

## **IX CONCLUSIONS**

Creating deep basements in an urban environment has always been a challenge. However, underground construction in increasingly congested environments is becoming more and more challenging as demand for prime real estate space is strong. The One Bryant Park project is a good example of what in all likelihood is to follow into the new century as new excavations will be constructed next and under subways, a scenario likely not anticipated by the early designers of subway tunnels. In this respect, the new excavation has created a small underground "Arc de Triumph" in Manhattan Schist under Sixth Avenue. Underground design and construction in complex site conditions requires thorough evaluation. Complimenting "conventional" -simplistic analyses and advanced finite element methods yields a balanced and comprehensive design approach that can be particularly insightful.

## **VI REFERENCES**

Similar modes of potential failure were also evaluated with finite element models. Preliminary finite element analyses indicated lateral movements of 0.06 inches of the tunnel, and validated the concept of conventional prestressed beam resting on two rock-pillars. Figure 9 shows preliminary finite element (crosses indicate major and minor principal stress directions). In the finite element model shown below, higher stress concentrations were observed at assumed rock joints that modified arching stresses. The subgrade in this preliminary model was at El. +0 or 7 ft deeper than the as-built subgrade as the design was not finalized at the time.

## IIX SUBWAY MONITORING

Monitoring of the subway structure was provided by Wang Engineering Services and consisted of seismographs to measure vibrations and strain gauges to measure changes in strain in the subway tunnel. Fifteen strain gauges were installed along the length of the tunnel in arrays of three. The gauges were placed on the subway walls and crown of the tunnel. The monitors were hooked up to remote sensing devices. Results of the strain gage monitoring program to date are shown on Figure 10. Results shown in this figure represent changes in stress levels and not the actual stress level. As it can be seen, the crown experienced a decrease in confining stress ranging from 150 psi to 300 psi when final subgrade was reached. Tunnel walls experienced similar increases in compression with the wall closer to the excavation showing slightly greater compression than the east tunnel wall. Most of the changes in stress levels were observed after excavation progresses beneath the third anchor level. Subsequently after construction has been completed, a more detailed finite element model has been performed reflecting as-built conditions with observed rock jointing patterns in order to match the measured behavior (Figure 11). This finite element modeling approach was successful in replicating the observed stress behavior during excavation.

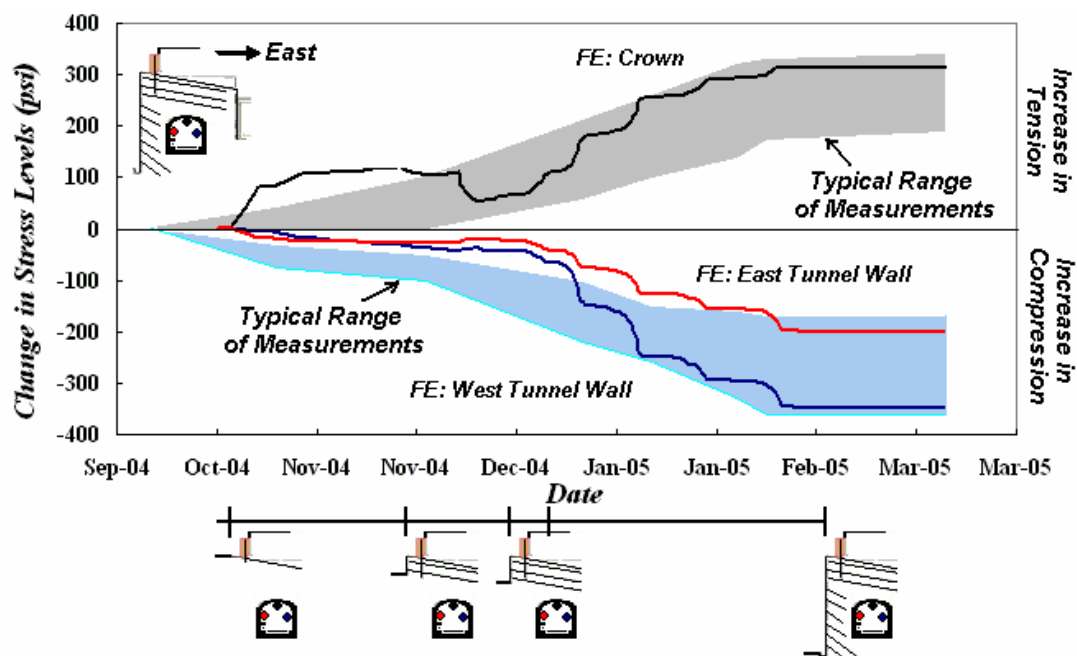


Figure 10: Benchmarking of measured strain data with finite element analyses

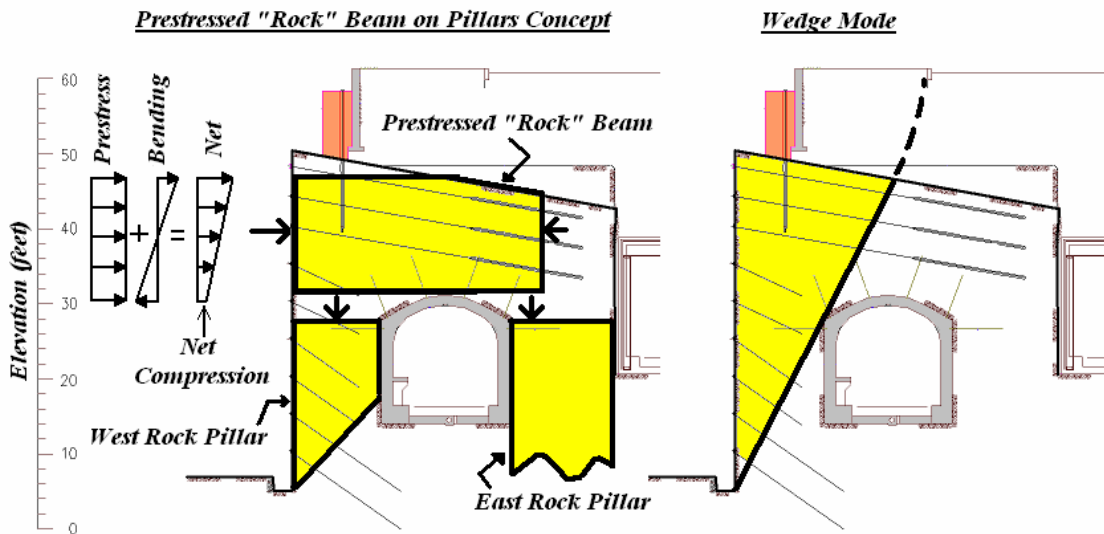


Figure 8: Illustration of Prestressed “rock beam” resting on pillars concept and typical wedge analyses at mined NYCT tunnel excavation section.

Bearing stresses on the rock pillar were evaluated and were found to be within building code presumptive values. In order to ensure that the rock-pillar integrity was maintained, four levels of passive rock bolts were installed (Levels 4, 5, 6, and 7). These rock bolts effectively “stitched” the rock pillars together thereby limiting any joint movement under the weight of the “rock beam” above. These rock bolts were 1-¼ inch O.D. threaded bars, grade 150 ksi and were also used along the cut-and-cover tunnel.

A series of wedge stability analyses were also performed, for critical stages of the excavation. Rock cohesion was ignored, and a relatively modest friction angle was used. The upper and lowest levels of anchors are basically effective in restraining “full” wedge failure modes. In contrast to conventional wedge analysis methodology, safety factors were not defined on the anchor capacity (i.e. service design). Instead, safety factors were evaluated based on available shear strength vs. mobilized shear strength ratio on examined joint conditions as seen below. This safety factor definition is consistent with finite element approach safety factor definitions. Safety factors of 1.5 or more were targeted as it was felt that this would minimize the potential for joint movement and damage to the mined tunnel.

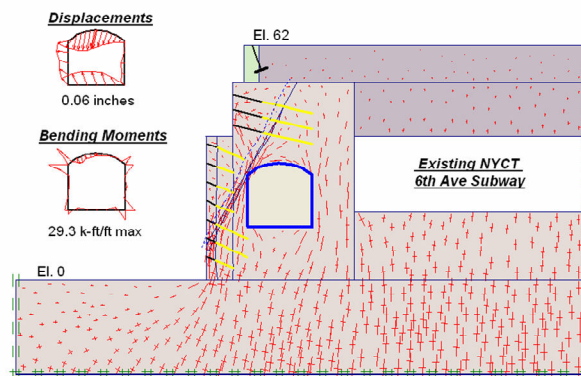


Figure 9: Preliminary finite element model analysis

Supporting the excavation along the mined subway tunnel was conceptually more challenging than along the cut and cover section. Removing rock west of the tunnel would compromise confinement of the rock arch and tensile stresses in the tunnel roof could potentially develop if nothing was done. In all probability the initial rock-arch was partially affected when the cut-and-cover subway tunnel was constructed immediately to the east in the 1930s. However, the effect of the 1930's excavation would be less significant than the new excavation since the jointing was much more favorable for excavation east of the mined tunnel.

Available drawings from the 1930's did not show any reinforcement of the existing horse-shoe shaped concrete liner. As a result, increases in tensile stresses on the liner could result in structural damage. Thus, in order to avoid such undesirable behavior the existing rock arch action had to be preserved. This has been achieved by providing a series of prestressed rock anchors and passive bolts. The top three anchor bolt levels above the mined tunnel were designed as to create a prestressed rock-beam that rests on two supporting rock pillars (Figure 8). These top anchors were actively loaded to ensure that rock over the mined tunnel would stay under compression and not experience any tensile stresses. Because of space limitations, rock anchors above the tunnel are inclined at smaller angles than lower levels. The top three rock anchors were 1-3/4 inch O.D. threaded bars, grade 150 ksi, and had a 20 ft long bond-breaker in order to develop all the force beyond critical wedges while maintaining the "rock beam" in compression.

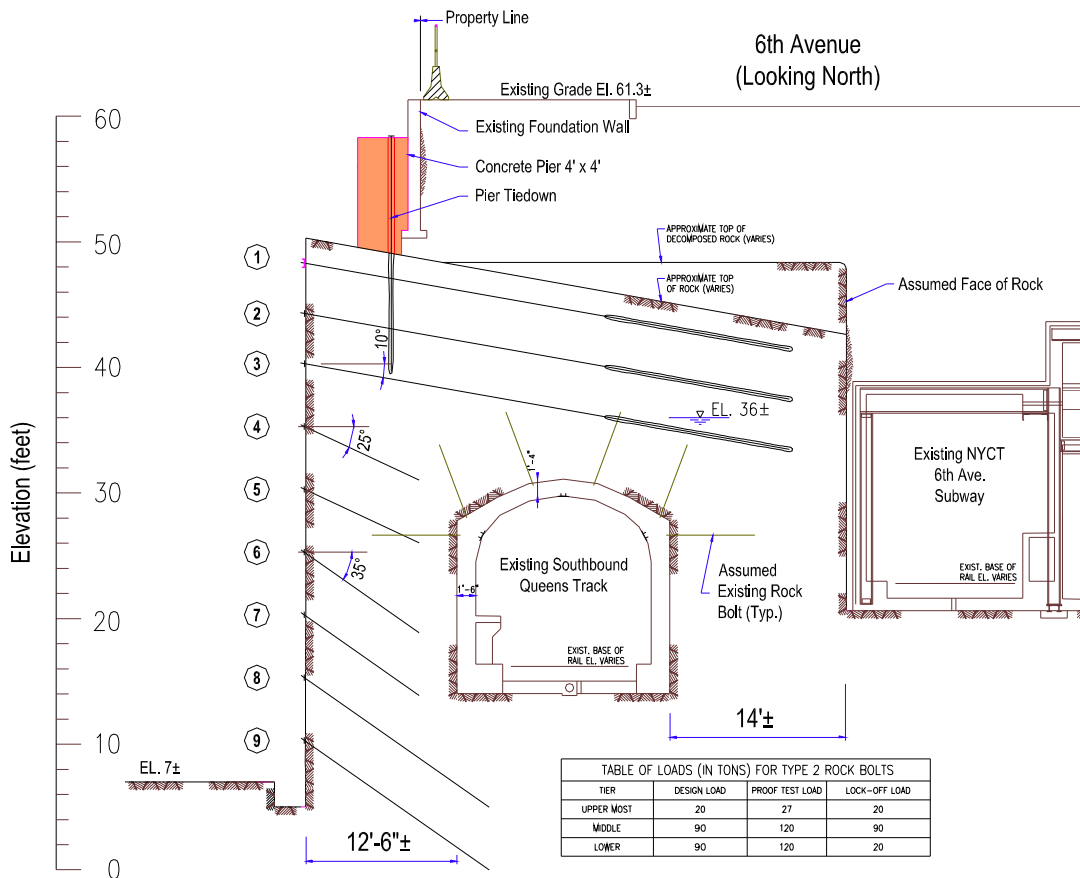


Figure 7: Section at 6<sup>th</sup> Avenue along mined NYCT tunnel.

surface. Stability of the existing concrete foundation wall was provided by a series of 4 ft x 4ft concrete pillars at 10 ft spacing resting on rock. Every concrete pillar is restrained by a prestressed tiedown anchor. At the cut and cover tunnel, rock wedge stability was evaluated for all stages of excavation.

Initial contract drawings envisioned using a system of three levels of rakers resisting sliding forces of the 12 ft wide rock strip west of the cut and cover tunnel. Minimal rock bolts were to be used to prevent localized block failures. The contractor preferred using only rock bolts as it would greatly simplify construction. Hence, a series of stability analyses for various stages were performed to optimize the design. This required longer and larger diameter bars for the lowest three levels of rock bolts, while all other bolts are 10 ft long. The lowest bolts were 1-7/8" O.D. grade 150 threaded bars. As it can be seen in Figure 6, the lowest three levels of bolts were inclined at steeper angles in order to avoid the subway tunnel. Rock bolts were designed to resist driving forces from soil, water pressure, surcharge, and from the cut-and-cover tunnel. A construction mishap compounded additional force requirements on the rock support system in this section. While the tiedowns stabilizing the concrete pillars were designed to have a bond zone of 10 ft only immediately beneath the rock surface (El. +44 to El. +34), they were actually constructed with a 15 ft bond zone starting from final subgrade (El. +7). This meant that the tiedown stabilizing force was now a driving force for the most critical rock joints that were dipping towards the excavation. Hence, the lowest level rock bolts had to be able to resist the increased load.

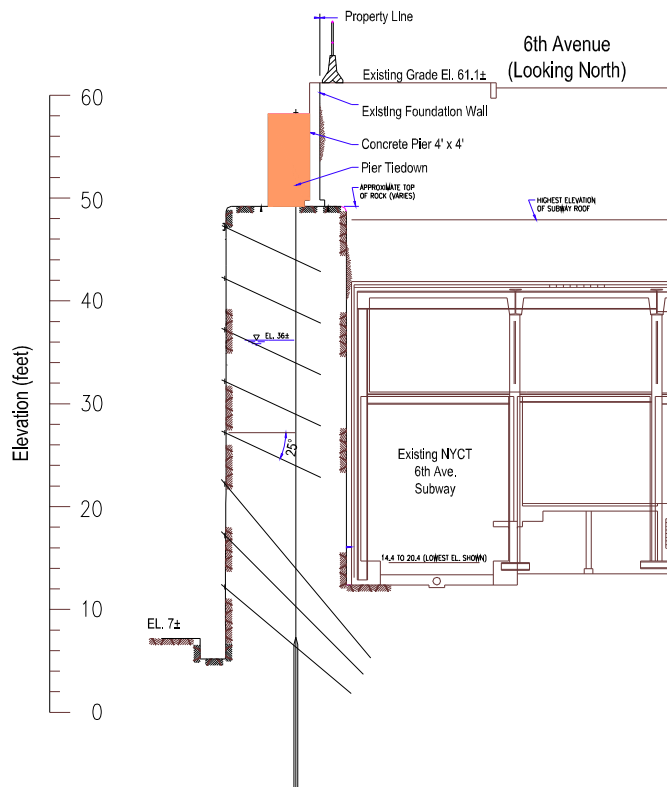


Figure 6: Section at 6<sup>th</sup> Avenue along cut-and-cover NYCT tunnel.

### C. Oriented Rock Core

Data derived from the oriented rock cores obtained in the oriented core boring are summarized on the stereonet shown in Figure 5. The stereonet graphically depicts the jointing, showing the dip direction and angle for joints parallel to and crossing foliation, and joint orientations in unfoliated rock. Foliation is the "layering" visible in metamorphosed rocks such as gneiss and schist which is similar to bedding planes in sedimentary rocks. The oriented rock cores from the boring contain foliated gneissic schist and schist taken between the depths of 9 to 26 feet, and unfoliated amphibolite retrieved from below the schist to the bottom of the boring.

Within the foliated portion of the oriented core, approximately 60 percent of the joints cut across the foliation, with shallow dip angles between about 5 to 40 degrees generally to the west. The joints parallel to the foliation dip more steeply at 30 to 60 degrees, half of which dip in a west-southwesterly direction. The majority of joints within the unfoliated core also dip to the southwest, but at shallower angles of 30 to 40 degrees. This orientation is similar to results from previous oriented core borings in the vicinity of Times Square.

The stereonet shows the alignment of the Sixth Avenue subway and the 42<sup>nd</sup> Street shuttle in order to assess the impact that joint orientations may have on rock excavations adjacent to these structures. Over 80 percent of the joints measured have a dip angle less than 50 degrees, which is favorable for excavation. The dip orientation is generally at an oblique angle toward (more favorable) the 42<sup>nd</sup> Street shuttle, and away from (less favorable) the Sixth Avenue subway. Dip angles from rock cores in other borings made around the site indicated some steeper joint sets could be expected with dip angles in the range of 60 to 70 degrees.

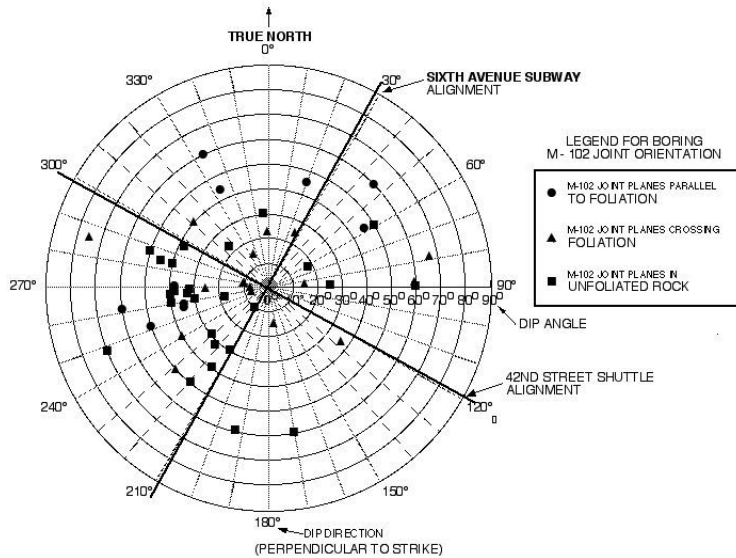


Figure 5: Stereonet showing dip angle and dip direction of rock joints

### VI SUPPORT OF ROCK EXCAVATION ALONG 6<sup>th</sup> AVENUE

Rock stability during excavation was analyzed using classical wedge analyses concepts. Since rock joints dipped at 60 deg to 70 deg mostly towards the excavation, two-dimensional analyses could be used. Two design sections were considered: a) at the cut-and-cover tunnel (Figure 6), and b) at the mined tunnel (Figure 7).

The new structure is setback from the property line in order to increase the sidewalk width, therefore, the old foundation wall of the existing building was used to retain soil above the rock

## V SUBSURFACE CONDITIONS

### A. Geologic Setting

The site area is on the Manhattan Ridge, a part of the Manhattan Prong, a formation of old and durable metamorphosed and folded bedrock. This formation is now termed the Hartland Formation and was previously known as the Manhattan Formation or the Manhattan Schist Formation. The bedrock has a relatively thin soil cover and an uneven surface. The natural bedrock surface is overlain with a thin mantle of decomposed and/or weathered rock. Overburden soils include glacial and post-glacial deposits and recent fills.

Prior to development, the site was surrounded by low hills and sporadic rock outcrops, as well as a stream channel cutting across the western portion of the block. The bedrock surface has since been altered by construction of buildings and subways as previously discussed.

### B. Subsurface Investigation Results

The subsurface conditions at the site varied significantly across the site. A relatively deep rock profile, extending 50 feet below grade was identified at the western portion of the site, in the vicinity of the pre-existing streambed. This rock depression was filled with decomposed rock, glacial till, alluvial sands and silts.

The borings in the vicinity of the Sixth Avenue tunnel indicated that rock is relatively shallow 10 to 20 feet below sidewalk grades. The rock was overlain by a man-made fill generally consisting of loose to medium compact brown to gray coarse to fine sand. A thin layer of decomposed rock was encountered in some of the borings.

The rock generally consisted of a medium hard to hard gneissic schist to schistose gneiss. Occasional pegmatite zones and zones of intermediate quality rock were encountered. An intrusion of serpentine/amphibolite rock was encountered in the boring on the corner of 43<sup>rd</sup> Street and Sixth Avenue. Recoveries in the rock in the vicinity of Sixth Avenue were generally good and Rock Quality Designations (RQD) varied from 12% to 100%, with an average of 62%. The rock quality generally increased with depth. A typical geologic section showing the boring results and the relationship of the subway tunnels with the site is shown on Figure 4.

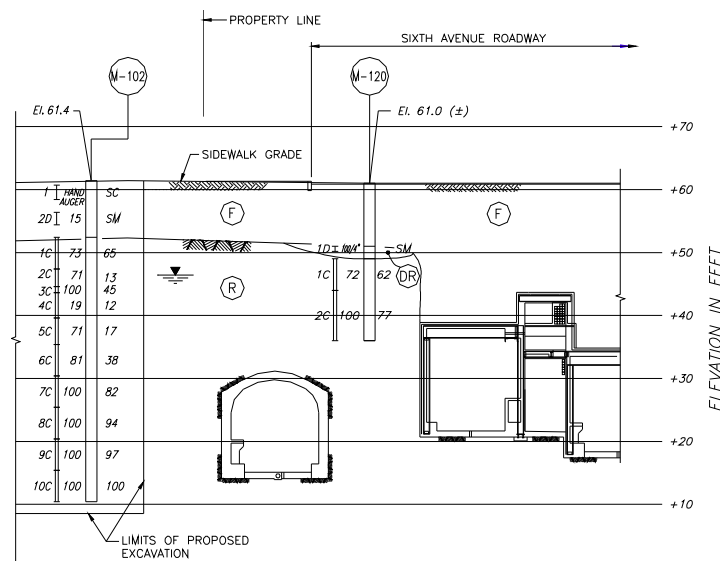


Figure 4: Typical Geologic Section along Sixth Avenue

### **III ADJACENT SUBWAY STRUCTURES**

The 42<sup>nd</sup> Street Shuttle subway borders the site to the south, about 20 feet from the property line, and its base of rail elevation slopes up to the west from about Elev. +33 to +38, or roughly 22 feet below grade in the vicinity of the site. The shuttle was the first subway constructed in NYC. It was constructed around the turn of the century using cut and cover techniques, and was opened in 1904.

The B, D, F, and V subway lines run beneath Sixth Avenue, and were constructed between 1936 and 1939. The construction was complicated by the presence of the 42<sup>nd</sup> Street shuttle and variable ground conditions. The base of the existing shuttle tunnel was eventually altered to become the roof of the Sixth Avenue subway. The majority of the subway was constructed using cut and cover techniques in the vicinity of the site, and that the subway line closest to the site enters a rock tunnel about 70 feet south of the 43<sup>rd</sup> Street property line. The subway is estimated to be about four feet east of the property line and its base slopes up to the south from Elev. +14 to +19. There are subway entrances on the sidewalk at the corner of 42<sup>nd</sup> Street and Sixth Avenue, and at mid-block on Sixth Avenue. The corner entrance was constructed in 1938, and extends to within one foot of the southern building line. The entrance on Sixth Avenue extends about 3.5 feet from the building line. These entrances will be reconstructed as part of this work.

### **IV SITE INVESTIGATION**

The subsurface investigation was performed in two phases as access to the majority of the site was not available during the early stages of the design process. The preliminary borings were performed in June of 2003 and the final investigation was performed in February 2004.

#### **A. Preliminary Investigation**

MRCE recommended six borings for the preliminary phase. Three of the borings were drilled through the sidewalk, with truck mounted rigs to determine overburden and rock characteristics at critical locations adjacent to existing subway lines. Two borings were drilled from within existing structures on the site, with an electric powered skid rig. The borings were made by Warren George Inc. under the continuous inspection MRCE. The three sidewalk borings were extended below the base of adjacent subway structures, while the interior borings were terminated in rock. A piezometer was installed in one boring to monitor groundwater levels.

Soil samples and Standard Penetration Tests (SPTs) were obtained through the overburden soils. Bedrock cores were obtained in rock. In order to determine the strike and dip angle of joints within the bedrock units, one boring was made with an oriented core barrel containing scribes that mark the core in advance of extraction from the ground. This permits the evaluation of the effects that rock joint orientation has on excavation and hence, the effects on nearby structures.

#### **B. Final Investigation**

Sixteen new borings were made for the final investigation. Twelve of the borings were made from within existing structures using limited access equipment and four borings were made from the sidewalk. An additional two piezometers were installed to monitor groundwater levels.

Two borings were drilled on Sixth Avenue to determine the rock depth and quality above the mined subway tunnel. These borings were limited to 25.0 ft depths. Because of the numerous utilities in Sixth Avenue, test pits were required to locate utilities and install six-inch pvc pipe sleeves in order to drill the two borings. A truck mounted drill rig using a N-series diamond core barrel was used for these two borings.

excavation progressed into sound rock in some locations. Along 43<sup>rd</sup> street, the rock surface is much higher and rock jointing is favorable. Here the façade of the old Miller Theater will be preserved and incorporated into the new building. Hence, the rock support system had to maintain stability of the façade. This paper will focus on the stabilization of the rock face along 6<sup>th</sup> Avenue where design and construction was most challenging.



Figure 2: Excavation picture at subgrade along 6<sup>th</sup> Avenue

## II SITE HISTORY

The site, located in Times Square has been developed since the late 1800's. Historic atlases and land books of Manhattan dating back to 1885 were researched to identify former structures at the site in an attempt to determine extents of possible buried foundations and basements.

The 1885 Atlas indicates that the site was occupied by row houses with backyards. Eventually, the row houses were replaced with larger commercial structures. By 1916, the four story Henry W. Miller Theatre and the twelve story Elks Club had been constructed along 43<sup>rd</sup> Street. The 20-story Remington building stood along 42<sup>nd</sup> Street, adjacent to the Elks Club. Figure 3 depicts the site in 1934 and is an indication of the amount of development that existed at the site.

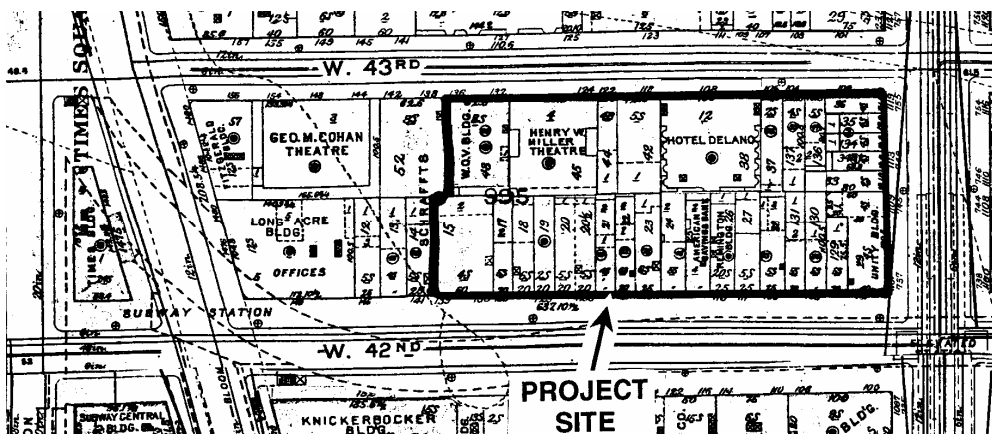


Figure 3: 1934 Manhattan Landbook, illustrating previous structures on site

# **ONE BRYANT PARK – CREATING THE UNDERGROUND MANHATTAN SCHIST ARC DE TRIUMPH**

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**Abstract:** One Bryant Park will be the latest highrise addition in the Times Square area. The site covers 2/3 of a city block bounded by 4 Times Square to the west, Sixth Avenue to the east, and 43<sup>rd</sup> and 42<sup>nd</sup> Streets to the north and south respectively. Subway structures lie below Sixth Avenue as well as 42<sup>nd</sup> Street. The project consists of constructing a 56 story commercial tower with three basement levels extending 55 feet below grade over the entire site footprint.

The deep basements and the adjacent subway structures provided numerous design and construction challenges, the most challenging is along Sixth Avenue. Here a mined tunnel in rock exists 12 feet east of the property line and immediately east of this tunnel, a cut and cover tunnel exists leaving a 12 ft pillar of rock between the two tunnels. The rock excavation has left a 14 ft rock pillar west of the mined tunnel, thus creating an underground rock arc that required stabilization during excavation. Design and construction aspects of this stabilization program, as well as other interesting information relating to the rock excavation will be presented.

## **I INTRODUCTION**

One Bryant Park will be the latest highrise addition in the Times Square area. The site occupies the occupies 2/3 of a city block bounded by 4 Times Square to the west, Sixth Avenue to the east, and 43<sup>rd</sup> and 42<sup>nd</sup> Streets to the north and south respectively (Figure 1). Subway structures lie below Sixth Avenue as well as 42<sup>nd</sup> Street. The project consists of constructing a 56 story commercial tower with three basement levels extending 55 feet below grade over the entire site footprint. Street grade is approximately at El. +62 with the new basement reaching to El. +7. Along 6<sup>th</sup> Avenue the rock surface ranged from 10 ft to 20 ft beneath street level. In the remaining of the site the rock surface varies widely throughout the site. Thus, the total cut in rock is approximately 43 ft deep along. Excavation along 6<sup>th</sup> Avenue started in late Oct-2004 and was completed in March 2005.

The new basement wall will be located approximately 13 ft west from existing 6<sup>th</sup> Avenue subway. While for most of the property length along 6<sup>th</sup> Avenue the subway was constructed with the cut-and-cover method, the most western subway track changes into a mined tunnel for the last 70 ft from 43<sup>rd</sup> Street. Adding to complexity, the remaining subway tracks east of the mined tunnel were also constructed with the cut-and-cover method and left a 14 ft rock pillar between the two tunnels as it can be seen in Figure 4. However, the new excavation is more critical than the old cut-and-cover tunnel excavation since it is constructed in unfavorable rock joint orientation. Crucial to the success of the project was the structural integrity of the possibly unreinforced concrete liner of the mined tunnel. During construction the tunnel has been regularly monitored for any signs of stress changes.

Along the cut-an-cover section rock support design was comparatively more straight forward than along the mined tunnel. Here rock bolts resisted overturning and sliding forces and stabilized the 12 ft wide strip of rock. This article focuses on design and construction aspects of excavation support along 6<sup>th</sup> Avenue and especially along the mined tunnel section.

Along 42<sup>nd</sup> Street, the excavation was supported by a conventional soldier pile and timber lagging wall braced by two to four levels of tiebacks. All soldier piles are “socketed” into sound rock, and