

HYBRID EXCAVATION SUPPORT SYSTEM FOR THE UNION STATION REVITALIZATION PROJECT

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Toronto's Union Station, a National Historic Site occupying an entire city block, is the busiest commuter rail transportation hub in Canada. An extensive project is being undertaken to revitalize Union Station while maintaining the historical significance of the building and minimizing disruption to commuters. A significant stage of the revitalization involves excavation indoors, to a depth of up to 5.5 m below the existing floor level to create space for a new transit concourse and a new lower-level pedestrian retail concourse. A hybrid excavation support system utilizing micropiles as soldier piles was constructed over an 18 month period between 2010 and 2011.

Development and testing of connections between the micropiles, shotcrete facing, lagging, walers, and tiebacks presented significant challenges. The existing viaduct structure was constructed in the 1920's on land reclaimed from Toronto Harbour, so there was significant (and ongoing) uncertainty with respect to buried obstructions including relic timber wharfs and abandoned steel and timber piles. Collectively all these conditions precluded the use of conventional methodology; new techniques, installed using modified equipment, and for the first time in the Greater Toronto Area, were required.

Details of the existing site conditions, installation challenges, design, construction and performance of the hybrid excavation support system inside this historic structure are presented.

INTRODUCTION

Union Station in Toronto, Ontario is the busiest passenger rail facility in Canada, with 65 million passengers annually and an average of 200,000 passengers each day. Construction of the station was completed in 1920. It has been designated a National Historic Site of Canada and inducted into the North America Railway Hall of Fame in the Facility and Structure category.

The Union Station Revitalization Project (USRP) was tendered in 2010 and awarded as a 6-year, \$450M construction management / trade contract package. Included was a large scale grade reduction, referred to as "The Dig Down", to create two basement levels and this required extensive excavation support constructed entirely indoors within the active station setting.

A hybrid excavation support system was constructed utilizing drilled-in, mechanically spliced, micropile casings as the 'soldier pile' elements. Although micropiles for direct structural support are commonplace within the Greater Toronto Area (GTA), this project represents the first use of micropiles as soldier piles in an excavation support system in the GTA.

PROJECT SETTING

Existing structures

The existing viaduct structure extends south from the station building (Headworks) and is an extremely robust reinforced concrete building consisting of an upper structural slab at the passenger platform level supported on columns

at 8.0 m centres which are in turn supported on unreinforced concrete piers founded on bedrock. The east (Bay Street) and west (York Street) zones feature a single basement level below the platform (Figure 1). The centre (VIA) zone has 2 basement levels below the platform. The upper

basement level in the VIA zone is also a structural slab. The lowest basement levels in all three zones are of slab-on-grade construction. The basement area has multiple uses including vehicle parking, storage, shipping / receiving, and the commuter rail concourse.

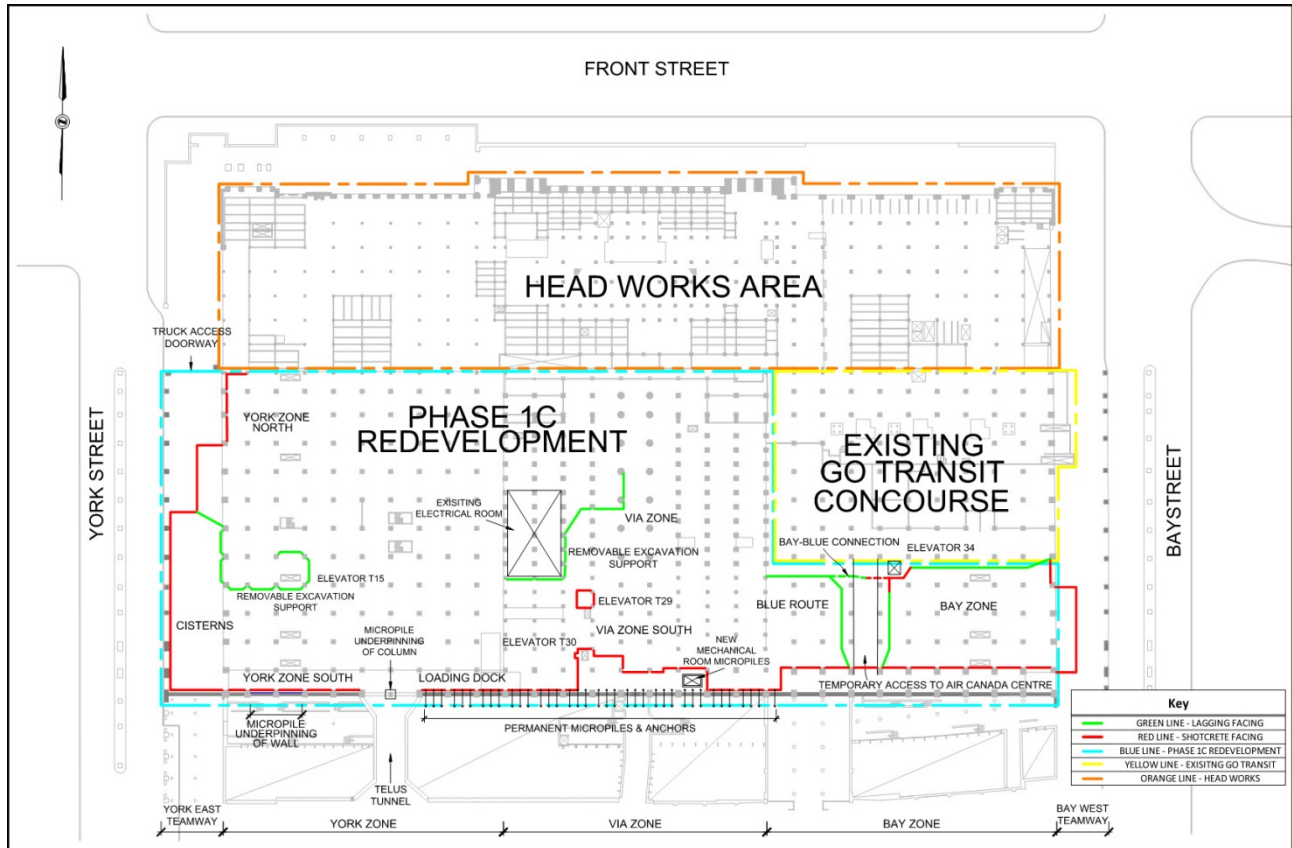


Fig. 1: Site plan

Proposed Structural Additions

The Dig Down will result in the existing basement levels, located below the viaduct south of the Front Street Headworks between York Street and Bay Street, being lowered (Figure 2) to make sufficient vertical clearance

for two floors where only one existed prior to the USRP. Proposed excavation depths are approximately 5.5 m in the York zone, 3.2 m in the VIA zone and 4.5 m in the Bay zone. Localized deeper excavations are also required for access tunnels, cisterns and sump pits.

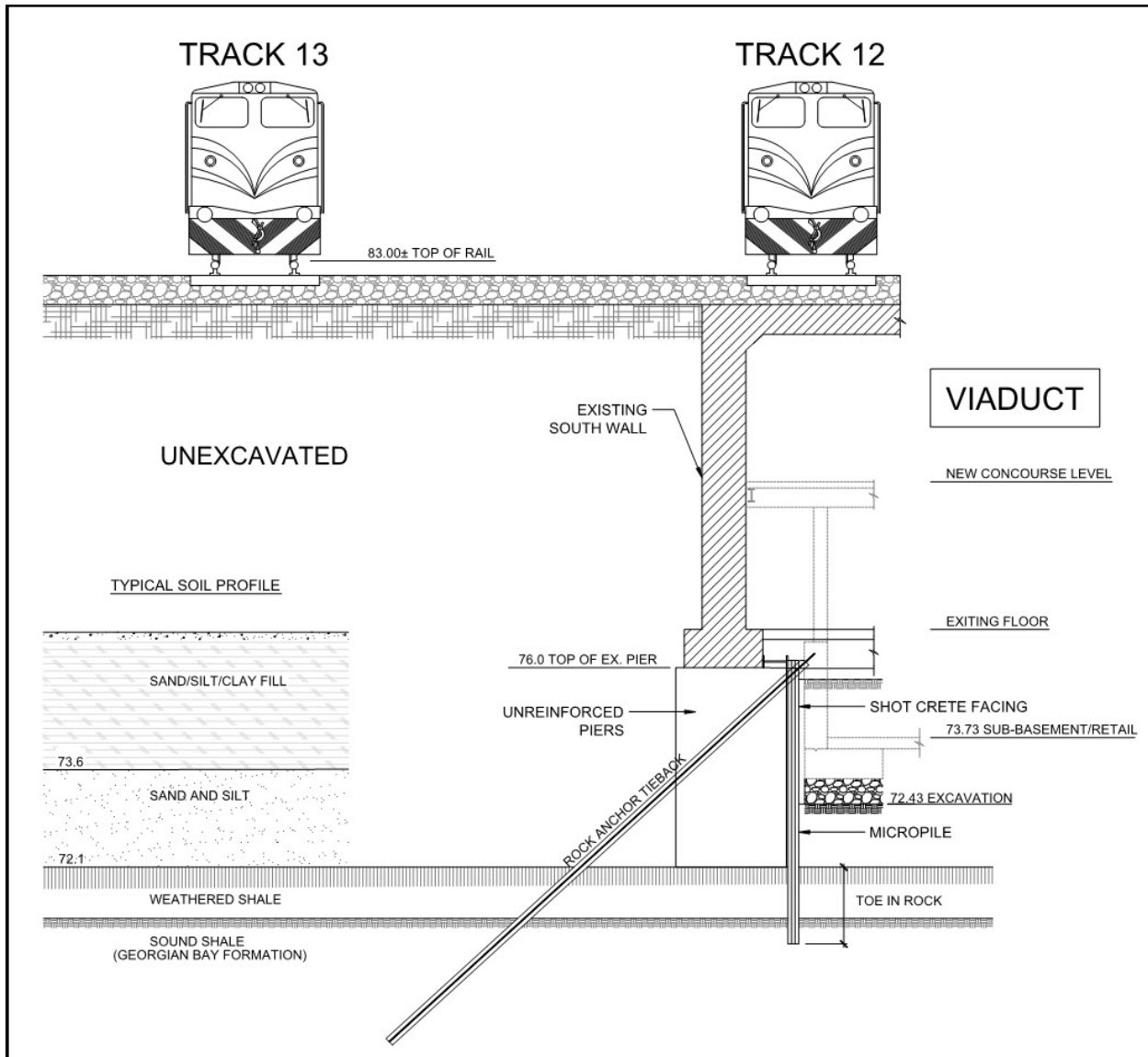


Fig. 2: Typical section at south viaduct wall showing new sub-basement

Low head room and restricted access work areas

The vertical clearance from the underside of the platform slab is 5.2 m in the Bay and York zones and 2.5 m in the VIA zone. The south wall of the viaduct retains 7 m to 8 m of filled ground underlying five additional tracks and passenger platforms. Access to the basement level for

construction equipment and materials is via a single truck door at the west end of the York zone. The west wall of the viaduct abuts York Street and the east wall abuts Bay Street. Both streets are busy arteries connecting the downtown area to the Harbourfront and to the Gardiner Expressway, downtown Toronto's arterial expressway.

SUBSURFACE CONDITIONS

There is a highly variable fill layer (the land was reclaimed from Lake Ontario in the mid to late 19th century) and, typical of such sites, several significant obstructions consisting of remnant wharfs and timber cribbing were encountered during construction of the excavation support and/or exhumed during bulk excavation during the Dig Down.

The naturally placed overburden consists of lake-filled deposits which range in texture from silt to clayey-silt to sandy-silt with some pockets of silty-clay material.

Below the lake-filled deposits, a layer of organic-rich silt, sand and silt to sand is present in thicknesses ranging 0.7 to 1.0 m. These deposits represent the original lakebed sediments. The organic silt layer contains traces of fine white shells, some organic material and wood fragments. The lower deposits of organic silt, sand and silt and silty sand are generally cohesionless and considered as 'flowing' or 'running' ground when no dewatering measures or installation of hydraulic barriers are undertaken.

Bedrock in this area of Toronto consists of the Georgian Bay Formation, a fissile to slightly fissile, grey mudstone to shale with interbedded, variable percentages of thin limestone, limy shale and sandstone. The upper zone is fissile, grey mudstone to shale with interbedded, variable percentages of thin limestone, limy shale and sandstone. The upper zone is weathered and varies in thickness from 0.5 to 1.0 m.

HYBRID EXCAVATION SUPPORT SYSTEM

Specified Requirements

At time of tender, the specified scope for the excavation support system to enable construction of the new sub-basement consisted of the following imperatives:

- Design and construction of temporary excavation support along the west (York Street) viaduct wall to enable excavation and construction of three interconnected cisterns.
- Design and construction of temporary excavation support along the south viaduct wall to enable excavation and construction of the new sub-basement and loading dock. The excavation support also had to accommodate permanent micropile foundations for a new mechanical room.
- Design and construction of temporary excavation support along the east (Bay Street) viaduct wall to enable excavation and construction of the new fuel storage facility and electrical room.
- Construction of permanent rock anchors and micropiles along the south viaduct wall to withstand rail and soil surcharges. The permanent components are to be incorporated into the temporary excavation support. Work is to be coordinated with the demolition of the existing concrete grade beam struts.
- Design and construction of temporary excavation support at the north and west sides of the Bay zone to maintain the existing commuter rail concourse in service while enabling excavation and construction of the new sub-basement. This excavation support is to be removed at a later stage of the project following construction of the new commuter rail concourse.

Contractor-designed Scheme

The tender documents defined only the minimum lineal extent and depth of excavation support as well as performance requirements

Although excavation depths were not excessive (5.5 m maximum), the overburden soils to be supported were susceptible to collapse which could have compromised the stability of the existing viaduct walls and areas beyond the viaduct walls including the Bay Street pedestrian walkway to the east, the York Street roadway to the west, and the tracks and passenger platforms to the south. In all of these areas, the excavation support was to be left in place and was to serve as a back form for the new concrete foundation walls and thus had to be constructed as a zero clearance system (i.e. no projection of walers or other elements which would interfere with the foundation wall construction). Conversely, all temporary excavation support, to be removed at a later stage, was not intended to serve as a back form.

Fellow DFI Member Isherwood Associates were retained by Geo-Foundations as the design engineers for the excavation support work and development of the design was a collaborative partnership between the two firms. Geo-Foundations provided input on constructability, methodology and logistics while Isherwood handled the detailed layout, design of the excavation support elements, and drawing preparation. A number of iterations were required to arrive at the final design.

The final design for the majority of the left-in-place excavation support featured drilled-in 178 mm micropile casings (Figure 3) at 1.8 m to 2.0 m spacing socketed 1.5 m into bedrock, 100 mm reinforced shotcrete facing secured to the micropile casings with field-welded clips, a 310 mm top waler field-welded to the micropile casings, and multi-strand rock anchor tiebacks angled at 45 degrees at every second pile and secured to the micropile casings with a field-welded connection. This base design was proposed for the York zone (west), Bay zone (east), and the south viaduct wall where no rail surcharge was present. Where rail surcharge was present (VIA zone and east part of the York zone), soldier beams consisted of a combination of alternating permanent 244 mm cased

and staging. Detailed design and methodology were left to the specialist trade contractors invited to submit proposals.

micropiles socketed 4 m into bedrock (with threadbar reinforcing) and intermediate, temporary 244 mm micropile casings socketed 1.5 m into bedrock. Pile spacing for this case varied from 1.0 m to 1.5 m. In line with each permanent micropile, a permanent solid bar rock anchor tieback angled at 45 degrees was provided with a prefabricated steel plate chair assembly linking the two elements (Figure 4). Top walers were also provided to tie the intermediate micropile soldier piles to the permanent micropile / anchor units.

Wherever the excavation support was to be removed at a later stage, timber lagging was secured to 178 mm micropile casings with field-welded tee sections in lieu of shotcrete facing. Walers and multi-strand rock anchor tiebacks were installed and secured to the micropile casings as described above.

Cased micropiles as soldier beams made sense for a number of reasons:

- The limited headroom and column spacings within the basement precluded the use of large conventional soil augering equipment able to install and remove temporary liners (to maintain hole stability and prevent caving) as well as drill into bedrock and through obstructions.
- The single access doorway made it difficult if not impossible to readily export drilling spoil and import ready mixed concrete to the pile locations, which would have been required with conventional methodology.
- Micropile casing is easily obtained in threaded sections in lengths as short or long as desirable, and can be installed with relatively compact drill rigs able to manoeuvre in the existing basement. Modification of each rig's drill mast to suit the available headroom is possible.
- The spoil volume is relatively small and can be collected in small (i.e. 5 cubic metre) bins for later export.
- Drill rigs can be equipped with tooling and bits which can effectively drill

- overburden, timber/stone obstructions, and bedrock. The casing can be advanced ahead of the drill bit thus minimizing the risk of soil caving.
- The bending capacity of the micropile casings employed was sufficient to resist the calculated bending moments in the excavation support system at reasonable (1.0 m to 2.0 m) pile spacings.
- The casing is filled with site-mixed neat cement grout upon completion, thus ready-mixed concrete truck access is not required.
- Shotcrete facing was well suited to the left-in-place excavation support mainly because of the increased rigidity of the overall system (as compared to timber lagging) as well as concerns over long term deterioration of the lagging. Lagging was employed for the removable excavation support in order to facilitate removal and because less system rigidity was required.

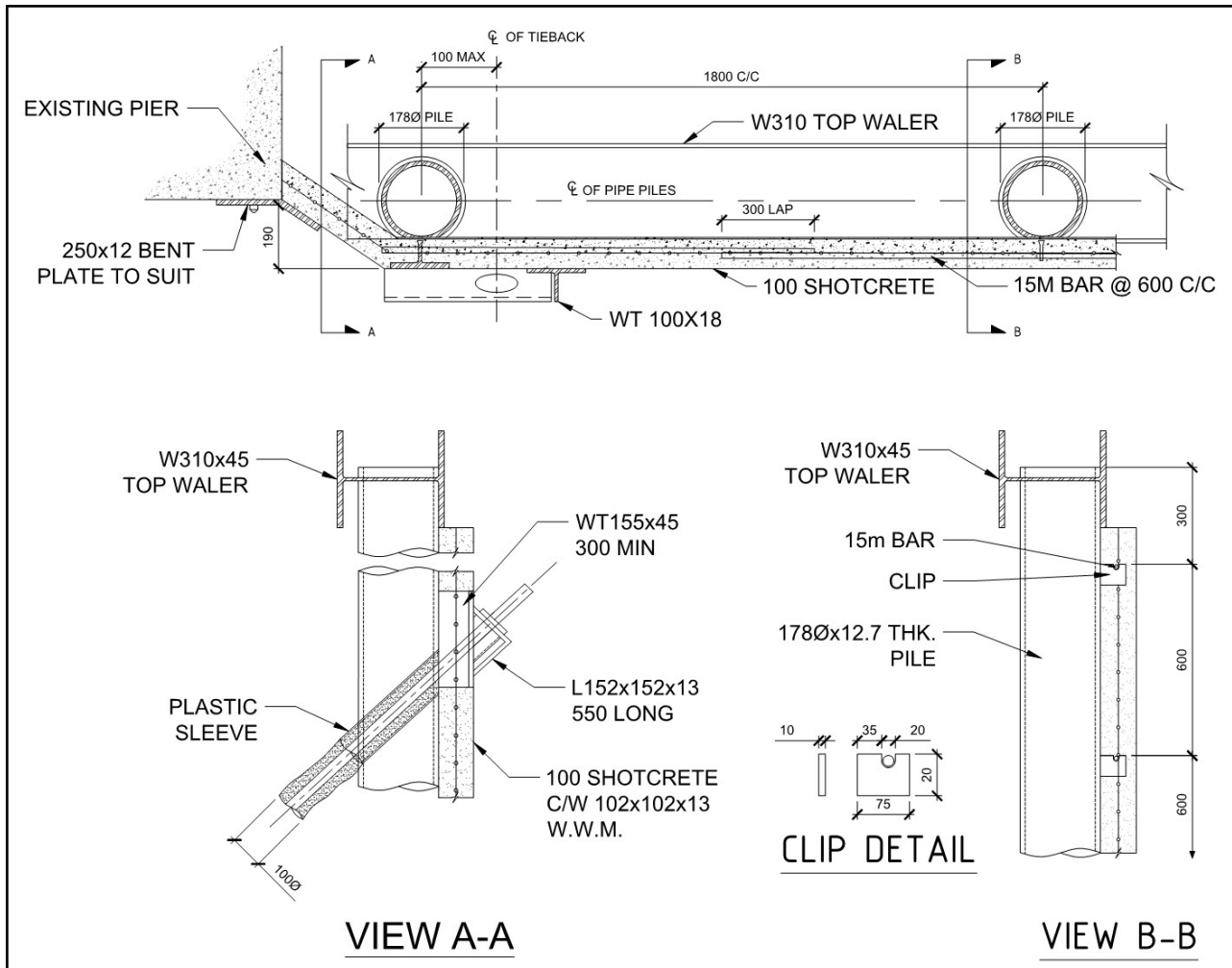


Fig. 3: Typical pipe pile and shotcrete detail

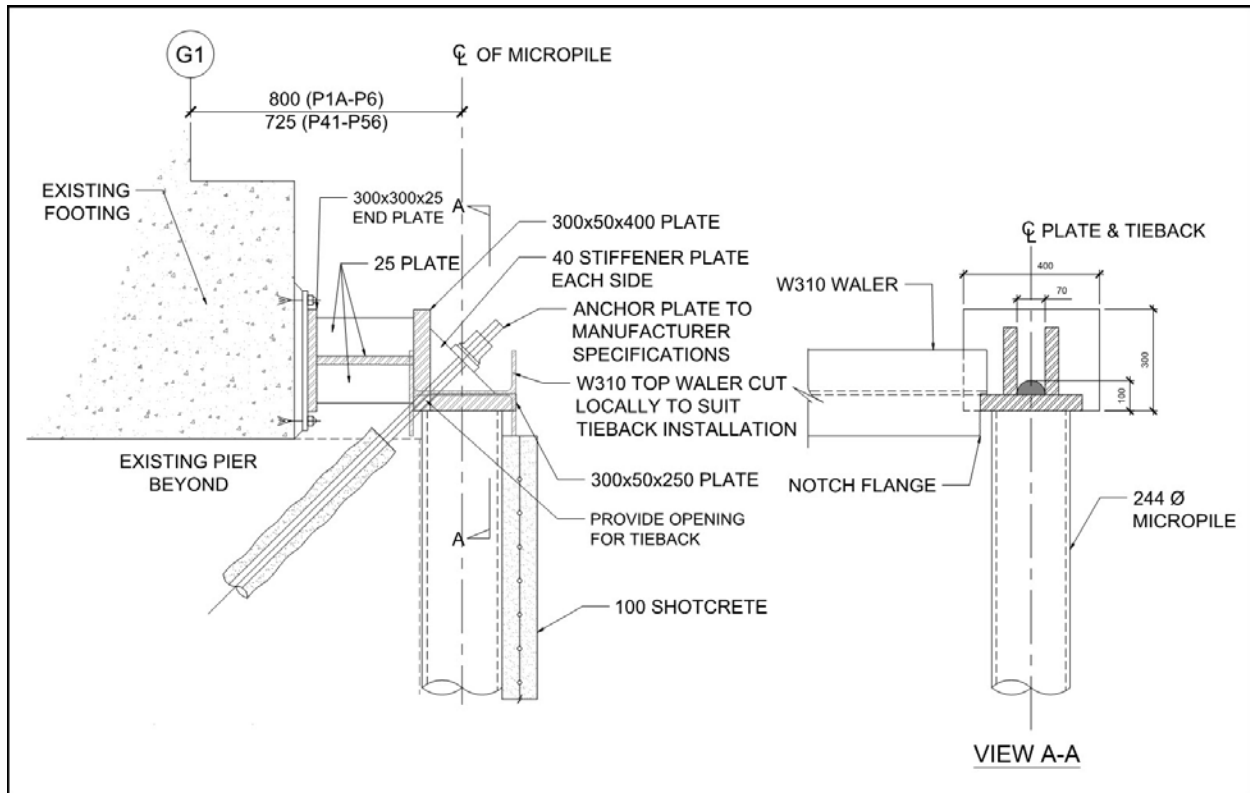


Fig. 4: Temporary excavation support with permanent tiebacks connection details

CONSTRUCTION CHALLENGES

As is the case with undertaking construction within any existing structure, and especially so when the structure is historic and constructed on reclaimed land, challenges were numerous and sometimes unexpected. Post-tensioning of tie backs results in strong bending forces imparted on the soldier, locally taxing the linkage system, so the precise details and design of this connection were crucial to success of the system. Compounding the challenges associated with the novelty of connecting a round soldier with a high strength connection that must remain buried behind the final face of the wall were the cramped quarters within which all the work had to take place and be evaluated for constructability and performance. Numerous field trials were required before the connection detail could be finalized, and separate methodologies had to be developed for securing the facing support members to the micropile soldiers dependent on whether the facing was permanent (shotcrete) or temporary (timber lagging).

There was significant trouble pumping concrete from the street access to the far rear of the job site. Numerous attempts were made to pump the concrete, but it could not be pumped with the size and percentage of aggregate best suited to a shotcrete wall mix. A change to the concrete mix design was required and eventually the entire process was changed from ready-mix concrete to pre-bagged, mixed-on-site wet process shotcrete.

Welding connections, completely field fitted, were used to transfer load from tie back anchor to soldier pile. It was soon discovered that some of the connection assemblies partially pre-fabricated in the shop prior to shipment to site were too long to safely handle and this led in the early stages of the work to alignment issues. The assemblies and degree of pre-fabrication were modified to make it easier to properly align each connection no matter the as-built vertical spacing of mechanical micropile casing splices. This required considerable on site modification of the original plans.

Multiple changes in scope took place long after commencement of excavation support works. One such change required underpinning – using hollow bar micropiles – of a portion of slab-on-grade that had subsided, requiring a novel connection detail to connect the micropiles with the slab. Another change required support – using permanent micropiles and high capacity solid bar rock anchors – of a portion of the south viaduct wall where existing compression strut grade beams had to be removed to enable the Dig Down.

SYSTEM PERFORMANCE

The performance of the excavation support system was monitored in real-time during construction by means of a comprehensive monitoring network, including inclinometers and precise surveying. Overall performance of the system was required to limit total movement, from start of construction, to less than 20 mm in any direction.

Testing

All tiebacks were load tested and locked-off at the specified design load. Special testing apparatus was provided for testing of the rock anchors along the Via zone, where post-tensioning forces of up to 1120 kN were applied. Quality control checks included specific gravity and unconfined compressive strength testing of the grout, material inspection, orientation and layout of all elements of the excavation support system.

Monitoring

Monitoring was an essential component of the execution of this project, considering the station was still in operation. A total of nine inclinometers were installed inside micropile soldiers, distributed across the extent of excavation shoring system. Monitoring of the inclinometers was done on a weekly basis. Precise survey monitoring of targets installed on the shoring system was conducted on a daily basis. Additionally, monitoring of piezometers, vibration and air quality was done by others.

Results

The excavation support system satisfied the performance requirements and no performance monitoring alarms were triggered throughout the excavation stage. At time of writing, all excavations had been advanced to target depth and average deflection recorded to date is 2 mm. At a few locations, movement occurred away from the excavation due to the presence of loose fill or disturbed materials within the upper 1.0 to 1.5 m behind the excavation support system, but nowhere has the movement exceeded the specified maximum 20 mm threshold.

Vibrations levels were acceptable throughout the installation of the excavation support system. All work was performed in conjunction with other subcontractors working in close proximity. Noise levels were also maintained at acceptable levels.

Figure 6 shows inclinometer results at the Via zone wall, where both rail and soil surcharges are present.

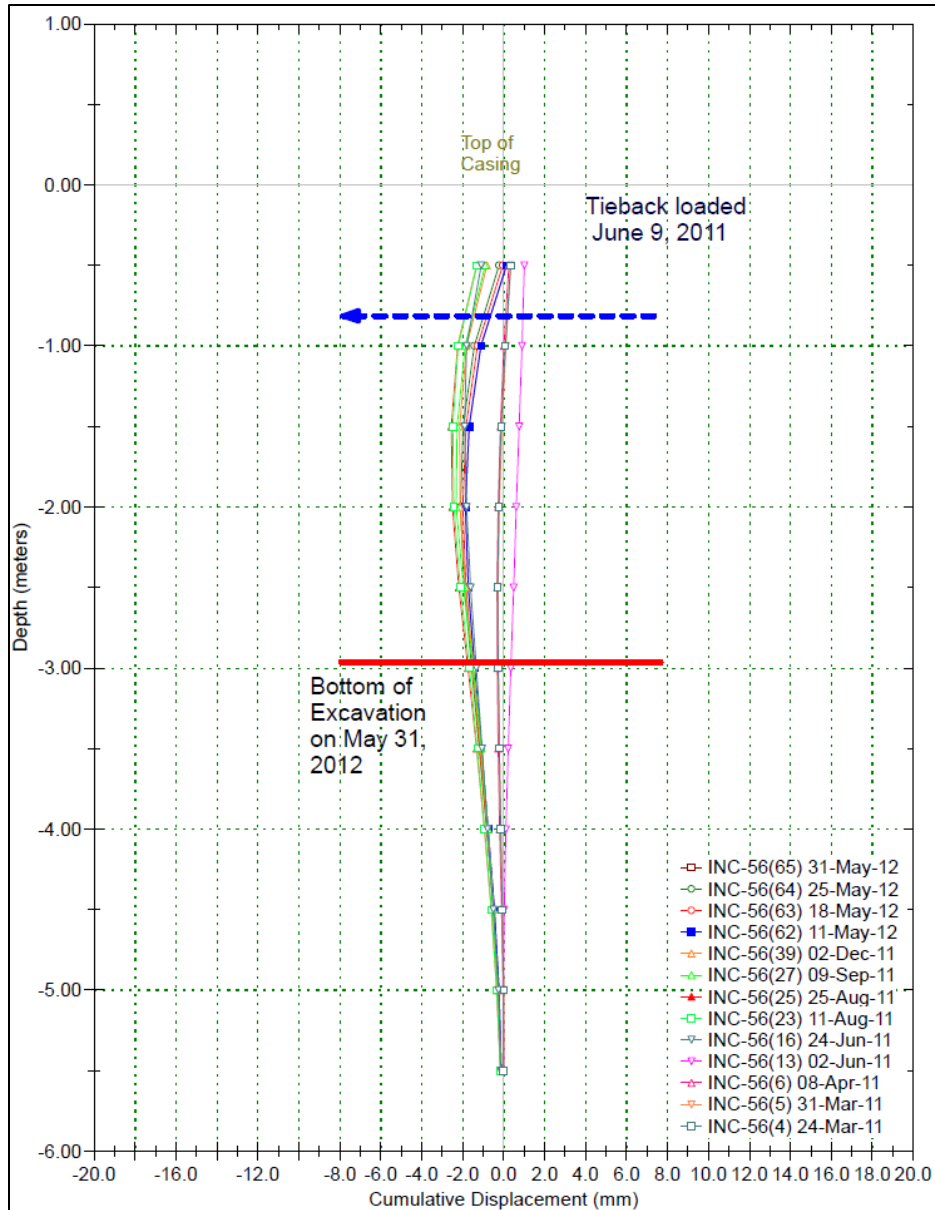


Fig. 5: Inclinometer Results (Via zone)

DISCUSSION

Excavation support is a fundamental element of heavy civil construction, especially in congested urban settings. The particular physical constraints at this site necessitated an approach incorporating methods and equipment far from ordinary.

In order to construct the project, already specialized equipment was further adapted and small diameter drilling was applied in such a

way, to the authors' knowledge, that had never been used for that purpose before. Extensive in-house modifications were made to the equipment to make it capable of performing within the very restricted physical constraints in the various work zones. Previously the equipment had been used to install permanent, direct-support foundation elements to retrofit existing structures, but never before for constructing earth retention elements.

Previously in the United States, micropile casings had been used as soldier piles, however these were of bigger diameter and with no splices of any kind, and installed with much bigger equipment (commensurate with unlimited footprint and headroom). In order to use micropiles as soldier beams in low headroom, multiple mechanical splices had to be incorporated into each soldier, and as such the precise connection details – both along the axis of the soldier pile and at the wall face at the point of tie-back anchor load transfer – were critical. The authors are unaware of any precedent of this technique being used for this application.

It is difficult to establish a cost comparison between the hybrid scheme and a conventional augered soldier beam and lagging approach due to the logistical constraints outlined above. The authors do believe that the hybrid scheme, which eliminated the requirement to handle and remove large volumes of drill spoil and the requirement to import ready-mixed concrete, minimized the potential delays to our work, and the work of other trades associated with site congestion and multiple truck movements through the single access doorway. The project likely realized a net economic benefit as a result.

CONCLUSIONS

Support of excavations as deep as 5.5 m was successfully achieved at the Union Station Revitalization Project using a hybrid scheme consisting of micropile soldiers in combination with rock anchor tie backs, shotcrete facing and timber lagging.

The hybrid scheme proved to be well suited to the physical and logistical constraints posed by the project setting.

The hybrid scheme also proved to be well suited to the challenging subsurface conditions present

at this site. As confirmed by the authors' experience constructing the work presented herein, a conventional approach to excavation support at this site would have been far more challenging, if not impossible to achieve.

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