ADAPTING UNDERPINNING AND EXCAVATION SUPPORT IN 200-YEAR-OLD NYC BUILDINGS

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With the rise in property values and market push of luxury construction in NYC we have seen the requirement for adapting classic underpinning design with modern construction techniques. This project, located within the trendy SoHo/NoLita district is where several existing 150 to 200-year old historic landmark structures are to be converted from institutional use to luxury residential townhouses and condominiums. In order to provide the required below grade space necessary for the proposed construction, the existing foundations on these historic landmark buildings would need to be extended up to 20 feet deeper than their original construction.

Several challenging technical aspects of the Project required employing some innovative solutions.Some of these challenges included preservation of historic building facades, lack of access agreements with abutting property owners, height restrictions and widely varying subsurface soil conditions. These non-homogenous soil conditions had an impact on the design, construction, and implementation of the proposed foundation and earth support systems. Perhaps the most technically challenging aspect of the design was the Project limitation not allowing underpinning of adjacent buildings. This requirement drove the design team to employ a less conventional offset braced mini-pile support wall abutting the neighboring property, in combination with more conventional hand-excavated underpinning piers along building walls on the interior of the site. These major foundation support efforts were all to take place concurrently, while the remainder of the building above underwent a full structural gut renovation. These activities were required to occur simultaneously in order to meet the client and developers rigorous schedule.

During this work, the underpinning design continually evolved as historic 19th and 20th century underpinning was encountered. As construction and development progressed within the first building, the adjacent larger building underwent construction. The adjacent condominium building required similar deepening of a cellar and this time also an overall expansion of the building foot print, which required the innovative use of segmental wall construction, deep conventional underpinning, and also the use of helical pipe piles and timber contact lagging as lateral earth support methods due to low overhead conditions of the shallow existing cellar.

Proactively developing efficient, effective, and safe foundation and earth support techniques and associated construction sequences for all of the support systems employed on the Project was critical to the wellbeing of the workers and overall success of the Project. In this paper, we will review the project access limitations, design parameters, support of excavation (SOE) and underpinning design, as well as a comparison of empirical settlement estimates with those obtained by real time monitoring and observation of the structures.

I INTRODUCTION

The Project, located within the trendy SoHo/NoLita district in Manhattan, New York, consists of several existing 150 to 200-year old historic three to four story brick and timber framed structures which are to be converted from institutional use to luxury residential townhouses and condominiums. The existing structures were first built starting in 1826 and generally consist of four stories and a basement, including a four-story brick building (a former catholic school and convent) that is designated as a landmark according to NYC Landmark commission, and a three-story brick building (1954 classroom addition) which was slated to be demolished. The existing landmark building has a partial basement and cellar. A rear courtyard occupies the southwestern half of the site with an existing ground surface elevation of approximately 43 (BPMD). The existing buildings encompass a total area of approximately 42,000 square feet.

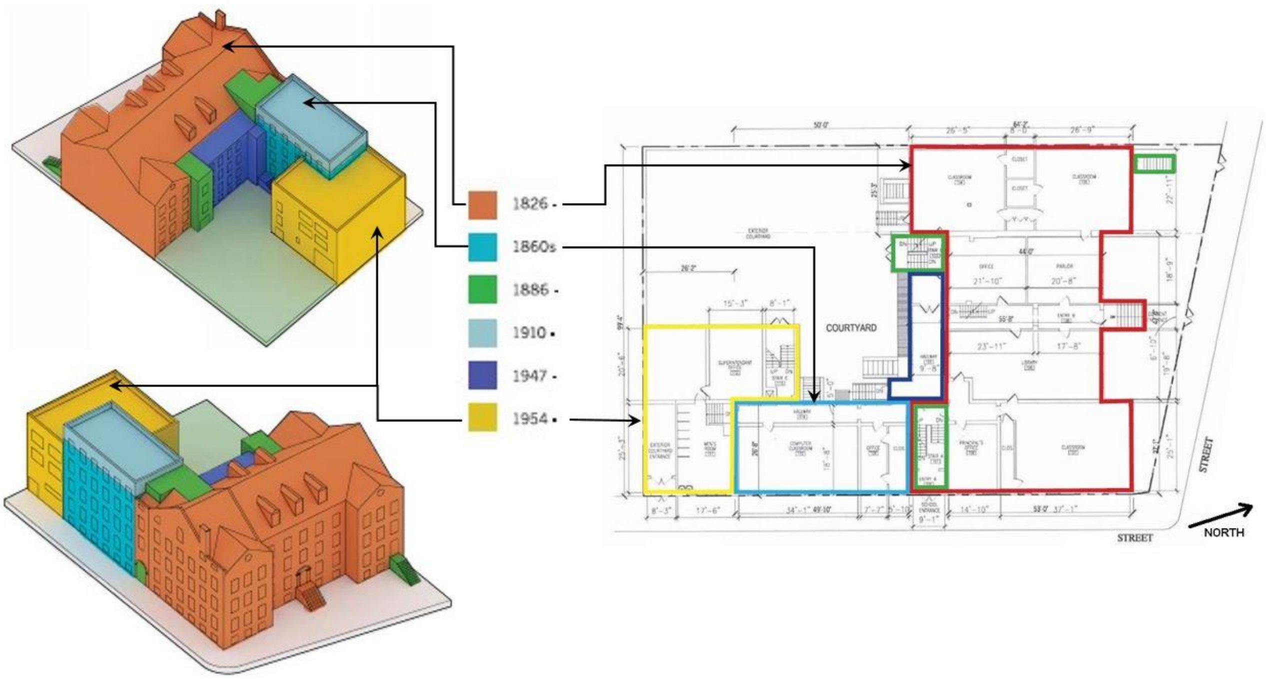

Figure 1: Existing Project Site Plan and Rendering [1]

The site is bounded by a six-story building with a cellar along the northern half of the western property line. A three-story vertical extension was constructed on this building in the last 50 years. The southern half of the western property line is bounded by rear yards of existing buildings. A five-story building with a cellar and one-story extension bound the site to the south. The Project site is located on a corner lot and bordered by streets along the north and east. A 12-feet high brick wall (retaining wall) is present along the southern half of the west property line and western half of the south property line.

The proposed construction consists of conversion of the landmark former school building into residential units and include demolition of non-landmark structures at the rear of the former school building. Three new additions will be constructed that will be four to six-stories in height with basement and cellar levels.

The proposed Condominiums in the existing 1826 building are located along the eastern part of the existing site. The proposed construction will include the gut renovation of the eastern wing of the existing landmark portion of the building and the 1860s Wing and converted into residential units. The proposed construction also includes a roof top addition to the 1860s Wing and construction of new 4 to 6-story structures with basement and cellar within the eastern half of the existing court yard. The cellar of the new structure extends to a depth of approximately 16.5 feet below existing sidewalk elevation corresponding to elevation 27.0. The existing cellar within the footprint of the existing landmark building and 1860s Wing will be extended an additional 10 feet to a depth of approximately 16.5 feet below existing sidewalk elevation corresponding to elevation 27.0.

The proposed Townhouse in the existing 1860s Wing is located along the western part of the existing site and will include the western wing of the existing landmark building and a portion of the rear yard. The western wing of the existing landmark building will undergo gut renovation and converted into residential units. The existing cellar within the footprint of the Townhouse will be extended an additional 11 feet to a depth of approximately 16.5 feet below existing sidewalk elevation (creating a new cellar level) corresponding to elevation 26.5. The existing rear yard will be excavated approximately 7 feet below existing ground surface elevation to match the depth of the existing basement at elevation 37.5.

The new Townhouse at the demolished 1954 classroom addition location is a newly constructed building located at the southern end of the property. The existing four-story addition (1954 classrooms addition) will be demolished and a new six-story building with a basement and a cellar will be constructed. The new building will extend approximately 65 feet west from the Mott Street property line. The cellar within the footprint of the proposed building will extend to a depth of approximately 14.5 feet below existing sidewalk elevation corresponding to elevation 28.5. The existing rear yard will be excavated approximately 3 feet below existing ground surface elevation to match the depth of the existing basement at elevation 40.

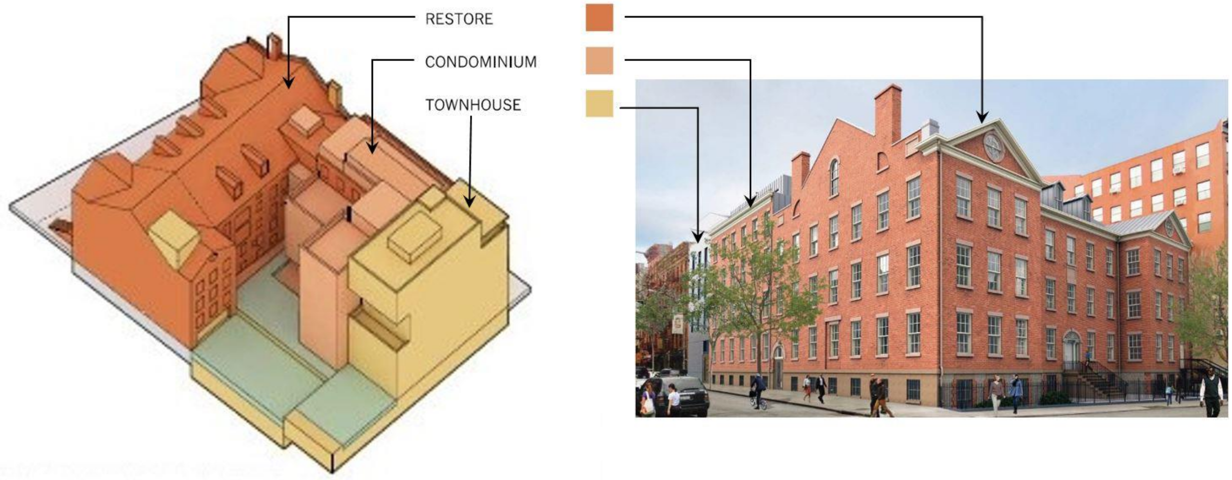

Figure 2: Proposed Project Site Renderings [1]

The proposed re-development of the buildings on this site will increase the useable square footage by nearly 63% to approximately 68,400 square feet. The condominium residents will have private storage areas, and will share a fitness center, yoga studio, and wine cellar located within the basement levels.

In order to provide the required below grade space necessary for the proposed construction, the existing foundations on these historic landmark buildings would need to be extended up to 20 feet deeper than their original construction.

II DESIGN PARAMETERS

Five test borings were drilled to obtain information on the overall soil profile and 17 test pits were excavated to observe exposed building foundations.

The generalized subsurface soil profile across the site consisted of: an approximately 10-14 foot thick stratum of Fill (NYCBC Class 7); atop layer of Sand & Gravel (NYCBC Class 2a/2b) ranging from 5-8 feet thick; underlain by and Upper Sand layer extending to a depth of nearly 80 feet below ground surface (b.g.s.); below which occurs an approximately 10 feet thick stratum of Silt & Sand (NYCBC Class 5a/3a); over a Lower Sand (NYCBC Class 3a) stratum; with borings terminating in Silt (NYCBC Class 5a) at a depth of approximately 100 feet. The measured depth to groundwater in the observation well was measured at 44.5 feet below existing ground surface corresponding to an approximate elevation of 1.0, which occurs below the bottom of excavation (BOE) elevation, and therefore did not have significant impact on the temporary earth support designs.

All of the temporary earth support and underpinning required on the Project occurred within the Fill, Sand & Gravel, and Upper Sand layers. Descriptions of these materials are summarized below:

- The Fill (NYCBC Class 7) stratum generally consists of a heterogeneous mixture of sand, silt, gravel, brick fragments, and concrete fragments. SPT N-values ranged between two (2) blows per foot and refusal in this stratum, indicating a wide variation in density.

- The SAND & GRAVEL (NYCBC Class 2a/2b) layer consists of Medium dense to very dense, fine to coarse Gravel, some fine to coarse Sand, trace of Silt and occasional boulders were encountered below the Fill stratum. SPT N-values ranged from twenty-four (24) blows per foot to refusal.

- The UPPER SAND (NYCBC Class 3a/3b) layer consists of Medium dense to dense, brown fine to coarse Sand with little to trace Silt was encountered below the Fill and Sand and below the Gravel stratum SPT N-values ranged from nineteen (19) to eighty (80) blows per foot.

Soil Type	Estimated Unit Weight (pcf)	Internal Friction Angle, ϕ (degrees)	Interface Friction Angle, δ (degrees)	Active Lateral Earth Pressure Coefficient (K_a)	Passive Lateral Earth Pressure Coefficient (K_p)
Fill (NYCBC Class 7)	120	28	20	0.36	2.8
Sand & Gravel (NYCBC Class 2a/2b)	120	32	22	0.31	3.3
Upper Sand (NYCBC Class 3a/3b)	120	32	22	0.31	3.3

Figure 3b: Table 3-1 from USACOE EM 1110-2-2504 [2]

The design parameters of the subsurface soils encountered on the site (Figure 3a), for the temporary earth support and underpinning design were estimated using Table 3-1 provided in the U.S. Army Corps of Engineers (USACOE EM 1110-2-2504), and Table 1 provided in the Naval Facilities Engineering Command Design Manual 7.02 (NAVFAC DM-7.02), shown below:

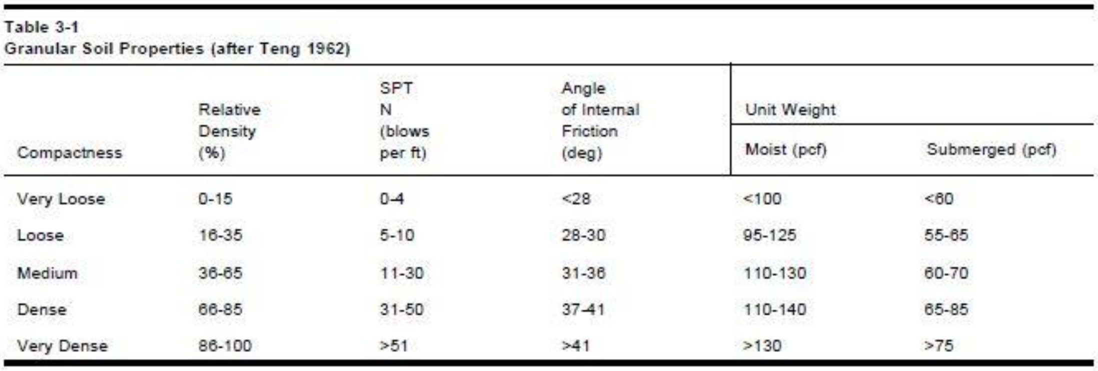

Table 3-1
Granular Soil Properties (after Teng 1962)

Compactness	Relative Density (%)	SPT N (blows per ft)	Angle of Internal Friction (deg)	Unit Weight	
				Moist (pcf)	Submerged (pcf)
Very Loose	0-15	0-4	<28	<100	<60
Loose	16-35	5-10	28-30	95-125	55-65
Medium	36-65	11-30	31-36	110-130	60-70
Dense	66-85	31-50	37-41	110-140	65-85
Very Dense	86-100	>51	>41	>130	>75

Figure 3b: Table 3-1 from USACOE EM 1110-2-2504 [2]

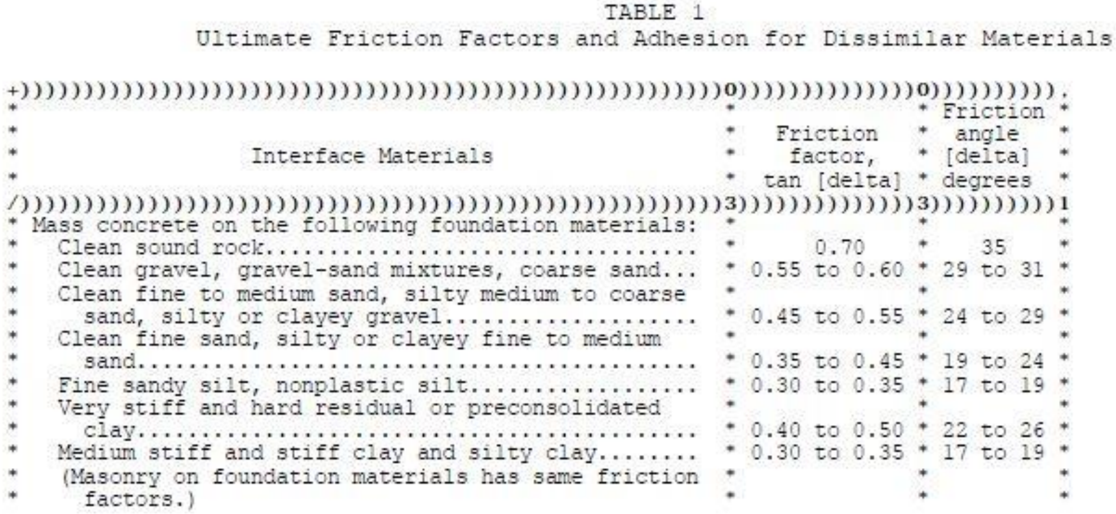

TABLE 1
Ultimate Friction Factors and Adhesion for Dissimilar Materials

Interface Materials	Friction factor, tan [delta]	Friction angle [delta] degrees
Mass concrete on the following foundation materials:		
Clean sound rock................................	0.70	35
Clean gravel, gravel-sand mixtures, coarse sand...	0.55 to 0.60	29 to 31
Clean fine to medium sand, silty medium to coarse sand, silty or clayey gravel..................	0.45 to 0.55	24 to 29
Clean fine sand, silty or clayey fine to medium sand...	0.35 to 0.45	19 to 24
Fine sandy silt, nonplastic silt.................	0.30 to 0.35	17 to 19
Very stiff and hard residual or preconsolidated clay...	0.40 to 0.50	22 to 26
Medium stiff and stiff clay and silty clay........	0.30 to 0.35	17 to 19
(Masonry on foundation materials has same friction factors.)		

Figure 3c: Table 1 from NAVFAC DM-7.02 [3]

Based on the low fines and moisture content of the soils encountered during the subsurface exploration GZA anticipated special measures may be required to stabilize the loose dry soils to minimize soil loss during underpinning and reduce impact on adjacent foundations and/or sidewalks.

At some of the underpinning locations at the 1860's wing the above mentioned loose/dry sand was encountered and was very unstable during underpinning pier excavation. Contractor implemented a permeation grouting program prior to underpinning a portion of the 1860's wing to reduce ground loss and minimize any impacts to the existing building foundation and adjacent sidewalks. The technique consists of drilling a hole in the soil, inserting an injection pipe into the ground and then pumping any number of liquefied materials into the problem area. The implementation of permeation grouting prevented the loss of soil during excavation and significantly reduced the potential for settlement during underpinning.

III PROJECT OBJECTIVES AND CHALLENGES

Due to the age and conditions of the existing historic buildings within the project site, the project required engaging some innovative solutions to successfully build the project as designed. One of the most technically challenging aspect of the design was the poor condition of the existing rubble foundation walls and/or the lack of access agreement with the neighbors which resulted in not allowing underpinning of existing or adjacent buildings. This drove the design team to employ a less conventional offset braced mini-pile/ helical pile support wall along a portion of the existing building and abutting the neighboring property, in combination with more conventional hand-excavated underpinning piers along building walls on the interior of the site.

IV DESIGN METHODOLOGY

The design of both the temporary support of excavation (SOE) and permanent underpinning systems required that the proposed loading conditions be carefully considered in accessing the design requirements. In addition to selecting representative soil parameters for both the active and at-rest conditions of the SOE and underpinning supporting systems, it was necessary for GZA to accurately estimate the surcharge forces applied to the vertical and lateral support elements.

Temporary construction equipment loading was determined based on the proposed equipment selected by the Contractor performing the work. Such equipment included excavators, loaders, drill rigs, concrete & material delivery trucks, and the like. Critical load cases and locations of the equipment were considered in generating Boussinesq pressure distributions along the walls surfaces being analyzed. Typical ground surcharge pressures considered in the designs included: 250-psf (HS-20 Vehicle Traffic); 400-psf (Medium Construction Equipment); and 600-psf (Large Construction Equipment).

Anticipated dead and live building loads for both the Project buildings as well as those located on the adjacent properties, requiring underpinning and/or lateral support, were computed based on the observed building materials, geometries, and intended use. The current NYC building code (2008 version at the time of the Project filing) was used for determining the assumed live load conditions. The bearing pressures generated based on the building wall loads were applied to the design sections as either surcharge pressures or axial loads depending on the wall system type and the relative location of the loads. Typical building wall bearing pressures considered in the designs included: 7.6-ksf x 1.5-ft (4-Story Brick Building); 9.9-ksf x 1.5-ft (5-Story Brick Building); and 13.7-ksf x 1.5-ft (7-Story Brick Building).

The temporary SOE systems were designed by applying the lateral earth pressures, based on Coulomb earth pressure theory, to the wall in conjunction with the Boussinesq surcharge pressures, in order to estimate member stresses and calculate toe embedment. The combined member stresses for vertical members (e.g. soldier piles), horizontal members (e.g. wales and struts), inclined members (e.g. rakers), and connections (e.g. welds, bolts, etc.) were checked using the allowable stress design (ASD) methods indicated in American Institute of Steel Construction (AISC) – 13th Edition. In the case of drilled micropile SOE elements, the Federal Highway Administration's "Micropile Design and Construction" (FHWA NHI-05-039) was used and considered a 50% pipe wall section reduction at threaded joint locations. To counteract this strength reduction, the composite action of the concrete used to fill the micropiles was accounted for by calculating an ultimate moment capacity passed on the reduced plastic section modulus and combined effective stiffness of the concrete and steel section. Deflections of the SOE members were computed using the methods described above. The ground surface settlement caused by the deformations of the SOE systems were estimated based on the lateral deflections using Clough and O'Rourke's method and compared to the maximum vertical settlement tolerance of ½-in considered on the Project. Toe embedment was calculated using limit-equilibrium methods, in which the passive soil parameters were divided by a factor of safety of 1.5. A soil arching factor of 3 times the pile diameter was considered in computing the maximum passive width of the piles used in the toe embedment calculations. Bracing loads were determined using the tributary area method based on the net pressure diagrams generated by the wall analysis. We used SupportIT© SOE wall analysis software by GTSoft Ltd. to perform the various temporary SOE wall analyses for the Project.

The underpinning and segmental wall systems were designed for both temporary and permanent conditions, depending on the geometry and specifics of the design section being analyzed. The lateral earth and surcharge pressures were applied to the underpinning in a similar manner as described above for the SOE wall systems. In addition to these lateral loads, axial loads were also applied based on the estimated building wall load to be supported, as summarized above. The critical case for underpinning stability occurred during the temporary conditions and neglected any beneficial contribution of floor live loading from levels above. Both sliding and overturning of the underpinning was checked against temporary factors of safety of FS=1.5 for the temporary conditions, in which the mobilized resisting forces resulting from axial loading, base friction, and toe embedment below bottom of excavation (BOE) were compared to the driving pressures resulting from the applied loading. Toe embedment was calculated in a similar manner as was done for the SOE systems, however the contribution of base friction due to axial loading was also considered. A minimum underpinning toe embedment of 1-foot below BOE was generally employed, however in several of the deep underpinning pier locations, toe embedment of up to 7.5-feet was required. minimum underpinning pier thickness of 2-feet were considered in accordance with the New York City Department of Buildings' (NYCDOB) requirements, and maximum pit lengths of 3-feet were considered at rubble stone foundation wall underpinning locations. Drilled in reinforcing dowels were designed to assist in engaging the existing wall system being with the supporting underpinning piers. At some of the deeper pier locations, lateral bracing was required for stability. Minimum bracing heights above BOE were calculated in order to achieve the minimum factors of safety for overturning and sliding. Bracing loads and stresses were also calculated in a similar manner as the SOE systems as described above. The concrete was then checked and steel reinforcing was designed as required using the principles and methods detailed in American Concrete Institute's ACI 318-08 "Building Code Requirements for Structural Concrete".

V SOE AND UNDERPINNING DESIGN

A. <u>1826 Building Proposed Townhouse</u>

The proposed renovations needed for the townhouse construction within the 1860's wing of the existing building required that the existing cellar level be lowered approximately 12 feet from the existing slab elevation. This was necessary to create a new cellar space for tenant storage as well as allow for construction of the pit required for a new residential elevator. A new basement level would also be constructed above the proposed lowered cellar level, increasing the usable space of the proposed townhouse. The test pits that were performed prior to construction indicated that the original stone rubble foundation walls extended approximately 8 feet below the existing cellar slab, so underpinning those existing foundation walls would be required to construct the proposed cellar foundations.

The existing stone rubble foundation walls were found to be in relatively poor condition during initial test pit explorations, so liner walls were required to be installed at the face of the existing foundation walls to maintain their stability during construction. Due to an increase in the proposed loading of building resulting from the change of use of the structure and current building code requirements, a mat slab was needed for foundation support. The proposed mat slab was required to engage the existing foundation wall underpinning to adequately transfer the loads to the subgrade soils. This was accomplished by providing dowel bar subs and couplers at the face of the underpinning to make the necessary mat slab reinforcing connections and lap splices.

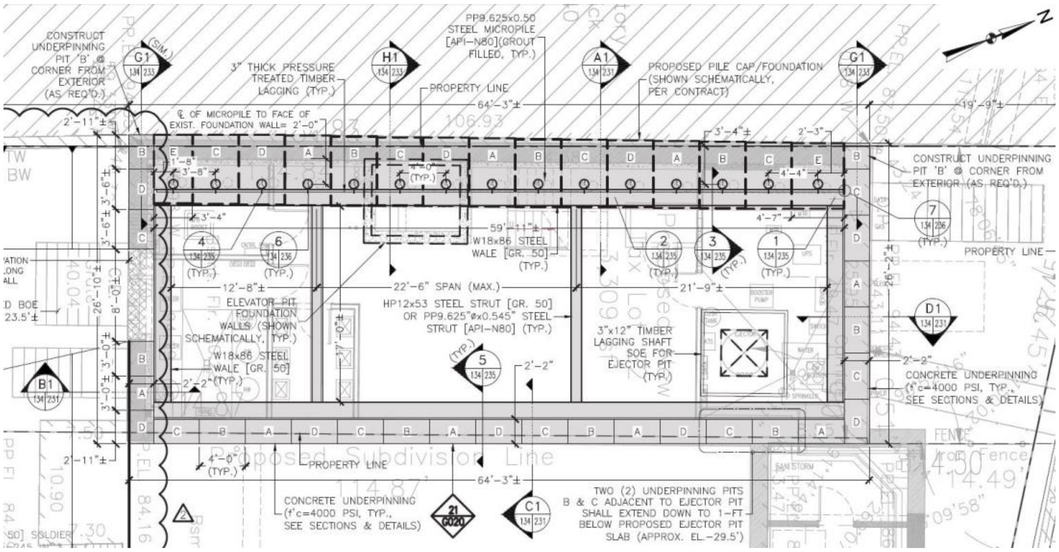

Figure 4a: Western Portion of the 1826 Building Proposed Townhouse Underpinning Plan

During pre-construction inspections, the west foundation wall was found to not be a common party wall shared by the neighboring building as originally suspected, but a separate wall built next to the neighboring foundation wall. The neighboring building's foundation wall would need to be adequately supported to facilitate the proposed Project building cellar construction. Permission was sought from the neighboring property owner to underpin their foundation wall, however due to apparent concerns of the neighboring property owner over the potential of foundation wall movement and the associated possible structural issues (e.g. settlement, cracking, etc.) which may result from underpinning their wall, the neighboring property owner did not give permission for their wall to be underpinned. This required an alternative innovative solution to be employed to build the Project as designed without undermining the neighboring building foundation.

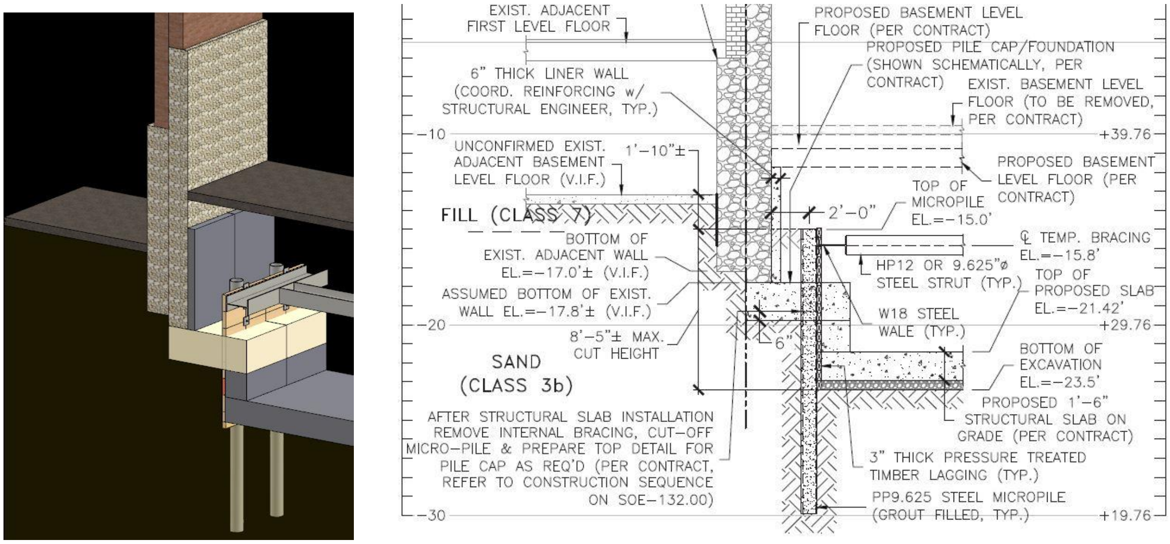

Figure 4b: Western Portion of the 1826 Building Proposed Townhouse Underpinning Section

The proposed solution for supporting both the existing building and neighboring foundation wall conceived by GZA was an offset support of excavation (SOE) wall, which would be located approximately 2 feet in front on the Project foundation wall. This system would be used on conjunction with conventional concrete pit underpinning located around the remaining perimeter of the building. A micropile and contact lagging system was selected for the offset SOE wall for ease and speed of installation, as well as the severely restricted headroom available within the existing cellar space. Using an offset SOE system meant that a load transfer mechanism was still required from the foundation walls to the mat slab and subgrade below, so it was proposed that the micropiles would could be engaged for both lateral and vertical foundation support. This was accomplished by designing the micropiles for both combined bending and axial loads. The micropiles were designed to have geotechnical capacity in the underlying sands. They were connected to the proposed Project foundations by toothing in segmental pile caps beneath the existing Project building foundation wall and casting them around the micropiles. The micropiles also required lateral bracing during the temporary construction conditions, due to the adjacent surcharge and lateral loading conditions, so bracing was provided across the cellar space to the opposite wall underpinning. Refer to Figures 4a and 4b.

B. <u>1860's Wing Proposed Condominiums</u>

The proposed renovations needed for the condominiums construction within the 1860 wing of the existing building required that the existing cellar level be lowered approximately 5 feet from the existing slab elevation. Similar to the townhouses constructed in the western portion of the 1826 Building, this was necessary to create a new cellar space for tenant storage as well as allow for construction of the pit required for a new residential elevator. Similarly, a new basement level would also be constructed above the proposed lowered cellar level, increasing the usable space of the proposed townhouse. The test pits that were performed prior to construction in this area indicated that the original stone rubble foundation walls extended only approximately 18 inches below the existing cellar slab, so underpinning those existing foundation walls would be required to construct the proposed cellar foundations.

The existing stone rubble foundation walls were found to be in similar condition at this location in the 1826 building, so liner walls were required to be installed at the face of the existing foundation walls to maintain their stability during construction. Unlike within the 1826 building, both the existing foundation walls and underpinning would provide all of the required foundation support in this area. This could be attributed to several factors, including less of a load increase due to the change in use of the building and more suitable soil conditions at this location. It should be noted that although the generalized soil stratigraphy remained relatively uniform across the site, the quality of the subsurface bearing soils varied greatly over relatively short distances, resulting in the differing foundation support types and requirements.

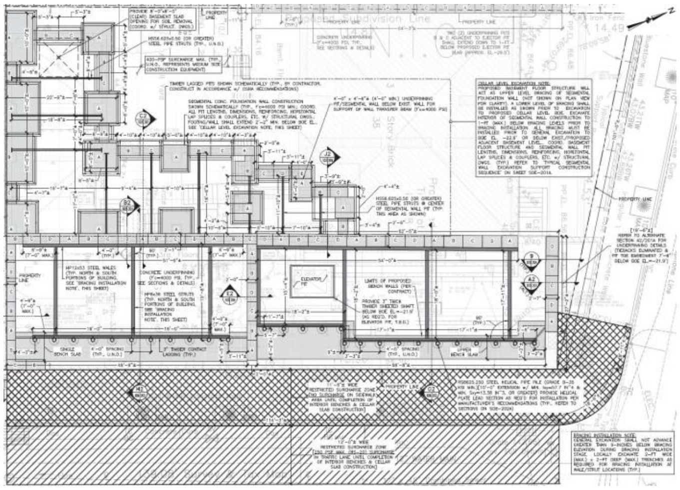

Figure 4c: 1860 Wing Proposed Condominiums Underpinning Plan

One of the greatest challenges for designing the required underpinning in this location was the large magnitude of the adjacent surcharge loads. The west foundation wall was located adjacent to the interior courtyard area of the site where heavy equipment would be operating throughout construction. The east foundation wall was located adjacent to the sidewalk and street which requires a 600-psf live load surcharge to be considered per the 2008 NYCBC. This is a requirement of the NYC building code and is presumed to be a provision to account for the possibility of heavy equipment traveling or operating next to existing structures within the city. These surcharges imparted large lateral earth pressures on foundation walls and underpinning, which necessitated the use of both deep underpinning pits and a bracing system at achieve the required lateral stability. The underpinning in this area was originally designed as deep concrete pits supported by earth tieback anchors, however due to the possible conflicts with below ground utilities within the street and the prohibitive costs associated with this due to both labor, materials, and schedule, a more creative solution was sought.

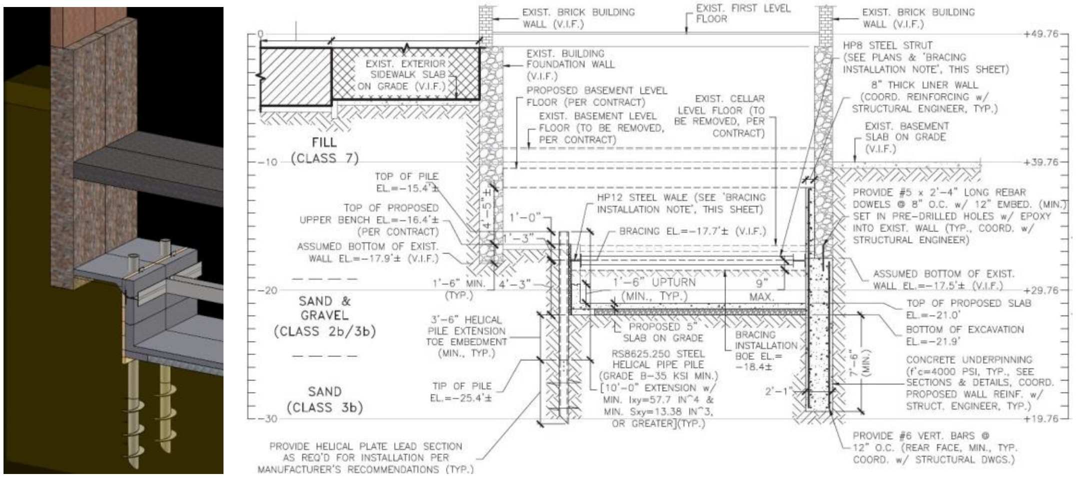

Figure 4d: 1860 Wing Proposed Condominiums Underpinning Section

GZA realized a balance between cost, constructability, and maximizing the usable space by employing a combination of both conventional and non-conventional systems. During initial stages of excavation within the cellar area, the existing east stone rubble foundation walls were found to be deteriorating and in general poor condition, therefore even limited excavation beneath these walls required for conventional underpinning had the potential for causing disintegration of the foundation walls. GZA therefore proposed that a liner wall be installed and an offset SOE wall like what was used in the 1826 building used. Similar to the 1826 building, low headroom clearance was an issue within the existing cellar space, however instead of micropiles, GZA proposed that helical pipe piles be used. The helical pipe piles could be installed in low headroom, very quickly with a small machine like a skid-steer (e.g. Bobcat). The helical pipe piles were required to be filled with grout for stiffness and additional structural capacity. These would be braced across the cellar space to the opposite side west wall, to conventional deep pit underpinning. Refer to Figures 4c and 4d.

C. <u>1954 Classroom Addition Proposed Townhouse</u>

The proposed townhouse located at the former 1954 Classroom Addition, required that the existing building structure in this location be demolished in its entirety in order to construct the new building. Like the townhouse foundation used in the 1826 building, a mat slab foundation would be required for this building. Unlike the proposed townhouse construction, permission was secured from the neighboring property owner to the south to underpin their existing foundation wall abutting the Project site. Conventional concrete pit underpinning was therefore designed for the south wall, as it represented the most efficient and cost effective option.

Since proposed townhouse at this location was the last to be constructed, and the heavy equipment required to install a conventional SOE system required for the proposed foundation construction was not mobilized on the site. The Contractor and Owner were seeking a way to construct the required foundations without installing a conventional SOE, to save both time on the schedule and construction costs.

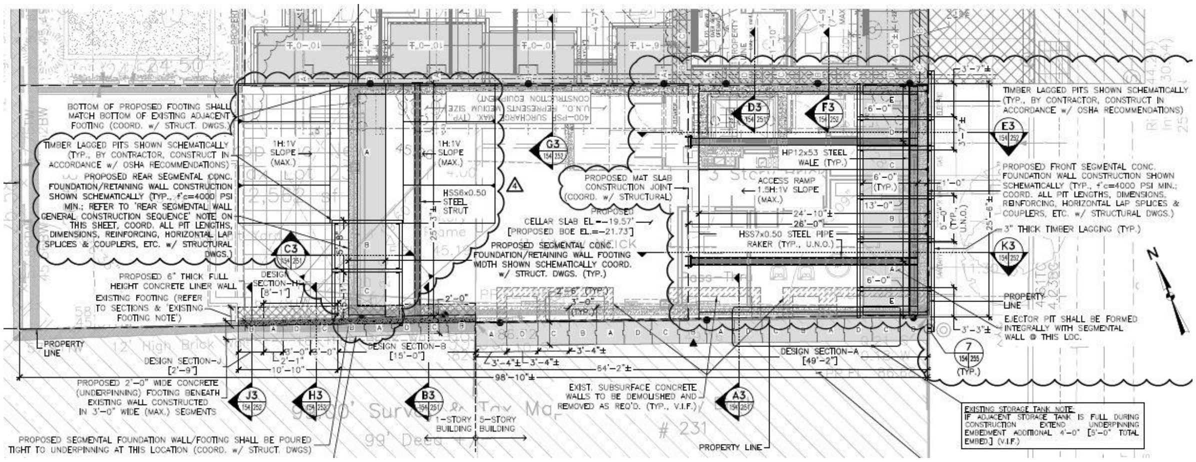

Figure 4e: 1954 Classroom Addition Proposed Townhouse Underpinning Plan

GZA proposed an inventive method to accomplish this goal by suggesting that a braced segmental foundation wall system be employed. With this system, the foundation walls and footings would be built incrementally, similar to the sequence in which underpinning is constructed, using timber lagged shoring pits. Once the permanent foundation walls and footing were built, a berm would be excavated in front of the walls, allowing for raker bracing to be installed to a portion of the permanent mat slab previously constructed. Once the bracing was installed the berm could be excavated, the remaining mat slab infilled, and building construction completed. Refer to Figures 4e and 4f.

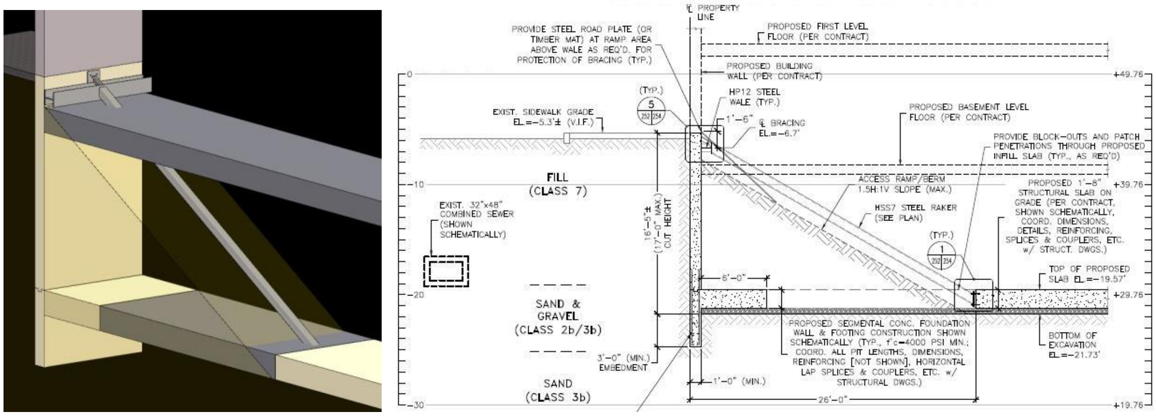

Figure 4f: 1954 Classroom Addition Proposed Townhouse Segmental Wall Section

VI SETTLEMENT OBSERVATIONS AND COMPARISON

The settlement monitoring program consisted up one Automated Motorized Total Station (AMTS) to monitor existing above ground structures and adjacent structures. The AMTS was relocated a total of 3 times to accommodate monitoring of the three buildings being underpinned. The AMTS monitored up to 18 prisms that were affixed to the adjacent structures and structures being underpinned or within the influence zone of the support of excavation as shown in Figure 5a. Monitoring data was collected every hour on a 24/7 basis during the excavation and foundation installation process using the AMTS for over eight months. Monitoring points that were not visible by the AMTS were monitored using conventional means of surveying. As presented in Table 5a settlement of the buildings being underpinned and adjacent structures within the zone of influence of the SOE was mostly negligible, with up to ½-inch maximum settlement in an isolated area see Figure 5b.

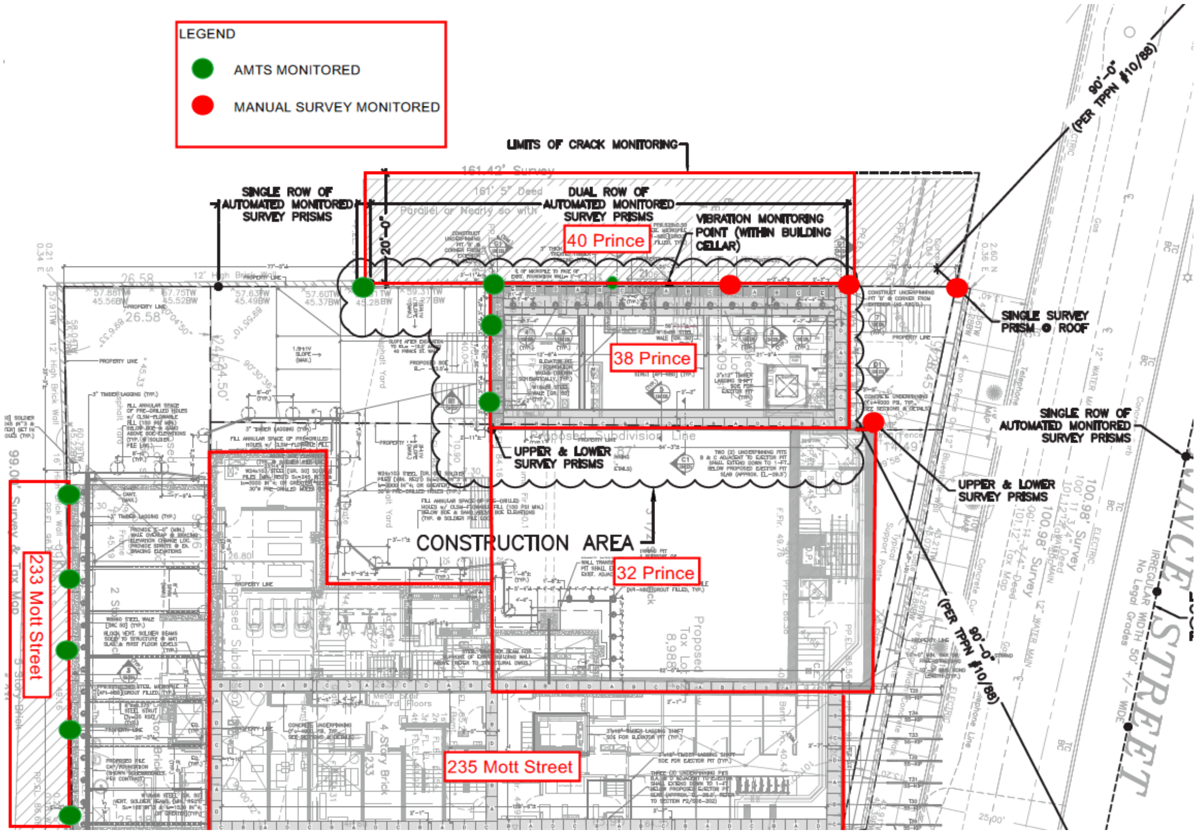

Figure 5a: Survey Monitoring Plan Monitoring Plan

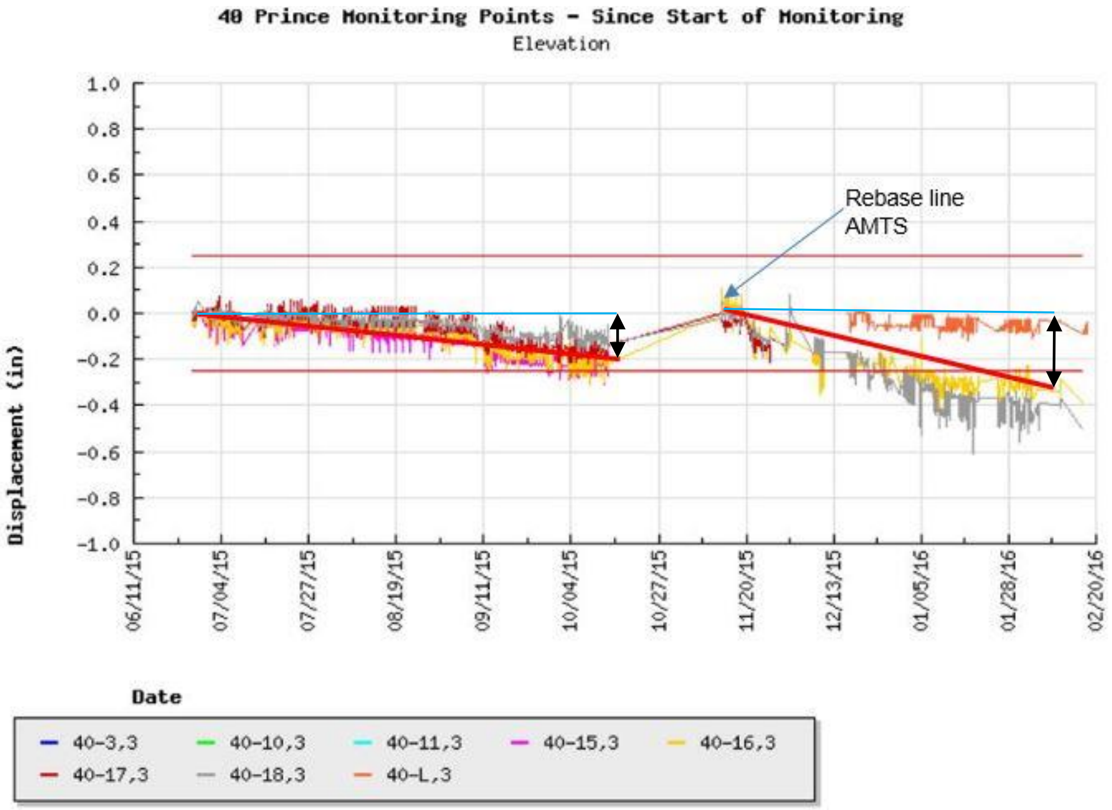

Figure 5b: 40 Prince Settlement Data

AMTS			Manual Survey*		
Northing	Easting	Elevation	Northing	Easting	Elevation
0.25''	0.25”	0.5”	0.1”	0.1”	0.25”

Table 5a: Summary of displacement during underpinning/excavation construction.
*Monitoring points typically located in areas with minimal or no underpinning.

The successful usage of this system was key during installation of underpinning and internal bracing within these historic buildings, installation of drilled soldier piles adjacent to existing foundation walls and during soil excavation to determine any possible damage to the historic landmark structures. Because of the frequency of the data collection we were able to closely monitor settlement and determine the cause of the settlement and adjust the construction process to reduce overall settlement and lateral movement. Total movement monitored was within the expected range of design.

VII CONCLUSIONS

Due to the efforts of inter-office coordination, GZA provided an innovative design and solutions to successfully build the project as conceived. GZA’s design was implemented very successfully resulting very little movement and or settlement of existing and/or adjacent buildings. GZA’s design drawings were also very detailed and of a very high quality to the point that the contractor was not required to submit shop drawings. GZA’s team effort resulted in a very satisfying client which contributed to an exceptionally high net fees and additional referral from other parties involved with the project.

Frequent coordination, quick responses to inquiries, timely adjustments to designs allowed to maintain unpredictable construction schedule. GZA was able to work with the Owner's rep, GM and Contractor through serval design changes to overcome construction challenges throughout the excavation and installation of the foundations. As part of the field inspection scope of the work, several GZA's junior staff were trained on the oversight of excavation support installation and underpinning construction.

GZA Proactively developed efficient, effective, and safe foundation and earth support system. We responded to the project team needs that included redesign based on field conditions and/or contractor's suggestions on a timely manner.

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