

A Foundation for Boston's Made Land: The Role of Ductile Iron Piles



Boston (credit Kyle Klein)

The city of Boston and the surrounding suburbs boast a fantastic sports culture, immense Revolutionary War era history, and a thriving center for education, technology and business. Yet the Boston landscape that you see while visiting today is far different than the 1600s colonial topography. Many centuries of urbanization around the city have completely altered the original terrain. Large areas of present-day Boston including many well-known landmarks like Fenway Park, Boston Logan International Airport, TD Garden and Boston's Seaport all reside on "made land" that was once part of tidal marshes or Boston Harbor and in-filled over the centuries as the city grew.

Shoreline expansion in these areas transformed already challenging geotechnical conditions created by Boston's geologic past and added an additional

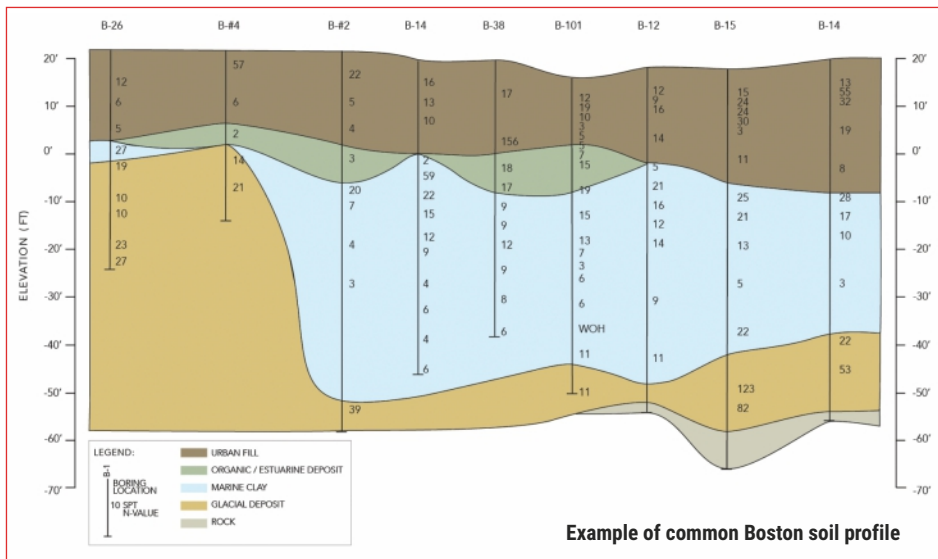


Boston shoreline comparison (1630 to present day)

level of complexity to foundation design and construction. In addition to the well-known thick and compressible Boston Blue Clay, extensive historic shoreline expansion left behind variable depth, heterogeneous "urban" fill underlain by highly

compressible organic/peat layers (estuarine deposits from former seabeds or marshlands). Beyond these unique geotechnical challenges, more common foundation construction challenges associated with most urban environments present themselves including working on constrained sites, managing vibrations, working with limited overhead and other challenges. As a result, foundation selection and construction are hardly straightforward.

Over the last 15 years, ductile iron piles have been used by project teams to address sites with these foundation challenges across Boston and well beyond. This article describes the history that created the current Boston landscape and presents geotechnical conditions, project challenges and design solutions from various projects at commonly known locations around Boston.



Boston's Geology and Geotechnical History

The Boston Basin describes the low-lying area now home to the city and surrounding towns. Boston itself was originally a peninsula known as Shawmut Peninsula that jutted out into today's Boston Harbor. Rock formations in the basin, particularly in Boston proper, most commonly consist of Cambridge Argillite, a soft sedimentary rock that can vary in weathering and strength. There is also a conglomerate, locally known as puddingstone, that features a much harder sedimentary rock consisting of rounded gravel and cobble in a finer sediment matrix. Ground conditions overlying the rock were largely created by periods of glacial advances and retreats during the Pleistocene Era. As a result, Boston and the surrounding areas became home to hundreds of prominent glacial features including drumlins and glacial terminal moraines, surrounded by depressed areas consisting largely of tidal marshes and waterways.

Glacial drumlins — circular or elliptical, smooth-sloped hills that are often found in groups — were common in and beyond the city, along with glacial terminal moraine hills formed by the advancement and readvancement of glaciers. These glacial hills were scattered across the city and out into the harbor. The original presettlement

prominent glacial hills on Shawmut Peninsula were named Tri-mount or Tremont and included Mount Vernon, Mount Pemberton and Beacon Hill. These hills, and others surrounding the city, rose prominently above the surrounding lowlands and provided strategic importance during revolutionary battles as fortified positions for either the British or colonial troops at places like Bunker Hill, Breeds Hill and many other famous landmarks. These glacial hills consisted of glacial tills and terminal moraine deposits with

significant amounts of sand and gravel as well as some cohesive soils mixed in place that later became important sources for filling operations.

A Period of Filling

Following the Revolutionary War and throughout the 1800s and into the 1900s, as the city grew, planners and early developers embarked on plans to increase the available usable land by filling in tidal areas and ponds previously formed by damming tidal areas. The history of the filling is thoroughly described in *Gaining Ground: A History of Landmaking in Boston* by Nancy Seasholes where she describes in detail the changes across Boston's landscape over time and motives at work to "create" more than one-sixth of the land we know today as Boston. Some of the larger and more famous filled areas included Mill Pond (now Boston's Bulfinch Triangle), the Back Bay area and East Boston's Jeffries Point area (now home to Logan Airport). Excavation of the prominent glacial hills in and around Boston was in full swing as material was used for land creation around the city. The filling was so significant during the



Leveling Beacon Hill (artwork by John Rubens Smith in 1811, courtesy Library of Congress)

1800s that material from outside of Boston was also transported by rail to meet the demand.

Today's Conditions and Challenges

Between massive excavated glacial hills and areas of filling, ground conditions around the city can now vary significantly. Sites characterized by shallow, competent glacial deposits, or even rock near the ground surface, can rapidly transition into areas containing thick heterogenous fill underlain by thick glacial tills and, even more commonly, into areas with undocumented fill and thick organics followed by deep, marine deposits of compressible Boston Blue Clay to depths of 150 ft (46 m) or more as you extend into much of the made land approaching Boston Harbor and its various tributaries. These latter conditions are then underlain by glacial till and rock, which can range from the very variable argillite to hard puddingstone.

Many common deep foundation solutions have been utilized over the years to address the geotechnical challenges. These include driven piles (steel H-piles, prestressed precast concrete piles, timber piles), drilled shafts, pressure injected footings bearing in the crust, drilled micropiles or minipiles, and helical piles. As sites became more urban and the availability of green field sites or projects with large laydown areas became fewer, foundation solutions became more limited. Nearly 15 years ago, ductile iron piles were first implemented in Boston to solve foundation challenges on urban sites.

Ductile iron piles are a modular, driven pile system. The European piling system is manufactured in standard 16.4 ft (5 m) lengths with a specialized plug and drive connection system that allows for rapid field connections. A medium-sized excavator and a hydraulic percussion or breaker hammer with a modified shank are used to drive piles. Unlike traditional pile driving, the high frequency of the percussion

hammer results in minimal vibrations. With capacities ranging from 25–100 T (222–890 kN), they can be installed to develop capacity in either end bearing or in friction. When installed with a dry installation approach (no exterior grout) they develop capacity by penetrating poor soils to terminate in very dense soil or rock like traditional piles. Alternatively, exterior grouted ductile iron piles are installed by simultaneously driving an oversized grout shoe while pumping cement grout through the hollow pile and out the pile tip to create a grouted displacement pile. As the pile is driven through the poor soils and into a competent bonding layer, the exterior grouted pile develops a highly efficient grout-to-ground bond capacity for friction resulting from densification caused by driving.

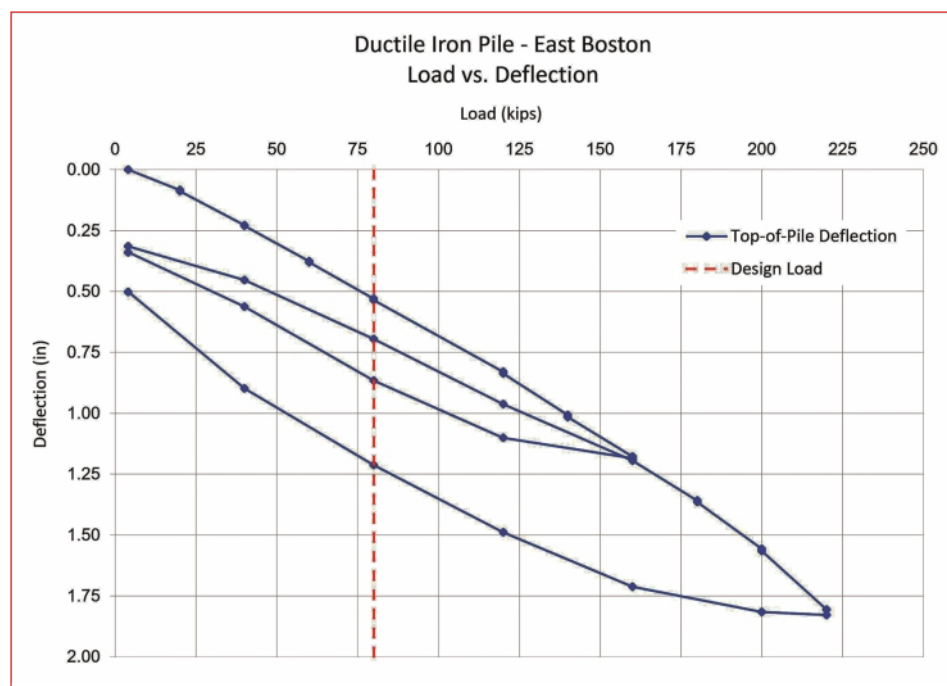
Though there are many projects supported by ductile iron piles throughout the Boston area, this article highlights specific project experience near a variety of famous Boston landmarks.

The Sky's the Limit

East Boston is located across Boston Harbor from the main downtown area and is home to Logan International Airport and rapidly redeveloping

residential neighborhoods. Portions of East Boston are characterized by shallow sandy glacial till left exposed after the removal of the glacial hills centuries earlier. The presence of fill, organics and marine soils increase as the depth to competent soils rapidly increases toward Logan Airport and Boston Harbor. For a 40-year period starting in the 1920s, this area of the city received massive filling operations as a small military airport was first created followed by the development of the much larger Boston Logan airport.

Part of the redevelopment activities, a four-story residential structure was proposed on a site located two blocks from Boston Harbor and a few blocks from Logan Airport on Webster Street. Up to 12 ft (3.7 m) of harbor infill followed by 5 ft (1.5 m) of organics and 35 ft (10.7 m) of very soft marine clay and silt was found on the site. Stiff glacial till (silt and clay) was encountered in the borings extending to the maximum depth of exploration of 70 ft (21.3 m) with rock anticipated below the glacial till. Low capacity (10 T or 89 kN) helical piles terminating in the stiff clay “crust” were considered along with driven timber and H-piles. Helical piles would have resulted in a significant quantity of piles



Load test results in East Boston

and vibrations were a concern for traditional driven piles. The team specified 40 T (356 kN) ductile iron piles to provide a low vibration deep foundation terminating in the glacial till or on rock.

A load test pile driven to terminate by reaching “set” in the glacial till at 76 ft (23.2 m) was tested to 200% of the design, unloaded and subsequently reloaded to observe performance at higher loads. The test was conducted to an ultimate load of 220 kip (979 kN), which was 275% of the design load. Deflections of 0.54 in (13.7 mm) were measured at the design load and 1.8 in (46 mm) at 275% of the design. A total of 43 production piles ranging in length from 65–85 ft (19.8–25.9 m) were then installed by Helical Drilling, in only three days. With the success on the Webster Street development, the system was implemented for foundation support for new residential projects at the opposite two corners of Orleans and Webster streets.

Take Me Out to the Ball Game

The Fenway District around Fenway Park, home of the Boston Red Sox baseball team, is located west of the main city center along the Mass Pike (I-90) corridor and the nearby Charles River. Ground conditions at a site just two blocks from Fenway Park consisted of up to 9 ft (2.7 m) of urban fill, followed by organics (former marsh deposits) extending to 28 ft (8.5 m). Thick marine clay (Boston Blue Clay) then extended to a depth of 175 ft (53.4 m) below grade to rock. Explorations showed the clay had very little desiccation (crust) before becoming soft to very soft consistency. The proposed 5,000 sq ft (465 sq m) site of a five-story apartment building was immediately adjacent to an existing brick-façade apartment building.

Original foundation plans specified 100 T (890 kN) capacity steel H-piles. However, transportation of the pile material through the narrow urban streets combined with limited laydown

and field splicing and vibration concerns adjacent to the existing building presented challenges. An alternative using 50 T (445 kN) capacity series 118 ductile iron piles was proposed by Helical Drilling and selected for the project based on greater efficiency with the actual loading demand. Prior to production installation, a load test pile was installed to terminate on rock at a depth of 175 ft (53.4 m) below grade. Due to the expense of load test reaction piles in the very thick marine clay, a gravity load test using concrete blocks was performed to 200% of the design load. Test results confirmed adequate performance to meet the design capacity. With production rates of over 1,000 ft (305 m) per day through the soft clay, 87 production piles were installed in two weeks. The high frequency installations resulted in vibrations of less than 0.3 in (7.6 mm) per second within 2 ft (0.6 m) of pile installation.

Pile installation near Fenway Park



Pile installation near TD Garden





Pile installation near TD Garden

Where the Championship Banners Hang

The Massachusetts Bay Transportation Authority's North Station and T.D. Garden, home of the Boston Bruins hockey team and Boston Celtics basketball team, sit just north of the Massachusetts State House on Beacon Hill and west of Boston's famous North End — home to fabulous Italian restaurants and Paul Revere's house. Beacon Hill and the North End were previously separated by a marshy cove in the harbor, which was dammed in the 1640s to form Mill Pond. By the early 1800s, property developers were allowed to backfill the pond to create this famous area of downtown Boston. Portions of Beacon Hill, Copps Hill and other surrounding areas were excavated to fill the pond over a 21-year period.

Along Friend Street, a side street across from "The Gahden," as you'd hear it pronounced locally, is where a seven-story residential building was planned on a site only 28 ft (8.5 m) wide. Haley & Aldrich's geotechnical exploration encountered 13 ft (4 m) of urban fill underlain by 17 ft (5.2 m) of peat followed by very stiff to soft marine clay to depths of 70 ft (21.3 m). At this site, the glacial till layer was only 1 ft (0.3 m) thick. The underlying Cambridge Argillite was highly weathered with standard penetration test N-values ranging from 40 blows per foot at the till interface to 120 blows/2 in (51mm) at the maximum drilled depth of 84 ft (25.6 m). The very narrow site was originally considered for micropiles. A ductile iron pile alternative proposed by Helical Drilling was selected because of the significant cost and time savings for installation. Series 170/9.0 piles were installed to terminate

after driving into the weathered rock to achieve set. Load testing verified a capacity of 50 T (445 kN). A total of 47 piles were in-stalled in nine days to depths of 68–75 ft (20.7–22.9 m). With the experience on the adjacent site, the system was then specified for foundation support on a second seven-story residential building and installed by McGue Excavating the following year.

One if by Land and Two if by Sea

Boston's Seaport area represents a significant area of development and land creation. In recent years, this portion of the city has been transformed from parking lots and industrial buildings to luxury residential apartments, corporate headquarters and upscale retail in addition to the actual seaport terminals where cruise ships depart. To better position emergency services to the expanding Seaport District, a new two-story emergency medical facility was planned along Black Falcon Pier. While the ground conditions included thick fill extending to 26 ft (7.9 m) and 9 ft (2.7 m) of peat, the marine clay at this site was only about 5 ft (1.5 m) thick followed by glacial till from 40–48 ft (12.2–14.6 m) at which point rock was encountered. The project geotechnical engineer, Haley & Aldrich, recommended ductile iron piles to resist loads of 100 kip (445 kN) (compression) and 15 kip (67 kN) (tension) for foundation support because of the tight site along the active seaport terminal area. HUB Foundation was selected as the geotechnical contractor for the piles and the design, which was prepared by McPhail Associates, and included series 118/9.0 piles installed to achieve set on rock. For piles subjected to both compression and tension loads, an exterior grouted ductile iron pipe with a 10.6 in (270 mm) diameter grout shoe was installed to construct a 10.5 in (267 mm) diameter grouted displacement pile that terminated on rock. A #8 (grade 75) centerbar was wet-set into the pile after installation to resist the tensile demands. A total of 42 piles were installed in three days at the site.

Pile installation in Boston's Seaport



How Do You Like Them Apples?

Near the Seaport District is South Boston locally known as "Southie." Many may remember the references to the area in the movie *Good Will Hunting* starring Matt Damon and Robin Williams. South Boston is home to one of the few remaining intact glacial drumlins as parts of the neighborhood jut out into Boston Harbor for water views to the north, east and south. Ground conditions in this area often consist of the native dense glacial till but transition rapidly toward the waterfront where land reclamation occurred.

An example of the rapid transition, and the site with the greatest amount of geotechnical variation highlighted in this article, is a utility substation project along K Street. This resiliency project involved construction of approximately 3,600 ft (1,100 m) of new retaining walls surrounding a critical utility substation along Boston Harbor. Explorations performed by Haley & Aldrich showed significant changes in depth to com-

petent materials. Borings in the southwest corner of the site (farthest from the water's edge), found urban fill extending to 18 ft (5.5 m) followed by only 4 ft (1.2 m) of stiff marine clay then medium dense to very dense glacial till. The conditions then rapidly changed along the wall alignment with the marine clay increasing in thickness up

to at least 46 ft (14 m) and top of glacial till depths extending to 75 ft (22.9 m) or more. In many locations, the till was less than 5 ft (1.5 m) thick before rock was encountered. Overall, top-of-till depths in the borings ranged from only 20–75 ft (6.1–22.9 m) or more below grade across the site.

The retaining wall foundation was subjected to compression, tension and lateral loads. Given the tight site constraints, vibration sensitivity and the potential for encountering obstructions including granite blocks (former buried sea walls), construction debris and other oversized materials, the project was originally designed for micropile support. While obstructions were anticipated in certain locations at the site, the majority of the borings did not encounter refusal in the fill. A unique hybrid solution was proposed by Phoenix Foundation Company that consisted of exterior grouted ductile iron piles at locations around the site where obstructions were not present and drilled micropiles at locations where obstructions would restrict ductile iron pile installation.

The design utilized series 118/9.0 ductile iron piles installed with a 270 mm grout shoe to construct a 10.5 in (267 mm) diameter grouted pile developing frictional capacity in the glacial till. A #8 grade 75 threadbar was

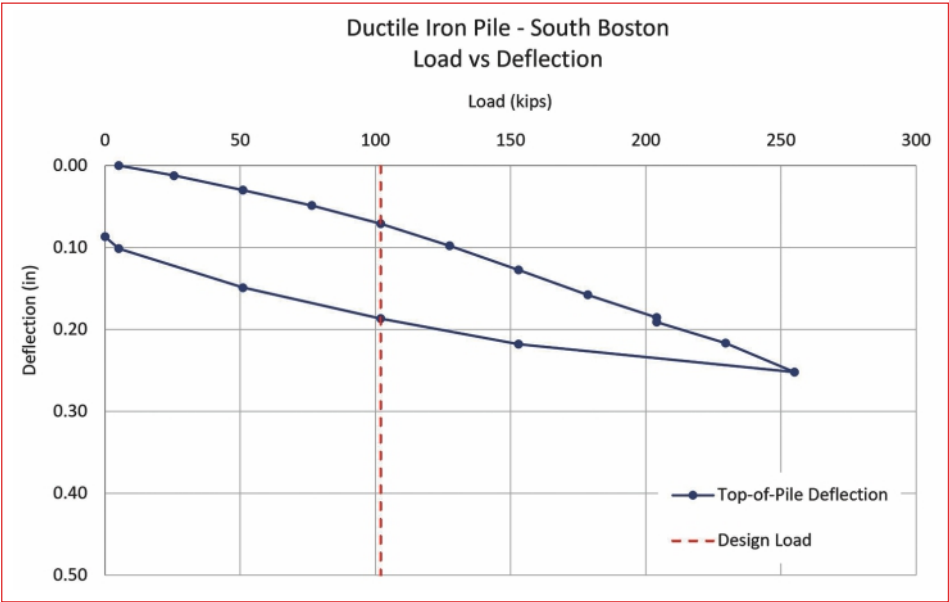


inserted full length for tension resistance. The piles were driven through the fill, organics and marine clay to terminate with a minimum bond length of 15 ft (4.6 m) into the glacial till. In cases where very dense till or rock was encountered before achieving the bond length, the pile was installed to achieve set. Following installation, a 10 ft (3 m) long piece of 9.625 in (244 mm) diameter, 0.472 in (12 mm) thick steel casing was installed in the exterior grout to provide increased lateral resistance in the upper portion of the pile.

Full-scale load testing was performed at multiple locations on the site to evaluate the pile performance in the variable conditions. After reaching acceptable performance at 200%, loads were increased to evaluate performance at loads of 250% for compression and lateral testing and 350% for tension testing. The load testing confirmed the adequacy of the system to resist the 51 T (454 kN) (compression), 10 T (89 kN) (tension) and 18.5 kip (82 kN) (lateral) design loads.

In production, the installations were phased as areas of work within the active substation were made available. Vacuum excavation was performed in the upper 4 ft (1.2 m) at all locations to verify the location was free of utilities.

Load test results in South Boston



Full-scale load testing was performed at multiple locations on the site to evaluate the pile performance in the variable conditions.

Test excavations were also performed in areas where obstructions were anticipated. This allowed Phoenix to establish zones for ductile iron pile installations and other zones for micro-pile installation. Overall, over 325 production ductile iron piles were installed on the project to depths ranging from 40 ft (12.2 m) to 120 ft (36.5 m). The remaining 375 piles were

installed as drilled micropiles, often drilling through up to 20 ft (6.1 m) of granite blocks and debris.

Summary

As geotechnical designers and contractors, our sites have a unique history and impact by human activities often untold to us. Sites around Boston present unique examples of this, with much of their history spanning hundreds of years back to colonial days and earlier. These activities have left challenges for foundations in the areas of many of Boston’s famous landmarks. In recent years, ductile iron piles have shown to be a cost-effective and reliable solution to deal with Boston’s geotechnical history and urban construction challenges.

Brendan Fitzpatrick, P.E., is the president of DuroTerra. He is a geotechnical engineer licensed in 15 states and has more than 25 years of design/build experience working closely with geotechnical contractors and engineers on ground improvement and deep foundation projects.