



March 28, 2017

## FOUNDATION INVESTIGATION AND DESIGN REPORT

**Highway 401 Structural Culvert, Site No. 21-489/C  
Structural Culverts Rehabilitation/Replacement  
Highway 35/115 and Highway 401  
Ministry of Transportation, Ontario  
G.W.P. 2186-15-00**

**Submitted to:**

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**GEOCRES No. 30M15-305  
Report Number: 1540419-3**

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REPORT





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# **PART A**

**FOUNDATION INVESTIGATION REPORT  
HIGHWAY 401 STRUCTURAL CULVERT, SITE NO. 21-489/C  
STRUCTURAL CULVERT REHABILITATION/REPLACEMENT  
HIGHWAY 35/115 AND HIGHWAY 401  
MINISTRY OF TRANSPORTATION, ONTARIO  
G.W.P. 2186-15-00**



## **1.0 INTRODUCTION**

Golder Associates Ltd. (Golder) has been retained by D.M. Wills Associates Ltd. (D.M. Wills) on behalf of Ministry of Transportation, Ontario (MTO) to provide Foundation Engineering services for the replacement of the structural culvert at Station (STA) 17+730 on Highway 401 in the Regional Municipality of Durham, Ontario (MTO Structural Site No. 21-489/C), approximately 1 km east of Holt Road in Clarington, Ontario, the location of which is shown on the Key Plan on Drawing 1.

The Terms of Reference and the Scope of Work for the foundation investigation are outlined in MTO's Request for Quotation, dated August 2015. Golder's proposal for the foundation engineering services associated with the culvert replacements is contained in Section 3.5 of D.M. Wills' Technical Proposal for this assignment. The work has been carried out in accordance with Golder's Supplementary Specialty Plan for foundation engineering services for this project, dated December 1, 2016.

This report addresses the investigation carried out for the structural culvert at about STA 17+730 on Highway 401 (MTO Structure Site No. 21-489/C) which has been identified for rehabilitation and construction of a relief culvert to the east of the existing culvert. The foundation investigation associated with the other culverts, which forms part of the Foundation assignment for this project are presented in separate reports.

## **2.0 SITE DESCRIPTION**

The existing structural culvert at Site No. 21-489/C is 92.7 m in total length, and consists of a 75 m long central section concrete box which is 4.3 m wide by 2.4 m high. The north and south extensions, which are 12.8 m and 4.9 m long, respectively, are both 4.3 m wide and 2.4 m high. The structure is located within an approximately 7.5 m to 10.5 m high fill embankment and has approximately 6.1 m of soil cover. Details of the culvert are summarized in Table 1 following the text of this report.

In general, the topography in the area of the culvert consists of a relatively flat lacustrine plain used for agricultural purposes with clusters of trees and brush present along the ditch line and Darlington Creek. The natural ground surface in the vicinity of the culvert is at about Elevation 87.0 m. The Highway 401 grade in the vicinity of the culvert is at about Elevation 94 m. The existing Highway 401 embankment consists of earth fill, with side slopes inclined at approximately 2 horizontal to 1 vertical (2H:1V). The ground surface at the borehole locations advanced for the culvert investigation, including through the existing Highway 401 embankment, varies between about Elevation 85.2 m and 94.2 m, referenced to Geodetic datum.

## **3.0 INVESTIGATION PROCEDURES**

The fieldwork for the foundation investigation associated with structural culvert Site No. 21-489/C was carried out between July 27, and September 6, 2016 in which a total of four boreholes were advanced at, or in the immediate vicinity of the culvert alignment, as shown in plan on Drawing 1.

The field investigation was carried out using a variety of drilling equipment as a result of the accessibility and restrictions associated with the terrain at the culvert site. The details of the drilling equipment and suppliers are listed below.



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Drilling Equipment	Supplied and Operated By
Truck-Mounted CME 75	Atcost Drilling Inc. of Gormley, Ontario
Track-Mounted Mini-Mole	Kodiak Drilling of Oakville, Ontario
Portable Equipment	OGS Drilling Inc. of Almonte, Ontario

The boreholes drilled by the truck-mounted CME75 drill rig were advanced through the overburden using 203 mm outer diameter (O.D.), 108 mm inner diameter (I.D.) hollow stem augers. The boreholes drilled by the track-mounted Mini-Mole rig were advanced through the overburden using 102 mm diameter solid stem augers. The boreholes completed with the portable equipment were advanced through the overburden using BQ and NQ sized casing with wash boring techniques. Soil samples were obtained continuously at some borehole locations but generally at intervals of depth of about 0.75 m and 1.5 m using a 50 mm O.D. split-spoon sampler operated by an automatic hammer on the drill rigs, performed in accordance with Standard Penetration Test (SPT) procedures (ASTM D1586<sup>1</sup>). Boreholes advanced by portable equipment employed a full-weight hammer lifted manually and dropped from the SPT height.

The results of the SPT testing as presented on the Record of Borehole sheets are uncorrected (not standardized for hammer efficiency, borehole diameter, rod length, etc.). The samplers used in the investigation limit the maximum particle size that can be sampled and tested to about 40 millimetres. Therefore particles that may exist within the soils that are larger than this dimension will not be sampled or represented in the grain size distributions. For the site stratigraphy, these larger sized particles may include cobbles and boulders.

A piezometer was installed in Borehole C3-4 to allow monitoring of the groundwater level at this site. The piezometer consists of a 25 mm diameter PVC pipe, with a slotted screen sealed within the silt and sand till deposit. The borehole and annulus surrounding the piezometer pipe above the screen and sand pack were backfilled with bentonite pellets to ground surface. The piezometer installation details and water level readings are noted on the Record of Borehole C3-4 in Appendix A. The other boreholes were backfilled with bentonite upon completion of drilling in accordance with Ontario Regulation 903 (Wells) (as amended). The groundwater conditions and water levels in the open boreholes were observed during and immediately following the drilling operations and are described on the Record of Borehole sheets in Appendix A.

The fieldwork was observed by members of Golder's engineering and technical staff, who located the boreholes, arranged for the clearance of underground services, observed the drilling, sampling and in situ testing operations, logged the boreholes, and examined the soil samples. The soil samples were identified in the field, placed in appropriate containers, labelled and transported to our Mississauga geotechnical laboratory where the samples underwent further visual examination and laboratory testing. All of the laboratory tests were carried out to MTO Laboratory and/or ASTM Standards, as appropriate. Classification testing (water content, Atterberg limits and grain size distribution) was carried out on selected soil samples. The results of the laboratory testing are summarized on the Record of Borehole sheets in Appendix A and provided in Appendix B.

A soil sample obtained during the field investigation in Borehole C3-2 at about the culvert invert elevation, using appropriate sampling protocols, was submitted to a specialist analytical laboratory under chain of custody

<sup>1</sup> ASTM D1586-11 Standard Test Method for Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils, ASTM International, West Conshohocken, PA, 2011





## FOUNDATION REPORT - STRUCTURAL CULVERT REPLACEMENT - HIGHWAY 401, SITE NO. 21-489/C

procedures for chemical analysis of conductivity / resistivity, pH and sulphate, and chloride content to assess the potential for the soil to cause corrosion to buried concrete and steel. The results of the analytical testing are discussed in Section 4.4 and are provided in Appendix C. Borehole locations were surveyed in the field relative to a fixed location on site. The as-drilled borehole locations were measured relative to existing site features and were subsequently converted into MTM NAD 83 coordinates in AutoCAD. The Geodetic elevation of the boreholes were obtained using the borehole locations and topographic information provided by D.M. Wills on January 20, 2016. The borehole locations given on the Record of Borehole sheets and shown on Drawing 1 are positioned relative to MTM NAD 83 Zone 10 northing and easting coordinates and the ground surface elevations are referenced to Geodetic datum. The borehole locations, ground surface elevations and depths drilled are as follows:

Culvert Location	Borehole	Location (m)		Ground Surface Elevation (m)	Depth of Borehole (m)
		Northing (Latitude)	Easting (Longitude)		
STA 17+730 (Town of Clarington)	C3-1	4860965.6 (-78.7102389797)	368258.7 (43.8859352057)	87.7	8.7
	C3-2	4860950.2 (-78.71013556)	368267.1 (43.8857957051)	94.2	17.2
	C3-3	4860928.8 (-78.7095213623)	368316.7 (43.8855987476)	94.0	17.0
	C3-4	4860913.3 (-78.7092701443)	368337.0 (43.8854577017 )	85.2	12.5

## 4.0 SITE GEOLOGY AND SUBSURFACE CONDITIONS

### 4.1 Regional Geology

This section of Highway 401 is located within the Iroquois Plain physiographic region, as delineated in *The Physiography of Southern Ontario*<sup>2</sup> and *Urban Geology of Canadian Cities*<sup>3</sup>. The Iroquois Plain extends around the western shores of Lake Ontario. The Plain is comprised of the flat to undulating lakebed and beaches of the former glacial Lake Iroquois, which occupied this area during the last glacial recession.

The surficial soils in this area of the Iroquois Plain are typically comprised of glaciolacustrine clays, silts and sands to gravelly sands, which are underlain by an extensive till deposit that is mapped in this area as the Bowmanville Till. Within the area approximately bounded by Holt Road and Morgan's Road, the surficial glaciolacustrine deposits are absent or of limited thickness and the Bowmanville Till unit is frequently present immediately below the ground surface. Between these limits, an extensive surficial deposit of clayey silt to silty clay is present over the Bowmanville Till (Karrow and White, 1998). More recent alluvial deposits of gravel, sand, silt and/or clay are present in the valleys associated with Bowmanville Creek, Soper Creek, Wilmot Creek and Graham Creek. The underlying bedrock surface is mapped at a depth of about 22 m at the site. The bedrock is described as limestone, dolostone, shale, arkose, sandstone of the Ottawa Group, Simcoe Group, and Shadow Lake formation.

<sup>2</sup> Chapman, L.J., and Putnam, D.F., 1984. *The Physiography of Southern Ontario*, 3rd Edition. Ontario Geological Survey, Special Volume 2. Ontario Ministry of Natural Resources.

<sup>3</sup> Karrow, P. F., and White, O. L., 1998. *Urban Geology of Canadian Cities*. Geological Association of Canada Special Paper No. 42. St. John's, Nfld.





## **4.2 General Overview of Local Subsurface Conditions**

The detailed subsurface soil and groundwater conditions as encountered in the boreholes advanced during this investigation, together with the results of the laboratory tests carried out on selected soil samples, are presented on the Record of Borehole sheets and the laboratory test sheets in Appendices A and B, respectively. The stratigraphic boundaries shown on the Record of Boreholes sheets and stratigraphic cross sections are inferred from non-continuous sampling, observations of drilling progress and in situ testing and are approximate. These boundaries, therefore, represent transitions between soil types rather than exact planes of geological change. Further, subsurface conditions will vary between and beyond the borehole locations.

The stratigraphy at the borehole locations at culvert Site No. 21-489/C consists of surficial layers of topsoil or asphalt as the roadway platform, underlain by non-cohesive and cohesive layer of embankment fill, in turn underlain by layers/deposits of hard clayey silt, firm clayey silt with sand, and pockets of loose to dense sand in places. The cohesive deposits are underlain by a till deposit which is comprised of compact to very dense silt and sand, sandy silt and silt. A detailed description of the subsurface conditions at the culvert crossing is provided in the following section of this report. Where relatively significant thicknesses of overburden were encountered, the various soil types are described in detail for each main deposit or stratum.

### **4.2.1 Asphalt**

In Boreholes C3-2 and C3-3 advanced at the Highway 401 grade, an approximately 150 mm thick layer of asphalt was encountered.

### **4.2.2 Topsoil**

A 50 mm thick layer of topsoil was encountered at ground surface in Borehole B3-1.

### **4.2.3 Embankment Fill**

Embankment fill approximately 7.8 m and 10.1 m thick was encountered below the asphalt in Boreholes C3-2 and C3-3 extending from Elevations 94.0 m and 93.8 m, respectively. The embankment fill consists of an upper granular layer approximately 0.6 m and 1.1 m thick consisting of gravelly sand to sand and gravel, and a lower cohesive layer consisting primarily of clayey silt, approximately 7.2 m and 8.9 m thick. Grinding of the augers was observed in Borehole C3-2 in the clayey silt fill at Elevations 89.9 m and 87.8 m and in the gravelly clayey silt fill between Elevations 92.5 m and 91.9 m, inferring the presence of cobbles. Our recent experience with trenchless crossings of major MTO highways suggests that there could be debris consisting of abandoned temporary works associated with the original culvert construction. This debris in the fill may consist of logs, stumps, and brush from the clearing and grubbing operations, and cobbles and/or boulders.

The SPT 'N'-values measured within the non-cohesive embankment fill generally range from 29 blows to 51 blows per 0.3 m of penetration, indicating a compact to very dense relative density. The SPT 'N'-values measured in the cohesive embankment fill range from 4 blows to 19 blows per 0.3 m of penetration, suggesting firm to very stiff consistency.

The natural water content measured on a sample of the non-cohesive embankment fill is about 7 per cent. The natural water content measured on seven samples of cohesive embankment fill ranges between about 9 and 21 per cent.



The results of grain size distribution tests completed on four samples of the fill are shown on Figure B1 in Appendix B.

Atterberg limits tests were carried out on three samples of the cohesive embankment fill. On two samples from Borehole 3-2, the tests measured a liquid limit of about 15 and 16 per cent, a plastic limit of about 11 per cent and a plasticity indices of about 4 and 5 per cent. The test results, which are plotted on a plasticity chart on Figure B2 in Appendix B, indicate that the material tested is comprised of clayey silt to silt of low plasticity. On the samples from Borehole 3-3, the test measured a liquid limit of about 31 per cent, a plastic limit of about 14 per cent and a plasticity index of about 17 percent, indicating that the material tested is a clayey silt of low plasticity as shown on Figure B2.

#### **4.2.4 Clayey Silt**

The topsoil in Borehole C3-1 is underlain at Elevation 87.6 m by a 2.8 m thick layer of clayey silt to sandy clayey silt containing trace organics. A gravel layer was encountered near the bottom of the deposit at approximate Elevation 85 m.

The SPT 'N' values measured within the clayey silt deposit range between 8 and 98 blows per 0.3 metres suggesting a firm to hard consistency.

The natural water content measured on a sample of the clayey silt deposit is 10 per cent.

An Atterberg limit test was also carried out on a sample of the clayey silt deposit and measured a liquid limit of about 34 per cent, a plastic limit of 19 per cent and a plasticity index of 15 per cent indicating a clayey silt of low plasticity, as presented on Figure B3 in Appendix B.

#### **4.2.5 Silty Sand**

A 2.3 m thick layer of silty sand was encountered at the ground surface in Borehole C3-4. The measured SPT 'N' values within the silty sand deposit range from 7 to 31 blows per 0.3 m indicating a loose to dense relative density. The silty sand deposit is classified as non-plastic based on the results of an Atterberg Limit test on the sample tested. The water content of the Atterberg Limits tested sample is 18 per cent. The result of a grain size analyses carried out on a sample of silty sand is presented on Figure B4.

#### **4.2.6 Clayey Silt with Sand**

A 0.8 m thick deposit of clayey silt with sand containing trace organics was encountered in Boreholes C3-1 and C3-2 at Elevations 84.8 m and 86.3 m. The deposit in Borehole C3-1 is gravelly.

The SPT 'N'-values measured within the clayey silt with sand deposit are 8 blows and 9 blows per 0.3 m of penetration, suggesting a stiff consistency.

The natural water content measured on a sample of the clayey silt with sand deposit is about 11 per cent.

The result of a grain size distribution test completed on a sample of the deposit is shown on Figure B5 in Appendix B.

An Atterberg limits test was carried out on a sample of the cohesive deposit in C3-1 and measured a liquid limit of about 19 per cent, a plastic limit of about 12 per cent and a plasticity index of about 7 per cent. The test result,



which is plotted on a plasticity chart on Figure B6 in Appendix B, indicate that the material tested is a clayey silt of low plasticity.

#### **4.2.7 Sand**

A 0.9 m and 0.7 m thick layer of sand was encountered below the clayey silt with sand deposit in Borehole C3-2 at Elevation 85.5 m, and below the silt and sand till deposit (discussed below) in Borehole C3-1 at Elevation 79.7 m. Borehole C3-1 was terminated in the sand deposit.

SPT 'N'-values measured in the sand layers are 67 blows and 109 blows per 0.3 m, in the respectively boreholes, indicating a very dense relative density.

The natural water content measured on a sample of the sand layer in Borehole C3-1 is about 11 per cent.

#### **4.2.8 Silt to Silt and Sand Till**

A glacial till deposit consisting primarily of silt and sand was encountered below the clayey silt, sand, fill and silty sand deposits/layers described above in all boreholes between about Elevations 84.6 m and 82.9 m. The silt and sand till deposit also encompasses materials described as gravelly sandy silt, silty sand and silt. The silt and sand till deposit is 4.3 m thick in Borehole C3-1, and in the remaining boreholes the deposit was penetrated to thicknesses ranging between 6.8 m to 10.2 m and terminated within the deposit. Although cobbles and boulders were not specifically encountered within the silt and sand till at the borehole locations, their presence should be anticipated given the depositional history of the glacial till, and as inferred by auger grinding within the gravelly sandy silt till deposit in Borehole C3-1, within the silt and sand to silty sand till deposit in Borehole C3-2 and within the silt and sand till in Borehole C3-4, at various depths.

The SPT 'N'-values measured within the silt and sand till deposit range between 25 blows and 117 blows per 0.3 m of penetration, and numerous 'N'-values greater than 100 blows for less than 0.3 m of penetration, indicating a compact to very dense relative density. .

The natural water content measured on thirteen samples of the silt and sand till deposit range between about 5 per cent and 12 per cent.

The results of grain size distribution tests completed on five samples of the silt and sand portion of the till deposit are shown on Figure B7 in Appendix B.

Atterberg limits tests were carried out on five samples of the silt and sand till and silt till portion of the deposit. Four of the samples measured liquid limits between about 11 per cent and 12 per cent, plastic limits between about 10 per cent and 11 per cent and plasticity indices between about 1 per cent and 2 per cent. The test results, which are plotted on a plasticity chart on Figures B8 and B9 in Appendix B, indicate that the fines portion of the material tested is silt of slight plasticity. One test on a sample from Borehole C3-2 of the silt and sand till portion of the deposit indicates the material as being non-plastic.

### **4.3 Groundwater Conditions**

The groundwater level in Borehole C3-1 was not established due to the use of wash-boring techniques to advance the borehole. The groundwater level was measured in the remaining boreholes upon completion of drilling operations at depths between 4.6 m and 12.2 m below ground surface, at between Elevations 84.9 m and 80.6 m.



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However, the water level observed in the open boreholes during and/or upon completion of drilling may not represent the longer-term, stabilized groundwater level at the site.

A standpipe piezometer was installed in Borehole C3-4 on the south side of Highway 401. The observed groundwater level in the monitoring well is shown on the Record of Borehole sheets and is summarized below.

Borehole	Depth to Water Level (m)	Groundwater Elevation (m)	Date of Measurement
C3-4	4.6	80.6	On Completion (July 27, 2016)
	0.5	84.7	March 28, 2017

The water level at the site is expected to fluctuate seasonally in response to changes in precipitation and snow melt, and is expected to be higher during the spring and periods of precipitation.

### 4.4 Analytical Testing of Soil Sample

Analytical testing was carried out on a composite soil sample constituted from Samples 8 to 10 from Borehole C3-2, from depths between 7.9 m and 10.7 m below ground surface (between Elevations 86.3 m and 83.5 m). The testing was carried out to assess the corrosivity and concrete degradation potential of the soils against the new culvert structure. The analytical test results from the specialist analytical laboratory are presented in Appendix C and are summarized below.

Parameter	Test Results
Soil Resistivity	1300 ohm-cm
Soil Conductivity	798 $\mu$ mho/cm
Sulphate Concentration	<20 $\mu$ g/g
Chloride Concentration	410 $\mu$ g/g
Soil pH	7.63

## 5.0 CLOSURE

Messrs. Pat Speirs and Michael Bentley, supervised the borehole investigation program. This report was prepared by Ms. Amelia Jewiston, B.A.Sc., and was reviewed by Ms. Dirka U. Prout, P.Eng., a senior geotechnical engineer with Golder. Mr. Jorge M.A. Costa, P.Eng., a Senior Consultant with Golder and Designated MTO Contact conducted an independent quality control review of this report.



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### Report Signature Page

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## **PART B**

**FOUNDATION INVESTIGATION REPORT  
Highway 401 STRUCTURAL CULVERT, SITE NO. 21-489/C  
STRUCTURAL CULVERT REHABILITATION/REPLACEMENT –  
HIGHWAY 35/115 AND HIGHWAY 401  
MINISTRY OF TRANSPORTATION, ONTARIO G.W.P. 2186-15-00**





## **6.0 DISCUSSION AND ENGINEERING RECOMMENDATIONS**

This section of the report provides foundation design recommendations for installation of a new relief culvert and retaining walls for the structural culvert (C-3) at STA 17+730 on Highway 401 in the Municipality of Clarington, Ontario (MTO Structural Site No. 21-489/C). The existing structural culvert is a 92.7 m long, 4.3 m wide by 2.4 m high concrete box culvert. It consists of a 75.02 m long central section with north and south extensions which are 4.8 m and 12.8 m long, respectively. There are gabion walls at the inlet and outlet of the existing culvert.

The current design, based on direction provided at the 60% executive meeting, requires the construction on of a new relief culvert using trenchless techniques adjacent to the existing culvert to meet hydraulic needs. The relief culvert will be offset from the existing culvert by 1 m. The existing culvert is to be rehabilitated with insertion of a new 3.25 by 2.1 m structural plate corrugated steel pipe arch, which will be grouted into the existing culvert. The skewed portion of the existing south culvert extension will be removed along with an existing section of gabion wall near the outlet of the new culvert. A new headwall and retaining wall will be constructed at the outlet. An existing gabion wall at the inlet will be replaced with a new Retained Soil System (RSS) wall.

The foundation investigation and design report with the interpretation and recommendations are intended for the use of the Ministry of Transportation, and shall not be used or relied upon for any other purposes or by any other parties including the construction or design-build contractor. The contractor must make their own interpretation based on the factual data in Part A of the report. Where comments are made on construction, they are provided in order to highlight those aspects that could affect the design of the project. Contractors must make their own interpretation of the factual information provided as it may affect equipment selection, proposed construction methods and scheduling.

This report addresses potential construction concerns and geotechnical problems associated with installation of the replacement culvert by means of a trenchless method. It also provides foundations engineering recommendations for the new retaining walls proposed for the inlet and outlet areas.

Based on the General Arrangement (GA) drawings provided by D.M. Wills on November 24, 2016, the proposed relief culvert will be a 3050 mm diameter pipe, installed with upstream and downstream invert at about Elevations 85.22 m and 84.16 m, respectively, which is about 0.2 m lower than the existing culvert. The currently proposed design indicates that the additional culvert will be installed about 1 m away from the existing culvert. Golder understands that the separation distance was based on space restrictions and hydraulic considerations. There is an increased risk of striking the existing culvert during construction because of this small separation distance depending on the selected means and methods. From a geotechnical perspective, the proposed minimum separation distance of 1 m is acceptable given the potential use of trenchless methods that have relatively high accuracy with respect to line and grade.

The contractor should be fully responsible for the selection of a trenchless technology which best fits the contract requirements and subsurface conditions. All trenchless work should be carried out in accordance with MTO's non-standard special provisions (NSSP), titled "Pipe Installation by Trenchless Method" dated December 2014, a copy of which is included in Appendix D, as modified by the recommendations provided in this report and by an experienced specialist contractor employing only qualified workers skilled in their trade under the direction of an experienced foreman. The work plan should include a provision for grouting around the outside of any temporary or permanent ground support systems should the need arise. It is recommended that the geotechnical aspects of the contractor's work plan for the trenchless undercrossing be reviewed by a qualified geotechnical engineer prior to construction.



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In general, when crossing beneath highways, trenchless operations should be carried out continuously (i.e. 24 hours per day) from the start until the installation is complete. Continuous operations assist with minimizing risks of equipment becoming bound in the excavation by time-dependent increases in friction and/or adhesion, uncontrolled ground losses, and other critical problems that may occur while the work area is unattended. Recommendations specific to the methodologies appropriate for this site are provided in the following report sections.

### 6.1 Consequence and Site Understanding Classification

In accordance with Section 6.5 of the Canadian Highway Bridge Design Code (CHBDC 2014) and its Commentary, a classification of 'typical' consequence has been assumed for the proposed replacement culvert section and foundation system. This consequence classification should be confirmed by D.M. Wills and the MTO.

The degree of understanding based on the scope of the foundation investigation and proximity of the boreholes to the culvert is considered 'typical' as described in Clause 6.5.3.2 of the 2014 CHBDC. The appropriate Ultimate Limit States (ULS) and Serviceability Limits (SLS) consequence factor  $\Psi$ , geotechnical resistance factors at ULS ( $\phi_{gu}$ ) and SLS ( $\phi_{gs}$ ), respectively from Tables 6.1 and 6.2 of the CHBDC have been used for design.

### 6.2 Anticipated Ground Conditions

Progressing from south to north, the subsurface conditions encountered along the proposed alignment generally consist of firm to very stiff clayey silt fill then transition to a mixed face with firm clayey silt fill above the springline and firm to stiff clayey silt with sand and very dense sand below the springline. At the inlet and below the north embankment sideslope, stiff to hard clayey silt is expected within the tunnel face. The invert of the proposed relief culvert will be at the interface of the embankment fill and native soils along most of the alignment. In particular, the invert will be within 1 m of the surface of the very dense sand and silt and sand till at approximate elevation 84 to 85 m. These glacial till at this elevation is significantly denser than the overlying fill and native materials.

The presence of cobbles and boulders in the fill and glacial till has been inferred from auger resistance/grinding encountered in the boreholes. In addition to cobbles and boulders in the fill, there is the potential for encountering debris in the fill as noted in Sections 4.2 and 6.3. Generally, the groundwater level along the tunnel profile is at or below the culvert invert, ranging between about Elevations 85 m and 81.0 m.

The behavior of the subsurface materials as described above can be classified using Terzaghi's Tunnelman's Ground Classification system as modified by Heuer (1974). The behavior of the materials within the tunnel alignment is summarized as follows:

Material	Tunnelman's Ground Classification	
	Above Groundwater Level	Below Groundwater Level
Fill (Clayey Silt)	Firm	Firm
Clayey Silt with Sand	Firm to Slow Ravelling	Fast ravelling
Sand	Slow ravelling	Cohesive running
Clayey Silt	Firm	Firm
Glacial Till (Silt, Sandy Silt, Silt and Sand and Silty Sand)	Slow ravelling	Fast ravelling



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Stand-up time would be range from a few hours to a day for the clayey silt fill, clayey silt and native silty clay and glacial till deposits. Depending on the relative density, the sands will stand for less than 1 hour to a few hours above the groundwater level or if properly dewatered. In the absence of proper ground support, the sands would run or flow with no stand-up time below the groundwater level.

Trenchless installations will be primarily affected by five factors associated with the subsurface and groundwater conditions, namely:

- The nature of the embankment fill: Fill along the alignment is anticipated to be cohesive and favourable for most types of trenchless technologies.
- Buried obstructions: Cobbles are inferred to be present within the fill based on auger resistance encountered when advancing the boreholes. Golder's experience with culvert replacements below MTO highways suggests that there could be debris consisting of abandoned temporary works associated with the original construction; logs, stumps and brush from previous clearing and grubbing operations and cobbles and boulders buried in the fill. Such obstructions have the potential to damage/clog/obstruct machinery and halt trenchless operations, particularly if there is no person-access to the excavation face to clear the obstruction.
- Mixed Face Tunnelling: Generally the vertical alignment will encounter either a full face of generally firm to very stiff cohesive fill or a mixed face with firm cohesive fill or firm to hard silty clay above the springline and firm to stiff clayey silt with sand below the springline. The proposed invert will be along the surface of the very dense glacial till which contains cobbles and boulders. In addition to the potential for encountering obstructions buried in the fill, the selected trenchless methodology must be adaptable to varying subsurface conditions which can change from firm in the cohesive fills and native deposits to cohesive running or ravelling in the sand, clayey silt with sand and glacial till. The selected methods and equipment must provide sufficient face support for the granular materials. In general, the native materials near the invert are denser/harder than the overlying fill. There is the potential for the casing/pipe to ride-up on the more resistant materials near the invert and into the softer (firm to stiff) overlying fills.
- Presence of cobbles and boulders: Cobbles and boulders should be anticipated in the fill and glacial deposits, as inferred from auger grinding observations and high SPT N-values at Boreholes C3-1 to C3-4. The advance of microtunnelling tunnel boring machines (TBMs) and jack and bore equipment can be hindered if not fully obstructed by cobble nest or boulders. The diameter of the proposed replacement culvert at this site is such that person entry for removal of obstructions is possible depending on the selected means and methods.
- Groundwater: This groundwater condition is favourable since it permits a wider range of trenchless methodologies to be used. However, those trenchless technologies/methods that do not provide effective face support to prevent ravelling, flowing or running of the native granular materials should be prohibited.

The Contract Documents should contain a NSSP warning the contractor of obstructions within the fills and glacial till and the difficulties associated with tunneling along the interface of the embankment fill underlying native soils, an example NSSP is provided in Appendix D.



## **6.3 Review of Trenchless Construction Methods**

Several methodologies were considered for execution of this crossing: horizontal auger boring (jacking-and-boring), pipe ramming, microtunnelling, hand mining or mechanically-assisted excavation within a shield with jacked pipe or steel liner plate or steel ribs and lagging, and conventional tunnelling with tunnel boring machine (TBM).

### **6.3.1 Jack-and-Bore**

Jack-and-bore involves forming a horizontal borehole through the ground from a drive shaft to an exit shaft by means of a rotating cutting head. The cutting head is attached to continuous-flight helical augers within a casing which transports spoils from the face to the drive shaft. The proposed pipe is larger than the maximum size of pipe that can be installed by jack-and-bore equipment and as such, this method is considered unsuitable and should be prohibited from use at this site.

### **6.3.2 Pipe Ramming**

Pipe ramming involves the use of a steel casing, inserted from a launch pit, and driven by a pneumatic percussion hammer or a hydraulic jacking system. The leading edge or head of the initial steel casing is fitted with a cutting shoe/band to reinforce pipe for open-face pipe ramming and reduce friction by creating a slight overcut. As the casing advances towards the exit pit, additional lengths of steel casing are welded on to the preceding piece. Bentonite or polymer lubricants may be used to facilitate advancement of the casing where the soil conditions dictate. The material within the casing is removed by augering after the casing is installed. The accuracy of the line and grade are comparable to the jack-and-bore method.

As noted above for a jack-and-bore installation, there are very few pipe ramming contractors in Ontario capable of installing 3.05 m diameter pipe or who possess large-scale ramming equipment (greater than 2 m in diameter). Since the length of the new culvert is approaching the upper limit of a typical pipe ramming operation, and given the subsurface conditions, use of pipe ramming is not considered practical for this site.

### **6.3.3 Microtunnelling**

Microtunnelling is a guided pipejacking process which uses a remotely controlled tunnelling machine to provide continuous support to the excavation face. It relies on a horizontal jacking force applied to the pipe to propel the remotely controlled microtunnel boring machine (MTBM) along with the pipe string through the ground. The pipe is typically installed while the bore is being advanced and serves both as temporary ground support and the final culvert. Specially designed jacking pipe made from steel, glass fibre reinforced plastic (GFRP) or reinforced concrete, and capable of transferring the jacking forces from the jacking reaction frame in the shaft to the MTBM, will be required. Entry and receiving shafts are required for microtunnelling operations. Dewatering will be required only at the shafts since most MTBMs can operate in saturated soils below the groundwater level. Microtunnelling is typically able to maintain high accuracy ( $\pm 25\text{mm}$ ) with line and grade control.

A slurry MTBM has a full-face rotating cutting head with openings through which the spoil enters a pressurized slurry chamber behind the head. The slurry is used to balance the hydrostatic pressure and convey suspended cuttings away from the face. Typically, MTBMs are ill-equipped to crushing or cutting boulders once they enter the machine even though some models have a crusher chamber which breaks down obstructions to a size which can be pumped with the cuttings. However, the volume, diameter or numbers of the cobbles and boulders may be such that the capacity of the crusher could be exceeded resulting in either abandonment of the bore or advancement of a rescue shaft to remove the obstructions and permit resumption of tunnelling. Typically, the best approach to penetrating ground that contains cobbles and boulders includes use of a combination of rock disc



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cutters and soft ground excavation tools on the MTBM face, relatively small face openings and an internal crushing chamber to further process the cut rock chips. If woody debris is encountered in the fill, it will likely clog the machine, also necessitating a rescue shaft and possibly repairs. The MTBM should be equipped for mixed face conditions. The selected cutting tools and methods should be compatible with variable ground conditions, including cobbles and boulders and layers of granular materials. Properly selected rock cutter discs should be used to cut the glacial tills and break cobbles and boulders at the face into smaller enough fragments to pass through the apertures in the face. Only closed-face machines equipped with rock cutters and a crusher changer should be used at this site. In addition to cobbles and boulders, the Contractor's work plan should include a method of dealing with debris in the fill materials.

An overcut will be required to: reduce frictional forces along the pipe string; reduce jacking forces; and facilitate steering. The overcut should be minimized by selection of an excavated diameter which results in an annular space between the excavated hole and outer diameter of the jacking pipe no greater than 40 mm. The annulus between the outside of the pipe and the ground should be immediately filled with bentonite slurry of an appropriate viscosity using lubrication ports in the pipes installed at regular intervals.

Care during operation is required to maintain adequate support at the face of the MTBM especially in granular deposits found near the proposed culvert invert in Boreholes C3-2 and C3-4. There is the potential for loss of the slurry away from the machine face when the MTBM is transiting through the sand and clayey silt with sand. The bentonite based slurry should be appropriately formulated, using suitable polymers and additives if necessary for the anticipated ground conditions to prevent fluid loss and maintain a stable ground condition at the face and around the MTBM. When installing the culvert in the sand deposit, the slurry should be sufficiently viscous to create a "filter-cake" to support the granular material. A seal will be required to close the annular space between the wall of the entry/exit shaft and the shield and pipes to retain soil behind the temporary shoring and stop backflow of the slurry into the pits.

The fill along the tunnel alignment is generally softer than the native deposits at and below the invert. Noting that the fill deposit and glacial till contain cobbles and boulders, the Contractor should be prepared for steering difficulties, deflection of the machine and increased wear or damage to the cutters or cutter housings due to high impact forces.

Person-entry to remove obstructions is generally not feasible for most MTBMs. It is possible that MTBMs of this size may permit person-entry depending on the machine configuration. Machines which are equipped with an additional door behind the cutterhead in order to change face tools or remove obstructions that is accessed through and air lock are preferred. It should be noted that 3 m is close to the upper limit of maximum diameter of a MTBM of 3.5 m. As such, there may be few contractors with this size of machine in Ontario.

Even if equipped with a crusher chamber and rock cutting tools, the MTBM will be stopped by boulders greater than one third of the diameter. Given the potential for encountering obstructions in the embankment fill and glacial till, there is a high to very high risk of these obstructions either impeding or halting the machine. This would result in the need to excavate a rescue shaft to free the machine resulting in lane closures and traffic disruptions. For this reasons, a microtunnelling installation at this site is considered to be only marginally feasible.

### 6.3.4 Hand or Mechanically-Assisted Mining

Hand mining or mechanically assisted excavation within a shield with jacked pipe, steel liner plate, or steel ribs and lagging is considered a feasible method for the culvert installation. In this method, the tunnelling process is carried out by removing excavated soil from the front cutting face and installing a liner to form a continuous ground





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support structure. The liner may be installed using a two-pass system or a single pass where the culvert pipe is jacked in during excavation and provides both temporary and permanent support. With a two-pass system, a conduit is installed between the entry and exit shaft by first installing a segmental temporary or primary liner. Once the full length of the primary liner has been constructed, a permanent or secondary liner is installed. The primary liner may consist of steel ribs and wooden lagging or steel liner plates. The secondary liner is typically of cast-in-place concrete construction but may be a smaller primary conduit (carrier) pipe of any suitable material. If the carrier pipe option is used, the annulus between the primary and secondary liners is grouted. The soil may be excavated using hand mining techniques and shields that include the capability of closing the face with breasting boards, plates or mechanical systems. The most economical option would be to install the culvert in a single pass using a steel pipe. Higher costs would be incurred for concrete pipes and two-pass systems.

In hand mining, excavation is conducted at the face using picks, shovels, or pneumatic hand held tools. Using conventional tunnelling or pipe jacking techniques, a protective shield, which may have a forward hood projection to provide additional face stability during soil excavation is usually required. If an articulated shield is used, line and grade corrections can be accomplished by activating the hydraulic propulsion cylinders. In a fixed shield, minor line and grade changes are accomplished by differential excavation in the desired direction.

Mechanically-assisted excavation is accomplished by using special shields equipped with power excavation devices. Such soil cutting devices can be rotary cutter booms mounted on the front of the shield, modified hydraulic backhoes (mini-diggers), or rotary boom cutters. The soil excavation rate of open-face mechanical excavation is much faster than that of hand mining. Due to the large diameter of this culvert, mechanically-assisted excavation will be necessary.

This method is adaptable to variable conditions along the culvert alignment. Dewatering at the entry and receiving shafts will likely be required. Due to the potential presence of sand and sandy layers at and near the invert level which may be saturated, the Contractor's selected equipment and methods must provide effective control of the stability of the face soils. Fore-piling or spiles driven into the ground ahead of the face will be necessary improve support for the tunnel crown. Use of a hooded shield where the top of the shield extends beyond the invert by providing an angled profile to the leading edge of about 60 degrees from the horizontal is recommended. This angle must be measured from the top of the shield to the invert. Since the tunnel will be advanced through granular materials with a loose zone near the outlet, the shield should have doors which can close off the entire face and retractable breast plates or horizontal bench plates to provide face support in these areas. Since the tunnel diameter is large, diaphragm stiffeners, which permit portions of the face to be sectioned off and allows work to proceed in the unblocked areas may also be used when advancing through the mixed face of clayey fill and loose native sand and clayey silt with sand.

The sand and glacial till deposits within approximately 1 m of the invert are expected to be partially saturated to saturated. It may be necessary to use horizontal lances/pipes or well points to control groundwater and prevent ground loss in these areas.

Over-excavation can lead to ground losses. The overcut should be limited to a maximum of 15 mm within the granular materials and 25 mm in the cohesive soils. It is important that care be taken with the installation of the liner in order to minimize settlements.

The materials along the proposed alignment are variable in texture and consistency/relative density. In addition, the alignment will proceed along the interface between the embankment fill and native materials. As such, the jacking forces will be variable and high jacking pressures and difficulty maintaining line and grade may be experienced when transiting through hard/very dense glacial tills along the invert, particularly if cobble nests or





boulders are present. For each separate jack, it will be necessary to use varying hydraulic pressures and travel movements to improve or correct steering.

Lubricants should be used where high jacking pressures are encountered. The use of bentonite based lubricants is recommended due to the predominance of granular and low plasticity cohesive materials. The spacing and number of grout ports should be optimized to result in even distribution of lubricant over the entire length of pipe and facilitate post-installation grouting of the annulus, if necessary.

Face access facilitates removal of cobbles, boulders and obstructions in the fill if encountered. The appropriate health and safety precautions associated with confined spaces as outlined in the current Ontario Regulation 213 in the Occupational Health and Safety Act (OSHA) must be observed by the contractor.

### **6.3.5 Conventional Tunnelling**

Depending on the selected equipment, it might be possible to the culvert using a tunnel boring machine (TBM). Since the ground conditions require continual support of the face, only closed-face tunnelling TBMs that provide support to the face to balance hydrostatic and earth pressures should be employed. Dewatering will be required at the entry and receiving shafts.

Depending on the contractor's available equipment and experience, the size of this installation allows for small diameter conventional (man-entry) TBMs to be used. In this case, face control and cuttings transport may be accomplished using "earth pressure balance" (EPB) technologies in which discharge from the chamber is controlled by pressure relieving gates or doors that open at pre-set pressures or loads. Another system uses a screw conveyor to remove materials from the chamber at rates that maintain specified pressures within much of the excavated chamber. Because of the potential for encountering cobbles, boulders and other obstructions, EPB TBMs that use screw conveyors should be avoided. While face pressures with the older relieving gate EPB systems are not as controlled as with screw conveyor systems, the combination of face opening sizes and relieving gate opening size allows for passage of cobbles, boulders, and smaller debris without clogging or damaging the machine and, providing flowing ground is controlled, can allow access to the face to remove larger obstructions. Some TBM systems are promoted as being "earth pressure balance" when they do not actually achieve the goals of the EPB technology. Such unacceptable systems rely only on doors that close the face or rely on jacking forces being transmitted to the steel sections of the machine face where this is then interpreted as "face pressure." Such systems should be prohibited for this project since they could result in significant ground losses and the consequential safety risks and claims. Also, older TBMs that do not include a secondary bulkhead and controlled muck discharge system should be prohibited for this project.

The machine should be equipped with disc cutters (as well as soft ground spade, drag bits and picks) to handle glacial till soils containing cobbles and boulders. The contractor should be prepared to deal with obstructions in the fill, sand and glacial till deposits.

Face stability should be constantly monitored. Over-excavation above or ahead of the TBM and lining should be avoided to maintain face stability. The overcut should be minimized by selection of a casing diameter which is similar to that of the TBM. Face pressure should be selected and maintained at values no less than the active earth pressure at the tunnel vertical centreline. If over excavation or ground losses occur, the annulus between the outside of the pipe and the ground and any voids at the face should be immediately filled with bentonite slurry of an appropriate viscosity and/or low strength grout.



The selected equipment, face tooling and methods must be able to adapt to changing ground conditions which include the presence of flowing, running or ravelling granular materials. Alignment may be affected by the presence of soils containing cobbles and boulders along the invert that are stiffer/denser than the materials near the invert.

## **6.4 Comparison of Tunneling Methods**

Trenchless construction methods described in Section 6.4 include various advantages and disadvantages depending on soil conditions, depth of cover, vertical and horizontal alignment, length of pipe installation, cost and availability of equipment, and carry varying levels of risk of successfully completing the installation. The advantages, disadvantages and relative costs and risks are compared in Table 2, following the text of this report.

Jack-and-bore and pipe ramming are not feasible due to the pipe diameter and length. Microtunnelling is marginally feasible since the MTBM may be stopped by woody debris in the fill or cobble nest or boulders that are greater than one third of the machine diameter. The most feasible methods of installing the relief culvert are hand mining or mechanically assisted excavation within a shield and, to a lesser degree conventional tunneling with an appropriately designed and operated TBM that is selected recognizing the risks of obstructions along the alignment. These two methods are less risky than microtunnelling since person-entry is possible to facilitate removal of obstructions.

## **6.5 Entry / Exit Shafts – Temporary Excavation and Groundwater Control**

The trenchless methods under consideration require entry and exit pits as part of the tunnel installation. Temporary excavations may be carried out using open cut methods. All excavation work should be carried out in accordance with the Occupational Health and Safety Act and Regulations (OSHA), with local regulations and as outlined in OPSS 902 (Excavating and Backfilling – Structures). The cohesive fill, silty sand and clayey silt with sand (properly dewatered or above the groundwater level) are classified as Type 3 soils. The native glacial till and sand if properly dewatered are considered Type 2 soils. The saturated silty sand would be a Type 4 material.

Excavations at the pits are expected to proceed below the inferred groundwater level of Elevation 85 m. Dewatering will be required at the entry and exit pits. The clayey silt with sand and silty sand at the entry and exit pit locations may be saturated. However since these deposits are limited in thickness and underlain by relatively low permeability sandy silt to silt and sand till, it may be difficult to effectively dewater these deposits particularly within 0.5 m of the sand/till interface. In this situation, it may be necessary to use closely spaced sumps (on the order of 5 m or less) around the perimeter of the excavation in order to effectively control the groundwater. It may be necessary to use well points, eductors or the like for the saturated granular till. The groundwater level should be lowered to at least 0.5 m below the base of the pit. The excavations should be protected from ingress of surface water. The appropriate NSSP should be included in the Contract Documents to alert the Contractor for the need for effective dewatering and control of surface water; an example NSSP is included in Appendix D. Provided proper groundwater control is in place, conventional temporary type open cuts may be developed with side slopes not steeper than 1 horizontal to 1 vertical (1H:1V) in these materials. Stockpiles of excavated material should be set back from the edge of the excavation by a distance at least equal to the excavation depth. Cobbles may be encountered within the embankment fill and native glacial till.

The entry and exit pits will be located near the toes of the highway embankment and must be designed to provide continuous support to preserve the stability of the embankment side slopes. Depending on the topography at the embankment toe, construction of a fully enclosed shaft may not be possible. If the culvert is to be installed using



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microtunnelling or pipe jacking, it would be necessary to incorporate a stand-alone reaction frame that includes ground anchors for initial launching of machine or shield tunnelling. The reaction frame or thrust block must be designed to accommodate the high jacking forces required to push the pipe segments through the ground for the entire length of the alignment if jacking is to be used.

The base of all entry/exit shafts should be designed to the loading associated with the weight of the pipe and selected tunneling equipment. It should be covered with a geotextile (such as an OPSS 1860 (Geotextiles) Class II with a Fabric Opening Size (FOS) less than or equal to 212  $\mu\text{m}$ ), a minimum 300 millimetre thick layer of OPSS.PROV 1010 (Aggregates) Granular 'A' or Granular 'B' Type II material and a 100 millimetre thick concrete working slab, with concrete having a 28-day compressive strength not less than 20 MPa.

The shafts could be constructed using soldier piles and lagging or a slide rail system provided that groundwater control systems are fully operational and demonstrated to be effective prior to excavation to installing lagging or working below the edge of slide rail panels. Due to the presence of very dense/hard glacial till as well as cobbles and boulders it would be difficult to install sheet piles. Steel H-piles for soldier piles should be installed in pre-drilled holes. The use of trench boxes and any system which does not provide continuous support to the excavation walls should be prohibited. An NSSP should be added to the Contract Documents which alerts the Contractor to the need for shoring systems to both provide continuous support to the excavation wall and maintain the stability of the embankment; an example NSSP is included in Appendix D.

The temporary excavation support system should be designed and constructed in accordance with OPSS.PROV 539 (Temporary Protection Systems). The lateral movement of the temporary shoring system should meet Performance Level 2 as specified in OPSS.PROV 539.

The design of internally braced soldier pile and lagging walls or other temporary support systems is the responsibility of the contractor. For design considerations, the system design should be based on trapezoid-shaped apparent earth pressure distributions using the design parameters given below. Where the support to the wall is provided by anchors or rakers, the wall design should be based on conventional active and passive earth pressure distributions using the design parameters given below. The internal bracing or raker/anchor supports must be designed to accommodate the loads applied from earth pressures and surcharge pressures from area, line or point loads as well as the effects of sloping ground behind the system. Passive toe restraint to the soldier piles may be determined using conventional passive earth pressure distribution acting over an equivalent width equal to three times the soldier pile socket diameter provided that the soldier piles are separated by more than three times the socket diameter.

For granular fill, the unfactored trapezoidal earth pressure distribution ( $p$  in  $\text{kN/m}^2$ ; constant with depth), can be calculated as follows:

$$p = 0.3\gamma H_T + q$$

where  $H_T$  = the total height (depth) of the excavation (in m)

$\gamma$  = soil unit weight (in  $\text{kN/m}^3$ )

$q$  = surcharge for traffic and other loading (in  $\text{kN/m}^2$ )

The earth pressure coefficients noted above are based on a horizontal surface adjacent to the excavation. If sloped surfaces are present, the coefficients should be adjusted accordingly. The above pressure distributions are the minimum pressures for the ultimate stress condition. A stiffer design may be required than predicted by these distributions in order to maintain displacements within an acceptable range.



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For cantilevered walls, the unfactored triangular earth pressure distribution ( $p$  in  $\text{kN/m}^2$ ; increasing with depth), can be calculated as follows:

$$p = K_a (\gamma H - u + q)$$

where  $K_a$  = active coefficient of earth pressure

$\gamma$  = soil unit weight (in  $\text{kN/m}^3$ )

$H$  = the height of the excavation at any point (in m)

$u$  = porewater pressure (in  $\text{kN/m}^2$ )

$q$  = surcharge for traffic and other loading (in  $\text{kN/m}^2$ )

As noted above, the selection and design of the protection system is the responsibility of the Contractor. The support systems may be designed using the following parameters:

Soil Type	Coefficient of Lateral Earth Pressure			Internal Angle of Friction (Degrees)	Unit Weight ( $\text{kN/m}^3$ )
	Active, $K_a$	At Rest, $K_o$	Passive, $K_p$		
Clayey Silt (Fill)	0.36	0.53	2.8	28	19.0
Clayey Silt with Sand	0.35	0.52	2.9	29	19.5
Silt, Sandy Silt, Silty Sand, Sand and Sand (Till) and Sand	0.27	0.43	3.7	35	22.0

The earth pressure coefficients noted above are based on a horizontal surface adjacent to the excavation. If sloped surfaces are present, the coefficient should be adjusted accordingly. A stiffer design may be required than predicted by these distributions in order to maintain displacement within an acceptable range.

## 6.6 Settlement Estimates and Monitoring

### 6.6.1 Settlement

Settlement above tunneled or trenchless installations are typically described as exhibiting the shape of an inverted normal probability distribution curve ("bell curve") with the maximum settlement at the centreline of the trenchless installation, tapering to near zero at some distance from the centreline. The ground surface settlement troughs above the culvert pipe are estimated to extend about 8 m on each side of its alignment for the proposed 3.05 m diameter culvert. The estimated ground surface/pavement settlement directly above the replacement culvert is expected to be about 15 millimetres assuming 2% volume loss. The estimated settlements assume that the tunnelling method and equipment are properly selected with good quality work carried out by an experienced contractor. Settlement monitoring of the Highway 401 undercrossing should be carried out prior to, during and after the trenchless installation to assess any effects of the work on the highway. In addition, the undercrossing construction should be independently monitored by qualified geotechnical personnel.



### **6.6.2 Instrumentation**

Consistent with MTO requirements, a monitoring program utilizing a combination of settlement monitors/points consisting of settlement points (SP) and surface settlement markers (SSM) is recommended. The standard MTO requirements have been slightly modified to minimize the requirements for lane closures during monitoring after the initial installation of the monitoring points. The SSM monitoring points could consist of hexagonal head bolts embedded in the pavement and marked with paint and/or flagging tape provided the bolts and flagging do not adversely affect traffic safety and the surveying can be carried out with sufficient precision ( $\pm 2$  mm). The proposed locations of the settlement monitoring points and installation details are shown on Drawing 2.

A total of 24 surface settlement markers (SSMs) and 4 settlement points (SPs) should be installed to measure settlement. The SSMs should be positioned on the culvert centre line and offset 3.0 metres from the centreline in both directions and be arranged in eight arrays oriented perpendicular to the undercrossing and be installed within the paved roadway outside and median shoulder and along the lane marking lines. One additional SSMs should be installed between each array. A total of four deep settlement points (SP) should be installed along the undercrossing centerline near the east and west ends of the bore path. The deep settlement monitors should consist of a steel rod anchored at a depth below the depth of frost penetration which for this site is 1.4 m, as interpreted from OPSD 3090.101 (Frost Penetration Depths for Southern Ontario) with the bottom 0.2 metres grouted in place. A riser pipe should be provided to separate the rod from the surrounding ground.

The monitoring point installations should be carried out under the direction of qualified geotechnical personnel and the subsequent survey monitoring should be carried out by the Contract Administrator or a licensed surveyor retained by the Project Team with the results being promptly reviewed by a qualified geotechnical engineer on an ongoing basis.

### **6.6.3 Establishment of Baseline Conditions**

A condition survey to document the existing pavement condition should be carried out prior to the start of construction. The condition survey should include notes and locations about visible flaws such as cracks, distortions, and deviations, heaves, and depressions. A baseline survey of the monitoring array should be carried out at least three times, prior to construction, with the points referenced to two independent benchmarks. Anomalous readings should be rechecked and/or discarded, as necessary. Acceptance of the baseline survey by all parties should be acknowledged in writing.

### **6.6.4 Monitoring Frequency**

Monitoring should be carried out at least once per shift during the construction period, including during temporary work stoppages, non-operational periods and weekends. More frequent readings will be required if anomalous conditions are encountered or alert levels are being approached or exceeded. Once construction has ceased, monitoring should continue weekly for the first month and monthly until such time at which all parties agree that further movement has stopped. The monitoring data should be evaluated to see if the magnitude of any movements detected during construction warrant continued monitoring beyond a period of two months following the crossing installation. Anomalous readings should be rechecked and/or discarded, as necessary.

The monitoring frequencies recommended above may be increased if review of alert or review levels are exceeded. If a total recorded movement of 10 millimetres (Review Level) relative to the baseline readings is achieved, this should trigger a review of the contractor's methods including construction rate, sequence and ground stabilization methods with a view to arresting excessive movements. An Alert Level of 15 millimetres



relative to the baseline movements should require cessation of construction. At this point, implementation of pre-planned settlement mitigation measures is required to assure public safety and maintain traffic flow.

### **6.6.5 Data Collection and Transfer**

The contractor should be responsible for the supply, install and establishing the baseline of the settlement monitoring points/markers. Ongoing review of the data should also be the responsibility of the Contractor and prime consultant and qualified geotechnical personnel (RAQs approved *High Complexity Consultant*) should be retained or contracted for technical support with Review and Alert Levels are exceeded.

## **6.7 Corrosion Assessment and Protection**

Soil corrosivity may affect the concrete pipes, retaining walls and headwalls, steel pipes and reinforced steel and other concrete elements buried in the soil. The long-term performance and durability of the structures are directly related to their respective corrosion resistance. Generally, the corrosivity of a structure depends on the soil resistivity, hydrogen ion concentration, salts (chloride and sulphate) concentrations and redox potential. The analytical results for a single composite sample are presented in Section 4.4 and included in Appendix C.

The analytical test results were compared to CSA Standard, CAN/CSA-A23.1-14 Table 3 ("*Additional requirements for concrete subjected to sulphate attack*") for potential sulphate attack on concrete. The sulphate concentration measured in the composite sample comprising native clayey silt with sand, sand and silt and sand till is less than 0.1 per cent, and therefore normal Portland Cement can be used in the subsurface concrete. Therefore, based on the test results of the single composite sample the effects of sulphates from within the existing fill and native deposits around the culvert may not need to be considered. However given that the culvert is located under the roadway shoulder and will be exposed to de-icing salt, consideration should be given to selection of a "C" type exposure class as defined by CSA A23.1 Table 1.

The soil has a pH of 7.6 and a resistivity of 1,300 ohm-cm. According to the MTO Gravity Pipe Design Guidelines (2014), the pH is not considered detrimental to culvert durability. However, the resistivity is in less than 2,000 ohm-cm, which indicates that the soil corrosiveness is severe ( $R < 2,000$  ohm-cm), as per Table 3.2 of the MTO Gravity Pipe Design Guidelines (2014). Based on these results some level of pipe protection will be required depending on pipe material may be required.

It is ultimately up to the designer to determine the appropriate exposure class and to ensure that all aspects of CSA A23.1 Section 4.1.1 "Durability Requirements" are followed.

## **6.8 Retaining Walls/Wing Walls**

The existing gabion retaining wall at the culvert inlet will be removed and replaced with a new reinforced soil system (RSS) wall. A new headwall and retaining wall will be constructed at the outlet. A portion of the existing gabion wall at the east side and south of the outlet will be removed.

### **6.8.1 Retaining Wall Options**

#### **Gabion Walls**

Gabion walls can be used for the new retaining walls at the inlet and outlet. Construction of a gabion wall is geotechnically feasible at the site. Gabion walls require the least amount of space behind the wall. Temporary shoring should not be necessary if this wall type is constructed. Gabion walls do not require an embedment depth equivalent to the frost depth provided they are founded on granular pads of 300 mm compacted thickness, and the foundations have adequate embedment to provide a stable structure. Advantages of gabion walls, compared





## FOUNDATION REPORT - STRUCTURAL CULVERT REPLACEMENT - HIGHWAY 401, SITE NO. 21-489/C

to more rigid structures, include the ability to accommodate differential settlements, dissipation of the energy of flowing water, and are free-draining provided an adequate filter is placed behind and below the wall. Gabion walls can be constructed relatively quickly with minimal equipment and materials. The life expectancy of a gabion wall can be extended by utilizing PVC-coated galvanized steel baskets. Gabion baskets and mats should meet the requirements of OPSS 403 (Gabion Baskets and Mats) and constructed in accordance with OPSS.PROV 512 for walls not exceeding 2 m in height. If a new section of gabion wall is to be greater than 2 m in height, design drawings should be provided for our review and analyses for stability prior to issuance of the final report. Walls greater than 2 m in height should be designed and constructed in accordance with MTO's RSS Design Guidelines (2008). The gradation requirements of the gabion stone (G-3 or G-10 as per OPSS.PROV 1004 – Aggregates, Miscellaneous) should be specified by the overall design engineers in consultation with the hydraulic engineer. Non-woven geotextile should be placed between the gabions and the backfill in accordance with OPSS.PROV 512, OPSS 1860, and the manufacturer's specifications.

### ***Reinforced Concrete Gravity and Cantilever Walls***

Construction of reinforced concrete gravity or cantilever walls is geotechnically feasible for this site. Compared to a gabion basket wall or RSS walls, footings for gravity and cantilever walls must be constructed with a frost protection cover of 1.4 m. This may result in a longer foundation construction time and require deeper excavations compared to a gabion basket wall or RSS wall. Groundwater control/dewatering will be required since the footing excavations will be excavated below groundwater levels. It is anticipated that concrete cantilever walls will be the preferred wall type from a structural engineering perspective for the retaining walls at the outlet.

### ***RSS Walls***

The height of the wingwalls is anticipated to be less than 3 m. Therefore, a RSS wall utilizing an interlocking block system and geogrid reinforcement is a geotechnically feasible alternative. In general, RSS walls are proprietary systems which are designed by the supplier and constructed in accordance with their specifications. The internal stability of the mechanically-reinforced soil walls should be verified by the RSS supplier/designer. If an RSS wall is selected, the geotechnical aspects of the global stability of the detailed retaining wall design should be reviewed prior to construction. Depending on the design approach selected, an embedment depth equivalent to the frost depth may not be required for foundations of a RSS wall. This wall type can be constructed relatively quickly and inexpensively using small equipment. An RSS wall is the preferred wall type from a structural engineering perspective for the replacement of the gabion retaining wall at the inlet.

### **6.8.2 Frost and Scour Protection**

All footings for walls should be provided with 1.4 m of earth cover or thermal equivalent for frost protection. Although it is not necessary to found gabion basket or RSS walls at depths greater than that required for frost protection and to provide sufficient embedment for stability, it must be sufficiently buried to prevent undermining by scour. All retaining wall footings should be adequately protected against scour as noted in Section 1.9.5 of the CHBDC (2014).



### 6.8.3 Drainage

All new or replacement retaining walls must incorporate surface drainage measures to minimize infiltration of surface water into the backfill behind the wall. It is recommended that a drainage swale be incorporated at the top of each wall with the flow directed to a positive outlet.

Longitudinal drains and/or weep-holes, as applicable, are to be incorporated into the design of replacement walls at these the site, depending on the type of wall selected.

### 6.8.4 Foundations – Retaining Walls

Gabion walls should have sufficient embedment to provide a stable structure. If required, a granular leveling course approximately 75 mm in thickness may be placed on the founding strata for gabion walls. Gabions must be founded on the dense to very dense native sandy silt to silt and sand till at or below elevation 84.0 m at the inlet and elevation 82.9 m at the outlet.

Reinforced concrete gravity and cantilever walls must be founded at or below Elevation 83.8 m at the inlet and elevation 82.7 m at the on the dense to very dense native sandy silt to silt and sand till. The RSS walls may be designed such that the facing blocks are constructed on concrete strip footings or a granular leveling pad. The levelling pad should be constructed with Granular A to a minimum thickness of 300 mm. Depending on the design selected by the RSS supplier, it may not be necessary to provide 1.4 m of earth cover or thermal equivalent for frost protection. However, the foundations must have adequate embedment to provide a stable structure. Typically the embedment depth, defined as the distance between the top of the levelling pad to the top of the adjoining finished grade, is a minimum of 500 mm. The recommended founding elevation for an RSS wall is similar to that provided for gabion walls.

Factored geotechnical resistance at Ultimate Limit States (ULS) of 400 kPa and a geotechnical resistance at Serviceability Limit States (SLS) of 200 kPa may be used for design of the retaining wall foundations. The SLS value corresponds to 25 millimetres of settlement.

### 6.8.5 Resistance to Lateral Forces/Sliding Resistance

The resistance to lateral forces/sliding resistance between the base of the retaining wall footings and the foundations soils should be calculated in accordance with Section 6.10.5 of the CHBDC (2014).

The factored horizontal geotechnical resistance,  $H_{ri}$ , is calculated as follows:

$$H_{ri} = \psi \phi_{gu} (A'c'_i + V \tan \delta_i) > H_r$$

The factored horizontal resistance may be calculated using the parameters in the following table:

Structure	Interaction	Angle of Friction, $\delta$ (degrees)	Coefficient of Friction, $\tan \delta$
Concrete Gravity or Cantilever Wall and RSS Block System Wall on concrete strip footings	Cast-in-place footing on Silt and Sand to Sandy Silt(Till), dense to very dense	35	0.70
RSS Block System Wall/Gabion Walls	Granular 'A' levelling pad	35	0.70
	Silt and Sand to Sandy Silt (TILL)	35	0.70



## 6.8.6 Lateral Earth Pressures for Design

The lateral pressures acting on the proposed retaining walls will depend on the type and method of placement of the backfill materials, on the nature of the soil behind the backfill, on the magnitude of surcharge including construction loadings, on the freedom of lateral movement of the structure, and on the drainage conditions behind the walls.

The following recommendations are provided concerning the design of the walls in accordance with the CHBDC (2014). It should be noted that these design recommendations and parameters assume level backfill and ground surface behind the walls. Where there is sloping ground behind the walls, the coefficient of lateral earth pressure must be adjusted to account for the slope.

- A compaction surcharge equal to 12 kPa should be included in the lateral earth pressures for the structural design in accordance with CHBDC Figure 6.6.
- If the wall support allows lateral yielding (unrestrained structure, such as typically the case for retaining walls), active earth pressures may be used in the geotechnical design of the structure. The granular fill should be placed in a wedged shaped zone with a width equal to at least 1.4 metres at the footing level against a cut slope which begins at the footing level and extends upwards at a maximum inclination of 1 horizontal to 1 vertical (Case (b) from commentary on CHBDC Figure C6.20).
- For walls backfilled using granular materials in accordance with Case (b), the following parameters (unfactored) may be assumed:

	<u>GRANULAR A</u>	<u>GRANULAR B TYPE II</u>	<u>GRANULAR B TYPE III</u>
Fill unit weight:	22 kN/m <sup>3</sup>	21 kN/m <sup>3</sup>	21 kN/m <sup>3</sup>
Coefficients of lateral earth pressure:			
'Active' or unrestrained, $K_a$	0.27	0.27	0.31
'Passive', $K_p$	3.7	3.7	3.3

The coefficients of lateral earth pressure above are provided for level backfill behind the wall and should be adjusted in the case of sloping backfill.

## 6.9 Construction Considerations

It is recommended that geotechnical review and consultation continue throughout the design and construction of the undercrossings due to the complexity of this project. A program of inspection and monitoring will be required during construction of the undercrossing to ascertain whether the intent of the design recommendations provided in this report are being met and that the various project criteria are being achieved.

### 6.9.1 Excavations for Retaining Wall Foundations

When excavating near the portions of the existing gabion wing wall that is to remain in place, care should be taken to ensure that the footings are not undermined and the founding soils are not disturbed. Care should also be taken during construction to avoid disturbance of the subgrades prior to pouring the footings or placing the blocks. All



## **FOUNDATION REPORT - STRUCTURAL CULVERT REPLACEMENT - HIGHWAY 401, SITE NO. 21-489/C**

existing fill and any topsoil, organics, and soft or loose soils should be stripped from the proposed founding areas prior to placement of the base. Subgrade preparation should be performed and monitored in accordance with OPSS 902 (Excavating and Backfilling – Structures) and as modified by these recommendations.

It is recommended that the footing excavations be carried out such that the final 0.5 m of excavation is completed with a Quality Verification Engineer (QVE) experienced in geotechnical engineering on site. The prepared excavation base should be inspected by the QVE to ensure that competent founding soil has been reached and granular base materials should be placed immediately after inspection to protect the founding materials. The QVE should assess the foundation conditions to determine if sub-excavation of unsuitable material is required. Sub-excavation, placement and compaction of fill should be carried out under the direction of the QVE.

Temporary erosion protection and sedimentation control measures should be implemented in accordance with OPSS 805 (Temporary Erosion and Sediment Control Measures). In addition, sediment control such as silt fences and erosion control blankets may be required during construction together with diversion of any flows to mitigate migration of fine soil particles.

### **7.0 CLOSURE**

This Foundation Design Report was prepared by Mr. Peter Giuliani, P.Eng., a member of the geotechnical engineering group. The technical aspects were reviewed by Ms. Dirka U. Prout, P.Eng., a senior geotechnical engineer. Mr. Jorge M. A. Costa, P.Eng., a senior consultant of Golder and Designated MTO Foundations Contact conducted an independent quality control review of this report.



## FOUNDATION REPORT - STRUCTURAL CULVERT REPLACEMENT - HIGHWAY 401, SITE NO. 21-489/C

### Report Signature Page

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## REFERENCES

Chapman, L. J., and Putnam, D.F., 1984. *The Physiography of Southern Ontario*, 3<sup>rd</sup> Edition. Ontario Geological Survey, Special Volume 2. Ontario Ministry of Natural Resources.

Heuer, R. E. (1974). "Important Ground Parameters in Soft Ground Tunneling." *Proceedings Specialty Conference on subsurface Explorations for Underground Excavations and Heavy Construction*, ASCE, Reston, VA., p.152-167.

Canadian Geotechnical Society. 2006. Canadian Foundation Engineering Manual, 4<sup>th</sup> Edition.

Canadian Standards Association (CSA), 2014. Canadian Highway Bridge Design Code and Commentary on CAN/CSA S6-14. CSA Special Publication, S6.1-14.

Karrow, P. F., and White, O. L., 1998. Urban Geology of Canadian Cities. Geological Association of Canada Special Paper No. 42. St. John's, Nfld.

Ontario Ministry of Transportation, 2014. MTO Gravity Pipe Design Guidelines: circular culverts and storm sewers, St. Catharines, Ontario

### **Ontario Occupational Health and Safety Act:**

Ontario Regulation 213/91 Construction Projects as amended by O. Reg. 443/09

### **Ontario Provincial Standard Drawing:**

OPSD 3090.101      Foundation, Frost Penetration Depths for Southern Ontario

### **Ontario Provincial Standard Specification:**

OPSS.PROV 539	Construction Specifications for Temporary Protection Systems
OPSS 902	Construction Specifications for Excavating and Backfilling – Structures
OPSS.PROV 1010	Material Specifications for Aggregates – Base, Subbase, Select Subgrade, Backfill Material
OPSS 1860	Material Specification for Geotextiles

### **Ontario Water Resources Act:**

Ontario Regulation 372/9      Amendment to Ontario Regulation 903

### **ASTM**

ASTM D1586-11 Standard Test Method for Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils, ASTM International, West Conshohocken, PA, 2011

ASTM D2573-94 Standard Test Method for Field Vane Shear Test in Cohesive Soil, ASTM International, West Conshohocken, PA, 2001





# TABLES



## FOUNDATION REPORT - STRUCTURAL CULVERT REPLACEMENT - HIGHWAY 401, SITE NO. 21-489/C

Table 1: Summary of Existing Culvert Details

Culvert Location (Township)	Culvert ID / Site No.	Approximate Height of Embankment / Cover <sup>1</sup>	Existing Culvert			Approximate Invert Elevation <sup>2</sup>		Boreholes
			Type	Approximate Dimension	Approximate Length	Upstream	Downstream	
STA 17+732 (Clarington)	C3	Up to about 10.5 m	Box Culvert	4.3 m x 24 m	92.7 m	85.22 m	84.16 m	4 Boreholes (C3-1 to C3-4)

Notes: 1. Embankment height is relative to existing ground surface level at the toe of embankment adjacent to the culvert and the thickness of culvert cover is based on drawings provided by D.M. Wills dated November 24, 2016

2. Culvert invert elevations are based on drawings provided by D.M. Wills dated November 24, 2016.



Table 2: Comparison of Trenchless Techniques for Culvert Replacement

Method	Feasibility	Advantages	Disadvantages	Estimated Relative Cost Factor <sup>2, 3</sup>	Risk/Consequence
Jack-and-Bore	Not Feasible	Length and diameter preclude the use of jack and bore <sup>1</sup>			
Pipe Ramming	Not Feasible	Length and diameter preclude the use of jack and bore <sup>1</sup>			
Microtunnelling	Marginally Feasible	Closed-face machine (slurry MTBM) equipped with rock cutters and crusher chamber required to deal with cobbles and boulders in the fill, sand and gravel and glacial till can provide adequate face support High accuracy for line and grade Dewatering required at shafts only Fastest rate of advance	No person access to face Even if MTBM equipped with rock cutters and crusher chambers, it will not be able to accommodate oversized boulders (larger than 1/3 the machine diameter) and operations will be halted Woody debris if encountered will likely clog the machine A rescue shaft will be needed to free machine if cobble nests, oversized boulders (> 1/3 machine diameter) or woody debris encountered Most expensive trenchless solution Requires largest work area at entry shaft due to the large amount of topside equipment Where fills are much softer/looser than the underlying dense to very dense native materials, the machine may be deflected by boulders requiring correction in line or grade	1.4 to 2.0	Encountering woody debris and oversized cobble nests or boulders - high to very high risk of not completing installation Tunnel invert along interface between embankment fill and native materials - low to moderate risk of not achieving line and grade if machine deflected by boulders in glacial till or hard/very dense soils Groundwater at the tunnel invert - low risk of ground loss due to flowing of sands if slurry MTBM selected and proper dewatering carried out at shafts
Hand Mining or Mechanically-Assisted Excavation within shield with jacked pipe, steel liner plate or steel ribs and lagging	Feasible	Highly adaptable to variable conditions along alignment Face access facilitates removal of cobbles, boulders and obstructions in the fill, sand and gravel and glacial till Good accuracy for line and grade Most economical solution with line and grade accuracy comparable to microtunnelling Smallest footprint required for entry shaft Potentially the most economical method of installing the culvert at low end of cost range. At high end of cost range, cost may be approaching conventional tunneling with TBM option.	Labour intensive: Due to the potential presence of sandy layers in the fill and at and near the invert level which may be saturated, the contractor's selected equipment and methods must provide effective control of the stability of the face (e.g., use of hooded shield, stiffeners, forepoling, retractable breast plates with doors etc.) Extensive delays may occur removing and breaking up oversized boulders with high strength, if encountered Unlike microtunnelling and conventional tunneling, dewatering by horizontal drainage lances/pipes from start and end shafts may be required to control flow in saturated sand and gravel Slowest rate of advance	1.0	Encountering woody debris and oversized cobble nests or boulders - low to moderate risk of not completing installation Tunnel invert along interface between embankment fill and native materials - low to moderate risk of not achieving line and grade if machine deflected by boulders in glacial till or hard/very dense soils Groundwater at the tunnel invert - moderate risk to high of ground loss due to flowing of sands; risk can be minimized with proper horizontal drainage within tunnel and effective dewatering at shafts
Conventional Tunnelling with Tunnel Boring Machine (TBM)	Feasible	Face access facilitates removal of cobbles, boulders and obstructions in the fill, sand and gravel and glacial till Closed-face machine must be used to provide effective control of face stability High accuracy with line and grade Dewatering required at shafts only	Older TBMs that do not include a secondary bulkhead and controlled muck discharge system (e.g., discharge gates controlled by load or pressure sensors) should be prohibited Machines can become jammed or clogged with wood and/or cobbles and boulders; face opening size for any TBM should be restricted so that rock pieces do not pass through the cutterhead and block screw conveyor or slurry systems Requires a work area at the entry shaft ranging from somewhat smaller than that needed for microtunnelling to comparable	1.0 – 1.5	Encountering woody debris and oversized cobble nests or boulders - moderate to high risk of not completing installation Tunnel invert along interface between embankment fill and native materials - low to moderate risk of not achieving line and grade if machine deflected by boulders in glacial till or hard/very dense soils Groundwater at the tunnel invert - low risk of ground loss due to flowing of sands if closed-face machine selected

Notes:

1. The availability of contractors in Ontario with large-scale jack and bore or pipe ramming equipment and experience installing pipes with diameters of 1.8 m or greater is rare or non-existent. The typical maximum casing sizes are 1.83 m for jack and bore and 2.44 m for pipe ramming.
2. The estimated relative cost factor represents an approximately simplified cost estimate for each option divided by the estimated cost for the least expensive option (e.g., a relative cost factor of 2 indicates that the trenchless technology option is twice as costly as the least expensive option).
3. Table to be read in conjunction with accompanying report.

Prepared By: PG

Checked By: DUP



# DRAWINGS

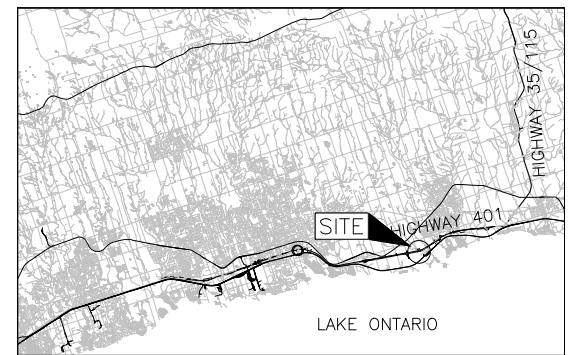
**METRIC**  
DIMENSIONS ARE IN METRES AND/OR  
MILLIMETRES UNLESS OTHERWISE SHOWN.  
STATIONS IN KILOMETRES + METRES.

CONT No.  
WP No. 2186-15-00



HIGHWAY 401  
DARLINGTON CREEK CULVERT STA 17+730  
BOREHOLE LOCATIONS AND  
SOIL STRATA

SHEET



KEY PLAN



SCALE  
6 0 6 12 km

## LEGEND

- Borehole - Current Investigation
- ⊥ Seal
- ⊥ Piezometer
- N Standard Penetration Test Value
- 16 Blows/0.3m unless otherwise stated (Std. Pen. Test, 475 j/blow)
- ≡ WL upon completion of drilling
- ≡ WL in piezometer

## BOREHOLE CO-ORDINATES

No.	ELEVATION	NORTHING	EASTING
C3-1	87.7	4860965.6	368258.7
C3-2	94.2	4860950.2	368267.1
C3-3	94.0	4860928.8	368316.7
C3-4	85.2	4860913.3	368337.0

## NOTES

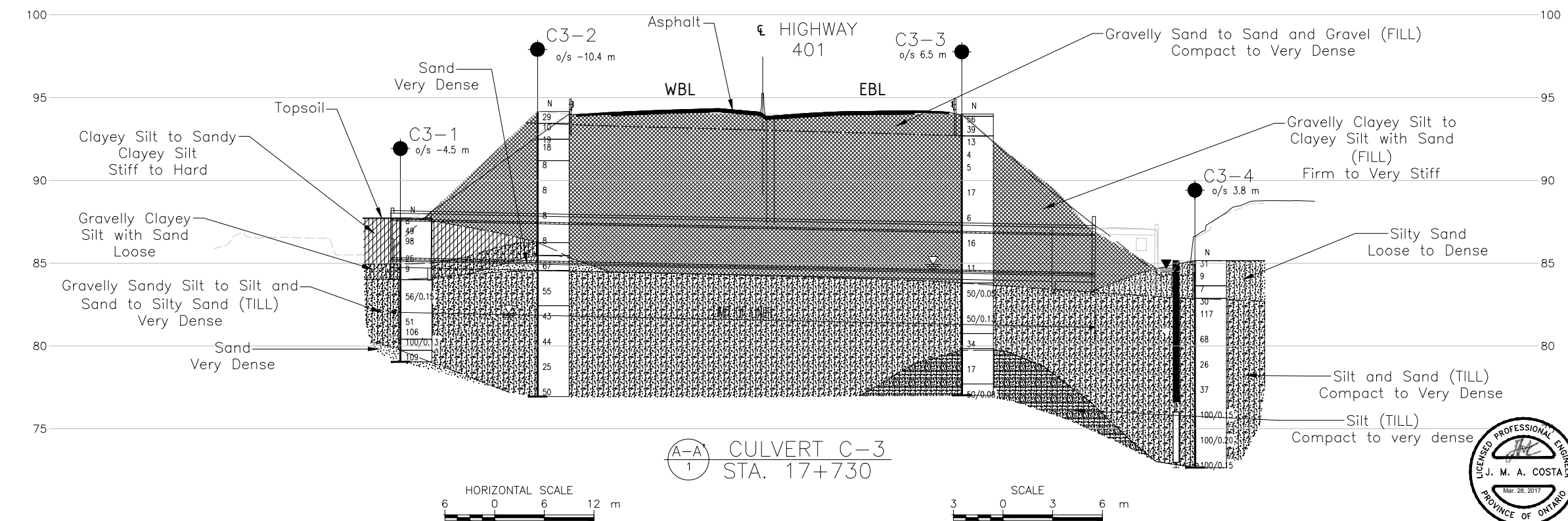
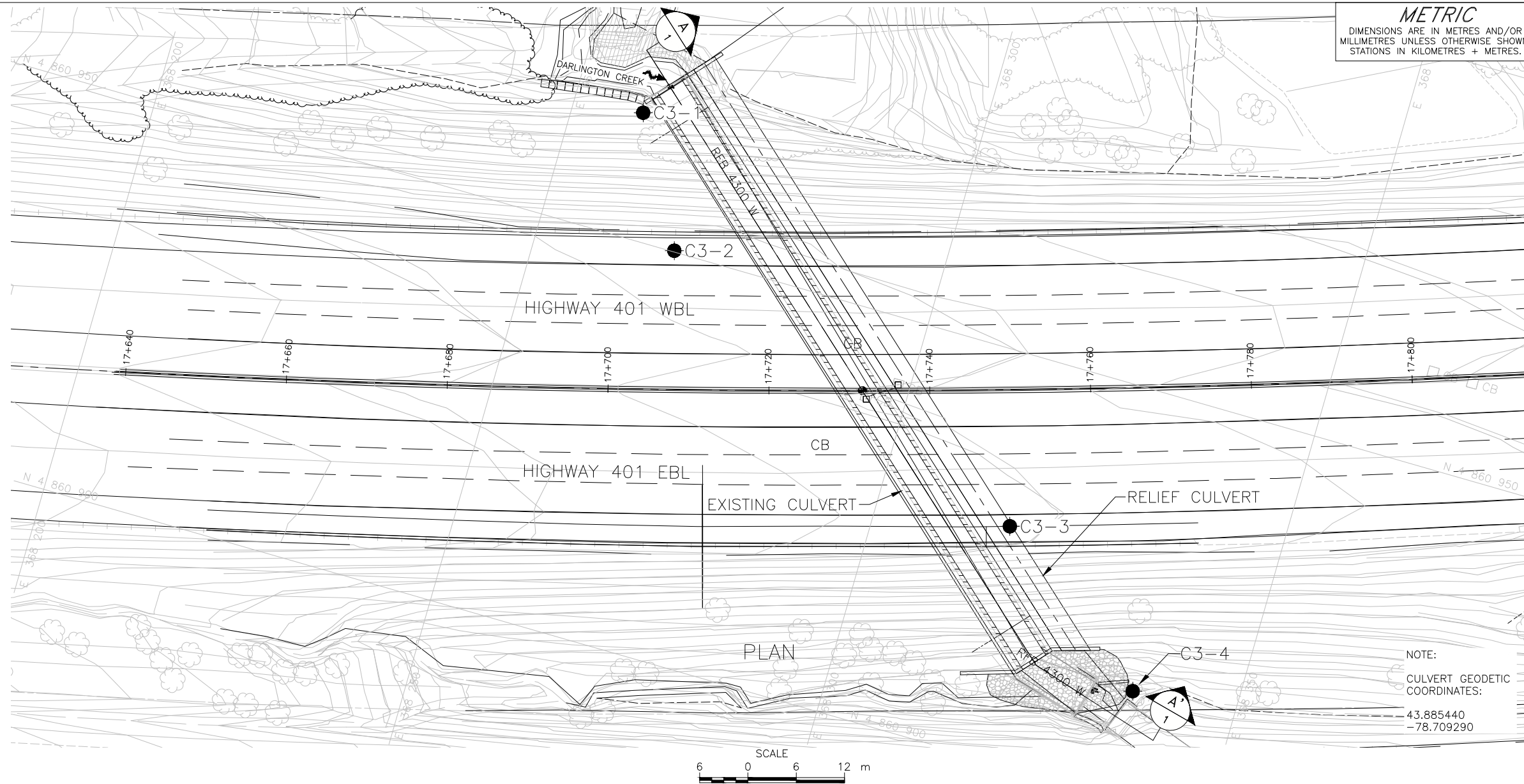
This drawing is for subsurface information only. The proposed structure details/works are shown for illustration purposes only and may not be consistent with the final design configuration as shown elsewhere in the Contracts Documents.

The boundaries between soil strata have been established only at borehole locations. Between boreholes the boundaries are assumed from geological evidence.

## REFERENCE

Base Plan and Contours provided in digital format by DM Wills, drawing file nos. 132306.dwg and 132307.dwg, received Jan. 20, 2016. Design Plan and Section provided in digital format by DM Wills, drawing file no. 4561-C2 GA.dwg, received Aug. 22, 2016.

NO.	DATE	BY	REVISION
Geocres No. 30M15-305			
HWY. 401	PROJECT NO. 1540419		DIST. .
SUBM'D. MCK	CHKD. MCK	DATE: 8/23/2016	SITE: 21-489/C
DRAWN: MR	CHKD. MK	APPD. JMAC	DWG. 1



A-A  
1  
CULVERT C-3  
STA. 17+730





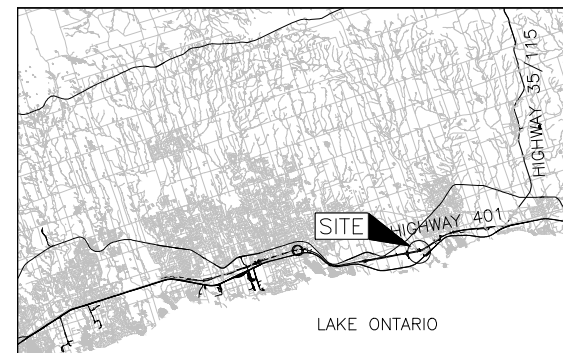
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MILLIMETRES UNLESS OTHERWISE SHOWN.  
STATIONS IN KILOMETRES + METRES.

CONT No.  
WP No. 2186-15-00



HIGHWAY 401  
DARLINGTON CREEK CULVERT STA 17+730  
SETTLEMENT MONITORING INSTRUMENTATION  
LOCATIONS AND DETAILS

SHEET



KEY PLAN

SCALE  
6 0 6 12 km

LEGEND

- ⊕ Surface Settlement Marker
- Settlement Point

### NOTES

This drawing is for subsurface information only. The proposed structure details/works are shown for illustration purposes only and may not be consistent with the final design configuration as shown elsewhere in the Contracts Documents.

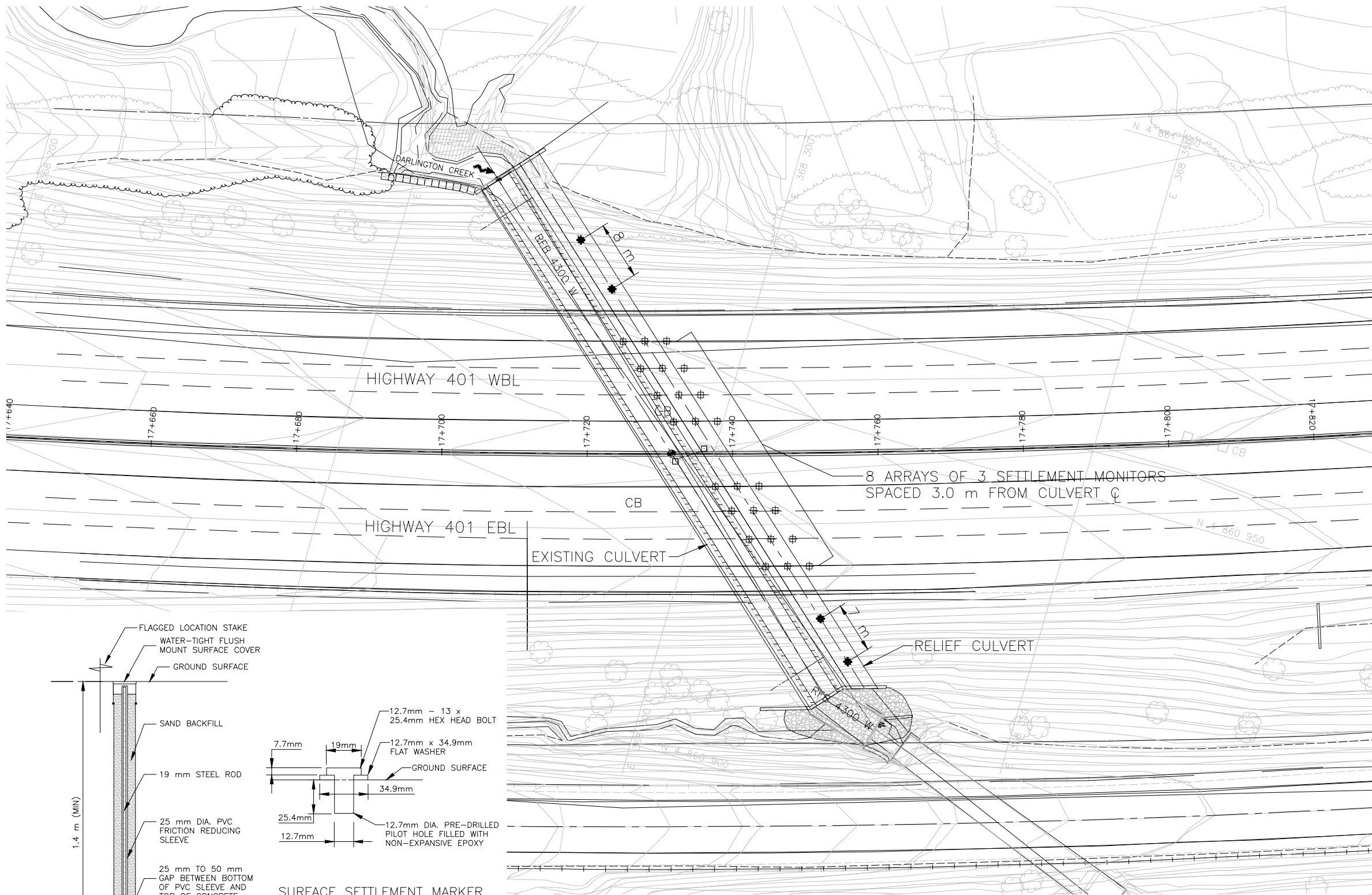
The boundaries between soil strata have been established only at borehole locations. Between boreholes the boundaries are assumed from geological evidence.

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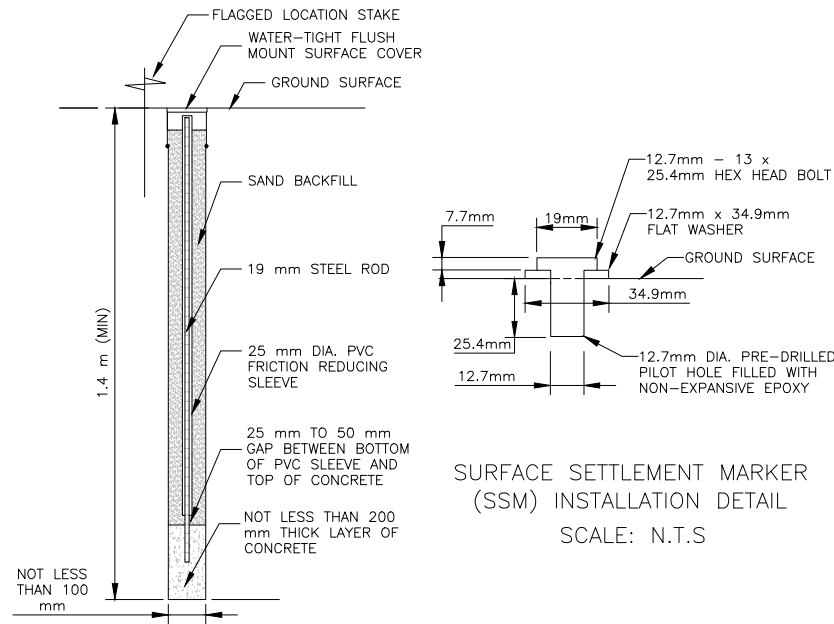
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HWY. 401	PROJECT NO. 1540419		DIST. .
SUBM'D. MCK	CHKD. MCK	DATE: 8/23/2016	SITE: 21-489/C
DRAWN: MR	CHKD. MK	APPD. JMAC	DWG. 2

NOTE:  
CULVERT GEODETIC  
COORDINATES:  
43.885440  
-78.709290



PLAN

SCALE  
6 0 6 12 m



SETTLEMENT POINT (SP)  
INSTALLATION DETAIL  
SCALE: N.T.S

SURFACE SETTLEMENT MARKER  
(SSM) INSTALLATION DETAIL  
SCALE: N.T.S

## SETTLEMENT MONITORING INSTALLATION DETAILS





# **APPENDIX A**

## **Record of Boreholes**



## LIST OF SYMBOLS

Unless otherwise stated, the symbols employed in the report are as follows:

### I. GENERAL

$\pi$	3.1416
$\ln x$ ,	natural logarithm of x
$\log_{10}$	x or log x, logarithm of x to base 10
g	acceleration due to gravity
t	time
FoS	factor of safety

### II. STRESS AND STRAIN

$\gamma$	shear strain
$\Delta$	change in, e.g. in stress: $\Delta \sigma$
$\varepsilon$	linear strain
$\varepsilon_v$	volumetric strain
$\eta$	coefficient of viscosity
$\nu$	Poisson's ratio
$\sigma$	total stress
$\sigma'$	effective stress ( $\sigma' = \sigma - u$ )
$\sigma'_{vo}$	initial effective overburden stress
$\sigma_1, \sigma_2, \sigma_3$	principal stress (major, intermediate, minor)
$\sigma_{oct}$	mean stress or octahedral stress $= (\sigma_1 + \sigma_2 + \sigma_3)/3$
$\tau$	shear stress
u	porewater pressure
E	modulus of deformation
G	shear modulus of deformation
K	bulk modulus of compressibility

### III. SOIL PROPERTIES

#### (a) Index Properties

$\rho(\gamma)$	bulk density (bulk unit weight)*
$\rho_d(\gamma_d)$	dry density (dry unit weight)
$\rho_w(\gamma_w)$	density (unit weight) of water
$\rho_s(\gamma_s)$	density (unit weight) of solid particles
$\gamma'$	unit weight of submerged soil ( $\gamma' = \gamma - \gamma_w$ )
$D_R$	relative density (specific gravity) of solid particles ( $D_R = \rho_s / \rho_w$ ) (formerly $G_s$ )
e	void ratio
n	porosity
S	degree of saturation

\* Density symbol is  $\rho$ . Unit weight symbol is  $\gamma$  where  $\gamma = \rho g$  (i.e. mass density multiplied by acceleration due to gravity)

#### (a) Index Properties (continued)

w	water content
$w_l$ or LL	liquid limit
$w_p$ or PL	plastic limit
$I_p$ or PI	plasticity index = $(w_l - w_p)$
$w_s$	shrinkage limit
$I_L$	liquidity index = $(w - w_p) / I_p$
$I_c$	consistency index = $(w_l - w) / I_p$
$e_{max}$	void ratio in loosest state
$e_{min}$	void ratio in densest state
$I_D$	density index = $(e_{max} - e) / (e_{max} - e_{min})$ (formerly relative density)

#### (b) Hydraulic Properties

h	hydraulic head or potential
q	rate of flow
v	velocity of flow
i	hydraulic gradient
k	hydraulic conductivity (coefficient of permeability)
j	seepage force per unit volume

#### (c) Consolidation (one-dimensional)

$C_c$	compression index (normally consolidated range)
$C_r$	recompression index (over-consolidated range)
$C_s$	swelling index
$C_{\alpha}$	secondary compression index
$m_v$	coefficient of volume change
$C_v$	coefficient of consolidation (vertical direction)
$C_h$	coefficient of consolidation (horizontal direction)
$T_v$	time factor (vertical direction)
U	degree of consolidation
$\sigma'_p$	pre-consolidation stress
OCR	over-consolidation ratio = $\sigma'_p / \sigma'_{vo}$

#### (d) Shear Strength

$\tau_p, \tau_r$	peak and residual shear strength
$\phi'$	effective angle of internal friction
$\delta$	angle of interface friction
$\mu$	coefficient of friction = $\tan \delta$
$c'$	effective cohesion
$c_u, s_u$	undrained shear strength ( $\phi = 0$ analysis)
p	mean total stress $(\sigma_1 + \sigma_3)/2$
$p'$	mean effective stress $(\sigma'_1 + \sigma'_3)/2$
q	$(\sigma_1 - \sigma_3)/2$ or $(\sigma'_1 - \sigma'_3)/2$
$q_u$	compressive strength $(\sigma_1 - \sigma_3)$
$S_t$	sensitivity

Notes: 1  
2

$\tau = c' + \sigma' \tan \phi'$   
shear strength = (compressive strength)/2



## LIST OF ABBREVIATIONS

The abbreviations commonly employed on Records of Boreholes, on figures and in the text of the report are as follows:

### I. SAMPLE TYPE

AS	Auger sample
BS	Block sample
CS	Chunk sample
DS	Denison type sample
FS	Foil sample
RC	Rock core
SC	Soil core
SS	Split-spoon
ST	Slotted tube
TO	Thin-walled, open
TP	Thin-walled, piston
WS	Wash sample

### II. PENETRATION RESISTANCE

#### Standard Penetration Resistance (SPT), N:

The number of blows by a 63.5 kg. (140 lb.) hammer dropped 760 mm (30 in.) required to drive a 50 mm (2 in.) drive open sampler for a distance of 300 mm (12 in.)

#### Dynamic Cone Penetration Resistance; $N_d$ :

The number of blows by a 63.5 kg (140 lb.) hammer dropped 760 mm (30 in.) to drive uncased a 50 mm (2 in.) diameter, 60° cone attached to "A" size drill rods for a distance of 300 mm (12 in.).

**PH:** Sampler advanced by hydraulic pressure

**PM:** Sampler advanced by manual pressure

**WH:** Sampler advanced by static weight of hammer

**WR:** Sampler advanced by weight of sampler and rod

#### Piezo-Cone Penetration Test (CPT)

A electronic cone penetrometer with a 60° conical tip and a project end area of 10 cm<sup>2</sup> pushed through ground at a penetration rate of 2 cm/s. Measurements of tip resistance ( $Q_t$ ), porewater pressure (PWP) and friction along a sleeve are recorded electronically at 25 mm penetration intervals.

### III. SOIL DESCRIPTION

#### (a) Non-Cohesive Soils

Density Index	N
Relative Density	Blows/300 mm or Blows/ft
Very loose	0 to 4
Loose	4 to 10
Compact	10 to 30
Dense	30 to 50
Very dense	over 50

#### (b) Cohesive Soils Consistency

	$C_u, S_u$	
	kPa	psf
Very soft	0 to 12	0 to 250
Soft	12 to 25	250 to 500
Firm	25 to 50	500 to 1,000
Stiff	50 to 100	1,000 to 2,000
Very stiff	100 to 200	2,000 to 4,000
Hard	over 200	over 4,000

### IV. SOIL TESTS

w	water content
w <sub>p</sub>	plastic limit
w <sub>l</sub>	liquid limit
C	consolidation (oedometer) test
CHEM	chemical analysis (refer to text)
CID	consolidated isotropically drained triaxial test <sup>1</sup>
CIU	consolidated isotropically undrained triaxial test with porewater pressure measurement <sup>1</sup>
D <sub>R</sub>	relative density (specific gravity, $G_s$ )
DS	direct shear test
M	sieve analysis for particle size
MH	combined sieve and hydrometer (H) analysis
MPC	Modified Proctor compaction test
SPC	Standard Proctor compaction test
OC	organic content test
SO <sub>4</sub>	concentration of water-soluble sulphates
UC	unconfined compression test
UU	unconsolidated undrained triaxial test
V	field vane (LV-laboratory vane test)
$\gamma$	unit weight

**Note: 1** Tests which are anisotropically consolidated prior to shear are shown as CAD, CAU.

### V. MINOR SOIL CONSTITUENTS

#### Per cent by Weight Modifier

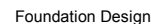
0 to 5	Trace
5 to 12	Trace to Some (or Little)
12 to 20	Some
20 to 30	(ey) or (y)
over 30	And (non-cohesive (cohesionless)) or With (cohesive)

#### Example

Trace sand  
Trace to some sand  
Some sand  
Sandy  
Sand and Gravel  
Silty Clay with sand / Clayey Silt with sand

PROJECT 1540419			RECORD OF BOREHOLE No C3-1			SHEET 1 OF 1			METRIC								
W.P. 2186-15-00			LOCATION N 4860965.6; E 368258.7 MTM ZONE (LAT. 43.885944; LONG. -78.710242)			ORIGINATED BY MB											
DIST HWY 401			BOREHOLE TYPE Portable Equipment, BW Casing Washboring (Manual Hammer)			COMPILED BY SZ/MR											
DATUM Geodetic			DATE August 30 to September 1, 2016			CHECKED BY MCK											
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 $\gamma$ kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa									
87.7	GROUND SURFACE																
87.9	TOPSOIL		1	SS	8												
	CLAYEY SILT to sandy CLAYEY SILT, trace organics Stiff to hard Brown becoming grey at a depth of 2.3 m Moist to wet		2	SS	49												
			3	SS	98*												
	- Gravel layer encountered between depths of 2.3 m and 2.9 m (Elev. 85.4 m and 84.8 m)		4	SS	25												
84.8																	
2.9	Gravelly CLAYEY SILT with SAND Firm Grey Wet		5	SS	9												27 36 28 9
84.0																	
3.7	Gravelly Sandy SILT (TILL) Very dense Grey Wet																
	- Casing grinding at a depth of 4.3 m (Elev. 83.4 m)		6	SS	56/0.15												
81.3			7	SS	51												
6.4	SILT and SAND, trace to some gravel, trace to some clay (TILL) Very dense Grey Wet		8	SS	106												10 42 36 12
			9	SS	147/0.28												
79.7																	
8.0	SAND, some gravel Very dense Grey Wet		10	SS	109												
79.0																	
8.7	END OF BOREHOLE																
	* Sampler Bouncing																
	NOTE:  1. Water level not established as water was introduced into the borehole during wash boring.																

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SHEET 1 OF 2

METRIC

PROJECT 1540419

W.P. 2186-15-00

LOCATION N 4860950.2; E 368267.1 MTM ZONE (LAT. 43.885804; LONG. -78.710139)

ORIGINATED BY MK

DIST HWY 401

BOREHOLE TYPE CME 75, 203 mm O.D., 108 mm I.D. Hollow Stem Augers (Auto Hammer)

COMPILED BY SZ/MR

DATUM Geodetic



DATE August 28, 2016

CHECKED BY MCK

[illegible]

Continued Next Page

+<sup>3</sup>, ×<sup>3</sup>: Numbers refer to Sensitivity      ○<sup>3%</sup> STRAIN AT FAILURE

PROJECT <u>1540419</u>		<b>RECORD OF BOREHOLE No C3-2</b>				SHEET 2 OF 2		<b>METRIC</b>										
W.P. <u>2186-15-00</u>		LOCATION <u>N 4860950.2; E 368267.1 MTM ZONE (LAT. 43.885804; LONG. -78.710139)</u>				ORIGINATED BY <u>MK</u>												
DIST <u>          </u> HWY <u>401</u>		BOREHOLE TYPE <u>CME 75, 203 mm O.D., 108 mm I.D. Hollow Stem Augers (Auto Hammer)</u>				COMPILED BY <u>SZ/MR</u>												
DATUM <u>Geodetic</u>		DATE <u>August 28, 2016</u>				CHECKED BY <u>MCK</u>												
SOIL PROFILE		SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT 					PLASTIC LIMIT   NATURAL MOISTURE CONTENT   LIQUID LIMIT			UNIT WEIGHT $\gamma$ kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%)		
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE			"N" VALUES	SHEAR STRENGTH kPa					W <sub>p</sub> W   W <sub>L</sub>					
	--- CONTINUED FROM PREVIOUS PAGE ---																	
	SILT and SAND to Silty SAND, trace to some clay, some gravel (TILL) Compact to very dense Grey Moist		13	SS	25		79											
							78											
77.0			14	SS	50		77											
17.2	END OF BOREHOLE																	
	NOTE:  1. Water level in open borehole at a depth of 12.2 m below ground surface (Elev. 82.0 m) upon completion of drilling.																	

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<b>PROJECT</b> 1540419		<b>RECORD OF BOREHOLE No C3-3</b>		SHEET 1 OF 2		<b>METRIC</b>	
W.P. 2186-15-00		LOCATION N 4860928.8; E 368316.7 MTM ZONE (LAT. 43.885607; LONG. -78.709525)		ORIGINATED BY MB			
DIST _____ HWY 401		BOREHOLE TYPE CME 75, 203 mm O.D., 108 mm I.D. Hollow Stem Augers (Auto Hammer)		COMPILED BY SZ/MR			
DATUM Geodetic		DATE September 6, 2016		CHECKED BY MCK			

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 $\gamma$ kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa						
								20 40 60 80 100	20 40 60 80 100					
94.0	GROUND SURFACE													
0.0	ASPHALT (150 mm)													
0.2	Gravelly sand (FILL) Dense to very dense Brown Dry		1	SS	51									
92.7			2	SS	39									
1.3	Clayey silt, trace to some sand, some gravel (FILL) Firm to very stiff Brown to grey Moist to wet		3	SS	13									
			4	SS	4									
			5	SS	5									
			6	SS	17									
			7	SS	6									
			8	SS	16									
			9	SS	11									
83.8														
10.2	SILT and SAND, trace to some clay, some gravel (TILL) Dense to very dense Grey Moist		10	SS	50/0.05									
	- Augers grinding at a depth of 11.6 m (Elev. 82.4 m)		11	SS	98/0.28									
			12	SS	34									
79.2														
14.8	- Augers grinding at a depth of 14.6 m (Elev. 79.4 m)													

Continued Next Page

+<sup>3</sup>, ×<sup>3</sup>: Numbers refer to Sensitivity      ○ 3% STRAIN AT FAILURE

GTA-MTO 001 S:\CLIENTS\MTOWHY\_401 &amp; HWY35-11502\_DATA\GINTHWY\_401\_AJAX\_TO\_NEWTONVILLE\_WITH\_LAT\_AND\_LONGS.GPJ GAL-GTA.GDT 3/28/17

PROJECT <u>1540419</u>		<b>RECORD OF BOREHOLE No C3-3</b>				SHEET 2 OF 2		<b>METRIC</b>									
W.P. <u>2186-15-00</u>		LOCATION <u>N 4860928.8; E 368316.7 MTM ZONE (LAT. 43.885607; LONG. -78.709525)</u>				ORIGINATED BY <u>MB</u>											
DIST <u>          </u> HWY <u>401</u>		BOREHOLE TYPE <u>CME 75, 203 mm O.D., 108 mm I.D. Hollow Stem Augers (Auto Hammer)</u>				COMPILED BY <u>SZ/MR</u>											
DATUM <u>Geodetic</u>		DATE <u>September 6, 2016</u>				CHECKED BY <u>MCK</u>											
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 (%)  GR SA SI CL	
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE			"N" VALUES	SHEAR STRENGTH kPa									
	--- CONTINUED FROM PREVIOUS PAGE ---						20 40 60 80 100 ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × REMOULDED					WATER CONTENT (%) 10 20 30					
77.0	SILT, some gravel, trace to some sand (TILL) Compact to very dense Grey Moist to wet		13	SS	17		78							○H			
17.0	END OF BOREHOLE  NOTE:  1. Water level in open borehole at a depth of 9.1 m below ground surface (Elev. 84.9 m) upon completion of drilling.		14	SS	50/0.08												

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PROJECT 1540419		RECORD OF BOREHOLE No C3-4		SHEET 1 OF 1		METRIC											
W.P. 2186-15-00		LOCATION N 4860913.3; E 368337.0 MTM ZONE (LAT. 43.885466; LONG. -78.709273)		ORIGINATED BY PKS													
DIST _____ HWY 401		BOREHOLE TYPE Mini Mole, 102 mm O.D. Solid Stem Augers (Auto Hammer)		COMPILED BY ZMR													
DATUM Geodetic		DATE July 27, 2016		CHECKED BY MCK													
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 (%)
85.2	GROUND SURFACE							20	40	60	80	100					
0.0	Silty SAND, some gravel, trace to some clay Loose to dense Brown Moist		1	SS	31												
			2	SS	9												
			3	SS	7												
82.9																	
2.3	SILT and SAND, trace to some gravel, trace to some clay (TILL) Compact to very dense Grey Moist to wet		4	SS	30												
			5	SS	117												
			6	SS	68												
			7	SS	26												
			8	SS	37												
			9	SS	100/0.1												
			10	SS	100/0.2												
			11	SS	100/0.1												
72.7																	
12.5	END OF BOREHOLE																
NOTE:																	
1. Water level in open borehole at a depth of 4.6 m below ground surface (Elev. 80.6 m) upon completion of drilling.																	
2. Water level measurement in piezometer:																	
Date	Depth	Elev.															
09/28/2017	0.5m	84.7m															

GTA-MTO 001 S:\CLIENTS\TOH\HWY\_401 &amp; HWY35-11502\_DATA\GINT\HWY\_401\_AJAX\_TO\_NEWTONVILLE\_WITH\_LAT\_AND\_LONGS.GPJ GAL-GTA.GDT 3/28/17



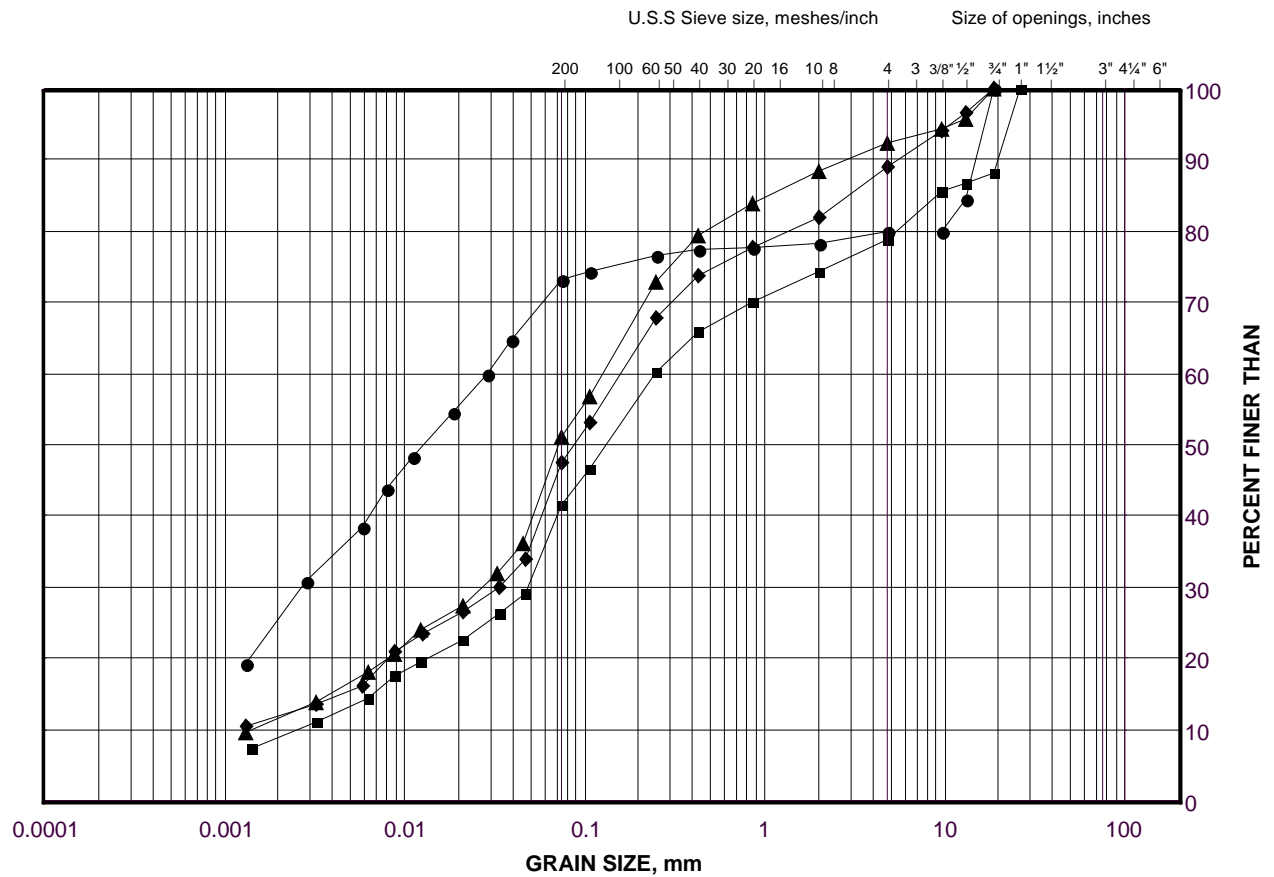
# **APPENDIX B**

## **Laboratory Test Results**

# GRAIN SIZE DISTRIBUTION

Clayey Silt (FIL)L

FIGURE B1



SILT AND CLAY SIZES	FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE
FINE GRAINED	SAND SIZE			GRAVEL SIZE		SIZE

## LEGEND

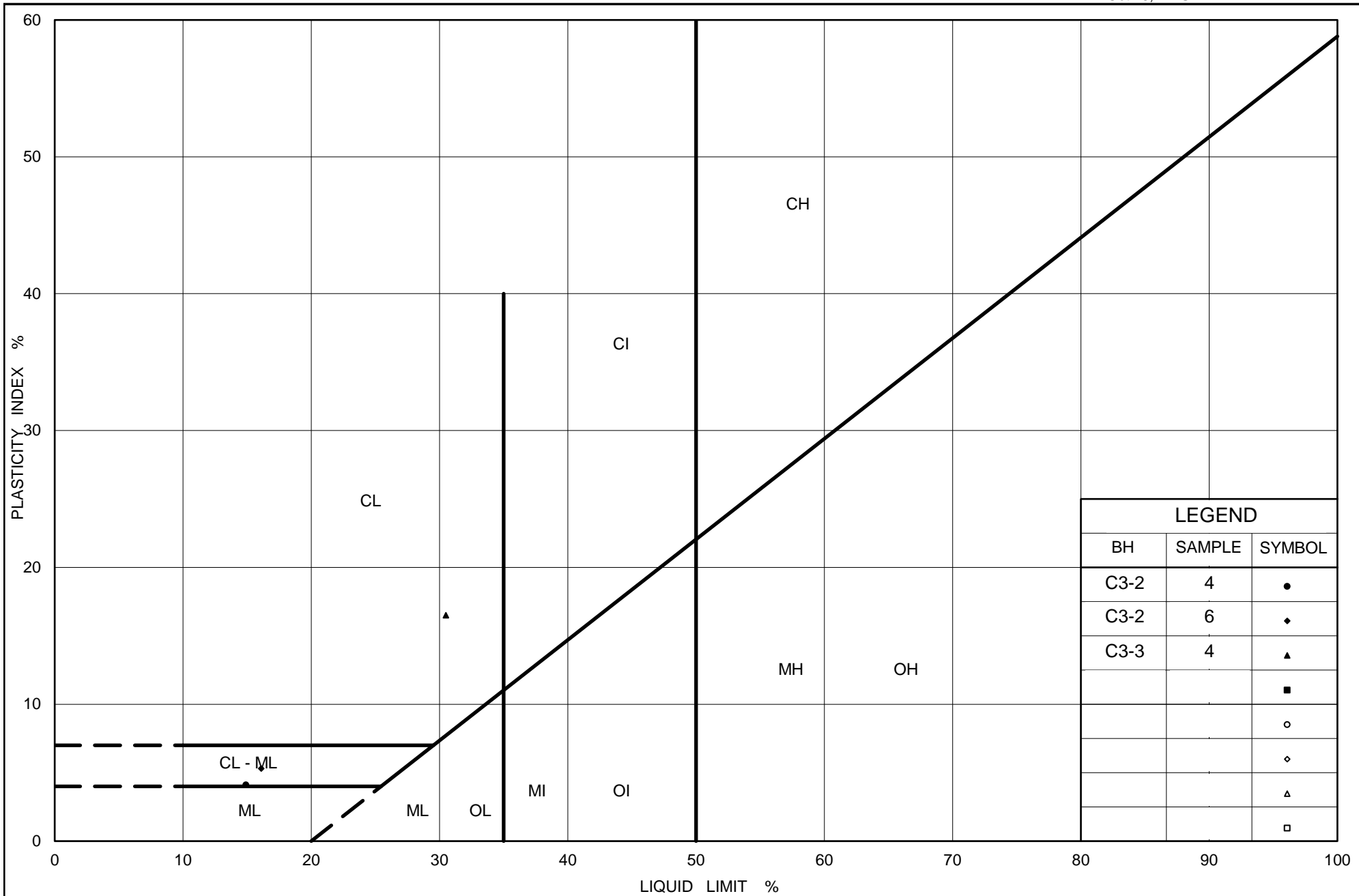
SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	C3-3	4	91.5
■	C3-2	4	91.6
◆	C3-3	6	89.1
▲	C3-2	7	87.8

Project Number: 1540419

Checked By: \_\_\_\_\_

**Golder Associates**

Date: 18-Oct-16



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## PLASTICITY CHART

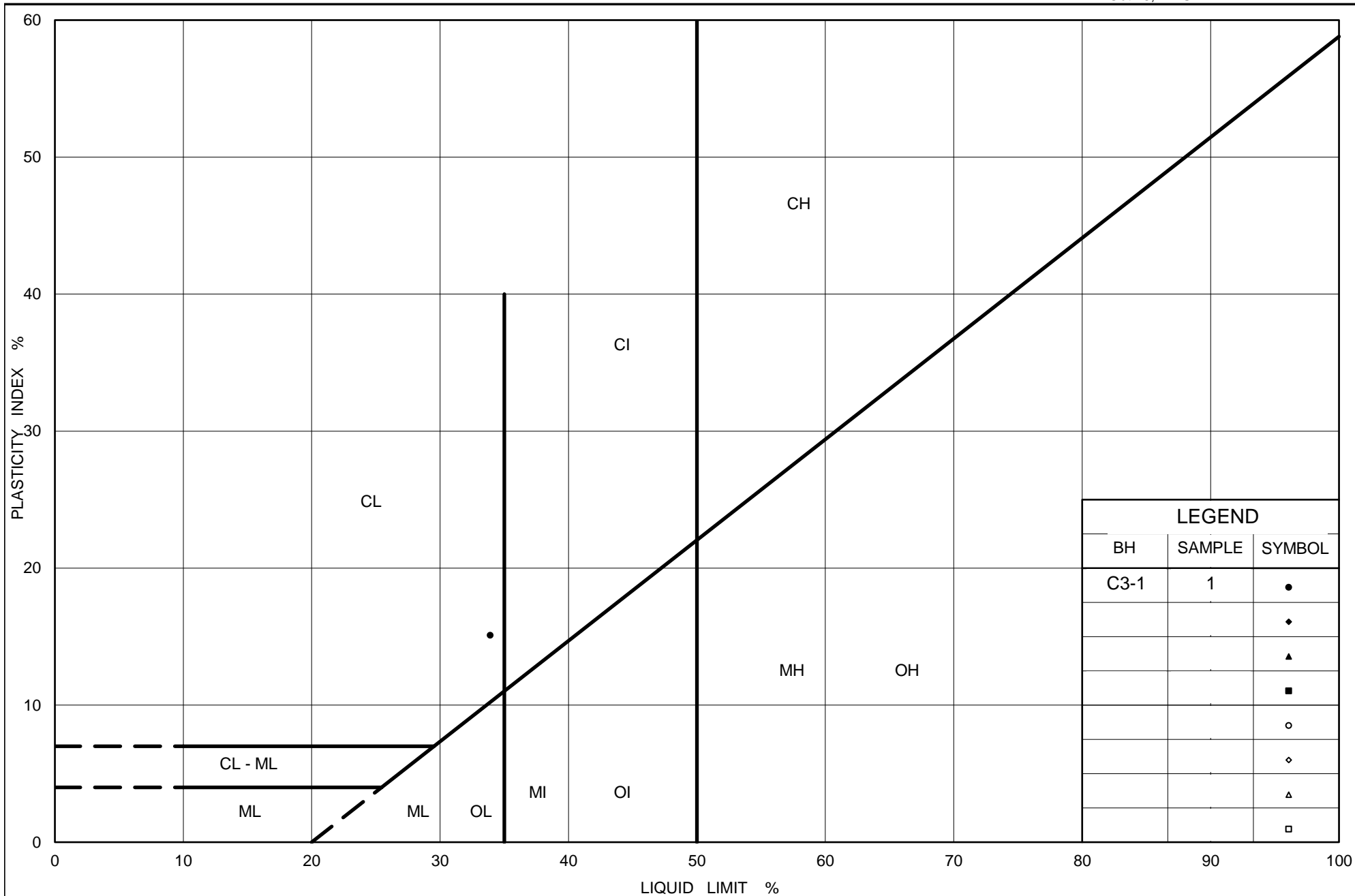
### Clayey Silt (FILL)

Figure No. B2

Project No. 1540419

Checked By:





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## PLASTICITY CHART

### Clayey Silt

Figure No. B3

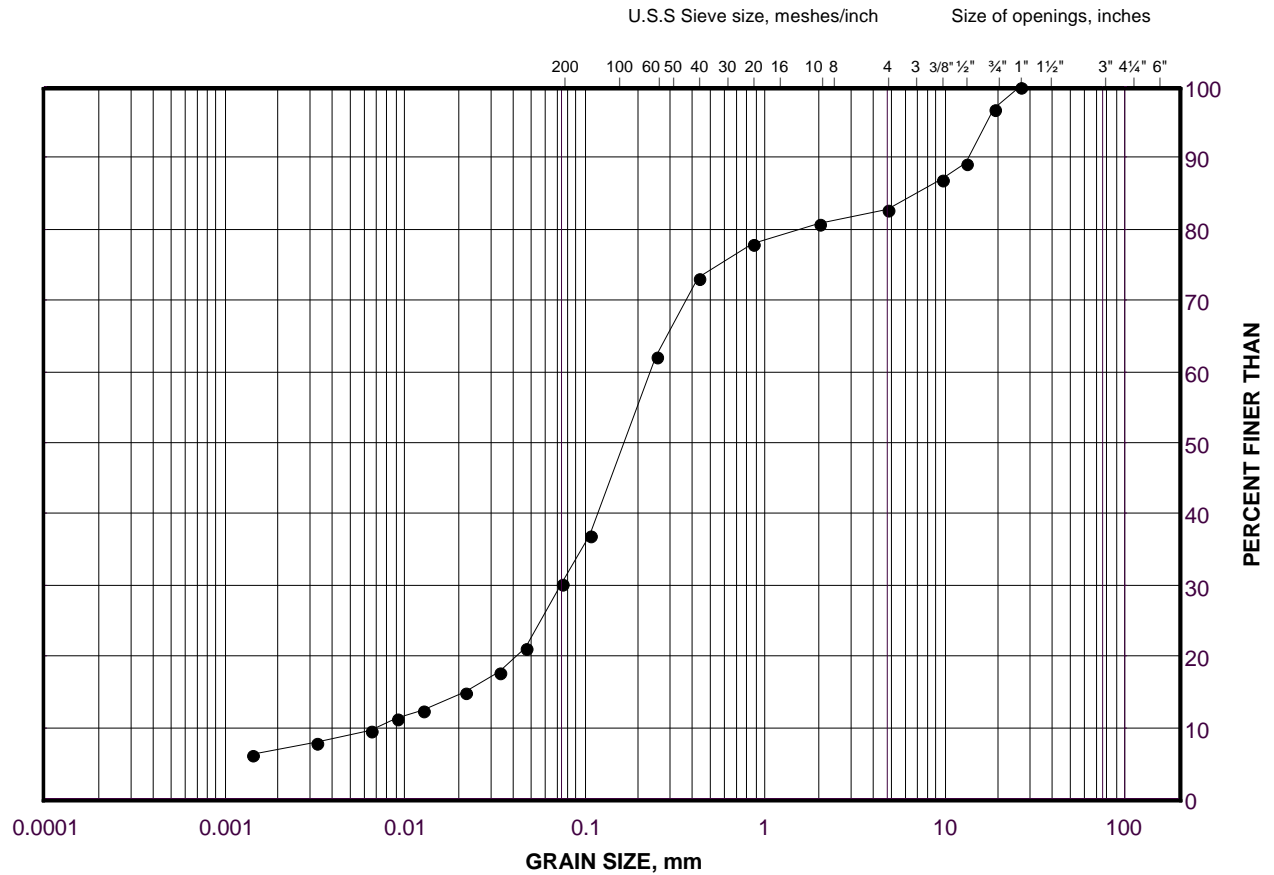
Project No. 1540419

Checked By:

# GRAIN SIZE DISTRIBUTION

Silty Sand

FIGURE B4



SILT AND CLAY SIZES		FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE
FINE GRAINED		SAND SIZE			GRAVEL SIZE		SIZE

## LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
•	C3-4	3	83.4

Project Number: 1540419

Checked By: \_\_\_\_\_

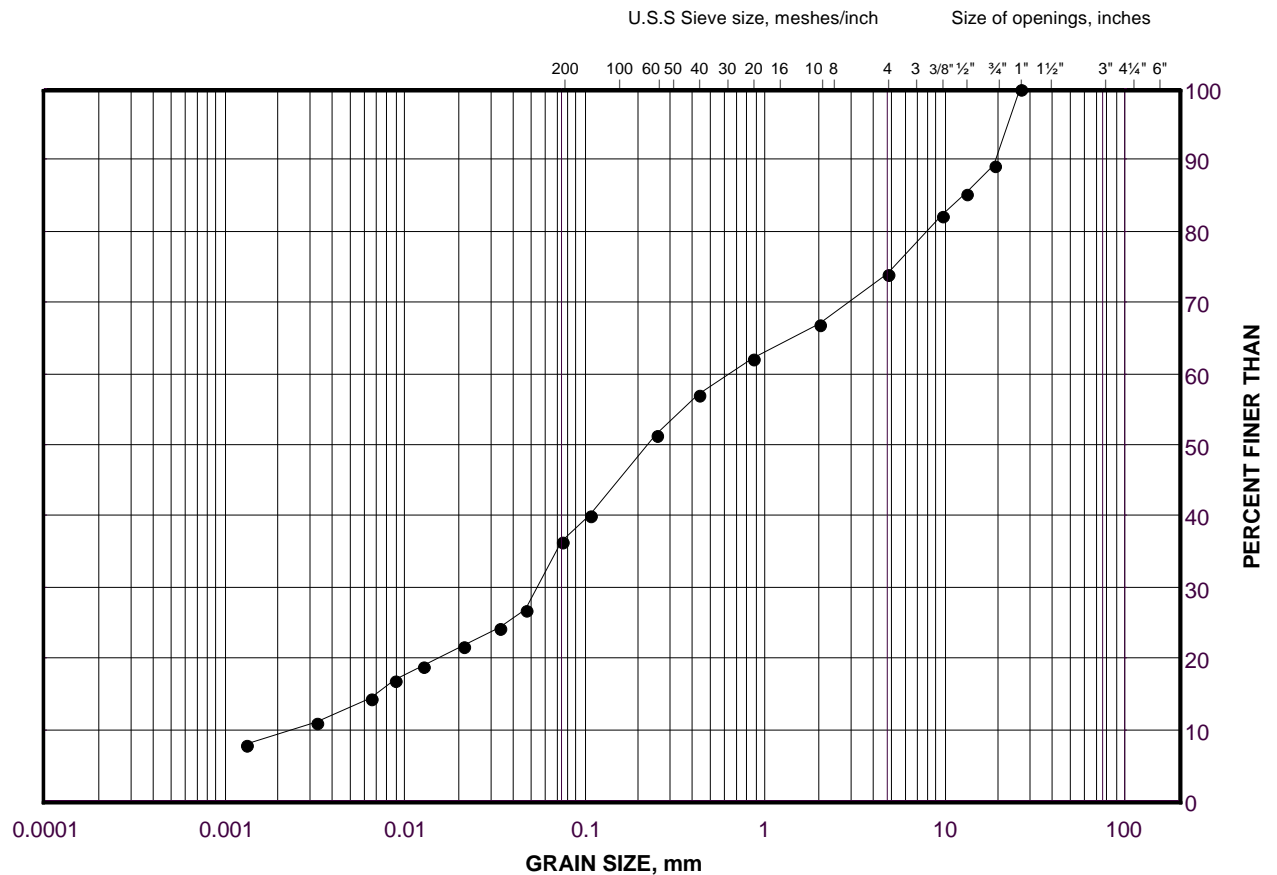
**Golder Associates**

Date: 18-Oct-16

# GRAIN SIZE DISTRIBUTION

Clayey Silt with Sand

FIGURE B5



SILT AND CLAY SIZES		FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE
FINE GRAINED		SAND SIZE			GRAVEL SIZE		SIZE

## LEGEND

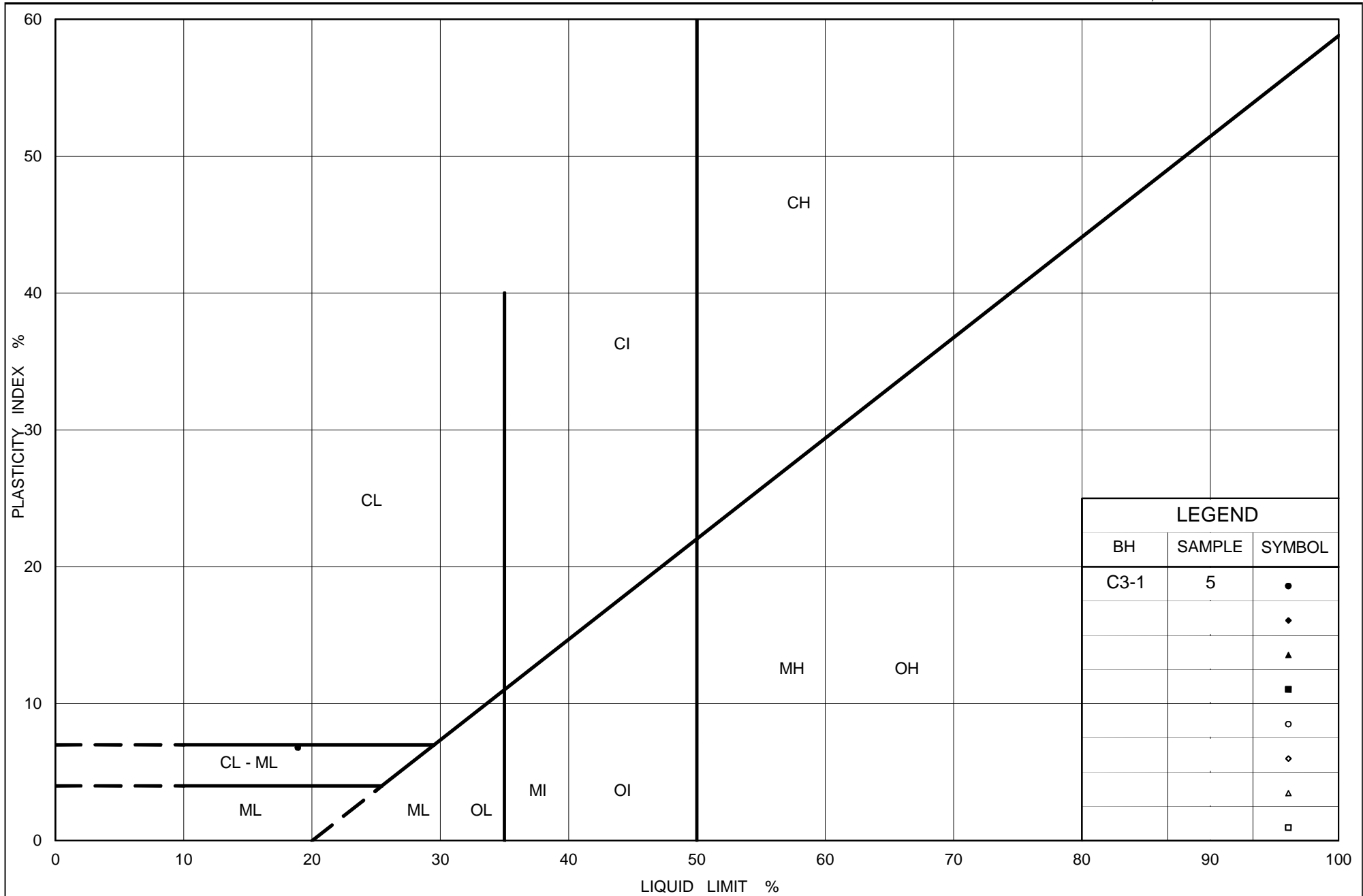
SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
•	C3-1	5	84.5

Project Number: 1540419

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Date: 18-Oct-16



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# PLASTICITY CHART Clayey Silt with Sand

Figure No. B6

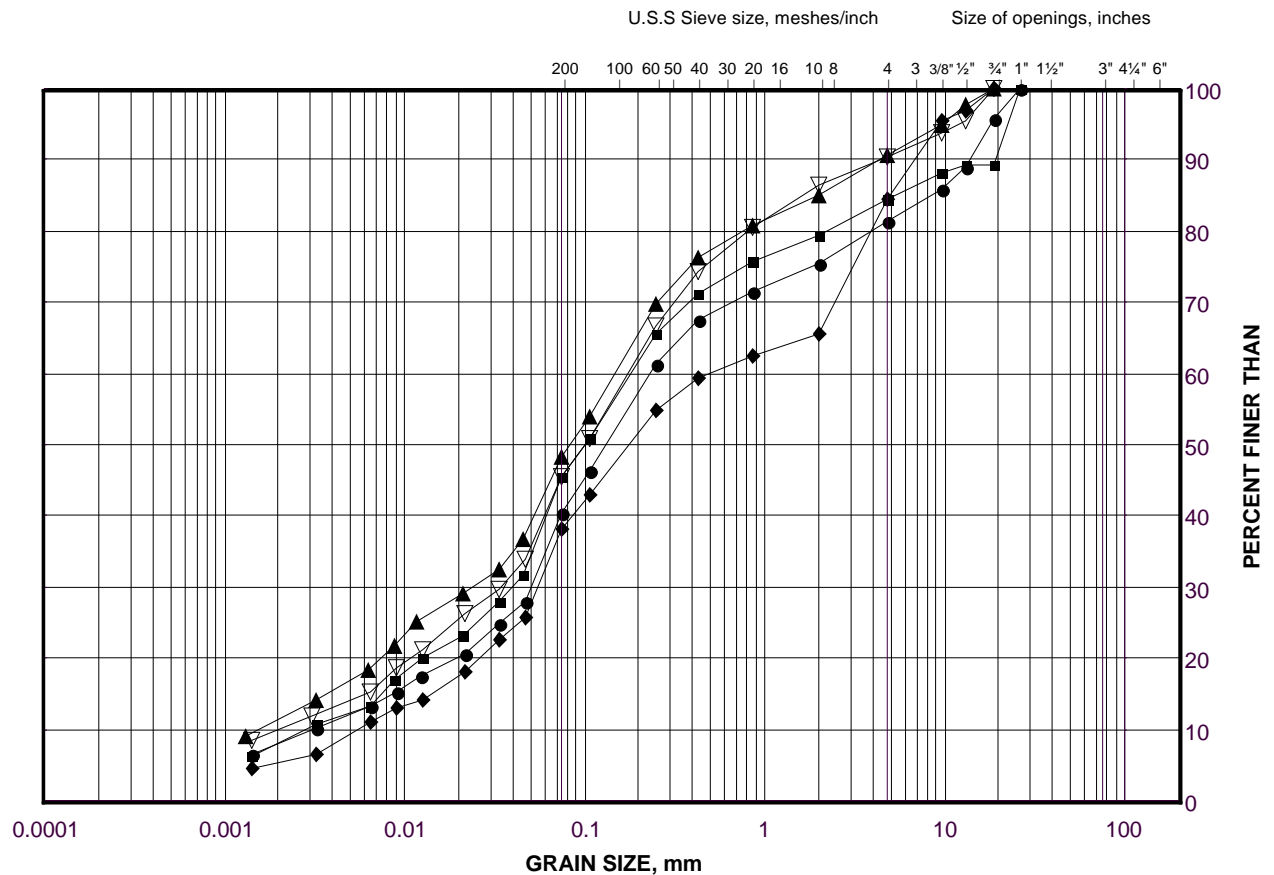
Project No. 1540419

Checked By:

# GRAIN SIZE DISTRIBUTION

Silt and Sand (Till)

FIGURE B7



SILT AND CLAY SIZES	FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE
FINE GRAINED	SAND SIZE			GRAVEL SIZE		SIZE

## LEGEND

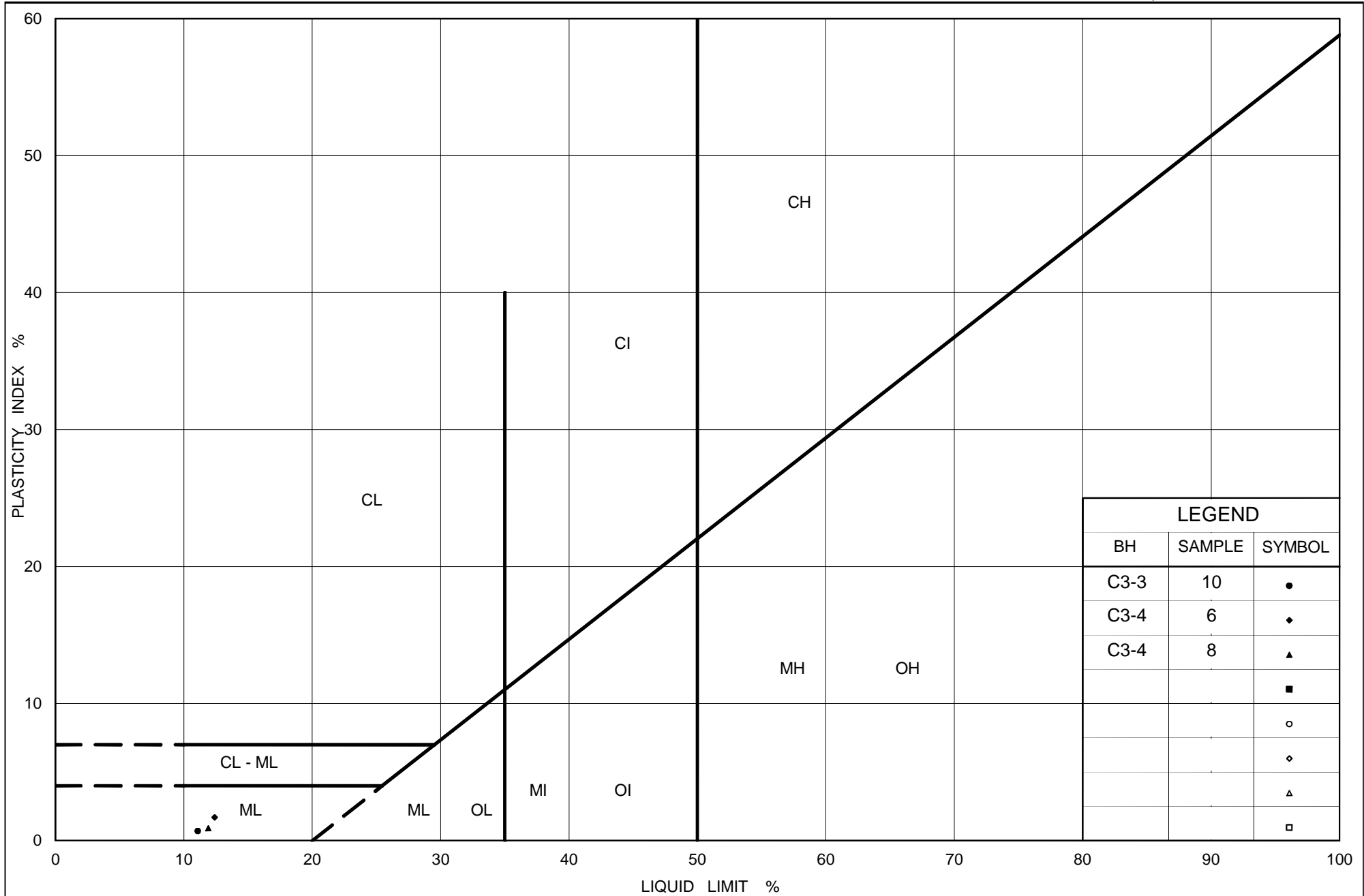
SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	C3-3	12	80.0
■	C3-2	12	80.2
◆	C3-4	6	80.3
▲	C3-1	8	80.7
▽	C3-4	8	77.2

Project Number: 1540419

Checked By: \_\_\_\_\_

**Golder Associates**

Date: 18-Oct-16



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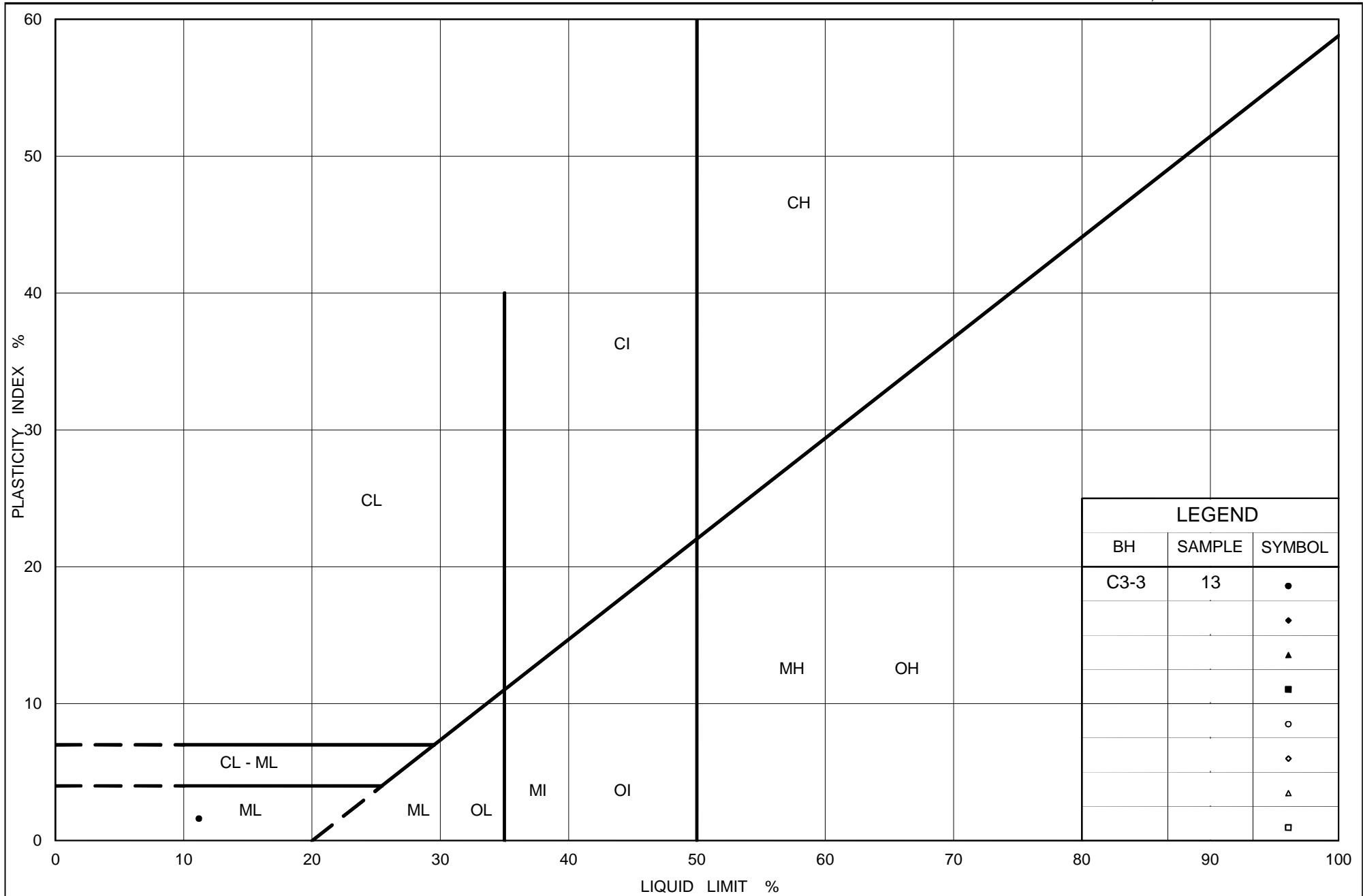
# PLASTICITY CHART Silt and Sand (Till)

Figure No. B8

Project No. 1540419

Checked By:





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## PLASTICITY CHART

### Silt (Till)

Figure No. B9

Project No. 1540419

Checked By:



# **APPENDIX C**

## **Analytical Test Results**

Your Project #: 1540419  
Your C.O.C. #: 573330-01-01

**Attention: Matt Kelly**

Golder Associates Ltd  
Mississauga - Standing Offer  
6925 Century Ave  
Suite 100  
Mississauga, ON  
CANADA L5N 7K2

**Report Date: 2016/09/29**  
Report #: R4184963  
Version: 1 - Final

**CERTIFICATE OF ANALYSIS**

**MAXXAM JOB #: B6K5174**

**Received: 2016/09/23, 12:57**

Sample Matrix: Soil  
# Samples Received: 5

Analyses	Date		Date Analyzed	Laboratory Method	Reference
	Quantity	Extracted			
Chloride (20:1 extract)	5	N/A	2016/09/29	CAM SOP-00463	EPA 325.2 m
Conductivity	5	N/A	2016/09/29	CAM SOP-00414	OMOE E3530 v1 m
pH CaCl2 EXTRACT	5	2016/09/28	2016/09/28	CAM SOP-00413	EPA 9045 D m
Resistivity of Soil	5	2016/09/23	2016/09/29	CAM SOP-00414	SM 22 2510 m
Sulphate (20:1 Extract)	5	N/A	2016/09/29	CAM SOP-00464	EPA 375.4 m

**Remarks:**

Maxxam Analytics has performed all analytical testing herein in accordance with ISO 17025 and the Protocol for Analytical Methods Used in the Assessment of Properties under Part XV.1 of the Environmental Protection Act. All methodologies comply with this document and are validated for use in the laboratory. The methods and techniques employed in this analysis conform to the performance criteria (detection limits, accuracy and precision) as outlined in the Protocol for Analytical Methods Used in the Assessment of Properties under Part XV.1 of the Environmental Protection Act.

Maxxam Analytics is accredited for all specific parameters as required by Ontario Regulation 153/04. Maxxam Analytics is limited in liability to the actual cost of analysis unless otherwise agreed in writing. There is no other warranty expressed or implied. Samples will be retained at Maxxam Analytics for three weeks from receipt of data or as per contract.

Reference Method suffix "m" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

\* RPDs calculated using raw data. The rounding of final results may result in the apparent difference.

**Encryption Key**

Please direct all questions regarding this Certificate of Analysis to your Project Manager.

Ema Gitej, Senior Project Manager

Email: EGitej@maxxam.ca

Phone# (905)817-5829

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Maxxam has procedures in place to guard against improper use of the electronic signature and have the required "signatories", as per section 5.10.2 of ISO/IEC 17025:2005(E), signing the reports. For Service Group specific validation please refer to the Validation Signature Page.

### RESULTS OF ANALYSES OF SOIL

Maxxam ID		DCX431	DCX432	DCX433	DCX434	DCX435		
Sampling Date		2016/08/23 10:00	2016/08/27 13:00	2016/08/28 13:00	2016/08/31 11:00	2016/09/08 02:00		
COC Number		573330-01-01	573330-01-01	573330-01-01	573330-01-01	573330-01-01		
	UNITS	C1	C2	C3	C4	C9	RDL	QC Batch
<b>Calculated Parameters</b>								
Resistivity	ohm-cm	1800	1900	1300	1500	880		4673817
<b>Inorganics</b>								
Soluble (20:1) Chloride (Cl)	ug/g	190	280	410	360	570	20	4681464
Conductivity	umho/cm	557	540	798	687	1130	2	4681504
Available (CaCl2) pH	pH	7.57	7.77	7.63	7.61	7.42		4679490
Soluble (20:1) Sulphate (SO4)	ug/g	200	26	<20	<20	<20	20	4681465
RDL = Reportable Detection Limit								
QC Batch = Quality Control Batch								

## TEST SUMMARY

**Maxxam ID:** DCX431  
**Sample ID:** C1  
**Matrix:** Soil

**Collected:** 2016/08/23  
**Shipped:**  
**Received:** 2016/09/23

Test Description	Instrumentation	Batch	Extracted	Date Analyzed	Analyst
Chloride (20:1 extract)	KONE/EC	4681464	N/A	2016/09/29	Alina Dobreanu
Conductivity	AT	4681504	N/A	2016/09/29	Neil Dassanayake
pH CaCl2 EXTRACT	AT	4679490	2016/09/28	2016/09/28	Neil Dassanayake
Resistivity of Soil		4673817	2016/09/29	2016/09/29	Automated Statchk
Sulphate (20:1 Extract)	KONE/EC	4681465	N/A	2016/09/29	Alina Dobreanu

**Maxxam ID:** DCX432  
**Sample ID:** C2  
**Matrix:** Soil

**Collected:** 2016/08/27  
**Shipped:**  
**Received:** 2016/09/23

Test Description	Instrumentation	Batch	Extracted	Date Analyzed	Analyst
Chloride (20:1 extract)	KONE/EC	4681464	N/A	2016/09/29	Alina Dobreanu
Conductivity	AT	4681504	N/A	2016/09/29	Neil Dassanayake
pH CaCl2 EXTRACT	AT	4679490	2016/09/28	2016/09/28	Neil Dassanayake
Resistivity of Soil		4673817	2016/09/29	2016/09/29	Automated Statchk
Sulphate (20:1 Extract)	KONE/EC	4681465	N/A	2016/09/29	Alina Dobreanu

**Maxxam ID:** DCX433  
**Sample ID:** C3  
**Matrix:** Soil

**Collected:** 2016/08/28  
**Shipped:**  
**Received:** 2016/09/23

Test Description	Instrumentation	Batch	Extracted	Date Analyzed	Analyst
Chloride (20:1 extract)	KONE/EC	4681464	N/A	2016/09/29	Alina Dobreanu
Conductivity	AT	4681504	N/A	2016/09/29	Neil Dassanayake
pH CaCl2 EXTRACT	AT	4679490	2016/09/28	2016/09/28	Neil Dassanayake
Resistivity of Soil		4673817	2016/09/29	2016/09/29	Automated Statchk
Sulphate (20:1 Extract)	KONE/EC	4681465	N/A	2016/09/29	Alina Dobreanu

**Maxxam ID:** DCX434  
**Sample ID:** C4  
**Matrix:** Soil

**Collected:** 2016/08/31  
**Shipped:**  
**Received:** 2016/09/23

Test Description	Instrumentation	Batch	Extracted	Date Analyzed	Analyst
Chloride (20:1 extract)	KONE/EC	4681464	N/A	2016/09/29	Alina Dobreanu
Conductivity	AT	4681504	N/A	2016/09/29	Neil Dassanayake
pH CaCl2 EXTRACT	AT	4679490	2016/09/28	2016/09/28	Neil Dassanayake
Resistivity of Soil		4673817	2016/09/29	2016/09/29	Automated Statchk
Sulphate (20:1 Extract)	KONE/EC	4681465	N/A	2016/09/29	Alina Dobreanu

**Maxxam ID:** DCX435  
**Sample ID:** C9  
**Matrix:** Soil

**Collected:** 2016/09/08  
**Shipped:**  
**Received:** 2016/09/23

Test Description	Instrumentation	Batch	Extracted	Date Analyzed	Analyst
Chloride (20:1 extract)	KONE/EC	4681464	N/A	2016/09/29	Alina Dobreanu
Conductivity	AT	4681504	N/A	2016/09/29	Neil Dassanayake

Maxxam Job #: B6K5174  
Report Date: 2016/09/29

Golder Associates Ltd  
Client Project #: 1540419  
Sampler Initials: MK

## TEST SUMMARY

**Maxxam ID:** DCX435  
**Sample ID:** C9  
**Matrix:** Soil

**Collected:** 2016/09/08  
**Shipped:**  
**Received:** 2016/09/23

Test Description	Instrumentation	Batch	Extracted	Date Analyzed	Analyst
pH CaCl2 EXTRACT	AT	4679490	2016/09/28	2016/09/28	Neil Dassanayake
Resistivity of Soil		4673817	2016/09/29	2016/09/29	Automated Statchk
Sulphate (20:1 Extract)	KONE/EC	4681465	N/A	2016/09/29	Alina Dobreanu

### GENERAL COMMENTS

Each temperature is the average of up to three cooler temperatures taken at receipt

Package 1	6.7°C
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**Results relate only to the items tested.**

## QUALITY ASSURANCE REPORT

QC Batch	Parameter	Date	Matrix Spike		SPIKED BLANK		Method Blank		RPD	
			% Recovery	QC Limits	% Recovery	QC Limits	Value	UNITS	Value (%)	QC Limits
4679490	Available (CaCl <sub>2</sub> ) pH	2016/09/28			99	97 - 103			0.48	N/A
4681464	Soluble (20:1) Chloride (Cl)	2016/09/29	NC	70 - 130	109	70 - 130	<20	ug/g	NC	35
4681465	Soluble (20:1) Sulphate (SO <sub>4</sub> )	2016/09/29	NC	70 - 130	107	70 - 130	<20	ug/g	NC	35
4681504	Conductivity	2016/09/29			99	90 - 110	<2	umho/cm	2.9	10

N/A = Not Applicable

Duplicate: Paired analysis of a separate portion of the same sample. Used to evaluate the variance in the measurement.

Matrix Spike: A sample to which a known amount of the analyte of interest has been added. Used to evaluate sample matrix interference.

Spiked Blank: A blank matrix sample to which a known amount of the analyte, usually from a second source, has been added. Used to evaluate method accuracy.

Method Blank: A blank matrix containing all reagents used in the analytical procedure. Used to identify laboratory contamination.

NC (Matrix Spike): The recovery in the matrix spike was not calculated. The relative difference between the concentration in the parent sample and the spiked amount was too small to permit a reliable recovery calculation (matrix spike concentration was less than 2x that of the native sample concentration).

NC (Duplicate RPD): The duplicate RPD was not calculated. The concentration in the sample and/or duplicate was too low to permit a reliable RPD calculation (one or both samples < 5x RDL).



### VALIDATION SIGNATURE PAGE

The analytical data and all QC contained in this report were reviewed and validated by the following individual(s).

*Cristina Carriere*

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Cristina Carriere, Scientific Services

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Maxxam has procedures in place to guard against improper use of the electronic signature and have the required "signatories", as per section 5.10.2 of ISO/IEC 17025:2005(E), signing the reports. For Service Group specific validation please refer to the Validation Signature Page.





# **APPENDIX D**

## **Non-Standard Special Provisions**

## **PIPE INSTALLATION BY TRENCHLESS METHOD – Item No.**

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Special Provision

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### **CONSTRUCTION SPECIFICATION FOR THE INSTALLATION OF PIPES BY TRENCHLESS METHODS**

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<b>4.0</b>	<b>DESIGN AND SUBMISSION REQUIREMENTS</b>
<b>5.0</b>	<b>MATERIALS</b>
<b>6.0</b>	<b>EQUIPMENT</b>
<b>7.0</b>	<b>CONSTRUCTION</b>
<b>8.0</b>	<b>QUALITY ASSURANCE- Not Used</b>
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#### **1. SCOPE**

This specification covers the general requirements for the installation of pipes by trenchless methods, including Jack & Bore, Pipe Ramming, Directional Drilling, and Tunnelling. The Contractor shall determine the most appropriate method of installation for each of the crossing locations.

This specification shall supersede OPSS 415 (Construction Specification for Pipeline Installation by Tunneling), OPSS 416 (Construction Specification for Pipeline and Utility Installation by Jacking and Boring) and OPSS 450 (Construction Specification for Pipeline and Utility Installation in Soil by Horizontal Directional Drilling).

#### **2. REFERENCES**

This specification refers to the following standards, specifications, or publications:

##### **Ontario Provincial Standard Specifications, General**

OPSS 180      Management and Disposal of Excess Materials

##### **Ontario Provincial Standard Specifications, Construction**

OPSS 401	Trenching, Backfilling, and Compacting
OPSS 404	Support Systems
OPSS 491	Preservation, Protection, and Reconstruction of Existing Facilities
OPSS 492	Site Restoration Following Installation of Pipelines, Utilities and Associated Structures
OPSS 517	Dewatering of Pipeline, Utility, and Associated Structure Excavation
OPSS.PROV 539	Temporary Protection Systems

### **Ontario Provincial Standard Specifications, Material**

OPSS.PROV 1004	Aggregates - Miscellaneous
OPSS.PROV 1350	Concrete - Materials and Production
OPSS.PROV 1440	Steel Reinforcement for Concrete
OPSS 1802	Smooth Walled Steel Pipe
OPSS.PROV 1820	Circular and Elliptical Concrete Pipe
OPSS 1840	Non-Pressure Polyethylene (PE) Plastic Pipe Products

### **American Society for Testing and Materials (ASTM) International Standards**

ASTM A252-93	Welding and Seamless Steel Pipe Piles
ASTM D2657-03	Standard Practice for Heat Fusion Joining of Polyelofin Pipe and Fittings
ASTM D3350	Standard Specification for Polyethylene Plastics Pipe and Fittings Materials
ASTM F894	Polyethylene Large Diameter Profile Wall Sewer and Drain Pipe

### **Canadian Standards Association Standards:**

CSA B182.6	Profile Polyethylene Sewer Pipe and Fittings.
CAN/CSA A5-93	Portland Cement
CSA W59	Welded Steel Construction (Metal Arc Welding)

## **3. DEFINITIONS**

For the purpose of this specification, the following definitions apply:

**Auger Jack & Bore:** a method of forming a horizontal bore in the subsurface by essentially simultaneously jacking ahead and rotating a cutter head, followed by removal of material from inside the bore by using an auger.

**Backreamer:** a cutting head suitably designed for the subsurface conditions that is attached to the end of a drill string to enlarge the pilot bore during a pullback operation.

**Bore Path:** a drilled path according to the grade and alignment tolerances specified in the Contract Documents.

**Design Engineer:** means the Engineer retained by the Contractor who produces the original design and working drawings. The design engineer shall be licensed to practice in the Province of Ontario.

**Design Checking Engineer:** means the Engineer retained by the Contractor who checks the original design and working drawings. The design checking engineer shall be licensed to practice in the Province of Ontario.

**Digger Shield/Hand Mining:** a method of forming a horizontal bore in the subsurface by essentially simultaneously jacking ahead while tunnelling advances using hand-mining (man-entry operation or “Jack

and Mine) or a “digger” type shield with a hydraulic excavator arm to remove materials from inside the liner pipe.

**Drilling Fluids:** a mixture of water and additives, such as bentonite, polymers, surfactants, and soda ash, designed to block the pore space on a bore wall, reduce friction in the bore, and to suspend and carry cuttings to the surface.

**Drilling Fluid Fracture or Frac Out:** a condition where the drilling fluid’s pressure in the bore is sufficient to overcome the in situ confining stress, thereby fracturing the soil and/or rock materials and allowing the drilling fluids to migrate to the surface at an unplanned location.

**Engineer:** a Professional Engineer licensed by the Professional Engineers of Ontario to practice in the Province of Ontario.

**Excavation:** includes all materials encountered regardless of type and extent. Excavation shall include removal of natural soil, large boulders, cobbles, wood and fill regardless of means necessary to break consolidated materials for removal.

**Environmentally Sensitive Area (ESA):** areas adjacent to construction that are off limits to the Contractor as specified elsewhere in the Contract.

**Fill:** man-made mixture of previously placed/handled materials such as sand, clay, silt, gravel, broken rock, sometimes containing organic and/or deleterious materials, placed in an excavation or other area to raise the surface elevation.

**Grouting:** injection of grout into voids.

**Guidance System:** an electronic system capable of locating the position, depth and orientation of the drill head during the directional drilling process.

**Directional Drilling (DD):** directional boring or guided boring.

**HDPE:** high density polyethylene.

**Inadvertent Returns:** the flow of unexpected fluids, saturated materials (or running soil) towards the drilling rig that typically originated from an artesian aquifer encountered during the drilling process.

**Loss of Circulation:** the discontinuation of the flow of drilling fluid in the bore back to the entry or exit point or other planned recovery points.

**Pilot Bore:** the initial bore to set directional controlled horizontal and vertical alignment between the connecting points.

**Pipe Jacking:** a method for installing steel casing or concrete pipe in the subsurface utilizing hydraulically operated jacks of adequate number and capacity to ensure smooth and uniform advancement without overstressing the liner/pipe.

**Pipe Ramming:** a method for installing steel casings utilizing the energy from a percussion hammer to advance a steel casing with a cutting shoe attached at the front end of the casing.

**Primary Liner (Support):** system installed prior to or concurrent with excavation, to maintain stability of an

excavation and to support earth or rock and any structure utilities or other facilities in or on the supported earth or rock mass, until the excavation is completed.

**Product:** pipe culverts, pipe sewers, watermain pipe and sanitary pipe.

**Pullback:** that part of the DD method in which the drill string is pulled back through the bore path to the entry point.

**Quality Verification Engineer (QVE):** an Engineer who has a minimum of five (5) years experience in the field of pipe installation using trenchless methods or alternatively has demonstrated expertise by providing satisfactory quality verification services for the work at a minimum of two (2) projects of similar scope to the contract. The Quality Verification Engineer shall be retained by the Contractor to certify that the work is in general conformance with the contract documents and to issue Certificate(s) of Conformance.

**Reaming:** a process for pulling a tool attached to the end of the drill string through the bore path to enlarge the bore and mix the cuttings with the drilling fluid. This typically includes multiple passes.

**Rock:** natural beds or massive fragments, or the hard, stable, cemented part of the earth's crust, igneous, metamorphic, or sedimentary in origin, which may or may not be weathered and includes boulders having a size equivalent to 0.3 m in diameter or greater.

**Secondary Liner:** concrete pipe, HDPE pipe or un-reinforced cast-in-place concrete, installed subsequent to tunnel excavation.

**Shaft:** vertically sided excavation used as entry and/or exit points from which the trenchless method is initiated or directed for the installation of product.

**Strike Alert:** a system that is intended to alert and protect the operator in the case of inadvertent drilling into an electrical utility cable. The strike alert system consists of a sensor and an alarm connected to the drill rig and a grounding stake. The alarm may be audio or visual or both.

**Slurry:** a mixture of soil and/or rock cuttings, and drilling fluid.

**Soil:** all materials except those defined as rock, and excludes stone masonry, concrete, and other manufactured materials; includes rock fragments having an equivalent size less than 0.3 m in diameter.

**Trenchless Installation:** an underground method of constructing a passage open at both ends that involves installing a pipe. For the purpose of this specification, the pipe may be installed by any of the various methods defined herein such as Auger Jack & Boring, Pipe Jacking, Pipe Ramming, Directional Drilling, or using a tunnelling machine or hand mining methods.

**Tunnelling:** An underground method of constructing a passage using a tunnel boring machine (TBM), a microtunnel boring machine (MTBM) or hand mining using a shield to support the opening.

## **DESIGN AND SUBMISSION REQUIREMENTS**

### **4.01 General**

The Contractor's documentation, submission requirements and installation methods shall specifically consider and address the subsurface conditions at each pipe crossing as identified in the Foundation Investigation Report or elsewhere in the Contract Documents.

#### **4.02 Working Drawings**

Three copies of stamped working drawings for portal or shaft construction, primary liner, excavation, secondary lining, dewatering and groundwater control and grouting shall be submitted to the Contract Administrator (CA) at least one week prior to the commencement of the work for information purposes. All submissions shall bear the seal and signature of the Design Engineer and Design Checking Engineer. The Contractor shall have a copy of the stamped working drawings at the site during construction.

As a minimum, working drawings/details pertaining to the tunnel design and construction shall include the following (as appropriate):

a) Plans, Elevations and Details:

- A work plan outlining the materials, procedures, methods and schedule to be used to execute the work;
- A list of personnel, including backup personnel, and their qualifications and experience;
- A safety plan including the company safety manual and emergency procedures;
- The work area layout;
- An erosion and sediment control plan that includes a contingency plan in the event the erosion and sediment control measures fail;
- A drilling fluid management plan, if applicable, that addresses control of frac-out pressures, any potential environmental impacts and includes a contingency plan detailing emergency procedures in the event that the fluid management plan fails;
- Lighting, ventilation and fire safety details as may be required by applicable occupational health and safety regulations; and
- Excavated materials disposal plan.

b) Design Criteria:

- Primary liner design details, if applicable;
- Design assumption and material data when materials other than those specified are proposed for use; and
- Drill path design, details of alignment and alignment control, maximum curvature and reaming stages.

c) Materials:

- Certification from the manufacturer that the product furnished on the contract meets the specifications cited in the manufacturer's product specification and that the materials supplied are suitable for the application; and
- Material mixture for filling voids and installation procedures.

d) Upstream/Downstream Portal Installation Procedure:

- The access shaft or entry/exit pit details designed and stamped/signed by the Design Engineer, as applicable; and
- Face support and other temporary support details, if applicable.

e) Primary Liner/Secondary Liner Installation and Grouting Procedure:

- Excavation and pipe installation procedures, including methods to handle obstructions and prevent soil cave-in; and
- Details of tunnelling equipment/methods to be used for the works.

f) Excavation and Dewatering:

- Ground control/dewatering details, as applicable, describing the proposed method for control, handling, treatment, and disposal of water.



g) Monitoring Method:

The methods to be employed to monitor and maintain the alignment of the installation.

#### **4.03 Site Survey**

Prior to commencing the work, the Contractor shall, at each pipe location, lay-out the alignment and install settlement monitoring points.

#### **4.04 Certificate of Conformance**

The Contractor shall submit details of the sequence and method of construction to the Quality Verification Engineer for review, prepared and stamped by the Design Engineer. The Contractor shall submit to the Contract Administrator a Certificate of Conformance sealed and signed by the Quality Verification Engineer a minimum of one week prior to commencement of work under this item. The Certificate shall state that the construction procedures are in conformance with the requirements and specifications of the contract documents.

The Contractor shall submit to the Contract Administrator a Certificate of Conformance sealed and signed by the Quality Verification Engineer upon completion of each of the following operations and prior to commencement of each subsequent operation for each pipe installation:

Site Surveying (as noted in Section 4.02)s  
Excavation for pits including dewatering of excavations  
Jacking/Ramming/Directional Drilling of Casing/Liner  
Installation of the Product  
Grouting Operations

Each Certificate of Conformance shall state that the work has been carried out in general conformance with the contract documents, specifications and/or stamped working drawings.

In addition, upon completion of the installation of the pipe at each location, the Contractor shall submit to the Contract Administrator a final Certificate of Conformance sealed and signed by the Quality Verification Engineer. The Certificate shall state that the pipe has been installed in general conformance with the Contractor's Submission and Design Requirements, stamped working drawings and contract documents.

The Design Engineer will not be permitted to carry out the work of the Quality Verification Engineer.

### **5. MATERIALS**

#### **5.01 Product**

The product shall be concrete pipe or high density polyethylene pipe as specified.

#### **5.02 Concrete**

Concrete shall be according to OPSS.PROV 1350. The concrete strength shall be as specified in the Contractor's design submission.

#### **5.03 Concrete Reinforcement**

Steel reinforcing for concrete work shall be according to OPSS.PROV 1440.

#### **5.04 Timber**

Timber shall be sound, straight, and free from cracks, shakes and large or loose knots.

#### **5.05 Grout**

The Contractor shall submit the proposed grout mix design for grouts to be used for lubricating jacking pipe and for filling of voids and annular spaces. Purging grout shall consist of a mixture of one part Portland cement conforming to the requirements of CAN/CSA A5-93 and two parts mortar sand conforming to OPSS.PROV 1004 wetted with only sufficient water to make the mixture plastic.

#### **5.06 Auger Jack & Bore Materials**

##### **5.06.01 Pipe Materials**

Steel pipe shall conform with ASTM A252-93 welded joints suitable for jacking operations. The Contractor shall select pipe class for pipe jacking.

Concrete pipe as per OPSS.PROV 1820.

Fittings shall be suitable for and compatible with the class and type of pipe with which they will be used.

#### **5.07 Pipe Ramming Materials**

##### **5.07.01 Pipe Materials**

Steel pipe shall conform with ASTM A 252-93 welded joints.

New steel casing when specified shall be smooth wall carbon steel pipe according to ASTM A252-93 Grade 2.

Used steel casing can be used provided that the steel casing can resist the applicable static and dynamic loadings.

Pipe wall thickness shall be determined by the Contractor based on static and dynamic loads from traffic loading and anticipated ramming forces for selected pipe and driven pipe lengths. The wall thickness shall be increased as required to ensure the casing is not damaged during handling and installation. The pipe minimum wall thickness shall be as per Table 1 of OPSS 1802.

Pipe segments shall be determined by the Contractor.

Steel pipe joints shall be pressure fit type or welded.

All steel casing pipe shall be square cut.

Steel casing pipe shall have roundness such that the difference between the major and minor outside diameters shall not exceed 1% of the specified nominal outside diameter or 6 mm, whichever is less.

Steel casing pipe shall have a minimum allowable straightness of 1.5 mm maximum per metre of length.

### **5.07.02 Mill Certificates**

For permanent casing, the Contractor shall submit to the Contract Administrator at the time of delivery one copy of the mill certificate, indicating that the steel meets the requirements for the appropriate standards for casings.

Where mill test certificates originate from a mill outside Canada or the United States of America the Contractor shall have the information on the mill certificate verified by testing by a Canadian laboratory. The laboratory shall be accredited by a Canadian National Accreditation Body to comply with the requirements of ISO/IEC Guide 25 for the specific tests or type of tests required by the material standard specified on the mill test certificate. The mill test certificates shall be stamped with the name of the Canadian testing laboratory and appropriate wording stating that the material conforms to the specified material requirements. The stamp shall include the appropriate material specification number, the date and the signature of an authorized officer of the Canadian testing laboratory.

## **5.08 Directional Drilling Materials**

### **5.08.01 Drilling Fluids**

The drilling fluids shall be mixed according to the manufacturer's recommendations and be appropriate for the anticipated subsurface conditions.

### **5.08.02 Pipe Materials**

High Density Polyethylene (HDPE) pipe as per OPSS 1840 shall be used in accordance with ASTM D3350.

The requirements for fittings shall be suitable for and compatible with the class and type of pipe with which they will be used and in according to CAN/CSA-B182.6 or ASTM F894.

The Contractor shall determine the required dimensional ratio (DR) of the HDPE pipe to support all subsurface conditions and hydrostatic pressures, and to withstand the grouting pressure and installation forces. The Contractor shall identify these forces in his submission requirements.

The Contractor's submission shall demonstrate, in conjunction with the manufacturer's specifications, that the heat resistance of the pipe material is sufficient to tolerate without damage the heat of hydration generated by grout curing.

Fittings shall be suitable for and compatible with the class and type of pipe with which they will be used.

Jointing of HDPE piping shall be completed by thermal butt fusion in accordance with manufacturer's recommended procedures and as outlined in the latest revision of ASTM D2657. All manufacturer's recommendations and procedures shall be followed during the jointing process.

Jointing of HDPE piping to other piping materials or appurtenances shall be completed using flanged connections.

## **5.09 Tunnelling Materials**

### **5.09.01 Primary Liner**

Tunnelling methods will require installation of a primary liner. The primary liner shall be designed by the

Contractor and the design/drawings shall be stamped/signed by the Design Engineer. The design shall be submitted to the Contract Administrator as specified herein.

## **5.09.02 Secondary Liner**

Concrete or High Density Polyethylene Pipe shall be used according to the following requirements.

### **5.09.02.01 Concrete Pipe**

Concrete pipe as per OPSS.PROV 1820 shall be used. The Contractor shall select the pipe class to withstand grouting pressure and installation forces. The Contractor shall identify these forces in his submission requirements.

Fittings shall be suitable for and compatible with the class and type of pipe with which they will be used.

### **5.09.02.02 High Density Polyethylene (HDPE)**

High Density Polyethylene (HDPE) pipe as per OPSS 1840 shall be used in accordance with ASTM D3350.

The requirements for fittings shall be according to CAN/CSA-B182.6 or ASTM F894.

The Contractor shall determine the required dimensional ratio (DR) to withstand the grouting pressure and installation forces. The Contractor shall identify these forces in his submission requirements.

Fittings shall be suitable for and compatible with the class and type of pipe with which they will be used.

Jointing of HDPE piping shall be completed by thermal butt fusion in accordance with manufacturer's recommended procedures and as outlined in the latest revision of ASTM D2657. All manufacturer's recommendations and procedures shall be followed during the jointing process.

Jointing of HDPE piping to other piping materials shall be completed using flanged connections.

## **6. EQUIPMENT**

### **6.01 Auger Jack & Bore Equipment**

Pipe auger jack & bore equipment shall be determined by the Contractor and shall be identified in the submission requirements specified herein.

Specific details of the manner in which rock or boulders will be broken and removed from the face and the face will be protected to prevent soil loss into the liner shall be submitted to the Contract Administrator for information purposes prior to proceeding with the works.

### **6.02 Pipe Ramming Equipment**

Pipe ramming equipment shall be determined by the Contractor and shall be identified in the submission requirements specified herein.

The pipe ramming hammer(s) shall be capable of driving the pipe casing from the drive pit through the existing subsurface conditions at the site.

Specific details of the manner in which rock or boulders will be broken and removed from the face and the face will be protected to prevent soil loss into the pipe shall be submitted to the Contract Administrator for information purposes prior to proceeding with the works.

### **6.03 Directional Drilling Equipment**

#### **6.03.01 General**

The directional drilling equipment shall consist of a directional drilling rig and a drilling fluid mixing and delivery system of sufficient capacity to successfully complete the product installation without exceeding the maximum tensile strength of the product being installed.

#### **6.03.02 Drilling Rig**

The directional drilling rig shall:

- consist of a leak free hydraulically powered boring system to rotate, push, and pull hollow drill pipe into the ground at a variable angle while delivering a pressurized fluid mixture to a guidable drill head;
- contain a guidance system to accurately guide boring operations;
- be anchored to the ground to withstand the rotating, pushing, and pulling forces required to complete the product installation; and
- be grounded during all operations unless otherwise specified by the drilling rig manufacturer.

#### **6.03.03 Drill Head**

The drill head shall be steerable by changing its rotation, be equipped with the necessary cutting surfaces and drilling fluid jets, and be of the type for the anticipated subsurface conditions,

#### **6.03.04 Guidance System**

The guidance system shall be setup, installed, and operated by trained and experienced personnel. The operator shall be aware of any magnetic or electromagnetic anomalies and shall consider such influences in the operation of the guidance system when a magnetic or electromagnetic system is used.

#### **6.03.05 Drilling Fluid Mixing System**

The drilling fluid mixing system shall be of sufficient size to thoroughly and uniformly mix the required drilling fluid.

#### **6.03.06 Drilling Fluid Delivery System**

The delivery system shall have a means of measuring and controlling fluid pressures and be of sufficient flow capacity to ensure that all slurry volumes are adequate for the length and diameter of the final bore and the anticipated subsurface conditions. Connections between the delivery pump and drill pipe shall be leak-free.

### **6.04 Tunnelling Equipment**

Tunnelling equipment shall be determined by the Contractor and shall be identified in the submission requirements specified herein.

Specific details of the manner in which rock or boulders will be broken and removed from the tunnel face

shall be submitted to the Contract Administrator information purposes. Use of rock fracturing chemicals shall only be considered subject to a field demonstration satisfactory to the Ministry prior to its use. Use of explosives is prohibited.

## **7. CONSTRUCTION**

### **7.01 General**

The Contractor shall notify the Contract Administrator at least 48 hours in advance of starting work. The proposed method of pipe installation to be used by the Contractor shall be submitted to the Contract Administrator for information purposes prior to commencing the work and shall be subject to the limitations presented in the following subsections.

#### **7.01.01 Layout, Alignment and Depth Control**

The location of the installation shall be established from the lines, elevations and tolerances specified in the Contract Documents. The pipe installation shall be to the horizontal and vertical alignments specified in the Contract Drawings. Deviations from location, alignment, grades and/or invert levels shall be corrected by the Contractor at no cost to the Ministry.

All reference points necessary to construct the pipe installation and appurtenances shall be laid out.

The Contractor shall calibrate tracking and locating equipment at the beginning of each work day, and shall monitor and record the alignment and depth readings provided by the tracking system at every 5 m in normal conditions and every 2 m where precise alignment control is necessary;

The Contract Administrator shall be provided with the assistance and access necessary to check the layout of the pipe installation and associated appurtenances.

All excavations shall be carried out in accordance with the Occupational Health and Safety Act (OHSA) of Ontario.

For directional drilling, the contractor shall ensure that during pilot hole drilling the maximum degree of deviation or “dog-leg” shall be 2.5 degrees per 9m drill pipe length. Any deviation exceeding 2.5 degrees will necessitate a pull-back and straightening of the alignment at the Contractor’s sole expense. The pilot hole exit location shall be within 0.5m of the target location.

#### **7.01.02 Construction Shafts**

Construction shafts shall be specified in the Contractor's submission. The boundaries and protection of these shall be as required to contain all disturbances to areas outside of the ESA limits.

Shafts shall be maintained in a drained condition.

A minimum 2.4 m high secure fence shall be installed around the perimeter of the construction shaft area with gates and truck entrances. The fence shall be removed on completion of the work.

#### **7.01.03 Protection Systems**

The construction of all protection systems shall be according to OPSS.PROV 539. Where the stability, safety, or function of an existing roadway, watercourse, other works, proposed works or ESA’s may be impaired due

to the method of operation, protection shall be provided. Protection may include sheathing, shoring, and piles where necessary to prevent damage to such works or proposed works.

#### **7.01.04 Settlement or Heave**

Any disturbance to the ground surface (settlement or heave) as a result of the pipe installation shall be immediately corrected by the Contract, at no additional cost to the Ministry.

#### **7.01.05 Stability of Excavation**

The construction methods, plant, procedures, and precautions employed shall ensure that excavations are stable, free from disturbance, and maintained in a drained condition.

The construction methods, plant, and materials employed shall prevent the migration of soil and/or rock material into the excavation from adjacent ground.

#### **7.01.06 Preservation and Protection of Existing Facilities**

Preservation and protection of existing facilities shall be according to OPSS 491.

Minimum horizontal and vertical clearances to existing facilities as specified in the Contract Documents shall be maintained. Clearances shall be measured from the nearest edge of the largest cut diameter required to the nearest edge of the facility being paralleled or crossed.

Existing underground facilities shall be exposed to verify its horizontal and vertical locations when the outlet pipe path comes within 1.0 m horizontally or vertically of the existing facility. Existing facilities shall be exposed by non-destructive methods. The number of exposures required to monitor work progress shall be as specified in the Contract Documents.

#### **7.01.07 Transporting, Unloading, Storing and Handling Materials**

Manufacturer's handling and storage recommendations shall be followed.

#### **7.01.08 Trenching, Backfilling and Compacting**

Trenching, backfilling, and compacting for entry and exit points or other locations along the pipe path shall be according to OPSS 401.

#### **7.01.09 Support Systems**

Support systems shall be according to OPSS 404.

If any open excavation will encroach into the highway embankment the protection system shall satisfy the requirements for Performance Level 2 as specified in OPSS.PROV 539.

#### **7.01.10 Dewatering**

The work of this Section includes control, handling, treatment, and disposal of groundwater. The Contractor shall review the foundation investigation report for reference to soil and groundwater conditions on the project site and plan a dewatering scheme accordingly.

The Contractor shall control groundwater inflows to excavations to maintain stability of surrounding ground, to prevent erosion of soil, to prevent softening of ground exposed in the excavation, and to avoid interfering with execution of the work.

The Contractor shall maintain excavations free of standing water at all times during excavation, including while concrete is curing.

Should water enter the excavation in amounts that could adversely affect the performance of the work or could cause loss of ground, the Contractor shall take immediate steps to control the inflow.

The Contractor is alerted that seepage zones of perched water within the fill materials should be expected, particularly where granular materials are excavated.

Dewatering shall be according to OPSS 517.

#### **7.01.11 Removal of Boulders**

The Contractor is alerted that cobbles and boulders should be anticipated in the soil deposits at the site. Accordingly, the Contractor shall address the removal of cobbles and boulders in the proposed method of construction. The Contractor shall immediately inform the Contract Administrator of any obstruction encountered.

#### **7.01.12 Record Keeping**

Verification record requirements of the alignment and depth of the installation shall be as specified in the Contract Documents. A copy of the verification records shall be given to the Contract Administrator at the completion of the installation.

#### **7.01.13 Testing**

Testing of the product installation shall consist of verifying the specified grade between the two ends of the pipe and passing of water from the inlet end of the pipe to the outlet end to confirm gravity flow conditions.

#### **7.01.14 Management and Disposal of Excess Material**

Management and disposal of excess material shall be according to OPSS 180. Satisfactory re-usable excavated material required for backfill shall be separated from unsuitable excavated material.

#### **7.01.15 Site Restoration**

Site restoration shall be according to OPSS 492.

#### **7.01.16 Supervision**

A qualified individual, who is experienced in the pipe installation by trenchless methods shall supervise the work at all times.

### **7.02 Auger Jack & Bore Installation**

#### **7.02.01 Method of Installation Procedure**



The installation procedure to be used shall be subject to the following limitations:

Hydraulically operated jacks of adequate number and capacity shall be provided to ensure smooth and uniform advancement without over-stressing of the pipe.

A suitably padded jacking head or collar shall be provided to transfer and distribute jacking pressure uniformly over the entire end bearing area of the pipe.

The jacking pipe shall be fully supported in the jacking pit at the specified line and grade.

Selection of the excavation method and jacking equipment shall take into consideration the conditions at each pipe crossing.

### **7.02.02 Pipe Installation**

Concrete pipe joints shall be water tight and according to OPSS.PROV 1820 and must withstand jacking forces, determined by the Contractor.

During the jacking of the liner the space between the liner and the wall of the excavation shall be kept filled with bentonite slurry. Upon completion of jacking, the space between the liner and the wall of the excavation shall be filled with grout.

The annular space between the liner and the product shall be fully grouted with a water tight, expandable and stable grout.

### **7.03 Pipe Ramming Installation**

For pipe ramming installation the following requirements apply:

Only smooth walled steel pipe shall be used. But welding of pipe joints shall conform to CAS W59.

Ramming equipment of adequate capacity shall be provided to ensure smooth and uniform advancement without overstressing of the pipe. Delays shall be avoided between ramming operations.

A ramming head shall be provided to transfer and distribute jacking pressure uniformly over the entire end bearing area of the pipe.

Two or more lubricated guide rails or sills shall be provided of sufficient length to fully support the pipe at the specified line and grade in the ramming pit. Pipe shall be installed to the line and grade specified.

Following installation of the liner pipe, all material shall be removed from the pipe to the satisfaction of the Contract Administrator. Any voids remaining between the pipe and the excavation wall shall be grouted as soon as the pipe is rammed. The annular space between the liner pipe and the product shall be fully grouted with a water tight, expandable and stable grout.

### **7.04 Directional Drilling Installation**

#### **7.04.01 General**

When strike alerts are provided on a drilling rig, they shall be activated during drilling and maintained at all times.

#### **7.04.02 Site Preparation**

The work site shall be graded or filled to provide a level working area for the drilling rig. No alterations beyond what is required for DD operations are to be made. All activities shall be confined to designated work areas.

#### **7.04.03 Pilot Bore**

The pilot bore shall be drilled along the bore path in accordance with the grade, alignment, and tolerances as indicated on the Contractor's submitted drilling plan to ensure that the product is installed to the line and grade shown on the Contract Drawings. The Contractor's methods shall take into consideration the conditions at each crossing within the pipe alignment and shall be suitable to advance through such obstructions such as cobbles and boulders and address the potential for deflection off these obstruction and/or soil conditions.

In the event the pilot bore deviates from the submitted path, the Contract Administrator shall be notified. The Contract Administrator may require the Contractor to pullback and re-drill from the location along the bore path before the deviation.

In the event that a drilling fluid fracture, inadvertent returns, or loss of circulation occurs during pilot bore drilling operations, the Contract Administrator shall be advised of the event and action shall be taken in accordance with the Contractor's submitted contingency plan.

At the entry and exit points, there is potential for ravelling of the existing soil, fill and or weathered rock areas along the alignment. This is conventionally addressed by the use of drilling fluid. However, casing may be required. The Contractor's methods shall take into consideration the potential need to install sections of casing to manage ravelling at or near ground surface.

If a drill hole beneath the highway must be abandoned, the hole shall be backfilled with grout or bentonite to prevent future subsidence.

The Contractor shall maintain drilling fluid pressure and circulation throughout the DD process, including during the initial pilot bore and during the reaming process.

The Contractor shall at all times and for the entire length of the installation alignment be able to demonstrate the horizontal and vertical position of the alignment, the fluid volume used, return rates and pressures.

#### **7.04.04 Drilling Fluid Fracture (Frac-Out)**

In order to reduce the potential for hydraulic fracturing of the hole during directional drilling, a minimum depth of cover of 5m is normally maintained between the pipe and the ground surface. Sections of the pipe close to the exit pit with less than 5m cover shall be cased. The Contractor shall ensure that drilling fluid pressures are properly set and controlled to prevent frac-out, for the depth of cover available between the bottom of the pavement structure (bottom of the subbase material) and the top of the bore.

Since fluid loss normally occurs in fault zones, fracture zones, or seams of coarse material, fluid migration does not always gravitate to the surface, thus making detection difficult. Once a fluid loss is detected, the Contractor shall halt operations immediately and conduct a detailed examination of the drill path and implement measures to mitigate fluid loss. If no surface migration is evident, resume operation while paying particular attention to fluid monitoring.

In the event of a fluid migration to the surface occurring, the Contractor shall halt all operations immediately, isolate the migration site, and recover fluids. Once the fracture is controlled, continue drilling operations with

the operator paying particular attention to the fracture points

#### **7.04.05 Reaming**

The bore shall be reamed using the appropriate tools to a diameter at least 50% greater than the outside diameter of the product.

#### **7.04.06 Product Installation**

##### **7.04.06.0 General**

The product shall be jointed according to manufacturer's recommendations. The length of the product to be pulled shall be jointed as one length before commencement of the continuous pulling operation.

The product shall be protected from damage during the pullback operation.

The minimum allowable bending radius for the product shall not be exceeded.

Product shall be allowed to recover before connections to new or existing facility are made. Product recovery time shall be according to manufacturer's recommendations.

##### **7.04.06.02 Pullback and Grouting**

After successfully reaming the bore to the required diameter, the product shall be pulled through the bore path. Once the pullback operation has commenced, it shall continue without interruption until the product is completely pulled into bore unless otherwise approved by the Contract Administrator.

A swivel shall be used between the reamer and the product being installed to prevent rotational forces from being transferred to the product. When specified in the Contract Documents, a weak link or breakaway connector shall be used to prevent excess pulling force from damaging the product.

The product shall be inspected for damage where visible at excavation pits and where it exits the bore. Any damage noted shall be rectified to the satisfaction of the Contract Administrator,

The pull back and reaming operations shall not exceed the fluid circulation rate capabilities. Reaming and back pulling operations shall be planned to insure that, once started, all reaming and back pulling operations are completed without stopping and within the permitted work hours.

The space between the pipe and the excavation walls shall be filled with grout.

#### **7.05 Tunnelling Installation**

##### **7.05.01 General**

The method of tunnelling shall be selected by the Contractor and shall be submitted to the Contract Administrator prior to commencement of the work for information purposes.

Excavation of native soil and fill shall be done in a manner to control groundwater inflow to the excavation and to prevent loss of ground into the excavation.

Methods of excavating the tunnel shall be capable of fully supporting the face and shall accommodate the

removal of boulders and other oversize objects from the face. Continuous ground support shall be maintained during excavation.

As the excavation progresses, the Contractor shall continuously monitor (every 2 m) indications of support distress, such as cracking, deflection or failure of support system and subsidence of ground near the excavation.

The Contractor shall advance the ventilation system as a regular part of the normal excavation cycle.

The Contractor shall provide lighting in accordance with OSHA requirements for the entire length of the tunnel.

The tunnel is to be kept sufficiently dry at all times to permit work to be performed in a safe and satisfactory manner.

The Contractor shall maintain clean working conditions at all times in tunnels.

In the event that excavation threatens to endanger personnel, the Work, or adjacent property, the Contractor shall cease excavation. The Contractor shall then evaluate methods of construction and revise as necessary to ensure the safe continuation of the work.

The Contractor shall maintain tunnel excavation line and grade to provide for construction of final lining within specified tolerances.

#### **7.05.01 Tunnelling Method**

The tunnelling method shall be suitable to provide face support in changing ground conditions that may be encountered during the progress of the work. The selection of the tunnelling method should consider the soil conditions at each pipe crossing and the presence of obstructions, such as cobbles and boulders, with respect to the tunnel alignment.

#### **7.05.02 Primary Liner (Support System)**

Primary support systems shall prevent deterioration, loosening, or unravelling of ground surfaces exposed by excavation.

The primary liner support system shall be designed and installed to achieve the intended performance requirements.

Primary liner support system shall maintain the safety of personnel, minimize ground movement into the excavation, ensure stability and maintain strength of ground surrounding the excavation.

The primary liner shall be designed to support all subsurface conditions and hydrostatic pressures and to withstand any additional loads caused by installation and grouting, and shall ensure that no ground loading or other loading will be placed on the new work until after design strength has been reached.

The primary liner shall be installed so that the exterior is as tight as possible to the excavated surface of the tunnel and allows the placement of the full design thickness of the secondary lining.

Primary support systems shall be compatible with the encountered ground conditions, with the method of excavation, with methods for control of water, and with placement of the permanent lining.

All voids between the primary lining and the surface of the excavation shall be filled with cement grout. If an unexpanded liner is used, the space outside the liner plates shall be grouted at least daily.

### **7.05.03 Secondary Liner**

#### **7.05.03.01 Placing of Grout**

The void outside the finished secondary liner shall be filled with cement grout according to the Contractor's submission.

Grout shall not be placed until the lining has achieved 85% of its specified strength or 30 MPa. Grouting shall be limited to such sequences and programs as are necessary to avoid damaging any part of the works or any other structure or property.

### **7.06 Instrumentation and Monitoring**

#### **Settlement Monitoring**

The work specified in this section includes furnishing and installing instruments for monitoring of settlement and ground stability.

Surface settlement markers (SSMs) and settlement points (SPs) for monitoring ground stability shall be installed at the pavement/ground surface level as detailed in the settlement monitoring plan. Two Benchmarks (BM) shall be installed by the contractor as described in this section.

The equipment and procedures used for settlement monitoring during construction must be capable of surveying the settlement point elevations to within 2 mm of the actual elevation.

#### **BENCHMARKS**

**Number and Locations of Benchmarks** The minimum number of Benchmarks for this crossing is two, and should be located in the field such that:

- Direct sighting is possible from all instruments to at least one Benchmark.
- Benchmarks are located in an area that will not experience ground movement as a result of the boring operations.
- Benchmarks are located in such a way to minimize interference with and damage by construction activities.
- The rod anchor elevation should be determined based on the subsurface conditions at each location and shall extend approximately 6 m into soil, or into soils having Standard Penetration Test 'N' value of greater than 50 blows per 0.3 m of penetration, whichever is less.

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#### **Materials for Benchmarks**

The contractor shall supply all materials and equipment required for the installation of the Benchmarks, as follows:

**Rod:** The contractor shall supply a steel pipe, Schedule 40, with an outside diameter not less than 25.4 mm, supplied in lengths as required to complete the installation. A rounded cap shall be installed at the top of the rod in such a way that a single survey point can be clearly identified and returned to.

**Sand:** The contractor shall supply clean, washed sand for backfilling around the friction reducing sleeve.

**Rod Anchor Grout:** The contractor shall supply cement-bentonite grout suitable for anchoring the rod at the bottom of the borehole

**Friction-Reducing Sleeve:** The contractor shall supply a friction-reducing sleeve consisting of Schedule 40 — 50.8 mm (2") outer diameter PVC pipe cut perpendicular to the axis of the pipe.

### **Installation of Benchmarks**

The Contractor shall install Benchmarks in accordance with the following:

**Borehole:** The borehole shall be advanced to the required depth using suitable drilling techniques. The diameter of the borehole shall be sufficient to fit the rod, friction-reducing sleeve and rod anchor. The sides of the borehole shall be stable and the borehole shall be free of drilling mud and debris.

**Rod:** The coupling of the rods shall be such that all sections have the same axis and no separation or contraction will occur at the couplings.

**Rod Anchor:** The rod shall be installed vertically in the borehole with its bottom end resting at the bottom of the borehole. The bottom portion of the rod shall be fixed against the surrounding native soil by grouting the bottom 300 mm of the borehole to form a concrete/soil anchor. Once grouting is completed and the rod anchor grout has set, the contractor shall pour clean sand in the lower 25 mm to 50 mm length of the borehole above the concrete/soil anchor to create a base for the end of the friction reducing sleeve to rest on. The elevation of the bottom of the rod anchor shall be determined by measuring the length of the rod to the ground surface elevation.

**Friction-Reducing Sleeve:** The friction-reducing sleeve shall be installed over the entire length of the rod above the rod anchor and sand, extending up to ground surface.

### **SURFACE SETTLEMENT MARKERS (SSM)**

The Surface Settlement Markers shall be installed on/within the pavement in a way such that they can be surveyed without the need for traffic protection.

The contractor shall install SSMs at the approximate locations shown on the Settlement Monitoring Instrumentation Locations and Details drawing. In general, the Surface Settlement Markers shall be located on the pavement of the highway and shall be installed to be in line with the pavement marking lines where installed within the travelled lanes in order to reduce visual distraction to drivers.

### **Materials for Surface Settlement Markers (SSM)**

The contractor shall supply all materials and equipment required for the installation of the Surface Settlement Markers, as follows:

**Hex-Head Bolt:** The contractor shall supply hardened steel hex-head bolt treated/coated to resist corrosion, with an exposed face of approximately 6 mm height. The face of the hex-head bolt shall be such that a single survey point can be clearly identified and returned to including the use of a scored line or paint marking, to eliminate the need for traffic protection, as may be required depending on the survey equipment used.

**Washer:** An appropriately sized washer shall be placed between the pavement surface and the head of the hex-head bolt, to minimize the potential for the head to be pushed into the pavement due to traffic travelling over the bolt.

**Epoxy:** The contractor shall use an appropriate high-strength, rapid-curing epoxy to secure the hex-head bolts into the asphalt or concrete pavement. The contractor shall ensure that the epoxy selected is non-expansive to ensure that the bolt is not pushed up from the hole.

### **Installation of Surface Settlement Markers (SSM)**

The contractor shall install Surface Settlement Markers at the approximate locations shown on the Settlement Monitoring Instrumentation Locations and Details drawing following the typical installation details as shown in addition to what is stated below:

The SSMs should be installed on the painted divider lines separating the driving lanes (at the approximate spacing shown on the drawings). The hex-head bolts shall be rigidly affixed so as not to move relative to the surface to which it is attached. The hex-head bolts shall be installed in a pre-drilled hole, with a washer placed on the surface of the asphalt pavement below the head of the bolt, and the assembly affixed into place using an appropriate high-strength, rapid-curing, non-expansive epoxy.

## **SETTLEMENT POINTS (SP)**

### **Materials for Settlement Points (SP)**

The Geotechnical Monitoring Consultant shall supply all materials and equipment required for the installation of the Settlement Points, as follows:

Rod: The Geotechnical Monitoring Consultant shall supply a steel rod as shown on the Settlement Monitoring Instrumentation Locations and Details drawing, supplied in lengths as required to complete the installation. A rounded cap shall be installed at the top of the rod in such a way that a single survey point can be clearly identified and returned to, where required to eliminate the need for traffic protection, and as may be required depending on the survey equipment used.

Sand: The contractor shall supply clean, washed sand suitable for backfilling around the friction reducing sleeve

Rod Anchor Concrete/Grout: The contractor shall supply concrete or cement-bentonite grout suitable for anchoring the rod.

Friction-Reducing Sleeve: The contractor shall supply a friction-reducing sleeve consistent with the detail shown on the Settlement Monitoring Instrumentation Locations and Details Drawing.

### **Installation of Settlement Points (SP)**

The contractor shall install Settlement Points at the approximate locations shown on the instrumentation and monitoring plan following the typical installation details as shown in addition to what is stated below:

A borehole shall be advanced to the required depth using suitable drilling techniques. The diameter of the borehole shall be sufficient to fit the rod, friction-reducing sleeve and rod anchor. The sides of the borehole shall be stable and the borehole shall be free of drilling mud and debris.

The rod shall be installed vertically in the borehole with its bottom end resting at the bottom of the borehole. The bottom portion of the rod shall be fixed against the surrounding native soil by grouting the bottom 200 mm of the borehole to form a concrete/soil anchor. Once grouting is completed and the rod anchor grout has set, the contractor shall pour clean sand in the lower 25 mm to 50 mm length of the borehole above the concrete/soil anchor to create a base for the end of the friction reducing sleeve to rest on. The elevation of the bottom of the rod anchor shall be determined by measuring the length of the rod to the ground surface elevation.

The friction-reducing sleeve shall be installed over the entire length of the rod above the rod anchor and sand, extending up to ground surface.

### **General Conditions**

The Contractor shall install all instruments a minimum of one week prior to the start of works. The contractor shall determine if an elevated platform is required to be able to have direct siting to the benchmark(s) and the roadway/railway instruments and construct an appropriate platform for use by the surveyor.

All survey work shall be performed by a licensed OLS (Ontario Land Surveyor) and/or OLIP (Ontario Land Information Professional) registered with the Association of Ontario Land Surveyors.

The contractor shall protect and avoid damaging instrumentation during construction. Instrumentation that is damaged as a result of the Contractor's operation shall be repaired or replaced by the Contractor within one business day. The costs for replacement/repair shall be borne by the Contractor.

At the completion of the job, the contractor shall decommission all instruments installed during the course of the work. For Benchmarks and Settlement Points, the steel rod shall be removed and the hole backfilled with fine sand up to the original ground surface. For Surface Settlement Markers, the hex head bolt shall be removed and the hole filled with a Crack Sealant, Rubberized Asphalt, Hot Poured, from an approved source

on the designated source materials list.

### **Reading and Reporting Requirements**

The Contractor shall submit to the Contract Administrator a site plan showing the locations of the monitoring points, a geodetic survey of the settlement monitoring points including station, offset and elevation recorded at the following time intervals:

- Three consecutive readings at least one week prior to commencement of the work (Baseline Reading)
- Once per shift during tunnelling operations period
- Weekly after completion of the work for one month, or until such time at which all parties agree that further movement has stopped.

All readings shall be submitted to the Contract Administrator for information purposes within 24 hours of the reading being taken. Each report shall include all survey data collected in tabular and graphical format as plots of time versus settlement in comparison to survey data collected prior to commencement of the work.

The contractor shall submit biweekly reports to the MTO Pavements and Foundations office during the monitoring period for information purposes. The biweekly report shall consist of a site plan showing the locations of the monitoring points, a geodetic survey of the settlement monitoring points including station, offset and elevation. The report shall also include all survey data collected in tabular and graphical format as plots of time versus settlement in comparison to survey data collected prior to commencement of the work. The biweekly reports shall be submitted in digital PDF format by e-mail to the MTO Foundations representative; Darren Berwick, at [darren.berwick@ontario.ca](mailto:darren.berwick@ontario.ca)

### **7.07 Criteria for Assessment of Roadway Subsidence/Heave**

Based on the monitoring of ground movement as specified, the following represents trigger levels that define magnitude of movement and corresponding action:

- Review Level: If a maximum value of 10 mm relative to the baseline readings is reached, the Contractor shall review or modify the method, rate or sequence of construction or ground stabilization measures to mitigate further ground displacement. If this Review Level is exceeded, the Contractor shall immediately notify the CA and review and discuss response actions. The Contractor shall submit a plan of action to prevent Alert Levels from being reached. All construction work shall be continued such that the Alert Level is not reached.

- Alert Level: If a maximum value of 15 mm relative to the baseline readings is reached, the Contractor shall cease construction operations, inform the Contract Administrator and execute pre-planned measures to secure the site, to mitigate further movements and to assure safety of public and maintain traffic. No construction shall take place until all of the following conditions are satisfied:

- The cause of the settlement has been identified.
- The Contractor submits a corrective/preventive plan.
- Any corrective and/or preventive measure deemed necessary by the Contractor is implemented.
- The CA deems it is safe to proceed.

## **9. MEASUREMENT FOR PAYMENT**

Measurement shall be by Plan Quantity Payment as may be revised by Adjusted Plan Quantity Payment in metres, following along the centre line of the pipes from centre to centre of maintenance holes or chambers (catch basins) or from/to the end of the pipe where no maintenance hole or chamber is installed, of the actual length of pipe installed by trenchless methods.

## **10. BASIS OF PAYMENT**



Payment at the contract price shall be full compensation for all labour, equipment and materials required for excavation (regardless of material encountered), dewatering, sheathing and shoring, supply and installation of pipe liners, settlement instrumentation and monitoring, site restoration, and all other work necessary to complete the installation as specified.

Payment for the rigid or flexible pipe conduits installed inside the pipe liners shall be paid separately under the appropriate tender items.

Where a protection system is made necessary because of the Contractor's operations (e.g. choice of trenchless installation method), the cost shall be included in this item and shall be full compensation for all labour, equipment and materials required to carry out the work including subsequently removing the temporary protection system and performing any necessary restoration work.

Payment for connecting intercepted drains and service connections shall be made on the following basis:

- a) Where such drains and service connections are shown on the contract drawings the cost of connections shall be included in the contract price for pipe installation.
- b) Where such drains and service connections are not shown on the contract drawings, the cost of connections will be considered an allowable extra to the contract.

Payment for removal of boulders/obstructions greater than an equivalent 0.3 m in diameter shall be on a time and materials basis. The Contractor shall inform the Contract Administrator when boulders/obstructions are encountered and prior to removal to allow for proper and accurate tracking of time and material charges.

## **DEWATERING AND CONTROL OF GROUNDWATER - Item No.**

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### **Non-Standard Special Provision**

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The contractor shall be alerted that the groundwater table was encountered between Elevation 85 to 81 m at the proposed new culvert location. It is estimated that the base of temporary excavations for the entry and exit shafts may be below the groundwater level as measured in piezometer installed in Borehole C3-4. Dewatering within the shaft excavations and along the tunnel alignment (depending on the construction method chosen) may be required and the excavation shall be kept stable during the work. It is considered that groundwater control using sumps may be adequate to control seepage from the cohesive gravelly clayey silt to clayey silt with sand but may not be adequate for control of groundwater from the granular till or silty soils present at the site; and it may be necessary to use well points, eductors or the like in these native deposits. The groundwater level should be lowered to at least 0.5 m below the base of the excavations. The excavations should be protected from ingress of surface water. The Contractor is to design and install appropriate measures to control the groundwater during construction.

### **Basis of Payment**

Payment at the contract price for the above tender item shall be full compensation for all labour, equipment and materials required to do the work.

END OF SECTION

**OBSTRUCTIONS - Item No.**

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**Non-Standard Special Provision**

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Cobbles and Boulders should be anticipated to be encountered within the embankment fill and native glacial till soils at the site, as inferred present from auger boring in Borehole C3-1 to C3-4. Although not encountered in the boreholes, debris consisting of abandoned temporary works associated with the original construction; logs, stumps and brush from the clearing and grubbing operations; and cobbles and boulders buried in the fill may also be present within the existing fill materials and near the fill / native soil interface. Consideration of the presence of these obstructions must be made in the selection of appropriate equipment and procedures for trenchless installation of the new culvert.

**Basis of Payment**

Payment at the lump sum contract price for this tender item shall be full compensation for all labour, equipment and materials for completion of the work.

END OF SECTION

As a global, employee-owned organisation with over 50 years of experience, Golder Associates is driven by our purpose to engineer earth's development while preserving earth's integrity. We deliver solutions that help our clients achieve their sustainable development goals by providing a wide range of independent consulting, design and construction services in our specialist areas of earth, environment and energy.

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