RIGID INCLUSIONS

Rigid Inclusions offer an economical approach for building on sites underlain by soft soil.

Above: Installing Rigid Inclusions for the construction of a train station.

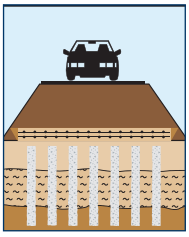
Above right: Installing Rigid Inclusions beneath a highway embankment. Rigid Inclusions provided support of the embankment and limited settlement and wait time between embankment construction and paving operations.

Rigid Inclusions (RIs) are high modulus/controlled stiffness grout columns typically installed through weak, highly compressible soils to reduce settlement and increase bearing capacity. A ground improvement system, RIs are not directly connected to foundations. A load transfer platform is often installed between the foundation and the RIs. Settlement reduction is achieved by reinforcement of the highly compressible soils. The geometry, composition, and spacing of RIs are designed based on the subsurface conditions, planned loading and the performance requirements. RIs have been constructed beneath buildings, embankments, and large loaded areas, such as tanks.

Keller has a long history of designing and constructing ground improvement solutions for small and large projects across North America. With its fleet of specialized equipment, Keller has successfully improved a wide variety of poor soil conditions while working on sites with operational and logistical challenges. Internally developed data acquisition software allows for production efficiency and a high level of quality control.

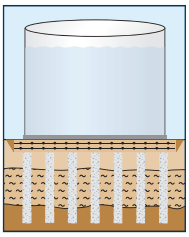
Technology & Applications . . .

Rigid Inclusions reinforce highly compressible soils using high modulus grout columns. Below are examples of structures that are well suited for support by RIs.



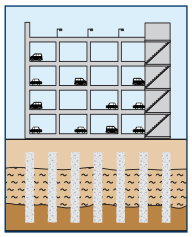
Roadway Embankments

Embankments can be built soon after construction of RIs without the surcharge and wait time required for consolidation to occur, reducing the schedule of transportation infrastructure projects.



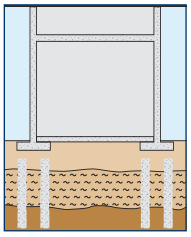
Storage Tanks

RIs can support heavily-loaded aboveground storage tanks to accelerate construction schedule, reduce total settlement, and protect against differential settlements that can threaten structural integrity.



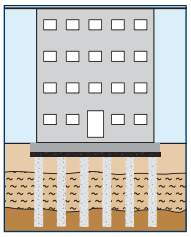
Parking Structures

Multi-level parking structures often have concentrated loads with large, shallow foundations which are well suited for support by RIs.



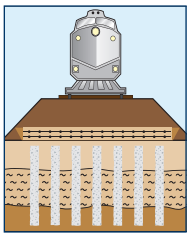
Isolated Spread Footings

RIs are well suited for reinforcement of soft soils beneath planned isolated or continuous spread footings.



Mat Foundations

Mat foundations are well suited to support buildings constructed over soft soils reinforced with RIs.



Railway Embankments

Similar to roadway embankments, railway embankments can be built over soft soils reinforced with RIs.

① *RIs to support future fill and building loads for a grocery store.*

② *A 10,000-square-meter addition to a building required RIs for slab and foundation support.*

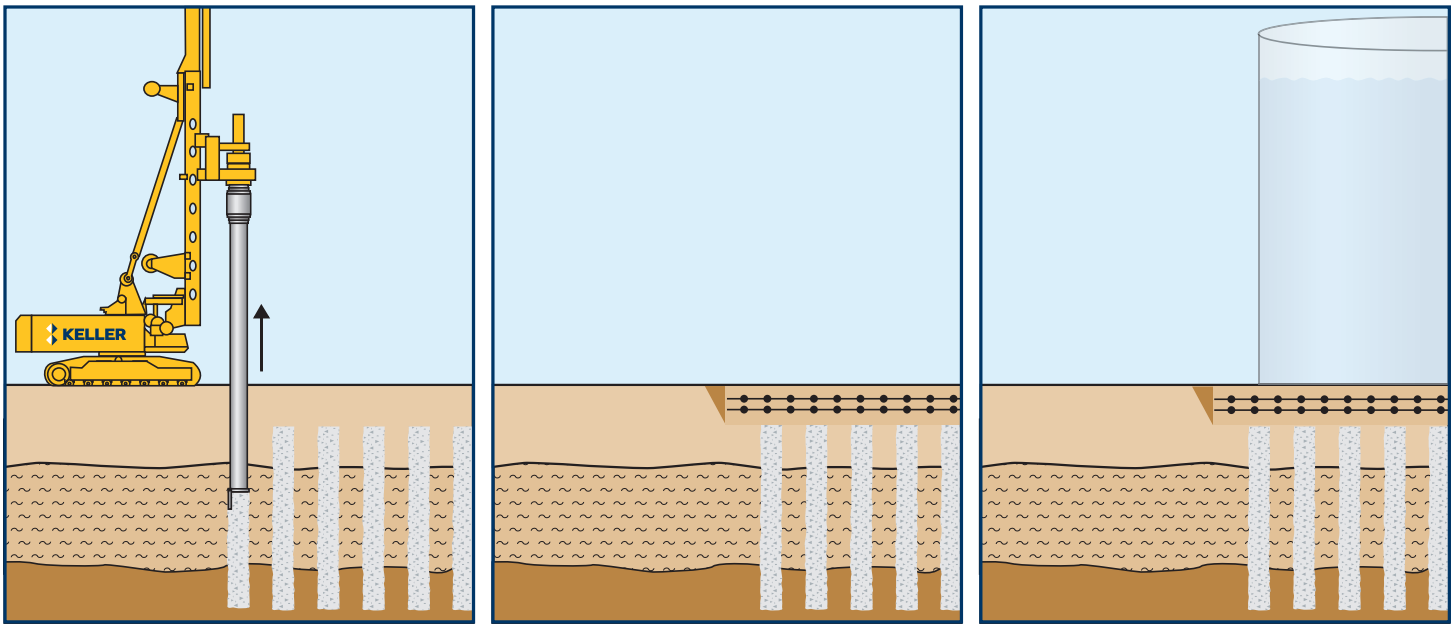
③ *RIs for an outlet mall through a thick compressible clay deposit. RIs reduced the total settlement of new fill required to achieve the planned finished floor elevation. RIs reduced the schedule compared to surcharging and waiting for consolidation to occur.*

④ *RIs to support and mitigate settlement of a new highway embankment.*

⑤ *A future train station being supported with RIs.*

KELLER

Procedures & Design Considerations . . .



Rigid Inclusion Procedure

The typical installation procedure incorporates a displacement tool mounted on a track-based rig. The equipment advances the tool to the design depth. Granular bearing soils, if present, are densified by displacement. As the tool is raised, the tip opens and the grout mix is pumped through the tool while maintaining a positive grout head during extraction.

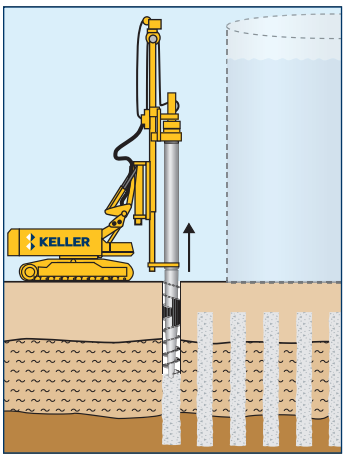
Design Considerations

RIs are particularly well suited for highly compressible soils. The size, length, and spacing of the RI reinforcement elements are designed based on the initial compressibility of the soil and performance criteria for the project.

Because of the complicated soil-structure interaction involved with RI design, Finite Element analysis often supplements traditional geotechnical and structural design calculations.

Load Transfer Platform

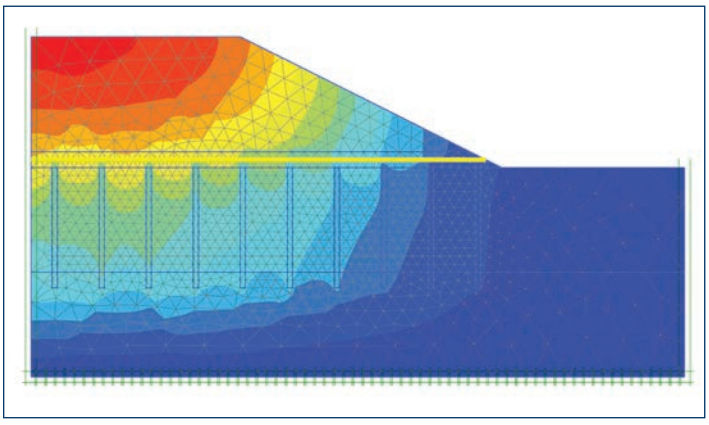
Load distribution to RIs can be provided by a load transfer platform (LTP), which is located between the top of the RIs and the bottom of foundations, slab, and/or embankments. A naturally occurring dense or hard stratum near the ground surface may reduce or eliminate the need for the LTP if the layer has sufficient engineering properties to transfer the load to the RIs.



Above: RI vibratory installation construction sequence.

Left: RI rig with drilled displacement tool.

Below: Finite-Element analysis is typically needed to evaluate the complex soil-structure interaction for the design of RIs.



KELLER

Equipment & Materials . . .

Rigid Inclusions have been used to increase allowable bearing pressure and decrease settlement for planned structures, embankments, and tanks.

Rigid Inclusion Rig

The RI rig is typically a fixed-lead track unit equipped with a displacement tool. When installation requires penetration of hard or dense soils, the locations can be predrilled or a drilled auger displacement process can be used.

Grout Delivery

The RI grout mix is either produced on site or delivered by ready mix trucks. A concrete pump is used to transfer the grout to the tool. The grout exits the bottom of the tool, filling the void created by the extraction of the tool. Data acquisition systems can be used to monitor grout placement versus extraction speed.

Grout Mix

The RI grout consists of Portland cement, aggregate, and water and may contain a mineral admixture and fluidifier. Each component is proportioned to produce a pumpable grout with sufficient mechanical properties to maintain column geometry in the soils being treated. The grout mix is designed to provide the 28-day unconfined compressive strength required to meet the design.

Pump transfers grout to RI tool.

Load Transfer Platform

When a load transfer platform is required, it is generally constructed immediately above the completed RIs. The platform consists of granular, structural fill soils and may be reinforced with one or more layers of biaxial geogrid and/or geotextile. The tops of the RIs are typically left slightly below the working surface to reduce the risk of damage by equipment performing subsequent earthwork.

Compaction of granular structural fill during construction of an LTP for a slab supported by RIs.

Quality Control . . .

Keller has developed proprietary data acquisition (DAQ) equipment and software for real-time monitoring of all parameters during the Rigid Inclusion process.

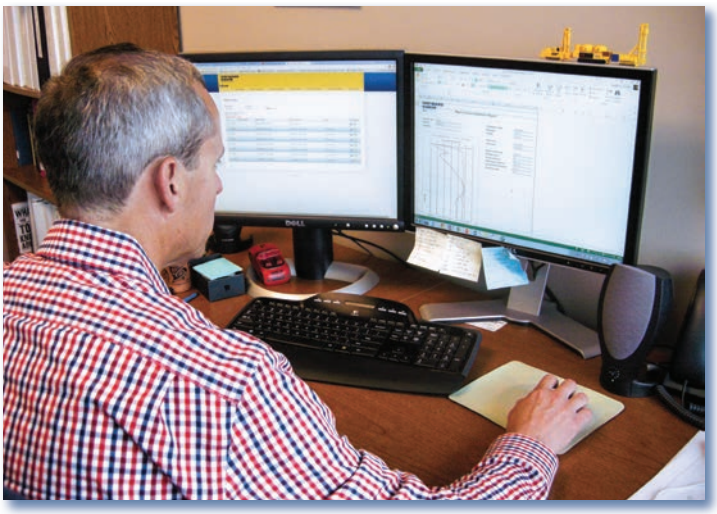
Quality control in the field begins with accurate layout of the RI locations. The tool is centered at each staked location within the specified tolerance. For each RI a log is generated providing the following:

- Project Information
- Column Identification
- Diameter
- Length
- Start Time
- End Time
- Penetration Depth
- Pump Stroke Count
- Neat Grout Volume (Theoretical)
- Actual Grout Volume
- Penetration Rate
- Crowd Pressure or Applied Torque

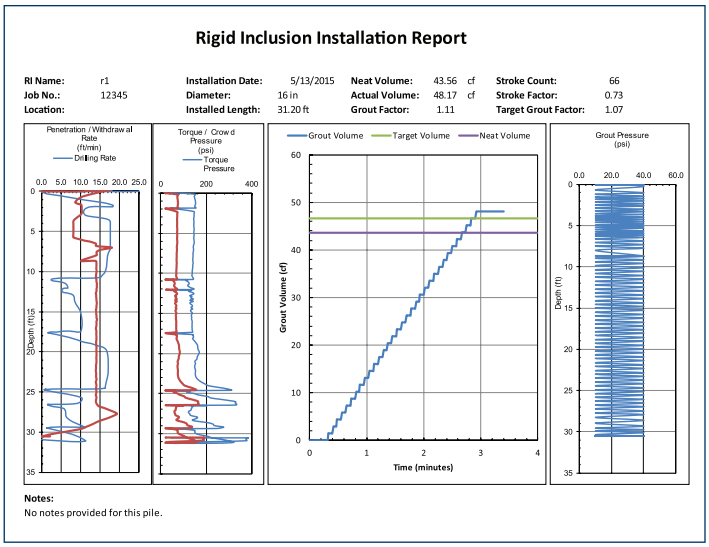
Keller has developed proprietary data acquisition (DAQ) equipment and software for real-time monitoring and recording of all parameters during the RI construction process. In-cab monitors display real-time quality control feedback to the operator and/or field engineer during construction, and graphically display data such as grout volume and depth alongside specified target values. The DAQ system transmits all data in near real-time to an online central database via cell modem.

The grout is regularly sampled and cast into cylinders for strength testing after curing. Load testing of a test RI, or group of RIs, can be performed to verify the design assumptions.

In-cab DAQ monitor displaying real-time quality control feedback during RI construction.



Data are transmitted from the field to a server to allow the project manager and designer to review. Reports are available to management and clients shortly thereafter.



Rigid Inclusion Installation Report

RI Name:	r1	**Installation Date:**	5/13/2015	**Neat Volume:**	43.56 cf	**Stroke Count:**	66
Job No.:	12345	**Diameter:**	16 in	**Actual Volume:**	48.17 cf	**Stroke Factor:**	0.73
Location:		**Installed Length:**	31.20 ft	**Grout Factor:**	1.11	**Target Grout Factor:**	1.07

Notes:
No notes provided for this pile.

Sample RI report.

KELLER

Advantages of Keller Rigid Inclusions

- *Advanced DAQ systems to document performance and provide quality control*
- *Over 40 techniques allow for alternate approaches when required by subsurface conditions*
- *Experienced in load transfer platform design*
- *Variety of equipment and tooling for a range of subsurface conditions and limited access*
- *Experienced with multiple installation methods*
- *Nearly 40 years of experience with a wide variety of applications*

Rigid Inclusion installation for a planned hotel.

You have a strong partner with Keller

As a leading specialty geotechnical construction firm, Keller provides a full range of ground engineering techniques and solutions, related to earth retention, foundation support, ground improvement, and ground treatment.

Built on a reputation of safety and quality, Keller sets the standard for performance and innovation through our commitment to the integration, implementation, and further development of advanced technologies for specialized geotechnical construction. With technical excellence, and teamwork at our core, we deliver projects safely, on budget and on schedule.

Offering a wide range of services, including design-build packages, Keller meets the needs of our clients by providing comprehensive cost effective solutions to the most complex problems.

KELLER

Design-Build Services for the Complete Range of Geotechnical Technologies

Grouting
Fracture grouting/compensation grouting
High mobility (rock/fissure) 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
Rigid inclusions
TRD - soil mix walls
Vibro compaction
Vibro concrete columns
Vibro (Aggregate) Piers®
Vibro stone columns
Wet soil mixing
Wick drains

Deep Foundations
CFA piles (auger cast)
Displacement CFA piles
Drilled shafts
Driven piles
Franki piles (PIFs)
Helical piles
Jacked piers
Macropiles®
Micropiles

Earth Retention
Anchors
Anchor block slope stabilization
Gabions
Micropile slide stabilization system (MS³)
Sculpted shotcrete
Secant or tangent piles
Sheet piles
Slurry wall - structural or cutoff
Soil nailing
Soldier piles & lagging

Additional Services
Dewatering
Ground freezing
Pit underpinning
Slab jacking

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

Keller Foundations Ltd.
A member of the Keller worldwide group of companies

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

THINK SAFE