**PDHonline Course C368 (2 PDH)**

# An Introduction to Soil Grouting

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**1. INTRODUCTION.** This material is intended to provide a brief introduction to soil grouting materials and procedures for those engineers not familiar with the technology and its application. It is not a comprehensive treatment of the subject.

Grouting is a widely used method for strengthening and sealing rock, soil and concrete. The possibilities for sealing structures are of great importance from both an economic and environmental point of view. The cost of grouting has in certain projects been as high as the cost of blasting and excavating the tunnel. To improve the technique for grouting with cement-based material, it is necessary to examine the properties of the grout mixture used.

In planning a grouting program for particular conditions, the engineer needs knowledge of the various types of grouts and their properties. The basic types of grouts now in use and their properties are discussed below. Types of admixtures and fillers used and their effects on the grout are also discussed. The most common types of grouts are Portland-cement, clay, chemical, and asphaltic grouts. No one grout is suitable for every situation. The properties of each specific grout make it desirable under certain circumstances. An important requirement for the selection of a grout is that its particles be substantially smaller than the voids to be filled. Figure 1 shows limiting grain sizes of materials that can be grouted by various types of grout. These data are based on experience and testing and should be used only as a guide. Another relationship can be determined by the groutability ratio, N , expressed by the equation

$$N = D_{15}/D_{85}$$

where $D_{15}$ is the 15 percent finer grain size of the medium to be grouted and $D_{85}$ is the 85 percent finer grain size of the grout. N generally should be greater than 25 but in some cases may be as low as 15, depending upon physical properties of the grout materials.

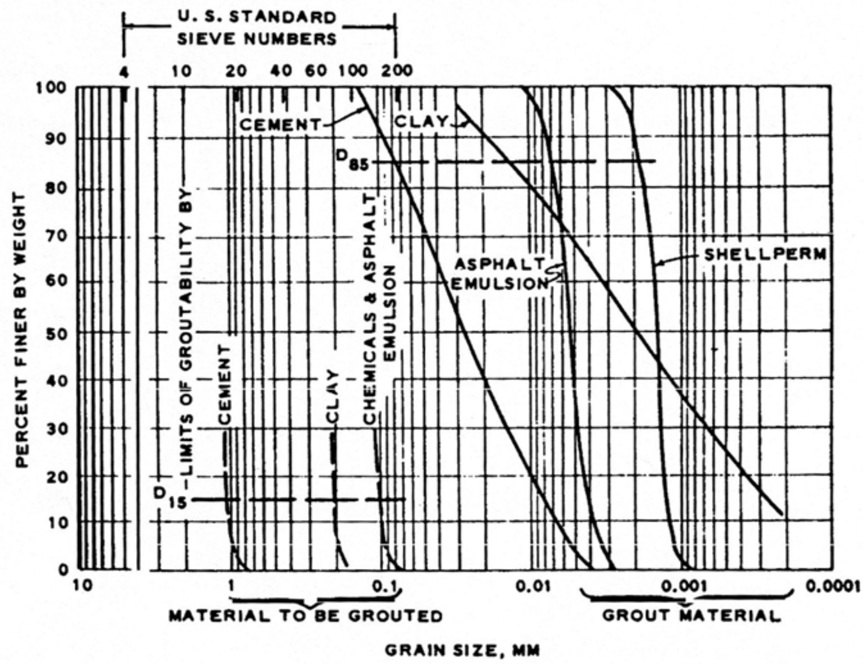


Figure 1

**2. PORTLAND-CEMENT GROUT.** Portland-cement grout is a mixture of portland cement, water, and, frequently, chemical and mineral additives. The properties of materials generally used in portland-cement grout are described below.

**2.1 Portland-Cements.** Five types of Portland-cement, produced to conf orm to the specifications of ASTM Designation C 150, are used in cement grouts.

2.1.1 *Type I* is a general-purpose cement suitable for most cement grout jobs. It is used where the special properties of the other four types are not needed to meet job requirements.

2.1.2 *Type II* cement has improved resistance to sulfate attack, and its heat of hydration is less and develops at a slower rate than that of type I. It is often used interchangeably with type I cement in grouting and is suggested for use where precautions against moderate concentration of sulfate in groundwater are important.

2.1.3 *Type III* cement is used where early strength gains are required in grout within a period of 10 days or less. It may also be used in lieu of type I or type II in injection work because of its finer grind, which improves its injectability.

2.1.4 *Type IV* cement generates less heat than type II cement and develops strength at a very slow rate. It is rarely used in grouting.

2.1.5 *Type V* cement has a high resistance to sulfates. It is not often used in grouts, but its use is desirable if either the soil to be grouted or the groundwater at the jobsite has a high sulfate content.

**2.2 Mixing Water.** Generally, water suitable for drinking may be regarded as suitable for use in grout. Ordinarily the presence of harmful impurities (e. g., alkalies, organic and mineral acids, deleterious salts, or large quantities of silt) is known in local water sources. If there is reason to suspect a water source, it should, be tested in accordance with CRD-C 400.

**2.3 Fillers.** Fillers in portland-cement grout are used primarily for reasons of economy as a replacement material where substantial quantities of grout are required to fill large cavities in rock or in soil. Almost any solid substance that is pumpable is suitable as a filler in grout to be used in non-permanent work. For permanent work, cement replacements should be restricted to mineral fillers. Before accepting any filler, tests should be made in the laboratory or in the field to learn how the filler affects the setting time and strength of the grout and whether it will remain in suspension until placed. All aspects of the use of a filler should be carefully studied. The economy indicated initially by a lower materials cost may not continue throughout the grouting operation. Additional personnel and more elaborate batching facilities may be needed to handle the filler. Some fillers make the grout more pumpable and delay its setting time. Such new properties may add to the costs by increasing both the grout consumption and the grouting time.

2.3.1 *Sand*. Sand is the most widely used filler for portland-cement grout. Preferably it should be well graded. A mix containing two parts sand to one part cement can be successfully pumped if all the sand passes the No. 16 sieve and 15 percent or more passes the No. 100 sieve. The use of coarser sand or increasing the amount of sand in the mix may cause segregation. Segregation can be avoided by adding more fine sand or using a mineral ad- mixture such as fly ash, pumicite, etc. Mixes containing up to 3/4-in. aggregate can be pumped if properly designed. Laboratory design of such mixes is recommended. Sanded mixes should never be used to grout rock containing small openings and, of course, should not be used in holes that do not readily accept thick mixes of neat cement grout (water and portland cement only).

2.3.2 *Fly Ash.* Fly ash is a finely divided siliceous residue from the combustion of powdered coal, and may be used both as a filler and as an admixture. Most grades of fly ash have about the same fineness as cement and react chemically with Portland-cement in producing cementitious properties. The maximum amount of fly ash to be used in grout mixtures is 30 percent by weight of the cement, if it is desired to maintain strength levels comparable to those of portland-cement grouts containing no fly ash.

2.3.3 *Diatomite*. Diatomite is mineral filler composed principally of silica. It is made up of fossils of minute aquatic plants. Processed diatomite is an extremely fine powder resembling flour in texture and appearance. The fineness of the diatomite may range from three times to as much as 15 times that of cement. Small amounts of diatomite may be used as admixtures to increase the pumpability of grout; however, large amounts as fillers will require high water- cement ratios for pumpability. As a filler, diatomite can be used where low strength grouts will fulfill the job requirements.

2.3.4 *Pumicite*. Pumicite, a finely pulverized volcanic ash, ashstone, pumice, or tuff, is also used as a filler in cement grout. Like fly ash and diatomite, it improves the pumpability of the mix and has pozzolanic (hydraulic cementing) action with the portland- cement.

2.3.5 *Other fillers.* Silts and lean clays not contaminated with organic materials are sometimes used as fillers. Lees, a windblown silt containing from 10 to 25 percent clay, is a suitable filler. Rock flour, a waste product from some rock-crushing operations, is also used as a filler. Rock flour produced during the manufacture of concrete sand is very fine but not always well graded. Grouts containing poorly graded rock flour are frequently highly susceptible to leaching. Most finely divided fillers increase the time required for the grout to set. It may be expedient to add an accelerator, described subsequently, to compensate for this.

**2.4 Admixtures .** Admixtures as described herein are substances that when added to portland-cement grout, impart to it a desired characteristic other than bulking.

2.4.1 *Accelerators*. Accelerators cause a decrease in the setting time of grout. These additives are used to reduce the spread of injected grout, to reduce the erosion of new grout by moving groundwater and to increase the rate of early strength gain. The most commonly used accelerator is calcium chloride. It can be added to the mixing water in amounts up to 2 percent of the weight of the cement. Greater percentages of calcium chloride increase the very real danger of having the mix set up in the grout plant. High alumina cement and plasters having a calcined gypsum base may be proportioned with Portland cement to make a grout having various setting times. Other accelerators include certain soluble carbonates, silicates, and triethanolamine. Small amounts of some accelerators are capable of producing instantaneous or near instantaneous setting of the grout. Triethanolamine added to some cements in the amount of 0.2 percent can produce such sets. When using accelerators, competent technical advice should be sought and preliminary tests conducted to determine the behavior of accelerators in the grout mix.

2.4.2 *Lubricants*. Fly ash and rock flour added to the grout mix increase its pumpability. Fluidifiers and water- reducing admixtures improve the pumpability or make possible a reduction in the water- cement ratio while maintaining the same degree of pumpability. Most of these substances are also retarders. Laboratory or field trial mixes should be batched and all pertinent effects observed and tested before adopting an unknown admixture for any project.

2.4.3 *Other effects.* Numerous other substances can be added to portland-cement grout to obtain special effects. Bentonite or other colloids, or finely powdered metal are added to grout to make it more viscous and stable powdered metals unite with hydration products of the cement and release tiny bubbles of hydrogen, which, in addition to increasing the viscosity, cause a slight expansion of the grout. Aluminum is the metal most often used. It is added at the rate of about 1 teaspoonful of aluminum powder per sack of cement. Very small amounts of carbohydrate derivatives and calcium lignosulfonate may be used as retarders. Sodium chloride is used to brine mixing water when grouting is performed in salt formations. This prevents erosion of in situ rock salt and provides a degree of bonding of grout to salt. Approximately 3 lb of dry salt for each gallon of water will provide a saturated mixture and will result in some retardation of the grout set.

**2.5 Effect of Groundwater.** Alkalis, acids, or salts contained in groundwater may cause more damage to portland-cement grouts placed in sandy soils than to these placed in clays. This increase in damage is a result of the sandy soils permitting rapid leaching as opposed to clays which tend to retard groundwater movement. In most clays, sulfate salts are found in very small quantities. Rich type V portland-cement grouts will not be damaged by low or moderate concentrations of calcium sulfate salts (gypsum). Portland-cement grouts should not be used in formations containing salts that consist of high concentrations of magnesium and sodium sulfates. Where such concentrations are found, the use of chemical grouts should be considered. Harmful chemicals in groundwater may come from a number of sources, e.g., manufacturing plant wastes, water from coal mines, leaching from coal storage and waste areas, and leaching of sodium or magnesium matter. Waters of some streams and lakes in the western United States are very harmful to Portland- cement grouts because of their alkaline content.

**2.6. Effect of Seawater.** Crazing and hairline cracks occurring in hardened—grouts because of shrinkage, temperature variations, and tension may permit the infiltration of seawater , which causes chemical decomposition of the grout. During hydration the higher silicates decompose into lower silicates and calcium hydroxide. The calcium hydroxide crystals dissolve slowly in water, resulting in subsequent decomposition of the clinker grains and liberation of new quantities of calcium hydroxide thus causing the cement to deteriorate. The free lime in the grout also reacts with magnesium sulfate in seawater and forms calcium sulfate, causing swelling in the interstices. Portland-cement grouts for use in the presence of seawater should contain air- entraining portland cement (type IIA) and waterproofing agents and have low water-cement ratios. Entrained air in grout increases the imperviousness of the grout. (Some modification of the usual mixing and dumping facilities may be required when using air- entraining cement to avoid having the sump tank overflow with froth. ) Waterproofing compounds that have been found to have a marked increase in promoting various degrees of im-permeability in portland-cement grouts are lime, fine-grained soils, tars, asphalts, emulsions, and diatomite. In addition to portland-cement grouts, chemical and pozzolan-cement grouts may be considered.

**3. CLAY GROUTS.** The primary purpose of any grouting project is to alter to a desired degree, the properties of an existing medium by the most economical means. Therefore, where conditions indicate that local clays. Will produce a grout that will give the desired results, they should be considered. In the following paragraphs, the properties of clay soils that make them suitable for a grout material are outlined, tests to be used in determining the suitability of clays are indicated, and guidance for the design of clay grouts is provided.

**3.1 Material.** Soils used as the primary grout ingredient can be divided into two classifications. One includes the natural soils found at or near the project with little or no modification required. The second includes commercially processed clay such as bentonite. The selection of a natural or processed material should be determined by an economic study considering (1) grout properties necessary, to meet job requirements, (2) quantity of grout required, (3) availability and properties of natural soils, (4) cost of modifying natural soils, if necessary to meet job requirements, (5) cost of importing a processed material that will meet job requirements, and (6) cost of mixing grout using either material. Generally, where large quantities of grout are needed, local materials will be more economical. For small quantities, it is generally more economical to bring in prepared material than to set up the required mining and processing equipment to use natural soil. In addition, any specific job may present additional factors to be considered.

**3.2 Natural Soils.** The use of natural soils is predicated on the existence of a suitable material within a reasonable distance of the project. Natural soils for use as a grout ingredient are of two types: (1) fine-grained soils with low plasticity that do not have gel properties and are more or less inert (silt and glacial rock flour) and (2) fine-grained soils of medium to high plasticity and with a high ion exchange capacity, which gives the material good thixotropic and gel properties. The types of soil covered under (1) above generally are used as fillers only. The types of soil covered under (2) above may be used both as fillers and admixtures. The best source of soils for grouts will be alluvial, eolian, or marine deposits. Residual clays may contain excessive coarse-grained material, depending upon the nature of the parent rock and the manner of decomposition. Glacial clays are generally the least suitable because of the usually large gravel and sand content. The properties of soils are for the most part determined by the quantity and type of clay minerals montmorillonite, present. Common clay minerals encountered are kaolinite, and illite. Kaolinite and montmorillonite are the most common and are found in various combinations in most fine-grained soils. Because of its ability to adsorb large quantities of water, a high percentage of montmorillonite is desirable for clay grouts. The clay minerals will generally make tip most of the material finer than 2 microns.

**3.3 Processed Clay.** The most commonly used commercially processed clay is bentonite, a predominantly montmorillonitic clay formed from the alteration of volcanic ash. The bentonite ore is crushed, dried, and finely ground to form the commercial products. Most bentonites exhibit a liquid limit of 350 to 500 and possess the ability to undergo thixotropic gelation. The gelling property is desirable to produce sufficient strengths in the injected grout to resist removal by groundwater under a pressure head. However, gelling can also create problems in pumping if not properly controlled.

**3.4 Testing Clays for Grouts.** In determining the suitability of a soil as a grout sufficient information for most projects can be obtained from a few common mechanical tests. Samples of the grout material should be handled and processed in conducting these tests in the same manner as that in which the material will be processed in the field when making the grout. For example, if the field procedure calls for air drying the raw material, the laboratory specimen should also be air dried.

3.4.1 *Gradation*. One important property of a clay grout is the grain- size distribution of its solid particles; this can be determined by a hydrometer analysis. The largest clay particles must be small enough to readily penetrate the voids in the medium to be grouted.

3.4.2 *Atterberg limits*. Atterberg limits are indicative of the plasticity characteristics of the soil. A high liquid limit (LL) and plasticity index (PI) generally indicate a high clay mineral content, high ion exchange capacity, or a combination thereof. Normally, a clay with a liquid limit less than 60 is not suitable for grout where a high clay mineral content and/or high ion exchange capacity is required.

3.4.3 Specific gravity. Refer to EM 1110-2-1906. The specific gravity (Gs) of the solid constituents of a soil mass is indicative, to some degree, of their mineral composition. In addition, the value is needed in computations involving densities and void ratios.

**3.5 Admixtures.** For the purpose of modifying the basic properties of a clay grout to achieve a required result, certain additives can be used.

3.5.1 *Portland cement*. Portland cements can be used in clay grouts to produce a set or to increase the strength. The amount of cement required must be determined in the laboratory so that required strength will be obtained and the grout will be stable. The presence of cement may affect the groutability of clay grouts,. a point which must be considered. For large amounts of cement the grout should be considered as a portland-cement grout with soil additive.

3.5.2 *Chemical*. There are several chemicals that can be used in soil grouts to modify the grout properties, but little experience has been reported in the literature. The effect that a chemical additive will have on a clay grout will depend on the mineralogical and chemical properties of the soil. Following is a partial listing of electrolytes that are used in quantities less than 5 percent, by weight, as stabilizing agents or flocculants in clay grouts.

| Stabilizing Agents | Flocculating Agents |
|---|---|
| Potassium nitrate | Aluminum sulfate |
| Potassium carbonate | Sodium sulfate |
| Sodium aluminate | Calcium chloride |
| Sodium silicate | Copper sulfate |
| Lithium carbonate | Ferrous sulfate |
| Sodium hydroxide | |

3.5.3 *Fillers*. Sands can be used as fillers in clay-cement grouts where voids to be filled are sufficiently large to Permit intrusion of these particle sizes. Where large quantities of grout take are anticipated, an economical gain will be achieved through use of sand fillers, without loss in quality of the grout.

**3.6 Proportioning Clay Grout.** Once a soil has been determined suitable as a grout material for a given job, it is necessary to determine the water and admixture requirements to achieve desired properties in the grout. The grout must have sufficient flowability without excess shrinkage, and after a specified time, it should develop a gel of sufficient strength. The flowability will depend upon the water- clay ratio, which from the standpoint of bleeding should be kept to a minimum. To provide a suitable gel, it might be necessary to use chemical additives such as sodium silicate to improve the gel strength at high water-clay ratios. Because of the wide range of physiochemical properties of fine-grained soils that affect grout properties, it is necessary to use a trial procedure to achieve the desired results. Trial batches with varying proportions of soil, water, and admixtures should be mixed, duplicating field conditions as closely as possible. Samples from the trial batches should be tested for stability, viscosity, gel time, shrinkage, and strength. From the results the most suitable mixtures can be selected and criteria for changes in the mixture proportions to meet field conditions can be determined. The batch size for trial mixes should be sufficient to provide adequate samples for the various tests.

**4. ASPHALT GROUTS.** Large subsurface flows of water are at times difficult to stop by grouting with cement, soil, or chemical grouts. For these conditions asphalt grouting has sometimes been used successfully, particularly in sealing watercourses in underground rock channels. Asphalt grout has ‘also been used to plug leaks in cofferdams and in natural rock foundations. Asphalt is a brown-to-black bituminous substance belonging to a group of solid or semisolid hydrocarbons. It occurs naturally or is obtained as a comparatively nonvolatile residue from the refining of some petroleums. It melts between 150° and 200° F. When used for grouting it is generally heated to 400° or 450° F before injection. Asphalt emulsions have also been used for grouting. These are applied cold. In the emulsion the asphalt is dispersed in colloidal form in water. After injection the emulsion must be broken so that the asphalt can coagulate to form an effective grout. Special chemicals are injected with the emulsion for this purpose. Coal-tar pitch is not a desirable material for grouting since it melts more slowly and chills more quickly than asphalt grout. When heated above its melting point, coal-tar pitch also emits fumes that are dangerous to personnel.

**5. CHEMICAL GROUTS.** In 1957 there had been some 87 patents issued for processes related to chemical grouting. Since then there undoubtedly have been more. These processes cover the use of many different chemicals and injection processes. The primary advantages of chemical grouts are their low viscosity and good control of setting time. Disadvantages are the possible toxic nature of some chemicals and the relatively high cost. Only a few of the more widely known types of chemical grouts are discussed in the following paragraphs. Because of the variety of the chemicals that can be used and the critical nature of proportioning, chemical grouts should be designed only by personnel competent in this field. Commercially available chemical grouts should be used under close consultation with the producers.

**5.1 Precipitated Grouts.**

5.1.1 In this process the chemicals are mixed in liquid form for injection into a soil. After injection, a reaction between the chemicals results in precipitation of an insoluble material. Filling of the soil voids with an insoluble material results in a decrease in permeability of the soil mass and may, for some processes, bind the particles together with resulting strength increase.

5.1.2 The most common form of chemical grouting utilized this process with silicates, usually sodium silicate, being the primary chemical. Sodium silicate is a combination of silica dioxide (Si02 ), sodium oxide (Na20), and water. The viscosity of the fluid can be varied by controlling the ratio of Si02 to Na20 and by varying the water content. Silicate can be precipitated in the form of a firm gel by neutralizing the sodium silicate with a weak acid. The addition of bivalent or trivalent cations will also produce gelation.

5.1.3 One problem in using sodium silicate in a grout is the prevention of instantaneous gelling prior to injection in the soil mass. This is overcome by either diluting the silicate and producing a soft gel or by injecting the silicate and the reactive compound separately in the ground. A third method consists of mixing an organic ester with the silicate prior to injection. The ester, by saponification , is slowly transformed into acetic acid, which neutralizes the s odium silicate, and ethyl alchol. The addition of an organic ester to a chemical grout results in sufficient setting time to permit adequate grout injection and a high- strength grout.

5.1.4 Another form of precipitation utilizes a combination of lignosulfite and bichromate (chrome lignin). Lignosulfite (or lignosulfonate) is a by-product of the manufacture of cellulose from pulpwood. When lignosulfites are mixed with a bichromate, a firm gelatinous mass will form. By varying the concentration of bichromate, the setting time may be controlled through a range from 10 min to 10 hr. The resulting gel strength will vary depending upon the nature of the lignosulfite, the concentration of lignosulfite and chrome, and the pH of the mixture. The viscosity increases with time. The hexavalent chromium is toxic and requires special precaution when mixing. After gelling, the product is not toxic, but under some conditions water will leach highly toxic hexavalent chromium from the gel. Possible contamination of water supplies should, be carefully considered.

**5.2 Polymerized Grouts.** Polymerization is a chemical reaction in which single organic molecules (monomers) combine together to form long chain like molecules. There is also cross linking of the molecules, resulting in rigidity of the product. In this process the soluble monomers, mixed with suitable catalysts to produce and control polymerization, are injected into the voids to be filled. The mixture generally has a viscosity near that of water and retains it for a fixed period of time, after which polymerization occurs rapidly. Because of the low viscosity, polymer grouts can be used in soils having permeability as low as $10^{-5}$cm/sec, which would include sandy silt and silty sand. The resulting product is very stable with time. The monomers may be toxic until polymerization occurs after which there is no danger. Some of the more common polymer- type grouts utilize the following chemicals as the basic material.

5.2.1 *Acrylamide*. There are available, under several different trade names , chemical grouts that use acrylamide and one of its derivatives as a base. One of these consists of a mixture of acrylamide and methylene -bisacrylamide, which produces a polymerization crosslinking gel when properly catalyzed, that traps the added water in the gel. These grouts are expensive, but because of the low viscosity, ease of handling with recommended equipment, and excellent setting time control, they are suitable for certain applications. The ingredients are toxic and must be handled with care, but the final product is nontoxic and insoluble in water..

5.2.2 *Resorcinol-formaldehyde.* This resin-type grout is formed by condensation polymerization of dihydroxybenzene (resorcinol) with formaldehyde when the pH of the solution is changed. The reaction takes place at ambient temperatures. The final product is a nontoxic gel possessing elastic-plastic properties and high strengths when tested in a mortar form. The grout has excellent set-time control, instantaneous polymerization, and a low viscosity prior to polymerization.

5.2.3 *Calcium Acrylate.* Calcium acrylate is a water-soluble monomer that polymerizes in an aqueous solution. The polymerization reaction utilizes ammonium persulfate as a catalyst and sodium thiosulfate as the activator. The rate of polymerization is controlled by the concentration of catalyst and activator. The solution has a low viscosity immediately after mixing that increases with time.

5.2.4 *Epoxy Resin*. Many different compounding of epoxy resins are available commercially. Some experiments have been conducted using epoxy resins as grout, and as a result of these experiments, one such epoxy was used with moderate success to grout fractured granite. The epoxy developed very good bond with the moist granite, was not too brittle, and the effective volume shrinkage during curing was very low. A summary of the physical properties of several commercially available chemical grouts is given in Figure 2.

Figure 2

PHYSICAL PROPERTIES OF GROUT

| Class | Example | Viscosity Centipoise | Gel Time Range, min | Unconfined Compressive Strength, psi |
|---|---|---|---|---|
| Precipitated grouts: | | | | |
| Silicate | | | | |
| (low concentration) | Silicate-bicarbonate | 1.5 | 0.1-300 | Under 50 |
| Silicate | Silicate-formamide (Siroc)† | 4-40 | 5-300 | Over 500 |
| (high concentration) | Silicate-chloride (Joosten) | 30-50 | 0 | Over 500 |
| Chrome lignin | TDM | 2.5-4 | 5-120 | 50 to 500 |
| | Terra Firma†† | 2-5 | 10-300 | Under 50 |
| | Blox-All‡ | 8 | 3-90 | Under 50 |
| | Lignosol‡‡ | 50 | 10-1000 | -- |
| Polymerized grouts: | | | | |
| Vinyl polymer | AM-9§ | 1.2-1.6 | 0.1-1000 | 50 to 500 |
| Methylol bridge polymer | Urea formaldehyde | 6 | 5-300 | Over 500 |
| | Herculox‡ | 13 | 4-60 | Over 500 |
| | Cyanaloc 62§ | 13 | 1-60 | Over 500 |
| | Resorcinol-formaldehyde | 3-5 | -- | Over 500 |
| Oil-based unsaturated fatty acid polymers | Polythixon FRD | 10-80 | 25-360 | Over 500 |
| Epoxy resin | 62E2§§ | 2-18 | -- | Over 500 |

## 6. GROUTING PROCEDURES

**6.1 General.** Regardless of the number of exploratory borings or other preconstruction investigations, information on the size and continuity of groutable natural openings in rock below the surface will be relatively meager at the start of grouting operations and only slightly better after the grouting is completed. The presence of groutable voids can be ascertained before grouting and verified by grouting, but their sizes, shapes, and ramifications will be largely conjectural. In large measure, the "art" of grouting consists of being able to satisfactorily treat these relatively unknown sub-surface conditions without direct observation. The discussions of grouting practices in this manual are intended to guide the apprentice, but not to replace experience. All the procedures and methods presented for grouting rock apply to portland-cement grouting; some of them apply equally well to grouting with other materials.

**6.2 Curtain Grouting**. Curtain grouting is the construction of a curtain or barrier of grout by drilling and grouting a linear sequence of holes. Its purpose is to reduce permeability. The curtain may have any shape or attitude. It may cross a valley as a vertical or an inclined seepage cutoff under a dam; it may be circular around a shaft or other deep excavation; or it may be nearly horizontal to form an umbrella of grout over an underground installation. A grout curtain may be made up of a single row of holes, or it may be composed of two or more parallel rows.

**6.3 Blanket or Area Grouting**. In blanket grouting the grout is injected into shallow holes drilled on a grid pattern to improve the bearing capacity and/or to reduce the permeability of broken or leached rock. Such grouting is sometimes called consolidation grouting. Blanket grouting may be used to form a grout cap prior to curtain grouting lower zones at higher pressures, or it may be used to consolidate broken or fractured rock around a tunnel or other structure underground.

**6.4. Contact Grouting.** Contact grouting is the grouting of voids between the walls of an underground excavation and its constructed lining. These voids may result from excavation over break, concrete shrinkage, or a misfit of lining to the wall of the excavation. The crown of a tunnel is a common locale for contact grouting.

**6.5 Mine and Cavity Filling.** Grout may be used to fill abandoned mines or large natural cavities underlying engineering structures to prevent or stop roof collapse and subsidence. The size of these openings permits use of a grout containing sand or sand and small gravel, If seepage control is involved, a second or a third phase of grouting may be required with the coarser ingredients omitted from the grout to properly seal the smaller voids. Mine maps should be used, if available, to reduce the number of holes needed to inject the grout. Observation holes should be used to check the distribution of grout from various injection points. If mine maps are not available and the size and orientation of haulageways and room spacings cannot be determined, coverage can be obtained by drilling on a grid pattern. If the mine workings extend beyond the boundaries of the area requiring treatment, bulkheads of thick grout should be constructed in all mine tunnels crossing the perimeter of the area to prevent the spread of grout beyond limits of usefulness. Large solution cavities, like mines, can be grouted with a coarse grout if sufficiently free from debris and muck. Since grout is unlikely to displace an appreciable amount of solution-channel filling, it may be necessary to provide access to the cavities and manually clean them prior to backfilling with concrete or grout. Cleaning is particularly important if seepage control is the purpose of the treatment.

**6.6 Order of Drilling and Grouting**. For grout curtains, holes are initially drilled on rather widely spaced centers usually ranging from 20 to 40 ft. These holes are referred to as primary holes and are grouted before any intermediate holes are drilled. Intermediate holes are located by splitting the intervals between adjoining holes; the first intermediates are midway between primary holes and the second intermediates are halfway between primary and first intermediate holes. Spacings between holes are split in this fashion until the grout consumption indicates the rock to be satisfactorily tight. All holes of an intermediate set in any section of the grout curtain are grouted before the next set of intermediates is drilled. Although primary holes are most often drilled on 20-ft centers, other spacings are equally acceptable. If grout frequently breaks from one primary hole to another, an increase in the primary spacing is indicated. If experience in apparently similar conditions suggests that a final spacing of between 5 and 10 ft will be satisfactory, a primary spacing of 30 ft may be in order since it will break down to 7.5 ft with the second set of intermediates. As the split-spacing technique reduces the intervals between grout holes, the average grout consumption per linear foot of hole should also become smaller. If the final spacings in a grout curtain constructed in rock that contains no large cavities are 5 ft or less, the total grout take for neat portland-cement grout is likely to average less than 0.5 cu ft of cement per linear foot of hole. In blanket grouting an area to serve as the foundation for a structure, it is well to arrange operations so that the final grouting in every section is done through intermediate holes drilled between rows of previously grouted holes.

This limits the travel of grout in the last holes and permits maximum pressure to be applied to all openings encountered. If the area to be consolidated is not bounded by natural barriers to grout travel, consideration should be given to establishing such a barrier by grouting a row of holes around the perimeter of the area before any other grouting is done. If the blanket-grouted area is to serve as the capping zone for deeper grouting, it must be tightened sufficiently by grouting to prevent appreciable penetration by the higher pressure grout injected into lower horizons. The final spacing of grout holes necessary to accomplish this will depend on the nature and orientation of the groutable openings in the rock, on the orientation of the grout holes, and on the grouting operations. In general, the more numerous the groutable openings, the more closely spaced the holes must be. Holes on 2- or 3-ft centers may be required in badly broken rock.

**6.7 Inclined Grout Holes.** In jointed rock, holes should be drilled to intersect the maximum number of joints practicable. , This may require directional drilling. If all the joints dip at angles less than 45 deg, vertical grout holes will be entirely satisfactory. On the other hand if joints are vertical or almost vertical and the holes are vertical, grouting must be done on spacings of a few inches to obtain the same degree of coverage possible with properly inclined holes on 5-ft centers. In practice, holes are usually not inclined more than 30 deg from the vertical because greater inclinations bring increased drilling costs which offset the savings accruing from fewer holes and wider spacings. The shortest seepage path through the grout curtain is along the joint most nearly normal to it. Therefore, to construct a grout curtain to control seepage with inclined grout holes, the holes should be inclined along the plane of the curtain, if the pattern of jointing is at all favorable. This provides for the greatest number of intersections of joints trending normal to the curtain. If more than one line of inclined grout holes is needed to construct the curtain, better coverage of joints trending normal to it can be obtained by staggering the holes in adjacent rows. Holes should not be staggered if the joints cross the curtain diagonally.

**6.8 Drill Water Loss.** Observations of the drill water during drilling operations can provide much information on the rock encountered by the drill. The cuttings carried by the water provide information on the type and color of the rock. Fluctuations in the quantity of the returning water are indicative of rock permeability. An abrupt change in the amount of water returning to the surface usually signifies that the drill has reached a permeable horizon. If all the drill water flows into this permeable zone, all the cuttings produced by the drill will be carried into it also. If drilling is continued, it is possible that the opening will become so clogged with cuttings that the drill water cannot enter it and will again vent from the top of the hole. In such fashion, openings of appreciable size can be lost to grouting but still remain hazards from the seepage standpoint since there is no assurance that water percolating through the rock will not remove the cuttings by piping. Therefore, to avoid clogging major groutable openings with cuttings, drilling should be stopped when all the water is lost, and the hole grouted. If there is sudden appreciable gain in water, drilling is also usually stopped and the hole grouted. This is done, not because of the possibility of plugging the permeable zone with cuttings, but because an opportunity is afforded to treat a groutable void of significant size on an individual basis. The same reason would be sufficient for grouting after a sudden water loss if the possibility of clogging with cuttings did not exist. If the drill rods do not drop to indicate a cavity at the point of water loss or gain, it is advisable to advance the hole 1 or 2 ft beyond that point to be sure that the hole is well into the permeable zone before grouting. Many cases of a second water loss within a foot of the first have been recorded. In these cases a cycle of drilling and grouting could have been avoided with the extra drilling. Sometimes specifications are written to provide for grouting if approximately half of the drill water is lost abruptly or if cumulative losses aggregate about half of the water being pumped into the hole. Judgment should be exercised in deciding that apparent water loss or gain is real. If the water source for the drill also supplies other operations, pressure fluctuations may cause volume changes in the drill water that are easily mistaken for losses or gains. Loss of return water caused by blocked bit or a collar of cuttings around the drill pipe may be construed as complete loss of drill water. In porous rock the water loss may increase gradually as the hole is deepened. If the pores are too small to accept the grout, nothing is accomplished by suspending drilling operations to grout.

**6.9 Pressure Testing and Pressure Washing.**

6.9.1 *Pressure Testing.* Pressure testing as used in drilling and grouting operations is the measured injection of water into a grout hole prior to grouting. Pressure washing is the term applied to washing cuttings and other filling out of openings in the rock intersected by the hole. Both operations are done through a packer set in the hole or through a pipe grouted in the top of the hole. In a stage-grouting operation (para 11a), pressure testing is used primarily to determine whether grouting is needed. If the hole does not take water at a given pressure, it will not take a grout containing solids at that same pressure. Pressure testing will also disclose the likelihood of and/or the potential locations of surface grout leaks and the depth at which a packer must be set to avoid them. In stop grouting (para 11c), normal pressure-testing techniques can be used to determine whether grouting is required in the lowest zone; but in the higher zones, this can be' done only if the lower zone or zones are tight at the pressure desired for the upper zone. The use of pressure testing with water in a stop-grouting operation to ascertain whether one or more stops can be eliminated costs as much as checking the hole with grout. Thus, if the lower zones are not tight, pressure tests in the upper zones need only be used to find locations for seating the packer in fractured rock or to check for potential surface grout leakage. In stage grouting it is good practice to always grout the first stage unless the water take in pressure testing is zero. The filling of small openings with low-pressure grout precludes high-pressure grout entering upper rock and heaving it while grouting lower zones. The maximum pressure for pressure testing should never exceed the maximum grouting pressure proposed for the same zone. Generally, it should be lower than the grouting pressure to ensure that the rock is not damaged. Careful control of pressure tests in stage grouting is especially important in this respect. If a hole is tight the pressure test can be completed in 5 to 10 min after the hole is full of water. If the hole takes water at an increasing rate during the pressure test, the operation becomes pressure washing.

6.9.2 *Pressure Washing.* Pressure washing a grout hole should be continued as long as an increase in the rate of injection can be observed. If the wash water vents from surface fractures or from nearby grout holes, the washing should be continued as long as the venting water is muddy. If two or more holes are interconnected, it is often advantageous to reverse- the flow of water in the subsurface openings by changing the pump line from one hole to another. If a large, partially filled cavity is encountered, removal of the filling by mining is indicated, since a large volume of water would be required for effective washing. On occasion grout holes on anticipated final spacings have been drilled ahead in a section of grout curtain to facilitate. the washing of nearby horizontal openings. After the washing is completed, all the split-spacing holes are filled with sand to prevent entry of grout from the primary holes. The intermediate holes are reopened for grouting by washing out the sand. This procedure is not recommended except for very unusual conditions or as an emergency expedient, because sand from the filled holes may enter groutable openings and make them ungroutable.

6.9.3 *Mixes.* Water-cement ratios of portland-cement grout can be indicated by either weight or volume. The volume basis is more convenient for field work and is commonly used. In field mixes a sack of cement is considered equal to 1 cu ft. The mixes most frequently used range from 4:1 to 0.75:1, by volume. These mixes may also be expressed as 4.0 and 0.75. Mixes as thin as 20:1 and as thick as 0.5:1 have been used, but mixes thinner than 6:1 and thicker than 0.6:1 are rare. In general, grouting is started with a thin mix. Thicker mixes are used as the behavior of the hole during grouting indicates its capacity to accept them.

Admixtures and fillers may be added to portland-cement grout to change setting time, increase the strength, or impart other characteristics to the grout. Sand is often used to provide additional strength for the contact grouting of tunnels.

6.9.4 *Pressures.* The control of grouting pressures is vital to the success of any grouting operation. This control is maintained by gages on the pump and at the collar of the hole. The grouting inspector must determine that the gage at the collar of the grout hole is accurate. Most grouting is done at pressures approaching the maximum safe pressure. An inaccurate gage, especially one that registers low, could result in the spread of grout into areas beyond any possible usefulness, or in wasteful surface breakouts, or in damage to a structure by displacing rock in its foundation. In such instances, grout is not only wasted, but the quantities injected may make tight ground seem open and require intermediate holes to check the adequacy of the work. A new gage is not necessarily accurate. A new gage or any gage in use should be checked frequently against a master gage of known accuracy or against a column of water or mercury. For accurate low pressures, low-pressure gages should be used. The dial of any gage in use should be carefully inspected. Many gages require a pressure equal to that measured by one increment on the dial to initiate movement of the indicator needle. In such a case, the first mark on the dial of a gage showing increments of 5 psi may actually indicate a pressure of 10 psi. This could be critical for near surface grouting where low pressures have to be carefully controlled. For very low pressures and sensitive conditions, a standpipe is sometimes used to prevent excessive pressures from being applied. The standpipe extends only high enough above the top of the hole to obtain the desired pressure by the weight of the grout column in the pipe. The grout line is inserted into but not connected to the standpipe. Thus, grout will overflow if it is supplied faster than the hole can accommodate it. An adjustment in the height of the standpipe is required for each mix used if the same pressure is maintained.

There is no way to precisely determine the maximum safe grouting pressure for a particular zone of grouting. A rule of thumb states that 1 lb of pressure per square inch can be used for each 1 ft of rock and each 2 ft of soil vertically above the point of grout injection. (Similar coverage is needed in directions other than vertical.)

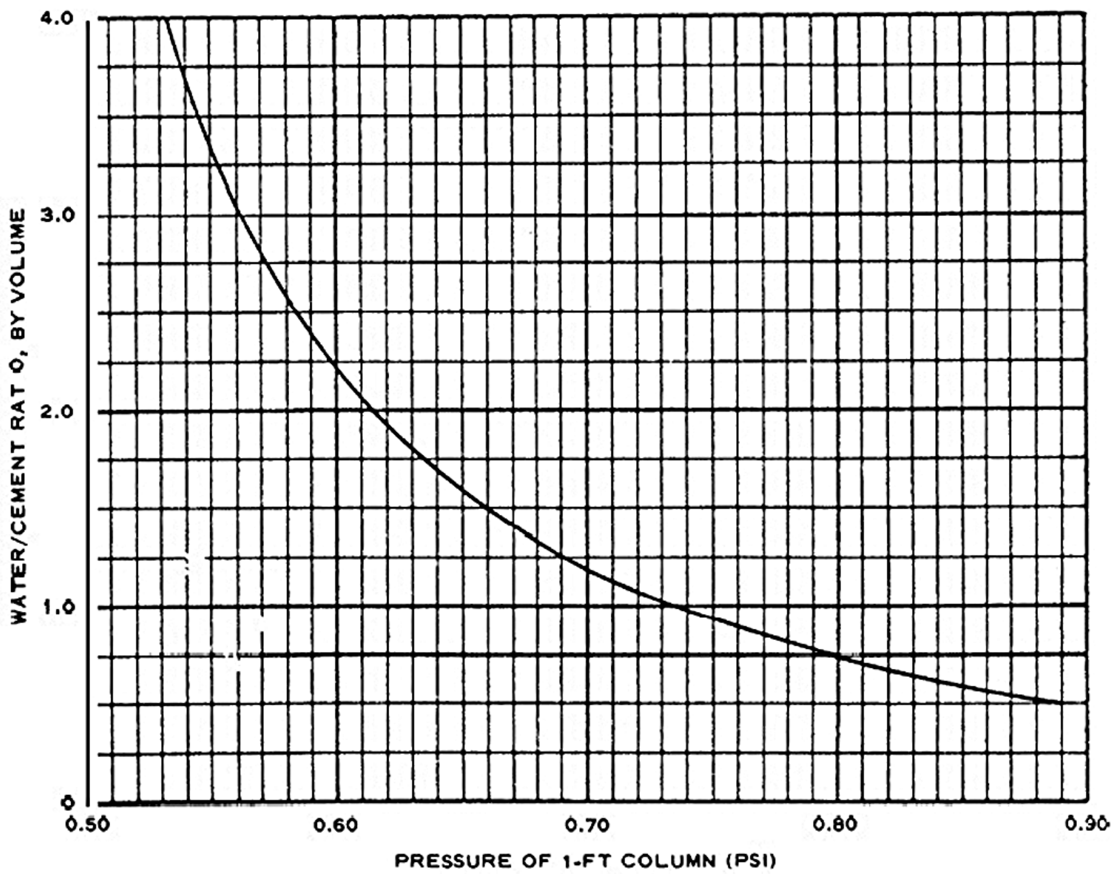


Figure 3

Pressure of Neat Cement Grout

Figure 3 shows the pressure exerted by a column of grout 1 ft high for various grout mixes. If an installation 100 ft below the surface is to be grouted from the surface, a pressure of 73 psi for 1:1 grout should be added to the gage pressure at the collar of the hole to obtain the effective grouting pressure at the level of the installation. In any grouting in which the grout may come in contact with a structure partially or entirely underground, the strength of the structure should be considered. This, rather than the rock or soil load, may limit the maximum safe grouting pressure. If in doubt, a structural engineer should be consulted. When a packer is used in a grouting operation, the inspector should be aware of the possibility that the gage may be reflecting the pressure required to force the grout through the orifice in the packer rather than the pressure needed to inject it into the rock. This condition will not exist for relatively tight holes or for any hole when the capacity of the opening through the packer is greater than that of the combined groutable openings intersected by the hole.

Grouting operations and techniques are not only influenced by the subsurface conditions encountered, but also by the purpose and objectives of the grouting program. Is the grouting intended to be a permanent treatment, or is it a temporary construction expedient? Is the tightest cutoff obtainable needed, or is something less than that acceptable? Should the maximum amount of grout possible be injected into the rock regardless of spread, or should an effort be made to restrict the spread to reasonable limits, or should it be restricted to very narrow limits ? The answers to these questions and the effects of the often overriding factors of time and cost form the basis for planning drilling and grouting operations. The treatment of a reservoir to permanently store a liquid pollutant is an example of one extreme. Sufficient time and money must be allocated and every effort and decision designed to provide the tightest seal possible, otherwise the project cannot be successful. At the other extreme, a grouting program may be conceived to reduce, but not necessarily to stop, seepage into an excavation during construction as a measure to save on dewatering costs. Time will be a factor if grouting delays other work. Cost is a factor, since the saving on dewatering costs must be a ceiling for grouting costs. Permanence of treatment is not vital in this case, and grouting techniques are directed toward constructing the most effective cutoff possible for a specified expenditure of time and money. In the first case, treatment would probably consist of grouting a curtain of multiple rows of holes to refusal with the average grout thinner than 1:1. A wetting agent or fluidifier might be used. Pressures on all intermediate holes would be kept as, high as safety from lifting permitted. Holes would be grouted each time an appreciable loss of drill water occurred. Maximum hole spacing after final splitting in each row would, of course, depend on conditions found, but would likely be less than 3 ft. In the second case, costs would govern all actions. If holes were shallow and drilling equipment available, holes would be cheap and spacings could be split to provide good coverage and keep the curtain narrow. If the grouting zone was deep or if drills could not keep ahead of the grouting, it would be less expensive to spread the grout farther from fewer holes. Thick mixes and low pressures would be used. Sand or other available filler would be added to the grout if economical and acceptable for the openings being grouted. In large openings accelerators would be used to reduce the spread of grout. Grouting would be stopped well before refusal to keep labor and plant costs from being disproportionately high. The objectives of most grouting operations fall between the imaginary example cited above. The objectives for all grouting should be clearly defined so that the designer, the project engineer, and the inspector will understand them and can then contribute to their realization.