GROUND IMPROVEMENT

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HISTORICALLY, when building on sites with poor soils, builders had two primary options to choose from – piling and removal and replacement. While some ground improvement techniques such as dynamic compaction have origins tracing back to the middle ages, it wasn't until the past half century that ground improvement began to gain wide acceptance and recognition as a viable option for addressing sites with problematic soils. The last few decades have seen a proliferation of the types of ground improvement techniques, installation methods, equipment capabilities, design methodologies, QA/QC requirements and procedures, and number of contractors offering ground improvement.

At many sites, excavating the problematic soils and importing and compacting fill is a viable solution. However, removal and replacement has its limitations, particularly when the problematic layers extend beyond a few feet. Where groundwater is high and deeper excavation is required, it may be necessary to dewater or install groundwater barriers such as cutoff walls or sheet piling. It may be necessary to protect adjacent structures by underpinning or with support of excavation systems. Deeper removal and replacement becomes very costly and cause schedule issues, especially when faced with preparing subgrades and placing fill in wet or frozen conditions. And of course, the prospect of unearthing contaminated soils or buried hazardous materials will strike fear in any developer or property owner.

Most civil and structural engineers are very familiar and comfortable with multiple types of piles and other deep foundation elements since these systems have traditionally been the default foundation systems for sites with problematic soils. These systems are tried and true, but are they always necessary? In many cases, ground improvement can result in savings by both eliminating deep foundations and allowing structures to be supported on shallow foundations systems, as if you were building at a site with competent soils.

To select the appropriate type of ground improvement for a site, it is important to understand what challenges the ground may pose for the support of the structure. Could excessive settlement occur due to soft or loose soils? Is the factor of safety against bearing capacity failure too low due to the presence of weak layers? Are slopes or embankments unstable? Would excessive differential settlement occur due to differential loading conditions or variability of soil conditions across the site. Is undocumented fill or buried debris present at the site? Is liquefaction a risk at the site? With all the potential issues that sites may face, the importance of a thorough geotechnical investigation cannot be overstated. To allow for the selection of the appropriate ground improvement system, and its optimization, it is critical that sites are characterized with sufficient coverage (and depth) of borings or soundings, and with ample laboratory testing to determine the characteristics and strength properties of the on-site soils.

Another vitally important aspect of ground improvement selection and design optimization is having a good understanding of the layout and actual loads for the proposed structure. In some cases, the highest building column loads are adapted as the design case for the entire structure – this results in an inefficient ground improvement design. Optimization of ground improvement comes from a deeper understanding – of the site, of the ground, and of the structure.

Rapid Impact Compaction (left) and Dynamic Compaction (right) are used to densify fill material to accommodate building construction at a site in New Jersey.

There are many different ground improvement systems adaptable to a wide array of site conditions, soils, and structure types. In general terms, there are three typical modes of soil improvement – densification, reinforcement, and drainage enhancement. Some systems provide

one of the modes of improvement, while other systems may provide two or three of the modes of improvement.

Densification is used to improve granular soils such as sand or gravel and is typically achieved by imparting vibration into the ground to prompt the granular soil grains to rearrange into a denser state. Densification can also result from the displacement of granular soils by elements that are drilled, vibrated, or grouted in place. Densification, also referred to as compaction, reduces compressibility, and increases shear strength, leading to improved bearing properties and reduced settlement of the treated soils.

Reinforcement is achieved by installing relatively stiff elements within soft, weak, or variable layers. The elements typically are installed by drilling, vibrating, or driving a casing or probe and filling the resultant void with grout or compacted stone to form a column. If the receiving ground is granular, densification of the surrounding ground is a corollary benefit of the installation for elements that are installed with displacement methods or during compaction of the stone column.

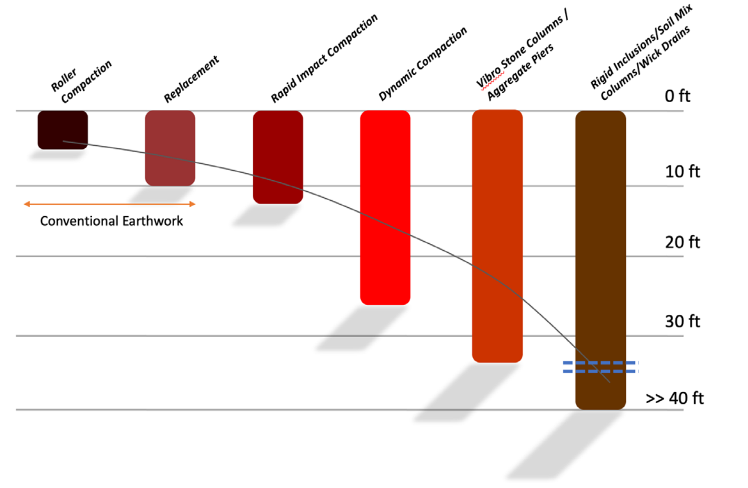
Soil preloads have long been used as a simple, economical method for preparing sites. In the simplest terms, a preload consists of a pile of soil that exerts stresses on the receiving ground that are similar or greater than the stresses that the ground will receive from the planned structure. As the preload remains in place, the underlying soil layers are squeezed and compressed. Where saturated clay layers are present, it can take months, years, or even decades for the consolidation to occur due to the lower permeability of clays. Keeping a preload in place for more than a few months is typically not practical. Vertical drains are commonly installed to expedite consolidation drainage in conjunction with preloads and also under fills, berms, dikes, levees, and reclaimed land.

Common Ground Improvement Techniques

Densification, reinforcement, and drainage enhancement can all be used to increase bearing, reduce total and differential settlement, increase shear resistance, and to mitigate liquefaction. Selection of the appropriate technique or combination of techniques is done on a case-by-case basis, and dependent on the geotechnical conditions, depth of problematic soils. the configuration and layout of the structure, loading conditions, settlement criteria, construction schedule and sequencing, size and location of project, and site access. Following are brief descriptions of some of the more commonly used techniques being used in the United States today.

Dynamic Compaction

Dynamic compaction uses large crawler cranes to drop weights that typically range from 10 to 20 tons repeatedly in a predetermined grid pattern to increase density and reduce voids in granular soils, fills, and landfill materials. Most effective for large-footprint sites, the technique is less effective in overly clayey or silty soils and where shallow groundwater is present. Because of the large amount of vibration introduced into the ground, special care should be taken when using dynamic compaction near utilities, buildings, or other vibration- or settlement-sensitive structures. A related technique, Rapid Impact Compaction (RIC) is used to compact soils when it is necessary to



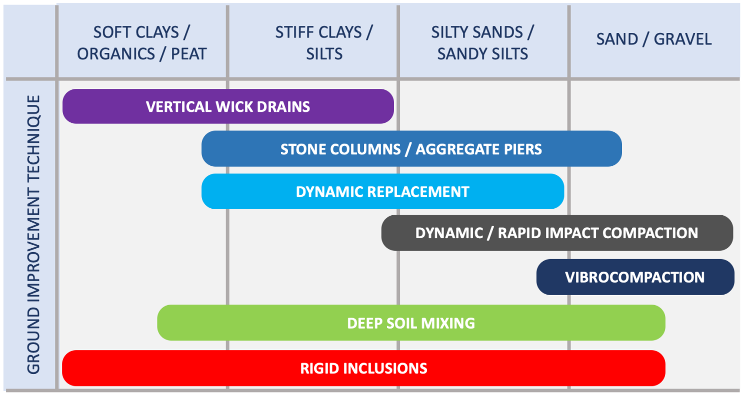
General depth of application for various ground improvement techniques

limit vibrations. RIC typically treats a shallower depth of soil and is performed using a pile-driving hammer that is mounted to the front of an excavator to pound a steel plate seated on the ground surface.

Vertical Drains

Wick drains are thin, flexible drains that typically measure 1/8-inch thick by 4-inch wide. The drains consist of a channelized plastic core encased in a geosynthetic filter fabric designed to let water in and keep soil particles out. The drains, typically spaced between 3 ft and 8 ft in a grid pattern, are pushed into the ground and can be installed to depths of well over 100 ft. Wick drains are used to alleviate excessive pore pressure that would build up in fine-grained soil layers when fill is placed, and act to speed up consolidation settlement; reducing the time necessary for soil preloads to stay in place, mitigating long term settlement of fills, and enhancing stability of embankments as construction progresses. To perform as intended, an outlet for the water flowing from the wick drains is necessary – this is typically in the form of a granular drainage blanket installed at the ground surface prior to wick drain installation.

Four drills installing Controlled Modulus Column (CMC)TM Rigid Inclusions to improve ground for a very large distribution center in South Dakota.



General range of applicable soil types for various ground improvement techniques

Where liquefaction is a potential risk, larger diameter drains know as Earthquake Drains can be installed. These drains are designed to alleviate pore pressure build up during seismic events such as earthquakes, and reduce both the likelihood of liquefaction occurring and the amount of liquefaction-induced settlement that occurs. The drains are typically comprised of a 4-in-diameter slotted, flexible, corrugated pipe encased in a geotextile fabric. The drains are driven into the ground at spacings that typically range from 5 to 10 ft.

Vibro Stone Columns/Aggregate Piers

Vibro stone columns are continuous vertical columns of compacted aggregate that are formed using a vibratory probe to create vertical inclusions with high stiffness and shear strength and improved drainage. Vibro stone columns typically range in diameter between 18 and 42 inches. When a vibratory probe is used to form the hole in which the stone column is constructed, then the elements are referred to as stone columns or vibratory stone columns. If separate drilling equipment is used to create the hole in which the stone is placed, then the elements are commonly referred to as aggregate piers.

Stone columns are commonly used to reduce settlement and increase bearing capacity of soils for the support of structures. Because of their high shear strength, they are also commonly used to enhance slope stability and prevent lateral spreading. Stone columns can efficiently mitigate liquefaction resulting from the significant densification of granular layers that occurs during installation; enhanced drainage capacity is also a benefit for liquefaction mitigation. In spite of the versatility of stone columns, slower installation rates and subsequent higher cost of stone columns deeper than about 40 feet make their use for deeper soils less viable. Stone columns are also not applicable for very soft clays or organic soils where the columns would be prone to bulging which would lead to excessive settlement or even failure.

Rigid Inclusions

Rigid Inclusions are grouted vertical elements that typically range in diameter from approximately 12 to 18 inches. Rigid Inclusions are well adapted to high surface loading conditions and strict settlement requirements and are used to support slabs-on-grade, isolated footings, and embankments on compressible clays, fills and organic soils.

When rigid inclusions are installed with displacement drilling techniques, the soil is displaced laterally, with virtually no vibration or spoil, eliminating the need to dispose of contaminated soil. The auger is screwed into the soil to the required depth increasing the density of the surrounding soil and increases its bearing capacity. During auger extraction, grout is injected under light pressure to build the column to stiffen and treat the surrounding soil. Driven casing methods are also sometimes used to install the elements. Rigid Inclusions are designed as a composite ground improvement system where the column reinforcements and the surrounding soil share the loads.

Rigid Inclusions have proven to be extremely versatile in treating a wide variety of soil conditions, including very soft, compressible layers, very deep layers (rigid inclusions have been installed to depths of over 150 ft) and contaminated soils, since spoil generation is minimal. Unlike pile foundation systems, rigid inclusions are not typically connected to foundations. A layer of compacted stone referred to as a load transfer platform (LTP) is typically installed above the Rigid Inclusion elements to help distribute the load from the structure to the underlying soil and Rigid Inclusion elements. The LTP allows for shallow foundations to be designed and eliminates the need for pile caps, grade beams, and structural slabs.

Conclusions

While this article does not cover every ground improvement technique that is available, it highlights a wide range of techniques available to treat a variety of problematic soil conditions. Ground improvement systems are intended to be elegant in their simplicity, and are used to support any number of structure types including warehouses, buildings, storage tanks, equipment and machinery pads, highway embankments, retaining walls, earthen fills, berms, dikes, and levees.

When comparing ground improvement to piling, it is important to understand that ground improvement may lead to savings related to foundation design and total construction costs, especially when not only the piling, but the associated pile caps, grade beams and structural slabs can be eliminated. An increasingly important benefit of ground improvement is environmental sustainability - in many cases less concrete and steel is used in the foundation system.

Menard Group USA is a design-build ground improvement contractor with offices across the USA, offering solutions for a wide range of soil conditions and structure types. For more information or to discuss an upcoming project, pls contact info@menardgroupusa.com or call (412) 620-6000.

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