Rendering of TELUS Sky Tower.

HCM Contractors Inc and RWH Engineering Inc Reach for the Sky From New Depths in Western Canada

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Project Summary

Set to transform the skyline and become Calgary's newest landmark, the TELUS Sky Tower is the next addition to the city's downtown core. Located in the corner block of 7th Avenue SW and Centre Street, directly adjacent to The Bow, the 59-story tower will be the third tallest building in Calgary, Alberta. The building is a combination of spaces for working and living that give the architecture its unique sculptural shape and vertical elegance to the skyline. The mixed-use TELUS Sky Tower was developed with an emphasis on sustainability using innovative design and technologies and will be Calgary's first building designed to LEED Platinum standards.

Most notably, the TELUS Sky project is the deepest excavation ever completed in Calgary. The excavation extended to a depth of 110ft to facilitate a seven level underground parkade. Currently in Canada only two other buildings have had similar excavation depths, however, the difference being their project footprints were much larger.

HCM Contractors Inc. (HCM) and RWH Engineering Inc. (RWH) became involved in the early stages of the project and were awarded the shoring scope prior to a geotechnical investigation being completed based on their in depth knowledge of the surrounding geological conditions and experience shoring in Calgary. The result was a Design-Build shoring solution in combination with monitoring services to be able to use an observational method approach and manage risk.

The TELUS Sky project presented unique challenges due to the small footprint of the project site and proximity to existing sensitive infrastructure; a 26-story building to the north separated only by a laneway, a 12-story building directly along the west side of the site, LRT tracks to the south and large Telus utility ducts surrounding the site. Keeping with the innovative project design approach, the final shoring solution consisted of a secant caisson wall perched above tied-back shotcrete rock protection and a zero-clearance tied-back shotcrete underpinning system extending full depth below the existing building.

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Excavation process with clamshell bucket.

Crane adapted with clamshell bucket.

Shoring Approach

HCM and RWH have now been associated with the Design-Build shoring solutions on the four tallest buildings in Alberta; The Bow, Brookfield Place and TELUS Sky Tower in Calgary and the Stantec Tower for the Edmonton Ice District Arena currently in construction.

The conditions encountered in downtown Calgary are typically non-cohesive overburden soils overlaying highly weathered, low strength bedrock. The overburden depth varies, extending approximately 20ft to 30ft (6m to 9m) and consists of poorly graded gravels with cobbles and boulders with few fines. The bedrock, known geologically as the Porcupine Hills Formation, is comprised predominantly of mudstone.

It is the rock composition that creates the risk in deep excavations in Calgary. The mudstone can contain weak zones and localized shearband layer(s) that are unable to be identified using conventional geotechnical sampling techniques. A shearband is a thin layer of clay material within the mudstone with a low shear strength and friction value. The occurrence of a shearband layer typically propagates movements resulting from the progressive failure of the weak mudstone when the confining overburden pressure and lateral support is removed during excavation activities.

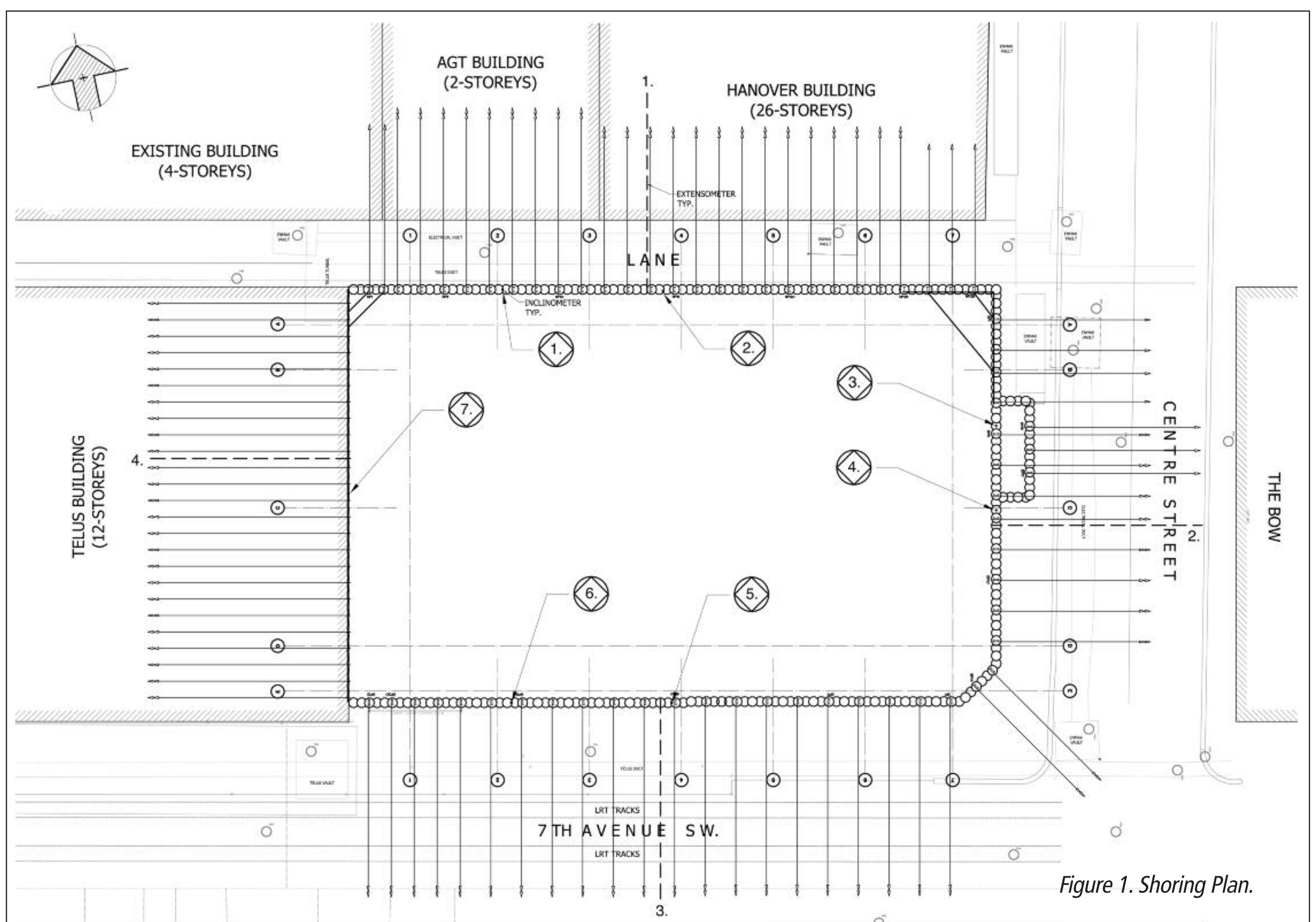

Figure 1. Shoring Plan.

The unknown rock parameters, and presence of weak rock and shearband layers make it challenging to accurately predict shoring performance and impact to the surrounding infrastructure prior to excavating.

HCM and RWH used their knowledge of the soil conditions, as well as knowledge acquired from the construction of previous projects in the area, The Bow and Brookfield Place, to develop the excavation support system for the TELUS Sky project. The result was a 26ft (8m) deep perched secant caisson wall that extended approximately 13ft (4m) into the bedrock over a 3 inch (75mm) thick shotcrete system that continued below in the excavated rock to the full excavation depth. The perched caisson wall was held back by two to three rows of post-tensioned anchors. Due to the proximity of the existing buildings along the north wall, the top row of anchors were installed at 45 degrees into the rock to maintain clearance beneath the existing building footings.

The shotcrete beneath the perched caisson wall was installed in a panel sequence to manage the weak mudstone and control deflections of the caisson wall. Once into the sound rock, a more conventional soil nailing approach was taken, spacing the shotcrete on equally sized horizontal and vertical panels with the same anchor lengths to tie the rock together as a block.

This approach was implemented on three sides of the site, however, due to proximity of the new foundation structure to the existing building on the west, a zero-clearance shoring solution was required. With HCM's extensive experience with shotcrete, a shotcrete underpinning system was designed to support the existing 12-story Telus building, extending 65ft (20m) below the footing. The first lift of shotcrete was excavated in a panel sequence with anchors installed on a tighter spacing to minimize differential settlement.

Bauer BG28 drill rig.

Rock anchor installation.

Construction

The installation of the shoring began January 15, 2015 with the vertical drilling of the caisson wall. Two Bauer* drill rigs were used, a BG24 and a BG28, to deploy 35 inch (880mm) diameter sectional casing for installing piles and fillers to ensure interlock was maintained and zero ground loss occurred. A two and three filler caisson wall sequence was followed, installing W18 (W460) piles on 7ft (2.1m) and 9ft (2.8m) spacing.

The piles were socketed a minimum of 13ft (4m) into the bedrock and to increase the bearing capacity and stability of the pile, the toes were enriched with cement increasing the concrete strength to 15MPa. Fillers were extended 3ft (1m) into the sound rock to help minimize groundwater seepage into the excavation and provide a predominately water tight system through the overburden.

Particular attention needed to be taken during

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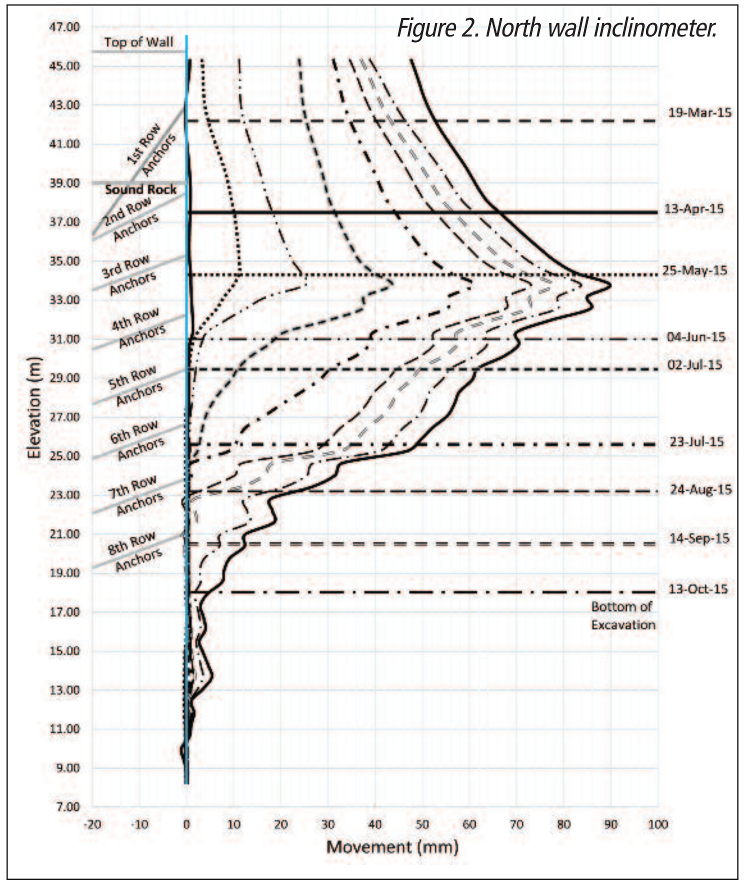

Figure 2. North wall inclinometer.

the pile installation along the North wall due to the vertical load induced on the perched caisson wall by the highly loaded 45 degree anchors. In order to minimize the vertical settlement of the wall, these piles were treated as end bearing foundation caissons, with the bottom of the holes cleaned to ensure adequate bearing on the rock.

Excavation began March 2, 2015. As the footprint of the project site was so small, at 196ft x 125ft (60m x 38m), excavation for the building presented unique challenges. After about 20ft (6m) a conventional access ramp could not be built to get trucks or machinery down into the site efficiently. Instead, the excavator came up with a unique approach, adopting an old-school dragline excavation method, using a modern hydraulic crane modified to hold a clamshell bucket. Then, in order to not delay excavation activities, a truck was continuously waiting underneath a hopper that the clamshell filled with the excavated material. The clamshell bucket was able to hold approximately 250 cubic ft (seven cubic meters) of material with each scoop. Using this process, over 2,825,000 cubic ft (80,000 cubic meters) of dirt was excavated from the building site taking approximately eight months, reaching final grade by mid-October.

Anchor installation began March 17, 2015. The top row of anchors were either extended into gravel or rock depending on the depth of overburden and tieback inclination. When the excavation reached rock, a toe pin located 1.65ft (500mm) into the rock was installed on the caisson wall to lock in the pile prior removing the passive resistance.

Beneath the caisson wall, a 3 inch (75mm) thick shotcrete soil nailing system was continued in the rock to the final excavation depth. A total of six rows of anchors were installed on 9ft (2.8m) horizontal and 9ft (2.8m) vertical panels. Panels were excavated and trimmed with a rotary mill to reduce the disturbance on surrounding infrastructure and over break of the rock, then meshed and 4350psi (30MPa) shotcrete applied to the rock face. Panels were completed on the same day to minimize any material loss or deterioration of the mudstone that can be caused from being left open and exposed to weather elements.

For the underpinning the first lift of shotcrete anchors were spaced on smaller 5ft (1.5m) horizontal by 5.5ft (1.6m) vertical panels. Shotcrete was installed using an A-B paneling sequence to control deflections. Anchors installed on the A panels were preloaded to 50% design load within 24 hours and prior to continuing with the excavation of the B panels. All anchors were stressed and locked-off to 100% design load prior to proceeding to second lift of shotcrete. Once the excavation was two lifts below the footing the panel size was increased to 9ft (2.8m) horizontal and 9ft (2.8m) vertical for the remaining excavation depth.

The completed shotcrete rock protection and underpinning covered over 40,000ft^2 (3680m^2) and was held back by over 450 anchors. Each anchor was proof stressed and locked-off to ensure it met the design requirements.

Finite Element Analysis

The excavation support system was not designed using a traditional calculation approach as typical soil loading diagrams become inadequate at these depths, particularly in the design of a perched caisson wall shoring system. Instead, the shoring required an extensive understanding of the geotechnical conditions of the area in combination with experience on previous projects in the area in order to design using Finite Element (FE) modelling.

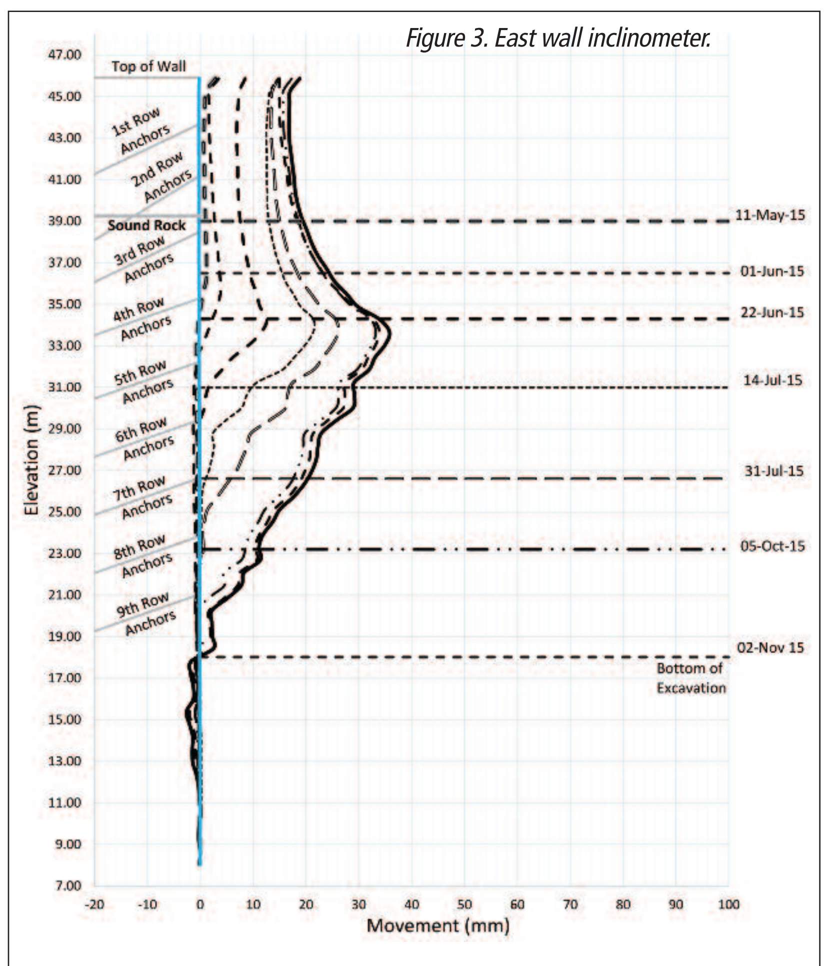

Figure 3. East wall inclinometer.

Past literature and FE modeling notes two main mechanisms that determine the behavior of excavation support systems in downtown Calgary soil conditions; release of locked-in stresses in bedrock and the presence and progressive failure of a weak layer of clay within the mudstone (shearband). In previous publications, it has been reported that during the excavation of the overburden soil and rock the resultant shearband deformations may extend beyond the shoring face as far back as three to four times the vertical bedrock excavation depth.

It was already determined through previous modeling and shoring performance that the forces from the locked-in rock stresses combined with the possible presence of a shearband are not able to be restrained using conventional shoring methods. Therefore, a perched wall was the excavation support system selected.

Shotcrete rock protection application.

The performance of the shoring is largely affected by the behavior of the rock, the value of in-situ rock stresses being the predominant factor affecting the predicted shoring deformations. Therefore, instead of using geotechnical parameters selected from borehole sampling, the models for TELUS SKY were calibrated by applying knowledge of the behavior of past shoring projects with similar subsurface conditions.

Using the monitoring data from the nearby Brookfield Place and The Bow excavations a back analysis was completed by simulating the locked-in rock stresses to determine appropriate rock properties. FE models were constructed for both excavations and the rock parameters varied to replicate the shoring behavior observed in the monitoring reports. For The Bow, the shearband was modeled at elevation (3349ft) 1021m based on the west wall inclinometer (refer to Figure 4) and for Brookfield Place the shearband was modeled at elevation (3370ft) 1027m.

A series of FE models were performed, both with and without the influence of the shear band, in order to estimate movements that may be experienced during the excavation for the TELUS SKY building as well as understand the risk to nearby infrastructure. Furthermore, modeling various subsurface conditions gave the project team and stake holders an understanding of the increased movement associated with encountering a shearband, which was not acknowledged in the geotechnical report. As the project site is located directly adjacent to The Bow, RWH designed the shoring with the shearband located at elevation (3349ft) 1021m. The simulated horizontal deformations of the shoring system produced the largest horizontal shoring movements near the shear band elevation, which was similar to the behavior observed at The Bow and Brookfield Place excavations. The average maximum horizontal movement predicted was 5 inches (125mm).

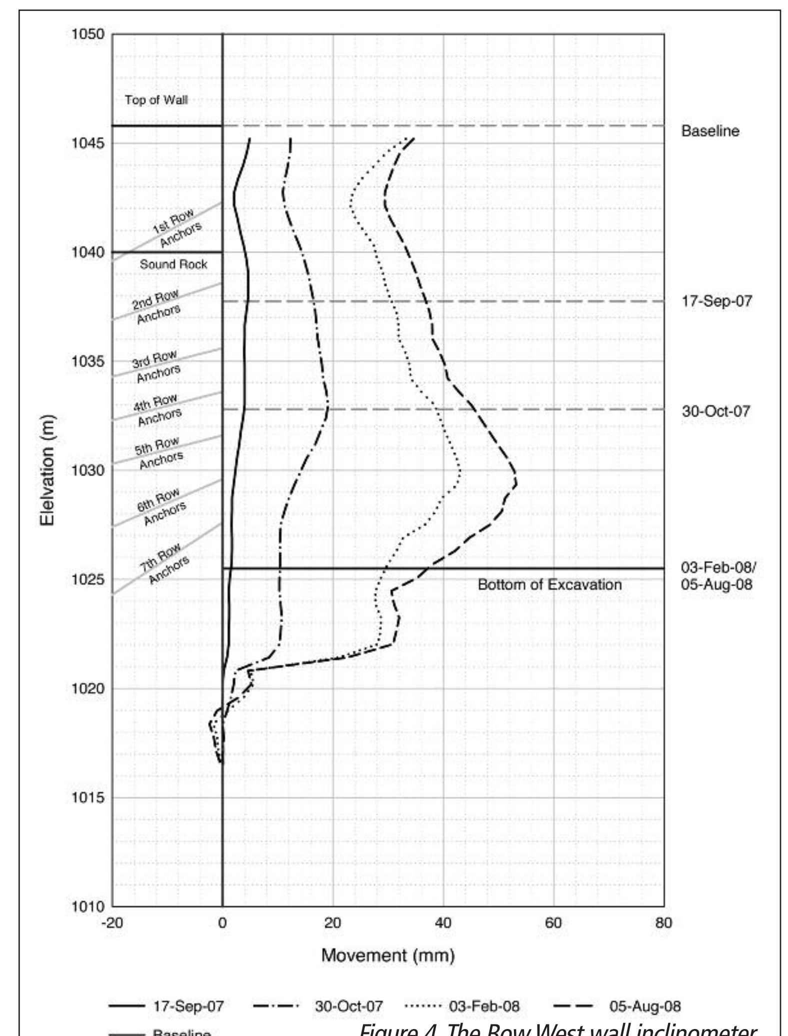

Figure 4. The Bow West wall inclinometer.

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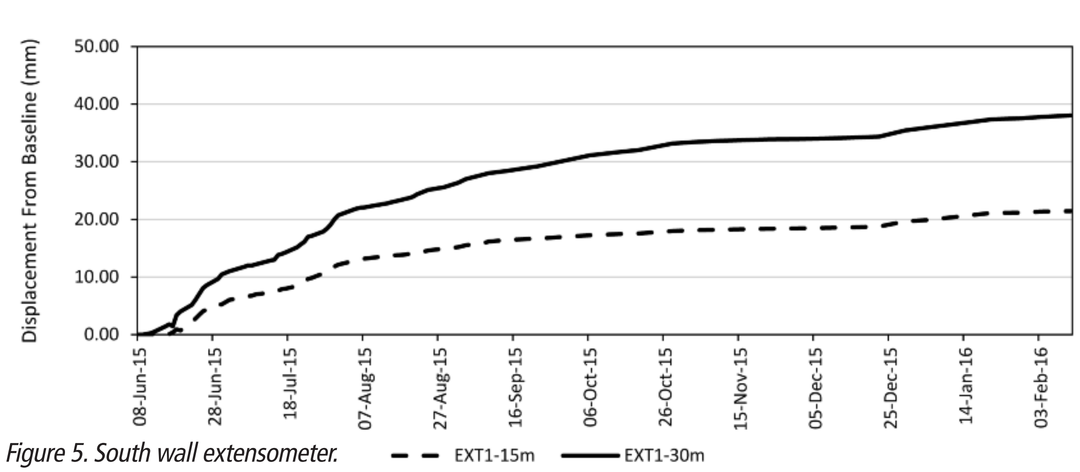

Figure 5. South wall extensometer.

Monitoring

RWH completed the precision monitoring on the TELUS SKY project which included both total station surveying and subsurface monitoring using inclinometers and extensometers. Figure 1 outlines the monitoring plan and the adjacent buildings surrounding the site. By completing the design and the monitoring through RWH, this ensured timely responses particularly during heavy excavation activities by allowing them to control duration between readings.

The adjacent buildings in the zone of influence of the shoring, LRT tracks and shoring walls were set up with survey targets which compared the readings to the baseline positions to determine the horizontal and vertical settlement movements. After the caisson wall was installed, six inclinometers were drilled through fillers to 33ft (10m) below the base of the excavation, and one in-place inclinometer was installed in the middle of the shotcrete underpinning wall. Once the excavation reached rock, four 115ft (35m) long extensometers were installed at 8ft (2.5m) below the top of rock.

The results of the monitoring indicated less movement was attributed to the presence of the shearband than as previously seen during the excavation of Brookfield Place and The Bow. There was a less prominent horizontal shift of the shoring and instead weak rock layers in the mudstone were what contributed to the shoring movement. There was an indication of a shearband at an approximate elevation of 3360ft (1024m) where a movement shift was present in all inclinometers. The north wall experienced the most movement, with a maximum horizontal displacement of approximately 3.55 inches (90mm) as shown in the Figure 2 inclinometer.

Most notably, on the east wall, directly adjacent to The Bow, the movement was reduced as a result of the rock stresses being released and shearband movement occurring during the previous excavation for this building. Movements were only 1.40 inches (35mm) as shown in the Figure 3 inclinometer. Comparably, the inclinometer for the adjacent wall at The Bow project is shown in Figure 4.

Although the movements experienced on the shoring were large, the extensometers showed the deformations of the rock behaved as a block and the movements propagated beyond the depth of the excavation. The Figure 5 extensometer shows there was 0.6 inch (15mm) of rock movement between 50ft and 100ft (15m and 30m). The target monitoring results showed the building shifting towards the excavation rather than differential movement occurring toward the excavation, further confirming that the rock deformations propagated beyond the excavation.

As expected, the movements were less than predicted as the geometry of the site helped to reduce the shoring movements, since the FE model used was 2-dimensional and did not consider any 3-dimensional benefits.

Conclusion

Introducing a full service Design-Build team early in the design stage offered benefits to the project through better construction suitability, lower costs and improved risk management. The project was designed and bid based on local knowledge of soil conditions only, as there was no geotechnical investigation completed at the time of tender. HCM working together with RWH was able to use their experience on previous shoring projects in the area to determine the most prudent shoring solution while ensuring that the project team was aware of the risks of excavating to large design depths.

As the performance of the shoring and movements is largely affected by the rock parameters which are not presented in traditional geotechnical reports, completing a back analysis using the monitoring results from similar excavations allowed RWH to better predict the shoring performance.

Using an observational approach by implementing a comprehensive precision monitoring program and performance evaluation against the FE models to confirm the stability of the shoring was successful on this project. The benefit of providing both the engineering and monitoring services allowed RWH to evaluate the shoring performance concurrently with excavation activities, reducing the risk in executing the TELUS SKY project in the challenging and unknown soil conditions.

**Indicates ADSC Member.*

Project Team

Owner:	7th Avenue Sky Partnership
Project Manager:	HCM Contractors Inc.* Ken Chong, P.Eng and Craig Rowe, P.Eng
Shoring Engineer:	RWH Engineering Inc.* Jason Weck, MESc, P.Eng and Kailey DenBraber, EIT
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Excavator:	Professional Excavator Ltd. Jan Gryckiewicz
Consultant:	Glotman Simpson Consulting Engineers

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