Grouting

Grouting is an in-situ ground improvement method comprised of a variety of techniques used to improve the engineering properties of soil and rock by injecting liquid, mixed suspensions, or semi-solid mixtures under pressure via boreholes.

Common grouting methods most likely to be used for Caltrans projects include:

- Conventional (Bulk-Infill) Grouting
- Compaction Grouting
- Jet Grouting
- Permeation Grouting

Common grouting materials can be either cement grout or chemical grout, depending on the grouting method used and the in-situ ground conditions.

The grouting method to be used depends on the project objectives, performance requirements, and subsurface conditions. A successful grouting project requires:

- Detailed geotechnical investigation

  The geotechnical investigation must be more detailed than is normally performed to identify in-situ conditions that could affect the effectiveness of the grouting program. Soil gradation, density, consistency, cavity size, presence of hardpan, gravels, depth of bedrock, groundwater, and the reasons for the grouting project, etc. can all affect the selection of grouting methods and grout mix design.

- Well defined performance requirements

  The objectives of the project and the reasons for using a grouting method, either to control settlement, increase shear strength, provide support, or control groundwater, must be identified. Then, performance requirements, such as compressibility, density of soil, shear strength of the matrix, or hydraulic conductivity of the grout columns should be established.

- Active monitoring during construction

  To adapt to subsurface conditions during construction, real time monitoring is needed so that grouting parameters can be adjusted, such as grouting pressure, rotation and lift rate, grout viscosity.

  To be able to monitor the contractor's quality control records, the Special Provisions need to include the requirements for the daily submittal and review of construction records, including hole location, depth, drilling and rotation rate, grout mix design, pumping rate, jet pressure, grout intake, spoil volume, etc.

- Verification of performance requirements

  A comprehensive grouting program must include a means to verify that performance requirements have been met. The verification and proof tests may include CPT soundings, load tests, core recovery, RQD, compression or shear tests of grout specimens, pressuremeter tests, packer tests of grout columns for hydraulic conductivity, and measurement of grout column diameters.

Grouting methods have a distinct economic advantage over removal and replacement. Grouting is generally less disruptive to the surrounding work area. Grouting methods also have their limitations. The general limitation of grouting methods is the soil type to be treated. Although the range of soil grouting methods available encompasses most soil types, individual methods are limited to specific soils as shown in the following figure. In general, most grouting methods are not effective in high plastic clays. For example, instead of squeezing the pore water out, compaction grouting may simply displace and not consolidate or densify fat clays.

Permeation grouting using certain chemical grouts may represent toxicity dangers to the groundwater and underground environment. Most grouting methods can cause ground movement and structural distress.

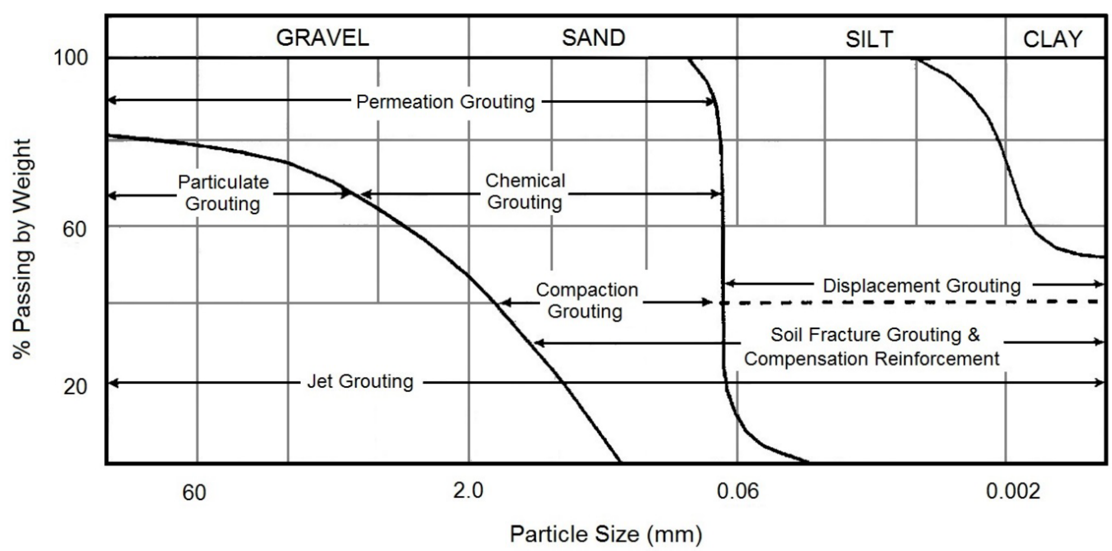

Figure 1 – Range of Applicability of Grouting Methods (from FHWA GEC No. 13 Ground Modification Methods Reference Manual – Volume II)

Project Initiation

During project initiation, the objectives of the project should be established, so that suitable construction methods can be evaluated and selected.

For projects on State Highways, grouting is typically used to control highway settlement, fill cavities caused by leaking drainage or water pipes, fill cavities caused by poorly placed reclaimed concrete as embankment backfill, and increase compressive and shear strengths. All construction methods other than grouting, such as piling, removal and replacement, stone columns, soil cement mixing, aggregate ramp columns, light weight fill, prefabricated vertical drains, surcharge and waiting periods, should be considered when evaluating and selecting the most suitable option based on project constraints, cost, and time.

Communicate with the Project Development Team for project constraints and construction time allowed. Present feasible options and their pros and cons. If necessary, reach out to the industry for practical construction constraints, equipment limitations, and feasible contracting methods.

Geotechnical Investigation

Literature Review

Refer to the Geotechnical Investigations module in the Geotechnical Manual for guidelines on performing literature searches and evaluating available information for applicability to grouting design and construction. Be sure to review proposed plan/alternatives and utility plans of the proposed project area from District or Structure Design for utilities or underground structures that may be affected by grouting work.

Subsurface Exploration

Perform the geotechnical investigation to identify subsurface conditions that may affect selection of grouting types and the design of the grouting program, including:

- Soil description, classification, fines content, and gradation
- Consistency and density of soils
- Strength and deformation characteristics of soils
- Groundwater conditions and elevations
- Cavity locations, extents, and depths
- Drill fluid monitoring
- Adjacent developments, sensitive building/facility

Refer to the references for the planning and execution of the geotechnical investigation program. Geotechnical investigations for grouting projects must be detailed and targeted. The investigation may require continuous sampling to obtain detailed subsurface stratigraphy. Small, fine-grained lenses should be noted, since these layers can retard the progression of some types of grouting.

Soil specimens should be retrieved and tested for particle-size distribution, Atterberg Limits, density, permeability, pH, compressibility, and shear strength.

The geotechnical investigation should also identify the extent that grouting is needed. Past use of the site should be identified, such as the presence of abandoned wells, cisterns, cesspits, etc. These items can absorb the grout and either increase the grout take or cause no ground improvement. In addition, the presence of utilities should be noted since the bedding materials of some utilities can cause a loss of grout as well.

Design and Analysis

Identify Project Objectives

Typical project objectives are:

- Fill cavity in embankment backfill
- Fill cavity caused by ground lost due to pipe leakage
- Control settlement
- Increase compressive and shear strength
- Lift highway pavement
- Create water barrier
- Liquefaction mitigation

Identify Project Constraints

Projects may have the following constraints:

- Traffic control – limited construction window
- Maintain pavement integrity
- Presence of underground utilities
- Construction wait periods
- Construction cost
- Environmental constraints

Establish Performance Requirements

Establish performance requirements of the grouting projects, such as:

- Maximum settlement under applied loads
- Maximum construction wait period
- Required compressive or shear strengths
- Required hydraulic conductivity of grouted zones
- Maximum allowable pavement heave and utility deformation

Select Grouting Method and Contracting Option

Select the grouting method based on site conditions, project objectives, constraints, and performance requirements. Determine the contracting option. There are two contracting options, prescriptive and performance based.

In the prescriptive contracting method, the designer provides:

- layout and depth of grout holes

- Diameter of treated columns, i.e. grout volume
- Grout pressure
- Grout terminating criteria in each lift
- Construction sequence within the treated zone

Advantages

- The quantity and cost of work can be easily estimated.
- The project contract may be executed quickly for emergency response.

Disadvantages

- Performance requirements may not be achieved by the prescribed layout of grout holes and construction parameters.
- Prescribed construction parameters may conflict with terminating criteria.
- Highly depends on the contractor's construction equipment and practices

In the performance-based contracting method, the designer provides:

- The limits of treated zone, including the horizontal and vertical extent
- Performance requirements for the treated zone

The contractor lays out the grout holes and designs the grouting parameters to achieve the performance requirements.

Advantages

- The quantity and cost of work can be easily estimated.
- The contractor is responsible for achieving the performance requirements in the treated zone.
- Less risk for cost increase

Disadvantages

- It is more difficult to estimate the cost of work because the cost is based on the unit volume of treated zone, instead of conventional quantities of number of grout holes and volume of grout.

Reporting

Grouting recommendations must be conveyed in a Geotechnical Design Report. Include the following in the *Recommendations* section:

- Reasons for the selected grouting method based on geotechnical requirements and constructability
- Delineation of treated zones, including areas, upper and lower limits
- Performance requirements of the treated zones

- For the prescriptive contracting option:
  - Provide recommended layout and depths of grout holes
  - When laying out the grout hole pattern, the geotechnical designer must ensure the performance requirements can be achieved by the specified construction parameters.
- For the performance-based contracting option:
  - No additional information is needed

Notes for Specifications

Standard special provisions and standard specifications are not available for geotechnical grouting work. Compaction grouting has a non-standard special provision available for use.

Work with the Specification Engineer in developing nSSPs for the grouting project.

For the prescriptive contracting option, include:

- Requirements for construction equipment, including grout mixer, pump plant, pressure gauges, drilling equipment,
- Required grout properties
- Sequence of grouting within the treated zones and with respect to other aspects of construction
- Details of ground surface monitoring
- Details of quality assurance tests, including test equipment, accuracy, load schedule, sampling or sounding frequency, and depth
- Locations and frequency of verification tests and proof tests and acceptance criteria

For the performance-based contracting method, the contractor is required to provide the layout of grout holes that are suitable for the equipment available to the contractor to achieve the performance requirement.

Provide:

- Performance requirements of the treated zones
- Details of ground surface monitoring
- Details of quality assurance tests, including test equipment, accuracy, load schedule, sampling or sounding frequency, and depths
- Locations and frequency of verification tests and proof tests and acceptance criteria

Other construction notes, including:

- Requirements and locations of a pre-construction survey and monitoring program during construction of existing structures

- A note recommending the Resident Engineer notify Geotechnical Design for the pre-construction meeting and to forward the Shop Drawings for review.
- Expected difficult construction conditions for drilling and grouting, such as boulders, cobbles, soil-rock interface, bedrock, very stiff clay layers, abandoned substructures, and the presence of groundwater

Geotechnical Review for PS&E

Review the Plans and Special Provisions to verify recommendations provided in the geotechnical report are incorporated

Geotechnical Tasks during Construction

Attend Pre-Construction Meeting

When requested by the Engineer, attend the pre-construction meeting.

Establish communication with the Engineer. Review the Geotechnical Design Report and the Special Provisions with the Engineer and the Contractor.

Review Shop Drawings

When requested by the Engineer, review shop drawings.

Common Construction Issues

Common construction issues for grouting are:

- Inaccurate estimate of grout volume
- Inaccurate estimate of grout hole spacing
- Insufficient grout column strength
- Wrong grout formulation for soil to be modified
- Unintended grout jacking
- Problems with grout equipment
- Issues with permeability
- Short work windows and limited workspace due to lane closure constraints
- Damage to highway facilities
- High cost due to limited availability of specialty contractors

The cause of these construction issues can be multifaceted. To avoid or reduce the impact of these issues, detailed deliberations, open communication with the PDT, and input from the industry during project development are needed.

In addition, the specifications should require the contractor to record every anomaly encountered in the drilling and grouting operations and to identify the reasons for the anomalies before continuing drilling and grouting operations.

Assist the Engineer to evaluate and identify the main causes of the problem and provide recommendations.

Appendix I: Grouting Methods Definition and Description

This appendix provides brief summaries of the four grouting methods commonly used in Caltrans projects. For detailed information, refer to the references provided in this module.

Conventional (Bulk Infill) Grouting

Conventional (Bulk Infill) grouting is a process that injects large quantities of cement-based grout at low pressures or by gravity to fill subsurface voids. Water and air within the cavity are displaced as grout is injected to either fill the cavity or to create a stable support to the roof or between the surrounding ground and structure. Conventional grouting can also be used to pretreat rock mass to permit other foundation systems to be built.

The grout is typically of low cement contents but has high volumes of cheaper, readily available materials such as aggregate, fly ash, or other industrial byproducts and is therefore low strength.

Quality Assurance may include:

- Coring to verify the presence of the grout
- Drilling and sampling for low cement content pastes
- Pressure testing the drilled holes with water or grout
- Video inspection

Advantages

- Low cost per unit volume of materials when using cheap fillers
- Minimum disturbance
- Strength of grout can be tailored to fit the in-situ condition
- Essentially yields full roof contact
- Grout can penetrate all voids with no fear of the grout flowing, washing away, or settling

Disadvantages

- When filling all voids with grout, the technology can become cost prohibitive. Little control where the grout goes.
- Difficulty obtaining sufficient knowledge of cavity's position, shape, and infilling.
- Cannot provide consistent reliable support in common karst conditions.

Compaction Grouting

Compaction grouting is a method that densifies soils by displacement of soils as grout is injected into the soil.

Compaction grouting involves pumping a low-slump grout, typically a 2-inch slump or less, at high pressures, about 100 to 400 psi, via a grout casing into the ground. The grout forms a bulb at the tip of casing and compress the surrounding soils. Unlike other grouting methods, compaction grouting does not strengthen the soil by cementation, instead it densifies the surrounding soil, resulting in an increase in the strength and stiffness of the soils.

Compaction grouting is more effective in cohesionless granular soils, collapsible soils, and unsaturated fine-grained soils. It is less effective in clays, poorly graded sands, and gravels

Compaction grouting has a wide variety of applications but is primarily used for soil densification (for both static and seismic enhancements) and for raising surficial structures. In soil densification applications, the soils should be free draining, such as gravels, relatively clean sands and some coarser silts. In fine-grained soils, pore pressures may not be able to dissipate and improvement may not be achievable. In these soils, compaction grouting may displace the soil, but not cause consolidation.

Grout mix design is a critical part of compaction grouting. The grout must have a high internal friction and a low slump to ensure a “grout bulb” forms. There are no mathematical models for compaction grouting to establish the spacing, rate of injection, limiting volumes, etc. Therefore, performance based contracting method allows the contractor, who is specialized in compaction grouting, to develop the compaction grouting parameters.

Typically, compaction grout pipes are spaced at 6 to 16 feet. The amount of grout required for soil densification ranges from 3 to 12 percent of the soil volume being treated. Normally, compaction grouts use particulate grouts such as Portland Cement Types I or II and sand.

Advantages

- Effectiveness has been well proven in practice.
- Can be implemented in areas of low head clearance.
- Directly treats areas that need improvement.
- Can be installed under existing structures.
- Little or no spoils.

Disadvantages

- Time consuming when used for densifying highway embankment due to traffic closure constraint.
- Can cause a build-up of excess pore pressure in fine grained soils.
- Quality control procedures can be time consuming.
- The performance of final product, densified soils, highly depends on grouting practice.

Jet Grouting

Jet grouting is a grouting method that injects water, air, and cement-based grout with high pressure (up to 7000 psi) and high velocity erosive jets of water or grout to remove and loosen soil, replace the removed soil with cement based grout, and then mix the grout into the loosened soil to form a grouted column of soil. As the drill string rotates and is withdrawn, an in-situ soil-grout mixed column is created. The erosive and mixing actions of the jet vary from various proprietary systems.

Jet grouting permits the shape, size, and properties of treated soil, usually a circular column, to be engineered in advance. Jet grouting can be used in all soil types, but the best results are typically achieved in cohesionless soils or soft cohesive soils. Highly plastic soils and fibrous peat soils that are less erodible are not recommended.

Jet grouting can be installed up to 150 feet deep but is generally less than 100 feet. Jet grouting can be performed both above and below groundwater table. Jet grouting can be used to create water barrier wall and slab.

The soil-grout mixed column can be 3 to 15 feet in diameter depending on the in-situ soil and grouting method and parameters used. Care should be taken to avoid surficial or lateral movement. The spoils created during the jetting should be continuously discarded.

Jet grouting can be used for a variety of applications:

- Water Control
- Settlement Control
- Underpinning
- Scour Protection
- Excavation Support
- Liquefaction Mitigation
- Treatment of Karst

Advantages

- Nearly unlimited configuration of column geometry
- Can be installed in areas of limited headroom
- Can be used in a wide range of soil types and groundwater conditions Minimal settlement

Disadvantages

- Installation may cause ground heave.
- Generated spoils, typically about 80% of treated volume, must be disposed of or used as fill. In plastic soils, a higher portion of the soils will become spoil.

There are three different types of jetting procedures:

- Single Fluid System – The fluid is the grout and uses a high-pressure (7,200 psi) jet to simultaneously erode the in-situ soil and inject the grout. This system only partially replaces the soil.
- Double Fluid System – A high-pressure grout jet is contained within a compressed air cone. This system produces a larger column diameter, provides a higher degree of soil replacement, although a lower strength soil-grout mix is created.
- Triple Fluid System – An upper jet of high-pressure (4,400 to 7,200 psi) water contained inside a cone of compressed air is used for excavation, with a lower jet injects grout, at a lower pressure, to replace the slurry soil.

Permeation Grouting

Permeation grouting introduce low viscosity solutions such as particulate suspensions or chemical grouts into clean sands and gravels or permeable discontinuities in rock without disturbing the structure of the ground (Littlejohn 2003). Permeation grouting is typically used to reduce permeability or increase strength of the soil or produce a cohesive structure or volume of the original soil mass.

Permeation grouting is intended to fill all (or most, i.e., 70% to 80% of) the natural pore spaces in a soil mass, without changing the structure or volume of in-situ soils. Grouts can thus be used to increase the cohesion between soil particles, thereby leading to increased strength and reduced permeability.

The type of grout used for permeation grouting depends on the grain size of the in-situ soil and the desired results. As a general rule, the finer the pores, the higher the cost of the grout. Therefore, it is normal to first fill larger pores with conventional particulate grouts, then to permeate into finer or residual pores with chemical grouts, or ultrafine grouts.

Structural permeation grouting is used when the objective of grouting is to improve the strength or rigidity of in-situ soils to prevent ground collapse, reduce otherwise unacceptable ground movement during construction, or improve bearing capacity. Underpinning is another application of structural permeation grouting wherein granular foundation support soils are strengthened so as to permit excavation adjacent to footings.

Waterproof permeation grouting is permeation grouting primarily for stopping the flow of water, which otherwise may cause ground movements or the flow of unacceptably large amounts of water into a construction area, or both.

Advantages

- May be used to reduce permeability or increase strength of the soil or produce a cohesive structure or volume of the original soil mass without disturbing the soil structures.

Disadvantages

- For very low permeability sands, the injection rate at permissible pressures may be so slow that grouting becomes unfeasible.
- Permeation grouting using certain chemical grouts may represent toxicity dangers to groundwater and the underground environment. Low toxicity chemical grouts, however, are now sufficiently available for most purposes and should be specified except for unusual circumstances.
- Expensive.

- Difficult to control the construction parameters to achieve the desire performance requirements.

For permeation grouting to be successful, the soils must be suitable. The suitability of soils for permeation grouting is based on the permeability of the soil. The preliminary evaluation of permeability, thus the suitability, can be based on the fines content of soils, i.e., the percentage of material passing the #200 sieve. The following table provides the approximate percentage of material passing the #200 sieve and the suitability of the soil for permeation grouting.

Table 1: Suitability of Soil for Permeation Grouting (Elias et al., 2006)

Percent Passing No 200 Sieve	Description
< 12	Readily suitable
12 – 15	Moderately suitable
15 – 20	Marginally suitable
> 20	Not suitable

After a preliminarily determination that permeation grouting is feasible an expert in the design of permeation grouting should be consulted to complete the final design.

References

1. *FHWA Geotechnical Engineering Circular (GEC) 013 Ground Modification Methods Reference Manual V. 1 and 2 (2017)*
2. *U.S. Army Corp of Engineers, Engineering Manual (EM)1110-2-3506 Engineering and Design – Grouting Technology (2017)*
3. *ASCE Geo-Institute (G-I)53-19, Compaction Grouting Consensus Guide (2019)*
4. *ASCE Geo-Institute (G-I), Jet Grouting Guideline (2016)*