Cover Feature

HCM Contractors and RWH Engineering – A Model For Success

By Jason Weck, MESc, P.Eng, Vice President, HC Matcon Inc. and Kailey DenBraber, EIT, RWH Engineering Inc.

Project Summary

Located in downtown Calgary, Alberta, the Herald Block excavation was completed as the first phase of the Brookfield Place Development Project. Once completed Brookfield Place will be a full city block development located between 1st and 2nd Streets and 6th and 7th Avenues SW and will consist of two commercial high rise towers complemented by approximately 22,000 square feet of shared public space. The design of the towers will combine modern architecture and sustainability with their glass building envelopes and are expected to achieve the LEED Gold standard for Core & Shell development.

The first phase of the project, The Brookfield Place East Tower will become the tallest building in Western Canada extending 56 storeys (810 ft) and consisting of 2.4 million square feet of office space, which will house the North American oil company Cenovus. The 72 ft deep excavation spans a full city block along 1st Street SW and facilitated the construction of six levels of underground parking for the Brookfield Place East Tower.

The depth of excavation became challenging in the soil conditions encountered in downtown Calgary, which typically consisted of poorly graded gravels and cobbles overlaying highly weathered, low strength bedrock. The unknown rock parameters and presence of weak rock layers added another level of risk to developing in this area.

HCM Contractors Inc. (HCM) along with RWH Engineering Inc. (RWH) took on the project as a Design-Build and was able to use their previous experience on projects in the area, as well as their extensive knowledge of the Calgary soil conditions to develop and construct the shoring solution. A perched secant caisson wall held with post-tensioned gravel and rock anchors was extended 10 ft into the bedrock and a 3 inch thick paneled shotcrete system was continued in the excavated rock face below the caisson wall to the final excavation depth.

Throughout the excavation, precision monitoring was performed by RWH Monitoring and the results were continuously reviewed to verify the performance of the shoring. An observational approach was taken by updating the numerical models with the monitoring data at various stages of the excavation to confirm expected shoring movements.

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Past Practice in Calgary

The soil conditions in downtown Calgary consist of 20 to 30 ft of poorly graded gravels with cobbles, boulders with few fines. The overburden overlays bedrock known geologically as the Porcupine Hills Formation and is comprised of predominantly mudstone, with the upper 3 to 13 ft of the rock surface being weathered.

Typically in downtown Calgary shoring has been completed with full depth piles and timber lagging systems that extend through the overburden and into the mudstone bedrock beneath the base of the excavation. Installing timber lagging boards in this material is challenging and often leads to sloughing behind the shoring due to loss of material during installation or the migration of soil and piping up the back of the shoring when water is introduced behind the lagging. Furthermore, lagging boards allow water to filter through into the excavation where it must then be managed and pumped out of the site. The use of full depth piles for the Herald Block project would have not been cost effective due to the depth of excavation. Piles would have been too long to ship to site in one piece, which would have required all piles to be spliced onsite prior to installation. Typically with piles and lagging where there is overburden over extensive bedrock lagging is installed to 3 ft into the rock and the remaining rock is left open between the soldier piles. However, unlike other places in Canada, the mudstone bedrock in Calgary is very weak and often contains softer layers requiring it to be supported with lagging the entire depth of the excavation.

Innovative Shoring Approach

Using their previous experience on The Bow Tower shoring project, HCM implemented a perched caisson wall over shotcrete shoring system as this system has many advantages over typical shoring practices in downtown Calgary. The perched caisson wall eliminated the need to splice piles as the piles only extended 10 ft into the bedrock, resulting in an average pile length of 40 ft. Ground loss and water infiltration in the overburden were managed through the caisson wall system. Piles and fillers were drilled with casing to ensure zero ground loss while providing a predominately water tight system which significantly reduced the water inflow rate into the excavation. Beneath the perched caisson wall 3 inch of shotcrete with tiebacks were installed in a panel sequence to manage the weak mudstone. The use of the shotcrete in the rock allowed for the excavation to be adjusted as required for a more accurate shoring face at larger depths to facilitate the one-sided forming of the structure. This was an important advantage as the face of excavation needed to be adjusted for the rock expansion and shear band movements. Further, this system was not subject to pile alignment issues into and out of the excavation which is an issue common to large depth pile systems. The perched caisson wall system brought significant benefits to the project.

Construction Process

The construction of the shoring system began on October 2013 with the installation of the secant caisson wall. Three Bauer* BG24 rigs were used to employ 34 inch diameter sectional casing in order to drill through 20 to 30 ft of gravel overburden consisting of cobbles and boulders and existing building foundations. Refer to Figure 1. The piles were socketed a minimum of 10 ft into the bedrock and the toes were enriched with cement to increase the concrete strength to 2200 psi to increase the strength and stability of the pile toe. Fillers were extended 3 ft into the rock to help minimize groundwater seepage into the excavation. A three filler caisson wall sequence was followed, installing W21x55 piles on 9.5 ft spacing. The drilling was carefully scheduled to install over 500 pile and fillers, while ensuring the correct sequencing was maintained.

The perched caisson wall consisted of one to three rows of anchors extending into the gravel or rock depending on the depth of overburden. On each pile a toe pin was located 2 ft below the top of rock to lock in the pile toe prior to excavating beneath it and removing the passive resistance

Below the caisson wall, a 3 inch thick shotcrete shoring system was continued in the rock to the final excavation depth. Five to six rows of anchors were spaced on a 10 ft horizontal and 6.5 ft vertical panel sequence. Panels were carefully excavated, meshed and shotcrete applied on the same day to minimize any material loss and deterioration of the mudstone due to the elements of the weather. Additionally, HCM used a rotary mill to trim the excavation face to minimize the disturbance of the rock. The shotcrete rock protection covered over 44000 ft^2 and was held back by over 620 anchors. Each anchor was precisely stressed and locked-off to confirm adherence to the design.

Figure 1 - Bauer BG24 piling rig.

Monitoring

RWH Monitoring completed the precision monitoring on the Herald Block project and the scope of services included total station surveying and subsurface monitoring using inclinometers and extensometers. The LRT tracks adjacent to the south shoring wall were monitored by a third party using precision laser scanning. The complete monitoring system included 425 survey targets, 30 settlement points, 9 extensometers, 6 inclinometers, and 3D point cloud scanning system. Figure 2 outlines the monitoring plan and

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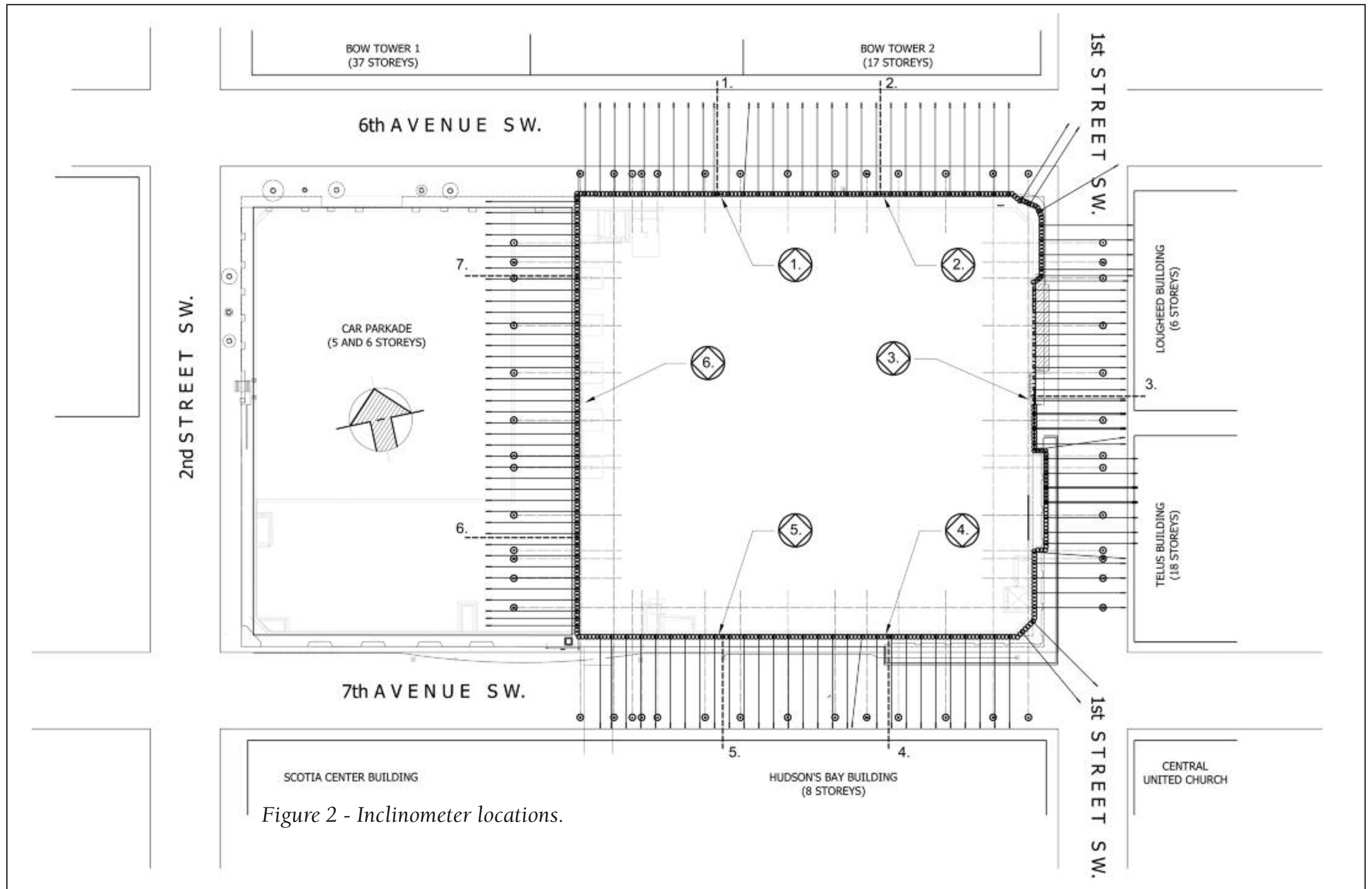

Figure 2 - Inclinometer locations.

the buildings surrounding the site.

The adjacent buildings and shoring walls were set up with survey targets which compared the readings to the baseline positions to determine the horizontal movement and settlement of the shoring and the structures in the zone of influence of the shoring. Settlement points used a similar technique to survey targets to determine the settlement of the adjacent roadways. Inclinometers and extensometers determined the subsurface deformations behind the shoring wall.

The precision scanning creates an as-built model of the adjacent railway from high density 3D point cloud data. Cross-sections from the reading's model were taken every 20 ft along the tracks and then compared to the baseline model. The LRT rails were analyzed for settlement that may affect the performance of the passenger trains.

Monitoring readings were completed weekly or more frequently at the discretion of RWH. By taking on the increased scope of the monitoring services, this allowed RWH to have flexibility in frequency and the ability to review and address movements with the project team concurrently with the excavation activities. RWH provided weekly monitoring reports for submission to outside stakeholders to allow for ongoing discussion on how to proceed going forward.

The results of the inclinometer reports indicated there were three distinct types of shoring movements contributing to the total deflection of the shoring. The shoring experienced typical soil deflection in the overburden of the perched caisson wall, as seen in most shoring systems. The increased deflections seen were due to the rock expansion caused by the release of locked-in stresses in bedrock and the shear band movement resulting in a shift of the shoring wall. Together the rock expansion and presence of the shear band attributed to approximately 1 to 1.25 inch of horizontal shoring movement. The shoring behavior can be seen in north wall inclinometer results in Figure 3.

The extensometer report showed the movements propagated beyond the excavation, which confirmed the theory the shoring shifted as a block. A sample of the extensometer results are shown in Figure 4. This was further confirmed by the lift-off tests conducted on the top row of anchors where it was seen the gravel anchors were within the design load limits, while it has been reported on previous projects in the area that rock anchors increased from the lock-off design load.

Finite Element Analysis

During the design stage, extensive FEM modelling (see Figure 5) was completed to provide predictive movements of the shoring. RWH reviewed several shoring schemes including the full length piles with timber lagging and perched caisson wall over shotcrete. The analyses determined there was minimal to no benefit to the full length piles which is often viewed as the stiffer system. The conclusion was 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. The only published shearband presence was at The Bow Tower excavation where it was located at elevation 1021 m (3349 ft). The final excavation depth of The Bow was elevation 1026 m (3366 ft) and even though the shearband was located beneath the base of the excavation there was still approximately 1 inch of horizontal movement. Refer to Figure 6 for The Bow inclinometer. RWH designed the shoring and completed a finite element analysis locating the shearband at elevation 1021 m (3349 ft) with the final excavation depth at elevation 1025 m (3363 ft). After the caisson wall was installed six inclinometers were drilled through selected filler piles to 33 ft below the base of the excavation. Once the inclinometers were installed and initialized, excavation commenced and it only took 22 to 33 ft of the 72 ft excavation until the presence of a shearband became evident in the north inclinometer. The location of the shearband was indicated at elevation 1027 m (3369 ft), 20 ft higher than RWH anticipated based on the review of The Bow. Refer to the east wall inclinometer in Figure 7. The 20 ft change in elevation was considered significant as Herald Block is located only 650 ft from The Bow. The change in location of the shearband had a dramatic effect on the FEM predicted shoring deflection.

Throughout the excavation an observational approach was taken to verify the FEM modelling. HCM was able to use their in-house engineering company RWH, in conjunction with RWH Monitoring, to continuously input the results of the inclinometer and target monitoring data into the FEM model and provide deflection predictions to interested stakeholders in order to assist in decisions regarding the potential impact on adjacent structures.

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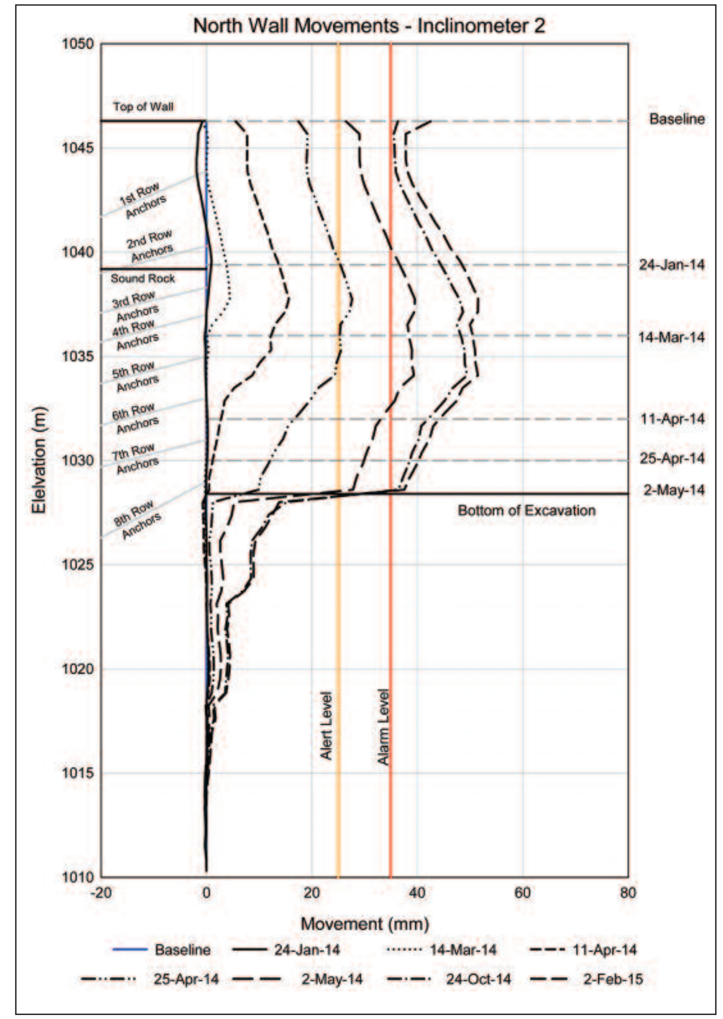

Figure 3 - Herald Block north wall inclinometer.

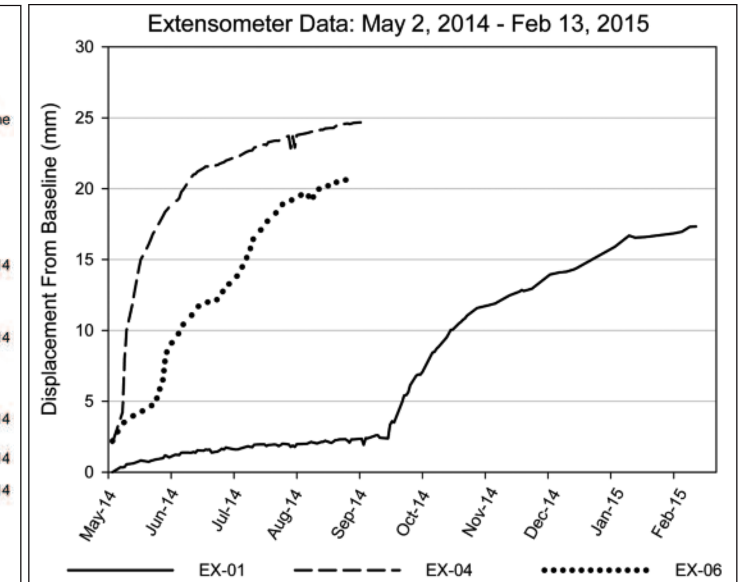

Figure 4 - Extensometer.

During construction the shoring incurred larger movements than anticipated as the shearband was located at a higher elevation than assumed. The south shoring wall was the last part of the site to be excavated and was located directly next to the Calgary LRT and the Bay Department Store. RWH performed a back analysis using the monitoring results from the north wall to determine potential movement outcomes that may occur when excavating to final depth. Presenting these potential outcomes HCM and RWH worked with the owner's representative to come to an agreeable solution with everyone having a clear understanding of the movement risks.

Risk of Shoring in Calgary

The rock composition in Calgary creates a risk in shoring at these depths. Within the mudstone there are weak zones and well as local shearband layers. The shearband is a thin layer comprised of clay slickensides with low shear strength and friction value which results in progressive failure of the weathered mudstone that propagates movements. It has been reported deformations may extend as far back as three to four times the vertical height of the bedrock excavation beyond the shoring face during the unloading of lateral support of overburden soil and rock during excavation. Shearbands are not able to be located using conventional geotechnical techniques and soil sampling. The performance of the shoring and movements are largely affected by the behavior of the rock as the main mechanisms that govern the shoring behavior are the locked-in rock stresses and the presence of a shearband. Without knowing the location of the shearband or the possibility of a shearband occurrence makes it challenging to determine shoring performance and impacts on the surrounding infrastructure. The owner on this project understood the risks and was willing to support and work with HCM along with RWH to get to the bottom of the excavation rather than take the approach that it was

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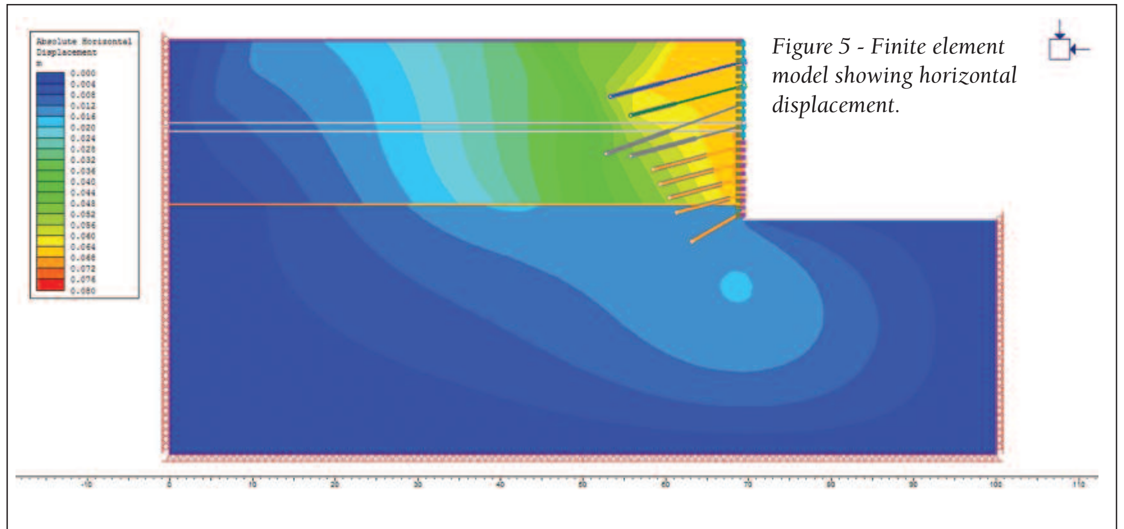

Figure 5 - Finite element model showing horizontal displacement.

a Design-Build problem. Completing deep excavations in Calgary with an owner who puts the risk completely on the contractor may lead to the shoring contractor dealing with severe financial impacts. Owners must be aware when constructing deep excavations in urban Calgary rock expansion that shearbands are something that cannot necessarily be retrained using conventional shoring methods.

Conclusion

Calgary can be a high risk area to design and install shoring. Geotechnical reports are not able to present the governing risks in shoring design for deep excavations into the bedrock. It is, therefore, important for the Design-Build contractor to work with the owner and their representatives to provide prudent solutions while ensuring that the owner is aware of the excavation risk. With so many unknowns regarding the way the mudstone bedrock will deform it is unreasonable for the shoring contractor to hold all the risk on the performance of the shoring and the effect it will have on the neighboring infrastructure.

At time of tender and commencement of construction the shearband was assumed at one location as the inclination was unknown and was expected to cause certain deflections. However, during construction the true location of the shearband became evident in the inclinometers and the change in condition had an effect of approximately 0.75 inch of additional movement. Shoring deformations become largely affected by the shearband and knowing the true inclination of the shearband is not feasible.

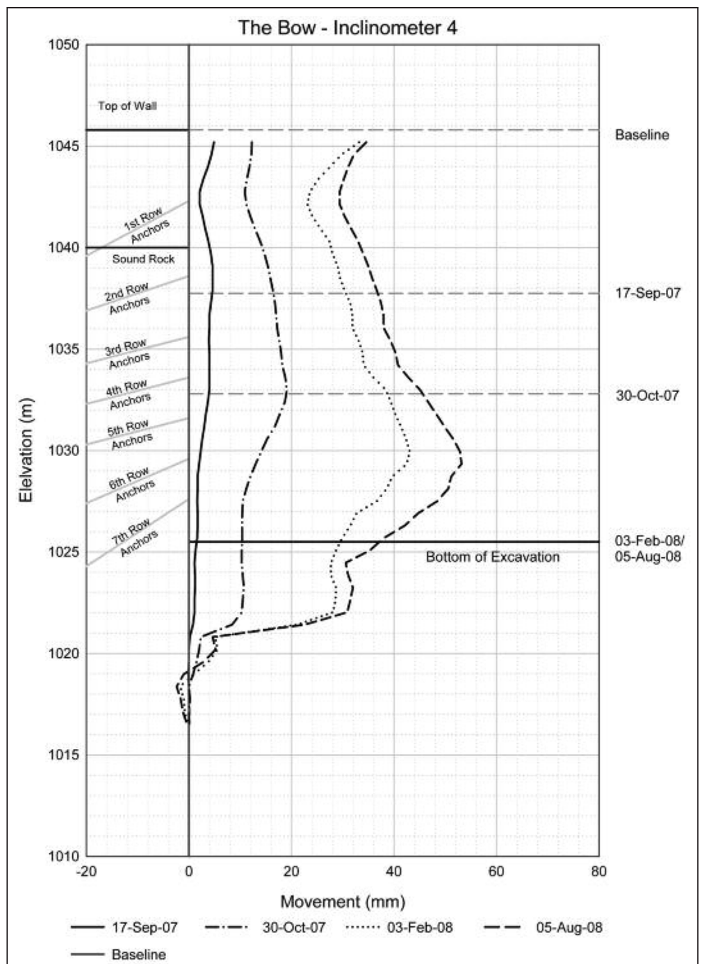

Figure 6 - The Bow Tower inclinometer 4.

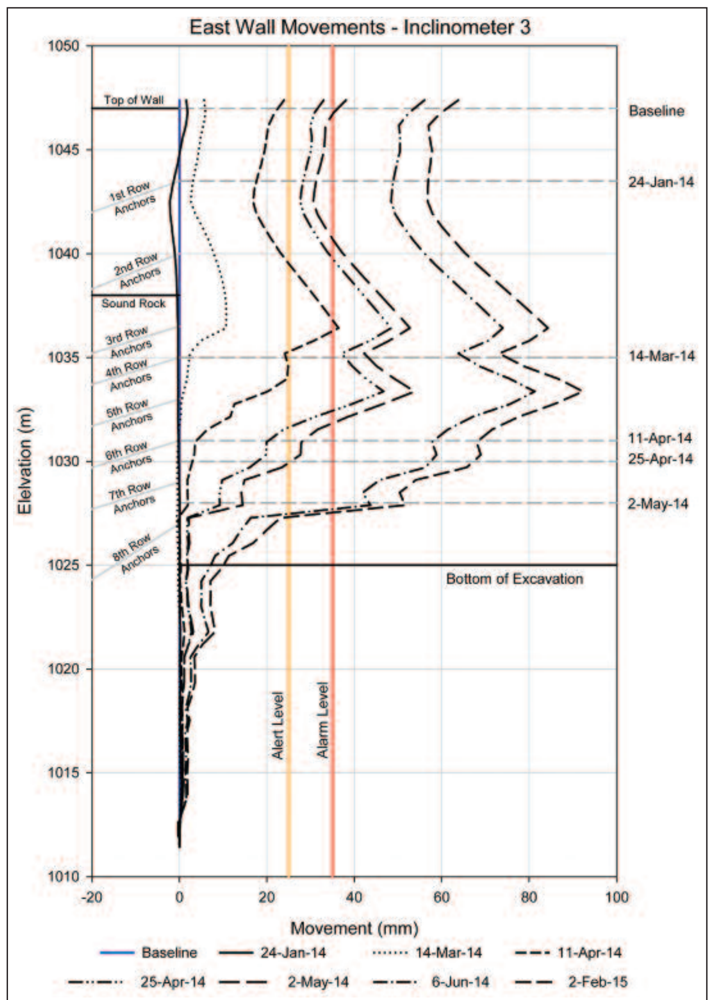

Figure 7 - Herald Block east wall inclinometer.

HCM, along with RWH, designed and implemented a perched caisson wall over a shotcrete shoring system on the Herald Block project by applying knowledge learned through previous experience constructing in the area. The final shoring solution offered key practical benefits, while providing economical and schedule savings to the overall project.

HCM recently began construction on the Telus Sky Project in downtown Calgary located adjacent to The Bow Tower project site. The excavation will extend 23 ft deeper than Herald Block to a final depth of 96 ft and includes zero-clearance shotcrete underpinning beneath the existing Telus building. RWH has completed extensive finite element modeling which will create the basis of a future article.

**Indicates ADSC Member.*

ADSC

Project Team

Project Manager: HCM Contractors Inc.* – Craig Rowe, P.Eng., Geoff Jilg

Shoring Engineer: RWH Engineering Inc. – Jason Weck, MESc, P.Eng., Kailey DenBraber, EIT, Denis Kondratenko, MESc, P.Eng.

Monitoring: RWH Engineering Inc. – Brendan Lemieux, P.Eng., Mike Janzen, EIT, Murray Down, EIT

Construction Manager: EllisDon Construction Services Inc. – Brad Storey, P.Eng.

Owner: Brookfield Properties Management Corporation

Consultant: Dialog

**Indicates ADSC Member*