Deep Foundations

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Artful Concrete Piles for Resilient NYC Pier

Hybrid Approach to Debris, Soft Soil

Deep Mixing Series: Lessons from Poland

Shoring Design of LA Rail Station

Hybrid Foundation Solution for Debris Fill, Compressible Soil

Load testing of ductile iron piles

FEATURE ARTICLE

Urban redevelopment projects are occurring more frequently than ever before as urban greenfield sites become limited and city planners and developers attempt to revitalize existing underdeveloped neighborhoods. However, because of the past usage of many urban sites (some dating back 100 years or more), designers and construction teams have to not only engineer foundations to accommodate the subsurface soil and ground water conditions, but also to work around the relic foundations or structures that have been left behind from previous developments. In these cases, a one-size-fits-all approach to foundations may not yield the most cost- and schedule-effective approach, and hybrid foundation systems have to be evaluated.

Project Background

The Alta XMBLY project is a residential redevelopment project being constructed by Wood Partners in Somerville, Massachusetts. The development consists of a new 63,000 ft^2 (5,853 m^2), 8-story building. The bottom three floors are a concrete podium for parking and residential purposes, followed by five levels of wood-framed residential structure above. Isolated column loads were up to 850 kips (3,781 kN), wall loads generally ranged from 3 to 7.7 kips per linear foot (klf), or 43.8 to 112.3 kN/m, and mat pressures were about 7 ksf (336 kPa). Site grades were planned to be increased by 2 to 4 ft (0.6 to 1.2 m) to raise the first floor of the building out of the floodplain.

The site was desirable for residential development because it is close to Boston and in proximity to major highways and public transportation. The site is located in the Assembly Row development area, a large mixed-use urban redevelopment.

Prior to the current redevelopment, the Assembly Row area consisted of tidal wetlands that were filled to create industrial areas close to Boston. The area was used for various manufacturing operations, oil storage structures and warehouses. The area also contained many railroad spurs and lines throughout the property. Based on a review of historical maps and photographs, the site was previously developed to have a manufacturing building, including a large smokestack structure present in

AUTHORS Michael J. Weaver, P.E., Haley & Aldrich, Michael Cronenberger, P.E., and Andrew Thompson, P.E., Helical Drilling

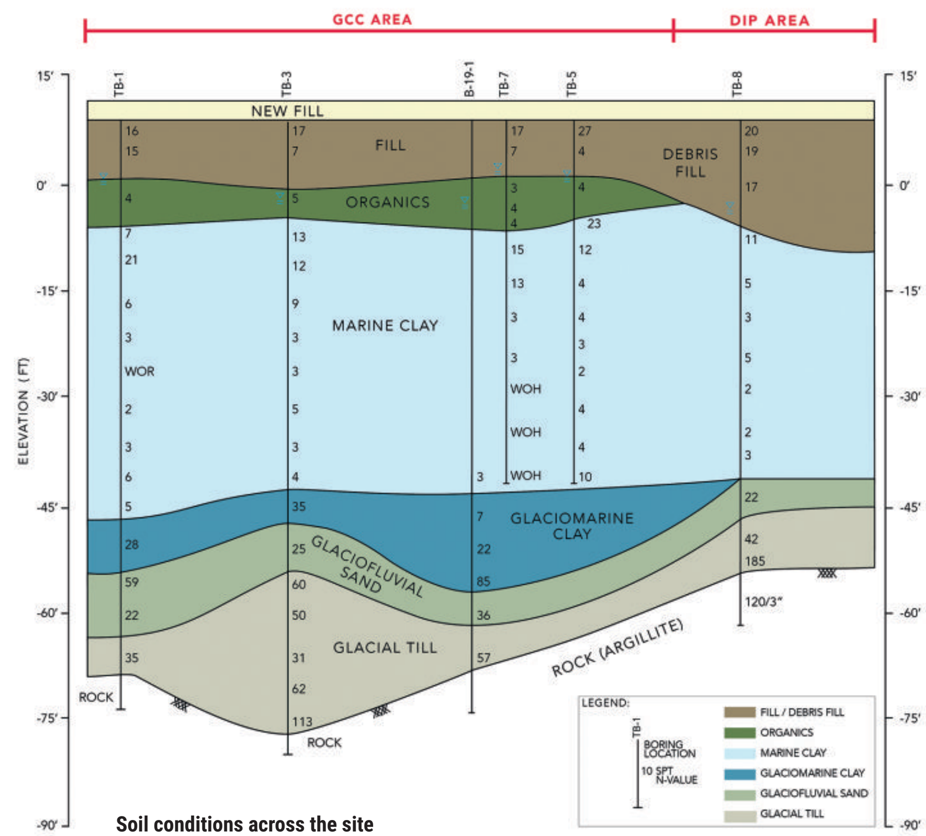
the southwest corner. These structures were demolished many years prior to current construction and the site has since been used as paved surface parking.

Subsurface Conditions

To explore the subsurface conditions at the site, the geotechnical engineer of record for the project, Haley & Aldrich, conducted several rounds of test borings, geoprobes and test pits. Data from the exploration programs indicated that the subsurface soil conditions generally consisted of five layers. Those subsurface layers consisted of fill, or debris-laden fill, extending between 8 and 17 ft (2.4 to 5.2 m) below the ground surface, followed by organic/estuarine deposits from 1.5 to 8.5 ft (0.5 to 2.6 m) thick, to marine (clay) deposits from 34.5 to 47.5 ft (10.5 to 14.5 m) thick, to glacial deposits of 15.5 to 36 ft (4.7 to11.0 m) thick. Below the glacial deposits, bedrock was encountered starting at elevations of -56 to -80.5 ft (-17.1 to -24.5 m).

The fill generally consisted of medium dense silty sand or sandy lean clay with various amounts of silt, gravel, brick, concrete, cinders and ash. Explorations conducted in the southwest corner of the site encountered significant debris consisting of concrete, reinforced concrete, steel, granite blocks and other building rubble from depths of 4 to 19 ft (1.2 to 5.8 m) below the existing site grades.

The organic/estuarine material was described as soft organic soil, fibrous peat or poorly graded sand with trace organic matter. The marine deposits consisted of lean clay that was slightly overconsolidated at the top of the layer and then became softer with depth. The glacial deposits transitioned twice: from a hard to very stiff sandy, lean clay (glaciomarine deposits) to a medium dense to very dense sand with silt and gravel (glaciofluvial deposits), and then to a dense to very dense sandy silt with gravel (glacial till deposits). Below the glacial deposits was bedrock consisting of an argillite or diabase material. Groundwater was generally observed to be approximately 8 ft (2.4 m) below the existing site grades.



Soil conditions across the site

Addressing Foundation Challenges

The fill and organic/estuarine deposits were not considered suitable for foundation bearing in their current condition. Haley & Aldrich evaluated the feasibility of improving the near-surface fill and organic/estuarine deposits using shallow ground improvement to transfer the building loads to the top of the marine clay deposit. However, foundations bearing above or in the marine clay would have been subject to excessive long-term settlements due to consolidation of the clay; this would have resulted from loadings imposed from the building and the weight of fill used to raise site grades.

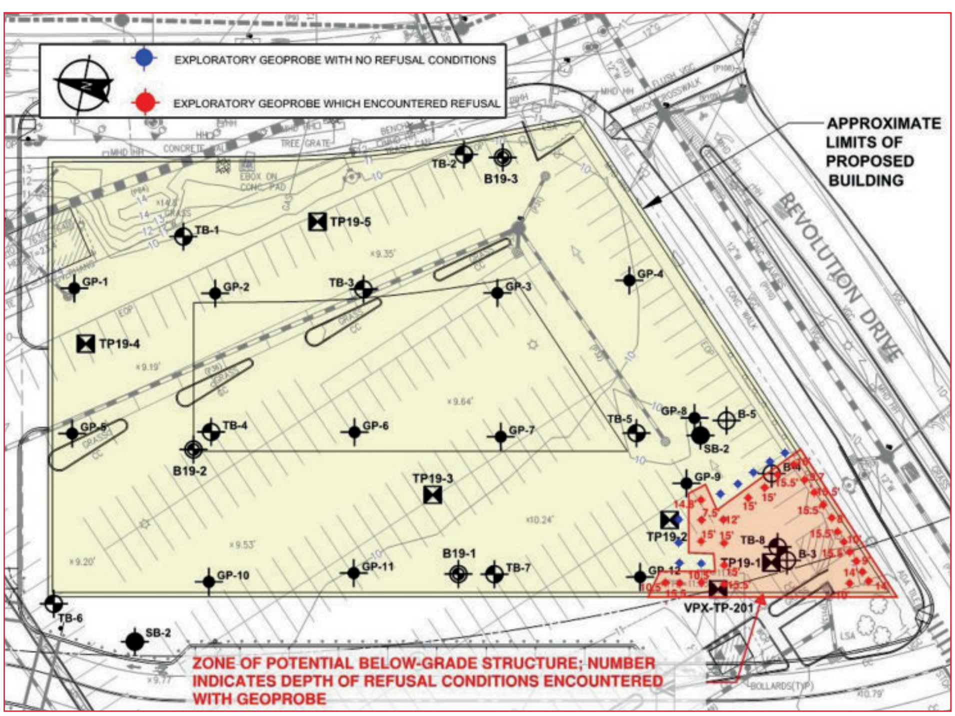
To reduce the predicted foundation settlements, the geotechnical engineer also evaluated several foundation options. They included deep driven piles or micropiles bearing in the glacial deposits/rock, improvement of site soils using deep ground improvement elements or site surcharging. In addition to evaluating foundation settlements, long-term settlements of the lowest level floor slab were evaluated. Ultimately, Haley & Aldrich recommended the building be supported on conventional spread footing foundations sized for 8,000 psf (384 kPa) allowable bearing pressure; these foundations would follow the installation of ground improvement elements consisting of Geopier GeoConcrete Columns (GCCs) that would stiffen the near-surface soils and transfer loads to natural, inorganic glacial deposits. The geotechnical engineer also recommended that the lowest level slab be constructed as a conventional slab-on-grade, following improvement of the existing fill and organic/estuarine deposits using shallow ground improvement (rammed aggregate piers). To further mitigate long-term slab settlement, there would also be a site-wide preloading program with placement of a soil surcharge to 6 in (152 mm) above the elevation of the lowest-level floor slab. Surcharge was to be placed for a period of at least 6 months prior to installation of ground improvement elements.

The ground improvement approach was suitable for all areas of the site except in the southwest corner, where up to 19 ft (5.8 m) of debris was encountered. Given the proximity of the area to the property line, the shallow groundwater table and environmental concerns related to excavation of the soil and management of the groundwater, the debris could not be removed prior to GCC installation. Since the presence of the debris would not allow for the advancement of the GCC elements, an initial solution involved micropiles advanced through the debris, clay and glacial till to transfer the building loads into competent rock. The project team recognized that a micropile solution had its drawbacks. That is, it would solve the constructability issues but result in a slow, expensive foundation installation.

Working closely with the project team, engineers with geotechnical subcontractor Helical Drilling considered solutions to advance a hole through the debris that would then allow for a driven pile system. With successful use of sonic drilling on other projects, Helical solicited the expertise from Eijkelkamp North America and their sonic drilling technology to provide a solution that would enable debris penetration. The low amplitude, high frequency operation of the sonic drilling action allows its tooling to be advanced through reinforced concrete and even solid steel, which comprised many of the obstructions (see the July/Aug 2020 *Deep Foundations* cover story for more about sonic drilling). It was determined that a Mito 60 sonic rig would provide the necessary features by drilling 12.75 in (0.32 m) diameter holes through the debris.

Although a technique had been identified to advance through the debris and provide a cased hole, a suitable deep foundation system was needed that could efficiently work with sonic drilling to limit the installation duration and foundation costs. With limitations set on the hole diameter that would penetrate obstructions while still providing a cased hole, use of GCCs was not practical. It was also determined that the installation schedule would be controlled by the duration of the sonic drilling. Further, pile installation needed to proceed immediately so that the tooling could be removed and used on the next hole to limit the predrilling cost. After studying several options, both traditional drilled micropiles and ductile iron piles (DIPs) were considered viable.

Cost estimates were performed for both systems. Engineers at Helical quickly realized that a small diameter, modular DIP solution would be more economical than micropiles. The DIP approach would limit the predrill hole size and extend through the fill, organics and marine soils to terminate in dense glacial till or rock. Haley & Aldrich's experience with this technique on other local projects provided the project team confidence the DIP system would perform well at the site.



Site plan with boring locations, areas of debris fill

Ductile Iron Pile Use

After concluding that ductile iron piles provided economic and schedule advantages, a full-scale preproduction load test was initiated to confirm design capacities. A pile section and capacity optimized for the building loads in this area was selected that would minimize the number of predrilled holes and provide settlement compatibility for the nearby GCC-supported foundations.

A Series 170/9.0 pile size with a 170 mm (6.7 in) diameter and 9 mm (0.35 in) wall thickness was selected to support a compression design load of 85 tons (756 kN). A test pile location was selected just outside of the buried debris area and near the location of a deep boring advanced to bedrock. The sacrificial ductile iron pile was driven with a Tramac V1800 percussion hammer and advanced to rock at a depth of 78 ft (23.8 m), where a termination criterion of 1 in (25 mm) or less in 50 seconds of driving was established. The test pile was instrumented with three sister bar strain gauges. Following the standard axial compression load test requirements of the Massachusetts State Building Code, loads were increased in 25% increments to a maximum load of 200% of design.

Sonic drilling and ductile iron pile installation

The test pile deflected 0.69 in (17.5 mm) at the design load of 85 tons (756 kN), and 1.50 in (38.1 mm) at the 200% load. The pile rebounded almost entirely, with a net downward movement of 0.14 in (3.6 mm) after the full load test cycle was complete. The load test results showed the pile successfully supported the full test load, and that more than 150% of the design load reached the bearing layer.

Based on the successful load testing program, a total of 61 pile locations were designed for the area characterized with the debris fill. During production installation, as the sonic drilling advanced through the debris, two modular 16.4 ft (5 m) DIP sections were immediately installed within the pre-drilled, cased hole. The first two sections were rapidly installed, followed by backfilling of the annular space within the cased hole. The sonic tooling was then removed to be used at the next hole location. At the conclusion of all sonic drilling, Helical moved back to each pile location, rapidly advancing the DIPs to their final depths, which ranged between 65 and 70 ft (19.8 and 21.3 m). The self-coupling bell and spigot ends of the DIPs made it easy to start and stop the system installation. The completion of the pre-drilling and setting of initial DIPs took about 3 weeks, while the ductile iron pile installation to final depth was completed in 5 days.

Sonic drilling core of buried foundation wall

Ground Improvement Steps

Based on the structural loads and geotechnical conditions, Geopier Foundation Company recommended using 16 in (0.41 m) diameter GCC for support of the foundations. To support the slab-on-grade, 20 in (0.51 m) diameter rammed aggregate piers were used. Foundations were designed to limit settlement to 1.5 in (38 mm) or less and to be compatible with the deflections of the DIP-supported foundations (i.e., that they would not result in excessive differential settlements as a result of differences in elements' stiffnesses).

A modulus load test program was performed on the GCCs to confirm the design assumptions. Sacrificial test piers and uplift reactions were installed, allowed to cure for at least 14 days, and then tested at up to 200% of the design load. The GCC test pier was installed to a depth of about 65 ft (19.8 m) to penetrate the marine deposits. During the test, the GCC exhibited acceptable stiffness and creep behavior to up to 200% of the design load, with a deflection of 0.52 in (13.2 mm) at the pier design stress of 140 ksf (6.72 MPa). Comparison with the DIP deflection of 0.69 in (17.5 mm) indicated the GCC and DIP systems would be compatible at the design loads.

In addition to the modulus load tests, several QC systems were implemented during production, including concrete slump testing, concrete cylinder collection and breaking, GCC mandrel calibration, concrete pump calibration, bottom-stabilization tests, crowd-stabilization tests, and monitoring of concrete pumping pressures. For each element's construction, Helical electronically logged the installation process, including installation length, concrete volume, driving resistance and pump pressures. Haley & Aldrich also provided a full-time representative to confirm installation was in accordance with the design submittal.

An ABI MOBILRAM TM 18/22 was mobilized for installation of the ground improvement system, taking about 5 weeks to complete. The TM 18/22 provided the depth reach and power required to penetrate the soil profile. Work was coordinated with the contractor's construction sequence plan and schedule, and proceeded around the site to allow site/foundation work to begin immediately following ground improvement installation. During construction, numerous obstructions were encountered. Shallow obstructions were easily excavated to allow pier installation to proceed. Where deep obstructions were encountered, the Helical design team quickly redesigned the ground improvement around the obstruction, and additional elements were installed (if needed) so production could continue.

The final ground improvement design included 1,200 ground improvement elements, including about 640 GCCs and 560 RAPs. While in production, Helical was able to install 25 to 70 elements per day. Production varied based on material supply, site access, element installation length, tooling changeover/repair, weather, etc.

Alta XMBLY building completing construction

Conclusion

Urban projects are increasingly difficult as available greenfield space near public transportation in metropolitan areas becomes harder to come by. Most sites have been previously developed and, as such, require engineers to not only consider existing subsurface soils and groundwater, but former developments left behind. The Alta XMBLY site in Somerville, Massachusetts, was no exception. Located near Boston, the site was previously filled land that had many past industrial uses. The design team conducted extensive subsurface explorations that in part identified urban fill overlying organics and a thick marine clay layer. Based on site conditions, the most economical approach to support the new development that included an 8-story building, and a grade raise was to found the building on shallow foundations following the installation of deep ground improvement (GCC) elements to limit long-term settlements, and shallow rammed aggregate piers to support the slab areas.


Geoconcrete column installation

However, exploration revealed a deep debris pocket from a former development. Due to its depth, location near the property line, a shallow groundwater table, and environmental concerns, the debris could not be removed to allow for ground improvement. The design and construction team then developed a hybrid foundation approach to provide the most cost-effective building approach by addressing the debris-laden fill area separately from the remainder. Ultimately, ductile iron piles were installed with a sonic predrill approach for cost-effectiveness and efficient debris management. The unique sonic technology enabled penetration of steel and other debris, while modular ductile iron piles could be easily installed within the sonic drill casing. When combined with the geoconcrete column and rammed aggregate pier ground improvement systems that allowed conventional, shallow foundations across the majority of the site, the hybrid approach yielded a deflection-compatible foundation solution of significant value to the owner.

Michael J. Weaver, P.E., is a senior associate and director of field services for Haley & Aldrich in Boston, Massachusetts. He has over 20 years of experience in providing geotechnical and environmental consulting services to public and private clients and is responsible for the training and development of the technicians and engineers performing field work at Haley & Aldrich.

Michael Cronenberger, P.E., is the specialty foundation division manager for Helical Drilling in Braintree, Massachusetts, where he oversees the piling, shoring and grouting projects for the company. He has 6 years of geotechnical and structural consulting experience and over 9 years of construction project management and design experience.

Andrew Thompson, P.E., is a ground improvement project manager for Helical Drilling in Braintree, Massachusetts. He has over 17 years of experience in geotechnical consulting and design/build construction.

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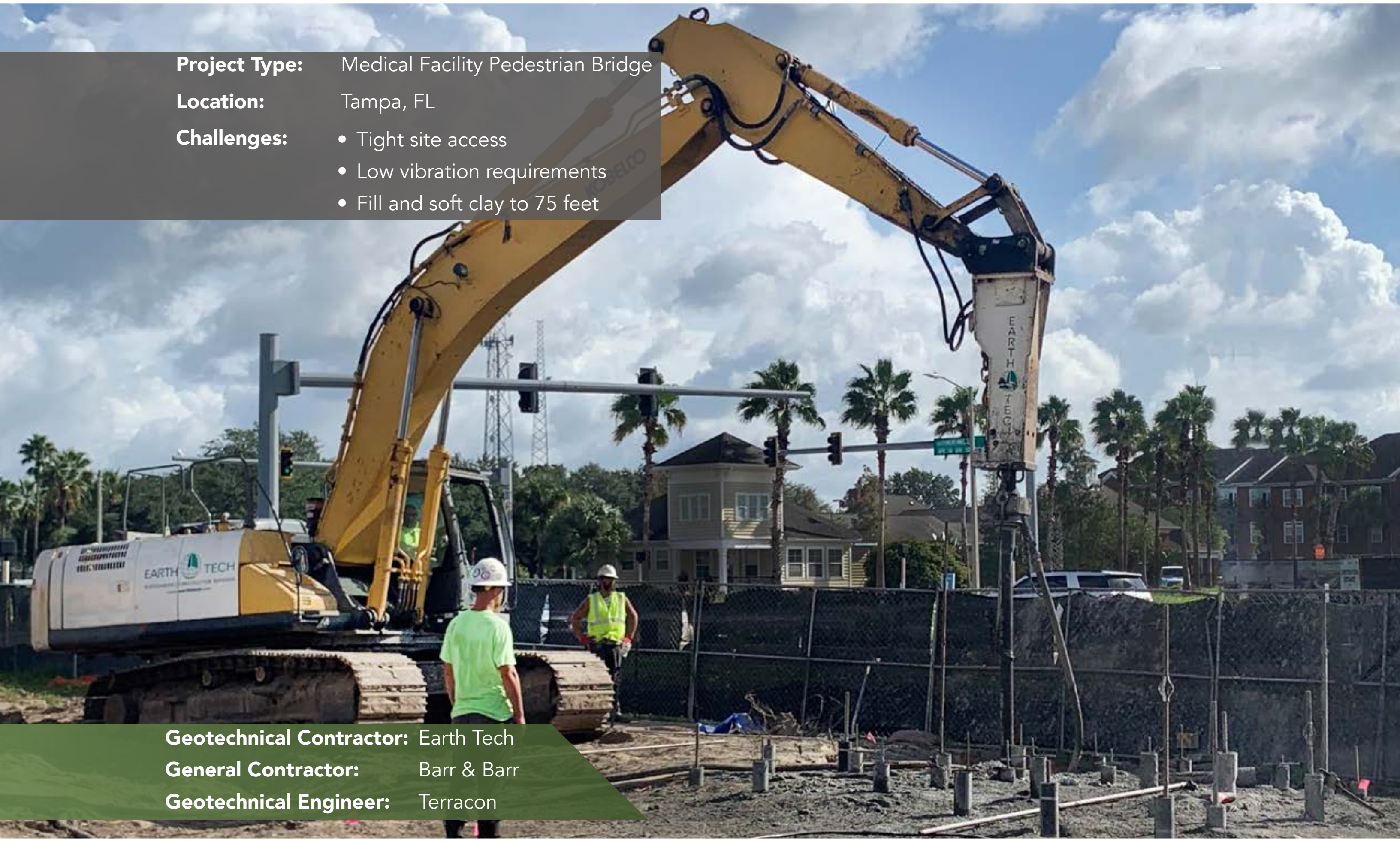

Geotechnical Contractor: Earth Tech

General Contractor: Barr & Barr

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