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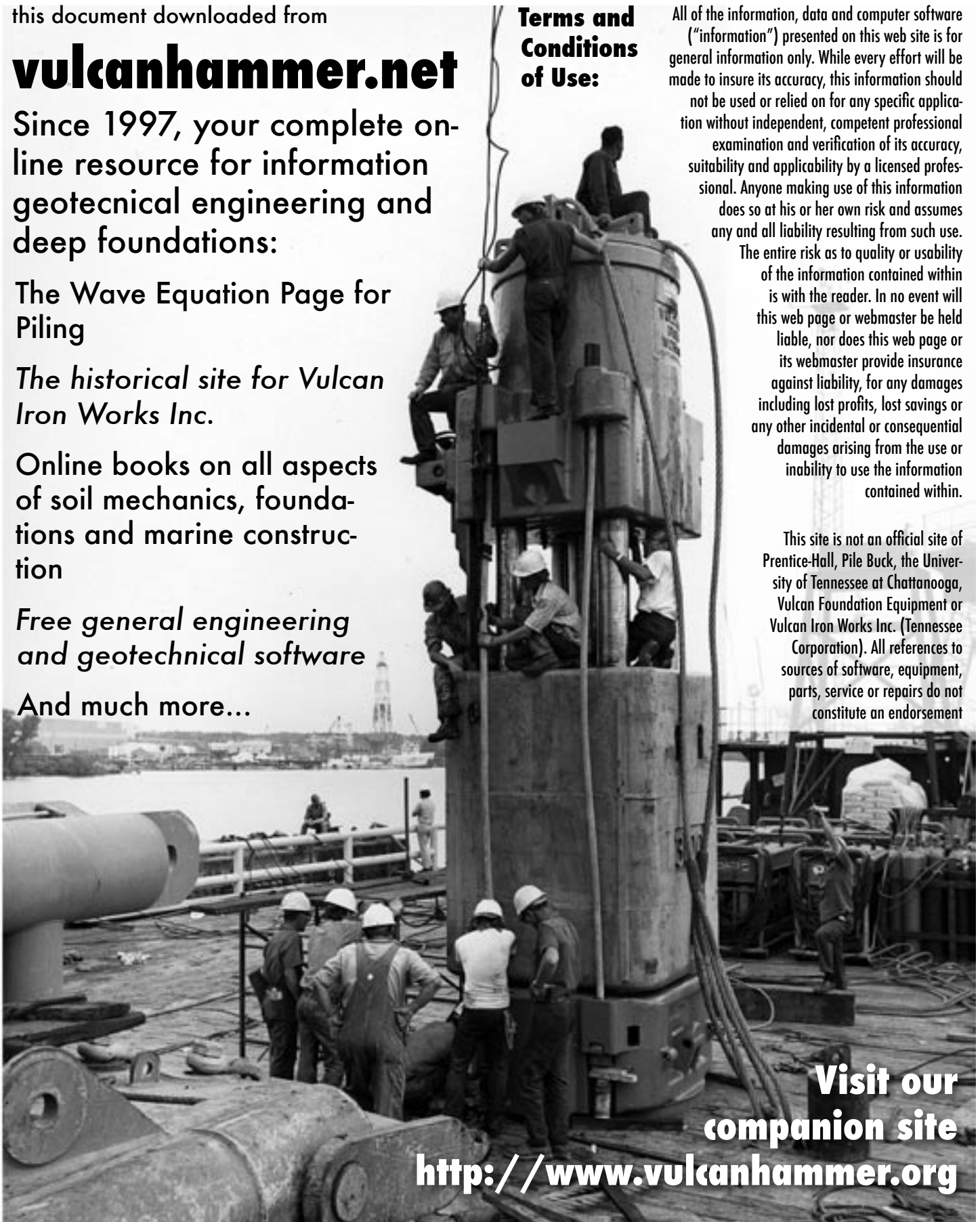
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UNIFIED FACILITIES CRITERIA (UFC)

GROUTING METHODS AND EQUIPMENT



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UNIFIED FACILITIES CRITERIA (UFC)
GROUTING METHODS AND EQUIPMENT

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U.S. ARMY CORPS OF ENGINEERS (Preparing Activity)

NAVAL FACILITIES ENGINEERING COMMAND

AIR FORCE CIVIL ENGINEER SUPPORT AGENCY

Record of Changes (changes are indicated by \1\ ... /1/)

Change No.	Date	Location

This UFC supersedes TM 5-818-6, dated 27 February 1970. The format of this UFC does not conform to UFC 1-300-01; however, the format will be adjusted to conform at the next revision. The body of this UFC is the previous TM 5-818-6, dated 27 February 1970.

FOREWORD

\1\

The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with [USD\(AT&L\) Memorandum](#) dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States is also governed by Status of forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA.) Therefore, the acquisition team must ensure compliance with the more stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

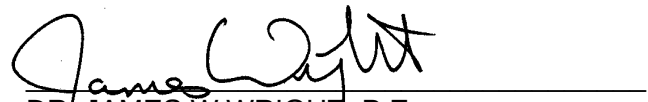
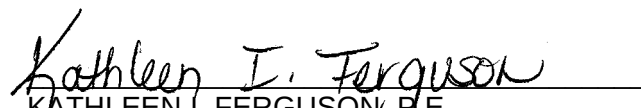
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DEPARTMENT OF THE ARMY TECHNICAL MANUAL
DEPARTMENT OF THE AIR FORCE MANUAL

GROUTING METHODS AND EQUIPMENT

This copy is a reprint which includes current
pages from Change 1.

DEPARTMENTS OF THE ARMY AND THE AIR FORCE

FEBRUARY 1970

TECHNICAL MANUAL
No. 5-818-6
AIR FORCE MANUAL
No. 88-32

DEPARTMENTS OF THE ARMY
AND THE AIR FORCE

Washington, D. C., 27 February 1970

GROUTING METHODS AND EQUIPMENT

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SECTION 1. INTRODUCTION

1. **PURPOSE AND SCOPE.** This manual was prepared to provide guidance in the use of pressure grouting as a means to correct existing or anticipated subsurface problems. Information on procedures, materials, and equipment for use in planning and executing a grouting project is included, and types of problems that might be solved by pressure grouting are discussed. Methods of pressure grouting that have proven to be effective are described, and various types of grouts and their properties are listed.

2. GENERAL CONSIDERATIONS.

a. Purposes of Pressure Grouting. Pressure grouting involves the injection under pressure of a liquid or suspension into the voids of a soil or rock mass or into voids between these materials and an existing structure. The injected grout must eventually form either a gel or a solid within the treated voids, or the grouting process must result in the deposition of suspended solids in these voids. The primary purposes of pressure grouting a soil or rock mass are to improve the strength and durability of the mass and/or to reduce the permeability of the mass.

b. Problems Related to Strength. Typical problems involving strength properties of a soil or rock mass include: (a) insufficient bearing capacity for structural elements such as footings, slabs, or mats; (b) insufficient strength to preclude sliding failures of embankments or cut slopes; (c) inherent mass instability of fractured rock formations; (d) sloughing or complete closure of vertical or horizontal tunnels; and (e) general structural weaknesses due to underground caverns or solution channels or due to voids that develop during or following construction.

c. Problems Related to Permeability. Problems related to permeability of a—soil or rock mass include: (a) reduction in strength of foundation materials due to high seepage forces; (b) loss of impounded water from a reservoir or storage area; (c) high uplift forces at the base of a water-retaining structure; (d) piping erosion through or under an earth dam; and (e) inability to complete excavations, shafts, or tunnels extending below the groundwater table due to caving and sloughing.

d. Selection of Methods of Treatment. Problems of the nature described above can often be treated by pressure grouting. However, other methods of treatment may be equally satisfactory and adaptable to the project. The selection of pressure grouting as the method of treatment should be based on an evaluation of all pertinent aspects of the problem, i.e., engineering needs, subsurface conditions, economic considerations, and availability of qualified supervisory personnel. In some respects, pressure grouting is an art based on natural and scientific laws but it requires experience and engineering

judgment. Rigid rules for the exercise of this art cannot be established, and only general procedures and guides can be presented in this manual. For these reasons, the services of personnel experienced in grouting should always be utilized.

SECTION 2. SUBSURFACE INVESTIGATIONS

3. **GENERAL REQUIREMENTS.** An investigation of subsurface conditions such as that normally made for foundation design purposes is usually sufficient to determine whether unfavorable conditions are present that can be improved by grouting. The discovery of any of the following in the course of these investigations warrants consideration of treatment by grouting if the success of the project could be affected thereby: soluble rocks or evidences of solution activity, prominent open joints, broken or intensely jointed rock, faulting, losses of circulation or dropping of drill rods during drilling, or unusual groundwater conditions.

4. SPECIAL REQUIREMENTS.

a. Exploratory Borings. Specific information on subsurface conditions is needed to plan the grouting program. In order to determine the scope and estimate the costs of the drilling and grouting operations in rock, information on orientation, attitude and spacing of joints, joint openings including type of filler if any, boundaries of rock types, location of faults, location of broken zones, depth to sound rock, and position of water table should be available. The borehole camera or television camera can be of particular assistance in obtaining this information. If soil is to be grouted, information on its stratification, density, grain size, and permeability will be required. If these data, as pertinent to the project, cannot be obtained from the design investigations or from rock exposed by the first excavation at the site, additional explorations (borings, trenches, etc.) should be made to supply the missing data.

b. Field Tests.

(1) Pressure tests. Pressure testing by pumping measured amounts of water into exploratory boreholes under known pressures serves a useful purpose if the injection of gel-forming grouts is contemplated. The results of the pressure tests will show the permeability of the soil or rock mass to water or other fluid of the same viscosity. The best way to determine the permeability of uniform, porous, water-bearing soil layers is by a pumping test, as discussed in Civil Works Technical Letter 63-16. Pressure testing of rock to learn whether it will accept a cement or clay grout is rarely worthwhile. If pressure testing is done for this purpose each tested increment of borehole should be examined by television or borehole camera to obtain information on the size of the openings that are presumed to take water.

(2) Test grouting. The most reliable means of obtaining realistic answers to questions on the capability of rock to take a grout containing solids in suspension is by test grouting. The test-grout program should be planned not only to provide information on the groutability of the rock, but also on the

most suitable mixes and probable quantities of grout, if the rock takes grout. Although recommended for the purpose stated, test grouting is seldom considered necessary if only cement grouting of rock is involved. Collective experience from scores of jobsites where cement grouting was performed in widely varying subsurface situations indicates that cement grout can be injected if one or more of the conditions listed in paragraph 3 has been found in preconstruction investigations. Test grouting of soils with chemical grout coupled with exploratory trenches and pits to observe the results is very helpful in estimating costs and effectiveness, and on large jobs may allow a considerable saving of costs to be made if representative areas are tested. By varying grouting techniques, optimum spacing of holes, pressures, injection rates, and setting times can be ascertained for each major set of

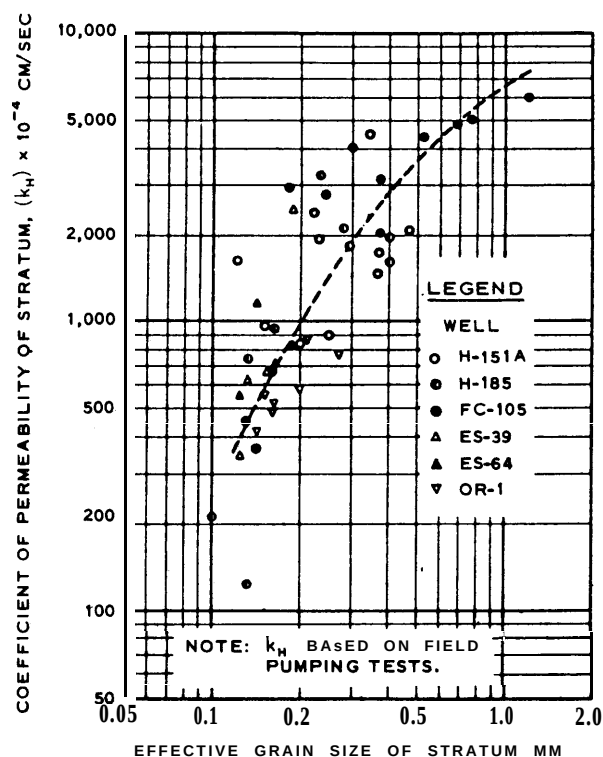
conditions. This permits obtaining satisfactory coverage with minimum quantities of drilling and grout.

c. Laboratory Tests.

(1) Permeability. Test procedures for determining the permeability of soil samples are described in EM 1110-2-1906. Laboratory permeabilities are generally somewhat smaller than field permeabilities determined from field pumping tests.

(2) Gradation. Procedures for performing grain-size tests are given in EM 1110-2-1906. The effective grain size (D_{10} size) of Mississippi River alluvial sands has been correlated with field permeability values and the results of this correlation are shown in figure 1.

(3) Density. The density and void ratio of undisturbed samples should be determined for use in making calculations and in evaluating the stability and permeability characteristics of the in-place soil mass. Test procedures are outlined in EM 1140-2-1906.



(From "Investigation of Underseepage and its Control, Lower Mississippi River Levees," TM 3-424, Vol 1, Oct 1956, U. S. Army Eng. Waterways Exp. Sta.)

Figure 1. D_{10} versus in situ coefficient of permeability-Mississippi River Valley Sands

(4) Chemical tests. Chemical analysis of groundwater samples should be made to determine the presence of calcium sulfate, magnesium sulfate, sodium sulfate, organic or mineral acids, and alkalis that may be detrimental to cement or chemical grouts. The pH of the water should also be determined.

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

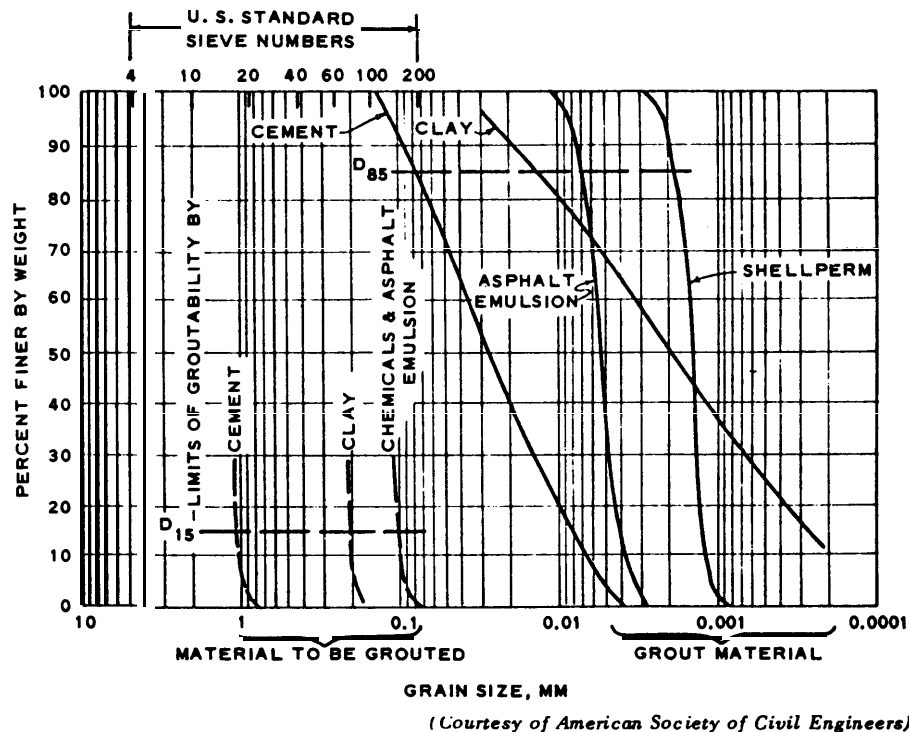


Figure 2. Soil and grout materials grain-size curves (see ref 35)

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 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.

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 up 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

Potassium nitrate
Potassium carbonate
Sodium aluminate
Sodium silicate
Lithium carbonate
Sodium hydroxide

Flocculating Agents

Aluminum sulfate
Sodium sulfate
Calcium chloride
Copper sulfate
Ferrous sulfate

(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.

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 physioc- hemical 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 petroleum. 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 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 sodium silicate, and ethyl alcohol. 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
Chrome lignin	Silicate-chloride (Joosten)	30-50	0	Over 500
	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

SECTION 4. GROUTING METHODS

10. GROUTING PROCEDURES.

a. 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 subsurface 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.

b. 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.

c. 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.

d. 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.

e. 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.

f. 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.

g. 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.

h. 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.

i. Pressure Testing and Pressure Washing.

(1) 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.

(2) 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.

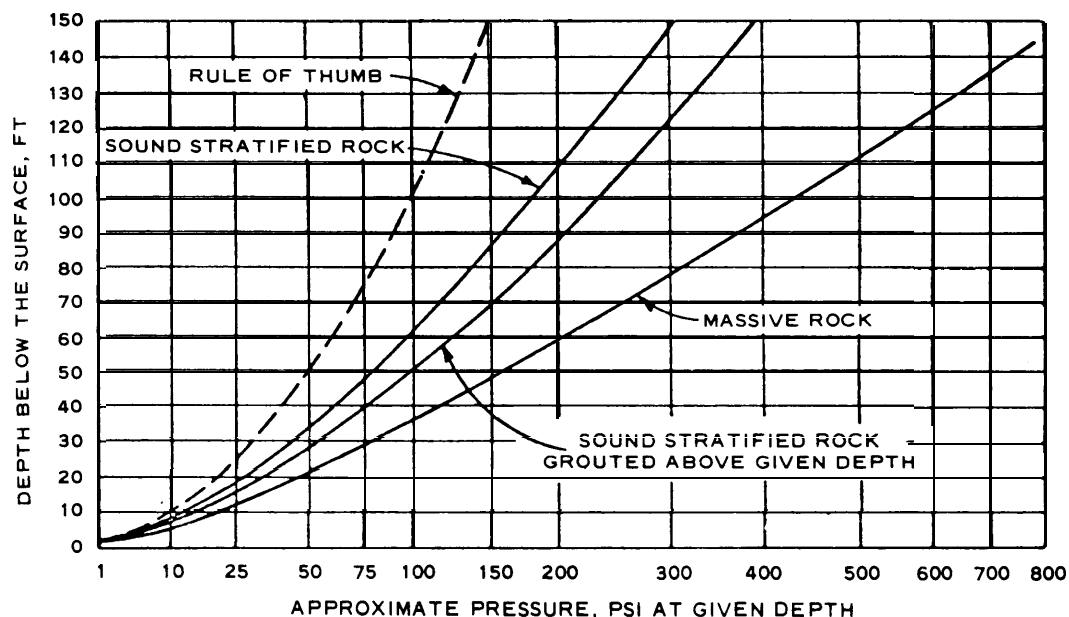
j. Mixes. Water -cement ratios of portland-cement grout can be indicated by either weight or volume. The volume basis is more convenient for field work and is commonly used. In field mixes a sack of cement is considered equal to 1 cu ft. The mixes most frequently used range from 4:1 to 0.75:1, by volume. 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.

k. Pressures.

(1) 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.

(2) 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.) The rule of thumb can be modified with caution as indicated in figure 3. The weight of the column of grout in



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Figure 3. Rough guide for grouting pressures

the hole may necessitate further modification of the gage pressure. Figure 4 shows the pressure exerted by a column of grout 1 ft high for various grout



Figure 4. Pressure of neat cement 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.

1. Program Objectives. 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.

m. Grouting Techniques. Grouting techniques vary from job to job as

m. Grouting Techniques. Grouting techniques vary from job to job as dictated by the subsurface conditions and program objectives, from organization to organization according to policy, and from inspector to inspector according to judgment and preference. Some of the procedures and items subject to modification by policy and field judgment as well as by grouting objectives are adjustment of mixes, changing grouting pressures, flushing of grout holes and washing the pump system during grouting, sudden refusal of a hole to accept grout, use of delays to reduce spread of grout, treatment of surface leaks, and completion of grouting.

(1) Mix adjustment for portland-cement grouts.

(a) The choice of the starting mix may depend on one or more of a variety of factors: concept of the groutable openings in the rock, time since drilling, pressure testing or pressure washing, position of water table relative to the zone to be grouted, and experience with grouting similar rocks. If the zone is below the water table, if the groutable openings have recently been wetted, if an appreciable part (but not all) the drill water was lost, or if the water take in the pressure test was at the rate of about 1 cfm, a starting mix of 3:1 (3 parts water to 1 part cement, by volume) grout might be the choice. If the rock is believed to be dry, or a pressure test result of less than 0.5 cfm has been obtained, it is likely that a 4:1 or thinner grout would be selected for starting the hole. If all the drill water was lost and the drill rods dropped an observable amount, and if the point of the water loss is below the water table or the rock is still wet from pressure testing or pressure washing, the starting mix could be a 2:1 grout. If the hole accepts a few batches of the starting mix readily without pressure buildup, thicker mixes should be considered in accordance with the objectives of the grouting program. In a relatively tight hole with the pressure quickly reaching the maximum allowable, the starting mix, if properly selected, should be continued until grouting is complete.

(b) Mixes are usually thickened by batching the new mix in the mixer and discharging it into the remaining thinner grout in the sump tank. For most small grout plants, the grout in the pump system (sump tank, pump, and both pump and return lines) will have essentially the consistency of the new grout after the second batch of new mix if the sump is pumped as low as possible for each batch and the grout lines are, not in excess of 100 ft in total length. If there is reason for an immediate thickening of the mix, the hole may be temporarily shut off and enough cement added to the grout in the sump to obtain the consistency desired in the pump system. Mixing is accomplished by agitation in the sump and by circulation through the pump and lines. Tables or charts showing cement content of various quantities of frequently used mixes are very useful for changing mixes or determining the amount of cement in a known quantity of grout (figs. 5, 6, and 7). Grout mixes are thinned by adding water to the sump tank in the amount needed to obtain the desired water-cement ratio and circulating until all the grout has the same consistency.

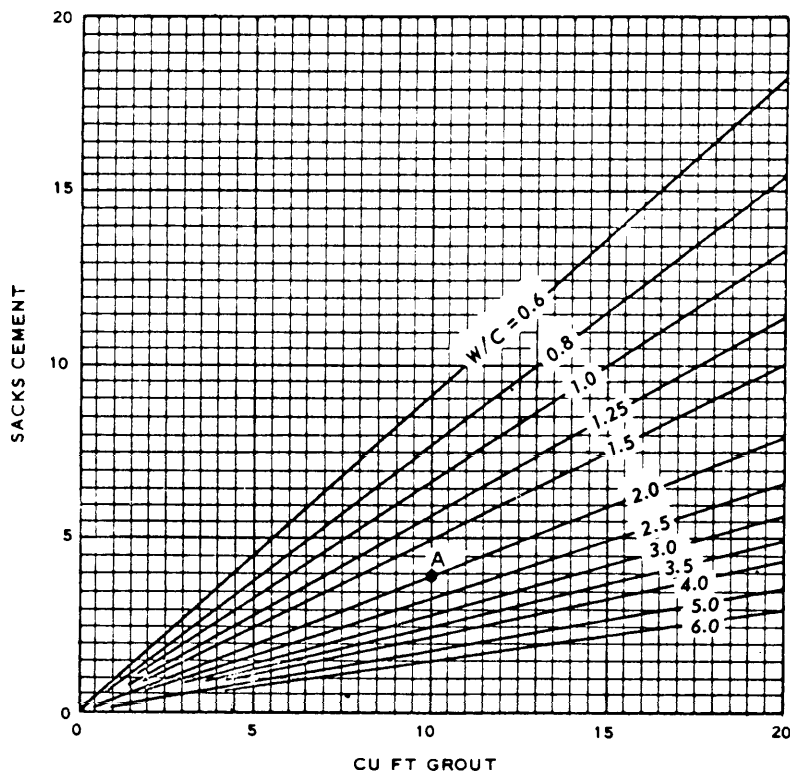


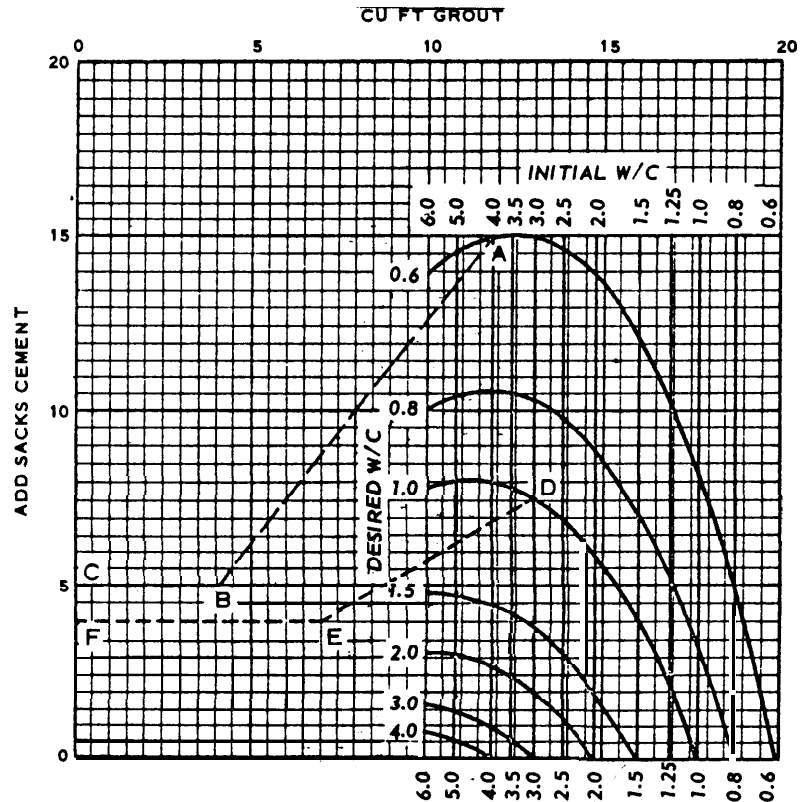
Figure 5. Cement content of portland-cement grout mixes

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.

(c) A common grouting practice is to thicken the mix until the desired pressure is reached and continue with this mix until the hole is completed. Another somewhat more sophisticated practice is to use the mix that will permit the injection of cement (not total grout mix but cement portion of the mix) at the maximum rate for a given pressure. Maintenance of the maximum rate of cement injection will require more frequent mix adjustments than the first-mentioned practice, but it tends to shorten the grouting period and reduce the spread of grout. This procedure also serves to guide the inspector in the selection of mixes. Groutable openings can be prematurely blocked and holes lost if the use of too thick grout is attempted. Increasing the consistency of the grout from 2:1 to 1:1 means that the hole must accept 67 percent more cement for the same rate of grout injection. In many instances it is better to change from 2:1 to 1.5:1 or other mix of intermediate consistency between 2:1 and 1:1 grout. If one of the objectives of the grouting program is to pump the maximum amount of grout (and cement) into the rock from each hole regardless of spread, mixes should be kept on the thin side.

Figure 6. Portland-cement grout thickening chart



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

(2) Pressure changes. One policy on grouting pressures advocates the adjustment of injection rates and mixes as necessary to reach and hold the maximum allowable pressure for as much of the grouting period as possible. While the adoption of this policy will result in denser grout, deeper penetration of groutable openings, and wider grout spread, it will also cause more lifting, more grout leaks, and more wasted grout, especially if the maximum allowable pressure is also the estimated maximum safe pressure. When the maximum safe pressure is exceeded, lifting or grout breakout will take place no matter how accurately or inaccurately it was estimated. Therefore, the

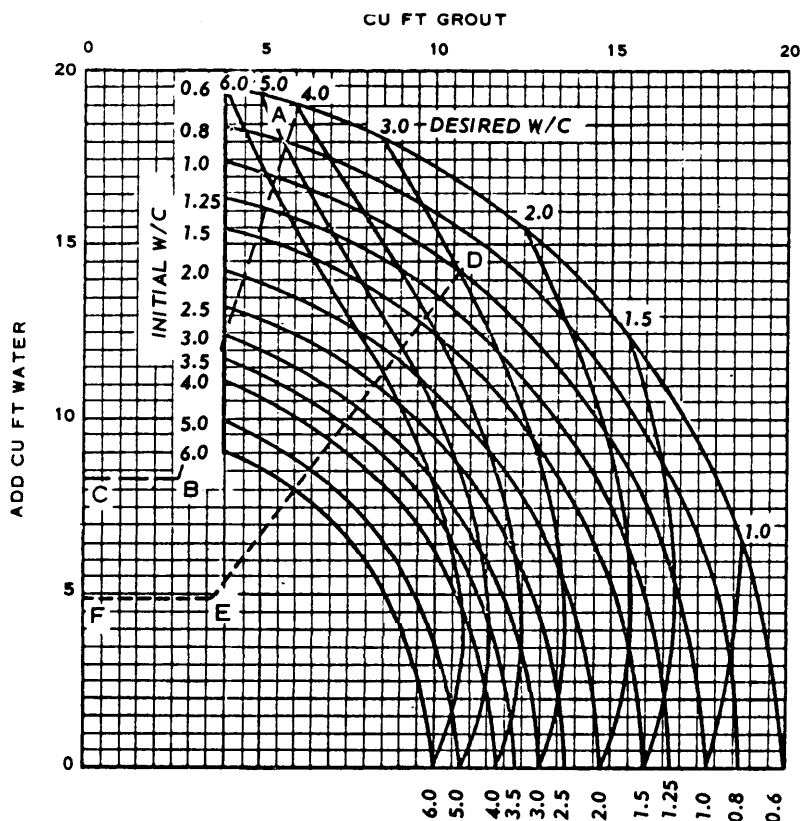


Figure 7. Portland-cement grout thinning chart

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.

maximum safe pressure should be approached cautiously. A more conservative policy is to raise the pressure incrementally to approximately three-fourths of the maximum allowable pressure, hold that pressure constant until definite slowing of the injection rate is apparent, then raise slowly and by increments to the maximum. This reduces the spread of the grout, but more important it usually permits the inspector to recognize lifting, if it takes place, and to stop grouting at its inception. When lifting occurs it is often accompanied by noticeable changes of pressure and grout consumption. These changes last only a short time and may pass unnoticed by the inspector

who is raising pressures rapidly with concurrent thickening of mixes to reach the maximum pressure as quickly as possible. However, the inspector who has learned the grouting characteristics of the hole by noting the change in injection rate for each added increment of pressure and who has observed and recorded the effects of each new mix on both the injection rate and the pressure has a good chance to notice out-of-character responses in the behavior of the hole. If the grouting pressure is close to the estimated maximum safe pressure and the injection rate quickens with a slight drop in pressure, lifting should be suspected.

(3) Washing pump system and grout holes. Although care and maintenance of equipment are properly a function of the contractor, maintenance needed to avoid jeopardizing a grouting operation should be directed by the inspector and provisions there for made in the specifications. Such maintenance includes keeping the pump system clean and in good operating condition during the grouting process. The pump system should be flushed with water at intervals that will vary with temperature, mix, and rate of injection. During extended periods of continuous grouting with thick mixes, it may be necessary to wash the system as often as once each hour. Consideration should be given to injecting several cubic feet of water into the grout hole at about the same frequency when using thick mixes, if not contrary to the objectives of the grouting program. (Washing or flushing to rejuvenate a hole may not be compatible with efforts to construct a narrow grout curtain.) Water is usually injected into a grout hole when grouting is suspended due to an emergency, or when it is stopped intentionally to permit grout already placed to set. This is done to maintain access to a readily groutable zone or cavity for additional grouting from the same hole. Every effort should be made to keep mixes thicker than 1:1 constantly moving. A very brief delay may cause the loss of the hole. Occasionally loss of hole from emergency delays can be prevented by jetting a pipe to the bottom of the hole and flushing out the stiff grout. This should be quickly followed by pumping a batch of water into the hole and, if that is successful, using a thin mix to resume grouting operations.

(4) Sudden refusal. The sudden refusal of a hole to take grout suggests several possibilities. Extraneous solid matter may have fallen into the grout and blocked the line, the packer, or the hole; the hole above the zone taking grout may have collapsed; the mix may be too thick; or the openings in the rock may be full. The various possibilities should be checked unless sudden refusal is routine at the site involved. First, if the injection rate is not quite zero, an attempt should be made to reopen the hole by pumping water into it. If this does not work, the grout line to and through the packer, if a packer is used, should be examined to make certain that grout is reaching the hole. As a last resort a probe can be dropped in the hole to learn whether it is open. The addition of an inert filler to the grout sometimes causes sudden stoppage in a hole. Fillers should be added cautiously if large, cavities are not known to be present. The filler should be taken out of the mix immediately if it

appears that it may cause premature stoppage.

(5) Delays. Delays lasting from a few minutes to several hours may be interposed in the grouting operations to prevent the grout from spreading beyond a reasonable distance, if in keeping with the grouting objectives. Accelerators may be used in connection with the delays. A succession of delays is sometimes used before a hole is completed. The amount of grout injected between delays or before the first delay will be a matter of policy and judgment, which should be based on knowledge of subsurface conditions. As long as the grout is considered to be fulfilling its intended purpose, grouting should not be interrupted. There is also the possibility that access from the hole to the void taking the grout will not remain open during the period of delay, even though water is injected to keep it open. The risk of losing the hole for further grouting and the cost of a new hole should be weighed against the cost of the grout saved by the delay before ordering the delay. If delays of several hours are desired, the contractor's grouting efforts may be directed elsewhere during the period of delay. If the delays are comparatively short and the contractor is required to stand by with his grouting equipment, the specifications should state how compensation will be made for the period of waiting.

(6) Treatment of leaks. Grout sometimes follows interconnected natural openings in rock to break out many hundreds of feet from the point of injection. Frequent and periodic checks of the area in the vicinity of the grout hole should be made during grouting operations. The inspector should observe all known wells, springs, or seeps for unusual discoloration or increase in flow. The area patrolled should be enlarged as the grout consumption increases. In the event that a leak occurs, the inspector should estimate whether it represents essentially all the intake of the grout hole or only a small part of the total. If all the grout seems to be venting, the pressure should be reduced, the mix thickened, if not already thick, and a small dike built to pond thick grout over the leak if possible; then the grouting should be stopped. The pond of grout will act as a reservoir to keep the vent full until the grout sets. If only a portion of the injected grout is venting, it may be worthwhile to expend considerable effort to save the hole. If the leak is in loose material, the procedure outlined above may be used, except that pumping should not be stopped but slowed to give the thick grout in the pond time to set. An accelerant may be added to the ponded grout. Sand is a good material to create a pond, since excess water in the grout can escape through it. If the leak is in relatively sound rock, it may be talked with oakum, wicking, burlap, wood wedges, or lead wool. Burlap is particularly good if the grout contains much excess water, since it can seep through the burlap leaving the cement to build up in the fracture. If the grout is not too thick, brief delays may be tried but without prior injection of water. After the leaking has stopped, normal operations may be gradually resumed. If the leaking cannot be completely stopped and represents only a small part of the grout injected, grouting can be continued at a reduced pressure. Often many

grout leaks can be avoided by treating leaks discovered during pressure testing or pressure washing. At this stage open cracks and fissures may be filled with a quick-set grout mix. The contractor's responsibility relative to talking and other treatment of leaks should be described in the specifications.

(7) Completion of grouting.

(a) Grouting may be continued to absolute refusal at the maximum grouting pressure, although this is not usually done. There are two methods that are most frequently used to determine when grouting is complete. One specifies that grouting shall continue until the hole takes no grout at three-fourths of the maximum grouting pressure. The other requires that grouting continue until the hole takes grout at the rate of 1 cu ft or less in 10 min measured over at least a 5-min period. This is often modified according to the mix and/or pressure used. The second specification is more readily correlated with pressure-test results than the first.

(b) If there is doubt about the completeness of treatment in any zone or area, a check hole or holes should be drilled. Such holes can be drilled to recover core for examination, or they may be drilled for study by the bore-hole camera or television camera. However, a quicker and less expensive check can be made by drilling and pressure testing another grout hole. If tight when pressure-tested with water, the rock is satisfactorily grouted; if the hole takes water, additional grouting is indicated.

11. DEFINITIONS.

a. Stage Grouting. In this method of grouting, progressively deeper zones are drilled and grouted in stages from the top of rock. A stage of drilling is complete when a predetermined depth of zone is reached or when a specified condition is encountered. A single zone may include more than one stage. Holes in a given area are drilled to their first stage of depth, grouting is done at low pressure, and the grout within the hole itself is subsequently removed by jetting or other methods before it has set sufficiently to require redrilling. (In the event that the contractor is ordered to leave the grout in the hole for any stage except the last one, payment for drilling grout is usually made at the rate of 50 percent of the cost of drilling rock.) Similar stages or cycles of drilling and grouting are repeated as necessary to reach the bottom of the first zone. After all first-zone grouting of primary holes in the area has been completed and a minimum period of 24 hr has elapsed since completion of grouting operations in any given hole, intermediate holes, located by the split-spacing method, are drilled and grouted to the bottom of the first zone. Upon completion of all split-spacing holes, the primary holes are drilled to their second zone depth and grouted at higher pressures. The process of drilling, washing, pressure testing, pressure washing, and grouting at progressively higher pressures is continued until the ground is satisfactorily tight to the required depth. If any stage of a hole is found to be adequately tight as determined by pressure testing, grouting of that stage is omitted and the hole left open for drilling in the next lower stage.

b. Series Grouting. Series grouting is similar to stage grouting except that each successively deeper zone is grouted by means of a newly drilled hole to eliminate the need for washing grout out of the hole before drilling deeper. Holes at regular intervals are drilled to the depth of the first zone and individually grouted from the top of rock at low pressure. The split-spacing method of reducing the grout-hole interval is followed until the uppermost zone refuses grout at the permissible pressure. After the first zone has been completed, another series of holes is drilled into the second zone and grouted from the top of rock at higher pressures, following the same procedure as outlined for the first zone. Additional series of holes may be drilled, depending upon the final depth of grouting required. The maximum pressure is applied to the deepest zone. The justification for using the higher pressures in the deeper zones in this method, and in the stage-grouting method, is based upon the assumption that a blanket or barrier, as provided by the previously grouted zones, prevents the escape of grout through, or the development of serious uplift in, the shallower zones.

c. Stop Grouting. In the stop-grouting method of grouting, the hole is drilled to full depth and a packer used to separate the hole into segments or zones for grouting purposes. Grouting is started in the lowest zone. After completion of each zone, the packer is raised to the top of the next higher zone; and grouting is resumed under a maximum pressure commensurate with the reduction of overlying load. The packer must be left in place after each grouting until the pressure on the newly placed grout has dropped to or below the maximum pressure contemplated for the next higher zone. The last stop, or packer setting, is at the top of rock. Usually, the packer is not removed from the hole until the grouting of all stops in the hole has been completed.

d. Circuit Grouting. Circuit grouting requires the use of a double-line grouting system (para 17a). The pump line is attached to a pipe that extends through an expansion plug or packer to within 5 ft of the bottom of the hole. When grout venting from this pipe fills the hole, it flows through a second opening in the expansion plug into the attached return line and back to the grout sump for recirculation. Thus, as soon as the pumping rate exceeds the rate at which grout is injected into the rock, the grout hole becomes part of the grout-circulation system. Circuit grouting may be used "to grout a hole drilled to full depth as a one-time operation or it may be used as a modification of any of the other grouting methods described.

e. Soil Grouting. The methods described in the preceding paragraphs were developed primarily for grouting rock and may or may not be applicable for grouting soil. Because of the lack of stability of borehole walls that may be encountered in soil, it may be necessary to provide support while grouting is in progress.

(1) Casing. A casing may be driven, jetted, or pushed to the full depth to be treated and then withdrawn as grout is pumped into the soil. The escape of grout up the contact surface of the casing and the soil may be a problem. This method is used extensively in chemical grouting at shallow depths.

(2) Grout sheath. In this method a flush-joint grout pipe is grouted in, using a special brittle grout that prevents leakage up the outside of the pipe. The grout pipe is then withdrawn a short distance, leaving a brittle grout sleeve below the pipe. Grout is then pumped into the soil through cracks produced by the pressure of the grout in the brittle grout sleeve below the end of the grout pipe.

(3) Pierced casing. A patented method has been developed for soil grouting in which the casing is grouted in using a special grout. The casing is then pierced at any selected point using a powder-impelled projectile fired from a device lowered into the casing.

(4) Tubes a manchette. In this patented method a perforated pipe is grouted into the hole with a special sleeve grout. The perforations are covered with short sections of a rubber sleeve (manchettes) on the outside of the pipe that act as one-way valves. A double packer is used to control the treatment location. The pressure on the grout pumped into the hole between the confining packers causes it to push past the small rubber sleeves covering the perforations, rupture the sleeve grout, and enter the soil. This device is suitable for injecting cement, clay, or chemical grout. In some instances the same holes and the same rubber-sleeved vents have been used for the injection of each of these grouts separately and in rotation into a soil. This permits economical impermeabilization of soil containing large voids with an expensive chemical grout by first filling the large voids with less costly clay and cement grout.

12. CRITIQUE.

a. Stage Grouting.

(1) Advantages. All grouting, regardless of depth of zone, is done from the top of rock, usually through a short pipe set in the top of the hole. This eliminates the need for packer assemblies required for stop grouting. A smaller hole can be used for stage grouting than for stop grouting since no packer is involved. Stage grouting has a flexibility that permits special attention to be given to almost any local condition encountered, provided the specifications are written to permit payment for the contractor's efforts. Drill cuttings from lower zones cannot clog groutable openings in higher zones. The grouting of all zones is done through a single hole, making drilling costs much less than for series grouting, which requires a new hole for each cycle of drilling and grouting.

(2) Disadvantages. The principal disadvantage of stage grouting is the ever-present danger of lifting or heaving the rock when grouting without a heavy confining load. This causes grout waste and may seriously damage the rock and/or any superjacent structure. Lifting occurs when grout at comparatively high pressures is actually injected into and displaces rock near the surface. Thinly bedded, horizontally stratified rocks are easily lifted. To prevent lifting such rocks, it is sometimes necessary to use pipes several feet long or to grout all but the first stage through a packer set in a reamed-out hole at a depth of several feet. In the first instance the upper few feet of rock are not grouted; in the second case, one of the advantages of stage grouting is lost since a packer must be set for each stage of grouting. A second major disadvantage of stage grouting, as compared with stop grouting, is its higher costs. A drill must be moved to and set up over each grout hole at least once for each zone in the hole and grout lines must be connected to the hole equally often. Both items add time and money costs to the job. Connections to grout holes are usually pay items; more are required for stage grouting. Labor is expended and grout is wasted for each stage of grout hole cleaned before deepening. If the cleanout is made prematurely, grout injected into the rock may flow back into the hole and be wasted also.

b. Series Grouting.

(1) Advantages. The advantages given above for stage grouting (except "the last listed) apply also to series grouting. Other advantages of series grouting are that all grouting is done from a new hole in freshly exposed rock (this provides for a maximum exposure of groutable voids) and grout injected into the rock is not lost by poorly timed cleanouts as in stage grouting.

(2) Disadvantages. The major disadvantages of stage grouting, i.e., danger of lifting and increased expenditure of time and money, apply to series grouting also. The increased amount of drilling makes series grouting the most expensive of the methods described.

c. Stop Grouting.

(1) Advantages. The stop-grouting method is the quickest and least costly method of grouting. This is primarily because of the time and labor saved by not having to move drills and grout lines repeatedly to and from the same hole. Grouting through a packer set at depth provides positive knowledge that grout under high pressure is not being injected into lightly loaded rock near the top of the hole, as may be the case in other methods of grouting. Stop grouting is the least likely to produce undiscovered lifting and resulting grout waste. Stop grouting is particularly well adapted to situations that require the highest pressures in the deepest zones.

(2) Disadvantages. Packers are sometimes hard to seat. This results in loss of time and may result in the loss of the packer by blowout. In

general, larger holes are required. Upper groutable zones may be clogged or partially clogged by cuttings from lower strata. The pressure required to pump grout through the relatively small opening in the packer may exceed the pressure needed to inject the grout into the rock.

d. Circuit Grouting.

(1) Advantages. Grout is kept alive in the entire hole until grouting is complete. Thus, small openings occurring below large ones can be grouted after the large openings are filled. Caving holes can be grouted by jetting the grout pipes through the caving zones. Holes can be flushed or washed more thoroughly during the grouting operation in circuit grouting than by any other grouting method.

(2) Disadvantages. If the packer is set near the top of hole, the entire hole must be grouted at a pressure low enough to prevent lifting of surface rock. If the packer is set several feet below the surface, the upper part of the rock is ungrouted. A large hole must be provided to the depth of the packer to permit installation of a packer large enough to accommodate both injection and return grout lines. Excessive time is required to assemble and disassemble grout pipe in the hole. Flush-joint pipe is needed to reduce loss of grout pipe since the packer must be left in the hole until the pressure on the grout dissipates.

e. Combining Methods. No large grouting job is likely to be completed using—only one grouting method in the strictest sense of the definitions. For example, if during the drilling of a hole for stop grouting, the drill water is lost, drilling is stopped immediately and the hole is grouted. In such cases it can be said that stop grouting is done by stages. In stage grouting if the upper rock is so fractured that it cannot be sealed well enough to withstand the higher pressures desired for the lower zones, it may be necessary to grout the lower zones through a packer set below the fractured rock. This again combines stage grouting and stop grouting. If a badly fractured upper zone extends over a considerable area, treatment may be by a grid of shallow holes grouted by the series- or stage-grouting methods to form a grouted-rock blanket before continuing with the lower zones in this area by stop, stage, or series grouting. Specifications should be flexible enough to permit the use of the method or methods best suited to whatever situation is encountered and should provide means of compensating the contractor for the work performed.

f. Selection of Method. Stage grouting and stop grouting are the two most common methods of grouting in the United States. Service records show that effective results can be obtained by either method. If grouting is delaying another construction operation and time is an important factor, stop grouting should be given serious consideration. If higher pressures are needed in lower zones of the grout hole than near the top, stop grouting is the

best suited method. Examples of the latter are reservoir rims, dam abutments, mine shafts or other similar deep excavations, and underground structures grouted from the surface. In some instances portions of grout holes must be drilled through rock above the horizons requiring treatment. Since grouting the upper rock is unnecessary, stop grouting is well adapted to this situation. If sufficient rock overlies the grouting horizon, it may be possible to grout the entire hole with one stop and with only low or gravity pressure at the collar of the hole. If the surface rock in the grouting area is thinly bedded and has a nearly horizontal attitude, stop grouting is the best method to avoid lifting. A stage of grouting is always required if the drill water is lost before the hole reaches final depth. Stage grouting should be used to prevent natural muds formed by drill cuttings from shales or similar rocks from filling or obstructing groutable openings at higher horizons. If it is desirable or necessary to consolidate the upper rock before proceeding with grouting at depth, stage or series grouting is indicated. If it is desired to grout the foundation of an existing structure at pressures comparable to the load imposed by the structure, series or stage grouting should be used, especially if the upper part of the foundation is known to contain groutable voids. In this case great care must be exercised to avoid lifting and tilting the structure. The danger of lifting is less if the rock is massive or medium bedded, if the joints are at high angles, or if the strata are steeply dipping.

SECTION 5. GROUTING EQUIPMENT

13. **INTRODUCTION.** Guidance for selecting or approving the specialized equipment necessary for a grouting project is provided below, and operational principles for the equipment are outlined and related to job requirements.

14. **DRILLING EQUIPMENT.**

a. **Percussion Drilling.** Percussion drills are operated by air-driven hammers. The best known types are the jackhammer, drifter, and wagon drill. The drill proper consists of a hollow steel rod, fitted with a fixed or detachable bit on one end and a shank on the other.

(i) **Operation.** Percussion drills are used for drilling in rock. The percussion drill does not reciprocate. Its shank fits into and is held loosely in the chuck at the forward end of the machine, where it is struck by a hammer-like piston actuated by compressed air. The compressor capacity necessary to operate a single-hammer drill ranges from 50 to 200 cfm, depending upon the size of the drill cylinder and the pressure at which air is supplied. During drilling the bit remains in close contact with the rock at the bottom of the hole at all times except during the slight rebound caused by impact of the hammer. Drills are provided with a mechanism that causes the drill steel rod to rotate between blows of the hammer. Cuttings or sludge are removed from the hole by air or water that passes through the machine, down the hollow drill steel rod to the bottom of the hole, and then rises up the hole to the surface. Removal of cuttings by water is preferred for grout-hole drilling but is not mandatory. Jackhammer drills, due to their light weight, are usually held in position by hand. Drifter-type drills are designed for tripod or bar mounts. The wagon drill, as commercially available, is comprised of a drill head mounted in leads that are supported on a track-, wheel-, or skid-mounted chassis.

(2) **Application.** Percussion drilling produces acceptable grout holes and, generally, is the most economical method of drilling shallow holes. This advantage decreases with depth and disappears at depths from 75 to 125 ft depending on the type of rock. In operation, the edges or wings of the bit wear away so that a progressively smaller hole is drilled. Therefore, when pertinent, the specifications should state the minimum acceptable size of grout hole.

b. **Rotary Drilling.** Rotary drilling is the process of making a hole by advancing a drilling bit attached to a rotating column of hollow drill pipe. The drill pipe is turned by a motor at speeds ranging from a few hundred to 3,000 or more rpm. Pressure on the bit is applied hydraulically or mechanically. Water is forced through the drill pipe to wash cuttings out of the hole. Drill rigs vary in size from small lightweight machines capable of drilling

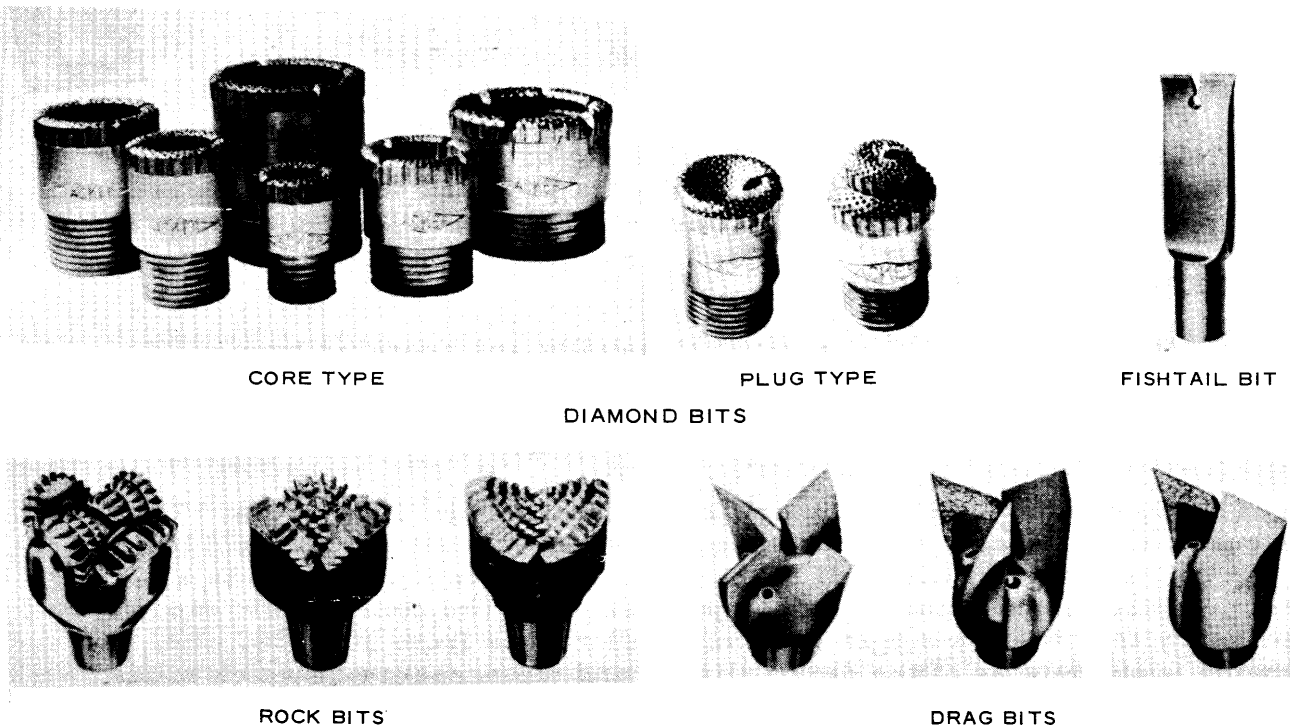


Figure 8. Drill bits

holes only a few hundred feet deep to large rigs that can drill holes miles in depth. The small rigs are usually satisfactory for grout-hole drilling and are desirable from the standpoint of portability. Drill bits adaptable to a great variety of subsurface conditions are available. Some of the common types are shown in figure 8 and are discussed below.

(1) Diamond bits. Diamond bits may be either core or plug type. Both types employ a diamond-studded bit to cut the rock. The bit is coiled and the hole continuously cleaned by water or compressed air pumped through the drill rods.

(a) Core type. The core-type bit consists of a hollow steel cylinder, the end of which is studded with diamonds. The bit is fitted to the lower end of a hollow steel chamber (core barrel) that is rotated rapidly while the bit is held firmly against the rock so that the diamonds cut an annular channel in the rock. The rock that lies within the channel and projects into the barrel constitutes the core.

(b) Plug type. Two varieties of plug bits are available commercially. One is a concave type, the head of which is depressed toward the center; and the other, a pilot type, has a protruding element, cylindrical in shape, but of a smaller diameter than the main bit head. Noncoring diamond bits have a wide

field of usefulness in foundation grouting. However, they are more costly than coring bits for drilling in extremely hard foundations and in badly fractured rock because of greater diamond cost. Since they produce only cuttings, more diamonds are required to make a given footage of hole than if a large part of the rock encountered is removed as core. The loss of one or two diamonds from the center of a noncoring bit (a not infrequent occurrence in drilling shattered rock) renders the bit useless for further cutting. The plug bit is less expensive than the core bit in deep holes due to the time saved by not having to pull out of the hole to empty the core barrel or to clean a blocked bit.

(c) Size. The sizes of diamond bits are standard and are generally shown by the code letters EX, AX, BX, and NX. The dimensions of each size are tabulated below. Most diamond-drilled grout holes are EX or AX in size. There is insufficient advantage in larger bits to justify their use. The possible advantage that the larger diameter bit may have in encountering more fractures than the smaller is more than offset by the fact that the greater economy of the small bit permits a closer spacing of holes for the same overall cost.

<u>Code</u>	<u>Size. in.</u>	
	<u>Hole</u>	<u>Core</u>
EX	1-7/16	7/8
AX	1-27/32	1-7/32
BX	2-5/16	1-5/8
NX	2-15/16	2-1/8

(2) Hard metal bits. Drill bits of hardened steel notched to resemble the teeth of a saw can be placed on the core barrel to substitute for a more costly diamond bit. In some soft rocks this type of bit will make a hole much faster, is not as easily blocked, and is much cheaper than a diamond bit. Often the teeth of such bits are faced with one of the alloys of tungsten carbide, or replaceable inserts of a hard alloy are welded into holes cut-into the bit blank. A noncoring bit can also be made with the hard alloys by studding the cap for a piece of drill pipe with bits of the steel rod containing the powdered alloy and adding waterways.

(3) Rock bits. Rock bits, like diamond bits, are attached to the bottom of a column of hollow drill pipe. The bit is made of toothed rollers or cones, each of which turns or rolls on the rock as the bit rotates with the drill pipe. Cutting is accomplished by crushing and chipping. The shape of the teeth, their attitude and number, and the number of rollers vary. Most bits have three or four cones or rollers; some have two. The teeth and other parts of the bits subjected to intense abrasion are made of hard alloys. Cuttings and sludge are washed out of the hole by circulating water or drilling mud through the drill pipe and back to the surface between the drill pipe and the walls of the hole. The roller rock bit is not extensively used for grout-hole drilling because the smallest available size is approximately the same as that of an NX diamond bit.

(4) Drag and fishtail bits. The drag bit is a general service bit for rotary drilling. Capable of drilling soft rock and most soils, it is used extensively in foundation explorations and grout-hole drilling. The fishtail bit is so named because of its resemblance to a fish tail. The divided ends of its single blade are curved away from its direction of rotation. , Other drag bits have three or four blades, which may or may not be replaceable. The cutters or cutting edges of the blades are made of hardened steel or are covered with hard alloys. Almost any desired size is available.

c. Summary. Drill bit types and the materials in which they are generally—used are as follows:

<u>Drill Bit Type</u>	<u>Principal Use</u>	<u>Not Well Suited for</u>
Diamond:		
Core	Rock and concrete	Unconsolidated soils
'Plug	Rock	Extremely hard rock, extremely soft rock, unconsolidated soils, and shattered or fractured rock
Hard metal	Soft rock, hard clay, and cemented soils	Hard rock and uncon- solidated soils
Rock	Rock	Unconsolidated soils and very hard rock
Drag and fishtail	Soft rock and soil	Hard rock
Percussion	Rock and concrete	Unconsolidated soils

15. GROUT PLANT.

a. Grout Mixers. Many types of grout mixers have been used, including hand-turned dough mixers, concrete mixers of various sizes, and especially designed grout mixers. Any machine is suitable that has the desired capacity and that mixes the grout mechanically to a uniform consistency. Two mixers can be arranged to discharge into the same sump to satisfy high capacity requirements. Manual stirring of cement and clay grouts in a tub is not satisfactory except in emergencies. Hand-powered dough mixers are not recommended because of their limited capacity.

(1) Central Valley-type grout mixer, 8-cu-ft capacity. During the grouting at several dams of the Central Valley Project, a small, air-operated, lightweight grout mixer was needed that could be set up and operated in a 5- by 7-ft gallery. The mixer shown in figure 9 was designed for

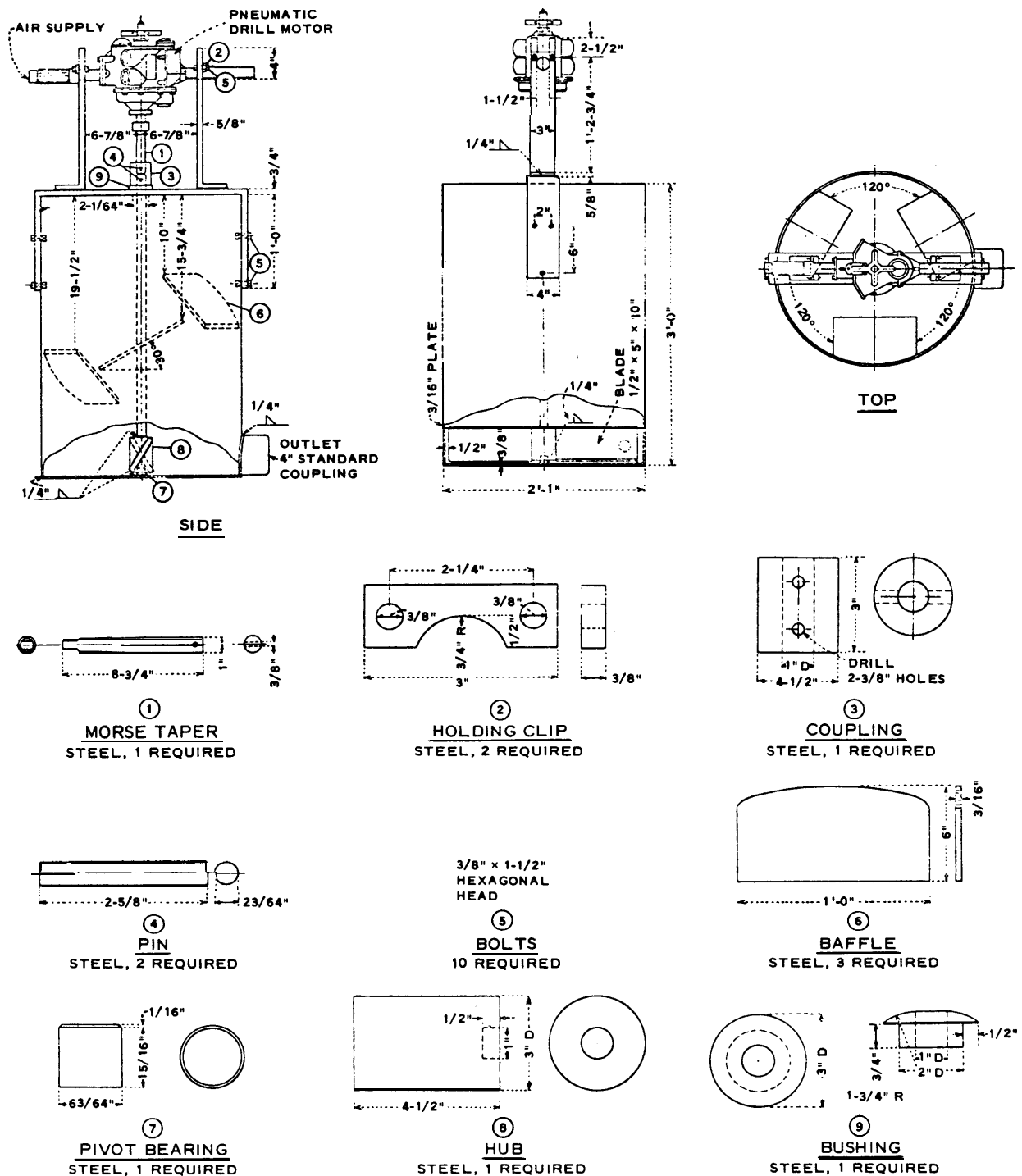


Figure 9. Central Valley-type grout mixer, 8-cu-ft capacity

this purpose. It was fabricated in a local shop economically.

(2) Grand Coulee-type grout mixer, 21-cu-ft capacity. In the grouting at Hoover Dam, considerable experimenting was done with various equipment for mixing grout. Concrete mixers were first used but were later discarded for the type mixer shown in figure 10. The body of this mixer is 30 in. (ID) by 48-1/2 in. long. There are 16 paddles in series of 4 mounted on a 2-in. -diameter shaft. The paddle shaft is supported on the back end by an extended babbbitted bearing with cap, and on the other end by a split-cap, rigid, babbbitted pillow block. The body is made of a 3/16 -in. plate with front head 1/4 in. thick and a removable back head 3/8 in. thick. The removable back head not only facilitates the removal of the paddles but also permits thorough cleaning and chipping out of hardened cement, if necessary. The shaft has supplemental bearing supports in the heads that consist of bronze - bushed, welded-in steel hubs. The charging chute is 18 in. in diameter at the top, 14 in. in diameter at its junction with the body, and 14 in. high. There is a small bag support on a 24- by 36-in. platform. Power is supplied by a 2.65-hp air motor that makes 65 rpm when supplied with air at 100 psi. Its consumption is approximately 85 cfm. A bolted coupling connects the motor to the mixer. The body is supported on two welded reinforced saddles attached to 4-in. I-beam skids which are not shown in the figure.

(3) Grand Coulee-type grout mixer, 27-cu-ft capacity. For the contraction joint grouting at Grand Coulee Dam, two 27-cu-ft mixers, as shown in figure 11, were purchased. They are similar to the 21-cu-ft model. These mixers are easy to run and to clean and are very flexible. They handle batches of grout made from 1 to 10 sacks of cement and do a thorough job of mixing. These mixers were powered by air motors.

(4) High-speed colloidal-type mixers. High-speed colloidal-type grout mixers are commercially available in both the single - and double -drum types. These mixers are equipped with small centrifugal pumps, which cause the grout to circulate at high speed while being mixed. Particles of cement may be broken and rounded to a significant degree in high-speed mixers. This results in an increase in pumpability and penetrability for portland-cement grout. In an emergency, grout can be pumped at low pressures into the foundation or other places with the centrifugal pumps of these mixers.

(5) Water meters. A satisfactory water meter is the single-disk type, size 1-1/2 in., and threaded for pipe connection. This type has a 6 -in. vertical register with a long hand that makes one revolution per cubic foot of water and a short hand that indicates 10 cu ft per revolution. For use in grouting, the meter should have a reset knob to set the hands to zero and a direct-reading totalizer. A screen should be provided if sand or rock particles are present in the water supply.

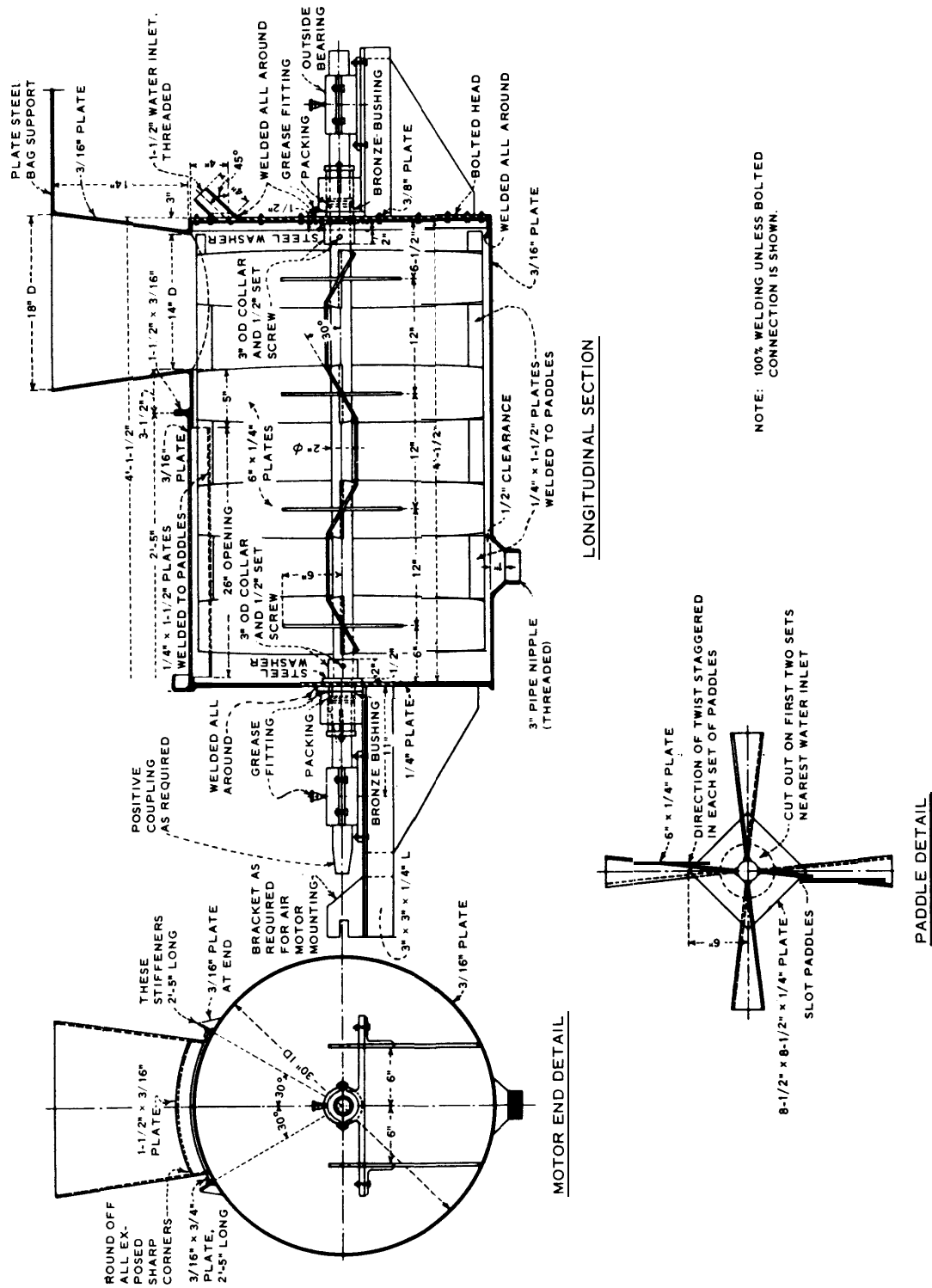


Figure 10. Grand Coulee-type grout mixer, 8-cu-ft capacity

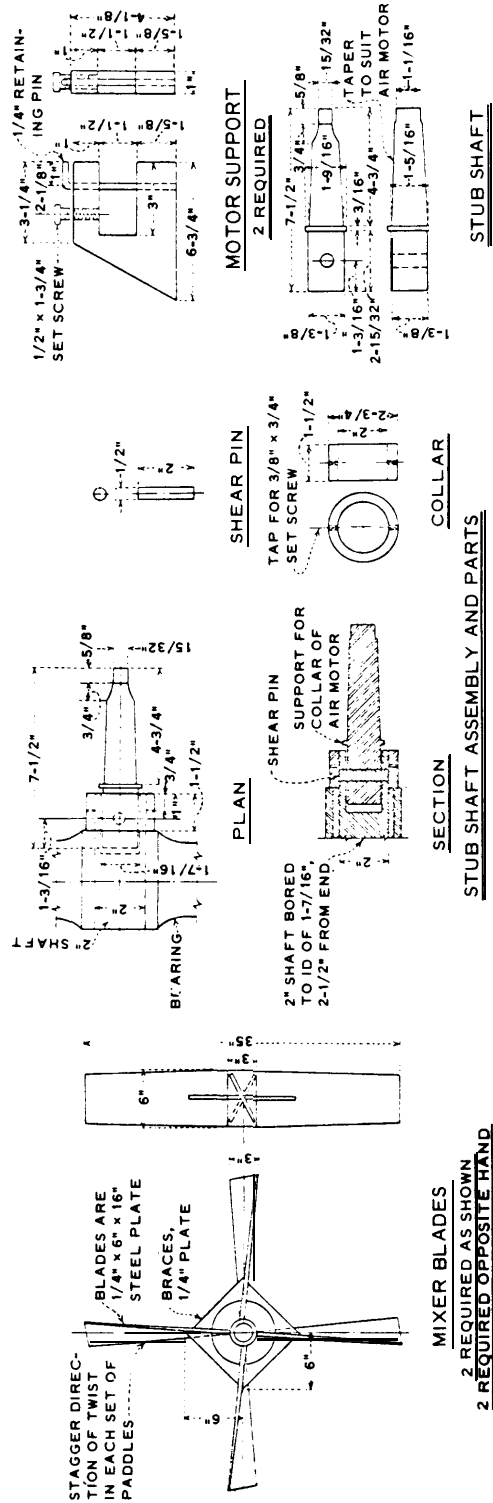
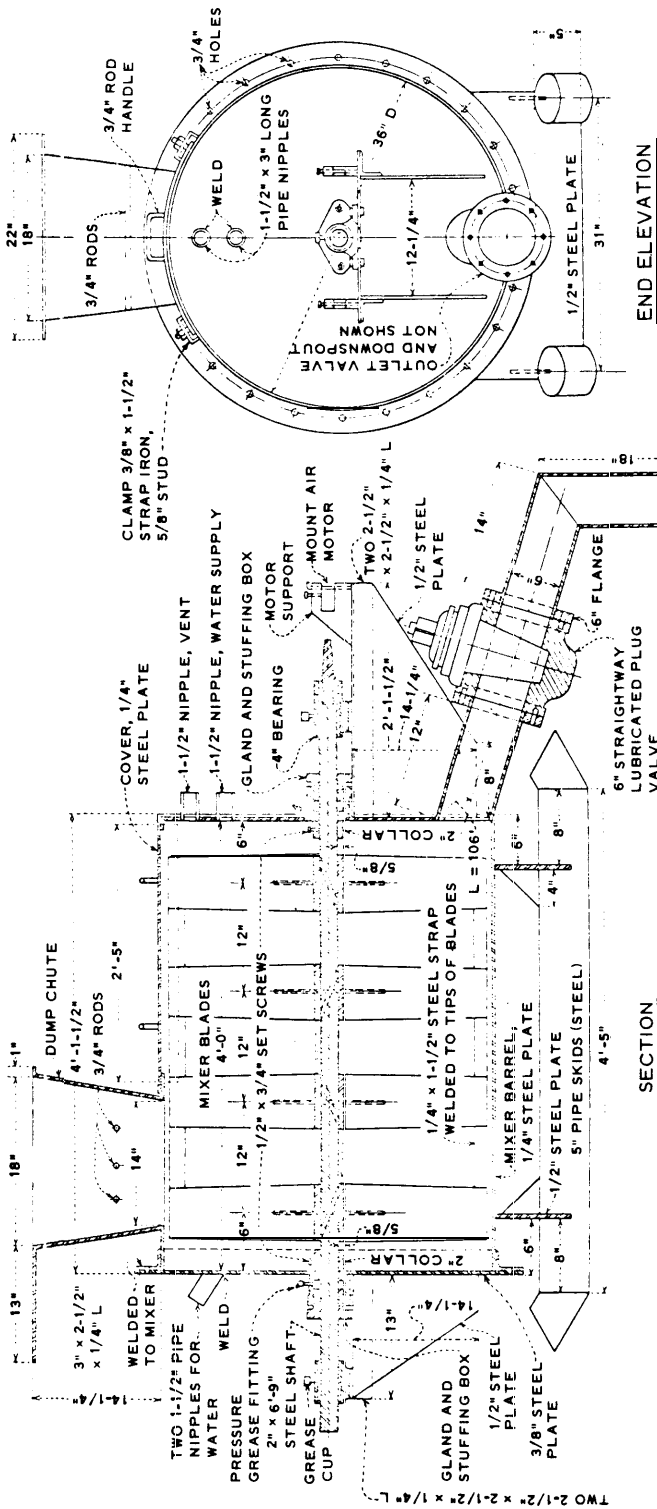


Figure 11. Grand Coulee-type grout mixer, 27-cu-ft capacity

(Courtesy of U. S. Bureau of Reclamation)

b. Agitators.

(1) **Agitator sumps.** After mixing, grout should be agitated to prevent settlement while it is being pumped. This can be done by pumping the grout into a sump equipped with a stirring blade. Figure 12 shows a type of agitator that has proved satisfactory. The agitator should have the same capacity as the mixer so that one batch of grout can be pumped while the next batch is being mixed. When emptying the grout from the mixer into the agitator, the grout should pass through a 1/8-in.-mesh screen to remove pieces of sacks, strings, wire, ties, or other foreign matter that may be dropped into the mixer.

16. PUMPS.

a. Types of Pumps. Pumps for cement grouting should be sufficiently flexible to permit close control of pressure and to provide for a variable rate of injection without clogging of valves and feed lines. With constant-speed pumps, special arrangements of the supply piping systems and valves are needed to provide close control of the grouting operation. Constant-speed pumps are powered by electric motors or internal-combustion engines. Variable speed pumps are hand operated, steam driven, or air driven.

(1) **Hand pumps.** Hand-operated pumps are used infrequently; they are satisfactory only when the amount of grout to be injected at any one time is very small. Their weak points are the check valves, which usually become plugged and stick after a short period of operation, and the packing, which frequently leaks grout as the pumping pressure is built up.

(2) **Air-driven pumps.** A number of air-driven pumps are commercially available. The reciprocating slush pump shown in figure 13 is available in sizes from 20 to 100 gpm at pressures from 200 to 500 psi when supplied with air at pressures of 100 psi. This type of pump is suitable for most cement and clay grouting.

(3) **Power-driven pumps.** Power-driven pumps have the same grout ends as the air-driven pumps, but require an external power source. This source is connected to the pump by gear, chain and sprocket, or V-belt drives. A wide variety of power sources are available.

b. Reciprocating Slush Pumps.

(1) **Line-type pumps.** The advantage of the line-type slush pump (fig. 13) is the accessibility of the valves. The discharge valves are located directly above the suction valves so that both can be removed through the same opening in the top of the pump "for cleaning or repair. The disadvantage of this type of pump is that it requires two types of suction and discharge valves and valve seats.

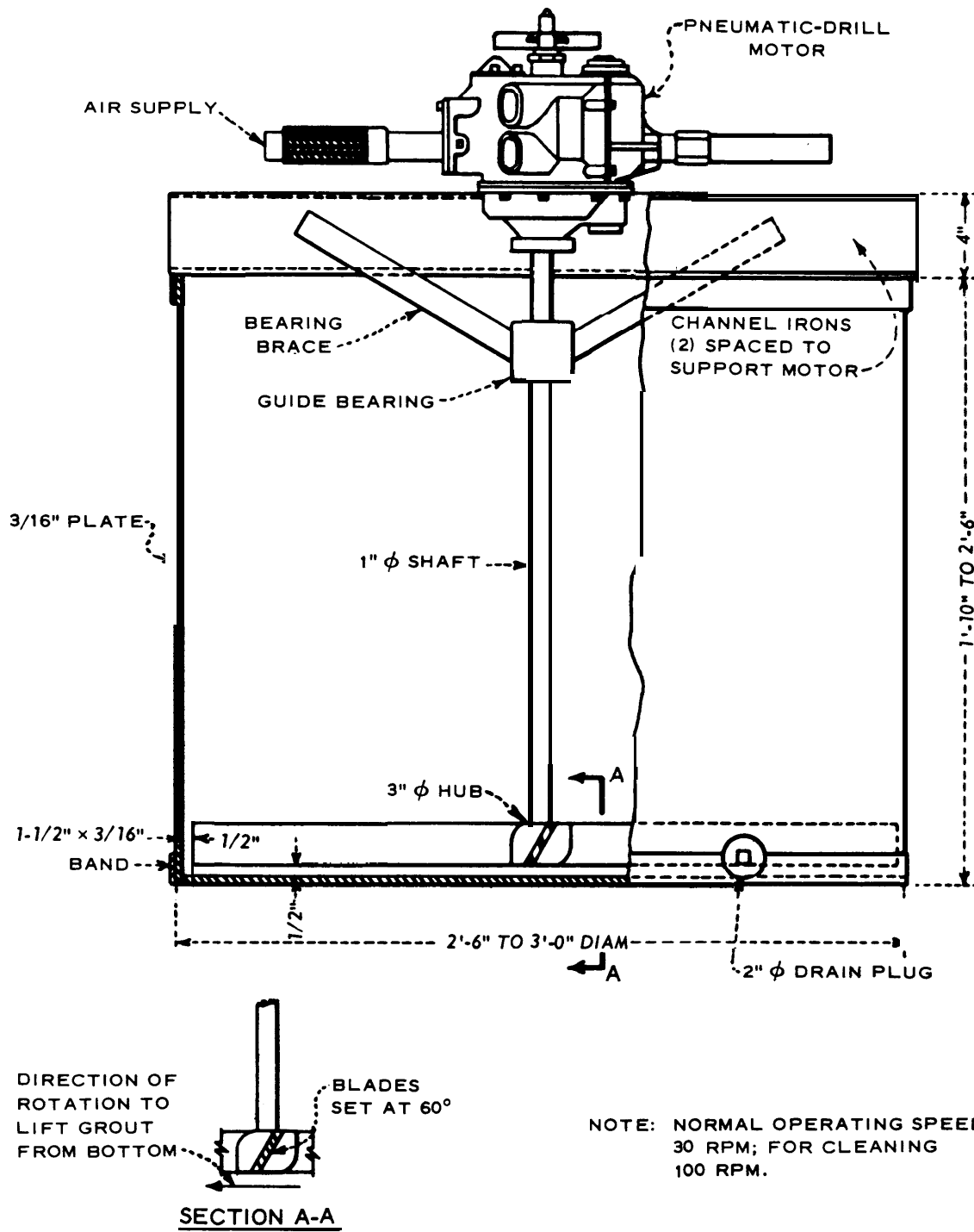
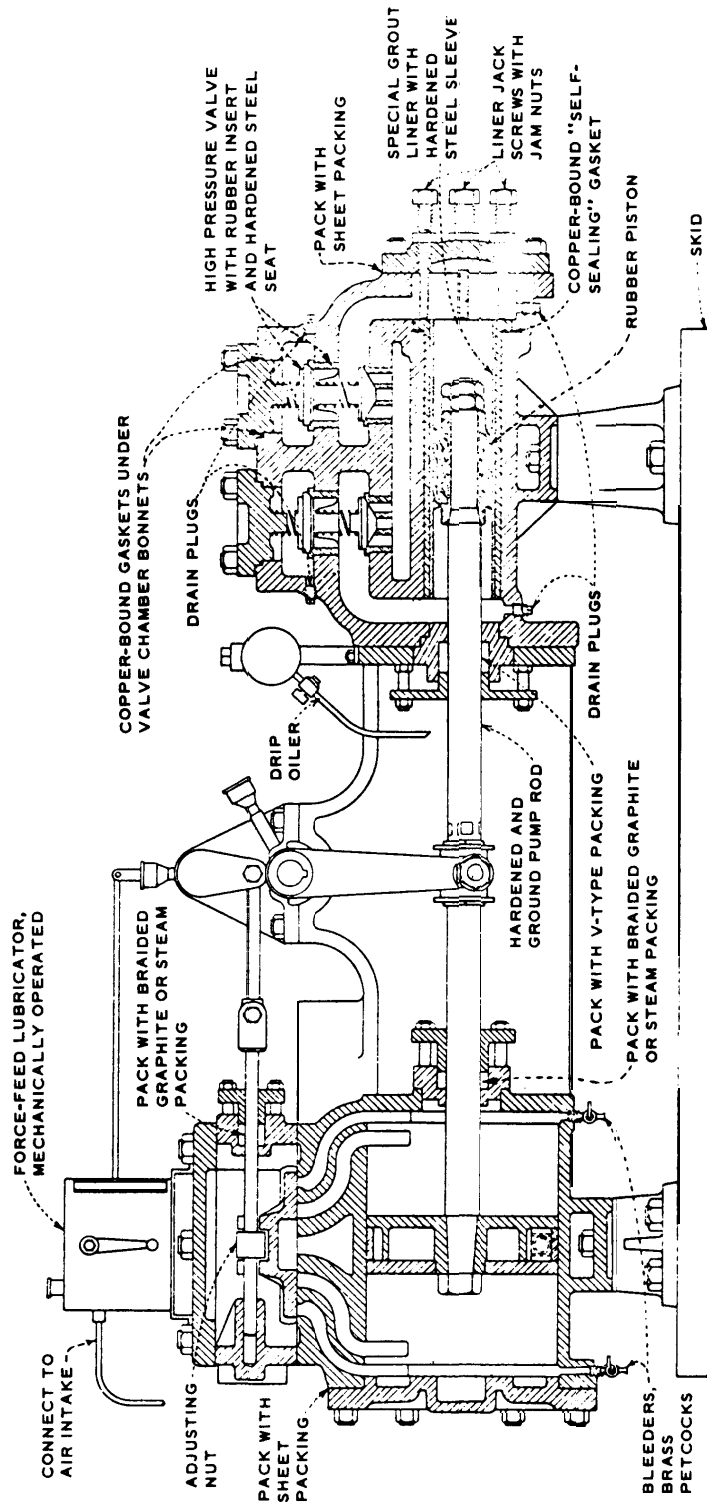


Figure 12. Grout agitator



NOTE: SECTION THROUGH NEAR CYLINDERS.

PUMPS OF THIS TYPE CAN BE OBTAINED IN SIZES VARYING FROM 5-1/4 x 3-1/2 x 5 IN. TO 10 x 7-1/4 x 10 IN. SIZES COMMONLY USED ARE 6 x 4 x 6 IN., 7 x 3 x 10 IN., 10 x 3 x 10 IN., AND 10 x 4-1/2 x 10 IN.

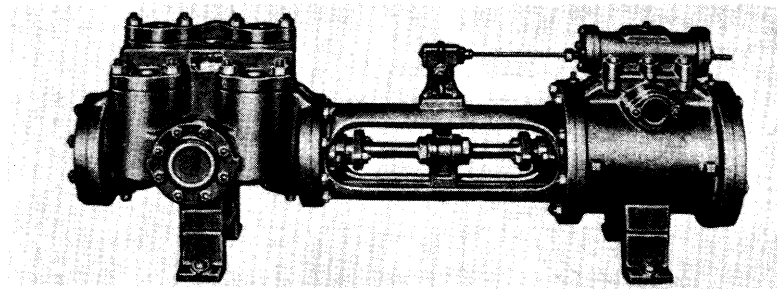
5-1/4 IN. IS DIAMETER OF AIR PISTON, 3-1/2 IN. IS DIAMETER OF LIQUID PISTON, AND 5 IN. IS THE STROKE.

(Courtesy of U. S. Bureau of Reclamation)

Figure 13. Reciprocating slush pump

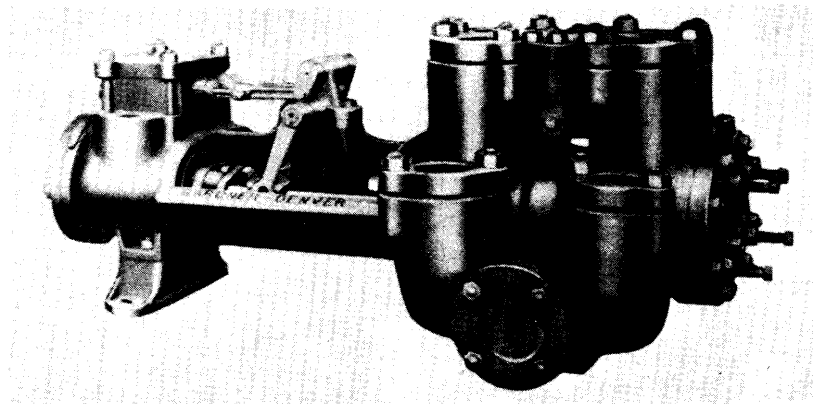
(2) Side-pot-type pumps. In the side-pot-type slush pump, each valve is in a separate pot or chamber with its own cover (fig. 14a). The advantage of this type of pump is that all valves and seats are interchangeable, and since each valve has a separate cover plate, the suction valves may be removed and cleaned without disturbing the exhaust valves, as is necessary in the line -type pump. Disadvantages are that grout usually collects in the bottoms of the valve pots and that the suction and exhaust ports are inconveniently arranged for cleaning.

(3) Divided fluid-cylinder valve -pot-type pumps. Although the action of this type of pump (fig. 14b) is not as smooth as that of a line -type pump, its interior parts are more readily accessible for cleaning. It is somewhat heavier than a line -type pump built for the same working pressure, the valves and seats are interchangeable, and the best pumps of this type have removable cover plates at convenient places for cleaning grout from the interior passageway.



a. SIDE-POT-TYPE PUMP

(Courtesy of Wagener Pump Division, Canton Stoker Corp., Canton, Ohio, Bulletin No. WS-150A)



b. DIVIDED FLUID-CYLINDER VALVE-POT-TYPE PUMP

(Courtesy of Gardner-Denver Co., Quincy, Ill., Composite Catalog 62-63)

Figure 14. Slush pumps

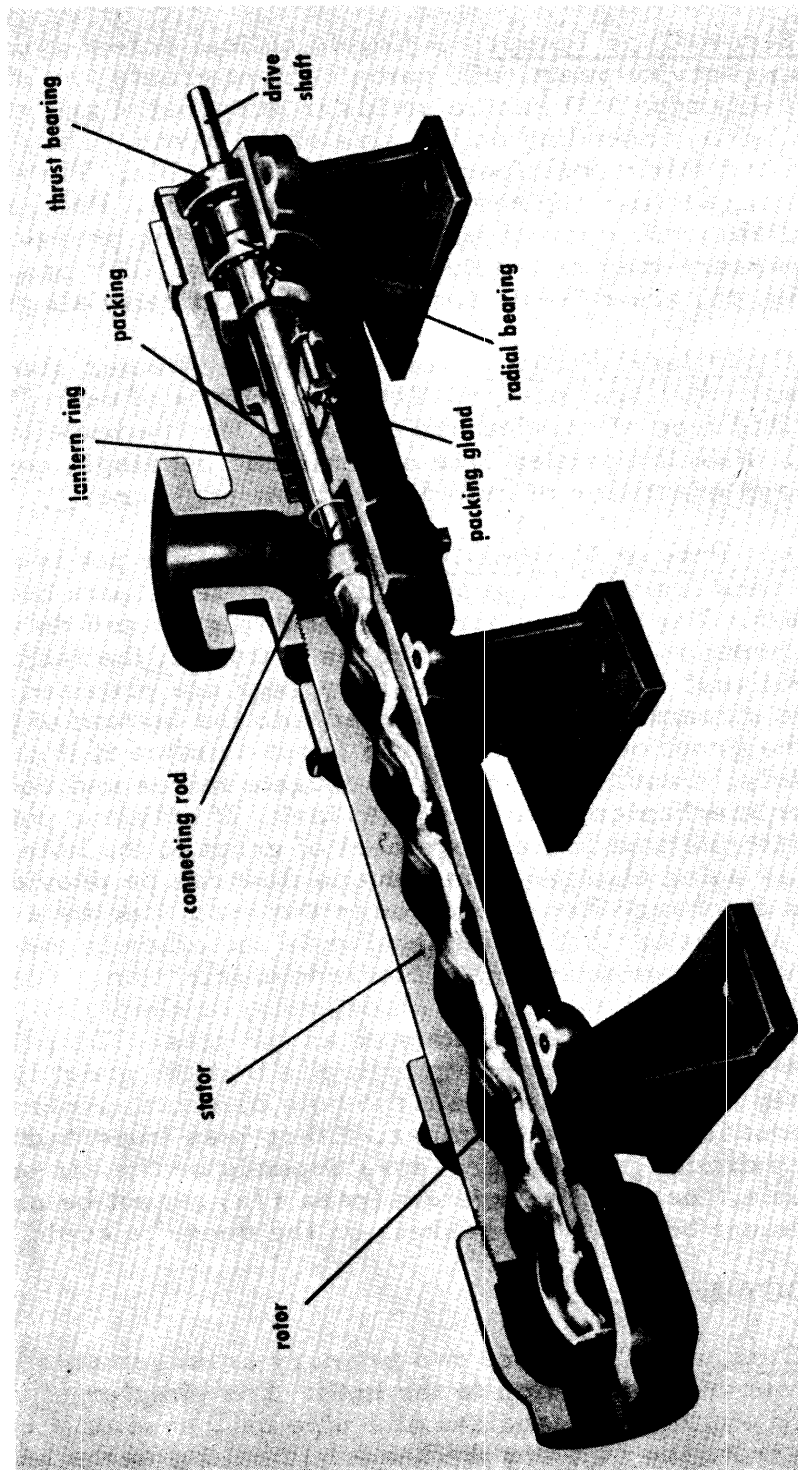
c. Screw-Type Pumps. A double helical screw-type pump, also called progressing-cavity pump, will pump cement grouts and other slurries. Pumps of this type will handle solids in suspension and will pass particles up to 7/8 -in. size, depending on the size of the pump. They have few working parts and are fairly free from mechanical trouble. They can be driven by air motors, gasoline engines, or electric motors. Pumps of this type presently available will operate up to 600 -psi working pressure. Pumps for higher pressure may be available in the future. The progressing-cavity type pumps (fig. 15) are suitable for pumping practically all grouts.

d. Centrifugal Pumps. Cement grout and other slurries have been pumped by centrifugal pumps. The weak points of centrifugal pumps when used for this type of service are the seals for the impeller shafts and their bearings. With the proper type of seals and bearings, centrifugal pumps can handle large quantities of materials at low pressure.

e. Air Pots or Pneumatic Grouters. An air pot is a cylindrical steel pressure tank from which grout or other material can be forced by compressed air. The tank is charged through a gasketed door at the top and discharged through the grout outlet at the bottom of the tank. Taps for air -inlet and air -exhaust valves and a pressure gage are provided. A small valve-controlled stream of air is introduced into the bottom of the tank, usually through the grout outlet, to keep the grout agitated if it cannot be discharged immediately. Grout is mixed in a separate mixer and conveyed through pipe or hose or mechanically to the grout tank. If only one pot is used, grouting must be intermittent since movement of grout to the hole stops while the chamber is being charged. Continuous flow can be provided by two pots, each having its discharge line connected to the grout line by a wye valve and being operated so that one pot is charged while the other is discharged. Pots with twin chambers also provide for continuous injection. The equipment is simple and can be shop made in an emergent y, or Gunitite or pneumatic-concreting equipment can be adopted as air pots. The principal disadvantage of air-pot-type equipment for grouting is that the grout in the tank is not visible and air may be injected into the hole before the, operator is aware that all the grout is out of the chamber. Other less important disadvantages are: (1) the maximum grouting pressure depends on the air pressure available, (2) a double -line grouting system (para 17a) cannot be used, and (3) constant attention must be given the gaskets on the doors to avoid air leaks.

17. GROUT LINES.

a. General. There are two primary arrangements of piping used to supply grout from the pump to the hole. The simpler of the two is the single-line system. It consists of a pipe or a hose or a combination of both, extending from the pump to the header (d below) at the hole. The pump speed controls the rate of injection. The second arrangement is the double -line or circulating system. This system has a return line from the header to the



(Courtesy of Robins and Myer, Pump Division,
Springfield, Ohio, Bulletin No. 30-C)

Figure 15. Cutaway section of progressing-cavity pump

grout sump in addition to the pump line of the single -line system. Thus, if the header connection to the hole is closed, grout can be continuously circulated from the grout sump to the pump, through the pump line, through the header, and back to the sump through the return line. While grouting, the amount of grout entering the hole through the header can be varied by opening or closing a valve on the return line without changing pump speed. The double-line system is generally preferred because it permits better control of grouting pressures and allows less material to settle out of the mix to plug the lines.

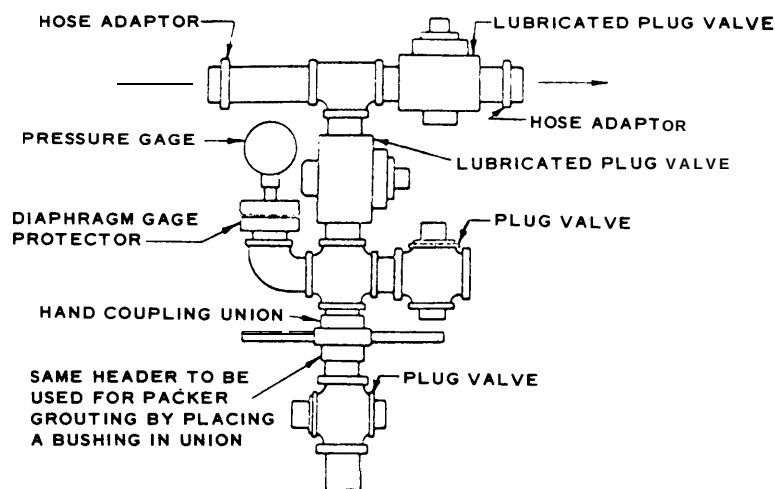
b. Hose. Flexible hose is most commonly used for suction and discharge lines. If the length of the discharge line is such that pipe is necessary, a short length of hose should be provided at the pump discharge and at the connection to the grout header. The hose should be not less than 1-1/2-in. diameter (inside) and capable of withstanding the maximum grouting pressure with an ample margin of safety. The suction line from the grout sump and water tank may be either pipe or hose of suitable diameter and should be as short as feasible. It should be provided with fittings at both ends. Hose is preferable to pipe because its flexibility permits ready interchange of the suction end between the sump and water tanks. Pipe; on the other hand, requires the installation of valves that will permit the pump to draw either grout or water as the occasion demands. It has been found that difficulty often arises because of clogging of the water valve on the grout line side.

c. Piping. Black steel pipe and fittings 1-1/2 in. in diameter are normally suitable for pressure lines; but where large quantities of grout are to be injected and the supply line is long, it may be desirable to provide a larger size pipe and connection hoses. Pipe must be capable of withstanding at least the maximum pressure to be applied in the grouting operation.

d. Grout Header. The grout header is usually assembled as a unit in order—that it may be moved from one grout hole to another. The assembly consists of the operating valves, a pressure gage, pipe, and the necessary fittings to attach the header to the hole and to attach the grout supply and return lines. The gage and the valves are described in more detail in e and f below. A header assembly is shown in figure 16. It should be noted that the pressure gage is so connected that by closing one valve it can be used for pressure-drop observations without interrupting the circulation of grout in the pump system.

e. Pressure Gages.

(1) Reliable pressure gages are essential in pressure grouting. They constitute the principal index to the behavior of the hole and the stresses that are being produced in treated material. If the hole is more than 100 ft horizontally or 20 ft vertically from the pump, there should be two gages in the



NOTE: ALL PIPE AND FITTINGS ARE 1-1/2" SIZE. PLUG VALVES TO BE USED THROUGHOUT FOR PRESSURES ABOVE 250 PSI. GROUT HOSE TO BE 1-1/2" WITH SCREW-TYPE COUPLINGS.

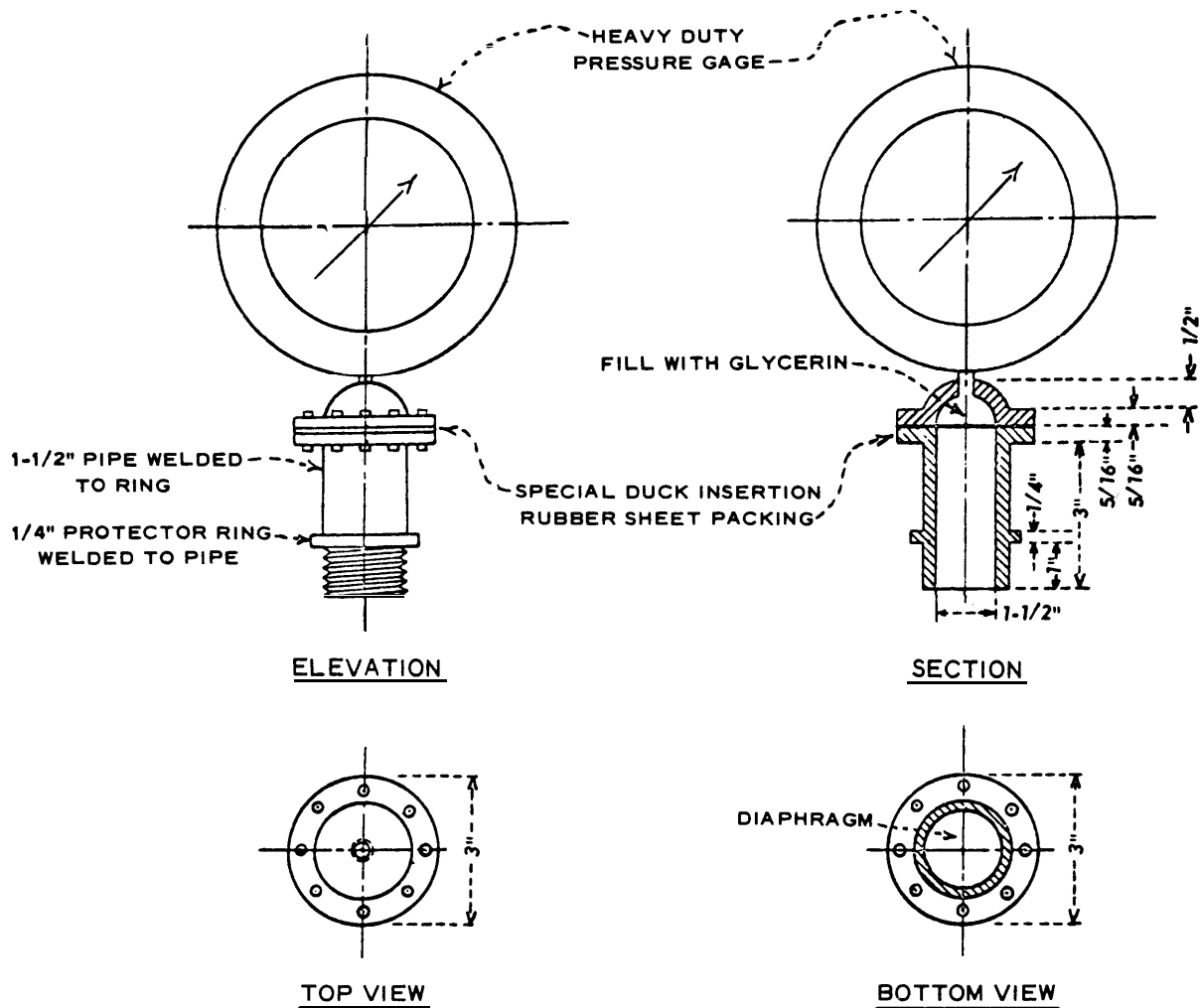
(Courtesy of American Society of Civil Engineers)

Figure 16. Direct grouting header (see ref 16)

grout line, one at the pump and the other at the hole for control. When there is the possibility of doing serious damage by the application of too much pressure, all gages should be installed in duplicate. Structures have been damaged by the unintentional application of excessive pressure occasioned by gage failure or sticking. Gages, the glass faces of which have been broken, should be condemned. Dust and grit tend to reduce the accuracy of the gage. This causes the gage to register falsely and results in pressures higher than those indicated being applied, with attendant higher grout injection. The gage used should have a pressure range comparable to that required. Thus, a 200-psi-capacity gage is not appropriate for grouting where a maximum pressure of 50 psi is contemplated.

(2) The moving parts of the gage must, for obvious reasons, be protected from direct contact with the grout. The simplest protective device for pressures greater than 200 psi is a short oil- or grease-filled siphon (pigtail) located between the gage and the grout. This consists of a 1/4-in. pipe with a 3-in. loop in its center. The pipe is filled with a light grade of water-proof grease. An alemite fitting, located between the gage and the pigtail, enables the operator to force open the passage should it become obstructed. However, grease makes the gage sluggish and its readings are not always consistent due to the effect of temperature changes on the fluidity of the grease. The most satisfactory device consists of a piece of 1-1/2- or 2-in. -diameter pipe 18 in. long that is stubbed off vertically above the grout line. The gage is fitted to the top of this stub by means of suitable bushings. All

joints should be made tight with litharge and glycerin or lead since the device is, in effect, an air dome and any small air leak will render it ineffective. The gage is very sensitive with this arrangement and the violent oscillations of the needle make exact readings difficult; but this objectionable feature can be largely obviated and the gage given additional protection by installing a gage saver, as shown in figure 17, between it and the air dome.



(Courtesy of U. S. Bureau of Reclamation)

Figure 17. Glycerin-filled gage saver

f. Valves for Grout Line. Plug valves should be used to control the flow of grout. Pressure relief valves are sometimes installed in the grout line as an added precaution in controlling grout pressures, but should not be

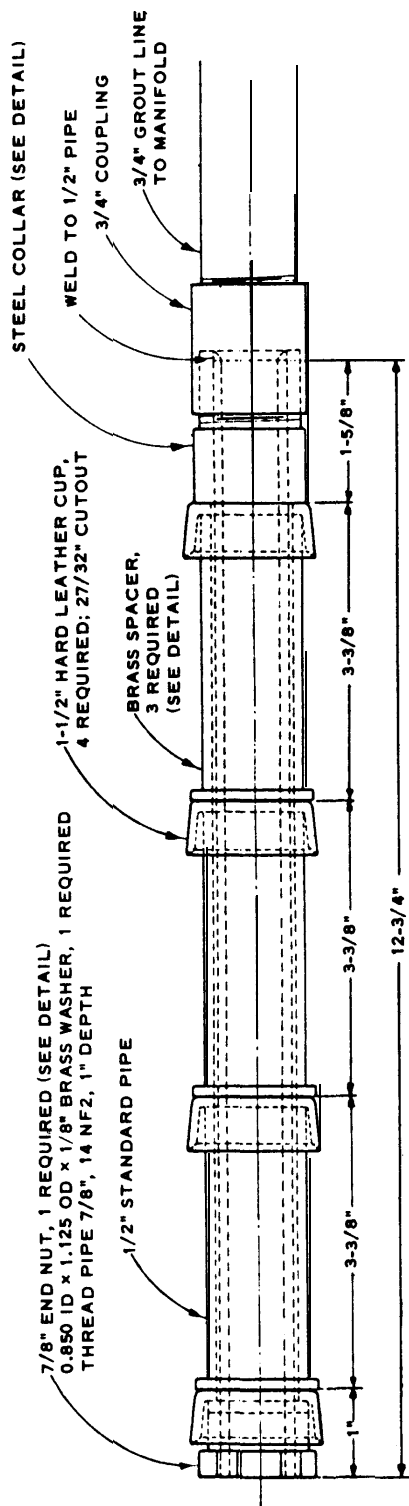
relied upon. Vigilance and hand-operated, quick-acting valves afford the only reliable means of controlling pressures. There are two types of quick-acting valves that are satisfactory for the grout lines. These are the so-called lubricated and nonlubricated plug valves. Lubricated valves should be installed throughout the entire system except for the first valve above the grout hole, where a nonlubricated valve should be used. They should be of a diameter to fit the pipe size, have threads inside, and should be capable of withstanding nonshock, cold water pressure equal to at least the maximum pressure to be applied. Both body and plug should be made of iron or semi-steel. The plug of the valve should be ground into its body to ensure perfect contact over the entire surface of the plug and to give smooth operation and perfect seating. The valves should be square headed, similar and equal to Walworth Company's standard iron cock No. 651.

18. PACKERS.

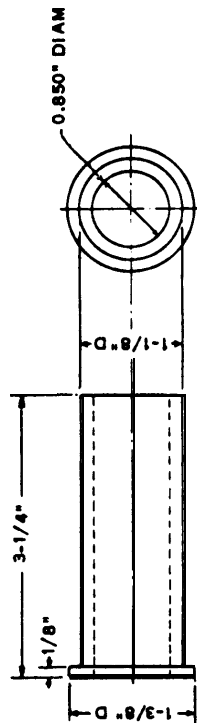
a. Introduction. There are three general types of grout packers in common use, the cup leather, the mechanically expanded rubber ring, and the pneumatically expanded rubber sleeve. Various methods of mechanically expanding the rubber ring or rings have been used, and each has its place for a particular condition. No effort will be made to illustrate all of the packers that have been used as all types are frequently modified and improved to fit local conditions. Each general type does, however, have characteristics making it most suitable. Initially, AX (2-in.) or BX (2-3/8 -in.) holes were thought to be the smallest size adaptable to the use of packers, but now they have been developed for all sizes from EX (1-4/2-in.) to NX (3-in.). Some difficulties arise when smaller holes are used. The packers to be described here are all for EX size holes.

b. Cup Leather Removable Grout Packer. The cup leather type shown in figure 18 is best suited to fairly hard rock where the drilled hole is not oversize and the walls are relatively smooth and true. This packer when suitably anchored has been used successfully for grouting pressures up to 750 psi. It is simple to construct, easy to maintain, and only requires a single pipe to lower it in the hole. Where high grout pressures are feasible, it is probably the best type of packer to use. If it should accidentally become stuck in the hole, a right-left coupling enables the crew to save the supply pipe string and the packer itself can be drilled out, if necessary.

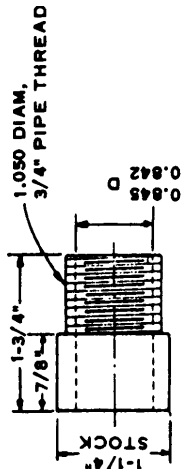
c. Mechanical Packer. The mechanically expanded type shown in figure 19 is adaptable to softer rock than the cup leather type, but it may be difficult to seat if the drill hole is too much over size. Its positive expanding action gives it an advantage in that it can be positively seated at any location if the hole is not too enlarged. When used at depths greater than 20 ft, flush-joint tubing is required and it is somewhat awkward to handle in a deep hole. Once seated the packer too can withstand fairly high pressure and has been used on many jobs.



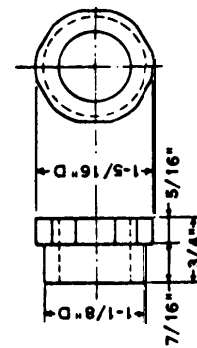
PACKER ASSEMBLY



DETAIL OF PACKER SPACER



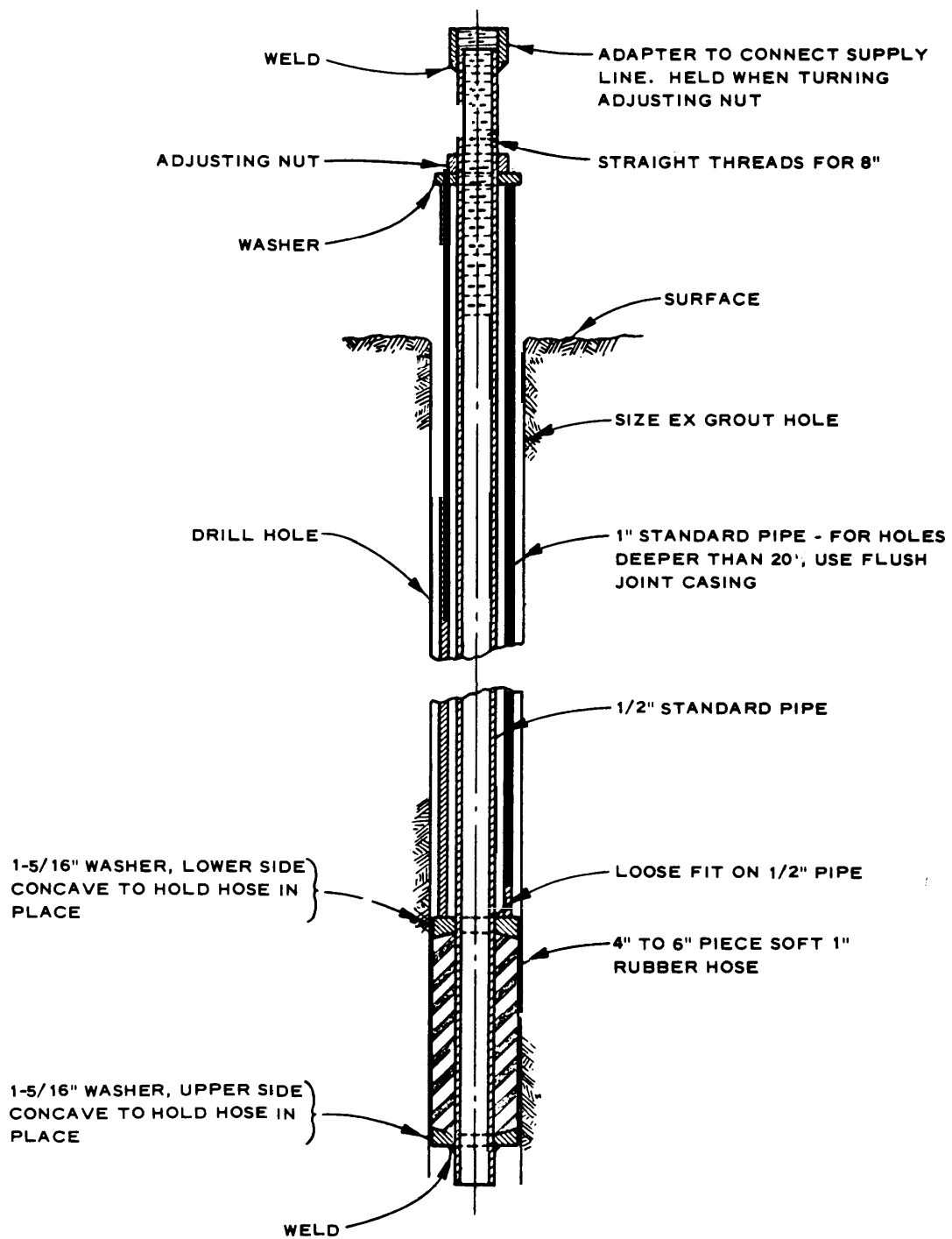
DETAIL OF COLLAR



DETAIL OF END NUT
MAKE FROM STANDARD 7/8" HEXAGONAL NUT

(Courtesy of U. S. Bureau of Reclamation)

Figure 18. Removable grout packer



(Courtesy of U. S. Bureau of Reclamation)

Figure 19. Mechanical packer

d. Pneumatic Packer. The pneumatic packer shown in figure 20 has proved suitable in soft and thin-bedded rocks where the drill holes are often somewhat over size. In fact the EX (1-1/2-in.) size can be seated in a 4-in. pipe when the proper rubber tubing is used and it is properly attached at the ends. The length of rubber sleeve should not be less than 18 in. Under conditions requiring large expansions and relatively high expanding pressure, double -tapered collars at either end may be necessary to prevent rubber breakage. It is not suitable for high grout pressures, but it will withstand 100 psi under poor conditions and will hold up to 200 psi if the hole is not too large or uneven. In weak sedimentary formations of alternating layers of shale and sandstone or lime stone, this packer has proved invaluable. It is now widely used where low pressures are dictated by foundation conditions.

19. **ASPHALT GROUTING EQUIPMENT.** Commercial asphalt heaters similar to those used by roofing contractors have been found satisfactory for heating asphalt for grouting. The heater should have a baffle near the outlet to prevent lumps from entering the supply line. Gear pumps, reciprocating pumps with ball valves, or 1-in. boiler-fed piston pumps have been used to pump hot asphalt grout through 1-1/2 -in. black iron pipe. Mixers are not needed for either hot asphalt or asphalt emulsions. A typical hot asphalt grout plant is shown in figure 21. Cement grouting equipment can be used for asphalt emulsions.

20. **CHEMICAL GROUTING EQUIPMENT.** The equipment required for chemical grouting will vary depending on the chemicals being used. Basically this equipment consists of mixing tanks; variable speed, positive -displacement-type pumps, control valves; and gages so that the proportioning of chemicals can be closely controlled. Self-contained mobile units are available that include all necessary components for the grout system. Generally, the se units have been developed by the grout manufacturer and are designed for a specific chemical process. In any case, all grouting equipment should be of a material that will not react with the chemicals being used.

21. **PLANT LAYOUT.**

a. Cement Grouting.

(1) Plants. The grout plant should consist of a mixer, agitator, sump, pump and necessary valves, gages, and lines to control the operation. Standby equipment may be required depending on the nature of the job. Cement grout plants vary in size from compact systems that may be truck-mounted to large automated systems that require dismantling for moving. Figures 22 and 23 illustrate the two extremes. In figure 22 both the single and return line pumping systems are shown with locations of valves and gages. The return line system is often preferred where grout take is small because of (a) good pressure control with no waste, (b) reduction of grout-line clogging

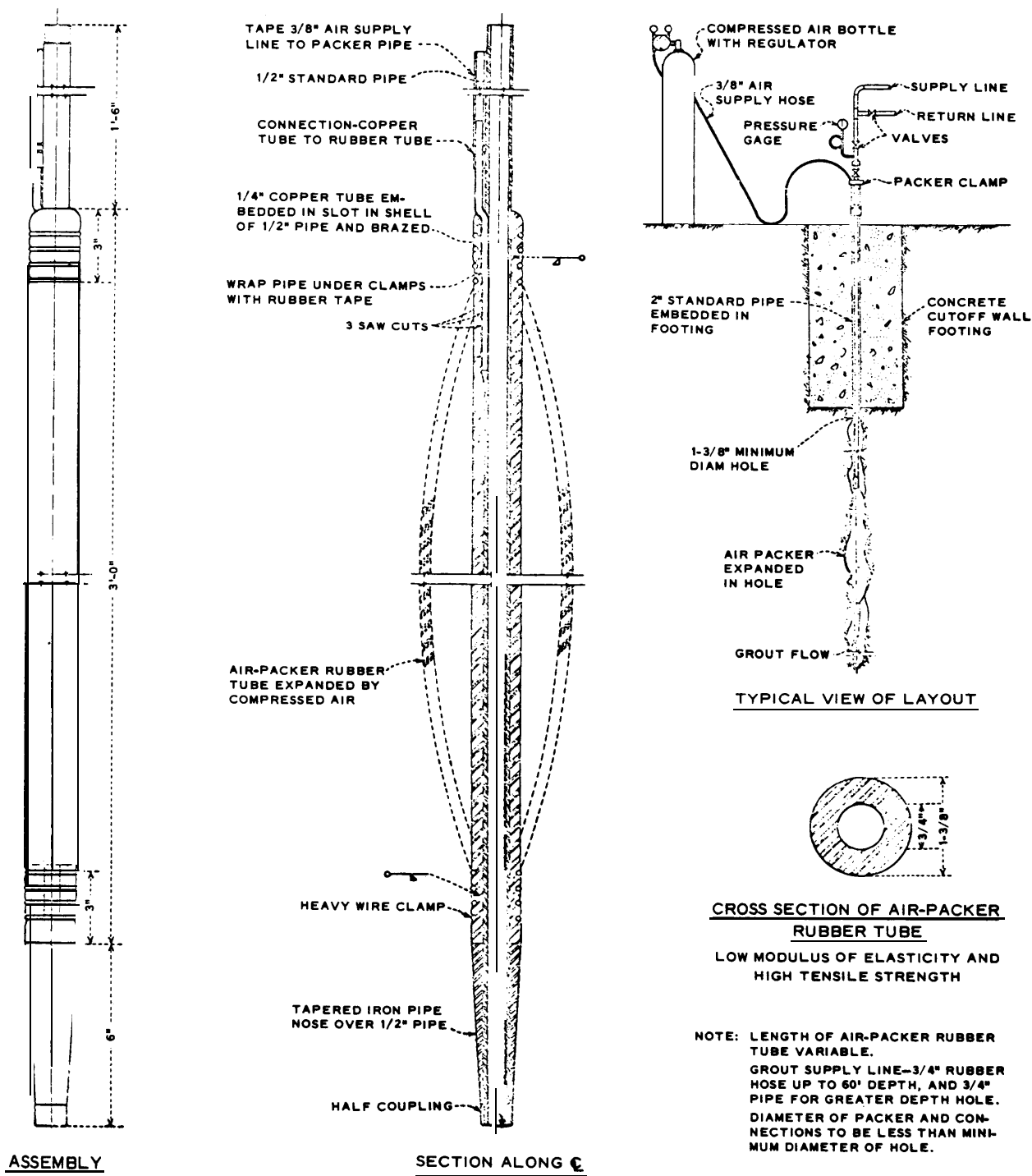
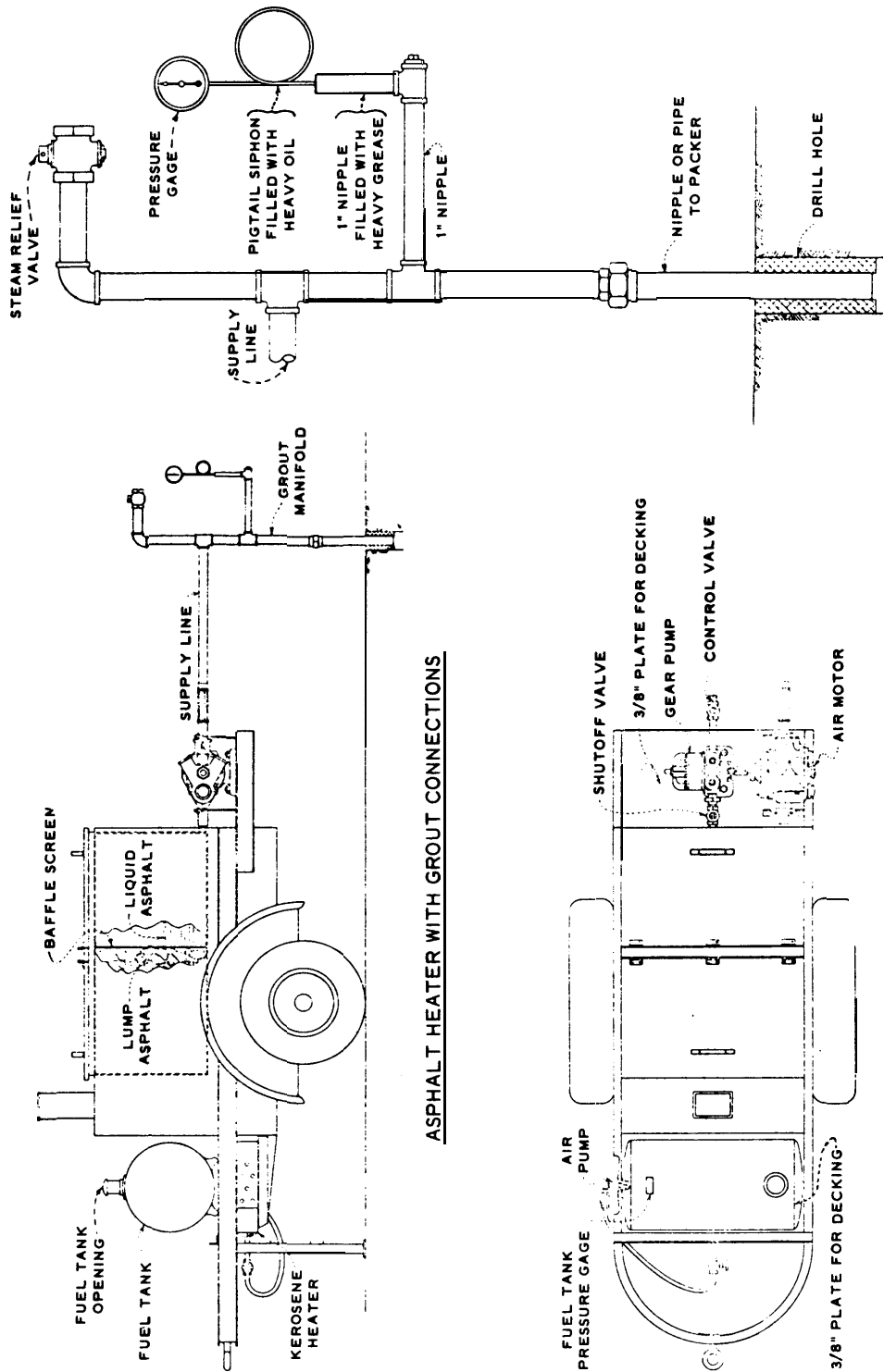


Figure 20. Air packer

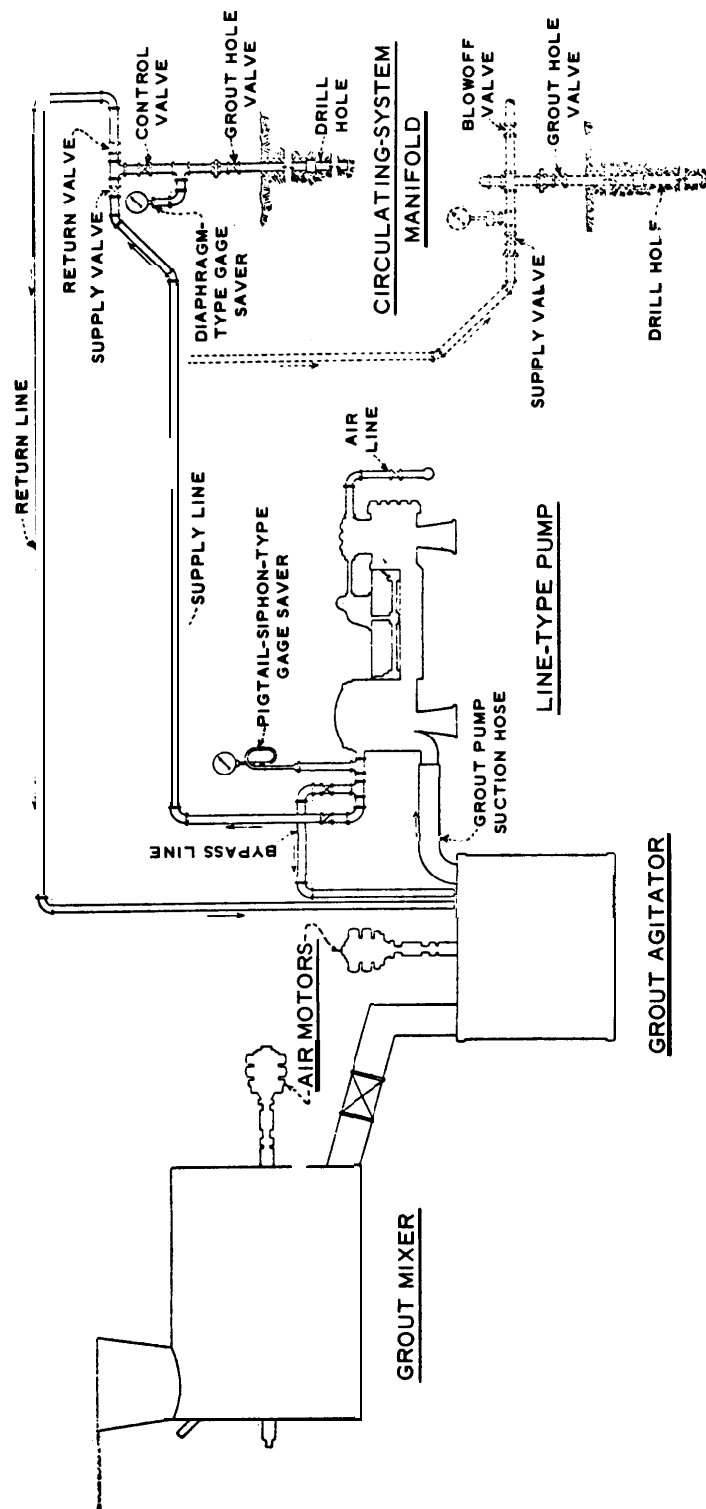
(Courtesy of U. S. Bureau of Reclamation)



TYPICAL ASPHALT GROUTING MANIFOLD
AND CONNECTIONS

(Courtesy of U. S. Bureau of Reclamation)

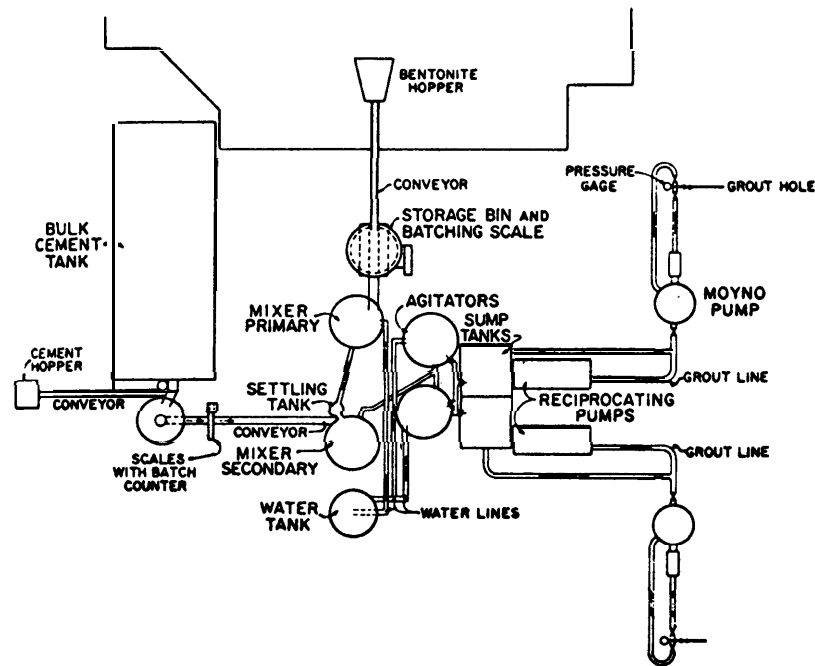
Figure 21. Asphalt grouting equipment and connections



SINGLE-LINE-SYSTEM
MANIFOLD

(Courtesy of U. S. Bureau of Reclamation)

Figure 22. Circulating and single-line grouting systems



(Courtesy of American Society of Civil Engineers)

Figure 23. Schematic of large grout plant (see ref 31)

due to sedimentation, and (c) maintenance of circulation with hole closed down. If the grout take is large, a single -line system may be preferred because of its simplicity.

(2) Operation. The batch system is more satisfactory than continuous mix. The necessary water for each batch should be run into the mixer and the cement dumped in as needed. After mixing thoroughly, the batch of grout should be dumped into the agitator for pumping, and the next batch started in the mixer to prevent delays between batches. On slow holes or where only small quantities of grout are injected at one time, one man may be able to operate both mixer and pump. On some portable plants the pump and mixer are mounted with control valves arranged so that one man can operate both pieces of equipment. For large operations, batching systems may be set up for automatic control with one operator.

b. Clay Grouting.

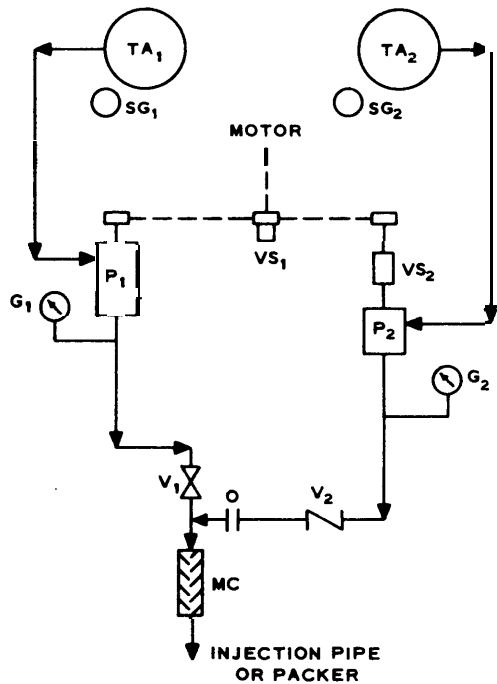
(1) Plant. Where processed clays such as commercial bentonites are used as the grout material, the grout plant and operation are similar to those used in cement grouting. When natural soils are used, the plant may have to be modified to allow for processing the raw material. Where this is necessary, in addition to the basic plant as shown for cement grouting, a drying

shed, crusher or grinder, screening equipment, and premixer may be required. The grout lines and control system are the same as for cement grouting.

(2) Operation. Normally the batching method is best suited to mixing clay grouts. For processed clays such as bentonite, the operation is similar to that for cement. For cement grouts containing bentonite, the cement should be mixed with water before adding bentonite. When natural soils are used, the raw material is delivered to the plant by truck, scraper, or conveyor and stockpiled under a storage shed if necessary. Where the grout design requires predrying, the soil is spread and worked to facilitate drying. Predrying may result in easier mixing, better dispersing, and better water control in the grout. Moist clay will require vigorous mixing for complete dispersion. The usual procedure is to crush or grind the raw soil and mix the water to disperse the particles. The mix is then discharged on screening equipment to remove lumps, foreign matter, and coarse material. The screened slurry is then run into the mixer for the addition of admixtures or into the sump for pumping to the holes.

c. Chemical Grouting. The equipment required and the assembly of a chemical grout plant are dependent on the chemical system employed. Adequate storage facilities for both dry and liquid components, mixing tools, proportioning systems, pressure control, and flushing lines are required. When a commercially produced chemical system is used, the manufacturer's recommendations for equipment and operations should be closely followed. For projects using custom design chemical processes, the plant equipment and operational procedures should be specified by the person or organization designing the mix. In any case, extreme caution should be exercised at all times to protect workmen from dangerous chemicals and fumes. An ample supply of water is required on all chemical grouting jobs. Figures 24 and 25 show schematic layouts for typical plants used for one of the commercial chemical grouts.

d. Asphalt Grouting. The principal items of equipment required for grouting with hot asphalt are heating tank, pump, supply lines, and gages in suitable arrangement such as shown in figure 21. The pressure gage is protected from the asphalt by using a 1-in. nipple and pigtail siphon. The nipple is filled with grease and the siphon with oil. In cold-weather operations, it may be necessary to heat supply lines. One method is to insert a heavy, insulated iron wire in the grout line. One end of the wire is connected to the bottom of the supply line, and the other to a high-amperage, low-voltage generator, such as used in commercial welding machines. The machine is grounded to the supply line to complete the circuit. Steam has also been used for heating lines, but has proved cumbersome and costly. When the asphalt is pumped in the hole, steam will form if water is present in the hole. Some of the steam will be caught in the supply line, and provisions should be made for bleeding it off to prevent it from blowing back into the heater. Extensive

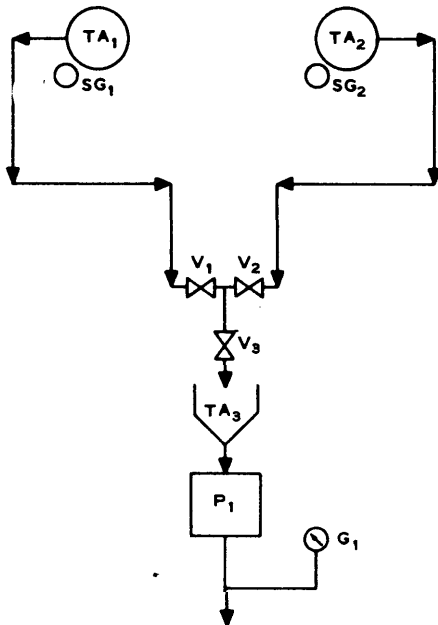


KEY OF COMPONENT PARTS

- TA₁ - MIXING TANK FOR AM-9 CHEMICAL GROUT, CATALYST DMAPN, AND KFe
- TA₂ - MIXING TANK FOR AMMONIUM PERSULFATE
- SG - SIGHT GAGES
- P₁ - POSITIVE DISPLACEMENT PUMP
- P₂ - POSITIVE DISPLACEMENT PUMP
- VS₁ - VARIABLE SPEED DRIVE
- VS₂ - VARIABLE SPEED DRIVE
- G₁ - DIAPHRAGM PRESSURE GAGE
- G₂ - DIAPHRAGM PRESSURE GAGE
- V₁ - QUICK OPENING VALVE
- V₂ - SPRING LOADED CHECK VALVE
- O - ORIFICE
- MC - MIXING CHAMBER
- TA₂ THROUGH MC SHOULD BE ALUMINUM, TYPE 316 STAINLESS STEEL, RUBBER, OR SOME PLASTICS
- TA₁ THROUGH V₁ CAN BE MILD STEEL, ALUMINUM, STAINLESS STEEL, RUBBER, OR PLASTICS

(Courtesy of American Cyanamid Co., Wayne, N. J.)

Figure 24. Proportioning system (see ref 40)



KEY OF COMPONENT PARTS

- TA₁ - MIXING TANK FOR AM-9 CHEMICAL GROUT, CATALYST DMAPN, AND KFe
- TA₂ - MIXING TANK FOR AMMONIUM PERSULFATE
- SG - SIGHT GAGES
- V₁, V₂, V₃ - QUICK OPENING VALVES
- TA₃ - BLENDING TANK FOR AM-9 CHEMICAL GROUT, CATALYST DMAPN, AND AMMONIUM PERSULFATE
- P₁ - POSITIVE DISPLACEMENT PUMP
- G₁ - DIAPHRAGM PRESSURE GAGE
- TA₂ THROUGH V₃ SHOULD BE ALUMINUM, TYPE 316 STAINLESS STEEL, RUBBER, OR SOME PLASTICS
- TA₁ THROUGH P₁ CAN BE MILD STEEL, ALUMINUM, STAINLESS STEEL, RUBBER, OR PLASTICS

(Courtesy of American Cyanamid Co., Wayne, N. J.)

Figure 25. Two-solution system (see ref 40)

precautions should be taken to protect workmen engaged in asphalt-grouting operations. Gloves, goggles, and ointments for application on exposed skin should be used by all grouting personnel.

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APPENDIX II

SAMPLE GROUTING LOG

1. In the grouting log (fig. II-1), the inspector has collected pertinent information from the drilling and pressure testing records and knows that he is going to grout zone 4 of a primary hole, that the hole is inclined 25 deg from the vertical, that the top of the zone to be grouted is 68 ft vertically below the surface, that the hole was pressure-tested at the rate of 0.5 cfm at 10 psi, and that the top of zone 4 is below the water table. From figure 4 (main text), he finds that pressures exerted by grout columns of 2:1 and 1:1 grout 1 ft high are 0.61 and 0.73, respectively. Grout columns of these mixes 68 ft high would exert pressures of about 42 and 49 psi. This means that if 1:1 grout is used, the maximum gage pressure should be 19 psi so that the total pressure at the top of zone 4 will not exceed 68 psi (1 psi per foot of vertical depth).
2. The inspector decides to start with 4:1 grout, although 3:1 grout would be an acceptable starting mix considering the pressure-test results and the fact that all of zone 4 is below the water table. After the header is in place with the valve to the hole closed and the valve on the return line open and the contractor is ready to begin grouting, the inspector asks for a three-sack batch of 4:1 grout. This should be enough to find out if the hole will take grout. (A two-sack batch would make little more than enough to cover the suction intake to the pump and fill the pump and grout lines.) A three-sack batch of 4:1 grout will make 13.5 cu ft since a sack of cement (94 lb) has a volume of only 0.5 cu ft when immersed in water. The volume of each batch mixed is entered under the heading 'Grout, Cu Ft. ' Note that the first entry in the column headed "Tank Reading" shows 12.0 cu ft of grout in the sump tank. This reading is made after the grout has been circulated through the pump and grout lines. The difference between 13.5 cu ft and 12.0 cu ft is the amount of grout required to fill the pump and lines. After circulating the grout and getting the tank reading, the inspector is ready to start grouting. The valve to the hole is opened and the valve on the return line is closed as required to divert grout into the hole at the pressure designated.
3. Pressure can be obtained as desired without completely closing the return line. The inspector asks that it be held to 10 psi while he determines the rate of injection. He does this by measuring the amount of grout in the tank after 5 min of pumping with a stick gage calibrated to read in cubic feet for that particular tank. He finds that 9.5 cu ft of grout remain in the tank. ' Thus, 2.5 cu ft of grout were pumped into the hole during the first 5 min of grouting, which gives a rate of 0.5 cfm. Usually the rate of injection, shown in the seventh column on the sample log, is computed on batch quantities, assuming that the level of grout in the sump tank is the same each time a new batch is discharged from the mixer. More frequent observations on the

Hole No. 23-2, Primary				Sta. 23+20		Date: 6/21/62		Water table about 20'	
Zone 4				Axis El. 564.4		Shift: 1600-2400 hrs		Press. test: 0.5 cfm @	
75'-100'; Inc. 250						Inspector: J. Jones		10psi 6/19/62	
Time	Mix	Cement/ Sacks	Grout Cu. ft.	Tank Reading	Gage Pressure	Grout cu. ft./min.	Cement cu. ft./hr	Remarks	
1738	4:1	3	13.5	120 cu. ft.	0	0.5		Started grouting at 1738 hrs	
1743				9.5	10			Vertical depth to Zone 4 is 68'	
1751		2	9.0		15	0.75	10.0	Add 42psi for 2:1 @ 49 psi	
1803	3:1	3	10.5		15	0.8	13.8	for 1:1. Add 38psi for	
1816		3	10.5		15-0	0.9	15.0	3:1 grout. Delay 1828 -	
1830		3	10.5		0-15	0.9	15.0	1830 hrs. Water line broken	
1842		3	10.5		20	0.95	16.4	1810 hrs. Repaired at	
1853	2:1	3	7.5		20	0.9	22.5	1828 hrs. Pressure at 0	
1901		3	7.5		20	0.9	22.5	during delay.	
1909		3	7.5		20	0.9	22.5		
1917		4	10.0		20	0.9	21.8		
1928		4	10.0		25	0.9	21.8	Checked area for leaks at 1845	
1939		4	10.0		26	0.8	19.2	" " " " 1945	
1951.5		4	10.0		26	0.75	17.8		
2005		4	10.0		26	0.5	11.4		
2026	3:1	3	10.5		27	0.75	12.9+		
2040		3	10.5		30	0.6	10.6		
2057		3	10.5		30	0.5	9.1		
2117		3	10.5		30	0.55	6.0		
2147		2	7.0	4.5+7.0	30				
2152				10.8		0.14			
2157				10.6		0.04		Completed grouting at 2157 hrs.	
		60.0		1.5 (line + pump)					
		3.5		12.1	Carried				
		56.5			forward				

Figure II-1. Sample grouting log

rate of injection can be made, if desired, by using the stick gage to measure the amount of grout pumped during any given time interval. The inspector may want to check the rate just before changing mixes to be sure that the last computed rate is continuing. Such observations may be recorded or not as the inspector wishes. According to the log the hole accepted 4:1 grout readily, so it is understandable that a thicker mix should be tried. The thicker 3:1 grout increased the rate of cement injection, although not as much as shown for the first batch. The first batch of a thicker new mix dumped into the remnants of the old mix is diluted. In this case the 10.5 cu ft of the 3:1 mix was diluted by about 6.0 cu ft of 4:1 mix remaining in the tank and circulating through the pump system. This dilution would give a mix of about 3.3:1 and a cement-injection rate for the first batch of 12.7 cfm rather than 13.8 as shown. The only time it is necessary to make this computation is at the completion of grouting if the new mix has not been used long enough to have its "as -mixed" proportions in the sump tank.

4. A delay of 2 min (1828-1830 hr) occurred as the result of a broken water-line. The water for the batch of grout discharged at 1816 hr was in the mixer when the line was broken, otherwise the delay would have been 12 min longer, since the line was broken 6 min before the batch was needed. It is good practice to charge the mixer with the water for the next batch immediately after discharging. This helps to keep the mixer clean and provides a small supply of water for emergency use.

5. After a few batches of 3:1 grout, it appeared that the hole would accept a thicker grout and the inspector changed the mix to 2:1 grout. The change from 3:1 to 2:1 grout causes a much greater increase in the rate of cement injection than changing from 4:1 to 3:1 grout. The inspector should carefully observe the effect of a change to a thick or moderately thick grout on the injection rate. In the case of the sample log there was some evidence of a reduction in rate after four batches. In reality it was not until the third batch of 2:1 grout that the hole was actually receiving 2:1 grout because of the diluting effect of the 3:1 grout left in the system when the 2:1 grout was introduced. The first evidence of a slowing rate of injection appeared in the fifth batch of 2:1 grout, which was dumped into the sump tank at 1928 hr. Despite the increase in pressure, the injection rate was the same as for the preceding batch with less pressure. It is probable that the inspector was aware of this slowing and raised the pressure as a consequence of it. The rate continued to decrease even with the pressure at the maximum allowable (26 psi on the gage and an additional 42 psi by weight of the grout column). The average rate of injection for the last batch of 2:1 grout mixed (2005 hr) was 0.5 cfm. It is probable that the rate at the end of the 24-min period of injection for this batch was about 0.3 cfm, although this was not recorded. Thus, there was reason to think that one more batch of 2:1 grout would finish the hole. Therefore, the mix was thinned toward the end of prolonging the grouting period and injecting additional cement. The gage pressure was raised to compensate for the reduction of pressure from the lighter weight

column of grout. Grouting was considered complete when the injection rate for the 3:1 grout dropped below 0.1 cfm for a 5-min period. This rate was determined by measuring the amount of grout in the sump tank at the beginning and end of the period.

6. The last tank reading shows that 10.6 cu ft of grout was left in the tank when the hole was finished, and the first tank reading indicated that 1.5 cu ft of grout was in the lines and pump. These two quantities together make 12.1 cu ft of 3:1 leftover grout. Since 12.1 cu ft of 3:1 grout contains approximately 3.5 sacks of cement, that number of sacks must be subtracted from the total number mixed for this hole to obtain the number of sacks (cubic feet) of cement actually in the hole. The 12.1 cu ft is carried forward to the next hole and would be a first entry in the log of the new hole if started with 3:1 grout. If the new hole should be started with 4:1 grout, 3.5 cu ft of water would be added to the leftover grout to make 15.6 cu ft of 4:1 grout.

7. A review of the pressures and injection rates recorded in the sample log reveals no sudden changes or abnormalities. The log contains no evidence of lifting or leakage. Minor fluctuations of rate would appear if the entries were not rounded off to the nearest 0.05 cu ft. The fluctuations are most often caused by recording time to the nearest half minute only. The increase of pressure by increments permits direct observation of the effect of each pressure change. This is particularly important in stage grouting because it is the practice to apply pressures to surface rock that in other situations could only be used for rock under heavy confining loads. If the grouting pressure in the sample log had been raised from 0 to 30 psi as fast as possible, the inspector, without visible evidence of lifting such as heaved rock or surface breakouts, would not have any way to be certain that lifting was not taking place.

8. If an additional column is needed on this log form to record quantities of filler or admixture in the grout, it can be provided by moving columns beginning with "Grout,, Cu Ft" to the right into the "Remarks" space. A second additional column can be made available by recording the "Tank Reading" data under "Remarks. "

APPENDIX III

NOTES FOR THE INSPECTOR

1. **STICK GAGES.** A stick gage calibrated in cubic feet to measure the volume of grout in an upright cylindrical tank can be made, if none is available when the equipment is brought to the jobsite. Given: a tank 2-1/2 ft high and 3 ft in diameter. The volume of this tank is 17.7 cu ft ($\pi r^2 \times \text{height}$). The height of the tank, 30 in., divided by 17.7 gives the depth of a cubic foot of grout in the tank in inches. Each cubic foot of grout fills approximately 1.7 in. of the tank. The stick gage may be made from a piece of 1- by 2-in. lumber. For ease in reading, the gage should be marked so that the correct reading for the amount of grout in the tank appears at the rim of the tank when the tip of the stick touches the grout. If there was 9.0 cu ft of grout in the tank described in the example, the mark for 9.0 cu ft would be 14.7 in. above the bottom of the gage. The gage may also be prepared by metering the water into the sump tank by the cubic foot and marking the gage appropriately for each level. If the tank has an outside well for the pump suction or a bulky agitator, this method of calibration is the most accurate.

2. **THINNING OR THICKENING CEMENT GROUT.**

a. The quickest way to change a given quantity of cement grout from one mix to another is by using conversion tables or charts. However, the inspector should be able to make the necessary computations without hesitation, if such tables or charts are not available.

b. The first step for controlled thinning or thickening of a given quantity of grout is to determine the amount of cement it contains. This is done by dividing the cubic feet of grout by the number of cubic feet of grout obtained from a one-sack batch of that grout, keeping in mind that a sack of cement in water has a volume of 0.5 cu ft. Examples: Find the number of sacks of cement in 12.6 cu ft of 4:1 grout, 1.5:1 grout, and 0.75:1 grout. In the order listed, 12.6 is divided by 4.5, by 2.0, and by 1.25, and the sacks of cement in 12.6 cu ft of grout for the three mixes in the same order are 2.8, 6.3, and 40.4.

c. To thin a grout add 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 mix desired. Example: Find the cubic feet of water necessary to thin 7.2 cu ft of 1:1 grout to 3:1 grout. The number of sacks of cement in 7.2 cu ft of 1:1 grout is $7.2 \div 1.5$ or 4.8. The difference between the figures representing the water in the water-cement ratios of the two mixes (3:1 and 1:1) is two. Two times 4.8 is 9.6. Therefore, 9.6 cu ft of water must be added to 7.2 cu ft of 1:1 grout to have 3:1 grout.

d. To thicken a grout, the volume of the cement solids, in cubic feet (one-half the number of sacks of cement in the grout) is subtracted from the cubic feet of grout to obtain the volume of water in the grout. Enough cement is added to have the desired water-cement ratio with this volume of water. It is preferable to add only whole sacks of cement.

Examples:

To thicken 9.0 cu ft of 4:1 grout to 1:1 grout
Mix contains 8.0 cu ft water and 2.0 sacks cement
Need to have 8.0 cu ft water and 8.0 sacks cement for 1:1 ratio
Add 6.0 sacks cement

To thicken 5.6 cu ft of 3:1 grout to 1:1 grout
Mix contains 4.8 cu ft water and 1.6 sacks cement
Need to have 4.8 cu ft water and 4.8 sacks cement for 1:1 ratio
Could add 3.2 sacks cement
But to avoid fractions of sacks of cement, add 0.8 cu ft water
and 4.0 sacks cement

To thicken 5.4 cu ft of 4:1 grout to 0.75:1 grout
Mix contains 4.8 cu ft water and 1.2 sacks cement
Need to have 4.8 cu ft water and 6.4 sacks cement for 0.75:1 ratio
Could add 5.2 sacks cement
But to avoid fractions of sacks of cement, add 0.6 cu ft water
and 6.0 sacks cement

e. Most chemical grouts are liquid grouts consisting of mixtures of liquids, and the consistency is usually not changed. The application and penetration of these grouts depend upon the gel or setting time, which can be regulated as required. As previously noted, chemical grouts vary widely in their physical properties and should be used under close consultation with or under the direction of personnel trained in the use of the particular chemicals being used.

3. PRESSURE OF GROUT COLUMN. As in changing grout from one mix to another, the quickest way to determine the pressure exerted by a column of grout is by using a chart. In case a chart similar to figure 4 (main text) is not at hand, the pressure in pounds per square inch exerted by a 1-ft column of any grout can be found by dividing the weight of a cubic foot of the grout by 144 (the number of square inches in a square foot). For portland-cement grout with no fillers or admixtures, it is necessary to know that a cubic foot of water weighs 62.4 lb and a sack of cement weighs 94 lb. Thus, for 2:1 grout a one-sack batch of grout contains 124.8 lb of water and 94 lb of cement for a total weight of 218.8 lb. Since a one-sack batch of 2:1 grout makes 2.5 cu ft, 218.8 lb must be divided by 2.5 to obtain the weight of 1 cu ft of the grout. Then 1 cu ft of 2:1 grout weighs 87.5 lb and exerts a pressure

of 0.61 psi ($87.5 \div 144$). In computing cubic-foot weights of cement grouts containing one or more additives, the weights of all additives in a single batch of the grout and the volume of the batch must be known. The most certain way to determine the volume of a batch containing several ingredients is by gaging the sump tank after a batch has been discharged.

4. **CHECKING LOW-PRESSURE GAGES.** Low-pressure gages should be checked before each use when that use is to register pressures of less than 5 psi. It is necessary that gages used for the first stage of grouting in stage grouting and the topmost stop in stop grouting be sensitive to pressures of 2 or 3 psi. The needle of a gage whose dial is marked to show pressures less than 5 psi can be moved from the peg by lung pressure. This is a quick check of gage sensitivity. Precise tests can be made as follows: A transparent plastic tube several feet long that can be attached to a gage and filled with water provides a means of an accurate check of low pressures. Each vertical foot of water in the tube above the level of the gage exerts a pressure of 0.43 psi. Thus, if the tube is held so that the water level is 5 ft above the gage, the gage should read slightly more than 2 psi. A U-tube of mercury can also be used to check low-pressure gages. One end of the open U-tube is connected to the gage by a tube containing a valve for the injection of air. Air pumped into the connecting tube causes the mercury to stand at different levels in each arm of the U-tube. Each 2 in. of differential between the mercury-column levels represents a pressure of approximately 1 psi. A differential of 10.17 in. of mercury should register on the gage as 5 psi.

5. **LIFTING CLUES.** When grout is injected at pressures greater than the rock can withstand, the rock is lifted or heaved. Surface evidences of lifting other than grout leaks are sometimes readily discernible, and where structures are involved damage may be substantial. When structures are present grouting should be accomplished without any lifting, and if lifting takes place grouting should be stopped immediately. It is important, therefore, to recognize signs or clues that lifting may be occurring. The inspector should watch for changes in the behavior of the hole each time pressure is raised. After the initial rupture of the rock, it may be noted that the pump labors less, the gage pressure may drop a few pounds, and the injection rate may increase. All these signs may occur simultaneously. If lifting takes place at a depth of several feet and is caused by cleaving of bedding planes, the hole may have a relatively high back pressure. This is a result of the rock pushing back on the grout. It can be checked by closing the valve between the grout line and the hole. The gage will then reflect the pressure of the grout in the hole. If it is nearly the same as the injection pressure and does not fall at a readily visible rate, it should suggest the possibility of lifting. If it falls rapidly it is pump pressure that is dissipating. Unfortunately, these signs and clues are not infallible. Some of the clues can be produced by grouting at least one other subsurface condition. During the grouting of solution channels or cavities compartmented by muck, a hole may show most of the indications of lifting without having any lifting involved. If grout breaks

from one compartment to another, it will quickly enlarge its channel in the soft filling, causing a pressure drop and an injection rate increase.

6. GROUTING IN FLOWING WATER. A channel carrying flowing water encountered during grouting operations should be closed by excavation and backfill if feasible. If at depth, this can sometimes be accomplished through large-diameter drill holes. Portland-cement grout is not usually effective at sealing voids filled with rapidly moving water. If the movement of water is caused by dewatering or other pumping activities, it is likely that such operations will have to be suspended before grouting can be successful. In the case of fairly large underground channels filled with naturally flowing water discovered by drilling for grouting, the flow must be essentially stopped before attempting to fill the channels with cement grout. As much information as possible on the size and shape of the channel should be obtained. The borehole television camera can be used to augment information from drilling and sounding. It may be possible to construct a barrier across the channel by drilling and backfilling cased 6-in. or larger holes, one at a time, spaced so that intermediate holes will overlap the primary holes. Since the casings would be left in place, they should be something other than steel so that they can be readily cut with a drill. A barrier may be created by introducing an inflatable bag attached to an injection pipe into the water-filled channel through a 6-in. hole. Grout or mortar is then pumped into the bag through the pipe to inflate it against the walls of the cavity. After the flow of water is stopped, grout can be pumped into the channel upstream from the barrier until it is filled sufficiently to satisfy the requirements of the project.

7. CLEANING GROUT HOLES. The injection of grout is only one of the subsurface operations that can result in lifting and damage to rock. Lifting can be done by water during drilling operations, and it can be done by compressed air used to blow sludge and cuttings out of grout holes. The best way to clean grout holes after drilling is completed is by washing them through the drill rods with the drill raised just above the bottom of the hole. Washing should be continued until the water returning to the surface is clear. If the hole has been stopped because of water loss, the washing should be continued for approximately 5 min unless it is certain that the drill water was lost into a large cavity. No washing is needed in that event. If air is used to clean the hole, the injection pipe should not have a diameter greater than half the diameter of the hole. If the annular space around the pipe is small, it may become clogged with debris ejected by the compressed air causing full compressor pressure to be exerted against the walls of the hole. Lifting is almost certain to take place if the compressor pressure greatly exceeds the load of overlying rock and soil. This risk also exists for percussion drilling when air is used to remove the cuttings.

8. SAFETY. Some of the dangers that attend pressure grouting with cement grout are briefly described here. An important thing to keep in mind is the

“pressure” part of pressure grouting. Cement is composed of jagged rock-like particles of matter that are very abrasive without pressure. Under pressure, cement grout can damage the skin or cause severe injury to the eyes. It is important that grout pipes and hoses be in good condition and all connections be properly made. If a grout line breaks while grouting at high pressure, grout can be ejected many feet with great force. If necessary for personnel to be exposed to cement dust, goggles should be worn to protect the eyes. If the weather is windy and dust conditions are severe, exposed portions of the skin should also be protected to avoid cement “burn.” Waste grout should be discarded away from the work area as a good housekeeping practice and to eliminate splashing hazards.

APPENDIX IV

RECORDS AND REPORTS

1. **RECORDS FOR PAYMENT.** Records of quantities that are pay items must be kept for meaningful administration of any contract. Of necessity these records must be accurate, understandable, and sufficiently detailed to justify their acceptance if at variance with data presented by the contractor. Details are very important for a drilling and grouting operation. As grouting progresses it should be continuously evaluated. Records that must be kept of pay items should be expanded to log form so that decisions to "split-space" or split-space only to a certain horizon, to decrease or increase grouting pressures, to use generally thinner or thicker mixes, or to make any of the many decisions that may be required can be based on case histories of operations at the jobsite. Therefore, in addition to listing quantities, when, where, and how the quantities were obtained should also be recorded. After completion of the grouting, there is very little surface evidence to indicate the extent of grouting, and there is no way to determine actual quantities if a running account is not available. A form listing all pay items should be prepared for submittal to the project office on a daily or shift basis. All quantities listed on this form should be taken from the detailed records kept by inspectors in field notebooks. Notebooks should be turned in as they are filled for preservation as part of the permanent project records.

a. Drilling. It usually is not possible to have a full-time inspector assigned to each drilling unit on grout-hole drilling; but if more than one unit is operating on the same shift, a full-time drilling inspector should be present. In any case the drilling should be inspected several times each shift to obtain needed data and ensure compliance with the specifications. The inspector should be available for the start of each new hole and at the completion of any hole, zone, or stage. If the holes are inclined, he must make sure that each new hole is started at the correct inclination and in the right direction. He must make certain that all cuttings are washed out of the hole at the completion of drilling and that the hole is then properly capped or plugged. For the records he must have hole number, location, elevation, size, inclination data, driller's name, and the feet drilled for each hole in which work was done on any date or shift. If pipe, zone, and size of hole are pay items, quantities for each must be recorded. The records should also show water losses and approximate formation contacts as determined by the driller, if no core is recovered. The hole number and its location, elevation, and inclination should be shown at the top of a page in a field notebook. It is preferable to have only one hole to a page, but all information on that hole may be kept on the page if properly dated. The notebook should be available to the grouting inspector.

b. Pressure Testing and Pressure Washing. The pressure-test and pressure-washing records should show the hole number, location, elevation, depth of hole, zone, stage or packer setting as appropriate, and the starting and completion times of all testing and washing. The rate and pressure at which water is injected must be shown. If water vents from other holes their numbers and locations should be given. If connecting to a hole is a pay item and more than one connection per test is made, all the circumstances involved should be entered in the record. Information on the water table should be included in the pressure-test book or in the drilling records or both. A separate notebook should be used to record all pressure-test and pressure-washing data, and it also should be available to the grouting inspector.

c. Grouting. The grouting record should be more elaborate than the other records described because grouting is a more complicated operation and the grouting log not only serves as a record of the pay quantities, but because it also is the only detailed record of the grouting treatment in existence. The interpretation of the grouting logs may have a major bearing on decisions for further treatment either during or after construction. The log of grouting operations must contain the hole number, location, elevation, data on inclination, position in the order of grouting (primary, first intermediate, etc.), information on the portion of hole being grouted (depths and/or elevations, and stage or zones), and the date and shift the work was done. The log should show the starting and completion times, the time mixes were changed, the time water was injected, and the time of delays and the reasons therefor. Pressures, injection rates, location of leaks, and any other information pertinent to the understanding of the operation should be given. The pay quantities of all ingredients should be shown clearly. If payment is by a volume or weight unit for both placing and furnishing the ingredients, each unit placed is also a unit furnished and must be paid for under both items. If leftover grout from the last batch mixed for any hole is carried forward to the next hole, it should be accounted for in the log for the new hole. Leftover grout that is allowable waste as a result of cessation of grouting operations is paid only under the item or items for furnishing ingredients, since it was not placed. There are many acceptable forms for grouting logs. The sample log in appendix II is one of several forms of grouting logs that have been used for portland-cement grouting. It illustrates how an accurate accounting of all grout mixed can be made. The record of each batch of grout and its rate of injection provides detail that is insurance against miscounting batches and provides data that can be readily scanned for indications of abnormalities such as lifting. It also permits a supervisor to second guess the inspector and to evaluate his judgment.

2. RECORDS FOR FUTURE REFERENCE. In addition to records that must be kept to administer the contract, records should be kept for future reference. The field notebooks are the basic "as-built" records. However, other summary-type records are also desirable. If quantities are summarized by

tables, drawings locating all holes should accompany the tables. For a grout curtain, a geologic section through the grout holes is the best presentation. Holes may be represented by single lines with grout takes shown by zones in volume of cement and/or other materials. Primary and intermediate holes should be distinguished. Pressures, mixes, and setting times should be shown with the holes or in notes. For blanket grouting, mine filling, or contact grouting, a plan view of the grouted area showing hole locations and other pertinent data, as listed above, is usually the best way to show the grouting. Work sheets similar to such drawings, if kept up to date, are very useful in evaluating the grouting effort as work progresses and serve as a base for the "as-built" drawings.

APPENDIX V

PAYMENT

1. **ESTIMATES.** The quantities involved in any drilling and grouting operation are rarely susceptible to accurate estimating. The estimates needed for bidding purposes should be the best approximations possible, but should not be considered more than that. The specifications should make provisions for increasing or decreasing quantities and for eliminating items as warranted during progress of work under the contract. Often-used bid items are discussed in the following paragraphs.

2. **BID ITEMS AND UNITS OF PAYMENT.**

a. **Mobilization and Demobilization.** This is a lump sum item and is compensation for assembling all necessary drilling and grouting equipment on the site and removing it therefrom. Payment for this item does not depend upon the amount of drilling and grouting done. Provisions may be made for partial payment to the contractor after mobilizing the equipment and for payment of the remainder of the item when the work is completed and the equipment removed from the jobsite.

b. **Drilling.** A bid item should be prepared for each type of drilling required, i.e., grout-hole drilling, drilling exploratory holes for core recovery, drilling hardened grout, etc. If more than one size of hole is required, separate items are needed for each size. If unusually deep holes are planned for a part of the job, a separate pay item should be added for this. If stage grouting is done, it may be desirable to provide separate items for each zone of drilling. If part of the holes are vertical and part inclined, separate pay items should be made for each. The size of grout holes and the type of drilling equipment may be left to the option of the contractor if a particular size is not needed. Adequate control of size for grouting purposes can be maintained by specifying that the hole shall be large enough to permit use of packers with grout openings of a specified minimum size. The plans and specifications should indicate clearly the location and extent of the work to be done and should show limiting depths and inclinations of all holes. The responsibility of the contractor for cleaning cuttings and sludge out of grout holes after drilling and for keeping them clean and free from surface pollutants until grouted should be cited. Payment is made by the linear foot of hole drilled. Water and air required for drilling and grouting or any auxiliary operation are not separate pay items. The contractor is expected to recover the cost of furnishing both air and water under one or more of the designated pay items.

c. **Pipe.** Pipe and fittings for use as nipples in grout holes or other use that results in permanent embedment should be paid by the pound.

d. Pressure Testing and Pressure Washing. This item is usually paid for by the hour and includes only pumping or injection time measured to the nearest minute.

e. Furnishing Ingredients for Grout. A separate bid item should be provided for each ingredient used in the grout (except water). Solids are usually measured for payment by the cubic foot or pound, liquids by the cubic foot or gallon. For cement grouting a sack of cement is considered as 1 cu ft. All costs involved in purchasing, handling, transporting, and storing the ingredient as necessary to have it available at the grout plant when needed are included in this item.

f. Connections to Grout Holes. A pay item for connecting the grout lines and header to the hole or packer is often included. Each connection, as discussed below, is considered a unit for payment purposes. The purpose of this item is to compensate the contractor for time and labor required to move the grout lines from one hole to another as needed to begin injection in a new location. Whenever such moves and connections are made in pressure testing or pressure washing, similar payment should be made. Moving a packer in a hole does not require any relocation of the grout lines; therefore, successive sets in the same hole do not require separate payments under this item,

g. Placing Grout. Payment for placing grout comprises compensation for all mixing, pumping, and cleanup costs. Payment can be made either by the cubic foot or other appropriate unit of measurement for each ingredient in the grout, except water, or payment can be made by the hour for pumping time as in pressure testing. If payment is by volume or weight, a separate item should be used for each ingredient. Payment by the hour provides for easy inclusion of periods of ordered short delays. These can be paid for at a specified percentage of the hourly rate for pumping. Ordered long delays of indefinite duration should not be included in this item since the contractor can continue operations at another location during these periods. If the stage-grouting method is to be required, cleaning grout out of holes before it takes a hard set should be a part of this item.

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