Practical Solutions

solutions for the practicing structural engineer

Urban Fills

How Ground Improvement Can Eliminate the Need for a Costly Deep Foundation System

By Chris Woods, P.E., LEED^AP BD+C

*Chris Woods, P.E., LEED^AP BD+C (**dchipurdue@hotmail.com**), is the Chief Engineer for the Paeonian Springs, Virginia based Densification, Inc., and presently serves on the Ground Improvement Committee of the Deep Foundations Institute (DFI).*

These days, finding an urban site, particularly in our older cities, that has not been impacted by previous developments might best be described as….impossible. Many sites developed in urban settings have been built and rebuilt throughout the years, and experience speaks to the fact that as the vast majority of these prior structures were demolished, little thought or care was given to what was left beneath the surface. When combined with factors beyond the developer's control, such as the existence of foundation systems supporting adjacent structures, buried utilities or transit tunnels, developing an appropriate foundation solution that can be designed, permitted, and most important, constructed in an economical way, becomes a significant challenge for the design team. In most instances, the approach taken by the geotechnical and structural engineers will determine whether or not the given site challenges are successfully overcome.

Figure 1: Typical foundation remnants on an urban site.

Typical Challenges to Foundation Design on Urban Sites

Depending on the location or age of the site and the nature of the previous development on a site, there could be a virtual cornucopia of foundation construction issues that need to be addressed. There could be uncontrolled fill material (often of poor quality) which was simply dumped back into a site after a former structure was razed or placed centuries ago if the site was reclaimed land near water. There could be decades-old foundation remnants that were left in place (or former bulkhead elements on reclaimed land sites). The most common example is basement structures in which the superstructure above grade was knocked into the basement and the site leveled, with foundation walls and basement slabs left in the ground (*Figure 1*). There could be elements of excavation support systems, such as soldier piles and lagging, that were installed to facilitate the construction of former development at the site. There could be environmentally-impacted soils resulting from the nature in which a site was used. In some rare instances, there could also be archaeological considerations such as former cemeteries or human remains that were undocumented. Sites may have one or more of these issues. No matter which way you look at it, any of these scenarios creates headaches from a foundation design and construction standpoint.

Typical Foundation Solutions

Once the site has been characterized from a geotechnical standpoint, the first step is always to identify the main concerns raised by the results of the investigation, and then to outline potential foundations solutions that can address the issues and be constructed in an economical manner. Generally, there are two solution paths that can be followed: deep foundations such as driven or drilled piles or caissons, or shallow or mat foundations constructed following the implementation of appropriate ground improvement measures.

After development of a list of feasible engineering solutions, two main factors, schedule and cost, generally determine the most appropriate solution. Ground improvement often provides the advantage in both categories, and as it relates to cost, can be significantly more appealing. Additionally, ground improvement programs can be strategically implemented in localized areas of poor soils, rather than the all-or-nothing approach that is generally required by deep foundations and structural floor slab systems. There will be occasions where there is no option but to use deep foundations, perhaps as to not damage immediately adjacent structures or to avoid imposing loads on adjacent transit structures; however, the use of ground improvement should never be readily dismissed in the urban setting, as it is often completely viable and more economical.

Common Ground Improvement Techniques in the Urban Setting

Of the potential issues that could exist at an urban redevelopment site, urban fill material is more often than not the primary issue to deal with during foundation design (*Figure 2*). The reality is, while some of the other issues can exist, the site would have been disturbed to create most of those conditions, leading to the placement of fill material. With this in mind, let's review some of the

Figure 2: Typical urban fill material.

Figure 3: Typical stone column layout and footing location.

generally applicable types of ground improvement for improving urban fill material.

Improvement methods discussed below are generally more applicable to granular types of material, rather than plastic silts or clays soils, as this tends to be the more common occurrence with urban fill. Specifically, the desired result of these methods is to densify the materials in-place, improving the engineering properties of the existing fill materials to the point that the materials are uniform and can be relied on to provide foundation support.

Stone Columns

Stone columns are also known in the industry by proprietary names such as Geo-Piers or Vibro-piers. The idea behind stone columns is to introduce stiff stone elements into the ground, while simultaneously densifying the surrounding soils during installation of each element. The columns are generally installed in clusters at foundation locations (*Figure 3*) and, if needed, on a grid pattern throughout the remaining areas of the site to provide floor-slab support. Stone columns tend to be slightly more applicable to soils having elevated quantities of fine-grained soils, but are still generally less applicable in areas of soft silts, clays, or organic materials, as some amount of confining pressure in the ground is required to facilitate installation of the columns. Stone column installation is possible to depths of up to about 100 feet, but generally used to depths of 50 feet or less.

The costs for stone columns generally ranges from \$2 to \$6 per cubic yard of soil to be improved; mobilization of the installation equipment is on the order of \$10,000 to \$20,000. There are not many situations that preclude the use of stone columns, as the vibration levels associated with installation are usually tolerable to adjacent structures. However, on sites with significant obstructions, a thorough pre-excavation job will be required to facilitate installation. Additionally, a site can be optimized to include stone columns in areas of poor quality soils within the site, but omit them in areas of better quality soils, providing flexibility and cost efficiency to the project.

Removal and Replacement

Removal and replacement consists of removing the fill material in question and replacing it as a structural fill. Constructability-wise, this option is generally feasible from depths on the order of 15-20 feet or less. The deeper you go, the more likely it is that excavation support measures will be required. In congested urban settings, this can easily become an issue. Another key design consideration with removal and replacement is to understand the foundation conditions of the structures bordering the site. If the required depth of excavation will go below the adjacent foundation levels and underpinning becomes required, it is likely that an in-situ option for ground improvement (such as stone columns or grouting) will be more cost effective and certainly more attractive from a risk management standpoint.

Removal and replacement can be an economically attractive option if you have suitable materials on-site, as the cost then generally boils down to the equipment and labor to perform the work. Typical earthwork costs are \$3-4 per cubic yard for soil being excavated, and \$4-5 per cubic yard of material being placed and compacted. If this option seems feasible based on preliminary studies, then high-end site characterization is generally recommended. Large amount of debris, obstructions, or environmentally-impacted soils can lead to a need for off-site disposal (usually at a premium) of significant quantities of material and a subsequent requirement for import of suitable material at additional cost and impact on the project schedule. Should these conditions be present, removal and replacement quickly becomes a less attractive option from a cost perspective.

Dynamic or Rapid-Impact Compaction

Dynamic compaction and rapid-impact compaction (RIC) are two distinct methods that consist of imparting high-level energy into the ground to densify soils in place. Dynamic compaction achieves this by dropping a weight ranging from 5 to 15 tons from a height varying from 60 to 100 feet across the site at multiple points on a grid pattern (*Figure 4, page 32*). This is generally effective to treat soils to a depth of about 30 feet. Alternatively, RIC is conducted using a hydraulic pile hammer mounted to the arm of a track-mounted backhoe. Given the scale of the equipment being used, RIC is generally effective to treat soils to a depth of 10 feet or less.

The biggest drawback to these methods is the level of vibration that is generated during execution. If sensitive buildings or utility structures exist within 80 or 90 feet of the site, this may not be the best solution for the project. However, there are techniques, such as seismic trenches, that can be employed to minimize the effects of vibrations off-site.

Where practical, dynamic compaction or RIC are almost always one of the most attractive options from a cost consideration, generally costing on the order of $2 per square foot of treated area and no spoils or excess materials from the process that require off-site disposal. Additionally, obstructions typical of urban fill that are encountered during the process are able to be removed as they are discovered.

Grouting

There are several types of grouting that can be utilized in ground improvement. For improvement of miscellaneous urban fills, compaction grouting tends to be the more cost-effective and readily used option. Compaction grouting consists of injecting low-slump grout on a grid pattern across a site to densify a given soil mass. Compaction grouting can be effective to depths of up to 50 feet or so, but does require some amount of overburden pressure, that is to say mass on top of the zone being grouted, to be effective.

Of the ground improvement methods discussed in this article, compaction grouting is on the higher end of the cost spectrum. Costs generally range from $100 to $300 per cubic yard of grout, with mobilization costing on the order of $10,000 to $15,000. Additional grouting treatment types can consist of chemical grouting or jet grouting; however, these methods tend to be more expensive than other methods and, as a result, are not as widely used.

It is always advantageous to involve specialty geotechnical contractors early in the process, as they may have specific insight on the chosen solution or input regarding potential techniques and the limitations of each. This will be beneficial for the development of accurate foundation and project cost estimates.

Design Considerations in Applying Ground Improvement

On a typical shallow foundation job, the geotechnical engineer performs an investigation and provides foundation design recommendations and seismic parameters to the structural engineer, usually with minimal interaction between the two. When it comes to the successful implementation of a ground improvement program, however, a constant dialogue between the two is required in an iterative process to optimize the ground improvement design. Specifically:

- Regardless of the level of improvement achieved, some level of post-construction settlement can always be anticipated with a shallow foundation solution. To that end, the geotechnical engineer will need a realistic understanding of the actual column loads in the proposed structure, along with how much total and differential settlement can be tolerated. At this stage, the dialogue between the geotechnical and structural engineers should be constant. When it relates to successfully implementing a ground improvement program, make no mistake – this interaction is critical.
- What are the boundary constraints? The design team needs to work together to understand the nature and composition of any bordering foundation systems, utilities, or transit tunnels in proximity to the site so that educated decisions can be made when it comes to assessing the impact of a given ground improvement technique beyond the limits of the site. Understanding the boundary conditions is of particular importance when it comes to evaluating a given ground improvement technique in conjunction with necessary underpinning or excavation support measures, or how construction-related vibrations could impact adjacent structures.

Figure 4: General photograph of dynamic compaction.

From a site characterization standpoint, there are several key issues which will likely be addressed by the geotechnical engineer; however, the entire design team should have a good understanding of the objectives of the exploration process so that pertinent information can be shared amongst the team as it is obtained. Specific exploration-related tasks completed by the geotechnical engineer typically include:

- soil borings to evaluate the general subsurface conditions at the site. As the design concept is developed and advanced, supplemental investigations can be conducted in specific locations to collect information critical to a successful design.
- test pits to better evaluate and assess the surficial conditions at the site. In the urban setting, test pits become invaluable for investigating and identifying former foundation elements or structures that might exist beneath the site.
- a comparison of pre-treatment investigation data to post-treatment investigation data, which is how most ground improvement methods are evaluated. Specifically, when methods that are being used to densify a given soil mass, it is most common to compare Standard Penetration Test N-values or Cone Penetration Test Soundings before and after the treatment to verify that the level of improvement required has been achieved.
- testing to obtain site-specific modulus values. On projects where design parameters, such as allowable bearing pressure, need to be optimized for the overall foundation design, flat-plate dilatometer testing can be performed to obtain site-specific modulus values for use in fine-tuning settlement estimates for the project.

This is by no means an exhaustive list of tasks, but rather the most commonly applicable in urban redevelopment projects.

Conclusions

There are several foundation-related issues that can arise on an urban site, almost all of them relate to the way a site has been utilized over time. These encumbrances can impact an entire site, part of a site, or the areas immediately surrounding a site. In any case, ways to successfully overcome them during construction need to be evaluated and developed in the design phase of a project. When considering the various options for foundation support of an urban structure, it is important to not immediately jump to the conclusion that deep foundations are the only viable solution, as it is highly likely that alternative solutions exist. There are several types of ground improvements applicable to an urban environment that are cost effective and flexible from an implementation standpoint, and that can help with schedule. However, for ground improvement solutions to be truly effective, constant and effective communication between the geotechnical engineer and the structural engineer during the design phase should always exists; if not, it most assuredly will be during the construction and litigation phases of a project.▪