CHAPTER 5
GROUT MATERIALS

5-1. Grout Materials.

a. Introduction. The user of portland cement grout must consider two major factors: (1) the compatibility of the individual materials and (2) the intended purpose of each of the constituents. The results of adding various materials to the grout mixture will enable the user not only to develop a wide range of physical properties in the grout but also to make adjustments in the field to meet changes in project conditions.

b. Portland Cements. The most common and best known hydraulic cements used worldwide as the basic ingredient for cement grouts are portland cements. Some of the cements listed below may not be economically available in all sections of the country. The availability of portland cement should be determined before the type is specified. Types of portland cement produced, and those which may be considered for use in grouting applications, are as follows:

(1) Type I portland cement. Type I is accepted as the general purpose cement for use in the vast majority of grouting applications when special properties of other types are not required.

(2) Type II portland cement. Type II is manufactured to resist moderate sulphate attack and to generate a slower rate of heat of hydration than that exhibited by Type I.

(3) Type III portland cement. Type III is used when high early strengths are desired, usually 2 weeks or less. It is considered for use in emergency repairs in instances that require grouting application or phases of grouting applications to be put into service quickly. Since particle size is smaller than in other types, it is sometimes specified for grouting fine cracks.

(4) Type IV portland cement. Type IV generates less heat during hydration than Type II cement. It develops strength at a much slower rate than Type I. It is considered for use in large mass grout placements when high temperatures of heat of hydration are objectionable.

(5) Type V portland cement. Type V is manufactured for use in grout exposed to severe sulphate action. It is used principally when a high sulphate content is present in soils or groundwaters.

(6) Air-entraining portland cement, Types IA, IIA, and IIIA. These types correspond in composition to Types I, II, and III, respectively. These cements contain small quantities of air-entraining materials that are incorporated by intergrinding them with the clinker during manufacture. They are rarely used in grouts and are only considered if a grout may be exposed to severe freezing and thawing conditions.

(7) Oil well cements. Cements manufactured for use in wells are subject to wide ranges of temperature and pressure and consequently differ from the ASTM types that are manufactured for use in a less harsh environment. In meeting well requirements the American Petroleum Institute (API) provides specifications covering eight classes of oil-well cements, designated Classes A, B, C, D, E, F, G, and H. The API Classes A, B, and C correspond to ASTM Types I, II, and III. There are no corresponding API Classes for ASTM Types IV and V.

c. Pozzolans. These materials are siliceous or siliceous and aluminous that in finely divided forms and in the presence of water chemically react with calcium hydroxide of portland cements to form compounds embodying cementitious properties. Pozzolans may be divided into three classes.

(1) Class N. This class includes raw or calcined natural pozzolans, such as certain diatomaceous earths; opaline cherts and shales; tuffs and volcanic ashes, such as pumicites, which may or may not be processed by calcination; and some clays and shales that require calcination to induce satisfactory properties.

(2) Class F and Class C. These are fly ashes that are finely divided residues resulting from combustion processes of ground or powdered coal. Fly ash is the most commonly used pozzolan for grouts.

d. Admixtures. Any material other than water, fine aggregate, and hydraulic cement added to the grout immediately before or during its mixing to alter its chemical or physical properties to a desired characteristic during its fluid or plastic state is classified as an admixture. The principal materials used for these purposes are as follows:

(1) Accelerators. The most widely used accelerator in grout mixtures is calcium chloride ($CaCl_2$). Generally, calcium chloride can be safely used in amounts up to two percent by weight of the cement. It is mainly used when early stiffening and setting of grout mixtures are desired. Use of calcium chloride in instances where grout may be exposed to cold weather is effective in minimizing the possibility of grout freezing during setting. This accelerator may aggravate sulphate attack, alkali-silica reaction, and in high concentrations, it acts as a retarder. It should not be used when the grout is in contact with steel. Other accelerators include certain soluble carbonates, silicates, and triethanolamine. Granular and flaked calcium chloride can be successfully used if added to the grout by being dissolved in a portion of the mix water.

(2) Retarders. The most commonly used retarders are organic chemicals, most likely lignosulfanic acid salts or hydroxylated carboxylic acid salts or modifications of these additives. Retarders are used to offset the undesirable accelerating effects of high placement temperatures and to prolong grout injection or placement time. A retarder may be required for temperatures above 70 degrees Fahrenheit.

(3) Water reducers. The kinds of materials used for retarders are essentially the same components for water reducers. They increase the pumpability of grout mixtures by increasing their fluidity and increase their strengths by reducing the water content of the mixtures while at the same time maintaining the same degree of fluidity. Water reduction also decreases the permeability and porosity of portland cement grout mixtures.

(4) Aluminum powder. Aluminum powder is sometimes used in portland cement grouts to produce shrinkage compensation or a slight to moderate amount of controlled expansion during the plastic state of the grout. This expansion is a result of the reaction of the alkalies of the cement with the aluminum, which produces a small amount of hydrogen gas in the grout. The amount and rate of the expansion is largely dependent on the temperature of the grout, the alkali content of the cement, and the type, fineness, and particle shape of the aluminum powder used. Unpolished, nonleafing powders of high purity and low grease have been found to be satisfactory in portland cement grouts. The expansion occurs during the fluid state of the grout and is completed prior to final setting of the grout. Two or three grams, or about 1 teaspoonful, of the powder per sack of cement is generally used. Laboratory or field trial mixtures are essential prior to the use of aluminum powder in project work.

(5) Fluidifiers. Fluidifiers in grout mixtures inhibit early stiffening, hold fine particles in suspension, and produce a controlled amount of expansion prior to initial setting. The composition of the fluidifier may include several constituents to produce the stipulated properties. The principal ingredients are usually a gas-generating additive, a retarder, and a dispersing agent. Pumpability of portland cement grout mixtures is improved by the addition of small to moderate amounts of finely ground fly ash, rock flour, pumicites, diatomites, and bentonites. These admixtures, with the exception of most fly ashes, will usually require an increase in mixture water. Trial mixtures should be tested for desired performance characteristics prior to using those materials in field work.

e. Fillers. Sometimes referred to as extenders, fillers are various types of materials used in grout mixtures to replace various amounts of cement, mainly for reasons of economy when substantial quantities of grout are required to fill large voids, trenches, and cavities, and to stem bore holes, shafts, and tunnels.

(1) Filler use. Caution should be exercised in the use of fillers as they tend to increase the setting time of grouts, and in the case of high water content grouts, may result in a high degree of shrinkage and strength loss. Silts and clays require careful selection as they may contain excessive amounts of organic materials. Accelerators and water-reducing admixtures should be considered when fillers are used.

(2) Fine mineral fillers. Rock flour, clay, fly ash, silt, diatomite, pumice, barite, and others are fine mineral fillers.

(3) Coarse fillers. Ordinary sand is the most common of all coarse grout fillers and is usually screened to a desired gradation. Two parts of sand to one part of cement by weight is the practical upper limit of sand content in a grout mixture unless mineral fillers or admixtures are used. Other coarse fillers where strength is not a consideration include shredded rubber, perlite, wood shavings and chips, shredded and chopped cellophane, crushed cottonseed hulls, mica flakes, steel, nylon and plastic fibers, plastic and polystyrene beads, and others.

(4) Mineral fillers. Care is required in the selection of mineral fillers as materials for permanent work. The fillers generally used are sand, rock flour, and fly ash; the latter has become more commonly used in recent years. Trial batches should be conducted when fillers are introduced in portland cement mixtures.

(5) Fly ash. Fly ash may be used both as a filler and an admixture, and in both instances it will produce cementitious properties in the grout mixture when the finely divided siliceous residue reacts chemically with the portland cement. The maximum amount of fly ash should not exceed 30 percent of the cement by weight as a replacement material of the cement if strength levels maintained at approximately the 28-day age are desired.

(6) Diatomite. Diatomite is made up of fossils of minute marine organisms and is composed principally of silica. The fineness of processed diatomite may range from three to 15 times finer than that of cement. It resembles fine powder in texture and appearance. Small amounts improve pumpability in grouts; however, in large amounts as a filler material, a very high water-cement ratio will be required and it can be used only to fulfill job requirements for low-strength grouts.

(7) Pumicite. Pumicite is a processed material produced from the pulverizing of volcanic ash, ashstone, tuff, or pumice. Pumicite serves not only as a filler, but in small amounts, it also promotes pumpability. Pumicite also produces pozzolanic cementitious properties in the mixture. The mixture water demand is higher than that of fly ash but not nearly as high as that required by diatomite.

(8) Bentonite. Bentonite is a montmorillonite sodium base clay often called gel, and has grown in use in recent years to improve the pumpability in grouts. Advantages of using bentonite also include its tendency to reduce shrinkage and to prevent bleeding. Bentonite may also be used as a filler; however, the mixture water demand, like that of diatomite, increases considerably. Strength reductions are consequently quite high. Mixtures using bentonite prehydrated prior to being mixed in the grout require approximately 75 percent less bentonite than those using bentonite introduced as a dry ingredient.

(9) Barite. A naturally occurring barium sulphate ($BaSO_4$), barite has a specific gravity of approximately 4.5. Processed barite resembles bentonite in physical characteristics. Barite has an extremely high water demand which results in low strength development in grouts. Barite can serve as a filler in small to moderate amounts when high density grouts are desirable and low strengths are acceptable.

f. Mixing Water. Water acceptable for drinking is generally accepted for use as the mixture water for grouts. The suspected presence of objectionable impurities, especially those in large concentrations, should be investigated. These impurities include dissolved sodium or potassium salts, alkalies, organic matter, mineral acids, sugars or sugar derivatives, and silts. Water obtained from natural sources "onsite" must be tested (CRD-C 400) and approved.

5-2. Portland Cement Grout Mixtures.

a. Proportioning.

(1) The water-cement ratio in grouting mixtures should be carefully considered. The ratio not only influences strength and workability but also affects pumpability, viscosity, penetration, grout take, setting time, and pumping pressures. A high water-cement ratio may also adversely affect the long-time durability of grouts used in various permanent types of grouting applications.

(2) The volume basis is commonly used in the field for the sake of convenience in that it eliminates batch weighings when precision weighing of constituents is not essential. Mixtures used in the field are frequently expressed as the ratio of the volume of water in cubic feet to one sack of cement having a "loose" volume of one cubic foot. The mixtures may range from 6:1 to 0.6:1 for much field work. Mixtures as thin as 10:1 are sometimes employed in rare cases; however, such admixtures as accelerators, retarders, fluidifiers, and water reducers may be required to modify these mixtures to meet certain job conditions. The volume of fluid grout actually produced by any combination of properly proportioned materials is equal to the sum of the absolute volume of cement plus absolute volume of filler material or significant amounts of admixtures plus volume of water. The absolute volume of one 94-pound sack of cement (using an average specific gravity of 3.15 for portland cement) is 0.478 cubic feet. Usually only approximations are necessary and one sack of cement can be assumed to yield 0.5 cubic foot.

b. Neat Slurries. Mixtures with a high degree of fluidity, which usually contain no sand and only cement and water and small amounts of modifiers that do not appreciably alter the fluidity characteristics of the mixtures, are referred to as slurries. Such mixtures have a very low viscosity and sometimes are referred to as self-leveling, thin, or highly fluid.

c. Foamed Slurries. Sometimes referred to as cellular grout, foamed slurries are used in special applications, such as backpacking, for buried hardened structures that will or might be subjected to impact or dynamic loading. This slurry is also used to protect monitoring instrumentation from shock blast when it is used in tests associated with nuclear or high-explosive testing and as a backfill material as well as a material that can be developed to control rates and amounts of permeability when such permeability is desired. This grout is also used in temporary construction because of its ease of excavation.

(1) Mixture. The slurry is composed of a water-portland cement mixture to which a proprietary foam is added in various amounts to obtain a range of strength and density levels that will result in low stresses and high strains. The foam is provided in liquid form and is transformed using a foam generator. One manufacturer of a foaming product describes his product as a hydrolized, neutralized, stabilized protein foaming agent.

(2) Physical properties. Compressive strengths may range from 50 to 1000 pounds per square inch and densities from 40 to 80 pounds per cubic foot. Type I or II cement is normally used in the neat phase of the slurry. The water-cement ratios normally range from 0.5 to 0.6 by weight.

d. Sanded Grouts. Sand in grouts is used mainly as a filler for reasons of economy. Other benefits include lower water-cement ratios, less heat of hydration, and less shrinkage. The higher the degree of sphericity of the sand, the better the pumpability becomes. Pumpability also increases with the fineness of the sand; however, a higher water content is required. Processed and bank run sands are usually screened over a No. 16 screen; however, they may frequently be used "as is." Natural or manufactured sand may also be used. A series of investigations was conducted by the U. S. Army Engineer Waterways Experiment Station (WES) covering the testing of sanded grouts. Physical characteristics of sanded grouts determined from these investigations are summarized in Appendix D. The investigations have indicated the following:

(1) Two parts of sand to one part of cement can be pumped without the aid of admixtures at normal temperatures.

(2) Small amounts of diatomite appreciably increase the sand-carrying capacity of grouts. Bentonite contents in excess of 10 percent by weight of cement permit enormous amounts of sand in mixtures but result in very little strength development due to their extremely high water demand.

(3) Sand deficient in material passing the No. 100 sieve requires the addition of finely divided mineral admixtures to increase the sand-carrying capacity of the grout. Sand containing as much as 25 percent of fines passing the No. 100 sieve can be successfully pumped at one to three ratios of cement to sand by volume or weight.

(4) The addition of fine materials requires increases in water contents when a given degree of fluidity is desired.

(5) Sands manufactured from limestone and traprock can be successfully pumped.

(6) Limestone fines were more efficient pound for pound in promoting pumpability than was fly ash or loess.

(7) When 1.5 parts of fly ash and 1.0 part of diatomite were proportioned to one part of cement by weight in mixtures containing crushed limestone having 10 percent fines passing the No. 100 sieve, 7.5 and 12.0 parts of sand could be pumped, respectively. High water contents and low strengths are also revealed.

(8) The quality of portland cement grout proportioned with 25 percent fly ash by weight of cement did not appear to be lower than similar grout without fly ash.

e. Groutability Ratio. Groutability ratio is an indication of the injectability of solid suspension grouts into granular materials. The "D" size is the designation given to the percentage-passing sieve size of a cement, sand, or gravel. A grout having 85 percent passing the No. 200 sieve is said to have a D_{85} of 74 microns, the sieve opening; and a sand having 15 percent passing the No. 16 sieve has a D_{15} size of 1,190 microns. The Groutability Ratio N is derived from these values and is expressed as D_{15}/D_{85}, which in this instance results in 1,190/74 = 16. Caution should be exercised in selecting N. The $N = D_{15}/D_{85}$ ratio may be satisfactory in the above case where N = 16. Groutability becomes questionable as N approaches 6, which is the value where filtering begins. 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 5-1 gives a graphic interpretation of this equation. It shows (1) typical grain-size curves for portland cement, Boston blue clay, ordinary asphalt emulsion, and special Shellperm asphalt emulsion, and (2) the lower limits (D_{15}) of sand groutable by the above-described grout materials.

f. Fluid Physical Properties. Fluidity is the major indication of the degree of pumpability or nonpumpability that a grout will exhibit. In addition to stiff and thin, fluidity is expressed in the three following terms. High fluidity is a fluid mixture of the "self-leveling" type, is highly flowable, often referred to as very thin, and is very low in viscosity. Moderate fluidity is a flowable mixture that is described as being within the limits of flowability having a moderate degree of viscosity. Minimum fluidity is a stiff mixture classified as being in the plastic range, exhibiting a few inches of slump, and described at times as being nonflowable or thick. Measurements of fluidity include grouts having time-of-efflux ranging between 10

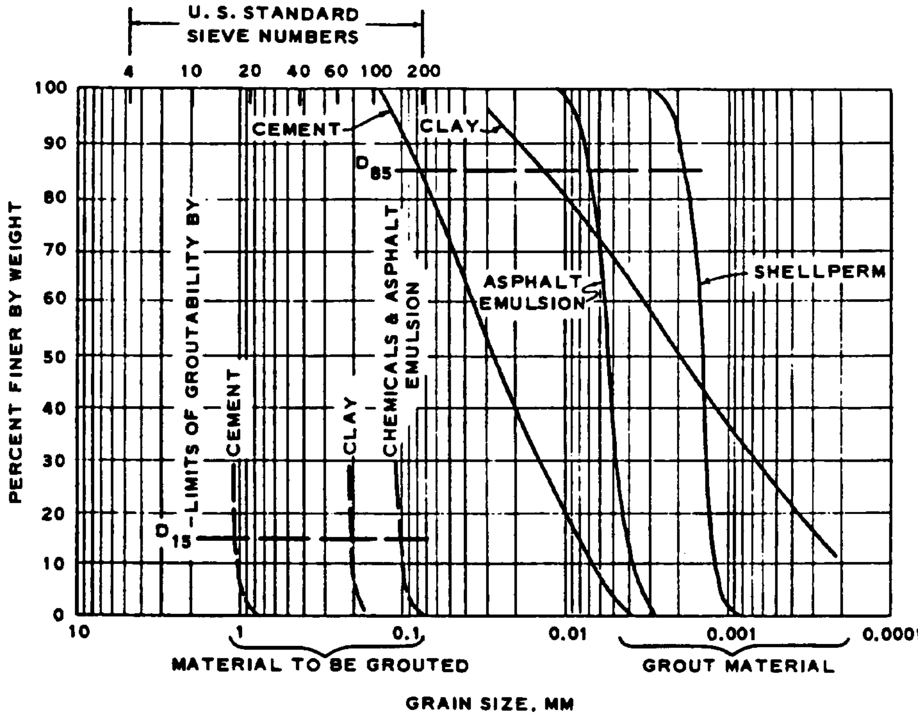


Figure 5.1 Soil and grout materials grain-size curves

and 30 seconds as measured by the flow cone test (CRD-C 611) are usually highly pumpable and range in viscosity from approximately 100 to 10,000 centipoises. The moderately fluid grouts will measure between 125 and 145 flow on the flow table at five drops. These viscosities may range between 10,000 and 50,000 centipoises and have slumps in excess of eight inches. Minimum fluid grouts, stiff and thick, exhibit flow table flows of 100 to 125 at five drops and slumps no greater than eight inches. High and moderate fluidity grouts may be pumped utilizing most types of grout pumps of the nonsurging variety when pressure applications are made; however, minimum fluidity grouts are usually placed in large cavities by using concrete pumps or tremies or may be placed in structural concrete cracks, scoured holes, or similar voids by means other than pumps or tremies.

g. Hardened Physical Properties. Most neat cement slurries having a high degree of fluidity will range in density from approximately 90 to 110 pounds per cubic foot and have compressive strengths ranging from a few hundred pounds per square inch for the conventional moderately thin mixtures to 2,000 pounds per square inch for the thicker type. Flexural strength of grouts will normally range from 10 to 15 percent of the compressive strengths. The modulus of elasticity (E) will be approximately half of that exhibited for concrete of the same level of strength. The moderately fluid grouts usually have densities in the range of 110 to 125 pounds per cubic foot and compressive strengths between 2,000 and 3,000 pounds per square inch, and the minimum fluidity types will have densities ranging from 125 to 140 pounds per cubic foot and compressive strengths between 3,000 and 6,000 pounds per square inch. In critical areas, such as for machine bases, laboratory strength tests may be conducted to determine suitable mixes. Shrinkage, permeability (CRD-C 48), and creep tests may also be desirable.

5-3. Special Cements and Mixtures.

a. Expansive Cements. Expansive cements have become commercially available in recent years principally for use in compensating for normal shrinkage occurring during the first few weeks of curing and hardening of grouts. These types of expanding cements are not to be confused with the expansion obtained by hydrogen, oxygen, or nitrogen gas liberation that occurs in grouts only during the fluid phase. A chemical compound present in expansive cement is an anhydrous calcium sulfoaluminate, which in the presence of lime, calcium sulfate, and water, hydrates to form ettringite and to produce the expansion. The bar method restrained expansion tests (American Society for Testing and Materials (ASTM) C 878) of the cements will range from approximately 0.04 to 0.10 percent. Grout mixtures containing these cements may be used under machine bases or column bases, for bolt anchorage, in concrete cracks, behind tunnel and shaft liners, for borehole and tunnel stemming, and in similar applications where drying shrinkage does not occur to a significant degree. These cements do exhibit early stiffening characteristics; consequently, retarding and water-reducing admixtures should be considered.

b. Gypsum Cements. Gypsum cements are generally quick setting, are commonly used for pothole and chuckhole quick repair, and are sometimes selected for use in rock and anchor bolting. Because of their quick setting properties, gypsum cements are sometimes used when temperatures are near freezing. A slight amount of expansion is normal in these types of cements. Caution must be exercised in their use as durability is questionable when they are exposed to aggressive environments (i.e., freezing, salts, high temperatures, wetting and drying). Gypsum cements are available in a wide range of setting times and strengths. Their behavior is quite variable from one brand to another. Gypsum cement is sometimes used as an admixture to accelerate the set of portland cements as well as in small quantities to overcome false set problems that may occur in portland cements. Gypsum cements should be evaluated in the laboratory before they are used, especially if the application will require a degree of permanence. They should not be used for permanent grout curtains in dams.

c. Quick-Setting Cements. Cements that reveal an initial and final setting time of approximately one-half that exhibited by normally setting cements, such as Type I or Type II, are considered quick setting. Gypsum, Type III, high alumina, and regulated-set cements, the latter containing haloaluminate, are the most commonly used when quick setting is required. High temperature environments will further accelerate the setting time of these quick sets to a point that may approach flash setting. Quick-set cements should be laboratory and field tested prior to use.

d. Fluid and Hardened Properties. Expansive cement, gypsum, and quick-setting cements require somewhat higher water contents than other types as a result of initial hydration, causing early stiffening. All must be batched and placed quickly to avoid setting up in mixers, pumps, lines, or buckets. Generally, the mixtures are initially self-leveling; however, within seconds or minutes, they begin to stiffen and set. Some gypsum cements will develop compressive strengths ranging up to 10,000 pounds per square inch in a matter of a few days. Type III cement grouts normally develop in 7 to 10 days age strengths that Types I, II, IV, and V develop in 28 days age. High alumina and regulated-set cements behave somewhat like Type III; however, they are somewhat quicker setting and higher in ultimate strength development.

5-4. Mixture Adjustments.

a. As noted in paragraph 5-2a the volume of fluid grout produced by any combination of properly proportioned materials is equal to the sum of the absolute volume of the cement plus the absolute volume of filler material or significant amounts of admixtures plus the volume of water. The absolute volume of loose material (e.g. cement, fly ash, diatomite, bentonite, and sand) is always computed from weight and specific gravity:

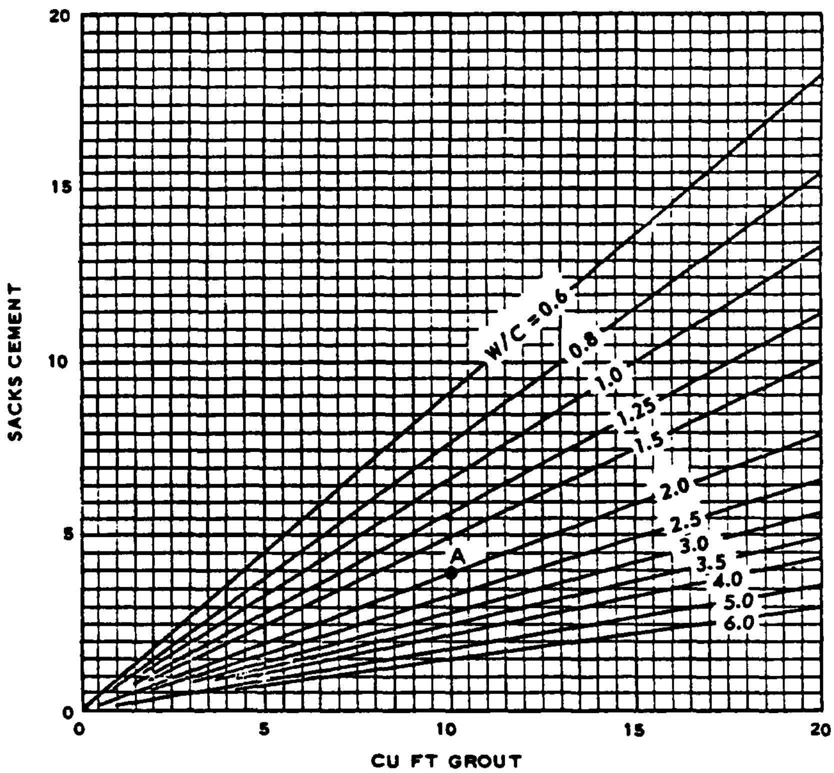
$$\text{Absolute Volume} = \frac{\text{weight of loose material}}{\text{specific gravity} \times \text{unit weight of water}}$$

and volume of liquids is computed:

$$\text{Volume} = \frac{\text{weight of liquid}}{\text{unit weight of liquid}}$$

b. When it is desirable to maintain a given yield for a grout batch, or to increase or decrease the amount of water or loose materials, the preceding computations must be made in making such adjustments whether such adjustments are made for improving pumpability, for increasing or decreasing strength of grout mixtures, or for possible adjustment of density or other desired physical properties. Strength may not be a controlling factor, as in much subsurface water control grouting, and thinning and thickening of the basic mixture may therefore be required to obtain the desired grout take at any given location of a downhole injection.

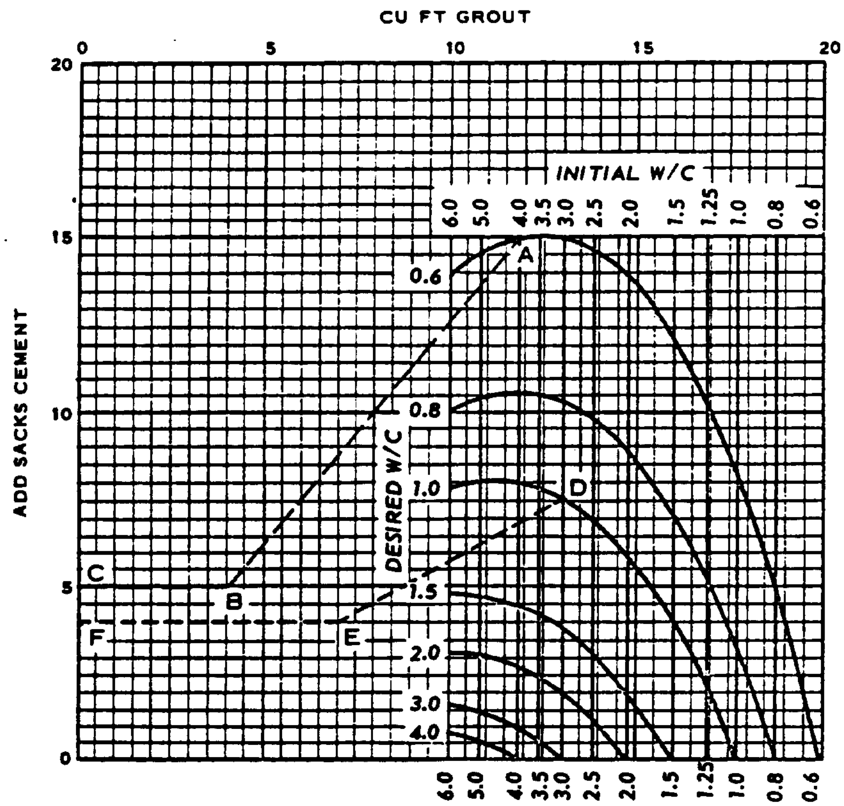
c. Figures 5-2, 5-3, and 5-4 are charts including portland cement content of mixtures, and portland cement thickening and thinning, respectively. For either thinning or thickening, the cement content of a given volume of



EXAMPLE: 10 CU FT OF 2.0 W/C GROUT (A) = 4.0 SACKS CEMENT.

NOTE: WATER-CEMENT RATIO (W/C) = CUBIC FEET WATER ÷ SACKS OF CEMENT.

Figure 5-2. Cement content of portland-cement grout mixtures



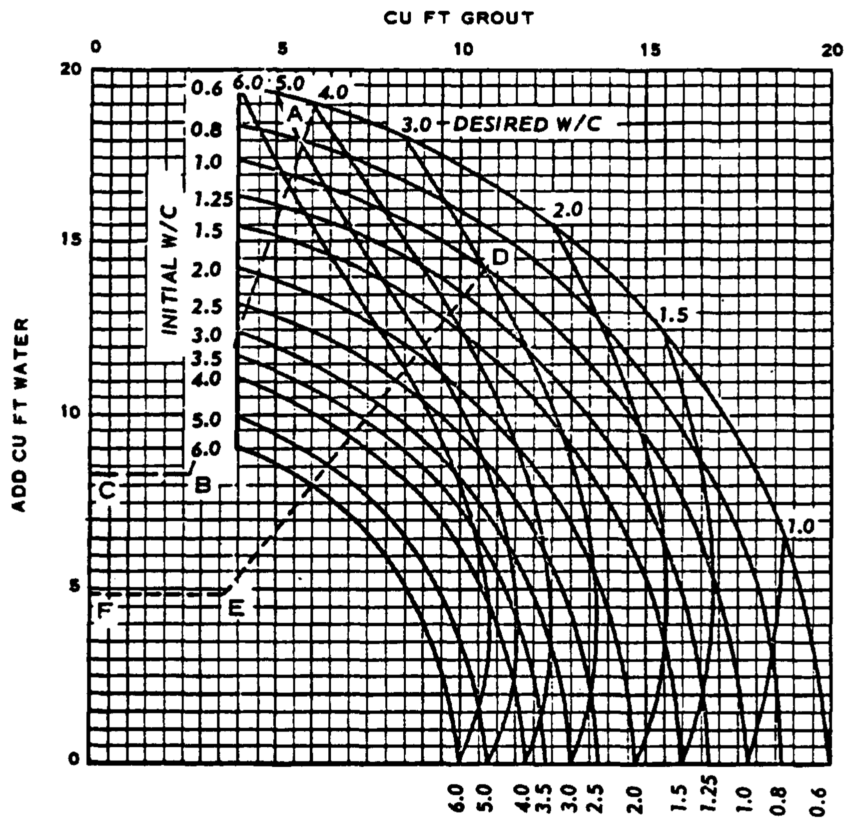
EXAMPLE 1: CEMENT REQUIRED TO THICKEN 4.0 CU FT OF 4.0 W/C GROUT TO 0.6 W/C (ABC) = 5.0 SACKS.

EXAMPLE 2: CEMENT REQUIRED TO THICKEN 7.0 CU FT OF 3.0 W/C GROUT TO 1.0 W/C (DEF) = 4.0 SACKS.

NOTE: WATER-CEMENT RATIO (W/C) = CUBIC FEET WATER + SACKS OF CEMENT.

FOR DETERMINATION OF QUANTITY OF CEMENT TO ADD, LAY STRAIGHTEDGE FROM POINT OF INTERSECTION OF DESIRED WATER-CEMENT CURVE AND VERTICAL LINE REPRESENTING INITIAL WATER-CEMENT RATIO TO POINT 0 AT LOWER LEFT-HAND CORNER OF CHART. READ AMOUNT OF CEMENT TO ADD ON LEFT SIDE OF CHART OPPOSITE POINT WHERE STRAIGHTEDGE INTERSECTS VERTICAL LINE REPRESENTING CUBIC FEET OF GROUT TO BE THICKENED.

Figure 5-3. Portland-cement grout thickening chart



EXAMPLE 1: WATER REQUIRED TO THIN 2.7 CU FT OF 0.6 W/C GROUT TO 4.0 W/C (ABC) = 8.3 CU FT.

EXAMPLE 2: WATER REQUIRED TO THIN 3.7 CU FT OF 1.0 W/C GROUT TO 3.0 W/C (DEF) = 4.9 CU FT.

NOTE: WATER-CEMENT RATIO (W/C) = CUBIC FEET WATER ÷ SACKS OF CEMENT.

FOR DETERMINATION OF QUANTITY OF WATER TO ADD, LAY STRAIGHTEDGE FROM POINT OF INTERSECTION OF INITIAL AND DESIRED WATER-CEMENT RATIO CURVES TO POINT 0 AT LOWER LEFT-HAND CORNER OF CHART. READ AMOUNT OF WATER TO ADD ON LEFT SIDE OF CHART OPPOSITE POINT WHERE STRAIGHTEDGE INTERSECTS VERTICAL LINE REPRESENTING CUBIC FEET OF GROUT TO BE THINNED.

Figure 5-4. Portland cement grout thinning chart grout is first determined. The cubic feet of grout is divided by the cubic feet of grout obtained from a one-sack batch, based on the absolute volume of a sack of cement being approximately 0.5 cubic foot.

EXAMPLE: Find the number of sacks of cement in a 12.6-cubic-foot batch of 4:1 grout and in a 12.6-cubic-foot batch of 0.75:1 grout.

For 4:1 mixture

4 (cubic feet of water) + 0.5 (solid volume of 1 sack of cement) = 4.5 cubic feet. 12.6 ÷ 4.5 = 2.8 sacks of cement

For 0.75:1 mixture

0.75 (cubic foot of water) + 0.5 (solid volume of 1 sack of cement) = 1.25 cubic feet. 12.6 ÷ 1.25 = 10.1 sacks of cement

d. The measured thinning of a grout requires the addition of cubic feet of water equal in number to the number of sacks of cement in the grout to be thinned multiplied by the difference between the figures representing the water in the water-cement ratios for the grout on hand and the mixture desired.

EXAMPLE: Determine cubic feet of water necessary to thin 7.2 cubic feet of 1:1 grout to 3:1 grout.

There are 4.8 sacks of cement in 7.2 cubic feet of 1:1 grout (7.2 ÷ 1.5 = 4.8).

The difference between the figures representing the water in the water-cement ratios of the two mixtures (3:1 and 1:1) is 2. The amount of water needed to bring 7.2 cubic feet of a 1:1 mixture to a 3:1 mixture is 9.6 (2 × 4.8 = 9.6).

e. The measured thickening of a grout is accomplished by subtracting the absolute volume of the sacks of cement in cubic feet from the cubic feet of grout to obtain the volume of water in the grout. Cement is then added to give the desired water-cement ratio with this volume of water. The adjustment should be made to the nearest whole sack so as to simplify batching operations. The following is an example of thickening:

Thicken a 5.6-cubic-foot mixture to a 1:1 mixture.

Mixture contains 4.8 cubic feet of water and 1.6 sacks of cement. Required are 4.8 cubic feet of water and 4.8 sacks of cement for producing a 1:1 ratio. The addition of 3.2 sacks could be made; however, to avoid fractions of sacks of cement during batching, add 0.8 cubic foot of water and 4.0 sacks of cement.

5-5. Chemical Grouts.

a. General Statement. Chemical grout provides the construction industry with a variety of benefits that are a result of improved gel-timing injection control and extended injectivity limits as well as increases in the strength development of various systems. Chemical grouts may be defined as true solutions composed of two or more chemicals that react to form soft, flexible gels, and semirigid and hard rigid gels.

b. Application Areas. Most chemical grout systems (e.g., acrylamides, silicates, and lignins) are used to increase the mass strength of soils and in subsurface water control. The great majority of applications are associated with foundation work. Epoxy and polyester resins are used not only in shallow crack repairs in concrete and rock but also for the emplacement of rock bolts and anchors. Water-base resins, somewhat higher in viscosity than acrylamide and silicate types but much lower than the viscosities common in portland cement grout, may be considered for grouting medium sands and coarse silts. Caution should be exercised in the use of chemical grouts since various systems have toxic and caustic constituents. Environmental restrictions may eliminate the use of certain chemicals for many grouting applications.

c. Self-Contained Systems. Self-contained two-component systems that could be classified as chemical grouts have recently become available. These systems are designed primarily for the anchoring of tendons, rebars, and rockbolts.

d. Reference. Engineer Manual EM 1110-2-3504 should be used as a guide when the use of chemical grouts is being considered. The manufacturer of those systems that appear to meet job requirements should be contacted for verification. Consideration should be given to conducting laboratory and field evaluations of the system or systems being considered as likely candidates for a given application.

5-6. Asphalt Grouts. Asphalt grouts have occasionally been used in successfully sealing moderate to large subsurface water flows in rock channels where cement grouts failed, or where the use of cement grout was not considered practical because of the configuration of the area to be grouted and the volume and velocity of the water flow. Hot asphalts and asphalt emulsions have been used to form barriers to water flow. Hot asphalts are generally heated to approximately 400° F when used for grouting. Care should be exercised in maintaining the heating temperature of a hot asphalt system below its reported flash point. Asphalt emulsions, immiscible in water, are applied cold and are suspended in water in colloidal form. Special chemicals are added to the mixture to cause "breaking," which brings about flocculation and subsequent coagulation in forming an effective grout. The control of coagulation time is an important factor to ensure that the proper amount of coagulation occurs at the proper time at the desired subsurface location.

5-7. Clay Grouts. Fine clays are useful as fillers in lean portland cement grouts. Benefits derived from their use include improved pumpability, injectivity, and economy. The two principal types of clays employed in grouting work are montmorillonite and kaolin. Attapulgite is a third type that is used in salt domes and in seawater grouting or other areas of application where moderate to high saline conditions are present. Bentonite is used in grout mainly because of its gel swelling properties, which are not exhibited by kaolin.