A REVIEW OF DRILLING AND GROUTING METHODS FOR EXISTING EMBANKMENT DAMS

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ABSTRACT

With the increasing emphasis being placed on dam rehabilitation and repair, more dam engineers are faced with the need to interface with drilling and grouting specialists. Regretfully, it is often the case that these specialists execute their work rather better than they explain their intentions, especially at the pre-award stage. This may lead to personal conflicts and professional disputes during the work, and so an unwillingness among dam engineers to entertain drilling and grouting techniques as favored options for future problems.

This paper provides generic classifications of drilling and grouting methods and materials for both rock and soil, so that the non-specialist can have a basic framework of reference. An extended bibliography is provided so that readers can research particular points of interest.

INTRODUCTION

Drilling and grouting techniques have many applications in the remediation of existing dams and their foundations. These can be broadly summarized as follows:

• <u>Concrete Structures</u>		
Seepage Control	-	sealing of the structure
	-	sealing of the foundation rock
Structural Repair	-	rebonding of the structure
Settlement Control	-	improvement and homogenization of the foundation rock
• <u>Embankments</u>		
Seepage Control	-	sealing of the core
	-	sealing of the foundation soil or rock
Liquefaction Control	-	improvement or retention of the dam and/or its foundation soil

Applications for concrete structures are described in detail by Bruce (1990, 1992), Bruce and DePorcellinis (1991), Houlsby (1990) and Weaver (1989) among others, and are not explored further in this review.

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Regarding embankment dams, there are numerous other activities involving drilling and grouting techniques, such as the placing and sealing of geotechnical instrumentation. However, most of the work is associated with remedial programs.

For many decades, technical demands and procurement/contracting procedures resulted in the drilling and grouting of U.S. dams being conducted according to relatively simple, rigid and standardized specifications. Indeed, these principles still form the core of the specifications being adopted for rock mass grouting on new dams today (Aberle, et al., 1990; Weaver, 1991). However, within the last few years, the difficult and typically original problems associated with major existing structures, and a certain and welcome flexibility in contracting practices (Nicholson and Bruce, 1992) have demanded the use of innovative and varied techniques. For example, drilling may have to be conducted through sensitive embankments and into unstable rock masses or heterogeneous soils, usually below the water table, without causing further damage to the foundation. Grouting techniques and materials have had to be adapted to the sealing of water pathways ranging from microfissures to karstic voids. And, of course, the grouting often has to be done in a high pressure/high flow seepage regime from locations which are not logistically ideal.

Geotechnical drilling and grouting is only one of the many technologies which impact engineers involved in dam safety and the associated remediation. It is an extremely dynamic and rapidly developing science, which does, still, owe much for its successful execution to the knowledge and experience of contractors who, for proprietary reasons, are often very protective of their knowledge. It is understandable, therefore, if the non-specialist dam engineer feels intimidation, or despair, when trying to unravel the mysteries of the drilling and grouting fraternity.

The purpose of this review is to provide generic classifications of the various drilling and grouting methods which are used, and a guide to the different classes of grouts which can be employed. Further detailed information can be found in the reference list.

DRILLING METHODS

Soil, Fill and Overburden

There are six generic techniques used by contractors in the United States, discounting vibrodrilling (which has major geological and environmental restraints), and the use of bentonite slurry supported open holes (often considered a potential hydrofracturing problem) (Bruce, 1989a; 1989b). As summarized in Table 1, these are as follows:

1. Single Tube Advancement. This is the most simple principle. In the drive drilling variant, the casing is percussed and pushed into the soil, without flush, and with a "knock-off" disposable bit. With external flush, the casing terminates in an open shoe or "crown" and is rotated into the soil using a strong flushing action (usually with water). The flush emerges from the casing and travels to the surface between the casing and the soil.

2. Rotary Duplex. The term "duplex" means the simultaneous advancement of an outer casing (with crown) and inner drill rod (with bit). The flush is passed down the drill rod, but then

DRILLING METHOD	PRINCIPLE	COMMON DIAMETERS AND DEPTHS	NOTES
1. Single Tube Advancement a) Drive Drilling	Casing, with "lost point" percussed without flush.	2-4 in. to 100 ft.	Hates obstructions or very dense soils
b) External Flush	Casing, with shoe, rotated with strong water flush.	4-8 in. to 150 ft.	Very common for anchor installation. Needs high torque head and powerful flush pump.
2. Rotary Duplex	Simultaneous rotation and advancement of casing plus internal rod, carrying flush.	4-8 in. to 200 ft.	Used only in very sensitive soil/site conditions. Needs powerful flush return. Needs high torque.
3. Rotary Percussive Concentric Duplex	As 2, above, except casing and rods percussed as well as rotated.	3-1/2 -7 in. to 120 ft.	Useful in obstructed/bouldery conditions. Needs powerful top rotary percussive hammer.
4. Rotary Percussive Eccentric Duplex	As 2, except eccentric bit on rod cuts oversized hole to ease casing advance.	3-1/2 -8 in. to 200 ft.	Obsolescent, expensive and difficult system for difficult overburden. Largely restricted to water wells.
5. "Double Head" Duplex	As 2 or 3, except casing and rods rotate in opposite senses.	4-6 in. to 200 ft.	Powerful, newer system for fast, drilling in worst soils. Needs large hydraulic power.
6. Hollow Stem Auger	Auger rotated to depth to permit subsequent introduction of tendon through stem.	6-15 in. to 100 ft.	Hates obstructions, needs care in cohesionless soils. Prevents application of higher grout pressures.

1 in. = 25.4 mm
1 ft. = 0.305 m.

Table 1. Summary of overburden drilling methods (Bruce, 1991)

emerges to the surface through the annulus between rod and casing. In this particular technique, the rods and casings are simultaneously rotated.

3. Rotary Percussive Duplex (Concentric). Similar to Technique 2 except that the drill bit also percussed. When a top hammer is used, the casings are simultaneously percussed, whereas if a down-the-hole hammer is used, only the drill bit experiences the percussive action.

4. Rotary Percussive Duplex (Eccentric). Similar to Technique 3 except that an eccentric drill bit reamer device on the rods is used to oversize the hole, to permit the casing to follow without rotation. After the duplex has reached target depth, the reamer is retracted into the casing so permitting the extraction of the rods. Both top drive and down-the-hole versions are available.

5. "Double Head" Duplex. Similar to Techniques 2 and 3 except that the rods and casings are rotated and advanced simultaneously but in opposite senses. This maximizes the penetration action for any given rig energy, and encourages hole straightness. It is especially useful in very difficult ground conditions (Bruce and Kord, 1991). Pure rotary, top drive or down-the-hole rotary-percussive options can be employed, together with a variety of normal sized or oversized drill bits.

6. Hollow Stem Auger. High torque and thrust are used to advance a screw with a hollow core (protected during penetration by a bottom plug). This is a traditional method of drilling cemented or cohesive soils, and soft argillaceous rocks.

The logic of choice is perhaps even more obscure than in rock drilling, and history and habit have ensured that not all methods are used by any one contractor, or in any one geographical region. Hollow stem augers are common around the Great Lakes and on the West Coast, while simple flushed casing and rotary duplex are favored in the East. The emergence of foreign-backed drill rental companies offering percussive duplex and double-head duplex capabilities has spread these techniques nationwide. Percussive duplex (eccentric) is in general decline for grout holes, although it is still regarded in certain quarters as the premier overburden drilling method. Any percussive duplex method may be considered for drilling through embankments although intuitively owners feel more comfortable with rotary methods. Water flush is most common, occasionally enhanced by foam, or bentonite mud, while drilling with "self hardening drilling muds" is also attractive in certain conditions. Air flush must be avoided due to the danger of pneumatic fracturing in the overburden.

Despite the resistance towards innovation apparent in every stratum of the industry, it does seem that domestic demand plus the easy availability of foreign technology is forcing major changes in attitudes towards soft ground drilling. The better contractors, at least, are adopting a refreshing degree of technical responsiveness to replace traditional paradigms.

Rock

There are three generic methods of rock drilling:

1. High Rotation Speed/Low Torque Rotary: relatively light drill

rigs can be used to extract core samples, when using a core barrel system, or can also be used simply to drill holes, using "blind" or "plug" diamond impregnated bits. Typically for holes up to 4 in. diameter.

2. Low Rotational Speed/High Torque Rotary: used with heavier rigs to drill holes of greater diameter to considerable depths. The penetration rate also depends on the thrust applied to the bit. Uses a variety of drag, roller or finger bits depending on the rock.

3. Rotary Percussive: the drill bit (cross- or button-) is both percussed and rotated. In general the percussive energy is the determinant of penetration rate. There are two options:
   - Top drive, where the drill rods are rotated and percussed by the drill head on the rig.
   - Down-the-hole hammer, where the (larger diameter) drill rods are only rotated by the drill head, and compressed air is fed down the rods to activate a percussive hammer mounted directly above the bit.

In principle, the prime controls over choice of drilling method should ideally be related to the geology, the hole depth and diameter, bearing in mind always the question of lineal cost (Figure 1). Hole linearity and drill access restraints may also have significant impact.

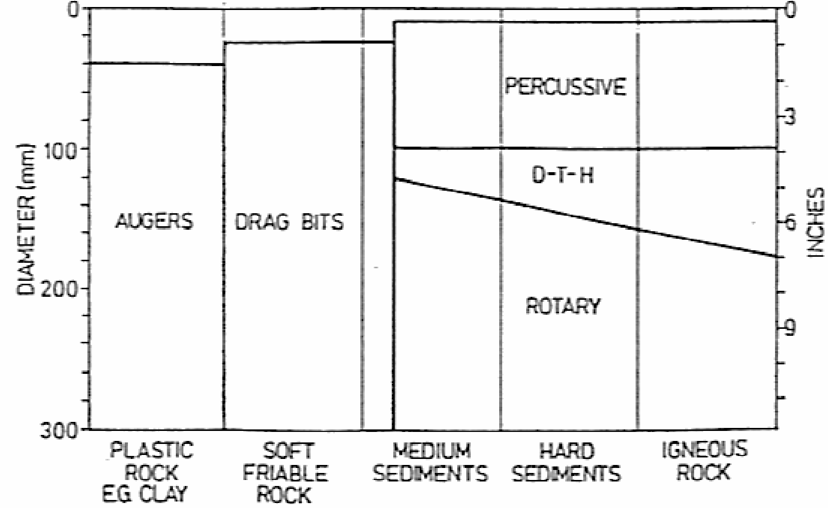
Overall, drilling is largely and traditionally conducted by rotary methods although the former insistence on diamond drilling is no longer so prevalent. Rotary percussion may be more economical in certain strata, assuming that it a) is conducted through a standpipe through the dam section to avoid potentially damaging vibrations, and b) employs water flush. With regard to this latter point, most specialists agree that air flush has a detrimental effect on the ability of fissures to subsequently accept grout (Houlsby, 1990; Weaver, 1991; Bruce, et al., 1991), while air flush should never be used in drilling alluvial, saturated foundation material.

GROUTING METHODS

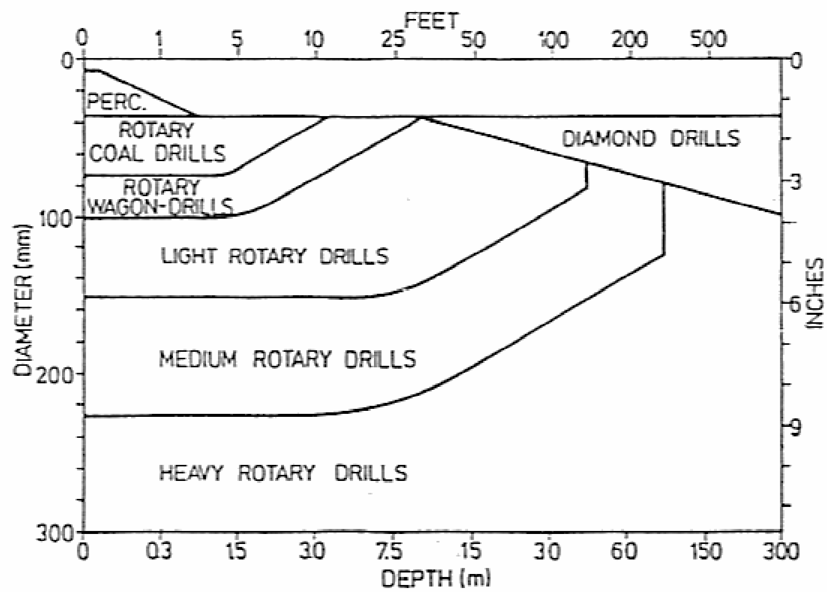
Soil, Fill and Overburden

Although it has been traditional to identify only four basic methods of soil grouting (Figure 2), the rapidly growing popularity of the Soil Mixed Wall (SMW) method has resulted in a fifth bona fide member.

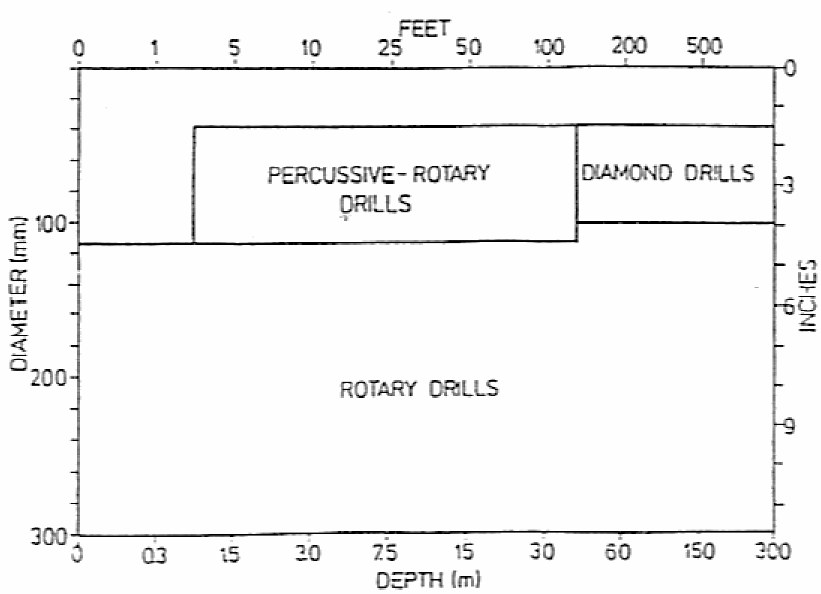
1. Permeation Grouting. Involves the infiltration of existing voids and pores with grouts. The granulometry of the soil largely dictates the choice of materials and so, to a large extent, the cost. Various methods of placement exist (Bruce, 1989a) but the most common range from the simple end of casing injection, to the sophisticated but precise tube à manchette (sleeved pipe) system. Interested readers are referred to the Proceedings of the ASCE Specialty Conferences (1982, 1992) and Karol's textbook (1990). The forthcoming European conference in London in November, 1992, provides a similarly rich source of modern data. Permeation grouting clearly reduces permeability and increases bearing capacity. By its intergranular "gluing" action it can also prevent liquefaction (Clough, et al., 1989)



Preferred methods of drilling different classes of rock and at different hole diameters. Depth of hole generalised



Preferred methods in soft friable rocks



Preferred methods in variable strata

Figure 1. General guides for selecting drilling method and equipment (McGregor, 1967)

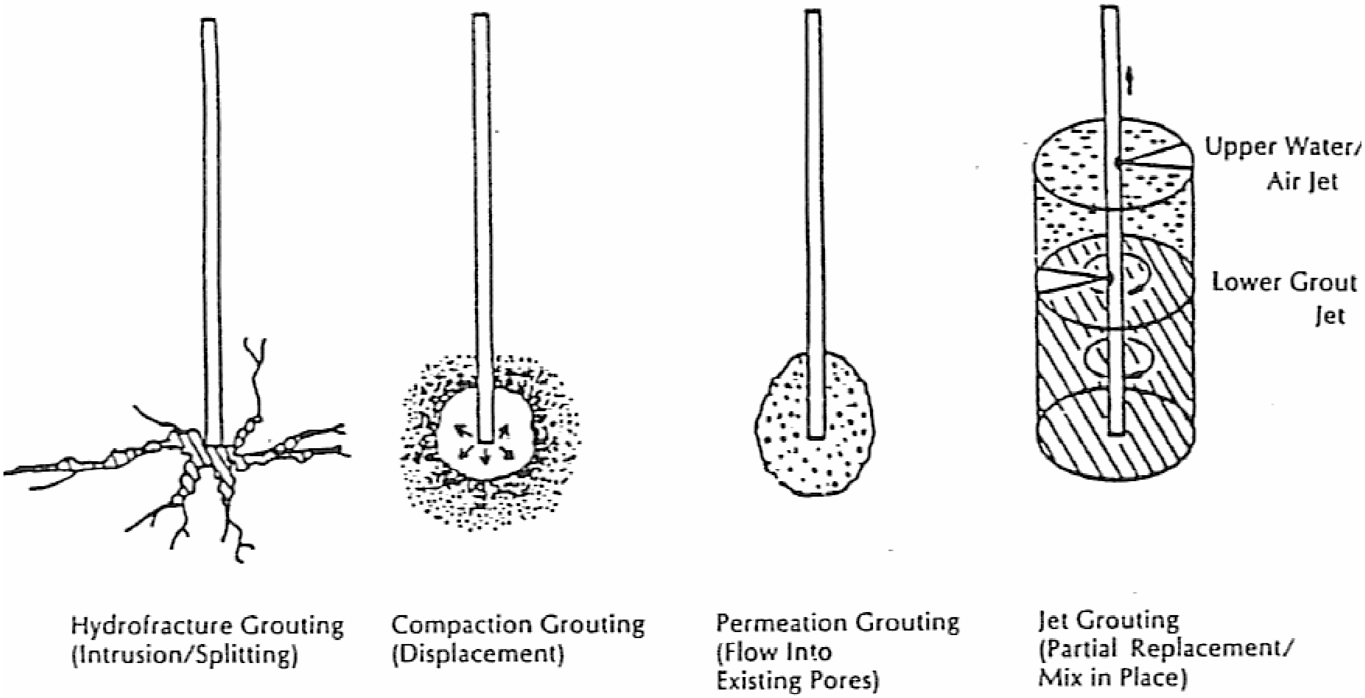


Figure 2. The four traditional categories of soil grouting

2. Compaction Grouting. This "uniquely American process" (Baker, et al., 1983) has been used since the early 1950's and continues to attract an increasing range of applications (Warner, 1982). In summary, very stiff "low mobility" grouts (Warner, 1992) are injected in predetermined regular patterns to increase the density of soft, loose or disturbed soil. When appropriate materials and grouting parameters are selected (Warner, et al., 1992) the grout forms regular and controllable coherent volumes, centered on the point of injection. Near surface injections may result in the lifting of the ground surface and associated structures, akin to the principle of slabjacking described by, for example, Bruce and Joyce (1983). Unlike other types of grouting, compaction grouting does not aim to reduce overall soil mass permeability; rather the densification it provides can be an important guard against liquefaction, for example, as conducted at Pinopolis West Dam, SC (Salley, et al., 1987).

3. Hydrofracture Grouting. Features the concept that stable, high mobility cementitious grouts are injected at relatively high rates and pressures to deliberately fracture the ground. The lenses, ribbons and bulkheads of grout so formed are conceived as increasing total stresses, filling unconnected voids, locally consolidating or densifying the soil, and providing a framework of impermeable membranes. It, therefore, has potential for seepage control and liquefaction mitigation. However, the process is relatively difficult to control, and may lead to unwanted ground heave or wasteful grout travels. It is rare outside the French grouting industry, although the work conducted at Mud Mountain Dam, WA (Eckerlin, 1992) is a clear demonstration of the methodology for sealing fissures in a desiccated clay core.

4. Jet Grouting. Was primarily developed in Japan in the early 1970's (Bruce, 1988) but was introduced into the States at the end of that decade. Restricted opportunities and a litigious mistrust of innovation have somewhat limited its national popularity despite the efforts of a small and determined band of proponents (Andromalos and Gazaway, 1989; DePaoli, et al., 1989; Kauschinger, et al., 1992; Welsh and Burke, 1991). There are three basic types of jet grouting in popular use but all feature the use of a high pressure fluid jet ejected laterally during the rotation and extraction of the drill rod to erode and/or grout the soil. The result is a column of "soilcrete", the diameter (up to 10 feet) and strength (up to 1500 psi) of which reflects the virgin soil, the grout mix design, and the operational parameters. Jet grouting has many inherent advantages as a ground treatment method especially its ability to be applied in all types of soil, and its reliance on cement based grouts only. However, many remain concerned about the high pressures employed, and remain skeptical about its economic competitiveness. Only one North American dam (John Hart Dam, BC) has had (minor) jet grouting, for a hydraulic cut-off (Imrie, et al., 1988). Cost appears to rule it out of other applications.

5. Mechanical Mix in Place. By convention, this method, typified by proprietary names such as SMW (Soil Mixed Wall) and DSM (Deep Soil Mixing) is still not regarded as grouting, even though its origins are over 30 years old (Jasperse and Ryan, 1992). However, it is fast becoming a popular process and can fulfill the same tasks as some of the other grouting methods (Taki and Yang, 1991). It features the introduction of cementitious grouts down the hollow stems of large diameter (20-40 in.) discontinuous flight augers as they are rotated to depth. Each rig may have up to 4 augers working in unison to encourage continuity of the soilcrete (Figure 3). Developments are being made with the injection of dry materials which react with the in-situ moisture of the soil (RODEM[S]). This method was used with distinction at Jackson Lake Dam, WY (Taki and Yang, 1991) to provide a hydraulic cut-off, and to form hexagonal cells to reduce foundation liquefaction potential. More recently it was used to form a similar seepage barrier in the rehabilitation of Cushman Dam, WA.

Rock

Rock grouting practice largely follows traditional lines (Ewart, 1985), although it would appear that more recent publications by specialists such as Houlsby (1990) and Weaver (1991) have had a refreshing and stimulating impact. As illustrated in Figure 4, there are three basic methods used for grouting stable rock masses:

1. Downstage (Descending stage) with top hole packer
2. Downstage with down hole packer, and
3. Upstage (Ascending stage).

Circuit grouting is, to the author's knowledge, no longer used.

The advantages and disadvantages of each method are summarized in Table 2. The competent rock available on most dam sites was ideally suited for upstage grouting and this has historically been the most common. Downstage methods have recently had more demand reflecting the challenges and difficulties posed by more difficult site and geological conditions which tend to characterize the remedial and hazardous waste markets. The work described by Weaver, et al. (1992), on the sealing of dolomites under an old industrial site at Niagara Falls, NY, represents a statement of the best of

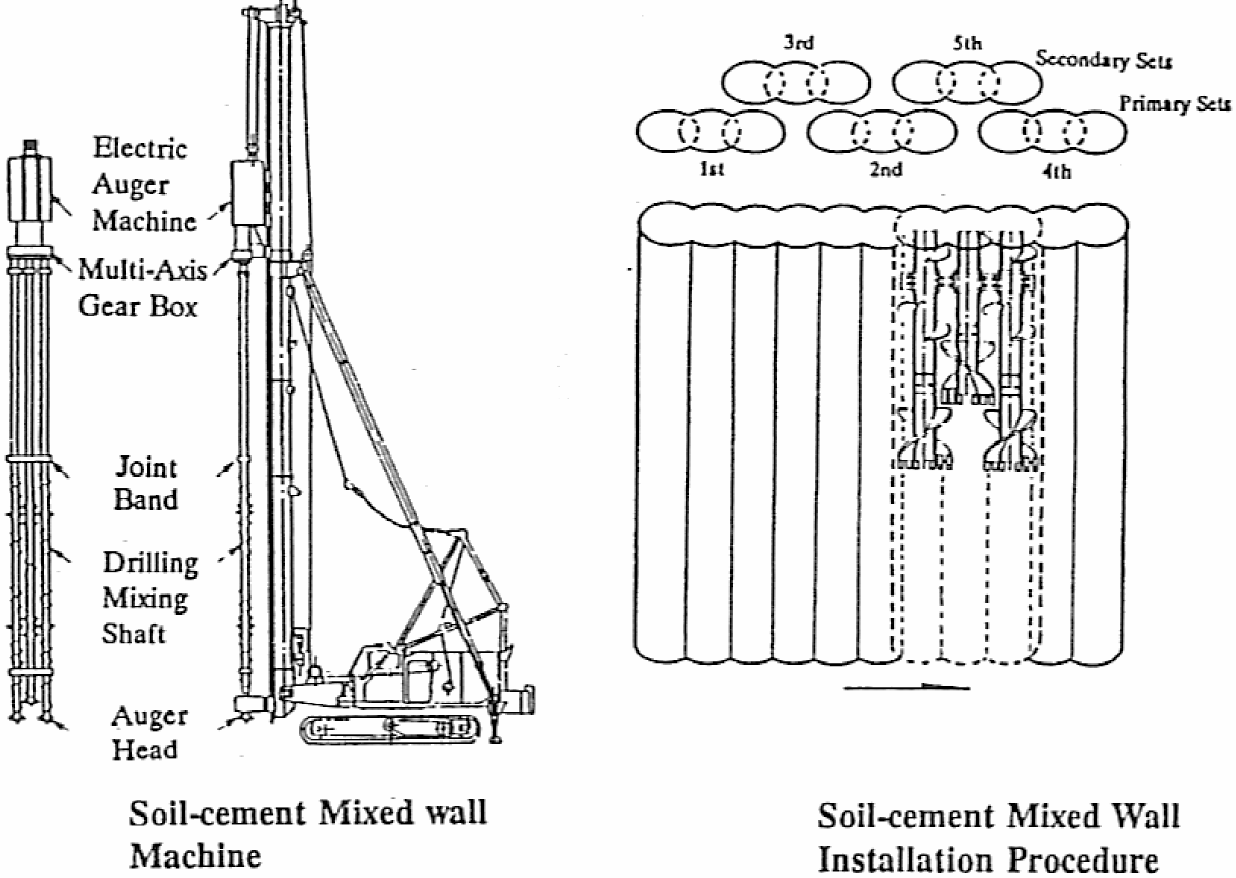


Figure 3. The concept of mechanical soil mixing (Taki and Yang, 1991)

American practice, while several other case histories were summarized by Bruce (1990, 1992).

In some cases of extremely weathered and/or collapsing bedrock, even descending stage methods can prove impractical, and two recent projects illustrate innovative trends. Firstly, at Lake Jocassee Dam, SC, a remedial grouting project was conducted (Bruce, et al., 1993) to reduce major seepages through the Left Abutment of the dam. Given the scope of operating within innovative contracting procedures, the contractor was able to vary the methods used in response to the extremely variable ground conditions actually encountered. Some holes permitted ascending stages, others needed descending stages, while the least stable had to be grouted through the rods during their slow withdrawal.

A second example is the grouting of poorly cemented hard rock backfill 2700 feet below ground level in a copper mine in Northern Ontario, Canada (Bruce and Kord, 1991). This medium proved so difficult to drill that none of the conventional grouting methods could be made to work. Instead, the first North American application of the MPSP system, devised by Rodio, in Italy, was called for. The Multiple Packer Sleeved Pipe system is similar to the sleeved tube (tube à manchette) principle in common use for grouting soils and the softest rocks (Bruce, 1982). The sleeve grout in the conventional system is replaced by concentric polypropylene fabric collars, clipped around sleeve ports at specific points along the tube (Figure 5). After placing the tube in the hole, the collars are inflated with cement grout, via a

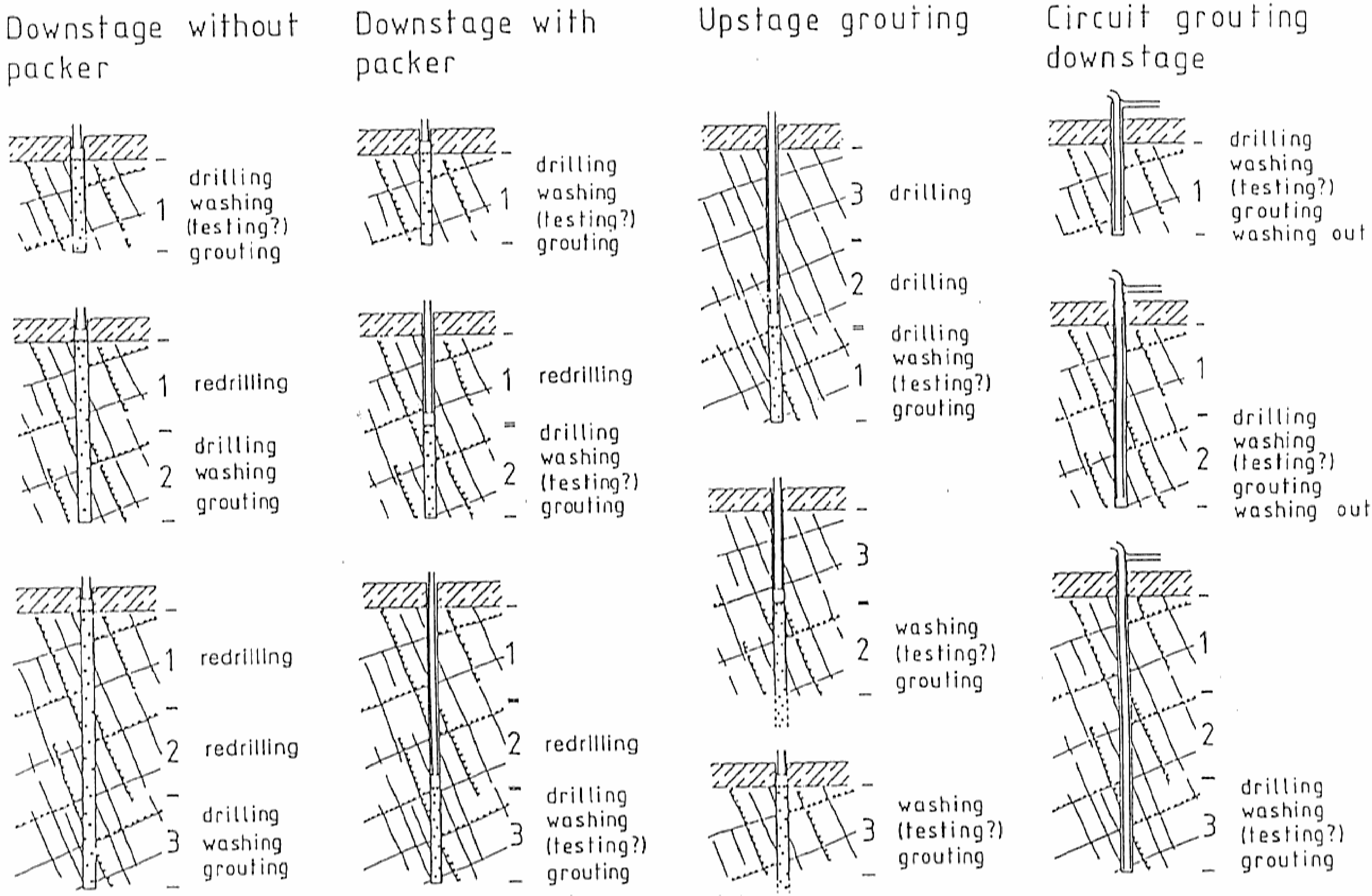


Figure 4. Conventional stage grouting methods for rock fissure grouting (Ewart, 1985)

	DOWNSTAGE	UPSTAGE
ADVANTAGES	1. Ground is consolidated from top down, aiding hole stability, packer seating and allowing successively higher pressures to be used with depth without fear of surface leakage. 2. Depth of hole need not be predetermined: grout take analyses may dictate changes from foreseen, and shortening or lengthening of hole can be easily accommodated. 3. Stage length can be adapted to conditions as encountered to allow "special" treatment.	1. Drilling in one pass. 2. Grouting in one repetitive operation without significant delays. 3. Less wasteful of materials. 4. Permits materials to be varied readily. 5. Easier to control and program. 6. Stage length can be varied to treat "special" zones. 7. Often cheaper since net drilling output rate is higher.
DISADVANTAGES	1. Requires repeated moving of drilling rig and redrilling of set grout: therefore process is discontinuous and may be more time consuming. 2. Relatively wasteful of materials and so generally restricted to cement-based grouts. 3. May lead to significant hole deviation. 4. Collapsing strata will prevent effective grouting of whole stage, unless circuit grouting method can be deployed. 5. Weathered and/or highly variable strata problemmatical. 6. Packer may be difficult to seat in such conditions.	1. Grouted depth predetermined. 2. Hole may collapse before packer introduced or after grouting starts leading to stuck packers, and incomplete treatment. 3. Grout may escape upwards into (non-grouted) upper layers or the overlying dam, either by hydrofracture or bypassing packer. Smaller fissures may not then be treated efficiently at depth. 4. Artesian conditions may pose problems. 5. Weathered and/or highly variable strata problemmatical.

Table 2. Major advantages and disadvantages of downstage and upstage grouting of rock masses (Bruce and Gallavresi, 1988)

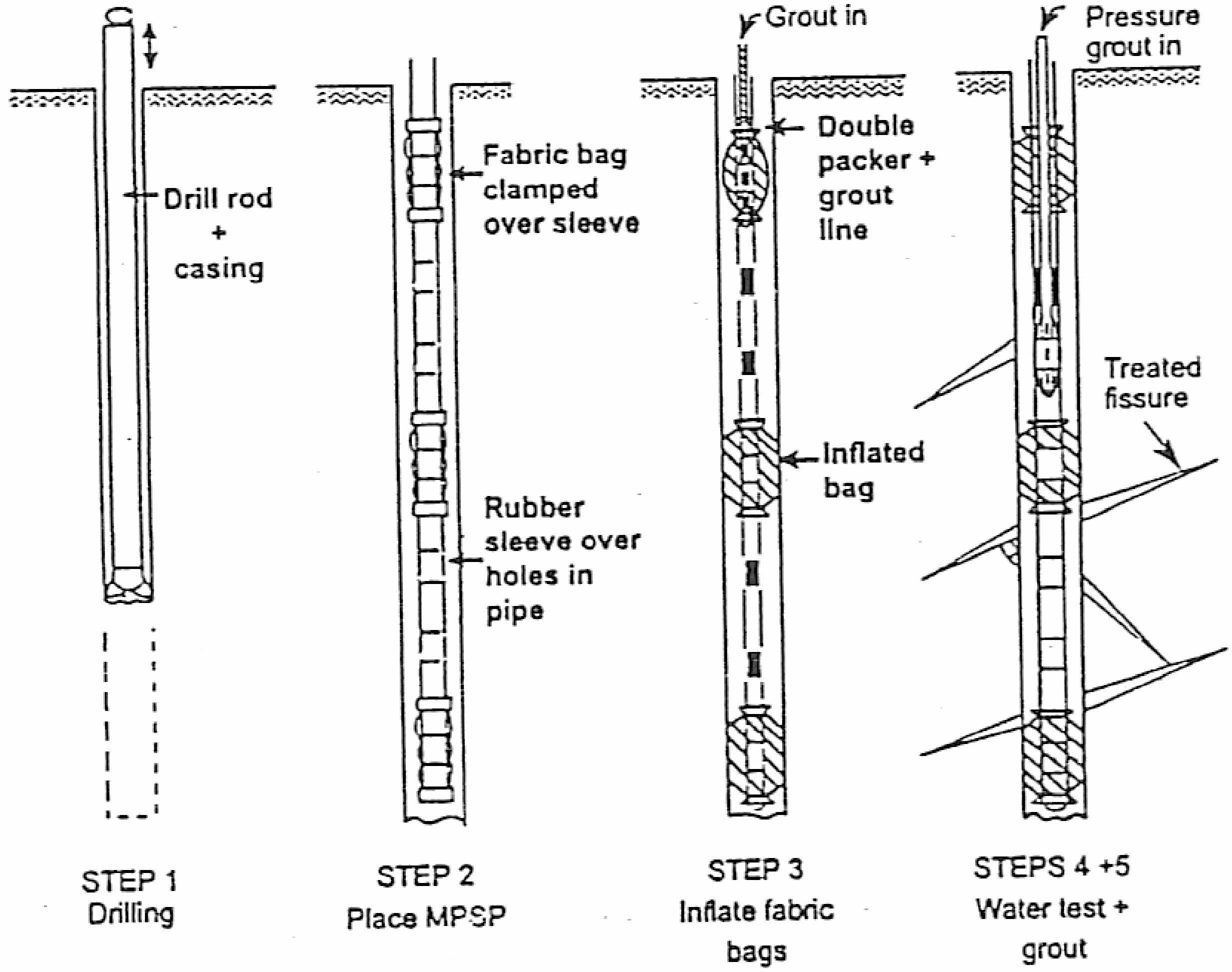


Figure 5. MPSP installation and grouting steps (Bruce and Kord, 1991).

double packer, and so the grout pipe is centered in the hole, and divides the hole into stages. Each stage can then be grouted with whatever material is judged appropriate, through the intermediate sleeved ports. Considerable potential is foreseen in loose, incompetent, or voided rock masses, especially karstic limestones (Bruce and Gallavresi, 1988). Several major dams in Europe and Asia have already been sealed using this technique.

GROUTING MATERIALS

There are a number of comprehensive but basically similar classifications of grout types (e.g., FHWA, 1976; Cambefort, 1977; Naudts, 1989; Karol, 1990 and AFTES, 1991). There are fundamentally three categories (Figure 6) which can be listed in order of rheological performance and cost:

1. Particulate (suspension or cementitious) grouts, having a Binghamian peformance.

2. Colloidal solutions, grouts which are evolutive Newtonian fluids in which the viscosity increases with time.

3. Pure solutions, non-evolutive Newtonian solutions in which the viscosity is constant until setting, within an adjustable period.

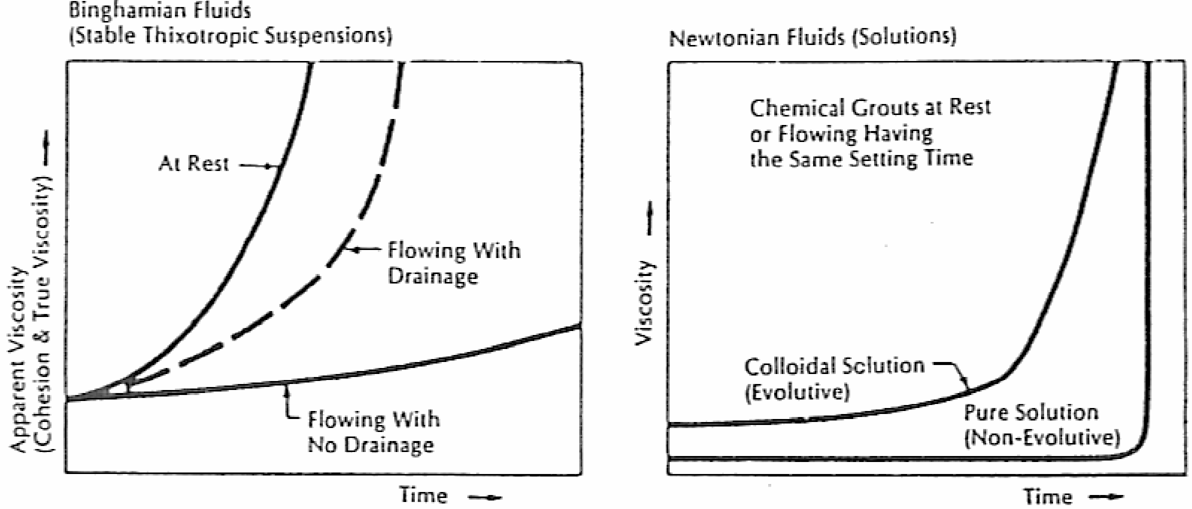


Figure 6. Rheological behavior of typical grouts (Mongilardi and Tornaghi, 1986)

Category 1 comprises mixtures of water and one or several particulate solids such as cement, flyash, clays or sands. Such mixes, depending on their composition, may prove to be stable (i.e. little or no sedimentation or bleeding) or unstable, when left at rest. Stable thixotropic grouts have both cohesion and plastic viscosity increasing with time at a rate which may be considerably accelerated under pressure.

Category 2 and 3 grouts are commonly referred to as "chemical grouts and are typically subdivided on the basis of their component chemistries, e.g., silicate based (Category 2) or resins (Category 3). The outstanding rheological properties of Category 3 grouts, together with their low viscosities permit permeation of soils as fine as silty sands ($k < 10^{-4}$ cm/s) (Figure 7).

RHEOLOGICAL CLASS	PARTICULATE SUSPENSIONS (BINGHAMIAN FLUIDS)			SOLUTIONS (NEWTONIAN FLUIDS)			GASEOUS EMULSIONS	
	UNSTABLE	STABLE		COLLOIDAL SOLUTIONS (EVOLUTIVE)		PURE SOLUTIONS (NON-EVOLUT.)		
MAIN TYPES OF GROUTS	CEMENT ONLY	CEMENT WITH BENTONITE OR CLAY	DEFLOCCULATED BENTONITE	CHEMICAL GROUTS: BASED ON SODIUM SILICATE – HIGH STRENGTH	CHEMICAL GROUTS: BASED ON SODIUM SILICATE – MEDIUM-LOW STRENGTH	CHEMICAL GROUTS: BASED ON ORGANIC RESINS	SWELLING GROUTS: BASED ON CEMENT	SWELLING GROUTS: BASED ON ORGANIC PRODUCTS
FIELDS OF APPLICABILITY	FISSURED ROCK AND MASONRY	GRANULAR SOILS: PREVAILING GRAVEL	GRANULAR SOILS: COARSE SANDS	MICRO-FISSURED AND POROUS ROCK; GRANULAR SOILS: MEDIUM-FINE SANDS	MICRO-FISSURED AND POROUS ROCK; GRANULAR SOILS: MEDIUM-FINE SANDS	MICRO-FISSURED AND POROUS ROCK; GRANULAR SOILS: FINE SILTY SANDS (SANDY SILTS)	LARGE VOIDS OR CAVITIES	CAVITIES WITH FAST FLOWING WATER
COEFFICIENT K OF PERMEABILITY (M/S)		> 5.10^{-4}	> 5.10^{-5}	> 5.10^{-5}	> 1.10^{-5} ①	> 1.10^{-6} ②		
SPECIFIC SURFACE S_s (m²/g)		< 0.5	< 1.5	< 1.5	< 4	< 10		
BASIC INJECTION PRINCIPLES	HIGH PRESSURE	CONTROLLED QUANTITY AND PRESSURE					LOW PRESSURE (FILLING)	

① LIMIT COVERED BY VISCOSITY/TIME EVOLUTION ② NORMAL LIMIT FOR UNIFORM IMPREGNATION

Figure 7. Categorization of grouts as related to groutable media (Gallavresi, 1992)

Details of their characteristics, properties advantages and disadvantages, are provided in the references above, but in this review the following subclassifications are presented:

PARTICULATE

1. <u>Cementitious Grouts</u>
   Fundamentally mixes of water and cement. They can include
   a) neat cement grouts (high strength, high durability)
   b) clay/bentonite cement (economic, stable, low strength)
   c) grouts with fillers such as sand (economic, void filling)
   d) for special applications (quickset, cellular, high strength)
   e) with improved penetrability (more efficient permeation of finer pores and fissures)

Category 1e) is especially relevant as much research (DePaoli, et al., 1992a, b) has been conducted recently into this aspect. Three avenues have been followed:

- improving rheology, using additives
- increasing stability to bleed and pressure filtration, also using additives
- reducing grain size, by using fine grained <u>cements</u> (e.g., Clarke, et al., 1992) or, better, by using site prepared fine grained <u>grouts</u> ("Cemill" Process)

COLLOIDAL SOLUTIONS

2. <u>Silicate Based Grouts</u>
   These conventionally comprise a mixture of sodium silicate and reagent solutions which react over time to produce a gel. Depending on component chemistries and concentrations, a wide range in viscosity, setting time, strength, stability and washout resistance can be achieved. The grain size of the soil being permeated also has a major control over the grouted soil properties.

PURE SOLUTIONS

3. <u>Resin Grouts</u>
   Resins are solutions of organic products in water or in a non aqueous solvent capable of causing the formation of a gel with specific mechanical properties under normal temperature conditions and in a closed environment. They react either by polymerization alone (activated by the addition of a catalyzing element) or by polymerization and polycondensation (arising from the combination of two components). They are used when cementitious or colloidal grouts are unable to provide certain desired properties such as very low viscosity, high early strength, variable setting time, chemical resistance, special rheologies, or resistance to groundwater flow.

   There are four categories:
   a) Acrylics
   b) Phenolics
   c) Aminoplastics
   d) Polyurethanes - water reactive
      - two component

To be generically comprehensive, one must also include a fourth category, namely "Miscellaneous" grouts. These include
   a) Bitumens (asphalt): used in particular waterproofing applications (Bruce, 1990; 1992)

b) Latex: coagulant polymer emulsions
c) Polyesters: comprising prepolymers in a reactant solution
d) Epoxies: giving high strength and adhesion
e) Furanic resins: polymerization of furylic alcohol and acid catalyst
f) Silicones: giving great flexibility and excellent chemical resistance
g) Silacsols: formed by reaction between an activated silica liquor and a calcium inorganic reagent. Give low viscosities, but high strength and great stability (Mongilardi and Tornaghi, 1986).

FINAL REMARKS

The topic of drilling and grouting techniques for dam rehabilitation is widely complex and challenging. However, as an introduction, various generic classifications can be established as a framework. The classifications identified in this paper help put in perspective the new developments which continue to occur in this important science. This paper is a very brief synopsis, and the interested reader is encouraged to pursue further details in the referenced publications.

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KEY WORDS

Drilling Techniques
Grouting Techniques
Grouting Materials
Embankment Dam Rehabilitation