Fulton street transit center – foundation design and construction in a dense urban environment

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ABSTRACT
The Fulton Street Transit Center (FSTC), in Lower Manhattan, will provide a new transportation hub for one of the most congested parts of New York City. The project includes significant station upgrades as well as new connections between the different subway lines and eventually linking with the redevelopment of the World Trade Center. The center piece is the glass clad Transit Center, on the corner of Broadway and Fulton Street. The excavation for the substructure required the underpinning of the existing buildings that abut the site on two sides, including the Federally listed Corbin Building to the south. On the other two sides are existing subway structures. The excavation was supported by internally braced secant pile walls in order to reduce the ground movements. Monitoring was carried out on all surrounding structures and extensively for the Corbin Building. Once at full depth, the 5ft thick raft foundation was cast directly on the local interbedded silt and sand soils and the secant piles were broken down to open the structure to the existing subway lines and the underpass beneath the 4/5 line that was constructed under an earlier construction contract. This paper concerns the design and construction of the substructure of the Transit Center and the underpinning and excavation beneath the Corbin Building.

RÉSUMÉ
Le Centre de Transit de Fulton Street (FSTC) dans le bas Manhattan sera une nouvelle plaque tournante pour le transport de l'une des parties les plus congestionnées de la ville de New York. Le projet comprend des améliorations significatives à la station ainsi que de nouvelles connexions entre les différentes lignes de métro ainsi qu'une liaison éventuelle avec le World Trade Center. La pièce maîtresse de ce projet est le Centre de Transit en verre situé au coin de Broadway et de la rue Fulton dans le bas Manhattan Les travaux d'excavation de l'infrastructure ont nécessité l'étayement des bâtiments existants sur deux côtés du site, incluant le bâtiment historique Corbin situé au sud tandis que des structures du métro sont présentes sur les deux autres côtés du site. L'excavation a été supportée par des renforts internes avec pieux sécants afin de réduire les mouvements de sol. Un contrôle précis a été réalisé sur toutes les structures environnantes ainsi que sur l'édifice Corbin. Une fois à la profondeur finale, la fondation de 5 pieds d'épaisseur a été coulée directement sur la surface interstratifiée de silt et de sable. Les piles sécantes ont été cassées afin d'ouvrir la structure aux lignes de métro existantes ainsi que le passage inférieur sous la ligne 4 / 5 qui a été construit lors d'un contrat précédent. Cet article traite donc de la conception et de la construction de l'infrastructure du Centre de Transit et l'étayement de bâtiment Corbin.

1 INTRODUCTION

The Fulton Street Transit Center (FSTC) is currently under construction in Lower Manhattan. When complete, in 2014, it will provide a new transportation hub for one of the most congested parts of New York City; improving access to and transfers between ten different subway lines and eventually linking with the Port Authority Trans Hudson (PATH) station at the World Trade Center. A rendering of the overall project is shown in Figure 1. The project includes significant upgrade work to five subway stations as well as new connections between the different subway lines. The center piece is the glass clad Transit Center, on the corner of Broadway and Fulton Street.

The project is being constructed as a number of separate construction packages. This paper focuses on the design and construction of the substructure of the Transit Center, Contract A-36119, highlights some of the key challenges faced and explains how these were overcome. The contract was undertaken by Skanska USA Civil Northeast.

In addition to the typical inner city constraints, the Transit Center site poses a number of unique problems. Geologically the site comprises up to 40ft of saturated vibration sensitive fine sands and silts making the control of ground movements a critical part of the project, especially when considering the historic nature of surrounding buildings and the need to make structural connections from the Transit Center to the existing subway structures.

To minimize the amount of ground movement, a stiff soil retaining system of internally braced secant pile walls was designed. Detailed finite element analysis was carried out in order to predict the likely amount of settlement during construction.

To reduce the amount of vibration induced settlement caused by the installation of the secant piles, the design required ground improvement ahead of pile installation.

A key part of the FSTC project is the incorporation of the historic Corbin Building into the structure. The design includes the construction of a new escalator inside the historic building and the excavation of the escalator pit below the footings.

Figure 2 is a plan view of the site, showing the locations of the Transit Center, Corbin Building and the A/C and 4/5 Stations. Figure 3 is a section through the final structure, from Fulton Street to the north to John Street to the south. The section shows the A/C station to the north of line T-A, the Transit Center between T-A and T-H and the Corbin Building south of T-H.

The construction of the substructure was successfully completed by Skanska in 2010.

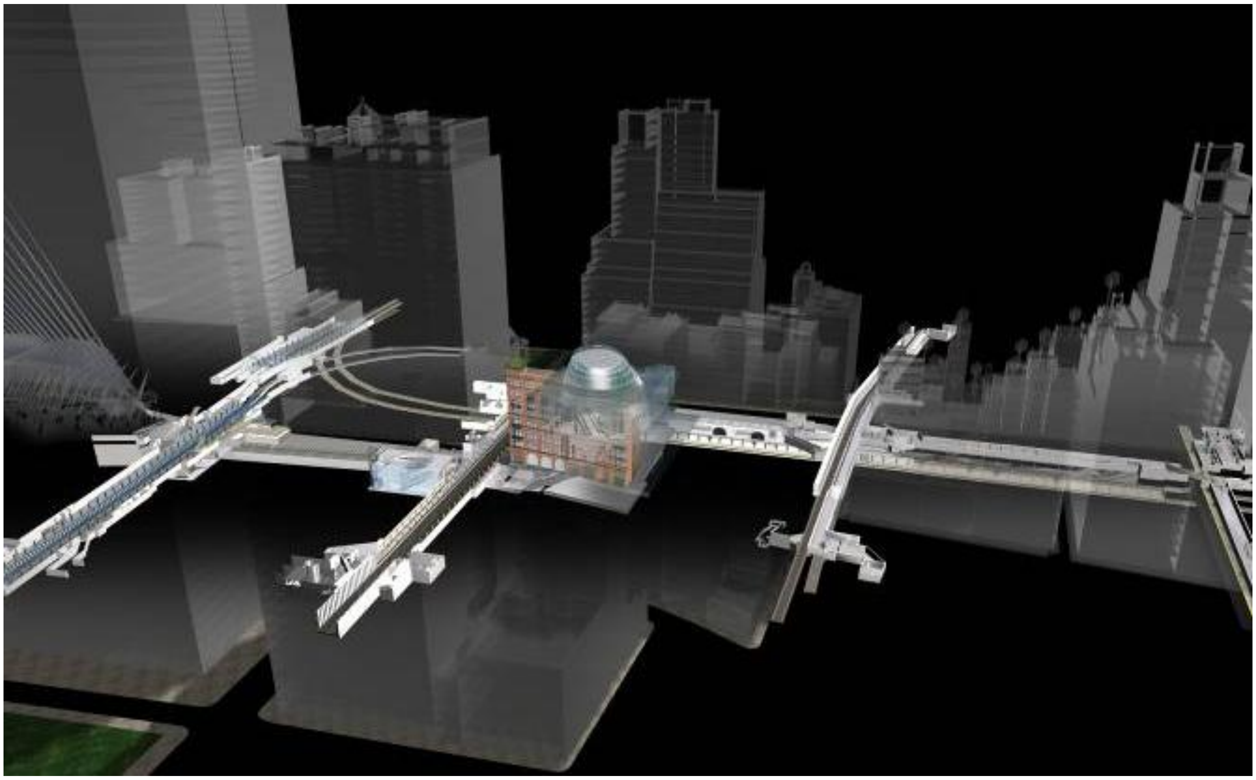

Figure 1. Rendering of the entire project site, facing north. Four north-south (from left to right: the R-W, 4-5, J-Z and 2-3 lines) and one west-east (A-C lines) subway lines can be seen. The Transit Center and Corbin Building are shown at the intersection of the 4-5 and A-C lines.

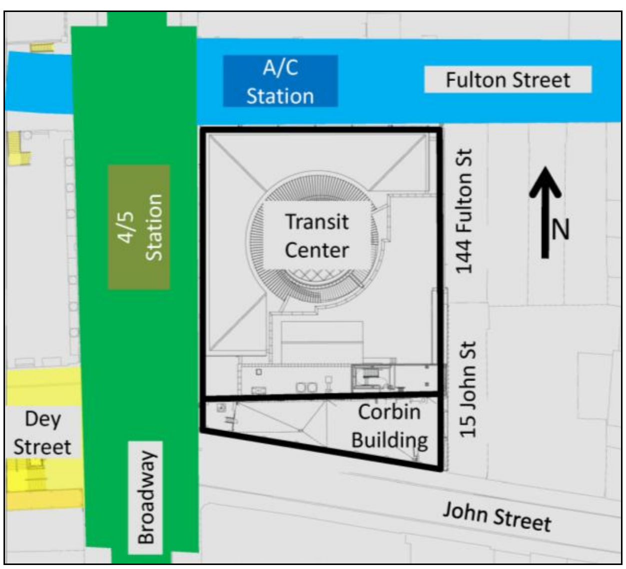

Figure 2. Plan view of the site showing the locations of the adjacent subway stations.

2 DESIGN

2.1 Substructure Design

The Transit Center includes two substructure levels. The lowest is the Concourse Level, which is in fact split between the Lower Concourse, which connects to the new underpass beneath the 4/5 Station under Broadway to the west, and the Upper Concourse, which connects to the A/C Station Mezzanine Level under Fulton Street to the north. The Lower Concourse is at elevation +94ft, and the Upper Concourse is at elevation +99ft. Above the Concourse, the Platform Level, at elevation +115ft, connects directly to the north bound platform of the 4/5 Station to the west. The Street Level slab is at approximate elevation +131ft. Note that all elevations are quoted in New York City Transit (NYCT) Datum which is 97.347ft below the National Geodetic Vertical Datum of 1929 (NGVD 29).

The structure is founded on a 5ft thick mat foundation, directly on the local soil. A schematic section through the building showing elevations is shown in Figure 4.

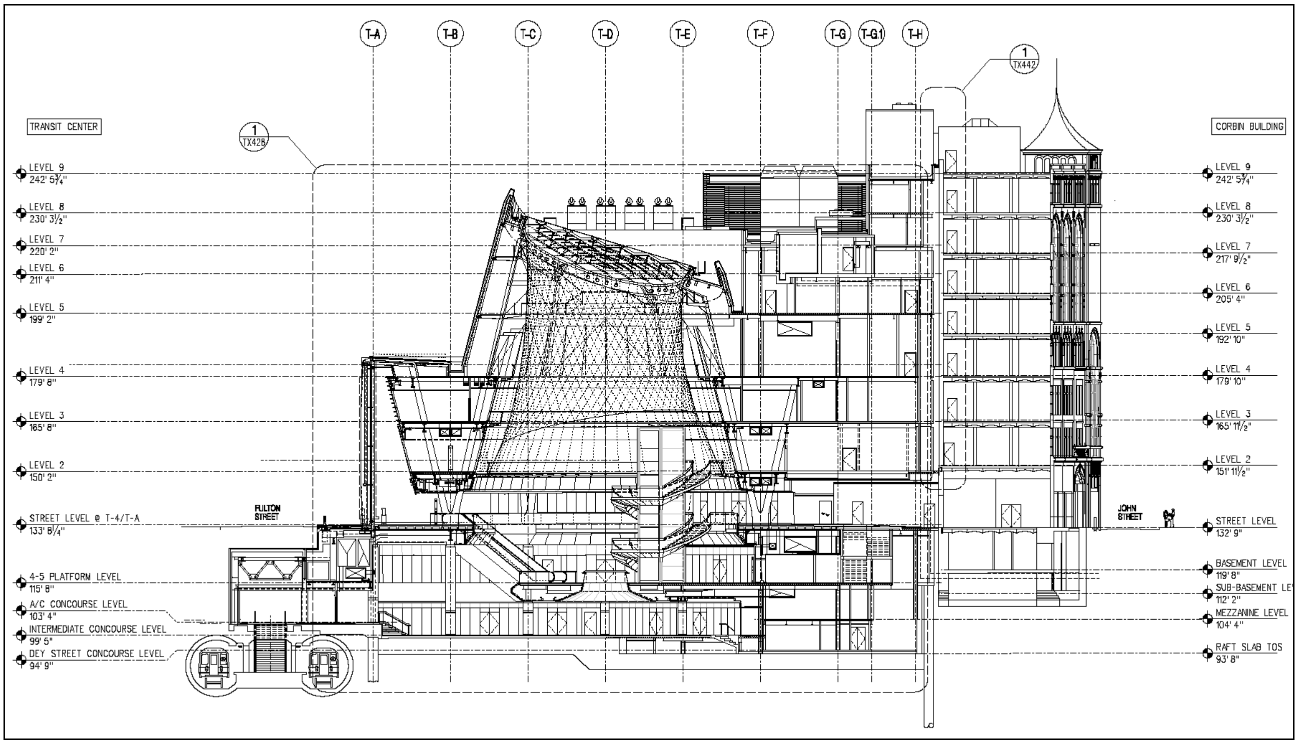

Figure 3. Cross section through the Transit Center and Corbin Building, facing east. The contract included all structural elements at Street Level and below, minus the upgrade work to the A/C station beneath Fulton Street.

An additional element of the design is the incorporation of the historic Corbin Building. Built in 1888, the Corbin Building is immediately to the south of the Transit Center and was constructed on shallow footings approximately 20ft above the final Transit Center founding level. The design includes the construction of an escalator pit below the footings to accommodate new escalators to carry passengers from street level on John Street down to the 4/5 Underpass beneath Broadway.

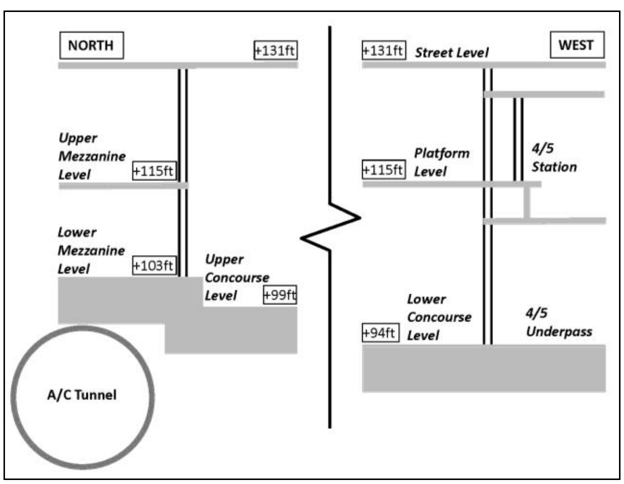

Figure 4. Schematic cross section through the north and west sides of the Transit Center, showing the elevations of the various levels.

2.2 Geology

The geology of Lower Manhattan comprises man made fill over glacial soils overlying local Manhattan Schist bedrock. The stratigraphy at the FSTC project site is shown in Table 1.

Table 1. Stratigraphy on site.

Elevation	Stratum	Description
+130ft	Fill	Brown very loose to dense sand with gravel, silt, brick fragments, wood, glass, concrete.
+105ft	Silty Fine to Medium Sand	Brown medium dense silty fine to medium sand.
+90ft	Stratified Silt and Silty Fine Sand	Reddish brown stratified silt and silty fine sand with occasional medium stiff to stiff clay partings.
+54ft	Glacial Till	Brown heterogeneous medium to very dense sand silt and gravel with frequent cobbles and boulders.
+30ft	Bedrock	Gray quartz mica garnet schist, up to 10ft decomposed rock above sound rock.

The fill material is mixed and uncontrolled, comprising building and other debris typical of inner city stratigraphy.

The glacial soils consist of layers of silt and sand overlying till. They were formed during the Pleistocene era (starting 200,000 years ago) when the pre existing soils were scoured from the bedrock and many of the surface features of the bedrock were formed. Above the bedrock, the till was formed by deposition by glaciers, as periglacial soils and as glacial outwash. The layers of fine sand, silt and clay above the till were deposited in glacial lakes that formed as the ice retreated towards the end of the Pleistocene (15,000 years ago).

Groundwater at the site is between +98 and +104ft.

2.3 Design Challenges

The location and the design requirements presented significant challenges that needed consideration during design. First among these was the need to maximize the use of space on the site while minimizing any ground movements. Surrounding the site to the south and the east are buildings on shallow foundations, while to the north and west are subway structures; all of these are highly sensitive to any ground movements that occur.

To accommodate the structure, excavation was required down to elevation +88ft and locally to +85ft for sump and elevator pits. To make this possible, and allow for the required dewatering, the substructure of the Transit Center includes a stiff, water tight soil retaining system of internally braced secant pile walls. The secant piles are overlapping 39.5in diameter bored concrete piles, toed 5 to 15ft into the stiff Glacial Till. Every other pile is reinforced by a W24x162 core beam.

In addition to retaining soil and street utilities during excavation, the secant piles are designed to take building loads from the Transit Center's perimeter columns, reducing the amount of load bearing directly on the ground through the 5ft raft slab.

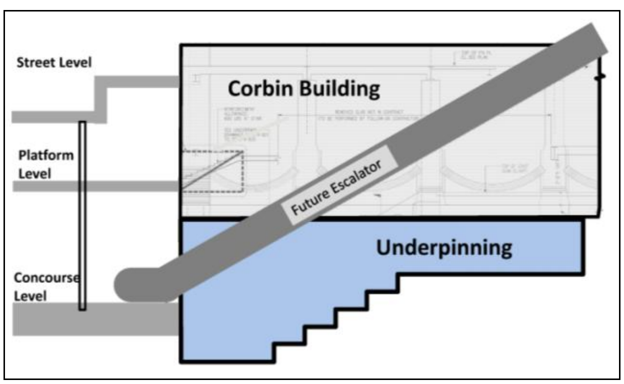

Figure 5. Schematic section showing the underpinning of the Corbin Building. Facing north.

The location of the Transit Center excavation is such that relatively high surcharge pressures exist due to the buildings on shallow foundations to the south and the east of the site, while to the north and west are lightly loaded subway box structures, built in 1933 and 1904 respectively. Detailed finite element analysis of the excavation and dewatering sequence was carried out using Plaxis to ensure that the unbalanced loads on the four sides of the site would not cause unwanted movements or stresses either to the walls or to the surrounding structures. The use of a finite element model allowed the soil structure interaction to be modelled through the entire excavation sequence, giving a good indication of the behaviour of the soil, the performance of the retaining walls and the impact on the surrounding structures.

As the excavation was to proceed to a lower elevation than the surrounding buildings, the neighbouring structures to the east were required to be underpinned. In addition, to accommodate the escalator pit beneath the Corbin Building, underpinning there was designed to extend to below the Transit Center foundation level at the western side, as shown schematically in Figure 5.

3 CONSTRUCTION

Construction was carried out by Skanska USA Civil Northeast and commenced in March 2009 and was substantially completed in August 2010.

Following the demolition of the existing structures on site and the underpinning of the buildings to the east with hand dug concrete piers, the first major activity was ground improvement in the form of jet grouting. Ground improvement was required in the contract primarily to stabilize the sensitive soils on site. Previous experience indicated that the vibrations due to the installation of the secant piles were sufficient to cause settlement within the stratified silts and fine sands beneath the site. These fine grained deposits, known locally as the 'Bull's Liver', quickly lose strength when disturbed or wetted and were of particular concern both during the piling and the excavation works.

Jet grout columns were formed at each pile location, through the stratified silts and sand and down to the Glacial Till below, to bind the soil and minimize settlement. The use of jet grout had the advantage of strengthening the ground, reducing the loads on the secant pile wall by effectively underpinning the surrounding buildings as well as reducing the permeability of the ground.

Figure 6. Aerial view of the Transit Center site, October 2009 (facing north from the Corbin Building).

The installation of the secant piles followed shortly after the jet grouting. To reduce the likelihood of settlement, the installation was carefully sequenced to ensure that adjacent piles were not installed before the first had had sufficient time to harden. In addition, it was decided to use a weaker concrete mix for the primary secants, reducing the vibrations caused by grinding the primaries during the installation of the secondary piles. All of the secant piles were embedded within the Glacial Till layer sufficiently to allow for the vertical loads to be imposed once the Transit Center is complete.

Figure 7. Excavation at full depth.

Once the secant piles had been completed, the capping beam was constructed and the temporary bracing system installed. Skanska decided to install a single layer of bracing, supported on four pipe piles drilled to rock in the center of the site, and relying on the additional stiffness provided by the capping beam to ensure that the movements were kept within tolerance. The bracing system is shown in Figure 6.

Once the bracing system was in place the site was dewatered to allow for the excavation of the 40,000 cubic yards of material. Prior to removal, soil testing had proved the soils to be contaminated non-hazardous, requiring measures to be taken on site and disposal to be carried out accordingly.

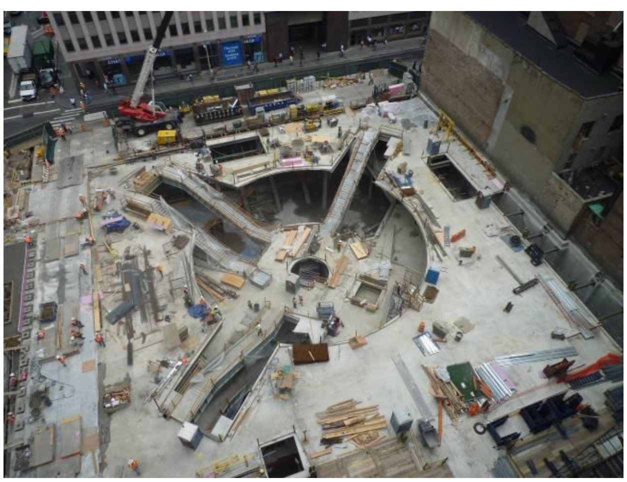

Figure 8. Completed Transit Center substructure, facing north.

While the fine sands drained relatively quickly, the rate of excavation was largely controlled by the rate at which the fine grained soils on the site would drain. Most of the excavation was completed within approximately 4 weeks. Despite the sensitive nature of the soil, it was found that as long as it was dry and relatively undisturbed, it was suitable for the pouring of the foundation slab. The foundation slab was poured in sections between November 2009 and January 2010.

Once the foundation slab had been poured, erection of the permanent steel commenced and the secant piles were broken down to the north and west of the site where connections were then made to the existing 4/5 Underpass slab and the A/C Station Mezzanine. The Platform and Street Level slabs were poured, followed by the construction of the various stairs. See Figure 8.

Figure 9. Hand excavated pit.

Concurrent with the excavation of the Transit Center site, the excavation beneath the Corbin Building was commencing. A secondary bath tub was constructed, using jet grout columns for groundwater cut off.

Figure 10. The escalator pit beneath the Corbin Building, facing west.

Once water tightness had been achieved, hand excavated pits were constructed and concrete underpinning piers were formed beneath the existing foundations. Thirty four pits were excavated, these were 5ft by 5ft and ranged from 10 to over 30ft deep, as shown in Figure 9. To reduce the likelihood of settlement, the pits were carefully shored and sequenced in a similar manner to the secant piles ensuring that no adjacent pits were opened at the same time.

Similarly to the Transit Center excavation, the rate of excavation, particularly of the earlier pits, was controlled by the drainage of the fine layers within the stratified fine grained deposits.

Once the underpinning piers had been completed, the excavation for the escalator pit was carried out, and the connections to the newly poured Transit Center substructure. See Figure 10.

4 GROUND MOVEMENTS

4.1 Secant Pile Deflections

During design, a series of finite element analyses were carried out as proof of design and in order to predict the likely wall deflections during the excavation. As the temporary bracing system was contractor designed, Skanska was required to carry out their own analysis to demonstrate that their proposed system would perform within the contract tolerances. The results of these analyses are both shown in Figure 11, along with the actual wall movements at the center of the south secant pile wall, measured by inclinometer. The south secant pile wall is the most heavily surcharged, as well as being adjacent to the deepest part of the excavation and therefore showed the highest deflections in the model, as well as during construction.

Figure 11 shows that the original design for the excavation predicted approximately 1.4in lateral movement, with the maximum movement at elevation +95ft, corresponding to the base of the excavation. It should be noted that as the bracing system was to be contractor designed, the designer's analysis assumed a bracing system to that used during construction that proved different from the system finally used.

The contractor's analysis predicted approximately 1in movement, with maximum movement occurring at elevation +98ft. The actual deflection was slightly more than 1in with maximum movement at +93.5ft. Although the elevation of actual deflection was different, the magnitude of deflection was predicted relatively close to the observed value.

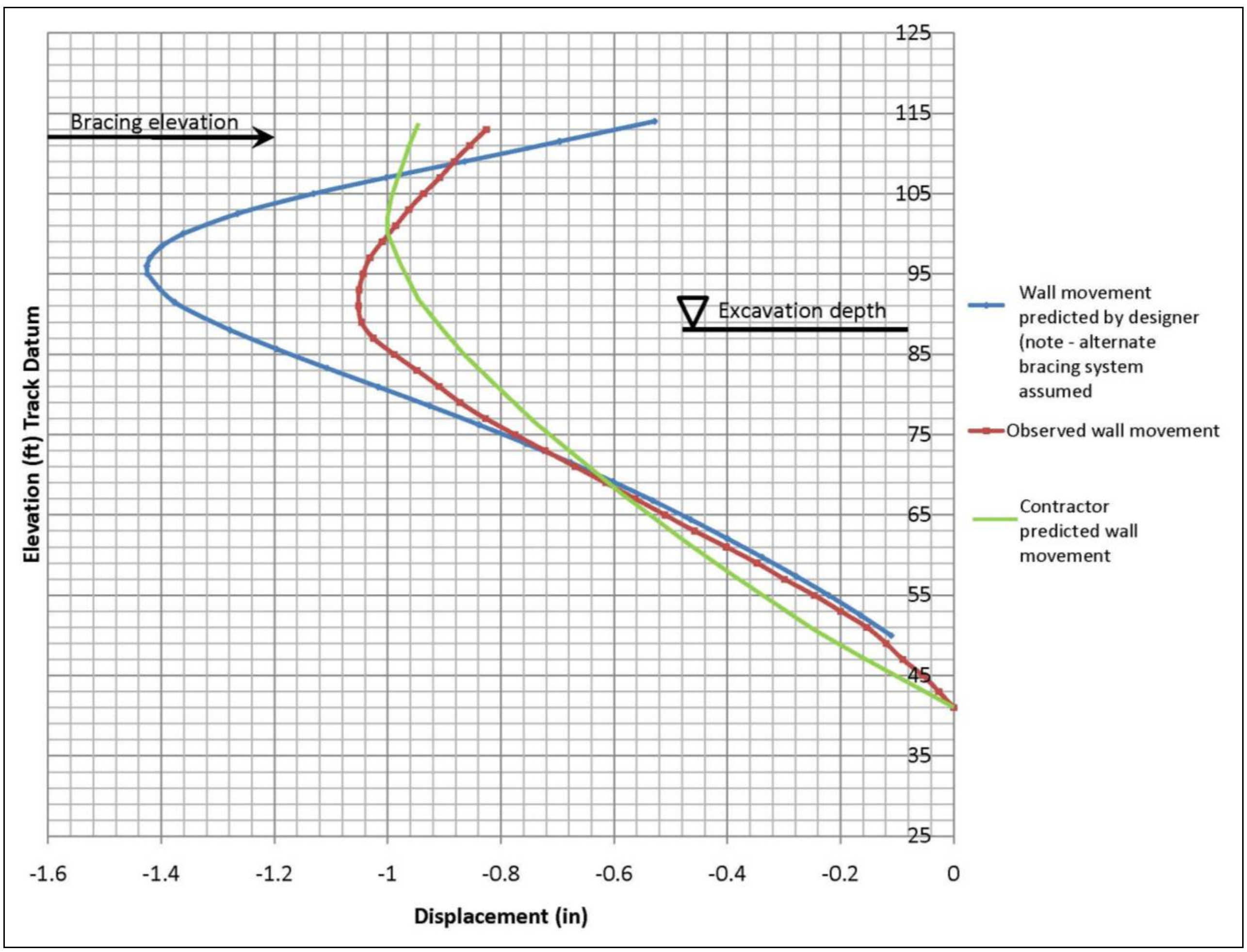

Figure 11. Plot showing the predicted and actual wall deflections for the center of the southern secant pile wall. Note that the movements predicted by the designer assumed a different bracing system to the one used during construction.

4.2 Settlements

The settlements of the structures on all four sides of the Transit Center site were monitored throughout the excavation and construction of the substructure. The buildings to the east of the site and subway structures to the north and south were monitored through the installation and monitoring of survey points using manual techniques.

Due to its sensitivity and significance the historic Corbin Building to the south was monitored more heavily. Liquid levels and tiltmeters were installed at the base of each of the building columns in the sub-basement throughout the construction. In addition, during the underpinning and excavation beneath the building, prisms through the length and height on the exterior of the building were continuously monitored using an Automated Total Station. All of the automated monitoring was also verified with manual surveying.

Settlement results for a sample point on the north wall of the Corbin Building and a sample point on the south are shown in Figure 12. These points represent the highest movements observed at the north and south faces of the structure.

The north wall of the Corbin Building, immediately adjacent to the Transit Center site shows approximately 0.6in of settlement before June 2009. This movement was due to the demolition of the existing buildings on the site (approx 0.475in), and the installation of the jet grout columns beneath the wall (approx. 0.125in). Once the jet grout was installed, the settlement of the wall due to the installation of the secant piles, excavation of the Transit Center site, construction of the underpinning piers and excavation of the escalator pit beneath the Corbin Building was relatively small, when compared to the south wall, only experiencing a further 0.4in of vertical movement.

The south wall of the Corbin Building is approximately 25ft further from the Transit Center site and was not underpinned by jet grout. It experienced little settlement due to the demolition of the existing buildings on site, and the installation of jet grout and secant piles to the north (0.25in). However, the south wall continued to settle throughout the remainder of the construction works, most significantly during the dewatering and excavation of the Transit Center site and of the Corbin Building site.

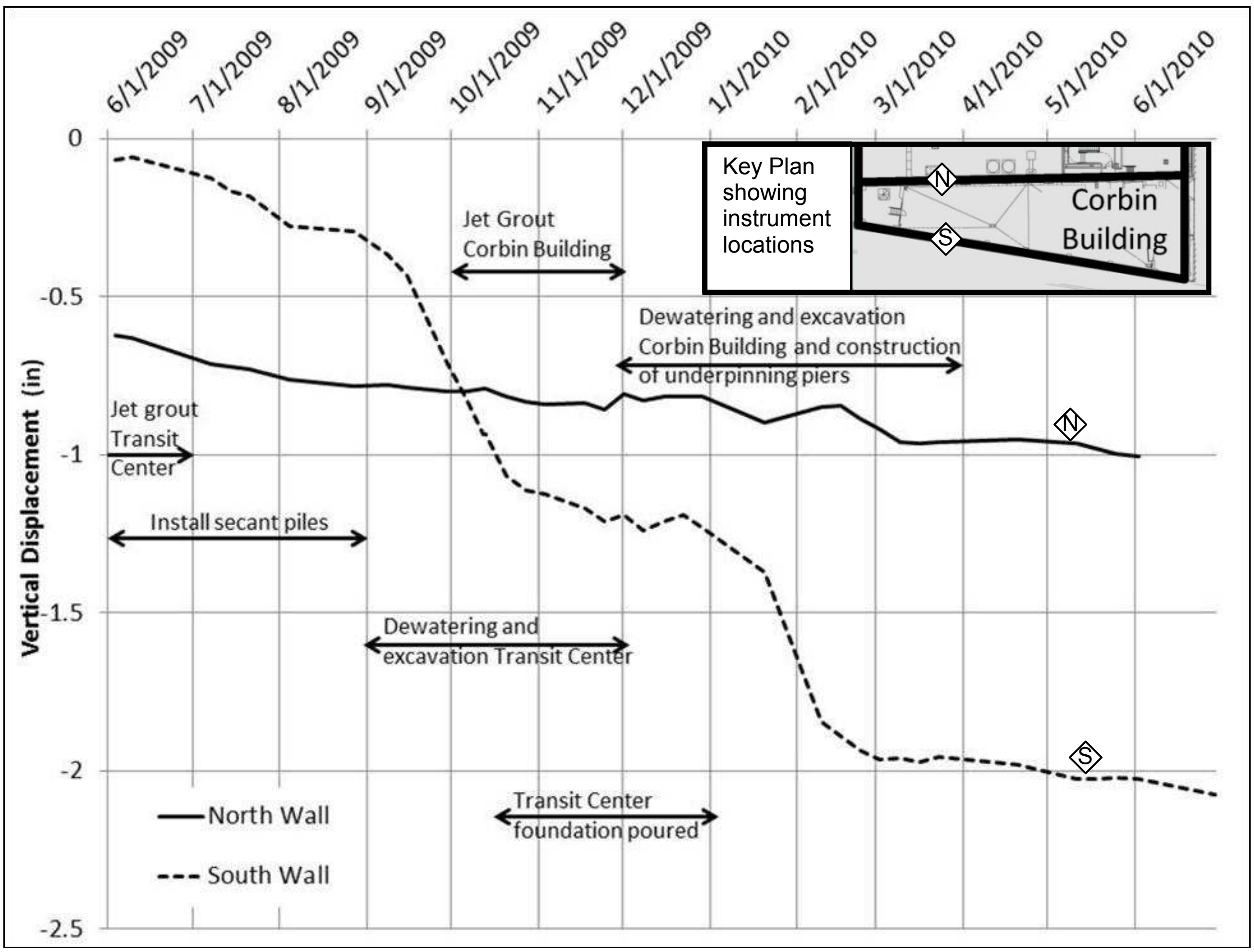

Figure 12. Plot showing the settlement for two of the columns of the Corbin Building, one in the north wall and one in the south. The north wall was underpinned with jet grout prior to the excavation of the Transit Center site.

The dewatering and excavation of the Transit Center site took place from September through November 2009, during that time the south wall of the Corbin Building settled by approximately 0.9in. By comparison, the north wall settled by less than 0.1in in the same time period. During the same period, a jet grout curtain was installed to create a water tight bath tub beneath the Corbin Building, as this was located away from the building footings the effect was not expected to be significant and the majority of the movement of the south wall during this period is assumed to be due to the main site works.

The second significant movement of the south wall occurred during the dewatering and excavation of the escalator pit beneath the Corbin Building itself, approximately 0.75in. Daily monitoring at the time indicated that the excavation, construction and the transfer of load onto the underpinning piers caused about 0.125in of this, the remainder being due to the dewatering and excavation of the escalator pit itself. Once the escalator pit was completed, settlements decreased to effectively zero.

The buildings to the east of the site and subway structures to the north and west showed little appreciable movement throughout the construction.

5 CONCLUDING REMARKS

There are a number of key factors during both design and construction of the Transit Center substructure that lead to its overall success as a project in such a congested area of the city:

- Of these factors, a good understanding of the ground risks based on site specific data, as well as local construction knowledge, was crucial. A number of elements were incorporated into the design and communicated to the contractor to reduce the potential impacts of the construction. This was enhanced by open communication throughout construction, allowing anticipation and fast response to issue as they occurred.
- A detailed understanding of the construction and history of the existing on site structures, particularly the Corbin Building. This enabled a more thorough interpretation of the ongoing monitoring results and confidence in the integrity of the building throughout.
- A detailed analysis of the excavation and construction both during design and once the construction sequence had been finalized, including an understanding of the likely unbalanced loads across the site, provided good predictions against which to compare the observed movements.
- The consideration of the location and the impact of construction were considered throughout design. This culminated in a number of requirements that were included to reduce the likely ground movements:
  - Ground improvement to bind the sensitive soils and reduce the settlements during installation of the secant piles.
  - Sequencing of the secant piling to ensure that adjacent piles were not constructed before the first had been allowed to harden.
  - Reducing the strength of the primary secant piles to reduce the vibrations caused by installation of the secondaries.
  - The final few feet of excavation was carried out immediately prior to the pouring of each section of the foundation slab and the soil was inspected to ensure that any disturbance of the ground was minimized.
  - The requirement for constant monitoring on all sides of the excavation as well as baseline monitoring of structures further from the site.
- The Corbin Building was inspected regularly by an engineer to observe any signs of structural damage.

In addition to the above, one of the key factors for success was frequent communication between the contractor, designer and owner, ensuring that all parties were fully informed throughout. During the most critical parts of the construction, meetings attended by senior stakeholders were held weekly, and sometimes more frequently, to review the monitoring data. In addition, structural inspections of the Corbin Building were carried out regularly throughout construction and the data fed into the decision making process.

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