Grouting between Foundations and Bases for Support of Equipment and Machinery

Reported by ACI Committee 351

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This report provides an overview of current practices of grouting for support of equipment and machinery. Materials and installation methods are described for hydraulic cement and epoxy grouts used as the load-transfer material between equipment bases and their foundations.

Characteristics of placed material, test methods for forecasting long-term performance, qualification of grout materials, foundation design and detailing considerations, and installation procedures are described. A listing of standard test methods and specifications is also included.

Keywords: bleeding (concrete); consistency tests; curing; durability; epoxy grout; formwork (construction); foundations; grout; hydraulic cement grout; inspection; mixing; placing; specifications; stiffness; strength; tests; volume-change.

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ACI 351.1R-99 became effective June 2, 1999.
This report supercedes ACI 351.1R-93.

CHAPTER 1—INTRODUCTION

1.1—General

This report provides an overview of current practices for grouting to support equipment and machinery. Recommendations are provided for those portions of the grouting operation where a consensus could be developed among knowledgeable manufacturers and users. For areas where opinions differ, various approaches are outlined. Many statements and much information contained in this report are based on unpublished manufacturers' data and observations by technical representatives and users. The committee has reviewed this unpublished information and considers it suitable for use in the document. This report describes materials and installation methods for grouts used as load-transfer material between machine or equipment bases and their foundations. Characteristics of the placed material, test methods for forecasting their long-term performance, and installation procedures are included. The information may also be appropriate for other types of applications where filling of the space between load-carrying members is required, such as under column baseplates or in precast concrete joints.

Machinery and equipment that have precise tolerances for alignment or require uniform support cannot be placed directly on finished concrete surfaces. Both the concrete surface and the machine base have irregularities that result in alignment difficulties and bearing load concentrations. For this reason, machine bases or soleplates are aligned and leveled by shimming or other means, and the resulting space between the machine base and the foundation filled with a load-transfer material.

The load-transfer materials most frequently used are hydraulic cement grouts and epoxy grouts.

1.2—Definitions

The following definitions are common terminology for baseplate grouting work under machinery and equipment bases. These definitions are based on the terminology in ACI 116R.

Grout—A mixture of cementitious materials and water, with or without aggregate, proportioned to produce a pourable consistency without segregation of the constituents; also a mixture of other constituents (such as polymers) with a similar consistency.

Dry pack—Concrete or mortar mixtures deposited and consolidated by dry packing.

Dry packing—Placing of zero or near zero slump concrete, mortar, or grout by ramming into a confined space.

Machine-base grout—A grout that is used in the space between plates or machinery and the underlying foundation that is expected to maintain sufficient contact with the base to maintain uniform support.

Hydraulic cement grout—A mixture of hydraulic cement, aggregate, water, and additives (except dry pack).

Preblended grout—A commercially available, factory blended mixture of hydraulic cement, oven-dried aggregate, and other ingredients that requires only the addition of water and mixing at the job site. Sometimes termed premixed grout.

Field-proportioned grout—A hydraulic cement grout that is batched at the job site using water and predetermined proportions of portland cement, aggregate, and admixtures.

Epoxy grout—A mixture of commercially available ingredients consisting of an epoxy bonding system, aggregate or fillers, and possibly other proprietary materials.

Consistency—The relative mobility or ability of freshly mixed concrete, mortar, or grout to flow; the usual measurements are slump for concrete, flow for mortar or grout, and penetration resistance for neat cement paste.

Fluid—The consistency at which the grout will form a nearly level surface without vibration or rodding; the consistency of a grout that has an efflux time of less than 30 sec from the ASTM C 939 flow cone.

Flowable—The consistency at which the grout will form a level surface when lightly rodded; the consistency of a grout with a flow of at least 125% at 5 drops on the ASTM C 230 flow table and an efflux time through the ASTM C 939 flow cone of more than 30 sec.

Plastic—The consistency at which the grout will form a nearly level surface only when rodded or vibrated with a pencil vibrator; the consistency of a grout with a flow between 100 and 125% at 5 drops on the ASTM C 230 flow table.

Volume change—An increase or decrease in volume due to any cause.

Thermal volume-change—The increase or decrease in volume caused by changes in temperature.

Settlement shrinkage—A reduction in volume of concrete or grout prior to the final set of cementitious mixtures, caused by settling of the solids and by the decrease in volume due to the chemical combination of water with cement. In the case of epoxy grout, minor settlement shrinkage may occur if the formulation includes volatile components.

Drying shrinkage—Shrinkage resulting from loss of moisture or a reduction in the volume of the cement component after hydration.

Bleeding—The autogenous flow of mixing water within, or its emergence from, newly placed concrete or mortar; caused by the settlement of the solid materials within the mass; also called water gain.

Creep—Time-dependent deformation due to sustained load.

Ettringite—A mineral, high-sulfate calcium sulfoaluminate ($3\ CaO \cdot Al_2O_3 \cdot 3\ CaSO_4 \cdot$ 30-32 H_2O), also written as $\{Ca_6[Al(OH)_6]_2 \cdot 24\ H_2O\}[(SO_4)_3 \cdot 1\text{-}1/2\ H_2O]$; occurring in nature or formed by sulfate attack on mortar and concrete; the product of the principal expansion-producing reaction in expansive cements; designated as "cement bacillus" in older literature.

1.3—Grout requirements

After placement and hardening in the space between a machine or equipment base and the foundation, the grout is expected to perform one of the following functions:

1. Permanently maintain the original level and alignment of the machinery or equipment and transfer all loads to the foundation when shims and other temporary positioning devices are removed.

2. Participate with shims or other alignment devices in the transfer of loads to the foundation.

3. Provide only lateral support or corrosion protection for shims or other alignment devices that are designed to transfer all loads to the foundation.

The descriptions given in this report are for applications where the grout is intended to transfer loads and maintain a long-term, effective bearing area without load-bearing shims left in place. While it is recognized that certain equipment and machinery, such as rock crushers used in the mining industry, have been grouted and the shims left in place, these applications are not covered in this document. When shims are left in place, the grouts described herein will, in most cases, participate with shims in the load transfer. The proportion of the load carried by the grout, however, depends on many variables such as size, number and location of shims, and the volume-change characteristics of the grout. Therefore, the participation of the grout cannot be determined accurately.

The most important requirement for a grout that is intended to transfer loads to the foundation is that it has volume-change characteristics that result in complete and permanent filling of the space. Plain grouts consisting of cement, aggregate, and water do not have these characteristics. Several other properties of the grout, such as consistency, strength, chemical resistance, and compatibility with the operating environment, are also important. These properties, however, are obtained more easily than the necessary volume-change characteristics.

For most applications, the space between the foundation and the machinery or equipment base can best be filled by flowing a grout into the space. To maintain permanent contact with the plate, a grout must be formulated using special additives with cementitious or epoxy systems. A plain sand-cement grout with this consistency could be placed in the space and may develop adequate strength. After placement, however, the sand-cement grout will lose contact with the plate because of settlement shrinkage and bleeding or drying shrinkage. The result will be an incompletely filled space, leaving the equipment resting primarily or completely on the shims or other alignment device.

1.4—Evolution of materials

1.4.1 *General*—Since the need for a material that can be placed between a machine base and the foundation developed, several placement methods and materials have evolved in an attempt to achieve the necessary volume-change characteristics.

1.4.2 *Dry-pack (damp-pack)*—One of the first methods for permanently filling a space was to ram or dry-pack a damp, noncohesive mixture of sand and cement into the space. The mixture contains only enough water for compaction and hydration but not enough to permit settlement of the grout's constituents. The grout mixture has the consistency of damp sand and is placed in lifts of approximately 3 to 5 in. in thickness. Each lift is rammed in place between the base plate and the substrate concrete using a flat-faced wooden or metal tool. The end of the tool not in contact with the grout may be struck with a hammer to increase compaction.

If properly placed, dry-pack grout is acceptable. It is difficult, however (and in many cases impossible), to achieve proper placement. Dry-packing requires an almost unobstructed space and must be installed by skilled workers under the review by the engineer.

1.4.3 *Grouts with aluminum powder*—Another early method for making grout was to add a small amount [usually 3 to 5 g per 90 lb (44 kg) of cement] of aluminum powder to a plastic or flowable grout. The aluminum powder reacts with the soluble alkalies in the cement to form hydrogen gas. The gas formation causes the grout to increase in volume only while it is in the plastic state. The expansion is difficult to control due to the difficulty of blending very small quantities of aluminum powder into the mixture and the sensitivity of the chemical reaction to temperature and soluble alkalies in the mixture. Aluminum powder grouts are discussed further in Section 2.2.3.2.

1.4.4 *Grouts with oxidizing iron aggregate*—In the 1930s, an admixture was introduced that contained a graded iron aggregate combined with a water-reducing retarder, an oxidant (or catalyst), and possibly other chemicals. When blended in the field with cement, fine aggregate, and water, oxidation of the metallic aggregate during the first few days after hardening causes sufficient volume increase to compensate for settlement shrinkage. Metal oxidizing grouts are discussed further in Section 2.2.3.4.

1.4.5 *Air-release system*—In the late 1960s, a grout was developed that used specially processed fine carbon. These carbon particles release adsorbed air upon contact with the mixing water and cause an increase in volume while the grout is in the plastic state. The material is less temperature-sensitive than aluminum powder and insensitive to the alkali content of the cement used. The air-release system is discussed further in Section 2.2.3.3.

1.4.6 *Grouts with expansive cements*—In the late 1960s, grouts were developed that use a system or combination of expansive and other hydraulic cements and additives to compensate for shrinkage. During hydration of these systems, a reaction between aluminates and sulfates occurs that produces ettringite. Because ettringite has a greater volume than the reacting solid ingredients, the volume of the grout increases. The reaction occurs from the moment mixing water is added and continues at a decreasing rate until sometime after the grout hardens. If properly proportioned, it will compensate for shrinkage and, when confined, will induce a small compressive stress in the grout. Grouts with expansive cement systems are discussed further in Section 2.2.3.5.

1.4.7 *Epoxy grouts*—Since the late 1950s, epoxy grouts have been used under machine and equipment bases. The epoxy grouts are usually two-component epoxy bonding systems mixed with oven-dry aggregate. These grouts are characterized by high strength and adhesion properties. They are also resistant to attack by many chemicals and are highly resistant to shock and vibratory loads. Epoxy grouts have traditionally shown linear shrinkage; however, manufacturers have various methods to reduce or eliminate shrinkage. Epoxy grouts are discussed further in Section 2.3.

1.4.8 *Preblending of hydraulic cement grouts*—Since the early 1950s, commercial grouts have been preblended and packaged. The packaged materials contain a mixture of aggregate, cement, and admixtures and require only the addition of water in the field. The use of the preblended packaged grout resolved many field problems caused by inaccurate batching and poor or highly variable aggregate or cements. Today, there are numerous preblended packaged grouts in wide use. They use several different systems for obtaining the necessary volume-change characteristics.

The use of preblended packaged grouts usually results in more consistent and predictable performance than can be obtained with field-proportioned grout. Most manufacturers of preblended grout have quality control programs that result in production of a uniform product.

CHAPTER 2—PROPERTIES OF GROUT

2.1—General

The performance of a grout under a machine or equipment base depends on the properties of the grout in both the plastic and hardened states. The most important properties are volume-change, strength, placeability, stiffness, and durability. The following sections discuss these properties of both hydraulic cement grouts and epoxy grouts, and their effect on grout performance.

2.2—Hydraulic cement grouts

2.2.1 *General*—Hydraulic cement grouts have properties in the plastic and hardened states that make them acceptable for most applications. They are suitable for transfer of large static compressive loads and for transfer of many dynamic and impact loads. They are not acceptable for dynamic equipment that exerts both vertical and horizontal loads, such as reciprocating gas compressors.

2.2.2 *Placeability*—The workability of a grout while in the plastic state must be adequate to allow placement of the grout under a baseplate. This property is related primarily to the consistency of the grout and its ability to flow and maintain these flow characteristics with time. For example, a relatively stiff grout may require rodding to aid in placement under a baseplate, but the grout may still be placeable if it has a long working time. On the other hand, a fluid grout may stiffen rapidly but require only a short time to be fully placed. Both of these grouts could have acceptable placeability.

2.2.3—*Volume change*

2.2.3.1 *General*—Except for dry-pack, plain grouts, which are mixtures of only cement, aggregate, and water, do not have the volume-change characteristics necessary for machine-base grout. After being placed under a plate, a plain grout will generally exhibit significant bleeding, settlement, and drying shrinkage. For use as a machine-base grout, admixtures or special cement systems should be used to compensate for or prevent bleeding, settlement, and drying shrinkage.

2.2.3.2 *Gas generation*—Several admixtures are available that react with the ingredients in fresh grout to generate one or more gases. The gas generation causes the grout to increase in volume while plastic. The expansion stops when the capability for gas liberation is exhausted or the grout has hardened sufficiently to restrain the expansion. The most common gas-generating material used is aluminum powder, which releases hydrogen. If the proper additive dosage is used, it will counteract settlement shrinkage and allow the grout to harden in contact with the baseplate. The expansion that is desired is somewhat greater than would be needed to counteract settlement shrinkage. Because the grout is vertically confined, expansion in excess of settlement shrinkage moves the grout laterally.

Where aluminum powder is used to generate gas, the amount added to a batch is small. Therefore, to obtain uniform dispersion in the mixture, it may be necessary to preblend the aluminum powder with the dry cement or use a commercial, preblended grout. The *Bureau of Reclamation Concrete Manual* (Catalog Number 1 27. 19/2: C 74/974) provides useful information on the dosage of grouting admixtures.

The total expansion of a grout with aluminum powder additive depends on several properties of the grout during various stages of hardening. The rate of gas formation is affected by the temperature of the grout. The total expansion of the grout is affected by the temperature, the soluble alkali content of the mixed grout, and the rate of hardening of the grout. The restraint provided to the grout as it develops strength limits the amount of expansion.

2.2.3.3 *Air release*—Several admixtures are available that react with water to release air. The released air causes the grout to increase in volume while plastic. The expansion stops when the capability for releasing air is exhausted or the grout has hardened sufficiently to restrain the expansion. The most common air-releasing material used is a fine carbon. If the proper dosage is used, it will counteract settlement shrinkage and allow the grout to harden in contact with the baseplate. The expansion that is desired is somewhat greater than would be needed to counteract settlement shrinkage. Because the grout is vertically confined, expansion in excess of settlement shrinkage moves the grout laterally. Unlike gas-generating grouts, special methods are not needed for blending fine carbon-based grouts, as a much higher portion of admixture is used. Fine carbon admixtures are less sensitive than aluminum powder to temperature and are insensitive to the chemistry of the mixture.

2.2.3.4 *Metal oxidation*—The addition of metal particles and an oxidant will not prevent settlement shrinkage but is designed to cause a compensating increase in volume in the hardened state. The expansion occurs because the oxidation products have a greater volume than the metal particles. The reaction begins after addition of water, and the expansion gradually ceases due to the combination of rigid vertical confinement, the hardening and strength development of the cement matrix, and the diminishing supply of moisture and oxygen.

Machine-base grouts that use this mechanism are usually preblended, which reduces the chance of proportioning errors. Such proportioning errors could affect the rate of expansion. Also, grouts using this mechanism should be used only under rigid bolted confinement. Unconfined areas such as exposed shoulders will disintegrate. Once the full strength is achieved under such confinement, however, exposure to moisture will not cause additional expansion

The equipment base plate should be rigid to withstand the force exerted on the base by the expansion of the grout so that the alignment of the equipment is not affected. These grouts should not be used to grout equipment subject to thermal movement, such as turbines or compressors, or be placed in contact with post-tensioned or prestressed cables, rods, or bolts due to the corrosive potential of the oxidate.

2.2.3.5 *Ettringite formation*—The use of expansive cements in grout will result in the expansive formation of ettringite during the plastic and hardened states. If properly formulated, the resulting expansion will compensate for shrinkage and may cause small compressive stresses to develop in grout under confinement.

Machine-base grouts using the expansive cements covered by ASTM C 845 do not have sufficient expansion unless additives are used to reduce settlement and provide expansion during the plastic state. The standard expansive cements are formulated to compensate for drying shrinkage in floor slabs. Drying shrinkage is generally in the order of 0.05%, whereas settlement shrinkage in grout is generally in the order of 1.0%.

As for most types of grout, grouts that are based on expansive cements may be affected by temperature, water content, and method of curing. Generally, to be used for machine bases, expansive cement grouts use other mechanisms, such as thickening agents, to limit the settlement shrinkage to a small enough value that ettringite formation required to overcome it will not cause disruption of the hardened grout.

2.2.3.6 *Other mechanisms*—Some preblended machine-base grouts are based on proprietary mechanisms for compensating for settlement shrinkage. Several preblended grouts minimize or eliminate shrinkage by using water reducers, combinations of hydraulic cements, thickening agents, or both.

2.2.4 *Strength*—The strength of a grout must be sufficient to transfer all loads to the foundation. The compressive loads result primarily from the weight of the machine. They may also, however, be due to anchor bolt prestress and static and dynamic forces resulting from equipment operation. Typically, compressive strengths of hydraulic cement grouts at 28 days are between 5000 and 8000 psi (35 and 55 MPa). Because the bond strength of hydraulic cement grout to steel is relatively low, the grout is not generally used to transfer tensile loads to the foundation.

The compressive strength of most hydraulic-cement grouts develops more rapidly than conventional concrete. For most installations using hydraulic-cement grouts, the equipment can be placed in service in 2 to 4 days, depending on the design strength requirements and the strength-gain characteristics of the grout. If high bearing loads are expected, however, longer waiting periods are required.

2.2.5 *Elastic and inelastic properties*—The modulus of elasticity of hydraulic-cement grouts is typically larger than that of the underlying concrete because of their greater strength. The typical modulus is 3000 to 5000 ksi (20 to 35 GPa).

If the compressive strength of a hydraulic-cement grout is stronger than that of the underlying concrete, its elastic modulus is also greater. The creep of hydraulic-cement grouts is about the same as concrete. The deformation of grout is usually not significant due to the relative thickness of the grout as compared to the foundation. The load-deformation characteristics of hydraulic-cement grouts are not significantly affected by temperatures less than 400 F (200 C).

2.2.6 *Durability*—The resistance of most hydraulic-cement grouts to freezing and thawing is good because of their high strength and impermeability. Their resistance to chemicals is usually the same as that of concrete. If adjacent concrete foundations, columns, or floors must be protected from chemical attack, exposed grout shoulders should be given similar protection.

2.3—Epoxy grouts

2.3.1 *General*—Epoxy grouts are used frequently where special properties, such as chemical resistance, high early strength, or impact resistance, are required. When epoxy grouts are subjected to high temperatures, their properties may be altered significantly. The following sections discuss the more important properties of epoxy grouts.

2.3.2 *Placeability*—The physical characteristics of an epoxy grout while plastic should allow placement of the grout under the baseplate. This property depends primarily on the consistency of the grout but is also dependent on its ability to flow and its ability to maintain these flow characteristics with time.

For epoxy grouts, the user should judge from experience and visual observation of the mixed grout whether the grout has adequate flowability to allow complete placement under the baseplate. The user should also evaluate the consistency of the grout with time to assure that placement can be completed before stiffening occurs.

2.3.3 *Volume change*—Neat epoxy grouts, which are mixtures of only the epoxy resin and hardener (catalyst, converter), do not have the volume-change properties necessary for a machine-base grout. After flowing under a plate, the neat epoxy grout will generally exhibit a shrinkage of several percent. Most of this shrinkage occurs while the resin is in a liquid state, and this allows most of the shrinkage to occur without stress buildup.

The grout may exhibit additional thermal shrinkage. Polymerization of epoxy is an exothermic reaction. The temperature drop that occurs after the completion of the reaction causes the thermal shrinkage that may result in stress buildup and may cause cracking.

For use as a machine-base grout, the epoxy grout usually contains specially blended aggregate, fillers, and/or other proprietary ingredients that will reduce or eliminate the shrinkage that generally occurs in the plastic state. Aggregate and fillers reduce the temperature during hardening by reducing the volume of epoxy resin per unit volume. The aggregate and fillers also help restrain the shrinkage.

Manufacturers specify various methods and placing procedures to control shrinkage to meet specific design requirements and tolerances. Their recommendations should be followed.

2.3.4 *Strength*—The long-term compressive strength of epoxy grouts is generally 50 to 100% greater than a hydraulic-cement grout mixed to a flowable consistency. The strength also develops much faster. At normal temperatures, specially formulated epoxy grouts may be loaded in less than 24 hr after placement. The strength of epoxy, however, may decrease when subjected to temperatures above approximately 120 F (50 C).

Epoxy grouts have high tensile strength and give high bond strength to cleaned and roughened steel and concrete surfaces. The higher strength and lower modulus of elasticity permit grouts to absorb more energy than hydraulic cement grouts when loaded by impact.

2.3.5 *Elastic and inelastic properties*—The modulus of elasticity for epoxy grouts varies because of differences in the quantity and type of aggregates and fillers, and the differing properties of resins and modifiers. In general, the modulus for filled epoxy grouts range from about 750 to 5000 ksi (5 to 35 GPa). Epoxy grouts generally have greater creep than hydraulic cement grouts, and at higher temperatures [above approximately 120 F (50 C)], the creep of epoxy grouts increases. At normal application temperatures and stresses, however, this is not generally a problem. Special epoxy formulations are available for temperatures up to 300 F (150 C). Significant changes in strength, stiffness, and durability properties, however, should be expected. The grout manufacturer should provide specific data in accordance with ASTM C 1181.

2.3.6 *Durability*—Epoxy grouts exhibit more impact and chemical resistance than hydraulic cement grouts. They are unaffected by moisture after hardening. Although epoxies are resistant to many chemicals that would damage or destroy hydraulic cement grouts, they are susceptible to attack by ketones and some other organic chemicals. The stiffness and durability of epoxy grouts is reduced at temperatures exceeding the transition temperature. This is usually about 120 F (50 C). Consult the manufacturer's literature for more precise information.

Epoxy grout installations may be affected by the difference in coefficient of thermal expansion of the epoxy and the adjacent concrete. The coefficient of thermal expansion for epoxy grout is about three to four times that for hydraulic-cement grouts. If a severe change in temperature occurs, wide shoulders or long pours without expansion joints or reinforcement may experience cracks, destruction of the concrete surface, or debonding at the concrete-grout interface.

CHAPTER 3—REQUIREMENTS OF MATERIALS FOR GROUT

3.1—General

The materials for machine-base grouts are usually qualified by performing tests or by obtaining test results or certifications from the manufacturer or an independent testing laboratory. The following sections discuss the general recommendations for the material to be used in grout.

3.2—Hydraulic cement grouts

The qualification of a hydraulic cement grout should be based on comparison of test results with predetermined requirements for volume-change, bleeding, strength, and working time. The temperature and consistency of the grout used for testing should be known and should be the basis for setting field requirements for as-mixed and in-place temperature and consistency or maximum water content.

3.2.1 *Preblended grouts*—The qualification requirements of preblended grouts may be based on the results of the tests performed in accordance with ASTM C 1090 or ASTM C 827 in combination with the performance evaluation test, as given in Section 4.4. Some manufacturers and users employ both laboratory methods to evaluate a grout. Generally, acceptable results from one of the standard test methods, along with successful results from a performance evaluation test, are sufficient for qualification of a grout.

Tests for bleeding in accordance with Section 4.2.5 should be considered along with the results of the performance evaluation test; that is, bleeding should be no greater than that of the grout mixture that passes the performance test. The results may be used to set field test limitations for bleeding or to verify compliance with specified bleeding requirements.

The qualification requirements for strength of preblended grout may be based on the compressive strength of the concrete on which the grout will be placed. Generally, 28 day strengths of 5000 to 6000 psi (35 to 40 MPa) are easily obtained for most preblended grouts.

The procedures that are expected to be used in the field should be considered for evaluating working time. Some grouts have long working times if agitated. Others may have longer working times but may have less desirable performance for other properties such as volume change or bleeding.

For some applications, additional qualification requirements or limitations may be necessary. Special requirements may include chemical resistance, resistance to freezing and thawing, impact resistance, or cosmetic appearance. Limitations on chloride ions, as given in ACI 318, may be placed on certain ingredients in grout to be used in contact with high-strength steels used in prestressed or post-tensioned construction.

3.2.2—*Field-proportioned grout*

3.2.2.1 *General*—The qualification requirements for field-proportioned grouts with a flowable consistency should be essentially the same as those for preblended grouts given in Section 3.2.1. For testing field-proportioned grouts, the standard height change tests are very important. The proportions of aggregate, cement, and admixtures may be adjusted to obtain the desired volume-change characteristics. The methods for proportioning grout are given in Section 3.2.2.5.

The only requirement for field-proportioned grouts used at dry-pack consistency is for compressive strength. Because the compaction of dry-pack affects the compressive strength as much as the proportions of the ingredients, special methods for making representative specimens should be developed by the engineer. Generally, 28 day strengths of 6000 to 8000 psi (40 to 55 MPa) are easily obtainable for most dry-packed grouts. The following sections discuss the requirements for the materials and the methods for proportioning field-proportioned grouts.

3.2.2.2 *Cement*—The hydraulic cement for field-proportioned grout generally is required to conform to ASTM C 150. Blended and expansive cements conforming to ASTM C 845 may be acceptable. Expansive cements are not generally used in field-proportioned grouts unless other additives are also used.

3.2.2.3 *Fine aggregate*—Fine aggregate for field-proportioned grouts should conform to ASTM C 33, ASTM C 144, or ASTM C 404. All three specifications require a continuous grading, place limits on deleterious material, and require tests for soundness.

The gradation of aggregate for field-proportioned grouts may require alteration in the field so that the maximum particle size is appropriate for the minimum grout thickness anticipated. For grout thickness over 3 in. (75 mm), the addition of 3/8 in. (10 mm) nominal, maximum-sized coarse aggregate should be considered.

3.2.2.4 *Admixtures*—Admixtures that reduce settlement shrinkage and provide expansion in the plastic state should be used in all field-proportioned grout mixtures. Chemical admixtures, such as superplasticizers, water reducers, and air-entraining admixtures, may also be used.

Most commercially available grouting admixtures contain a material that reacts chemically with alkalies in the cement to form a gas. They may also contain a water-reducing admixture. Admixtures based on other mechanisms for compensating or preventing settlement shrinkage or for reducing bleeding are available.

3.2.2.5 *Proportioning of field-proportioned grout*—The proportioning of flowable field-proportioned grouts involves the determination of the ratio of aggregate to cement, the water content, and the dosage of the grouting additive necessary to obtain the desired volume-change characteristics. The aggregate used for proportioning should be obtained from the job or from the proposed source for the job.

The ratio of aggregate to cement and the water content should be determined from trial batches at standard laboratory temperature using a constant preliminary admixture dosage and a constant consistency. The ratio of aggregate-to-cement for minimum water is usually 1.5 to 2.5 by weight, depending mainly on the fineness of the aggregate. The compressive strength of mixtures with minimum water and a flowable consistency is usually 4000 to 6000 psi (25 to 40 MPa) at 28 days. Ice-cooled water is sometimes used to reduce the necessary amount of mixing water to control bleeding or to increase the strength, placeability, and working time.

The dosage of the grouting admixture should be determined from trial batches run at the selected ratio of aggregate to cement to optimize volume-change and bleeding characteristics, which are normally specified if critical to the application. Initial batches should be run at laboratory temperatures. Volume change and bleeding should also be determined for specimens cast and maintained at minimum expected placement temperature and at the most flowable consistency or maximum water content. If specified volume-change or bleeding requirements are not met at the lower temperatures, admixture dosage may be increased or proportions adjusted. The *Bureau of Reclamation Concrete Manual* provides useful information on the dosage of grouting admixtures.

The proportions of dry-pack grout are not as critical as for grouts of plastic or flowable consistency. Therefore, proportioning from trial batches is usually not necessary. Dry-pack with an aggregate-to-cement ratio of 2.5 to 3.0 by weight will generally compact well and have compressive strengths of about 6000 to 8000 psi (40 to 55 MPa) at 28 days.

3.2.3 *Water*—Unless otherwise allowed by the manufacturer or designer of the grout, water for preblended or field-proportioned grout should be potable. If the water is discolored or has a distinct odor, it should not be used unless 1) it has a demonstrated record of acceptable performance in grout or concrete, or 2) the 7 day compressive strength of specimens made with the water is at least 90% of the compressive strength of identical specimens made with distilled water.

If grout or dry-pack is to be placed in contact with high-strength steel bolts or stressed rods or in contact with dissimilar metals, limits should be placed on the chloride and sulfide ion contents of the water. Allowable maximum chloride ion concentration given in various documents ranges from 100 to 600 ppm. Little or no information or guidance is given for sulfide ion content, although it is recognized as a corrosive medium.

3.3—Epoxy grouts

The qualification of epoxy grouts should be based on comparison of test results with predetermined requirements for volume change, strength, creep, and working time. At the present time, however, no ASTM method for determining volume change exists for epoxy grouts. The performance evaluation test discussed in Section 4.4 may be used as an indication of acceptable performance.

The temperature and ratio of the polymer bonding system to aggregate should be known and be the basis for setting field requirements. Generally, compressive strength of at least 8000 psi (55 MPa) is obtained easily for most epoxy grouts.

Qualification requirements for working time, thermal compatibility, and creep resistance for epoxy grouts are necessary and should be established because these properties vary greatly among different epoxy grouts.

CHAPTER 4—TESTING OF GROUT

4.1—General

The following sections discuss the test methods used for evaluation of machine-base grouts. Except for dry-pack grout, Sections 4.2 and 4.3 cover the common tests for various properties of hydraulic cement and epoxy grouts, respectively. The results of these tests are useful for evaluating the properties of grouts both before and during placement and in service.

Section 4.4 covers a test that is applicable to both hydraulic cement and epoxy grouts. Although the test does not yield quantitative results, it is useful as an overall measure of placeability and in-service performance of a grout.

4.2—Hydraulic cement grouts

4.2.1 *General*—The evaluation of hydraulic cement grout should include tests for volume change, strength, setting time, working time, consistency, and bleeding. For field-proportioned grout, the tests should be performed on grout made from job materials. The proportioning methods for field-proportioned grout are given in Section 3.2.2.5.

4.2.2 *Preparation of test batches*—The equipment and methods used for preparation of test batches may affect the results of many of the tests performed on grout. The conditions of the tests may also affect the applicability of the results to field situations. The following sections discuss some of the considerations that should be examined before preparation of test specimens.

4.2.2.1 *Mixers for test batches*—Test batches of grout are mixed frequently in a laboratory mortar mixer similar to that specified in ASTM C 305. The laboratory mixer and the field mixer may not achieve equivalent mixing. The water content for a specific flow may be different using the laboratory mixer than the field mixer because of mixer size, as well as size of the batch.

4.2.2.2 *Temperature of test batches*—Test results obtained on grouts mixed, placed, and maintained at standard laboratory temperatures are sometimes different than the results that may be obtained at the maximum and minimum placing temperatures permitted in the field. Tests should be performed near both the maximum and minimum field placing temperature for volume change, bleeding, working time, consistency, setting time, and strength.

The temperatures of test batches may be varied by adjusting mixing water temperature, storing materials at elevated or lowered temperatures, or a combination of the two. Molds for tests should be brought to the desired temperature before use and should be maintained at that temperature for the duration of the test.

4.2.2.3 *Batching sequence for test batches*—The batching sequence and mixing time or procedure used for test batches will affect the results of all tests. For preblended grouts, the contents of the entire bag of grout should be mixed for the test batch. This ensures that segregation of the materials in the bag will not affect the results. If a full bag cannot be used, then dry materials should be blended to assure uniformity. Most manufacturers recommend that some or all water be added to the mixer before the dry preblended grout, and then mixed for 3 to 5 min. The recommendations of the engineer or the manufacturer of the grout should be followed. The mixing procedure and batching sequence used for making test batches should be recorded. It should be as close as possible to the procedure to be used in the field.

4.2.2.4 *Consistency of test batches*—The consistency of test batches should be the most flowable consistency that may be used for placement in the field, or the maximum recommended by the manufacturer or designer of the grout. Field personnel should be prohibited from using larger water contents than were used for tests. The maximum water content or flow recommended by the manufacturer of preblended grouts should not be exceeded.

Tests at the minimum permissible flow or water content are not usually required because the performance of a grout is usually improved by lower water contents if it can still be properly placed.

4.2.3—*Volume change*

4.2.3.1 *General*—Volume change of machine-base grouts should be evaluated by using test methods that measure height change from time of placement. The most common methods used for evaluating the volume-change characteristics of a grout are the micrometer bridge described in ASTM C 1090 and the optical method described in ASTM C 827. Both tests evaluate volume change by measurement of height change.

ASTM C 1090 measures height change from time of placement to 1, 3, 14, and 28 days; ASTM C 827 measures height change from time of placement to time of setting. Grouts exhibiting a slight expansion by the micrometer bridge or 0 to 3% plastic expansion by ASTM C 827 are more likely to perform well in the performance evaluation test in Section 4.4.

4.2.3.2 *Micrometer bridge (ASTM C 1090)*—The micrometer bridge test method described in ASTM C 1090 measures height change in grout between the time it is placed and 1, 3, 14, and 28 days of age. In this procedure, grout is placed in a 3 in. diameter by 6 in. high (75 by 150 mm) steel cylinder mold. A clear glass plate is placed on top of and in contact with the grout and clamped down on the rim until 24 hr after starting the mix. The position of the surface of the grout at time of placement is determined by immediately taking micrometer depth gauge measurements from a fixed bridge over the cylinder to the top of the glass plate and later adding the measured thickness of the plate, taken after it has been removed. Movement of the grout, after it has set and the plate has been removed,

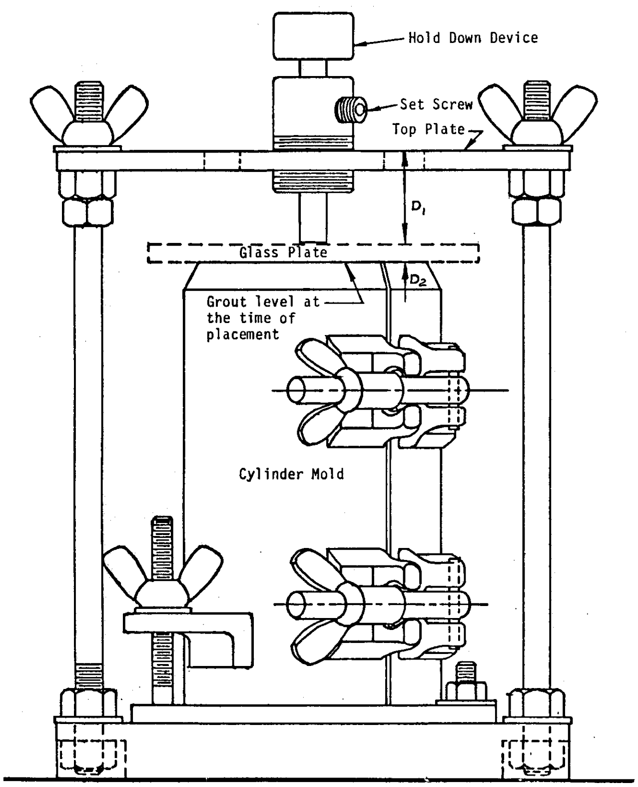

Fig. 4.1—*Micrometer bridge (ASTM C 1090).*

is measured directly to the surface of the grout for up to 28 days. Specimens should be prevented from losing or gaining moisture. See Fig. 4.1.

The micrometer bridge method, in some respects, models an actual baseplate installation. The main difference being that in the test, the plate is placed onto the grout instead of the grout being placed under the plate. The grout is completely confined vertically until the plate is removed 24 hr after starting the mix. The advantage that the micrometer bridge has over simulated baseplate tests is that it provides a numerical measurement and uses much less material. The fact that the method is generally available makes possible the evaluation of tests submitted by a vendor. This test method also permits measurement of expansion after hardening.

4.2.3.3 *Optical method (ASTM C 827)*—ASTM C 827 measures the unconfined height change in grout from time of placement until the grout hardens. The grout is placed in a 2 by 4 in. (50 by 100 mm) cylinder and a plastic ball is placed into the top of the grout. Vertical movement of the ball is measured using an optical procedure that indicates either shrinkage or expansion. See Fig. 4.2.

The test method does not attempt to model baseplate installations, as the top surface and ball are unrestrained throughout the test. The advantages that the optical method has over simulated baseplate tests are that it provides a numerical measurement and uses much less material. The fact that the method is generally available makes possible the evaluation of tests submitted by a vendor.

4.2.3.4 *Other volume change test methods*—Length change test methods such as ASTM C 157 and ASTM C 806

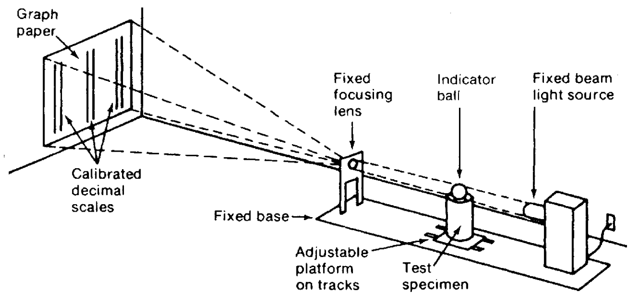

Fig. 4.2—*Optical method (ASTM C 827).*

are not applicable for measuring the total volume change of grouts. Neither method measures length change until after the grout has hardened, nor do they detect height change. ASTM C 940 is sometimes used for in-process testing of unconfined height change and bleeding. It is relatively insensitive to a small height change and is most appropriate for recognizing gross errors in formulation or mixing of gas-liberating grouts.

4.2.4 *Consistency*

4.2.4.1 *General*—The consistency of a hydraulic cement grout can be determined using one of the following devices.

4.2.4.2 *Flow table*—The flow table specified in ASTM C 230 is used in the laboratory to determine the consistency of plastic or flowable grouts. The consistency of fluid grouts exceeds the range of the flow table.

The flow table is a circular brass table 10 in. (250 mm) in diameter. Grout is placed on the table into a bottomless cone-shaped mold with a base diameter of 4 in. (100 mm) and the mold then carefully lifted, leaving fresh grout unsupported laterally. A shaft is then turned with a crank or motor. A cam on the shaft causes the table to be raised and then dropped a specified distance. The impact causes the grout to increase in diameter. The average increase in diameter is measured usually after five drops on the table in 3 sec. (For cement tests in accordance with ASTM C 150, the flow is measured at 25 drops in 15 sec.)

The consistency is reported as the diameter increase of the grout expressed as a percent of the diameter of the mold base. The flow table will accommodate a flow of 150% before the grout runs off the table.

The flow table is usually only used in a permanent laboratory, although it has been used in field laboratories for large projects.

4.2.4.3 *Flow cone*—The flow cone specified in ASTM C 939 is used in the field and laboratory to determine the consistency of fluid grouts. Grouts of plastic and flowable consistency are not tested generally by the flow-cone method.

The flow cone is a funnel with a top diameter of 7 in. (180 mm) and an orifice diameter of 1/2 in. (13 mm). The grout is placed to the top of the conical section (1725 mL) with the orifice covered with a finger. The finger is then removed from the orifice and the time measured until the cone is evacuated completely. The flow cone is also used in the laboratory and field for making adjustments to water content to obtain a desired consistency.

4.2.4.4 *Slump cone*—A slump cone as defined in ASTM C 143 has been used occasionally to measure consistency of grout in the field. The slump cones usually are standard 12 in. (300 mm) cones; however, 6 in. (150 mm) cones are sometimes used. Either the slump or the diameter of the grout is measured. The results are less precise than those from a flow table; however, it is often the only practical method for measuring the consistency of plastic and flowable grouts in the field.

4.2.5 *Bleeding*—Bleeding can be measured in the field and laboratory in accordance with ASTM C 940. The test method involves placing 800 mL of fresh grout into a 1000 mL graduated cylinder and covering to prevent evaporation. The bleed-water that collects on top of the grout before initial set is measured. Typical values range from no bleeding for many preblended grouts to 5% for plain sand-cement grouts with a flowable consistency. Tests for bleeding should be conducted at temperatures corresponding to the lowest expected placing temperature.

Modifications of the test using different types of containers and different procedures are sometimes used in the field.

4.2.6 *Compressive strength*—The compressive strength of hydraulic cement grouts is determined using 2 in. (50 mm) cube specimens. The placing and consolidation procedure in ASTM C 109 is inappropriate for dry-pack, flowable, or fluid grouts, but is satisfactory for stiff or plastic consistencies. Fluid and flowable grouts are placed in two layers and are each puddled five times with a gloved finger.

The manufacturer of preblended grouts should be contacted for recommendations regarding molding, storing, and testing of specimens.

After the grout is struck off, it is covered with a metal plate that is restrained from movement by clamps or weights. Restraint for at least 24 hr is desirable for all types of grouts and is particularly important because unrestrained expansion usually results in lower strength than would occur in grout under a baseplate. If cubes are stripped in 24 hr, they should be placed in saturated limewater until 1 hr before testing.

4.2.7 *Setting and working time*—The time of setting of grouts is determined by one of the following methods: ASTM C 191, C 807, C 266, C 953, or C 403. The methods all give a valid reproducible indication of the rate of hardening of grout. The initial and final times of setting, determined by the five methods, are not generally the same. The results from time-of-setting tests should not be used as an indication for the working time of a grout. The working time should be estimated by performing consistency tests at intervals after completion of mixing.

4.3—Epoxy grouts

4.3.1 *General*—The evaluation of epoxy grouts should consist of tests for strength and evaluation of creep, volume change, working time, and consistency. Evaluation can be made by testing, visual observation of actual field applications, or other experience.

4.3.2 *Preparation of test batches*—Test batches of epoxy grout are prepared by first mixing the resin and hardener, and then adding the aggregate or filler. Mixing of the resin and hardener is done by hand or by an impeller-type mixer on an electric drill rotating at a slow speed (less than 500 rpm) so that air will not be entrapped. After the aggregate is added, mixing is completed by hand or in a mortar mixer. Impeller-type mixers should not be used for grout with aggregate or fillers because air may be mixed into the grout. The air would then slowly migrate to the top surface after placement, resulting in voids under a plate.

4.3.3 *Volume change*—There is no generally accepted method or ASTM method for testing the volume or height-change properties of an epoxy grout. Instead, ASTM Committee C-3 has developed C 1339 to measure flowability and bearing area. Most test methods for epoxies measure length change after the grout has hardened. Those methods do not measure the height change from the time of placement until the time of hardening. Some manufacturers modify ASTM C 827 to measure height change of epoxy grouts by using an indicator ball with a specific gravity of 1/2 of the specific gravity of the epoxy mix.

Although the performance evaluation test discussed in Section 4.4 does not provide quantitative measurements for epoxy grouts, it may be useful for identifying epoxy grouts that do not have acceptable volume-change properties.

4.3.4 *Consistency*—The consistency of epoxy grouts is normally not measured using the flow table or flow cone for hydraulic cement grouts. The manufacturer usually gives the precise proportions to be used with epoxy grouts. Therefore, the user should determine if the consistency obtained is sufficient for proper field placement at the temperatures to be used.

4.3.5 *Compressive strength*—Compressive strength tests on epoxy grouts can be performed using 2 in. (50 mm) cubes, or on 1 by 1 in. (25 by 25 mm) cylinders. The specimens are made and tested in accordance with ASTM C 579. Where anticipated installation and in-service temperatures will be much lower or higher than normal temperatures, special tests should be performed at those temperatures.

4.3.6 *Setting and working time*—The times of setting, determined using the methods given in Section 4.2.7, are not applicable for epoxy grouts. The size of the specimen is also critical for epoxy grouts. Times of setting are longer for small specimens and shorter for large specimens.

Most ASTM methods, such as ASTM C 580, designate standard laboratory conditions of 73.4 ± 4 F (23 ± 2.2 C) to establish a standard basis for testing materials. Higher or lower temperatures may affect grout properties such as flowability, working time, strength and cure rate. Where anticipated installation and in-service temperatures will be much lower or much higher than normal temperatures, special tests should be performed at those temperatures.

4.3.7 *Creep*—ASTM C 1181 is the accepted method for testing the long-term creep properties of epoxy grout. The manufacturer should provide creep information in accordance with this method.

4.4—Performance evaluation test

4.4.1 *General*—The performance evaluation test is commonly termed "a simulated baseplate test." Although the test is not an ASTM standard method, some users find that the test provides a means to evaluate the overall placeability and in-service performance of a grout. The test apparatus essentially consists of a baseplate that simulates a typical grouting application. The test provides information that can be used along with the results of the test methods discussed in Sections 4.2 and 4.3 to determine the acceptability of the grout and the placement method for a specific application.

4.4.2 *Apparatus*—The apparatus generally consists of a stiff steel plate or channel supported on shims a few inches above a rigid concrete base. The plate is held down by bolts anchored in the concrete. The plate is commonly 1 by (2 or 3) ft [300 by (600 or 900) mm] with the grout flowing in the long direction. The bottom of the baseplate is usually waxed to facilitate the removal of the plate after the grout has hardened. Some grouts, however, particularly some epoxies, may require bond to the plate to maintain contact with the plate during hardening. For these grouts, the recommendations of the grout manufacturer or designer for preparation of steel surfaces should be followed.

The concrete surface under the plate is usually the smooth, hard-trowelled laboratory floor, waxed to prevent bond. Roughening and saturation of the base surface to approximate field conditions may be feasible in some instances where a waste slab is available, but the use of a smooth base will not greatly affect placeability over a flow distance as short as 2 to 3 ft (600 to 900 mm). Whether or not the base is rough does not affect the ability of a grout to maintain contact with the plate. See Fig. 4.3.

The space between the plate and the concrete is usually near the maximum expected for field applications. Tests with the maximum gap are helpful in evaluating the capability of a grout to maintain contact with the plate. Tests using the minimum permitted or expected gap may be necessary when problems with placeability or flow distance are anticipated.

Formwork for the test should be the same as used in the field and should comply with the recommendations of Section 6.5.

4.4.3 *Procedure*—The batching, mixing, and placing of grout for the test should attempt to model the methods to be used in the field. As discussed in Sections 4.2.2 and 4.3.2, the methods used to prepare the grout may result in changes in placeability or performance.

For epoxy grouts and preblended grouts, the manufacturer's recommendations for mixing and placing should be followed. Particular attention is required to assure that the final grout level around the plate perimeter is above the bottom of the plate, as recommended by the manufacturer.

The grout is placed in a headbox (Section 6.5.2) located on one short side of the plate. The grout should then be flowed under the plate using the procedures to be used in the field. The flow of grout should not be assisted by strapping, rodding, or vibration unless these methods will be employed in the field application. Curing and protection of the grout should be in accordance with Sections 8.1 or 8.2.

4.4.4 *Evaluation of results*—The intent of this section is to guide the reader in evaluating performance tests to supplement physical property testing. The performance evaluation test does

Fig. 4.3—Performance evaluation test apparatus.

not provide quantitative results. It does provide information that, when used with results of other tests, provides an indication of whether or not the materials and placement procedures specified will result in the desired in-place installations. The test sometimes identifies problems related to placing that are independent of the grout being used. These problems could be incomplete placement, surface voids, or air entrapment.

The baseplate test provides a means of evaluating the placeability of a grout by visually observing the effects of grout consistency, working time, and, to some degree, setting time on the placing operation.

Some laboratories and users employ sounding methods to identify major areas of the plate where grout is not in contact. Some users and manufacturers, however, do not believe the method is reliable. The laboratories that use the sounding methods generally use a 1/2 in. (13 mm) steel rod to sound the plate at ages up to 28 days for hydraulic cement grouts and 3 days for epoxy grouts. The rod is held vertically and dropped about 1 in. (25 mm). A hollow sound indicates lack of contact. A ringing sound may indicate tight contact. The sounding method does not detect the presence of small bubbles or voids caused by placing methods. These are detected

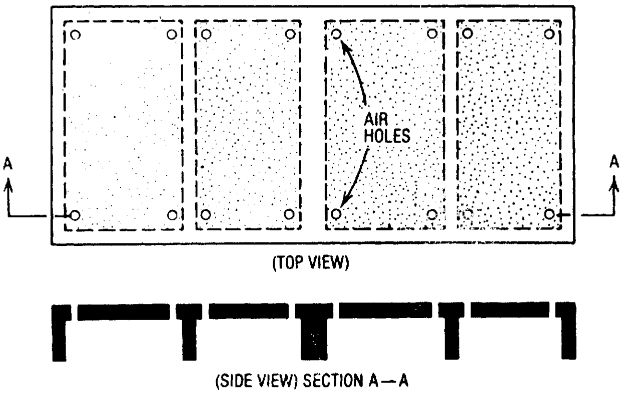

Fig. 5.1—Air relief holes.

visually after the plate is removed. Sounding methods are not reliable for plates more than 1 in. (25 mm) thick that must be lifted to check grout surface and effect of placement method.

After the grout has hardened, the baseplate test provides some information on the capability of the grout to maintain contact with the plate. The plate should be removed and the grout surface inspected for voids and weak surface material.

Voids in the grout surface may be caused by inadequate placing technique or by bleeding of the grout. Placing voids are generally larger and deeper than voids caused by bleeding. Bleeding voids frequently look like "worm tracks." Placing voids usually indicate that improper placing procedures were used or the grout was too stiff. Small, randomly distributed placing voids that account for less than 5% of the plate area are usually considered acceptable.

A weak surface may be caused by bleeding or settlement shrinkage of the grout. Bleeding results in an increased water content of the hydraulic cement grout at the surface. Settlement shrinkage may result in separation or layering of the grout near the surface. As the grout settles, some grout will adhere to the plate, resulting in separation or layering. Bleeding voids, weak surfaces, and obvious shrinkage may result in unacceptable in-service performance for a grout. If the baseplate tests indicate unacceptable performance for a grout, changes in water content, proportions, or maximum grout thickness should be considered.

When epoxy grouts are tested, the bottom and sides of the baseplate should be thoroughly waxed to prevent bonding of grout. The plate should be sounded at 3 days and then removed. The use of threaded jack bolts to support the plate will also facilitate plate removal. The grout surface should be evaluated for weak areas, foamy or cellular areas, bubbling, and the amount of large irregular placing voids. Because of the higher strengths of epoxy grouts, some users accept uniformly distributed voids of up to 25% of bearing area if the resulting baseplate bearing stress is less than the allowable stresses provided by the manufacturer. If the grout manufacturer requires bonding, the plate should be sandblasted and the bond evaluated by sounding.

CHAPTER 5—GROUTING CONSIDERATIONS FOR FOUNDATION DESIGN AND DETAILING

5.1—General

The success of a grouting operation depends, to a great extent, on the design of the foundation and machine or equipment base, the clearances provided for the grout, and the provisions made for obtaining complete filling of the space. The following sections discuss some of the design and detailing requirements for obtaining acceptable grouting.

5.2—Machine or equipment bases

The machine base should be detailed so that grout can be placed beneath the plate without trapping water or air in unvented corners. If possible, perpendicular stiffeners should be placed above the plate.

If grout cannot be placed from one edge and flowed to the opposite edge, air vent holes must be provided through the plate to prevent air entrapment. A vent hole 1/4 to 1/2 in. (6 to 13 mm) in diameter should be placed through the plate at the intersection of all crossing stiffeners and at each point where air may be trapped. See Fig. 5.1.

If possible, grout holes for placement of the grout should be located so that grout does not travel more than about 48 in. (1.2 m). The grout holes should be placed so that grouting can be started at one hole and continued at other holes to insure that the grout flows under all areas of the plate.

Holes for pumping grout are typically 3/4 to 2 in. (19 to 50 mm) in diameter and threaded for standard pipe threads. Grout holes for free-pouring grout are typically 3 to 6 in. (75 to 150 mm) in diameter. Recommended procedures are discussed under Section 7.4.2.

5.3—Concrete foundation

The concrete foundation should be designed to have sufficient stiffness to prevent flexural tension in the grout and to prevent thermal warping caused by temperature differential or change.

If severe changes in temperature are expected, wide shoulders over 6 in. (150 mm) or long pours should have expansion joints and/or reinforcement to minimize cracks or horizontal fractures near the concrete-grout interface.

5.4—Anchorage design

The design of anchor bolts or other devices may have an effect on grout performance. For vibrating machinery or impact loading, it is important for the grout to be maintained in compression. This can usually be accomplished by uniformly torquing the anchor bolts after the grout has developed a significant portion of its ultimate strength.

5.5—Clearances

The clearances provided for grout between the machinery base and the underlying foundation are often a compromise between two opposing requirements: minimum thickness of grout for optimum economy and performance, versus maximum clearance under the baseplate for ease and proper placement.

For flowable hydraulic cement and epoxy grouts placed by gravity, the minimum thickness should be about 1 in. (25 mm) for 1 ft (300 mm) flow length. For each additional ft (300 mm) of flow length, the thickness should be increased about 1/2 in. (13 mm) to a maximum of about 4 in. (100 mm). For grouts with a plastic consistency placed by gravity, the clearances should be increased by 1/2 to 1 in. (13 to 25 mm) above that designated for flowable grouts. For fluid grouts, the clearance can generally be reduced by 1/4 to 1/2 in. (6 to 13 mm), but should not be reduced to less than 1 in (25 mm). For placements made by pumping through connections in the plate, the clearances do not have to be increased. If it is anticipated that a grout hose may be placed under the plate, adequate clearance for the hose must be provided.

For installations to be dry-packed, the clearances should be about 1 to 3 in. (25 to 75 mm). Large clearances make compaction impractical. To allow proper compaction, the width of the area to be dry-packed from any direction should be less than 18 in. (460 mm). Shims and jack bolts have a direct impact on dry packing. Shims can be displaced causing movement, and both can prevent proper compaction.

CHAPTER 6—PREPARATION FOR GROUTING

6.1—General

The following sections discuss the surface preparations and formwork for grouting of machinery or equipment base. The manufacturer of preblended or epoxy grouts may modify or supplement the following recommendations.

6.2—Anchor bolt

If anchor-bolt sleeves are to be grouted, sleeves, holes, and similar items should be cleaned of debris, dirt, and water by oil-free compressed air or vacuum.

Concrete in the holes should be saturated with water for 24 hr and the water removed just prior to grouting with hydraulic cement grout. For epoxy grouts, all surfaces should be dry unless specified otherwise by the grout manufacturer.

Anchor-bolt sleeves and holes that are to be grouted should be grouted before pouring grout under the plate. This is necessary to assure that the grout maintains contact with the plate. If the total placement is attempted in a single pour, air and (in the case of hydraulic cement grouts) unremoved water may rise to the grout surface. This will result in settlement of the grout, seriously reducing the contact areas of the plate. In areas subjected to freezing temperatures, sleeves should be protected from the damaging effects of freezing water.

6.3—Concrete surface preparation

The concrete surface on which the grout will be placed should be relatively flat without deep pockets or grooves, which would seriously hinder removal of saturation water or flow of grout.

The surface should be roughened by green-cutting, chipping or other means to remove all laitance and to provide a full amplitude of approximately 1/4 in. (6 mm). This procedure should remove all laitance and unsound or insufficiently cured material. The roughened and cleaned surface should be protected from subsequent contamination.

If the surface is roughened by chipping, only small hand tools or a small pneumatic hammer should be used. Nail-point tools should be avoided because of the possibility of initiating cracks in the surface of the foundation. For the same reason, large jack hammers or paving breakers should not be used. The surface should be thoroughly cleaned and protected from subsequent contamination. For hydraulic cement grouts, the concrete surface should be continuously saturated with water for at least 24 hr just prior to grouting. The saturation of the surface is to prevent water from being absorbed rapidly from the grout. The rapid loss of water will result in shrinkage. For dry-pack grout, the loss of water could result in insufficient hydration. For epoxy grouts, the surface should be dry unless otherwise specified by the manufacturer.

6.4—Metal surfaces

Metal surfaces that will be in contact with hydraulic cement grouts should be cleaned of all paint, oil, grease, loose rust, and other foreign matter. For epoxy grouts, the metal surface should be sandblasted to bright metal unless the manufacturer states sandblasting is not necessary. If grouting will be delayed for an extended time, an epoxy primer consisting of resin and converter may be used over sandblasted surfaces to prevent corrosion. If bond to the baseplate is desired, the grout manufacturer's recommendations should be followed.

6.5—Formwork

6.5.1 *General*—The design of formwork for grouting should take into account the type of grout, the consistency of the grout, the method of placement, and the distance the grout must travel. The forms should be built so that the grout can be placed as continuously and expeditiously as possible.

The forms for all types of grout should be rigid, sufficiently tight-fitting, and sealed (such as taped or caulked) to prevent leakage. They should also extend at least 1 in. (25 mm) above the highest grout elevation under the machine base. Forms may also be provided to prevent grout from flowing over the top surface of the machine base or baseplate. Forms should be coated with compatible form oil or wax or lined with polyethylene to reduce absorption of liquid and to facilitate form removal. Care should be used to prevent contamination of the concrete surface or the underside of the machine base with form release agent. To facilitate form removal and improve the appearance of the finished grout, chamfer strips may be attached to the form. Forms for epoxy grout or other areas where bond is not desired should be coated with a thick wax coating or lined with polyethylene, and be watertight.

The following sections discuss the configuration of the forms for specific methods for placing the grout.

6.5.2 *Forms for placement of fluid or flowable grouts*—Where the grout will be placed from one side of the baseplate and flowed to the other side, the forms should be constructed to provide a method for developing a head on the placing side. The forms should also have sufficient clearance to permit strapping or rodding if such methods are acceptable to the grout manufacturer and specifier.

Fig. 6.1—Headbox.

The forms on the placement side should extend above the bottom of the plate to form a headbox. The headbox should begin 2 to 4 in. (50 to 100 mm) from the plate and slope away from the plate at about 45 degrees. The slope on the form permits the grout to be poured under the plate with a minimum of turbulence and air entrapment. The form on the opposite side should be 2 to 4 in. (50 to 100 mm) from the plate and should extend at least 1 in. (25 mm) above the bottom of the plate. The height of the headbox depends on the distance the grout must flow. In general, the height above the highest grout elevation under the plate should be about 1/5 of the travel distance for the grout. A portable headbox with the same configuration may be used. See Fig. 6.1.

On the side of a plate parallel to the direction of grout flow, the forms should generally be less than 1 in. (25 mm) from the plate.

For placements where the grout will be pumped under the plate through grout holes in the plate, the forms should be at least 4 in. (100 mm) outside the plate on all sides. The forms should extend at least 1 in. (25 mm) above the highest grout elevation under the plate. Forms may also be built on top of the plate to prevent excessive spillage onto the top of the plate. Alternately, the top surface can be waxed or oiled to make clean up easier.

6.5.3 *Forms for dry-packing*—For placement of dry-pack, the forms do not need to be as tight-fitting as for flowable grouts, but should be more rigid. The constant compaction of the dry-pack will loosen forms unless they are well braced. If movement of forms occurs during compaction, it may result in insufficient compaction.

6.6—Safety and handling of epoxies

Epoxy grout should be handled strictly as required by the manufacturer's instructions and material safety data sheets. Some individuals have skin sensitization problems with epoxy grout materials, and proper handling and safety should be employed. Furthermore, some epoxy grouts emit objectionable and even hazardous vapors. Care should be exercised in handling them, particularly in enclosed areas. Use of positive ventilation can assist in removing the vapors.

CHAPTER 7—GROUTING PROCEDURES

7.1—Consistency

The consistency needed for placement of a grout depends on the clearance provided between the machine base and the foundation, on the complexity of the machine base, and on the method of placement. The clearances and flow distances provided should be compared with the recommendations given in Section 5.5.

The water content or consistency of the grout should not exceed the maximum or minimum determined from qualification tests or recommended by the manufacturer. The water content is determined by the consistency necessary for placement. In general, the water content or flow should be the minimum that will reliably result in complete filling of the joint space to be grouted.

The consistency for placement by dry-packing (Sections 1.2 and 1.4.2) should be in accordance with the definition for dry-pack consistency. The water content should be adjusted if the dry-pack becomes rubbery or crumbly.

The consistency for epoxy should be that resulting from use of the manufacturer's recommended proportions. Placement should not be attempted with any grout if the resulting consistency is not suitable for the existing clearances and flow lengths using the method proposed.

7.2—Temperature

The ambient temperature, the grout temperature at placing, and the temperature of the foundation and baseplate all affect the workability, time of setting, strength, bleeding, and volumetric characteristics of a grout. The temperatures should therefore be adjusted to be within the ranges recommended by the manufacturer for preblended grouts or the range of temperatures for which grout performance has been evaluated. For temperatures above or below those ranges, additional qualification tests should be performed or approval obtained from the manufacturer.

The temperature of the foundation and baseplate may be reduced to within the permissible placing range for the grout by cooling with ice or cold water. Under cold conditions, ambient, plate, and foundation temperatures can be increased by using heating blankets or heated enclosures. The as-mixed temperatures of hydraulic cement grouts may be reduced by using cold water, ice, or precooled dry materials. The components of epoxy grout may be precooled to the desired temperature. Under cold conditions, the initial as-mixed temperature can be increased by using warm water in hydraulic cement grouts or by storing the ingredients for hydraulic cement or epoxy grouts in a warm area. Some epoxy grout manufacturers also have accelerators for use during cold conditions.

7.3—Mixing

7.3.1 *Hydraulic cement grouts*

7.3.1.1 *General*—Hydraulic cement grouts should be mixed using methods and equipment that will result in grout of uniform consistency that is free of lumps.

7.3.1.2 *Mixers*—For plastic, flowable, and fluid grouts, horizontal shaft mixers with a stationary drum are desirable, normally recommended by grout manufacturers, and commonly used. Vertical shaft mixers may also be used if approved by the manufacturer. Provided that the mixers are clean and equipped with rubber-tipped blades with close tolerances, these mixers generally provide adequate shearing stresses in the fresh grout to break up all lumps and adequately disperse the constituents. These mixers also permit the dry materials to be added with the water while the mixer is operating, which decreases mixing time and increases production. Portable revolving-drum concrete mixers are not recommended because they will not generally break up lumps. Production rates are generally lower for revolving-drum mixers because of difficulty in batching bagged material and because of buildup of materials in the drum.

Mixing of small quantities of plastic, flowable, or fluid grout in a bucket using a propeller-type mixer and drill motor is acceptable, provided the drill speed is slow enough to prevent entrapping air into the grout. Hand mixing does not provide sufficient energy to disperse constituents or to break up lumps, and should therefore be prohibited. Caution should be observed in using only portions of a package of preblended grout to be certain that all ingredients are represented properly in the portion taken.

Generally, preblended grouts are batched by placing the minimum amount of water in the mixer followed by the dry grout ingredients and then adding more water to achieve the desired consistency, unless otherwise recommended by the manufacturer. For field-proportioned grouts, the water should be placed in the mixer followed by the cement, additives, and aggregate, in that order.

For grouts at dry-pack consistency, mixing is best accomplished in a horizontal shaft mortar mixer. Hand mixing, however, may be used. For hand mixing, cement and aggregate should be blended before addition of water. Mixing should be performed on a watertight platform by repeatedly turning the mass over with a shovel and final mixing accomplished by rolling and rubbing the material between gloved hands.

7.3.1.3 *Mixing time*—The mixing time should be all the time necessary to provide uniform consistency and break up all the lumps. For preblended grouts, mixing time should comply with the manufacturer's recommendation. Grout should be placed as soon as possible after the completion of mixing. If the grout must be held in the mixer after the completion of the specified mixing time, the grout should be agitated at slow speed. No water should be added after the initial mixing is completed. The time that a batch can be held will be less at higher ambient temperature and may be brand specific.

7.3.2 *Epoxy grouts*—Epoxy grouts should be batched and mixed in accordance with manufacturer's recommendations. In general, the grout is mixed only long enough to insure that uniform consistency and complete aggregate wetting are achieved. The liquid components of epoxy grouts are normally mixed in a bucket using a wooden hand stirrer for 3 to 5 min. Some manufacturers recommend a slow-speed drill and an impeller mixer. The aggregate is usually mixed into the preblended epoxy mixture in a mortar box, mortar mixer, or revolving-drum mixer operated at low speed.

7.4—Placing

7.4.1 *Poured placements*—When grouts are to be placed from the perimeter of a machine base, the forms should be constructed, as discussed in Section 6.5.2, so that a pressure head can be developed in a headbox on one side of the plate. All placement should be made from one side of the plate. Placement should begin at one end of the plate and continue at that point until the grout rises above the bottom of the plate on the opposite side of the plate. Then, the placement point or portable headbox should be moved slowly along the side of the plate from one end to the other. The placement point should be moved at the same rate as the face of grout moves along the length of the plate on the opposite side. The continuous movement of a single face of grout prevents air entrapment. Grout should not be placed at various locations along one side because the movement of the grout cannot be monitored and air can easily be trapped between placing points. For the same reason, grout should not be poured toward the center from opposite ends.

To encourage flow of grout, steel packing straps can be inserted on placement side and moved slowly back and forth. Chains should not be used because they tend to entrap air bubbles. Some manufacturers of preblended grouts allow limited use of vibrators or plungers to assist grout flow. Machine base plates with stiffeners or other obstructions on the underside should be vented. Suggestions on venting are in Section 5.2. The grout should be worked toward the vent until grout reaches the vent. For thick placements, control of heat generation and shrinkage is critical and the manufacturer's recommendations for thick placements should be followed.

7.4.2 *Pumped placement*—When grout is to be placed through holes in the machine base, the forms should be constructed as recommended in Section 6.5.2. Pumping should begin at the grout inlet nearest one end of the plate. Grout should be pumped into that inlet until it flows up into an adjacent inlet and flows from the entire plate perimeter adjacent to the inlet. The pump line can then be moved to the adjacent inlet and pumping continued. The pump line should be moved to successive inlets until grouting is complete. Grout should not be pumped into more than one inlet simultaneously or before grout flow has reached an adjacent inlet because air may be trapped.

When a hose is to be used to pump grout under the plate, the hose should be inserted under the plate to the point farthest

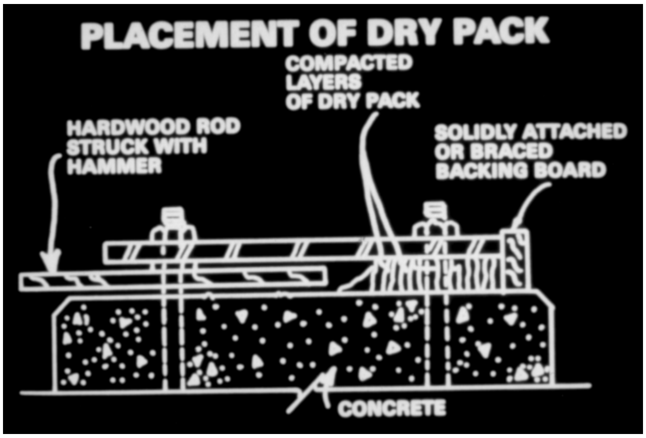

Fig. 7.1—Dry pack.

from the point of insertion. The hose should be withdrawn as grout is pumped under the plate. The hose outlet should remain embedded in the grout mass to prevent development of air pockets.

7.4.3 *Dry-pack placement*—Dry-pack placement and compaction should begin against a solid backing. The dry-pack grout should be placed in layers having a compacted thickness of approximately 1/2 in. (13 mm). Each layer of grout should be compacted over its entire surface with the square-cut end of a hardwood rod or board driven with a hammer. The striking force should be sufficient for compaction of the material without moving the plate out of alignment. The direction of tamping should be varied so that all dry-pack is compacted. The surface of each layer should be inspected visually by the installer prior to placement of the next layer to ensure that the entire surface has been compacted. Just prior to placement of the next layer, the compacted dry-pack layer should be rubbed with the end of the tamping rod to provide a slight roughness to aid bond to the next layers. See Fig. 7.1.

Proper water content has been achieved if the dry-pack does not slough and is not rubbery or crumbly. Batch size should be small enough to minimize the need for retempering.

7.5—Removal of excess material

No forms or grout (except spillage) should be removed from the formed shoulders until the grout has stiffened sufficiently to ensure that the grout will not sag below plate level when cut back at a slope of about 45 deg from the bottom of the plate. The sloped surface provides some later confinement for the grout under the plate and provides a more uniform dispersal of the compressive stresses near the plate edge, and can help conduct process fluids or lubricant leaking from the equipment away from the machine base.

Epoxy grouts are formed to the desired configuration and poured to the desired final elevation. Epoxy grouts are not generally cut back.

CHAPTER 8—CURING AND PROTECTION

8.1—Hydraulic cement grouts

8.1.1 *General*—After they have been placed, hydraulic-cement grouts should be protected from excessive moisture loss and from extremes in temperature. The following sections give recommendations for moisture retention and cold and hot weather protection. For preblended grouts, these recommendations should be used unless the grout manufacturer specifies otherwise.

8.1.2 *Moisture retention*—The exposed surfaces of newly placed grout must be protected from rapid moisture loss. Moisture loss can be prevented by keeping the exposed surfaces wet for a given period of time or by applying a curing compound.

Continuous moist curing for a few days after placement is generally preferred because the resulting grout surface will have higher strength and will be more durable. Moist curing is generally achieved by applying wet rags or burlap to the exposed surfaces. The wet rags or burlap can then be covered with plastic to prevent excessive evaporation. Soaker hoses are sometimes used.

When moist curing is used, the grout surfaces should generally be kept wet and saturated for at least 7 days before the surface is permitted to dry. A shorter period of moist curing is permissible if a curing compound is applied immediately after moist curing is suspended.

The main problem with the use of only moist curing is that it is impractical or difficult to enforce. Frequently, moist curing will be initiated correctly, but the grout surface may be permitted to dry prematurely because of weekends, shift changes, or other circumstances.

8.1.3 *Protection from temperature extremes*—After placement of a grout, the foundation and machine or equipment base should be kept at a temperature that is within the temperature range specified for placing of the fresh grout. The temperature should be maintained within this range until the grout reaches final set. After final set, the grout should be protected from cold or hot weather conditions until sufficient strength is achieved.

During cold weather, grout must be kept warm enough to allow hydration to occur at a significant rate and to prevent damage by freezing. The grout should be maintained about 50 F (10 C) for at least 3 days and protected from freezing for at least 3 additional days. During hot weather, grout should be kept cool enough to prevent excessive heat development. If the temperature of the grout is excessive at an early age, thermal shrinkage may occur when the grout cools to normal ambient temperatures. The ambient temperature of the air surrounding the foundation and machine base should be maintained below 100 F (38 C) for at least 3 days through the use of shade, wet burlap, soaker hoses, or other procedures.

8.2—Epoxy grouts

As the curing of epoxy grouts is generally not affected by exposure to air, the main consideration after placing is protection from temperature extremes. Temperature of the foundation and baseplates must also be considered. During hot weather, epoxy-grouted equipment or baseplates are usually shaded to provide uniform curing conditions.

The rate of polymerization of an epoxy is related to the temperature of the mixture. At temperature near 0 F (-18 C), the polymerization of many epoxies will nearly cease. As the temperature of the foundation and machine base increases, the temperature of the epoxy increases due to heat flow from the surrounding materials and also from a resultant acceleration in the exothermic polymerization reaction. Because most epoxies for grout are formulated to be placed at temperatures of less than 100 F (38 C), it is desirable to maintain the air temperature around the foundation at less than 100 F (38 C). At higher installation temperatures, the polymerization produces higher curing temperatures, which will increase the thermal stress when the grout cools.

CHAPTER 9—CONSTRUCTION ENGINEERING AND TESTING

9.1—General

Continuous construction engineering is required to provide quality assurance and guide contractor quality control. Quality control should be performed on a regular basis to ensure that:

1. The preblended cement or epoxy grout has not exceeded its shelf life.

2. The foundation has been properly prepared, cleaned, and saturated for hydraulic cement grouts, or kept dry for epoxy grout and protected from contamination.

3. The formwork is tight and has adequate stiffness.

4. The required tests listed in Sections 9.2 and 9.3 are performed at the specified frequency.

5. The correct placing methods are used.

6. Curing is initiated at the correct time and maintained for the correct time period at the proper temperature.

7. Shims, wedges, or other leveling devices are removed, if required, and any necessary repairs are made.

8. Temperature of the baseplate and air are within specification limits.

The following sections give recommendations for sampling and testing of hydraulic cement grouts and epoxy grouts.

9.2—Hydraulic cement grouts

Hydraulic cement grouts with plastic, flowable, or fluid consistency should be sampled in the field and tested for volume change, bleeding, and compressive strength. Grouts with dry-pack consistency should be tested for compressive strength.

The frequency of sampling should be based on the volume of grout placed or on the total baseplate area grouted in a specified time period. For preblended grouts, sampling on the basis of volume is more appropriate. Generally, a sample should be taken at least every other day. Samples of grout and dry-pack should be taken and test specimens made at the installation site.

If cores of hardened in-place grout are taken for the purpose of determining strength, the user should specify that strength be determined on specimens whose length is equal to their diameter.

This allows the test to approximate the cube strength test, which is usually specified for the original qualification of the grout. If test samples can not be obtained that meet the length-to-diameter criteria, the comparison to cube strength may not be valid. It should be borne in mind that grout is loaded along the short dimension of its position in place, rather than in the long dimension as for concrete in columns, beams, and slabs.

Dry-packing operations require nearly constant inspection to ensure that the proper layer thickness and compactive effort are being used. A worker can easily increase his production by using large layer thicknesses. If possible, an occasional dry-pack installation should be dismantled to check for areas of insufficient compaction.

9.3—Epoxy grouts

After initial qualification, epoxy grouts should be sampled in the field and tested for compressive strength. The frequency of sampling should be based on the volume of grout placed. At least one sample should be taken from each shipment or production lot. A simple field check procedure for assuring the correct proportions of hardener and resin is to make a small test cookie and cure in a toaster oven at elevated temperature.

9.4—Documentation

Documentation must be maintained for all job site inspection and testing. This documentation should include the location of the installation, the type and brand of grout used, the environmental conditions at the time of grout placement, and the results of all physical tests (for example, volume change, bleeding, and strength).

CHAPTER 10—REFERENCES

10.1—Recommended references

The documents of the various standards-producing organizations referred to in this document are listed with their serial designations. The documents listed were the latest revisions at the time this document was written. Because some of these documents are revised frequently, generally in minor detail only, the user of this document should check directly with the sponsoring group if it is desired to refer to the latest revision.

These publications may be obtained from the following organizations:

ACI

116R Cement and Concrete Terminology

117 Standard Specification for Tolerances for Concrete Construction and Materials

318/318R Building Code Requirements for Structural Concrete

ASTM

C 33 Specification for Concrete Aggregates

C 109 Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in or 50-mm Cube Specimens)

C 143 Test Method for Slump of Portland Cement Sources

C 144 Specification for Aggregate for Masonry Mortar

C 150 Specification for Portland Cement

C 157 Test Method for Length Change of Hardened Cement Mortar and Concrete

C 191 Test Method for Time of Setting of Hydraulic Cement by Vicat Needle

C 230 Specification for Flow Table for Use in Tests of Hydraulic Cement

C 266 Test Method for Time of Setting of Hydraulic Cement Pastes by Gillmore Needles
C 305 Practice for Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency
C 403 Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance
C 404 Specification for Aggregates for Masonry Grout
C 579 Test Methods for Compressive Strength of Chemical-Resistant Mortars and Monolithic Surfaces
C 580 Test Method for Flexural Strength and Modulus of Elasticity of Chemical-Resistant Mortars, Grouts and Monolithic Surfacing
C 806 Test Method for Restrained Expansion of Expansive Cement Mortar
C 807 Test Method for Time of Setting of Hydraulic Cement Mortar by Modified Vicat Needle
C 827 Test Method for Change in Height at Early Ages of Cylindrical Specimens from Cementitious Mixtures
C 845 Specification for Expansive Hydraulic Cement
C 939 Test Method for Flow of Grout for Preplaced-Aggregate Concrete (Flow cone method)
C 940 Test Method for Expansion and Bleeding of Freshly Mixed Grouts for Preplaced-Aggregate Concrete in the Laboratory
C 953 Test Method for Time of Setting of Grouts for Preplaced Aggregate Concrete in the Laboratory
C 1090 Test Method for Measuring Changes in Height of Cylindrical Specimens from Hydraulic Cement Grout
C 1107 Specification for Packaged Dry, Hydraulic Cement Grout (Nonshrink)
C 1157 Performance Specification for Blended Hydraulic Cement
C 1181 Test Methods for Compressive Creep of Chemical-Resistant Polymer Machinery Grouts
C 1339 Standard Test Method for Flowability and Bearing Area (Concrete Manual Catalogue Number 1 27.19/2: C 74/974)

These publications may be obtained from the following organizations:

American Concrete Institute
P. O. Box 9094
Farmington Hills, MI 48333-9094

ASTM
100 Barr Harbor Drive
West Conshohocken, PA 19428

Bureau of Reclamation
U.S. Department of the Interior
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