K E L L E R

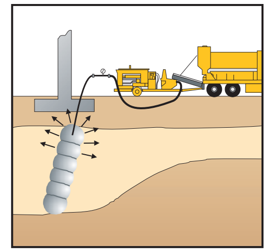
COMPACTION GROUTING

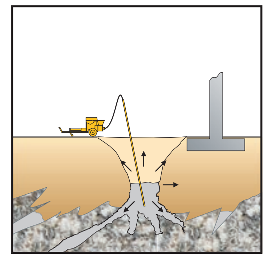
Compaction grouting improves a wide range of ground conditions by displacement, for a variety of site improvement and remedial applications.

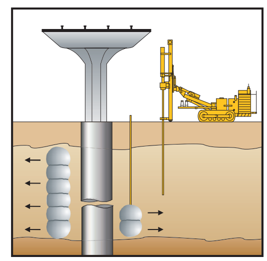
Compaction grouting was used to seal this 160-foot diameter sinkhole that extended down to the Floridan aquifer.

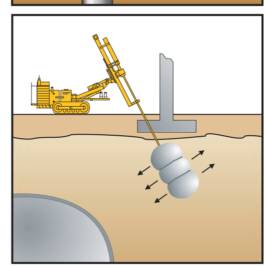
When a properly designed compaction grout is injected into loose soils, homogeneous grout bulbs are formed that displace, densify and thus strengthen the surrounding soil. The technique was originally developed in the 1950's as a remedial measure for the correction of building settlement, and used almost exclusively for that purpose for many years. Over the past twenty years, however, compaction grouting technology has evolved to treat a wide range of subsurface conditions for new and remedial construction. These include rubble fills, poorly placed fills, loosened or collapsible soils, sinkhole sites, and liquefiable soils.

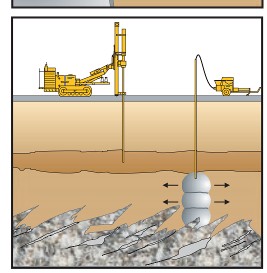
Keller's compaction grouting techniques offer an economic advantage over conventional approaches such as removal and replacement or piling. Compaction grouting can be accomplished where access is difficult and space is limited. Since compaction grouting's effectiveness is independent of structural connections, the technique is readily adaptable to existing foundations.

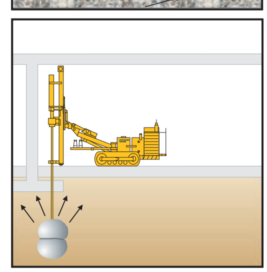










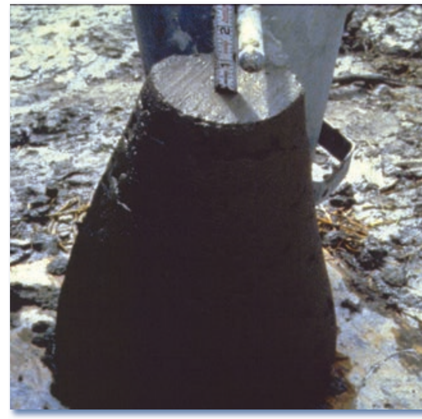


KELLER

THINK SAFE

Compaction Grouting Technology…

Compaction grouting improves ground conditions by displacement. A very viscous (low-mobility), aggregate grout is pumped in stages to displace and densify the surrounding soils. By sequencing the grouting work from primary to secondary to tertiary locations, this densification process can be performed to achieve significant improvement. Keller's compaction grouting capability, spanning more than 25 years, is enhanced by the control features provided by the Denver System: batching-on-demand, and specialized, high pressure injection.



The grout mix must have specific characteristics: a very low mobility (low slump) mixture that is 'pumpable' but, upon installation, exhibits an internal friction enabling it to remain intact and displace the surrounding soil without fracturing it.

Site Investigation

For successful compaction grouting, comprehensive knowledge of subsurface conditions is important. In order to prepare a suitable program, a geotechnical engineering consultant will develop a site investigation report, which will generally contain site geology and history, soil gradation, and the in situ horizontal permeability of each treatment stratum. Type and condition of nearby structures and utilities, together with plan and elevation locations, will further assist program development.

Geotechnical Considerations

Conditions necessary for optimum compaction grouting results:

1. 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).

2. When compaction grout is injected into saturated soils, a pore pressure increase occurs as a result of ground displacement. This increased pressure must dissipate for effective densification to take place. Therefore, the grout injection rate should be slow enough to allow pore pressure dissipation. Sequencing of grout injection is also important.

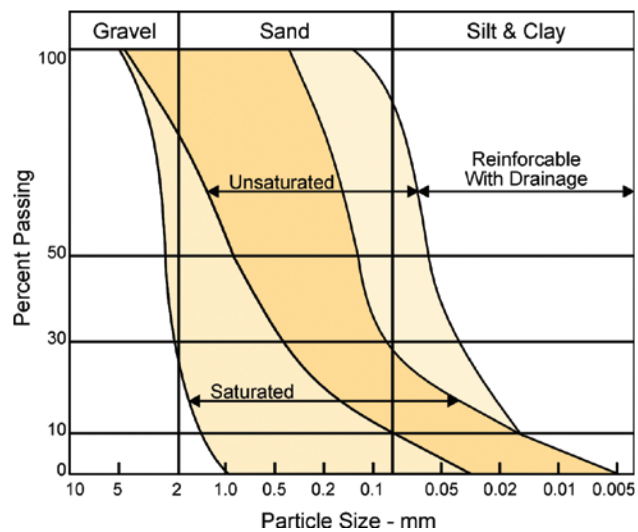
3. Compaction grouting can usually be effective in most silts and sands, provided that the soil is not near saturation.

4. Soils that lose strength during remolding (saturated, fine-grained soils; sensitive clays) should be avoided.

5. Greater displacement will occur in weaker soil strata. Excavated grout bulbs confirm that compaction grouting focuses improvement where it is most needed.

6. Collapsible soils can usually be treated effectively by adding water during drilling prior to compaction grout injection.

7. Stratified soils, particularly thinly stratified soils, can be cause for difficult or reduced improvement capability.

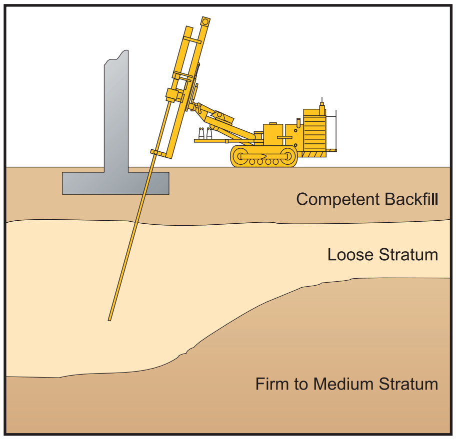


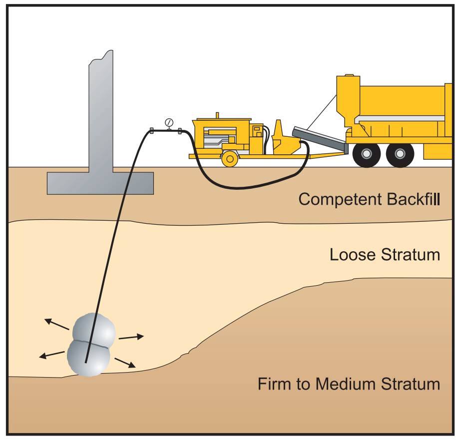
Range of soils that will show improvement by post-testing. Compaction grouting can also be used to reinforce soils beyond this guideline, provided that drainage is enhanced.

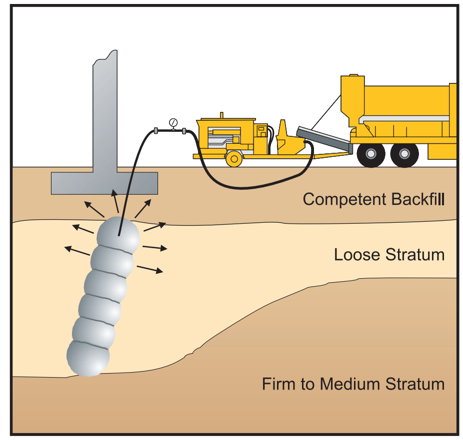
KELLER

"The design and application of compaction grouting is always site-specific, considering the entire above- and below-ground conditions."

Compaction Grouting Delivery Methods







Installation of grout pipe:

- *Drill or drive casing*
- *Location very important*
- *Record ground information from casing installation*

Initiation of grouting:

- *Typically bottom up, but can be top down*
- *Grout quality important*
- *Pressure and/or volume of grout is usually limited*
- *Slow, uniform stage injection*

Continuation of grouting:

- *On-site batching can aid control*
- *Grout quality important*
- *Pressure, grout quantity and indication of heave are controlling factors*
- *Sequencing of plan injection points very important*

Improvement Conditions

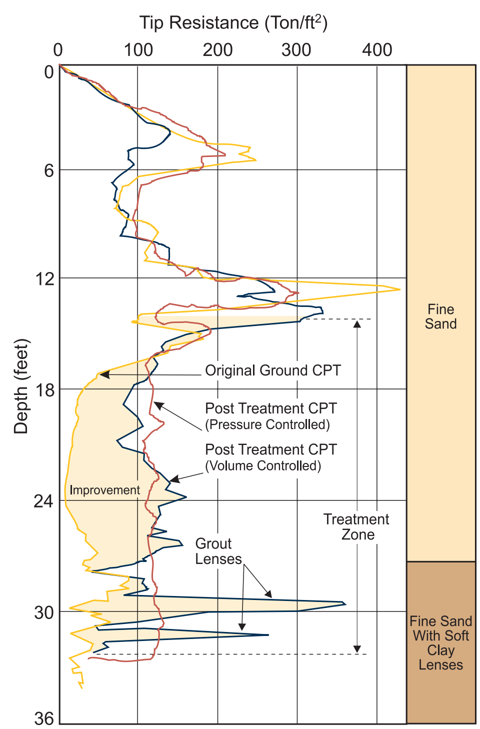
Typically greater than 1,500 psf overburden stress is required to maximize densification. Limited densification can be achieved with less overburden. This stress can come from overburden soils, surcharge loads and/or foundation loads. When densification is the primary intent, a replacement ratio and pressure criterion is applied to each stage of compaction grouting. This ratio is determined based on the existing density, the soil density range, and the amount of displacement necessary to affect the improvement.

$$\text{Replacement Ratio (RR)} = \frac{\text{CG Volume}}{\text{Treatment Volume}} \sim 5 \text{ to } 15\% \text{ (typical)}$$

Experience has proven that treatment spacing should not exceed 6 to 10 ft. From this, a compaction grouting volume can be calculated. The maximum pressure criterion prevents fracture and ground heave and compensates for stiff zones in the treatment area. Vertical stages are usually set at 2- to 3-ft intervals; tighter grid spacing will generally lead to better results.

Quality Control/Quality Assurance

Quality control includes procedural inspection and documentation of the work activity, testing to ensure proper mix design and injection rates, and verification of ground improvement where applicable. Ground improvement can be assessed by Standard Penetration Testing, Cone Penetrometer Testing, or other similar methods. Data recording of important grouting parameters has been utilized on sensitive projects.



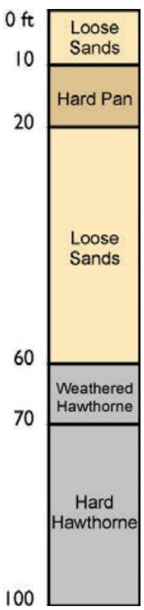
Cone Penetrometer Test results, such as the ones illustrated above for volume cut-off and pressure cut off, show the degree of improvement achieved by compaction grouting.

KELLER

Case Histories . . .

Karstic Regions

Pre-treatment for prevention of potential sinkholes is common. This usually involves drilling down to and into the limestone surface to locate and fill any cavities, followed by improvement of the loose soil above the rock surface. A denser, less erodible soil results, better able to arch over any sinkhole that might develop in the future.



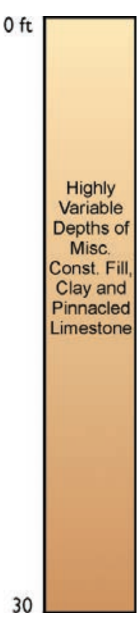
Summit Office Building
Maitland, Florida

Maitland is an active sinkhole area and also a desirable commercial real estate market. Development proceeds with a significant risk of sinkhole-related structural damage. To reduce the high risk of sinkhole development at the Summit Office Building site, compaction grouting was used to improve the soils at each stone column location. A total of 14,350 cu yds of compaction grout was injected at 340 grout point locations at depths of 80 to 120 ft. Grade beams were incorporated into the foundation design to span between columns. After completion of the grouting program, an irrigation well triggered three sinkholes on the site, but not within the treated areas.

Compaction grouting to pre-treat the Summit site reduced the risk of future sinkhole activity.

Active Sinkholes

Where this condition develops, injection casing is installed around the perimeter of the depression, and aimed at the throat of the limestone opening. The compaction grouting program includes first filling the void at depth, followed by staged treatment to densify the loosened soil in and above the cavity. Due to the inverted cone shape of loosened soil, structures that exist near the cone can often be lifted back to near original elevation.



Dalesford Lake Development
Berwyn, Pennsylvania

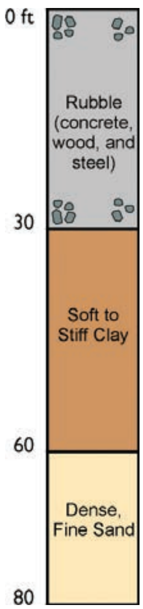
A luxury, four-unit townhouse structure founded on timber piles had exhibited structural distress related to sinkhole activity. Subsurface investigation revealed 5 to 30 ft of miscellaneous construction fill, including wood chips and building materials, overlying clay soil. Beneath this, pinnacled karstic limestone was encountered at depths ranging between 10 and 30 ft. Compaction grouting was performed to stabilize the driven pile foundation, re-establish ground contact with the structure, and halt the soil piping that resulted from sinkhole activity. Grout pipes were installed at 68 interior, low headroom locations, and 90 exterior locations, to average depths of 16 to 21 ft. The work was successfully completed while the building remained occupied.

Compaction grouting was performed at interior and exterior locations, with minimal disturbance to townhouse residents.

“Compaction grouting treats a wide range of subsurface conditions to solve an equally wide variety of structural problems.”

Rubble Fill

Construction debris and other similar fills are often placed in an uncontrolled manner. This results in a very porous, voided matrix that can deform and settle over time due to the migration of soil into the voids. To close the void spaces and minimize potential settlement impact, compaction grouting is applied in a regular pattern.



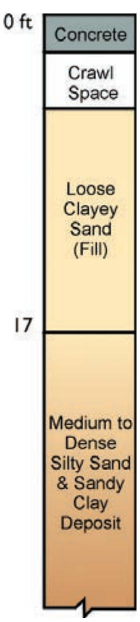
One Woodway Plaza
Houston, Texas

Over several years, a four-story office building’s foundation element had undergone major settlement. Built in the early 1970s on spread footings, deep grade beams and drilled caissons, the structure sits on 30 ft of construction rubble fill, beneath which are competent soils. A significant part of the rehabilitation program involved compaction grouting 33 ft deep to stabilize the fill and lift spread footings back to the original elevation. Work was accomplished at night, with more than 3,600 cu yds of grout pumped through 467 low-headroom, interior locations. The settled footings were raised up to 8 inches. In addition, drilled caissons were underpinned with micropiles, and an anchored retaining wall was constructed to stabilize a failed MSE wall.

Compaction grouting stabilized the rubble fill underlying a four-story building and successfully restored the building to near original elevation.

Poorly Placed Fill

Provided sufficient overburden stress exists, a proper program of compaction grouting can treat the poorly placed fill material. This is often utilized when structure deformation alerts the owner to the problem, and an unobtrusive approach to foundation restoration is needed.



WMATA Station Platforms
Rockville and Landover, Maryland

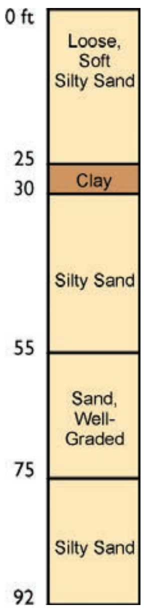
Areas of poorly compacted granular fill beneath two Washington Metro Area Transportation Authority subway platforms had resulted in up to three inches of settlement. Consolidation of the fill was achieved through compaction grouting by the Denver System. Over 150 grout points were established for the 2 platforms. Following coring through the concrete platforms, 2-inch ID casing was pneumatically driven in 3-ft, battered sections to between 9 and 17 ft. Low mobility grout was delivered via the specially designed, on-site mobile batching and pumping unit that typifies the Denver System. Limited station access required this unit to operate across the tracks from the platforms. Although casing installation was accomplished during station operating hours, grouting was limited to line shut-down hours of 1 to 4 a.m.

The Denver System of compaction grouting was used to consolidate fill beneath two, settling subway platforms.

Case Histories . . .

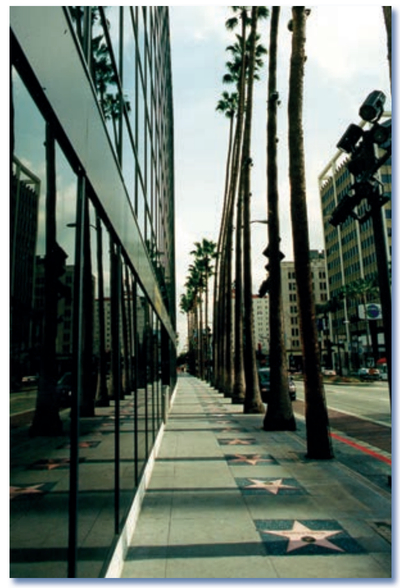
Loosened Soil: Pre-Treatment

Construction-generated ground disturbance can often be the cause of soil loosening near the work area. This can affect nearby structures. The injection of compaction grout soon after the disturbance occurs can compensate for the disturbance by re-establishing the original stress state and prevent deformations beyond the work area.



La Reina Building
Hollywood, California

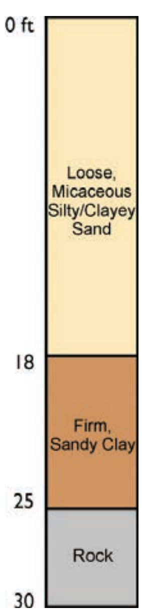
The La Reina Building is a six-story glass and steel office complex founded on large spread footings. The building sits 80 to 90 ft directly above the alignment of a new, twin-tube subway tunnel. Compaction grouting was used to protect the building against settlement resulting from foundation soils being loosened during tunneling. As the tunneling machine passed beneath the building, grouting was initiated just following the advancement of the tunnel shield and expansion of the tunneling precast segments. The complex array of 150, precisely angled compaction grout pipes were positioned within 5 ft of the tunnel crown. Gyroscopic survey of installed pipe tip locations and as-built CAD drawings aided the critical sequencing of tunneling and grouting.



Compaction grouting through pre-placed pipes, prevented tunneling-induced settlements during subway construction beneath this building on Hollywood Boulevard.

Loosened Soil: Post-Treatment

This is often a man-made condition resulting from nearby construction…subsurface utility backfill, tunneling, poorly stabilized excavations. Knowledge of how the condition occurred is useful, as the treatment zone must be accurately located to provide the desired benefit. Ground improvement is usually undertaken to re-establish the previous stress state, instead of providing improvement beyond.



Industrial Plant
Northwestern Georgia

The combination of a high water table, leaking water pipe and a loose soil profile had initiated settlement beneath a 300-ft long rail siding structure. Over time, these settlements had been compounded by heavy, dynamic train loads that induced slab cracking. This was aggravated when fines pumping through the cracks further loosened the subsurface soils. Compaction grouting was performed on 2- to 4-ft centers in a primary/secondary sequence to depths of up to 18 ft to reinforce and densify the loosened soils. Careful scheduling of the grouting program allowed the facility to remain operational around the clock. This enabled the owner to keep the plant fully on-line an extra four weeks before a scheduled repair shutdown, thus limiting major plant disruption.

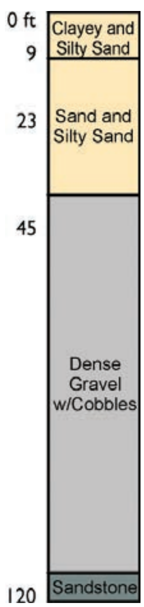
Compaction grouting densified soils beneath a siding structure while the plant remained fully operational.

KELLER

“Compaction grouting clients range from homeowners to commercial developers to major state and industrial clients.”

Liquefiable Soils

For these conditions, ground improvement consists of density increase, cellular containment, and/or reinforcement. In all cases, soil permeability is an important parameter in determining the rate of compaction grouting so that improvement results.



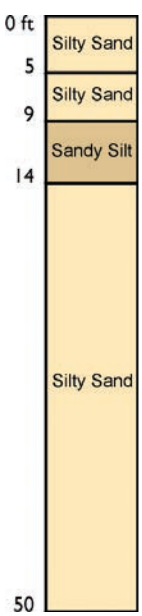
LRT Extension, Morena Segment San Diego, California

In the Mission Valley area of San Diego, three light rail transit bridges are supported by individual piers. The piers bear on 9-ft diameter caissons up to 130 ft deep. These caissons are founded in dense sands and gravels underlying potentially liquefiable soils. Although the caissons are founded below the zone of liquefaction, they rely on support from the surrounding soils for lateral stability. Prior to bridge construction, compaction grouting was performed to depths of between 45 and 115 ft around 6 abutments and 68 caissons to densify and reinforce the soils, mitigating their liquefaction potential and thereby ensuring the long-term protection needed for the caissons and the bridge superstructure in the event of an earthquake.

Pre-treatment with compaction grouting for long-term liquefaction mitigation protected the integrity of caissons supporting light rail piers.

Collapsible Soils

Collapsible soil conditions exist in specific regions where wind-blown silts have accumulated or intermittent stream flow deposition has occurred. Treatment of these soils is possible by forcing a restructuring of the fine grains into a tighter configuration. The replacement quantity of compaction grout by volume can be higher than normal for sites like this, as the pretreatment condition can be very loose.



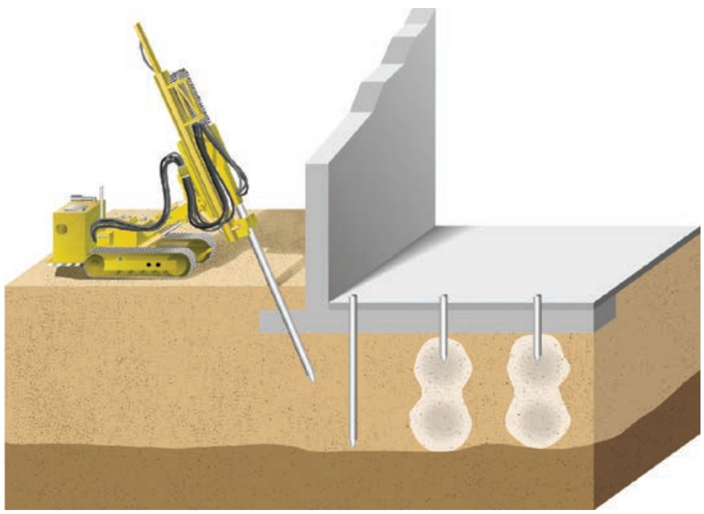
Hampton Inn, Albuquerque, New Mexico

In the five years since construction, a Hampton Inn had settled almost 2.5 inches. Data indicated that the moisture contents of the upper 20 ft of soils were now higher than at the time of construction. Modeling tests indicated a soil collapse potential of 5 to 7 inches. Compaction grouting was performed to varying depths at 150 locations to target the higher moisture content soils, with the majority of the work done in limited headroom within the occupied building. Total grout take for the project represented 14.5 percent of soil volume for the treated zone. Post-grouting survey results indicate that movement of the structure has slowed to a rate of less than .0625 inches per year.

Remedial compaction grouting successfully treated collapsible soils beneath the hotel, reducing future settlement potential to an acceptable level.

Advantages of Keller's Compaction Grouting

- *Pinpoint treatment*
- *Speed of installation*
- *Wide applications range*
- *Effective in a variety of soil conditions*
- *Can be performed in very tight access and low headroom conditions*
- *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*
- *Enhanced control and effectiveness of in situ treatment with Denver System*



You have a strong partner with Keller

Keller is North America's leader in geotechnical construction, offering the full range of construction services for deep foundations, ground improvement, groundwater control, instrumentation and monitoring, liquefaction mitigation, releveling structures, slope stabilization, support of excavation, and underpinning. Keller is annually ranked #1 in the profession by Engineering News-Record (ENR).

Headquartered in Hanover, Maryland, Keller has over 60 offices servicing North America. Since its inception, Keller has established itself in the forefront of geotechnical specialty contracting, evolving and expanding to meet the increasingly complex needs of the construction community. Keller offers design-build and bid-build services for the widest array of geotechnical construction applications.

Keller has the experience and innovation to assist engineers, contractors, and owners with identifying and constructing the most economical solution that satisfies the requirements of each project, typical or unique.

KELLER

Design-Build Services for the Complete Range of Geotechnical Technologies

Grouting
Compensation (fracture) grouting
High mobility (cement slurry) grouting
Injection systems
Jet grouting
Low mobility (compaction) grouting
Permeation (chemical) grouting
Polyurethane grouting

Ground improvement
Cutter soil mixing
Dry soil mixing
Dynamic compaction
Earthquake drains
Rapid impact compaction (RIC)
Rigid inclusions
Vibro compaction
Vibro concrete columns
Vibro (aggregate) Piers®
Vibro stone columns (vibro replacement)
Wet soil mixing
Wick (PVD) drains

Deep foundations
Cased CFA piles
CFA (auger cast) piles
Displacement CFA piles
Drilled shafts
Driven piles
Franki piles (PIFs)
Helical (screw) piles
Jacked in piles
Load bearing elements (barrettes)
Macropiles®
Micropiles
Tangent bearing elements (TBEs)

Earth retention
Anchors
Anchor block slope stabilization
Cutter soil mixing (CSM)
Diaphragm walls
Gabion systems
Interlocking pipe piles
Micropile slide stabilization system (MS³)
Sculpted shotcrete
Secant or tangent (contiguous) piles
Sheet piles
Soil nailing
Soldier piles and lagging

Groundwater control
Dewatering
Ground freezing
Groundwater treatment
Slurry cutoff walls
TRD - Soil mix walls
Tremie bottom seals

Additional services
Access/drop shafts
Pit underpinning
Slab jacking

Website www.keller-na.com
Email info@keller-na.com

Keller North America
A member of the Keller worldwide group of companies

For a complete list of our offices, visit: www.keller-na.com

THINK SAFE