Lecture 20

NPTEL Course

GROUND IMPROVEMENT

GROUND TREATMENT USING GROUTING

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Grouting technology has become a common ground improvement method used frequently for underground and foundation constructions. The process of grouting consists of filling pores or cavities in soil or rock with a liquid form material to decrease the permeability and improve the shear strength by increasing the cohesion when it is set. Cement base grout mixes are commonly used for gravely layers or fissure rock treatment. But the suspension grain size may be too big to penetrate sand or silty-sand layers. In this case, chemical or organic grout mixes are also used. In recent years, the availability of ultrafine grout mixes has extended the performance of hydraulic base grout for soil treatment.

Sandy gravel soil treated using ultrafine cement mix

- The grout mix can be generally classified into four types:
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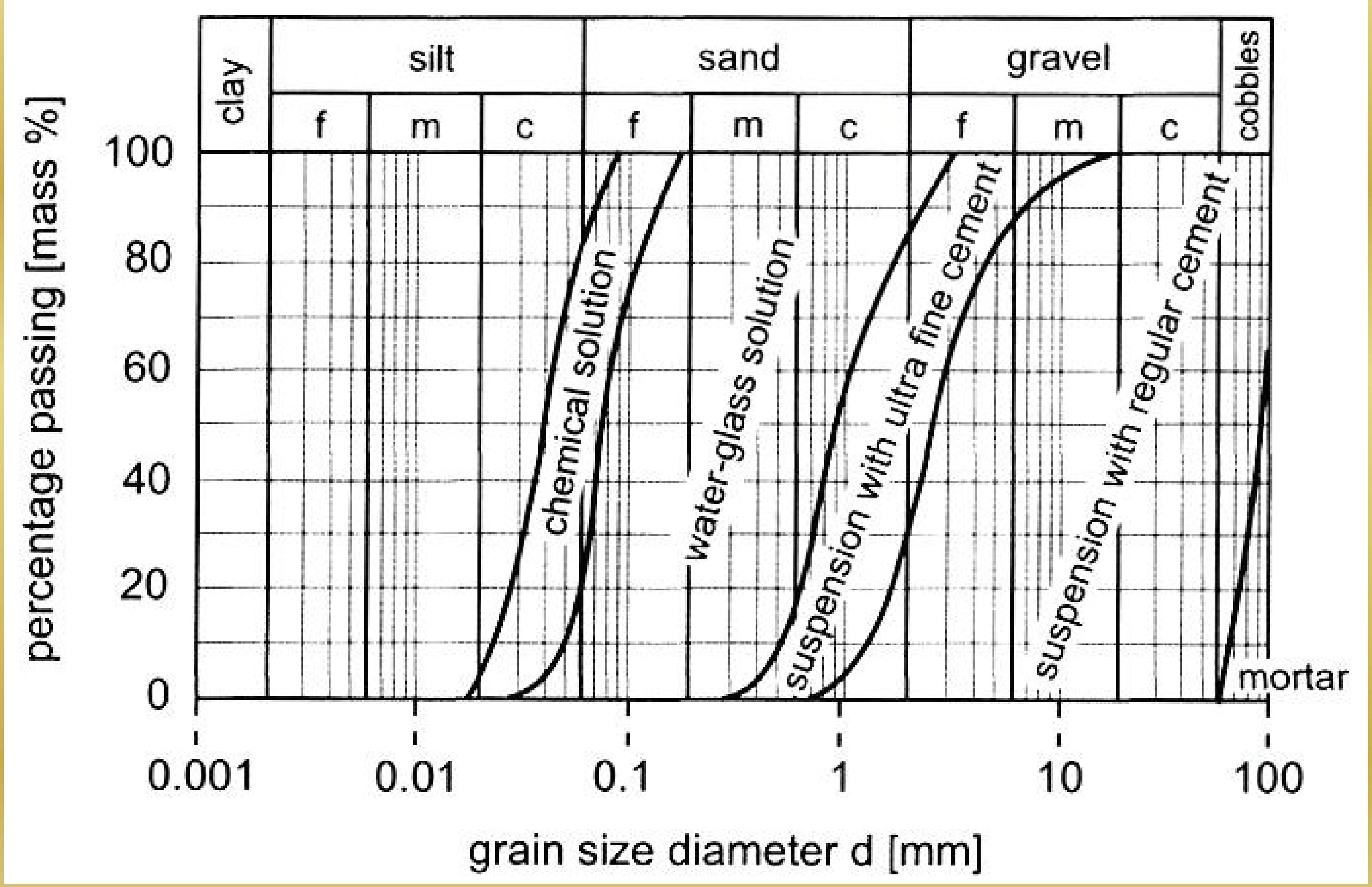
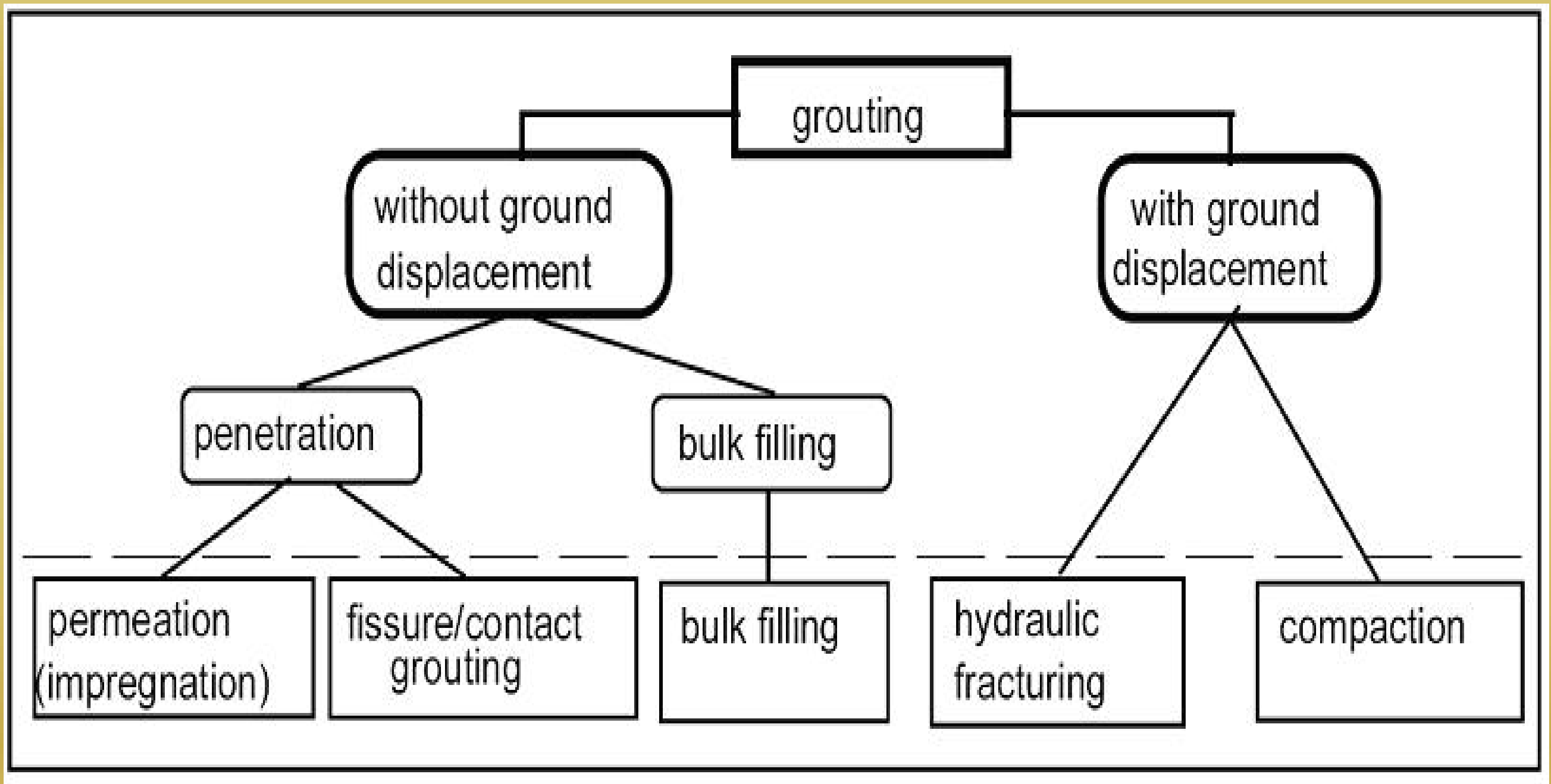
- (1) mortar and pastes such as cement to fill in holes or open cracks;
- (2) suspensions such as ultra-fine cement to seal and strengthen sand and joints;
- (3) solutions such as water glass (silicate) and
- (4) emulsions such as chemical grout.

The operational limits of different grout mix are dependent on the type of soils and the grain size distribution of the soil.



clay
silt
sand
gravel
cobbles
f
m
c
f
m
c
f
m
c
percentage passing [mass %]
100
80
60
40
20
0
chemical solution
water-glass solution
suspension with ultra fine cement
suspension with regular cement
mortar
0.001
0.01
0.1
1
10
100
grain size diameter d [mm]

Classification



- The design for grouting and/or alternatives needs
- (a) preliminary design or project planning and feasibility studies; adequate investigation to be carried out at the feasibility stage includes the characterization of ground and ground water and identifications of fractured rock, weathered rock, granular soils (alluvium, sand, & silts etc.), natural cavities (karsts), or galleries (mine workings, tunnels, storage galleries etc.).
- (b) detailed design or special studies.

Investigation methods

- Drilling and direct inspection to accurately locate and determine local conditions;
- Taking coring samples for laboratory tests;
- Drilling with drilling data recording to locate fissured zones, voids and the interface between structure and surrounding ground;
- Borehole logging with BHTV Scanner examination (optical/seismic);
- Non-destructive geophysical investigations (seismic resistivity);
- Water testing (constant head or falling head tests conducted in borehole;
- Underground flow & temperature measurements;
- Pumping test to assessment of initial hydraulic conditions.

Criteria for design

- The grout volume to be injected depends on ground porosity, geometry of the treated zone, grout hole spacing, stage length and total depth to be treated.

- The groutability of soil with particulate grouting has been evaluated based on the N value (Mitchell and Katti 1981)
- N is defined as $N = (D_{15})_{Soil} / (D_{65})_{Grout}$.
- Grouting is considered feasible if $N > 24$ and not feasible if $N < 11$
- Another alternative is to use $N_c = (D_{10})Soil / (D_{95})Grout$. Grouting is considered feasible if $N_c > 11$ and not feasible if $N_c < 6$ (Karol, 2003).

- Akbulut and Saglamer (2002) proposed a new N value as:

$$N = \frac{D_{10(soil)}}{D_{90(grout)}} + k_1 \frac{w/c}{FC} + k_2 \frac{P}{D_r}$$

- where w/c is the water cement ratio of the grout; FC is the total soil mass passing through 0.6 mm; P is the grouting pressure; D_r is the relative density of the soil; k_1 and k_2 are two constants. K_1 = 0.5 and k_2 = 0.01 1/kPa are suggested. Soil is considered groutable when N > 28 and not groutable when N < 28.

Categories of Grouting

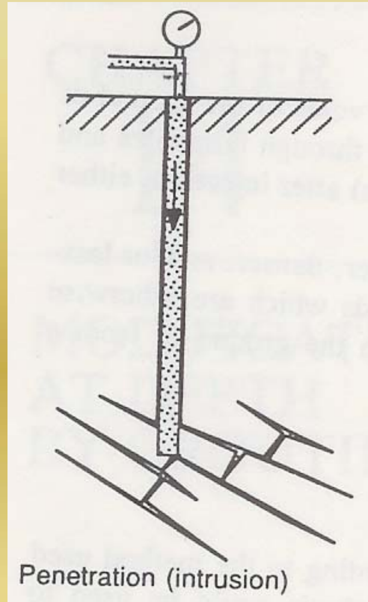
a. Penetration grouting

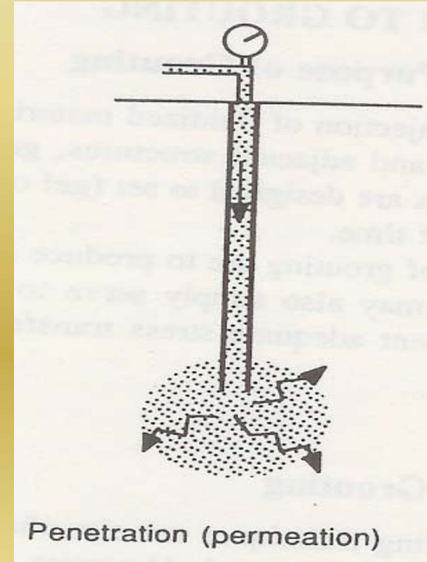
b. Displacement grouting

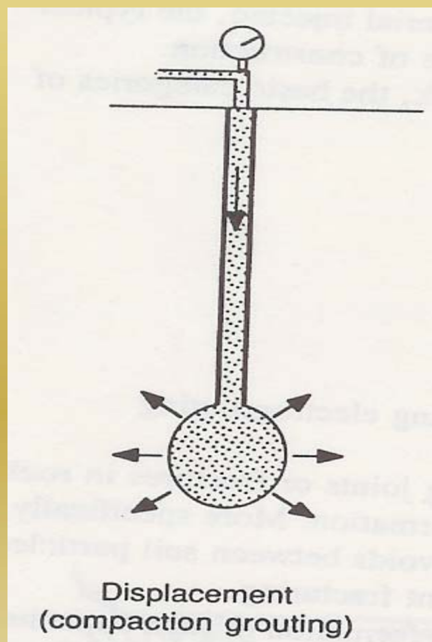
c. Compaction grouting

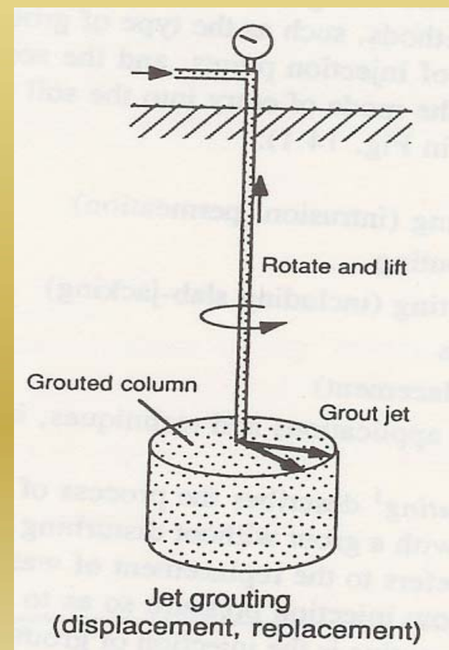
d. Grouting of Voids

e. Jet grouting

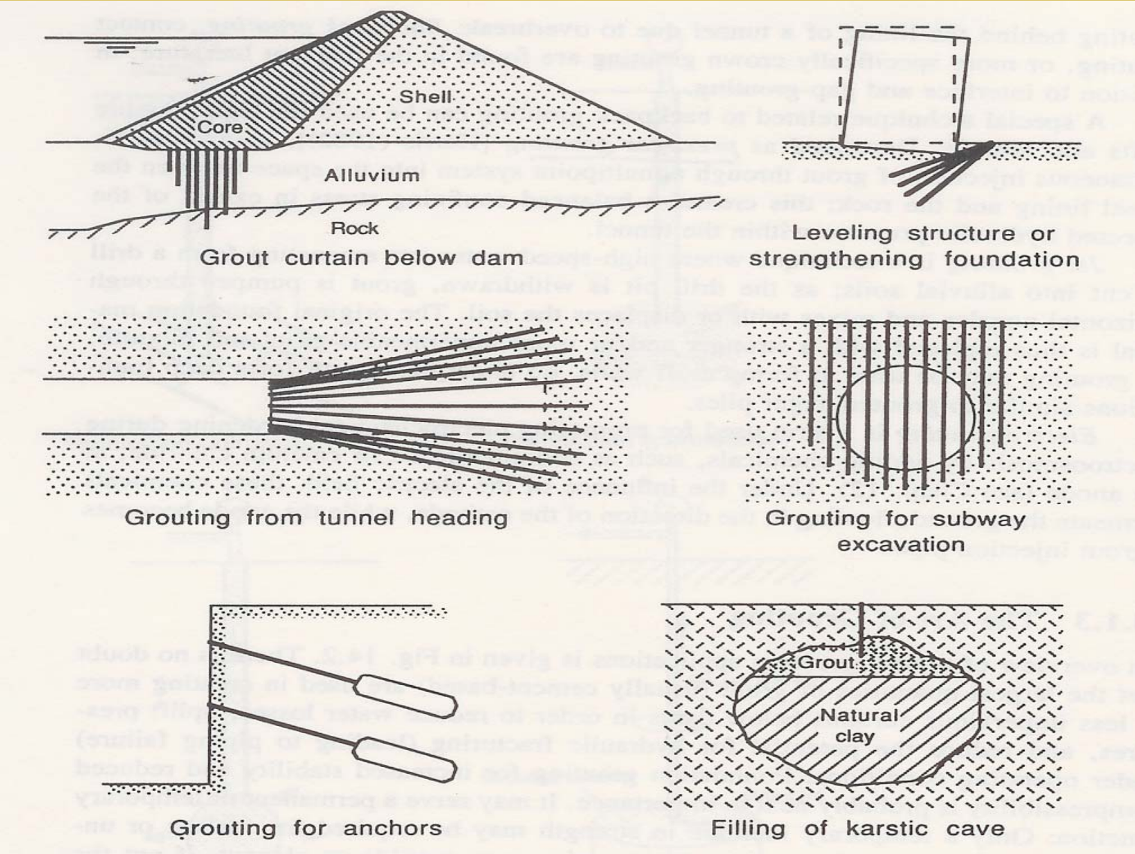








Schematic representation of basic modes of grouting



Typical applications of Grouting

Classification of Grout Materials

	State							
	Suspensions			Liquids			Aerated emulsions	
	Unstable		Stable	Chemical products				
Grout type	Cement	Bentonite + cement	Deflocculated bentonite	Sodium silicate hard gels	Sodium silicate diluted gels	Organic resins	Cement foams	Organic foams
Range of uses	Fissures	Sands and gravels, k m/s					Cavities	High water flows
		$>5 \times 10^{-4}$	$>10^{-4}$	$>10^{-4}$	$>10^{-5}$	$>10^{-6}$		
Grouting control	Refusal pressure	Limited quantities					Filling	
Relative cost for the products to fill 1-m³ voids	4.2 (deposit with γ_d = 1.5)	1 (cement 200 kg; betonite 30 kg)	0.8–1	6	2–4	10–500	1.2	10

Source: After Cambefort (1987).

Compaction Grouting

Compaction grouting is a ground treatment technique that involves injection of a thick-consistency soil-cement grout under pressure into the soil mass, consolidating, and thereby densifying surrounding soils in-place. The injected grout mass occupies void space created by pressure-densification. Pump pressure, as transmitted through low-mobility grout, produces compaction by displacing soil at depth until resisted by the weight of overlying soils.

When injected into very dense soils or bedrock, compaction grout remains somewhat confined, since the surrounding material is quite dense. However, when injected into under-consolidated or poorly-compacted soils, grout is able to "push" these materials aside.

When grouting treatment is applied on a grid pattern, the result is improved compaction of displaced soils, and greater uniformity of the treated soil mass. As a secondary benefit, the resulting grout columns add strength in the vertical axis, as typical grout compressive strengths exceed those of the surrounding soils.

Compaction grouting applications include densification of foundation soils, raising and relieving of structures and foundation elements, mitigation of liquefaction potential, augmentation of pile capacity and pile repair, and densification of utility trench backfill soils.

Although densification of foundation soils subject to long-term settlement remains to be the principal application, ground improvement methods incorporating compaction grouting methods have become increasingly accepted by the engineering community as a means of mitigating liquefiable soils influencing existing facilities. Inherent in the grouting process is the capacity to work in areas of limited access and existing improvements to treat discrete zones within the soil profile.

Permeation Grouting

Permeation grouting is a term used to describe a ground treatment method in which grout is injected into a porous medium without disturbing its original structure. In geotechnical engineering, this usually refers to the process of filling the pores and joints in a soil and/or rock deposit to change its geotechnical properties. Almost any grout material may used for permeation grouting, but there are distinct limits on the grout mix used for specific types of soil or rock. Applications are for enhanced foundation bearing value, improvement of excavation character in sands and reduction of liquefaction potential.

Permeation Grouting

The image shows a sample of permeation grouted sand from a project that required steep-walled footing excavations in running sands. The proposed excavation area was permeation grouted with a microfine cement slurry prior to cutting footing trenches, resulting in a significant reduction in project cost. Unconfined compressive strength tests performed confirmed the improvement

Particulate grouts are typically water-based slurries of cement, fly ash, lime or other finely ground solids that undergo a hardening process with time. These materials may be used to fill pores and joints in soil and rock, provided the grout particles are small enough to be carried through the pore or joint openings. A good rule of thumb is that the effective particle diameter in the grout suspension should be less than the dimension of the pore or joint aperture divided by 5.

Slurry grout mixes used for permeation grouting are designed primarily to promote passage of the grout particles into the porous medium. The grain size of the slurry is matched to the pore aperture and steps are taken to assure the grout particles are properly dispersed in the grout.

Both high speed mixing and wetting agents are used to break up clumps and aggregations of grout particles that would cause the grout to have a lager apparent grain size than the actual grain size of the slurry. Water content is adjusted in the mix design to control the mean free path between the slurry particles rather than simply providing enough water to allow complete hydration.

Two types of slurries are used. The stable slurries exhibit less than 10% bleed (separation of water from the slurry) at final set. Unstable slurries bleed from 10 to 90% of the water prior to setting.

When solids and water are mixed, the solid particles begin to settle out and water is displaced upward (bleed). The forces acting in the suspension to reduce the settling of the particles are random impacts of water molecules against the particle, viscosity of the water, interparticle attraction and friction. Since the interparticle attraction is inversely proportional to the square of the mean free path length between particles and the other forces are inversely proportional to the cube of the particle diameter, either reducing the particle size or increasing concentration reduces the bleed. As a general rule, for Portland Cement grout 0.66 : 1 is the water to cement ratio (by weight) which is the borderline between stable and unstable grout.

Stable slurries are too thick to be used for permeation grouting of all but the most coarse grained soils or extremely fractured rock. Unstable slurries having water to cement ratios from 0.66 : 1 to 3 : 1 (by weight) may be used to permeation grout granular soils with effective grain size down to coarse sand or fractured rock with joint widths as low as 0.01 inch. However, the bleeding of these grouts causes channels and open pathways to remain through the grout.

To eliminate the effect of bleed on Portland cement grout, additives are used to hold the cement grains in suspension at water to cement ratios that would otherwise be quite unstable. The most common additive is a water suspension of bentonite. Even small amounts of bentonite increase the interparticle forces dramatically and hold the cement particles in suspension.

Typically, element/bentonite grout used for permeation grouting has water to cement ratio varying between 1 : 1 and 2.65 : 1 and exhibits zero bleed.

In many cases, it is necessary to grout soil and rock formations having an effective pore aperture smaller than the allowable aperture for Portland cement grout. Type III cement or microfine cement grouts are used to grout these finer materials. The grain size of Type III cement is about 20 microns v. 50 microns for Type II, while the grain size of the microfine cement grouts is between 4 to 8 microns. (Note: at smaller grain sizes, the interparticle attraction forces become very large in comparison to the weight of the grain and the benefits of reducing grain size are lost).