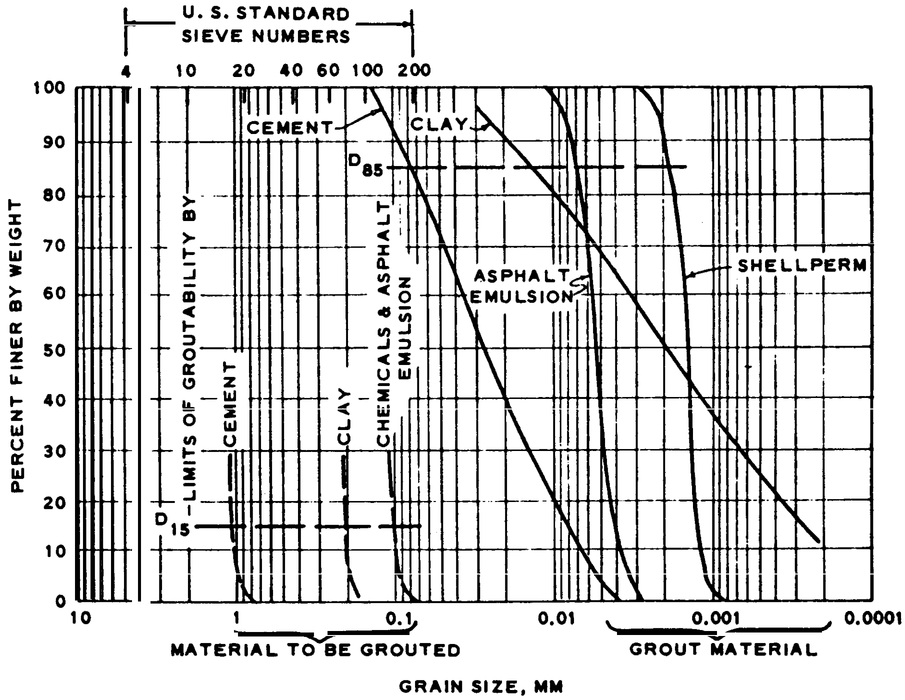
SECTION 3. GROUTS

5. INTRODUCTION. In planning a grouting program for particular conditions, the engineer needs a 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 grout 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 conditions. An important requirement for the selection of a grout is that its particles be substantially smaller than the voids to be filled. Figure 2 shows limiting grain sizes of materials that can be successfully grouted by various types of grouts. These data are based on experience and



(Courtesy of American Society of Civil Engineers)

Figure 2. Soil and grout materials grain-size curves (see ref 35)

testing and should be used only as a guide. Another relationship can be determined by the groutability ratio, N , expressed by the equation

$$N = \frac{D_{15}}{D_{85}}$$

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 2 gives a graphic interpretation of this equation. It shows (a) typical grain-size curves for portland cement, Boston blue clay, ordinary asphalt emulsion, and special Shellperm asphalt emulsion, and (b) the lower limits (D_{15}) of sand groutable by the above-described grout materials.

6. 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.

a. Portland Cements. Five types of portland cement, produced to conform to the specifications of ASTM Designation C 150 (see ref 15), are used in cement grouts.

(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) 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 groundwaters are important.

(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.

(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.

(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.

b. 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 (see ref 9).

c. 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 nonpermanent 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.

(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 admixture 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) 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.

(3) Diatomite. Diatomite is a 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.

(4) Fumicite. 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.

(5) Other fillers. Silts and lean clays not contaminated with organic materials are sometimes used as fillers. Leess, 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.

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

(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) 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.

(3.) Other effects. Numerous other substances can be added to portland-cement grout to obtain special effects, Bentonite or other colloids, or finely powciered 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.

e. Effect of Groundwater. Alkalies, 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.

f. 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 impermeability 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.

7. 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.

a. 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.

b. 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

† The term clay as used herein is broader than that defined in the Unified Soil Classification System (see ref 13) and covers all fine-grained soils, regardless of clay content and plasticity.

of clay minerals present. Common clay minerals encountered are kaolinite, montmorillonite, 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.

c. 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.

d. 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.

(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 (see EM 1410-2-1906). The largest clay particles must be small enough to readily penetrate the voids in the medium to be grouted.

(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 (see ref 36).

(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.

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

(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.

(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, as reported by Kravertz (35), 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) 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 econmical gain will be achieved through use of sand fillers, without loss in quality of the grout.

f. 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.

8. 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 (see ref 54 and 57). 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.

9. CHEMICAL GROUTS. In 1957 there had been some 87 patents issued for processes related to chemical groutings (see ref 43). 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.

a. Precipitated Grouts.

(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.

(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 (SiO_2), sodium oxide (Na_2O), and water. The viscosity of the fluid can be varied by controlling the ratio of SiO_2 to Na_2O 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.

(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 methol 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.

(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.

b. 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 a 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.

(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..

(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.

(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.

(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. The details of these experiments and the field grouting operations are contained in reference 8. A summary of the physical properties of several commercially available chemical grouts is given in table 1. The values shown were obtained from various publications.

TABLE 1. PHYSICAL PROPERTIES OF CHEMICAL GROUTS

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 (high concentration)	Silicate-formamide (Siroc)†	4-40	5-300	Over 500
	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

† Diamond Alkali Company
†† Intrusion Prepakt, Inc.
‡ Halliburton Company
‡‡ Lignosol Chemical, Ltd.
§ American Cyanamid Company
§§ George W. Whitesides Company