrete is placed. If necessary, it should be dampened well in advance of concreting. Where ground or surface water presents a problem, a positive system of underground drainage should be provided. There should not be any muddy or soft spots at the time of placing.

9.2.2 *Vapor barriers*

Vapor barriers are waterproof membranes of 4 to 6 mil (0.10 to 0.15 mm) polyethylene or roofing paper. They should be resistant to deterioration as well as to puncture by construction traffic.

If there are no drainage or soil problems or if the region is arid and not irrigated or heavily sprinkled, a vapor barrier may not be needed under the slab. A vapor barrier is frequently used (though not always specified) where floor coverings, household goods, or equipment must be protected from damage by moist floor conditions. When a vapor barrier is used, the fresh concrete loses water only by bleeding, and not by absorption by the subgrade, so it has less opportunity for reduction of the water-cement ratio before the concrete hardens. The hardened cement paste thus contains a little bit more water and more shrinkage potential than if no vapor barrier were used. It is also slightly weaker. Both characteristics may contribute to more cracking when using a vapor barrier.

To minimize the drying shrinkage cracking that may occur in a thin slab over a vapor barrier, a 2- to 3-m. (50- to 75-mm) layer of damp sand over the vapor barrier has sometimes been used. However, some regard it as impractical because care must be taken to avoid mixing the sand blanket into the concrete during placement. Such mixing is harder to avoid if the slump is high.

Vapor barriers should be overlapped 6 in. (150 mm) and sealed at the joints and should be carefully fitted and sealed around all slab openings. If a coarse granular subbase is used, a layer of sand over the subbase (under the membrane) is recommended to prevent puncturing during concrete placement.

A 4 in. (100 mm) granular subbase may be used in lieu of a vapor barrier if the floor covering or its adhesive will not be affected by moisture and if the subsoil is well drained.

9.2.3 *Edge insulation*

For slab-on-ground floors in areas that are heated or mechanically cooled, the thermal resistance of the insulation around the perimeter of the floor should be not less than shown in Table 9.2.3. Insulation may be installed in either of two ways. It may extend downward from the top of the slab for not less than 24 in. (600 mm). Alternatively, it may be installed downward to the bottom of the slab and then horizontally beneath the slab for a minimum total distance of 24 in. (600 mm). Insulation should be placed as shown in Fig. 9.2.3(a) and Fig. 9.2.3(b).

9.2.4 *Heating ducts*

Heating ducts may be embedded in the slab as described in Section 6.2.3.3. Metal ducts may be used if

*See References 15 and 16

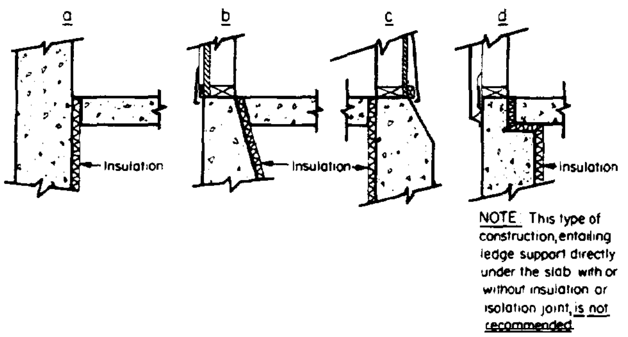

Fig. 9.2.3(a)-Type A slab insulation details

the concrete is not made with calcium chloride, chloride-containing admixture, or other chloride-containing materials. Wax-impregnated paper heating ducts are also used. The clear distance between ducts must not be less than the diameter of the duct or the dimension of the smaller side of the duct. However, if this should require more than 6 in. (150 mm) clear distance, 6 in. may be used.

9.2.5 *Electrical conduit and water pipes*

When electrical conduit or water pipes are embedded in the floor, they must have at least 1½ in. (38 mm) of concrete cover. Neither aluminum nor other nonferrous conduit should be used in the same floor with steel.

9.3-Placing and finishing

9.3.1 *Placing concrete*

The concrete should be discharged as near as possible to its final position and against the concrete already in place. Concrete must not be placed faster than it can be spread, straightedged, and darbied or bull floated, because darbying or bull floating must be performed before bleeding water begins to collect on the surface.

To obtain good surfaces and avoid cold joints, the size of the finishing crew should be planned with regard for the effects of temperature and humidity on the rate of hardening of the concrete. If construction joints become necessary, they should be produced with suitably placed bulkheads. If desired, provisions can be made in the bulkheads to key the joints into further work.

Spreading the concrete should be done with a short-handled square-end shovel or a specifically designed hoe-like tool. Vibrators should not be used to spread concrete. Compacting is usually accomplished in the operations of spreading, vibrating, screeding, and darbying or bull floating. Grate tampers or mesh rollers should not be used. If there is reinforcement, it should be adequately supported (Section 6.2.3.2), and workmen should be warned not to walk or stand on the reinforcement. A person's weight can bend or displace the steel to the bottom of the concrete, where it is ineffective.

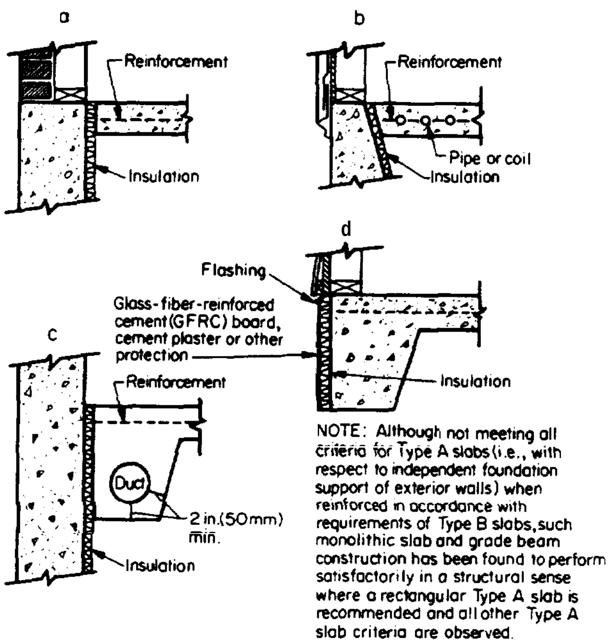

Fig. 9.2.3(b)- Type B slab insulation details

9.3.2 *Striking off*

Striking off, commonly called screeding, involves moving a straightedge supported on the screeds back and forth lengthwise in short strokes while moving it slowly forward along the surface. This evens off the surface to a specified location. Vibratory mechanical screeds or strikeoffs are now commonly used on large areas.* Striking off must be done immediately after placement. This is a critical operation that has the greatest effect on surface tolerances.

9.3.3 *Darbying*

A darby is a tool used to smooth out ridges, fill in voids left by the straightedge, and slightly embed the coarse aggregate. This prepares the surface for the subsequent edging, jointing, floating, and troweling. Darbying should be done immediately after striking off and must be completed before any excess moisture or bleeding water is present on the surface. Finishing slabs when excess moisture or bleed water is on the surface may cause dusting or scaling.

9.3.4 *Bull floating*

The bull float is generally used for the same purpose as a darby, but is easier to use on a large area because of its long handle. However, the long handle does not permit applying much leverage, and so it is more difficult to smooth the surface than with a darby.

9.3.5 *Waiting*

It is usually necessary to wait for the concrete to stiffen slightly before proceeding further. No subsequent operation should be done until the concrete will sustain foot pressure with only about ¼-in. (6-mm) indentation.

*Additional details on vibration are given in ACI 309

9.3.6 *Edging*

Edging is generally done on sidewalks, driveways, and steps to form a radius along isolation and construction joints and at the edges of the slab. An edger should not be used if the floor is to be covered with tile. Edging produces a neater looking edge that is less vulnerable to chipping. The concrete should not be edged until all bleed water and excess moisture have left the surface or been removed.

In most floor work, after the forms are stripped and before the adjacent slab is placed, edges at construction joints may be lightly rubbed with a stone to remove sharp edges and fins.

9.3.7 *Jointing*

Jointing should be done immediately after edging. If a floor is to be covered with flexible tile, jointing is usually considered unnecessary. If contraction joints are hand-tooled, the cutting edge, or bit, of the jointing tool should be deep enough to cut ¼ the thickness of the slab. A T-bar or angle bar may be used to displace coarse aggregate before using hand jointing tools. This simplifies the job and makes better working joints. Jointing to the depth required may be difficult without using a displacement bar. Sawing is often preferable. If jointing only for decorative purposes, jointers with shallower bits may be used, but these joints are not considered contraction joints for crack control purposes.

It is good practice to use a straight 1 x 8-in. (25 x 200-mm) board as a guide when making the groove in the concrete slab. If the board is not straight, it should be planed true to prevent detracting from the appearance of the finished slab.

On large flat surfaces, it may be more convenient to cut joints with a power saw fitted with an abrasive or diamond blade (Section 10.4). Plastic inserts can be used in the fresh concrete in lieu of deep-tooled or sawed joints.

9.3.8 *Floating*

After edging and hand-grooving operations, the slab should be floated. This embeds large aggregates just beneath the surface; removes slight imperfections, humps, and voids; and compacts the concrete. It also consolidates mortar at the surface, where it will be needed for troweling.

If floating is done by machine, a troweling machine with float shoes attached should be used. It is difficult to set a definite time to begin floating. The time depends on concrete temperature, air temperature, relative humidity, and wind. When the water sheen disappears and the concrete will support a person with only about ¼-in. (6-mm) indentation, it is ready to be floated.

The float should be used to remove the marks left by the flanges of the edger and jointer unless these marks are wanted for decoration. If the marks are to be left, the edger or jointer should be run over them again after floating is completed.

Floating and troweling are not necessarily required for all exterior slabs such as driveways. These operations tend to lower the slip resistance, and in areas where weather exposures are severe, floating and troweling may be detrimental to the durability of the slabs.

9.3.9 *Troweling*

As just noted, troweling can be undesirable for slabs to be exposed to severe weather. Troweling produces a smooth, hard surface. It is begun immediately after floating and should never be done to a surface that has not been floated. If troweling is done by hand, the concrete finisher floats and then steel trowels one area before moving his kneeboards to the next.

If necessary, tooled joints and edges should be rerun before and after troweling to maintain true and uniform lines.

For the first troweling, whether by power or by hand, the trowel blade must be kept as flat against the surface as possible. If the trowel blade is tilted or pitched at too great an angle, the surface will have a "washboard" or "chatter" appearance. For first troweling, it is recommended that the trowel should not be new and less than 4¾ in. (120 mm) wide. An older trowel that has been broken in can be worked quite flat without the edges digging into the concrete.

The density and smoothness of the surface can be improved by timely additional trowelings. There should be a lapse of time between successive trowelings to permit the concrete to harden more. As the surface stiffens, each successive troweling should be made with progressively smaller trowels tilted progressively more to enable the concrete finisher to use sufficient pressure.

The purpose of each additional troweling is to increase the compaction of fines at the surface, giving greater density and more wear resistance. Two trowelings are recommended if the floor is to be covered with tile; this will give a closer surface tolerance and a better surface for the application of tile. More trowelings may be desirable on floors that are to remain uncovered. Very hard troweling can lead to surface discoloration (Section 11.2.6).

9.3.10 *Ornamental surfaces*

Production of colored, textured, geometrically designed, or exposed aggregate surfaces requires special techniques.*

CHAPTER 10-CURING, SAWING, SEALING, AND WATERPROOFING

10.1-General

Properly mixed, placed, and finished concrete also requires proper curing. This involves preventing loss of moisture from the concrete and maintaining a temperature in the concrete-40 to 90 F (4 to 32 C) - suitable for maturing of concrete. Favorable curing conditions should be maintained as long as practical. Three to five

*See ACI 302.1R.

days are considered minimum requirements for summer conditions. In the winter, favorable curing conditions should be maintained even longer.

The importance of curing cannot be overemphasized. This is particularly true of slabs, where improper or inadequate curing can severely diminish serviceability by causing soft and dusting surfaces, scaling surfaces, porous concrete, or cracked and scaled concrete. The desirable properties of concrete such as strength, watertightness, durability, and wear resistance of the surface are enhanced by proper curing. In residential work the curing is still widely omitted. Anyone concerned about good quality residential concrete should make sure that curing is properly carried out.

10.2-Moisture for concrete curing

It is necessary that moisture and moderate temperatures be available during the hydration (chemical reaction with water) of the portland cement in concrete. If no moisture is available, or if the temperature drops much below 40 F (4C), the hydration reaction practically stops; under these conditions concrete strength and other desirable properties develop very slowly.

Unless surface condition is of importance, and unless the increased possibility of cracking can be tolerated, concrete in wails and columns generally does not require surface curing because the considerable thickness of walls and columns does not permit losing as great a portion of their water as do thin slabs.

Moisture loss can be minimized by using one of the following materials and methods.

10.2.1 *Wet coverings*

Burlap, cotton mats, or other fabrics, kept continuously wet, provide excellent curing conditions. They should be placed as soon as the concrete is firm enough to resist surface damage. The entire surface should be covered including edges of slabs. Dirty fabrics should be avoided since they may cause discoloration of the concrete surface.

10.2.2 *Waterproof paper*

Paper should be applied as soon as the concrete is firm enough to resist surface damage. Concrete should be thoroughly wetted to insure adequate moisture before placing the paper. Waterproof paper may produce surface mottling or discoloration (Section 11.2.6). Edges of adjacent sheets should be overlapped 3 to 4 in. (75 to 100 mm). Edges should be heavily weighted with sand to conceal them enough to keep wind from displacing the sheets and prevent breezes from blowing under the sheets and drying the concrete surface.

10.2.3 *Plastic sheets*

Polyethylene sheets are good moisture barriers, but like waterproof paper, they may produce surface mottling or discoloration (Section 11.2.6). Plastic sheets should be applied to a thoroughly wetted surface as soon as concrete is firm enough to resist surface damage. Sheets should be overlapped and weighted in the manner described above for waterproof paper.

10.2.4 *Curing compounds*

Use of a spray-on, roll-on, or brush-on membrane-forming liquid is probably the easiest, cheapest, and most practical way to cure concrete, although not as effective as other methods. The liquid curing compounds should be applied as soon as final finishing is completed. Application by rolling or brushing should not be done before the surface is firm enough to resist marring. Concrete surfaces should be damp when a curing compound is applied. If necessary, the surface should be fog sprayed with water before applying the curing compound. The curing compound should be applied at a uniform rate; the usual values of coverage range from 150 to 200 ft²/gal. (3.5 to 4.5 m²/L). When feasible, two applications at right angles to each other are suggested for more complete coverage. If the floor is to be covered with tile, the curing membrane should be compatible with the tile adhesives to be used.

10.2.5 *Ponding*

A method sometimes used for curing slabs is to build earthen or sand dikes around the edges of the slab and pond water within the enclosed area. While this method is effective for curing, it is labor intensive and may also discolor the slab.

10.2.6 *Sprinkling*

Sprinkling may be done provided the concrete is kept continuously wet. This method requires constant attention (since the surface cannot be allowed to dry out) and, for this reason, is best used in conjunction with a suitable moisture-retaining covering.

10.3-Curing temperature

When air temperatures are below 50 F (IO C) or above 90 F (32 C), special curing procedures are required as discussed next.

10.3.1 *Cold weather curing*

Below 40 F (4 C) in concrete, the rate of hydration of the cement slows down considerably, and therefore, the rate of strength gain of the concrete is greatly reduced. If the new concrete freezes while its compressive strength is less than 500 psi (3.5 MPa) or is in a saturated condition when frozen, it may be damaged permanently.

Concrete must never be placed on frozen ground (Section 9.2.1). Snow, ice, and frost must be removed from forms and reinforcing steel before concrete is placed.

Concrete temperature should be a minimum of 55 F (13 C) when placed. Concrete must also be protected from freezing until it has gained sufficient strength [approximately 500 psi (3.5 MPa)], usually at an age of 48 hr. Non-air-entrained concrete should never be allowed to freeze and thaw when it is in a saturated condition. Until air-entrained concrete has developed a compressive strength of 3500 psi (24 MPa), it also should not be allowed to freeze and thaw in a saturated condition. These considerations are especially important if concrete is placed in the late fall.*

After curing, a period of air drying greatly increases the resistance of air-entrained concrete to deicers.+ Slabs placed in the spring or summer undergo periods of drying in the normal course of aging. Slabs placed in the fall, however, often do not dry out enough before it is necessary to use deicing agents. This is especially true of slabs placed in the fall and cured by membrane-forming compounds. These membranes remain intact until worn off by traffic, and thus, adequate drying may not occur before the onset of winter. This should be of concern in fall placement of driveways, sidewalks, patios, steps, garage slabs, and other projects where deicers will be used. For such work it is preferable to use curing methods that allow drying to begin as soon as the curing period is completed. The required time for sufficient drying to take place cannot be pinpointed due to variations in climate and weather conditions. However, homeowners should be warned that it is a good rule not to use deicers until the concrete has been through its curing period plus 30 days of drying. For repair of scaling see Section 11.2.2.

Because wood forms and plywood facing on metal forms do provide some thermal protection, they should be left on longer in cold weather. The top exposed concrete should be covered with straw and tarpaulins. All-metal forms provide little protection from freezing. Exposed slabs should be covered with insulating blankets or a layer of straw of over 6 in. (150 mm) and a tarpaulin. If space heaters are used for heating interior slabs, the heaters must be vented to the outside air and care taken to prevent the concrete surface from drying out. Use of unvented heaters will result in a dusting surface, an especially troublesome problem for the owner.

10.3.2 *Hot weather curing*

Special precautions are necessary during hot weather. It is recommended that the temperature of the concrete not be more than 90 F (32 C) when delivered. When air temperatures are high and hauls are long, ready-mixed concrete suppliers can lower the concrete temperatures by methods such as icing, sprinkling of aggregate stockpiles, and sprinkling of truck-mixer exteriors. Similar methods can also be used for site-mixed concrete.

Temperatures higher than 90 F (32 C) in the delivered concrete tend to cause high water demands at the job site, faster setting times, and more difficulty for placing and finishing crews. In constructing flatwork, subgrades (but not vapor barriers, if used) should be dampened before placing concrete. Concrete should be placed as quickly as possible to allow finishing procedures to be accomplished uniformly and at the proper times. To prevent plastic shrinkage cracking, it may be necessary, before final finishing, to protect against rapid evaporation of moisture from the surface of the concrete. This can be done by spraying on an evaporation retardant or monomolecular film, by continuous spraying with a fog nozzle, or by covering temporarily with polyethylene sheeting.‡ As soon as the finishing operations have been completed on any portion of the slab, curing of that area should be initiated immediately.§

10.4-Sawing

Sawing should be delayed until the concrete has hardened enough so that the edges of the joint will ravel only slightly during cutting. If sawing is delayed too long, drying shrinkage may cause tension to build up enough for cracks to develop at unsightly directions ahead of the saw when it approaches the edge of the slab. The best time to saw is usually 4 to 12 hours after finishing, but weather conditions have a strong influence on the timing.

10.5-Filling or sealing joints

Isolation joints are filled with preformed asphalt-impregnated fiber sheeting or similar material placed before concreting begins. Joint materials that extrude when compressed should not be used. Construction joints usually are not filled.

Sealing contraction joints in slabs on grade is optional. In interior slabs the main reason for sealing contraction joints is to prevent them from collecting dirt. After interior slabs have dried to a relatively constant moisture content (which may require several months to a year), the joints usually do not open and close much. This is because there is not usually much further change in moisture content or temperature. (An exception would be floors in unheated garages in northern climates.) For this reason joint sealants for interior slabs do not ordinarily need to have much extensibility. Semiflexible epoxies or other minimally extensible sealants are suitable.

In exterior slabs the main reason for sealing contraction joints is to keep out pebbles and other debris as well as water, snow, and ice. If hard materials have intruded a joint when it is open, the subsequent closing of the joint can lead to spalling or a blowup. This problem is less troublesome in climates with little wetting and drying or not much change in temperature, or little of both. The problem is also small if contraction joints are located at frequent intervals, as they tend to be in sidewalks. A secondary reason for sealing joints in driveways on soil subgrades is to keep water from draining through the joint into the soil, possibly leading to problems with loss of support for the slab. Since these various conditions are not factors for all exterior slabs, not all outdoor contraction joints require sealing.

Either elastomeric or mastic sealants may be used for sealing contraction joints in exterior slabs. Elastomeric sealants are more effective in rejecting stones and dirt. Mastic sealants are more likely to flow out of the joint

*Additional guidelines are in ACI 306R.
+This has been shown by both laboratory studies and field experience.
‡Further details are given in ACI 302.1R.
§Additional guidelines for hot weather concreting are found in ACI 305R.

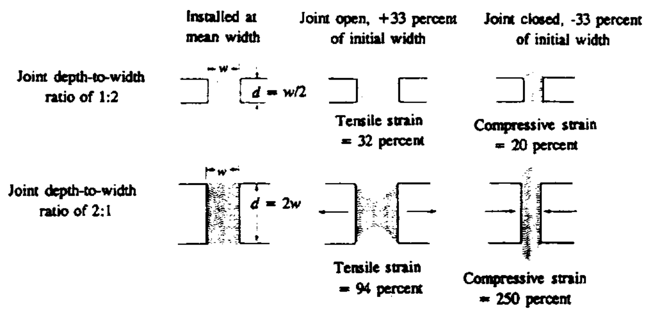

Fig. 10.5(a)-For contraction joints, the recommended depth-to-width ratio is 1:2, as shown at the top of the figure. Stresses shown are calculated on the assumption that sealant is installed when the joint is at mean opening and that width changes shown are ± 33 percent of width when sealed

and stick to shoes. They are not as sensitive to the shape factor, however. The shape factor is of great importance for elastomeric sealants; usually, the joint must be wide enough initially and sealed to a sufficiently shallow depth to produce a shape factor, or depth-to-width ratio, of 1:2 [Fig. 10.5(a)]. If the depth is greater than this in relation to the width, stresses will be much higher for the same amount of joint opening, as indicated in the figure, increasing the possibility of failure. A further disadvantage of a higher depth-to-width ratio is that more sealant is required. Four times as much sealant is required for the depth-to-width ratio shown at the bottom of the figure than for the one shown at the top.

One means of limiting the depth is to install tape or other bond breaker as shown at the left of Fig. 10.5(b). Another method is to install a filler that functions as a support, or backup material, as shown in the center of the same figure. A third method is to use a tube or preformed closed-cell rod as a backup and to tool the surface, but this may increase peeling stresses at corners and lead to failure in bond.

Contraction joints in basement walls should be sealed on the outside with a chemically curing elastomeric sealant, preferably a polysulfide, polyurethane, or silicone [Fig. 7.1.4.2(b)].

Before being sealed, joints must be thoroughly cleaned of dirt and debris by blowing with compressed air or wire brushing. Priming the surface may be required for some sealants. The manufacturer's recommendations for sealing should be followed.

10.6-Sealing flatwork surfaces

Not all concrete in slabs to be exposed to deicers contains enough air-either because of bad practices or because job difficulties caused the air content to be less than specified. Such concrete can be made more resistant to the attack of deicing agents by applying two coats of boiled linseed oil. The oil should first be thinned with an equal amount of mineral spirits, turpentine, or naphtha.

At the time the oil is applied, the temperature of the concrete should be 50 F (10 C) or higher so that the oil will penetrate the concrete and dry fast enough. The

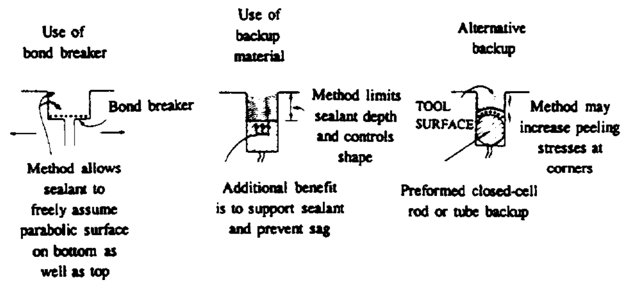

Fig. 10.5(b)-In contraction joints, bond breakers or backup materials may be used as shown to assure the desired depth-to-width ratio and avoid bonding to the concrete on the bottom surface of the sealant

concrete surface must also be dry and free of coatings or curing compounds so that the oil will penetrate properly. The diluted linseed oil should be applied at the rate of about 360 to 450 ft²/gal. (9 to 11 m²/L) for the first application and 630 ft²/gal. (15 m²/L) for the second application. It has been found that linseed oil treatments should be repeated every year or two.

The linseed oil treatment produces a slippery surface until the oil is absorbed, and it is made even more slippery if it is rained on at this time. Consequently, both foot and auto traffic should be kept off the treated surface until it has dried sufficiently. An alternative is to apply sand to reduce slipperiness during the drying period.

Linseed oil should not be used on floors that are to receive any bonded surfacing such as tile or a topping. The oil is likely to prevent proper bonding.

Recommendations regarding other coatings to combat salt scaling have been made on the basis of recent research studies of materials used as sealers for bridges, however, there are many other suitable sealers on the market that are not included in these reports.*

10.7-Waterproofing and dampproofing barrier systems for exteriors of basement walls

An important distinction is made between waterproofing and dampproofing. The definitions of these two terms are as follows: "Waterproofing is a treatment of a surface or structure to prevent the passage of water (in liquid form) under hydrostatic pressure. Dampproofing is a treatment of a surface or structure to resist the passage of water (in liquid form) in the absence of hydrostatic pressure.[+]

Water leakage problems should be reduced or eliminated by using good construction practices with high-quality concrete and proper drainage (Section 8.2).

Membrane waterproofing is the most reliable type of barrier to prevent liquid water under a hydrostatic head from entering a structure from under ground. Traditionally, waterproofing barriers consist of multiple layers of bituminous-saturated felt or fabric cemented together with hot-applied coal tar pitch or asphalt. There are also cold-applied systems that use multiple applications of asphaltic mastics and glass fabrics. Liquids, sheet-applied elastomers, and preformed elastomer-

*References 17 and 17a.
+Definitions given in ASTM D 1079 and accepted by ACI Committee 515.

modified bituminous sheets are also being used. The number of plies or thickness and the type of materials required will vary with the job conditions.

Dampproofing barrier systems may consist of a suitable coating applied to exposed surfaces or preformed films such as polyethylene sheets. Dampproofing coatings may not bridge cracks, so if cracks are present or develop later, dampproofing may not be effective.*

Local codes may dictate what may or may not be required for waterproofing and dampproofing, including both site drainage and wall coating. Often, the main cause of foundation leakage is improper drainage.

CHAPTER 11-REPAIR OF SURFACE DEFECTS

11.1 -Defects in walls and columns

Some defects on formed surfaces can be traced to poor consolidation practices.†

The repair of defects on vertical surfaces must not be undertaken until the nature and cause of the defects have been identified so that the causes can be removed or accommodated if they still exist. The subject of repair is organized here in terms of various kinds of defects.

11.1.1 *Surface air voids*

Small air voids in the surface of concrete, sometimes referred to as bug holes, are almost impossible to eliminate completely on some jobs.‡

Proprietary products are available for simplifying the job of finishing walls and eliminating surface voids. These consist of a unit packaged mixture of sand and cement that is mixed on the job with water and a unit of acrylic or other latex. If color matching is important, it may be desirable to make trial mixes using both white and gray cements, as described in the next section. The mixture is brushed uniformly onto the surface and into the voids. No moist curing procedure is undertaken because one function of the latex is to retain water for curing.

11.1.2 *Honeycomb*

Honeycomb produces a larger surface defect than the one described as a surface void. Honeycomb is a void left in the concrete from failure of the mortar to fill the spaces among coarse aggregate particles. It is evidence of segregation.

If the honeycombed area is large, it should be chipped away to a depth of 1 in. (25 mm) or more with edges perpendicular to the surface. An area extending at least 6 in. (150 mm) beyond all of the area to be patched should be wetted to prevent water from being absorbed by the patching mortar. A grout of 1 part portland cement and 1 part fine sand by weight should be mixed with enough water to produce a paint-like consistency and brushed into the surface. Immediately afterward, a dry pack patching mortar should be applied. If color is not important-for example, below grade-prepackaged mortars that do not contain calcium chloride or gypsum are often convenient for this purpose. Otherwise, the patch should be made of the same material in the same proportions as used for the concrete except that the coarse aggregate is omitted. It should not, however, be richer than 1 part cement to 3 parts sand. Proportioning can be done by substituting enough white portland cement for part of the gray cement to produce a color that will match the surrounding concrete. This proportion will have to be determined ahead of time by making three trial batches: one with gray cement, one with 1/3 of the gray cement replaced by white cement, and one with 2/3 of the gray cement replaced by the white cement. These mixes should be finished, cured, and dried before selecting one of them for use.

The mixing water content of the patching mix should be the minimum amount best for handling and placing. The mortar should be compacted into the opening and screeded off to protrude slightly from the surrounding surface and then left undisturbed for 1 to 2 hours before finishing. It should finally be finished in a manner that removes the excess and makes the patch plane with the surrounding surface.

Special effort will have to be made to produce a finish that resembles the surrounding surface. Where unlined forms have been used, the final finish may be made to match the rest of the concrete by striking off the surface with a straightedge spanning the patch and held parallel to the direction of the form marks.

11.1.3 *Tie holes*

Ordinarily, flat snap ties do not create leaks when snapped off, but any voids below grade created by snapping off the exposed ties should be patched. This prevents corrosion of the tie and the possible development of spalling and leakage. Round or oval ties may create a leak if twisted off, and they should be patched if below grade or if appearance requires it. The holes should be thoroughly wetted and packed solid and tight with mortar. Any excess mortar at the surface can be struck off flush with a cloth. If holes pass all the way through the wall, a plunger type of grout gun should be used to force the mortar through the wall, starting at the inside face. A piece of canvas or burlap should be held over the hole at the outside face, and when excess mortar appears at the surface, it should be struck off flush with the surface by using the cloth.

11.1.4 *Sand streaking*

Sand streaking is a linear blemish in the surface of concrete caused by bleeding of water. The visual effect is a sandy vertical streak. The surface can be made uniform by the same procedure used for repairing surface voids.

11.1.5 *Peeling*

Peeling occurs when thin flakes of mortar break away from a concrete surface. This may be caused by

*Information on materials and methods for waterproofing and dampproofing is given in ACI 515R, Chapters 4 and 5.

†See ACI 309.2R.

‡Measures for minimizing the number of air voids have been described in References 18, 19, and 20

deterioration of the surface or by adherence of surface mortar to the forms when the forms are removed. The surface can be made uniform by the method used for repairing surface voids. Sometimes a textured acrylic paint may be effective.

11.1.6 *Popouts*

In residential concrete, popouts are more common in exterior slabs than in walls. When popouts do occur in walls, they can be repaired by the methods described in Section 11.2.5.

11.1.1 *Efflorescence*

Efflorescence is a deposit, usually white in color, on a concrete surface. Usually it appears on walls just after the structure has been completed, but it may also appear at a later time in the structure's life or reappear after removal. Efflorescence is caused by the movement of soluble salts from within the wall to the surface. This only occurs when moisture is moving to the surface. The moisture may be excess mixing water as it comes to the surface, water absorbed into the exterior surface of the wall from rain, water condensed in the wall from moisture moving outward from inside the building in winter (or inward in summer), or water from leakage at some other point in the building.

If efflorescence is light, it may be possible to remove it by dry brushing or washing with water. If this does not work, it may be necessary to wash the surface with a diluted solution of muriatic acid made by mixing 1 part of acid with 10 or 20 parts of water. Workers should wear goggles and rubber gloves and avoid breathing acid fumes. The diluted acid should first be tested on a small, inconspicuous part of the wall to be sure that it does not seriously attack the surface and change the texture too greatly. Care should be taken to protect any vulnerable areas below the foot of the wall from acid attack.

Work should proceed from top to bottom. The surface of the wall should first be dampened with clear water before the acid is applied. This prevents the acid from being absorbed too deeply into the wall. After the acid treatment, the surface should be thoroughly flushed with clear water to remove the soluble salts produced by the acid.

The acid treatment is likely to change the appearance of the wall slightly, and for this reason, it is necessary to subject the whole wall to the acid treatment to prevent mottled effects.

11.1.8 *Discoloration*

A large number of materials and conditions can lead to discoloration in concrete. Some of these may be listed as follows:

11.1.8.1 *Change in mix*- A change in the brand or type of cement or the water-cement ratio or the addition or elimination of calcium chloride can change the color from one batch of concrete to the next. (Most accelerating admixtures and nonretarding water reducers contain calcium chloride).

11.1.8.2 *Aggregate transparency-Dark* areas of the surface over aggregate particles reveal the locations of large aggregate particles that are covered only by the very finest particles of the mix, which remain between the particle and the form face. These areas usually lighten in color as the concrete dries.

11.1.8.3 *Hydration discoloration-This* effect may have any of several causes.

a. When water leaks through the joints between forms, a dark discoloration develops where fine particles of aggregate and cement are drawn toward the joints. (A low water-cement ratio produces a darker color than a high water-cement ratio.)

b. When grout is lost between forms, a sand-textured strip is produced with a dark discoloration.

c. Moisture lost into unsealed plywood causes a dark-colored surface. The darkest areas develop where the absorbency is greatest.

d. A dark-colored area can be produced by use of more absorbent wood in some formwork panels than in others.

e. Variation in color can also be caused by differences in concrete pressure during placing. If a higher lift is put in the form, the increased concrete pressure can cause more water to be absorbed and thus result in a different color.

11.1.8.4 *Segregation discoloration*- Segregation of concrete causes a variation in the water content on the surface and a consequent difference in color.

11.1.8.5 *Drying discoloration-Where* formwork has warped away from the concrete at the top and left an air gap, permitting rapid drying out of a part of the surface, a difference in color will be produced.

11.1.8.6 *Cold joints*- A horizontal or sloping demarcation line is likely to be visible where a cold joint exists between successive lifts. A cold joint prevents penetration of the vibrator into the lift below, leaving an obvious difference in appearance and color due to the abrupt difference in degree of consolidation. The treatment of these various troubles will depend to some extent on how bad they are and how they have been produced. Many of them can be obscured by a rub-down with grout containing 1 part portland cement to 1½ parts fine sand by weight mixed to the consistency of thick paint. Alternatively, an acrylic modified cementitious coating such as described in Section 11.1.1 may be applied.

11.1.8.7 *Improper concreting and finishing practices*-Dark or light areas can result from any of a number of improper finishing practices, including formation of spots where water stands longer before evaporating, extra hard troweling, curing with sheet materials (though such curing is often desirable), non-uniformity of water-cement ratio in all areas, or uneven application of dry shake materials.

11.1.9 *Stains*

The subject of stains is a special matter. Most stains are produced during the service life of concrete rather than during construction. The treatment of the stain depends to a large extent on what has caused the stain.*

11.2 -- Defects in floors, patios, driveways, and other flatwork

11.2.1 *Blistering*

Blistering of slab surfaces is caused by various combinations of factors that lead to collection of air below a stiff, sticky surface before the concrete hardens. Blisters often begin to break free at a very early age, leaving a scaled surface (Section 11.2.2). There is no simple way of repairing blistered surfaces satisfactorily.†

11.2.2 *Scaling*

Scaling is the flaking off of the top layer of mortar or laitance. Most scaling caused by freezing and thawing of concrete exposed to deicers can be prevented by entrained air incorporated in the mix in the proper amount. On driveways, sidewalks, or patios where this has not been done, scaling may occur. Even where deicing salts have not been purposely spread, they may be carried by automobiles and drip off onto garage floors and driveways. Slabs may also scale when no salt has been applied if the top surface has had water applied to it during floating or troweling, has had bleed water worked into the surface during various finishing operations, or was floated too early and overfinished.

Scaling can be repaired by grinding. It can also be repaired by patching or resurfacing. Before applying a patch, all loose concrete should be removed to a depth that leaves nothing but sound concrete. Edges of the patch should be cut vertically. A depth of at least 1 in. (25 mm) should be removed throughout the whole area to be patched. The same procedure should then be followed that is described in Section 11.1.2, except that the surface should be finished in a manner that corresponds to the recommendations in Sections 9.3.8, 9.3.9, and possibly 9.3.10 and duplicates the quality of the good concrete in the surrounding slab.

If the concrete is to be subjected to further applications of deicers it should be treated with two coats of boiled linseed oil (Section 10.6).

11.2.3 *Plastic shrinkage cracking*

Plastic shrinkage cracking occurs under various combinations of circumstances that produce very rapid drying and consequent shrinking of the concrete surface before the concrete has hardened (Section 9.1.2). If plastic shrinkage cracking occurs, repair of the hardened concrete is not always mandatory. After concrete hardens, plastic shrinkage cracks seldom get deeper and wider.‡

11.2.4 *Drying shrinkage cracking*

When concrete is plastic or fresh, it normally occupies the largest volume it will ever occupy. When it is dry, cold, and completely carbonated, it has its smallest volume. The varying conditions of moisture, temperature, and age in between these extremes cause the concrete to shrink and swell or contract and expand slightly. If provision is not made for these normal volume changes, and if the rules of good concreting are not observed, cracks may result. Not every crack needs attention, but methods are available for cracks that do. Often opening and closing of a crack may continue, and if so, rigid patching materials cannot be used to patch these cracks. An elastomeric caulking material that remains relatively flexible is required.

A method of repair is to widen the crack and seal it with an elastomer. Widening can be done with a saw or routing tool. The opening should be made about ½ in. (13 mm) wide and 1 in. (25 mm) deep with a square shoulder. The sides of the joint should be cleaned by air blasting or hosing with water. The joint should not be sealed until dry. A compressible filler (backup) material should be used to fill the bottom half of the joint. Rod or tubing of polyethylene, large enough to require 50 percent compression when inserted, is useful. A good grade of polyurethane, polysulfide, or silicone sealant should then be applied to the top half of the joint. Many such materials are two-component sealants and should be thoroughly mixed according to the manufacturer's directions. In repairing exterior flatwork, if appearance is not of particular concern, a bituminous sealant may be satisfactory.

If the crack is in an indoor location where there will be temperature changes of no more than about 40 F (change of about 22 C) and no further drying shrinkage, the crack can be sealed with an epoxy compound. If so, the crack need be routed only ½ in. (13 mm) deep, and no backup material is needed. If the crack is vertical, a nonsagging formulation should be used and forced in well to produce intimate bond.

Epoxy injection techniques may be used to seal cracks. With this method no routing of cracks is required.

11.2.5 *Popouts*

Popouts are conical craters left when a small portion of the concrete surface breaks away because of internal pressure. This internal pressure is usually generated by the permanent swelling of something within the concrete such as a piece of pyrite, hard-burned lime, hard-burned dolomite, coal, shale, soft fine-grained limestone, or a piece of chert. Such materials, if present, may have been introduced as contaminants, or they may be natural constituents of the aggregate. Sometimes popouts do not occur until the concrete is at least a year old, although sometimes they appear rather early in its life. Popout holes range from about ⅜ to 2 in. (10 to 50 mm) or more in diameter. In certain areas of the country, some occurrence of popouts is common, except where extra money has been spent in construc-

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*Details may be found in References 21 and 22.

†One method is to grind the whole surface until it is plane. Another method, described in ACI 302.1R and in Reference 23 is to apply a bonded topping. However, this leads to a higher elevation of the slab.

‡If the cracks are to be filled, the epoxy grouting methods described in ACI 503R can be used.

tion to obtain special materials that minimize popouts.

Popouts frequently occur from the absorption of water in the concrete. Sometimes, however, all that is needed for the expansion to occur is a season of high humidity. If only a limited number of popouts appear, it may be that other popouts will continue to appear over a longer period, and repairs undertaken early may have to be supplemented by similar repairs later.

If a popout is new, one may not be certain that the expansion of the embedded particle is complete. Consequently, it may be necessary to drill deeply enough to remove all of the offending material. For larger particles, a small core drill may be useful. The resulting hole should be repaired in the same manner as described in Section 11.1.2, filling the hole with a dry pack mortar that resembles the surrounding concrete.

Recommendations have recently been published on the use of acrylics as adhesives or as additions in patching compounds. These materials do not change color in the sun, are compatible with the strengths and thermal coefficients of concrete, and do not materially change the color of concrete when used as an emulsion in the mixing water.*

11.2.6 *Discolorations*

Floors and other flatwork can be discolored by the "greenhouse effect." This is caused when the flatwork has been cured by an impermeable moisture barrier such as polyethylene film. Under this film on warm days, water condenses in places where the film is not in contact with the concrete and runs down and collects in places where it is in contact or in low spots on the concrete surface. The differences in water content at various parts of the surface result in differences in amount of curing and variations in color.

Use of calcium chloride in the concrete can aggravate the problem. Light spots on a dark background may be experienced if the concrete is made with low-alkali cement and dark spots on a light background if the alkali is high. The degree of discoloration depends on the extent of moist curing.

Dark and light spots are sometimes produced by repeated and vigorous troweling of the surface which results in a combination of abrasion of the metal from the trowel onto the concrete and a pronounced reduction of the water-cement ratio at the surface.

Other factors that cause any variation in the absorptive capacity of the concrete can produce dark and light areas. One such factor is absorption of moisture from the concrete by the subgrade during the period before the concrete has hardened, causing variable porosity in the slab. This underscores the importance of uniformly dampening the subgrade before concrete is placed.

If there are large areas of contrasting color caused by the use of different concrete-making materials, the only solution is to apply some type of opaque coating, either a paint or colored wax.

Dark spots in concrete that contains no calcium chloride can sometimes be removed by washing the concrete down with water. If the concrete contains chloride, it may be necessary to wash the area several times. The sooner the washing is done, the more effective it may be.

Light spots on concrete flatwork are harder to remove. One method is to apply a 10 percent solution of sodium hydroxide (also called caustic soda or lye) and allow it to remain in place for I or 2 days before removing by thoroughly washing the surface. The treatment is most effective if applied soon after the concrete curing has been terminated.

If the preceding methods fail, dibasic ammonium citrate should be applied to the dry discolored surface.+

Aggregate transparency (Section 11.1.8.2) can be a problem in flatwork as well as in formed surfaces. It tends to disappear with time.

Stains in flatwork can be treated in the same manner as in formed surfaces (Section 11.1.9).

11.2.7 *Dusting*

Dusting, the development of a powdered material at the surface of hardened concrete, can occur either indoors or outdoors but is more likely to be a problem when it occurs indoors. Dusting is associated with weak concrete at the surface and is caused by one or more of the following:

overly wet mixes,

floating and troweling bleed water into the surface,

clay, dirt, or organic materials in the aggregate,

use of dry cement shakes to dry the surface so concrete can be finished earlier,

water applied to the surface by finishers,

unvented heaters for cold weather protection, and

inadequate curing, especially in dry weather.

To prevent dusting:

Use concrete with the minimum slump required for job conditions (Table 2.2).

Delay floating and troweling until all free water or excess moisture has disappeared and concrete has started its initial set.

Use only clean, well-graded fine and coarse aggregates in the mix.

Do not use dry cement or any mixture of cement and fine sand as a dry-shake to speed up finishing.

Do not apply water to the surface during finishing.

Vent salamanders and other fuel-burning heaters to the outside during winter construction and provide sufficient ventilation.

Properly cure the concrete for the specified time; concrete that is not cured will often be weak and the surface easily worn by foot traffic.

Dusting may be remedied by grinding or by applying floor sealing products based on sodium metasilicate (water glass) or silicofluorides.

When a dilute solution of sodium metasilicate soaks into a floor surface, the silicate reacts with calcium

*Guidance for the use of these materials as well as the more familiar epoxies, is given in ACI 546.1R. Further guidance on epoxies is given in ACI 503R. and specifications for use of epoxies are given in ACI 503.2 and ACI 503.4.

+The procedure is given in Reference 24.

compounds to form a hard, glassy substance within the pores of the concrete. This new substance fills the pores and after drying gives the concrete a denser, harder surface. The degree of improvement depends on how deeply the silicate solution penetrates. For this reason, the solution should be diluted significantly to make it penetrate deeply enough.

The treatment consists of three or four coats applied on successive days. If the concrete is new it should be air dried for 10 to 14 days after the end of moist curing. This gives a reasonably dry surface to aid penetration. The first coat should be a solution of 4 parts water to I part silicate. The second coat should be of the same proportions and applied after the first one has dried. The third coat should be a 3-to-1 solution applied after the second coat has dried. The treatment is completed as soon as the concrete surface gains a glossy, reflective finish.

Zinc, sodium, and magnesium silicofluoride sealers are applied in the same manner as water glass. These silicofluoride compounds can be used individually or in combination, but a mixture of 20 percent zinc and 80 percent magnesium silicofluorides gives excellent results. For the first application, I lb (0.5 kg) of the silicofluoride should be dissolved in 1 gal. (4L) of water. For subsequent coatings, the solution should be 2 lb (1 kg) to each gallon (4 L) of water. The floor should be mopped with clear water shortly after the preceding application has dried to remove encrusted salts. Safety precautions must be observed when applying silicofluorides due to the toxicity of these salts.

It is important to note that the preceding sealing products will not convert a poor-quality floor into a good-quality floor. They are simply a means of upgrading a dusting floor while also improving its wear and chemical resistance.

CHAPTER 12 - REFERENCES

Standards, specifications, and committee reports

ACI 116R-78	Cement and Concrete Terminology
ACI 117-81	Standard Tolerances for Concrete Construction and Materials
ACI 201.2R-77 (Reaffirmed 1982)	Guide to Durable Concrete
ACI 211.1-81	Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete
ACI 212.1R-81	Admixtures for Concrete
ACI 212.2R-81	Guide for Use of Admixtures in Concrete
ACI 301-84	Specifications for Structural Concrete for Buildings
ACI 302.1R-80	Guide for Concrete Floor and Slab Construction
ACI 303R-74	Guide to Cast-In-Place Architectural Concrete Practice
ACI 304-73 (Reaffirmed 1978)	Recommended Practice for Measuring, Mixing, Transporting and Placing Concrete
ACI 305R-77 (Revised 1982)	Hot Weather Concreting
ACI 306R-78	Cold Weather Concreting
ACI 309-72 (Revised 1982)	Standard Practice for Consolidation of Concrete
ACI 309.2R-82	Identification and Control of Consolidation-Related Surface Defects in Formed Concrete
ACI 318-83	Building Code Requirements for Reinforced Concrete
ACI 318.1-83	Building Code Requirements for Structural Plain Concrete
ACI 347-78	Recommended Practice for Concrete Formwork
ACI 503R-80	Use of Epoxy Compounds with Concrete
ACI 503.2-79	Standard Specification for Bonding Plastic Concrete to Hardened Concrete with a Multi-Component Epoxy Adhesive
ACI 503.4-79	Standard Specification for Repairing Concrete with Epoxy Mortars
ACI 512.2R-74	Precast Structural Concrete in Buildings
ACI 515R-79	A Guide to the Use of Waterproofing, Dampproofing, Protective, and Decorative Barrier Systems for Concrete
ACI 531-79 (Revised 1983)	Building Code Requirements for Concrete Masonry Structures
ACI 53IR-79	Commentary on Building Code Requirements for Concrete Masonry Structures
ACI 531.1-76 (Revised 1983)	Specification for Concrete Masonry Construction
ACI 546.1R-80	Guide for Repair of Concrete Bridge Superstructures
ASHRAE 90A-80	Energy Conservation in New Building Design
ASTM A 82-79	Standard Specification for Cold-Drawn Steel Wire for Concrete Reinforcement
ASTM A 185-79	Standard Specification for Welded Steel Wire Fabric for Concrete Reinforcement
ASTM A 496-78	Standard Specification for Deformed Steel Wire for Concrete Reinforcement
ASTM A 497-79	Standard Specification for Welded Deformed Steel Wire Fabric for Concrete Reinforcement
ASTM A 615-82	Standard Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement
ASTM A 616-82a	Standard Specification for Rail-Steel Deformed and Plain Bars for Concrete Reinforcement
ASTM A 617-82a	Standard Specification for Axle-Steel Deformed and Plain Bars for Concrete Reinforcement

ASTM A 706-82a	Standard Specification for Low-Alloy Steel Deformed Bars for Concrete Reinforcement
ASTM C 33-82a	Standard Specification for Concrete Aggregates
ASTM C 94-81	Standard Specification for Ready Mixed Concrete
ASTM C 143-78	Standard Test Method for Slump of Portland Cement Concrete.
ASTM C 150-81	Standard Specification for Portland Cement
ASTM C 309-81	Standard Specification for Liquid Membrane-Forming Compounds for Curing Concrete
ASTM C 330-80	Standard Specification for Lightweight Aggregates for Structural Concrete
ASTM C 387-82	Standard Specification for Packaged, Dry, Combined Materials for Mortar and Concrete
ASTM C 494-81	Standard Specification for Chemical Admixtures for Concrete
ASTM C 595-82	Standard Specification for Blended Hydraulic Cements
ASTM C 618-80	Standard Specification for Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete
ASTM C 685-81	Standard Specification for Concrete Made by Volumetric Batching and Continuous Mixing
ASTM C 803-79	Standard Test Method for Penetration Resistance of Hardened Concrete
ASTM C 805-79	Standard Test Method for Rebound Number of Hardened Concrete
ASTM C 873-80	Standard Test Method for Compressive Strength of Concrete Cylinders Cast in Place in Cylindrical Molds
ASTM C 900-78-f	Tentative Test Method for Pullout Strength of Hardened Concrete
ASTM D 994-71 (Reapproved 1982)	Standard Specification for Preformed Expansion Joint Filler for Concrete (Bituminous Type)
ASTM D 1079-79	Standard Definitions of Terms Relating to Roofing, Waterproofing, and Bituminous Materials
ASTM D 1751-73 (Reapproved 1978)	Standard Specification for Preformed Expansion Joint Fillers for Concrete Paving and Structural Construction (Nonextruding and Resilient Bituminous Types)
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APPENDIX -- GLOSSARY FOR THE HOMEOWNER

The following definitions have been written for ease of understanding and may not rigidly comply with technical definitions found elsewhere in ACI documents.

Admixture -- A material other than water, aggregates, and hydraulic cement used as an ingredient in concrete. (See also **Air entrainment** and **Water-reducing. set-controlling admixtures.)**

Aggregate -- The natural or crushed stone and sand, which are the ingredients that make up the largest fraction of most concrete mixtures.

***Aggregate transparency** -- Discoloration of a concrete surface consisting of darkened areas over coarse aggregate particles immediately below the surface.

Air entrainment -- The intentional incorporation of minute air bubbles in concrete to improve durability to freezing and thawing exposures or to improve workability. Accomplished either by use of an air-entraining admixture or an air-entraining cement.

Anchor -- A steel unit set in concrete (sometimes by attaching to the formwork) for later use in attaching something else to the concrete.

***Architectural concrete** -- Concrete to be exposed to view for which the constructor must take special care to provide a satisfactory and pleasing appearance.

***Arris** -- The ridge formed by the meeting of two surfaces.

***Backfill** -- The soil that is compacted into place to correct for overexcavation.

Beam -- A structural member subject to bending. generally used horizontally to support a slab or wall.

Bleeding -- The movement of water within fresh concrete toward the top surface and its collection there. caused by settling of the solid materials.

Blistering -- Formation of thin. raised flaws on the surface of concrete during the finishing operation or soon afterward. which are not always easily noticeable before the concrete hardens.

***Blowup** -- The rise of two concrete slabs where they meet as a result of greater expansion than the joint between them will accommodate. Blowups are likely to occur only in unusually hot weather at locations where joint, have become filled with incompressible materials. They often result in cracks on both sides of the joint and parallel to it.

***Boring** -- The removal by drilling of a sample of soil for tests.

Bug holes -- See **Surface air voids.**

Bulkhead -- A partition inserted in formwrork to block fresh concrete from flowing into another section of the formwork.

Bull float -- A T-shaped tool with a large flat blade attached with a hinged joint to a long handle used to smooth the surface of freshly screeded concrete flatwork.

Calcium chloride -- A salt, sometimes supplied in solution or found as an ingredient in admixtures, used to accelerate the setting or strength gain of concrete but sometimes contributing to rusting of reinforcing steel or (in the case only of use as an admixture) discoloration of flatwork surfaces.

Cast-in-place -- Concrete deposited in Ihe place where it is required to harden rather than precast and moved into position after curing and hardening.

***Caulking** -- The filling of a joint with a material suitable for sealing out dirt and moisture. Better-grade materials for this purpose are commonly known as sealants.

Cement -- The powder (usually portland cement) which. when mixed with water and aggregate. slowly reacts chemically with the water to form the bonding agent that holds the aggregate together, producing concrete. (The term "cement" should not be misused to refer to concrete.)

Chair -- A device used to hold reinforcing bars in their proper position during placing and working of concrete.

Chert -- A fine-grained siliceous rock that is absorptive of moisture and susceptible to expanding, sometimes causing trouble with popouts when it is present in small quantities in the coarse aggregate of concrete.

Chute -- A sloping trough down which concrete moves from the ready-mixed concrete truck to a receptacle or form.

Clay -- A very fine natural soil with plastic properties when moist. Some soils contain clay mixed with other ingredients.

Cold joint -- A joint, usually visible, in a concrete walI or floor where the fresh concrete has bonded imperfectly or not at all to the previously placed concrete because too much time has elapsed between placements.

Column -- A concrete member (usually vertical to support a floor or roof), with slender proportions. that takes compression loads.

***Compressible soil** -- A soil that undergoes more than a usual amount of decrease in volume when loaded.

Concrete -- A composite material made of portland cement or other hydraulic cement, aggregate, water, and sometimes admixtures. which hardens when the cement reacts chemically with water.

***Concrete element** -- A discrete concrete portion of a structure, or pavement, such as a wall, column. beam. floor, sidewalk, or curb.

Construction joint -- The plane where two successive placements of concrete meet but do not bond cementitiously. UsualIy, it is only necessary to use a keyway for load transfer across the joint, but sometimes dowels or reinforcing steel are required to cross the joint to hold the concrete on both sides together.

Contraction joint -- A joint purposely designed to accommodate movements in concrete inevitably caused by temperature changes and drying shrinkage. Made by forming, tooling, or sawing a groove in a concrete structure, this creates a weakened plane so that cracking will occur along this predetermined line and not at random locations.

Control joint -- Same as **Contraction joint**.

Conveyor -- A continuous belt for moving fresh concrete from a ready-mixed concrete truck to a location on the site to which the truck does not have ready access.

Cure -- To retain moisture in concrete for a prescribed period and at a desirable temperature to allow the cement to chemically react with water and reach the required strength level and other desirable properties of concrete.

Curing compound -- A liquid that can be applied to the surface of newly placed concrete to retain water in the concrete long enough for it to be cured.

Curling -- The turning up of the edges and particularly the corners of a slab caused by the drying or cooling of the top surface faster than the bottom surface.

Darby -- A long, straight, flat surface with inclined handle used in the early stage of leveling operations on concrete slabs.

Deformed bar -- A steel reinforcing bar with raised deformations on the surface to provide an Interlock with the surrounding concrete.

***Degree day** -- See **Heating degree day**.

Dowel -- A steel pin or bar extending into two adjoining portions of a concrete construction to connect them and transfer load.

Durability -- The ability of concrete to resist weathering action. chemical attack, abrasion, and other conditions of service.

Dusting -- The appearance of a powdery material on the surface of hardened concrete coming from the concrete itself.

Edging -- The operation of tooling the edges of a fresh concrete slab to provide a rounded corner.

Efflorescence -- A deposit of salt or salts, usually white, formed on a surface. The substance is one that has emerged in solution from within the concrete and has been deposited by evaporation.

Expansion joint -- Same as **Isolation joint.**

Expansive soil -- A soil subject to considerable increase in volume change with resulting uplift or distortion of concrete members. This is a severe problem in a few areas of the United States.

Fault -- A vertical movement of a slab or other member adjacent to a joint or crack so that there is an abrupt change in surface elevation from one side of the joint to the other.

Fill -- See **Backfill.**

***Finishing** -- Operations such as floating and troweling that produce a surface of the desired smoothness, density, and flatness: operations that are made easier by a well-proportioned mix that is adequately cohesive and plastic.

*This word is not defined in ACI 116R. "Cement and Concrete Terminology."

Flatwork -- A general term that encompasses floors, patios, walks. driveways, and other slabs-on-ground.

Floating -- The operation of finishing a fresh concrete slab surface by using a hand or power float.

***Flow line** -- A detectable line on a concrete wall or column usually departing somewhat from horizontal that shows where the concrete in one placement has flowed horizontally before the succeeding placement has been made. Good concreting practices should eliminate most evidence of flow lines.

***Flowing concrete** -- Concrete to which has been added water-reducing, set-controlling admixture or admixtures to produce a temporarily high slump to aid in placing and consolidation.

Fly ash -- A finely divided glass-like powder recovered from the flue of a coal burning industrial furnace. It is sometimes used as a mineral admixture in concrete to react with the cement and modify or enhance the properties of the concrete.

Fooling -- The part of the foundation that spreads and transmits the load to the soil.

Form -- A large mold of lumber or prefabricated elements set up to support and contain concrete until it has gained suficient strength to be self-supporting.

Form coating -- A liquid that may be applied to the surface of the form for one or more of the following purposes: to protect the form surface and give it long life, to retard the set of the surface of the concrete to make it easy to expose the aggregate at a later time. or to promote the ease with which formwork can be removed (stripped) from the concrete. (See also Form release agent.)

Form release agent -- A liquid applied to the surface of a form to promote easy removal (stripping) of the form from the concrete.

***Form sealer** -- A Iiquid applied to the surface of a form to reduce or overcome its absorptivity of moisture from the concrete.

***Form spacer** -- A temporary) wood or steel insert placed between side panels of a form to resist the tension of the ties, until concrete has been placed.

Form spreader -- See **Form spacer.**

Form tie -- A manufactured steel wire, bar, or rod specially designed to prevent concrete forms from spreading due to the fluid pressure of freshly placed concrete.

Girder -- A large beam, usually horizontal. that serves as a main Structural member.

***Grade** -- The prepared surface on which a concrete slab is cast. To prepare a plane surface of granular material or soil on which to cast a concrete slab.

***Grade tamper** -- A hand tool or powered device for compacting the grade by a pounding action.

Grout -- A mixture of cement and water and sometimes fine sand proportioned to produce a pourable consistency without separating.

***Hard-burned dolomite** -- The product of heating dolomitic rock hot enough to change the magnesium carbonate to magnesium oxide, a constituent which slowly expands on reaction with water.

***Hard-burned lime** -- The product of heating limestone hot enough to change the calcium carbonate to calcium oxide, which can undergo expansion when it slowly reacts with water.

***Heating degree day** -- The number of days in the heating season times the difference between the inside temperature of 65 F (18 C) and the average daily outside temperature. The U.S. Weather Bureau and utility companies can supply data for various localities.

Honeycomb -- Voids left in concrete where cement and sand particles have not filled the spaces among the coarse aggregate particles.

***Hydration discoloration** -- Discoloration of a concrete surface by uneven hydration of the cement. There can be several causes.

***Insert** -- Anything other than reinforcing steel that is rigidly positioned within a concrete form for permanent embedment in the hardened concrete.

Isolation joint -- A built-in separation between adjoining similar or dissimilar elements of a concrete structure, usually a vertical plane. Can also be used to separate two concrete structures such as a walk and a driveway or a patio and a wall. Purpose is to prevent movements of the individual parts from causing cracks in the concrete.

***Jointing** -- The process of producing joints in a concrete slab with a metal hand tool made for the purpose.

Keyway -- A recess or groove made in one placement of concrete that is later filled with concrete of the next placement so that the two lock together.

*Lateral pressure -- Pressure exerted in a horizontal direction against formwork by the hydraulic fluid pressure of fresh concrete.

Lintel -- A horizontal structural element above a window or door to support the wall above.

Load-bearing wall -- A wall designed and built to carry vertical and shear loads in addition to just its own weight.

Low-alkali cement -- A portland cement that contains the equivalent of not more than 0.6 percent sodium oxide for use in construction in situations where high-alkali cement might give rise to disruptive expansion from alkali-silica reaction. The problem of alkali-silica reaction is limited to only a few areas of the United States.

***Mesh roller** -- A finishing tool consisting of a rolling drum attached to a handle, of which the surface of the drum is made of mesh. sometimes used for pushing over the surface of fresh concrete to embed coarse aggregate.

***Mobile placer** -- A small belt conveyor mounted on wheels that can be readily moved to the job site for conveying concrete from the ready-mixed concrete truck to the forms or slab.

Monolithic concrete -- A large block of cast-in-place concrete containing no joints other than construction joints.

Muriatic acid -- A mineral acid more properly known as hydrochloric acid. available at most hardware stores, sometimes used for cleaning or acid etching concrete or removing efflorescence.

Peeling -- The breaking off of very thin layers of mortar from a concrete surface, either by deterioration or by adherence of the mortar to the concrete forms at the time they are removed.

*Penetration -- An opening through which pipe, conduit, or other material passes through a wall or floor.

Permeable concrete -- Concrete with higher-than-normal susceptibility to having water pass through it. The permeability of high-quality concrete can be so low that it is only one millionth that of low-quality concrete.

Placeability -- Fresh concrete's capability of being easily placed and consolidated, largely dependent on composition and proportions. Concrete that has good placeability is likely to have good finishing qualities, though these two qualities are not identical.

Plastic shrinkage -- The shortening of the surface of fresh concrete from rapid evaporation of moisture due to low humidity, high winds, high temperature. or a combination that often leads to the creation of cracks before the concrete has been finished.

***Ponding** -- The creation and maintenance of a pond of water on the surface of a concrete slab for the purpose of curing.

Popout -- A small fragment of concrete that has broken away from the concrete surface because of internal pressure, leaving a conical pit.

Portland cement -- A hydraulic cement conforming in composition and properties to the requirements of ASTM Standard C 150. There are many different brands of portland cement, all of which conform to the specification.

Pozzolan -- A finely divided material which is not itself a cement but which reacts chemically with the products of hydration of portland cement to form a cementitious binder. Sometimes used as a mineral admixture in concrete to modify or enhance the concrete properties.

***Prepackaged concrete** -- Bagged material consisting of a dry preproportioned mixture of cement, coarse and fine aggregate, and sometimes admixtures, usually used for small jobs. Water is added at the mixer.

psi -- Abbreviation for pounds per square inch. (In the new SI metric system, units of pressure are expressed in megapascals.)

***Pump** -- A specially designed machine capable of forcing fresh concrete through a pipeline or hose of a diameter in the range of about 3 to 6 in.

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*This word is not defined in ACI 116R. "Cement and concrete Terminology."

***Pyrite** -- A mineral which is a sulfide of iron that, if it occurs in aggregate used in concrete, can cause popouts and dark brown or orange-colored staining.

Ready-mixed concrete -- Concrete batched in a concrete plant and mixed in a plant or in the truck mixer that delivers the concrete in a plastic, unhardened state.

***Reinforcing bars** -- Steel bars embedded in concrete to act with the concrete in resisting forces. (See also **Deformed bars**.)

***R-value** -- Coefficient of thermal resistance. A standard measure of the resistance that a material offers to the flow of heat. Expressed in terms of degrees F x hr x ft/Btu.

Sand streaking -- A line of exposed fine aggregate on the surface of formed concrete caused by bleeding of water from the concrete.

Scaffolding -- A temporary structure to support a platform for workmen, tools, materials, and cart, or to support formwork for an elevated slab or beam of concrete.

Scaling -- Flaking or peeling away of a surface portion of hardened concrete.

Screed -- A firmly established grade strip or side form that. in combination with another strip on the other side, serves as a guide for striking off the surface of a concrete slab to the desired level.

Sealant -- Extensible material used to seal a joint to exclude water and solid foreign materials.

Sealer -- A liquid composition applied to the concrete surface to diminish the absorption of water, solutions of deicers. or other liquids.

Segregation -- Partial separation of the various materials that make up concrete during the transporting, handling. and/or placing operations, resulting in a non-uniform product.

***Seismic zone** -- An area of the country in which earthquake intensity is likely to fall within the designated range for that zone as specified in standard building codes.

Shale -- A laminated sedimentary rock that is not very hard and can be readily reduced to clay and silt.

Sheathing -- The material used to form the contact face of forms.

Shoring -- Props or posts of timber or other materials used temporarily to support concrete formwork.

Silt -- A granular material formed from rock disintegration small enough to pass a sieve with 200 openings to the inch.

Slab -- A flat or nearly flat horizontal surface of plain or reinforced concrete used as a floor, roof, pavement, patio, or walk.

***Sleeve** -- A pipe or tube passing through formwork for a wall or slab through which pipe, wires, or conduit can be passed after the forms have been stripped.

Slump -- A simple, convenient measure by a standard test method of the consistency of freshly mixed concrete.

Spalling -- The breaking away of a small shape or chunk of concrete, usually by expansion from within the larger mass.

Stress -- The intensity of the internal force within concrete. The stresses usually considered are those of tension or compression, although stresses of torsion or shear can be important. Stress IS expressed mathematically in terms of force per unit area.

Striking off -- The process of shaping the surface of a freshly placed concrete slab by using a straightedge tool or a special machine to level it to the elevation of the screeds.

Stripping -- The process of removing forms from concrete after it has hardened.

***Sulfate soils** -- Soils that contain soluble sodium sulfate or magnesium sulfate or both, which migrate into the concrete and attack the calcium aluminate portion of the cement. This causes disintegration of the concrete.

Superplasticizer -- See **Water-reducing, set-controlling admixture.**

***Surface air voids** -- Small round or irregular cavities usually not more than ⅛ in. in diameter resulting from air bubbles trapped in the surface of formed concrete during placement and compaction. Sometimes called bug holes.

***Temperature steel** -- Welded wire fabric or deformed bars used in concrete walls in the amounts needed to keep cracks tightly closed.

***Thermal conductance** -- The rate at which heat will flow through a unit area of wall or roof. See **U-value**.

***Thermal resistance** -- Resistance that a unit area of a material offers to flow of heat. Expressed in terms of R-value.

Tie-bar -- A deformed bar embedded in concrete at a joint to hold the abutting edges together.

Tolerance -- The variation permitted from the dimension given, for example, from the planeness of a floor or from the location or alignment of a concrete wall. ACI Committee 117 is compiling recommendations for standard tolerances

Troweling -- Smoothing and compacting the surface of a concrete slab by strokes of a trowel.

***U-value** -- Coefficient of heat transmission. A standard measure of the rate at which heat will flow through a unit area of known thickness. Expressed in terms Btu/hr x ft^2 x deg F.

***Unbalanced fill** -- The height of outside finish grade above the basement floor or inside grade.

Vibrator -- An oscillating power tool used to agitate fresh concrete to eliminate entrapped air (but not entrained air) and bring the concrete into intimate contact with formed surfaces and embedded materials.

Wale -- A long horizontal formwork member used to hold vertical framing members in place

***Water-reducing. set-controlling admixture** -- Any of a number of chemical materials or combinations of chemical materials added to concrete to enhance the performance of concrete in both the plastic and hardened states. ASTM C 494 outlines "normal range" materials (Types A through E) and "high-range" or "superplasticizing" materials (Type F and G).

Waterstop -- A thin sheet of metal, rubber, plastic, or other material inserted in a form across a joint to obstruct the flow of water through the joint.

Welded wire fabric -- A mesh made of longitudinal and transverse wires crossing at right angles and welded together for use as reinforcement in concrete. Supplied in either sheets or rolls.

Wheel load -- The part of a vehicle's weight that is transmitted to a pavement, walk, or slab as the vehicle stands on it or passes over it.

Workability -- The ease of response of concrete to mixing, placing, compacting, and finishing.

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*This word is not defined in ACI 116R "Cement and Concrete Terminology."

This report was submitted to letter ballot of the committee, which consists of 17 members; I6 were affirmative and 1 abstaining. It has been processed in accordance with Institute procedure and is approved for publication.

ACI Committee 332
Residential Concrete Work

William H. Kuenning, Chairman

Joseph A. Dobrowolski
G. Robert Fuller
E. A. Gale
Joan T. Grim
Rolland L. Johns
Blair A. Kiefer
Frank J. Lahm
Leo M. Legatski
J. W. Meusel*
Leo P. Nicholson
Willard S. Norton
William C. Panarese
Robert D. Sawyer
Billy M. Scott
Virgil Vonder Haar
Robert J. Witenhafer

Mario J. Catani, R. Kirk Gregory. C. E. Lovewell. Perry Petersen (former committee chairman, deceased), L. Michael Shydlowki, and Richard R. Vandegriff (deceased) are former members of this committee who contributed substantially to preparation of this guide.

*One of two former committee chairmen under whose direction most of this guide was prepared.