One Dalton Hotel & Residences:
Implementation of a Ground Movement Control Measure for a Deep Excavation in Boston Blue Clay

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Abstract

Construction of the 3-level below-grade space for a new 61-story tower in Boston required excavation to depths of up to 47 ft and up to 25 ft below adjacent structure foundations. The excavation required the removal of the stiff clay crust that would have provided increased lateral wall support and basal stability. Historically, excavating to this depth for building construction in the Boston area was avoided due to excessive ground movements that tend to occur with removal of the stiff clay crust. To compensate for this problem, concrete lateral support elements referred to as “subgrade struts” were installed below the bottom of the excavation prior to mass excavation. During excavation, the struts limited wall movements, controlled basal heave, and prevented excessive settlement of the adjacent structure. The successful implementation of the struts was the result of a collaborative effort between the design team, contractor, and the contractor’s geotechnical engineer.

Introduction & project background

The One Dalton project site, located in the Back Bay neighborhood in Boston, Massachusetts, is an approximately 28,544 square foot triangular parcel that did not have any existing above ground structures (Figure 1) but included an underground loading dock area for the adjacent building (Colonnade Building at 101 Belvidere) extending to a depth of 25 ft below ground surface along the southeast side. The loading dock area consisted of a ramp accessed from street level leading down to an underground truck bay, a turntable, and loading docks. The site is bounded on the other two sides by Belvidere and Dalton streets along which there are no immediately adjacent existing structures. The site is generally flat with ground surface at approximately El. 17.5. Elevations are in feet and refer to Boston City Base Datum which is 5.65 feet below the National Geodetic Vertical Datum (NGVD 1929).

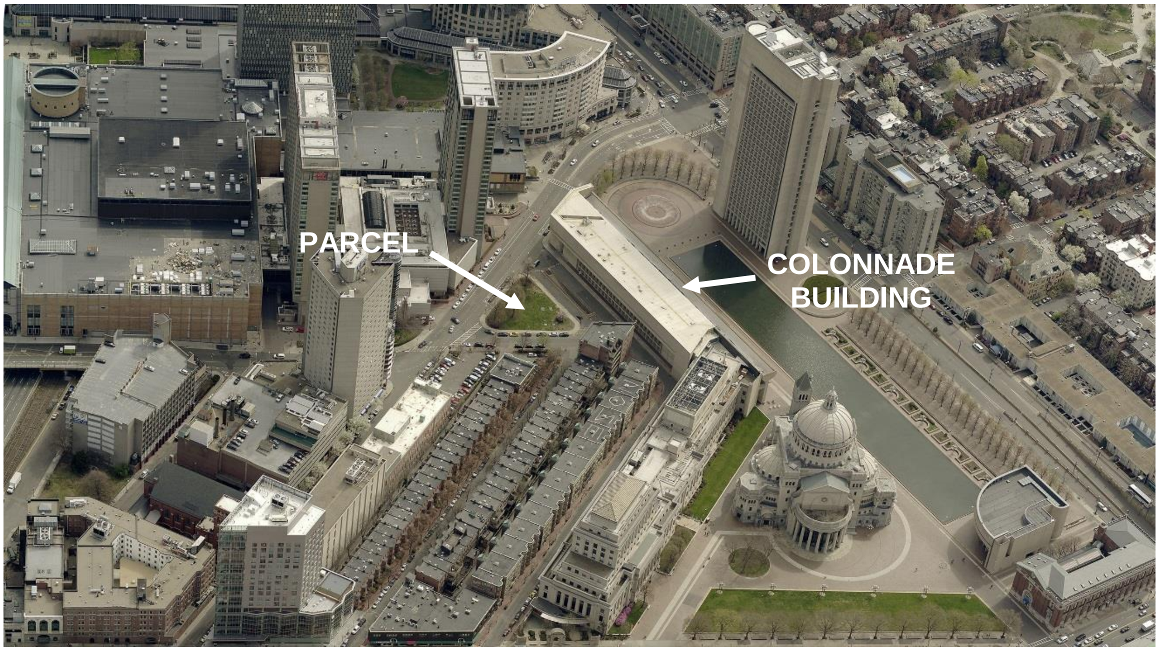

Figure 1 – Aerial view of the One Dalton parcel.

The new development included the construction of a 61-story hotel and residential tower with a plan footprint area at grade of approximately 21,600 square feet and three levels of below-grade space requiring excavation to depths of up to 47 ft below site grades, with localized deeper excavations to 55 ft. Figure 2 shows a rendering of the new tower. Permanent walls for the new below-grade space consisted of concrete diaphragm walls (or slurry walls) and secant pile walls. The wall systems were generally terminated in clay to provide groundwater cut-off and served as temporary and permanent earth support. The new tower was supported on foundations composed of reinforced concrete load bearing elements (LBEs) and secant pile elements, both types of elements were socketed into bedrock.

The deep excavation and its proximity to the Colonnade Building, supported on shallow foundations, required careful selection of wall and foundation construction methods and relatively stiff excavation support systems to limit ground movements and reduce the likelihood of damage to the building. Furthermore, the deep excavation led to removal of the stiff clay crust and necessitated additional lateral support below the base of the excavation to control lateral wall movements.

Figure 2 – Digital rendering of the One Dalton tower (from OneDalton.com).

Subsurface conditions

The site is located on filled land in the Back Bay neighborhood of Boston, Massachusetts. Subsurface soil conditions at the site generally consisted of a layer of urban fill followed by organic deposits, marine sand and clay deposits, glaciomarine deposits, and bedrock. The range of observed thickness of each soil stratum in the boring explorations is summarized in Table 1 below and illustrated in the subsurface profile in Figure 3.

The excavation for the new tower terminated within the marine clay deposit which consisted of a stiff, overconsolidated clay crust 10 to 12 feet thick followed by about 115 feet of softer, more compressible, slightly overconsolidated to normally consolidated clay. The undrained shear strength of the clay crust was estimated to be about 1500 to 1700 psf whereas the soft clay undrained shear strength was estimated to be about 1300 psf at the top and increasing with depth.

Foundations for the tower were socketed into bedrock. Bedrock at the site is part of the Cambridge Argillite formation and the observed degree of weathering in the core samples ranged from fresh to slight. Zones of tuffaceous Argillite were observed within the Argillite bedrock. An altered Mafic Dike was also encountered at some boring locations with an observed degree of weathering ranging from slight to high. Unconfined compressive strength values of the Argillite and altered Mafic Dike samples that were tested ranged from 780 psi to 12,426 psi.

Stratigraphic Unit	Approximate Top Elevation, Range (ft, BCB)	Observed Thickness Range (ft)	Notes
Fill	17.5	11 to 14	-
Organic Soils	5	3 to 8	-
Marine Sand	-3	12 to 17	Bearing stratum for Colonnade Building foundations
Marine Clay	-15 to -19	110 to 118	Bottom of new excavation, stiff clay crust removed
Marine Silt (within Marine Clay)	-21 to -23	2.5 to 7.5	-
Glaciomarine Deposits	-126 to -135	2.5 to 10	-
Bedrock (Argillite and Altered Mafic Dike)	Approx. -140	-	Sockets for LBEs and Secant Piles

Table 1 – Summary of soil subsurface conditions.

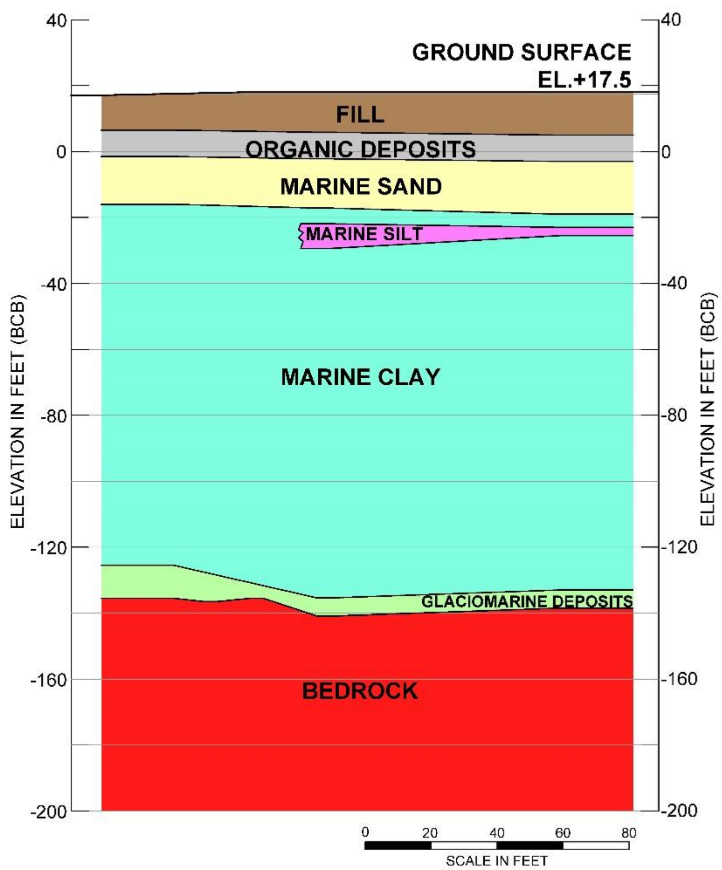

Figure 3 – Soil subsurface profile.

Adjacent structures

The adjacent Colonnade Building is a five-story concrete structure supported on shallow footings and pressure-injected footings (PIFs) bearing in the marine sand layer. Design bearing pressures for the Colonnade Building foundations closest to the excavation ranged from 6100 to 7500 psf based on the available drawings. The excavation for the new tower extended approximately 20 to 25 feet below the bottom of the Colonnade Building's foundations (Figure 4).

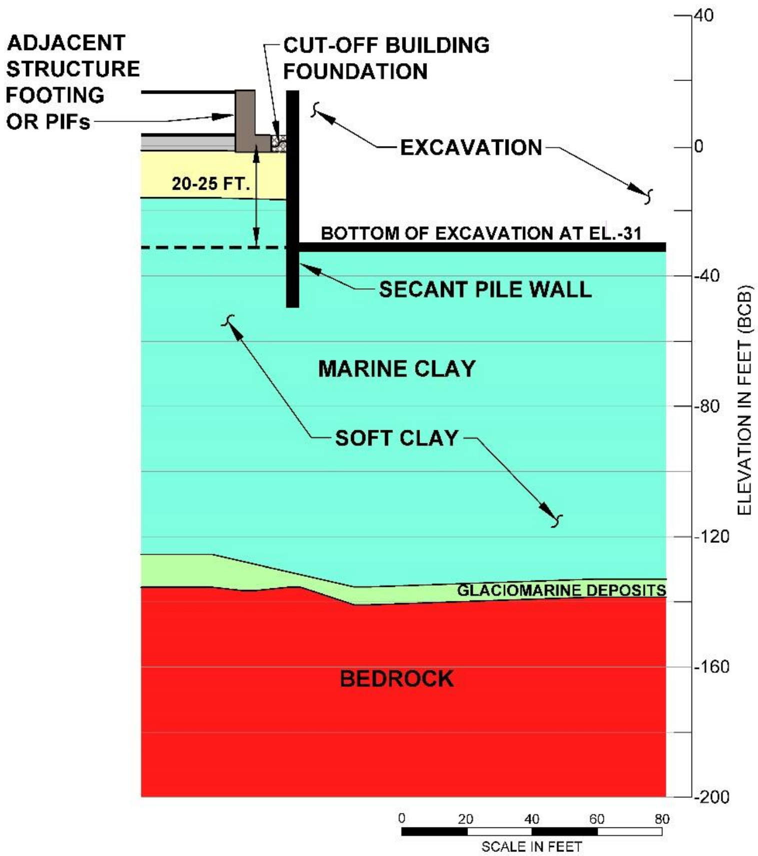

Figure 4 – Planned excavation and adjacent structure foundation.

As part of the new development, the loading dock connected to the Colonnade Building was demolished. In addition, portions of the Colonnade Building foundations that protruded into the site were saw-cut and then removed.

New tower foundations and excavation support

Foundations

The new tower is supported on rock-socketed LBEs and secant piles. Figure 5 shows the foundation and basement wall plan layout. Deep, rock-socketed foundation elements are shown in orange and wall elements that terminate in the clay are shown in yellow (slurry wall panels) or blue (secant piles).

The LBEs were made up of individual 2.5 feet or 4 feet thick by 9 to 10 feet long reinforced concrete panels and are rectangular-shaped (part of a series or stand-alone) or cross-shaped (two orthogonal panels). LBE rock socket lengths ranged from 10 feet to 19 feet with geotechnical compression load capacities as high as 12,500 kips for a single rectangular panel and 16,500 kips for a cross-shaped element. The 4 ft thick LBEs generally supported higher loads than the 2.5 ft thick LBEs.

The rock-socketed secant piles located along the Colonnade building were 39 inches in diameter with an embedded W24x176 steel section and a 36-inch diameter rock socket. Rock sockets ranged from 5 to 8 ft long except for one element that had a 13-foot long rock socket, geotechnical compression load capacities ranged from about 1300 kips to almost 2000 kips per rock-socketed secant pile. The maximum geotechnical uplift capacity was about 1300 kips corresponding to the secant pile with the longest rock socket.

Excavation Support

The LBEs, secant piles, and slurry wall elements were designed to resist the permanent soil, water, surcharge (construction and adjacent building), and seismic lateral pressures and the temporary loading conditions during excavation, bracing installation, and subsequent bracing removal.

The slurry wall panels were 2.5 ft thick reinforced concrete elements extending to El. -48 or approximately 18 feet below the bottom of excavation.

The secant pile wall was composed of overlapping 39 inch diameter piles with an embedded W24x176 steel section every other pile. These elements also extended to approximately El. -48 or about 18 ft below the bottom of excavation.

Installation

The LBEs, secant piles, and slurry wall elements were installed from existing site grades. The LBEs and slurry wall elements were installed using slurry trench methods. Each LBE panel was excavated under slurry using a clamshell bucket (in soil) or a hydromill (in bedrock). The steel reinforcement cage was then lowered into the hole and the panel was filled with concrete (compressive strength of 7000 psi) using tremie methods. A wide-flange steel section was utilized as an end-stop in primary panels. LBE panels were installed in a sequence where no two adjacent panels were open at the same time with consideration for concrete curing times.

The secant piles were drilled using a full-depth temporary casing and concreted prior to pulling the casing to minimize ground loss. Cased installation was used next to the Colonnade Building foundations because the potential settlement due to loss of ground was a major concern.

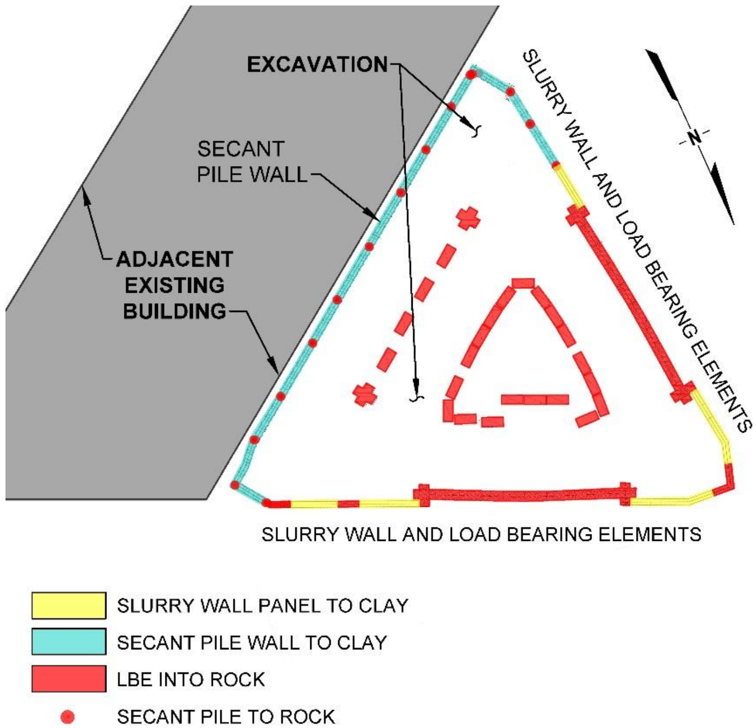

Figure 5 – New tower foundation and basement wall plan.

Below-grade construction and subgrade struts

The original planned excavation and bracing sequence consisted of three to four main cuts, each about 10 ft to 13 ft deep. No additional bracing was initially planned below the bottom of excavation although grouting under the Colonnade Building foundations was contemplated. Staged construction analyses were performed using the finite-element software program Plaxis. The lateral deflection of the secant pile wall adjacent to the Colonnade Building was predicted to be about 1.7 inches without the use of subgrade struts.

The predicted lateral deflection of the secant pile wall raised concerns about the potential for excessive settlement of the Colonnade Building. Further analyses of the secant pile wall indicated that additional lateral support below the base of the excavation, put in place before the excavation reached the lowest level, could help control deflections. After discussions between the project team and the owner and considering the construction schedule and equipment that would be available on-site, it was decided that subgrade struts would be used. Subgrade struts are unreinforced rectangular concrete panels installed below the bottom of the excavation to act as lateral support for the embedded portion of the wall.

Figure 6 shows the excavation plan with the locations of the subgrade struts. There are seven subgrade struts, five extend from the secant pile wall and terminate in soil without connecting to any other structural elements, the remaining two extend from the secant pile wall to a cross-shaped LBE on the adjacent side. The struts that terminated in soil were approximately 30 ft long and were sized based on skin frictional resistance along the sides and bottom of the strut.

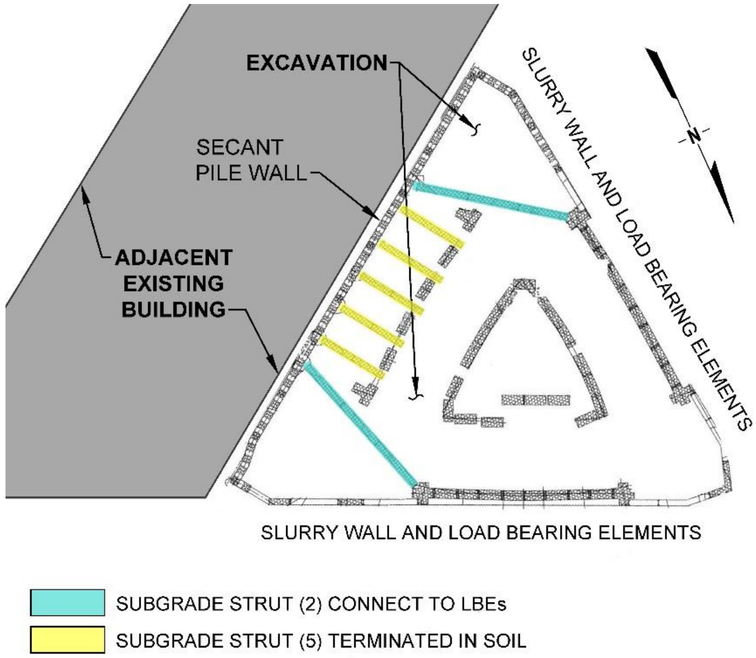

Figure 6 – Subgrade strut locations.

Secant pile wall and foundation elements were installed from existing site grade prior to mass excavation. The first cut was performed to El. +2 and then the subgrade struts were installed from this elevation using slurry trench methods. For each strut, a trench was excavated under slurry to El. -47 and tremie concrete was placed up to El. -31. The rest of the trench from El. -31 up to El. +2 was filled with cement bentonite to facilitate removal during mass excavation. Each subgrade strut was 2.5 ft wide, 16 ft deep, and consisted of unreinforced concrete with compressive strength of 2500 psi. Positive contact between the secant pile wall and subgrade struts was achieved by using a clamshell bucket with one scalloped side that followed the surface shape of the secant pile wall.

After the subgrade struts were completed, the first level of bracing was installed prior to mass excavation below that level. The mass excavation was conducted in three stages of excavation followed by brace installation. Three levels of temporary internal bracing (corner and cross-lot bracing) were installed, at El. +10, -3, and -16. Temporary bracing consisted of 36-inch diameter steel pipe elements and were preloaded to 50% of their design brace load. The bottom of excavation was approximately El. -31 next to the secant pile wall with some deeper areas near the middle of the site for elevator pits and other building requirements. Figure 7 shows a cross section of the secant pile wall and subgrade strut after the final excavation stage.

A 6-inch thick concrete mud mat was installed after reaching the bottom of excavation. Temporary bracing removal and floor slab installation was done in three stages after the mud mat was installed. Floor slabs were installed at El. -31, -11, and +4.4.

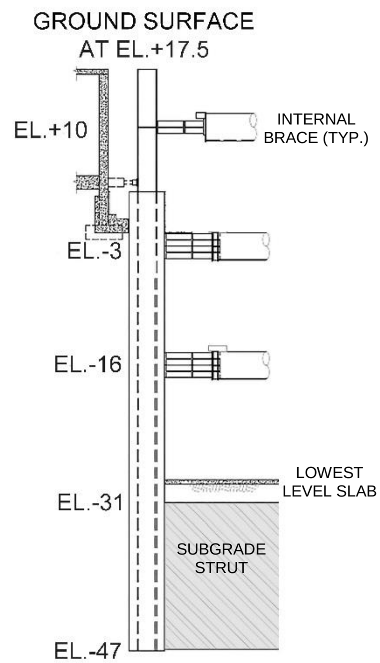

Figure 7 – Bracing and subgrade strut configuration along secant pile wall.

Construction instrumentation and wall performance

Instrumentation

Foundation wall and Colonnade Building movements were monitored during construction using a combination of inclinometers, building survey reference points, and tiltmeters.

Inclinometers are instruments used to measure the lateral movement of below-grade walls and deep foundation elements. Inclinometer casings were installed to depths within select slurry wall and secant pile elements such that "fixity" was achieved at the bottom of the inclinometer.

Survey reference points were used to measure changes in vertical positioning of points located on the exterior of the adjacent Colonnade Building by optical survey. The Colonnade building owner also elected to install survey targets on the building exterior to provide real-time monitoring using automated total station equipment.

Tiltmeters are used to measure the tilt angle of a surface about an axis. Tiltmeters were installed on the fifth floor of the Colonnade Building.

Inclinometers were read weekly and Colonnade Building reference points were surveyed weekly. The automated total station recorded data at 15 to 30 minute intervals. Tiltmeters recorded data continuously. Figure 8 shows the instrumentation location plan for the project.

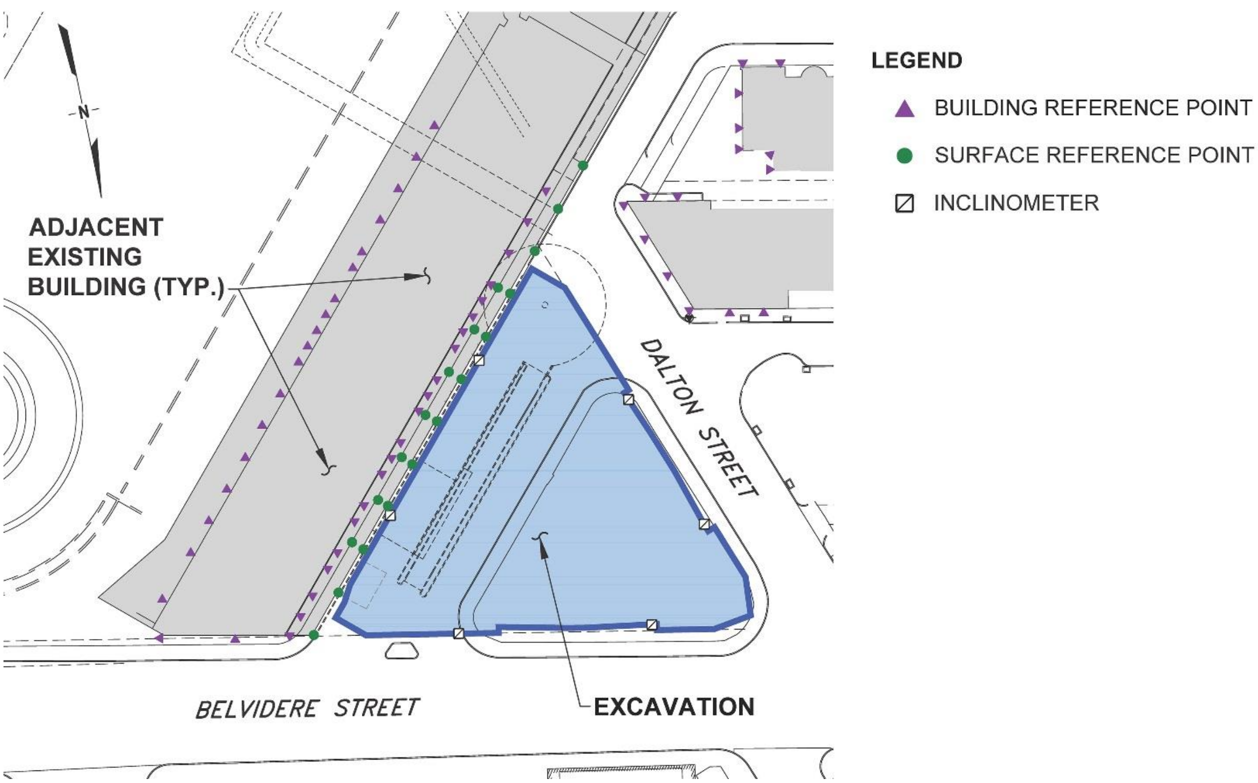

Figure 8 – Project instrumentation location plan.

Wall Performance

Figure 9 shows the lateral displacement profile at various stages of construction for an inclinometer located within the secant pile wall next to the Colonnade Building. The bottom of the excavation was reached at the end of August 2016 and the displacement profiles are shown through March 2017. The approximate vertical extent of the subgrade struts is also shown. By March 2017, six months after the maximum excavation depth was reached, the maximum lateral displacement was observed to be about 1.0 inch. The shape of the displacement profile shows the restraining effect of the subgrade struts.

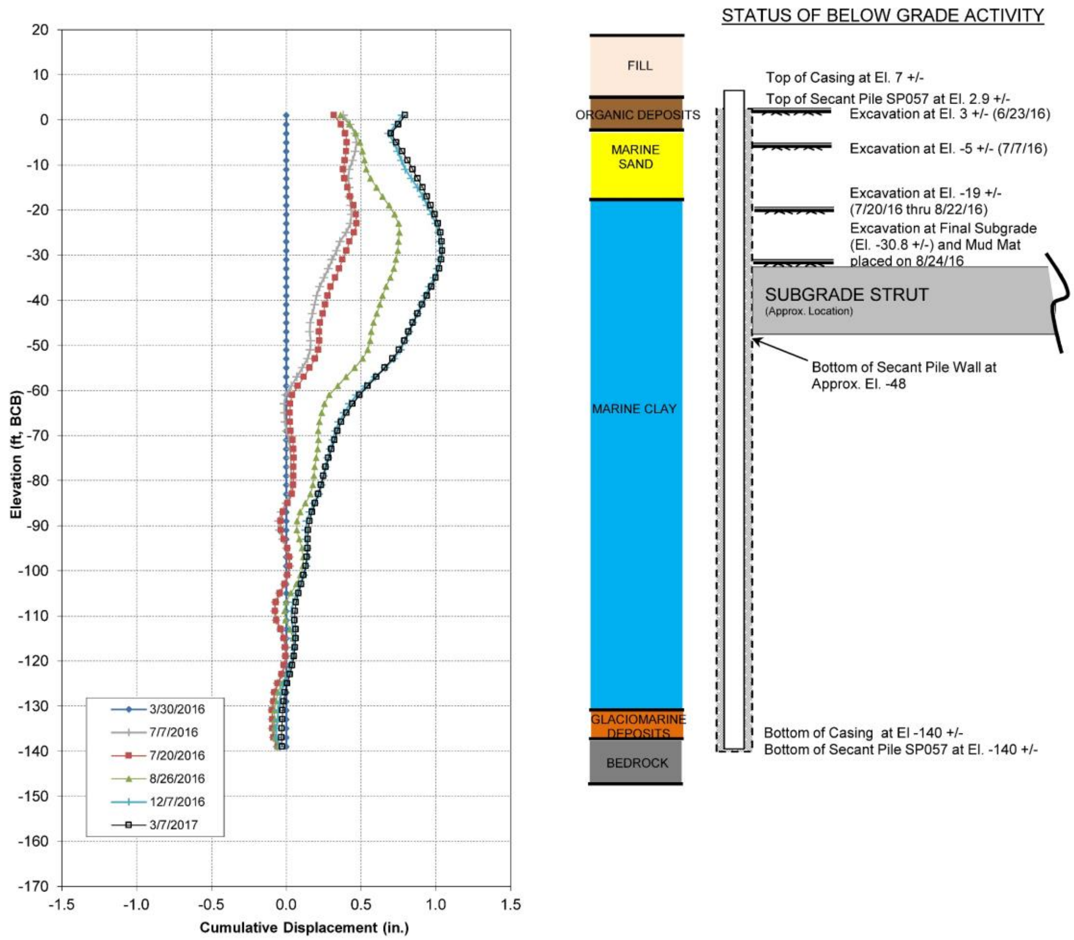

Figure 9 – Secant pile wall lateral displacement profile and approximate subgrade strut location.

Figure 10 shows the measured settlement at survey points 101-BS-12 located along the column line nearest the excavation and 101-BS-30 located on the eastern side of the Colonnade Building. Relevant construction periods are shown on the plot. At 101-BS-12, secant pile installation resulted in about 0.4 inch of settlement. Excavation and bracing installation for levels 1, 2, and 3 (L1, L2, and L3, respectively) each added about 0.1 inch of settlement (total of 0.3 inch during excavation and brace installation). Final excavation to the bottom elevation below the third brace level added another 0.2 inch of settlement. Further settlement occurred after final excavation. In total, the measured settlement at 101-BS-12 was about 1.1 inch. At 101-BS-30 on the other side of the Colonnade Building, the measured total settlement is about 0.2 inch.

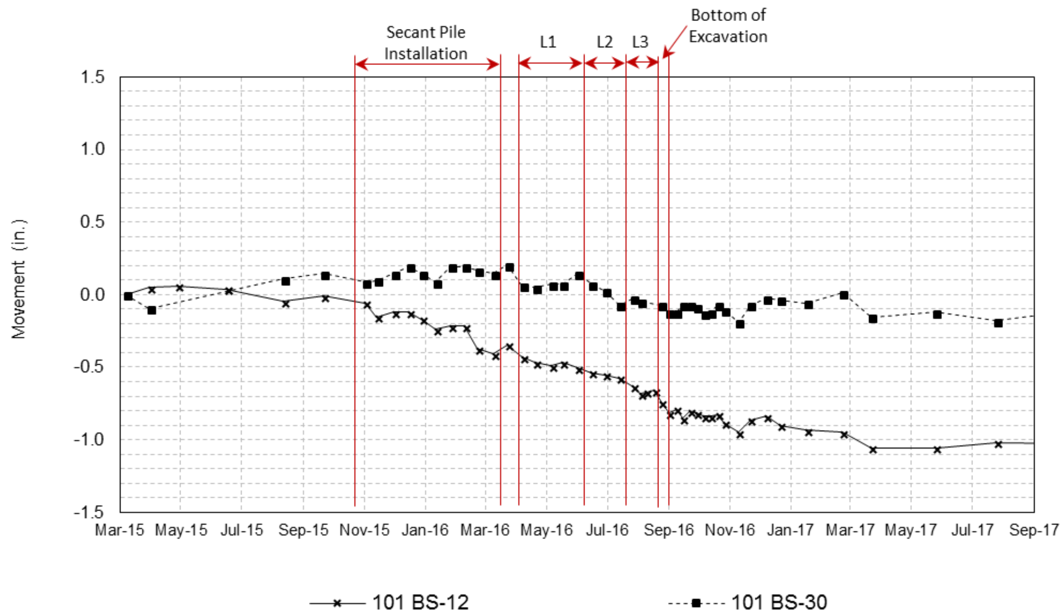

Figure 10 – Colonnade Building vertical movement (settlement) at two survey point locations.

Conclusions

The deep excavation removed the stiff clay crust that would have provided lateral support at the bottom of the wall. This increased the risk of excessive lateral movement of the secant pile wall and settlement of the adjacent building. Staged construction analyses indicated that lateral wall support below the base of the excavation would limit movements if installed prior to mass excavation. Concrete subgrade struts were selected as the most feasible solution given the project parameters (e.g., schedule, mobilized equipment). Seven subgrade struts were installed along the secant pile wall below the bottom of excavation prior to mass excavation. The subgrade struts successfully limited the lateral deflection of the secant pile wall to about 1.0 inch and the settlement of the Colonnade Building foundations to about 1.1 inch. About 50% of the Colonnade Building settlement occurred during secant pile installation (i.e., before mass excavation).

Wall movements in deep excavations in soft soil can be controlled by providing a stiff lateral support system. And in soft soils, added support below the bottom of the excavation should be considered to further stiffen the lateral support system. To be effective, such lateral supports must be in place prior to excavation and must be installed tight to the wall so that the supports are engaged immediately without any slack in the system.

Acknowledgments

Owner: One Dalton Owner LLC
Owner's Representative: AECOM Tishman
Architect: Pei Cobb Freed & Partners/Cambridge Seven Associates, Inc.
Construction Manager: Suffolk
Structural Engineer: WSP
Foundation Specialty Contractor: TREVIICOS