

# Utilization of Micropiles at the Expansion of BMO Field, Toronto, Canada

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## **ABSTRACT**

BMO Field is an outdoor stadium located on the shores of Lake Ontario in Toronto, Canada. It was opened in 2007. The venue was originally constructed for the Major League Soccer franchise, *Toronto FC*, but was expanded starting in 2014 to accommodate the Canadian Football League's *Toronto Argonauts* in time for the kickoff to the 2016 season. From 2014 to 2016, a \$120 million (CAD) renovation project was completed that included an 8,400-seat expansion, significant upgrades to the hospitality zones, and twin canopies that will keep most of the spectators under cover. The west canopy is founded on micropiles.

The micropiling portion of the project consisted of the installation of 46 piles, with factored tension/compression loading as high as 3000 kN /4000 kN per micropile, all for support of new pile cap and grade beam foundations for the west canopy. Alignments range from vertical to 1:4 batters. Sizing and selection of micropile central reinforcement at this project was governed by EA as stipulated by the structural engineer,  $EA_{min}$ . This aspect, combined with the particularly deep rock sockets driven by the high magnitude uplift forces, led to a unique opportunity to forego full scale load testing.

Micropiles were selected for this project due to severely restricted access at the west canopy column bases' locations. The stadium's existing infrastructure includes a state of the art *SubAir* system consisting of boilers and piping previously installed at the cost of several millions of dollars. The system heats (and, when necessary, drains) the soil below the playing surface, keeping the natural grass field healthy and happy regardless of the season or the weather. Selected portions of this system would have had to be demolished to accommodate conventional deep foundations, whereas the micropiles were able to be constructed from inside an existing utility closet with no modification to any aspect of the existing *SubAir* system infrastructure.

This paper provides a detailed case history of this project, looking at the design of the micropiles, their installation and the QA/QC measures utilized.

## **1.0 INTRODUCTION**

For a six week period at the end of 2016, the national and international professional sports spotlight shone very brightly on Toronto's newly refurbished BMO Field, beginning with the Grey Cup Championship game (Canada's equivalent to the SuperBowl) in November, then the Major League Soccer MLS Cup final (broadcast in 70 countries), and finally the NHL Centennial Classic outdoor ice hockey game on New Year's Day 2017. For those of us involved in designing and constructing the refurbishments, the stadium could not have looked better. The centerpiece of the 120 million dollar (CAD) project was the new twin canopy set that provides cover to the east and west grandstands at the 36,000 capacity stadium. While construction of foundations for the east

grandstand was straightforward – large-diameter drilled shafts bearing on rock approximately 6 metres below existing grade – design and construction of foundations for the west canopy was considerably more involved, primarily due to the presence of an existing, multi-million dollar *SubAir* system crowding the footprint of the new foundations. Incorporation of highly loaded (in both tension and compression) micropiles into the foundation design for the west canopy made foundation construction not only possible, but also both safe and efficient.

Also known as the Canadian National Soccer Stadium, BMO Field is located at Exhibition Place on the north shore of Lake Ontario in downtown Toronto, Canada. The stadium is home to Canada's National Soccer Team, as well as MLS franchise, Toronto FC and most recently the Canadian Football League's Toronto Argonauts. In 2014, a major renovation project was undertaken at BMO Field to increase the seating capacity by 8,400 seats and construct canopies to cover the grandstands. The expansion also included changes to allow for the use of the facility by a CFL team.

A key feature of the improvements at BMO Field was the construction of twin canopies that will span the entirety of each of the east and west grandstands. Each of the new canopies is supported by "super columns". While the east canopy super columns are supported on large diameter drilled shafts (typically referred to in Toronto as caissons) the west canopy super columns are supported by foundations comprised of micropile-supported pile caps and grade beams constructed within existing indoor spaces. The west canopy micropiles are capable of resisting substantial uplift, compressive and lateral forces, and are socketed several metres into shale bedrock. Figure 1 shows the BMO field renovations in progress looking north.

The micropiling scope at BMO Field consisted of installation of 46 piles, with factored loading ranging from 3000 kN in tension to 4000 kN in compression per micropile. Alignments range from vertical to 1:4 batters. The configuration of each pile is comprised of a permanent casing embedded 0.300 m into bedrock, and bundled bar central reinforcing that extends the full depth of pile into a 4 metre to 9 metre long rock socket. The micropile design on this project was governed by  $EA_{min}$ , as stipulated on a pile by pile basis by the structural engineer. This aspect of the design, combined with the fact that the rock socket depths were designed to be particularly deep in consideration of ensuring adequate embedment to mobilize sufficient bedrock mass during factored uplift loading, enabled the micropile designer to offer considerable savings to the owner by foregoing full scale load testing.

Micropiles were selected for this project due to access restrictions at the locations of the west canopy foundations and the presence of a state of the art *SubAir* system that heats and/or drains the soil below the playing surface. Selected portions of this multi-million dollar system would have had to be demolished to accommodate conventional piling rigs, whereas micropiling drill rigs could access the pile locations via utility closets with no alterations required to any component of the existing system.



**FIGURE 1: BMO FIELD RENOVATIONS IN PROGRESS, LOOKING NORTH**

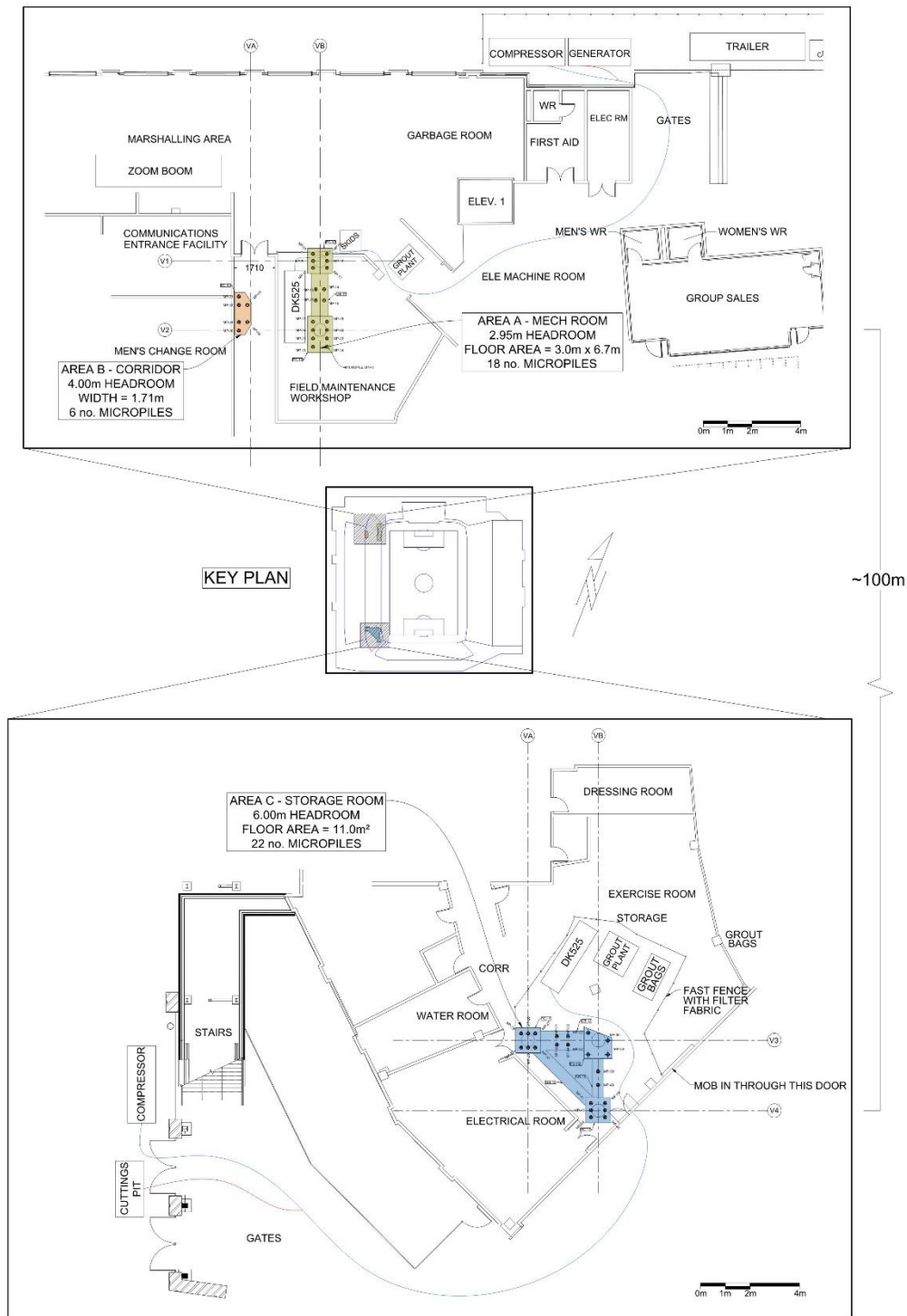
## **2.0 PROJECT SETTING**

Access restrictions from existing floor plans, low headroom and multiple buried services (Fig. 2) resulted in major foundation constructability challenges. In order to avoid the buried services, the pile cap excavations were completed prior to micropile installation, using an engineered excavation support system consisting of micropile soldier piles and hardwood lagging. The shoring allowed seamless relocation of underground utility services away from the trajectory of micropiles and expedited the construction of pile caps and grade beams, an important step in achieving the schedule goals of the general contractor, PCL Constructors Canada Inc. The shoring system in the mechanical room [Area A] and the delivery/storage room [Area C] comprised of 140 mm diameter drilled pipe soldier piles, welded tee sections, 75 mm thick lagging boards, walers and struts. At the hallway [Area B], the shoring system consisted of a trench box which was created by interlocking 150 mm thick timbers and steel angles as corner supports.

The piles were installed in three main work areas, designated Areas A, B and C (Fig. 2), each with its own unique combination of lateral and headroom restrictions. An excavation support system was installed at Areas A & C prior to pile installation to allow for relocation of existing buried services (Fig. 5) prior to drilling. Installation of a steel piling template and suspended steel plate platforms was carried out to facilitate high precision construction of the piles and enable the safe construction of the pile caps. All piles in Areas A and C were installed from temporary suspended platforms with top-of-plate elevation coincident with finished floor grade, covering the supported temporary excavation footprint and steel pipe templates with robust steel plating capable of safely supporting the load of the electric-over-hydraulic crawler drill rig.

In order to address the requirement for high precision layout (i.e., exacting tolerances with respect to pile locations in plan and pile batter), steel pipe templates were installed inside the excavation support system. After the steel templates were installed 2.13 metres below grade, a mudslab was

poured to secure the assembly in place during drilling. Road plates were used to cover the excavation and provide a working platform for the drill rig. All micropiles were constructed with the aid of the templates.



**FIGURE 2: MICROPILE WORK AREAS**

The mechanical room [Area A] presented the most challenging combination of above-grade working conditions, where the available headroom was only 2.95 metres. Setting up over each pile location was challenging due to crowding from highly sensitive mechanical equipment and piping. A total of 18 no. micropiles were constructed in Area A. Extra emphasis was placed on safety since only one access route was available to the small footprint (3.0 m x 6.7 m) work zone. This also created restrictions in terms of maneuverability.

In total, 6 micropiles were constructed in a 1.7-metre-wide hallway [Area B], which was only accessible via a 2.0 m high x 1.5 m wide doorway. This narrow hallway required extra consideration during drilling as it was within close proximity to a shallow-founded shear wall – the lateral offset was only 400 mm. The working grade was sloped at 6% with available headroom of just 4 metres. The maximum load carrying micropile in Area B was designed to resist 3000 kN (ULS) axial tension, 2690 kN (ULS) axial compression with a minimum stipulated EA,  $EA_{min}$  of 1080 MN.

In Area C, 22 no. micropiles were constructed in headroom of 6.0 metres. These micropiles were the largest load carrying piles installed, with 1925 kN (ULS) axial tension, 3975 kN (ULS) axial compression and requiring an EA exceeding 1420 MN. Workers had to avoid making excessive noise, as offices were located near this area. MLS games were also in session every other weekend, so cleanliness of the working area and clear delineation of the hoarded area and its hazards was especially important in order to adequately protect both the public from the construction hazards and the micropiling equipment from the public.

### **3.0 SUBSURFACE CONDITIONS**

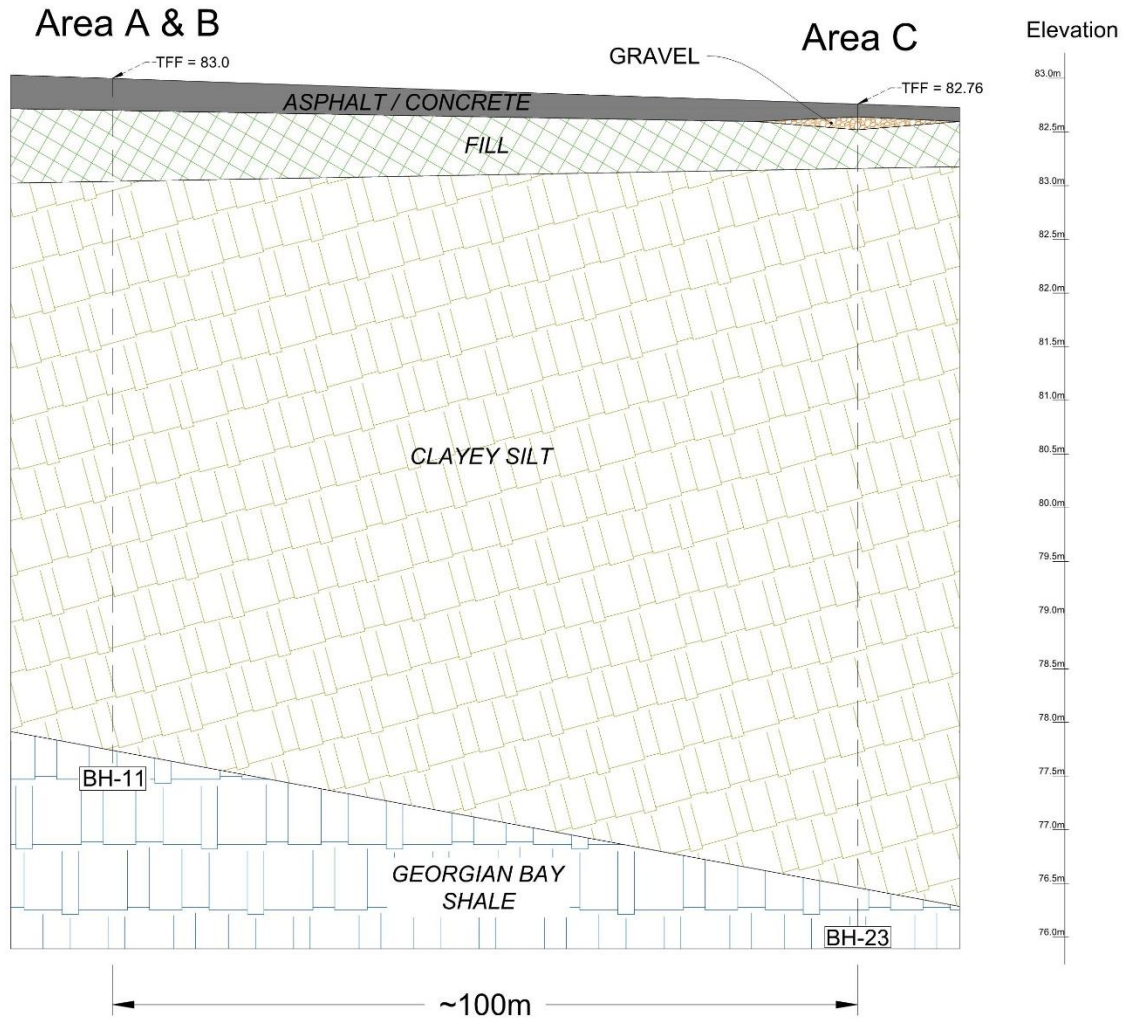
The proposed micropile locations were covered by existing concrete slabs-on-grade overlying fill soils as thick as 1.5 metres. Fill at this site is comprised of cohesionless sand and gravel, or crushed stone aggregate in some areas.

Clayey silt till is present below the fill layer. The clayey silt till found at the site is predominantly of very stiff to hard consistency with SPT 'N' values ranging from 25 to 90. There are lenses of wet sand and gravel present in deeper levels of the till deposits.

Glacial till is underlain by bedrock of the Georgian Bay Formation comprising of laminated to thinly bedded grey shale. The depth to bedrock ranges from 4.6 to 7.6 metres below existing grade. The bedding of the Georgian Bay Formation is typically flat lying with the upper 1 to 2 metres comprised of weathered shale. All micropiles were socketed in sound rock.

The approximate depth to the groundwater table is 1.5 metres below existing grade but the clayey silt till generally prevents the migration of water. Figure 3 shows a typical profile of the subsurface conditions at the BMO Field site.

No particularly corrosive soils were identified in the project geotechnical investigation.



**FIGURE 3: SUBSURFACE PROFILE**

#### **4.0 MICROPILE DESIGN CONSIDERATIONS**

Detailed micropile design was completed in accordance with the USFHWA Micropile Design and Construction Guideline (Publication no. FHWA SA 97-070), June 2000, using Load Resistance Factored Design (LRFD) Method. Each micropile features a permanent casing embedded a minimum of 0.3 m into bedrock to stabilize the drilled hole, and bundled-bar central reinforcing that extends the full depth of pile into a rock socket 4 to 9 metres deep in sound shale bedrock. The small footprint of Areas A, B, and C (Fig. 2) imposed strict limitations on the space available for the footprints of the new pile caps and grade beams, which in turn limited the quantity of micropiles, driving the need for micropiles capable of individually resisting particularly significant loads. Consequently, high capacity micropiles with the ability to withstand factored loads per micropile as high as 3000 kN in axial tension and 4000 kN in axial compression were required. In light of this particularly high loading, the structural engineer stipulated, on a pile by pile basis, an  $EA_{\min}$  for each micropile, ranging from 780 MN to 1420 MN.

#### 4.1 Micropile Structural Design

The stipulated minimum individual pile EA necessitated (relative to what would be required if strength alone governed) a relatively large cross sectional area of steel per micropile, and this aspect motivated the selection of a multiple-bar central reinforcement arrangement to enable ease of installation within the close quarters of the mechanical closet in which the micropile construction was staged. As a conservative measure the EA of the casing and grout was ignored in the calculation. As can be seen in Table 1, three different bundled bar arrangements were employed to meet or exceed, on a pile type by pile type basis, the stipulated loads and minimum EA. Pile Type 1 reinforcement consists of a 2 - #18 bar bundle; Pile Type 2 reinforcement consists of a 3 - #18 bar bundle. Pile Type 3 reinforcement consists of a 3 - #20 bar bundle.

In conformance with ASTM A615, the minimum cross sectional area of each #18 bar is reported by the manufacturer, Williams Form Hardware, as 2581mm<sup>2</sup>; similarly, the cross-sectional area of steel of a single #20 bar is 3168mm<sup>2</sup>. As can be seen in Table 1, stipulated minimum EA ranged from 770 MN to 1420 MN. For the lightest loaded and least stiff pile type (Type 1 @ P<sub>t</sub> = 2000kN; EA<sub>min</sub> = 770 MN), a 2 - #18 bar bundle was used. For the highest loaded and most stiff pile type (Type 3 @ P<sub>c</sub> = 3995kN; EA<sub>min</sub> = 1480 MN) a 3 - #20 bar bundle was used.

Employing the calculation for stipulated EA: cross sectional area, **A** multiplied by Young's modulus, **E**, the actual stipulated EA of the most lightly reinforced micropile Type (designated BMO Type 1) is 2 x 2581mm<sup>2</sup> x 200000 MPa = 1032 MN. The majority of the micropiles on the project are comprised of 3 - #18 bar bundles, for which a minimum EA of 1080 MN per pile was required and an EA<sub>o</sub> of 1548 MN per pile was constructed. The most demanding EA requirement at four micropile locations in Area C required a EA<sub>min</sub> of 1420 MN, and for this case, a 3 - #20 bundle was used to deliver a constructed pile EA<sub>o</sub> of 3 x 3168mm<sup>2</sup> x 200000 MPa = 1900 MN. In order to house the 3 - #20 bars, a larger diameter casing was warranted; the casing at these piles was upsized from 245 mm to 273 mm diameter. After upsizing the bar sizes sufficiently to satisfy the stipulated minimum EA requirements, the axial strength requirements were already easily satisfied, including the governing (with respect to strength) section immediately below the tip of the casing. A 100 year assumed service life was used for the design of the micropiles at this site by incorporating corrosion "protection" via consideration of a 1.6 mm sacrificial outer shell (per USFHWA Chapter 5 / Table 5.14.3.3 prescription) at each of the bundled bars that make up the central reinforcement over the full depth of pile. All central threaded bars extend from the bottom of the rock socket, through the casing, into the pile cap, and project above the top bearing plates a sufficient distance (Fig. 7) to enable positioning and engagement of the top plates by a set of upper hex nuts (1 upper nut per bar).

Consideration of sacrificial steel as a means of providing corrosion "protection" is the authors' career-long preference for the mandatory designing against losses resulting from corrosion of the principal micropile reinforcement. In stark contrast to corrosion protection via encapsulation, the area of steel reinforcement is significantly greater for sacrificial steel-based designs on an

equivalent strength basis and, consequently, sacrificial steel based designs should outperform equivalently strong encapsulated designs for the first 100 years after their respective installations.

Sacrificial steel was the method used for the BMO Field micropiles, and it was imperative that the stipulated minimum EA must be satisfied for the 100-year condition because, presumably, if the performance of the super columns relies on micropile EA as stipulated at time = 0, performance of the super column foundations at time = 100 years must surely also rely on pile EA at time = 100 years. Table 1 lists the  $EA_0$  and  $EA_{100}$  for each pile type. Note that  $EA_{100}$  exceeds  $EA_{min}$  for all pile types.

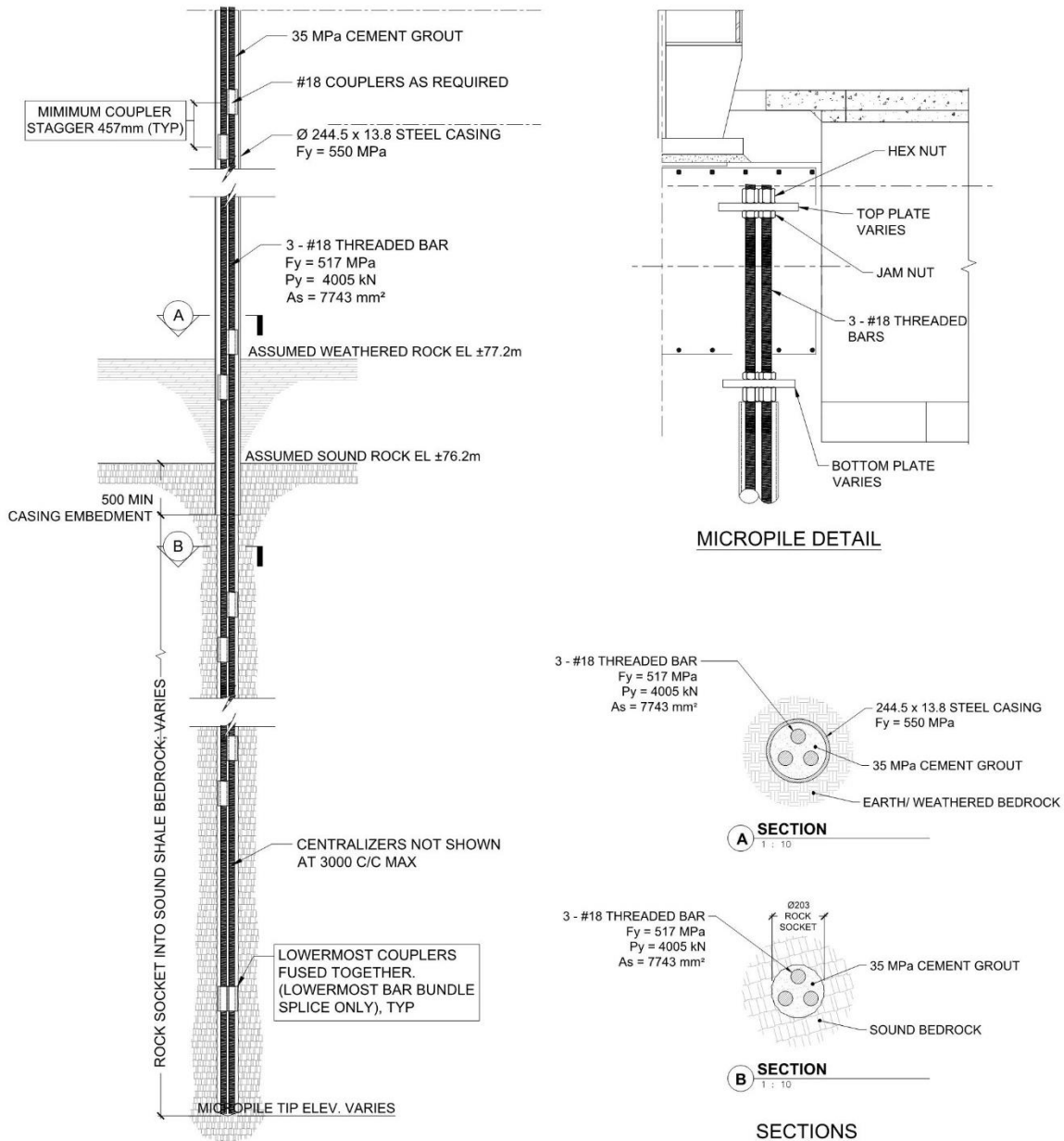
The micropile design called for 30 MPa neat cement grout using Type GU (USA Type 1) cement mixed in a high-shear colloidal mixer at maximum 0.45 water-to-cement and a minimum specific gravity of 1.85 g/cm<sup>3</sup>.

Drilling of individual micropile holes was completed in two stages: advancement of the thick-walled permanent casing to sound rock using concentric, percussive duplex drilling technique, followed by drilling of the rock socket using down-the-hole percussion with air-and-water flush. The casing acted as a protective conduit from surface to bedrock and helped stabilize the borehole and was left in place to make a more robust compression-resisting and bending-resisting installation.

**TABLE 1: SUMMARY OF MICROPILE DESIGN CHARACTERISTICS**

<b>Bundle</b>	<b>Area of Steel, <math>A_0</math> (catalogue) (mm<sup>2</sup>)</b>	<b>100 Year Area of Steel, <math>A_{100}</math> (mm<sup>2</sup>)</b>	<b><math>EA_0</math> (MN)</b>	<b><math>EA_{100}</math> (MN)</b>	<b><math>EA_{min}</math> as Stipulated by Structural Engineer (MN)</b>	<b>Factored Compression Load as Stipulated by Structural Engineer (kN)</b>	<b>Factored Tension Load as Stipulated by Structural Engineer (kN)</b>
<b>3 - #20 bars</b>	9504	8709	1900	1741	1420	3995	1925
<b>3 - #18 bars</b>	7743	6819	1548	1363	1080	2690	3000
<b>2 - #18 bars</b>	5162	4546	1032	909	770	980	1190





**FIGURE 4: TYPICAL MICROPILE FOR A MINIMUM EA OF 1080 MN**

## 4.2 Micropile Geotechnical Design

Recognizing the potential value to the project in terms of significant cost savings, schedule optimization and health and safety risk mitigation, the micropile designer/constructor, Geo-Foundations, tabled a proposal whereby the dozens of past high-magnitude static compressive load tests performed at other, representatively constructed micropiles socketed in the Georgian Bay shale and constructed by Geo-Foundations (Bruce & Gurpersaud, 2012), could be taken as proxy for the present project, thereby eliminating costly, potentially hazardous pile load testing. This approach was accepted by the structural and geotechnical consultants based on their

collective knowledge of micropile utilization in Ontario and their careful study of the detailed past test results.

Without even considering the strength of the medium into which it is bonded, the geotechnical capacity of any micropile depends as much on the workmanship employed as on the drilling and grouting methods selected for its construction. In other words, a micropile's capacity is, much more so than other, large diameter drilled foundation technologies, very process-sensitive. This sensitivity extends to the actual geotechnical properties of the ground into which load is transferred via grout-to-ground bond stress. Before any micropile designer can possibly consider foregoing load testing to verify design assumptions, he/she must be assured that the assumed design properties are certain to be realized at all constructed micropiles. This was a reasonable supposition applicable to the BMO Field project. Numerous load tests have been performed at various past projects constructed by Geo-Foundations, on micropiles socketed in Georgian Bay shale, and every one of these tests has proved, unequivocally, that micropiles socketed in Georgian Bay shale using percussive drilling with air and water flush and grouted using 35 MPa grout delivered via Type A grouting can safely and reasonably be designed using an assumed ultimate grout-to-rock bond stress value of 1750 kPa. This value was used for the BMO Field micropile design without confirmation via load testing.

As one last concession to foregoing load testing at this project, the grouting procedure was upgraded to Type B (per USFHWA designation) with the certain knowledge that Type B grouting should perform as well as, and likely better than, the Type A grouting that was employed at the load tested piles taken as proxy for BMO Field pile load testing. All piles were pressure grouted through the top of the casing following successful completion of tremie grouting.

With the permanent casing being terminated 0.3 metres into sound rock, all potential load transfer over the length of cased pile embedded in the overburden and weathered rock above the top of the rock socket was, appropriately, ignored. This approach was adopted despite all piles being grouted via Type B grouting.

## **5.0 MICROPILE CONSTRUCTION**

The super columns for the east canopy were installed in open areas (and on grade) which allowed for the relatively simple and straightforward installation of large diameter caissons. However, micropile construction was the only viable option for the west canopy given the need to locate its pile cap/ grade beam inside the restricted access and low headroom of an existing mechanical closet. The added benefits of utilizing micropiles included a relatively quiet installation and small footprint operation, allowing all nearby amenities to perform uninterrupted.

Permanent casing was installed from grade into sound rock using a rotary percussive concentric duplex drilling system. Subsequently, the rock socket was installed and the drill string was extracted once the casing wall and rock socket were cleaned with jets of compressed air and water.

Each micropile had a unique bar arrangement, predicated on its unique frequency of bar splices resulting from its combination of available overhead clearance and load resisting requirements. The central reinforcement at every pile consisted of a bundled threaded bar arrangement, extending from the bottom of the rock socket, through the casing, into the pile cap, and above its

eventual cutoff elevation. These bars were installed using a staggered layering of splice locations as follows: (a) the starting assembly included equal bar lengths, (b) the second layer consisted of 2.1, 2.6 and 3.0 metre long bars to create a staggered effect, (c) all subsequent layers included bars of equal lengths, which continued the staggered layering effect, and (d) the last layer included the same length bars as the second layer so that all bars ended at the same elevation. The staggered layering approach was implemented as a means of avoiding weak (with respect to bending) cross-sections.



**FIGURE 5: RELOCATED UNDERGROUND SERVICES & DRILLING TEMPLATE**

In order to improve the micropile detailing (a.k.a. finishing) operation, a “finder” type spacer was placed above the last coupler and the portions of bars extending into the pile cap were greased. The spacer guaranteed the correct centre-to-centre distance of the portions of the threaded bars projecting above the underside of pile cap so that the nuts could be placed without interference from one another; the grease prevented adhesion between the central threaded bars and grout body so that the nuts could be affixed without great effort (such as what is experienced when attempting to turn a hex nut onto grout-fouled threaded bar). Each micropile was then tremie grouted, and once the casing was full, the grout was pressurized by injecting additional grout under pressure through the top of the casing (USFHWA Type B grouting). The micropile detailing work included removing the casing and grout above the cut-off elevation, and installation of the top and bottom bearing plates (Fig. 7).

An electric-hydraulic drill rig on a crawler base, using a remotely located generator and compressor, was used in Areas A and B due to limited available space. The pneumatic-powered grout plant, featuring a high-shear colloidal mixer with a mechanical agitator hopper, was placed

adjacent to both of these work areas. A diesel-powered drill rig with a telescopic drill mast was used in Area C.



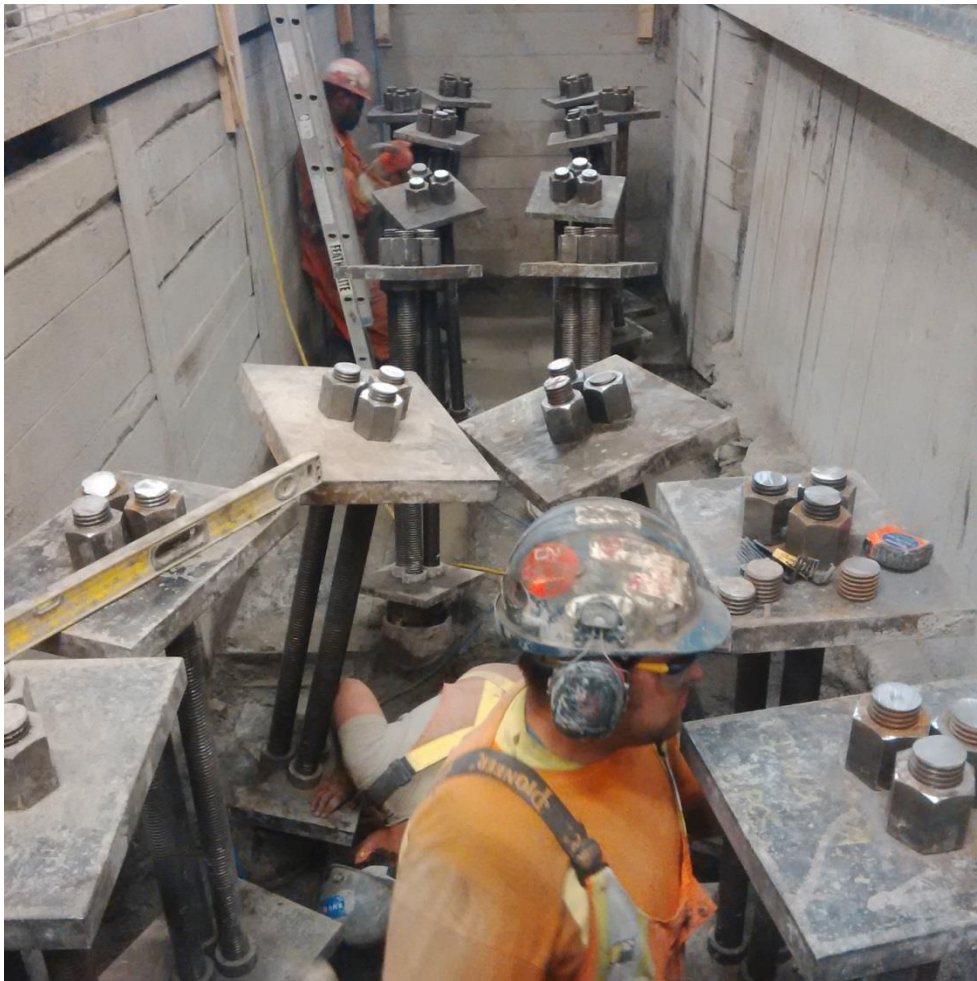
**FIGURE 6: MICROPILE DRILLING IN AREA A**

## **6.0 QUALITY CONTROL / QUALITY ASSURANCE**

Specific gravity testing of the grout was conducted at least once for each micropile. Testing was completed in accordance with the method described in API Recommended Practice 13B-1 with a calibrated *Baroid* Mud Balance. Also, two sets of cubes were taken per micropile for unconfined compressive strength (UCS) testing. Actual cube test break results ranged from 41 to 92 MPa.

Comprehensive real time quality control was performed by a full time designate of the micropile engineer of record using a 64-point *Inspection and Testing Protocol (ITP)*, which consisted of multiple *Hold, Measure & Record, Witness, Verify and Review* points (see attached Appendix). A record of piling summarizing construction dates, rock socket lengths, grout quantities consumed, casing and threaded bar schedules including casing and threadbar splice locations, cut-off elevations, along with remarks, was completed for each micropile. This comprehensive approach to inspection and testing resulted in the filing of 12 non-conformance reports, each of which was deemed minor and was reviewed in detail before ultimately being accepted and signed off by the micropile engineer. At the conclusion of the project, the micropile engineer penned a letter to the

structural engineer testifying to the completeness of the micropile scope of work and the fitness of the micropiles to perform as intended.



**FIGURE 7: DETAILED MICROPILES IN AREA A**

## **7.0 DISCUSSION**

No micropile load tests were conducted at BMO Field. The authors wish to make very clear that this paper does not advocate for the elimination of load testing from micropile projects. Micropile performance will always be, much more so than in the case of conventional foundation technologies, closely aligned to the drilling and grouting methodology and workmanship employed in their construction, and load testing of representatively constructed, sacrificial, pre-production micropiles ought to be an integral component of every micropile design. It is most important, in the case of BMO Field, to recognize that, in a sense, load testing WAS conducted, because the load tests considered from other sites and taken as proxy for BMO Field load testing, were representative of the proposed BMO Field design in every aspect: magnitude of loading, drilling method, key construction personnel involved, and rock socket geology. The micropiles constructed at BMO Field represent a rare case where engineering judgement (closely aligned

with the specific experience) of a seasoned designer/practitioner stood as a reasonable alternative to full scale load testing, especially when considering the health and safety risks avoided. The decision to forego micropile load testing at BMO Field was both well informed, and not taken lightly.

The early involvement of the specialty design-build micropile contractor on this project provided significant cost savings to the Owner. In the past, Geo-Foundations has conducted numerous load tests on micropiles rock-socketed into Georgian Bay Formation shale (Bruce & Gursaud, 2011 & 2012). The value-engineering proposal to forego load testing was based on the contractor's extensive applicable local experience, and acceptance of this proposed approach by the owner's principal consultants enabled the reasonable elimination of a costly pre-production static compression load test on a sacrificial micropile.

Design of the micropiles was well coordinated with the project design team which included the owner's Structural and Geotechnical consultants. The  $EA_{100}$  of the piles was the governing structural requirement, and close communication between the structural engineer and micropile engineer identified, early in the collaborative process, the importance of stipulated,  $EA_{min}$  to foundation performance. The close interaction with the Owner's team also allowed for pile arrangement design optimization within tight quarters.

Time was of the essence on this project, with important project milestones predicated on micropile scope completion in a timely matter. Optimization was achieved by incorporating the design and installation of the excavation support system within the speciality micropile contractor's scope of work.

The geotechnical reports indicated the presence of numerous historic, abandoned foundations potentially present in the subsurface profile at this site. Micropiles constructed using percussive duplex drilling method significantly enhanced the contractor's ability to construct the micropiles at this site through any and all buried obstructions encountered.

An electric powered drill rig was used in Areas A and B to maintain the air quality in that work space. The drill rig was selected for this project based on the available clearances, environmental and safety concerns. The drilling operation was carried out using a low-energy process in order to avoid any impact on existing adjacent services, as well as preserving harmony with respect to the ongoing operations at the facility.

## **8.0 CONCLUSIONS**

Micropiles were successfully installed under restricted access conditions to support significant loads from canopy-supporting super columns at BMO Field in Toronto. A significant amount of planning and input by a specialty foundation trade contractor accelerated the construction schedule, satisfied the design requirements and mitigated potential risks associated with existing buried and above-grade infrastructure. The design-build approach to the micropile scope, including early contractor involvement and including the support of excavation required to enable construction of new pile caps, provided numerous benefits and cost savings to the owner, as well as ensuring that all important and possibly obscure performance requirements were addressed

prior to construction. This collaborative approach significantly improved the project's chances of avoiding surprises/setbacks during the construction phase.

All micropiles were installed in a safe manner with a high level of quality control at the BMO Field site. The design bases, construction sequence and installation methods employed were integral to the successful execution of the micropile scope of work.

## **9.0 ACKNOWLEDGEMENTS**

Jim Bruce, P. Eng., of Geo-Foundations was the designer for the micropiles. Entuitive, Inc. were the owner's structural engineer; Terraprobe Inc. were the owner's geotechnical engineer.

The authors wish to thank PCL Constructors Canada Inc. for their usual excellent job of procurement and delivery, in all respects, of this special project. Thanks also are due the micropile construction superintendent, drill rig operators, grout plant operators, labourers, field engineers and CAD technicians from Geo-Foundations Contractors Inc. who contributed to the safe and successful delivery of the BMO Field Micropile Project.

## **10.0 REFERENCES**

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**APPENDIX**

***Inspection and Testing Protocol***





## 220115 BMO FIELD EXPANSION - MICROPILES

### MICROPILE INSTALLATION - INSPECTION AND TEST PLAN

Structure: Super column to support a Canopy		Task: Permanent Micropile Installation		
Micropile No. (Mark): <i>MPO2</i>		Date: <i>Mar 25, 2015</i>	Reference Drawings: <i>MPI, MP2, MP3, MP4</i>	
Prepared by: Anojan Sivaloganathan		<i>&amp; 26</i>	Reference Specification:	
No.	Quality Control Attributes	QC Point	QC Initial/Date	Comments
1	Ensure all drawings are the latest revision and stamped for Construction.	R	<i>JY 3/15</i>	<i>construction drawings received on 24 Mar 2015</i>
2	Verify material has been received and checked	V	<i>JY 3/25</i>	
3	Verify layout and location for drilling	H	<i>JY 3/25</i>	<i>using template, setup in place before drilling</i>
4	Verify drill mast is plumb for vertical piles prior to drilling	V	<i>JY 3/25</i>	
5	Verify azimuth and batter of the drill mast for batter piles prior to drilling	V	<i>N/A</i>	
6	Check casing assembly schedule for this micropile prior to casing installation	V	<i>JY 3/25</i>	<i>total casing length 27'</i>
6a	Verify permanent casing joints are in full contact shoulder-to-shoulder at splice #1	V	<i>JY 3/25</i>	
6b	Verify permanent casing joints are in full contact shoulder-to-shoulder at splice #2	V	<i>JY 3/25</i>	
6c	Verify permanent casing joints are in full contact shoulder-to-shoulder at splice #3	V	<i>JY 3/25</i>	
6d	Verify permanent casing joints are in full contact shoulder-to-shoulder at splice #4	V	<i>JY 3/25</i>	
6e	Verify permanent casing joints are in full contact shoulder-to-shoulder at splice #5	V	<i>JY 3/25</i>	
6f	Verify permanent casing joints are in full contact shoulder-to-shoulder at splice #6	V	<i>JY 3/25</i>	
7	Verify permanent casing is embedded in sound rock to minimum specified depth of 0.5m.	H	<i>JY 3/25</i>	
9	Record date of casing installation, total casing length and geodetic elevation of casing tip.	M	<i>JY 3/25</i>	<i>total casing length 27' = 8.23 m</i> <i>plate RL = 83.60</i> <i>TOP casing = 83.78 (no thread)</i> <i>TIP casing = 83.78 - 8.23 = 75.55</i>
8	Verify rock socket length is greater than specified minimum length.	H	<i>JY 3/26</i>	<i>measured depth = 17.15 (from plate RL)</i> <i>PILE bottom = 66.45</i>
10	Confirm casing wall and rock socket are cleaned with jets of compressed air and water	V	<i>JY 3/26</i>	<i>socket length = 75.55 - 66.45 = 9.1m &gt; 9m</i>
11	Verify tremie grout tube is secured to bottom of bar	V	<i>JY 3/26</i>	
12	Check bar assembly schedule for this micropile prior to central bar bundle installation	V	<i>JY 3/26</i>	<i>9.5' + 7' + 3x9' + 10'</i> <i>9.5' + 8.5' + 3x9' + 8.5'</i> <i>9.5' + 10' + 3x9' + 7'</i>
12a(i)	Confirm full penetration of bottom bar into splice #1a	V	<i>JY 3/26</i>	
12a(ii)	Confirm full penetration of bottom bar into splice #1b	V	<i>JY 3/26</i>	



## 220115 BMO FIELD EXPANSION - MICROPILES

<b>MICROPILE INSTALLATION - INSPECTION AND TEST PLAN</b>				
<b>Structure: Super column to support a Canopy</b>			<b>Task: Permanent Micropile Installation</b>	
<b>Micropile No. (Mark):</b> MP 02.		<b>Date:</b> Mar 25, 26, 2015	<b>Reference Drawings:</b> MP1, MP2, MP3, MP4	
<b>Prepared by:</b> Anojan Sivaloganathan			<b>Reference Specification:</b>	
No.	Quality Control Attributes	QC Point	QC Initial/Date	Comments
12a(iii)	Confirm full penetration of bottom bar into splice #1c	V	JY 3/26	
12a(iv)	Confirm full penetration of top bar into splice #1a	V	JY 3/26	
12a(v)	Confirm full penetration of top bar into splice #1b	V	JY 3/26	
12a(vi)	Confirm full penetration of top bar into splice #1c	V	JY 3/26	
12b(i)	Confirm full penetration of bottom bar into splice #2a	V	JY 3/26	
12b(ii)	Confirm full penetration of bottom bar into splice #2b	V	JY 3/26	
12b(iii)	Confirm full penetration of bottom bar into splice #2c	V	JY 3/26	
12b(iv)	Confirm full penetration of top bar into splice #2a	V	JY 3/26	
12b(v)	Confirm full penetration of top bar into splice #2b	V	JY 3/26	
12b(vi)	Confirm full penetration of top bar into splice #2c	V	JY 3/26	
12c(i)	Confirm full penetration of bottom bar into splice #3a	V	JY 3/26	
12c(ii)	Confirm full penetration of bottom bar into splice #3b	V	JY 3/26	
12c(iii)	Confirm full penetration of bottom bar into splice #3c	V	JY 3/26	
12c(iv)	Confirm full penetration of top bar into splice #3a	V	JY 3/26	
12c(v)	Confirm full penetration of top bar into splice #3b	V	JY 3/26	
12c(vi)	Confirm full penetration of top bar into splice #3c	V	JY 3/26	
12d(i)	Confirm full penetration of bottom bar into splice #4a	V	JY 3/26	
12d(ii)	Confirm full penetration of bottom bar into splice #4b	V	JY 3/26	
12d(iii)	Confirm full penetration of bottom bar into splice #4c	V	JY 3/26	
12d(iv)	Confirm full penetration of top bar into splice #4a	V	JY 3/26	
12d(v)	Confirm full penetration of top bar into splice #4b	V	JY 3/26	
12d(vi)	Confirm full penetration of top bar into splice #4c	V	JY 3/26	
12e(i)	Confirm full penetration of bottom bar into splice #5a	V	JY 3/26	
12e(ii)	Confirm full penetration of bottom bar into splice #5b	V	JY 3/26	



# 220115 BMO FIELD EXPANSION - MICROPILES

## MICROPILE INSTALLATION - INSPECTION AND TEST PLAN

<b>Structure:</b> Super column to support a Canopy		<b>Task:</b> Permanent Micropile Installation		
<b>Micropile No. (Mark):</b> MP02		<b>Date:</b> March 26, 2015	<b>Reference Drawings:</b> MPI, MP2, MP3, MP4	
<b>Prepared by:</b> Anojan Sivaloganathan			<b>Reference Specification:</b>	
No.	Quality Control Attributes	QC Point	QC Initial/Date	Comments
12e(iii)	Confirm full penetration of bottom bar into splice #5c	V	JY 3/26	
12e(iv)	Confirm full penetration of top bar into splice #5a	V	JY 3/26	
12e(v)	Confirm full penetration of top bar into splice #5b	V	JY 3/26	
12e(vi)	Confirm full penetration of top bar into splice #5c	V	JY 3/26	
13	Ensure there are no couplers in the red zone	V	JY 3/26	pile cutoff level = $83.16 - 0.45 - 1.6 + 0.1 = 81.65$ top of 7' coupler = $80.82 < 81.65$
14	Confirm the finder is at the appropriate elevation	V	JY 3/26	
15	Verify central bar bundle extends to bottom of the hole	H	JY 3/26	top of bar about 0.8m below plate hole.
16	Verify central reinforcement extends above eventual cutoff elevation	H	JY 3/26	top of bar: $66.45 + 16.31 = 82.76$ . suggested bar cutoff 83.00 <span style="float: right;">needs to be extended</span>
17	Record total length of central reinforcement.	M	JY 3/26	total length of bars = $53.5' = 16.31$ m.
18	Confirm maximum centralizer spacing along threadbar does not exceed 10' c/c.	V	JY 3/26	A.S
18a	Verify PVC centralizers are used for vertical piles	V	JY 3/26	
18b	Verify steel centralizers are used for battered piles.	V	N/A	
19	Verify cement used for grouting is free of lumps	W	JY 3/26	
20	Ensure grout has minimum s.g at grout plant of 1.85 g/cm <sup>3</sup>	H	JY 3/26	SG = 1.91
21	Record specific gravity of sampled grout	M	JY 3/26	
22	Ensure grout injection continues until efflux at top of casing has specific gravity $\geq 1.85$ g/cm <sup>3</sup>	H	JY 3/26	measured by Anojan.
23	Record date of grouting and total tremie grout take	M	JY 3/26	$26 \times 40 \text{ kg/bag} = 1040 \text{ kg}$
24	Record volume of grout & pressure during type B grouting	M	JY 3/26	$2 \times 40 \text{ kg/bag} = 80 \text{ kg}$ . 80 psi and top of casing lifted.
25	Verify six sample cubes are cast per micropile	V	JY 3/26	cubes done by consultant.
26	Verify micropiles left undisturbed a minimum 72 hours	V	JY 3/26	
<b>Date of Work Complete:</b>			<b>Date of Record Complete:</b> 3/29/2015	
Performer or Work Supervisor			JY. QC Inspector Initials	
			JUN YIN. QC Inspector Name	

Legend: H – Hold Point W – Witness Point M – Measure & Record V – Verification R – Review Documents