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 s—hallow 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 in. volved, 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 indictive 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

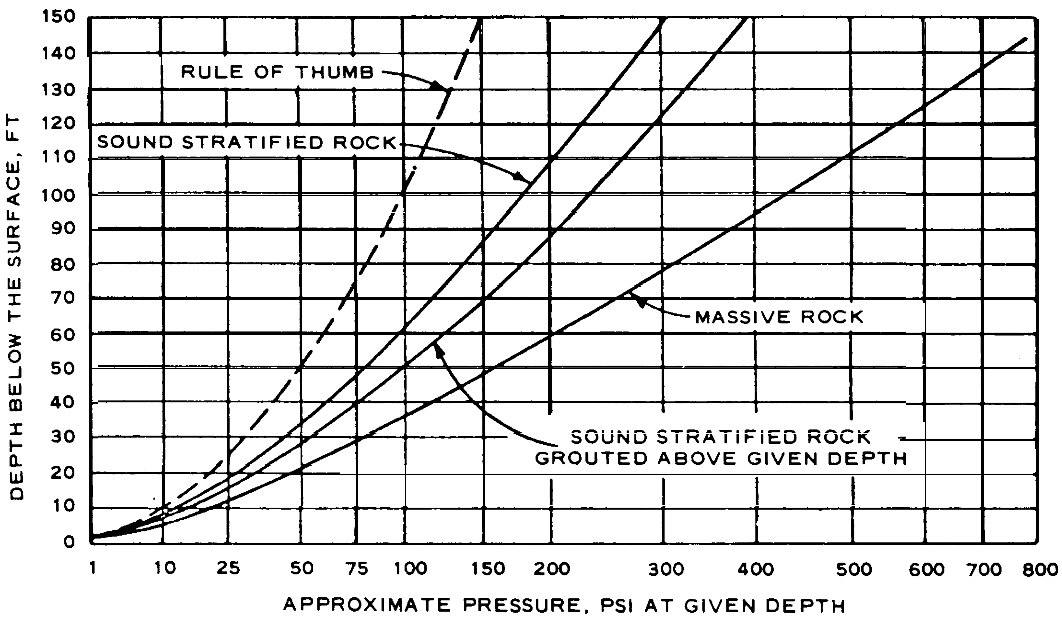

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Figure 3. Rough guide for grouting pressures

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

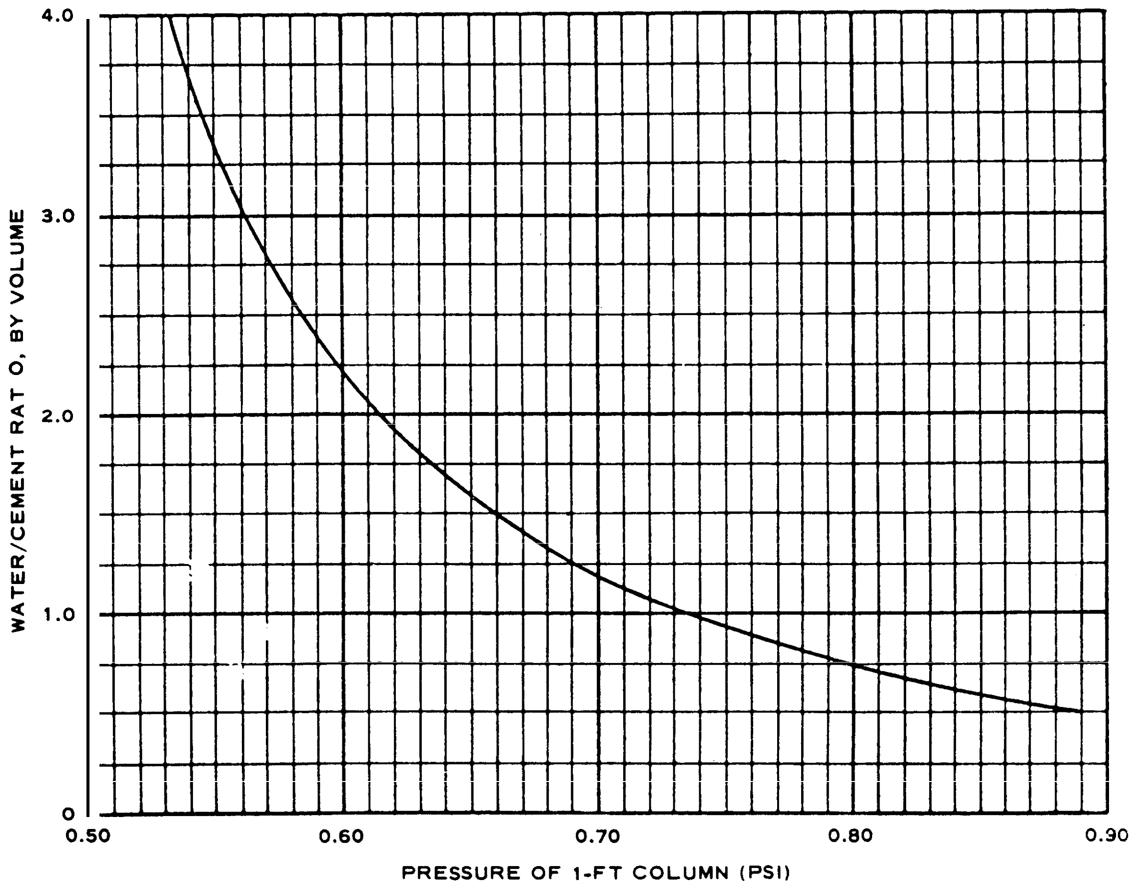

Figure 4. Pressure of neat cement grout

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.

l. 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.

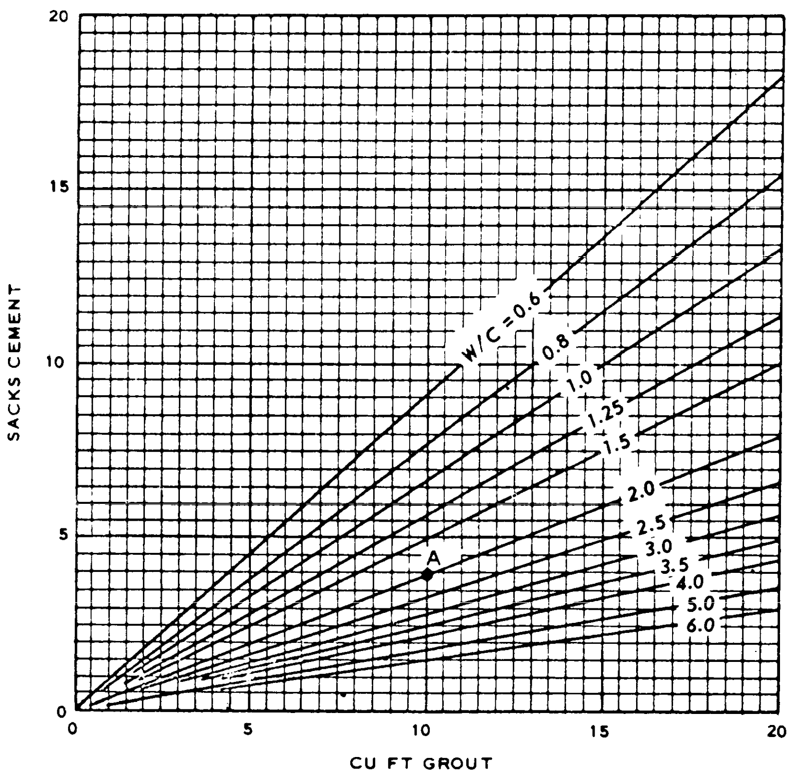

Figure 5. Cement content of portland-cement grout mixes

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.

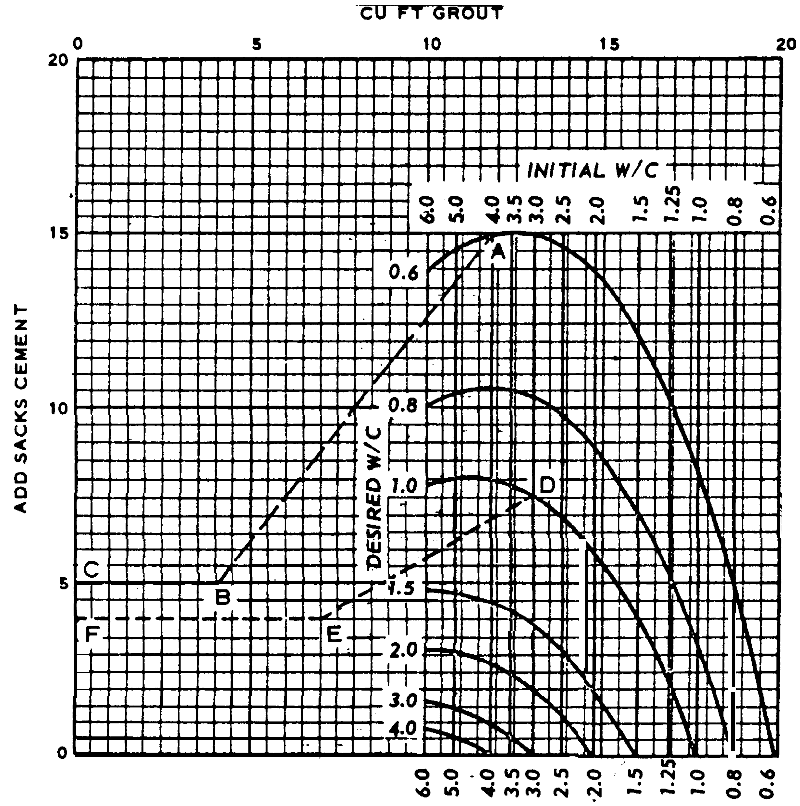

Figure 6. Portland-cement grout thickening chart

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

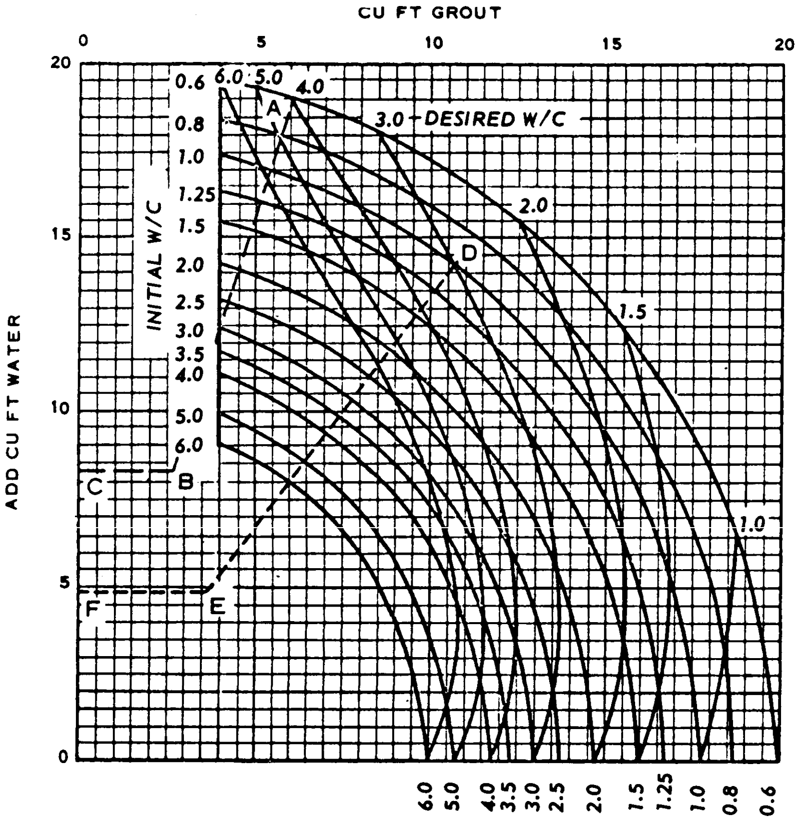

Figure 7. Portland-cement grout thinning chart

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 bf 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, if 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 o 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.