Micropiles for Highway 3, Grand River Bridge Replacement, Cayuga, Ontario

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ABSTRACT
The Grand River Bridge at Cayuga, Ontario is a two-lane, 5-span structure carrying Ontario Highway 3 over the Grand River. At the time of the works described herein, the bridge was over 100 years old and in dire need of refurbishment and upgrades. All bridge retrofitting work was required to be completed in a manner that prevented interruption of traffic on Highway 3 and minimized impact on the river bottom. Prior to demolition of the existing steel superstructure, a temporary alignment was constructed adjacent to the existing bridge to detour traffic from the existing structure. The new bridge deck constructed on the temporary alignment was supported by temporary, rock-socketed micropiles before eventually being jacked sideways onto the refurbished existing bridge piers after each of the four existing piers was retrofitted with 18 rock-socketed micropiles.

To support the temporary detour bridge, steel caissons were driven through river bottom sediments to the top of bedrock, then augmented by the installation of micropiles at their open-bottom bases before the steel caissons were converted to piers. The permanent micropiles were installed through the existing bridge piers and socketed in rock using a rotary duplex concentric drilling process. Challenging ground conditions were encountered during drilling of the micropiles that necessitated special, modified drilling and grouting procedures. Micropile technology provided game changing options for the Highway 3, Grand River Bridge Replacement Project. An overview of the successful project execution, challenges encountered, micropile design, testing and quality control are outlined in this paper.

RÉSUMÉ
Le pont de Grand River à Cayuga, en Ontario, est une structure à 5 voies et à deux voies qui porte l'autoroute 3 de l'Ontario sur la rivière Grand. Au moment des travaux décrits ici, le pont avait plus de 100 ans et avait grand besoin de rénovations et de mises à niveau. Tous les travaux de rénovation du pont devaient être complétés de manière à empêcher l'interruption du trafic sur l'autoroute 3 et minimiser l'impact sur le fond de la rivière. Avant la démolition de la superstructure d'acier existante, un alignement temporaire a été construit à côté du pont existant pour détourner le trafic de la structure existante. Le nouveau pont-pont construit sur l'alignement temporaire a été soutenu par des micropiles temporaires, rock-socketed avant d'être éventuellement relevés sur les quais de pont existants remis à neuf après que chacun des quatre piles existants ait été équipé de 18 micopiles à socquettes.

Pour soutenir le pont de détour temporaire, les caissons en acier ont été conduits par les sédiments du fond de la rivière au sommet du substrat rocheux, puis augmentés par l'installation de micropieux à leurs bases ouvertes avant que les caissons en acier ne soient transformés en piles. Les micropiles permanents ont été installés à travers les piles du pont existantes et ont été moulés dans la roche à l'aide d'un processus de forage concentrique rotatif duplex. Des conditions environnementales difficiles ont été rencontrées lors du forage des micropieux qui nécessitaient des procédures spéciales de forage et de jointement modifiées. La technologie Micropile a fourni des options de changement de jeu pour le projet de remplacement de la route 3, Grand River Bridge. Un aperçu de l'exécution réussie du projet, des défis rencontrés, de la conception des micropiles, des tests et du contrôle de la qualité est décrit dans ce document.

1. Introduction
Ontario Highway 3 crosses the Grand River at the town of Cayuga. Rehabilitation of the existing, historic 2-lane, five-span steel truss bridge began in 2012 and was completed in 2016. The project included reinforcing the original bridge piers with micropiles to support a new, 4-lane structure. There were numerous intricate layers to the project which included the phased demolition of the old structure while preserving its piers and the erection of a new 188 m long, 14.6 m wide, five-span, concrete-slab-on-steel-girder bridge atop the existing piers. Prior to demolition, temporary bridge piers were installed adjacent to the existing bridge. The new bridge deck was constructed atop these temporary bridge piers to allow for uninterrupted traffic flow across the Grand River at Highway 3.

The bridge’s owner, MTO, awarded contract MTO-2012-3007 to Dufferin Construction who in turn awarded the specialty micropile scope to Geo-Foundations. The sub-contractor’s scope included the design and construction of steel piling cofferdams to enable construction of widened abutments, design and construction of micropiles for the temporary detour bridge, and design and construction of micropiles for the reconstructed permanent bridge. Micropile foundations were constructed to support the temporary detour bridge piers located downstream of the existing bridge. The detour bridge girders spanned 6 bents of in-river piers, 3 piers per
bent, founded on 4 micropiles per pier. Factored micropile loading was 1955 kN axial compression per individual micropile. Detour micropile construction was staged from barges in the river, with single-stroke drilling staged from a lead-mounted crane.

By utilizing micropiles to refurbish the existing piers, all permanent impact on the river bottom footprint was reduced to zero. The new bridge deck was jacked in place from the temporary bridge piers to the existing piers retrofitted with 18 no. micropiles constructed through each existing pier. The jack and slide was done during a weekend due to the required bridge closure.

The project delivery was via Construction Manager General Contractor model (CMGC), whereby the Construction Manager worked under contract with the Owner’s design team to develop the project documents.

2. Subsurface conditions

Ground conditions at the site are typical of most of the Grand River Valley, with river silts underlain by sandy gravel overlying bedrock of highly varying quality and weathering. The degree and depth of bedrock weathering is particularly noteworthy, with thick layers of solution cavities and mud seams often alternating between layers of fresh bedrock.

The river water surface is around elevation 176m and approximately 2 meters deep. The river bed consists of a 1-2 m thick sand and gravel layer, underlain by a layer of Dolostone fragments, extending to elevation 172m, which is the top of the highly weathered Dolostone Bedrock, named Bertie Formation. Underneath is a slightly weathered Dolostone/Shale/ Evaporites layer, named the Salina Formation. The Bertie Formation is vuggy, porous and laminated, through which drilled holes collapsed and significant grout loss was experienced during construction of the micropiles. Figure 1 shows the subsurface profile along the existing bridge alignment.

3. Temporary Micropiles for the Detour Bridge

Prior to micropile installation, 15 pieces of Ø 1.83m steel caisson were driven for the detour bridge. An additional 3 pieces were driven to create a bent on the river bank. Each steel caisson was installed to the top of bedrock and augmented with 4 no. rock-socketed micropiles. The soil inside the caisson was cleaned out prior to the installation of micropiles.

In total, 72 no. temporary micropiles were constructed as deep foundations to support these steel caissons arranged as four micropiles inside each steel caisson. Each micropile was designed for a factored axial compressive load of 1955 kN (ULS) and consisted of:

- 1 - #24 (76 mm dia.), Py = 2277 kN; Fy=517 MPa threaded bar, x 12.8 m long
- 152 mm dia. x 12 m deep rock socket
- 250 x 250 x 50 mm thick steel bearing plate (Fy=350MPa)
- Type GU cement grout @ 0.45 W/C (by weight); UCS 35MPa at 28 days

Figure 2 shows the set-up for the installation of temporary micropiles inside temporary steel caissons. Figure 3 illustrates a cross section of the detour bridge.
3.1 Temporary Micropiles Installation

The installation system consisted of a Sany 1500 crane, 24m x 18m floating barge, a lead system, hydraulic rotation motor, drill rods, down-the-hole hammer with Ø152mm button bit, and an Atlantic AD1010 grout mixing plant.

The installation procedure was as follows:

- A guiding template was placed into the Ø 1.83m steel caisson. The guiding template consisted of 4 pieces of Ø178mm steel pipes arranged to fit a four micropiles arrangement and extending from top of bedrock to 1m above top of caisson.
- Once fit exactly into place each guiding template was permanently secured by pouring a 0.5 m thick layer of tremie concrete.
- Placed working platform on top of the steel caisson to facilitate operation.
- The lead system was suspended vertically over the working platform and drilling proceeded through the guiding template down to bedrock.
- Rotary percussive boring method (uncased) was used with air flush.
- At the completion of drilling, the hole was cleaned by injecting alternating jets of water and compressed air through drill rods extending to the bottom of the hole until all return flush was clear of suspended solids.
- The drill rods were retracted and the hole was checked to verify unobstructed passage to full depth. The central threaded bar was then inserted into the drilled hole, complete with centralizers and tremie grout tube until the bar rested at the bottom of the hole.
- The micropile was immediately thereafter tremie grouted. A superplasticizer (BASF - PS1466) was added to the grout mix.

![Figure 2: Micropile installation inside temporary steel caissons](image1)

![Figure 3: Cross-section of detour bridge piers](image2)
3.2 Construction Issues - Temporary Micropiles

Compressed air was used to actuate the down-the-hole hammer and to evacuate cuttings as the drill string was advanced through the porous Bertie Formation and the overlying soils. During drilling air bubbles were observed inside the Ø 1.83 m caisson and in the water nearby. Once the air pressure was released, sand and rock debris flowed back into the hole and often caused the bit to plug. Whenever this condition was encountered, drilling was stopped to prevent damage to the tooling. In such cases pre-grouting was performed with the aim being to consolidate the surrounding rock mass. This modified procedure had a significant impact on the drilling production rate.

A summary of the construction of the temporary micropiles follows:
- Installation of the 72 no. temporary micropiles took 85 calendar days to install, from August 19 to November 11, 2013.
- 27 out of 72 micropiles were pre-grouted and re-drilled, with some holes re-drilled and re-grouted more than once.
- Total pre-drill length: 659.3 m, representing 76% of the theoretical drill length 864 m (72 x 12 m),
- Total grout volume: 161.48 m³, roughly 10.3 times the theoretical hole volume.
- Anti-washout (BASF - UW450) was added to the grout during the pre-grouting, at a dosage of 0.5% by weight of cement.

Figure 4 displays the grout volume distribution of the 72 no. temporary micropiles. The average grout volume was 2.24 m³ vs. a theoretical volume of 0.21 m³. It was typical for micropiles which were installed earlier to take more grout compared to those installed later. The rock formation was locally consolidated by the micropile grouting. Adjacent micropiles were spaced 647 mm centre-to-centre inside each caisson.

4. Permanent micropiles through existing piers

While the traffic was rerouted to the detour bridge in 2014, the old bridge deck was demolished down to the tops of the existing piers after which the top of each existing pier was further demolished to top elevation EL. 179.464. The rehabilitation of the existing bridge piers included the installation of 72 no. permanent, rock-socketed micropiles, arranged as 18 no. micropiles installed from the top of each pier, extending deep into bedrock to permanently support each refurbished pier.

Each permanent micropile was designed for a factored axial compression load of 914 kN (ULS) and was configured as follows:
- 550MPa permanent steel casing, Ø 273 mm x 13.8 mm thick, 15.24 m length (Piers 1, 4) and 16.76 m length (Piers 2, 3)
- Permanent micropile casings featured mechanical splices, via API thread-form pin x box threaded joints, typically at 3 m centre-to-centre spacing.
- Central reinforcement consisting of 517 MPa threaded bar, 1 - Ø 63 mm, corrosion protected via encapsulation by manufacturer prior to shipment to site.
- Rock socket, 9.8 m long, Ø 225 mm
- Bar spliced with couplers on site, each coupler capable of safely withstanding 125% of bar yield strength,
- Grade 350W bearing plate, 350 x 350 x 50 mm, placed on top of casing and secured in place with a hex nut.
- Type GU cement, w/c = 0.45 by weight of cement; UCS = 35 MPa at 28 days.

4.1 Installation of permanent micropiles

The entire micropile operation utilized a 24mX18m floating barge, Link-Belt 750 crane, DK620 and DK50 drill rigs, Atlantic AD1010 grout mixing plant and a working platform. The installation method was as follows:
- A working platform was set-up on top of each pier. In addition, a plywood curtain was erected around each pier to ensure no cuttings and grout spoils fell into the river.
- At each pile location a 0.6 m high guide pipe, battered at 1H/12V was installed.
- A Ø 305 mm hole was advanced through the guide pipe, into the existing concrete pier extending to approximately 1 meter above drilling elevation. All drill cuttings were directed into a sealed bin.
- A DK-620 drill rig was used to advance a Ø 273 mm casing using Numa Superjaws up to 1 meter into the Salina formation, using rotary percussive concentric duplex boring method with air flush. The inside of the casing was aggressively cleaned with alternating jets of water and compressed air prior to retracting the duplex tooling.
- Drilled a 9.8 m deep rock socket with a down-the-hole hammer and Ø 225 mm button bit, using rotary percussive drilling process with air flush.
- At the completion of drilling, the hole was cleaned by injecting alternating jets of water and
compressed air through drill rods extending to the bottom of the hole until all return flush was clear of suspended solids.

- At the completion of drilling and flushing, the drill rods were retracted prior to installation of the central DCP threaded bar, complete with centralizers and tremie grout tube until the bar rested at the bottom of the hole.
- Tremie grouted the micropile and measured the specific gravity. A superplasticizer (BASF - PS1466) was added to the grout mix.

- Grouted the annular space between the Ø273mm casing and drill hole wall. Grout was placed from the top of the platform until the annular space was full.

Figure 5 shows the set-up for micropile installation at Pier #3 (existing structure). The arrangement of the permanent micropiles at the existing piers is illustrated in Figure 6.

Figure 5: Micropile installation at existing Pier #3

Figure 6: Permanent micropile arrangement at existing piers
4.2 Construction Challenges:

To avoid collapsed holes during the temporary micropile installations, the Ø 273mm temporary casings were extended, considerably deeper than originally intended, into the Salina Formation. Air bubbles were observed in the river near the piers during drilling. Upon completion of drilling, the water level inside the casing was the same elevation as the river.

The water level and grout level inside the casing were closely monitored. Fresh grout could not reach the casing collar after the tremie-injected grout volume reached the theoretical hole volume. The water level inside the casing elevated slowly but dropped once injection stopped. At Pier #4, micropile MP#137 took 115 bags of cement grout (yield of 3600 L) and 2.5 hours of grouting without reaching the casing collar.

Two main concerns surrounded this problem. Firstly, since the grout flow path was unknown and the pier was in a river, the grouting volume needed to be controlled to avoid potential environmental concerns. Secondly, the time needed to grout a single pile was problematically excessive.

It was decided that the micropiles should be grouted in two stages.

Primary grouting stage:
- The micropile was grouted up to an injected grout volume of 1250 litres, about 1.3 times the net theoretical volume of the rock socket.
- After a 1-hour wait, grouting was continued until fresh grout was observed coming out of the casing. Primary grouting was limited to 2000 liters and 2 hours of injection. A detailed record of water level inside the casing was maintained.

Secondary grouting stage:
- If no fresh grout was observed coming out of the casing during the primary stage, grouting resumed after an interlude of 12 hours. Prior to the resumption of grouting, the grout level inside the casing was measured.

The grouting summary is provided in Table 1. In this table, the theoretical hole volumes were 910 liters per pile at piers #1&4, and 970 liters per pile at piers #2&3.

In total, 37 of the 72 micropiles were grouted via two stages. The ratio of total grouting volume to theoretical hole volume varied between 1.84 to 2.36 among the four piers.

<table>
<thead>
<tr>
<th>Location</th>
<th>Theoretical volume of rock socket (m³)</th>
<th>Primary grouting vol. injected (m³)</th>
<th>Secondary grouting vol. injected (m³)</th>
<th>Piles requiring secondary grouting</th>
<th>Percentage increase in grout injection per pier relative to theoretical vol. (%)</th>
<th>Interlude between primary and secondary grouting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pier #1</td>
<td>16.40</td>
<td>27.23</td>
<td>6.58</td>
<td>15 out of 18</td>
<td>236</td>
<td>May 6 to May 27, 2016</td>
</tr>
<tr>
<td>Pier #2</td>
<td>17.46</td>
<td>27.45</td>
<td>0.69</td>
<td>7 out of 18</td>
<td>184</td>
<td>Oct 23 to Nov 3, 2014</td>
</tr>
<tr>
<td>Pier #3</td>
<td>17.46</td>
<td>29.14</td>
<td>3.26</td>
<td>9 out of 19</td>
<td>206</td>
<td>Oct 3 to Oct 20, 2014</td>
</tr>
<tr>
<td>Pier #4</td>
<td>16.40</td>
<td>29.92</td>
<td>1.28</td>
<td>6 out of 18</td>
<td>216</td>
<td>Sep 5 to Sep 26, 2014</td>
</tr>
</tbody>
</table>

5. Load testing

The specification stipulated three types of micropile load testing and established loading ranges and acceptance criteria for each. These included static axial compression performance testing and tension testing of sacrificial piles, and proof testing of production piles.

5.1 Performance test of LT-1:

The performance test was carried out by cyclically loading on a sacrificial pre-production micropile LT-1 in static compression to verify the design assumptions and the appropriateness of the proposed installation procedures. The testing location was at the river bank, as mutually agreed by the contractor and the Owner’s representative. The test load was 3896 kN (i.e. 2.0 times the factored axial resistance at ULS). In order to mimic the 72 temporary micropiles, the same rock socket size (12m long x Ø 152mm) was drilled from the top of bedrock.

The specified acceptance criteria were 30 mm maximum total movement at 0.78DL and no more than an additional 3 mm of total vertical movement from 0.78 DL to 0.88 DL. The measured movements were within the acceptance criteria. The load vs. displacement plot is shown in Figure 7.

5.2 Tension testing of TD2 & 4:

After completion of the performance testing in compression, two of the four sacrificial anchors employed in lying down, TD-2& TD-4, were loaded in tension to assess the ultimate grout-to-rock bond.

The tension test load was 1185 kN and the calculated grout-to-rock average bond stress reached 310 kPa. The test load was limited to 0.9 times the yield strength of the Ø57mm bar; the applied stress was 0.92 and 2.4 times the average bond stresses of the temporary piles and permanent piles respectively.
5.3 Proof testing of temporary micropile C-3:

Static compression proof test was conducted on production micropile C-3, inside a Ø 1.83m steel caisson. The test load was 3106 kN (i.e. 1.6 times the design load). Four sacrificial reaction piles were installed to conduct the proof test. The total movement was much less than the specified criterion, which was the same criterion as stipulated for the performance test.

5.4 Proof testing of permanent micropiles at the piers

Proof testing was conducted on 4 no. permanent micropiles. The testing apparatus was set up on the working platform located at the top of the existing piers. Two nearby production micropiles were used as reaction anchors to hold the testing beam. The proof testing arrangement is shown in Figure 8.

The test load was 1409 kN (i.e. 1.54 DL), inclined at 1H/12V. The total movement was well below the acceptance criteria of 30mm at 0.78 DL (see table 2).

On Piers #1 and #4, the annular spaces around the piles were fully grouted as specified and the measured movements were less than 2 mm. For comparison, on the other two test piles, the annular spaces were purposely not grouted, and their movements were larger: 4.29mm and 3.20mm on Pier #2 and #3, respectively. The testing results are summarized in Table 2:

![Figure 7: LT-1 Performance load test plot](image)

![Figure 8: Proof testing at the top of an exiting pier](image)

<table>
<thead>
<tr>
<th>Test location</th>
<th>Micropile configuration</th>
<th>Maximum Test Load</th>
<th>Total Movement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance test - LT-1 at river bank,</td>
<td>Ø75mm, 1034 MPa threaded bar, 8.5m inside casing, 12m in bedrock; 245mm x 12.7mm thick casing through overburden, 0.3m into bedrock; rock socket diameter 152mm.</td>
<td>3896 kN (2.0 DL)</td>
<td>25.76mm</td>
</tr>
<tr>
<td>Tension test - TD-2&amp;4, at river bank</td>
<td>Ø 57mm, 517 MPa threaded bar; 8.5m in soil and 8.0m in bedrock. Socket diameter 152mm.</td>
<td>1185 kN</td>
<td>11.75 mm and 13 mm, respectively</td>
</tr>
<tr>
<td>Proof test C-3 inside Ø 1.83m caisson at river bank</td>
<td>Ø75mm, 1034 MPa threaded bar, 12m in bedrock, rock socket diameter 152mm.</td>
<td>3106 kN (1.6DL),</td>
<td>7.35 mm</td>
</tr>
<tr>
<td>Proof test of micropile at Pier#1 &amp; 4</td>
<td>Ø 63mm DCP threaded bar inside 15.2m long, Ø 273mmX 13.5mm casing. Socket: 9.8m long Ø 229 mm</td>
<td>1409 kN (1.54 DL)</td>
<td>1.57mm and 1.01mm, respectively</td>
</tr>
<tr>
<td>Proof test of micropile at Pier#2 &amp; 3</td>
<td>Ø 63mm DCP threaded bar inside 16.76 m long, Ø 273mmX 13.5mm casing. Socket: 9.8m long Ø 229 mm</td>
<td>1409 kN</td>
<td>4.29mm and 3.20mm, respectively</td>
</tr>
</tbody>
</table>
6. Discussions

A significant amount of consolidation grouting of the rock mass was required during the installation of the detour bridge micropiles. The micropiles were installed inside of the 1829 mm diameter steel caissons which were advanced to the top of bedrock. Drilling of the micropiles inside the steel caissons were initially done using open-hole drilling technique. However, the condition of the rock mass encountered resulted in cave-ins during drilling.

Non-cohesive deposits were expected between the underside of existing structure and the top of rock which required special micropile drilling techniques including duplex (simultaneous advancement of casing with the bore) drilling. At the detour, however, there was a completely different expectation: because the micropiles are collared inside the bottoms of the 1829 diameter caissons, the entire micropile embedment depth is in rock. This is the reason why the detour micropiles featured no permanent casing in their completed state, nor feature the use of temporary casing at any time during construction: every detour micropile was designed on the basis that its entire embedment depth is in rock.

Cased-hole drilling is typically required when there is an expectation that a drilled hole will collapse in on itself if not otherwise protected from doing so. Open hole drilling is used when the wall of the hole can be counted on to support itself. Small diameter drilled holes in bedrock are constructed exclusively – except in the most rare and extreme cases – using open hole techniques. The detailed design of the detour micropiles, including much thought toward construction method, was based on the reasonable assumption that the drilled holes – despite the expectation of intersecting pervasive voids, vugs, solution cavities and mud-filled seams – could and would be drilled using open-hole technique.

The bedrock encountered during construction of the detour micropiles in many instances collapsed into the drilled holes. The collapsed holes were unfit for use until treated, because a clean, open hole to full depth is a prerequisite of any rock-socketed micropile design, and an integral component of the construction method. Where preconditioning was required, the collapsed hole was tremie grouted to refusal, allowed to cure undisturbed overnight, and re-drilled the next day in the hope that the hole would behave (stand open and otherwise unsupported) as required. In some cases, the degree and depth of the collapse negated the ability to succeed with just one round of pre-treatment. At some locations, two and three rounds of pre-treatment were required.

The utilization of micropiles at the Highway 3 Grand River Bridge project typifies the sublime nature of micropile technology where, seemingly contradictorily, incongruously high capacities are relatively easily achieved using “gentle touch” construction methods. Even across the narrow spectrum of micropile installation (i.e. drilling and grouting) techniques available, there is a broad-range continuum of energy-sensitive installation techniques, from non-percussive / synthetic mud flush drilling +Type A gravity grouting at the lowest energy end of the spectrum to double-head, concentric percussive duplex drilling + Type B pressure grouting at the higher energy end of the spectrum. Particularly telling is the fact that double-head, concentric percussive duplex drilling, despite being toward the high-energy end of the micropile installation spectrum was, appropriately, selected for, and utilized effectively, at the refurbishment of the Grand River Bridge at Cayuga. Unlike conventional deep foundation methods, such as large diameter drilled shafts or driven piles, the entire foundation refurbishment scope was constructed with zero long-term impact on existing structure footprint and perfect preservation, at all times throughout micropile construction, of the existing mode of foundation (bearing on non-cohesive soils).

7. Conclusions

Micropile technology provided game changing options for the Highway 3, Grand River Bridge Replacement Project. The proposed scope of work was completed in a safe, technically suitable and environmentally friendly manner by utilizing micropiles designed and installed by Geo-Foundations Contractors.

A modified grouting method was a sound engineering solution, equitable to the Owner’s costs and environmental impact, and was able to be aligned with the contractual and engineering basis of the contract.

References