Compaction and Jet Grouting

Alan Ringen, PE
Senior Vice President

Breakthroughs in Tunneling Short Course

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Geotechnical Grouting: The injection of pumpable fluid materials into a soil or rock formation to change the physical characteristics of the formation.
Grouting Principles

- Grouting can...
  - Add cohesion to granular soils
  - Decrease permeability
  - Reduce or offset settlements
  - Provide excavation support
  - Mitigate liquefaction potential
Grouting Principles

• Grouting can prevent...
  • Collapse of granular soils
  • Settlement under adjacent foundations
  • Utility damage
  • Tunnel day-lighting
Grouting Types

- Slurry Grout
  - Intrusion

- Chemical Grout
  - Permeation

- Compaction Grout
  - Displacement

- Jet Grout
  - Erosion

- Fracture Grout
  - Compensation
Applicable Range of Soils by Method

![Graph showing the applicable range of soils by method.](image)
Grouting Types

- Slurry Grout (Intrusion)
- Chemical Grout (Permeation)
- Compaction Grout (Displacement)
- Jet Grout (Erosion)
- Fracture Grout (Compensation)
Compaction Grouting uses displacement to improve ground conditions. A low-mobility aggregate grout is pumped in stages, forming grout bulbs, which displace and densify the surrounding soils.
Compaction Grouting Applications

- Karstic Regions (sinkhole remediation)
- Rubble Fill
- Poorly Placed Fill
- Loosened Soil: Pre-Treatment
- Loosened Soil: Post-Treatment
- Liquefiable Soils
- Collapsible Soils
- To compensate for ground loss during tunneling
Compaction Grouting Applications
Compaction Grouting Process

Installation of grout pipe:

- Drill or drive casing
- Location very important
- Record ground information from casing installation
Compaction Grouting Process

Initiation of grouting:
• Typically bottom up, but can be done top down
• Grout rheology important (low mobility, not necessarily low slump)
• Slow, uniform stage injection
Compaction Grouting Process

Continuation of grouting:

• Pressure, grout quantity, injection rate, and indication of heave are controlling factors.

• Usually pressure and/or volume limited.

• On-site batching can aid control.

• Sequencing of injection points very important.
Compaction Grouting to Mitigate Tunnel Induced Settlement
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

More…
Geotechnical Considerations, continued

- Soils that lose strength during remolding (saturated, fine-grained soils; sensitive clays) should be avoided.
- Greater displacement will occur in weaker soil strata. Exhumed grout bulbs confirm that compaction grouting focuses improvement where it is most needed.
- 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 cause for difficult or reduced improvement capability.
- Rate of tunnel advance and tunneling method.
Compaction Grouting QA/QC

Quality Control includes procedural inspection and documentation of the work activity (injection rates, pressures, and ground heave or structure movement), testing to ensure proper mix design, and verification of ground improvement where applicable.

Quality Assurance can be assessed by Standard Penetration Testing, Cone Penetrometer Testing, or other similar methods. Computer data recording of important grouting parameters has been utilized on sensitive projects.
Compaction Grouting Advantages

- Pinpoint treatment
- Speed of installation
- Wide range of applications
- Effective in a variety of soil conditions
- Can be performed in very tight access and low headroom conditions
- No need to connect to footing or column
- Non-hazardous
- Minimal waste spoil disposal
- Economic alternative to removal and replacement or piling
- Minimal impact to surface environment
Grouting Types

- Slurry Grout (Intrusion)
- Chemical Grout (Permeation)
- Compaction Grout (Displacement)
- Jet Grout (Erosion)
- Fracture Grout (Compensation)
Jet Grouting is a versatile hydraulic erosion and mixing system used to create various geometries of soil-cement in-situ generally with limited access required.
Jet Grouting Systems

- Three traditional jet grouting systems: Single, Double, & Triple Fluid

- Selection of a system is generally determined by:
  - Soil type
  - Application
  - Required geometry, strength, & permeability
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 in situ and mixes it with a cement grout slurry.

Single fluid jet grouting is most effective in cohesionless soils.
Double Fluid Jet Grouting

A two-phase internal fluid system is employed for the separate supply of grout and air down to different, concentric nozzles.

The grout erodes the soil in similar manner as with Single Fluid. However, erosion efficiency is increased by shrouding the grout jet with air.

Jet Grout columns with diameters over 3 feet can be achieved in medium to dense soils, and more than 6 feet in loose soils.

The double fluid system is more effective in cohesive soils than the single fluid system.
Triple Fluid Jet Grouting

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 soil-cement mix.

Triple fluid jet grouting is the most effective system for cohesive soils.
Jet Grouting Process
Large Diameter Jet Grouting

Enhanced tool development has lead to several jet grouting systems, typically modified double fluid, that are capable of creating significantly larger soil-cement columns.

These systems use opposing nozzles and highly sophisticated jetting monitors specifically designed to focus the injection media. Using very slow rotation and lift rates, soil-cement column diameters of 10-16 feet (3-5m) can be achieved.

These systems are most effective and efficient for mass stabilization applications or where surgical treatment is necessary at depth.
Jet Grouting Process
Jet Grouting Considerations

- Jet grouting is effective across the widest range of soil types.
- It is an erosion based system.
Jet grouting is an erosion based system, therefore soil erodibility plays a major role in predicting geometry, quality and production.

Cohesionless soils are typically more erodible than cohesive soils.
Jet grouted soil-cement mix strengths are highly variable, particularly in layered soils. This chart represents an estimate of the average results expected.
Jet grouting offers an alternative to conventional grouting, chemical grouting, deep slurry trenching, proprietary underpinning systems, or the use of compressed air or freezing in tunneling.

Jet grouting should be considered in any situation requiring control of groundwater, or excavation of unstable soil, whether water-bearing or otherwise.
Jet Grouting Applications
Jet Grouting

Design Considerations for Underpinning
- Bearing capacity of the system
- Retaining system evaluation for lateral earth pressures and surcharge loads
- Settlement review
- Strength adequacy of the system

Design Considerations for Excavation Support
- What depth is necessary and what shear strength and geometry of soil-cement will resist the surcharge, soil and water pressure imposed after excavation?
- Are soil anchors or internal bracing necessary?

Design Considerations for Groundwater Control
- What integrity is possible from interconnected soil-cement elements and how much water can be tolerated through the soil-cement barrier?
Jet Grouting

Operating Parameters

The operating parameters of air, water and/or grout flow, and pressure, together with monitor rotation and withdrawal speed are selected (following detailed engineering assessment of soil conditions) and are automatically controlled and monitored throughout construction. Reduced flow or increased withdrawal speed produces a smaller jet grout geometry. These parameters are dependent on the specific system, equipment and tooling utilized by the specialty contractor.
Jet Grouting Design

Theoretically, treatment depth is unlimited, but Jet Grouting has rarely been performed to depths greater than 164 feet (50m).

Treatment can also be pinpointed to a specific strata. The size of the soil-cement mass to be created is determined by the application.

Accurate, detailed and frequent description of soil type, with reasonable assessment of strength or density allows these predictions to be made with confidence.
Jet Grout Design Geometries

The size of the soil-cement mass is determined by the application.

The width or diameter of each panel or column is determined during the design stage based on the soils and system to be employed.

If required, shear and/or tensile reinforcement can be incorporated into the soil-cement.
Jet Grouting Advantages

- Nearly all soil types are groutable and virtually any cross section is 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
- Treatment to specific subsurface locations
- Designable strength and permeability
- Only inert components
- No harmful vibrations
- Maintenance-free
Jet Grouting QA/QC Methods

- Daily report forms -- procedures of treatment
- Data acquisition systems record all jet parameters
- Sampling of waste materials -- conservative relative assessment of in situ characteristics
- Core samples
Jet Grout Docking Block for TBM

Jet Grouting was used to stabilize soil ahead of a TBM in order to perform unanticipated maintenance in front of the cutter head at a depth of 120 feet, 80 feet below the water table.
Jet Grout Shaft Bottom Seal & Break In/Out Blocks
Questions?

Thank You!

Alan R. Ringen, P.E.
Senior Vice President
JAFEC USA, Inc.
2025 Gateway Place, Suite 180
San Jose, CA 95110
408.472.6175