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A CASE 2 MICROPILE NETWORK EMPLOYED AT A RAPID EXCAVATION RAILWAY PROJECT

Jim Bruce[1] and Matthew Janes[2]

ABSTRACT

Case 1 micropiles are now commonplace in the Greater Toronto Area (GTA) geotechnical construction market. Conversely, Case 2 micropile structures remain rare. The at-grade crossing of King Road and the CN rail tracks in Burlington, ON was reconstructed during a 96-hour railway corridor shutdown in 2012 with the help of a mirrored pair of Case 2 micropile networks installed to provide excavation support of the steep temporary cuts required for the trench into which a prefabricated tunnel structure was jacked into place.

A pure Case 2 micropile network – with minimal toe embedment beyond the dredge line and no structure connecting the micropile tops to one another – was ideally suited to the needs of this project. There were two performance imperatives: ensuring slope stability during temporary staging of heavy excavation equipment at the crest of the slope during the first hours of excavation, and ensuring slope stability for the duration of the fully cut slope condition in order to protect the safety of workers present at the base of the cut. Settlement control at the crest was not a driver of design.

1488 lineal metres of hollow bar micropile were installed in a 5-grid arrangement to support, in the fully cut condition, 303 square metres of slope face. The constructed Case 2 network enabled the tunnel push, with significantly less volume of excavation than would otherwise be required, to be completed in just 4 days of railway corridor closure. Details of the various design imperatives, micropile construction process, Case 2 network geometry, design checks and system performance are presented and discussed.

[1] *Geo-Foundations Contractors Inc., Acton, ON, Canada* jbruce@geo-foundations.com
[2] *Isherwood Associates, Mississauga, ON, Canada*

INTRODUCTION

CN is the largest railway operator in Canada. Burlington, Ontario is a city of population 175,000 located on the shore of Lake Ontario, 55 km southwest of Toronto. The Windsor to Montreal rail corridor is the busiest in Canada and passes through Burlington. Prior to October 2012, the intersection of King Road and the CN tracks in Burlington consisted of an at-grade crossing of two automobile traffic lanes and four rail tracks. A grade separation project was constructed in 2012 resulting in four lanes of automobile traffic crossing beneath the rail tracks inside a cast-in-place concrete structure (Fig. 1). In order to minimize the project's impact on CN's ongoing operations, the underpass structure was cast-in-place immediately outside its eventual location before being jacked into position inside an excavation dug and backfilled during a planned 96-hour rail traffic closure actually completed in 84 hours.

Rapid excavation was facilitated by installation, during night shifts in the preceding months, of mirrored Case 2 micropile networks, on opposing sides of the trench excavation into which the prefabricated concrete tunnel box was pushed into place. The presence of the micropiles enabled the excavation to have steeper walls with less distant offsets from the sides of the tunnel box, thereby significantly reducing the volume of cut required and the length of track to be removed and replaced. The micropiles also reduced the risk of raveling and localized toe instability due to groundwater seepage.

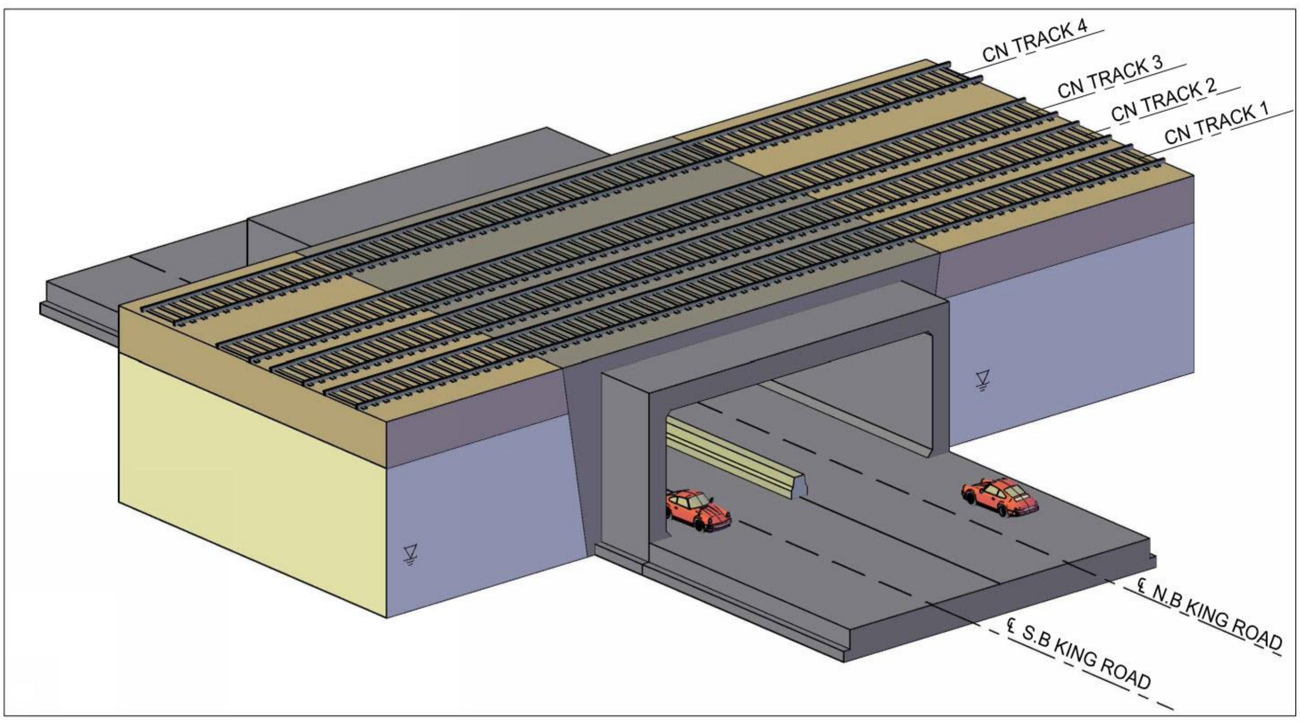

Figure 1: Isometric view of completed grade separation

SLOPE STABILIZATION – OBJECTIVE

Two principal factors made a Case 2 micropile wall an attractive approach at this project. First, the slope support scheme had to be constructed entirely in advance of the rail corridor closure, during limited-window interruptions to ongoing railway operations. Second, it was recognized, since the newly placed tunnel would be backfilled in the usual manner with compaction and ballast placement and intense grading immediately prior to reconstruction of the ties and rails, there was an unusually high tolerance for movements at the crest and face of the slopes. Said another way, the slope faces could move inwards towards the excavation, and the crests of the slopes could settle several tens of millimetres, as long as the global stability was assured and large soil block movements (such as the type that could jeopardize the safety of workers at the base of the slope) were prevented.

In its fully cut geometry, the slopes would be 8 metres high. Stability concerns were legitimized by the high groundwater table and problematic dewatering history at this site, combined with the 5 metre thick sand layer over clay silts within the middle portion of the excavation (Fig. 2). Without undertaking some measures to stabilize the soil, the

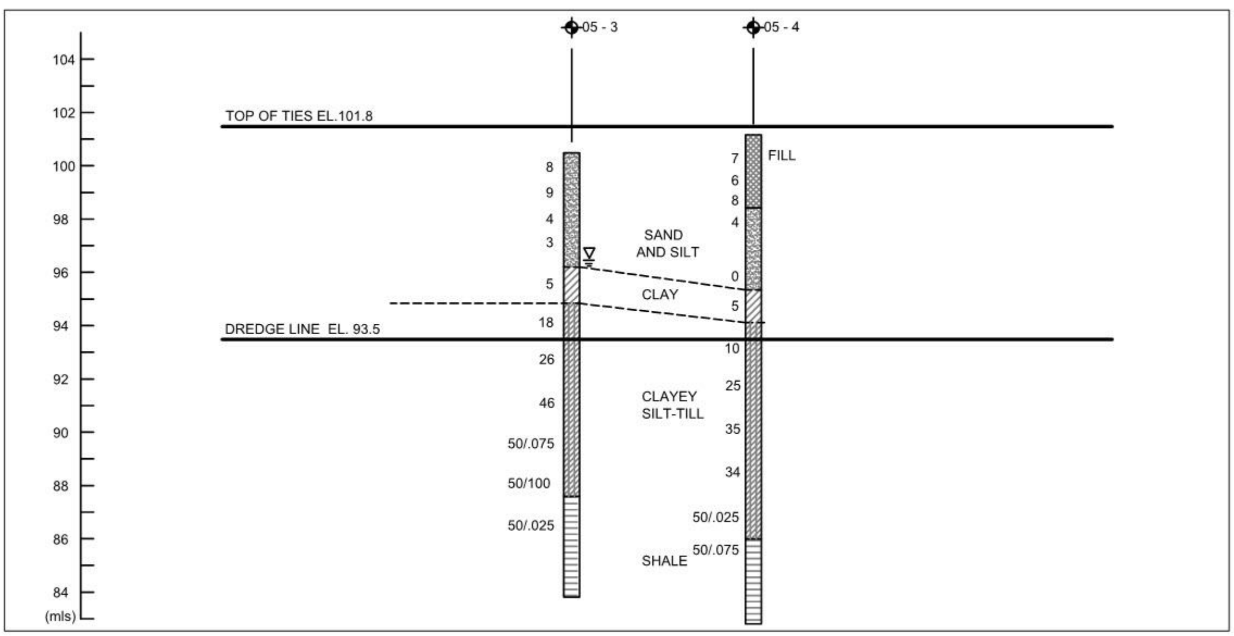

Figure 2: Soil profile

breadth of the cut and the slope of its walls would have been excessive and problematic towards meeting the project's scheduling goal. By installing Case 2 micropile networks – one for the south cut face and one for the north cut face – the breadth of the excavation beyond the width of the jacked structure could be minimized, and the slopes could be steepened to 1H:6V so that the bulk volume of excavation outside of the tunnel footprint and the amount of rail requiring demolition and reinstatement were both significantly reduced (Fig. 3). Also, incorporating a formally engineered slope support system would allow the constructor to comply with local health and safety legislation with respect to protection of personnel working at the base of the cut slope, both in terms of offset distance of the toe and the steepness of the cut slope.

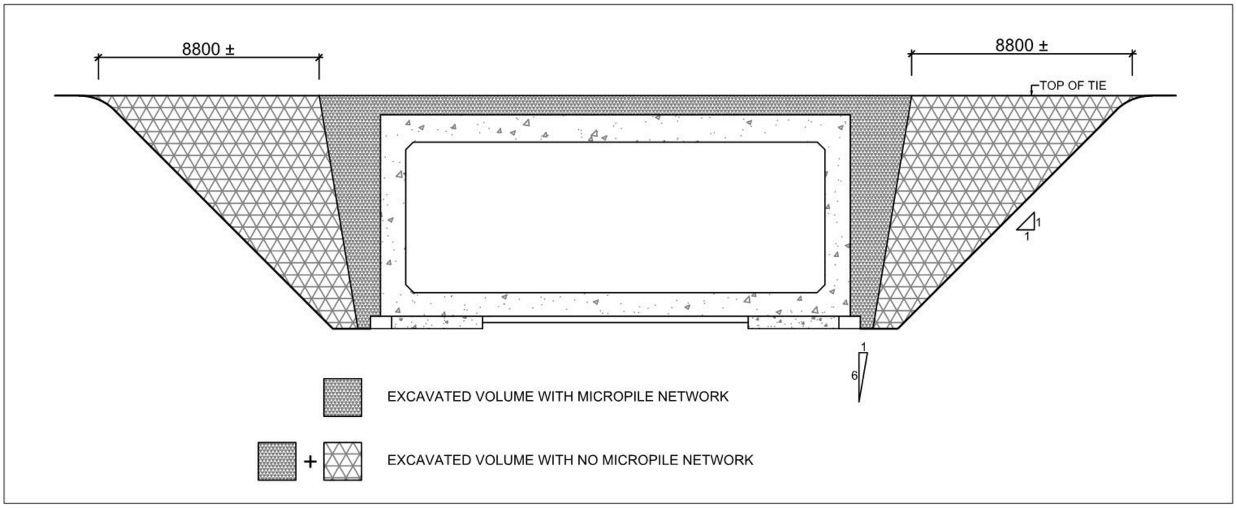

Figure 3: Comparison of excavation extent with and without micropile network

CASE 2 MICROPILE NETWORKS – DESIGN

Case 1 vs. Case 2 Micropile-supported Structures

Case 1 micropile walls are distinguished from Case 2 micropile networks principally by the mode and direction of loading acting on the micropiles. Stated simply, Case 1 micropiles carry loads directly to an appropriate bearing stratum, with resistance to loading, whether axial or lateral or both, provided principally by the strength of the micropile reinforcement (FHWA, 2000). Case 2 micropiles, on the other hand, work as inclusions in the soil mass, enhancing the grout-to-soil interaction necessary for the soil mass, as a reinforced whole, to resist applied loads such as surcharge, overturning, etc.

Furthermore, for Case 2 networks retaining a grade separation, the design and stability analysis is based on the micropiles forming a reinforced soil mass which is similar to a dam. The matrix is analysed for plastic deformation of the soils between the micropiles and the structural failure of the micropile in either compression/ tension or shear. The driving force is simply that anticipated by Rankine or Coulomb wedge failure theory. Analysis of the face support or stability is generally empirical. The soil will arch between the exposed micropiles with varying effectiveness based upon grain size, grain size distribution, cohesion and moisture content. The changing nature of the soil upon continued exposure must be evaluated, as well as the effects of exposure on intended face performance. For example, the soil might be expected to effectively arch but spall –

such a scenario would be acceptable in terms of structural performance but unacceptable for worker entrance to the base of the cut face.

Figure 4 illustrates these differences, using two examples designed and constructed by the authors – note particularly the discrepancy in toe embedment depth, the ancillary connecting structure at the Case 1 wall, and the quantity of micropiles per unit length of wall/ slope crest.

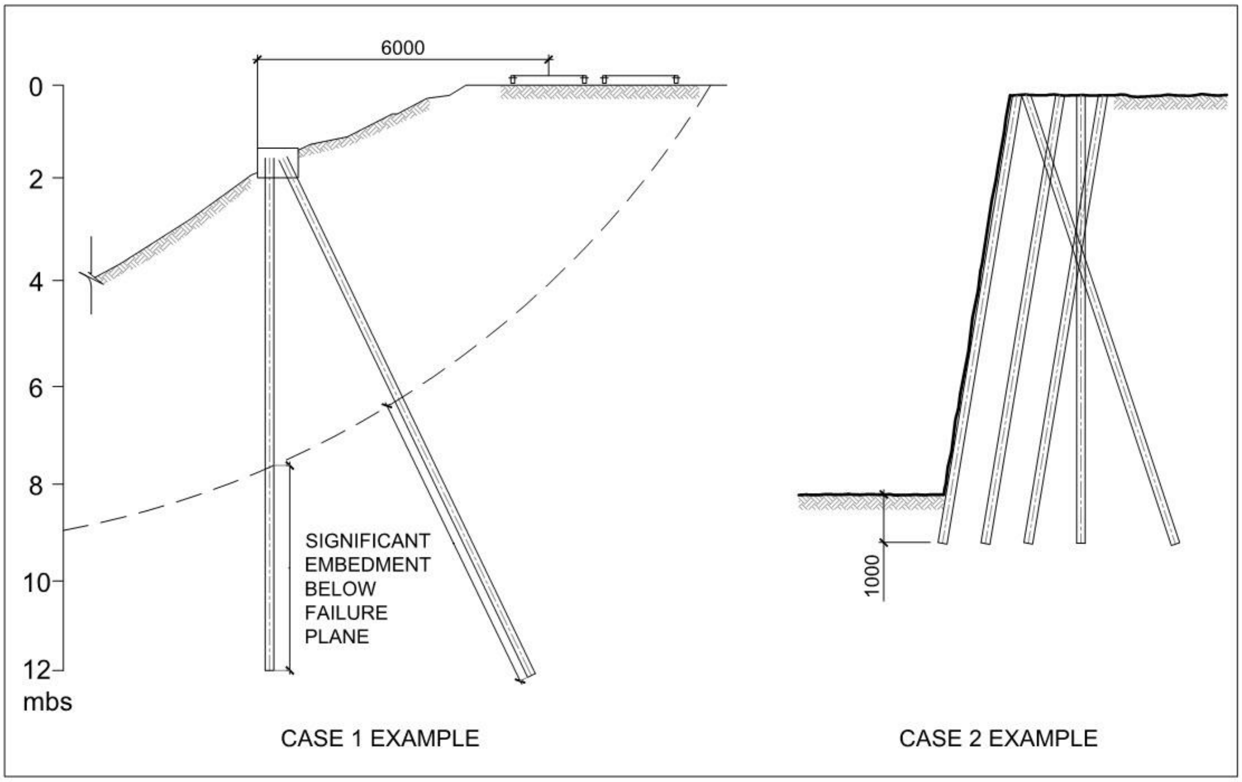

Figure 4: Comparison between Case 1 and Case 2 micropile-supported structures

<u>Construction Approach</u>

In order to suit the specific needs of this project, the slope support scheme had to be:

- Installed long in advance of the planned railway shutdown
- Installed quickly, at high production rates to accommodate brief construction windows
- Suitable for embedment in predominantly sandy soil below the groundwater table
- Capable of delivering copious volumes of grout in a short time
- Capable of producing a suitably irregular grout body for optimized soil-to-grout-to-soil interaction
- Constructed using nimble equipment capable of being demobilized off the tracks at short notice

In addition to these considerations, the scheme's performance could not be dependent on construction of a cap beam, as the time and scheduling logistics required to support such an undertaking were not acceptable to CN.

Design Approach

Analysis was conducted using classical Coulomb theory to generate driving forces (Figure 5). A trapezoidal thrust is derived from soil and surcharge (equipment) loading. Resisting forces are generated against sliding and overturning through base shear and the mass of the micropile-contained soil block rotating about the toe of the

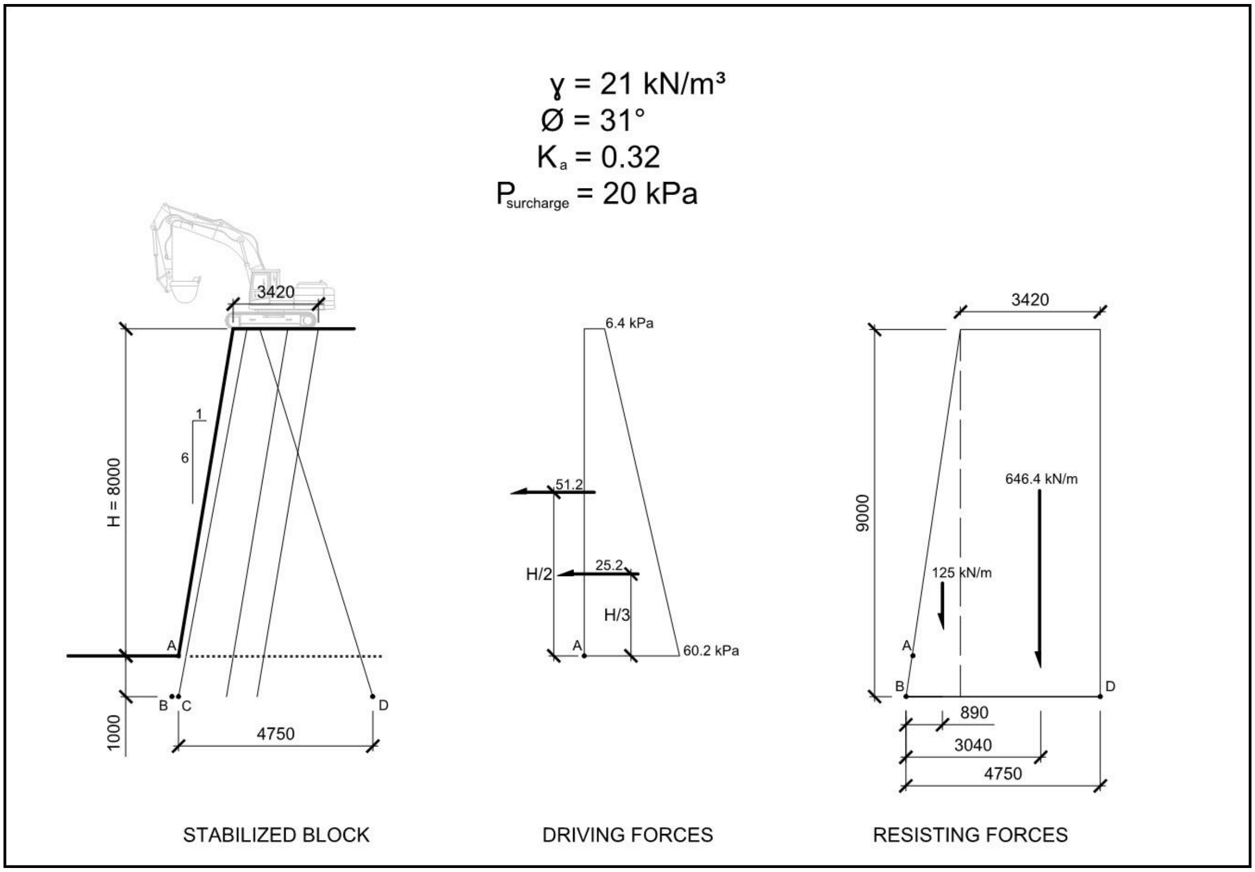

Figure 5: Graphical depiction of driving and resisting forces

slope (Point A). Shear resistance is assumed to occur along the plane coincident with the tips of the micropiles (Points C to D). Although it might be reasonable to assume a shear plane exists at the plane of the base of the excavation (with the projection of the micropile tips providing additional shear resistance), it is instead assumed the micropile-reinforced soil shifts the shear plane lower, to the micropile tips. Using this assumption, a factor of safety of 1.74 was obtained against base shear, which was deemed adequate. Resistance to overturning is provided by the mass of the soil knit together by the micropile matrix. The soil mass was assumed to encompass a block of soil extending from the excavation face, down to the base of the micropiles (Point B), and backwards to a vertical plane intersecting the tips of the back-raked micropiles (Point D). Under this geometry, rotation about the base of the excavation face (Point A) provides a factor of safety against overturning of 2.67.

Micropile Geometry

Case 2 micropiles were arranged in three rows of front-battered piles and one row of back-battered micropiles (Fig. 6). The centre-to-centre spacing of the front row micropiles was 800 mm; the middle row 1200 mm and the back row 1600 mm. A single row of back-battered micropiles, spaced at 3200 mm, was incorporated into the wall configuration for added stability. Toe embedment was designed to be 1000 mm below the dredge line. Deeper toes were not justified, as this system was designed around reinforcing the soil to create a strengthened mass more so than embedding a geostructural diaphragm. Spacing of front row micropiles was based on global stability and raveling prevention. Spacing of the middle and back rows was based on the optimal geometry for tying the soil mass together with the least number of micropiles. An additional row of plumb micropiles, offset 1350 mm from the crest and spaced at 1200 mm, was added as a means of providing additional support for the heavy excavation equipment intended for the initial stages of excavation, with the existing ballast layer left in place to act as the load transfer platform for these particular piles.

MICROPILE CONSTRUCTION

In total, 155 micropiles, consisting of *Titan* 40/20 hollow bar with 115 mm diameter cross-cut drill bits, each 9.6 metres long (on axis), were installed using the continuous grout flush (injection bore) process. The entire micropile network was installed from existing grade (top of ties), with the railway in full operation. For the most part, night shifts were employed (Fig. 7) in order to provide the micropile drilling and grouting operation with the opportunity to perform uninterrupted (for 5 hours at a time, on good days). Two drill rigs were employed, supplied with grout from one grout plant. Median production rate was 7 micropiles per overnight shift per drill rig.

In stark contrast to standard grout-flush micropile work conducted atop railway ballast – where fouling of the ballast is a major concern to the rail operator and hence much precaution is undertaken in pursuit of managing grout spoil – the grout spoil was permitted to enter the ballast for the sake of better engaging the upper layer of supported soil. This concession was granted by the rail operator with the knowledge that the lateral extent of fouled ballast was already slated to be removed during the shutdown. Secondary grouting (next day or later) was employed as necessary to ensure full grout cover through the ballast layer. Micropile reinforcement was cut off at top of tie.

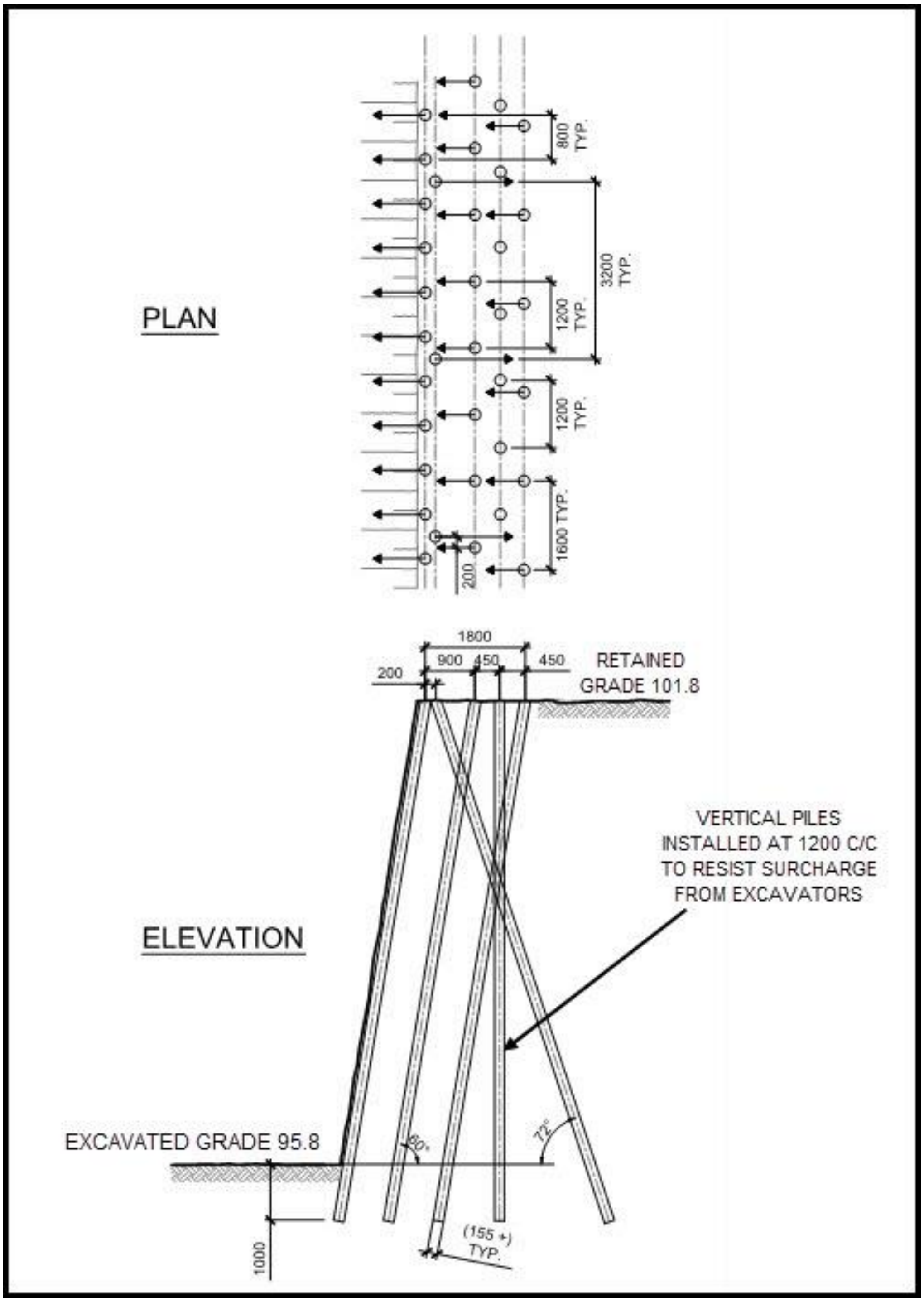

Figure 6: Micropile network: arrangement and cross section

Figure 7: Light weight drill rig installing micropiles during night shift

SYSTEM PERFORMANCE

A test segment was constructed several metres to the south of the rail tracks in order to evaluate the likely performance of the actual micropile network. This test segment, 3 metres in breadth and 8 metres high when cut, consisted of 7 front-battered micropiles arranged in 3 rows, 1 back-battered and 1 plumb micropile, all representatively drilled and grouted. After one week of curing, the segment was exposed, otherwise unprotected, but with precautions in place to ensure no live load surcharge was resisted atop the segment, for a period of 10 days for visual observation. No formal measurements of slope crest movements were made; no negative performance issues were observed.

Exhumed micropiles from within the sand layer showed a gross pile diameter of 155 mm with minimal visual variation of diameter throughout the sand layer.

In the days prior to excavation and long after completion of micropile installation, the excavation staging plan was revised from a single phase of bulk excavation with the entire supported slope maintained intact, to a two phase exercise. The first excavation phase consisted of bulk excavating, to the greatest extent possible, with large 330-class excavators positioned atop the crest of the slope and excavating from both sides in toward the middle, while the second phase took the excavation to completion using only smaller equipment, with nothing staged from the crest of the slope. Despite this aspect not having been considered at time of design, conformance with this staging plan necessitated exhumation and removal of the tops of the micropiles after the conclusion of the first phase of excavation.

Although the rail operator balked at giving the time and space necessary to install an inclinometer (as proposed by the micropile contractor), the micropile network's performance can be inferred /approximated from empirical evidence gathered throughout the railway shutdown. The crest of the slope supported multiple heavy excavators without issue, the entire slope was cut without incident, and the cut stayed supported for the entire duration of the tunnel push despite the fact that much weeping of groundwater was observed through the cut face. The micropiles undoubtedly saw significant loading; the performance of the system was self-evident and satisfactory to its end user. Much to the satisfaction of the excavation trade contractor, no hand digging was required to deal with any raveling at the base of the cut, ahead of or behind the leading edge of the tunnel during advance.

DISCUSSION

The Case 2 micropile network approach posed better value to this project's needs compared to similar options available using Case 1 micropiles or conventional earth support methods, but only because of the requirement for 100% completion of the support system long before the rapid excavation and jacking phase of the project and the lack of stringent settlement/ movement limits at the slope crest.

The excavation support market in the GTA is worth approximately $300M annually, with braced/anchored secant wall and braced/anchored pile and lagging making up 85% of this market, and special techniques such as anchored shotcrete, soil nailing, micropile, driven sheet pile and cantilever walls making up the remaining 15%. Not surprisingly, the vast majority of excavation support is designed to limit movements /settlement of adjacent ground to within strict thresholds. Goals include support of adjacent ground/ structures, slope stabilization, and code compliance to ensure worker safety. The specific needs at CN King Rd – slope support and worker safety, with little regard to the magnitude of movement at the slope crest and consequently no need for pre-loading / pre-stressing of the support system – were ideally suited to a pure Case 2 micropile approach.

At the CN King Road grade separation project, 1488 lineal metres of micropiles were installed in order to successfully support 303 m^2 of supported face. Inclusive of night shift premium and design fees (but excluding excavation and rail traffic control) this contract was delivered at a cost to the owner of $1,500 USD per square metre of supported face. Although this price does not compare favourably with typical GTA braced/anchored secant wall or pile and lagging wall pricing, the means and methods required to construct such conventional, large diameter support systems precluded their implementation at this project.

Case 1 and Case 2 micropiles have found a niche in the GTA market for near-zero-clearance and limited access excavation support applications, but until there is a sea change in market drivers (e.g. much stricter vibration limits, noise limits, etc.), micropiles will always lose out in head to head competition with conventional excavation support techniques, principally on price.

Not including hybrid designs, micropile-supported excavation support is still in its infancy in the GTA market. Compared to over 135 constructed projects employing direct-support Case 1 micropiles in the GTA since 2001, the authors have personally been involved in only 7 projects constructed (and another 5 pursued but not constructed) using micropiles for excavation support, and of these 12, only one was a pure Case 2 network.

With more restrictive settings and increasingly stringent vibration limits, the trend toward further utilization of micropile techniques for urban excavation support within the GTA market is self-evident.

CONCLUSIONS

Installation of Case 2 micropile networks at this site saved a significant volume of excavation and a significant length of rail track demolition & reconstruction.

The application of micropile technology at this schedule-driven project proved successful due to the ability of the micropile network to be embedded long in advance of being put into service, and the ability for the micropile network to resist loading without any of the micropiles having to be connected to an ancillary cap beam.

The safe staging of the rapid excavation, most notably the ability to safely position heavy equipment at the crest of the slope, was enabled, and worker safety was enhanced, by the presence of the Case 2 micropile networks.

The Case 2 micropile networks performed as required, including control of face raveling and sloughing, despite the presence of the groundwater table.

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