STRUCTURAL PRACTICES

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A Soil Improvement Primer

By Carrie Johnson, P.E.

Because increased development has led to the need to use marginal sites, and because many types of soils can be modified so that they are a viable support material for many types of structures, soil improvement (also called ground modification) has become an important consideration for many project types. The goal of soil improvement is typically to allow the development to be constructed on a shallow foundation system. In cases where the alternatives are to remove and replace soils, surcharge the site or install settlement plates and wait for an extended period of time, or extend deeper foundations through the relatively weak soil layers to a suitable bearing layer, soil improvement is often an economical option.

The costs of the different methods, and the soils for which they are most effective, vary greatly. The intent of this article is to highlight the basic merits of each system. There are a number of soil improvement methods available, and the list continues to expand as building owners push to build on land that was previously deemed undesirable. The common names for many of these methods have been trademarked, which makes comparing the different options difficult. The following explains what each technique involves, what improvements can be expected, and what type of soil it is best for improving.

Categories

Each technique for improving soils can be categorized as one of the following:

1) Soil Stabilization – mixing soil with cementitious materials.
2) Compaction – applying mechanical energy.
3) Consolidation – preloading the soil.
4) Grouting – pressure injecting grout into the soils.
5) Soil reinforcement – adding a stronger material.

Selection

Although the recommendation for foundation type and soil improvement methods typically falls into the geotechnical engineer's area of expertise, it is important for the structural engineer to be aware of what those recommendations mean, recognize the cost implications, and ask questions accordingly. Typically, the structural engineer provides the geotechnical engineer with information about the anticipated loading to the foundation, the expected framing systems, and the settlement criteria. The geotechnical engineer then makes recommendations for the foundation system, and the structural engineer utilizes those recommendations to provide a final design. Communication during this process is essential to ensure that all of the appropriate options are being considered. The selection of the best method will depend on a number of factors, including:

1) Type and degree of modification required – to improve settlement, slope stability, bearing capacity, etc.
2) Area, depth, and total volume of soil requiring improvement.
3) In-situ soil type and its initial properties.
4) Availability of equipment, materials, and experienced contractors.
5) Time available.
6) Cost.
7) Environmental constraints, including effects of adjacent structures.
8) Accessibility.

Dry Soil Mixing

Dry soil mixing, sometimes referred to as lime stabilization, improves the characteristics of soils with high moisture content (>40%) – such as clays, peats, and other weak soils – using a dry cementitious material as a binder. The process involves using a mixing tool to blend the dry cement with the soft, wet soil and is often very cost-effective. The dry binder utilizes the moisture inherent in the wet soils during the hydration reaction. Binder types include lime, cement, a lime-cement mixture, or a mixture of slag and cement. The typical dosage is approximately 10% by weight of soil. The dosage amounts vary and should be identified in a laboratory and then verified on-site during installation, because results in the field will likely deviate from the laboratory ideal.

Both shallow and deep applications are common. With shallow applications, a mass mixing technique is utilized, involving a mixing tool mounted on a machine with low pressure tracks. Deep applications are done in columns of soil with a soil mixing tool. The tool is rotated into the ground, a binder is injected, and then the tool is rotated at high speed during withdrawal to mix the binder with the soil.

With dry soil mixing, you can expect to increase bearing capacity, decrease settlement, mitigate liquefaction during earthquakes, and increase shear stability to improve slope stability.

Wet Soil Mixing

The process for wet soil mixing is similar to that for dry soil mixing, except that a water-cement slurry is used instead of dry cement. In very wet soils, the wet soil method can result in columns that are not as strong; however, it provides stronger columns in dryer soils. Wet soil mixing is typically more expensive than dry soil mixing.

Wet soil mixing is also an effective method to form ground water barriers, to stabilize contaminants, or as a chemical treatment for soils with undesirable chemical properties. It is most suitable for soft or loose soils with a lower moisture content than those where dry soil mixing is effective.

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Dynamic Compaction

Dynamic compaction is the dropping of a heavy mass onto the ground surface to densify the soils below. The weights used are typically on the order of 10 to 25 tons at heights between 30 and 100 feet. Testing of this method has shown that it can impact soils at depths of over 100 feet. The underlying concept is that by imposing a loading onto the soil that is higher than will be imposed by the proposed construction, the soil will be over-consolidated, thereby minimizing any future settlement. Dynamic compaction is done with a number of passes in a grid pattern. The spacing of the grid, as well as the number of passes, must be verified during installation.

With dynamic compaction, the biggest impact is on settlement, since it collapses any voids. It can also be utilized to prevent soil liquefaction during earthquakes and to increase the density of fills in land reclamation sites.

Dynamic compaction is most suitable for sands with less than 5% fines. It can also be effective on sands with up to 12% fines, but success depends on clay content, grain shape and size, and the water table. It is not recommended for sands with over 12% fines or for clays.

Dynamic Replacement

Dynamic replacement is similar to dynamic compaction. In this method, stone or suitable granular fill is driven and compacted into the ground using high energy pounders to form large–diameter dense columns to reinforce the soil. This method is often referred to as stone columns. Cohesive, mixed and layered soils generally do not densify easily when subjected to vibration alone. With dynamic replacement, these columns of crushed stone are intended to increase bearing capacity, but the designer needs to be aware of the variation in soil conditions between the dense columns and the less dense in-situ soil. The design should include a layer of soil to transition between these two conditions, or a foundation system that effectively spans between them.

Dynamic replacement can effectively reduce foundation settlements, increase bearing capacity, mitigate soil liquefaction during earthquakes, and increase the shear strength of the soil to improve slope stability.

Dynamic replacement is most suitable for sands with less than 12% fines, but vibro-compaction (discussed below) or dynamic compaction may be more cost-effective for sands with less than 5% fines. It can also be effective on silty soils or clays. It is not recommended for sensitive soils that lose strength when vibrated.

Vibro-Compaction

Another similar method is vibro-compaction, which is typically used to densify clean, cohesionless soils. This method uses probe-type vibrators hung from cranes or mounted on piling equipment to densify granular soils to depths over 100 feet. The action of the vibrator, usually accompanied by water jetting, reduces the inter-granular forces between the soil particles, allowing them to move into a denser configuration, typically achieving a relative density of 70 to 85%.

Vibro-compaction can effectively increase bearing capacity, mitigate soil liquefaction during earthquakes, densify soils, and reduce foundation settlements.

Vibro-compaction is most suitable for sands with less than 5% fines. It can also be effective on sands with up to 12% fines, but success depends on clay content, grain shape and size, and the water table. Is not recommended for sands with over 12% fines or for clays.

Compaction Grouting

Compaction grouting is a technique that displaces and densifies loose granular soils, and stabilizes subsurface voids or sinkholes, by injecting a slow-flowing grout mixture into the soil. The method involves extending a pipe to the maximum injection depth and then injecting grout as the pipe is slowly extracted.

This method is effective where there is a potential for sinkholes, or any type of underlying void that could form a depression, or sag, at the surface. The most common causes of subsidence are aquifer system compaction, drainage of organic soils, underground mining, sinkholes, and permafrost.

Compaction grouting can also be used as a remedial measure for an existing structure that has experienced settlement. It is effective in treating both foundation systems and slabs on grade.

Compaction grouting can effectively reduce foundation settlements, increase bearing capacity, and mitigate soil liquefaction during earthquakes.

Compaction grouting is effective on almost any type of soil and can be used to treat existing sinkholes or to reduce the potential in sinkhole-prone areas.

Injection Systems

Injection stabilization is used to reduce heave on expansive clays, using pressure injection of various types of fluids to reduce the shrink/swell potential of the in-situ soils. This method is also referred to as chemical injection and is used to change the expansion/contraction cycles of the soil. It uses a unit that drives injection pipes beneath either an existing structure or a new building pad. A solution is then injected in the soil. Common injection systems include lime, potassium, water, and electrochemical pressure.

Rapid Impact Compaction

Rapid impact compaction is a technique that densifies shallow, loose granular soils using a hydraulic hammer struck repeatedly by an impact plate. The energy is transferred through the plate to the soils and the particles are rearranged into a denser configuration. The impact is typically applied in a grid pattern, and the spacing is determined by the underlying soils and the proposed configuration and loading of the structure.

Rapid impact compaction is used to reduce settlement, increase bearing capacity, increase density and stiffness of the soils.

Rapid impact compaction is most effective on loose granular soils, where the depth of the loose soils is relatively shallow and there are denser underlying soils.

Rigid Inclusions

Rigid inclusions is a soil improvement technique that utilizes high modulus concrete columns to transfer loads through weak strata to a firm underlying stratum. A pipe is extended down to the firm soils. The pipe is then filled with a concrete mix with high internal friction and extracted.

Utilizing rigid inclusions increases bearing capacity and decreases settlement of the structure.

Specifications and Quality Assurance

The price tag on these systems can vary tremendously, both between methods and between installers. Competitive bidding on the basis of a well-defined specification for how the system is expected to perform is recommended.

The specification should also include a proper Quality Assurance and Quality Control program to ensure that all equipment used is fully instrumented and monitored, and that testing is done to verify the results in the field. Since some of these techniques are highly specialized, it is appropriate to require evidence that the installer has successfully performed the method a number of times previously.■