HCM's Innovative Excavation Support System for Canadian High Rise

by Jason Weck, Martin Halliwell and Craig Rowe

West wall of excavation.

Project Summary

The Hill Centre Tower III project is located in downtown Regina in the province of Saskatchewan, Canada. The 20 story Tower is the most dramatic change in Regina's skyline in the past 20 years and is located on the corner of 12th Avenue and Hamilton Street. The foundations for the Tower are as deep as 9.1m (30ft), providing two levels of underground parking.

The main tenant is slated to be the Mosaic Company, who will be occupying the upper floors of the new building. Mosaic Company is the world's largest producer and marketer of concentrated potash and phosphate.

The Hill Centre Tower III developer, Harvard Developments, Inc., took advantage of the low vacancy rate in office buildings in Regina, to construct a class 'A' office tower. The low vacancy rates

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The award for the project came on September 6, 2010, and had an aggressive timeline set by the developer. ADSC Contractor Member firm, HCM Contractors, along with RWH Engineering, Inc., started design immediately.

The soils within the upper 9.1m (30ft) were fairly homogenous and consisted of high plasticity clay with some silt. The soils were moist with estimated shear strength of 150kPa (3100psf). The water content of the clay stratum ranged from 33% to 39%, which is above its plastic limit of 22% to 25%. Below the silty clay was a hard unoxidized till, which extended beyond a depth of 25m (82ft).

RWH Engineering, Inc.

RWH Engineering, Inc., (RWH) is part of the HC Group of companies, which was established in 2009 by Craig Rowe, P.Eng., Jason Weck, P.Eng., and Martin Halliwell, P.Eng. RWH is a fully licensed, in-house design firm who works solely for HCM Contractors (HCM) and HC Matcon, Inc. The firm was established to service HCM projects efficiently, providing both schedule benefits and innovation in the contractor companies. RWH was the shoring engineer for the Hill Centre Tower III project. In addition to being the shoring engineer, RWH performed the precision monitoring and QA/QC.

Project Schedule

This project was tendered in August 2010 with an aggressive timeline for completion. The award was given to HCM on September 6, 2010. HCM engaged RWH, and the shoring design commenced. RWH worked closely with J.C. Kenyon Engineering

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(JCK) to resolve concerns with the tendered drawings that benefited both firms, as well as the owner. RWH issued engineered shop drawings for review on September 20, 2010, and on September 30th, HCM began the drilling for installation of the drilled shafts.

Project Timeline

- August 3, 2010, project tendered
- September 6, 2010, project awarded
- September 20, 2010, RWH completed first revision of shoring drawings
- September 30, 2010, HCM begins drilling for drilled shafts
- February 4, 2011, all shoring and all drilled shafts complete.

Figure 1: Installing high capacity tiebacks on north wall.

Concerns with Conventional Shoring Techniques

The as-tendered excavation shoring proposal for the Tower III building depicted soldier piles and timber lagging on the east and south sides, a secant pile wall was on the west, and a permanent 30MPa (4350psi) secant pile wall with rebar cages on the north

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side with a single row of tiebacks.

HCM was concerned about the time constraints to install a single row of highly loaded tieback connections or use multiple levels of tiebacks. In addition to shoring, deep belled drilled shafts were required for the building foundation.

The shoring and excavation was to be carried out in the winter; this caused concerns about the aggressive timeline and production related issues attributed to the cold. The average temperature for Regina is -10°C and -17°C, for November and December, respectively.

Innovative and Efficient Solution

RWH/HCM working with JCK, redesigned the north shoring wall to incorporate the permanent belled drilled shafts into the secant pile wall. As part of the redesign, rather than using the shoring wall for the permanent foundation wall as was tendered, given their location, RWH integrated the belled drilled shafts into the secant pile wall. Rebar cages were substituted with W piles with rebar cages welded to them below the base of the excavation. This redesign allowed for an increase in the square footage of the building as well as for the proper application of the water proofing.

In addition to the north wall concerns, HCM was concerned

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about the tieback and connection requirements for the east, west and south sides. Typically, for piles and timber lagging, internal walers are required for highly loaded tiebacks. Installation of internal walers is welding-intensive and time consuming. Due to neighboring buildings and underground services, HCM/RWH felt that the most efficient way to provide lateral support for the design was to use one highly loaded tieback per pile, installed on a 45 de-

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gree angle, resulting in a tieback load in excess of 550kN (125kips). (Figure 1) HCM contemplated using their in-house system of Shotcrete Over Soldier Piles (SOSP) rather than piles and lagging to fast track the schedule. However, some consideration for the Regina winters (in particular the conditions in December/January) was required as shotcreting is difficult in extreme cold events. It was decided that shotcreting was only efficient up until the end of November.

RWH, working with HCM, came up with an innovative high capacity shoring connection that did not require internal walers

The high capacity connection was installed in approximately half the time of the equivalent connection with an internal waler. In addition to saving time, the concrete ring waler also added redundancy to the overall shoring system by tying all the piles together.

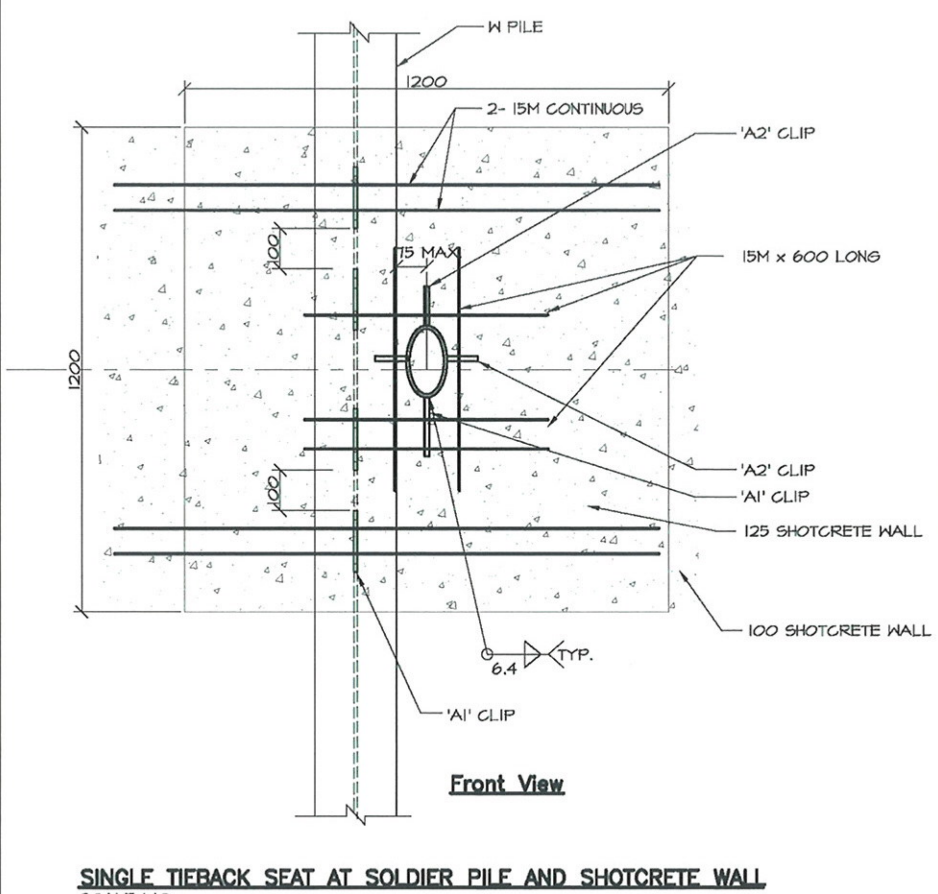

Figure 2: High capacity shotcrete connection.

and that used the benefit of continuity from the by-pass shotcrete (a prior HCM/RWH innovation), but only at the tieback level. Face-connected lagging, commonly used in Western Canada, could be completed in the colder months, after drilled shafts and tiebacks were completed.

By-pass shotcrete is placed around the pile face. Tabs with pre-punched holes are welded to the face of the pile. Rebar is run continuously across all piles and through the pre-punched holes, (See detailed Advantages/Features Section of this SOSP by HCM/RWH).

The high capacity connection used 100 mm (4in) diameter pipe with pre-punched tabs welded on the site to allow for rebar continuity. The high capacity connection (with the tabs) was fabricated in the shop, shipped to site, and installed with minimal on-site welding required. The connection relied on a grid of 15M rebar around the pipe and several rows of 15M rebar running the full length of the shoring wall, providing a concrete ring waler effect. (Figures 2 and 3)

The high capacity connection was installed in approximately half the time of the equivalent connection with an internal waler. In addition to saving time, the complete ring waler also added redundancy to the overall shoring system by tying all the piles together.

One of the shoring requirements was that the shoring had to be cut down 1.8m (6ft) below grade at the end of the job. Because of this requirement, HCM chose to use timber lagging for the upper part of the shoring, transition to SOSP for the high capacity connection, then finished using timber lagging below the shotcrete due to the winter temperatures. Contact lagging and SOSP was used to save time and improve shoring performance.

To mine behind the flange efficiently, the concrete used for the pile is typically 0.4MPa (60psi); however, the use of contact lagging allows for the use of 5MPa (725psi) concrete. Using 5MPa (725psi) vs 0.4MPa (60psi) concrete provides a stiffer system, which deflects less. (Figure 4)

Shotcrete On Soldier Pile Shoring Systems (SOSP) Description

The Shotcrete On Soldier Pile Shoring system is a hybrid system which applies the benefits of Shotcrete Shoring (Soil Nailing) with the benefits of Soldier Piles to reduce both cost and scheduling constraints in certain critical excavation shoring applications. To replace lagging, the use of shotcrete as a facing system is facilitated by welded clips acting as adhesion members. The use of spigot tieback connections embedded in the shotcrete place, after tiebacks are drilled, is part of the innovation with high load rotation transfer.

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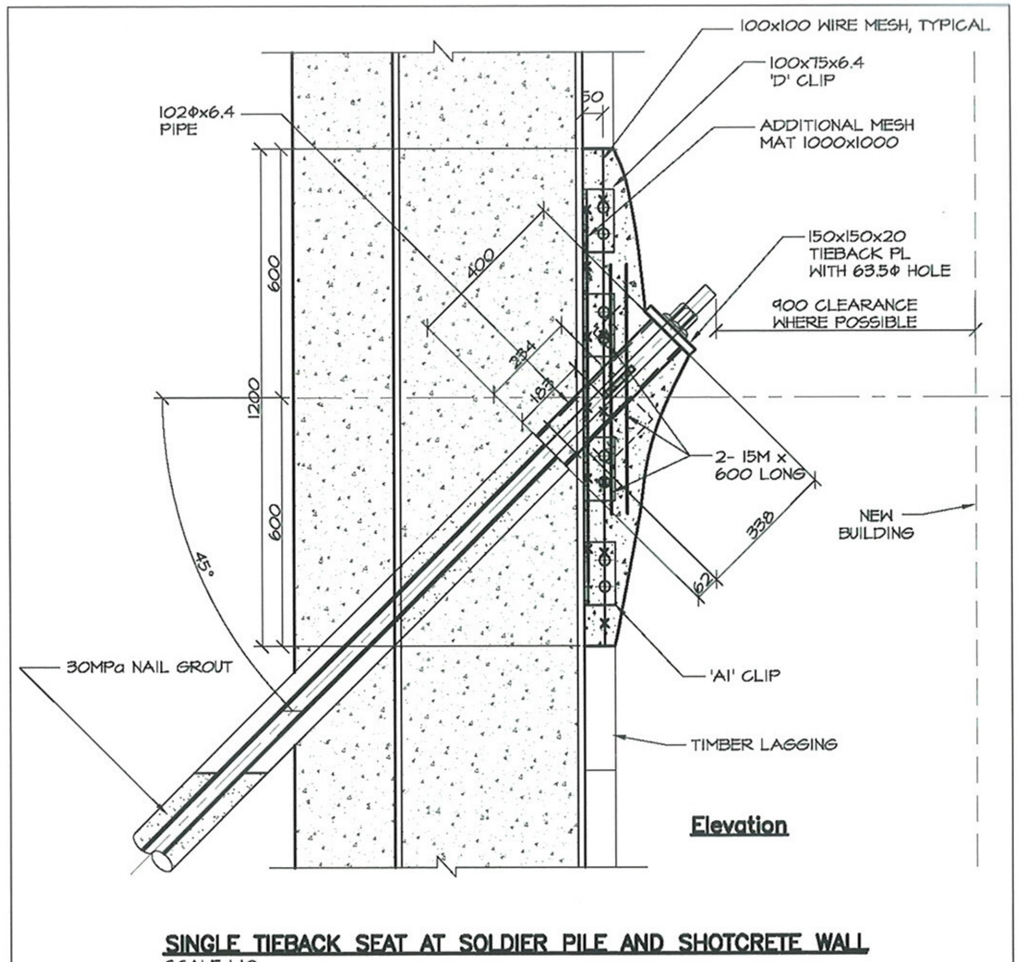

Figure 3: High capacity connection detail.

SOSP Features & Advantages

- Applicable to long soldier pile toe systems.
- Applicable to 'Perched Pile' concepts on shotcrete walls (SWOS ADSC HCM, February 2008).
- Applicable to 'Face Applied' lagging systems for tieback levels (SOSP ADSC Regina 2011).
- Fast application field welded adhesion clips.
- Fast excavator trimming line at pile face. Less shotcrete face waste with continuity of rebar and engineered rebar spacing relative to wall thickness, span and use.
- Fast tieback 'Spigot' connections non-field welded installed after drilling.
- Increased pile strength backfills for high tieback load for anti-pile rotation.
- High schedule speed in face area (SF) per day applied with all anchor connections completed.
- In certain applications, lower costs over secant walls/diaphragm walls, which are favored over lagging systems next to buildings.
- Zero voiding benefits of shotcrete facing on earth in comparison to wood lagging backfills.
- No wood rot next to buildings when SOSP full facing system in shotcrete.
- Soldier piles allow for the first level anchors of a shotcrete system to be below services behind walls.
- Increased pile strength backfill on upper length can allow for one mix used per hole vs. strength mix.
- Improved soil arching between piles when soils require face time, allowing non-panel sequences in shotcrete applications.

Numerical Modeling

RWH completed several finite element analyses using Plaxis to model the stages of construction. Using the baseline geotechnical report, input parameters for the models were determined.

Due to the nature of the highly plastic clay, the Ko parameter was varied to determine the influences on the shoring as well as the location of the tieback. The constitutive model provided estimates of vertical and lateral movement of the shoring wall, bending moment, axial load, soil movements, and changes in stresses.

A typical Plaxis section of the shoring wall depicting the lateral movement of the shoring is shown in Figure 5.

Construction

HCM arrived onsite shortly after being awarded the contract. The first piece of equipment to show up was a Bauer* BG24, which was used to install all perimeter piles as the shoring drawings were being finalized.

During pile installation, a soft, 2m (7ft) thick layer of clay was discovered 1m (3ft) below the bottom of excavation. RWH, working closely with HCM, performed a global stability analysis which resulted in deepening pile toes and lengthening tiebacks to account for this condition.

After pile installation, lagging was installed to the top of the concrete ring waler, berm sculpted and anchors installed. HCM's Casagrande* M9 installed R51 IBO* anchors with a 150mm (6in) diameter sacrificial clay bit. The IBO is a self drilling bar that uses grout to flush soil cuttings. The use of grout during drilling pro-

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vides a good soil-grout bond.

The nature of the cohesive soil allowed for a 1.2m (4ft) vertical cut after anchor installation. Pre-punched clips were welded on the pile face, followed by the installation of the high capacity pipe connection. 15M rebar was strung continuously, then 100x100 (4in x 4in) 9 gauge mesh was attached to the rebar. Once all of the reinforcement was installed, shotcrete was sprayed creating a continuous band of reinforced concrete.

Figure 4: Contact lagging and SOSP.

Deep Foundations

Even with a 9.1m (30ft) deep parkade structure, the soils did not provide suitable bearing capacity for the 20 story building. The structural engineer, J. C. Kenyon, determined that under-reamed

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"belled" drilled shafts were the most cost effective means of supporting the column loads, which were as high as 16000kN (3600kips). These loads were supported by installing 1600mm (64in) diameter shafts with 4950mm (16ft) diameter bells approximately 12.2m (40ft) below the bottom of the excavation.

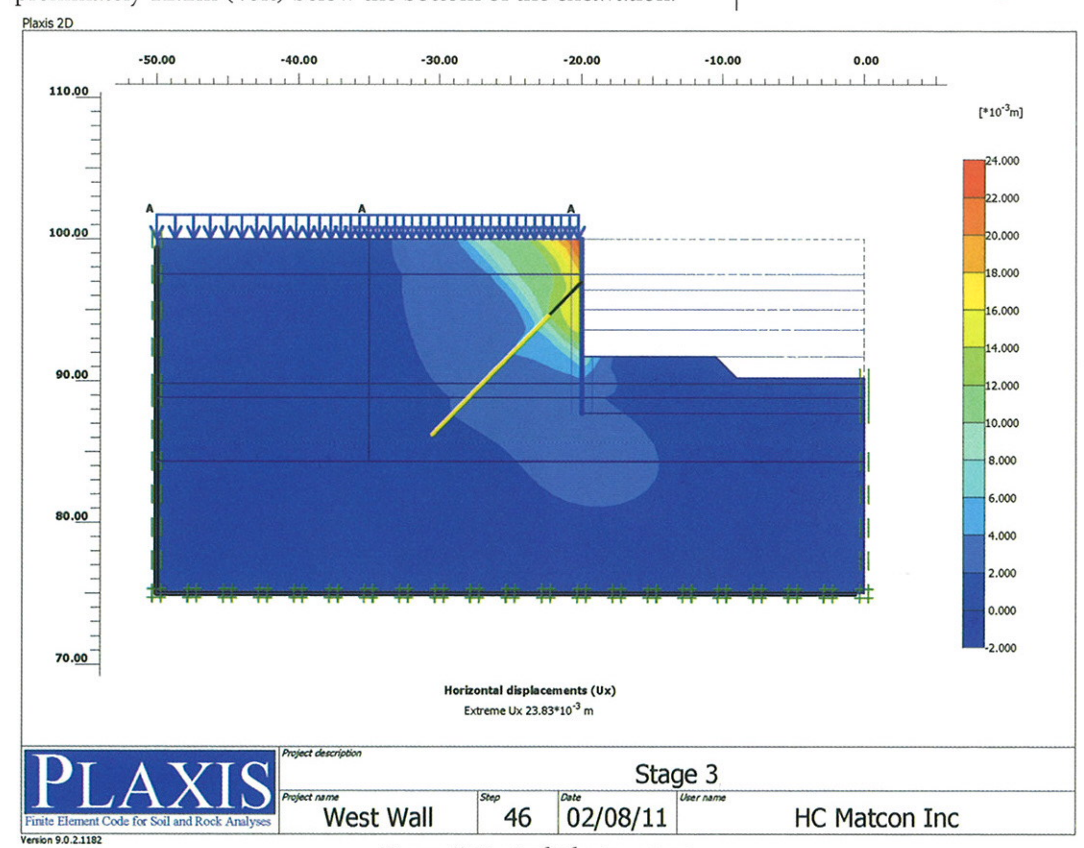

Figure 5: Typical Plaxis output.

These drilled shafts were constructed by augering to the approved stratum, and by installing the belling tool. The belling tool is made of a cylindrical body with expanding wings that form a cone on the bottom of the drilled shaft – increasing end bearing surface area. The tool is attached to the drill rig and the bell is formed by repeatedly taking larger bites until the bell is constructed to the design diameter.

Due to the required large diameter bell, HCM had to build the 4950mm (16ft) diameter belling tool specifically for this job. HCM used their in-house fabrication shop to complete the design and fabrication. (See Figure 6 depicting the HCM team.)

While this method of pile installation is very common in this region, the installation and in-

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Figure 6: HCM team with belling tool.

spection method were different than those usually specified. Typically, belled drilled shafts are specified to be hand-cleaned by the contractor followed by down-hole inspection. When the bell has been formed, a laborer is lowered into the hole to remove all loose material from the base. A temporary safety liner was installed in the hole to ensure that the soil does not cave in. Following cleaning, the inspector enters the hole to verify cleanliness and dimensions.

In this case, the base of each drilled shaft was specified to be machined cleaned. Typically, allowable bearing pressures are lower for machine-cleaned bases than hand-cleaned since the cleaning is

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not as thorough. Inspection was facilitated through the use of a down-hole camera and an electronic measuring device that ensured the geometry of the belled drilled shafts met specification.

Since many inspectors in the region are more familiar with hand-cleaned bases, getting approval to place concrete in the machine-cleaned drilled shafts was a difficult process that involved repeated iterations of cleaning and inspection until the base was acceptable. This placed additional schedule pressure on HCM. After several belling tool modifications and a process of continuous improvement, this procedure was simplified and perfected.

Monitoring

Throughout the duration of the project, monitoring was carried out. On three of the four sides of shoring, inclinometers were installed on the piles. In addition to inclinometers, targets for total station monitoring were also installed on all pile faces. Inclinometers were installed approximately in the middle of the shoring walls. Since RWH performed the monitoring, it allowed for easy comparisons of observed deflections versus predicted deflections from the Plaxis modeling. Monitoring was completed at every excavation lift. Using monitoring in conjunction with the predictive model, shoring modifications and changes in construction method could be implemented should monitoring observations indicate deflections significantly different than the model.

Monitoring provides reassurance/risk reduc-

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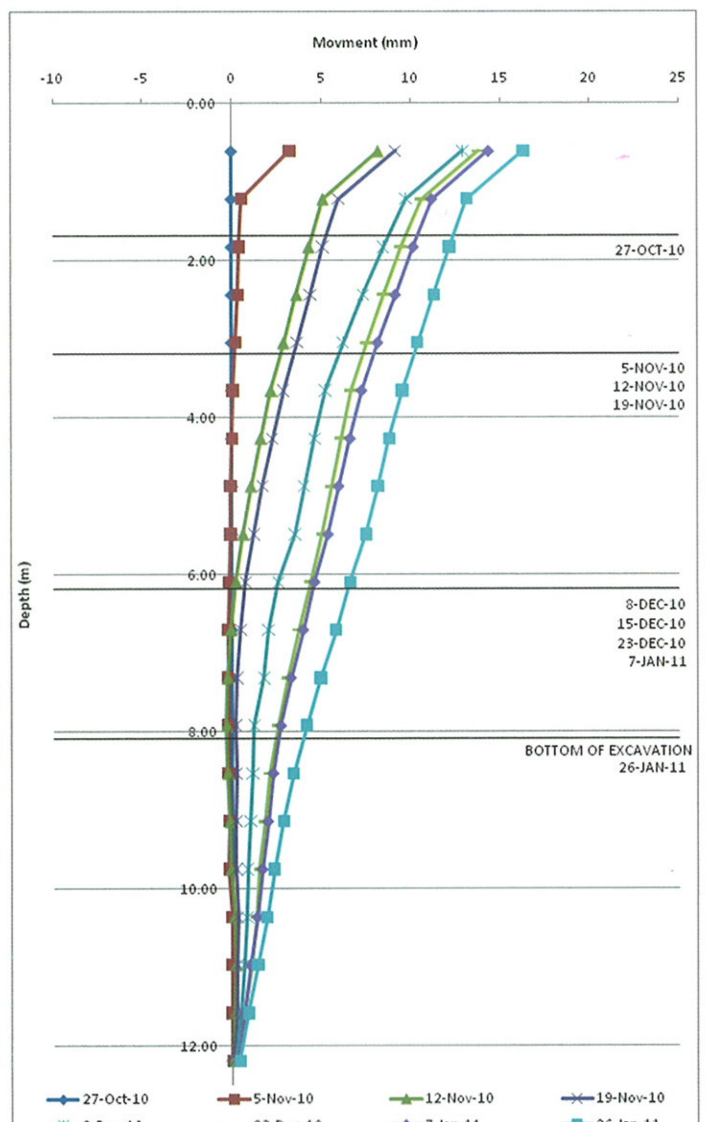

Figure 7: Inclinometer results.

tion as well as allowing RWH to confirm assumptions made during the design phase.

Shoring Performance

The maximum shoring wall movement on the project was observed by an inclinometer located in the area of deepest excavation. The maximum movement recorded was 15mm (0.6in) which is less than 0.2% of the height of excavation. RWH Plaxis model predicted a maximum lateral shoring movement of 22mm. (Figure 7).

Summary

The use of contact timber and SOSP in conjunction with the innovative high capacity shotcrete connection provided cost savings, redundancy and reduction in construction duration. In addition to increased building space, the redesign of the north wall allowed for construction of a conventional structural wall with water proofing.

Completing the design using RWH allowed for efficient turnaround time on shoring shop drawings, enabling HCM to start drilling onsite within weeks of being awarded the contract.

Performing a finite element analysis and conducting monitoring to verify design parameters added level of risk reduction and ability to use observational methods for design, which lead to more efficient pile sections and tiebacks than would have been the case if the given tendered parameters were used.

**Indicates ADSC members.*

ADSC

Southwest corner of excavation.

Project Team

Shoring Design-Build Contractor	HCM Contractors Inc.* Craig Rowe, P.Eng, Project Manager and Jeff Gibbs, Superintendent
Shoring Designer	RWH Engineering Inc. Jason Weck, P.Eng, Sr. Engineer and David Wang, Design Engineer
Monitoring	RWH Engineering Inc. Mike Janzen, EIT
Structural Engineer	JC Kenyon Engineering Inc. Jim Kenyon, P.Eng
General Contractor	Graham Construction Ron Jordan, Project Manager

**Indicates ADSC Member*