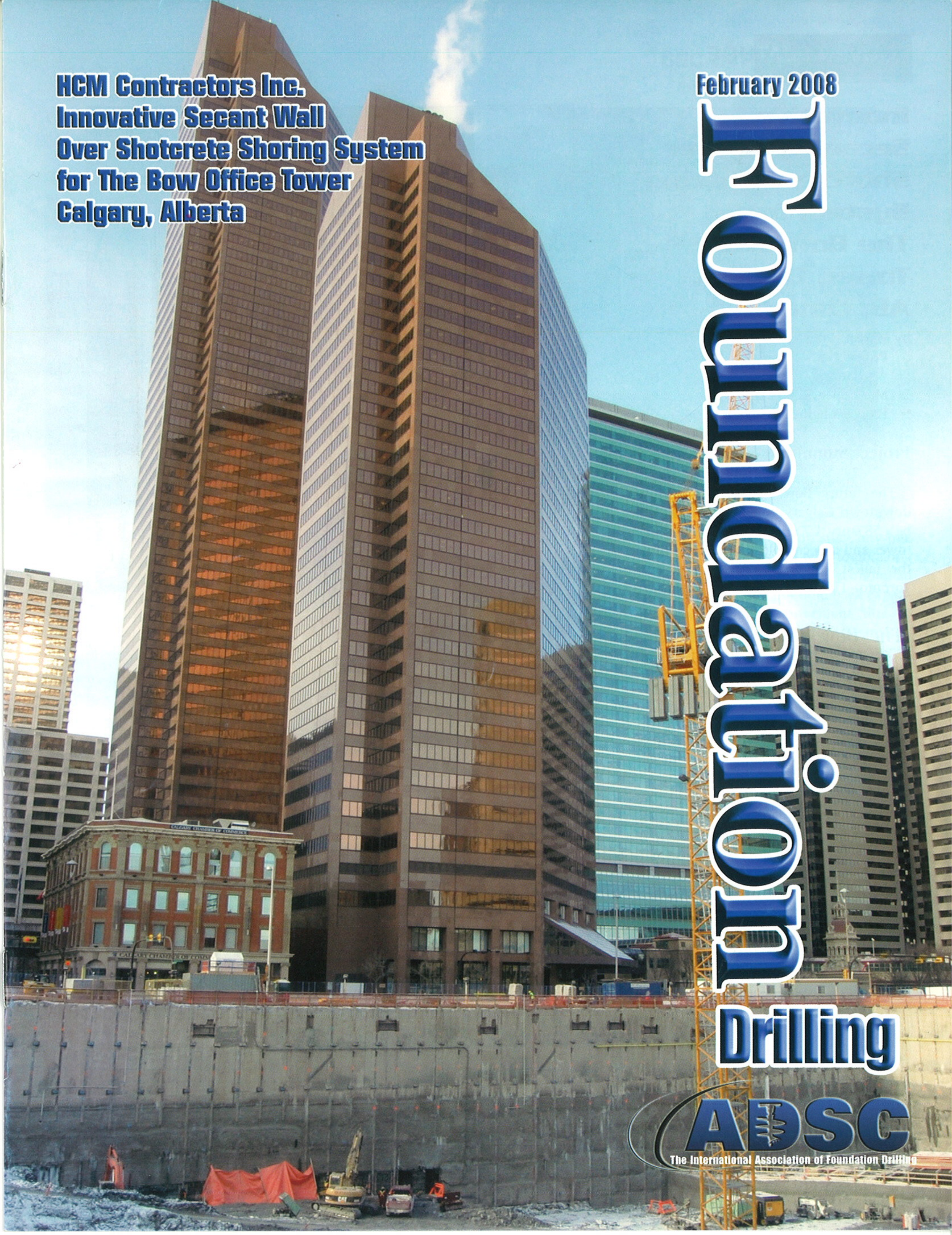

Foundation Drilling

February 2008

HCM Contractors Inc. Innovative Secant Wall Over Shotcrete Shoring System for The Bow Office Tower Calgary, Alberta

ADSC
The International Association of Foundation Drilling

Innovative Secant Wall Over Shotcrete Shoring System for The Bow Office Tower, Calgary, AB, Canada

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Project Summary

The future Bow building, located in downtown Calgary, Alberta, Canada, will be a 58 story, 1.7 million square foot office tower and arts complex. The Bow will be the tallest building in Canada west of Toronto. The Bow will be an impressive

The Bow will be the tallest building in Canada west of Toronto.

addition to the Calgary skyline and serve as a catalyst to redevelop the east side of Calgary's downtown. The energy efficient design, which employs aerodynamic building geometry, natural light, natural ventilation, and other energy saving measures, is expected to reduce energy use by about 30 percent compared over conventional tower design. The Bow's developer, Matthews Southwest of Dallas, Texas, hired a leading team of European Architects to arrive at a building design that is both unique and functional. The Bow building will be the new headquarters for EnCana, a leading Alberta-based oil and gas company. Fueling the construction boom in Calgary is the northern Alberta tar sands development. The building foundation will be 70 ft. deep, providing 6 levels of underground parking and have a footprint of nearly 2 city blocks, including the complete removal and reconstruction of 6th Avenue S.E.

Northwest corner of the site where special shoring was constructed for forming of The Bow raft slab on grade.

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The excavation is developed in the difficult soil and bedrock conditions typical of downtown Calgary. The site geology is composed of 15 to 30 ft. of water-bearing poorly graded gravels, cobbles and boulders, which overlay bedrock highly susceptible to weathering under contact with water and oxygen. The HCM/Isherwood design/build team constructed a unique anchored shoring system composed of a secant pile wall which transitions into shotcrete at a depth of 30 ft to overcome the challenges presented. An advanced monitoring program was used to verify design assumptions and ensure performance of the shoring wall.

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Concerns with Conventional Shoring Techniques

The as-tendered excavation shoring proposal for the Bow building called for full depth piles with a combination of secant walls near the existing buildings and timber lagging away from the buildings. The history of lagging in Calgary gravels is one of significant ground loss and water seepage at the rock interface. The ground losses generally result in excess movement of adjacent structures and water seepage causes significant weathering and weakening of the rock face. These conditions create significant construction difficulties associated with ground loss and movements. The HCM/Isherwood secant wall over shotcrete (SWOS) design was able to avoid lagging related ground loss reducing site dewatering issues and the other problems attributed to freezing winter conditions in Calgary, Alberta.

Efficient Solutions in Design and Construction

The HCM/Isherwood project team proposed a design/build excavation support solution to fit the challenging soil conditions that exist in downtown Calgary. The shoring system was designed to effectively mitigate the troublesome Calgary soil and bedrock conditions, and to economically control movement of adjacent structures.

Two of the major issues the shoring solutions addressed include: difficult excavation and drilling through water-bearing, poorly-graded gravels, cobbles and boulders, and excavation and support of the predominantly weak mudstone bedrock with layered siltstone and sandstone seams. The weak mudstone is susceptible to severe weathering under contact with water and oxygen. The HCM/Isherwood project team designed and constructed a continuous caisson secant wall through the gravel, penetrating into the weathered rock (to a depth of 30 - 34 ft.), integrated with an underlying anchored shotcrete shoring system below to a depth of up to 70 ft. The shotcrete utilizes post-tensioned anchors to effectively preload the rock formation into a stable mass. This innovative shoring solution was well suited to the variable soil conditions of Calgary while saving the developer approximately $2 million in construction costs.

Casagrande B250 and Bauer BH-24H drilling first sequence of secant wall.

Controlling settlement of surrounding structures was the main concern of all the stakeholders. The presence of high horizontal rock stress and shear bands in the lower rock layers made movement prediction difficult. While the project team judged the ground loss in the overburden as controllable, the historical movements due to shear band effect in the rock were deemed impossible to stop since any pile or anchor system would tend to go along for the ride. Similarly an economical anchor design could not hold back expansion induced rock movement due to release of locked in horizontal stresses. Historically, movements of deep excavations could approach 100 mm. The observational method is used for the design, which relies upon detailed monitoring of the ground movements with continuous evaluation and comparison to predictions

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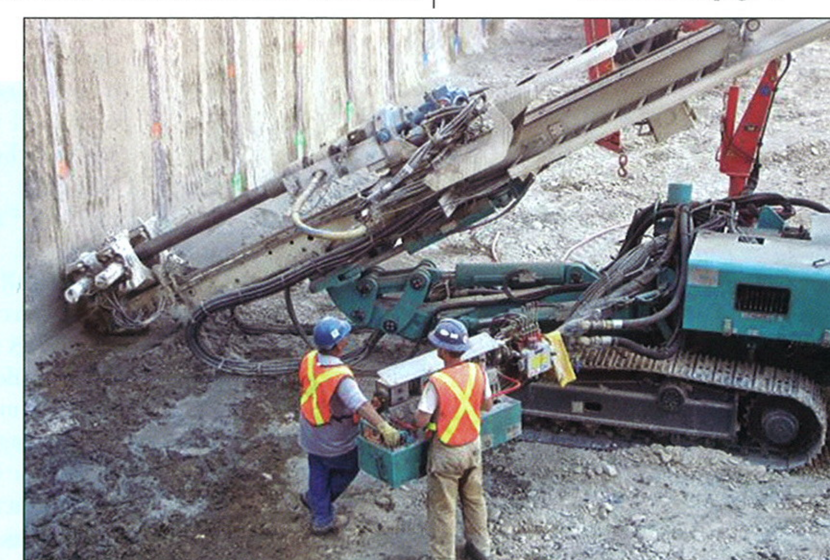

Casagrande M9 drilling for top row anchors in secant wall.

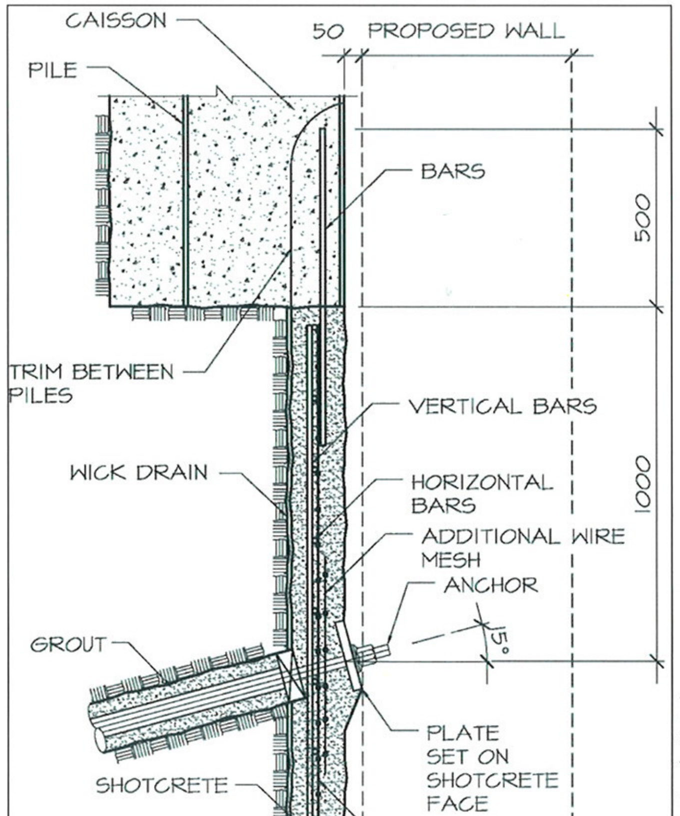

Figure 1. Soldier pile and shotcrete interface detail.

HCM rotary cutter trimming secant wall flush and preparing transition to shotcrete.

throughout construction. Design anchor preloads were lowered and lift off tests conducted throughout construction to confirm no anchor yielding events would take place. Additionally, an in-depth monitoring program was executed throughout the life of the project to verify design assumptions and to ensure movements were within expected ranges.

Secant Wall Over Shotcrete (SWOS) Method of Shoring

The Bow shoring solution consisted of anchored interlocking secant wall in the upper gravel overburden combined with an anchored shotcrete wall in the rock materials. The secant wall was constructed with W18 x 45 soldier piles at 2100 mm (7 ft.) spacing, set in 5 MPa (725 psi) concrete. Filler piles and soldier piles were installed to approximately 30 ft. below existing grade, ensuring a minimum penetration of 6 ft. into the weathered rock, sealing the water in the gravel and eliminating all upper ground loss. A 200 mm (8") interlock was used on 880 mm (35") caissons. Secant walls received two rows of Williams* 1-3/8" diameter Grade 150 bar anchors, designed to control earth pressures and develop significant wall-soil friction to support the vertical weight of the secant wall. Additional vertical capacity of the caisson wall was achieved by extending every second filler pile 8 to 10 ft. below the neighboring soldier pile and fortifying the concrete toe with extra cement mixed in-situ. The transition zone from secant wall to shotcrete wall was carefully designed and built as shown in Figure 1.

The shotcrete wall was constructed below the caisson wall into the layered bedrock. Five lifts of anchors were installed over the final 30 – 35 ft. of excavation, consisting of #11 Grade 75 bars spaced at 10 ft. centers. Shotcrete application was conducted between 24 - 48 hours after trimming to prevent excessive weathering and exposure to the elements. Wick drains and drainage board were employed to relieve localized water in the rock layers and prevent erosion of the rock face behind the shotcrete.

West wall trimmed and ready for second row anchor installation.

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Special considerations for this innovative shoring solution included:

- Two-dimensional Fast Lagrangian Analysis of Continua (FLAC) was used to predict wall movements and anchor loads under the proposed anchored shoring scheme. The analysis was conducted in stages with results providing soil stress and strain, tie back load, structure displacements, axial, shear, and moment forces.
- Sequencing of the caisson wall drilling operation to keep two full size self-casing drills operating at optimum productivity, as well as meeting the construction manager's requirements for scheduling of other trades.
- Alert and Action-level deflection parameters were set to allow the design/build team to react with supplementary construction measures to higher than anticipated movements.

Raft slab construction using shotcrete shoring.

Site Conditions

The soil conditions on the site generally consist of either fill and/or fluvial deposits within the upper 6 to 10 ft. of the site which were, in turn, underlain by gravel to depths between 20 and 30 ft. below original grade. Underlying the gravel is the Calgary bedrock, the most important stratum in the geological profile. The local bedrock formation in downtown Calgary is a freshwater sedimentary deposit, the Paskapoo Formation that, although known geologically as shale, exhibits more "soil-like" than "rock-like" properties. The rock is fragmented with subordinate lenses and/or layers of moderately indurate siltstone and sandstone. Generally, the cementing agent in this type of rock formation is clay, and thus, the mudstone, when in a state of rebound and exposed to water, has a tendency to revert to the soil type comprising the bedrock. In-situ horizontal stresses up to twice the vertical stress (Ko = 2) have been back-calculated at nearby sites downtown. Another concern for the construction team was the potential for shear band propagation along weak layers of mudstone that are known to have low residual strengths. These layers naturally exist at an elevated stress state that is near the rock's yield strength due to the high in-situ horizontal stresses.

6th Avenue divided the north and south halves of the site. Removal of the roadway required special construction phasing early in the project. Timely reinstatement is a top priority of the construction schedule. The St. Regis Hotel and No. 1 Royal Canadian Legion building are located immediately adjacent to the new Bow foundation at the south east corner of the site and bear on spread footings founded between 10 and 15 ft. below original grade. The Andrew Davison building is founded on a bedrock-supported raft slab along the east side of the excavation. The location of these existing structures required that special consideration

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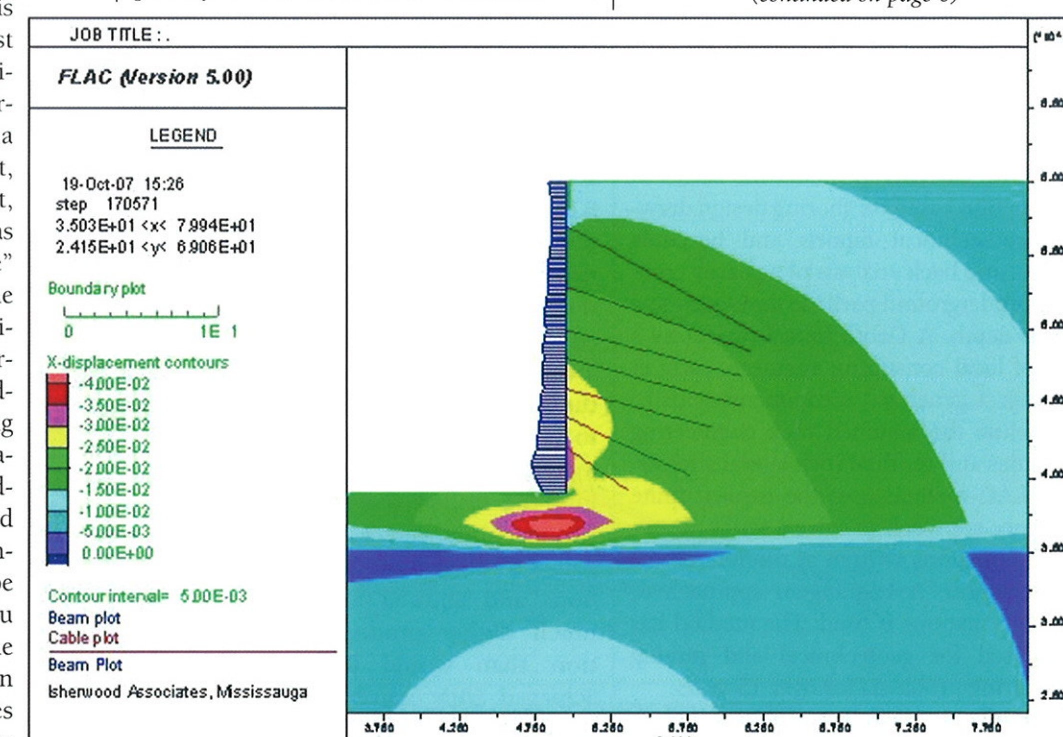

Figure 2. Predicted lateral wall and soil displacements using FLAC.

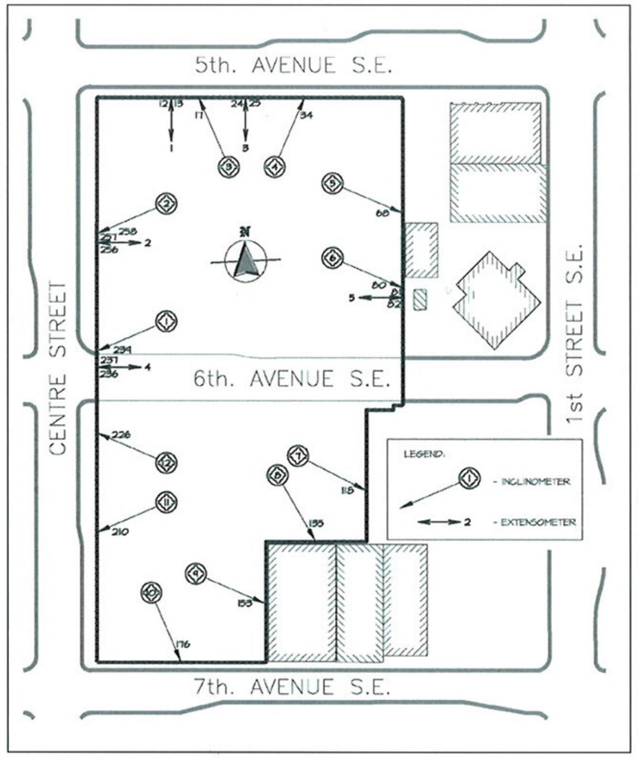

Figure 3. Plan view of instrument locations.

be taken when planning the length, angles and spacing for the top anchors in the secant wall. Two rows of self-drilling Titan 40/20 hollow bars supplied by Con-Tech Systems* were installed near the Andrew Davison building where there was insufficient clearance to install a full-length top anchor.

Numerical Modeling

Isherwood Associates completed numerous FLAC analyses to model the stages of construction based on shoring design drawings, geotechnical reports and borehole records, and back analysis of a nearby completed underground parkade developed to a similar depth. A Geotechnical review by a team of local consulting engineers early in the project generated recommendations to help refine the assumed rock engineering properties and residual rock lateral stresses. The FLAC method uses the explicit finite difference approach to solve a series of governing equations written at discrete points within a grid. A Lagrangian approach to grid deformations is used. The method has been used for geotechnical and mining engineering problems for over 15 years.

Four different modeling scenarios included the following parametric analyses:

- Ko = 0.6, no shear band (baseline)
- Increased lateral rock stress, Ko = 2.0
- Weak shear band with approximately 5% the strength of neighboring sound rock at various depths below original grade,
- Combined elevated lateral rock stress and shear band effects at depth

Results of the modeling provided predicted soldier pile and caisson wall lateral and vertical movements, bending moment, axial load, anchor axial load and soil movements and stresses. Figure 2 is a sample section showing predicted wall and soil deformations due to a possible shear band at 25 m (82 ft.) depth.

Construction

HCM Contractors began construction in early June 2007 with installation of secant wall piles. Two European track-mounted drill rigs were purchased specifically for this job; a Bauer* BG-24H and Casagrande* B250. Site soil conditions generally required the careful use of sectional Leffer style bolted casing through the localized cobbles and the perched water table to avoid caving and ingress of groundwater into the drilled shafts. The machines were well suited to the soil conditions and allowed for much higher production than would be achieved with conventional drills, which in the Calgary gravels, would typically require double and triple telescoping casing to handle standard temporary caisson liners to depths of 30 ft. The secant wall shafts were drilled in a leapfrog fashion that allowed for 'closing' shafts to be installed before neighboring piles had cured to full strength. This also provided for excavation and tie-back installation to proceed as soon as possible. HCM undertook several additional responsibilities on the project to ensure high quality installation and performance of the shoring including: secant pile and anchor layout, trimming of the secant wall and rock berms using two 20 ton excavators equipped with a variety of tools including a hydraulic rotary cutter, and partnership with Monir in collecting monitoring data from inclinometers, extensometers and total station targets.

A post-tender design modification required that 44 soldier piles be drilled to full depth to carry construction loads from an umbrella steel staging platform.

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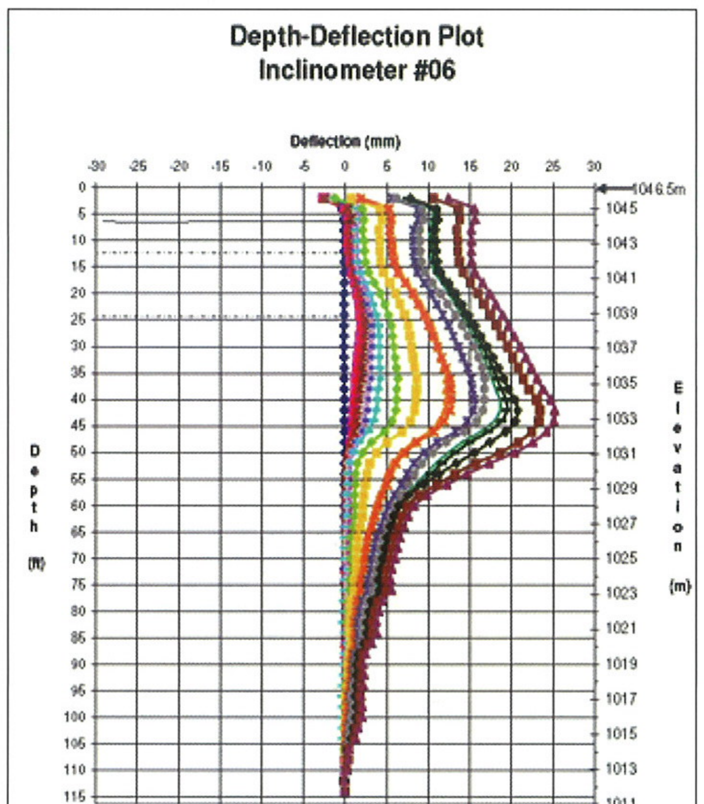

Figure 4. Lateral displacement of wall measured by inclinometer #06.

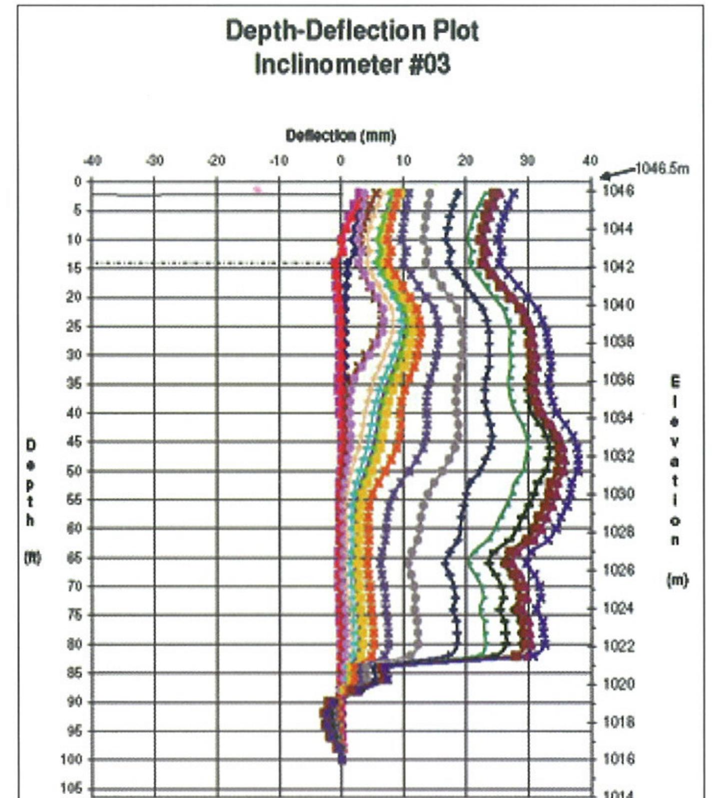

Figure 5. Effect of deep-seated shear band on lateral displacement of north wall.

The exterior of the platform is to be supported by the secant wall and will facilitate structural steel erection for the Bow Tower. These piles were installed in pairs and outfitted with a horizontal 'saddle' beam designed to support steel rafters at variable distances below the top of secant wall. The saddle beams were installed within the secant wall space by both excavator mill and hand chipping of the 5 MPA (725 psi) secant pile concrete to expose the inside face of the pile web and flange where the welding connections were made.

The construction manager's scheduling required initial excavation to be concentrated mainly in the north block of the site to enable placement of the critical path building raft slab on the lower rock formation. The tie-back anchors were installed by two Casagrande M9 hydraulic rotary drills. Two AirTrac drills were added for anchor production goals, once excavation had advanced into the sound rock. The AirTrac drills could produce open holes, as opposed to the top anchors which were advanced with casing through the gravel and the cobbled overburden into the rock below. Careful control of shotcrete wall movements was achieved by using a double benching procedure. As the project progressed and the design-build team became familiar with the condition of the bedrock, shotcrete trimming procedures were modified from two-panel sequencing to ribbon cutting.

Monitoring

The probability of significant lateral earth pressures and weak shear band effects in the layered rock presented unacceptable risk to the project team. Therefore, a monitoring program was implemented to provide reliable information pertaining to shoring performance and the behavior of the rock mass as excavation proceeded. The information was integrated with the FLAC analysis permitting refinement of the design and adjustment in the field during construction (Terzaghi's Observational Method).The program included 12 No. 35 m (115 ft.) deep inclinometers, 10 No. 25 m (82 ft.) long extensometers (at rock level), tie back lift off testing and precision survey targets on multiple elevation levels. Please refer to Figure 3 for instrument locations.

The inclinometers were drilled adjacent to piles by drilling through the secant wall and well into the bedrock below the final

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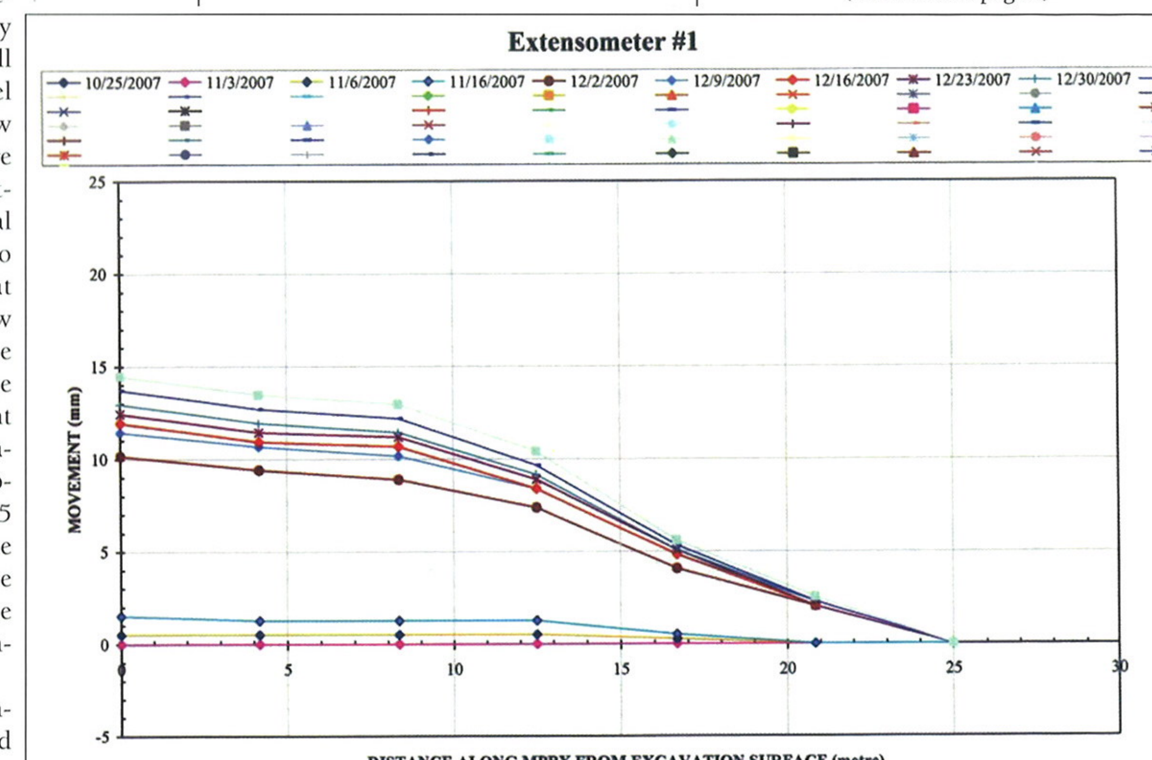

Figure 6. Rock expansion behind north wall measured by extensometer #01.

PROJECT TEAM

Shoring Design Build Contractor:	HCM Contractors Inc., ADSC Contractor Member Martin Halliwell, P. Eng., Project Manager Jeff Gibbs – Site Superintendent Ed Oram – Site Superintendent
Shoring Designer:	Isherwood Associates, ADSC Technical Affiliate Matthew Janes, P. Eng., Project Mgr. Tom Lardner, E.I.T., – Project Engineer
Monitoring:	Monir Precision Monitoring Ivan Barua, – Project Manager
Construction Manager:	Ledcor Construction Mike Michalezki – Construction Manager Jim Beeton, C.E.T. – Project Manager
Geotechnical Design:	AMEC Earth & Environmental Limited Kelly Johnson, E.I.T. – Project Manager

excavation grade. The inclinometers were read weekly.

Figure 4 illustrates the profile of inclinometer #06 and is the cumulative displacement from the bottom of inclinometer to the top and compared to initial readings; the plot shows a maximum movement of roughly 25 mm (1.0"). The consistency of the readings below the excavation validates the data collected. As modeled by several FLAC analyses, Figure 5 shows the profile of inclinometer #03 and represents the effect of the shear band movement within the bedrock.

The 10 SMART (Stretch Measurement to Assess Reinforcement Tension) multi point borehole extensometers from Mine Design Technologies were installed at a shallow inclination just below the surface of the rock at various locations in the SWOS wall, as shown in Figure 3. Each extensometer is a modified cable which has six anchor points, evenly spaced along the length of the 25 m (82 ft.) instrument. The installation of each extensometer was done through a hole drilled on the face of the excavation, inserting the cable into the hole and grouted in place with a mix designed to have similar properties to native material.

As expected the points near the face of the excavation showed the greatest movement. In the case of extensometer #01, as shown in Figure 6, the node closest to the wall showed a displacement of 14.5 mm (0.57"), in contrast with the deepest node, which showed no movement.

Shoring Performance

Maximum shoring wall movement on the project at the time of authoring was 60 mm (2.4") as detected by the inclinometers and precision survey. The secant wall alignment was set back 50 mm (2.0") to allow for some movement without narrowing of the final wall assembly. The typical inclinometer showed more movement in the rock and less in the gravels, due to approximately 25 - 50 mm (1-2") of shear band effect. Anchor loads showed moderate to high increase on preloads during lift offs. Extensometers indicated a good distribution of the rock expansion into the excavation to a distance of 25 m (82 ft.) from the shoring face. The movement distribution resulted in no sudden anchor breaks or anchor preload increases, due in large part to the design of the rock mass block anchoring.

Summary

The innovative SWOS shoring system is proving to be well suited to the geological profile found in Calgary, Alberta. The shoring system has demonstrated the ability to efficiently develop through the wet gravels while economically controlling structural movements due to ground loss. Factors that contribute to the ongoing success of the project include the ability accurately model shoring wall deformations and associated loads and stresses, the diligent construction of the design/build shoring solution and the careful observation of the movements of the shoring wall and expansive rock formation.

**Indicates ADSC Associate Members.*■