GROUND IMPROVEMENT

Extending the Use of Spread Footings

Andrew F. Brengola, P.E and Allen L. Sehn, Ph.D., P.E

Ground improvement methods are often used to reduce settlements and/or increase bearing capacity for new construction. In most cases, the purpose is to allow the use of conventional spread footings which are typically the most economical foundation system. Some of the methods can also be used to improve the support of existing structures or to provide support for excavations. There are numerous ground improvement methods available, and selection of the best method depends on the properties of the soil at the site and other project specific factors. An overview of the most commonly used methods is presented with detailed discussion on methods that are being used more extensively today. Guidance on selecting the most appropriate technique for various situations along with estimated installation costs for each technique is provided.

INTRODUCTION

Ground improvement includes systems that use the ground or some modification of it, to transfer or support loads. Ground improvement can increase soil strength and stiffness and/or reduce permeability. In many situations, ground improvement can be used to support new foundations or increase the capacity of existing foundations in place of bypass systems, such as piling, caissons, or remove and replace. In doing so, the ground improvement system reduces the overall foundation cost by allowing the new structure to be built on spread footings with a slab on grade rather than pile caps and a structural slab. It has been estimated that a savings of four to eight dollars per square foot of building can be realized. For a large super market, department store or home improvement store the savings can be in excess of one million dollars. In the case of an existing structure, ground improvement allows the use of existing foundations with little to no modification.

In choosing a ground improvement system it is first necessary to accurately characterize soil conditions at the site. Material types, stratigraphy and groundwater conditions must be determined above, below and in the treatment zone. Typical properties of importance in the treatment zone include gradation, plasticity, moisture content, organic content, strength and consolidation properties. Properties of the proposed structure including column loads, slab loads and tolerable total and differential settlements are also required in the analysis.

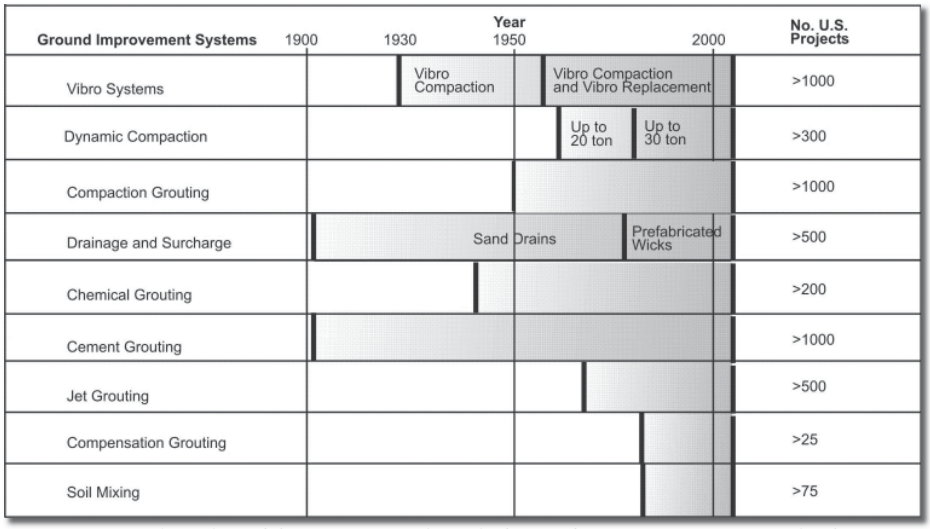

Figure 1: General timeline of the most commonly applied ground improvement systems. Also shown is the number of projects that are estimated to have been completed in the U.S. to date.

GROUND IMPROVEMENT SYSTEMS

Drainage and Surcharge is a very old means of ground improvement. For this system, consolidation properties of the soil and the spacing of the vertically installed drainage elements will govern the design and construction schedule. Ground stability issues may require staged loading and waiting periods to ensure safe construction. This system offers cost advantages in soft silty and clayey soil if the project schedule permits adequate construction time.

Dynamic Compaction utilizes the densification energy of weights up to 30 tons, dropped from heights of up to 100 feet to improve mainly granular soil, construction debris or sanitary landfill within 30 feet of the ground surface. The improvement is evident from the surface elevation change produced by repeatedly dropping the weight in a grid pattern. The resulting large ground vibrations can adversely affect nearby structures.

Compaction Grouting, also known as low mobility grouting, utilizes the controlled injection of low slump cementitious grout in stages to form columns of grout bulbs in free draining granular soils. As the bulbs are formed, the surrounding soil is displaced and densified. This technique is ideal for remediating or preventing structural settlements under existing foundations, and for re-leveling structures that have experienced differential settlement.

Vibro Systems started with development of the depth vibrators that produce horizontal vibration in the ground. Vibratory energy at the tip of the depth vibrator effectively rearranges the soil grains into a tighter configuration, increasing the density of the granular soil, thereby increasing bearing capacity while reducing potential settlements due to foundation loads. Vibro Compaction is used to mitigate liquefaction potential in seismic areas.

Vibro Replacement was born when it was found that backfilling the probe hole with gravel sized stone particles would increase the densification effect, and leave a stiff, dense stone pier for reinforcement, expanding Vibro System's applicability to a much wider range of soil types. Vibro Replacement can densify silty sands with silt contents up to 30%, and finer-grained soil types can be reinforced by creating high modulus stone columns to reduce deformation and increase shear strength. When water jetting usage was restricted, the construction community developed equipment able to dry "bottom feed" the stone, yielding higher displacement capacity and increased densification.

Although Vibro Replacement is capable of installing stone columns to depths of over 100 feet, numerous projects require reinforcement of the ground to depths of 30 feet or less. As such, specialized equipment has been developed to quickly and efficiently install short aggregate piers, or Vibro Piers, to depths up to 30 feet. Vibro Piers are capable of densifying surrounding granular soils up to a 5 foot radius. In weak or compressible soils, Vibro Piers are typically spaced at 6 to 10 foot centers under embankments, tank foundations, and floor slabs. Closer spacing is utilized under spread footings. Unlike other methods that utilize tampers, Vibro Piers are installed using the dry bottom feed method and pre-augering of soils is rarely required. As such, this method offers additional advantages in contaminated soils. In addition, the costly installation of a temporary casing is not required to maintain a stable hole when working in collapsible soils or when installation is below the water table.

In very weak cohesive or organic soils that offer less than adequate confinement to stone columns, concrete can be pumped through a depth vibrator creating a Vibro Concrete Column (VCC). Similar to Vibro Piers and stone columns, VCCs reduce settlement, increase bearing capacity, and increase slope stability. In general, costs for methods range from $2 to $8 per cubic yard of soil to be treated plus the cost of backfill and mobilization.

Jet Grouting is an erosion-based system that relies on kinetic energy of high velocity jetted fluids to break down the soil structure and remove a portion of it while mixing it with cementitious grout slurry. The resulting soil cement mixture is referred to as soilcrete.

Single fluid system Jet Grouting relies on high velocity grout exiting the injection nozzles to erode the surrounding soil. Double fluid system Jet Grouting utilizes concentric nozzles with high velocity grout exiting the inner nozzle while air exits the outer nozzle. The air shroud reduces the friction of the soil on the grout exiting the nozzles and increases the focus of the grout stream. In addition, the air assists with the venting of the jet grouting spoils to the surface. As a result, the double fluid system produces a larger diameter, higher quality soilcrete column. Triple fluid systems utilize water and air through concentric nozzles to erode the surrounding soil while grout is pumped though separate nozzles below the concentric nozzles. The triple fluid system generally results in the highest quality columns, however, these columns are generally smaller than those produced by the double fluid system.

Experience with specialized equipment and performance is necessary to select the appropriate system and parameters. Since Jet Grouting is erosion based, it can be effective across the widest range of soil types. Although Jet Grouting rarely is used as a system of mass ground improvement, the newest variant called SuperJet has been applied for this purpose. Depending on the insitu soils at the project site, unconfined compressive strengths of the resulting soilcrete can range from 50 to 1000 psi. Costs for Jet Grouting can range from $100 to $300 per cubic yard of treatment.

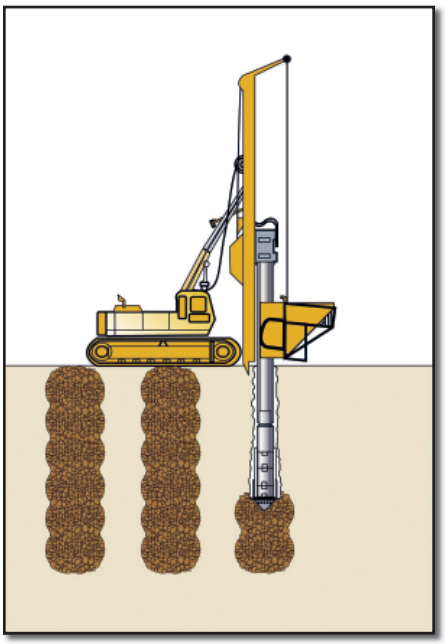

Figure 2: Vibro Piers with the dry bottom feed method stone is introduced through the vibrator tip. Displacement is 100% of the Vibro Pier diameter, creating little or no waste.

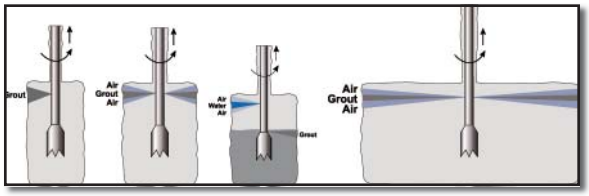

Figure 3: Jet Grouting systems (left to right are Single Fluid, Double Fluid, Triple Fluid and SuperJet).

Figure 4: Jet Grouting next to an existing pile cap in restricted space at an operational power plant.

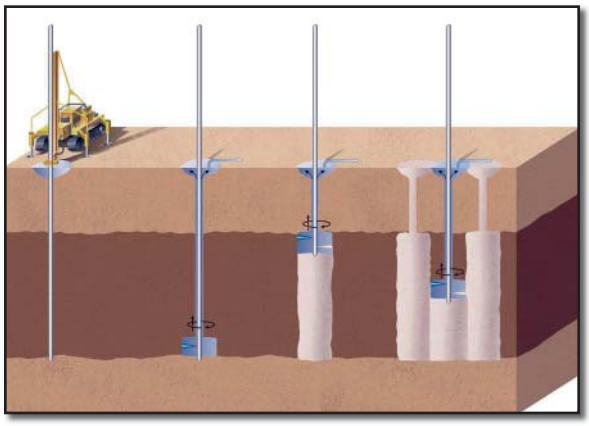

Figure 5: The Jet Grouting process.

Wet Soil Mixing is a mechanical mixing system whereby insitu soils are sheared and mixed with cementitious slurry to create soilcrete columns similar to those produced by Jet Grouting. Mixing may be performed by single or multiple axis mixing tools. Single axis tooling uses more mechanical mixing energy to insure thorough mixing, but offers reduced cost for mass mixing by virtue of high productivity.

Dry Soil Mixing is a bottom-up mechanical mixing system, shearing precut soil and combining it with pneumatically injected powder binders (usually cement and lime). Dry soil mixing is appropriate for very wet and soft soils untreatable by other methods.

SUMMARY

There are a variety of techniques to improve weak or compressible soils. The selection and success of the a ground improvement system is dependent on having a complete understanding of the soil conditions, structural loads, and tolerable settlements.▪

Figure 6: Soil Mixing reduced settlements and allowed construction of 310-foot diameter fuel oil storage tanks over soft soils.

Andrew F. Brengola, PE, is New England Area Manager, Boston, MA, for Specialty Geotechnical Contractor, ***Hayward Baker Inc.*** *Allen L. Sehn, Ph.D., PE, is Chief Engineer at Hayward Baker headquarters in Maryland. Both authors can be reached at 800-456-6548.*

A Ground Improvement Solutions Table, to assist in determining appropriate treatment methods, can be found in the HBKnowledgeBase, www.HaywardBaker.com. *Photos provided by Moretrench Geotech.*