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Times Square Redevelopment: A Below Grade View

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ABSTRACT

The paper describes the design and construction of the foundations for two new high-rise structures in New York City (NYC). The sites are located in the heart of Times Square, bound by 42nd Street to the north, 41st Street to the south, and Broadway to the east. Below grade, active subways and subway stations abut the sites, extending as much as 50 feet into the property. The work involved the demolition of existing structures, excavation of debris and rock to depths exceeding 30 feet below grade, bracing adjacent subway structures around the site, installing high capacity caissons immediately adjacent to the deeper subways, and adapting existing foundations to accommodate the new building foundations. Of particular interest is the preservation of the adjacent historic New Amsterdam Theatre that included vibration and settlement monitoring during construction. Due to the unique site constraints, close collaboration of the Engineers with the Owner, Foundation Contractors, and New York City Transit (NYCT) was required. Innovative solutions for the foundation design were applied to accommodate several construction stages and allowed the projects to be completed without adversely affecting the subways, pedestrian traffic or the historic theatre. The projects received several awards, including the 2001 New York Association of Consulting Engineers (NYACE) Platinum Excellence Award in Geotechnical Engineering and Historical Preservation Plan, and the 2003 NYACE Gold Engineering Excellence Award.

Times Square, arguably one of the best known destinations in the world, has undergone and continues to undergo a re-development aimed at attracting corporate tenants to the area. In 1985, Mueser Rutledge Consulting Engineers (MRCE) performed a preliminary subsurface evaluation of Sites 1 through 4, shown in Figure 1. The study consisted of one boring at each site and was performed on behalf of the NYC Economic Development Corporation (EDC) to assist in evaluating the development of the sites. All four sites have since been developed with high-rise office buildings.

MRCE was involved with the planning, design and construction of the foundations of Sites 1, 2 and 4. This case history will focus on the design and construction of the foundations for the towers owned by Boston Properties on the last two sites to be developed: 5 Times Square (Site 4) and 7 Times Square (Site 1).

Usable land is at a premium in Manhattan, and the Owner never wavered on constructing from property line to property line with full basements. As both sites are relatively narrow, sacrificing space was not an option. The zoning laws in Times

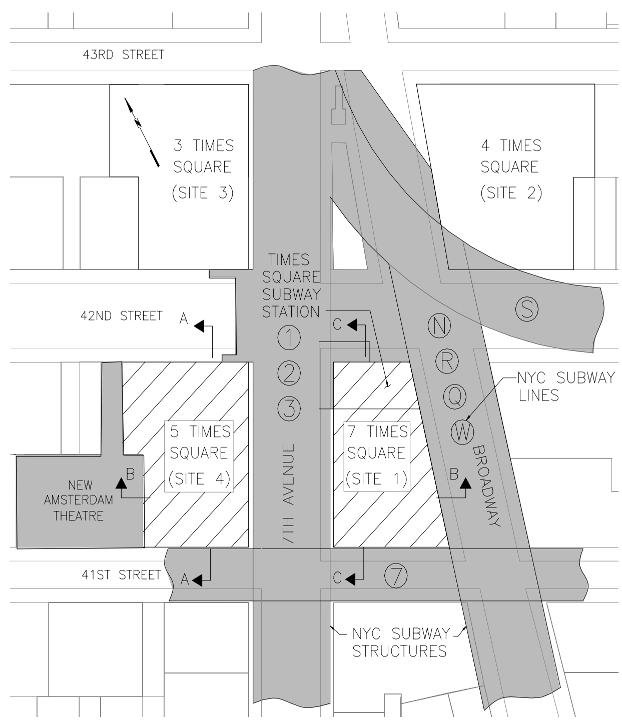

Fig. 1. Site Plan.
Sites 1 & 4 are the focus of the present study

Square are unique and allow construction from property line to property line, with no required setbacks for the proposed building heights. This situation, coupled with the narrow building lots, contributed to higher than usual building loads at the perimeter foundations, requiring innovative foundation solutions.

GEOLOGIC SETTING AND SITE HISTORY

The Times Square area is part of the Manhattan Prong called the Manhattan Ridge, a formation of old and durable metamorphosed and folded bedrock, now termed the Hartland Formation. The bedrock generally has a thin soil cover and uneven surface overlain in some areas with a thin mantle of decomposed and/or weathered rock. Overburden soils include glacial and post-glacial deposits and recent fills.

The map shown in Figure 2 illustrates the pre-developed topographical features of Times Square, as noted on a survey published in 1874 by Egbert Viele. A topographical high point is roughly centered around Times Square. It is likely that the original bedrock was near the ground surface as the map indicates sporadic rock outcrops in this vicinity. The bedrock surface has been altered dramatically by the construction of buildings and subways.

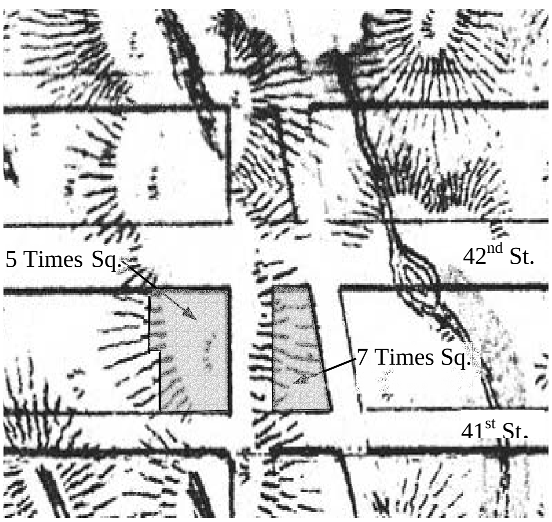

Fig. 2. Times Square Topographic Map (Viele, 1874)

In preparing the Geotechnical Reports for the two sites, MRCE researched historical atlases and Manhattan landbooks dating back to 1885 to identify former structures at the sites to help identify previous basement locations. Prior to 1890, the sites were generally occupied by low-rise residential housing and hotels with shallow basements. However, the 1899 Atlas indicated that a 12-story hotel with two basement levels replaced the low rise structures in the middle portion of the 5 Times Square Site. In the late 1890s, The New Amsterdam Theatre was constructed adjacent to this site. The Theatre is a steel framed structure with basement levels varying from 10 to 20 feet below grade, with the deeper basement at the southern half of the building.

The 7 Times Square Site was developed with hotels since 1885. The most notable structure was the Heidelberg Building, built at the turn of the 20th Century and occupied the northern portion of the site, with basements extending about 40 feet below grade. The above grade portion of this structure was demolished in the early 1980s and replaced with a subway station and The Times Square Brewery. The structure's foundations were left in place, which led to conflicts with the new structure's foundations. South of the Heidelberg , an 11 story structure was demolished as part of this work.

Transit improvements have been made in and around the Times Square area since the early 1900s. The 1, 2 and 3 Subway Lines that run below 7th Avenue were constructed circa 1915 using cut and cover techniques and extend about 28 feet below grade. The N, R, Q & W Subway Lines that run below Broadway were also constructed in 1915 using cut and cover techniques and extend about 38 feet below grade. The 7 Line that runs below 41st Street was constructed later, using both cut-and-cover and tunneling methods as it runs below the other subway structures at a depth of about 55 feet below grade.

As shown in Figures 3, 4, and 5, the subway structures are very close to the property lines. In some cases, the stairwells and passageways abut the property lines. The 42nd Street Subway Station that services these lines is located in the northern 50 feet of the 7 Times Square site. This station was required to remain operational through most of the foundation work.

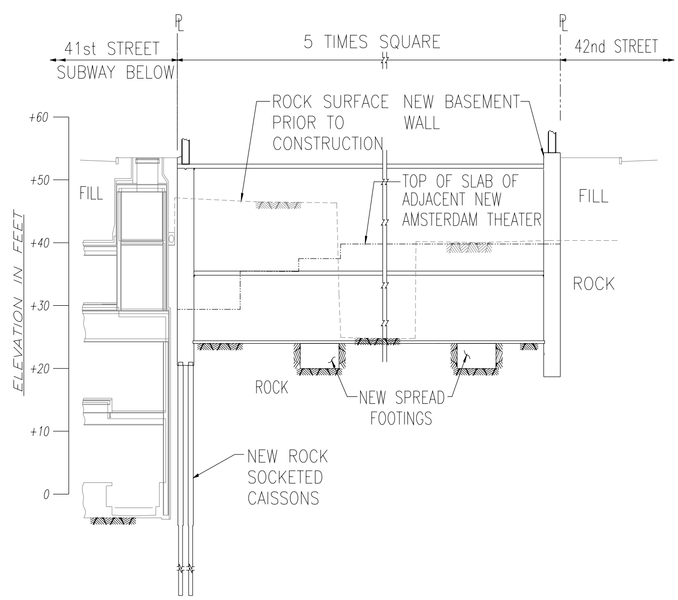

Fig. 3. Section A-A, looking west at 5 Times Square

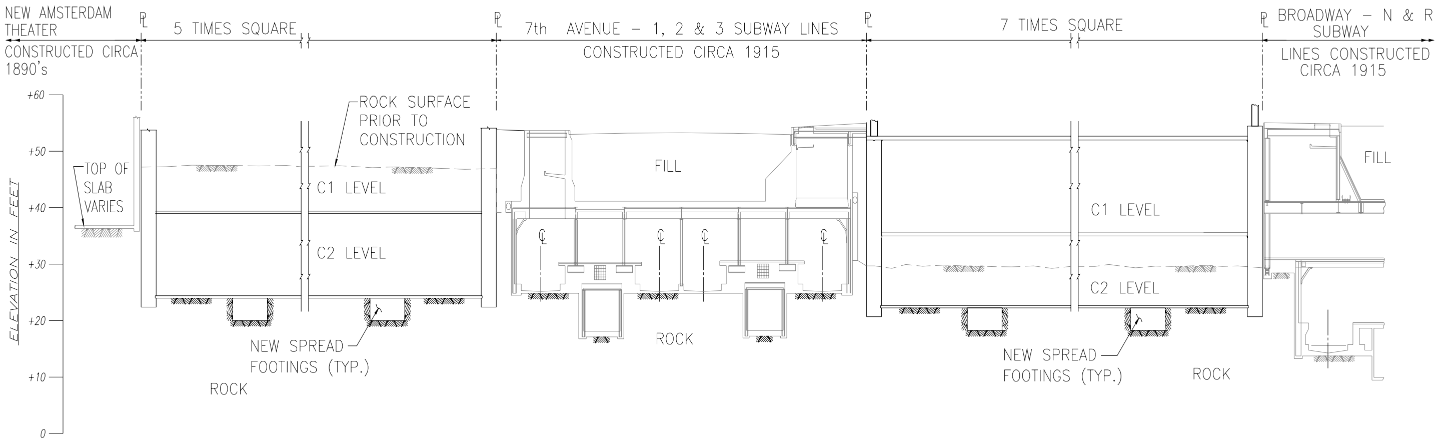

Fig. 4. Section B-B, looking north

5 TIMES SQUARE (SITE 4)

5 Times Square was the first of the two sites developed by Boston Properties and is 37 stories tall, with two basement levels extending 30 feet below grade. The structure occupies the entire site and has a footprint of 27,100 square feet, with a total rentable area of about 1 million square feet. The building is currently occupied by Ernst and Young. The site, located on the southwest corner of 42nd Street and 7th Avenue, posed numerous challenges to the design team as excavating the basements would include extensive rock excavation below the existing foundations of the adjacent historic New Amsterdam Theatre. In addition, new foundations were required adjacent to the subway structure that extends 55 feet below grade at 41st Street. These features are shown in Figure 3. The foundation work also required staging to avoid interference with the matinee performances of "The Lion King" at the New Amsterdam Theatre as well as the heavy pedestrian, subway and vehicular traffic of Times Square.

Subsurface Investigation

MRCE planned and implemented a limited subsurface investigation that included four borings to characterize the overburden and bedrock characteristics. Site access restriction limited the number of borings that could be made. Borings were made with both truck-mounted rigs and skid rigs.

One boring was made on the sidewalk using a skid rig and another was made using an electric powered skid rig drilled from inside one of the structures. All of the borings extended into rock and three of them cored rock using an oriented core barrel so that the orientation and strike of the rock joints could be determined. Two piezometers were installed to measure groundwater levels.

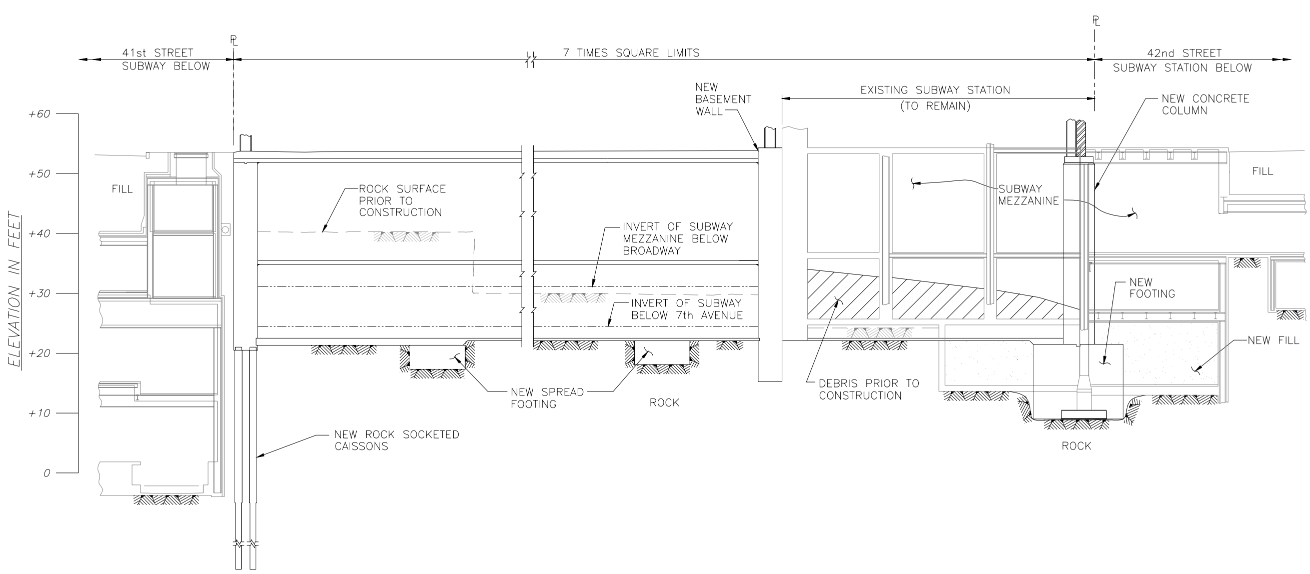

Fig. 5. Section C-C, looking west at 7 Times Square

The results of the subsurface investigation indicated that there was a relatively thin layer of fill overlying very competent rock. The rock consisted of a mica schist and schistose gneiss. Some borings indicated a thin layer of weathered or decomposed rock at the top of the rock. The top of rock was generally encountered between 5 and 12 feet below street grade. The oriented rock coring indicated that the predominant joint set was trending to the southwest with dip angles between 40 and 75 degrees. Groundwater was measured at about 30 feet below grade.

Recommendations

Foundation Design. MRCE recommended shallow foundations for the majority of the structure with an allowable bearing pressure of 60 tons per square foot (tsf), the highest bearing pressure allowed by the NYC Building Code. Due to the expected minor groundwater seepage through the rock joints, the basement slab was designed as a slab-on-grade atop a gravel drainage course connecting to sumps. Along the 41st Street property line where the subway structure was less than 2 feet in plan from the property line and 26 feet below the base of the proposed basement level, rock socketed caissons excavated with a down-the-hole hammer were recommended to carry the foundation loads below the invert of the subway structure. Extensive meetings with NYCT, discussions with drilling contractors and research into the effects of the down-the-hole hammer on adjacent structures were required to gain approval during the design process, as NYCT guidelines do not permit the use of down-the-hole-hammers within 5 feet of the subway structure. A strict monitoring plan consisting of seismographs and strain gauges to monitor the effect of the caisson installation on the subway structure was agreed upon. The foundation design features are shown in Figure 3.

Excavation Support. The oriented rock core data obtained from the borings indicated that the north face and east face of the excavation would be unfavorable. MRCE recommended pattern bolting of the rock along the north face with soldier pile and lagging to support the fill over the rock. The east face required bracing of the NYCT structure, which was only about four feet from the property line. The west face, adjacent to the New Amsterdam Theatre required special care as the quality of rock directly below the footings was largely unknown. MRCE recommended that the rock initially be excavated in two-foot lifts and rock bolts and channels installed to create a grade beam of rock immediately below the Theatre's footings. Channel drilling of the rock was also required along all faces of the excavation to prevent over-break of the rock and to limit vibrations transmitted to adjacent structures from the excavation work.

MRCE recommended the use of pneumatic hammers to break up the rock mass. Blasting was not considered an option due to the proximity of the subway structures, the New Amsterdam Theatre, and NYCT restrictions.

Construction Monitoring. MRCE prepared an Historic Protection Plan to monitor the Theatre during construction. The Theatre, constructed in the late 1890s and significantly renovated in 1995, is a steel framed structure with columns and exterior masonry walls bearing on rock. The interior public spaces of the Theater contain intricate plaster finishes and paintings as shown in Figure 6 that date back to the original construction and were considered prone to cracking as a result of construction vibrations.

The preservation plan included twenty-two crack gauges, six vertical and horizontal movement monitoring points and six seismographs. Seismographs were set to notify the Resident Engineer on site via a beeper when trigger levels were reached. The plan also indicated the measurement frequencies and limit criteria for each monitoring point. Vibration levels were set at 0.35 inches per second (ips) as a warning level and 0.5 ips as a limit level.

Foundation Construction

General excavation started in November 1999 and the foundations were substantially completed in August 2000. The General Contractor was Morse Diesel, now known as AMEC, and the Foundation Contractor was Civetta-Cousins. Excavation started at the south end of the site, an at grade parking lot, while buildings were being demolished at the north

Fig. 6. Architectural finishes at the New Amsterdam Theatre

end. Rock was generally encountered about 8 feet below grade at the south end of the site.

The entire perimeter of the site, approximately 700 lineal feet, was channel drilled in 12-foot lifts with air-track rigs, as shown in Figure 7. This was required as the theater and subway structures were immediately adjacent to the property lines. The site was excavated in stages, taking advantage of the intact rock berms to brace the subway structures as adjacent excavation continued. Once adequate bracing was installed, the rock berms were excavated and replaced with bracing. The majority of the rock was broken up with large track-mounted pneumatic hammers and removed with backhoes loading up to dump trucks at street grade. In some areas adjacent to the Theatre, the rock was predrilled and split to limit vibrations. The maximum vibration levels were not exceeded at the NYCT structures, but there were occasional exceptions to the vibration criteria at the New Amsterdam Theater. On these occasions, the cause of the vibration was identified and changes were made to work, such as using lighter equipment and rock splitters. Meetings were held on a bi-weekly basis with the 42nd Street Development Corporation to keep all parties informed of the work progress and any other issues.

Fig. 7. Channel drilling adjacent to the New Amsterdam Theatre

The channel drilling along the perimeter of the site created a relatively vertical rock face. The rock quality was very good and did not ravel into the excavation. Civetta-Cousins installed rock bolts and channels below the New Amsterdam Theatre, in accordance with MRCE recommendations, as shown in Figure 8. No measurable settlement or displacement of the Theatre was recorded during the project.

Fig. 8. Rock bolting below the New Amsterdam Theatre

The foundation system along the 41st Street subway, consisting of conventional 18-inch diameter concrete filled caissons with a steel core, was re-designed by Civetta-Cousins to suit their equipment. They elected to install 12-inch diameter "mini-caissons" with three high-strength steel No. 20 bars as a core, filled with neat cement grout, with working capacities of 250 tons. These mini-caissons are not conventional caissons as

Fig. 9. Caisson installation at 5 Times Square adjacent to NYCT subway structure

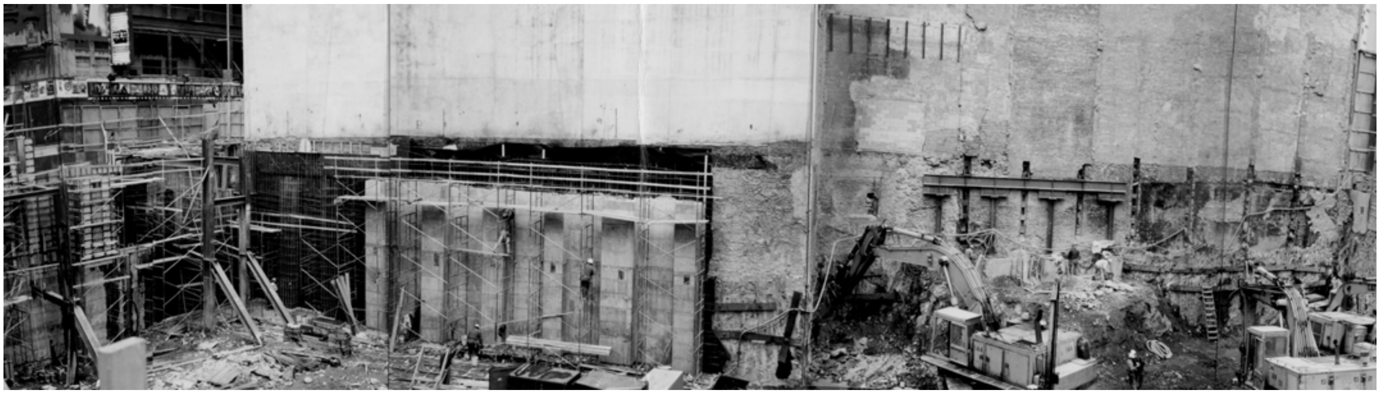

Fig. 10. Panoramic view of 5 Times Square during construction, looking southwest

defined in the NYC Building Code because they are smaller than 18 inches in diameter and utilize high strength steel. A variance was obtained from the NYC Building Dept for the 12-inch mini caissons. As shown in Figure 3, the mini-caissons were drilled through rock adjacent to the subway and extended about 8 feet below the subway invert. The mini-caissons were cased from subgrade to the base of the subway to eliminate load transfer to the subway. Due to the high loads and unique core, mini-caissons were load tested to twice the design load. The load test was successful and production commenced.

The mini-caissons were installed using a down-the-hole hammer, within 3 feet of the subway tunnel, as shown in Figure 9. Civetta-Cousins was required by NYCT to monitor both vibrations and strains on the subway during installation of the caissons. The vibrations generated by the work were well below the acceptable levels of 2.0 ips, and no measurable strain increase due to the work was measured. Use of the down-the-hole hammer was the only option to install these high capacity caissons with minimal impact on the subway. The successful installation of these mini-caissons with minimal effects on the adjacent subways allowed NYCT to accept the use of this type of equipment in such close proximity to the subway structures. Thirty rock tie-downs were installed to withstand uplift forces caused by wind loads. These anchors were 1.25 inch diameter double corrosion protected anchors with working loads of 200 kips and about a 15 foot bonded length. Measures were taken to isolate these anchors from the steel reinforcing in the building walls to prevent transmission of stray electric currents through the structure.

Spread footings were used to support column loads at all other locations of the structure. Rock quality was very good and footing subgrades were approved for an allowable bearing pressure of 60 tsf. Once the footings were cast and the columns set, drainage stone was placed on the intact rock subgrade and the slab-on-grade was cast. A general view of the site is shown in Figure 10 illustrating the tight working conditions. The building was officially opened and occupied in May of 2002.

7 TIMES SQUARE (SITE 1)

This site, although just across the street from 5 Times Square, provided new and different challenges during the design and construction phases. 7 Times Square is 47 stories tall, with an overall height to top of crown of 730 feet. It has two basement levels extending 30 feet below grade over the full site. As shown in Figure 1, the structure occupies the entire site and has a footprint of 22,000 square feet, with a total rentable area of about 1.2 million square feet. The planned use for the building is office space with retail at the ground level. When completed, 7 Times Square was the final building constructed as part of the Revitalization of Times Square. Due to the site constraints, designing and constructing the foundations was akin to placing the final piece of a puzzle. Figures 4 and 5 are sections showing the proximity of the subway structures to the site.

<u>Subsurface Investigation</u>

Nine borings were made around the site perimeter to investigate the overburden and rock characteristics. Due to site constraints, drilling borings in the center of the site was not possible. Two of the borings were made from within the subway station at the north end of the site using an electric powered rig. The remaining borings were made from street level using a skid rig. One oriented core boring was made to confirm the strike and dip of rock joints.

The results of the subsurface investigations indicated a layer of man-made fill overlying bedrock. The top of rock ranged from about 15 feet below grade at the south to 50 feet below grade at the north end and consisted of mica schist and schistose gneiss. The deeper rock was anticipated at the north end of the site, beneath the old Heidelberg Building. As only one boring was made in this area, it was difficult to estimate the extent of the deep basement and the designers had to rely on old drawings. The oriented rock core indicated that the predominant joint set was trending to the southwest with a dip angle between 40 and 75 degrees, similar to the 5 Times Square site.

Fig. 11. 7 Times Square site, looking south during foundation construction

Recommendations

Foundation Design. MRCE recommended shallow foundations for the majority of the structure with an allowable bearing pressure of 60 tons per square foot (tsf), with an alternative 40 tsf design where the borings encountered zones of lesser quality rock. Along the 41st Street property line where the subway structure was 26 feet below the base of the excavation and less than 2 feet from the property line, MRCE recommended using 12-inch diameter "mini-caissons" similar to those used at 5 Times Square.

Due to the narrow width of the building in the east west direction, larger than usual column loads were concentrated at the corners and perimeter columns. The southeast and southwest corner columns were a major concern as they were adjacent to the deep subway below 41st Street and had column loads in excess of 16,000 kips. Foundation elements for these columns had to transfer the column loads below the base of the subway box, which was 55 feet below grade and only 1.5 ft south of the property line. The close proximity of the subway box prevented the use of caisson groups with conventional core sections.

The initial design consisted of a 7-foot diameter caisson below each corner column at 41st Street, with three built up W14 x 730 core sections installed in each caisson. Although unconventional in size, the single caisson was the only way to transfer the loads using material strengths and stresses allowed by the NYC Building Code. This foundation system was also approved by NYCT. The caisson would be advanced by making multiple bores with a small diameter down-the-hole hammer, followed by excavation between the bores.

The north end of the site was unique and required particular attention during both the design and construction phase. The north end was occupied by a subway station and brewery that were supported on the foundations of the previously demolished Heidelberg Building. The brewery superstructure was demolished and removed, but the subway station remained active throughout the construction of the foundations and would be included in the final building.

The proposed locations of the new north end footings overlapped the existing footings to remain, as shown in Figure 5. The challenge for the designers was to incorporate the existing foundations with the new foundations where this occurred. MRCE recommended that the excavation be made down to rock on all sides of the existing footing, and at that time a decision on the allowable bearing capacity would be made. The design called for encompassing the existing footings within the new footing. Borings indicated that rock in this area ranged from 30 feet to over 50 feet below grade, suggesting that earlier deep basements had existed at this end of the site.

Excavation Support. As subways surround the site on all four sides, the excavation sequence was a major concern to both the Owner and NYCT. MRCE prepared support of excavation drawings for the site and met with potential foundation contractors early in the design process to seek their input in how they would approach the project considering the tight conditions and relatively deep rock excavation. The primary focus of the design was to adequately brace the subway structures as the excavation progressed. Staged excavation and earth and rock berms were used in the design. The Engineers and potential foundation contractors recognized that it was important to reach the corner column locations early as they would prove to be difficult to construct. This early collaboration between the Engineers and foundation contractors was instrumental in streamlining the design of the excavation support system.

Foundation Construction. The general excavation started in June 2001, and the foundations were substantially completed in April 2002. The Construction Manager was Turner Construction Co. and the Foundation Contractor was Urban Foundations/Engineering, LLC.

Urban proposed an alternative concept, using high strength steel in the core and high strength grout to accommodate the loads. In lieu of one large diameter caisson, they proposed three smaller diameter caissons at each column location.

Urban Foundations requested that MRCE and Thornton Tomasetti re-design the foundation elements, utilizing 75 ksi steel and a circular core section. The final design of the caisson for the south corner columns consisted of three 26-inch diameter holes containing 13-inch diameter solid steel cores with 10,000 psi grout. To aid shear transfer to the grout, 1.5-inch wide, 0.75-inch thick plates were welded to the core section at 12-inch vertical intervals. A variance was obtained from the NYC Building Department for the use of high strength steel in the caisson cores. This innovative foundation solution illustrated the collaboration between the Foundation Contractor, Owner and Engineers that ultimately led to a practical solution to a very difficult foundation problem.

Urban also requested that the Engineers re-size the 12-inch diameter "mini-caissons" along the 41^{st} Street property line, to larger 18-inch diameter caissons to suit their equipment. It is interesting to note that Civetta-Cousins, the Foundation Contractor at 5 Times Square, re-sized the larger diameter caissons to the smaller 12-inch diameter "mini-caisson," while Urban re-sized the smaller caissons to larger caissons.

Because the site was very constricted and the subway station had to remain active, the northern 50 feet of the site was not accessible to heavy machinery. As a result, the site was very congested as shown in Figure 11. The site was excavated in distinct quadrants, as there was little room to stockpile excavated rock or to operate multiple machines. A portion of the existing basement structure, shown in Figure 11, was left in place during the majority of the foundation work to serve as construction ramp. Prior to rock removal adjacent to NYCT structures, the site perimeter was channel drilled to provide a vibration cut-off and to control rock over break. The rock was excavated using large track mounted backhoes and pneumatic hammers. Vibration monitors were installed in the subways to monitor construction vibrations. In general, construction vibrations did not exceed the 2.0 ips limits of NYCT.

The rock quality at the site was poorer than the rock at 5 Times Square, due primarily to the jointing and weathered zones encountered. Consequently, most of the footing subgrades were downgraded from 60 tsf to 40 tsf. The caissons along the south foundation wall were excavated using a down-the-hole hammer drill rig, as shown in Figure 12. For the corner columns, a 12-inch diameter pilot hole was drilled initially. The hole was then reamed out to 26 inches in diameter using a specially designed bit, as shown in Figure 13. This sequence was chosen to limit vibrations during drilling and to limit the drift of the drilling tool as the caissons were installed within 6 inches of the subway box.

Fig. 12. Drilling corner caissons adjacent to NYCT structures

Fig. 13. Down-the-hole hammer drill bit

After the hole was drilled and flushed clean, a template was set to plumb the 13 inch diameter cores and to properly align them. Due to the high loads, practically no deviation was allowed in the setting of the core as shown in Figure 14. Once the core was installed the caisson was tremie grouted with 10,000 psi grout that was batched on the site. A 26 inch thick steel base plate was used to transfer the column loads to the caissons. No damage to the subway structure was reported during the construction of these caissons, and the subway vibration levels were kept below the 2.0 ips criteria.

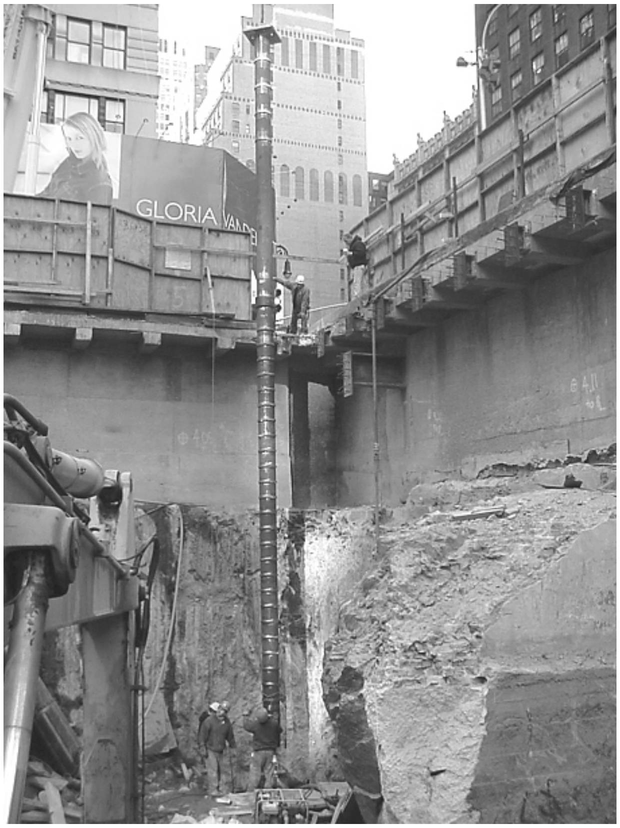

Fig. 14. Installing 13-inch diameter core in column caisson

Foundation construction at the north end of the site, below the subway station, proved to be very difficult and time-consuming. Due to limitations on access and headroom, only small-sized equipment, as shown in Figure 15, was used to excavate the debris and rock from within the basement. Engineering decisions were made relating to the quality of rock and the casting of the footings as the proposed footing locations were exposed. In some cases a portion of the existing footing was removed and in others the existing footing was incorporated into the new footing. All of the steel grillages and steel columns that were abandoned in place and/or incorporated into the new structure were sandblasted. Once the columns and footings were installed, drainage stone was placed on the intact rock subgrade and a slab-on-grade was cast.

7 Times Square provided numerous designs and construction challenges that were a result of tight working conditions, heavy column loads, and a compressed schedule.

SUMMARY AND CONCLUSIONS

- The use of historical information was critical in preparing geotechnical reports at both sites as access restrictions prevented the implementation of a large scale subsurface investigation.

Fig. 15. Excavating with small equipment around existing foundations below active subway station

- The rock at both sites was excavated using pneumatic hammers. Blasting was not required. The hard rock had fairly steep joint sets that allowed the rock to be peeled away.

- Rock footing subgrades were approved at 60 tsf at 5 Times Square and 40 tsf at 7 Times Square indicating the variability of rock quality within the same formation in relatively close proximity.

- The implementation of the Historic Preservation Plan provided strict limits and tolerances that protected the New Amsterdam Theatre's architectural finishes while allowing construction to continue.

- The innovative use of high strength steel and grout in foundation caissons at the sites allowed economical construction of high-capacity caissons where site constraints precluded conventional caissons. These foundation innovations were also driven in large part by the expertise and equipment of the Foundation Contractors.

- As redevelopment continues in heavily developed urban areas such as Manhattan, these types of foundation innovations will become more prevalent.

- The 5 Times Square and 7 Times Square case histories illustrate that early coordination between the Foundation Contractors, Construction Managers, Engineers, Owner, and Public Agencies was required to successfully construct both towers in a timely fashion, without impacting the intense pedestrian, vehicular and subway traffic in Times Square.

ACKNOWLEDGEMENTS

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The project team members listed below are those who were directly involved with the foundation work:

<u>5 Times Square</u>

Owner	Boston Properties
Architect	Kohn Pederson Fox Associates PC
Structural Engineer	Thornton-Tomasetti Engineers
Geotechnical Engineer	Mueser Rutledge Consulting Engineers
Site/Civil Engineer	Vollmer Associates LLP
Construction Manager	AMEC
Foundation Contractor	Civetta Cousins

<u>7 Times Square</u>

Owner	Boston Properties
Architect	Skidmore Owings & Merrill LLP
Structural Engineer	Thornton-Tomasetti Engineers
Geotechnical Engineer	Mueser Rutledge Consulting Engineers
Site/Civil Engineer	Vollmer Associates LLP
Construction Manager	Turner Construction Co.
Foundation Contractor	Urban Foundations/Engineering, LLC

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