



## Reixinger Road, Niagara Falls, ON

*Associated Engineering*

**Type of Document:**

Geotechnical Investigation Report

**Project Name:**

Proposed Trenchless Watermain Installation  
Reixinger Road and QEW  
Niagara Falls, Ontario

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## 1. Introduction and Background

This report presents the results of the geotechnical investigation carried out at the site of the proposed watermain installation. The installation is planned to be carried out using a trenchless installation technique over a length of approximately 142 m along Reixinger Road and will cross below Queen Elizabeth Way (QEW) in Niagara Falls, Ontario. The tunnel invert will be approximately 6 m below the existing pavement surface and planned to consist of a 300 mm pipe with a 900 mm diameter steel casing.

The investigation was authorized by Mr. Collin Halliwell on behalf of Associated Engineering.

The purpose of this investigation was to determine the subsoil and groundwater conditions at the site by advancing four (4) boreholes and based on an assessment of the factual borehole data provide an engineering report containing general geotechnical recommendations pertinent to the proposed construction.

The comments and recommendations given in this report assume that the above-described design concept will proceed into construction. If changes are made either in the design phase or during construction, this office must be retained to review these modifications. The result of this review may be a modification of our recommendations or the requirement of additional field or laboratory work to check whether the changes are acceptable from a geotechnical viewpoint.

### 1.1 Site Description & Geological Setting

The site of the trenchless watermain installation extends for a length of approximately 142 m between the Reixinger Road cul-de-sacs on either side of the Queen Elizabeth Way (QEW) in Niagara Falls, Ontario. Reixinger Road has a rural cross section whereas the QEW has 3 lanes and paved shoulders each in the north and southbound directions.

Based on the Ministry of Natural Resources and Forestry Map 2496 *Niagara-Welland Southern Ontario, Quaternary Geology*, the native soil at the site consists of glaciolacustrine deeper water clay and silt.

## 2. Field Investigation

### 2.1 General Fieldwork

A total of four (4) boreholes, numbered BH-101 to BH-104, were advanced at the site of the proposed construction at the approximate locations shown on Drawing No. 1 in Appendix A. The boreholes were advanced to depths ranging from approximately 9.6 to 10.1 m below grade. It should be noted that the proposed alignment was not available at the time of the investigation.

The fieldwork for this investigation was carried out on April 16 and May 16, 2020. Drilling and sampling operations were completed by a combination of auger and split-spoon techniques using truck mounted drilling equipment owned and operated by a specialist drilling subcontractor. Prior to the commencement of the drilling operations, the public-owned underground services were located to minimize the risk of contacting any such services during

the drilling operations. Traffic control procedures in accordance with Book 7 were implemented for the duration of the investigation.

Soil samples were obtained using a 51 mm (2 inch) outside diameter split spoon sampler in conjunction with Standard Penetration Tests (ASTM D1586) at depths noted on the borehole logs in Appendix A. The Standard Penetration Test (SPT) N values were recorded as indicated on the borehole logs. Pocket penetrometer and in-situ shear vane tests were carried out in the cohesive soils to estimate the undrained shear strength and provide an assessment of the consistency of the in-situ soils.

Groundwater levels within the boreholes were measured prior to backfilling. 50 mm diameter monitoring wells equipped with flush-mount protective caps were installed at two (2) of the borehole locations to allow for stabilized groundwater level measurements and subsequent hydrogeological testing (if required). The remaining boreholes were backfilled upon completion of drilling in accordance with O.Reg. 903 (using a cement/bentonite mixture) and capped with cold patch asphalt.

Ground surface elevations at the borehole locations were interpolated by EXP from the baseplan drawing entitled *Montrose Road Reixinger Road Lyons Creek Road Topobase 2018 NFO* provided by Associated Engineering.

## 2.2 Environmental Testing

Limited environmental testing was conducted on selected soil samples recovered from the boreholes as part of this geotechnical investigation. Due to limited historical knowledge of the site and surrounding properties, the test parameters selected were metals and inorganics (O.Reg. 153). A total of four (4) samples were submitted from the boreholes to a certified laboratory for analytical testing to determine the chemical quality of the material for off-site disposal during construction. Additional contaminants may be present in the soil from historic site or surrounding property use that were not analyzed. Groundwater was not tested as this was beyond the scope of work.

Dedicated nitrile gloves (i.e. one pair per sample) were used during sample handling. The soil samples were placed in laboratory-supplied glass jars and clean ice-packed coolers prior to and during transportation to the subcontracted laboratory, AGAT Laboratories (AGAT) of Mississauga, Ontario. The samples were transported/submitted under Chain of Custody documentation.

## 2.3 Site Assessment Criteria

The assessment criteria, Site Condition Standards (SCS), applicable to a given site in Ontario are established under subsection 168.4(1) of the Environmental Protection Act. Tabulated generic criteria are provided in "Soil, Ground Water and Sediment Standards for Use Under Part XV.1 of the Environmental Protection Act" ("the SGWS Standards"), MECP, July 2011. These criteria are based on site sensitivity (sensitive or non-sensitive), groundwater use (potable or non-potable), property use (residential, parkland, institutional, commercial, industrial, community and agricultural/other), soil type (coarse or medium to fine textured) and restoration depth (full or stratified restoration). In addition, site specific criteria may be established based on the findings of a risk assessment carried out in accordance with Part IX and Schedule C of Ontario Regulation 153 (O. Reg. 153). The SGWS Standards specify SCS for soil, groundwater and sediment that are tabulated as follows:

Table 1: applicable to sites where background concentrations must be met (full depth) such as sensitive sites where site-specific criteria have not been derived

Table 2: applicable to sites with potable groundwater and full depth restoration

Table 3: applicable to sites with non-potable groundwater and full depth restoration

Table 4: applicable to sites with potable groundwater and stratified restoration

Table 5: applicable to sites with non-potable groundwater and stratified restoration

Table 6: applicable to sites with potable groundwater and less than 2 m of overburden above bedrock

Table 7: applicable to sites with non-potable groundwater and less than 2 m of overburden above bedrock

Table 8: applicable to sites with potable groundwater and less than 30 m from a water body

Table 9: applicable to sites with non-potable groundwater and less than 30 m from a water body

For assessment purposes, Table 3 SCS for Industrial/Commercial/Community (ICC) property use with medium to fine textured soil was selected. The results were also compared to the Table 1 SCS for Agricultural property use to provide additional disposal options. The selection of the applicable SCS is based on the following factors:

- It is understood that the site is not considered a sensitive site
- To the best of EXP's knowledge, all properties within 250 m of the site are serviced by the municipal water supply and groundwater is not used as a potable water source either on or within 250 m of the site
- The site is not located in an area designated in a municipal official plan as a well-head protection area or other designation identified by the municipality for the protection of groundwater
- There is no intention to carry out a stratified restoration at the site
- The predominant soil type on the site is considered to be fine textured and bedrock was not encountered within the upper 2.0 m
- No water body exists within 30 m of the site

### 3. Subsurface Conditions

Details of the subsurface conditions encountered during the drilling program are summarized on the borehole logs in Appendix A.

The logs include textural descriptions of the subsoil and groundwater conditions and indicate the soil boundaries inferred from non-continuous sampling and observations during drilling. These boundaries reflect approximate transition zones for the purpose of geotechnical design and should not be interpreted as exact planes of geological change. The "Notes on Sample Description" preceding the borehole logs form an integral part of and should be read in conjunction with this report.

### 3.1 Soil Stratigraphy

The boreholes were each advanced along the travelled roadway and typically encountered the pavement structure overlying fill and/or native silty clay. Details of the encountered materials are provided in the following subsections.

#### 3.1.1 Pavement

Each of the boreholes advanced at the site were drilled on the travelled roadway and encountered surficial asphalt or surface treatment. Granular fill was encountered below the wearing surface at each borehole location and consisted of crusher run limestone. The encountered pavement thicknesses are summarized in the tables below.

Table 3-1: Pavement Summary (Reixinger Road)

Borehole No.	Surface Treatment Thickness (mm)	Granular Thickness (mm)
BH-101	15	320
BH-104	20	400
<b>Average</b>	<b>20</b>	<b>360</b>

Table 3-2: Pavement Summary (QEW)

Borehole No.	Asphalt Thickness (mm)	Granular Thickness (mm)
BH-102	200	1170
BH-103	200	850
<b>Average</b>	<b>200</b>	<b>1,010</b>

#### 3.1.2 Fill

Silty clay fill was encountered below the pavement structure at Boreholes BH-101 and BH-103 and extended to depths of approximately 1.1 m to 2.3 m below existing grade, respectively. The silty clay fill contained trace sand and gravel, was brown, and in a moist state. Moisture contents of the fill ranged from 18 to 26 percent. In some locations, the fill was noted to contain trace black organic staining and odour.

#### 3.1.3 Silty Clay

Native silty clay was encountered below the fill and/or pavement structure and extended to the borehole termination depth at each of the borehole locations. The silty clay contained trace sand with occasional gravel, was brown (becoming grey below about 5 to 7 m), and in a moist to wet state. Moisture contents of the stratum ranged from 19 to 38 percent. SPT N values of the stratum ranged from 2 to 21 blows per 305 mm of penetration.

Based on estimated undrained shear strengths from pocket penetrometer measurements and in-situ shear vane tests ranging from 55 kPa to greater than 225 kPa, the stratum is classified as stiff to hard in consistency. The silty clay was typically noted to become weaker with depth. Silt seams and layers were noted to be present in the silty clay stratum and a silt stratum was interbedded in the silty clay at Borehole BH-104. The silt contained trace sand, was brown, and in a wet state.

Based on twelve (12) grain size analyses of the native silty clay stratum, the material consisted of 24 to 65 percent clay, 34 to 75 percent silt, and 0 to 1 percent sand. The liquid limit ranged from 34 to 53 and the plasticity index ranged from 20 to 34, indicating the stratum typically is of intermediate plasticity.

### 3.2 Groundwater Conditions

Groundwater conditions were monitored in the open boreholes during and upon completion of the drilling operations. The boreholes contained no free water upon completion of drilling, but the retrieved samples were noted to become very moist to wet typically below depths of about 3 m, with perched water present in silt seams as noted on the borehole logs. As noted previously, 50 mm diameter groundwater monitoring wells were installed at two (2) borehole locations with the groundwater depths and elevations summarized in the table below.

Table 3-3: Groundwater Level Measurements

Borehole No.	Groundwater Depth / Elevation (m)	
	Upon Completion	April 27, 2020
BH-101	no free water	1.1 / 176.1
BH-104	no free water	1.3 / 176.2

Seasonal variations in the water table should be anticipated, with higher levels occurring during wet weather conditions (spring thaw and late fall) and lower levels occurring during dry weather conditions.

## 4. Environmental Considerations

In accordance with the scope of work, chemical analyses were performed on selected soil samples recovered from the boreholes. Copies of the laboratory Certificates of Analysis for the tested soil samples are provided in Appendix C.

### 4.1 Soil Analysis

EXP submitted one (1) soil sample from each borehole (4 samples total) for metals and inorganics analysis. The results of the metals and inorganics analysis together with the applicable Table 1 (Agricultural) and Table 3 (ICC) SCS are presented below in Table 4-1.

Table 4-1: Analytical Results for Metals & Inorganics in Soil

Parameter	Table 1 SCS (Agricultural)	Table 3 SCS (ICC)	BH-101 SS4 (2.3–2.9 m)	BH-102 SS6 (3.8–4.4 m)	BH-103 SS7 (4.6–5.2 m)	BH-104 SS4 (2.3–2.9 m)
Antimony	1	50	<0.8	<0.8	<0.8	<0.8
Arsenic	11	18	5	5	8	6
Barium	210	670	186	131	135	140
Beryllium	2.5	10	0.8	0.8	0.7	0.7
Boron	36	120	16	16	12	11
Boron (Hot Water Soluble)	NV	2	0.28	0.67	0.3	0.37
Cadmium	1	1.9	<0.5	<0.5	<0.5	<0.5
Chromium	67	160	29	31	27	26
Cobalt	19	100	14.3	13.7	13.9	14.2
Copper	62	300	23	26	25	25
Lead	45	120	8	10	9	9
Molybdenum	2	40	0.7	0.6	0.7	0.7
Nickel	37	340	33	30	28	31
Selenium	1.2	5.5	<0.4	<0.4	<0.4	<0.4
Silver	0.5	50	<0.2	<0.2	<0.2	<0.2
Thallium	1	3.3	<0.4	<0.4	<0.4	<0.4
Uranium	1.9	33	0.8	0.9	0.8	0.9
Vanadium	86	86	38	41	37	35
Zinc	290	340	68	69	64	64
Chromium VI	0.66	10	<0.2	<0.2	<0.2	<0.2
Cyanide (free)	0.051	0.051	<0.040	<0.040	<0.040	<0.040
Mercury	0.16	20	<0.10	<0.10	<0.10	<0.10
Electrical Conductivity (uS/cm)	0.47	1.4	<b>0.523</b>	<b>1.78</b>	<b>0.503</b>	<b>0.76</b>
Sodium Adsorption Ratio (unitless)	1	12	0.876	<b>1.34</b>	0.576	0.701

Notes: Concentrations are expressed in µg/g except where noted  
**Bold** indicates an exceedance of the Table 1 SCS (Agricultural)  
**Bold and shading** indicates an exceedance of the Table 3 SCS (ICC)

The following Table 3 (Industrial/Commercial/Community) SCS exceedances were noted:

- Electrical Conductivity: BH-102 SS6

The following Table 1 (Agricultural) SCS exceedances were noted, in addition to the Table 3 SCS exceedances noted above:

- Electrical Conductivity: BH-101 SS4, BH-103 SS7 and BH-104 SS4
- Sodium Adsorption Ratio: BH-102 SS6



The site is a municipal roadway and as such, elevated levels of salt-related parameters (EC and SAR) are likely associated with the application of de-icing and salting substances for the purpose of snow and ice removal. As per Section 2 of Ontario Regulation 339 of the Revised Regulations of Ontario, 1990 (Classes of Contaminants – Exceptions) and section 48 (3) of Ontario Regulation 153/04, the concentrations of EC/SAR are deemed to not be an exceedance and therefore these parameters are not considered contaminants of concern. Based on the above, the following options for soil disposal are presented:

Table 4-2: Summary of Soil Disposal Options

Option	Description	Advantages	Disadvantages/Considerations
1	Re-use excess soil on site	<ul style="list-style-type: none"> <li>Least expensive option</li> <li>None of the samples tested has exceedances for the applicable Table 1 (with EC/SAR exception)</li> </ul>	<ul style="list-style-type: none"> <li>Must be geotechnically suitable for re-use and meet project specifications</li> <li>Potential limitations for stockpiling/temporary storage</li> </ul>
2	Dispose of excess soil at third party site	<ul style="list-style-type: none"> <li>Less expensive than landfill disposal</li> <li>All samples meet Table 1 SCS (with EC/SAR exemption)</li> </ul>	<ul style="list-style-type: none"> <li>Sites may be difficult to find at time of construction</li> </ul>
3	Dispose excess soil at licensed landfill	<ul style="list-style-type: none"> <li>Landfills usually open to accepting soils</li> </ul>	<ul style="list-style-type: none"> <li>Most expensive option</li> <li>Requires TCLP samples prior to landfill acceptance</li> <li>Environmentally unsustainable</li> </ul>

Note that the above-provided off-site disposal comments are applicable at the time of this report. However, new excess soil regulations (O.Reg. 406/19) begin to come into effect on January 1, 2022, and additional testing may be required during construction to satisfy the regulatory requirements for off-site disposal. EXP can be contacted to provide additional guidance and testing in this regard, as required.

## 4.2 Quality Assurance

Details regarding quality assurance measures taken in the field, including instrument calibration, decontamination procedures, use of dedicated equipment, sample storage and Chain of Custody documentation are provided above.

The subcontracted laboratory used during this investigation, AGAT Laboratories, is accredited by the Standards Council of Canada/Canadian Association of Laboratory Accreditation in accordance with ISO/IEC 17025 – “General Requirements for the Competence of Testing and Calibration Laboratories” for the analysis of all parameters for all samples in the scope of work for which SCS have been established under Ontario Regulation 153/04 as amended by Ontario Regulation 511/09 and Ontario Regulation 179/11.

The “Protocol for Analytical Methods Used in the Assessment of Properties under Part XV.1 of the Environmental Protection Act” (“the Analytical Protocol”), MECP, July 2011, establishes criteria used in assessing the performance of analytical laboratories when the data are used in support of the filing of Records of Site Condition.

The laboratory quality assurance program included the analysis of laboratory duplicate (replicate) samples, method blanks, spiked blanks, spiked samples and samples of reference materials in accordance with the Analytical Protocol. These analytical results comprise portions of the Certificates of Analysis in Appendix C.

## 5. Discussion and Recommendations

It is understood that the proposed watermain is planned to be installed for approximately 142 m using a trenchless installation technique below the QEW. The tunnel invert is planned to be approximately 6 m below the existing pavement surface and the pipe will be 300 mm in diameter with a 900 mm diameter steel casing (MTO *medium complexity*). A plan and profile drawing with subsurface geotechnical information for the proposed trenchless installation is provided in Drawing No. 1 in Appendix A. We offer the following comments and recommendations for the planned construction.

### 5.1 Trenchless Installation Methods

The following tables summarize some of the possible alternatives for the pipe installation and the subsections below provide a discussion of the various trenchless installation options in order to determine the rank shown in Table 5-1.

Table 5-1: General Comparison of Trenchless Installation Methods

Installation Method	Advantages	Disadvantages	Rank
Microtunneling	<ul style="list-style-type: none"> <li>Handles wide variety of ground conditions</li> <li>Steerable horizontally to maintain and adjust alignment</li> <li>Suitable for tunneling under groundwater table</li> <li>Alignment can be adjusted to avoid obstructions</li> <li>Suitable for steel, reinforced concrete, and fiberglass pipes</li> <li>Local contractors available</li> </ul>	<ul style="list-style-type: none"> <li>Obstructions problematic</li> <li>Requires large area for jacking shaft and support equipment</li> <li>Requires sophisticated equipment</li> <li>Higher relative cost over jack and bore, pipe ramming, or HDD</li> </ul>	1

Installation Method	Advantages	Disadvantages	Rank
Horizontal Directional Drilling (HDD)	<ul style="list-style-type: none"> <li>Handles wide variety of ground conditions</li> <li>Steerable both horizontally and vertically to maintain and adjust alignment</li> <li>Does not require staging pits if site is able to accommodate maximum entry and exit angles</li> <li>Suitable for tunneling under groundwater table</li> <li>Local contractors available</li> <li>Short mobilization time</li> <li>Rapid drilling</li> <li>Only minor settlement is expected if fluid is well controlled</li> <li>Suitable for installation of pipes up to 1.2 m in diameter (max 750 mm is more common) and longer lengths</li> </ul>	<ul style="list-style-type: none"> <li>Potential for inadvertent drilling returns (i.e. frac-out)</li> <li>Requires drilling fluid to maintain the bore which could allow subsidence</li> <li>May require longer bore or staging pits to meet required entry and exit angles</li> <li>Obstructions problematic, but alignment can be adjusted to avoid obstructions</li> <li>Annular space filling required (fluid or grouting)</li> <li>May not be suitable for high degree of alignment accuracy</li> </ul>	2
Jack and Bore	<ul style="list-style-type: none"> <li>Handles wide variety of ground conditions</li> <li>Auger can be manually removed to permit removal of obstructions such as cobbles and boulders</li> <li>Minimal surface disruption</li> <li>Vertically accurate (slope of 0.2% achievable)</li> <li>Relatively simple operation</li> <li>Commonly used in Ontario</li> <li>Short mobilization time</li> <li>Suitable for steel pipes up to 1.8 m in diameter</li> <li>Lower relative cost than microtunneling</li> </ul>	<ul style="list-style-type: none"> <li>Requires large area for jacking shaft and support equipment</li> <li>Obstructions can be problematic</li> <li>Pipe can be difficult to steer</li> <li>Short and long-term settlement possible</li> <li>Fluid to support annular space required</li> <li>Water ingress problematic</li> <li>Not suitable for tunneling below groundwater</li> <li>Difficulty in squeezing, fast raveling, and flowing soils and requires a soil plug for face support or may not be feasible</li> </ul>	3
Pipe Ramming	<ul style="list-style-type: none"> <li>Not very sensitive to ground condition</li> <li>Suitable for steel pipes up to 1.8 m in diameter and best up to 50 m long</li> <li>Accommodates obstructions well</li> <li>Little surface settlement</li> <li>Soil removed after pipe in place</li> </ul>	<ul style="list-style-type: none"> <li>Pipe can be difficult to steer/direct</li> <li>Ground heave possible</li> <li>Large entry pit size</li> <li>Vibration and noise</li> <li>Slower than other trenchless methods</li> <li>Difficulty in squeezing, fast raveling, and flowing soils</li> </ul>	4

Table 5-2: General Comparison of Technical Issues Associated with Trenchless Methods

Typical Limitations	Tunneling Method			
	Jack & Bore	Horizontal Directional Drilling (HDD)	Pipe Ramming	Microtunneling
<b>Length of drive and diameter</b>	<ul style="list-style-type: none"> <li>Drive lengths to 150 m</li> <li>Diameters up to 1800 mm are feasible</li> </ul>	<ul style="list-style-type: none"> <li>Drive pullback lengths of several hundred meters are feasible</li> <li>In Southern Ontario, HDD diameters less than 750 mm are commonplace but larger bores add risk, complexity and considerable cost</li> </ul>	<ul style="list-style-type: none"> <li>Generally best suited to short watercourse crossings where risks of ground heave are low</li> <li>30 to 60 m drives are typical</li> <li>Diameters of 1800 mm are technically feasible with a large hammer; however, the stability and integrity of the soil plug in the lead pipe segment is less certain with larger diameters</li> </ul>	<ul style="list-style-type: none"> <li>Drive lengths of 300 m are typical, provided that Intermediate Jacking Stations (IJS) are launched every 75 m</li> <li>Micro tunnels up to 1500 mm dia. can be readily constructed in Ontario; 3000 mm dia. may be feasible by specialists</li> </ul>
<b>Ability to control line and grade</b>	<ul style="list-style-type: none"> <li>Average control of line and grade</li> <li>Limited ability to steer and to correct grade</li> </ul>	<ul style="list-style-type: none"> <li>Specialized tracker system is needed to control line and grade</li> <li>Fair to good</li> </ul>	<ul style="list-style-type: none"> <li>Relatively poor</li> </ul>	<ul style="list-style-type: none"> <li>Good</li> <li>Line and grade control to within <math>\pm 40</math> mm is feasible over 300 m drive</li> </ul>
<b>Ability to control ground surface displacement</b>	<ul style="list-style-type: none"> <li>Poor</li> <li>No ability to retain running ground</li> </ul>	<ul style="list-style-type: none"> <li>Fair</li> <li>Ground heave and hydro fracturing may result from excessive rates of pullback</li> <li>Bore stability relies on good quality control and circulation of drilling mud</li> </ul>	<ul style="list-style-type: none"> <li>Poor</li> <li>Risk of ground heave is moderate to high</li> <li>If soil plug washes out or is breached, then excessive ground loss and settlement will occur</li> </ul>	<ul style="list-style-type: none"> <li>Good</li> <li>Slurry shield MTBM can balance earth pressures in the shield to a variety of soil and groundwater conditions</li> <li>Full and immediate ground support by means of jacking pipe</li> </ul>
<b>Ability to deal with mixed face ground conditions</b>	<ul style="list-style-type: none"> <li>Mixed face conditions will likely cause line and grade deviations to occur</li> <li>Overmining may result when augering is labored due to hard ground</li> <li>Augers may jam on rock slabs</li> </ul>	<ul style="list-style-type: none"> <li>Mixed ground may interfere with line and grade control</li> </ul>	<ul style="list-style-type: none"> <li>Mixed face conditions will likely deviate the line and grade</li> </ul>	<ul style="list-style-type: none"> <li>Good</li> <li>High pressure water jets are necessary to breakdown cohesive clays</li> </ul>

Typical Limitations	Tunneling Method			
	Jack & Bore	Horizontal Directional Drilling (HDD)	Pipe Ramming	Microtunneling
<b>Ability to deal with flowing or unstable face conditions</b>	<ul style="list-style-type: none"> <li>No ability to deal with flowing or unstable face conditions</li> <li>Flowing soils may result in total collapse or excessive ground loss</li> <li>Method is unsuitable in cohesionless soils below the water table</li> </ul>	<ul style="list-style-type: none"> <li>Bore wall stability can be maintained with suitably viscous drilling fluid and filter cake buildup on bore wall</li> <li>Risk of pipe jamming during pullback if stones or cobbles become dislodged from crown of bore</li> </ul>	<ul style="list-style-type: none"> <li>The ability to retain flowing ground depends entirely on maintaining a soil plug in the lead pipe segment; if the plug breaches, then the bore may fail</li> </ul>	<ul style="list-style-type: none"> <li>Slurry shield MTBMs are better suited to flowing ground conditions than any other trenchless method</li> </ul>
<b>Ability to deal with cobbles, boulders, and other obstructions</b>	<ul style="list-style-type: none"> <li>For bores &gt;900 mm, auger removal and personnel entry are needed to break up boulders, however the tunnel face must be cohesive for this to be safely conducted</li> </ul>	<ul style="list-style-type: none"> <li>Cobbles and rock slabs may jam pipe in bore during pullback</li> <li>Boulders will result in a failed bore</li> </ul>	<ul style="list-style-type: none"> <li>May require removal of soil plug to remove/breakup boulder which could possibly compromise tunnel stability</li> </ul>	<ul style="list-style-type: none"> <li>Combination of disk and pick cutters is needed</li> <li>Person entry not practical</li> <li>Wood troublesome</li> </ul>

#### 5.1.1 Microtunneling Technique

The microtunneling method provides continuous support of the excavation face is suitable to install the proposed watermain. The Microtunneling Boring Machine (MTBM) is usually equipped with a slurry spoil removal system to control any groundwater inflow and counterbalance the earth and hydrostatic pressure while tunneling.

Considering the site conditions, the major advantage of micro-tunneling method for this project is that its performance should be less affected by groundwater levels and the wet silt seams and layers. The major disadvantages of micro-tunneling for this project is considered to be the relatively high costs of mobilization and installation, especially given the relatively small tunnel diameter. This option will be less expensive if potential bidders have equipment available in-house.

#### 5.1.2 Horizontal Directional Drilling (HDD) Technique

If there is enough space to achieve entry and exit angles as recommended in ASTM F1962 (12° to 15° for bore entry and 10° for bore exit), Horizontal Directional Drilling (HDD) may considered for the installation, provided the drill hole is at all times supported with a properly designed drilling fluid. The drilling may also be conducted from within an excavation to achieve the required entry and exit angles, though this mitigates one of the benefits of the HDD method. The drilling fluid should be designed by a specialist contractor, based on such factors as the soil type, diameter and depth of the opening, rate of drilling etc., and may have to be adjusted as construction proceeds. The fluid pressure should not exceed the in-situ overburden pressure. Higher pressure could cause fracturing of the soils and loss of the drilling fluid, which in turn could cause instability and even collapse of the drill hole. Installation should follow requirements in OPSS 415 and 450.

The cutting tool and the drilling fluid must be able to handle the different materials encountered (silty clay fill and very stiff to hard silty clay with wet silt seams). With good construction control and no loss of drilling fluid, settlement at the area directly above the drill hole should be minimal.

### 5.1.3 Jack and Bore Technique

The jack and bore method involves drilling a borehole from a jacking pit (entry pit) with a rotary cutter head within the confines of a steel casing or liner which is jacked ahead at least one pipe diameter for support. The casing is pushed through the soil with a hydraulic ram, and soil is removed with an auger. The auger transports spoils from the cutting head back to the jacking pit. Installation should follow the requirements in OPSS 415 and 416.

Based on the proposed tunnel diameter, pipe jacking using mechanical means is feasible for the proposed installation in the stiff to very stiff silty clay. However, the elevation and gradient of the pipe must be closely controlled during the course of the jack and bore. Lubricant selected based on the characteristics of the surrounding soil may be provided to reduce the friction between the casing and the tunnel walls. Though not encountered during the investigation, any obstacles such as cobbles or boulders could make the pipe jacking difficult. However, one of the advantages of using the jack and bore method for the pipe installation is that the auger can be manually removed to permit clearing of these obstructions or it may be equipped with rock-cutting teeth. EXP recommends the lead auger be kept at least one casing diameter behind the lead end of the casing to minimize the potential for ground losses.

Considering the low permeability of silty clay, groundwater inflow into the tunnel is typically anticipated to be relatively minor and controllable by using pumps of sufficient capacity from the jacking and/or receiving pit. To reduce potential for loss of ground and associated disturbance, it is recommended the casing be jacked as far ahead of the lead auger as practical, and for a distance of at least one casing diameter. The jacking and boring operations should be continued without stoppage until completion. Furthermore, any significant voids between the casing and the surrounding soil should be filled with pressurized cementitious grout to mitigate the potential for settlement.

Generally, tunneling using pipe jacking method is a relatively slow and labour-intensive process. The actual tunnel advance rate is a function of soil conditions encountered, method of soil excavation, spoil removal, pipe liners materials, and field conditions.

### 5.1.4 Pipe Ramming Technique

Pipe ramming involves the use of a steel casing inserted from a launch pit and driven by a pneumatic percussion hammer system. The leading edge or head of the initial steel casing is fitted with a cutting shoe/band to reinforce the pipe for open-face pipe ramming and reduce friction by creating a slight overcut. Additional lengths of steel casing are welded on to the preceding piece, as the casing advances towards the exit pit. Lubricants (bentonite or polymer) may be used to facilitate advancement of the casing. In some conditions, this method is well suited to installation of pipes below operating highways if no material is removed from within the pipe until it emerges sufficiently beyond the far edges of the roadway. Material within the casing is removed by augering usually after the casing is installed. In some cases, or when resistance to driving becomes too great, materials are partially or fully removed from within the casing prior to completion.

## 5.2 Discussion of Trenchless Installation Methods

The proposed tunnel invert is expected to be constructed at approximately Elev. 171.8 m, or about 6 m below the existing pavement surface. The soil conditions anticipated along the tunnel alignment predominantly consists of very moist to wet, stiff to very stiff silty clay with wet silt seams. Depending on the tunnelling methodology, this may also include the silty clay fill or granular fill. Groundwater level measurements of 1.1 m (Elev. 176.1 m) and 1.3 m below grade (Elev. 176.2 m) were obtained from the monitoring wells at Boreholes BH-101 and BH-104, respectively and so the tunnelling will be carried out below the groundwater level.

The silty clay with silt seams is classified as *slow ravelling* to *squeezing* soil in Terzaghi's Tunnelman's Ground Classification (Appendix D). The undrained shear strength of the undisturbed silty clay along the proposed alignment is estimated to be 75 to greater than 135 kPa based on pocket penetrometer measurements and in-situ shear vane tests; the overload factor (ratio of overburden pressure at anticipated spring line elevation to undrained shear strength) does not exceed 3.0.

The chosen method of tunneling and specific equipment must be capable of dealing with the encountered subsurface conditions. The encountered cohesive materials will have a "sticky" behaviour which can bind to the tunneling equipment, significantly slowing progress or requiring alternative procedures or removal before progress can continue.

Though not encountered during the investigation, a review of potential obstructions from previous construction, such as existing or abandoned piles, tiebacks, conduits, etc. should be carried out. Existing utilities and the age and condition of those within the zone of influence should also be established. It is recommended that the horizontal distance between any existing pipes and the proposed tunnel be at least 3 pipe diameters. The installation procedures must conform to the applicable OPSS and ASTM standards, manufacturer requirements, and industry standard practices.

Given the subsurface conditions and relatively high groundwater level encountered along the proposed tunnel alignment, microtunneling, HDD, and jack and bore, would each be considered possible, with microtunneling and HDD being the preferred methods as dewatering of the tunnel would not be required. Microtunneling would also provide full tunnel face support which would prevent ingress of the saturated slow ravelling soils. Additionally, the drive length of 142 m is nearing the practical limits of jack and bore and pipe ramming methods. Pipe ramming through the very stiff silty clay may be difficult and require lubricants and/or additional equipment to permit removal of any obstructions. If jack and bore is pursued, to reduce potential for loss of ground and associated disturbance, it is recommended the casing be jacked as far ahead of the lead auger as practical, and for a distance of at least one casing diameter.

Provided construction is carried out in accordance with the recommendations herein and applicable standards and industry standard practice, any settlement/heave of the overlying pavement is anticipated to be minimal.

### 5.3 Access Pit Construction and Backfill

The following subsections include recommendations for excavations, dewatering, lateral earth pressures, and backfill pertaining to the construction of the access pits used in trenchless pipe installation.

#### 5.3.1 Access Pit Excavations

Depending on the tunneling method chosen and the excavations that will be required to implement them, protection system(s) will likely be required to protect existing infrastructure or limit the extent of excavations. Recommendations for temporary shoring are included in the subsequent section.

Excavations for the proposed access pits are anticipated to extend to depths of approximately 6 m and are expected to be carried out below the pavement structure and silty clay fill and into the native stiff to hard glaciolacustrine silty clay. Provided positive groundwater control measures are implemented where required, open-cut excavations may be undertaken using a mechanical shovel capable of excavating hard silty clay.

The contractor should be aware that the slope height, slope inclination, or excavation depths must in no case exceed those specified in local, provincial, or federal safety regulations. For guidance, above the groundwater level, the fill materials and stiff native silty clay can be classified as Type 3 Soil, while the very stiff to hard native silty clay can be classified as Type 2 Soil.

In accordance with OHSA regulations, if the excavation contains more than one type of soil, the excavation shall be constructed according to the type with the highest number. Sloughing may be encountered from the granular pavement layer and where loose fill or water bearing zones are present. Locally, where loose/soft materials are encountered, or within zones of persistent seepage at depth, it may be necessary to flatten the slopes.

The boreholes contained no free water upon completion of drilling, though insufficient time had passed for the groundwater level to stabilize in the open boreholes. Groundwater level measurements of 1.1 m (Elev. 176.1 m) and 1.3 m below grade (Elev. 176.2 m) were obtained from the monitoring wells at Boreholes BH-101 and BH-104, respectively and the soils were noted to become very moist to wet below approximately 3 m from ground surface. As such, excavations below the groundwater level should be anticipated and some dewatering will be required and should be completed in accordance with OPSS 517 and SP 517F01.

Perched water infiltration from fill materials and existing utility bedding as well as seepage from native soils should be anticipated. Given the predominantly fine-grained nature of the encountered fill and native soils, groundwater infiltration into the excavations is expected to be controllable using construction sump pumping techniques.

During construction, measures should be implemented to manage accumulation of precipitation, seasonal fluctuations in the groundwater table, flow from bedding of existing services, and variation in soil and hydrogeological properties beyond those encountered during the course of this study. Note that it is the responsibility of the contractor to ensure dry conditions are maintained within the excavation at all times. Seasonal variations in the water table should be anticipated, with higher levels occurring during wet weather conditions (spring thaw and late fall) and lower levels occurring during dry weather conditions.



All collected water should discharge a sufficient distance away from the excavated area to prevent the discharge from re-entering the excavation. Sediment control measures such as silt fences should be provided at the discharge point of the dewatering system. Caution should also be taken to avoid any adverse impact to the environment.

### 5.3.2 Temporary Shoring of Access Pits

The need for temporary shoring will depend on the geometry of the required excavations and nearby infrastructure. Protection systems (design, materials, construction, maintenance, monitoring and removal) will be required to meet the specifications set out in OPSS 539. The lateral movement of the temporary shoring system should meet Performance Level 2 as specified in OPSS 539.

To mitigate potential for settlement of adjacent infrastructure, support systems are to be placed so backfilling can occur while the support system is gradually removed. The lateral earth pressure acting on supported excavation walls may be computed using the following equation:

$$p = K (\gamma h + q)$$

where

- $p$  = lateral earth pressure intensity at depth  $h$  (kPa)
- $K$  = earth pressure coefficient
- $\gamma$  = unit weight of retained soil
- $h$  = depth to point of interest (m)
- $q$  = surcharge load acting adjacent to the wall at the ground surface (kPa)

The above expression does not consider hydrostatic pressure as it is assumed dewatering will be carried out as required, otherwise the hydrostatic pressure must be included for the groundwater levels measured on the site. The table below lists earth pressure parameters for given materials. These recommendations assume level backfill and ground surface behind the temporary shoring.

Table 5-3: Material Types and Earth Pressure Properties

Material	Friction Angle, $\phi'$ (unfactored)	Coefficient of Active Earth Pressure, $K_a$	Coefficient of Passive Earth Pressure, $K_p$	Coefficient of Earth Pressure at Rest, $K_o$	Unit Weight, $\gamma$ (kN/m <sup>3</sup> )
Granular A or Granular B Type II	33	0.29	3.39	0.46	22
Silty Clay Fill	25	0.41	2.46	0.58	18
Native Silty Clay	28	0.36	2.77	0.53	19

The mobilization of full active or passive resistance requires a measurable and perhaps significant shoring movement or rotation. Therefore, unless the structural element can tolerate these deflections, the at-rest earth pressure should be used in design.

If applicable, the effect of compaction surcharge should be considered in the calculations of active and at rest earth pressures. The lateral pressure due to compaction should be taken as at least 12 kPa at the surface, and its magnitude should be assumed to diminish linearly with depth to zero at the depth where the active (or at rest) pressure is equal to 12 kPa. This pressure distribution should be added to the calculated active (or at rest) pressure. Notwithstanding, lighter compaction equipment and smaller lifts should be used adjacent to walls to prevent overstressing.

## 5.4 Ground Movement Monitoring

Ground movement monitoring is required at all MTO crossings. Condition surveys should be carried out before the construction takes place and after the completion of the tunneling. The survey should document the pavement surface conditions (i.e. cracks, distortion and deviations, heaves, and depressions) and any surrounding infrastructure (bridges, culverts, etc.). The methodology of the settlement monitoring program is outlined in the following subsections.

### 5.4.1 Monitoring Points

The monitoring should consist of surface and deep settlement points along the center line of the proposed tunnel. The deep settlement points should be installed above the crown of the tunnel and below the frost penetration depth of 1.2 m. The spacing of the surface and deep settlement points should not exceed 5.0 m. Locations of the settlement points are subject to the landowner approval where traffic disruption might occur.

### 5.4.2 Reading Frequency

An average of at least two (2) readings should be taken to establish the initial conditions. A minimum of three (3) sets of readings should be taken daily during construction and work stoppages. The monitoring should be extended after the construction completion for at least two (2) weeks provided all settlements have stopped.

### 5.4.3 Data Collection and Data Transfer

A procedure should be established in consultation with the City and landowners to ensure that the monitoring data will reach all parties as soon as possible. The consultant and the contractor should interpret monitoring data as needed. The Geotechnical Engineer should be contacted for technical support in the interpretation of the ground movements and review of the contractor response when review and alert levels are reached.

### 5.4.4 Criteria for Assessment – Review and Alert Levels

An average of two initial readings shall be recorded as baseline readings, all the subsequent readings should be compared to the baseline reading. A maximum value of 10 mm relative to the baseline reading shall be considered as a review level, at which, the method, rate and sequence of construction, or ground stabilization measures should be reviewed or modified to mitigate further ground movement before construction proceeds. Movements of 15 mm relative to the baseline should be considered as an alert level; operations must stop and the pre-planned measures are to be implemented to mitigate further movement and ensure public safety.

## 5.5 Frost Considerations

If construction proceeds during the winter months, the base of the trench and all fill materials should not be allowed to freeze. In the Niagara Falls area, a frost penetration depth of approximately 1.2 m can occur in open, unheated areas without snow cover. Any services without a minimum of 1.2 m of earth cover (or minimum depths specified by the Region) will require equivalent insulation for frost protection.

## 5.6 Soil Corrosivity

The parameters used to analyze the soil potential to corrode ductile iron are from the appendix to ANSI/AWWA C105/A21.5 Standard and were developed for ductile iron piping. This “10 point” soil evaluation system considers the effect of soil resistivity, pH, redox potential, sulfides, and moisture, and assigns points for various values of each parameter. Soil is considered corrosive to ductile iron when 10 or more points are tabulated. The complete test results are included in the Certificate of Analysis in Appendix C.

Table 5-4: Determination of Points for Soil Corrosion of Ductile Iron

Borehole and Sample No.	pH	Sulphate (µg/g)	Sulphide (%)	Chloride (µg/g)	Resistivity (Ω-cm)	Redox Potential (mV)	Moisture/ Drainage
BH-101 SS4 Corrosivity Points (Total = 7)	8.22	310	<0.05	29	1,910	176	wet
	0	---	0	---	5	0	2
BH-103 SS7 Corrosivity Points (Total = 7)	8.06	311	<0.05	55	1,990	111	wet
	0	---	0	---	5	0	2

The calculated points for the soil samples tested was 7. Therefore, the soil material represented by the sample tested indicates that the soil is not corrosive to ductile iron piping.

The concentration of soluble sulphate in the soil samples collected ranged from 310 to 311 µg/g (0.031 to 0.0311%), indicating a moderate degree of sulphate exposure for buried concrete structures. As such, buried concrete structures should be designed for at least Exposure Class S-3 in accordance with CSA A23.1. However, it should be noted that these are localized samples and results from different areas may indicate higher soluble sulphate concentrations.

## 6. General Comments

The information presented in this report is based on a limited investigation designed to provide information to support an overall assessment of the current geotechnical conditions of the subject property. The conclusions presented in this report reflect site conditions existing at the time of the investigation.

EXP Services Inc. should be retained for a general review of the final design and specifications to verify that this report has been properly interpreted and implemented. If not accorded the privilege of making this review, EXP Services Inc. will assume no responsibility for interpretation of the recommendations in the report.

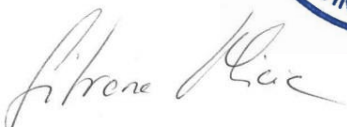
The comments given in this report are intended only for the guidance of design engineers. The number of boreholes required to determine the localized underground conditions between boreholes affecting construction costs, techniques, sequencing, equipment, scheduling, etc., would be much greater than has been carried out for design purposes. Contractors bidding on or undertaking the works should, in this light, decide on their own investigations, as well as their own interpretations of the factual borehole results, so that they may draw their own conclusions as to how the subsurface conditions may affect them.

More specific information, with respect to the conditions between samples, or the lateral and vertical extent of materials, may become apparent during excavation operations. Consequently, during the future development of the property, conditions not observed during this investigation may become apparent; should this occur, EXP Services Inc. should be contacted to assess the situation and additional testing and reporting may be required. EXP Services Inc. has qualified personnel to provide assistance in regard to future geotechnical and environmental issues related to this property.


We trust this report is satisfactory for your purposes. Should you have any questions, please do not hesitate to contact this office.

  
Dilsher Bhangal, P.Eng., M.Eng.  
Geotechnical Project Manager



  
Silvana Micic, Ph.D., P.Eng.  
Senior Geotechnical Engineer

  
Jeffrey Golder, P.Eng.  
Manager, Hamilton Geotechnical Services

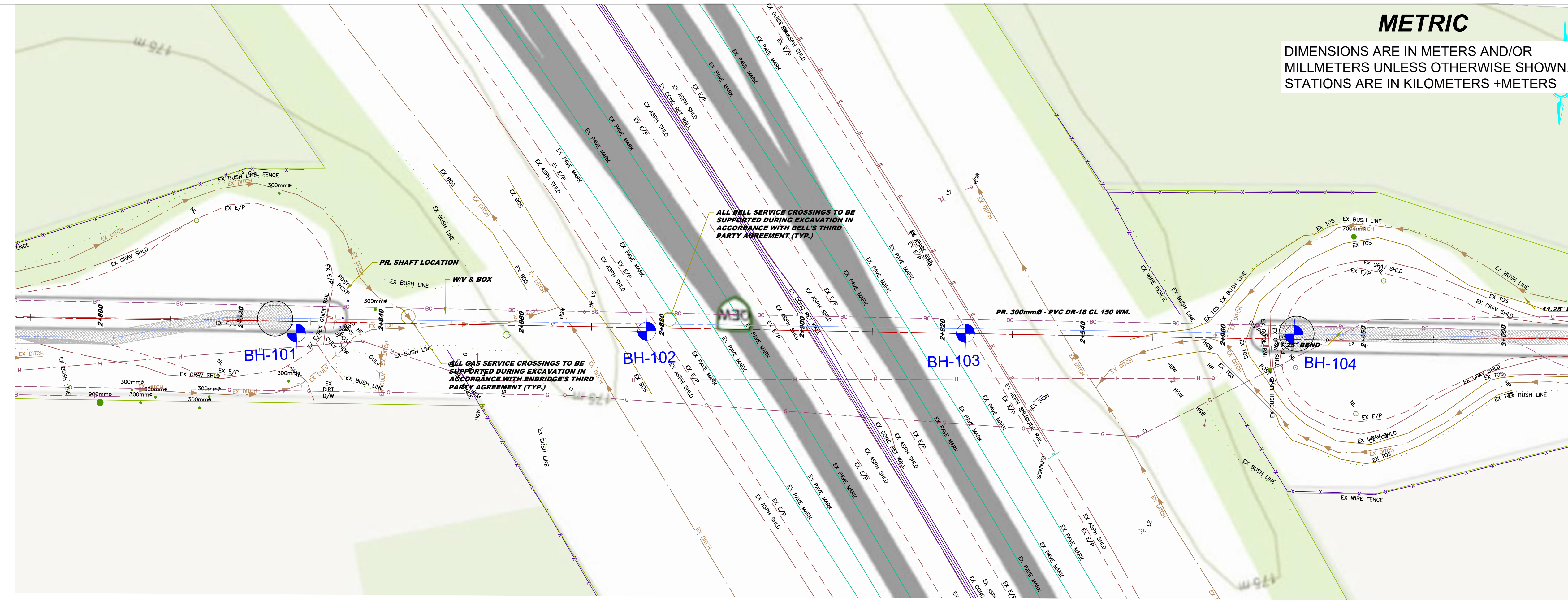
  
Stan Gonsalves, M.Eng., P.Eng.  
Executive Vice President  
MTO Designated Contact



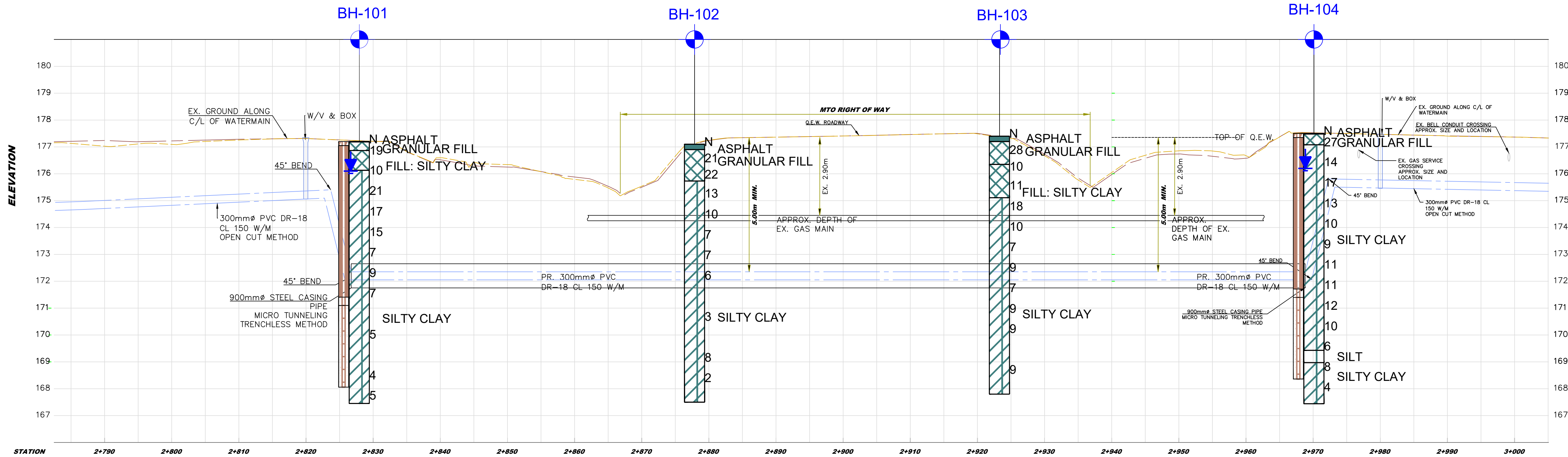
## Appendix A

Drawings & Borehole Logs





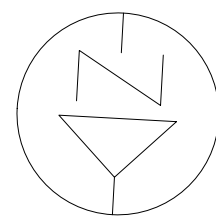
PLAN



PROFILE

BOREHOLE LOCATION PLAN AND PROFILE

PROPOSED TRENCHLESS WATERMAIN  
INSTALLATION  
REIXINGER ROAD AND QEW  
NIAGARA FALLS, ON



SHEET



EXP Services Inc.

KEY PLAN



LEGEND

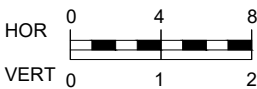
- Boreholes Location
- Standard Penetration Test (Blows/0.3 m)
- Water Level in Piezometer (most recent) (W. L. STABILIZED)
- Piezometer

SOIL STRATA SYMBOLS

- Asphalt
- GRANULAR FILL
- FILL: SILTY CLAY
- SILT
- SILTY CLAY

BH ID.	ELEVATION	COORDINATE NAD 83 (ZONE UTM17)	
		NORTHING	EASTING
BH 101	177.2	4766630.5	653390.1
BH 102	177.1	4766627.5	653340.2
BH 103	177.4	4766625.3	653294.9
BH 104	177.5	4766622.9	653248.1

SCALE (m)



SUBMISSION FOR MTO REVIEW			
GEOCRES NO.			
PROJECT NO. HAM-00801890-A0			
SUBM'D SH	CHECKED DB	DATE	10/01/2021
DRAWN SH	CHECKED DB	APPROVED JG	DWG. 1

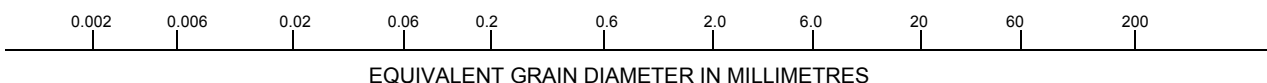


## Notes on Sample Descriptions

1. All sample descriptions included in this report follow the International Society for Soil Mechanics and Foundation Engineering (ISSMFE), as outlined in the Canadian Foundation Engineering Manual. Note, however, that behavioral properties (i.e. plasticity, permeability) take precedence over particle gradation when classifying soil. Please note that, with the exception of those samples where a grain size analysis has been made, all samples are classified visually. Visual classification is not sufficiently accurate to provide exact grain sizing or precise differentiation between size classification systems.

### UNIFIED SOIL CLASSIFICATION

CLAY (PLASTIC) TO SILT (NONPLASTIC)	FINE	MEDIUM	CRS.	FINE	COARSE
	SAND			GRAVEL	



### ISSMFE SOIL CLASSIFICATION

CLAY	SILT			SAND			GRAVEL			COBBLES	BOULDERS
	FINE	MEDIUM	COARSE	FINE	MEDIUM	COARSE	FINE	MEDIUM	COARSE		

2. Fill: Where fill is designated on the borehole log it is defined as indicated by the sample recovered during the boring process. The reader is cautioned that fills are heterogeneous in nature and variable in density or degree of compaction. The borehole description may therefore not be applicable as a general description of site fill materials. All fills should be expected to contain obstruction such as wood, large concrete pieces or subsurface basements, floors, tanks, etc., none of these may have been encountered in the boreholes. Since boreholes cannot accurately define the contents of the fill, test pits are recommended to provide supplementary information. Despite the use of test pits, the heterogeneous nature of fill will leave some ambiguity as to the exact composition of the fill. Most fills contain pockets, seams, or layers of organically contaminated soil. This organic material can result in the generation of methane gas and/or significant ongoing and future settlements. Fill at this site may have been monitored for the presence of methane gas and, if so, the results are given on the borehole logs. The monitoring process does not indicate the volume of gas that can be potentially generated nor does it pinpoint the source of the gas. These readings are to advise of the presence of gas only, and a detailed study is recommended for sites where any explosive gas/methane is detected. Some fill material may be contaminated by toxic/hazardous waste that renders it unacceptable for deposition in any but designated land fill sites; unless specifically stated the fill on this site has not been tested for contaminants that may be considered toxic or hazardous. This testing and a potential hazard study can be undertaken if requested. In most residential/commercial areas undergoing reconstruction, buried oil tanks are common and are generally not detected in a conventional geotechnical site investigation.
3. Till: The term till on the borehole logs indicates that the material originates from a geological process associated with glaciation. Because of this geological process the till must be considered heterogeneous in composition and as such may contain pockets and/or seams of material such as sand, gravel, silt or clay. Till often contains cobbles (75 to 200 mm) or boulders (over 200 mm). Contractors may therefore encounter cobbles and boulders during excavation, even if they are not indicated by the borings. It should be appreciated that normal sampling equipment cannot differentiate the size or type of any obstruction. Because of the horizontal and vertical variability of till, the sample description may be applicable to a very limited zone; caution is therefore essential when dealing with sensitive excavations or dewatering programs in till materials.

## Notes On Soil Descriptions

4. The following table gives a description of the soil based on particle sizes. With the exception of those samples where grain size analyses have been performed, all samples are classified visually. The accuracy of visual examination is not sufficient to differentiate between this classification system or exact grain size.

Soil Classification		Terminology	Proportion
Clay and Silt	<0.060 mm	"trace" (e.g. Trace sand)	1% to 10%
Sand	0.060 to 2.0 mm	"some" (e.g. Some sand)	10% to 20%
Gravel	2.0 to 75 mm	adjective (e.g. sandy, silty)	20% to 35%
Cobbles	75 to 200 mm	"and" (e.g. and sand)	35% to 50%
Boulders	>200 mm		

The compactness of Cohesionless soils and the consistency of the cohesive soils are defined by the following:

Cohesionless Soil		Cohesive Soil		
Compactness	Standard Penetration Resistance "N" Blows / 0.3 m	Consistency	Undrained Shear Strength (kPa)	Standard Penetration Resistance "N" Blows / 0.3 m
Very Loose	0 to 4	Very soft	<12	<2
Loose	4 to 10	Soft	12 to 25	2 to 4
Compact	10 to 30	Firm	25 to 50	4 to 8
Dense	30 to 50	Stiff	50 to 100	8 to 15
Very Dense	Over 50	Very Stiff	100 to 200	15 to 30
		Hard	>200	>30

### 5. ROCK CORING

Where rock drilling was carried out, the term RQD (Rock Quality Designation) is used. The RQD is an indirect measure of the number of fractures and soundness of the rock mass. It is obtained from the rock cores by summing the length of the core covered, counting only those pieces of sound core that are 100 mm or more length. The RQD value is expressed as a percentage and is the ratio of the summed core lengths to the total length of core run. The classification based on the RQD value is given below.

RQD Classification	RQD (%)
Very Poor Quality	<25
Poor Quality	25 to 50
Fair Quality	50 to 75
Good Quality	75 to 90
Excellent Quality	90 to 100

$$\text{Recovery Designation \% Recovery} = \frac{\text{Length of Core Per Run}}{\text{Total Length of Run}} \times 100$$



# RECORD OF BOREHOLE No BH-101

1 OF 1

METRIC

W.P. \_\_\_\_\_ LOCATION \_\_\_\_\_ ORIGINATED BY DB  
DIST Niagara Falls HWY \_\_\_\_\_ BOREHOLE TYPE Diedrich D-50 Truck Mount. Solid Stem. \_\_\_\_\_ COMPILED BY DB  
DATUM Geodetic \_\_\_\_\_ DATE 2020.04.16 - 2020.04.16 LATITUDE \_\_\_\_\_ LONGITUDE \_\_\_\_\_ CHECKED BY JG

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					PLASTIC LIMIT W <sub>P</sub>	NATURAL MOISTURE CONTENT W	LIQUID LIMIT W <sub>L</sub>	UNIT WEIGHT γ  kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa									
177.2	Road Surface							20	40	60	80	100					
170.0	ASPHALT: (~15 mm thick)		1	SS	19												
176.9	GRANULAR FILL: (~320 mm thick)																
0.3	FILL: silty clay, trace sand and gravel, brown, moist																
176.1			2	SS	10												
1.1	SILTY CLAY: trace sand, brown, moist, hard, occasional gravel, intermediate to high plasticity silt seams at 1.5 m																
			3	SS	21												
			4	SS	17												
	very moist, very stiff below 3.1 m		5	SS	15												
			6	SS	7												
			7	SS	9												
	wet with silt seams at 4.6 m and 5.3 m		8	SS	7												
				VANE													
	trace gravel, grey below 6.9 m		9	SS	5												
				VANE													
	stiff below 7.9 m		10	SS	4												
			11	SS	5												
167.5	Borehole terminated at 9.8 m depth.																
9.8																	
	NOTES: 1. This drawing is to be read with the subject report and project number as presented above. 2. Interpretation assistance by EXP is required before use by others. 3. Borehole remained dry upon completion. Water level at 1.1 m depth on April 27, 2020.																

+ 3, × 3: Numbers refer to Sensitivity ○ 3% STRAIN AT FAILURE

# RECORD OF BOREHOLE No BH-102

1 OF 1

METRIC

W.P. \_\_\_\_\_ LOCATION \_\_\_\_\_ ORIGINATED BY DB  
 DIST Niagara Falls HWY QEW BOREHOLE TYPE CME-75 Truck Mount. Solid Stem. COMPILED BY DB  
 DATUM Geodetic DATE 2020.05.16 - 2020.05.16 LATITUDE \_\_\_\_\_ LONGITUDE \_\_\_\_\_ CHECKED BY JG

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT				PLASTIC LIMIT W <sub>P</sub>	NATURAL MOISTURE CONTENT W	LIQUID LIMIT W <sub>L</sub>	UNIT WEIGHT γ	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa								
								○ UNCONFINED      + FIELD VANE								
177.1	Road Surface						20	40	60	80	100					
178.9	ASPHALT: (~200 mm thick)						20	40	60	80	100					
0.2	GRANULAR FILL: (~1170 mm thick)		1	SS	21											
			2	SS	22											
175.7	SILTY CLAY: trace sand, brown, moist, hard, occasional gravel, silt seams, intermediate plasticity		3	SS	13											
1.4	very stiff below 2.3 m		4	SS	10											
			5	SS	7											
	very moist below 3.8 m		6	SS	7											
	grey below 4.6 m		7	SS	6											
				VANE												
	wet, stiff below 6.1 m		8	SS	3											
				VANE												
			9	SS	8											
			10	SS	2											
				VANE												
167.5	Borehole terminated at 9.6 m depth															
9.6	NOTES: 1. This drawing is to be read with the subject report and project number as presented above. 2. Interpretation assistance by EXP is required before use by others. 3. Borehole remained dry upon completion.															

+ 3, × 3: Numbers refer to Sensitivity ○ 3% STRAIN AT FAILURE

# RECORD OF BOREHOLE No BH-103

1 OF 1

METRIC

W.P. \_\_\_\_\_ LOCATION \_\_\_\_\_ ORIGINATED BY DB  
DIST Niagara Falls HWY QEW BOREHOLE TYPE CME-75 Truck Mount. Solid Stem. COMPILED BY DB  
DATUM Geodetic DATE 2020.05.16 - 2020.05.16 LATITUDE \_\_\_\_\_ LONGITUDE \_\_\_\_\_ CHECKED BY JG

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					PLASTIC LIMIT W <sub>P</sub>	NATURAL MOISTURE CONTENT W	LIQUID LIMIT W <sub>L</sub>	UNIT WEIGHT γ	REMARKS & GRAIN SIZE DISTRIBUTION (%)			
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa										WATER CONTENT (%)		
								○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × LAB VANE												
177.4	Road Surface							20	40	60	80	100								
177.2	ASPHALT: (~200 mm thick)							20	40	60	80	100								
0.2	GRANULAR FILL: (~850 mm thick)		1	SS	28		177													
176.4			2	SS	10		176													
1.1	FILL: silty clay, trace sand and gravel, brown, moist, black organic staining and odour rootlets at 1.5 m		3	SS	11															
175.1			4	SS	18		175													
2.3	SILTY CLAY: trace sand, brown, moist, hard, silt seams, low to intermediate plasticity		5	SS	10		174													
	very stiff below 3.1 m		6	SS	7		173													
			7	SS	9		172													
	grey, very moist below 4.6 m		8	SS	7		171													
			9	SS	9		170													
	150 mm thick silt layer at 6.1 m and 6.9 m		10	SS	9		169													
	wet below 6.9 m			VANE			168													
	200 mm thick silt layer at 8.4 m		11	SS	9															
	stiff below 8.7 m																			
				VANE																
167.8																				
9.6	Borehole terminated at 9.6 m depth																			
	NOTES: 1. This drawing is to be read with the subject report and project number as presented above. 2. Interpretation assistance by EXP is required before use by others. 3. Borehole remained dry upon completion.																			

+ 3, × 3: Numbers refer to Sensitivity ○ 3% STRAIN AT FAILURE

ONTARIO MTO LOGS MTO.GPJ ONTARIO MTO.GDT 6/24/20

# RECORD OF BOREHOLE No BH-104

1 OF 1

METRIC

W.P. \_\_\_\_\_ LOCATION \_\_\_\_\_ ORIGINATED BY DB  
 DIST Niagara Falls HWY \_\_\_\_\_ BOREHOLE TYPE Diedrich D-50 Truck Mount. Solid Stem. COMPILED BY DB  
 DATUM Geodetic DATE 2020.04.16 - 2020.04.16 LATITUDE \_\_\_\_\_ LONGITUDE \_\_\_\_\_ CHECKED BY JG

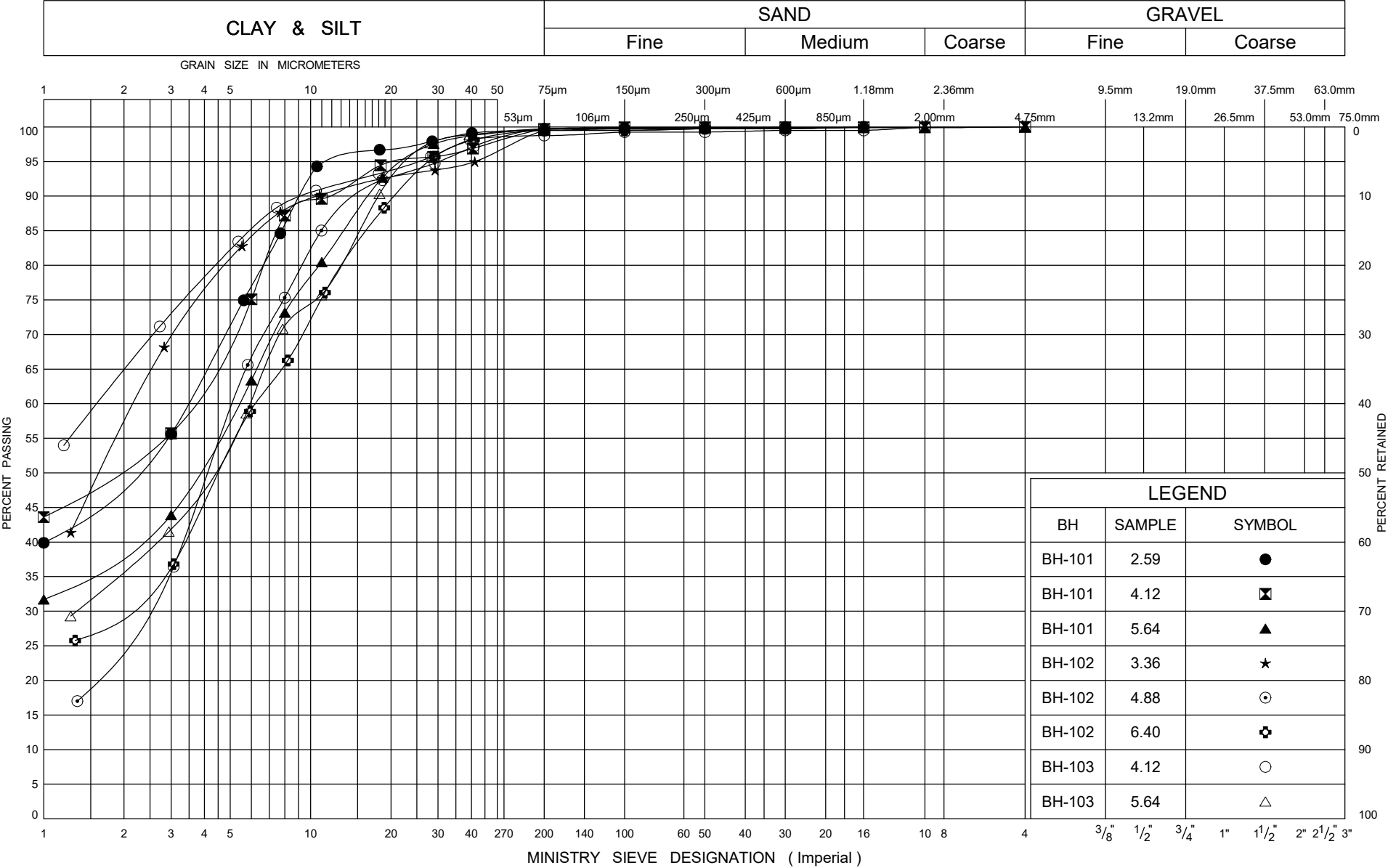
SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT W <sub>P</sub>	NATURAL MOISTURE CONTENT W	LIQUID LIMIT W <sub>L</sub>	UNIT WEIGHT  γ  kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa						
								○ UNCONFINED	+ FIELD VANE	● QUICK TRIAXIAL	× LAB VANE			
177.5	Road Surface													
177.0	ASPHALT: (~20 mm thick)		1	SS	27									
177.1	GRANULAR FILL: (~400 mm thick)													
0.4	SILTY CLAY: trace sand, brown, moist, hard, occasional gravel, intermediate plasticity													
			2	SS	14									
			3	SS	17									
	very stiff with silt seams at 2.3 and 3.1 m		4	SS	13									
	wet below 3.1 m		5	SS	10									
			6	SS	9									
	stiff below 4.6 m silt seams at 4.6 m		7	SS	11									
			8	SS	11									
	silt seams below 6.1 m		9	SS	12									
			10	SS	10									
	trace gravel, grey below 7.6 m													
169.4			11	SS	6									
8.1	SILT: trace sand, brown, wet, loose													
169.0														
8.5	SILTY CLAY: trace sand and gravel, grey, wet, stiff		12	SS	8									
			13	SS	4									
				VANE										
167.4														
10.1	Borehole terminated at 10.1 m depth.													
	NOTES: 1. This drawing is to be read with the subject report and project number as presented above. 2. Interpretation assistance by EXP is required before use by others. 3. Borehole remained dry upon completion. Water level at 1.3 m depth on April 27, 2020.													

+ 3, × 3: Numbers refer to Sensitivity ○ 3% STRAIN AT FAILURE

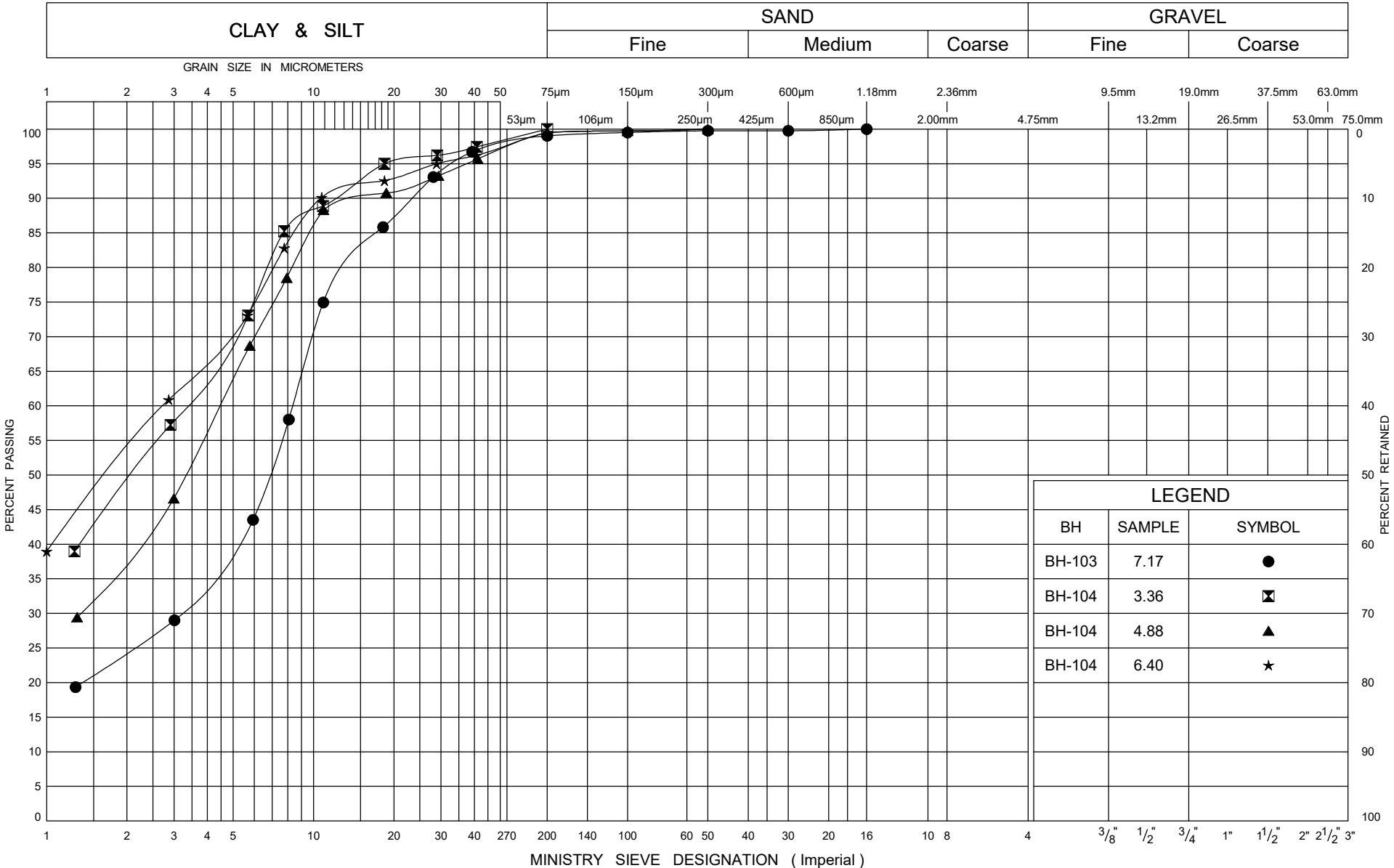
## Appendix B

### Laboratory Test Results

UNIFIED SOIL CLASSIFICATION SYSTEM



UNIFIED SOIL CLASSIFICATION SYSTEM



LEGEND		
BH	SAMPLE	SYMBOL
BH-103	7.17	●
BH-104	3.36	⊠
BH-104	4.88	▲
BH-104	6.40	★

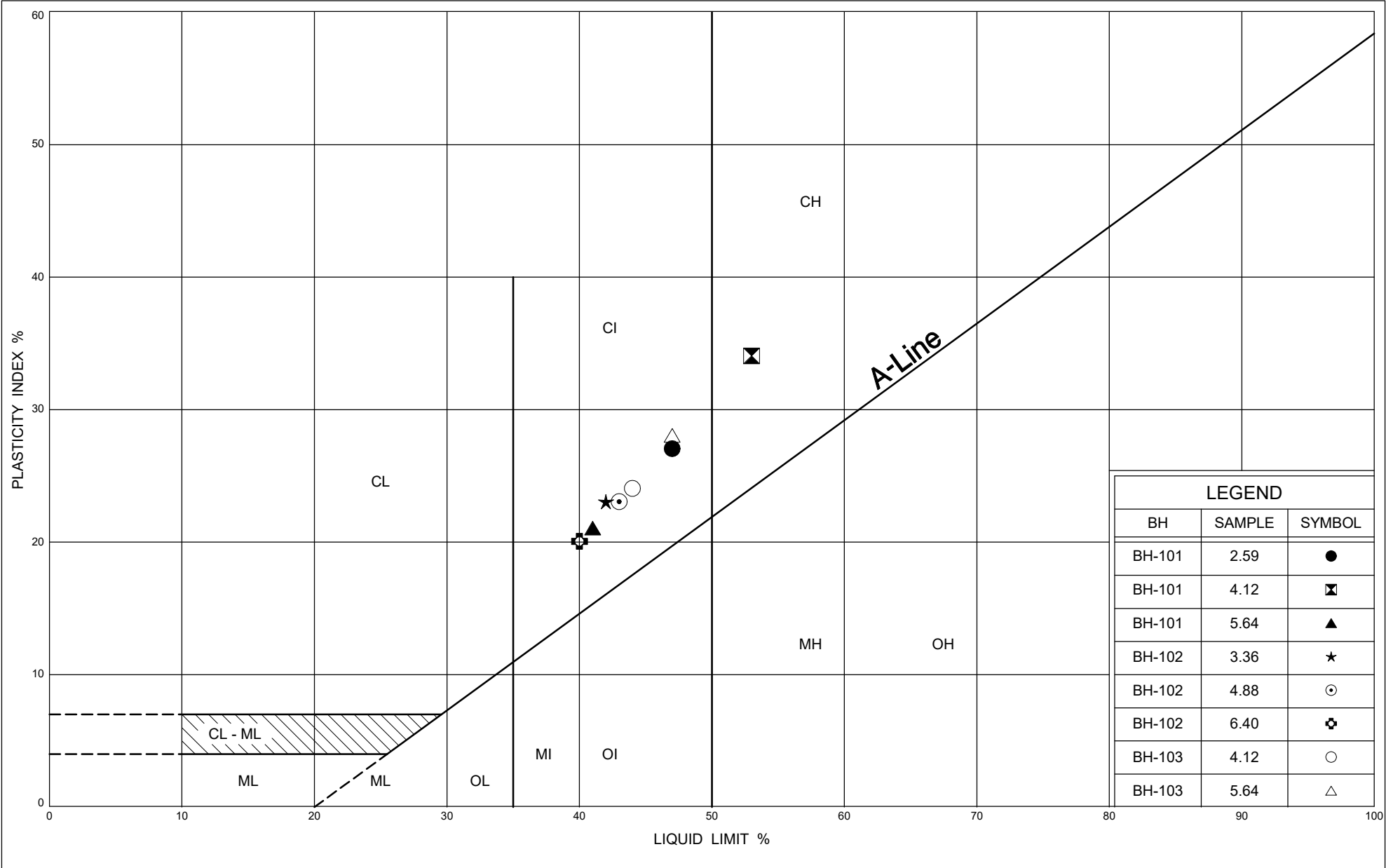


GRAIN SIZE DISTRIBUTION

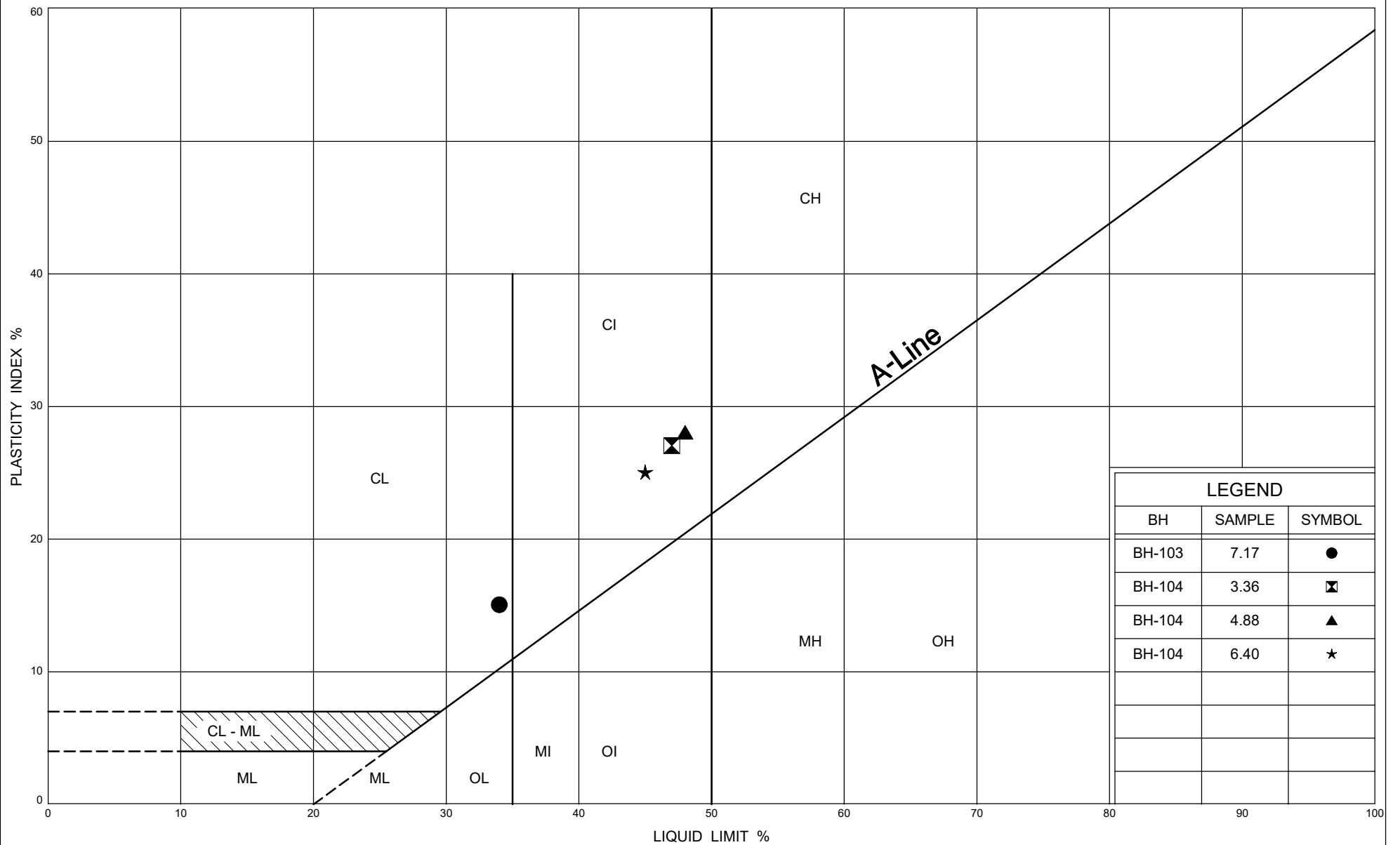
FIG No 2

W P

HAM-00801890-A0







LEGEND		
BH	SAMPLE	SYMBOL
BH-103	7.17	●
BH-104	3.36	▣
BH-104	4.88	▲
BH-104	6.40	★

## PLASTICITY CHART



Ministry of  
Transportation

FIG No 4

W P

HAM-00801890-A0

## Appendix C

### Certificate of Analysis

**CLIENT NAME: EXP. SERVICES INC.**  
**1266 SOUTH SERVICE ROAD, SUITE C1-1**  
**STONE CREEK , ON L8E 5R9**  
**(905) 573-4000**

**ATTENTION TO: Dilsher Bhargal**

**PROJECT: PROPOSED WATERMAIN INSTALLATION**

**AGAT WORK ORDER: 20T603410**

**MISCELLANEOUS ANALYSIS REVIEWED BY: Amanjot Bhela, Inorganic Lab Manager**

**SOIL ANALYSIS REVIEWED BY: Jacky Zhu, Spectroscopy Technician**

**DATE REPORTED: Jun 18, 2020**

**PAGES (INCLUDING COVER): 10**

**VERSION\*: 2**

Should you require any information regarding this analysis please contact your client services representative at (905) 712-5100

\*Notes

VERSION 2: Revised report issued June 18, 2020.

*Disclaimer:*

- *All work conducted herein has been done using accepted standard protocols, and generally accepted practices and methods. AGAT test methods may incorporate modifications from the specified reference methods to improve performance.*
- *All samples will be disposed of within 30 days following analysis, unless expressly agreed otherwise in writing. Please contact your Client Project Manager if you require additional sample storage time.*
- *AGAT's liability in connection with any delay, performance or non-performance of these services is only to the Client and does not extend to any other third party. Unless expressly agreed otherwise in writing, AGAT's liability is limited to the actual cost of the specific analysis or analyses included in the services.*
- *This Certificate shall not be reproduced except in full, without the written approval of the laboratory.*
- *The test results reported herewith relate only to the samples as received by the laboratory.*
- *Application of guidelines is provided "as is" without warranty of any kind, either expressed or implied, including, but not limited to, warranties of merchantability, fitness for a particular purpose, or non-infringement. AGAT assumes no responsibility for any errors or omissions in the guidelines contained in this document.*
- *All reportable information as specified by ISO/IEC 17025:2017 is available from AGAT Laboratories upon request.*



**AGAT** Laboratories

## Certificate of Analysis

AGAT WORK ORDER: 20T603410

PROJECT: PROPOSED WATERMAIN INSTALLATION

5835 COOPERS AVENUE  
MISSISSAUGA, ONTARIO  
CANADA L4Z 1Y2  
TEL (905)712-5100  
FAX (905)712-5122  
<http://www.agatlabs.com>

CLIENT NAME: EXP. SERVICES INC.

ATTENTION TO: Dilsher Bhargal

SAMPLING SITE:

SAMPLED BY:

### Sulphide

DATE RECEIVED: 2020-05-20

DATE REPORTED: 2020-06-18

		SAMPLE DESCRIPTION:		BH101 SS4	BH103 SS7
		SAMPLE TYPE:		Soil	Soil
		DATE SAMPLED:		2020-04-16	2020-05-16
Parameter	Unit	G / S	RDL	1097526	1136485
Sulfide	%	0.05	<0.05	<0.05	<0.05

Comments: RDL - Reported Detection Limit; G / S - Guideline / Standard

1097526-1136485 Analysis was performed at AGAT, 5623 McAdam.

Analysis performed at AGAT Toronto (unless marked by \*)

Certified By:





# AGAT Laboratories

## Certificate of Analysis

AGAT WORK ORDER: 20T603410

PROJECT: PROPOSED WATERMAIN INSTALLATION

5835 COOPERS AVENUE  
MISSISSAUGA, ONTARIO  
CANADA L4Z 1Y2  
TEL (905)712-5100  
FAX (905)712-5122  
<http://www.agatlabs.com>

CLIENT NAME: EXP. SERVICES INC.

ATTENTION TO: Dilsher Bhargal

SAMPLING SITE:

SAMPLED BY:

### Corrosivity Package

DATE RECEIVED: 2020-05-20

DATE REPORTED: 2020-06-18

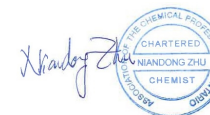
		SAMPLE DESCRIPTION:		BH101 SS4	BH103 SS7
		SAMPLE TYPE:		Soil	Soil
		DATE SAMPLED:		2020-04-16	2020-05-16
Parameter	Unit	G / S	RDL	1097526	1136485
Chloride (2:1)	µg/g		2	29	55
Sulphate (2:1)	µg/g		2	310	311
pH (2:1)	pH Units		NA	8.22	8.06
Electrical Conductivity (2:1)	mS/cm		0.005	0.523	0.503
Resistivity (2:1) (Calculated)	ohm.cm		1	1910	1990
Redox Potential 1	mV		NA	176	115
Redox Potential 2	mV		NA	226	111
Redox Potential 3	mV		NA	189	108

**Comments:** RDL - Reported Detection Limit; G / S - Guideline / Standard

**1097526-1136485** EC, pH, Chloride and Sulphate were determined on the extract obtained from the 2:1 leaching procedure (2 parts DI water: 1 part soil). Resistivity is a calculated parameter. Redox potential measured on as received sample. Due to the potential for rapid change in sample equilibrium chemistry with exposure to oxidative/reduction conditions laboratory results may differ from field measured results.

Analysis performed at AGAT Toronto (unless marked by \*)

Certified By:





# AGAT Laboratories

## Certificate of Analysis

AGAT WORK ORDER: 20T603410

PROJECT: PROPOSED WATERMAIN INSTALLATION

5835 COOPERS AVENUE  
MISSISSAUGA, ONTARIO  
CANADA L4Z 1Y2  
TEL (905)712-5100  
FAX (905)712-5122  
<http://www.agatlabs.com>

CLIENT NAME: EXP. SERVICES INC.

ATTENTION TO: Dilsher Bhangal

SAMPLING SITE:

SAMPLED BY:

### O. Reg. 153(511) - Metals & Inorganics (Soil)

DATE RECEIVED: 2020-05-20

DATE REPORTED: 2020-06-18

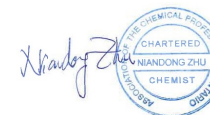
		SAMPLE DESCRIPTION:		BH101 SS4	BH104 SS4	BH102 SS6	BH103 SS7
		SAMPLE TYPE:		Soil	Soil	Soil	Soil
		DATE SAMPLED:		2020-04-16	2020-04-16	2020-05-16	2020-05-16
Parameter	Unit	G / S	RDL	1097526	1097536	1136484	1136485
Antimony	µg/g		0.8	<0.8	<0.8	<0.8	<0.8
Arsenic	µg/g		1	5	6	5	8
Barium	µg/g		2	186	140	131	135
Beryllium	µg/g		0.5	0.8	0.7	0.8	0.7
Boron	µg/g		5	16	11	16	12
Boron (Hot Water Extractable)	µg/g		0.10	0.28	0.37	0.67	0.30
Cadmium	µg/g		0.5	<0.5	<0.5	<0.5	<0.5
Chromium	µg/g		5	29	26	31	27
Cobalt	µg/g		0.5	14.3	14.2	13.7	13.9
Copper	µg/g		1	23	25	26	25
Lead	µg/g		1	8	9	10	9
Molybdenum	µg/g		0.5	0.7	0.7	0.6	0.7
Nickel	µg/g		1	33	31	30	28
Selenium	µg/g		0.4	<0.4	<0.4	<0.4	<0.4
Silver	µg/g		0.2	<0.2	<0.2	<0.2	<0.2
Thallium	µg/g		0.4	<0.4	<0.4	<0.4	<0.4
Uranium	µg/g		0.5	0.8	0.9	0.9	0.8
Vanadium	µg/g		1	38	35	41	37
Zinc	µg/g		5	68	64	69	64
Chromium, Hexavalent	µg/g		0.2	<0.2	<0.2	<0.2	<0.2
Cyanide, Free	µg/g		0.040	<0.040	<0.040	<0.040	<0.040
Mercury	µg/g		0.10	<0.10	<0.10	<0.10	<0.10
Electrical Conductivity (2:1)	mS/cm		0.005	0.523	0.760	1.78	0.503
Sodium Adsorption Ratio	NA		NA	0.876	0.701	1.34	0.576
pH, 2:1 CaCl2 Extraction	pH Units		NA	7.91	7.86	7.82	7.65

Comments: RDL - Reported Detection Limit; G / S - Guideline / Standard

**1097526-1136485** EC was determined on the DI water extract obtained from the 2:1 leaching procedure (2 parts DI water:1 part soil). pH was determined on the 0.01M CaCl2 extract prepared at 2:1 ratio. SAR is a calculated parameter.

Analysis performed at AGAT Toronto (unless marked by \*)

Certified By:



## Quality Assurance

CLIENT NAME: EXP. SERVICES INC.

AGAT WORK ORDER: 20T603410

PROJECT: PROPOSED WATERMAIN INSTALLATION

ATTENTION TO: Dilsher Bhargal

SAMPLING SITE:

SAMPLED BY:

### Miscellaneous Analysis

RPT Date: Jun 18, 2020			DUPLICATE			Method Blank	REFERENCE MATERIAL		METHOD BLANK SPIKE			MATRIX SPIKE			
PARAMETER	Batch	Sample Id	Dup #1	Dup #2	RPD		Measured Value	Acceptable Limits		Recovery	Acceptable Limits		Recovery	Acceptable Limits	
								Lower	Upper		Lower	Upper		Lower	Upper

**Sulphide**

Sulfide 1097526 1097526 &lt; 0.05 &lt; 0.05 NA &lt; 0.05 100% 90% 110%

**Sulphide**

Sulfide 1136485 1136485 &lt; 0.05 &lt; 0.05 NA &lt; 0.05 98% 90% 110%

Certified By:




## Quality Assurance

CLIENT NAME: EXP. SERVICES INC.

PROJECT: PROPOSED WATERMAIN INSTALLATION

SAMPLING SITE:

AGAT WORK ORDER: 20T603410

ATTENTION TO: Dilsher Bhargal

SAMPLED BY:

### Soil Analysis

RPT Date: Jun 18, 2020			DUPLICATE			Method Blank	REFERENCE MATERIAL			METHOD BLANK SPIKE			MATRIX SPIKE		
PARAMETER	Batch	Sample Id	Dup #1	Dup #2	RPD		Measured Value	Acceptable Limits		Recovery	Acceptable Limits		Recovery	Acceptable Limits	
								Lower	Upper		Lower	Upper		Lower	Upper
O. Reg. 153(511) - Metals & Inorganics (Soil)															
Antimony	1136434		<0.8	<0.8	NA	< 0.8	125%	70%	130%	98%	80%	120%	99%	70%	130%
Arsenic	1136434		6	6	0.0%	< 1	106%	70%	130%	105%	80%	120%	99%	70%	130%
Barium	1136434		143	145	1.4%	< 2	107%	70%	130%	109%	80%	120%	111%	70%	130%
Beryllium	1136434		1.0	1.0	NA	< 0.5	90%	70%	130%	108%	80%	120%	84%	70%	130%
Boron	1136434		9	10	NA	< 5	86%	70%	130%	107%	80%	120%	79%	70%	130%
Boron (Hot Water Extractable)	1136434		0.57	0.62	8.4%	< 0.10	99%	60%	140%	97%	70%	130%	99%	60%	140%
Cadmium	1136434		<0.5	0.5	NA	< 0.5	104%	70%	130%	101%	80%	120%	102%	70%	130%
Chromium	1136434		34	35	2.9%	< 5	101%	70%	130%	112%	80%	120%	106%	70%	130%
Cobalt	1136434		16.9	17.1	1.2%	< 0.5	97%	70%	130%	108%	80%	120%	98%	70%	130%
Copper	1136434		19	19	0.0%	< 1	88%	70%	130%	108%	80%	120%	92%	70%	130%
Lead	1136434		38	38	0.0%	< 1	106%	70%	130%	112%	80%	120%	100%	70%	130%
Molybdenum	1136434		1.0	1.0	NA	< 0.5	109%	70%	130%	107%	80%	120%	102%	70%	130%
Nickel	1136434		24	25	4.1%	< 1	94%	70%	130%	105%	80%	120%	95%	70%	130%
Selenium	1136434		0.9	0.5	NA	< 0.4	120%	70%	130%	102%	80%	120%	98%	70%	130%
Silver	1136434		<0.2	<0.2	NA	< 0.2	98%	70%	130%	104%	80%	120%	100%	70%	130%
Thallium	1136434		<0.4	<0.4	NA	< 0.4	108%	70%	130%	104%	80%	120%	98%	70%	130%
Uranium	1136434		1.0	1.0	NA	< 0.5	114%	70%	130%	109%	80%	120%	103%	70%	130%
Vanadium	1136434		52	53	1.9%	< 1	103%	70%	130%	105%	80%	120%	100%	70%	130%
Zinc	1136434		115	119	3.4%	< 5	100%	70%	130%	109%	80%	120%	115%	70%	130%
Chromium, Hexavalent	1136434		<0.2	<0.2	NA	< 0.2	90%	70%	130%	85%	80%	120%	97%	70%	130%
Cyanide, Free	1128577		<0.040	<0.040	NA	< 0.040	96%	70%	130%	100%	80%	120%	95%	70%	130%
Mercury	1136434		<0.10	<0.10	NA	< 0.10	103%	70%	130%	98%	80%	120%	93%	70%	130%
Electrical Conductivity (2:1)	1138204		0.244	0.243	0.4%	< 0.005	101%	80%	120%						
Sodium Adsorption Ratio	1136434		1.23	1.25	1.6%										
pH, 2:1 CaCl2 Extraction	1136114		7.46	7.40	0.8%		100%	80%	120%						
Corrosivity Package															
Chloride (2:1)	1135439		207	208	0.5%	< 2	94%	70%	130%	104%	80%	120%	106%	70%	130%
Sulphate (2:1)	1135439		107	108	0.9%	< 2	96%	70%	130%	101%	80%	120%	102%	70%	130%
pH (2:1)	1135439		8.10	8.19	1.1%	NA	100%	90%	110%						
Electrical Conductivity (2:1)	1138204		0.244	0.243	0.4%	< 0.005	101%	80%	120%						
Redox Potential 1							100%	90%	110%						

Comments: NA signifies Not Applicable.

pH duplicates QA acceptance criteria was met relative as stated in Table 5-15 of Analytical Protocol document.

If the RPD value is NA, the results of the duplicates are under 5X the RDL and will not be calculated.

Certified By:





## Method Summary

CLIENT NAME: EXP. SERVICES INC.

AGAT WORK ORDER: 20T603410

PROJECT: PROPOSED WATERMAIN INSTALLATION

ATTENTION TO: Dilsher Bhangal

SAMPLING SITE:

SAMPLED BY:

PARAMETER	AGAT S.O.P	LITERATURE REFERENCE	ANALYTICAL TECHNIQUE
<b>Miscellaneous Analysis</b>			
Sulfide	sub	sub	LECO

## Method Summary

**CLIENT NAME:** EXP. SERVICES INC.

**PROJECT:** PROPOSED WATERMAIN INSTALLATION

**SAMPLING SITE:**
**AGAT WORK ORDER:** 20T603410

**ATTENTION TO:** Dilsher Bhargal

**SAMPLED BY:**

PARAMETER	AGAT S.O.P	LITERATURE REFERENCE	ANALYTICAL TECHNIQUE
<b>Soil Analysis</b>			
Chloride (2:1)	INOR-93-6004	modified from SM 4110 B	ION CHROMATOGRAPH
Sulphate (2:1)	INOR-93-6004	modified from SM 4110 B	ION CHROMATOGRAPH
pH (2:1)	INOR 93-6031	MSA part 3 & SM 4500-H+ B	PH METER
Electrical Conductivity (2:1)	INOR-93-6036	modified from MSA PART 3, CH 14 and SM 2510 B	EC METER
Resistivity (2:1) (Calculated)	INOR-93-6036	McKeague 4.12, SM 2510 B, SSA #5 Part 3	CALCULATION
Redox Potential 1	INOR-93-6066	modified G200-09, SM 2580 B	REDOX POTENTIAL ELECTRODE
Redox Potential 2	INOR-93-6066	modified G200-09, SM 2580 B	REDOX POTENTIAL ELECTRODE
Redox Potential 3	INOR-93-6066	modified G200-09, SM 2580 B	REDOX POTENTIAL ELECTRODE
Antimony	MET-93-6103	modified from EPA 3050B and EPA 6020B and ON MOECC	ICP-MS
Arsenic	MET-93-6103	modified from EPA 3050B and EPA 6020B and ON MOECC	ICP-MS
Barium	MET-93-6103	modified from EPA 3050B and EPA 6020B and ON MOECC	ICP-MS
Beryllium	MET-93-6103	modified from EPA 3050B and EPA 6020B and ON MOECC	ICP-MS
Boron	MET-93-6103	modified from EPA 3050B and EPA 6020B and ON MOECC	ICP-MS
Boron (Hot Water Extractable)	MET-93-6104	modified from EPA 6010D and MSA PART 3, CH 21	ICP/OES
Cadmium	MET-93-6103	modified from EPA 3050B and EPA 6020B and ON MOECC	ICP-MS
Chromium	MET-93-6103	modified from EPA 3050B and EPA 6020B and ON MOECC	ICP-MS
Cobalt	MET-93-6103	modified from EPA 3050B and EPA 6020B and ON MOECC	ICP-MS
Copper	MET-93-6103	modified from EPA 3050B and EPA 6020B and ON MOECC	ICP-MS
Lead	MET-93-6103	modified from EPA 3050B and EPA 6020B and ON MOECC	ICP-MS
Molybdenum	MET-93-6103	modified from EPA 3050B and EPA 6020B and ON MOECC	ICP-MS
Nickel	MET-93-6103	modified from EPA 3050B and EPA 6020B and ON MOECC	ICP-MS
Selenium	MET-93-6103	modified from EPA 3050B and EPA 6020B and ON MOECC	ICP-MS
Silver	MET-93-6103	modified from EPA 3050B and EPA 6020B and ON MOECC	ICP-MS
Thallium	MET-93-6103	modified from EPA 3050B and EPA 6020B and ON MOECC	ICP-MS
Uranium	MET-93-6103	modified from EPA 3050B and EPA 6020B and ON MOECC	ICP-MS
Vanadium	MET-93-6103	modified from EPA 3050B and EPA 6020B and ON MOECC	ICP-MS
Zinc	MET-93-6103	modified from EPA 3050B and EPA 6020B and ON MOECC	ICP-MS
Chromium, Hexavalent	INOR-93-6068	modified from EPA 3060 and EPA 7196	SPECTROPHOTOMETER
Cyanide, Free	INOR-93-6052	modified from ON MOECC E3015 and SM 4500-CN- I	TECHNICON AUTO ANALYZER
Mercury	MET-93-6103	modified from EPA 3050B and EPA 6020B and ON MOECC	ICP-MS

## Method Summary

CLIENT NAME: EXP. SERVICES INC.

AGAT WORK ORDER: 20T603410

PROJECT: PROPOSED WATERMAIN INSTALLATION

ATTENTION TO: Dilsher Bhangal

SAMPLING SITE:

SAMPLED BY:

PARAMETER	AGAT S.O.P	LITERATURE REFERENCE	ANALYTICAL TECHNIQUE
Sodium Adsorption Ratio	INOR-93-6007	McKeague 4.12 & 3.26 & EPA SW-846 6010C	ICP/OES
pH, 2:1 CaCl <sub>2</sub> Extraction	INOR-93-6031	modified from EPA 9045D and MCKEAGUE 3.11	PH METER



## Appendix D

Soil and Rock Tunneling Behaviour

**Table D-1: Typical Classification for Soils and Rocks**

Classification		Behavior	Typical Soil Types
Firm		Heading can be advanced without initial support, and final lining can be constructed before ground starts to move.	Loess above water table; hard clay, marl, cemented sand and gravel when not highly overstressed.
Raveling	Slow raveling	Chunks or flakes of material begin to drop out of the arch or walls sometime after the ground has been exposed, due to loosening or to over-stress and "brittle" fracture (ground separates or breaks along distinct surfaces, opposed to squeezing ground). In fast raveling ground, the process starts within a few minutes, otherwise the ground is slow raveling.	Residual soils or sand with small amounts of binder may be fast raveling below the water tale, slow raveling above. Stiff fissured clays may be slow or fast raveling depending upon degree of overstress.
	Fast raveling		
Squeezing		Ground squeezes or extrudes plastically into tunnel, without visible fracturing or loss of continuity, and without perceptible increase in water content. Ductile, plastic yield and flow due to overstress.	Ground with low frictional strength. Rate of squeeze depends on degree of overstress. Occurs at shallow to medium depth in clay of very soft to medium consistency. Stiff to hard clay under high cover may move in combination of raveling at excavation surface and squeezing at depth behind surface.
Running	Cohesive – running	Granular materials without cohesion are unstable at a slope greater than their angle of repose (approx. 30° - 35°). When exposed at steeper slopes they run like granulated sugar or dune sand until the slope flattens to the angle of repose.	Clean, dry granular materials. Apparent cohesion in moist sand, or weak cementation in any granular soil, may allow the material to stand for a brief period of raveling before it breaks down and runs. Such behavior is cohesive-running.
	Running		
Flowing		A mixture of soil and water flows into the tunnel like a viscous fluid. The material can enter the tunnel from the invert as well as from the face, crown, and walls, and can flow for great distances, completely filling the tunnel in some cases.	Below the water table in silt, sand, or gravel without enough clay content to give significant cohesion and plasticity. May also occur in highly sensitive clay when such material is disturbed.
Swelling		Ground absorbs water, increases in volume, and expands slowly into the tunnel.	Highly preconsolidated clay with plasticity index in excess of about 30, generally containing significant percentages of montmorillonite.

\*Modified by Heuer (1974) from Terzaghi (1950)



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**Table D-2: Tunnel Behavior: Sands and Gravels**

Designation	Degree of Compactness	Tunnel Behavior	
		Above Water Table	Below Water Table
Very Fine Clean Sand	Loose, $N \leq 10$	Cohesive Running	Flowing
	Dense, $N > 30$	Fast Raveling	Flowing
Fine Sand with Clay Binder	Loose, $N \leq 10$	Rapid Raveling	Flowing
	Dense, $N > 30$	Firm or Slowly Raveling	Slowly Raveling
Sand or Sandy Gravel with Clay Binder	Loose, $N < 10$	Rapid Raveling	Rapidly Raveling or Flowing
	Dense, $N > 30$	Firm	Firm or Slowly Raveling
Sandy Gravel and Medium to Coarse Sand		Running ground. Uniform ( $C_u < 3$ ) and loose ( $N < 10$ ) materials with round grains run much more freely than well graded ( $C_u > 6$ ) and dense ( $N > 30$ ) ones with angular grains.	Flowing conditions combined with extremely heavy discharge of water.





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**Table D-3: Soft-ground Characteristics (after British Tunneling Society, BTS, 1990)**

Ground	Description
Firm ground	Ground in which the tunnel can be advanced safely without providing direct support to the face during the normal excavation cycle and in which ground support or the lining can be installed before problematic ground movement occurs. Where this short-term stability may be attributable to the development of negative pore pressure in the fine-grained soils, significant soil movements and/or ground loading of the tunnel lining may occur later. Examples may include stiff clays and some dewatered sands. A closed-face tunneling machine may not be needed in this ground type.
Raveling ground	Ground characterized by material that tends to deteriorate with time through a process of individual particles or blocks of ground falling from the excavation surface. Examples may include glacial tills, sands and gravels. In this ground a closed-face tunneling system may be required to provide immediate support to the ground.
Running or flowing ground	Ground characterized by material such as sands, silts and gravels in the presence of water, and some highly sensitive clays that tend to flow into an excavation. Above the water table running ground may occur in granular materials such as dry sands and gravels. Below the water table a fluidized mixture of soil and water may flow as a liquid. This is referred to as running or flowing ground. Such materials can sometimes pass rapidly through small openings and may completely fill a heading in a short period of time. In all running or flowing ground types there will be considerable potential for rapid over-excavation. Hence, a closed-face tunneling system will be required to support such ground safely unless some other method of stabilization is used.
Squeezing ground	Ground in which the excavation-induced stress relief leads to ductile, plastic yield of ground into the tunnel opening. The phenomenon usually is exhibited in soft clays and stiffer clays over a more extended period of time. A closed-face machine may be required to provide resistance to squeezing ground, although in some conditions there is also a risk of the TBM shield becoming trapped.
Swelling ground	Soil characterized by a tendency to increase in volume due to absorption of water. This behavior is most likely to occur either in highly over-consolidated clay or in clays containing minerals naturally prone to significant swelling. A closed-face machine may be useful in providing resistance to swelling ground although, as with squeezing ground, there is a risk of the shield becoming trapped.
Weak rock	Weak rock may be regarded effectively as a soft-ground environment for tunneling because systems used to excavate soft-ground types may also be applied to weak rock materials such as chalk. Weak rock will often tend to be self-supporting in the short term with the result that closed face tunneling systems may not be needed. However, groundwater may be significant issue. In these instances a closed-face machine is an effective method of protecting the works against high volumes of water ingress that could also be under high hydrostatic pressure.
Hard rock	A closed-face TBM may also be deployed in normally self-supporting hard rock conditions. The main reason would be to provide protection against groundwater pressures and prevent inundation of the heading.
Mixed ground conditions	Potentially, the most difficult of situations for a closed-face tunneling system is that of having to cope with a mixture of different ground types either along the tunnel from zone to zone or sometimes from meter to meter, or within the same tunnel face. Ideally the vertical alignment would be optimized to avoid, as far as possible, a mixed ground situation, however, in urban locations the alignment may be constrained by other considerations. For changes in ground types longitudinally, a closed-face machine may have to convert from a closed-face pressurized mode to an open non-pressurized mode when working in harder ground types to avoid over stressing the machine's mechanical functions. Such a change may require some modification of the machine and the reverse once again when the alignment enters a reach of soft, potentially unstable ground. In the case of mixed ground types across the same face, the tunneling machine will almost certainly have to operate in a compromise configuration. In such cases great care will be needed to ensure that this provides effective ground control. A common problem, for example, is a face with a hard material in the bottom and running ground at the top. In this situation the TBM will generally advance slowly while cutting the hard ground but may tend to draw in the less stable material at the top leading to over-excavation of the less stable material and subsequent subsidence or settlement at the surface. Different ground types at levels above the tunnel will also be of significance. For example, in the event that over-excavation occurs, the presence of running or flowing materials at horizons above the tunnel will increase the potential quantity of ground that may be over-excavated and again lead to subsidence or surface settlement. Another potential problem occurs when a more competent layer exists over potentially running ground in which case possible over-excavation would create voids above the tunnel and below the competent material, giving rise to potential longer-term instability problems.