CHAPTER VII

GROUTING

1. Compaction Grouting
2. Chemical Grouting
3. Cement Grouting
4. Jet Grouting
5. Fracture Grouting

Compaction Grouting

Compaction grouting is a technique whereby a slow-flowing water/sand/cement mix is injected under pressure into a granular soil.

- Compaction grouting is a soil and foundation-support improvement process that increases bearing capacity.
• The grout forms a bulb that displaces and hence densifies, the surrounding soil.

• Compaction grouting is a good option if the foundation of an existing building requires improvement,

  since it is possible to inject the grout from the side or at an inclined angle to reach beneath the building.
Compaction Grouting
Compaction Grouting Applications

- Karstic Regions
- Rubble Fill
- Poorly Placed Fill
- Loosened Soil: Pre-Treatment
- Loosened Soil: Post-Treatment
- Liquefiable Soils
- Collapsible Soils
Compaction Grouting Applications

- To Compensate for Ground Loss During Tunneling

- To lift and re-level roads and existing structures,

- To block the flow-path of liquids,

- To remediate sinkholes.

This grouting process is one of the best tools to improve the foundations of structures.

Compaction grouting is usually applied in stages from the lowest point upward.

On shallow applications, it can be injected from the top down.

This method compacts the upper area of the soil first so that the upper layer becomes a dense cap of overburden to help contain the pressure at lower levels.

When applied in a grid layout, the treated soil has a greater uniformity throughout its entire mass.
Compaction Grouting Geotechnical Considerations

Several conditions must exist in order for compaction grouting to yield its best results:

- The *in situ vertical stress* in the treatment stratum must be sufficient to enable the grout to displace the soil horizontally

(if uncontrolled heave of the ground surface occurs, densification will be minimized).
• The grout injection rate should be slow enough to allow pore pressure dissipation.

Pore pressure dissipation should also be considered in hole spacing and sequencing.

• Sequencing of grout injection is also important.

• If the soil is not near saturation, compaction grouting can usually be effective in most silts and sands.
• Soils that lose strength during remolding (saturated, fine-grained soils; sensitive clays) should be avoided.

• Collapsible soils can usually be treated effectively with the addition of water during drilling prior to compaction grout injection.

• Stratified soils, particularly thinly stratified soils, can be caused for difficult or reduced improvement capability.

Range of Improvable Soils
Advantages of Compaction Grouting

- Pinpoint treatment
- Speed of installation
- Wide applications range
- Effective in a variety of soil conditions
- Can be performed in very tight access
- Non-hazardous
- No waste spoil disposal

- No need to connect to footing or column
- Non-destructive and adaptable to existing foundations
- Economic alternative to removal and replacement or piling
- Able to reach depths unattainable by other methods
- Minimal impact to surface environment
Chemical Grouting

• **Structural Chemical Grouting** is the permeation of sands with fluid grouts to produce sandstone like masses to carry loads.

• **Water Control Chemical Grouting** is the permeation of sands with fluid grouts to completely fill voids to control water flow.

**Chemical (Permeation) Grouting Applications**

• For lagging (covering, casing) operation

• Support of footing

• Grouted tunnel support

• Grouted cut-off wall

• Grouted pipeline support
Soil "Groutability"

![Diagram of soil groutability](image)

<table>
<thead>
<tr>
<th>Gravel</th>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Chart" /></td>
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<td><img src="image" alt="Chart" /></td>
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</tbody>
</table>

Percent Passing

Particle Size - mm
Chemical Grouting Assurance (QA) Methods

- Permeability
- Inspection Pits
- Pressuremeter Testing (PMT)
- Standard Penetration Testing (SPT)
- Reinjection Testing
- Radar Profiling
- Seismic Velocity (shear wave) Profiling

Chemical Grout Types

- Sodium Silicates
- Acrylates
- Acrylamides
- Polyurethanes
- MC-Silicates
**Cement Grouting**

Cement Grouting, also known as Slurry Grouting,

is the intrusion under pressure of flowable particulate grouts into

- open cracks and voids and
- expanded fractures.
Slurry Grouting Applications

- Rock foundation treatment for dams
- Rock cut-off curtains
- Pressure injected anchors
- Stabilization of gravels and shot rock

Slurry Grout Materials

- Cement
- Clay (Bentonite)
- Sand
- Additives
- Microfine Cement
- Fly Ash
- Lime
- Water
Jet Grouting

- Jet grouting is an *in-situ* mixing of soils with a stabilizer (usually neat cement grout).

- The stabilizer is injected at very high pressures (between 300 and 600 bar) through a nozzle of small diameter.
Important Geotechnical and Structural Considerations

• Jet Grouting is effective across the widest range of soil types, of any grouting system, including silts and some clays.

• Because it is an erosion based system, soil erodibility plays a major role in predicting geometry, quality and production.

• Cohesionless soils are typically more erodible than cohesive soils.
The grout is injected at high velocity, which enables the jet grouting process:

- to destroy the natural matrix of the soil and
- creates a mixing of the stabilizer with the in-situ soils.

The result is a homogeneous and continuous structural element with predetermined characteristics.

Jet grouting can be applied to a wide range of soils from:

- non-cohesive, poorly graded granular soils
- to cohesive plastic clays.

The jet grouting technique is a superior alternative to other grout injection methods owing to its fundamental differences.
JET GROUT INJECTION METHOD

- Drilling is performed using rotary drilling techniques and an external water flush with special drill rods and bits.

- Upon the completion of the advancement of the drill rods to the design depth, the jet grouting process commences.

- The grout is forced out of the lateral nozzle at high pressure and velocity, thus destroying the soil matrix and forming consolidated elements.
Jet Grouting Process
• Many structures and geometries can be achieved by altering the parameters of the jetting procedure.

• The illustrated procedure details the creation of a jet grout column by continuous controlled rotation of the drill string at pre-set lifting increments.
Advantages of Jet Grouting

• Nearly all soil types groutable and any cross section of soilcrete possible

• Most effective method of direct underpinning of structures and utilities

• Safest method of underpinning construction

• Ability to work around buried active utilities

• Can be performed in limited workspace

• Specific in situ replacement possible

• Treatment to specific subsurface locations

• Designable strength and permeability

• Only inert components

• No harmful vibrations

• Maintenance-free

• Much faster than alternative methods
APPLICATIONS

• Soil Stabilization Excavation Support Systems

• Structural Underpinning

• Seepage Barrier/Cutoff Walls

• Environmental Remediation

Jet Grouting Applications
There are three traditional jet grouting systems.

- Selection of the most appropriate system is generally determined by
- the in situ soil,
- the application, and
- the physical characteristics of soilcrete (i.e. strength) required for that application.

However, any system can be used for almost any application, provided that the right design and operating procedures are used.

**JET GROUTING SYSTEMS**

Jet 1 - Single Fluid.

Jet 2 - Double Fluid.

Jet 3 - Triple Fluid.
Jet Grouting Systems

Jet 1 - Single Fluid Jet Grouting (Soilcrete S)

- This system is the most simple, as well as the method of choice of most qualified specialty contractors.

- The system has been tested and developed in Italy since the mid 1970’s to its present state-of-the-art.
• Grout is pumped through the rod and exits the horizontal nozzle(s) in the monitor at high velocity [approximately 650 ft/sec (200m/sec)].

• This energy breaks down the soil matrix and replaces it with a mixture of grout slurry and in situ soil (soilcrete).

• The neat cement grout is injected through a small nozzle at high pressure and mixes with the in-situ soil.

• This method produces the most homogeneous soil-cement element with the highest strength and the least amount of grout spoil return.

• Single fluid jet grouting is most effective in cohesionless soils.
Jet 2 -Double Fluid.

- The two fluids referred to in this method are neat cement grout and air.

- The neat cement grout is injected at a lower pressure and is aided by a cone of compressed air, which shrouds (cover) the grout injection.

- The air reduces the friction loss allowing the cement grout to travel further from the injection point thereby producing greater column diameters.

- However, the presence of the air reduces the strength of the column as compared to the single fluid method, and produces more spoil return.
Jet 3 - Triple Fluid.

The three fluids referred to in this method are neat
- cement grout,
- air and
- water.

Unlike Jet 1 and Jet 2, water is injected at high pressure and is aided by a cone of compressed air, which shrouds the water injection.
• **Grout, air and water** are pumped through different lines to the monitor. Coaxial air and high-velocity water form the erosion medium.

• **Grout** emerges at a lower velocity from separate nozzle(s) below the erosion jet(s).

This separates the erosion process from the grouting process and tends to yield a higher quality soilcrete.

• **Triple fluid jet grouting** is the most effective system for cohesive soils.

• The grout is injected through a separate nozzle below the water and air nozzles to fill the void created by the air lifting process.

• Jet 3 is a soil replacement method not an *in-situ mixing method*. 
**Jet Grouting**

**Range of Jet Grout Element Properties**

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Column Diameter</th>
<th>Soilcrete Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Jet 1</strong></td>
<td>2' - 3' (up to 3.5&quot;)</td>
<td>1000 - 3000 psi</td>
</tr>
<tr>
<td>Sands &amp; Gravels</td>
<td>2' - 3'</td>
<td>250 - 1000 psi</td>
</tr>
<tr>
<td>Clay</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Jet 2</strong></td>
<td>3' - 6' (up to 10&quot;)</td>
<td>500 - 2000 psi</td>
</tr>
<tr>
<td>Sands &amp; Gravels</td>
<td>3' - 5'</td>
<td>150 - 1000 psi</td>
</tr>
<tr>
<td>Clay</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Jet 3</strong></td>
<td>5' - 8'</td>
<td>500 - 1500 psi</td>
</tr>
<tr>
<td>Sands &amp; Gravels</td>
<td>3' - 6'</td>
<td>150 - 750 psi</td>
</tr>
<tr>
<td>Clay</td>
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</tbody>
</table>
Fracture Grouting

Fracture Grouting, also known as Compensation Grouting

Because the process requires only that the soil is fractured,

Fracture Grouting may be used in most low permeability soil types ranging from weak rocks to clays.

Fracture Grouting Soil Types
Fracture Grouting Applications

Typical applications of the Fracture Grouting process are:

• Reduction or reversal of differential settlement

• Reduction or reversal of total settlement

• Prevention of the settlement of buildings as tunneling is carried out
Method of Working - Fracture Grouting

• Sink Shaft

• Install sleeved pipes

• Condition grout

• Inject grout as necessary

• Reinjection unlimited, without redrilling