# Cementitious Grouts and Grouting

by Steven H. Kosmatka

Cementitious grout is a versatile construction material used in many applications. This engineering bulletin provides a brief description of the ingredients, properties, proportions, tests, mixing, and placing of cementitious grout for various applications. Over 50 tables and figures illustrate particular items of interest. The text is not intended as a complete discussion of the subject but rather a concise review of grout and its applications. Readers are encouraged to consult the references for more-detailed information.

Specific subjects on grout can be located in the text through use of the extensive table of contents and index. The Appendix contains commonly referenced standards by ASTM and the U.S. Army Corps of Engineers. A table of metric conversion factors is also included in the Appendix.

The author wishes to acknowledge contributions made by many individuals and organizations who provided valuable assistance in the writing and publishing of this bulletin. A special thanks to William C. Panarese, Manager of Construction Information Services for PCA, for his review of the manuscript; Wayne Adaska at PCA for reviewing sections on slurry-trench walls, soil grouting, and rock grouting; Robert Packard at PCA for reviewing sections on slabjacking and undersealing; Richard Helmuth at Construction Technology Laboratories, Inc., for reviewing grout properties; William Babcock of Five Star Products, Inc., for reviewing sections pertaining to nonshrink grout; Arden Orr for her editorial work; Richard C. Wagner of Wagner Design Services for his layout design and production; and the staff of PCA and Construction Technology Laboratories, Inc., for technical information, reference materials, drafting, and coordination of production activities.

The author has tried to make this a concise and current reference on cementitious grout technology. As there is always room for improvement and new grouting techniques and applications are constantly developing, readers are encouraged to submit comments to improve future printings and editions of this book.

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*Caution:* Avoid prolonged contact between unhardened (wet) cement or grout mixtures and skin surfaces. To prevent such contact, it is advisable to wear protective clothing. Skin areas that have been exposed to wet cement or grout, either directly or through saturated clothing, should be thoroughly washed with water.

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# Cementitious Grouts and Grouting

Grout is a valuable and versatile construction material, as illustrated by the number of grout applications in Table 1. Unfortunately, standard guidelines for its properties and potential uses are limited or are often difficult to obtain. This publication will briefly review grout—what it is, its properties, and its use in construction.

Cementitious grout is a mixture of hydraulic cement* and water with or without aggregates and with or without admixtures. Depending on the application, it is usually proportioned to produce a pourable consistency, like very wet mortar or soupy high-slump concrete, without segregation of the constituents. Stiff grouts, however, are used for some applications. Making a distinction between grout, mortar, and concrete is sometimes difficult due to the like ingredients and properties. This similarity results in an occasional interchange of terms.

**Table 1. Cementitious Grout Applications**

| |
|---|
| Anchor bolts |
| Ballast grouting |
| Bonding grout |
| Ceramic tile |
| Column baseplates |
| Dam foundations |
| Demolition |
| Flowable fill |
| Foundation grouting (stabilization) |
| Foundation jacking (lifting) |
| Ground anchors |
| Groundwater control |
| Grout cleandown |
| Joints between precast units |
| Machine bases |
| Masonry walls |
| Oil Wells |
| Postplaced-aggregate concrete |
| Post-tensioning ducts |
| Preplaced-aggregate concrete |
| Railroad track stabilization |
| Reinforced masonry walls |
| Repair |
| Rock grouting |
| Slabjacking |
| Slurry-trench cutoff walls |
| Soil grouting |
| Stone-masonry restoration |
| Structural repairs |
| Subsealing (undersealing) |
| Toppings |
| Tunnels |
| Underlayments |
| Waterproofing of inground structures |

## GROUT INGREDIENTS

Grout can be made from many different materials proportioned in a wide range of amounts depending on the grouting application. For example, neat cement grout contains hydraulic cement and water with or without admixtures. Sand or sanded grout refers to any grout containing fine aggregate. Grout can also be made of other ingredients, resinous grouts for example.** The more common materials used in cementitious grout are listed in the following sections along with their respective American Society for Testing and Materials (ASTM) or other standard designation. Materials applicable to specific grouting techniques will be presented later.†

### Cementitious Materials

The cementitious materials used in grout include one or a combination of the following: portland cement (ASTM C150), blended hydraulic cement (ASTM C595), expansive hydraulic cement (ASTM C845), ground slag (ASTM C989), or oil-well cement (American Petroleum Institute Specification 10). Type I (ASTM C150) normal portland cement would be used unless special considerations are involved. For example, for moderate or severe sulfate resistance, ASTM C150 portland cement Type II or V, respectively, would be used (see Table 2). When sulfate-resistant cement is not available, see Reference 72 for alternatives. If high-early strength or small particle size are required, ASTM C150 Type III cement would be applicable. Cement

*Hydraulic cements react with water to form a hardened paste that maintains strength and durability in water and also maintains its properties upon drying.

**Soil grouts (i.e., bentonite, silt), bituminous grouts (asphalt emulsions), and chemical grouts, (i.e., epoxy, polyester, sodium silicate, acrylate polymer, calcium chloride, aluminate, and others) are not the subject of this publication.

†ASTM and U.S. Army Corps of Engineers standards related to grout or referred to in the text are listed on pages 55 and 56. Refer to References 59 and 66 for more extensive information on cements, aggregates, water, and admixtures.

**Table 2. Types of Cement for Grout Exposed to Sulfate Attack**

| Sulfate exposure | Water-soluble sulfate ($SO_4$) in soil, percent by weight | Sulfate ($SO_4$) in water, ppm | Cement type (ASTM C 150 or C 595) |
|---|---|---|---|
| Negligible | 0.00–0.10 | 0–150 | No restrictions |
| Moderate* | 0.10–0.20 | 150–1500 | II, IP(MS), IS(MS), P(MS), I(PM)(MS), I(SM)(MS) |
| Severe | 0.20–2.00 | 1500–10,000 | V |
| Very severe | Over 2.00 | Over 10,000 | V plus pozzolan** |

*Seawater.

**Pozzolan that has been determined by test or service record to improve sulfate resistance when used in grout containing Type V cement.

Adapted from References 30 and 72.

with low-alkaki content (to resist alkali-aggregate reactivity) and low heat of hydration options can be specified. Blended hydraulic cements can be used to meet normal or special needs. Expansive grout can be made with expansive cement (ASTM C 845) or expansive admixtures. Ultrafine (microfine) cement is portland cement or blast-furnace slag ground very fine (less than about 10 microns) for use in permeating into fine soil or thin rock fissures. The fineness of cementitious and other fine materials can be analyzed by ASTM C 430 and C 786 or with a commercial particle size distribution analyzer.

Oil-well cements, used for sealing oil wells, are usually made from portland cement clinker or from blended hydraulic cements. Generally they must be slow-setting and resistant to high temperatures and pressures. The American Petroleum Institute Specifications for Materials and Testing for Well Cements (API Specification 10) includes requirements for nine classes of well cements (classes A through H and J). Each class is applicable for use at a certain range of well depths, temperatures, pressures, and sulfate environments. The petroleum industry also uses conventional portland cements with suitable cement-modifying admixtures. Expansive cements have also performed adequately as well cements.

## Water

Almost any natural water that is drinkable and has no pronounced taste or odor can be used as mixing water for making grout. Water of questionable suitability can be used for making grout if the requirements in Table 3 are met. Excessive impurities in the mixing water not only may affect setting time and strength, but also may cause efflorescence, staining, corrosion of reinforcement, volume instability, and reduced durability. When grouting around high-strength steel (more than 80 ksi) or dissimilar metals, the maximum chloride- and sulfide-ion content of the water should be limited to about 100 ppm and 10 ppm, respectively. Additional information on the effects various impurities in mix water have on cementitious materials is in References 11 and 66.

**Table 3. Acceptance Criteria for Questionable Water Supplies**

| | Limits | Test method |
|---|---|---|
| Compressive strength, minimum percentage of control at 7 days | 90 | ASTM C 109* |
| Time of set, deviation from control in hr:min | from 1:00 earlier to 1:30 later | ASTM C 191* |

*Comparisons should be based on fixed proportions and the same volume of test water compared to control mix using city water or distilled water.

## Aggregates

Aggregates, when used, are added essentially as a filler and to improve particular properties. Both fine and coarse aggregates can be used. Depending on the application, aggregate meeting ASTM C 33, ASTM C 404 (for masonry grout), ASTM C 144, or other specification can be used. The aggregate essentially should be free of harmful amounts of organics, be nonstaining, be sound, and have an appropriate grading for the application.

## Mineral Admixtures and Fillers

Finely divided mineral admixtures are sometimes used to improve certain properties such as flowability, to aid or supply additional cementitious reactions, or to act as fillers. Impermeability and resistance to sulfate attack, alkali-aggregate reactivity, and bleeding can be improved with certain mineral admixtures. Mineral admixtures include ground granulated blast-furnace slag (ASTM C 989), natural pozzolans and fly ash (ASTM C 618), silica fume, and ground stone. Certain types of clays are useful in geotechnical grouting applications to reduce bleeding, improve pumpability and injectivity, and act as a filler. Bentonite, for example, is mainly used for its gel-swelling properties. Hydrated lime (ASTM C 207) is used for masonry grout.

## Chemical Admixtures

Accelerating (ASTM C 494), air-entraining (ASTM C 260), retarding (ASTM C 494), water-reducing (ASTM C 494), and superplasticizing (ASTM C 1017) admixtures can be used to alter the properties of grout where permitted. Gas-forming admixtures, aluminum powder, and other materials can be used to cause expansion. Foaming admixtures (ASTM C 869) develop lightweight grouts of high fluidity. Pigments (ASTM C 979) can be used to color grout for architectural appearance or hazard warning. Red grout to embed utility lines or pipelines can signify their presence and give warning of a potential hazard if penetrated. Superplasticizers can greatly increase the fluidity of a grout without increasing water content. Water-retentive admixtures (gelling agents) are used to make thixotropic grouts* to suspend cement particles and reduce bleed-

*Thixotropic materials, like mayonnaise, are low-viscosity, thin liquids during agitation, but when agitation stops, they form stiff, high-viscosity liquids (gels) or even solids.

ing. Grout fluidifiers meeting ASTM C 937 and Corps of Engineers CRD-C619 specifications should help control stiffening, hold fine particles in suspension, induce controlled expansion, reduce mixing water, improve water retention, and reduce bleeding of grout.

## GROUT PROPERTIES

The required properties of grout, such as strength and consistency, and the proportions of grout ingredients depend on the grouting application. The proportions of ingredients and choice of ingredients must be determined in the laboratory to obtain certain properties such as expansion, strength, and fluidity, unless established proportions are used, such as for masonry grout (ASTM C 476). Field testing is performed as specified. Field sampling can be done according to Corps of Engineers standard CRD-C620, ASTM C 1019, or other applicable specification. The following discussion is general in nature. For more specific information refer to the applicable grout application later in the text or see References 59 and 66.

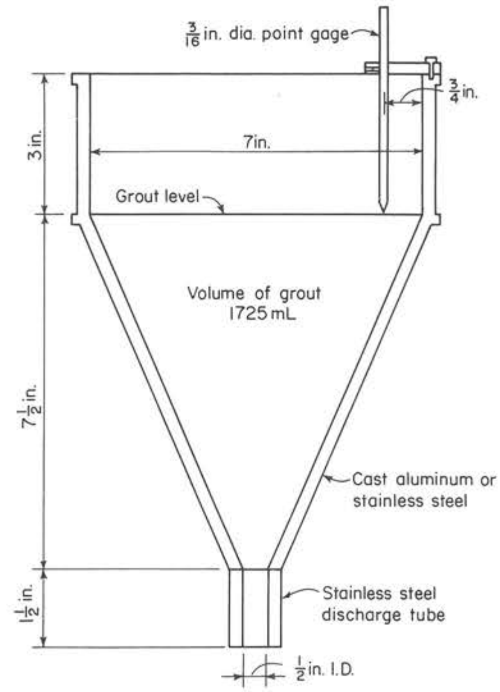
### Consistency

Consistency refers to the ability of grout to flow. The consistency of fresh grout varies with application. Grout can range in consistency from a near-water or very-thin-paint consistency to an almost thick, stiff mortar or thixotropic* consistency, depending on the application and desired workability.

Consistency is especially important with respect to bond strength. Fluid grouts have better bond than stiff dry grouts. Grouts for self-leveling applications or filling voids without vibration must be very fluid.

Consistency can be measured with various techniques, such as the flow cone or flow table. The flow cone, ASTM C 939 and Corps of Engineers CRD-C611, measures consistency by monitoring the time for a specific amount of grout to run out of the cone (Fig. 1). This time period is called the efflux time. The flow cone is used for thin fluid grout with an efflux time of 35 seconds or less. Fluid grouts are considered to have an efflux time of 10 to 30 seconds—they form a near-level surface without vibration or rodding. Water has an efflux time of 8 seconds.

The flow table, ASTM C 230, is used for thick grouts (Fig. 2). The test measures the spread of grout after the table is dropped a specified number of times within a certain time period. The flow-table test for grout per ASTM C 827 uses 5 drops in 3 seconds with the ASTM C 230 flow table. Using the ASTM C 827 consistency test (flow table), grout consistency can be defined as follows: (1) a stiff plastic grout has a flow of less than 100%, (2) plastic grout has a flow between 100% and 125%, and (3) a flowable grout has a flow between 125% and 145%. Plastic grout levels off only after vibration or rodding while a flowable grout levels off with light vibration or rodding.




(a)

(b)

**Fig. 1. (a) Cross section of flow cone for measuring consistency meeting ASTM C 939 and Corps of Engineers CRD-C611. (b) Grout discharge and timing to determine efflux time or time of flow (time it takes the grout to discharge from the cone).**

*Thixotropic materials, like mayonnaise, are low-viscosity, thin liquids during agitation, but when agitation stops, they form stiff, high-viscosity liquids (gels) or even solids.

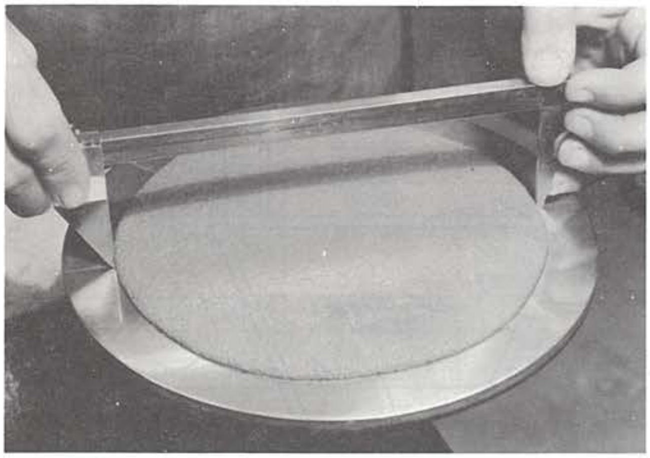


**Fig. 2. Flow table for measuring consistency (ASTM C 109, C 230, and C 827).**

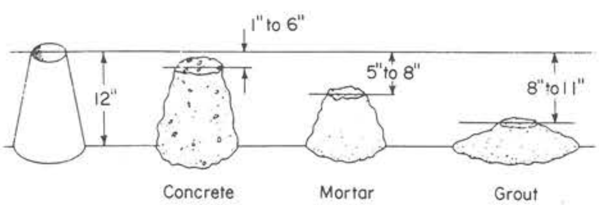



**Fig. 3. Slump test comparison of concrete, mortar, and masonry grout.**

A modified flow cone, flow table, or other test should be used for thixotropic grouts and grouts with a flow-cone efflux time of more than 35 seconds. A 12-in. ASTM C 143 slump cone and sometimes a 6-in. cone are also used in the field to control the consistency of plastic and flowable grout. Fig. 3 illustrates the difference in consistency for concrete, mortar, and masonry grout as measured by the slump test (ASTM C 143). Additional consistency tests are the Brookfield viscometer (ASTM D 4016) and the Marsh funnel (Reference 80).

Admixtures can be used to increase fluidity without increasing water content. The stiffest consistency that can be applied should be used to avoid the negative aspects of high water contents often used to make thin grout.

## Workability and Working Time

Workability is the ease with which a grout can be placed, handled, and consolidated without segregation or excessive bleeding. Without good workability, a grout can be difficult to handle and result in a poor-quality product. The amount of time a grout remains workable is called the working time or pot life, which varies with grout types and needs. The working time of a grout should be known before it is used on a project. Proprietary grout manufacturers should provide working times for their products. Working time should be of a sufficient period to allow for transport, handling, and placing of grout at a comfortable pace. Retempering—adding water and remixing the grout to regain desired consistency or workability—should be avoided to maintain the strength, durability, and other properties of the grout. Grout that becomes unworkable should be discarded and replaced with new grout. Working time can be tested by running consistency tests over time.

## Bleeding, Settlement, and Water Retention

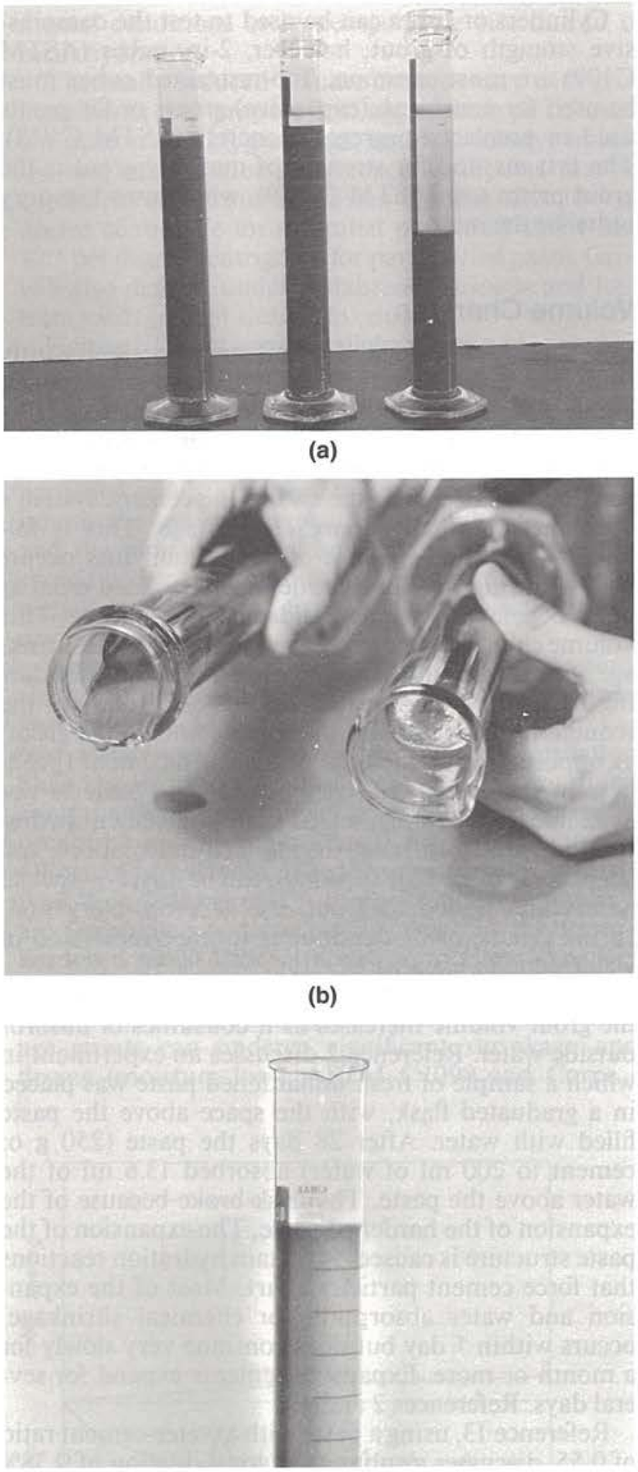
Bleeding may be described as the development of a layer of water at the top of freshly placed grout caused by sedimentation (settlement) of solid particles (cement and any aggregate) and the simultaneous upward migration of water. Excessive bleeding can result in a surface with a high water-cement ratio causing poor durability and reduced strength; even a water pocket or void can develop (Fig. 4). After evaporation of bleed water, the hardened surface will be lower than the freshly placed surface. This reduction in volume or vertical dimension from time of placement to initial set is often called settlement shrinkage.

The bleeding rate and bleeding capacity (total settlement per unit of original paste or mortar height) increases with initial water content, grout height, and pressure (see Fig. 5). The water-retention property—ability of grout to keep water in the grout and cement particles in suspension—signficantly affects bleeding. High water-retentivity grouts, such as thixotropic grouts, allow little or no bleeding (Fig. 4). Use of water-retention or gelling agents, certain general chemical admixtures, air entrainment, silica fume and other mineral admixtures, clays, and finer cements can also reduce bleeding. Grouts used to fill voids, provide support, or provide watertightness by intimate contact should have low-bleeding properties to avoid development of water pockets between the grout surface and the item grouted.

Bleeding can be tested according to ASTM C 232, C 243, and C 940, or by tests described in Reference 48. Pressurized bleeding tests are described in References 21 and 34. Water retentivity can be tested according to ASTM C 941 or Corps of Engineers CRD-C612. Also see References 3, 6, and 62.

## Setting and Hardening

The setting, hardening, strength development, and other properties of grout are due to a chemical reaction called hydration that occurs between cement and water in the cement paste. Each hydrating cement particle forms a type of fiberlike growth on its surface that gradually spreads until it links up with the growth from other cement particles or adheres to adjacent substances such as aggregate. The formation of this growth structure (primarily calcium silicate hydrate) is responsible for the paste's binding or cementing action. Without water, hydration stops, thereby terminating any further strength gain. Therefore it is important to retain moisture in the grout until the desired strength has been achieved. Generally, this is not a problem for many grouting applications, as grout is often placed in locations where the water in the grout cannot readily escape. After sufficient hydration, the paste, along with



(a)

(b)

(c)

**Fig. 4. (a) Illustration of settlement of cement particles (bleeding) in grouts with water-cement ratios by weight of 0.3:1, 0.7:1, and 2:1 (left to right). All cylinders contain 250 ml of grout and were photographed 1 hour after the grout was mixed and placed in the cylinders. Note the accumulation of bleed water for grouts with the higher water-cement ratios. (b) The consistency of thixotropic grout (right) prevents the grout from flowing from the cylinder after agitation is stopped. (c) Thixotropic grout has little to no bleeding or settlement of cement. This low water-cement ratio thixotropic grout was undisturbed in a 250 ml graduated cylinder for 2 hours.**

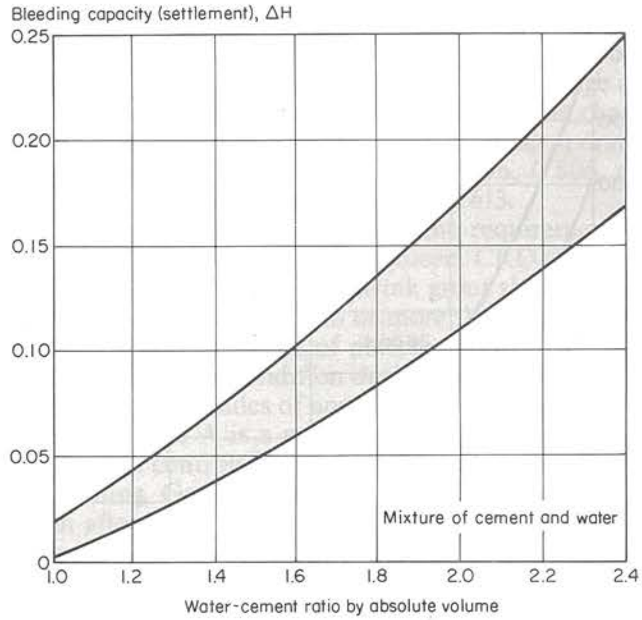



**Fig. 5. Range in relationship between bleeding capacity (total settlement per unit of original grout height) and water content of grouts made with normal portland cement and water. To convert water-cement ratio by absolute volume to water-cement ratio by weight, multiply by 0.3175. Reference 6.**

any encapsulated aggregate, forms a hardened grout of stonelike appearance and properties. Once hydration is deemed sufficient to accomplish the desired properties, curing can be terminated; any remaining water in the grout will evaporate from the microscopic pores and capillaries within the paste. The time of set can be tested according to Corps of Engineers CRD-C614 or applicable ASTM standards C 191, C 266, C 403, C 807, or C 953. Also see the section "Strength" following.

## Strength

The compressive, flexural, and tensile strength required of a grout depends upon the grouting application, whereas the strength actually achieved by the grout is a direct result of the amount of cementitious materials and water in the grout as well as degree of hydration. The strength of grout is directly related to the water-cement ratio. As the water-cement ratio is reduced, the strength increases (Fig. 6). Also as long as sufficient moisture (relative humidity greater than 80% in the grout), unhydrated cement, and void space are present in the grout, the strength will increase, as illustrated in Fig. 7.

An excess of water causes not only low strength but also excess bleeding, increased shrinkage, and reduced durability. The time of set is reduced and strength development increased with reduced water-cement ratios and higher temperatures. Bond strength is more dependent on consistency than the amount of water in grout; a wetter grout bonds better than a very dry grout. See Reference 66 for hot- and cold-weather precautions.

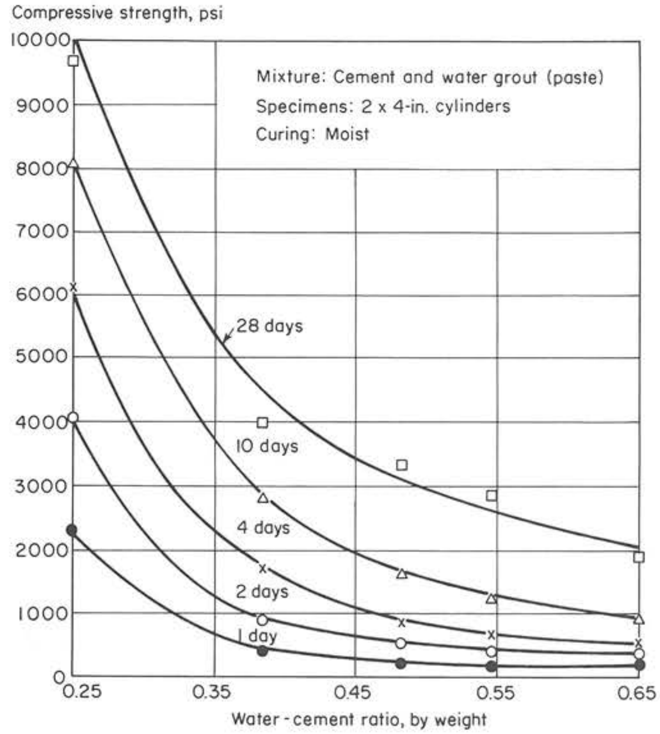



**Fig. 6. Relationship between water-cement ratio and compressive strength for grout. Reference 1.**

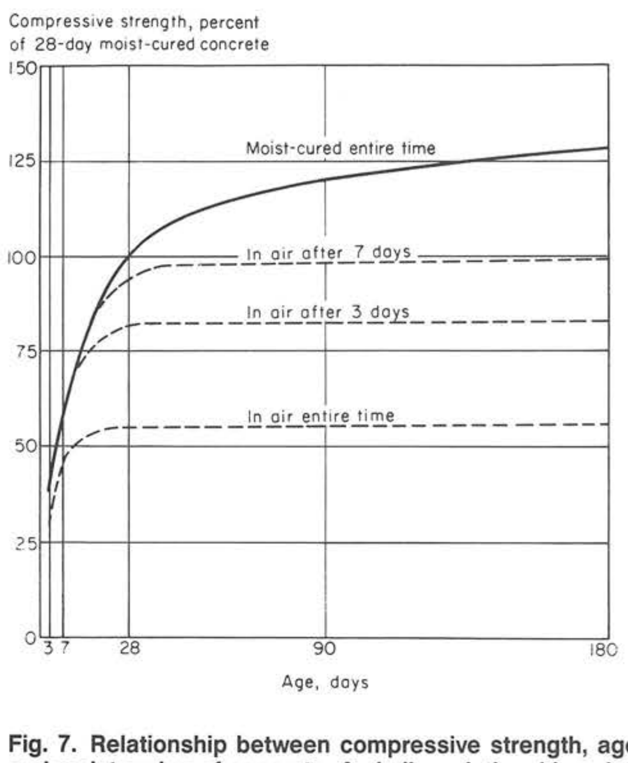



**Fig. 7. Relationship between compressive strength, age, and moist curing of concrete. A similar relationship exists for grout. Strength increases with age as long as moisture and a favorable temperature are present for hydration of the cement. Adapted from Reference 30, Fig. 9.**

Cylinders or cubes can be used to test the compressive strength of grout; however, 2-in. cubes (ASTM C 109) are most common. Top-restrained cubes must be used for nonshrink (expansive) grouts or for grouts used in preplaced aggregate concrete (ASTM C 942). The test method for strength of masonry grout is the grout prism test (ASTM C 1019), which uses masonry units for the mold.

## Volume Changes

The volume of hardened grout can vary significantly from the original volume of the fresh unhardened grout. The shrinkage of unhardened grout by settlement or bleeding was discussed earlier. A cement and water paste first undergoes a very slight transient expansion that occurs at the end of the cement system's dormant (nominally nonreactive) stage. This is followed by a small amount of contraction that occurs before, during, and after hardening in isolated grout as normal cement hydrates and consumes water. This volume change has been referred to as chemical shrinkage, autogenous shrinkage, or absorption of water during hardening. Chemical shrinkage also refers to the reduction of cement and water (reactants in the grout) as opposed to the increase of hydrated cement (products in the grout). If water outside the paste is not available (for example, sealed samples), cement hydration will cause internal drying (self-desiccation) and slight shrinkage. This shrinkage can be offset by special admixtures added to grout, use of proprietary nonshrink grouts, or by continuous future submersion in water, causing expansion.

When the grout is kept saturated (exposed to water) the grout volume increases as it consumes or absorbs outside water. Reference 2 discusses an experiment in which a sample of fresh unhardened paste was placed in a graduated flask, with the space above the paste filled with water. After 28 days the paste (250 g of cement to 200 ml of water) absorbed 13.6 ml of the water above the paste. The flask broke because of the expansion of the hardened paste. The expansion of the paste structure is caused by certain hydration reactions that force cement particles apart. Most of the expansion and water absorption (or chemical shrinkage) occurs within 1 day but does continue very slowly for a month or more. Expansive cements expand for several days. References 2 and 49.

Reference 13, using a paste with a water-cement ratio of 0.55, discusses a submerged grout dilation of 0.38% after 23½ hours. Bleeding stopped at 1 hour 12 minutes and expansion started at 1 hour 30 minutes. The dilation of different cements was reported to range from 0.09% to 2.1% at a water-cement ratio of 0.55.

Hardened grout changes volume slightly with changes in temperature, moisture content, and load. Chemical effects such as carbonation cause shrinkage, and sulfate attack and alkali-aggregate reactivity cause expansion. Hardened grout expands slightly as temperature rises and contracts as temperature falls, although it can expand slightly as any free water present in the grout freezes. Temperature changes are caused by environmental conditions or by temperature rise due to cement hydration.

Thermally induced volume changes vary with grout ingredients and proportions, aggregate type (if used), temperature range, grout age, ambient relative humidity, and other factors. Reference 14 reports that the coefficient of thermal expansion is about $12 \times 10^{-6}$ per degree centigrade for saturated paste and about $25 \times 10^{-6}$ per degree centrigrade for partly dried paste. Grout will also deform under instantaneous loads and long-term loads (creep) similar to concrete.

Hardened grout expands slightly with a gain in moisture and contracts with a loss in moisture as illustrated in Fig. 8. The amount of moisture-related shrinkage of grout is directly related to the fresh grout's water content and the amount of water that is lost from the hardened grout. Therefore to keep shrinkage to a minimum, the water content of fresh, unhardened grout and the moisture loss from recently hardened grout should be kept to a minimum. This volume reduction caused by water loss from hardened grout is called drying shrinkage.

Aggregate, if present, helps restrain or resist volume change of the paste; therefore the amount and size of aggregate should be maximized to reduce shrinkage (see References 10 and 66 for more information). Shrinkage is not normally a problem when grouting in continuously moist or wet environments. There are occasions in which grout used for waterproofing or filling voids may need to be the nonshrink or expansive type. Nonshrink grouts (usually proprietary products) are formulated to have no shrinkage in the fresh or hardened moist state, although some slight expansion is usually expected. Ideally, nonshrink grouts should have no drying shrinkage; however, some nonshrinkage grouts can undergo significant shrinkage upon drying (moisture loss). ASTM C 1090 and Corps of Engineers CRD-C621 are used to test for hardened volume change of moist specimens. ASTM C 827 can be used to test early (unhardened) volume change and can be extended to analyze hardened volume change with grout in both an evaporative or nonevaporative condition. Also see ASTM C 157, C 596, C 806, and C 940 and Corps of Engineers CRD-C613.

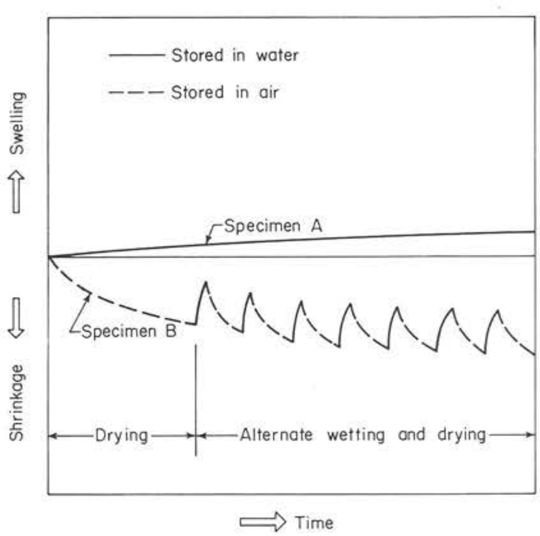



**Fig. 8. Schematic illustration of moisture movements in hardened grout. If grout is kept continuously wet, a slight expansion occurs. However, if drying occurs, the grout shrinks. Further wetting and drying causes alternate swelling and shrinkage. References 10 and 66.**

Nonshrink grout should meet the requirements of ASTM C 1107 or Corps of Engineers CRD-C621. According to CRD-C621, nonshrink grout should have a volume at 28 days equal to or more than (up to 0.4%) the volume at the time of placement (grout is maintained in a moist condition during test). ASTM C 1107 specifies three grades of nonshrink grout, Grades A, B, and C. Grade A is a prehardening, volume-adjusting grout that controls grout volume by expansion before hardening. Grade B grout controls volume by expansion after hardening. Grade C grout uses a combination of prehardening and posthardening volume control. ASTM C 1107 has limits on early-age height change and 28-day moist-cured hardened-grout height change. After the moist cure test, ASTM C 1107 specimens are exposed to air for 28 days and tested for drying shrinkage. See "Grouting Column Baseplates, Machine Bases, Anchors, and Precast-Panel Joints" for more information on nonshrink grout.

## Temperature Rise

Temperature rise can be a problem where thermal cracking of mass grouting is of concern. The amount of heat generated in a cementitious grout depends upon the fineness, amount, and type of cementitious material, the placing temperature, available heat loss, and volume or thickness of grout. When thermal cracking is a concern, the grout should be kept as cool as possible, and a low cement content and low-heat-of-hydration cement should be used. Low-heat-of-hydration pozzolans are also very helpful for mass grouting or pours where temperature rise must be kept to a minimum.

## Durability

Durability refers to the ability of hardened grout to withstand deterioration in its service environment. Grout that is to be exposed to sulfate soils or waters should use sulfate-resistant cements as recommended in Table 2 and use a high cement content (low water-cement ratio). If alkali-aggregate reactivity is a potential problem, low-alkali cement should be used and pozzolans that reduce alkali-silica reactivity should be considered. Air entrainment should be used for freeze-thaw environments. Freeze-thaw resistance can be tested by ASTM C 666. Resistance to deicers can be tested by ASTM C 672.

Grout should be stable after hardening. Some grouts contain materials that may allow the grout to expand significantly after hardening. These should be avoided in certain environments as excessive expansion may occur, resulting in cracking and disintegration of the grout.

## Permeability

The permeability of hardened grout is reduced as the amount of hydrated cementitious material increases, moist curing continues, and the water-cement ratio decreases (see Fig. 9).

As ingredient proportions and required grout properties depend on the grouting application, refer to the grouting applications sections of this publication for more information.

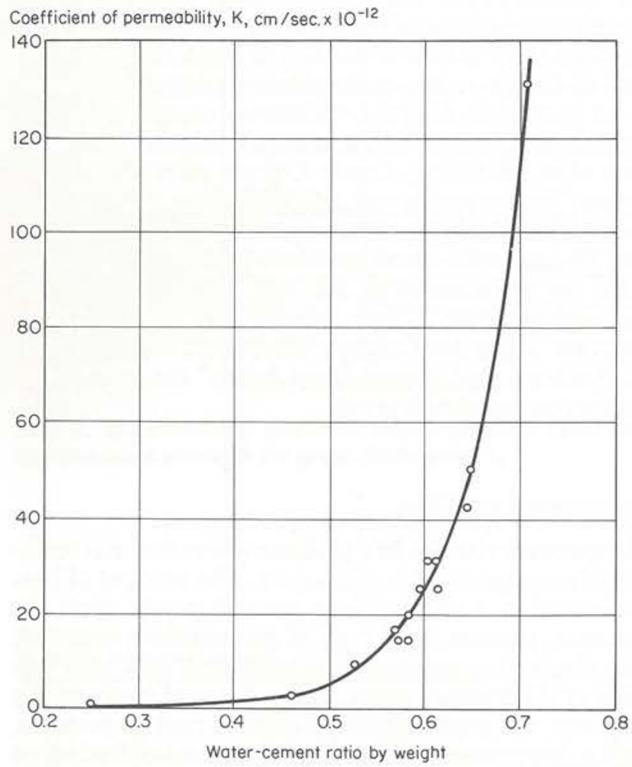



**Fig. 9. Relationship between water-cement ratio and permeability of neat cement grout. A low water-cement ratio results in low permeability. Reference 9.**

## MIXING AND PLACING GROUT

### Measuring Grout Materials

Measurement of grout ingredients should be completed in a manner that will ensure the uniformity of mix proportions, yield, and workability from batch to batch. Material quantities are usually expressed by weight or by loose (bulk) volume. For granular materials, loose or bulk volume includes the volume the particle mass occupies plus the air space between particles. Absolute volume is the volume occupied only by particle mass.

Experience has shown that the amount of sand can vary considerably due to moisture bulking when proportioning by bulk volume. Fig. 10 shows how loose sand with varying amounts of moisture occupies different volumes. Loose, damp sand may consist of from

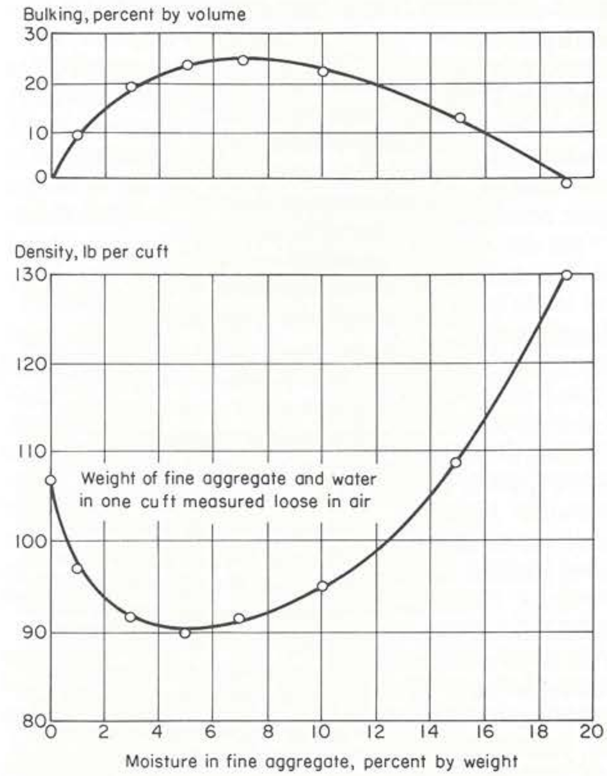



**Fig. 10. Relationship between bulk weight per cubic foot, volume increase, and moisture content for a particular sand. Reference: PCA Major Series 172.**

75 to 110 pcf of sand itself, plus the weight of the water. For rough computations, a cubic foot of loose, damp sand is estimated to contain 80 lb of dry sand.

Ordinary sand will absorb water amounting to 0.2% to 2.3% of the weight of the sand. In the field, damp sand usually will have 3% to 8% moisture, so most of the water is on the surface of the sand. Measuring aggregate by weight and adjusting for moisture content (as is done for ready mixed grout) is the most accurate method of measuring grout ingredients.

Grout ingredients other than sand are often sold in bags labeled only by weight. Since grout is sometimes proportioned by loose volume, it is necessary to know that one bag of portland cement has a powdered volume of 1 cu ft and a weight of 94 pcf, masonry cement weighs about 70 pcf, hydrated lime weighs 40 pcf dry, and hydrated lime putty weighs 80 pcf, water weighs 62.4 pcf, one gallon of water weighs 8.34 lb and has a volume of 0.134 cu ft, and 1 cu ft of water is 7.48 U.S. gallons. Aggregate bulk density can vary from 75 to 110 pcf for normal-weight aggregate.

Volume proportions are significantly different than weight proportions. For example, a 1:4¼:1 (1 cu ft or bag of cement:4¼ cu ft of aggregate:1 cu ft of water) mix by volume would have weight proportions of 1:4¾:⅔ (94 lb of cement:446 lb of aggregate:62 lb of water), assuming the unit weight of the aggregate was 105 pcf. Absolute volume computations are given in Reference 66 and Table 4 provides quick conversion

**Table 4. Water to Cement Ratio Relationships**

| Water to cement ratio by bulk volume, water volume:1 bag (1 cu ft) of powdered cement, cu ft | Water to cement ratio by weight, water weight:cement weight, lb | Water to cement ratio by absolute volume, water volume:cement solids (particle) volume, cu ft |
|---|---|---|
| 0.3:1 | 0.20:1 | 0.63:1 |
| 0.4:1 | 0.26:1 | 0.84:1 |
| 0.5:1 | 0.33:1 | 1.04:1 |
| 0.6:1 | 0.40:1 | 1.25:1 |
| 0.7:1 | 0.46:1 | 1.46:1 |
| 0.8:1 | 0.53:1 | 1.67:1 |
| 0.9:1 | 0.60:1 | 1.88:1 |
| 1:1 | 0.66:1 | 2.1:1 |
| 2:1 | 1.3:1 | 4.2:1 |
| 3:1 | 2.0:1 | 6.3:1 |
| 4:1 | 2.7:1 | 8.4:1 |
| 5:1 | 3.3:1 | 10.5:1 |
| 6:1 | 4.0:1 | 12.5:1 |
| 7:1 | 4.6:1 | 14.6:1 |
| 8:1 | 5.3:1 | 16.7:1 |
| 9:1 | 5.9:1 | 18.8:1 |
| 10:1 | 6.6:1 | 20.9:1 |
| 11:1 | 7.3:1 | 23.0:1 |
| 12:1 | 8.0:1 | 25.1:1 |
| 13:1 | 8.6:1 | 27.2:1 |
| 14:1 | 9.3:1 | 29.3:1 |
| 15:1 | 10.0:1 | 31.4:1 |
| 20:1 | 13.3:1 | 41.8:1 |
| 30:1 | 19.9:1 | 62.7:1 |

Assumptions: Specific gravity of 1 for water and 3.15 for cement. Unit weight of 62.4 pcf for water and 94 pcf for powdered cement. Density of 196.56 pcf for cement particles.

To convert ratios not shown above, multiply the bulk volume water value times $\frac{62.4}{(1)(94)}$ or 0.664 to obtain weight ratios and multiply bulk water volume by $\frac{196.56}{94}$ or 2.091 to obtain absolute volume ratios.

As the values above are ratios, they are applicable to any weight, mass, or volume unit. Cubic foot and pound units are common to U.S. grouting practice and are used here for illustration. Some European countries use cement-water ratios, which are merely the inverse of the above ratios. Bulk volume and weight ratios are the most common.

For converting water values to gallons, note that 1 gallon of water weighs 8.34 lb and has a volume of 0.134 cu ft. 1 cu ft of water is 7.48 U.S. gallons.

between volume and weight units. The absolute volume of grout ingredients reflects the volume of grout produced (neglecting the air content).

The practice of measuring sand by the shovel for job-mixed grout on small jobs can result in oversanding or undersanding the mix. For more positive control, the following method is suggested: Construct one or two wooden boxes, 12 in. square and 6 in. deep, and use them to measure the sand required in a batch. Add the cementitious materials by the bag. Then add water, measuring by the pail. When the desired consistency of mix is attained, mark the level of the grout in the mixing drum. Use that as the mark for later batches when sand will be added by the shovelful to the water and cement mixture.

Proprietary packaged grout is preproportioned and therefore only water need be added. The manufacturer's directions for mixing should be followed.

## Mixing Grout

To obtain good workability, uniformity, and other desirable properties of grout, the ingredients must be mixed thoroughly. With the possible exception of very small jobs, grout should be machine mixed. Depending on the grouting application, type of grout, and amount required, grout can be ready mixed in a central mixing plant or truck mixer (ASTM C94), mixed in a mobile mixer (ASTM C685), mixed on site in a mortar mixer, or mixed in a special grout mixer such as a high-shear, colloidal mixer. For example, grout for column or machine baseplates could be mixed in a mortar mixer while ready-mixed grout would be more practical for masonry grout. After all batched materials are together, they should be mixed from 3 to 5 minutes with conventional equipment such as a mortar mixer. The grout should be used within 1½ hours after mixing or within its specified working time.

## Handling Grout

Grout can be transported about the jobsite by pump, wheelbarrow, bucket, or other method that does not allow segregation of materials. The grout should be placed at a rate that does not induce cold joints. Consolidation by vibration, rodding, or other methods should be performed as necessary to remove voids. Additional information in mixing and placing grout can be found under individual grouting applications.

# REINFORCED GROUTED MASONRY WALLS

Grout is an essential element of reinforced brick or concrete masonry (block) construction (Fig. 11). The

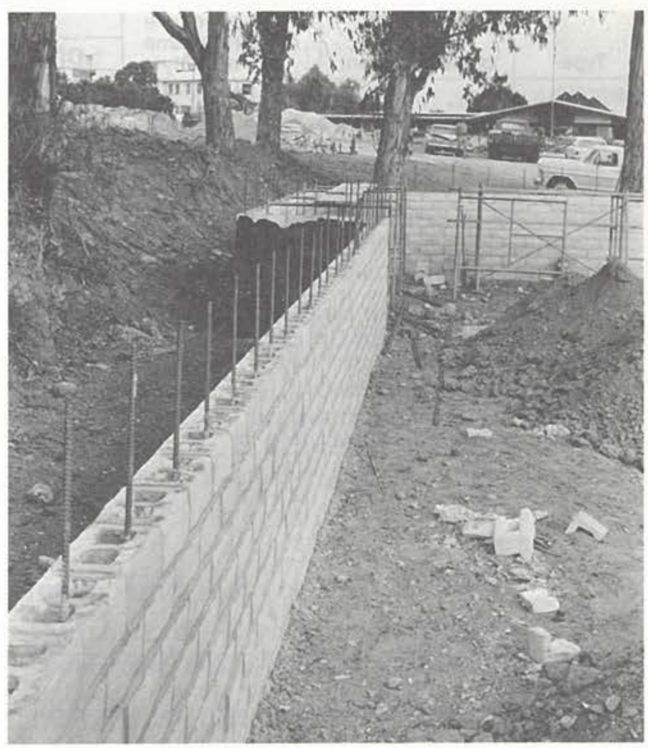


**Fig. 11. Reinforced concrete masonry wall. Reference 73.**

grout bonds the masonry units and steel reinforcement so they act together to resist loads. Either core holes in the masonry units or the space between wythes are grouted. Reinforced masonry is essential in earthquake zones.

Grouting of brick or block walls serves several purposes: (1) it increases the cross-sectional area of the wall and aids in resisting vertical loads and lateral shear loads, (2) it bonds the wythes together, and (3) it transfers stress from the masonry to the reinforcing steel when a wall is subjected to lateral forces due to wind, earthquake, or earth pressure.

Grouted unreinforced masonry walls are similar to reinforced masonry walls but do not contain reinforcement. Grout is sometimes used in load-bearing wall construction to give added strength to hollow walls by filling a portion or all of the cores. It is also used for filling bond beams and occasionally the collar joint (space between wythes) in two-wythe wall construction.

## Grout Selection

Masonry grout is composed of a mixture of cementitious material and aggregate to which sufficient water is added to cause the mixture to flow readily into the masonry cores and cavities without segregation. Unless otherwise specified, grout mix proportions conform to the requirements of ASTM C476 (Table 5).

The fineness or coarseness of a grout is selected on the basis of the size of the grout space to be filled as well as the height grouted (see Table 6). Fine and coarse grout and aggregate size and gradation are defined in ASTM C476 and ASTM C404. Building codes and standards sometimes differ on specific values of maximum grout aggregate size versus clear opening, so the governing document should be consulted.

For fine grout (grout without coarse aggregate), the smallest space to be grouted should be at least ¾ in. wide, as occurs in the collar joint of two-wythe wall construction.

In high-lift grouting where the smallest horizontal dimension of the space to be grouted is about 3 in., a coarse grout with ½-in. maximum-size coarse aggregate (or pea gravel) may be used. Some specifying agencies stipulate that ¾-in. maximum-size coarse aggregate may be used when the grout space is 4 in. or greater. The maximum size of the aggregate and consistency of the mix should be selected considering the particular job conditions to ensure satisfactory placement of the grout and proper embedment of the reinforcement.

## Specifications and Codes

Grout for use in masonry walls should comply with the requirements of ASTM C476 (see Table 5); Building Code Requirements for Masonry Structures—ACI-ASCE 530; and Specifications for Masonry Structures—ACI-ASCE 530.1 (see References 33, 76, and 77).

The grout ingredients should meet the requirements of ASTM C150 and C595 for cement, C5 for quick-

**Table 5. Masonry Grout Proportions by Volume (ASTM C 476)**

| Type | Parts by volume of portland cement or blended cement | Parts by volume of hydrated lime or lime putty | Aggregate, measured in a damp loose condition: Fine | Aggregate, measured in a damp loose condition: Coarse |
|---|---|---|---|---|
| Fine grout | 1 | 0 to 1/10 | 2¼ to 3 times the sum of the volumes of the cementitious materials | |
| Coarse grout | 1 | 0 to 1/10 | 2¼ to 3 times the sum of the volumes of the cementitious materials | 1 to 2 times the sum of the volumes of the cementitious materials |

**Table 6. Maximum Pour Heights and Specified Grout Types with Respect to Grout Space**

| Maximum grout pour height, ft | Specified grout type* | Minimum width of grout space, in.**·† | Minimum grout space dimensions for grouting cells of hollow units, in.†·‡ |
|---|---|---|---|
| 1 | Fine | ¾ | 1½ by 2 |
| 5 | Fine | 2 | 2 by 3 |
| 12 | Fine | 2½ | 2½ by 3 |
| 24 | Fine | 3 | 3 by 3 |
| 1 | Coarse | 1½ | 1½ by 3 |
| 5 | Coarse | 2 | 2½ by 3 |
| 12 | Coarse | 2½ | 3 by 3 |
| 24 | Coarse | 3 | 3 by 4 |

*Fine and coarse grouts and aggregates are defined in ASTM C 476 and C 404.
**For grouting between wythes.
†Grout space dimension equals grout space width minus horizontal reinforcing bar diameter.
‡Area of vertical reinforcement shall not exceed 6% of the area of the grout space.
Adapted from Reference 77.

lime, C207 for hydrated lime, and ASTM C404 for aggregates. All of the materials included in ASTM C476 are satisfactory for use in grout. Most projects using large volumes of grout obtain the grout from a ready mixed concrete producer; the use of lime then becomes uneconomical because of the expense in handling. Grout manufacturers also have suggested specifications.

Practice has shown that a grouting-aid admixture may be desirable when the concrete masonry units are highly absorbent. The desired effect of the grouting aid is to reduce early water loss to the masonry units, to promote bonding of the grout to all interior surfaces of the units, and to produce a slight expansion sufficient to help ensure complete filling of the cavities.

Do not use chloride admixtures in grout because of possible corrosion of reinforcement, metal ties, or anchors. The use of any admixture must be approved by the project engineer.

## Strength

As an alternate to ASTM C476 (Table 5) grout proportions, grout can be proportioned to have a compressive strength (ASTM C1019) equal to or exceeding the specified compressive strength of the masonry, f'm, but not less than 2000 psi.

The mix proportions in Table 5 will produce grouts with a compressive strength of 600 to 2500 psi at 28 days, depending on the amount of mixing water used, when tested by conventional laboratory methods using nonabsorbtive molds (as are used for sampling and testing mortar and concrete). However, the actual in-place compressive strength of grout generally will exceed 2500 psi because, under ordinary conditions, some of the mixing water will be absorbed by the masonry during the time the grout is placed and prior to setting and hardening. This absorption of moisture, in effect, reduces the water-cement ratio of the in-place grout and increases the compressive strength. The moisture absorbed and held by the surrounding masonry during the period immediately following placement of grout helps to maintain the grout in the moist condition needed for satisfactory cement hydration and strength gain.

## Consistency

All grout should be of a fluid consistency but only fluid enough to pour or pump without segregation. It should flow readily around the reinforcing steel and into all joints of the masonry, leaving no voids. There should be no bridging or honeycombing of the grout.

The consistency of the grout as measured using a slump test (ASTM C143) should be based on the rate of absorption of the masonry units and on temperature and humidity conditions. The slump should be between 8 and 11 inches. The slump should be about 8 in. for units with low absorption and about 10 in. for units with high absorption (see Fig. 3).

## Mixing

Whenever possible, grout should be batched, mixed, and delivered in accordance with the requirements for ready mixed concrete (ASTM C94). Because of its high slump, ready mixed grout should be continuously agitated after mixing and until placement to prevent segregation.

Mixing of masonry grout on the jobsite is usually not recommended unless unusual conditions exist. When a batch mixer is used on the jobsite, all materials should be mixed thoroughly for a minimum of 5 minutes. Grout not placed within 1½ hours after water is first added to the batch should be discarded.

## Placing

Even though masonry grout is quite fluid, it is a good practice to consolidate the grout by rodding or vibration to ensure that it encompasses all the reinforcing steel and completely fills the voids. Grout pours up to 12 in. high are consolidated by vibration or rodding (puddling). Grout pours more than 12 in. high are consolidated by vibration and reconsolidated after settlement and initial water loss occurs. Because grout mix water is absorbed by the masonry units, there is a slight volume reduction of the grout. Therefore, the use of shrinkage-compensating admixtures or expansive cement is sometimes recommended on highlift grouting construction. The expansion of this type of grout counteracts the volume change due to loss of water to the masonry units.

Masonry grout is usually delivered in a truck mixer and pumps are used to place the grout in the walls. The grout is placed in lifts up to 5 ft deep.

## Curing

The high water content of masonry grout and the partial absorption of this water by the masonry units will generally provide adequate moisture within the masonry for curing both the mortar and grout. In dry areas where the masonry is subjected to high winds, some moist curing (such as fogging or protection with plastic sheeting) may be necessary. Grout placed during cold weather is particularly vulnerable to freezing during the early period after grouting because of its high water content. To offset cold temperature, grout sand and water can be heated and heated enclosures or covers can be used to protect masonry when temperatures are below 40°F. References 59, 66, 73, and 77 discuss methods of achieving good curing during hot and cold weather.

## Sampling and Testing

ASTM standard C1019 can be used for quality control of uniformity of grout during construction or as an aid in helping to select grout proportions. For making compressive test specimens the standard uses molds formed with masonry units having the same absorption characteristics and moisture content as the units used in the construction. This simulates in-the-structure conditions, where water from the grout is freely absorbed by the units, thus reducing the water-cement ratio of the grout and increasing its strength (see Fig. 12). Grout specimens for compressive tests should not be cast in the usual cylinder molds used for concrete samples because the high water content of the grout would cause low strength results not indicative of actual in-the-wall strength. A minimum of ½ cu ft of grout should be sampled for slump and strength tests. The grout sample should be obtained as the grout is placed into the wall. The specimen should be a nominal 3 in. or larger square prism with a height of twice the width. Three test prisms should represent one grout sample.

When required, grout samples should be taken and tested as per ASTM C1019 for each 5000 sq ft of masonry. Also, a sample should be taken whenever there is any change in mix proportions, method of mixing, or materials used.

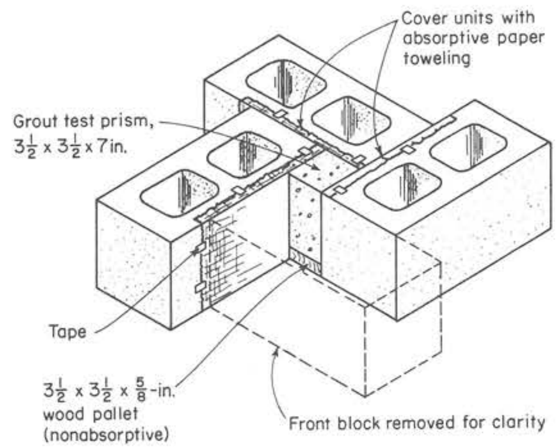



**Fig. 12. ASTM C1019 method of using masonry units to form a prism for compression-testing of masonry grout.**

## Building Reinforced Concrete Masonry Walls

For reinforced concrete masonry wall construction (Fig. 11) the procedures used in laying masonry units, placing reinforcing bars, and pouring grout vary with the size of the job, the equipment available, and the preferences of the contractor. Therefore, this section covers only the general requirements of common procedures.

**Procedures Before Grouting.** Solid or hollow concrete masonry units should be laid so that their alignment forms an unobstructed, continuous series of vertical cores within the wall framework. Spaces into which reinforcement will be placed should be at least 2 in. wide. No grout space should be less than ¾ in. or more than 6 in. wide; if the grout space is wider than 6 in., the wall section should be designed as a reinforced concrete member.

Two-core, plain-end units are preferable to three-core units because the larger cores allow easier placement of reinforcing bars and grout. Also, these units are more easily aligned to create continuous vertical core spaces. When open-end masonry units are used, they are arranged so the closed ends are not abutting.

The mortar bed under the first course of block should not fill the core area because the grout must come into direct contact with the foundation. All head and bed joints should be filled solidly with mortar for the full thickness of the face shell. With plain-end units, however, it is not necessary to fill the head joint across the full unit width. Also, when a wall is to be grouted intermittently (for reinforcement 16, 24, 32, or 48 in. on center), only the webs at the extremity of those cores containing grout are mortared. When a wall is to be solidly grouted, none of the crosswebs need be mortared since it is desirable for the grout to flow laterally and form the bed joints at all web openings.

Mortar protrusions that cause bridging and thus restrict the flow of grout require an excessive amount of vibration or puddling to assure complete filling of the grout space. Hence, care is necessary that mortar projecting more than ⅜ in. into the grout space be removed and that excess mortar does not extrude and fall into the grout space. The mason can prevent mortar from extruding into the grout space by placing the mortar no closer than ¼ to ½ in. from the edge of the grout space and troweling the mortar bed upward and outward, away from the edge, thus forming a bevel. Mortar droppings in the grout spaces of multiwythe walls can be caught and removed by using a removable wood strip.

Vertical reinforcement may be erected before or after the masonry units are laid. When reinforcing bars are placed before the units, the use of two-core, open-end, A- or H-shape units becomes desirable in order for the units to be threaded around the reinforcing steel. When the bars are placed after the units, adequate positioning devices are required to prevent displacement of the bars during grouting. Both vertical and horizontal reinforcement should be accurately positioned and rigidly secured at intervals by wire ties or spacing devices (Fig. 13). The distance between reinforcement and the masonry unit face or formed surface must not be less than ¼ in. for fine grout and ½ in. for coarse grout.

Horizontal reinforcement is placed as the wall rises. The reinforcing bars are positioned in bond-beam, lintel, or channel units, which are then solidly grouted (Fig. 14). Where the wall itself is not to be solidly grouted and cored bond-beam units are used, the grout may be contained over open cores by placing metal lath in the horizontal bed joint before the mortar bed is spread for the bond-beam units. Paper or wood should not be used as a grout barrier because of fire-resistance requirements.

To ensure solid grouting of bond beams, it may be necessary to fill those portions of the bond beams between the vertically grouted cores as the bond-beam courses are laid, especially if the spacing of vertically grouted cores is greater than 4 ft. Otherwise, the grout may not flow far enough horizontally from the cores being grouted to completely fill the bond beams.

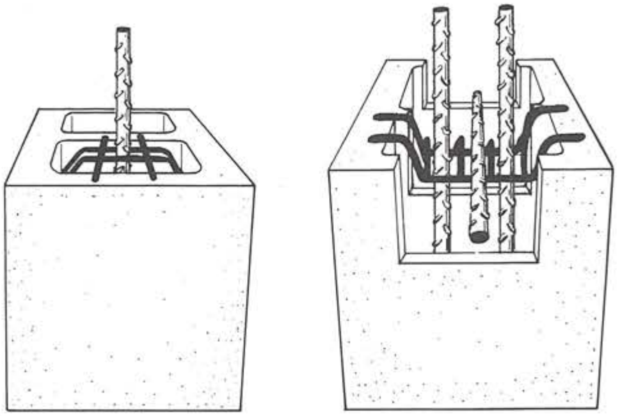


**Fig. 13. Spacing devices for positioning reinforcement in masonry. Reference 73.**

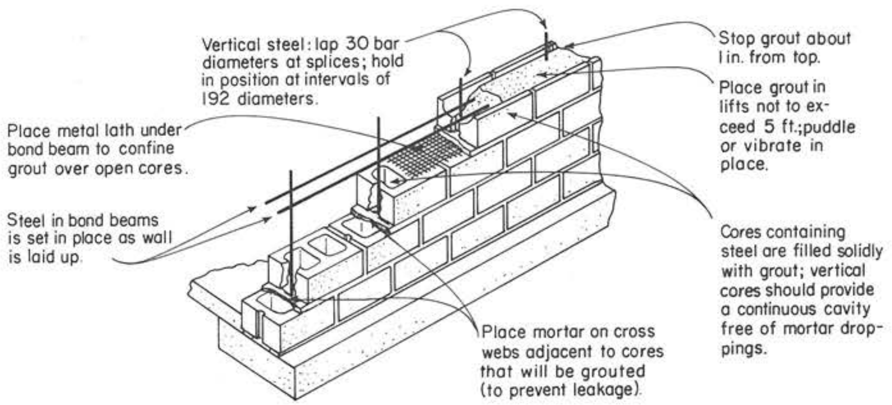



**Fig. 14. Low-lift grouting of a typical single-wythe reinforced masonry wall. Reference 73.**

A concrete masonry wall should be grouted as soon as possible to reduce shrinkage cracking of the joints. However, placing grout before the mortar has been allowed to cure and gain strength may cause shifting or blowout of the masonry units during the grouting operations. Therefore, to fill the cavity in two-wythe masonry or in large cavities of a masonry section (made up of two or more units and containing vertical joints, such as pilaster sections), grout should be poured only after the mortar in the entire height of the wall has been cured a minimum of 3 days during normal weather or 5 days during cold weather. The hydrostatic or fluid pressure exerted by freshly placed grout on the masonry shell may be ignored when filling hollow-core masonry units; thus it is not necessary to cure mortar in hollow-unit masonry walls for longer than 24 hours before grouting.

**Low-Lift Grouting.** Of the two grouting procedures in general use—low- and high-lift* grouting—low-lift grouting is the simplest and most common. This procedure requires no special concrete masonry units or equipment.

In low-lift grouting of a single-wythe wall, the wall is built to a height not exceeding 5 ft before grout is pumped or poured into the cores. This operation is repeated by alternately laying units and grouting at successive heights not exceeding 5 ft. In high-lift grouting, the wall is built to full story height first before grouting the cores or cavities.

Typical reinforced, single-wythe, hollow masonry construction using low-lift grouting is shown in Fig. 14. Vertical cores to be filled should have an unobstructed alignment. Refer to Table 6 for minimum grout space dimensions. Also, the vertical reinforcing bars may be relatively short in length because they need to extend only above the top of the lift a moderate distance for sufficient overlap with the reinforcing bars in the next lift. The minimum lap length for bars in tension or compression should be $0.002d_bF_s$ in inches, where $d_b$ is bar diameter and $F_s$ is allowable tensile or compressive strength of reinforcement (Reference 76). Lap length should never be less than 12 in. As an alternate choice, vertical steel may extend to full wall height for one-story construction or to ceiling height (plus overlap for splicing) for multistory construction. However, since the long lengths of steel require the use of open-end units, some masonry contractors prefer to splice the steel just above each 5-ft lift.

Grout is handled from the mixer to the point of deposit in the grout spaces as rapidly as practical (Figs. 15, 16, and 17). Pumping or other placing methods that prevent segregation of the mix and limit grout splatter are used. On small projects, the grout is poured with buckets having spouts or funnels to confine the grout and prevent splashing or spilling onto the face or top surface of the masonry. Grouting should be done from

*A "lift" is the layer of grout pumped or poured in a single continuous operation. A "pour" is considered to be the entire height of grouting completed in one day; it may be composed of a number of successively placed grout lifts.

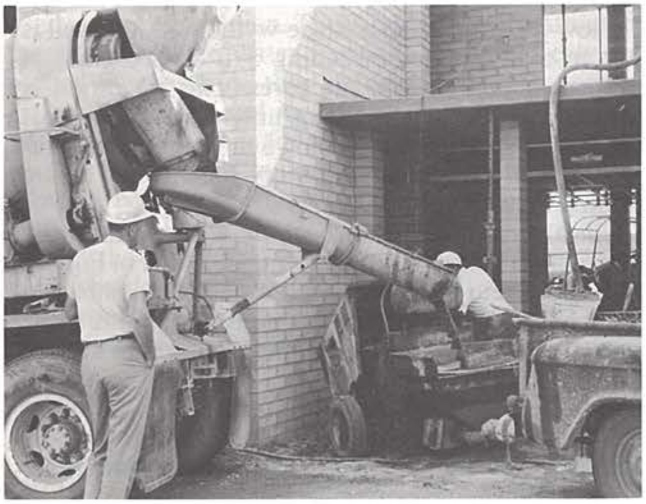


**Fig. 15. Ready mixed grout is delivered by truck mixer into a pump hopper. Note the delivery hose extending to work above. Reference 73.**

**Fig. 16. While helping to handle the grout hose, a laborer controls the pump shutoff with a hand button. Reference 73.**

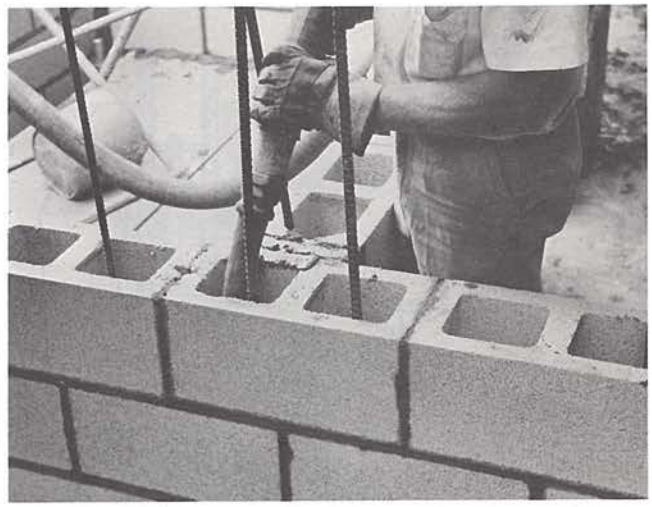


**Fig. 17. View of grout discharging from the pump delivery hose into a core. Reference 73.**

**Fig. 18. Grouting is stopped about 1 in. below the top of the block to form a key with the next lift. Reference 73.**

the inside face of the wall if the outside will be exposed; dried grout can deface the exposed surface of a wall and be detrimental to the mortar bond of the next masonry course. On most projects, grout pumps are recommended to save time and money.

Whenever work is stopped for one hour or longer, a horizontal construction joint should be made by stopping the grout pour about 1 in. below the top of the masonry unit to form a key with the next lift (Fig. 18).

During placement, grout should be rodded (usually with a 1x2-in. wooden stick) or mechanically vibrated to ensure complete filling of the grout space and solid embedment of the reinforcement. It takes very little effort to do this consolidation job properly because of the fluid consistency of the grout. When high-absorption masonry units are used, it may be necessary to rerod or revibrate the grout 15 to 20 minutes after placement; this will overcome any separations of the grout from the reinforcing steel and eliminate voids caused by settlement of the grout and absorption of water into the surrounding masonry. Overvibration, however, must be carefully avoided at this stage; more hazardous than during initial consolidation, it can cause blowouts, broken ties, cracked masonry units, or segregation of the grout.

In low-lift grouting of masonry with two or more wythes, the exterior wythe is laid up a maximum of 18 in. above the interior wythe. After the interior wythe is laid, the cavity between the wythes is grouted in lifts not to exceed six times the width of the grout space, with a maximum of 8 in. A minimum mortar-curing period usually is not necessary before grouting. Grout is poured into the grout space to within 1 in. of the top of the interior wythe and then consolidated.

Where there are more than two wythes, the middle wythe (usually of brick size) may be built by "floating" the units in the grout space, that is, pushing the units down into the grout so that a ¾-in. depth of grout surrounds the sides and ends of each unit. No units or piece of a unit less than 10 cu in. in size should be embedded in the grout by floating.

**High-Lift Grouting.** With this procedure, grouting is delayed until the wall has been laid up to full story height. High-lift grouting is intended for use on wall construction where reinforcement, openings, or masonry unit arrangements do not prevent the free flow of grout or inhibit the use of mechanical vibration to consolidate the grout properly in all cores or horizontal grout spaces. The vertical cores should have an unobstructed alignment, with a minimum dimension of 3 in. and a minimum area of 10 sq in. In two-wythe masonry the minimum dimension of the grout space (cavity) between wythes is 2 to 3 in., depending on the governing code and pour height (Table 6), and the maximum is 6 in.

Vertical bulkheads extending the entire height of the wall should be provided at about 26 ft on center to control the flow of the grout horizontally. In a hollow-unit masonry wall, such barriers are made by placing mortar on crosswebs and blocking the bond-beam units with masonry bats set in mortar. In a multiwythe wall, the barriers are laid into the grout spaces as the wall is erected. In addition to confining grout to a manageable area, these barriers may be used as stiffeners or points to locate wall bracing.

Proper preparation of the grout space is one of the most important features of high-lift grouting. It is necessary, before grouting, to remove all mortar droppings and debris through cleanout openings. Not less than 3 in. in size, a cleanout opening is located at the bottom of every core in hollow-unit reinforced masonry containing dowels or vertical reinforcement and in at least every other core that is grouted but has no vertical bars. Cleanouts should be provided in solidly grouted masonry at a maximum spacing of 32 in. on center. In a two-wythe masonry wall, the cleanouts are provided at the bottom of the wall by omitting alternate units in the first course of one wythe. The governing standard or building code should be consulted to verify requirements for cleanout openings.

Cleanout openings in the face shells of units should be made before the units are laid. A special scored unit that permits easy removal of part of a face shell is occasionally used. Also, an alternate cleanout design makes use of header units, as shown in Fig. 19.

It is considered good practice to cover the bottom of a grout space with a 2- to 3-in. layer of sand or a polyethylene sheet to act as a bondbreaker for the mortar droppings. The grout space is flushed at least twice a day (at midday and quitting time) with a high-pressure stream of water or, to keep the masonry from being moistened unnecessarily, the mortar droppings and projections are dislodged with a long pole or rod as the work progresses. After the masonry units are laid, the sand or polyethylene sheet is removed, compressed air is used to blow any remaining mortar out of the grout space, and the space is checked for cleanliness and the reinforcement for position. A mirror is a good inspection tool for looking up into the grout space through a cleanout opening.

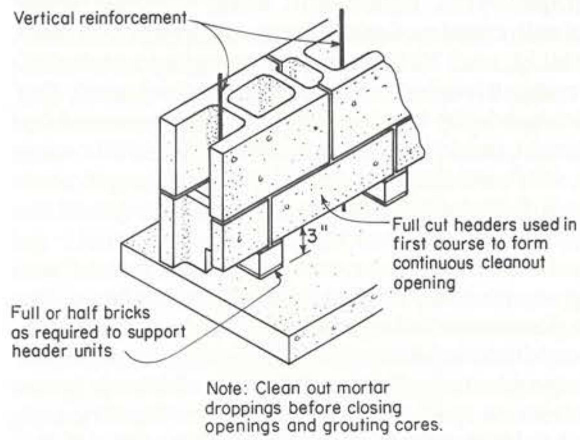



**Fig. 19. Alternate cleanout opening detail. Reference 73.**

Before grouting, the cleanout openings are closed by inserting masonry units or the face shells that were left out, or by placing formwork over the opening to allow grouting right up to the wall face. Grouting need not be delayed until the face-shell plugs or cleanout closure units are cured, but they should be adequately braced to resist the grout pressure.

In high-lift grouting, intermediate horizontal construction joints are usually not permitted. Once the grouting of a wall section is started, one pour of grout to the top of the wall (generally in 5-ft maximum lifts) should be planned for a workday. Should a blowout, an equipment breakdown, or any other emergency stop the grouting operation, a construction joint may be used if approved by the inspector. The alternatives are to wash out the fresh grout or else rebuild the wall.

For economical placement, a uniform 5-ft lift of grout is generally pumped into place and immediately (not more than 10 minutes later) vibrated. Each succeeding lift of grout is pumped and consolidated after an appropriate lapse of time, a minimum of 30 and a maximum 60 minutes (depending upon weather conditions and masonry absorption rates), to allow for settlement shrinkage and the absorption of excess water by the masonry units. This waiting period also reduces the hydrostatic pressure of the grout and thus the possibility of blowout. In each lift, the top 12 to 18 in. of grout is reconsolidated before or during placement of the succeeding lift.

In multiwythe construction, the total length of a wall that can be grouted in one pour is limited. It is determined by the number of sections (bounded by vertical bulkheads) that can be grouted to maintain the one-hour maximum interval between successive lifts in any section.

The maximum height of a pour is limited by Table 6 and by practical considerations such as segregation of grout, the effect of dry grout deposits left on the masonry units and the reinforcing steel, and the ability to consolidate the grout effectively. Under some circumstances, the maximum height of pour may be 12 ft for

8-in., single-wythe, hollow-unit walls, 16 ft for walls with a single curtain of reinforcing steel (walls less than 12 in. thick), and 20 ft for walls with two curtains of reinforcement (walls 12 in. or more in thickness). On the other hand, the height of pour may be governed by story height, and thus 8-in., single-wythe walls may have a 20-ft height of pour. When the grout pour exceeds 8 ft in height, building codes sometimes require special inspection of the work.

Extreme care should be used to prevent grout from staining any masonry wall that will be exposed to view. If grout does contact the face of the masonry, it should be removed immediately. Also, soon after the wall has been fully grouted, all exposed faces showing grout scum or stains (percolated through the masonry and joints) should be washed down thoroughly with a high-pressure stream of water. If necessary, further cleaning may be done after curing and before final acceptance by the architect.

The time- and money-saving advantages of high-lift grouting on large projects are obvious. The vertical steel can be placed after the wall is erected and, even on a job of moderate size, the grout can be supplied by a ready mixed concrete producer and pumped in a continuous operation. The main disadvantages of high-lift grouting may be the need for a grout pump or other means of pouring grout rapidly and the requirement for cleanout openings at the base of the wall. See Reference 73 for more information on masonry construction.

## GROUT CLEANDOWN

A grout cleandown (sack-rubbed finish) can be used to impart a uniform color and appearance to a smooth, clean, formed surface of cast-in-place concrete. After defects have been repaired, the surface should be saturated thoroughly with water and kept wet during grout operations. A grout consisting of 1 part cement, 1½ to 2 parts of fine sand, and sufficient water for a thick, creamy consistency should be applied uniformly by brush, plasterer's trowel, or rubber float to completely fill air bubbles and holes.

The surface should be vigorously floated with a wood, sponge-rubber, or cork float immediately after applying the grout to fill any small air holes (bugholes) that are left and to remove some excess grout. The remaining excess grout should be scraped off with a sponge-rubber float. If the float pulls grout from holes, a sawing motion of the tool should correct the difficulty. The grout remaining on the surface should be allowed to stand undisturbed until it loses some of its plasticity but not its damp appearance. Then the surface should be rubbed with clean, dry burlap to remove all excess grout. All air holes should remain filled, but no visible film of grout should remain after the rubbing. Any section being cleaned with grout must be completed in one day, since grout remaining on the surface overnight is too difficult to remove.

If possible, work should be done in the shade and preferably during cool, damp weather. During hot or dry weather, the concrete can be kept moist with a fine fog spray.

The completed surface should be moist-cured by keeping the area wet for 36 hours following the cleandown. When completely dry, the surface should have a uniform color and texture.

## CERAMIC TILE

Portland cement grout is the standard grout for ceramic tile, although noncementitious grouts are available for special purposes (Fig. 20). Tile grout can be modified to provide extra whiteness, color, mildew resistance, hardness, flexibility, water retention, and other properties. Both sanded and neat cement grouts are used. The grouts use ASTM C150 white or gray portland cement, a very fine aggregate, and applicable admixtures. Grout ingredients must be measured accurately and the grout must be mixed thoroughly in a slow-speed mixer to a uniform consistency. Specified water-cement ratios must not be exceeded. Mixed grout should be used within 1 hour after mixing. A brief description of cementitious grouts for tile follows.

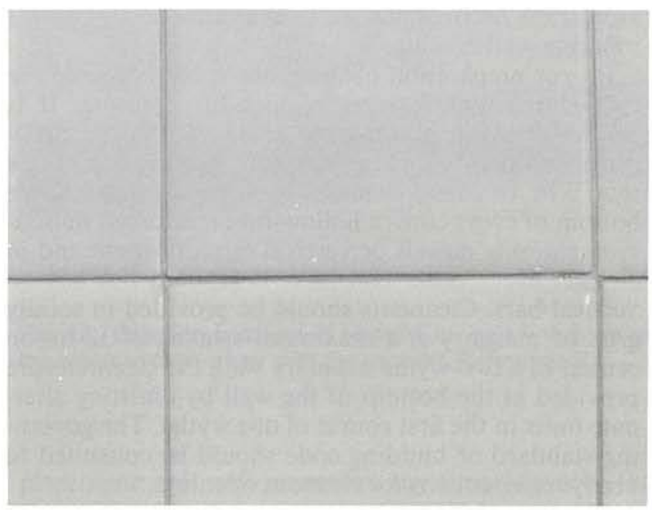


**Fig. 20. Portland cement grout is the standard grout for ceramic tile.**

### Commercial Portland Cement Grout

Commercial portland cement grout is a factory-packaged mixture of portland cement, fine sand, and other ingredients which when mixed with water produces a water resistant, dense, and uniformly colored grout. The 28-day compressive strength, ASTM C109, should be at least 3500 psi. The grout must also meet other applicable requirements such as tensile, shear, and flexural strength as specified by ANSI A118.6 (Reference 47). Floor applications include ceramic mosaics, quarry, and paver tile.

## Sand-Portland Cement Grout

Sand-portland cement grout is a mixture of cement, fine sand, and water proportioned and blended together at the jobsite. Grout proportions by volume with respect to joint width are as follows:

| Joint width | Cement | Sand | Lime (optional) |
|---|---|---|---|
| 1/8 in. and less | 1 | 1 | 1/5 or less |
| 1/2 in. and less | 1 | 2 | 1/5 or less |
| More than 1/2 in. | 1 | 3 | 1/5 or less |

Sand-portland cement grout is used with ceramic mosaic tile, paver tile, and quarry tile.

## Dry-Set Grout

Dry-set grout is a proprietary grout (like commercial grout) consisting of cement and an additive for extra water retention for grouting walls and floors for ordinary use. Wall tile may not need to be soaked prior to using dry set grout, as is needed for other cement grouts, although very dry environments may require dampening. The minimum 28-day compressive strength, ASTM C109, is 3000 psi. ANSI A118.6 should be consulted for additional requirements, such as water retentivity and additional strength requirements.

## Latex-Portland Cement Grout

Latex portland cement grout is merely any portland cement grout to which a latex admixture is added to help cure the grout and make it less absorptive and more stain and crack resistant. The latex also increases bond strength and water resistance. Special cleaning procedures and materials are usually recommended for this grout however. Absorption of sanded grout is about 10% to 20% whereas the absorption of latex cement grout is about 3% to 5% (Reference 53). The 28-day compressive strength should be at least 3000 psi. ANSI A118.6 provides additional requirements.

## Grout Installation

As with all grout installation, mortar beds must harden sufficiently before grouting to hold the tile in place. This usually requires a 48-hour cure. All joints must be clean and spacers, strings, and pegs must be removed. The joints should be dampened, except for some dry-set grout applications. However, there must not be any puddles of water in the joints during grouting. Using a rubber float, grout is spread and pressed into the joints until they are completely full. The grout is finished to the depth of cushion on cushion-type tile or finished flush with the surface on square-edged tile. To prevent scratching the tile surface, a rubber-faced trowel should be used with sanded grout when grouting glazed tile. The mortar bed should not show through and no voids or low spots should exist. The tile is then wiped clean with a damp cloth or sponge to remove excess grout from the tile joints and from the face of the tiles. Commercial, sand-portland, or dry-set grout is then moist-cured for 72 hours. Plastic sheet over wetted tile is an effective damp-curing method.

Table 7 provides information as to where the above grouts can be used. For more information on grout materials, tests, properties, and installation, see References 17, 39, 46, 47 (ANSI standards A108.10 and A118.6), 53, and 61.

## TOPPINGS AND UNDERLAYMENTS FOR FLOORS

Many proprietary thin toppings and underlayments are available for floor applications. They are often referred to as self-leveling (nontroweling) or trowelable materials (see Fig. 21). These materials are primarily used to provide a smooth, level floor surface as well as repair floors that have deteriorated, sagged, scaled, or became worn. These materials reduce sound and heat transmission between slabs as well as provide additional fire resistance. The toppings provide the actual wearing surface of a floor, whereas underlayments must

**Table 7. Tile Grout Application Guide**

| | Grout type | | | | |
|---|---|---|---|---|---|
| | Commercial portland cement | | Sand-portland cement | Dry-set | Latex portland cement |
| Tile type | Wall use | Floor use | Wall-floor use | Wall-floor use | |
| Glazed wall tile (more than 7% absorption) | ✓ | | | ✓ | ✓ |
| Ceramic mosaics | ✓ | ✓ | ✓ | ✓ | ✓ |
| Quarry, paver, and packing-house tile | ✓ | ✓ | ✓ | | ✓ |

All of these grouts can be used in interior and exterior locations, dry and intermittently wet areas, and areas subject to prolonged wetting. These grouts are also available in a wide range of colors. For locations requiring extra resistance to stains, chemical attack, cracking, or requiring other properties, consider using chemical grouts.

Adapted from Reference 61.

**Fig. 21. Self-leveling floor toppings and underlayments are very fluid grouts that are easily placed by small-line pumps.**

be covered with a floor covering material such as tile or carpet. Particular underlayments or toppings are formulated to be applied over old or new floors constructed of cast-in-place concrete, precast concrete, wood, tile, and terrazzo, as well as floors with cut-back adhesive residue present and floors exposed to moisture. Some can also be placed over radiant-heating pipes. Indoor toppings are used for warehouse floors, hallways, and indoor parking garages. Certain topping materials can be used outdoors.

## Composition

Toppings and underlayments are composed of a combination of cement, sand, air, water, admixture, and sometimes coarse aggregate, polymer modifiers, or fibers. The dry materials are usually blended together and packaged in bags for easy use on small projects.

Lightweight cellular concrete is an underlayment material (floor fill) containing normal grout or concrete ingredients along with a foaming agent that produces a high air content. The high air content provides low weight and added fire and sound resistance. It is usually centrally batched using normal bulk materials and not bagged. Besides underlayment applications, cellular concrete is used to insulate roof decks. See Reference 66 for more information on lightweight concretes for these and other applications.

## Properties

Toppings and underlayments are formulated for minimal shrinkage, rapid strength gain, and flowability without segregation. However, these and other properties can be adversely affected by an excessive amount of water. Too much water will cause dusting, low strength, and shrinkage cracks. Self-leveling underlayments must be pumpable and be able to level off after minor screeding. Trowelable mixes have a stiffer, less-watery consistency.

These materials weigh from 100 to 120 pcf dry and have compressive strengths of 1000 to 7500 psi after 28 days. Cellular concrete has a minimum strength of 1000 psi for residential applications or 1500 psi or more for commercial underlayments (strength can be increased to 3000 psi or more by reducing air and sand content). Cellular roof fill has a strength of around 160 psi and an air-dry density of 25 to 30 pcf. Many noncellular underlayments range in strength from 3000 to 6000 psi. Topping mixes tend to have strengths around 5000 to 7500 psi after 28 days. Topping and underlayment working times vary from 10 to 60 minutes. They can be walked on in 2 to 24 hours and a floor covering placed in 1½ hours to 7 days or more after placement, depending on the product.

The shrinkage characteristics of various topping and underlayment products can vary considerably, therefore the manufacturer should be consulted as to crack control and joint spacing. Depending on the floor size, some underlayments require no joints whereas others would. Joint spacings commonly range from 10 to 30 ft. Joints in the base slab must be reflected in toppings.

The minimum and maximum thicknesses depend upon individual products and where or how they are used. Thin underlayments (less than 1 in. deep) are usually bonded. The range of allowable thicknesses varies from ⅛ in. to 4 in. Thicknesses greater than ½ to 1½ in. use added aggregate to reduce shrinkage. Minimum thickness over wood may be more than over concrete. The minimum for a cellular concrete fill is about 1½ in. (¾ in. bonded over precast concrete). Cellular concrete is placed over bonded or unbonded moisture barriers.

## Application and Installation

Before toppings or underlayments are placed, the subfloor must be cleaned. Subfloors must be dust free, solid, and free of coatings (paint, wax, etc.). ASTM standards D4258, D4259, D4260, D4261, and D4262 can be helpful in preparing concrete subfloors. A primer is then applied by roller, brush, sprayer, or squeegee to seal the subfloor and aid bond. For cellular concrete underlayments, the floor need be only broom clean with holes filled prior to applying an unbonded moisture barrier (such as kraft paper) or bonded moisture barrier (such as liquid latex). Strip contraction joints should be installed as needed.

The topping or underlayment mix is then mixed by traditional or special mixing equipment, depending on the product. Small quantities of certain products can be mixed in a pail or drum with an electric drill and paddle and poured directly onto the floor. Large jobs use automatic equipment to mix and then pump the grout to the desired location. A rake or squeegee is used to spread the poured or pumped self-leveling grout, after which most self-leveling materials need no further finishing as they are self-smoothing. Perimeter chalk lines and plastic guides on the subfloor help control the grout depth. Some coating and concrete resurfacing products are designed to be spray-applied. Metal reinforcement is usually not used or needed.

The material must then be allowed to set and harden before any further work can be done on the floor. See the earlier discussion and consult the manufacturer as to the time when the product can be walked on, construction continued, or a floor covering applied. As moisture can interfere with the performance of many floor coverings, before placing a floor covering, the moisture condition of the slab should be tested or a test installation should be made of the product to be used. One moisture test is the plastic-sheet test (ASTM D4263). If no moisture condenses under the sheet after 16 hours, the floor is dry enough for some floor coverings (also see References 42 and 66). Full-depth concrete floors may require more than 2 months of drying before floor coverings or even some underlayments can be installed to avoid moisture-related problems. For more information on these materials, see References 51, 58, 64, and 79.

**Fig. 22. Application of a bonding grout a few feet ahead of overlay concrete. The grout must not dry before the concrete is placed.**

## BONDING GROUT AND REPAIR GROUT

### Bonding Grout

Bonding grout is used to "glue" fresh mortar or concrete to old concrete for thin-bonded overlays, patches, and two-course floors. Bonding grout is commonly used to bond concrete overlays onto bridge decks, parking garage slabs, floors, and highway pavement. The grout must be applied to a clean, roughened surface (to provide better mechanical bond). The surface must be free of dirt, sand, oils, coatings, paints, and deteriorated concrete. Good-quality concrete must be exposed. The concrete surface can be cleaned and unsound concrete removed by sandblasting, water blasting, scarification, shotblasting, chipping, high-pressure air (to remove loose debris), or other methods (see ASTM D4258 and D4259). Cracks are sometimes filled with a flowable epoxy to reduce reflective cracking in overlays.

Cement-and-water bonding grout or sanded bonding grout is brushed onto a dry or damp (never wet) concrete surface immediately prior to placement of fresh mortar, repair grout, or concrete (Fig. 22). The $1/16$- to $1/8$-in.-thick layer of bonding grout must not be allowed to dry before the overlay or patching mix is placed, otherwise the dry grout may hinder proper bond and result in delamination of the patch or overlay. A typical sand-cement bonding grout consists of 1 part cement to 1 part sand by volume and enough water to make a paintlike consistency. For small jobs the grout can be mixed in a pail or drum using an electric drill and paddle.

### Repair Grout

Repair grout is used to repair spalled or defective areas of concrete that occur during or after construction. These cementitious grouts vary in consistency from very stiff mixtures to trowelable and sometimes flowable proprietary mixtures.

**Fig. 23. A mixture of cement, sand, and just enough water to form a ball when compressed in the hand makes a good low-shrink mixture to repair or fill voids in concrete. This mixture is referred to as dry-pack mortar or dry-pack grout.**

Dry-pack grout, also called dry-pack mortar, consists of a stiff mixture of 1 part (by volume) cement, $2\frac{1}{2}$ parts sand (passing a No. 16 sieve), and only enough water so that the mixture will form a ball when squeezed gently in the hand (Fig. 23). A one- to two-hour prehydration period before using the grout is helpful in reducing shrinkage.

Bolt holes, tierod holes, and other cavities that are small in area but relatively deep can be filled with a dry-pack grout. Honeycomb and other defects in concrete should be cut out to expose sound material before repair. If defective concrete is left adjacent to a patch, moisture may get into the voids; in time, weathering action will cause the patch to spall. The edges of the defective area should be cut or chipped straight and at right angles to the surface—or slightly undercut—to provide a key at the edge of the patch. Featheredges should not be permitted. The patch geometry should resemble a square or deep rectangle. The cavity should be cleaned of oil and loose material and kept damp for several hours. A bonding grout should be brushed onto the void surfaces but not allowed to dry before the repair grout is placed. The dry-pack grout should be vigorously tamped into place in ⅜-in. to ½-in. layers, with each layer given a scratch finish to improve bond with the subsequent layer. The final layer can be finished to match the surrounding concrete by floating, rubbing, or tooling or on formed surfaces by pressing a section of form material against the patch while still plastic. Vigorous tamping and moist curing (3 to 7 days) will ensure good bond and minimum shrinkage of the patch. Large patches and thin-bonded overlays need concrete instead of grout for the repair material for economic, shrinkage, and durability concerns.* Nonmoving cracks can also be routed out, cleaned, and grouted. Moving cracks can be routed out, cleaned, primed, and sealed with an elastomeric sealant. Several proprietary cementitious and noncementitious (resin) grouts are available to fill cracks. Often routed crack repairs look worse than the original crack.

Proprietary repair grouts, often nonshrink or polymer-modified grouts, are also used in concrete repair to patch or fill voids as described above. Some polymer-modified grouts can be placed in thin applications and sometimes in near-featheredge areas. Packaged, dry, rapid-hardening grout for repairing concrete should meet the requirements of ASTM C928. Proprietary grouts are usually applied by trowel, but some are spray applied. A test patch should be placed in an inconspicuous area to determine the suitability of the repair grout and method.

Grout is also used to make slurry-infiltrated fibrous concrete that can be used in repairs needing high flexural strength (about 5000 psi), high compressive strength (10,000 to 20,000 psi), high abrasion resistance, and a large amount of ductility. The patch area is cleaned and prepared as described earlier. Fibers, usually made of steel and about 1 in. long, are placed into the void or patch area until the void is full. A low-viscosity slurry (grout), consisting of cement, water, and admixtures such as fly ash and superplasticizer, is poured into the bed of fibers. The grout-filled patch is then textured as desired or an aggregate wearing course can be added. The fiber volume in this product can range from 6% to 18%. This technique can also be used for constructing full-depth walls, slabs, and other concrete elements or products. For more information on slurry-infiltrated fibrous concrete, contact the University of New Mexico Research Institute and the New Mexico State Highway Department.

For more information on repair grout applications see the sections in this book on "Grout Cleandown," "Toppings and Underlayments for Floors," and "Preplaced-Aggregate Concrete." Also see References 66, 69, and 79.

## FLOWABLE FILL

Flowable fill, also called controlled-density fill or controlled-low-strength material, is a fluid mixture of cementitious materials, water, and aggregate used in place of soil backfill. Flowable fill doesn't require the labor-intensive compaction and hauling effort of soil backfill; it eliminates or reduces settlement; it sets up within a few hours; and it has a strength comparable to or greater than compacted soils.

Flowable fill is used in backfilling foundations, retaining walls, trenches, bridge abutments, underground tanks, culverts, and utility cuts from sewer, water, gas, and electric line repair (Fig. 24); as fill for abandoned wells, tanks, sewers, and manholes; in temporary slabs; as subbase for pavements, slabs, and foundations; and in pipe bedding. The strength is low enough for easy future excavation with conventional equipment but strong enough to support the loads without settlement.

The mix proportions and strength are designed for each particular application. The amount of materials per cubic yard of flowable fill range from 50 to 200 lb of cement, 2000 to 3000 lb of fine or fine and coarse (1-in. maximum) aggregate, 350 to 800 lb of water, and 50 to 400 lb of fly ash or other pozzolan. The slump is typically 6 in. to 8 in. A mix used by the Iowa Department of Transportation (IDOT Specification 957, Supplemental Specification for Flowable Mortar) for fill over culverts and other projects consists of the follow-

*This concrete should have a low water-cement ratio, often with a cement content equal to or greater than the concrete to be repaired. Cement contents often range from 600 to 850 lb per cubic yard and the water-cement ratio is usually 0.45 or less. The aggregate size should be preferably no more than ⅓ the patch or overlay thickness. A ⅜-in. maximum-size coarse aggregate is commonly used. The sand proportion can be higher than usual, often equal to the amount of coarse aggregate, depending on the desired properties and application.

**Fig. 24. Flowable fill used to backfill a utility trench along a street.**

ing: 100 lb of ASTM C150 Type I cement, 300 lb of ASTM C618 Class C fly ash, 2600 lb of aggregate (100% passing the ¾-in. sieve and 0% to 10% passing the No. 200 sieve), and about 585 lb of water, which, when mixed together, produces a grout with a flow-cone time of efflux (Corps of Engineers CRD-C611) of about 12 seconds (after the plus ¼-in. aggregate is removed).

Flowable fill can be batched and mixed using ASTM C94 procedures and equipment for ready mixed concrete or prepared in an ASTM C685 mobile mixer. Typical compressive strength ranges from 50 to 200 psi, which is more than the strength of most natural soils.

Flowable fill can be discharged directly from the truck mixer or transported by pumps, buckets, or other methods to the placement location. Due to its fluid nature, no additional spreading, handling, or consolidation is usually needed.

Low-density cellular concrete with cement, water, and about 80% air (produced by a foaming agent) is also used as flowable fill for geotechnical applications. Typical air-dry densities range from 15 to 75 pcf (20 to 80 pcf as cast) with compressive strengths of 10 to 300 psi. It is used as regular fill and for special locations where a low density is required, such as over tanks, tunnels, and belowground buildings. It is also of importance in placement locations needing extra sound-deadening and thermal-resistance properties.

Flowable fill generally performs better than compacted backfill, with no problems due to settlement, frost action, or localized zones of stiffness. American Concrete Institute Committee 229, Controlled-Low-Strength Materials, is preparing a state-of-the-art report on this subject. For more information, see References 45, 50, 66, and 74.

## GROUTED POST-TENSIONING DUCTS

Post-tensioned prestressed concrete uses either bonded or unbonded tendons to prestress the concrete and counteract tensile stress caused by service loads. Bonded tendons are placed in ducts or voids and stressed, and then the ducts are grouted. The grout protects the tendons from corrosion (by keeping out air, water, and chlorides) and develops bond between the prestressing steel, ducts, and surrounding concrete. Unbonded tendons are greased and plastic covered, allowing the tendon to move free of the surrounding concrete, unlike bonded tendons. An advantage of unbonded tendons is the elimination of costly and time-consuming grouting. Bonded tendons, on the other hand, have structural advantages in primary structural elements, such as beams, and are commonly used in bridges. Unbonded tendons are commonly used in floors.

The ducts in bonded post-tensioning can be formed by a ferrous metal sheath that will retain its shape during concrete placement. The sheath must be able to transfer bond stresses as required. Ducts can also be cored; however, any debris from coring must be removed by pressurized air or water and the duct walls moistened before grouting. The ducts must have grout openings at both ends and the duct area must be at least twice the area of prestressing steel when several bars, strands, or wires make up the tendon or at least ¼ in. larger than the diameter of a single wire, bar, or strand tendon. Ducts must also be checked for blockage (with forced air for example) before grouting. Damaged ducts must be repaired before grouting.

Grout injection points must be provided in the end anchorage and sometimes at high points along the duct. Vents must be provided at 50-ft spacing, at all high points in the duct length, or at any points where changes in duct cross section occur and air may become trapped. Drain holes may be provided at low points to prevent the accumulation of water that may freeze and cause damage. The injection and outlet points and vents must be inspected before grouting to ensure that they are clear of obstruction and can be properly closed.

Grout used in post-tensioning ducts consists of portland cement, water, and admixtures. Admixtures are used to reduce water content and bleeding, increase flowability, or cause expansion. Aluminum powder or other expansive admixture can be used to achieve 5% to 10% expansion in the unrestrained grout. Sand is not used in practice but it may be of benefit in tendons with large void areas. Pozzolans such as fly ash are sometimes used. Silica fume or latex modifiers can be used to drastically reduce grout permeability for chloride-laden locations. Steps to reduce bleeding, such as use of bleed-reducing (water-retention) admixtures to make thixotropic grouts, are especially important to eliminate voids (Fig. 25). Water retentivity or bleeding under pressure can be tested by a method in Reference 21. Bleeding as tested by the method in Reference 48 should not exceed 2% of grout volume 3 hours after mixing. Bleeding is significantly reduced with use of thixotropic grouts. The maximum water-cement ratio should be 0.45 (preferably less) with ASTM C150 Type I or II cement, which should result in a cube compressive strength of about 4000 psi at 28 days.

The grout should be proportioned to provide a fluid consistency with a flow-cone efflux time of 11 seconds

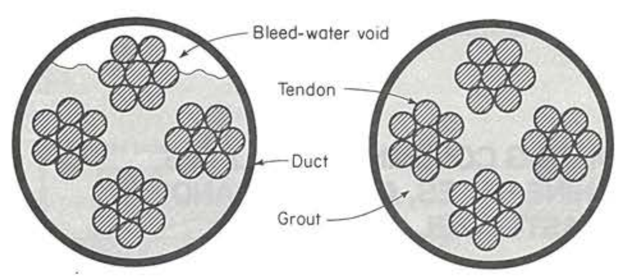



**Fig. 25. Grout for post-tensioning ducts should completely embed the tendons and fill the duct as shown at the right. Grout with little to no bleeding should be used to prevent formation of voids (left) that can expose the tendon to future corrosion problems. When a duct is curved, all the strands are packed together on the inside of the curvature.**

or more (ASTM C939 or Corps of Engineers CRD-C611). A modified flow-cone test or other test should be used for thixotropic grouts using water-retentive admixtures.

Grout should be mixed in a high-speed, high-shear colloidal mixer for 1½ to 3 minutes to blend the ingredients uniformly. Disk shear mixers operating around 1750 rpm are most effective with thixotropic grout. After the grout is batched and mixed, additional water should not be added to restore any loss in flowability (discard the grout). Grout should be agitated until pumped.

The pump, positive displacement type, should be able to produce an outlet pressure of at least 150 psig but not more than 250 psig at the tendon inlet; the pump should be able to grout an entire duct within 20 minutes. If blockage occurs or grouting is significantly interrupted, all grout must be flushed from the duct and the duct must be regrouted. A screened pump influent is used to remove particles larger than 0.125 in. from the grout. The grout hopper should be kept full to keep out air bubbles. Grout should be pumped continuously through the duct until no water or air bubbles appear in the grout leaving the duct.

In grouting vertical or near-vertical ducts, particular care is needed to prevent any tendency for the grout to bleed, which would result in water pockets. At these points there would be no protection to the cable or bond transference. Grout stability necessitates the use of admixtures to reduce bleeding when grouting vertical ducts.

Grouting of ducts requires close attention and supervision considering that it is the stage that determines the durability of the prestressing tendons in post-tensioned cast-in-place concrete. The mere observation of grout being introduced at one end of a duct and seen emerging from the other end is certainly not complete assurance that the duct is completely and properly filled.

Although the aim in grouting ducts is to completely fill the duct with grout, some voids will usually be present. The goal in grouting ducts should be to minimize voids by using the best grout and the best grouting practices. This should result in adequate tendon protection. For additional information on grouting of post-tensioning ducts, see References 19, 20, 21, 24, 34, and 48.

## GROUTING COLUMN BASEPLATES, MACHINE BASES, ANCHORS, AND PRECAST-PANEL JOINTS

There is no standard practice for fastening and bedding either column bases or machine bases to their concrete foundations. Many methods are used that give satisfactory results. Some of the more common practices are discussed here and certain recommendations are made based on the general principles of grouting and concreting.

### Column Bases

Steel baseplates placed on top of concrete piers or foundations and to which structural steel columns are fastened vary considerably in area, thickness, and weight. Smaller baseplates can simply be set on the freshly placed concrete after subsidence has taken place but before the concrete has hardened thoroughly. The plate is then leveled and lightly tamped into place to proper elevation. Larger and heavier baseplates cannot be handled in this manner and a more exacting procedure is necessary to assure accurate placement and uniform distribution of the greater load involved. In most cases the concrete is finished some distance below the bottom of the baseplate, which is then set in position and the space between the concrete and baseplate is filled with nonshrink cement grout (Fig. 26).

The space between the top of a foundation and the baseplate varies from about 1 in. to 3 in. The greater depth is used with the larger bases and, being easier to fill, is preferred by some contractors. However, shrinkage and settlement, which are to be avoided, increase with the thickness of the layer of grout unless stiffer, leaner mixes are used for deep beds.

Baseplates are generally set on steel shims or wood wedges at the proper elevation over the concrete foundation. Occasionally three threaded holes are provided in the plate into which leveling screws are inserted, thus avoiding the use of shims or wedges. These are used only with very large, heavy plates. A steel bearing plate about 4x4 in. is placed under each screw. In thick bases the top part of the hole may be made larger than the screw to reduce the amount of threading. Another method is to weld a nut on the underside of the plate at each hole, thus avoiding the necessity for threading the holes in the plate. Shims, wedges, or screws are usually removed after the grout has hardened.

Grout consistencies vary from fluid mixtures that flow into place to stiff mixtures of damp-earth consistency that must be tamped into place. The shrinkage and strength of the grout are influenced by the amount

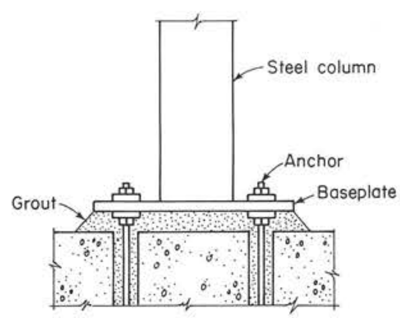



**Fig. 26. Grouted column baseplate with grouted anchor bolts. A grout face sloped 45° from the plate is used to prevent cracking. Anchors embedded in original concrete are also used.**

of water used. As the amount of water is increased, shrinkage increases and strength of the grout decreases. The amount of water, therefore, should be kept to a minimum and should be as carefully controlled as are the other materials.

The top of the hardened concrete pier or foundation should be cleaned of laitance and dirt before setting the baseplate and should be well saturated with water before grouting. A form may be built around the baseplate, or sand dikes may be used to confine the grout. The top of the form should extend above the bottom of the baseplate.

Fluid grout mixtures are placed from one side of the baseplate or through one or more holes near the center of the plate. Placing should be continued at the one location until the space is entirely filled, the grout flows from under all edges of the plate, and the level of grout is higher than the bottom of the plate. A stiff wire moved back and forth in the grout will help to release entrapped air, distribute the grout and assure more complete contact with the bottom of the plate. When grouting is done through a hole in the plate, a funnel or pipe fitted into the hole will provide pressure to force the grout into place.

Stiffer mixtures can be placed from the edges of the baseplate and tamped into position with a board, steel bar, or other tool. In this case, the mixture should be of such consistency that when a sample is squeezed in the hand only enough water will come to the surface to moisten the hand. Tamping should not be so hard as to raise or otherwise displace the plate.

## Machine Baseplates

Grouting of machine and other equipment bases is done for a number of reasons: (1) to take up irregularities in the foundation and bedplate to assure that the machine rests firmly and properly aligned on the foundation, (2) to properly transfer loads to the foundation, (3) to prevent lateral shifting of the machine, and (4) in some cases to increase the mass of the bedplate for the purpose of reducing vibration. Anchor bolts are used to hold the machine down, but any lateral thrust should be resisted by the grout against which the ribs of the bedplate bear. Bolts should be tightened only enough to hold the machine snugly against the foundation and prevent vibration. Bolts may fail when, in addition to high initial load, they are subjected to repeated stresses due to operation of the machine. An insufficient height of grout inside the machine base is sometimes the cause of such failures. The procedures used for setting machine bedplates are similar to those used for column bases.

Where there is a possibility of oil or water flowing under the bedplate, the grout should not extend up around the outside of the bedplate but should be cut off flush with the side faces or sloped away from the lower edge. There is also the possibility that grout on the outside may crack and break off due to lateral movement of the bedplate.

Large bedplates may be provided with several holes through which the grout can be placed, although placing is often done from the edge and is generally as satisfactory as placing through holes. Forms for retaining the grout are usually built of wood. Formwork for fluid or flowable grout placed from one side should be 2 to 4 in. from the edges of the bedplate receiving and expelling grout. The form should be up to 1 in. from the plate on the sides parallel to grout flow. All forms should extend at least 1 in. above the highest grout level under the baseplate. When placing is done by pumping through holes, the forms are usually built 4 to 6 in. outside the bedplate as shown in Fig. 27a. Again, forms must be built to a level of at least 1 in. above the bottom of the plate or highest grout level. Excess grout can be cut away when it has stiffened but before it has thoroughly hardened, and the exposed surface outside the bedplate can be finished to desired texture.

When placing is to be done from the side of the baseplate and grout is to be placed to a higher level than the lower edge of the plate, it is necessary to provide a vent in each recess so that air can escape. If

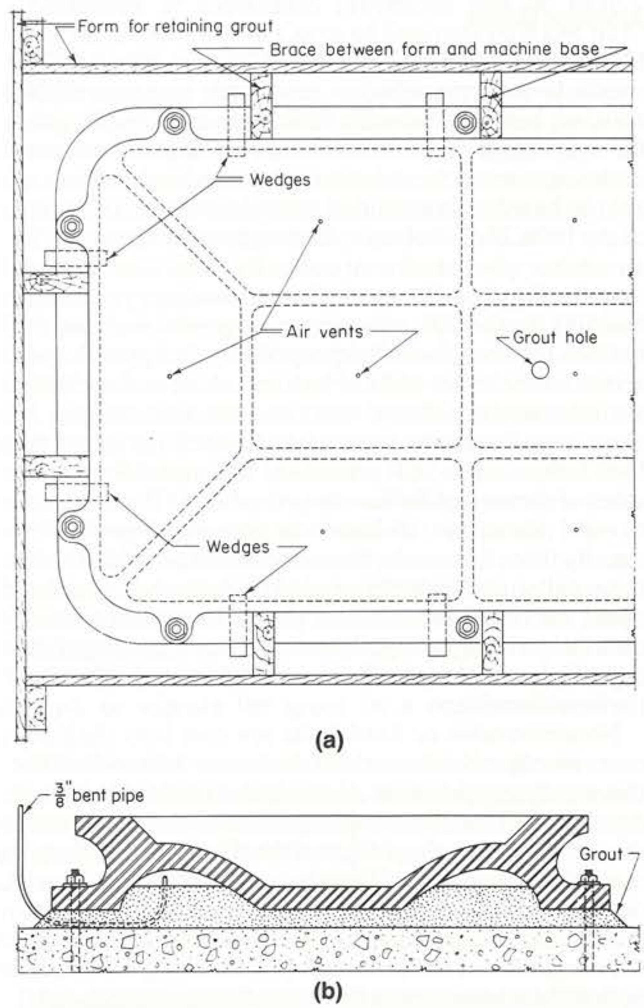



**Fig. 27. (a) Machine base with wood form in position for grouting. Observe locations of air vents and grout holes. (b) Machine base showing alternate method of venting pockets.**

not provided by the manufacturer, small holes of 1/4-in. to 1/2-in. diameter may be drilled in the bedplate for this purpose. Instead of vent holes, U-shape pieces of 1/4-in. or 3/8-in. pipe may be used under the lower edge of the bedplate with the ends extending above the level to be grouted, as illustrated in Fig. 27b. In some cases the air is exhausted by connecting a hose from the pipe to the intake of a compressor or to an ejector. A short length of gage glass can be inserted in the hose to guard against drawing grout into the compressor. The compressor intake is throttled to regulate the pressure.

To bring the machine to proper level, wedges and shims are usually provided to each anchor bolt. After the machine has been leveled and aligned, the nuts on the anchor bolts are tightened to bind the machine firmly into place against the wedges. Wedges may be of steel or hardwood, but wood wedges are suitable only for small machines. Wood wedges should be removed. Removal of steel wedges is left to the discretion of the contractor. If they are to be removed, however, care should be taken to see that all are removed, as a single wedge left in place may cause damage.

## Anchor Bolts

Many types of anchor bolts are used. In general, they can be broadly classified as removable and nonremovable, or fixed. Removable bolts are usually provided for very large machines because of the difficulty of lowering the machine onto rigidly fixed bolts. Removable bolts must be provided with sleeves the full length of the bolts. Such bolts are fastened at the lower end by an anchor plate and nut or cotter. The anchor plate may be simply a flat steel plate, an ordinary cast-iron building washer, or a cast-iron plate with lugs on the bottom, or one of several proprietary designs. To gain access to the lower ends of bolts, pockets or handholes are cast in the sides of the concrete foundations. In very large foundations, tunnels to the interior of the foundation are often provided, with pockets in the sides of the tunnel for access to the bolts. The diameter or side dimension of cast-iron plates and washers is usually from four to six times the diameter of the bolts, the smaller multiple being used with large bolts. Steel plates are usually square and somewhat larger, the side dimension being about eight times the diameter of the bolt. Holes in the plates are usually 3/8 in. larger than the bolt diameter.

Nonremovable or fixed bolts are cast into the fresh concrete. Standard machine bolts are often used for the smaller machines. A straight headless bolt will develop sufficient bond with concrete—enough to equal the tensile strength of the bolt—if it is embedded in the concrete to a sufficient depth. That depth will depend on factors such as the strength of the concrete, the tensile strength of the steel used in the bolt, and the roughness of the bolt shaft (for example, a threaded bolt will bond better to concrete than a smooth bolt). The head on a bolt provides additional anchorage. Small bolts, 1 1/4-in. diameter and less, are often hooked at the lower end and larger sizes may be provided with a nut and washer or plate to secure mechanical anchorage. U-bolts and plates or pieces of angle iron to which two or more bolts are attached are sometimes used.

If some adjustment of the bolt is considered necessary, sleeves for the upper part of small bolts and for the full length of bolts over 1 1/4 in. diameter may be provided and these sleeves later filled with grout. Partial sleeves vary in length from 4 in. up, but in general should be from 10 to 15 bolt-diameters to provide sufficient lateral adjustment of the top of the bolt. Drilled holes in bedplates are usually 1/8 in. larger than the bolt for bolts up to 7/8 in., 1/4 in. for 1-in. to 2 1/2-in. bolts, and 3/8 in. for larger bolts. Cored holes in concrete are 1/4 in. larger or more than corresponding drilled holes. Because of these small clearances, fixed bolts must be placed very accurately.

Sleeves may be of thin sheet metal, pipe, plastic, or other material. They vary in size but it is desirable to make the sleeve diameter about twice the bolt diameter, with a minimum radial clearance of not less than 1/2 in. around the bolt. Sleeves that are to be grouted usually extend 1/2 in. above the level of concrete in the foundation. A board holding them in position at the top will prevent concrete from entering the sleeves. A washer may be used at the lower end of full-length sleeves to prevent concrete entering at that end.

A number of proprietary anchor-bolt sleeves are made of heavy one-piece plastic construction. The anchor bolt is inserted into a hole in the bottom of the sleeve and threaded through a hole in the top to the required projection. The assembly is bolted to a template in proper position before concrete is cast. After the concrete has hardened, the template is removed and the top portion of the sleeve is cut out with a knife. The anchor bolt can be adjusted for accurate alignment before grouting the pocket formed by the sleeve.

Templets that have been carefully designed and constructed are required to hold bolts and sleeves within the necessary tolerance while placing concrete in foundations. They are usually made of wood but sometimes steel sections or plates are used. Reasonably skilled workmen should be able to set anchor bolts to a tolerance of 1/4 in. using a wood templet. If closer tolerance is required as in some of the larger foundations, a steel templet is recommended. A steel plate 1/8 or 1/4 in. thick, held in place by wood framing, may be used, and occasionally the baseplate itself can be used as a templet. Spotting and drilling the holes in the templet after all the forms and templets have been positioned generally give the best results. Templets are usually attached to the foundation forms, but if there is likely to be any movement of the forms it is better to support the templet entirely independently of the forms so the movement will not affect alignment of the bolts. In any event, the templet must be rigid enough so that bolts are not disturbed by workmen bumping the templet or standing on it while placing concrete.

To keep the bolts accurately aligned during concrete placement, it is necessary to provide some means for holding them other than merely allowing them to hang from the templets. Nuts and washers, drawn up tight, on the underside as well as on the topside of the templet, are helpful. Diagonal braces, spotwelded or wired to the bolts, are sometimes used to keep the lower ends of bolts from getting out of line.

When placing concrete in the foundation, care should be taken to puddle or vibrate the concrete around the bolts without disturbing their position. After the concrete has been placed but before it has hardened, it is advisable to check the position of bolts and to be sure that they stand vertically.

When bolts are to be placed in hardened concrete it is necessary to drill holes larger than the bolt, then fasten the bolt in the hole. The holes are often made with star drills. Electric rotating drills have been used for smaller holes up to about ¾ in., and core drills are used for holes larger than about 3-in. diameter. Attempts are sometimes made to make the hole larger at the bottom than at the top. One method when using a star drill is to drill the hole vertically a few inches, then tilt and rotate the top of the drill to form a tapered hole. Another method is to drill the hole vertically the full depth; then a smaller drill held at an angle is used to taper the bottom of the hole.

While various materials have been used to fill the annular space around anchor bolts set in drilled holes, nonshrink cement grout is widely used because it has proved very effective in bonding the bolt securely in place. A minimum clearance of ¼ in. around the bolt is desirable for grouting, although clearances of ⅜ to ½ in. are better. Bolts fitted with washers are used in some cases to increase anchorage, but of course larger diameter holes are then necessary.

When the hole is ready to be grouted it should be free of water, particles of concrete, and other materials. Bolts free to move can be moved up and down a few times to free the grout of air and obtain consolidation. When the bolt is fixed, care should be taken in placing the grout to entrap as little air as possible; a small rod or stiff wire can be used to puddle the grout.

As in all other work in which portland cement is used, grout used in setting column or machine bases and anchor bolts should be protected from rapid drying. Exposed surfaces of freshly placed grout should be protected for a few days by covering with burlap that is kept wet or protected by other means. This precaution will prevent crazing and cracking that accompany rapid drying. It also produces a stronger grout having a higher bond value.

There is a wide array of proprietary concrete anchors for fastening objects to concrete. This discussion has been primarily concerned with cast-in-place anchor bolts and bolts set into drilled holes using cementitious grouts. For more information, see "Fastening to Concrete," *Concrete Technology Today,* PL831B, Portland Cement Association, March 1983, and "A Guide to Concrete Anchors," by Paul Hollenbach, *The Journal of Light Construction,* Vol. 7, No. 6, March 1989, Richmond, Vermont, pages 39–45.

## Grout

Proprietary preblended nonshrink grout, meeting ASTM C 1107 or Corps of Engineers specification CRD-C621 is usually used for grouting machine bases, column baseplates, anchors, and joints in precast panel construction. Preblended nonshrink grout, usually packaged in bags, contains cement, dry sand, water-retentive admixtures, and expansive admixtures or ingredients to which only water is added at the jobsite. Unlike plain grout, nonshrink grout is usually chosen because it is formulated to have no shrinkage in the moist state and have little to no bleeding; it usually expands slightly to squeeze out excess water and holds firmly against the item grouted. If grout shrinks or bleed water collects at the surface, a steel plate, for example, will not be bonded to the grout and will not be properly supported. If grout expands in the unhardened state and shrinks after hardening, a void can also develop. Excessive expansion of grout after hardening can move the grouted item and severely crack the grout. Field-proportioned nonshrink grout, with 1 part cement to 1.5 to 2.5 parts sand by weight plus special admixtures, is usually used only on very large projects. All grouts should be tested for specification compliance. Also see the section on "Volume Changes" under "Grout Properties" for more information on nonshrink grout.

Shrinkage or expansion properties can be tested using the procedures in Corps of Engineers CRD-C621, ASTM C 1090, or ASTM C 827. CRD-C621 and ASTM C 1090 measure hardened, nonevaporative volume change from the time placed after unhardened grout is restrained. ASTM C 827 measures volume change in the unhardened state (evaporable or nonevaporable condition) but does not restrain the unhardened grout.

Compressive-strength test cubes (ASTM C 109) must be restrained from all sides to simulate the confined conditions common to these grouting applications. Compressive strength is generally 5000 to 8000 psi. Consistency tests, such as the flow-cone test (ASTM C 939) or flow-table test (see ASTM C 230 and C 827) can give an indication of the workability, placeability, and working life and can be used as a quality-control measure. Working life is around 10 to 45 minutes. Too short a working time (rapid stiffening) can result in ineffective placement and consolidation, voids, loss of contact area with the grouted element, cold joints, blockage, and other problems if grouting is not performed in a very timely manner. Excessively long working time can allow bleeding and water pockets. The working time should be sufficient to pump, plunge (tamp), or vibrate the grout in a comfortable time period.

Metallic and nonmetallic nonshrink grouts are available. Both contain cement, mineral aggregate, and admixtures, but metallic grout also has a metallic aggregate. Older catalyzed metallic grouts relied on oxidation of metallic particles for expansion whereas modern metallic grouts usually have expansion systems (often with air- or gas-forming materials) like nonmetallic grout.

If nonshrink grout is not available, a regular stiff (dry pack) sand-cement grout can be used, but with great caution (see Fig. 23). Dry-pack grout has about 2.5 to 3 parts sand to 1 part cement by weight. Settlement or shrinkage of the grout can be reduced to a minimum by delaying its placing. The grout should be mixed, then allowed to stand in a mortar box or other container for about 1 to 2 hours to allow prehydration, then be remixed thoroughly without adding water. It is desirable to keep the mortar box covered to prevent evaporation. Dry-pack grout must be rammed or tamped into place and therefore is difficult to use. Tests should be run to make sure this grout and procedure are acceptable for particular projects.

## Preparation for Grouting

Concrete surfaces to be grouted must be clean and free of curing compounds, oil, coatings, and dirt. The surface should be roughened to a depth of 1/4 in. by sandblasting, waterblasting, lightweight chipping, or other methods to provide a better mechanical bond (see ASTM D 4258 and D 4259). The surface can be roughened before the concrete is hardened. The metal surfaces to be grouted, such as machine bases, and column baseplates, should be thoroughly cleaned to expose bare metal just before grouting to provide maximum bond between the grout and metal. Holes for anchors should be cored or drilled and must be clean and free of water, dust, and debris. Water can be blown out of grout holes with oil-free compressed air. Machine or structural elements that must not be bonded to the grout should be covered with plastic sheeting or a debonding agent. Concrete surfaces should be moistened for about 24 hours before grouting to prevent moisture loss from the grout to the concrete; however, no free-standing water should be present while grouting.

Foundation plates should be leveled and set to the desired location by shimming or adjusting the leveling and locking nuts. The minimum clearance between the plate and base concrete should be 1 in. plus (1) 1/2 in. for each foot of flow length over 1 ft for flowable grout, (2) 1 in. for plastic grout, and (3) 1/4 in. for fluid grout. Pumped grout need not have extra clearance. Dry-pack-grout clearance should be 1 to 2 in. (dry-packing should be limited to about 1 1/2 ft in any one direction). Spaces greater than 3 in. deep can be grouted with a pea-gravel grout to reduce temperature rise and volume change. If pea gravel is not available, 1- to 3-in. lifts of nonshrink grout can be used. Equipment anchors should be a significant distance away from the edge of the grout face to avoid cracking. Expansion joints every 3 to 4 ft and uniformly spaced reinforcing steel should be considered for very long grout placements to minimize cracking. To avoid rapid setting of the grout, do not let the steel plates get excessively hot in the sun; also, do not let them get so cold that hardening of the grout may be retarded or the grout may freeze.

Forms, if needed, should be properly secured and form-release agents applied. The grout space should be designed to avoid air entrapment. In large baseplates, use air relief holes at each point where air may be trapped and use grouting holes to provide grouting access (Fig. 27). Grout holes should be spaced no more than 4 ft apart and they should be 3/4 in. to 2 in. in diameter for pressure grouting and 3 in. to 6 in. for free-pouring grout.

A 2-in.-diameter hole in the concrete should be used for anchors an inch or less in diameter. Larger anchors should have a hole diameter of twice the bolt diameter. Often the hole can be filled with grout first and then the anchor inserted into the hole and vibrated. Drilling anchor holes after a machine is in place is an efficient and accurate method that avoids the chance that preset anchors may need to be moved due to placing inaccuracies or machine changes.

## Mixing and Placing Grout

Grout for baseplates, anchors, and precast-panel joints should be mixed to a uniform condition in a horizontal shaft, mortar mixer. Only the specified amount of water should be added so as not to exceed the required water-cement ratio. The water is added to the mixer followed by the dry ingredients. The grout should be mixed for 3 to 5 minutes or as specified by the product manufacturer. The water content and consistency of the grout depend upon the grouting application and grout product. Small placements with easy access can use a dry-pack or stiff plastic grout with a nonsag consistency that does not need forming (see Fig. 23). Dry-pack grout should be compacted in layers of about 1/2 in., with the layer interface slightly roughened. Stiff plastic grout is used for small baseplates, filling joints between cast-in-place concrete and precast panels, and grouting short anchors. A flowable grout is thinner than a stiff plastic grout but thicker than a fluid grout. Flowable grout needs a form for placement and is used for grouting moderate-size plates, joints between precast concrete elements, and long anchors. Vibration, pumping, air holes, and grout holes can be used to assist in placing flowable grout in difficult locations such as those with large plates, shear keys, skirt plates, and waffle plates. A fluid grout with a self-leveling consistency and flow-cone time of 10 to 30 seconds can be used with watertight forms for tight clearances. In any case, it is usually best to use the stiffest grout that can be placed for the application to minimize both shrinkage and the formation of voids at the surface. Retempering (adding water and remixing to regain original consistency) should not be allowed as it can result in excessive shrinkage and reduced strength. Also see the section "Consistency" under "Grout Properties."

After mixing, grout must be placed within its working time. Grout must be placed in a continuous monolithic manner to avoid cold joints and to completely fill the grout space and produce intimate contact with the grouted item. The grout should be placed in one direction from one side to the other to monitor grout movement properly and to avoid air entrapment. Stiff-plastic, plastic, and flowable grout can be plunged and vibrated into place. Steel straps, moved back and forth, can facilitate placement. Vibration of fluid mixes should be avoided as vibration may cause bleeding and air entrapment.

Pumping is very useful to transport grout long distances, to grout several small or large locations, to grout difficult installations with many obstructions, and to grout long vertical and horizontal anchors. The pumpline nozzle should remain in the grout during grouting to avoid air entrapment and the placement should move from the back of the plate to the front. Before pumping, the pump, line, and nozzle should be flushed with water and a cleansing plug sent through the hose to check for blockage and to wet the line. Grouting should continue until the grout in the form is either (1) higher than the bottom of the baseplate or (2) higher than the highest required grout level.

After placement but before final set, the forms can be removed, the grout cut back at a 45-degree angle down from the baseplate to the concrete base, finished with a wood float or brush finish, and cured at 40 to 90 degrees F with wet burlap or plastic sheet for 7 days or as specified. To avoid edge-cracking and spalling, a 45-degree grout face is recommended (see Fig. 26), although a vertical, flush grout face is also satisfactory. Inadequate curing, early wetting and drying, or excessive finishing can cause hairline cracks. Machinery can be put into service immediately following the grout curing period. References 7, 43, 63, 65 and 71.

## PREPLACED-AGGREGATE CONCRETE

Concrete can be made by injecting a cement-sand grout into a mass of preplaced coarse aggregate. This method of placing concrete is especially adaptable to underwater construction because of the ability of the grout to effectively displace water surrounding the aggregate. It is adaptable to repair work and in general to new structures where placement by conventional means may be difficult because of the extreme congestion of reinforcement or embedded items.

Where concrete of low volume change is required, preplaced-aggregate concrete has a marked advantage over normal concrete; because of point-to-point contact of the coarse aggregate, its drying shrinkage is reduced 50% or more. The low drying shrinkage (along with thermal and strength properties similar to normal concrete) makes preplaced-aggregate concrete an excellent repair material as few stresses would exist at the old and new concrete interface. This method of placing concrete has been used in the construction of bridge piers, atomic reactor shielding, heavyweight concrete placement, reactor vessels, and architectural concrete. It has also been used to form plugs for outlet works in dams and tunnels, for embedment of penstock and turbine scroll cases, and for a variety of repair work.

While general contractors can train their crews to do this work, it usually is subcontracted to a specialty contractor with the necessary equipment and an experienced crew.

### Materials and Proportioning

Grout for preplaced aggregate concrete usually consists of (1) cement (ASTM C 150 or C 595), (2) pozzolan (ASTM C 618), (3) fine aggregate meeting the grading in Table 8 and requirements other than grading of ASTM C 33, and (4) admixtures (ASTM C 494), particularly grout fluidifiers (ASTM C 937) to reduce bleeding, water content, cement content, and water-cement ratio. Retarding admixtures (ASTM C 494) also are used to keep the grout plastic for long placing times and to allow insert pipes to remain in the grout for long periods. Air-entraining admixtures (ASTM C 260) can be added to improve freeze-thaw resistance.

The preplaced coarse aggregate (not in the grout) must be clean and meet the grading requirements in Table 7 and the requirements other than grading in ASTM C 33. The aggregate is usually graded to exclude sizes under ½ in. and to have a void content of 35% to as high as 50%. One cubic yard of preplaced-aggregate concrete uses 27 cu ft of coarse aggregate by bulk volume, due to the point-to-point aggregate contact.

**Table 8. Gradation Limits for Coarse and Fine Aggregates for Preplaced-Aggregate Concrete**

| Sieve size | Grading 1<br>For ½ in. minimum size coarse aggregate, percent passing | Grading 2<br>For ¾ in. minimum size coarse aggregate, percent passing | Grading 3<br>For 1½ in. minimum size coarse aggregate, percent passing |
|---|---|---|---|
| Coarse aggregate | | | |
| 1½ in. | 95–100 | — | 0.5 |
| 1 in. | 40–80 | — | — |
| ¾ in. | 20–45 | 0–10 | — |
| ½ in. | 0–10 | 0–2 | — |
| ⅜ in. | 0–2 | 0–1 | — |
| Fine aggregate | | | |
| No. 4 | — | — | 100 |
| No. 8 | 100 | 100 | 90–100 |
| No. 16 | 95–100 | 95–100 | 80–90 |
| No. 30 | 55–80 | 55–80 | 55–70 |
| No. 50 | 30–55 | 30–55 | 25–50 |
| No. 100 | 10–30 | 10–30 | 5–30 |
| No. 200 | 0–10 | 0–10 | 0–10 |
| Fineness modulus | 1.30–2.10 | 1.30–2.10 | 1.60–2.45 |

Adapted from Reference 40.

The water to cement plus pozzolan ratio usually ranges between 0.4 and 0.5 by weight and the ratio of cement to pozzolan is around 3 to 1 by weight for normal strength (3000 to 5000 psi) concrete. The amount and size of fine aggregate used in the grout depends on the strength, pumpability, and void-penetrability requirements. A ratio of 1 part cementitious material to 1 part sand by weight is common for structural applications. Massive applications will use a ratio of up to 1 to 3 with grading 3 aggregate. An example of a 3000 psi and 4000 psi mix (at 28 days) would be a 2:1:3 mix and 3:1:4 mix (cement:fly ash:sand). Coarse aggregate content of the final concrete product is more than is used in conventional concrete.

The consistency of the grout when tested in the ASTM C 939 flow cone should have efflux times (flow times) of about 22 seconds for walls and repair work, 18 to 26 seconds for underwater and mass concrete placements, and 35 to 40 seconds for high-strength and special applications. The composition and consistency of the grout is related to the coarse-aggregate size, mixer-charging sequence, mixing time, and injection procedure. The grout must be proportioned in the laboratory according to ASTM C 938. The following tests are used to establish grout mix proportions and properties: flow—ASTM C 939; expansion and bleeding of freshly mixed grout—ASTM C 940; water retentivity—ASTM C 941; and compressive strength—ASTM C 942. The compressive strength and density of preplaced-aggregate concrete can be determined by ASTM C 943 cast cylinders or by core testing.

## Preparation and Placement

Conventional forms may be used for preplaced-aggregate concrete but they must be properly aligned, rigidly supported, and sufficiently watertight. If the forms are not watertight the grout may leak through. Certain nonhardening joint sealants should not be used to seal forms as the sealer may yield under the grout pressure. The forms must resist the fluid pressure of grout normally weighing 125 to 130 pcf.

For repair work, deteriorated concrete must be removed to expose clean, sound concrete before placing forms, which should be at least 3 in. from the exposed concrete surface.

## Delivery, Insert, and Vent Pipes

A single-line pipe system is preferred over manifold systems to properly distribute the grout within the aggregate. The line should be of a size able to deliver grout at a velocity of 2 to 4 ft per second. Too slow a velocity can cause segregation and line blockage. An excessively rapid flow can cause grout to flow *over* adjacent grout (producing air pockets) rather than permeate through the aggregate upward from the bottom.

The grout delivery hose, rated at 400 psi or more, should have a diameter of 1¼ to 1½ in. for 500-ft lengths and 2 in. for 1000-ft lengths. Insert pipes of ¾ in. to 1½ in. diameter spaced 4 to 12 ft apart are used to inject the grout into the mass of preplaced aggregate. Schedule 40 pipe is used for depths of up to 50 ft. Greater depths may require Schedule 120 or other stronger pipe. The pipe should be placed vertically within 6 in. of the bottom or placed horizontally at various locations. Valves should be rapidly responsive and of the plug or ball type. As a rule of thumb, the grout will form a 1:4 (vertical to horizontal) slope in air and a 1:6 slope underwater. Vent pipes should be placed through blockouts or other obstructions to remove entrapped air or water and to allow grouting to proceed. Grout should come through the vent pipe upon filling the grout space.

## Placing Coarse Aggregate

After forms are in place and loose fine material is removed from the foundation or placement area, the washed and screened coarse aggregate can be placed into the forms. The aggregate should not be flushed with water after it's in place to avoid stirring up fines that could coat the lower aggregate and interfere with bond to the grout or cause honeycomb. For underwater placements with fine materials present, the aggregate should be lowered in a manner that will minimize disturbance of any fine sediment. For dry placements, water can be slowly placed in the form through the grouting pipes to wet the aggregate for grouting and minimize disturbance of fines. The water level should be above the coarse-aggregate or grout level to maintain the aggregate in a saturated state. The saturated aggregate prevents water loss from the grout and grout thickening. The water is usually left in the form during grouting but it can be drained away just prior to grouting as long as the aggregate stays wet.

Coarse aggregate can be placed with buckets and flexible elephant trunks to prevent segregation, placed underwater through pipes to control the placing rate and minimize stirring up fines, or placed by bottom dump barges or self-unloading ships. Consolidation of the aggregate by vibration or rodding is usually not needed; however, rodding and air lancing can be helpful in areas with large amounts of reinforcement or with overhead repairs. Grouting should be done shortly after placing the aggregate in water to avoid fines from settling on the aggregate, especially in highly organic or sludge-laden waters.

## Grouting

The grout can be mixed in a (1) vertical-spindle paddle-type double-tub mixer (most common), (2) horizontal-shaft mixer for large jobs, (3) pan or turbine mixer, (4) revolving-drum concrete mixer, or (5) colloidal (shear) mixer that mixes cement and water at a high speed first, followed by mixing with sand in an open impeller pump. The grout is then transported with a positive displacement-type pump to the injection point. A gage on the pump assists in monitoring the grout placement.

Both the horizontal-layer and advancing-slope injection techniques start grouting at the lowest location in the forms or placement. The horizontal-layer method completes one layer of grout before the next layer is started; however, vertical insert pipes must remain embedded at least 1 ft in grout as they are withdrawn with each injection or layer. With horizontal insert pipes, grouting continues until grout flows through the next-higher insert or port. The next lift is injected through the insert above the completed layer. This continues until the formation of several layers fills the form.

The advancing-slope injection technique is used for wide (not deep) applications not suited for the horizontal-layer method. With advancing slope, the first set of inserts at the narrow portion of the form is grouted until the grout surfaces. The grout slope, usually 1:5 to 1:10 (vertical to horizontal), is advanced across the placement with continued pumping until the form is filled.

Injection rates vary from about 1 to 4 cu ft per minute depending on the pumping equipment, aggregate void content, grout fluidity, and type of placement. The grout's surface should be monitored constantly to control the placement. The grout surface can be observed through the horizontal inserts or, in vertical placements, can be observed by checking the grout depths in a 2-in.-diameter pipe with ½-in. slots. An underwater 1-in.-diameter float, resting on top of the grout, helps make the depth determination. The grout depth-check pipes are left in place and not removed after grouting. Electronic depth-detection systems are also available.

### Joints and Finishing

If grouting is delayed beyond the time the grout stays plastic, a cold joint can be allowed to form by pulling insert pipes out to a level just above the grout. Grouting is later continued by bringing the insert pipes near the hardened grout surface and slowly pumping grout to embed the ends of the pipes again. Bond strength across the joint is usually adequate as the coarse aggregate particles protrude from the previous grout layer into the new grout layer. Construction joints are formed like cold joints except the grout layer should be about 12 in. below the coarse-aggregate surface. If the grout is brought to the surface, the smooth surface must be abraded by chipping or sandblasting to resume construction.

The last layer or surface grout must be placed slowly enough to avoid displacing the aggregate. A removable wire screen can help hold surface aggregate in place. Although internal vibration should be avoided, external form vibration can help smooth the surface at the form.

Horizontal surfaces can be screeded or troweled by flooding the aggregate with grout, working pea gravel into the surface and finishing as per conventional cast-in-place concrete. The concrete is then cured like conventional concrete. See References 40, 44, 66, and 81 for further information.

## POSTPLACED-AGGREGATE CONCRETE

Postplaced-aggregate concrete is an alternate procedure to preplaced-aggregate concrete. With postplaced-aggregate concrete, the grout is placed in the form or cavity first, followed by placement of the aggregate. The grout mixtures can be proportioned with a lower water content since pumping through injection pipes is not necessary. The grout level must be kept above the aggregate. This method of placing concrete can be quick and economical. Much of the discussion on application and materials for preplaced-aggregate concrete also applies here. However, preplaced-aggregate concrete would be expected to have less shrinkage than postplaced-aggregate concrete because of the better point-to-point contact betweeen aggregate particles. Reference 35.

## RESTORING OLD STONE MASONRY BY PRESSURE GROUTING

This discussion is confined largely to pressure grouting old stone masonry structures of two types: (1) those with earth on the far side, such as retaining walls, abutments, and solid spandrel arches; (2) those not backed by earth, such as piers and open spandrel arches.

### Grout

The size of the particles in the grout and the consistency of the grout must be suited to the passageways it must follow. Neat grout will not flow freely into spaces smaller than about three times the largest cement particle, which, based on the 0.0028-in. opening in the 200-mesh sieve, would be 0.0084 in. These limitations also apply to other finely pulverized materials and sand.

Except in large cavities where thick mortar or concrete can be placed, sand should all pass the 30-mesh sieve and have a large portion passing the 50- and the 100-mesh sieves. Coarser particles will settle out of suspension and lose their coating of cement paste. Mortar sand is usually satisfactory.

The proportions of portland cement to sand will depend upon the size of spaces to be filled and will vary from a neat grout to about a 1:1 cement to sand mix.

Mixing is best done mechanically. It is best to put 50% or more of the mixing water into the mixer before the dry ingredients and then the remaining water. A continuous supply of grout is preferable to an intermittent one, especially for the larger job and where each hole requires a large volume of grout.

In determining the consistency to use, it is desirable to start with a definite volume of mixing water and 1 bag of portland cement. For grouting old masonry it should seldom be necessary to use more than 10 to 12 gallons of water per bag of cement. If this first mixture is taken readily, then, with the same amount of water and more cement, repeat the trials until the consistency is satisfactory. Grouts with as little as 4½ gallons of water per bag of cement have been handled.

## Holes

In general, a suitable size for the hole is 1½ in. in diameter, and the number of holes provided should be liberal. Holes are usually drilled perpendicular to the face; although, for grouting footings, holes may be drilled at 45 degrees or other convenient angles.

Where it is desired to form a blanket of grout at the back of a wall or arch, the holes should be drilled entirely through the wall. When grouting in such holes, the contractor should be on the alert to detect the escape of wasteful quantities of grout.

In some cases, holes drilled vertically from top to bottom of a wall or pier, even penetrating the foundation, are advisable. With this method, pipe smaller than the drilled holes and having a short section of flexible hose (packers) near their ends, are inserted nearly to the bottom of the holes. Progressively the pipe with the packers are pulled up as grouting is completed at various levels. The grout pressure causes the packer to swell and confines the grout flow to the lower layers.

## Pressure

It is rarely necessary to use pressures in excess of 100 psi and pressures greater than 25 to 50 psi are seldom needed. Pressure should be steady to ensure a continuous flow of grout. If pneumatic equipment is used, it is important to cut the supply of air as soon as grout flow ceases. Where the grouting equipment is located above the point of application, gravity without the assistance of a grout pump will often be sufficient.

## Mixing Equipment

It is important that the grout supply be continuous to keep the grout pumps working effectively. Five bags of cement, 5 cu ft of sand, and enough water to give the desired consistency can be mixed with hand tools in a wood box 16 ft long, 2 ft wide, and 1 ft deep. Smaller mixing boxes are used where less grout is to be handled.

Power-driven grout mixers are preferable to hand mixing, although a small concrete mixer with the clearances in back of the mixer blades closed and splash plates fixed at the discharge chute may be used. It is desirable that the mixer discharge through a screen into a tank or a sump equipped with an agitator.

Paddle blades on a shaft mounted in a horizontal cylindrical tank turned by motor are also satisfactory. The agitator tank serves as an air chamber from which the grout may be discharged into the delivery line. A small "mud jack" has also been satisfactorily employed.

Where the mixer and pump are combined in one unit, the dry material should be screened before mixing. If the mixer and pump are in separate units, the grout should pass through a screen before it enters the pump.

## Discharge Lines

The grout pump should be placed near the point of delivery. In some cases it is desirable to insert short (8-in.-long) pipe nipples into the drilled holes. These nipples are threaded to receive a pipe coupling from the delivery line. In many cases if the delivery pipe has a rubber-hose terminal, the pressure of the grout will hold it tightly enough in the hole without other provision.

Where a single line is used for grout delivery, a blowoff near the discharge end of the line is useful to prevent plugging, to release air pressure and to clean out the line. This may be easily arranged by supplying a tee just back of the end plug cock and attaching a 1-in. plug cock and pipe to the side outlet of the tee.

## Grouting Procedure

Where the objective is to solidify the interior of old stone masonry, grout holes should be drilled to within a short distance of the opposite face. The sealing or pointing of joints should be deferred until after pressure grouting so that they may serve as vents for the water and air displaced as grouting progresses.

The order of grouting of holes—whether from top to bottom, or vice versa—is usually immaterial if the air and water are allowed to escape. Grouting should be continued at any one hole until refusal. Should the grout escape from an adjacent nipple or hole it should be plugged or capped and any seams, cracks, or joints through which grout escapes should be calked with paper or burlap as soon as thick grout appears. Grouting should progress around a structure until all holes at any one level have been completely grouted.

The choice of grout consistency is made by trial as already described. It is frequently advisable to pump clear water into the holes at the start of operations in order to wash out dirt and other fine material, as well as to establish a guide for the proper consistency of the grout. After the completion of each grouting operation or temporary shutdown, it is advisable to force clear water through the pump until the discharge line flows clear, after which the pump cover should be removed and the valve chambers thoroughly cleaned. Reference 8.

# ROCK GROUTING

Portland cement grout placed under pressure is used to seal fissures, cracks, and bedding planes in limestone, sandstone, shale, and other rock formations. This makes rock foundations under dams structurally adequate (by improving bearing capacity of unstable or heavily fractured rock) or watertight (by using grout curtains—Fig. 28). Concrete tunnel linings are often grouted to seal the space between the concrete and rock or soil. The grouting of tunnels also strengthens and waterproofs these underground excavations. Although the following discussion is aimed at grouting rock foundations under dams, it is also applicable to grouting for other related purposes.

## Extent and Location of Grout

Surface geology, cores from drill holes, and results from water pressure tests are important guides in planning a grouting program. In addition, refined pressure testing, the electric resistivity log, the borehole camera, and case histories should be used to evaluate the grouting and estimate length of grout holes and quantities of materials required. The natural groundwater table is a useful indicator of subsurface conditions.

The foundation of a high dam must be grouted more carefully and to a greater depth than is necessary for a low dam because of the higher pressure that forces water through seams and cracks. A section of the foundation along the upstream edge of the dam must be made impervious to form a watertight curtain. This curtain need not be thick, but it must withstand the water pressure and must extend beyond the ends of the dam and to a depth that will prevent water from going around it. It must reach and make watertight any stratum of broken or seamy rock exposed to the surface in the reservoir area in the vicinity of the dam even if this stratum is below an impervious stratum at the damsite.

Grout curtains are made up of one or more lines of grout holes placed roughly perpendicular to the groundwater flow lines to cut off or reduce water flow. The depth increases with anticipated hydrostatic head. A rough rule of thumb is to place the grout curtain to a depth of two-thirds the dam's hydraulic height.

Area grouting (consolidation grouting) uses a regular pattern of closely spaced holes in shallow zones to increase bearing capacity and reduce groundwater flow and piping of dam materials. Cavity filling uses a sandy grout to fill voids.

Rarely is it necessary to grout rock with a permeability of less than $10^{-5}$ cm/sec. (1 Lugeon permeability unit); cement grout can be used to grout rock with permeabilities greater than this. Normal cement grout can be used in fissures as small as about 0.1 mm (0.004 in.) although successful cement grout permeation is often limited to 0.5-mm (0.02-in.) fissures and larger. Ultrafine cement can be used for smaller fissures. See References 15, 25, 35, and 36 (pages 129–151) for further information.

## Grouting Methods

A brief discussion of common grouting methods follows. A combination of more than one method at a time is commonly used.

The split-spaced method is performed by drilling and grouting primary holes first, usually 10 to 40 ft apart. After the primary holes are grouted, secondary holes are drilled between primary holes and grouted. Additional holes are drilled and grouted if necessary to split the spacing of the previous holes. This technique is used in conjunction with some of the following grouting methods.

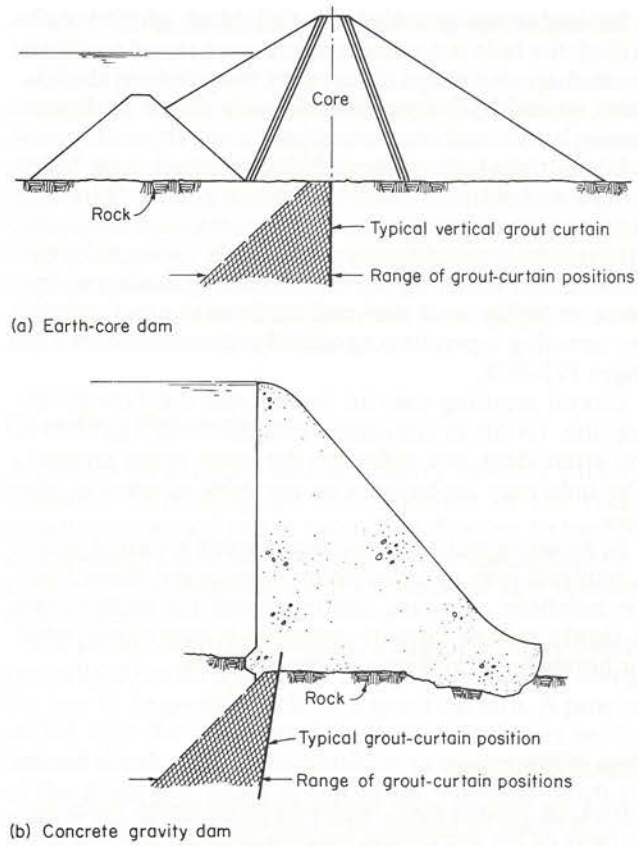



**Fig. 28. Examples of grout-curtain locations for dams.**

Ascending-stage grouting, also called stop grouting, packer grouting, and upstaging, is a preferred method in which the grout hole is drilled to its full depth. The holes are washed and pressure tested with water for 5 minutes. Packers (devices inserted in holes to localize grouting) are set and zones or stages are grouted at successive stops from the bottom to the top of the grout hole. The packers or expanding plugs are set at successively higher positions in the hole with each stage until the top is reached.

Descending-stage grouting, also called successive-stage grouting and simply stage grouting, consists of drilling the first-stage hole, washing and pressure testing it, grouting the hole, and then washing the grout out of the hole. After 24 hours, the next stage hole is drilled and the above procedure repeated for this and subsequent holes until the specified depth is achieved. Grouting pressure increases with each downward stage.

Series grouting is similar to descending-stage grouting, except that the grout hardens in the hole (is not washed out) and therefore the hole for the next stage must be drilled through the previous stage along with the rock below.

In single-stage grouting, the full depth of the hole is drilled; the hole is washed and pressure tested and then grouted in one stage. It is used in grouting shallow holes, about 20 ft deep, in relatively sound rock containing only small cracks and joints.

In multiple-hole or manifold grouting several holes are grouted simultaneously from one pump. Only one hole is grouted at a time with traditional methods. Multiple-hole grouting uses a manifold to control grout distribution (flow) and pressure. The grouting equipment is highly instrumented to monitor and control the grouting operation accurately. See Reference 32, pages 792–808.

Circuit grouting uses an in-flow and out-flow grouting line. Grout is circulated in and out of the hole if the grout does not infiltrate the zone being grouted. The hole may be entirely or partially grouted at one time.

In gravity grouting, also called tremie grouting, grout is pumped into an open hole. When grout flows from the borehole, pumping continues and the tremie pipe is slowly raised. Gravity grouting is commonly used for borehole backfilling and cavity filling.

## Grout Mixtures

Grout for sealing rock foundations to make them watertight or for increasing bearing capacity should consist of portland cement and water. The water-cement ratio by bulk volume* normally ranges from 0.6:1 to 6:1; however, mixtures used may vary from thick grout, with a water-cement ratio of 0.5:1 to 1:1, to very thin grout with a water-cement ratio of 6:1 to 30:1 depending on conditions or technique. The general approach of thickening the grout as grouting progresses has been very successful. The goal of thickening is to use the thickest practical grout that can be placed without affecting reasonable penetration. Initial grouting with thick grouts can lead to bulking and inadequate filling of fine voids. Continued use of unnecessarily thin grout leads to formation of bleed-water pockets. Thin grout is also less durable than thick grout in the presence of percolating groundwater.

Thick grout is used when openings are large and it is necessary to plug them quickly to prevent useless grouting of large areas or waste of grout that escapes to the surface. However, thin grout can be forced into small openings at lower pressure than thick grout. When grout escapes to the surface, or an excessive amount is taken by a single hole (more than 20 cu ft in a 15-minute run for 50-ft stages), grout is being wasted and the hole should be grouted with thicker grout. Experience and judgment are needed to determine best consistency.

A water-cement ratio of 2:1 by volume is considered an optimum and very successful basic mix. A ratio of 3:1 is often used and suggested for the starting mix for fine cracks (0.75 mm) and a ratio of 1:1 for wide cracks (1.25 to 2.5 mm). Grouts with water-cement ratios greater (thinner) than 5:1 have been known to be nondurable under certain circumstances. This is due to their being leached away by water seepage over time and incomplete grout filling caused by bleed pockets. Also, overly thin grouts can be washed away with seepage during grouting. The thickest grout that will penetrate the rock should be used to maximize durability of the grout. In light of this, the practice of thickening the grout as grouting progresses is very beneficial. For example, the starting grout may have a water-cement ratio by volume of 5:1 to 2:1 and as grouting progresses, the grout water-cement ratio is reduced to a point that does not adversely affect the grouting. Suggested thickening steps are 3:1, 2:1, 1:1, 0.8:1, 0.6:1, and 0.5:1 (Reference 32, pages 317–331, and Reference 57). The time at which a grout is thickened depends on the grout take. Generally the steps are taken after a certain minimum period of time for the quantity of grout take to allow grouting of the finest voids. Grouting continues in stages until refusal. Too thick a grout chokes off the hole. Some engineers desire the minimum grout strength to be 700 to 1400 psi (Reference 32, page 291).

Depending on the availability of the right type of cement, a fine-grained cement is preferred because larger cement grains tend to form a "bridge" that prevents further grouting of a fissure. Cement for crack and joint grouting should be sufficiently fine to permeate very thin openings and be slow setting to prevent partial set and plugging of the grout system before the spaces are completely filled. Generally an air-separated cement with 100% passing a No. 100-mesh sieve (150-micron sieve) will be satisfactory. Fly ash, clay, or other pozzolans and very fine sand can also be used in some instances. Most regular portland cement particles are less than 75 microns (0.003 in.).

Very fine rock fissures, less than about 0.1 mm to 0.5 mm, are not always possible to grout with normal portland cement grouts because the cement particles are too large. Extra-fine-ground portland cement or microfine (ultrafine) cement with particles less than about 10 microns can be used in neat grout to grout voids that are too small for normal cement (see References 32, pages 77–91, and 37, pages 129–151).

Grout is mixed in paddle-type mixers powered by air motors or high-speed colloidal impeller mixers (necessary for mixes with bentonite). Vertical paddle-type agitators keep cement in suspension after mixing and maintain the grout supply for the pump. Colloidal mixers produce grout of greater uniformity, pumpability, and permeation than regular mechanical mixers.

## Pressures

The grouting pressure used depends on rock and fissure characteristics and the objective of the grouting. The U.S. rule of thumb for maximum pressure is 1 psi per foot of rock cover plus 0.5 psi per foot of soil overburden. European practice uses higher pressures, up to 4.4 psi per foot to better penetrate and dilate the fissures. Some specifications permit grouting at pressures equivalent to the hydrostatic head of water to be

*Powdered loose volume of cement.

resisted plus 40% or 50%. Others require pressures of two or three times the hydrostatic head. Pressures used on different projects have ranged from 0 to 1000 psi.

Care must be taken to prevent displacing rock by building up static pressure in horizontal seams. A lower grouting pressure can be safely used; however, it requires more holes than would otherwise be necessary.

It is often advantageous to cover the foundation with a layer of concrete several feet thick before grouting, especially where rock is badly broken. This permits higher initial pressures than would be safe without it. Grouting may be done through this concrete or from a gallery in the dam a few feet above the rock.

While the U.S. rule of thumb may allow 1 psi per foot of depth, the pressure to be used in grouting is not defined by any theory that can tell exactly what pressure to use. It depends on what pressure a given rock can withstand without fracturing or lifting, and this can be determined only from a field test.

It is of most importance to have experienced jobsite grouting supervision. The success and safety of the grouting program ultimately lie in the judgment of the field supervisor in adjusting and tailoring grouting techniques to the conditions encountered in each grout hole.

Grout pumps are available for low- to high-pressure grouting. Variable speed is desirable and the pressure and injection rate must be controllable. The helical screw-rotor-type pump and duplex-piston-type pump are most common.

### Grout Holes

Each grout hole should be properly located with respect to other grout holes and geological conditions. The hole should be angled to intercept the largest practicable number of joints and fractures, and the walls of the holes should be as clean as possible. Hole spacing starts with primary holes about 10 to 40 ft (typically 20 to 25 ft) apart; the holes are then grouted. Next secondary holes are drilled and grouted at regular intervals between the holes previously drilled. Curtain hole spacing as close as 2 to 10 ft may be required. Only in-place tests can show the effectiveness of grouting treatment with the final spacing defined by the results achieved.

Grout holes, about 1½ in. to 3 in. in diameter, should be drilled so that the least number of lineal feet of hole will effectively reach all areas to be grouted. In general, this will be accomplished by drilling holes in a plane parallel to the upstream face of the dam. In that plane, holes should be sloped so that each will cut the largest number of joints or bedding planes. Care must be taken to prevent holes from diverging widely and leaving ungrouted areas.

The most effective grout hole is drilled by equipment that does not plug the seams with sludge. A diamond rotary drill is the standard and preferred drill. Satisfactory results can be obtained with percussion drills on shallow holes where cuttings can be easily removed. However, percussion-type drilled grout holes using air to remove cuttings typically receive only 30% as much grout as diamond-rotary-drilled holes (Reference 27). After drilling, holes are washed and water-pressure tested.

Grout pipes should be fastened in the holes just deep enough to stand the pressure without blowing out. Some attempts have been made to clean out disintegrated and loose material from joints and bedding planes by drilling a series of holes and forcing water, compressed air, or a mixture of water and air from one hole to the next. It is neither possible nor necessary to wash out the soft material. Usually this process opens a channel in a seam from one hole to another, providing a means of escape for the grout.

### Grouting Procedure

A pattern of primary and secondary holes is usually followed. Depending on the condition of the rock, grouting is carried out in ascending (bottom to top) or descending (top to bottom) stages. The ascending procedure will be followed wherever possible as it is more economical.

For the ascending procedure, a row of primary holes, typically 20 to 25 ft apart, is drilled into the rock along the line to be grouted to form a grout curtain. A pipe is sealed into the top of each hole or a packer is set to desired depth. The grout machine is connected to one of the pipes and grout is forced in. The first batch is usually made very thin and will usually be taken at low pressure. If the hole continues to take thin grout at low pressure, it is evident that the grout is flowing outside the area where it is needed. The grout is then thickened as specified or until refusal at the highest safe pressure. Typical refusal criteria is about 1 cu ft of grout in 20 minutes at 50 psi, 1 cu ft in 15 minutes at 50 to 100 psi, and 1 cu ft in 5 minutes at pressures greater than 100 psi. The machine is then disconnected and moved to the next hole where the operation is repeated. When a section has been grouted to refusal at the specified pressure through the first shallow, widely spaced holes, a second row of holes (spaced evenly between the first) is drilled to the same depth and grouted in the same way. Drilling and grouting of holes is continued until the last holes take only enough grout to fill them and no more grout can be forced into the rock at the pressure used. The rock along the grouting line is thus consolidated so that it will resist displacement and water as a unit. See References 4, 16, 25, 27, 32, 35, 36, 37, 56, and 57 for more information.

## GROUND ANCHORS

Ground anchors are employed in construction whenever load on a structure or structural component may cause it to move upward or away from its foundation. Common applications for anchors are in ski jumps, lighthouses, towers, masts, chimneys, tall buildings, oil platforms, stabilizing dams and cliffs, weirs, retaining walls, mines, tunnels, pipelines, water tanks, coffer dams, roofs, and load tests.

The use of ground anchors is increasing dramatically as new uses for them are found and better anchoring techniques are developed. Anchors wholly in rock are easily protected against corrosion and can develop very great capabilities. Permanent rock anchors are constructed by established, time-proven methods and have an excellent record of performance.

Anchors in soils such as clay, silt, sand, or gravel are more complex in every respect. Because of the problems relating to drilling anchor holes in soils, removing the drilling debris, soil contamination of the grout, and waterproofing of the drill hole, permanent ground anchors in soil have rarely been used. Temporary anchors in soil, however, have become widely employed in basement or retaining-wall applications during construction.

A ground anchor with a mechanical friction-type lower anchorage is known as a rock bolt and is widely used in tunneling and mining for rock support. Portland cement grout provides adhesion between the rock and bolt and it protects the bolt against corrosion. One type of rock bolt uses a perforated sleeve and a stiff sand-cement grout. A grout filler sleeve is inserted into the drilled hole. When the bolt or ribbed bar is pushed into the sleeve through the grout, the grout is pushed through the perforation to tightly fill the space between the hole and bolt (Reference 26).

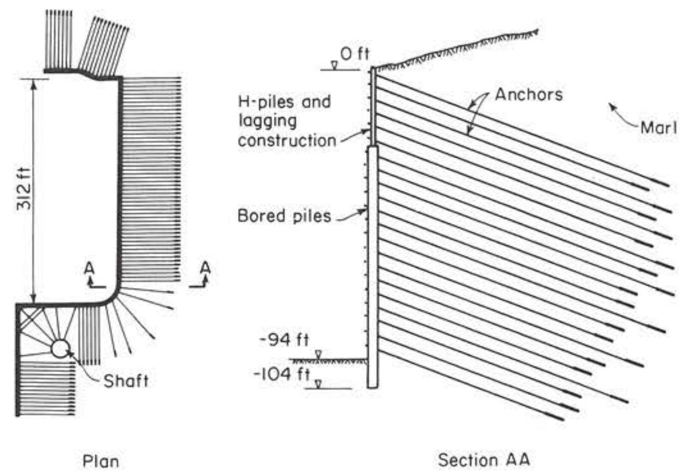



**Fig. 29. Plan of excavation for retaining wall illustrates the complexity of ground anchoring systems and the need to study the full site to avoid anchor installation in unexplored ground. Adapted from Reference 29.**

## Geological Review

The first and perhaps most important step is to review the geological environment in which the anchors are to be set. This review will indicate the feasibility of ground anchors as well as determine the design of the anchor. Both lateral and horizontal variations in the ground must be reviewed and the distance between investigation locations will vary with the ground structure. Accordingly, soil investigation should occur at least every 20 yards. Of equal importance is knowing the total area or dimensions where the anchors will potentially be used, to avoid placing anchors in unexplored soil (Fig. 29). A knowledge of the ground conditions cannot be overemphasized as minor variations can significantly affect the operation of an anchor system.

Thin layers of silt, sand, or clay can have a significant effect on the shear and softening characteristics of the soil. In some cases, air or water flushing of the bore hole can erode sand or silt-filled fissures. As a result, this can severely reduce or limit the amount of load that can be carried by anchors in clay or silt. With rock, any discontinuities, the orientation of the rock, and joint continuity, are all vital. Soil samples should be well documented and examined from each stratum and at maximum intervals of 5 ft in thick strata, along with intermediate samples for soil-classification analysis. If the strata is extremely variable, continuous sampling and analysis may be required especially in and around the area where the anchor will be located. In the area where the anchor will be located, soil analysis tests should be made at least every 3 ft in the bore hole. A continuous core should be recovered from rock strata, with core diameters of not less than 3 inches. Double- or triple-core barrels should be used when sampling difficult or weak rock. The density and stress-strain characteristics are also helpful. Long-term groundwater studies are also essential to the design of the project and the anchor system.

Classic soil properties should be studied. For example, the grading and permeability of the soil can influence the distance the grout will permeate. Plasticity indices in cohesive soils can dictate the type of anchor and drilling method. The shear strength of the soil should be determined as well as the effect the load will have on the soil characteristics. Data such as compressibility characteristics will indicate the possibility of any loss of prestressing. Uniaxial strength and sometimes tensile strength are determined on rock test cylinders.

## Grout Mixture

Ordinary hydraulic cements, including class G oil-well cements, are used, with consideration given to any special property such as sulfate resistance. Admixtures, if used, should be intended to increase workability, reduce bleeding, or slightly expand the grout. Admixtures should not have more than 0.1% chlorides, sulfates, or nitrates, and the use of calcium chloride admixture is usually forbidden. Many think the grout should have a minimum 28-day strength of about 5800 psi. The grout should bleed no more than 1% by grout volume. Water-cement ratio generally ranges from 0.35 to 0.5 by weight.

## Drilling

Drilling methods used include rotary, percussion or rotary-percussion mechanisms, and sometimes vibratory driving methods. Diamond core drilling is rarely used for anchor holes because of high cost and possible bond reduction due to the smoothness of the bore. Ideally, the drilling method should cause a minimal amount of disturbance of the surrounding soil. Care must also be given to hole stability to ensure that drilling or flushing does not lose soil. After the holes are drilled, they should be tested for watertightness by measuring the rate of water loss or gain in the drill hole. This will be useful in analyzing the amount of possible grout loss. If the water loss is greater than three liters per minute per atmosphere measured over 10 minutes, pregrouting should be performed.

### Grouting

The purpose of the grout in a ground anchor is to fix the anchor so that the applied loads are transferred from the tendon to the surrounding ground. The grout also protects the tendon against corrosion and fills voids or fissures in the ground prior to the installation of the tendons. Mixing is usually done with high shear action mixers to obtain a uniform grout. Grouting should be performed in a continuous operation; if a delay lasts longer than the setting period of the grout, the tendon should be removed and the grout flushed out. After the grout has achieved the specified strength, the tendon should be stressed to the required force and monitored to compare it with the behavior of other control anchors. The tendons should not be stressed more than 80% of their characteristic strength. After completion of the construction, the anchors should be proof loaded to 1.25 to 1.5 times the working load for temporary and permanent anchors, respectively. Proof loading will confirm the anchorage design and quickly pinpoint any major errors in the design or construction. This way the safety and performance of the anchor is ensured up to the proof load. Refer to References 29 and 78 for more information.

## SLABJACKING

Slabjacking is pressure grouting used to raise a depressed section of pavement or other concrete element by forcing a flowable grout under it. A slab can be restored to its original intended appearance and integrity. It is especially helpful in areas where subbases have been washed away or settlement has occured. Slabjacking can be used to raise and level walkways, patios, depressed or sunken floors, tennis courts, or pavement. When correctly done, slabjacking can be much more economical than slab replacement, it can be performed in a short period of time with minimal disruption to traffic and use of the slab.

### Equipment

Grout holes can be made with any type of drill that will produce a clean hole with no surface spalling or breakouts on the underside of the slab. Most drilling is done with pneumatically operated rotary percussion drills.

The mixer should be capable of thorough, homogeneous mixing and should be the positive shear type for thorough mixing. Some contractors use a high-speed colloidal mixer operating in the range of 800 to 2000 revolutions per minute. This creates a true colloidal mix that will keep the solids in suspension and resist dilution by the free water being displaced from under the pavement. For small jobs (for example, patio lifting), a mortar mixer is adequate.

The grout pump should be capable of applying 50- to 400-psi pressure at the outlet end of the discharge hose and a pumping rate as low as 0.1 cu ft per minute. The pump should be of the positive displacement type and should be equipped with horizontal mixing paddles. The agitation from such mixing maintains a uniform consistency and assists in feeding the grout to the pump's suction unit.

Grout packers are used to prevent the extrusion of grout from the injection holes. They are inserted in the holes and expand under the pressure of pumping. Hoses carry the grout to the injection holes, bypass lines ensure continuous circulation, and valve manifolds and pressure gages control pump pressure and volume. Wooden plugs are driven into the filled holes as pumping is completed to keep the grout from extruding. Stringline and blocks are used to check vertical alignment during slabjacking operations.

### Drilling

Grout holes drilled through a slab are 1¼ in. to 2½ in. in diameter and are spaced about 5 to 8 ft apart and 1½ to 2½ ft from joints and edges. Holes should be vertical and carefully drilled so that they are circular and wood plugs will fit tightly to completely stop grout extrusion when adjacent areas are grouted.

High-speed drills mounted on large rubber-tire tractors are frequently used for pavements (Fig. 30). The

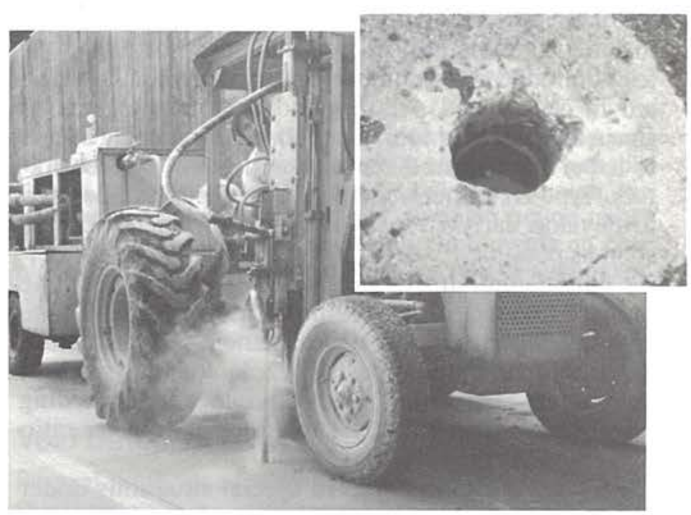


**Fig. 30. (a) Hole drilled through slab for pressure grouting. (b) Tractor-mounted drill and attached air compressor. Reference 31.**

drill frame is sometimes weighted to increase drill pressure. Units with a hammer weight of 45 lb are satisfactory; drills of greater weight and greater downward pressure can result in cone-breakout damage to the underside of the slab and subsequent radial cracking.

Depth of the grout holes will vary with underlying materials and construction. In general, drilling should be through both slab and subbase, as experience has shown that voids are often found just under the subbase. The exit hole of the grout-injection packer, however, should not be any lower than the bottom of the concrete slab to allow grout to fill all voids below the concrete. Where grout flow is difficult to get started, washing or blowing out a small cavity at the bottom of the grout hole will furnish a supply of grout to help initiate its flow to surrounding voids.

## Grout Mix

Materials for slabjacking grout must yield a mix that remains insoluble, incompressible, and nonerodable after it is put in place and has hardened. The grout must be flowable so that it can move through small openings to fill existing voids. At the same time the grout must have sufficient body to be able to displace free water from under the slab and must have adequate strength and durability. Sand-cement grout and neat grout are both used. Finely divided minerals or pozzolans are also often used. Sand-cement grouts typically contain 25% to 30% cement by volume and enough water to produce a flow time of about 20 seconds (ASTM C939 or Corps of Engineers CRD-C611).

Sand specifications are normally adjusted to meet local availability. The typical angular shape of most sands that tends to limit pumpability and flowability can be improved by the addition of bentonite to hold the sand in suspension. However, the strength of the grout is reduced by this addition. Lime and various types of pozzolans have been used where sufficient fines are not available.

Other admixtures used in slabjacking grouts have included (1) expanding material to offset shrinkage, (2) friction reducers or pumping aids to increase flow and aid in cleanup, (3) wetting and dispersing agents to give a more uniform mixture, (4) water-reducing agents to lower the required water content, and (5) accelerators. Type III cement, or special cements, can be used to develop early strength to restore traffic or use as soon as possible.

Cement and lime-dust grout with a cement-lime ratio of about 1:4 by volume is used by some state highway departments. A typical cement-pozzolan grout has 1 part cement to 3 parts pozzolan (usually fly ash) by volume. For small voids and locations needing regrouting, a neat grout, 1:1 to 1:6 cement-water ratio by volume, is used.

Permeable grout is used in special situations under pavement where the water table is high and drainage is necessary. In one project, 1 part cement and 0.7 parts water plus foam and calcium chloride was used to make a permeable grout with a coefficient of permeability of $6.1 \times 10^{-5}$ cm/sec. and an average compressive strength at 7 days of 520 psi (Reference 32, pages 849–858).

Grout consistency varies with the project's needs. Very thick grout can be used to lift a slab to the desired location and thinner grouts can fill any remaining voids. Thick grouts are also used near slab edges to prevent leakage.

## Pumping and Lifting Techniques

Hole patterns for slabjacking must be determined in the field, usually by the jacking-crew superintendent, who must take into consideration (1) size or length of the slab area to be raised, (2) elevation difference, (3) subgrade and drainage conditions, (4) location of joints and cracks, (5) cause of settlement, (6) slab thickness, and similar local circumstances. Four-foot-wide sidewalk panels can be lifted with 1 or 2 holes, whereas, larger and thicker panels require at least 3 uniformly distributed holes (3 to 8 ft apart or more and at least 1½ ft from the edge).

Lifting should be done in increments of about ¼ in. with frequent changes in injection locations to keep slab stresses to a minimum to avoid cracking. The rate of grout injection should be uniform and as slow as possible consistent with economy, usually a minimum of ¼ cu ft per minute to a maximum of 1½ to 2 cu ft per minute. Initial pumping is usually at the slower rate and is increased as lifting progresses. As the desired elevation is approached, the lifting rate should be reduced.

Regrouting in new drill holes and further slabjacking is necessary when grout extrudes from joints, cracks, or the pavement edge before the target elevation is reached. Gage pressures for slabjacking are usually under 200 psi, with an occasional need for additional pressure to 1000 psi to initiate lifting. Typical lifting pressures at the injection point are often less than 25 psi. Gages must be continually monitored for sudden pressure changes. A rapid increase could signal a grout stoppage that could be followed by a buildup of pressure and an excessive lift and cracking if pumping were to continue. A sudden reduction in pressure could indicate a loss of lift from subsurface leakage, escaping grout at slab edges, and grout migration into new voids.

In conducting slabjacking operations, the ambient temperature is important. When raising individual slabs to correct faulted joints or other elevation differences, if the prevailing temperature is high, the concrete may be in compression and the slab ends may not be free to move. Joints may need to be sawed free in order to complete the lifting process. This type of correction might be more successful in cooler weather with the concrete in tension and the joint more open.

On the other hand, when correcting a profile deficiency of greater length involving several slabs or panels, the work will more likely be successful when the slabs are in compression and the joints tight so that an entire run of depressed pavement can be lifted uniformly. This must be done in increments by raising all slabs a small amount. Excessive lifting of any one slab may result in cracking. The work should progress toward the low point in the depression or outward from it.

## Slab-Elevation Control During Jacking

In slabjacking, an arrangement of stringlines and blocks is generally used to determine when the desired elevation has been reached and pumping can be discontinued. The stringline is usually positioned about 1 in. above the desired grade. Gage blocks placed on the slab indicate the progress of lifting. As the blocks approach the stringline, the rate of lifting is slowed; pumping is stopped completely when the blocks touch the line (Fig. 31).

Where the section of pavement being jacked is on a vertical curve, the offset distances must be calculated and applied to the gage-block heights to align the slab surface properly.

Elevation control is also possible with conventional surveying equipment. By whatever means of control available, the experienced, modern slabjacking crew can raise virtually any slab to within ⅛ in. of plan grade without creating undue cracking or other defects in the slab.

**Fig. 31. Bridge approach is raised 5½ in. in typical slabjacking project. Observe stringline and block used to control final elevation of slab.**

## Plugging and Cleanup

After slabjacking has been completed in a hole and the discharge pipe removed, the hole should be plugged immediately. Temporary plugs are of wood tapered to fit in the hole to retain the pressure of the grout and stop any return flow of the mixture. When all voids have been filled or when slabjacking to the desired elevation has been accomplished, the temporary plugs are removed and the holes filled with a stiff one-to-three cement-sand grout or an approved concrete mixture. These areas are then finished to match the pavement texture and elevation. For more information on slabjacking, see Reference 23 and PCA's *Cement-Grout Subsealing and Slabjacking of Concrete Pavement*, IS212P (Reference 31).

# SUBSEALING (UNDERSEALING)

Cement-grout subsealing, also called undersealing or highway grouting, is a void-filling corrective process (Fig. 32). It consists of pumping a cement-grout mixture under pressure through holes drilled in a slab to fill voids and depressions under the slab and reduce damage caused by excessive pavement deflections. The purpose of subsealing is to stablize a slab without raising the slab. The voids under pavements are usually near cracks, joints, or pavement edges. The voids are caused by (1) pumping, the expulsion of water and soil through an open joint or shoulder as traffic drives over the joint, (2) consolidation, the compaction of base material beneath the slab caused by repeated heavy truck traffic, (3) subgrade failure caused by overloading of the subgrade near joints or loss of load-bearing capacity due to oversaturation of the subgrade, and (4) bridge approach failure caused by consolidation and washout of fill material. Subsealing grout fills these voids and keeps water from collecting under joints and edges, provides support, and therefore prevents deterioration of pavement due to foundation or support problems. Subsealing procedures and equipment are similar to those used in slabjacking (see previous topic, "Slabjacking").

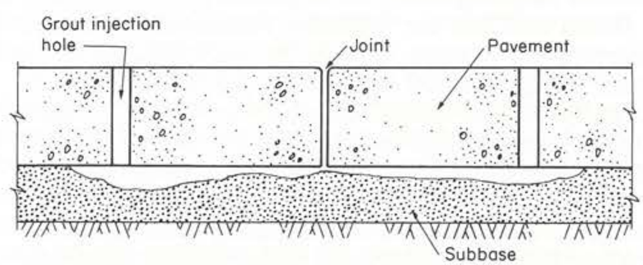



**Fig. 32. Typical void under pavement near a joint caused by subgrade failure, subbase washout, subbase consolidation, or pumping action. As tires roll over the slab, the pavement deflects resulting in a pumping action under the slab that washes the soil away. Grout holes on both sides of the joint will be used to fill the void by subsealing techniques.**

## Void Detection

Several methods of void detection are in use. Perhaps the simplest is a visual inspection of the pavement to locate areas of distress. The presence of holes or depressions in the shoulder edge adjacent to the mainline pavement or stains on the shoulder indicates either pumping or blowing; ejected fines or granular material at these locations is almost certain evidence of voids under the slab. Indications of excessive vertical movement of the pavement at joints or cracks usually suggests the presence of an open space between slab and subbase or subgrade that permits such movement to occur. Likewise, faulting of joints or cracks is evidence that openings under the slab have allowed water movement, migration of material, and buildup of fines.

Another method of void detection is proofrolling the pavement with heavily loaded rubber-tire equipment. The application of heavy proofrolling loads causes deflection or pumping, signaling the presence of voids and the need for subsealing. Mississippi requires a single axle to be loaded to a gross weight equal to or greater than the maximum legal tandem-axle load allowed on the class of highway being restored, with a maximum of 25 tons. Proofrolling is done at very slow speed, about two miles per hour. Inspectors watch for areas that deflect above a specified minimum, and these areas are marked for subsequent subsealing. To avoid binding at the joints, proofrolling should be done in cool weather when the pavement is contracted.

Deflection of the pavement during proofrolling cannot always be detected by normal visual checks. Benkelman or other beams equipped with sensitive dial gages to be read visually or recorded electrically can be used.

Under heavy wheel loads, the magnitude of deflection, when sufficiently large, indicates the presence of a void. These deflection measurements reveal points of inadequate support, difference in deflection across joints, and effectiveness of load transfer at the joint. Usually, a movement greater than 0.02 in. is considered excessive, but this limit may vary with the type of subbase and subgrade in the supporting layers.

Other methods for measuring deflection and thus determining location of voids under pavements include nondestructive testing equipment such as the Dynaflect, Road Rater, Thumper, and Falling-Weight Deflectometer. These measure the deflection response of a pavement under a dynamic load. Other nondestructive testing equipment, such as ground-penetrating radar, infrared analysis, themography, and radioactive tracers, in conjunction with visual observation will normally yield adequate information on the presence and extent of voids to be filled.

Since pumping and erosion are most likely to occur at joints and cracks in the pavement, these locations are also where voids are usually found. Recent experimental grout subsealing has concentrated void-filling efforts only at joints and major transverse cracks.

## Hole Patterns

Hole patterns for effective distribution of grout under the pavement are not easily determined in advance. Some preliminary testing is often necessary to locate holes in a way that will ensure good grout distribution. Where a hole pattern is selected for repetition in each panel, it should provide sufficient holes to permit grout to reach all voids existing beneath the pavement.

Hole patterns will vary with the concrete pavement design, that is, whether jointed plain, jointed with mesh reinforcement, or continuously reinforced. Each design varies in panel length, performance characteristics, and distress patterns, and subsealing techniques must be adjusted accordingly.

The use of a predetermined hole pattern and a fixed numer of holes often results in forcing grout into areas under slabs where no voids exist and where subsealing is not required. A more efficient and economical approach is to determine void locations and areas needing subsealing beforehand, as discussed in the section "Void Detection." Ideally the hole location should intercept a void at its farthest distance from the joint or crack. This allows the grout to flow farther laterally and more completely fill the void before exiting through the joint. Usually the voids are under joints and therefore about two grout holes are placed on each side of the joint at a distance of 12 to 24 in. from the joint.

In France, the old method of filling cavities under the pavement was similar to that used for slabjacking, namely, drilling four or five holes at locations throughout the slab and injecting grout at alternate holes under high pressures. This practice is costly and slow and has largely been discontinued.

A new French technique is to limit the injection of grout to the location where it is most needed in a plain jointed design—the voids on each side of transverse joints. Two grouting holes of 1¼-in. diameter are drilled in each 12-ft-lane width directly through each transverse joint, about 1.5 ft from the longitudinal joint and the same distance from the outer edge of the slab. The holes are blown out with compressed air. Grouting is then initiated by gravity or under low pressures (60 to 70 psi maximum) and continued until the grout flows from the joints or until refusal is indicated. French engineers have concluded that the new pattern is superior in several ways:

1. It distributes the grout better in relation to the problem to be treated.
2. Less grout, about 50%, is used with the new pattern.
3. The new pattern is more effective in reducing deflections at joints.
4. The new pattern is just as, or more effective in overall restoration of the pavement as the old.

Experiments using the two-hole-per-lane technique have been conducted in the United States by the American Concrete Pavement Association and are currently under observation.

Holes for subsealing should be 1 to 1.5 in. in diameter and drilled with pneumatic, hydraulic, or diamond core drills. Only a small amount of down pressure should be applied on the drill to prevent cratering (breakout) at the bottom of the hole. Drilling is stopped as soon as the drill bit cuts through the concrete.

## Grout

The grout for subsealing is thinner than grout used for slabjacking because the grout must be able to permeate into voids as thin as 1/16 in. The grout usually consists of about 1 part cement to 3 parts fly ash by dry powder volume to 1.5 to 3 parts water to produce a flow-cone time of 9 to 20 seconds (ASTM C939 or Corps of Engineers CRD-C611). Fluidifiers, superplasticizers, retarders, and accelerators can also be helpful on some projects. The 7-day compressive strength (ASTM C109) should be at least 600 psi and the ultimate strength under the slab should be about 1500 to 4500 psi. After injection, the grout should become thixotropic within 1 to 10 minutes and initial set should occur between 1 and 6 hours.

Permeable grout with foam can be used for special locations with a high water table (see grout discussion under "Slabjacking" and Reference 32, pages 849–858).

## Grouting Equipment

Special grouting plants (trucks) with bulk or bagged material storage, a high-speed colloidal mixer to wet cementitious particles rapidly, and an injection pump, are commonly used for highway applications to minimize labor and material handling costs. High-pressure and high-velocity centrifugal pumps and paddle-blade-type mixers are the most common types used. Subsealing grout should not be mixed in mortar mixers or ready mixed concrete trucks to avoid higher water demand and balling up (clumping) of grout.

Both piston pumps and nonpulsing-progressive-cavity pumps are used; however, the pulsing action of the piston pump may prematurely press water out of the grout. Pump pressures of 75 to 200 psi are used, but low pressures and low pumping rates are preferred to better control the placement and avoid overstressing or lifting the slab.

Either drive packers or expanding rubber packers (mechanical packers) are used to seal the grout hole for injection. The packers are merely injection pipes with valves. The grout hose is connected to the top of the packer and the bottom end of the packer is inserted into the grout hole. Drive packers are usually used with 1-in.-diameter holes and are tapped into place with hammers. Expanding rubber packers, used for holes 1.5 in. or more in diameter, have a steel outer sleeve with a short rubber sleeve at the bottom, all placed over an inner pipe. After this packer is placed in the hole, the steel sleeve pushes on the rubber sleeve causing the rubber to expand within the hole and seal it.

Ames dials and uplift beams are used to monitor the slab for movement. As the purpose of subsealing is only to fill voids beneath the slab and not to raise the slab, grouting must be stopped when any uplifting is detected. No more than 0.05 in. of uplifting should be allowed. The uplift detection beam is supported at stationary points off the slab or at a distance away from the grouting area that will not be affected during the injection. The monitoring point is over the injection area.

The hose between the pump and packer should be 1 to 1.5 in. in diameter. After injection is completed, the holes must be plugged to prevent the grout from leaking out before it has set.

## Grouting Procedures

After the voids are located and the holes drilled, the packer is usually first placed in the hole closest to the center line. The grout is pumped at a low rate and low pressure until the slab begins to raise or the grout comes through an adjacent hole, joint, or crack. The packer is then inserted in the next hole and the process repeated. Grouted holes are appropriately plugged. Grouting holes near the centerline first followed by those near the shoulder drives trapped water to the outside of the slab. Additional holes can be drilled as needed to fill the voids.

At least 24 hours after subsealing, the pavement can be tested again by proofrolling to check the stability of the grouted pavement. Regrouting can be performed as required until all voids are filled and the pavement is sufficiently stable.

Subsealing is an effective, nondestructive, and inexpensive way to maintain a pavement and avoid deterioration by treating slab foundation problems. Subsealing is also used before patching and overlay work to assure the quality of the subbase. For more information on subsealing, see PCA's *Cement-Grout Subsealing and Slabjacking of Concrete Pavements*, IS212P (Reference 31) and Reference 41.

# FOUNDATION JACKING (LIFTING AND LEVELING STRUCTURES)

Buildings and heavy structures that have unevenly settled, due to soil subsidence or washout of soil under a foundation, can be lifted and leveled with pressure grouting in a manner similar to slabjacking of pavement. Two techniques can be used—permeation grouting and compaction grouting.

Permeation grouting, also called penetration or conventional grouting, uses a thin grout to fill voids or pores between the soil particles, resulting in a distribution of grout throughout the soil. First, the soil characteristics and grout plan are established. A vertical grout curtain is sometimes placed around or adjacent to the grouting area to contain the grout, by preventing or limiting lateral movement. The grout is slowly pumped through a series of pipes into weak layers of soil some distance below the foundation. Grouting continues until the structure is lifted to the designed level. Several days of grouting in stages are often necessary to lift the structure properly. The grout must be designed for the particular application and soil. Both neat cement and sand-cement grout are used. A mix used for permeation grouting on one project consisted of cement—94 lb; fly ash—70 lb; water—14 gallons; and a grout fluidifier. Grouting may start with a thin grout and progress to a thicker grout to increase lifting pressure. Pressures commonly range from 75 to 300 psi. Adjacent structures must be cut free of the structure to be lifted and an engineer must determine if the structure's base can withstand the lifting forces. If needed, the base can be enlarged. Some structures that have been successfully lifted and leveled include grain elevators, silos, a mine-hoist headframe, and buildings.

Compaction grouting, unlike permeation grouting, uses a stiff grout to displace the soil. The grout forms a bulblike mass of grout in the soil that does not permeate into the soil. The grout is injected into a layer of soil beneath the foundation. As the grout mass grows, it compacts the soil and develops uplift forces after a certain amount of grout is injected. This force lifts the structure.

Compaction grouting is especially useful in soils finer than medium sand and can be used in many clays. For lifting and stabilizing, the best compaction-grouting procedure is to start immediately below the foundation and work downward to a firm bearing. After the first-stage grout is placed and set, it is drilled through, and the next grout mass is placed. This continues until firm material is found, the layer depth is fully grouted, or sufficient lift is achieved. The slump of the grout should not exceed 2 in.

In the lifting of a particular masonry building that had settled, a sand-cement compaction grout was pumped at pressures between 50 and 800 psi to depths of 15 to 30 ft. The soil was a silty to clayey sand fill over a sandstone bedrock. Grout holes, 2 in. diameter, were spaced 6 ft apart. The foundation was lifted about 3 in. Most of the lifting occured after the grout stages reached bedrock. Each of the last 2 or 3 stages (bulbs of grout mass) lifted the building ½ to 1 in. Cracks in the building's masonry, caused by the original settlement, were observed to close, at which time grouting was discontinued to avoid damaging the structure. Lifting was avoided in the early stages and each grout stage used about 2 cu yd of grout, which was allowed to set overnight. That stage was then drilled through to continue downward grouting to form the next stage. Settlement after compaction grouting was negligible. Some minor settlement is expected due to a delayed redistribution of soil pore pressure or possible grout shrinkage. Between 150 to 175 cu yd of grout were used. The pumping rate was about 2.5 cu ft per minute. See the next section and Reference 32, pages 923–937, for more information.

## SOIL GROUTING

Soil is grouted to increase its bearing capacity, reduce or halt settlement, increase shear resistance to stabilize it against lateral movement, reduce water flow (permeability), or increase the cohesive strength of friable ground prior to excavation. Soil grouting can be performed (1) to increase soil bearing capacity before a structure is built, (2) to reduce expected settlement due to new loads on an existing structure, (3) to stop unexpected settlement of a foundation in place, (4) to reduce water flow to an existing or future inground structure such as the waterproofing of a basement, (5) to reduce the flow of liquids through dams and embankments made of granular materials, and (6) to stabilize and contain soil contaminated with hazardous chemicals. Walls of grout can also retain soil and water during foundation excavation. Soils that can be grouted range from coarse gravels and sands to silty and clayey materials.

Neat cement grouts and special grouts such as ultrafine (microfine) cement grout, with particles less than about 10 microns, are used in pressure grouting to permeate and stabilize soil. Compaction grouting uses a stiff low-slump grout to densify or consolidate soil. Jet grouting is a technique that uses grout under high pressure to form concretelike columns to serve as a seepage barrier, improve soil strength, or support foundations without prior excavation. The following discussion will present information on these and related soil grouting methods. Rock grouting was discussed earlier.

### Permeation Grouting

Permeation grouting, also called penetration or conventional grouting, consists of using a thin grout to permeate the soil and fill pores and voids between soil particles (Fig. 33). The grout hardens and provides added strength and water tightness to the soil. Each type of soil can be identified by its index properties such as particle-size distribution and void content.* X When the size of spaces between particles of soil is smaller than the size of Type I or II portland cement grains, which are primarily less than 75 microns, then a regular cement grout will not satisfactorily stabilize the soil. Type III portland cement is preferred over Type I or II for its finer grind. The grind can be adjusted so that about 100% of the cement particles are smaller than 45 microns. Ultrafine (microfine) cement with particles less than about 7 to 10 microns and an average particle size of 3 to 4 microns is used to grout soils with fine pore spaces, such as fine sand with a coefficient of permeability of $10^{-3}$ to $10^{-4}$ cm/sec. Regular X cement grout can permeate granular soils with a permeability above about 0.5 cm/sec. Ultrafine cement has a permeation ability similar to chemical grouts, but without toxic concerns (see Reference 32, pages 77–91, and Reference 52).

Regular neat portland cement grout has been used to permeate gravel and coarse sand. Bentonite and fly ash are used on some projects with cement. Ultrafine cement is used in grouting sands and even some silts. Bentonite (2% to 5% by weight of water) is used in some grouts to reduce bleeding by suspending cement particles. In gravels with large connected voids (about ¼ in. or more), a cement and sand grout can be used for stabilization.

The pore size of the sand primarily dictates what grouting materials are used. References 15 (pages 1–32), 27, and 52 present information on the groutability of various grouting materials with respect to the pore size and grain size of available soils. Treatment of the pores of fine soils is not always possible using portland cement. The very small spaces between soil particles

*For more information on soils, see ASTM D 2487 and D 2488 and PCA's *PCA Soil Primer*, EB007S.

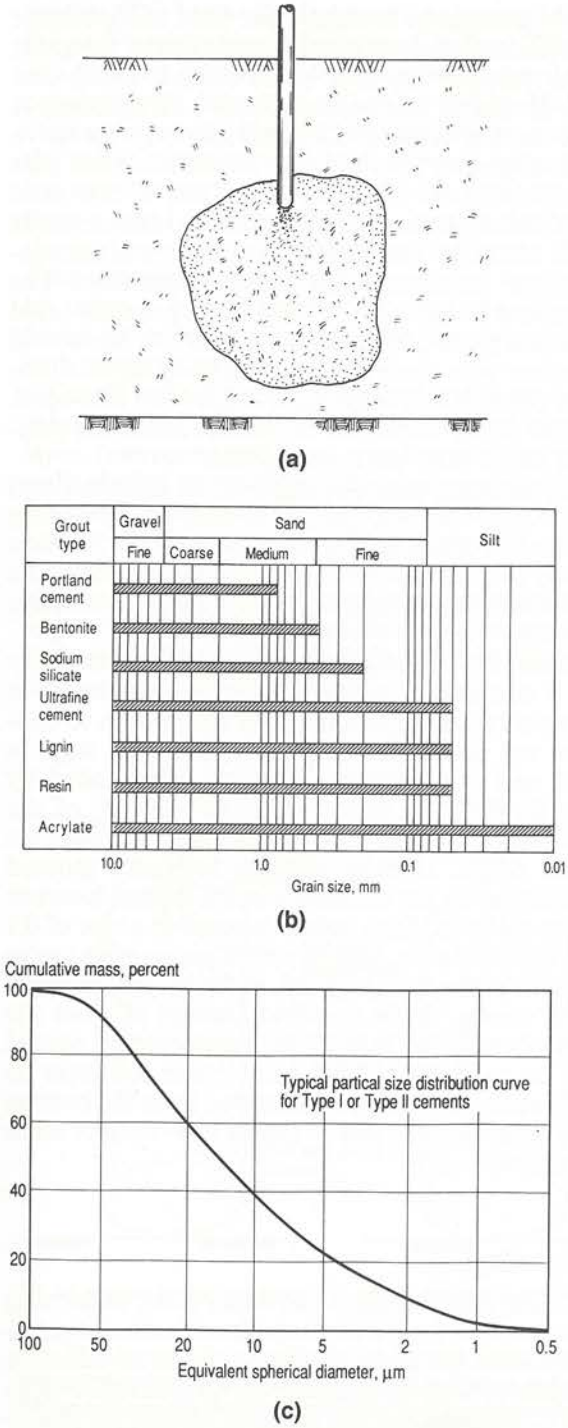



**Fig. 33. (a) Permeation grouting forces the grout into pores and voids in the soil without displacing the soil. The grout and soil combination become a hardened mass. (b) Permeation limits for grouts with respect to soil grain size and ASTM D 2487 soil descriptions. (c) Particle size distribution curve for ASTM C150 Type I or II cements.**

will be bridged by the larger cement particles; this arching action and infilling of the smaller voids leads to a filtering out of the cement, leaving undergrouted areas. For very fine soils such as silts, the use of a chemical fluid or ultrafine cement is recommended (see Fig. 33b). Many chemical grouts are available only as proprietary products. The toxic effects of chemical grouts should be evaluated before they are used. If a neat portland cement is grouted into a material it cannot permeate, such as clay with very fine pores, the grout will displace the soil and form grout bulbs or follow planes of weakness. Sands with a grain size of more than 0.8 mm can be grouted with a portland cement grout. Soils, such as fine sand or some silts, with a grain size greater than 0.05 mm, can be grouted with ultrafine cement. As a rule of thumb the pore size of the soil should be at least three times the maximum grain size of the cement. The grout particles should be less than $1/10$ the size of the soil particles for single-size homogenous soils. The permeability of the soil should not be less than 0.5 cm/sec. for portland cement grout or less than about $10^{-4}$ cm/sec. for ultrafine cement grout. These criteria are only rough guidelines as each grouting situation is different.

The grout ingredient proportions vary with the purpose of the grouting and the properties of the soil to be grouted. Neat cement grouts have proportions similar to those used in rock grouting but will vary considerably depending on site conditions. The water-cement ratio by bulk (loose) volume can range from 0.5:1 to 20:1 with most mixes under 10:1. A wide range of amounts of clay, fine sand, silt, and fly ash have also been used.

Grouting pipes, 1 to 2 in. diameter, are often inserted about 2 to 10 ft apart. Grout pressures up to 200 psi or more can be used, although pressures are usually under 50 psi. Ultrafine cement, used to strengthen foundations of poorly graded fine to medium sand, has been grouted at 25 to 40 psi through 2-in. holes with pumping beginning at the bottom of the hole (Reference 52). The equipment and grouting procedures for permeation grouting are similar to those of the "Rock Grouting" discussion earlier. Grout mixers for example are often the paddle-type or colloidal high-speed impeller mixers.

Permeation grouting, using neat portland cement grout with or without mineral fillers or admixtures, has primarily been used (1) for grout curtains, consisting of one to three rows of grout holes, to reduce seepage of water under dams, (2) to stabilize foundations under commerical and industrial buildings as well as dams to limit settlement, and (3) to control water seepage into basements, to name just a few applications. Ultrafine cement has been used (1) to grout unconsolidated angular gravel tuff for a dam, (2) to grout fine to medium sand for a tunnel, (3) to strengthen foundations, and (4) to contain and stabilize hazardous waste in soils. Permeabilities as low as $10^{-9}$ cm/sec. have been observed in soils after grouting with ultrafine cement.

## Deep-Soil Mixing

A related alternate to permeation grouting is deep-soil mixing. With this method an auger mixer attached to a crane or backhoe blends the soil and an injected grout together—essentially making soil-cement in place. A much broader range of grouts and materials can be used, regular cement grout, for example, and there is no concern about particle size. An overlapping of auger-mixing injection points assures a uniform and consistent grouting operation. Depths up to 120 feet can be stabilized (grouted) with this technique. Deep-soil mixing is used to stabilize hazardous chemicals in soil and to increase a soil's bearing capacity. See the cover for a photograph of deep-soil mixing equipment.

## Compaction Grouting

Compaction grouting consists of pressure grouting a stiff low-slump sand-and-cement grout through pre-drilled holes into soil to consolidate it by compaction (Fig. 34). The stiff grout does not permeate the soil but maintains a grouted mass by displacing the soil and forming a bulblike or columnlike form. The grout mass can be 3 ft or more in diameter. Compaction grouting can be used in almost any type of granular material including fine-to-medium sands and even clays with adequate drainage. Soil is significantly densified at a radial distance of 1 to 6 ft or more from the soil-grout interface.

Compaction grouting has been used to stop settlement of structures by grouting some distance beneath the structure. Pile friction has been increased by compaction grouting a short distance adjacent to and along both sides of a pile. Pile end bearing capacity has been increased by grouting on both sides of a pile, but only near the bottom of the pile. Culverts and pipe have been stabilized by compaction grouting the soil on both sides of the culvert or pipe. Grouting 6 to 8 ft above a tunnel roof to compensate for lost ground during soft-tunneling operations has been used to eliminate surface settlement. Compaction grouting has also been used to reduce the earthquake-liquification potential of some soils.

The grout used for compaction grouting should have a slump consistency (ASTM C143) of less than 1 in.; however, slumps up to 2 in. have been used. Higher slumps make grouting difficult to control as the grout tends to fracture the soil, cause surface lifting and leakage problems, and reduce effective compaction. A cement content of about 12% provides a compressive strength of greater than 400 psi. The sand should pass a No. 8 sieve and no more than 20% of the sand particles should be less than 50 microns. Coarse sands result in blockage under the high pressures as segregation occurs. Admixtures are generally not used. The grout cannot be mixed with the same equipment used for flowable grout but should be mixed in a horizontal batch mixer with blades using a chopping action. Continuous pugmill and auger-type mixers are also used. The grout pump should be capable of achieving pressures of 600 to 1000 psi in a 2-in. line.

Grout injection holes, about 2 in. in diameter and spaced 8 to 12 ft apart, are drilled with rotary drilling equipment at carefully engineered locations. The first 4 ft or so of the hole has a steel casing cemented into it. Future drilling and grouting are performed through the casing.

Grouting is performed in vertical stages where only 5 to 8 ft of a hole is grouted at one time. Grouting is usually performed from the top to the bottom to densify the soil more effectively. After the first stage is grouted and has hardened, the hole is extended by drilling through the first stage to the bottom of the second stage. The sequence is repeated throughout the specified depth. Usually primary holes are grouted first, followed by the secondary holes located between the primary holes. Each hole is grouted at a rate of 0.1 to 2 cu ft per minute, usually with a piston-type pump until uplift of the soil is sensed, sufficient resistance to grouting occurs, or the specified amount of grout per stage is placed. The base of the grout column should rest or be partially grouted into a firm soil layer or rock. Grouting can also be performed from the bottom up. See References 22 and 32 (pages 694–707) for more information.

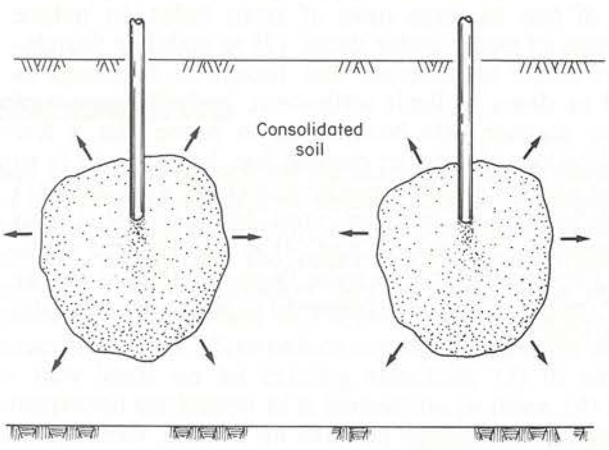



**Fig. 34. Bulblike mass of grout formed by compaction grouting. The grout displaces the soil (rather than permeating it), thereby consolidating and strengthening the soil in all directions from the grout mass.**

## Jet Grouting

Jet grouting uses a cement-and-water grout under very high pressure to form a concretelike column. Jet grouting is used in soft soils such as clay (1) to underpin structures to stop settlement, (2) to construct load-bearing members without prior excavation, (3) to control water flow (seepage cutoff walls), (4) to control subsidence over tunnel excavations, and (5) to construct cofferdams. Jet grouting has the advantage of use in clay, whereas other methods have limited use in clays. Both penetration and excavation techniques of jet grouting are used.

Jet grouting by penetration consists of first drilling the grout hole and placing a jetting pipe into the hole with the jetting nozzle at the bottom. The end of the pipe will be the base of the "soilcrete" column. The grout, with a water-to-cement ratio of about 1:1, is pressurized to 4000 to 6000 psi and jetted horizontally into the soil through jet ports at the bottom of the pipe. The pipe is slowly rotated and lifted at about 1 ft per minute. The high-velocity grout impinges and shatters the soil, penetrating it for several inches. This results in a blended mixture of cement grout and soil forming columns with diameters of 2 to 2½ ft (Fig. 35a).

In an alternate method, jet grouting by excavation, the soil is excavated with high-pressure water (a washing-away action) and replaced with cement grout to form a grout column. The soil slurry is discharged to the surface as it is replaced by the grout. Six-foot-diameter cement-grout columns (piles) can be made by using a 4-in. diameter injection pipe (Fig. 35b). Some jet-grouting methods also use pressurized air with the grout or water jet.

Cutoff walls for seepage control use interconnected columns, side by side, grouted down to an impervious layer. Interconnected rows are also used for retaining walls during excavation. Staggered separate columns are used to improve the bearing capacity of soils for new or existing structures. Single columns are drilled through foundations to underpin footings. Horizontally or vertically interconnected grout columns are used to provide support over tunnels during excavation. See References 32 (pages 680–693), 55, and 68 for more information.

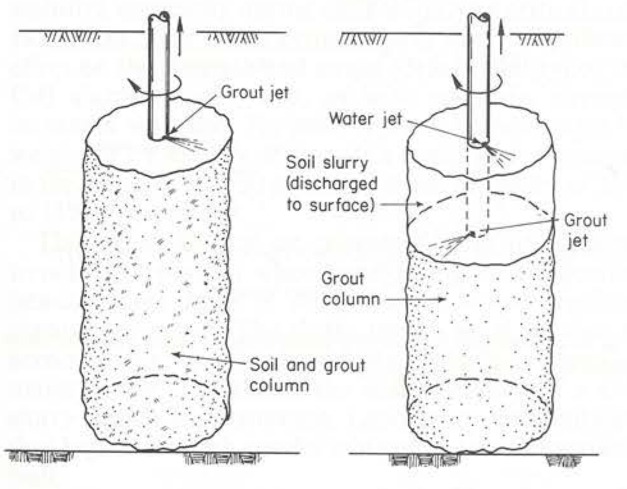



**Fig. 35. Jet grouting methods (a) by soil penetration that intimately mixes grout and native soil to form a column and (b) by soil excavation that removes soil in a slurry form and replaces it with grout. In the latter method two or three lines in the injection pipe independently transport the grout, water, air, or slurry.**

## OIL-WELL GROUTING

Oil-well grouting, often called oil-well cementing, refers to the practice of pumping of a cement-and-water grout through the steel casing to critical locations in the well. The grout is placed in the annulus around the casing (between the casing and the open hole) or in the hole below the casing, to restrict movement of water, oil, or gas between soil or rock formations and to bond and support the casing. The grout also protects the casing from corrosion, prevents blowouts, and seals off voids in the ground.

The grout or cement slurry consists of cement, water, and often a cementing additive (admixture). The American Petroleum Institute's API Specification 10, Specifications for Materials and Testing for Well Cements (Reference 75), lists nine classes of oil-well cement—Classes A through H and J. Each class is applicable to particular well depths, temperatures, pressures, and sulfate environments. The classes are available in one or more of three types: Type O—ordinary, Type MSR—moderate sulfate resistant, and Type HSR—high sulfate resistant. The cements are chemically similar to portland cement (essentially hydraulic calcium silicates). Only classes A, B, C, G, and H are available in the United States. A brief description of where the API cements are used follows:

Class A—for 0- to 6000-ft depth; available in ordinary Type O only. Similar to ASTM C150 Type I cement.

Class B—for 0- to 6000-ft depth and moderate-to-high sulfate resistance; available as Types MSR and HSR.

Class C—for 0- to 6000-ft depth and high early strength; available as Types O, MSR, and HSR.

Class D—for 6000- to 10,000-ft depth and moderately high temperatures and pressures; available as Types MSR and HSR.

Class E—for 10,000- to 14,000-ft depth and high temperatures and pressures; available as Types MSR and HSR.

Class F—for 10,000- to 16,000-ft depth and extremely high temperatures and pressures; available as Types MSR and HSR.

Glass G—for 0- to 8000-ft depth as manufactured, or with accelerators and retarders to cover a wide range of depths and temperatures; available as Types MSR and HSR.

Class H—for 0- to 8000-ft depth as manufactured, or with accelerators and retarders to cover a wide range of depths and temperatures; available as Type MSR and HSR.

Class J—for 12,000- to 16,000-ft depth as manufactured for extremely high temperatures and pressures, or with accelerators and retarders for a wide range of depths and temperatures. API is considering removing Class J from its specification.

Other cements used in oil-well grouting include portland cement with cement-modifying admixtures, portland-pozzolan cements, and expansive cements (ASTM C845, Types K, S, and M).

Oil-well grouts are used in a wide range of temperatures and pressures. Temperatures range from below freezing in permafrost to 2000°F and pressure varies from atmospheric to 30,000 psi. With cementing additives, cementitious grouts can be adjusted to accommodate the various conditions encountered. Cement additives are usually powders that are dry blended with the cement, although many can be added to the mixing water at the jobsite. Additives can be used to vary the compressive strength of grouts from 200 psi to 20,000 psi, vary density from 6 to 21 lb per gallon, accelerate or retard set time, cause expansion, reduce heat of hydration, adjust flow and filtration properties, and influence other properties.

Oil-well grout design is based on well depth, temperature and pressure, pumping time, required strength to support the casing, permeability requirements, and other factors. Grout mixers, pumps, packers, and other grouting equipment similar to that used for soil and rock grouting are used for cementing oil wells. Reference 60 provides excellent information on grout design and placement.

## SLURRY-TRENCH CUTOFF WALLS

A slurry-trench cutoff wall is a nonstructural underground wall that serves as a barrier to the horizontal flow of water and other fluids. It is constructed with the aid of a viscous stabilizing liquid known as slurry (Fig. 36). The two most common types of slurry trenches are referred to as soil-bentonite (S-B) and cement-bentonite (C-B). In the S-B method, a bentonite-water slurry, is introduced into the trench during excavation to provide sidewall support. After the trench is excavated to its required depth, a mixture of soil, bentonite, and water is placed into the trench displacing the bentonite-water slurry. Generally the excavated soil is used in the backfilling operation; however, if it contains an excessive amount of contaminated or undesirable material such as cobbles or clay lumps, a selected backfill material may be required.

In the C-B method, cement is added to the bentonite-water slurry just prior to its introduction into the trench. In addition to serving as a stabilizing fluid to maintain an open trench during excavation, the cement-bentonite slurry remains to harden and form the permanent cutoff wall. Although in most cases either method can be used, a C-B slurry trench offers many advantages over the S-B method, such as (1) not being dependent on the availability or quality of the backfill material, (2) being more suitable in weak soils where trench stability may be a concern, (3) providing a cleaner operation, and (4) reducing the trench width since the S-B method requires a minimum width to permit free flow of the backfill material.

Fig. 36. Cement-bentonite slurry-trench construction. Reference 38.

Unlike a concrete diaphragm wall that serves as a structural foundation wall, the slurry-trench cutoff walls have been used to (1) dewater areas prior to excavation, (2) control groundwater infiltration from waste disposal sites (Fig. 37), (3) control water seepage for dams, dikes, cofferdams, and lakes, and (4) help collect hazardous liquid chemicals. Slurry trenches have many advantages over other seepage control techniques such as grouting, sheetpiling, and well-pumping systems. Slurry trenches provide a continuous uniform seepage barrier. For dewatering applications, only the water level within the confines of the slurry trench is affected. With a pumped dewatering system, however, drawdown of the water table may extend well beyond the limits of excavation and cause problems, especially in environmentally sensitive areas.

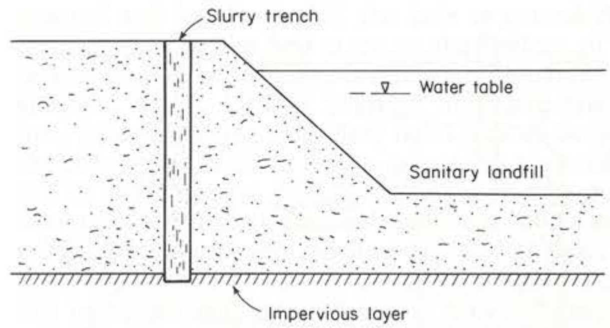



Fig. 37. Example of a slurry-trench cutoff wall used to stop water infiltration from a sanitary landfill.

### Excavating Techniques

The excavating methods for slurry trenches depend upon the required depths, design widths, and subsurface materials. Principal types of excavating equipment include the backhoe and the clamshell. Standard backhoes have depth limitations of about 40 ft; however, some slurry-trench contractors have modified standard backhoes to excavate effectively to depths of more than 70 ft. Minimum trench widths are controlled by the thickness of the boom, dipper stick, and bucket. For shallow trenches using small backhoes, this width may be as little as 1 ft. Deeper trenches require wider booms resulting in trench widths between 2 to 3 ft. For depths beyond the reach of a backhoe, hydraulic or mechanically operated clamshells used in combination with a backhoe are the most efficient and economical method of excavation. Originally developed for structural diaphragm wall construction, these specially designed clamshells have excavated to 250-ft depths.

An alternating-panel method is employed. A series of primary panels are initially excavated. Following completion of at least two adjacent primary panels, excavation of the secondary panels can begin. Secondary panels are narrower to allow a minimum overlap into the primary panels and assure continuity of the trench.

## Design

The parameters usually considered when designing a C-B slurry trench are permeability, strength, and deformability. Other factors of importance may be durability and permanence or, in the case of waste containment, the compatibility of the slurry trench to the waste.

Permeability is the most important factor. Both laboratory and field tests indicate permeabilities of C-B slurry trenches range from 1 to 0.1 ft/per year ($10^{-6}$ to $10^{-7}$ cm/sec.)

Since a C-B slurry trench is not intended to resist bending moments or significant shear stresses, structural strength usually is not a primary consideration. The trench is generally designed to achieve a strength equivalent to that of the surrounding soil. However, on projects where slurry trenches are constructed through unstable material such as peats and mine spoils, trench stability, especially during excavation, is a critical consideration. The water-cement ratio has a significant effect on the strength and strain (deformability) of the C-B slurry trench. Also, as with concrete, strength increases with age. Typically a water-cement ratio by weight of 7:1 to 3:1 will provide a compressive strength in the range of 5 to 50 psi and a strain at failure of 25% to 15%, respectively.

The deformability or compressibility of a slurry trench is important when considering its application beneath large dams in seismic areas where displacements may occur. The slurry trench must be able to accommodate the displacements without cracking. A major factor that affects the deformability of a C-B slurry trench is its strength. Laboratory tests indicate that higher strength results in a stiffer, less-deformable wall.

Slurry trenches may or may not be permanent applications. When used as a temporary dewatering method in lieu of a wellpoint or deep-well system, the slurry trench may be needed for only a short time. On the other hand, a slurry trench constructed as a cutoff or seepage barrier beneath a dam must perform for the life of the structure. For applications that involve contaminated water or exposure to pollutants, it is important to check the effect the liquid has on the slurry trench and use appropriate design precautions.

Slurry mix designs will vary depending upon the type of application, materials used, and mixing and construction techniques. Occasionally a mix design established in the laboratory may require modification in the field to improve workability and facilitate construction. A typical mix consists of 3 bags (282 lb) of portland cement and one bag (100 lb) of bentonite per cubic yard of water (1685 lb). This results in a water-cement ratio by weight of about 6:1. Admixtures are also used as needed to control slurry properties. The Marsh funnel (Reference 80) is often used to monitor consistency.

## Mixing Methods

Cement-bentonite slurry is prepared in a two-step process. First, bentonite is mixed with water to form a bentonite-water slurry. A standard practice is to mix and store the bentonite-water slurry in a cement-free environment until the bentonite platelets have fully hydrated. The bentonite-water slurry is then transferred into a mixing chamber where cement is added and homogeneous cement-bentonite slurry is obtained.

The three basic types of mixers generally used in slurry-trench construction, either alone or in combination, are

1. Venturi or flash mixer
2. Colloidal mixer
3. Paddle mixer

The venturi or flash mixer is used in preparing the bentonite-water slurry. Water is pumped under high pressure through a venturi system, which causes a pressure drop. The pressure drop creates a suction action that draws the bentonite powder into the venturi. The bentonite is metered so its flow is proportioned properly for the volume of water. The resultant mix is then stored in ponds or tanks until hydration is complete, generally overnight. After the bentonite has fully hydrated, the bentonite-water slurry may be transferred into a paddle mixer where cement is added.

Paddle mixers are generally low-shear mixers that may be used to prepare the bentonite-water slurry or simply to mix the cement into an already hydrated bentonite-water slurry. The mixing time required to fully hydrate the bentonite depends upon the type and grade of bentonite and type of paddle mixer. It usually takes longer than a colloidal mixer; therefore, its use is generally confined to smaller slurry-trench sites or in combination with the venturi mixing method.

Colloidal mixers are high-shear mixers. Water is metered into a mixing chamber and recirculated by means of a high-speed/high-shear centrifugal pump. The mixing chamber may also be equipped with rotary propellers to assist in the mixing. Bentonite, which is slowly added to the circulating water, disperses and hydrates quickly under the high-shearing action. Once hydrated, cement is then added. The bentonite-water slurry may also be pumped to a storage tank or transferred to an adjacent mixer where cement is added. Additives such as dispersing agents, if used, are introduced into the hydrated bentonite-water slurry just before cement is added. Many colloidal mixers are capable of mixing slurry continuously as well as in individual batches.

More information, including specifications, on slurry trenches can be found in PCA's *Cement-Bentonite Slurry Trench Cutoff Walls,* IS227W, Reference 38.

# GROUTING BALLAST FOR TRACK BASES

The ballast of railroad track can be grouted to improve track support and improve railroad crossings. Permeating a layer of stone with portland cement grout is simply another method for building a concrete slab, and the resulting characteristics of the concrete are due in large part to the net water-cement ratio of the grout as it is left to harden (see "Preplaced-Aggregate Concrete"). This net water-cement ratio is usually considerably lower than that of the grout in the mixer. The grout mixture used is chosen for its penetrating ability. After it is discharged onto the ballast, the grout progresses through the stone and along the subgrade, losing some free water through absorption to any dry surfaces contacted. Even more free water is lost upon bleeding.

Grouting of ballast allows for practically no interruption to traffic either during construction or after the work is completed. In many cases, it is necessary to replace the old ballast with new material before grouting. The new ballast should be compacted sufficiently so that the track maintains rigidity under train movement. After placing the new ballast it may be used under traffic for a while to compact it. If any settlement occurs, the track should be lifted and ballast retamped. This operation should be repeated until there is no settlement; then it is ready for grouting. On some jobs a locomotive has been run over the track to secure more rapid compaction than would occur under normal traffic.

## Aggregate

Ballast stone ranging between 1 in. and 2 in. or 1½ in. and 2½ in. is recommended. Not more than 5% should pass the ¾-in. sieve.

During transporting or in stockpiling, the finer sizes and dust tend to work to the bottom of the stone. Hence, even though the stone supplied meets the specifications, the method of distributing it on the subgrade should ensure against concentrations of small sizes.

Do not use ordinary concrete sand for the grout. It is almost always too coarse. The sand should never be coarser than the No. 16 sieve for all sizes of stone. Sand having the maximum amount of fine particles within the limits of the specifications in the No. 100–50 sieve sizes and with rounded grains is preferred. There are basic reasons for using fine sand. A uniform, smooth-flowing grout is the objective. Large particles not only tend to choke the passages through the stone but tend to settle at the least hesitation in flow and more easily lose their coating of cement.

## Grout

Materials for the grout can be proportioned by volume or preferably by weight. Unless job tests indicate differently, a grout composed of 94 lb (one bag) of portland cement to 188 lb of surface-dried, but saturated, sand is recommended. The free-moisture content of the sand should be determined. The sand weight is adjusted and the amount of free moisture is deducted from the total quantity of water to maintain the desired mix. Thus if the free moisture in the sand is 5%, a 1:2 mix by weight will be 94 lb of cement to 188 lb × 1.05, or 197.4 lb sand. The water for the mix then will be reduced by $\frac{0.05 \times 188}{8.34}$ or 1.1 gallon per bag of cement.

A flow-curve plotting time of flow versus water content can be a big help in maintaining the grout at uniform fluidity (Fig. 38). The grouts studied should range from those too thick to those greatly overwatered.

A flow of 20 to 25 seconds and corresponding water content is commonly used. Too much water washes the sand grains clean and results in plugging as indicated by the quick turnup of the curves in Fig. 38. Too little water produces a flow too sluggish for permeation. A flow curve will demonstrate that the flow is quite sensitive to the amount of water.

By catching a bucket of grout from the discharge pipe during grouting and comparing its flow through the flow cone with the job flow curve, an accurate checkup may be obtained at any time. The flow curve also indicates the correction that should be made in the quantity of water if the flow is not at the rate desired.

The effectiveness of the penetration may be observed either by digging occasional craters in the stone (Fig. 39), or setting wire mesh baskets, or punching bars into the stone ahead of the grout. When the subgrade or stone is excessively dry, it should be well sprinkled ahead of grouting. Laborers should be on the alert to prevent the escape of grout under or through joints in the forms with earth, burlap, or other materials. After grouting, all of the ballast aggregate should be submerged in grout and the grout finished as desired.

| Fluidities for proper penetration | |
|---|---|
| Coarse aggregate size, inches | Recommended flow time, seconds |
| 2 1/2 - 3 1/2 | 23 - 25 |
| 2 - 3 | 23 - 25 |
| 1 1/2 - 2 1/2 | 21 - 23 |
| 1 - 2 | 20 - 22 |
| 3/4 - 1 1/2 | 19 - 21 |

| Gradation of sand | | | |
|---|---|---|---|
| Sieve size, No. | Percent passing | | |
| | Coarse sand | Medium sand | Fine sand |
| 4 | 97 | 100 | 100 |
| 8 | 88 | 96 | 100 |
| 16 | 67 | 74 | 96 |
| 30 | 43 | 46 | 77 |
| 50 | 14 | 12 | 17 |
| 100 | 2 | 2 | 1 |

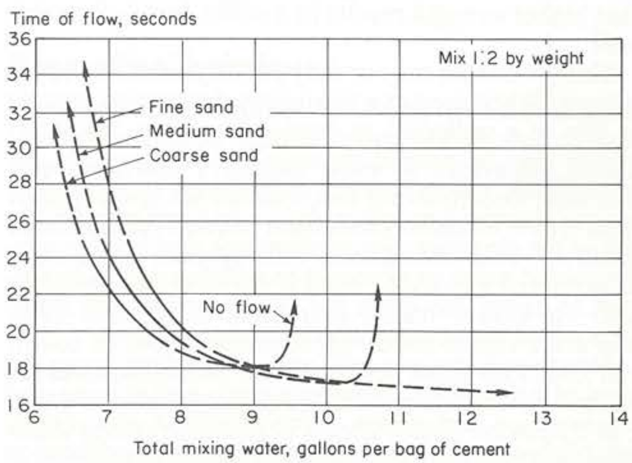



**Fig. 38. Typical flow curves for grouts made of fine, medium, and coarse sands. Solid lines show suitable flow range. Fig. 1 illustrates the flow cone. Different sands and cements will produce different flow curves. Reference 5.**

**Fig. 39. A hole in the ballast gives assurance that grout is penetrating voids in the stone completely. Reference 5.**

Grout may be mixed in concrete mixers, truck mixers, or special grout mixers. Ample mixing capacity should be provided to prevent the grouting operation from becoming the bottleneck of the construction. Delivery to the stone may be made down chutes or through a hose.

A trough placed across the rails and into which the grout can be chuted is a convenient device for spreading the grout uniformly across the width of the track. The trough, illustrated in Fig. 40, has its bottom perforated with 1-in. holes. The trough is moved ahead as the ballast stone becomes completely filled with grout.

As in other concrete work, grouted ballast should be kept moist for about 7 days after the grout hardens or a curing compound should be applied. Where a pavement is to be used over the grouted ballast, for example at crossings, it is often placed the next day. In cases where there is delay in paving, the grouted ballast should be sprinkled to keep it moist. Reference 5.

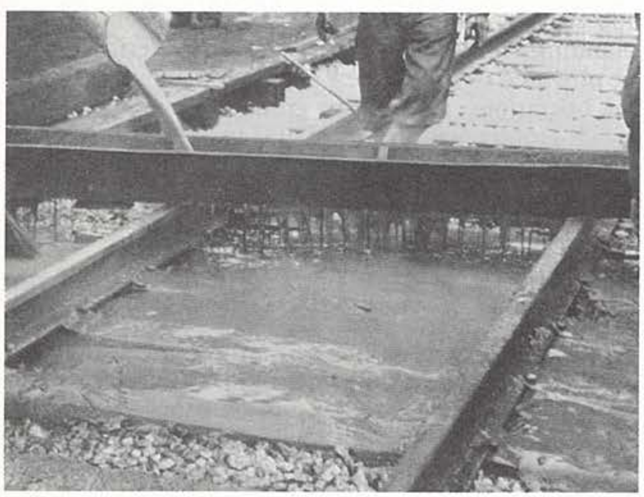


**Fig. 40. Grout is deposited into the stone ballast by use of a trough that is moved forward as voids in the ballast become filled with grout. Reference 5.**

## STABILIZING RAILROAD TRACK BY PRESSURE GROUTING

Unstable roadbed conditions due to poor drainage, yielding soil, or development of water pockets and soft spots can be treated by pressure grouting with portland cement grout (Figs. 41 and 42). Small jobs can be carried on as routine maintenance with regular local track labor and equipment, and extensive roadbed stabilization can be done with extra crews using appropriate equipment.

Successful results have been obtained with equipment and accessories improvised from material and parts found at railroad shops or those regularly carried in stock. Thus little new mechanical equipment is required, although several good commercially manufactured grouting units of both pneumatic and hydraulic types are available.

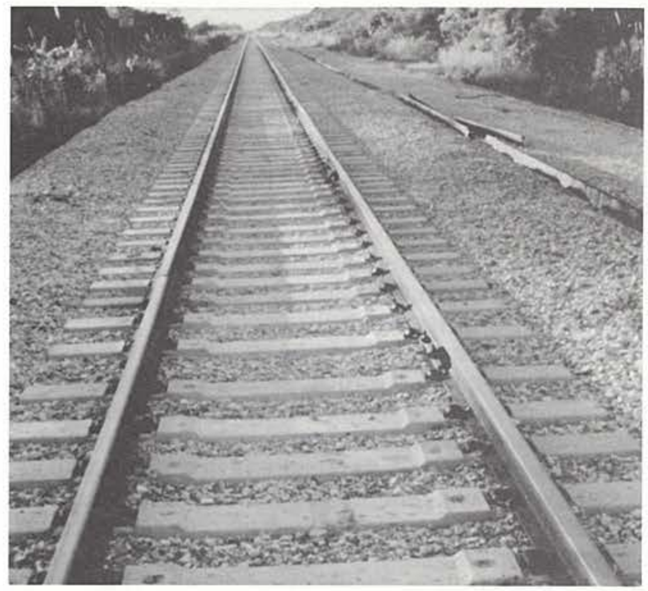


**Fig. 41. Unstable railway roadbed can be treated by pressure grouting.**

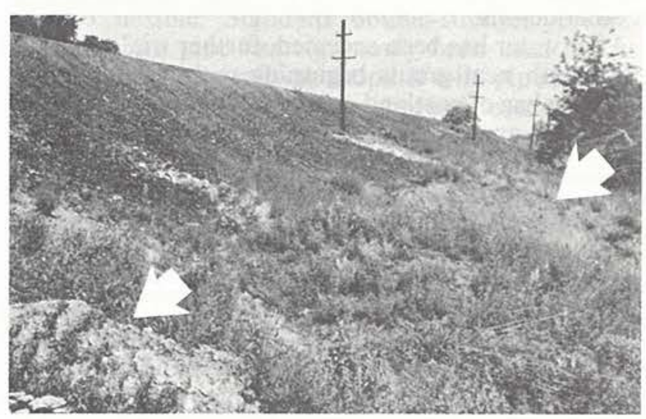


**Fig. 42. The bulges on the fill slope of this railway roadbed show presence of water pockets. Reference 12.**

## Track Conditions Suited for Pressure Grouting

Grout is most easily injected into porous ballast or where water passages are fairly well defined or where cleavage planes exist. Grout will not penetrate clay or ballast so permeated with clay as to be practically embedded. Between relatively clean ballast and complete embedment are all degrees of clay content. The amount and distribution of clay will determine the technique to be used and the degree of successful penetration.

Grout can be received only as air, water, or other existing material is displaced. If this material is liquid, as in a water pocket, it may be driven to new locations, escape though vents, or force confining barriers to yield. Injecting water just prior to grout injection will wash out clay and other solid materials and by erosion will open up passages for the entrance and uniform distribution of the grout.

## Grout

Grout must penetrate the material sufficiently to prevent the accumulation or passage of water and to consolidate the mass enough to restore the load-carrying capacity of the subgrade. The grout must be uniformly smooth and cohesive enough to retain its original consistency while being injected and must contain particles small enough to penetrate voids and passages in the subgrade. Just what proportions of cement, sand, and water to use will depend on the physical conditions of the material to be grouted. An excess of water may result in washing sand grains clean or in separating the water and cement from the mix when under pressure. It is well to remember that while low-cost grout is desirable, an apparent saving in the cost of materials may be more than offset by increased cost of injection and less effectiveness in reducing maintenance cost (Fig. 43).

Choice of grout proportions and consistency should usually be made by trial, since the requirements vary with the subgrade conditions encountered. Start with water. If water is refused at the maximum pressure available—at least 100 psi—it will be futile to attempt to inject grout at that level. Trials should be repeated at other depths.

After water has been accepted, further trials may be made with neat grouts beginning with 10 gallons of water per bag of portland cement. If this is taken freely, reduce the amount of water and add some sand—for example, 50 lb per bag of cement.

If the flow indicates that a still thicker grout will be received, increase the amount of sand until the desired consistency is secured up to a maximum of about 400 lb of sand per bag of cement. Little economy is gained in first cost by using leaner mixes since delays in operation due to line plugs and other problems offset any saving in cement. Experience also indicates that greater savings in annual maintenance have been obtained when rich mixes have been used.

Do not attempt to use sand unless 100% of it will pass a No. 16 sieve and preferably a No. 30 sieve. Even

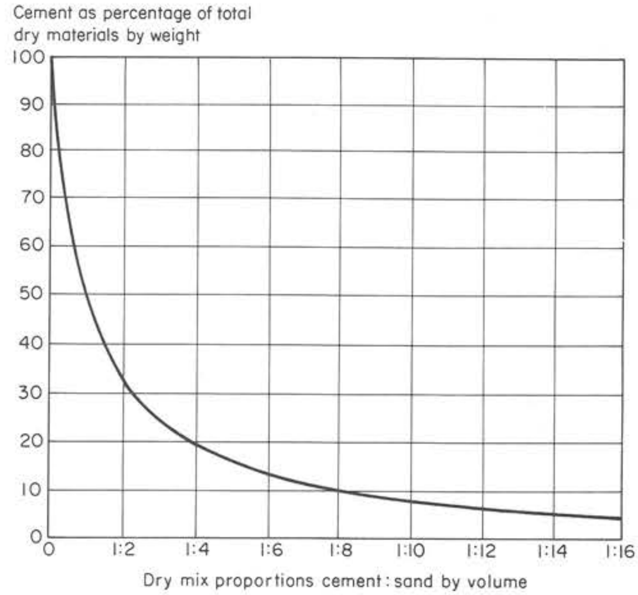



**Fig. 43. The chart shows the ratio of cement to total dry materials in grouts of different proportions. It is apparent that only slight savings in cement volume and costs can be realized by using lean grout. Grouts leaner than 1:6 are seldom used because the slight saving in cement cost may be more than offset by the cost of line stoppages caused by overly lean grouts. Reference 12.**

finer sand is better. The dry materials should be passed through a coarse sieve (¼-in. mesh) just before the mixing operation to remove lumps of sand or cement and foreign material. If the sand is lacking in very fine particles, a small amount of clay or fly ash (10% to 15% by volume of sand) can be added to the grout to provide these fines and help prevent segregation.

It is impossible to estimate accurately the quantity of grout required for any particular project. Normally, the volume of grout accepted varies from ½ to 10 cu ft per track foot, but on some large-fill grouting projects 100 cu ft or more per foot of track has been used. In planning a grouting program, enough materials should be provided to keep a crew supplied without interrupting operations. An average grouting crew operating a single grouter will use from 100 to 150 cu ft of grout per day. At least one day's supply of materials should be kept ahead of work.

## Equipment

Mixing equipment and grout-injecting equipment should be of liberal size (6-cu ft minimum capacity) so that it will not restrict grouting operations. Essential spare parts should be kept on hand to prevent shutdowns.

All grout materials should be thoroughly and uniformly mixed to prevent segregation and clogging of the grout lines and injection points. Mixing may be done a number of ways: in a combined mixer and pressure tank by a bladed shaft driven by an air or gasoline motor; with paddles in a tub; or by other grout-mixing equipment.

Grout is mixed by adding the water first, followed by the cement and sand. The grout should have a soupy consistency, generally from 3 to 5 gallons of water being used for each 1 cu ft of dry materials. Once mixing operations have started they should be continued until all of the grout in the tank is injected. Grout should not be allowed to remain in the injector for more than about 5 minutes since settlement may occur that will clog the equipment. No grout should be permitted to stand in the discharge lines. The lines should be blown out occasionally to prevent plugs. All operations should be controlled carefully so that a continuous supply of grout is provided to prevent interruptions in the work.

Effective grouting can be done with pneumatic or hydraulic pressure. Pneumatic equipment should be simple and portable. The pressure tank should have an airtight charging door and should have appropriate connections for controlling the air supply and discharging the grout. There are commercially built pneumatic grouters on the market that combine in a single unit the functions of mechanically mixing and injecting the grout.

Pneumatic equipment should be able to provide at least 100 psi, but best results are generally obtained with pressures of 40 to 60 psi at the injection point. If too high a pressure is maintained in the tank, segregation of the ingredients of the grout may occur with resultant line plugs, or the grout as deposited in the subgrade may be of nonuniform quality.

It is important that all grouting equipment and particularly the pressure tank and connections be kept clean and free from accumulation of hardened grout. All parts of the equipment should be readily accessible for cleaning and the tank should be constructed to encourage uniform agitation and have no dead zones where grout can deposit and harden.

Hydraulic equipment also should be simple and portable. Hydraulic pressure builds up gradually until grout is accepted and somewhat higher hydraulic pressures can be used than are generally satisfactory with pneumatic equipment. After the initial resistance has been overcome and water or grout starts flowing, the pressure needed for continued flow usually drops off considerably. Distribution of grout proceeds steadily as governed by local resistance. When grout breaks through weak places or finds a vent, hydraulic pressure is immediately reduced.

## Auxiliary Equipment

The usual track, carpenters and plumbers tools, pipelines and connections, water barrels, blocking, and other miscellaneous items available to track crews are necessary. A small hand- or gas-driven pump may be needed if water is obtained from a stream or ditch.

The grout discharge line should be as straight and have as few fittings and valves as possible. All parts should be designed to discourage line plugs. Connections should be of a type quickly broken and blowoffs or bypasses should be provided to quickly clear the line and permit easy cleaning. A 1¼-in. or 1½-in.-diameter rubber hose discharge line has been found satisfactory. The hose should not be too long because the tendency to plug and the difficulty of cleaning increase with length.

Discharge lines composed of 50-ft-long sections and ranging in length from 50 to 400 ft have been used. For pneumatic machines, experience has shown that lengths of 50 ft to 150 ft are most effective and permit best coordination between the workers at the injection points and the grout machine. Longer lines are more subject to plugging, but if they can be used they will permit a longer length of track to be treated from each setup. Longer discharge lines can be used with the hydraulic-type grouter, with lengths frequently ranging from 250 to 400 ft.

Grout flow usually is regulated by a valve at the pressure tank. Air pressure entering the tank is controlled by another valve. A blowoff valve permits releasing the pressure in the tank in the event of a line plug. It has been found helpful to equip the grout tank with an air-pressure-reducing valve to regulate maximum air pressure in the tank. The reducer can be set for any desired tank pressure.

Occasionally grout flow is controlled by a valve on the discharge line at the injection point. Every effort should be made to eliminate valves and fittings on the discharge line; the tank-valve method for controlling the flow of grout is preferred.

Usually all necessary control may be accomplished by providing a quick-acting coupling at the injection point. The connection of the discharge line to the grout point should be simple and permit rapid coupling and uncoupling. A standard air-hose coupling or a standard threaded pipe union is satisfactory for the purpose.

Provision should be made to relieve stoppages in the discharge line quickly. It is effective to uncouple the grout line at the injection point and blow the stoppage out by means of a blowoff valve connected to an air bypass line on the grout tank or by connecting the line directly to the air compressor. The grout is permitted to blow until flow is established. Grout is wasted in a ditch or caught in a bucket.

Injection points must withstand severe treatment in driving and pulling. Large pipes offer too much resistance to driving; small pipes and pipes with thin walls are too flexible. Standard double-strength 1¼-in.-diameter iron pipe has commonly been used and is usually available at railway shops. If 1-in. pipe is used, an appropriate bushing will be needed to connect to the 1¼-in. discharge line. For the average track job, 25 to 50 injection points will be needed. The injection points are left open at the tip and threaded at the top to receive a standard coupling or a threaded driving cap.

Where ballast permits easy driving, the tip of the pipe may have a loose-fitting metal pilot plug (usually an old bolt head or rivet head). A cleaning rod—1-in. diameter and 6 to 8 ft long—with a loop handle at one end is used to drive the plug out and free the tip.

Another type of point is made from 1¼-in. outside-diameter seamless steel tubing that has been fitted at the upper end with a driving head and a short length of hose with a "glad hand" coupling. Grout leaves the point through two ⅝-in. diameter holes located on opposite sides of the pipe near the hardened-steel bullet-nosed tip.

Points for track grouting are generally made in 6- and 10-ft lengths. Several threaded nipples with couplings ranging in length from 18 in. to about 4 ft should be available to accommodate the few places where greater depths must be reached. For unstable fills and cuts, grout points of 12- to 20-ft lengths may be required.

In long-seasoned roadbed, the ballast usually offers high resistance to driving the injection points. Sometimes under such conditions a solid-steel spud bar of slightly larger size than the injection point is first driven to the desired depth and then withdrawn, leaving a hole to receive the injection point. As the spud bar is driven it should be kept loose by twisting with large Stillson wrenches or other effective means. The injection points are then set in the holes thus formed and easily driven to any depth desired. Usually no pilot plugs are needed in these injection points, as any material that plugs them may be pushed out with the cleaning rod.

Both spuds and injection points may be driven either by hand or power. The heads of spuds will withstand the abuse of driving without much damage. Driving heads are needed for driving injection points. For light driving, pipe couplings are adequate and can be reused a number of times. Where heavy resistance is encountered, special heavy threaded metal caps are needed. Driving by hand may be accomplished with 12-lb to 18-lb sledges, weighted pipe sleeves (40 to 50 lb), or weighted rods worked inside the pipe through a drilled hole in the driving head. When air is available an airhammer may be used. Specially made drophammers are advantageous when using long injection points.

The driving head should be designed to protect the threaded ends of injection points during driving. It can be made to bear against a collar welded to the point just below the threads. A better design is one in which a driving head, with the shaft machined down to provide a shoulder, bears against a standard pipe coupling screwed on the upper end of the injection point. The driving head should be designed to fit into or to be fastened snugly around the barrel of the airhammer so the hammer will not jump off the driving head while in use and injure someone.

The pulling of spuds and injection points is another operation in which suitable methods and tools will expedite the job. Pulling may be done with large Stillson pipe wrenches or a chain and claw bar. In more stubborn roadbed, jacks reacting against thick iron plates with holes to slip over the points may be effective. A steel pinch plate about ¾ in. thick having a hole slightly larger than the point is a useful device. With the point passing through it, the pinch plate is placed on the ground. With the tie plate for a fulcrum and a claw bar for a lever, an effective uplift is obtained, and by pumping the claw bar up and down, a rapid ratchet action may be produced. Several efficient commercially built pipe pullers are available.

## Summary of Equipment and Accessories

Air compressor (portable preferred), capacity 75 to 100 cu ft per minute at pressure up to 100 psi

Grout mixer, type determined by local conditions, as discussed

50 to 400 ft of rubber discharge hose, 1¼-in. or 1½-in. diameter, with fittings to connect to grouter and injection points

25 to 50 injection points, in desired lengths and with necessary accessories such as extension pipe, nipples, couplings, and metal plugs

¼-in. screen to remove foreign material and lumps from sand, cement, and the grout

2 solid steel spud bars, 1¾-in. diameter or 1⅜-in. square and 5 to 6 ft long

1 point puller

Small water pump if water is to be obtained from streams or ditches

Water storage tanks as determined by job conditions

Air tools, to include one or more air hammers or equivalent with air lines to operate them

4 driving caps to fit injection points

1¾-in. rock drill bit if unusually hard ballast is anticipated

Carpenter, plumbing, and track tools and equipment usually assigned to track crews using air equipment

Timber blocking

Spare fittings, gaskets, and minor critical parts subject to quick wear or breakage

Fuel and oil

Platform 3 to 5 ft high

Ramrod for ramming out plugs

500 to 1000 ft of water hose or pipe

## Procedure

Occasionally test pits or cross trenches, to determine the nature of the material under the track at the more troublesome spots, are desirable. A practical advantage of the pressure grouting method is that varying undertrack conditions are accurately sensed by the resistance encountered as the points are being driven. Usually the top portion of the ballast is compact making the early resistance hard. Then the point passes through a zone of less resistance until the clay line in the bottom of the water pocket is reached; and as the point enters the clay, resistance again changes. Since grout cannot be forced into clay, driving should stop at this clay line. If driven deeper, the point should be pulled back free of the clay before grouting is begun (Fig. 44).

In case the injection point is too short to reach the clay line, it may be lengthened by adding a nipple and driven deeper. This lengthening is seldom necessary in grouting soft spots and water pockets because the pocket is usually so enclosed that the injection grout

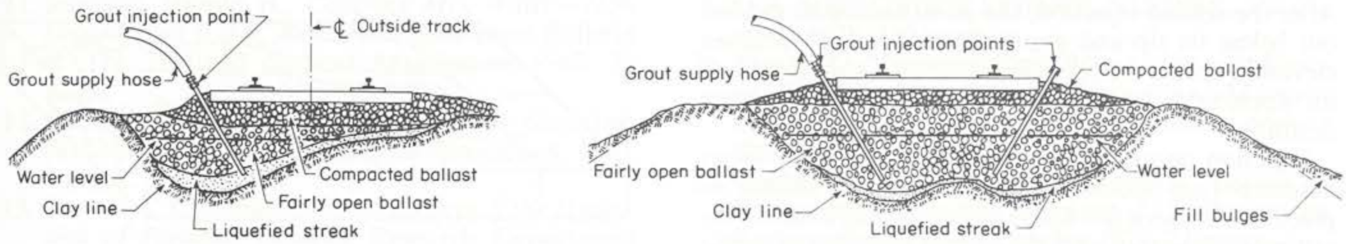



**Fig. 44. Common types of water pockets and treatment. Grouting of multiple track (left) is usually required only under the outside rail because lateral support is weakest along the shoulders. Treatment from both sides is usually needed for single track (right). On fills, bulges usually appear farther from the track than in cuts and often down the slope. Reference 12.**

displaces the liquid material at depths well below the tip of the injection point. Long points frequently are required in grouting high fills, and for these it is advantageous to use pipes in sections connected by threaded couplings. Adding lengths of pipe as required eliminates the necessity of driving long points from a platform, which is difficult. Besides, there is less chance of the points bending as they are pulled.

Injection points are generally driven at the outer ends of ties at an angle to bring the tip approximately under the rail. The angle of driving is not critical and may vary from 45 to 15 degrees with the vertical, but adequate clearance should be given between the points and passing trains. In case injection points are installed between rails, they may be set either vertically or at an angle, but the top of the pipes must be below the top of the rail.

When slides or other areas of yielding soil are grouted, injection points should be spaced to give maximum grout distribution. For sliding fills or sidehills of cuts, grout points spaced about 5 ft apart should be driven at the toe of the slope, up the sides and on the shoulders in addition to the points driven along the ends of the ties. Location of the points and depths to which they should be driven will depend on the conditions encountered in the field.

Before grouting, a track level board should be placed across the rails opposite the point being grouted to guard against the track heaving out of cross level. Promptness in cutting the air supply immediately after grout clears the point will forestall much heaving of track.

An orderly sequence of grout injections is advisable for efficient operation and the recording of construction data. Work should start at one end of a pocket and move progressively ahead. The option of injecting water into 10 to 12 points immediately preceding grouting can have a beneficial washing and lubricating effect.

To control the upper limit of the injected grout, pits may be dug between the ties or just beyond the tie ends, with their bottoms at the level above which grout should not rise. Usually this is not necessary because the top ballast contains too much fine material to permit much grout to penetrate it except in occasional porous areas. The affected ballast is usually only weakly cemented and may be easily loosened with tamping tools. If grout breakthroughs occur in the top ballast or in the shoulders or between tracks, grouting should be transferred to another point. Later, after this grout has stiffened, another injection should be tried. This may often be done less than an hour later.

Grout injections should be continued at a point as long as grout is being accepted, provided there are no breakthroughs that waste grout or the track is not being heaved objectionably. If grout is refused at a lower depth, the point should be progressively raised until grout is taken. Grout welling up or spouting from other points indicates that a channel has been opened between their tips. The venting pipe should then be plugged, either by screwing on a standard pipe cap or by driving in a wooden plug, and grout injection continued at the first point. Grout appearing in the side of a ditch or down the slope of an embankment indicates that the grout has found a path of least resistance. Sometimes this flow may be checked by shoveling and tamping dirt at the vent. If this is not effective the injection should be changed to a new point. Should grout blow back up on the outside of the pipe, the flow may be checked by stamping fine material around the pipe, or by letting it rest a few minutes while injecting grout at another point.

If grout flow ceases while pressure is on, prompt location of the plug and clearing of the line will avoid trouble. First pull the point progressively to a higher elevation while the grout is under pressure. If grout still will not flow, then open the blowoff valve or uncouple the hose at the injection point to clear the line. If the line clears, transfer the connection to the next injection point while pulling and clearing the plugged point. If the plug is in the line, pounding with a wooden mallet may clear it; if this fails apply back pressure. This is a good time to check the consistency of the grout. Plugs composed mostly of sand indicate the amount of sand should be reduced and possibly a much finer sand should be substituted. Do not add water to the grout under these conditions.

Should there be doubt as to the effectiveness of grouting at any location, another injection may be tried after rodding out the point or additional injection may be made through new points installed the next day.

After the second injection, the point should be rodded out below its tip and grouting attempted at a lower elevation before the point is pulled up. Other locations for application of grout should be tried as appear desirable.

Injection points should be rodded out before grout hardens. They should not be permitted to remain in place more than a few hours after grouting because the setting of the grout and the compaction due to traffic may make pulling difficult. In case passing trains cause grout to spout from the points, these should be capped or plugged not only to prevent loss of grout but also to take advantage of the wider distribution of grout caused by pressure from the trains. Special early-strength cements are helpful in opening the rail to traffic.

Before considering the treatment at any location completed, the record should be reviewed to be sure that all points have been grouted before moving to a new location.

Following grouting, the track is brought to final line and surface and should require little or no further attention other than normal track maintenance. It is advisable to mark the treated locations with stakes so that comparative maintenance records may be kept. Equipment and accessories should then be carefully cleaned and checked so that worn and broken parts may be renewed and spares restocked for use at a new location. Reference 12.

## DEMOLITION GROUTING

Demolition grouting is used to fracture or break up concrete or stone. It is used in the demolition or renovation of concrete dams, pavements, buildings, bridge piers, machinery bases, and other concrete structures (Fig. 45). It is very useful in removing boulders and rock formations.

The demolition process consists of (1) coring a pattern of 1.5-to 2-in.-diameter holes spaced about 10 to 15 hole diameters apart into the concrete or rock, (2) filling the holes by pouring or pumping with a special cement and water grout, (3) waiting for the grout to hydrate, expand, and fracture the concrete or rock by exceeding its tensile strength, and (4) removing the broken-up material with conventional equipment. The holes in which the grout is placed must not be looked into for safety reasons. The advantages of using demolition grouting techniques over explosives include little to no noise, no vibration, no flying debris, no dust, and the ease of use. The stone-quarry industry also uses this type of grout in place of explosives.

Demolition grout consists of water and a special highly expansive proprietary cement. These grouts can develop expansive pressures in the range of 3000 psi in 12 hours to 9000 psi at 48 hours—far exceeding the tensile strength of concrete or rock. The grout is mixed and handled like regular portland cement grout. Follow manufacturers directions for proportioning the grout. Ice water is often used as mix water to control the reactivity of the grout during placement. Usually only special, highly expansive cements are used; however,

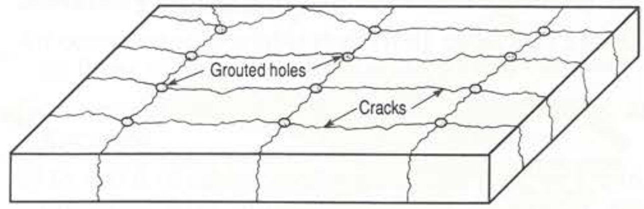



**Fig. 45. Illustration of demolition grouting used to break up a thick concrete slab.**

ASTM C845 expansive hydraulic cements can produce sufficient expansion pressures for some applications. The use of regular ASTM C150 portland cement with an expansive admixture also has possible applications in demolition grouting.

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74. *Utility Cuts and Full-Depth Repairs in Concrete Streets,* IS235P, Portland Cement Association, 1988, 8 pages.
75. *API Specification for Materials and Testing for Well Cements,* API Specification 10, American Petroleum Institute, Washington, D.C., 1988.
76. *Building Code Requirements for Masonry Structures,* ACI 530-88/ASCE 5-88, American Concrete Institute, Detroit, and American Society of Civil

Engineers, New York, 1988.

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79. *Resurfacing Concrete Floors,* IS144T, Portland Cement Association, Skokie, Illinois, 1989.
80. *Specification for Oil-Well Drilling Fluid Materials* (Marsh funnel test), API Specification 13A, American Petroleum Institute, Dallas, 1988.
81. Mech, George J., "Rehabilitation of Peoria Lock Using Preplaced-Aggregate Concrete," *The REMR Bulletin,* U.S. Army Corps of Engineers, Vicksburg, Mississippi, October 1989, 4 pages.

# APPENDIX

## ASTM Standards

American Society for Testing and Materials (ASTM)* documents related to aggregates, cement, and grout that are relevant to or referred to in the text:

| | |
|---|---|
| C 5 | Specification for Quicklime for Structural Purposes |
| C 33 | Specification for Concrete Aggregates |
| C 42 | Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete |
| C 70 | Test Method for Surface Moisture in Fine Aggregate |
| C 94 | Specification for Ready-Mixed Concrete |
| C 109 | Test Method for Compressive Strength of Hydraulic Cement Mortars (using 2-in. or 50-mm Cube Specimens) |
| C 141 | Specification for Hydraulic Hydrated Lime for Structural Purposes |
| C 143 | Test Method for Slump of Portland Cement Concrete |
| C 144 | Specification for Aggregate for Masonry Mortar |
| C 150 | Specification for Portland Cement |
| C 157 | Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete |
| C 191 | Test Method for Time of Setting of Hydraulic Cement by Vicat Needle |
| C 207 | Specification for Hydrated Lime for Masonry Purposes |
| C 230 | Specification for Flow Table for Use in Tests of Hydraulic Cement |
| C 232 | Test Method for Bleeding of Concrete |
| C 243 | Test Method for Bleeding of Cement Pastes and Mortars |
| C 260 | Specification for Air-Entraining Admixtures for Concrete |
| C 266 | Test Method for Time of Setting of Hydraulic Cement by Gillmore Needles |
| C 403 | Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance |
| C 404 | Specification for Aggregates for Masonry Grout |
| C 430 | Test Method for Fineness of Hydraulic Cement by the 45-$\mu$m (No. 325) Sieve |
| C 476 | Specification for Grout for Masonry |
| C 494 | Specification for Chemical Admixtures for Concrete |
| C 566 | Test Method for Total Moisture Content of Aggregate by Drying |
| C 595 | Specification for Blended Hydraulic Cements |
| C 596 | Test Method for Drying Shrinkage of Mortar Containing Portland Cement |
| C 618 | Specification for Fly Ash and Raw or Calcined Natural Pozzolan for Use As a Mineral Admixture in Portland Cement Concrete |
| C 666 | Test Method for Resistance of Concrete to Rapid Freezing and Thawing |

*ASTM, 1916 Race Street, Philadelphia, Pa. 19103.

C 671 Test Method for Critical Dilation of Concrete Specimens Subjected to Freezing

C 672 Test Method for Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals

C 685 Specification for Concrete Made by Volumetric Batching and Continuous Mixing

C 786 Test Method for Fineness of Hydraulic Cement and Raw Materials by the 300-μm (No. 50), 150-μm (No. 100), and 75-μm (No. 200) Sieves by Wet Methods

C 796 Test Method for Foaming Agents for Use in Producing Cellular Concrete Using Preformed Foam

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 869 Specification for Foaming Agents Used in Making Preformed Foam for Cellular Concrete

C 878 Test Method for Restrained Expansion of Shrinkage-Compensating Concrete

C 928 Specification for Packaged, Dry, Rapid Hardening Cementitious Materials for Concrete Repairs

C 937 Specification for Grout Fluidifier for Preplaced-Aggregate Concrete

C 938 Practice for Proportioning Grout Mixtures for Preplaced-Aggregate Concrete

C 939 Test Method for Flow of Grout for Preplaced-Aggregate Concrete

C 940 Test Method for Expansion and Bleeding of Freshly Mixed Grouts for Preplaced-Aggregate Concrete in the Laboratory

C 941 Test Method for Water Retentivity of Grout Mixtures for Preplaced-Aggregate Concrete in the Laboratory

C 942 Test Method for Compressive Strength of Grouts for Preplaced-Aggregate Concrete in the Laboratory

C 943 Practice for Making Test Cylinders and Prisms for Determining Strength and Density of Preplaced-Aggregate Concrete in the Laboratory

C 953 Test Method for Time of Setting of Grouts for Preplaced-Aggregate Concrete in the Laboratory

C 979 Specification for Pigments for Integrally Colored Concrete

C 989 Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars

C 1017 Specification for Chemical Admixtures for Use in Producing Flowing Concrete

C 1019 Method of Sampling and Testing Grout

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 (Nonshrinkable)

D 2487 Classification of Soils for Engineering Purposes

D 2488 Recommended Practice for Description and Identification of Soils (Visual-Manual Procedure)

D 4016 Test Method for Viscosity of Chemical Grouts by Brookfield Viscometer (Laboratory Method)

D 4258 Practice for Surface Cleaning Concrete for Coating

D 4259 Practice for Abrading Concrete

D 4260 Practice for Acid Etching Concrete

D 4261 Practice for Surface Cleaning Concrete Unit Masonry for Coating

D 4262 Test Method for pH of Chemically Cleaned or Etched Concrete Surfaces

D 4263 Test Method for Indicating Moisture in Concrete by the Plastic-Sheet Method

E 380 Metric Practice

## Corps of Engineers Standards

U.S. Army Corps of Engineers standards related to grout are listed below.*

CRD-C611 Test Method for Flow of Grout Mixtures (Flow-Cone Method)

CRD-C612 Test Method for Water Retentivity of Grout Mixtures

CRD-C613 Method of Test for Expansion of Grout Mixtures

CRD-C614 Method of Test for Time of Setting of Grout Mixtures

CRD-C619 Specification for Grout Fluidifier

CRD-C620 Method of Sampling Fresh Grout

CRD-C621 Specification for Nonshrink Grout

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*Available from U.S. Army Engineer Waterways Experiment Station, P.O. Box 631, Vicksburg, Miss. 39180.

## Metric Conversion Factors

The following list provides the conversion relationship between U.S. customary units and SI (International System) units. The proper conversion procedure is to multiply the specified value on the left (primarily U.S. customary values) by the conversion factor exactly as given below and then round to the appropriate number of significant digits. For example, to convert 11.4 ft to meters: $11.4 \times 0.3048 = 3.47472$, which rounds to 3.47 meters. Do not round either value before performing the multiplication, as accuracy would be reduced. A complete guide to the SI system and its use can be found in ASTM E 380, Metric Practice.

| To convert from | to | multiply by |
|---|---|---|
| **Length** | | |
| inch (in.) | millimeter (mm) | 25.4 E |
| inch (in.) | micron (μ) | 25,400 E |
| inch (in.) | centimeter (cm) | 2.54 E |
| inch (in.) | meter (m) | 0.0254 E |
| foot (ft) | meter (m) | 0.3048 E |
| yard (yd) | meter (m) | 0.9144 |
| **Area** | | |
| square foot (sq ft) | square meter (sq m) | 0.09290304 E |
| square inch (sq in.) | square centimeter (sq cm) | 6.452 E |
| square inch (sq in.) | square meter (sq m) | 0.00064516 E |
| square yard (sq yd) | square meter (sq m) | 0.8361274 |
| **Volume** | | |
| cubic inch (cu in.) | cubic centimeter (cu cm) | 16.387064 |
| cubic inch (cu in.) | cubic meter (cu m) | 0.00001639 |
| cubic foot (cu ft) | cubic meter (cu m) | 0.02831685 |
| cubic yard (cu yd) | cubic meter (cu m) | 0.7645549 |
| gallon (gal) Can. liquid | liter | 4.546 |
| gallon (gal) Can. liquid | cubic meter (cu m) | 0.004546 |
| gallon (gal) U.S. liquid** | liter | 3.7854118 |
| gallon (gal) U.S. liquid | cubic meter (cu m) | 0.00378541 |
| fluid ounce (fl oz) | milliliters (ml) | 29.57353 |
| fluid ounce (fl oz) | cubic meter (cu m) | 0.00002957 |
| **Force** | | |
| kip (1000 lb) | kilogram (kg) | 453.6 |
| kip (1000 lb) | newton (N) | 4,448.222 |
| pound (lb) avoirdupois | kilogram (kg) | 0.4535924 |
| pound (lb) | newton (N) | 4.448222 |
| **Pressure or stress** | | |
| kip per square inch (ksi) | megapascal (MPa) | 6.894757 |
| kip per square inch (ksi) | kilogram per square centimeter (kg/sq cm) | 70.31 |
| pound per square foot (psf) | kilogram per square meter (kg/sq m) | 4.8824 |
| pound per square foot (psf) | pascal (Pa)† | 47.88 |
| pound per square inch (psi) | kilogram per square centimeter (kg/sq cm) | 0.07031 |
| pound per square inch (psi) | pascal (Pa)† | 6,894.757 |
| pound per square inch (psi) | megapascal (MPa) | 0.00689476 |
| **Mass (weight)** | | |
| pound (lb) avoirdupois | kilogram (kg) | 0.4535924 |
| ton, 2000 lb | kilogram (kg) | 907.1848 |
| grain | kilogram (kg) | 0.0000648 |
| **Mass per volume (density)** | | |
| pound per cubic foot (pcf) | kilogram per cubic meter (kg/cu m) | 16.01846 |
| pound per cubic yard (lb/cu yd) | kilogram per cubic meter (kg/cu m) | 0.5933 |
| **Temperature** | | |
| degree Fahrenheit (°F) | degree Celsius (°C) | $t_C = (t_F - 32)/1.8$ |
| degree Fahrenheit (°F) | degree Kelvin (°K) | $t_K = (t_F + 459.7)/1.8$ |
| degree Kelvin (°K) | degree Celsius (°C) | $t_C = t_K - 273.15$ |
| **Velocity** | | |
| mile per hour (mph) | kilometer per hour (km/hr) | 1.60934 |
| mile per hour (mph) | meter per second (m/s) | 0.44704 |
| **Permeability** | | |
| darcy | centimeter per second (cm/sec) | 0.000968 |
| feet per day (ft/day) | centimeter per second (cm/sec) | 0.000352 |

*E indicates that the factor given is exact.
**One U.S. gallon equals 0.8327 Canadian gallon.
†A pascal equals 1.000 newton per square meter or 1 MPa = 1 N/mm².

Note: One U.S. gallon of water weighs 8.34 pounds (U.S.) at 60°F and has a volume of 0.134 cu ft.
One cubic foot of water weighs 62.4 pounds (U.S.).
One milliliter of water has a mass of 1 gram and has a volume of one cubic centimeter.
One U.S. bag of cement weighs 94 lb.
One cubic foot of water is 7.48 U.S. gallons.

The prefixes and symbols listed below are commonly used to form names and symbols of the decimal multiples and submultiples of the SI units.

| Multiplication Factor | Prefix | Symbol |
|---|---|---|
| $1{,}000{,}000{,}000 = 10^9$ | giga | G |
| $1{,}000{,}000 = 10^6$ | mega | M |
| $1{,}000 = 10^3$ | kilo | k |
| $1 = 1$ | — | — |
| $0.01 = 10^{-2}$ | centi | c |
| $0.001 = 10^{-3}$ | milli | m |
| $0.000001 = 10^{-6}$ | micro | μ |
| $0.000000001 = 10^{-9}$ | nano | n |

For example, one millimeter is 1000 microns and 0.001 meters.

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