HYBRID SHORING SOLUTIONS FOR A CHALLENGING EXCAVATION PROJECT ADJACENT TO A SUBWAY – 21 AVENUE ROAD, TORONTO

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Yorkville Plaza II, a 40-storey signature condominium residence, is scheduled to open on Avenue Road in Toronto's prestigious Bloor-Yorkville neighbourhood in spring 2017. In close proximity to Toronto's subway system, the new tower requires six levels of underground parking, founded in wet, silty sand.

Isherwood Geostructural Engineers (Isherwood) was retained in April 2012 by developer Camrost-Felcorp to provide a shoring and excavation solution to address the challenging site conditions. A 31-storey upscale residential building under renovation with three levels of parking, owned by Camrost-Felcorp, flanks the site on the north. Situated on the eastern border is a 7-storey building with three levels of parking. Avenue Road, a four-lane arterial road that brings heavy commuter traffic into downtown Toronto, runs along the western border, and on the southern border of the site is a busy City road that brings traffic into the popular Yorkville area. The tunnel for the Toronto Transit Commission's (TTC) overburdened east-west subway is located 14.5 m to the south, running below an existing 26-storey neighbouring building. Electrical and communication utilities (Bell) are closely located along the southern side. Non-documented existing excavation shoring, installed in the early 1970s, on the southern and western sides compounded the difficulties presented by the TTC tunnel.

This paper presents the unique, non-conventional hybrid shoring solution Isherwood developed to address the challenges presented by the site, as well as other complications that surfaced during the project: non-encroachment requirements (no tiebacks) beneath uncooperative neighbours, tight geometry to install shoring, and Toronto's two coldest winters in decades.

THE PROJECT

Yorkville is an affluent neighbourhood in the heart of Toronto with a vibrant mix of high-rise towers, residential homes, tony restaurants and flagship shops. Located within walking distance of the City's business district and easily accessible by subway, Yorkville is a highly sought residential area. Yorkville Plaza II, planned by developer Camrost-Felcorp, is a projected 40-storey glass tower at the corner of Cumberland and Avenue Roads. Located steps from Toronto's renowned Royal Ontario Museum, University of Toronto and the fashionable Bloor-Yorkville district, Yorkville Plaza II will offer residents stunning, panoramic views of and access to the best of downtown Toronto. The development requires six levels of underground parking, with three levels undermining the high-rise buildings to the north and east and extending into wet, silty sand.

Isherwood was retained in the spring of 2012 to design the excavation shoring. Isherwood's scope also included field support, design, verification and monitoring. Finite Element Analysis was employed to confirm Isherwood's design and anticipated movement of the south shoring wall and the TTC subway tunnel.

Figure 1: Future Yorkville Plaza II

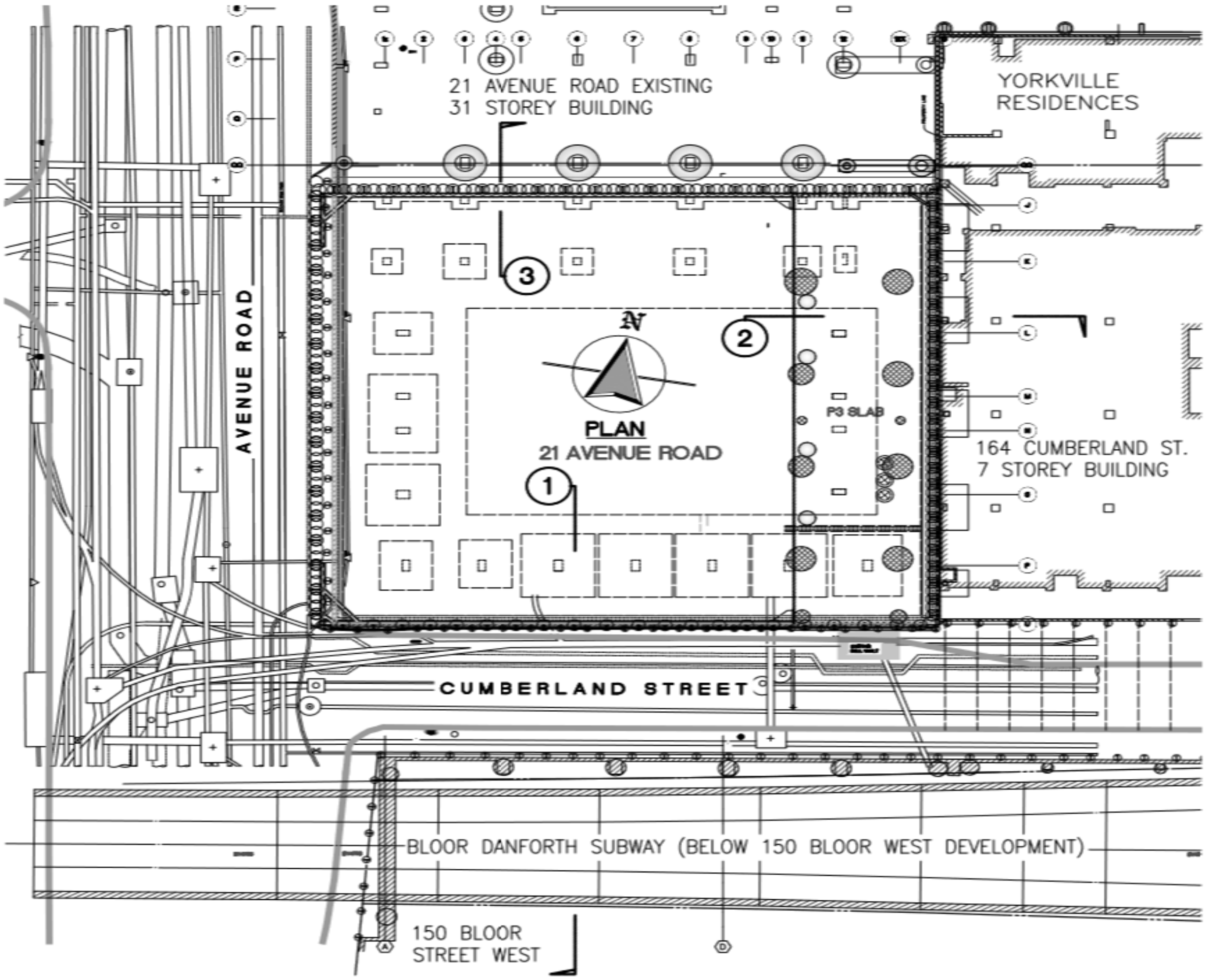

Figure **2**: Plan of the site

The existing site was severed in two, with the proposed condominium tower slated for the southern portion. On the north half of the site stands a 31-storey building (Yorkville Plaza I at 21 Avenue Road), with three levels of underground parking, sitting on belled caissons which were one foot from the back of the proposed shoring wall. Constructed in the early 1970s, Yorkville Plaza I is currently being converted from the Four Seasons hotel to luxury condominiums by Camrost-Felcorp. To the east, directly adjacent to the proposed shoring, stands a 7-storey building (164 Cumberland Road) with three levels of parking, supported on spread footings founded on clayey silt. The tunnel for the TTC's busy east-west subway, a double box structure built by cut-and-cover in the 1960s, is located 14.5 m to the south, running below an existing 26-storey building. Bell fibre optic communication cables and electrical lines, along with storm and sanitary sewers, are situated on the south and west sides of the site, leaving limited room to install shoring. Due to the heavy volume of commuter traffic on the four-lane arterial road (Avenue Road) to the west, site access and lane closure were not permitted here. Although the southern road (Cumberland Road) is the main entrance into the Bloor-Yorkville area, a partial lane closure was permitted, allowing construction access.

Soil Conditions

Borehole records revealed the upper 9 m of soil consisted of sand/fill (0 to 3 m) and varved, silty clay (3 to 9 m). Below 9 m were four layers: upper silty sand, dense silty sand, lower silty sand, and shale. The lower wet silty sand presented challenges for the sixth underground level. From past experience on sites in the area, Isherwood knew shoring installation and dewatering would be difficult in this soil. Often the contractors had had to drill under balanced slurry and place concrete by using tremie, and sites had been stalled waiting for the taxed dewatering systems to lower the water level below the excavation level.

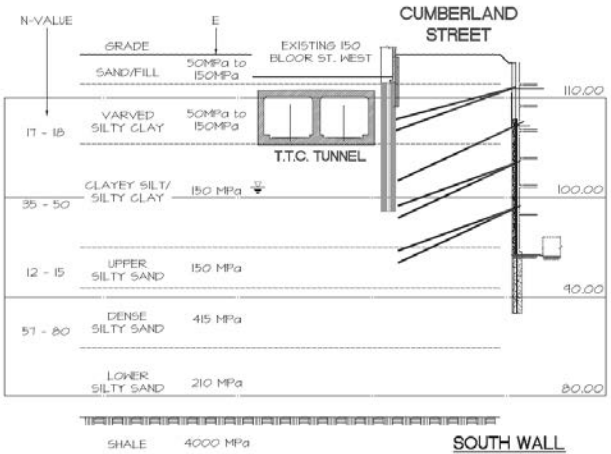

Figure 3: Soil stratigraphy and modulus profile

Initial Proposed Solution: June 2012

Based on the difficult soil conditions, the neighbouring buildings and the TTC tunnel, and to limit entry of water into the excavation, Isherwood proposed a secant wall (called caisson wall in Toronto) with tiebacks be installed all around the perimeter of the site. Isherwood recommended the south and west walls be drilled from grade and the north and east walls be drilled from the P3 grade to match the elevations of the adjacent garages. The shoring to the north and east would be designed to withstand the surcharge from the two neighbouring buildings, and the shoring to the south was designed to meet the TTC's stringent restrictions on movement and to have minimal impact on the utilities. To the west, the shoring would support the arterial road and would be coordinated around the existing shoring and utilities.

Limitations of the Site

A major complication was the limited space available to install conventionally sized shoring on the south wall due to the presence of communication and electrical utilities. At the start of the project, the client assured Isherwood it would arrange to have these utilities moved, so a permit set of drawings with a secant wall and three rows of tiebacks was prepared, with the shoring positioned south of the existing shoring. Compounding the situation was a 40-year-old shoring system from the existing building on the south and west walls, positioned exactly in the location of the future shoring. As shoring drawings were not available, both the precise location and the configuration of this existing shoring were unknown. To ensure clearance from the existing shoring system, the new shoring to the south and west was positioned 600 mm from the future wall.

The demolition of the existing 4-storey building and three levels of underground parking posed another challenge. The parking garage to be demolished was linked to the parking of the existing 31-storey building to the north. The consultant team recommended using the rubble from the demolition as a bermed drilling bench but needed a solution to support the rubble between the drilling bench and the existing parking. Isherwood was asked to provide a shoring solution for this dilemma. In addition to accounting for the load from retaining the rubble, the shoring needed to support a Liebherr LB 36, one of the industry's largest drill rigs. After thorough review, Isherwood designed a shoring system consisting of a self-supporting block of weak concrete, which resisted the berm and drill rig in friction.

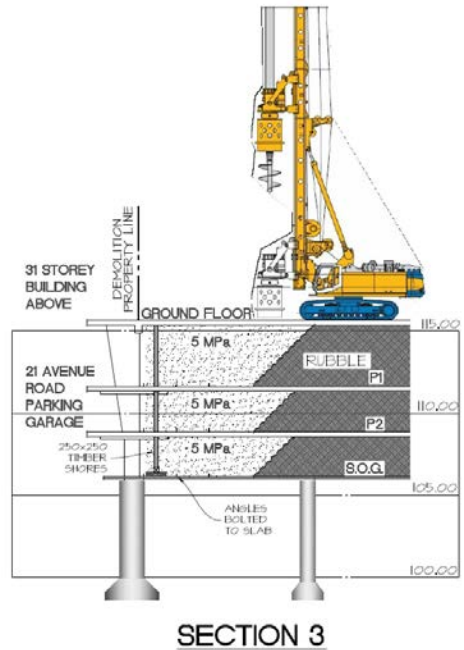

Figure 4: Shoring for rubble berm

Unknown Challenges

After meeting with the utility companies, Camrost-Felcorp learned moving the utilities further south into the street and away from the shoring would cost more than $1 million and create a one-year delay. Therefore Isherwood was asked to prepare revised drawings with shoring designed to fit between the existing shoring and the utilities. As the exact locations of the existing utilities and shoring at the south and west walls were unknown, exposure and survey of the utilities and existing shoring was necessary.

Complicating things further, Camrost-Felcorp concluded it would not be able to obtain a tieback encroachment with the high-rise development 12 m to the south of the site, straddling the TTC tunnel. To accommodate for the non-encroachment scheme, in November 2012 Isherwood prepared another design using soldier pile and lagging on the south wall, with shallower piles and four rows of double tiebacks (approximately 35% shorter than the previous single tiebacks). It was a bolder design than the original one, which had a secant wall with longer tiebacks. Furthermore, with the soldier pile and lagging, a more robust dewatering system would now be required. The finite element model showed the new shoring design would have 25% more movement than the previous design, but the predicted movement of the TTC tunnel was still within the acceptable level of 2 mm.

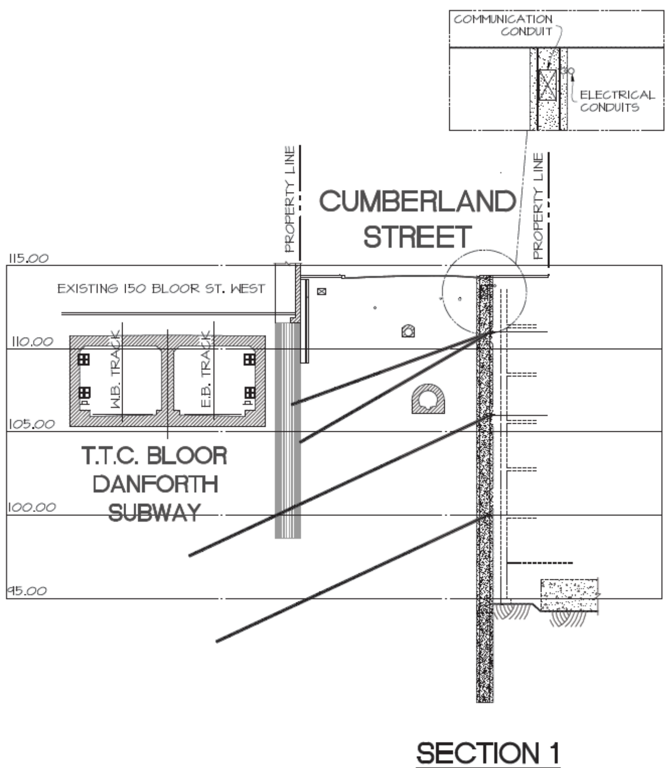

Figure 5: Before (longer tiebacks, secant wall and stiffer piles)

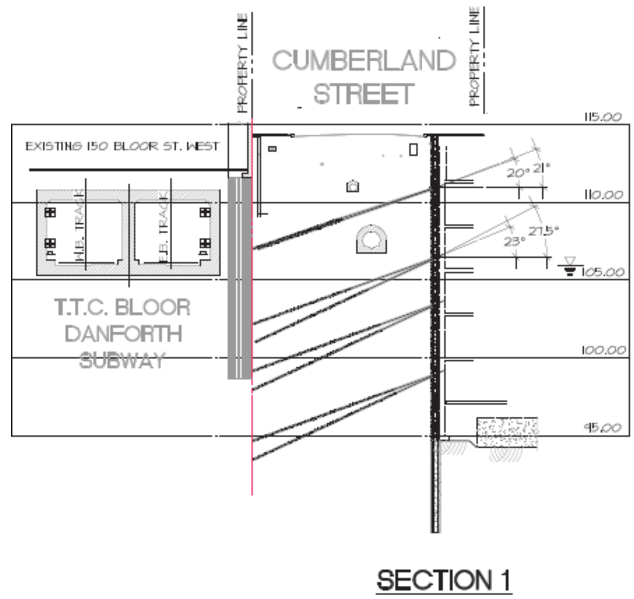

Figure 6: After (shorter tiebacks, soldier pile and lagging and smaller piles)

When access to Cumberland Road was finally gained in March 2013, the pre-construction site investigation showed an electrical cable to be in the way of the future shoring and a Bell conduit only 500 mm from the edge of the existing foundation wall, much less than shown on the City drawings and infringing on the ability to install soldier piles. The combination of the limited clearances and reinforced concrete wall from the existing parking structure made the latest design unfeasible. As the shoring contractor Drillco (now called Geo Foundations) had already been hired to install the shoring, Isherwood partnered with them to find a hybrid solution to designing and installing shoring on the south wall.

Monitoring

Isherwood's standard practice is to monitor shoring and employ the Observational Method. Isherwood hired Monir Precision Monitoring Inc., an expert in the field of instrumentation monitoring, to monitor the shoring, the adjacent buildings, and the TTC subway tunnel to the south of the excavation. The monitoring included visual survey of the top of the piles with accuracy of 2 mm or better, 7 inclinometers with accuracy of 1 mm or better, precision survey of the surrounding buildings and the TTC with accuracy of 1 mm or better, and electrolevels in the TTC tunnel, which measured the relative displacement across the joints in the subway and the tilt of the subway boxes. The electrolevels were read in real time and had an accuracy of 0.1 mm over 1 m. The goal was to ensure redundancy in the monitoring at all times to confirm or back up results when needed.

For the south wall, a monitoring plan was established with the TTC which included monitoring frequency and alert/review levels with associated action plans. The remaining walls were read weekly or bi-weekly, depending on the excavation rate and site conditions, and the surrounding buildings were read monthly. In case of unexpected movement, frost issues or site concerns, the reading frequency would be adjusted accordingly.

Isherwood and Geo Foundations would need to depend on the monitoring to suggest and implement the following solutions for their client.

SOLUTIONS (1): SHORING DESIGN FOR THE SOUTH WALL

It was clear by April 2013 there was inadequate room to install conventional shoring, so Isherwood and Geo Foundations brainstormed alternative solutions. A standard alternative, such as shotcrete and lagging using smaller vertical piles, was not viable due to constructability and stiffness concerns. As original shoring construction drawings were unavailable, Isherwood did not know the depth or the size and weight of the existing piles, but safely assumed the piles would be at least as deep as the 3 levels of existing parking. When the requested survey plan of the existing shoring was received, site visits were made to determine the cross-sections of the piles. This enabled Isherwood to piece together a schematic of the shoring. It became apparent constructability and sequencing would be the most critical components of this design.

Based on information available, Isherwood and Geo Foundations designed a unique and significantly more complicated telescoping hybrid shoring system, which used the existing shoring for the upper portion of the excavation (first 7 m). The balance of the excavation would be retained by new soldier piles and lagging supported by soil anchors. In order to install the lower shoring and not lose future building space, the upper shoring was lagged to the back of the existing piles, a complication which exposed the existing shoring. Modified tieback connections were required to achieve this clearance and to connect the lower and upper piles.

This hybrid shoring solution was novel in our experience in Toronto. However, as the solution worked on paper and Isherwood had monitoring to back it up and ensure it was stable, Camrost-Felcorp decided to proceed.

Design Details

To protect the utilities and reduce movement, a 20-mm thick back flange plate was welded to the top 3 m of the existing piles, the elevation of the first row of double tiebacks. For the next 4 m, lagging was specified to be installed to the back of the piles to provide space for the installation of the new piles. From this elevation, 7 m below grade, new W310 piles were installed to below the base of the outside of the future foundation wall and in front of the old shoring.

Figure 7: Upper shoring with plates, tiebacks, and lagging

A conventional double waler section was modified to connect the upper (existing) shoring with the lower (new) shoring and accommodate the second row tiebacks required at the same elevation. The resulting design detail used W310 tees and S310 sections to attach the waler to the new/old shoring.

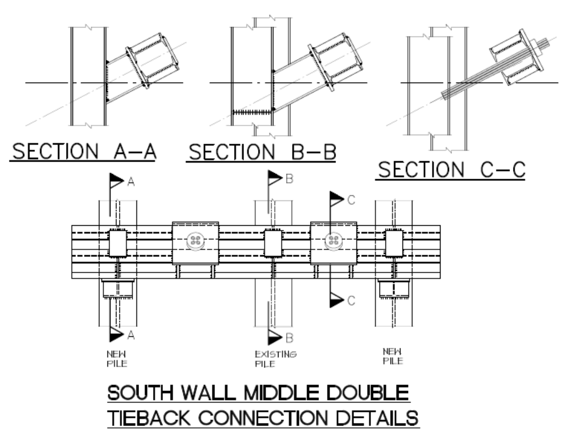

Figure 8: Double waler details

The remaining south wall shoring, below second row tiebacks to final grade, was conventional soldier pile and lagging with two rows of double tiebacks.

Figure 9: View of south wall excavated to third row of tiebacks

Installation by Geo Foundations: October 2013

To satisfy the design and installation requirements, a modified drilling procedure was implemented using a Liebherr LB 28 drill rig equipped with 20 m of Leffer casing and a Linkbelt TTC750 service crane. Conventional drilling techniques typically require a minimum clearance of 150 mm from the edge of the existing shoring wall to the edge of the drilled shaft due to the outward projection of the drill rig rotary head. To avoid this installation clearance restriction, a 6 m long casing was used to extend the drive can and keep the rotary head above street elevation. With the rotary head positioned above the existing shoring wall, the temporary casing could be installed flush to the existing shoring.

Using the 6 m drive can extension, a 5 m starter section of casing was installed and advanced to refusal. The drive can extension was then disconnected and augering commenced. Subsequently, the extension was reattached and the casing was advanced further. This procedure was repeated until the 5 m casing length was 1 m above working grade and the next piece of casing could be attached. Using this technique, the hole was advanced to the founding elevation, fully cased, with minimal water ingress.

Using a 610-mm diameter steel pipe hoisted, held in place using the Linkbelt crane, the drilled shafts were concreted from street elevation. The 6 m casing extension was then reconnected at the working grade elevation in order to remove the temporary casing in sections. Once the entire length of casing was removed, a new pile was placed (wet set) with the Linkbelt, flush to the back of the hole. Any difficulty advancing the piles was overcome using the Liebherr LB28 crowd, ensuring the piles all reached the desired depth.

Figure 10: Drilling at south wall

Challenges Along the Way – South Wall

Once the top 2 m of the existing shoring was excavated and the existing piles exposed, significant rusting of the top 1.2 m and varying other portions of the piles was observed. The rust raised concerns of the structural integrity of these piles, prompting new steel splices to the top 1.2 m and replacement of the other rusty sections with welded steel plates.

Figure 11: Rust on existing piles

When excavation reached the base of the original shoring and the tops of the toes were exposed, Isherwood learned the existing piles had been driven rather than drilled, bringing into question whether there was adequate vertical capacity in the old/existing shoring as the toes were exposed further. As there were no concrete toes, by the time the site had been excavated to the third row of tiebacks, the top shoring had started to settle by over 15 mm, raising concern whether the waler was strong enough to support the vertical load. To address this issue and prevent further settlement, Geo Foundations installed vertical V-shaped cross strapping.

Figure 12: South wall V cross-bracing

Monitoring Results of the South Wall

At final excavation in early April 2015, the inclinometers installed on the lower piles showed acceptable movements of up to 17 mm into site. There were no inclinometers on the top portion of the shoring, only pile targets, and these indicated an average 34 mm of into-site movement across the south wall.

This shoring was exposed during two of Toronto's coldest winters in decades with weeks of continuously below-freezing weather. As a result, there was significant upper shoring movement due to frost. During the first winter (2013/14), with the site excavated halfway down, the top shoring moved up to 23 mm into site due to frost and rebounded back an average of 18 mm in the spring of 2014. During the second winter (2014/2015), frost blankets as well as heaters on the south wall were installed to mitigate the risk of frost movement.

Figure 13: South wall with frost blankets in place

SOLUTIONS (2): SHORING DESIGN FOR THE EAST WALL WITHOUT TIEBACKS

Challenges

In August 2013, three months after the start of construction, based on a business decision, Camrost-Felcorp informed Isherwood they would not obtain a tieback encroachment agreement with the neighbour directly to the east. Normally, struts or rakers would be considered in a non-encroachment situation; however, the wet silty sandy conditions at the deep raft slab almost 25 m below existing grade made the installation of conventional rakers unfeasible, and the site was too wide (45 m) and architecturally complicated to economically strut cross-site.

The team had long discussions about the risk and cost of bracing the east wall without tiebacks, and how to avoid movement, especially at the 7-storey building with three parking levels immediately adjacent to the east shoring wall. As the control of movement is a function of cost, Isherwood asked the client to clarify the amount of allowable movement of the existing building as a guide to help design the shoring. This amount was specified as half an inch to one inch (12.5 to 25 mm).

Since an alternative approach to the conventional non-encroachment techniques was required, Isherwood explored innovative concepts for Camrost's consideration. After reviewing the sketches and analyzing the costs and impact to schedule, installing a portion of the permanent slab at the P3 level and using the slab as a horizontal truss was determined to be the best solution. Although Isherwood had used slabs to provide primary excavation support, this had never been done at a significant settlement-sensitive building.

What We Did – East Wall

To secure and brace the footings of the existing building, the partial permanent P3 slab was to be pre-loaded. The slab would have to be strengthened to withstand the pre-loading to 29 MN (2,900 tons). The vertical shoring wall was a secant wall with heavy W610 piles in every second drilled shaft.

Figure 14: After the piles were installed, the slab was installed by forming on the top of the soil. Structural Engineers Jablonsky Ast and Partners designed the slab.

To control the movement, unique connection details were required. Look-outs and four 1300-mm diameter drilled shafts were installed to vertically support the west edge of the slab, and custom slab-to-pile connections, designed to withstand the significant horizontal load, were staggered along the north and south walls.

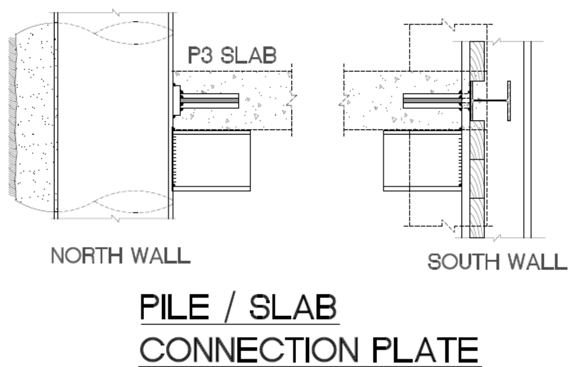

Figure 15: Horizontal slab connection

Free-moving, pre-loaded struts, which ran the full length of the north and south walls, were braced against the west secant wall and the P3 slab buttress. The connections at the piles needed to prevent the struts from buckling and also allow the struts to slide during pre-loading. After pre-loading, the struts would be welded in place.

Figure 16: Strut for slab on south wall

To limit the movement of the east shoring wall it had to be pre-loaded against the slab. A pre-loading detail was designed to install pancake jacks into the slab at the east wall in 26 locations.

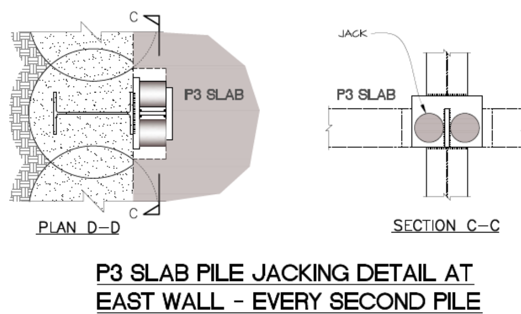

Figure 17: Jacking detail for east wall

Knee braces with a waler were used to provide intermediate support to the shoring between the slab and the base of the excavation.

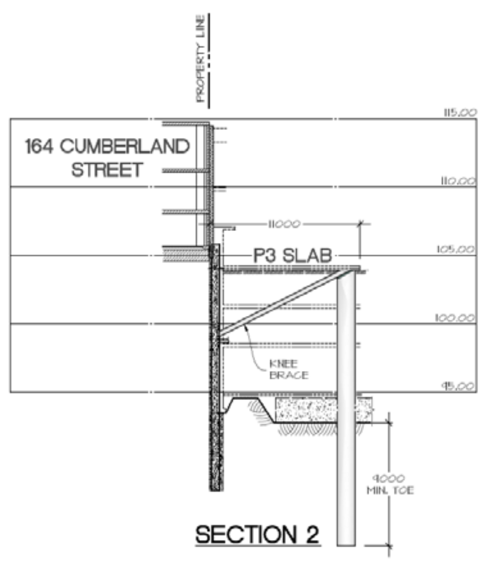

Figure 18: Section at P3 slab

Figure 19: Knee braces at east wall

Live Monitoring and Pre-Loading – East Wall

To ensure the neighbouring building was not damaged during pre-loading, a construction and pre-loading sequence was determined along with real-time survey monitoring. Before the slab was pre-loaded, inclinometers were read and survey measurements were taken of the building to the east and the shoring.

First, the two long struts running east-west across the site were simultaneously pre-loaded in 25% increments, up to 3000 kN per strut. Dial gauges were placed at the east and west secant walls and on the west face of the slab, along with magnetic tapes on the jacking plates to record the displacement.

Figure 20: Pre-loading strut

A maximum of 1.7 mm of movement was measured at the secant reaction wall on the west side of the site, and a maximum of 1.4 mm of flexural movement of the structural slab. Total jack extension at the jacking location was 15 mm on the south strut and 10 mm on the north strut. The building and the shoring to the east had negligible movement. The load was locked in by welding the jacking plates and struts.

To ensure balanced pre-loading, the east wall was pre-loaded simultaneously against the structural slab, using 26 jacks at 13 locations connected in parallel to one pump. The jack loads were increased in tandem in 25% increments to 450 kN each. Total average jack extension at each jacking location ranged from 2 mm to 5 mm.

Figure 21: Pre-loading jacks at east wall

Real-time survey monitoring was carried out during the east wall pre-loading process. Up to 2 mm of flexural movement was noted on temporary targets installed on the west edge of the slab. Magnetic tape measures were placed at every jacking location. Negligible movement (≤ 2.0 mm) was noted on both the east wall shoring piles and targets on the 145 Cumberland St. structure to the east.

Figure 22: East wall, excavating below P3 slab

Performance of the Shoring After Excavation

Upon reaching final grade of the east wall in January 2015, the shoring at the slab had moved 9 mm into site from an initial average of 4 mm before installation. The maximum movement of the shoring below the slab was 12 mm and the building to the east had moved ≤ 4 mm, beating the target set by the owner.

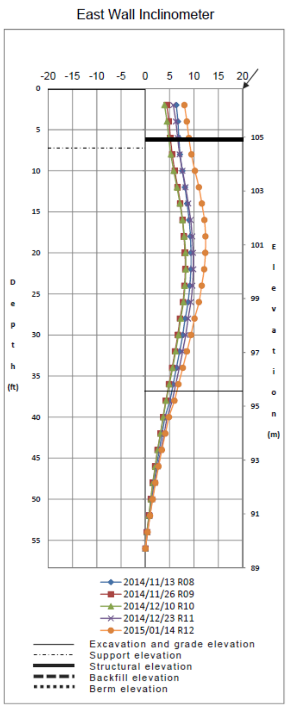

Figure 23: Inclinometer plot at final grade

Figure 24: East wall, at final grade, March 2015

CONCLUSION

Isherwood and Geo Foundations managed to accomplish a deep excavation without using conventional bracing on one wall, while using a telescoping hybrid solution incorporating 40-year old shoring on another wall. Despite several changes in scope along the way, Isherwood and Geo Foundations designed innovative solutions which proved successful.

The use of the observational method was crucial in managing the risk, and confirmed Isherwood's complex shoring and structural calculations. Comprehensive layered monitoring was used at all stages of the excavation, which assisted with design and construction changes on site.

As Toronto densifies, tighter and deeper sites are being explored more regularly, often with weaker and wetter soils. The novel methods of demolition, incorporation of existing shoring, and employing a structural slab for temporary bracing, which were used in this project, will become less rare. The authors hope this project paper will become a benchmark for future projects.

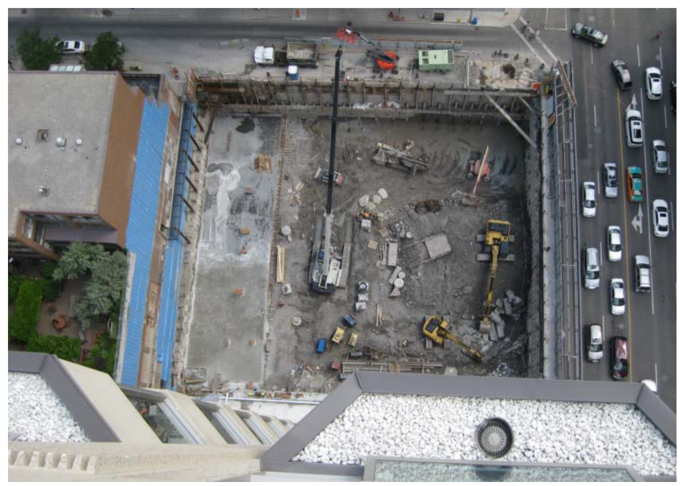

Figure 25: Looking down at the excavation

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