



## **FINAL REPORT**

### **FOUNDATION INVESTIGATION AND DESIGN REPORT Highway 11 Centerline Culvert – 750 m South of Alpine Ranch Road, MacAulay Township, Huntsville Area**

**GWP 322-00-00  
MTO Geocres No. 31E-311**

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# Ministry of Transportation

## Foundation Investigation and Design Report GWP 322-00-00 MTO GEOCRES No. 31E-311

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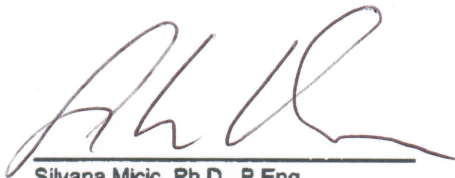
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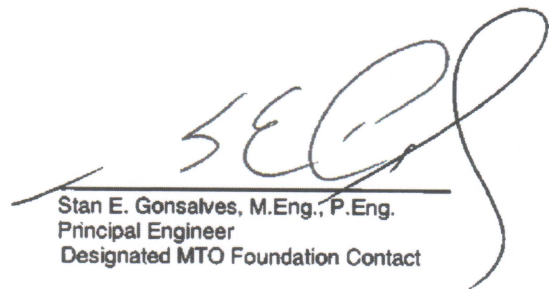
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# Part I: FOUNDATION INVESTIGATION REPORT

## 1.1 Introduction

This report presents the results of a geotechnical investigation completed by exp. Services Inc. (exp.) for the replacement of a Highway 11 centreline culvert located 750 m south of Alpine Ranch Road in MacAulay Township, Huntsville Area. The existing culvert was installed in 1975 and consists of two parts: (i) a concrete box structure lined with 900 mm ID smooth wall plastic pipe, and (ii) a 1.8 m diameter Corrugated Steel Pipe (CSP). The concrete box culvert is approximately 70 m long and it goes through the SBL highway embankment. The CSP culvert has three sections – 15 m, 23 m and 93 m in length going under the NBL highway embankment. The existing culvert is experiencing distress and bracing have been installed to control movement. In this investigation two alignments were explored; the current and a proposed more direct alignment. The site plan showing both alignments is included in Appendix B.

The work was undertaken under Agreement # 5009-E-0060, Assignment No. 3. The terms of reference were as presented in the Request for Quotation (RFQ) by Ministry of Transportation (MTO) dated February 24, 2011.

The purpose of the investigation is to examine the soil conditions at the location of the existing culvert alignment and new proposed culvert alignment. The site specific geotechnical investigation consisted of test borings, borehole logging, and field and laboratory testing. This foundation investigation report has been prepared specifically and solely for the project described herein. It contains the factual results of the investigation and the laboratory testing.

## 1.2 Site Description and Geological Setting

### 1.2.1 Site Description

The site is located on Highway 11 in MacAulay Township, District of Muskoka, Huntsville Area, approximately 750 m south of Alpine Ranch Road. It is distanced approximately 8.5 km north of the Town of Bracebridge, Ontario. At the location of the existing culvert both lanes of the roadway (SBL and NBL) are within a fill section. The culvert crosses the SBL and NBL highway embankments and conveys collected surface water from the valley at the west side of the embankment. The drainage in the area generally consists of roadside ditches which drain into nearby streams. It appears that the culvert connects a meandering stream feeding the North Branch Muskoka River. The site plan is shown on Drawing 1 in Appendix B.

The existing culvert consists of a 70 m long concrete box lined with 900 mm ID plastic pipe under the SBL embankment and a 1800 mm diameter by 131 m long CSP under the NBL embankment. Two sections of the CSP culvert experienced distress and were braced in 2009 at 12 locations to prevent further movement. The third section of the CSP culvert is now also showing signs of distress.

In 2008 and 2010, sinkholes occurred in the east embankment adjacent to the NBL coinciding in location with the 45 degree bend in the CSP culvert. These sinkholes have since been filled. The photo exhibiting that area is shown in Appendix A.

The terrain in the area of the culvert is steeply undulating. Within the right of way, the slopes of the embankment are covered with large size stones and some vegetation. The inlet (west) side is relatively clear of trees and bushes. The outlet (east) side is very steep, rocky and covered with bushes and trees. The embankment is approximately 15 m high. Photos showing the site are included in Appendix A.

### 1.2.2 Geological Setting

The Ontario Geological Survey Map of Precambrian Geology in the Bracebridge area (Map P.3411) shows the area to be Mafic-Rich Gray Gneiss bedrock covered by sediments from the Pleistocene and Holocene Epoch. The area is identified as Lacustrine Plain consisting of thick sand sequences and fine-textured glaciolacustrine deposits (massive to well laminated silts and rhythmically laminated or varved silts and clays). A review of the Quarternary Geology of the Huntsville-Penetanguishene Area Report by the Ministry of Northern Development and Mines, Ontario (MNDM) in 1994 indicates that because of the specific topography within gneissic bedrock area it may contain organic deposits as well.

## 1.3 Investigation Procedures

### 1.3.1 General

The field work for this investigation was performed between May 11 and May 30, 2011, during which time ten (10) boreholes were advanced at the site to depths of between 6.1 m and 23.3 m. Five (5) boreholes were drilled along the existing culvert, two (2) boreholes were drilled in the inlet/outlet (common vicinity for existing and proposed alignments), and the remaining three (3) boreholes were drilled along the proposed new alignment. Drawing 1 in Appendix B shows the locations of the ten boreholes.

Boreholes on the embankment crest (i.e. BH-2, BH-3, BH-4, BH-7, BH-8 and BH-9) were advanced using a CME 750 rubber tire off-road drill rig, equipped with a hollow stem auger and standard soil sampling equipment operated by a specialist drilling contractor, Ontario Soil Drilling. Due to difficult access, boreholes at the toes of embankment (i.e. BH-1, BH-5, BH-6 and BH-10) were advanced by hand drilling/sampling equipment operated by Sonic Soil Sampling (Ontario) Inc.

During the drilling of the boreholes on the crest, soil samples were obtained using a 51 mm outside diameter (O.D.) split-spoon sampler in accordance with Standard Penetration Test (SPT) procedures (ASTM D 1586), at intervals shown on the attached borehole logs (Appendix C). The original field (uncorrected) SPT "N" values were recorded on the borehole logs as recommended in the Canadian Foundation Engineering Manual (pg. 40) and used to provide an assessment of in-situ consistency or relative density of non-cohesive soils. In addition, dynamic cone penetration testing was utilized in all boreholes to verify the soil consistency condition established by the SPT tests. The resistance to

penetration is measured as the number of blows for each 0.3 m advance of the conical point into the undisturbed ground and plotted on the borehole log sheets in Appendix C.

During the drilling of the boreholes at the toes of embankment, soil samples were obtained using a 70-pound pionjar, at intervals shown on the attached borehole logs (Appendix C). Dynamic cone penetration tests were performed besides the drilled boreholes and the number of blows was recorded and used to assess relative density of the soil deposit. Since the manual hammer of 31.7 kg was used for hand testing, which is half of the conventional hammer weight (63.5 kg), the corresponding blow counts plotted on the borehole logs (Appendix C) were factored by 0.5.

The groundwater levels in the open boreholes were observed and recorded throughout the drilling operations. After completion boreholes were sealed by bentonite in accordance with accepted practice for decommissioning of boreholes (Ontario Reg 903 as amended by Ontario Reg. 372).

The fieldwork was supervised by a member of exp.'s engineering staff who directed the drilling and sampling operation, logged borehole data in accordance with ASTM D 2487-06, Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System), and retrieved soil samples for subsequent laboratory testing and identification. All of the recovered soil samples were placed in labelled moisture-proof bags and returned to exp's Markham and Brampton laboratories for additional visual, textual and olfactory examination.

Details of the soil strata encountered in the boreholes are included in attached borehole log sheets in Appendix C, and plotted on the profiles in Appendix B.

The locations of the boreholes were determined by MTO and exp on a site plan, and these locations were surveyed and staked in the field by exp prior to drilling. The borehole locations (referenced to the MTM NAD27 coordinate system) and ground surface elevations (referenced to the geodetic datum- MTO BM 294-67, Elev. 314.642 m) are shown on Drawing 1 in Appendix B.

### 1.3.2 Laboratory Testing

All samples returned to the laboratory were subjected to visual examination and classification. The laboratory testing program included natural water content and grain size distribution tests on approximately 25% of the collected soil samples. To address concerns regarding pipe corrosion, chemical tests (i.e. pH, electrical conductivity/resistivity, and sulphate and chloride levels) on selected soil and water samples were performed. All of the laboratory tests were carried out to MTO and/or ASTM Standards as appropriate.

The laboratory test results are provided on the attached borehole log sheets in Appendix C. The results of the grain size analyses are presented in Appendix D.

### 1.3.3 Previous Investigation

No foundation reports are available in the MTO GEOCRES library for this site.

## 1.4 Subsurface Conditions

### 1.4.1 General

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 borehole log sheets in Appendix C. Laboratory test results are also provided in Appendix D. The “Explanation of Terms Used in Report” preceding the borehole logs in Appendix C forms an integral part of and should be read in conjunction with this report. ASTM D 2487-06, Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System), was used for classification of soils encountered on the site (Appendix E).

A borehole location plan and cross section soil profiles along the existing and proposed culvert alignments are provided in Appendix B. The stratigraphy of ground below the culvert inlet and outlet was confirmed by BH-1 and BH-6, respectively. The stratigraphy within highway embankments along the existing and proposed alignments and ground below was verified through drilling BH-2, BH-3, BH-4, BH-5, BH-7, BH-8, BH-9, and BH-10.

It should be noted that the stratigraphic boundaries indicated on the borehole logs and cross section soil profiles are inferred from non-continuous sampling, observations of drilling progress and results of Standard Penetration Tests and Dynamic Cone Penetration Tests. These boundaries typically represent transitions from one soil type to another and should not be regarded as exact planes of geological change. Further, subsurface conditions may vary between and beyond the borehole locations.

A summary of the soil and groundwater conditions encountered in the boreholes is provided below.

### 1.4.2 Subsurface Conditions at Culvert Inlet and Outlet

BH-1 and BH-6 were drilled at inlet and outlet locations, respectively, which are common vicinity for existing and proposed culvert alignments. In general, the subsurface conditions at these locations consist of a thin layer of silty sand fill underlain by native sandy silt deposits. The deposits typically contain trace organics and root fibers.

#### 1.4.2.1 Silty Sand Fill

Silty sand fill was encountered at the ground level at the inlet and outlet locations of the existing culvert. This silty sand fill layer has a thickness about 0.8 m. It extends to approximate elevations of 281.7 m at the inlet and 279.4 m at the outlet.

The fill consists of silt and sand, and trace organics. The layer is dark brown in color, and wet. The results of the dynamic cone penetration tests classify this silty sand fill as very loose in compactness condition.

Laboratory testing performed on selected samples consisted of moisture content and grain size distribution tests. The test results are as follows:



Moisture Content:

- 23.3% to 30.8%

Grain Size Distribution:

- 71% sand; and
- 29% silt

The results of the moisture content and grain size distribution tests are provided on the record of borehole sheet in Appendix C. The results of the grain size distribution tests are also provided on Figure 1 in Appendix D.

#### 1.4.2.2 Sandy Silt

Sandy silt deposits were encountered below the fill in BH-1 and BH-6 drilled at the inlet and outlet of the existing/proposed culvert, respectively. This sandy silt layer extends to the depth of approximately 6.1 m, corresponding to approximate elevations of 276.4 m at the inlet side and 274.1 m at the outlet side. Both boreholes were terminated in this layer.

The deposit consists of sand and silt, trace gravel and organics. The sandy silt is brown to grey in color, and wet. The dynamic cone penetration tests performed within the sandy silt deposit indicate a very loose to loose relative density.

Laboratory testing performed on selected samples consisted of moisture content and grain size distribution tests. The test results are as follows:

Moisture Content:

- 17.3% to 23.1%

Grain Size Distribution:

- 19% to 58% sand; and
- 42% to 81% silt

The results of the moisture content and grain size distribution tests are provided on the record of borehole sheet in Appendix C. The results of the grain size distribution tests are also provided on Figure 2 in Appendix D.

#### 1.4.3 Subsurface Conditions within Highway Embankment along the Existing Culvert

Boreholes BH- 2, BH-3, BH-4, BH-5, and BH-10 were located and drilled along the existing culvert. The results of drilling of these boreholes show that the subsurface conditions within the highway embankment along the existing culvert consist of a surficial layer of sand and gravel fill followed by silty sand fill, and then underlain by native sandy silt deposits.

#### 1.4.3.1 Asphalt

At BH-2 drilled on the crest of SBL highway embankment, asphaltic concrete was encountered at ground surface. The thickness of the asphaltic concrete layer was 20 mm and the top elevation of this layer is approximately 298.7 m.

#### 1.4.3.2 Sand and Gravel Fill

Sand and gravel fill was encountered in the boreholes drilled at the shoulders of the highway, i.e. BH-2 (SBL) and BH-4 (NBL). At BH-2 the sand and gravel fill was found below surface asphalt, while at BH-4, the sand and gravel fill was encountered at the ground surface. The thickness of the sand and gravel fill ranges from 0.6 m (BH-2) to 0.9 m (BH-4). This layer at the SBL highway embankment extends from elevation of about 298.7 m to 298.1 m. At the NBL embankment the layer extends from elevation of approximately 296.6 m to 295.7 m.

The composition of this layer is sand and gravel. It is brown in color, and moist. SPT “N” value was around 16 to 17 blows per 300 mm penetration, classifying the material as compact in compactness condition.

The moisture contents of the sand and gravel fill samples are between 4.9% and 8.0%. The results of the moisture content are provided on the record of borehole sheet in Appendix C.

#### 1.4.3.3 Silty Sand Fill

Silty sand fill was encountered in all boreholes drilled through the highway embankment along the existing alignment. At BH-2 and BH-4, this layer was found below the pavement base, while at BH-3, BH-5 and BH-10 it was encountered at the ground surface. This silty sand fill layer has a thickness ranging from about 1.4 m (BH-5 and B-10) at the east toe of the embankment to 16.2 m (BH-2) at the crest of the embankment. It extends to depths between 1.4 m and 16.8 m, corresponding to approximate elevations of 281.6 and 281.9 m, respectively.

The fill consists of silt and sand, trace to some gravel, and trace to some organics. The layer is brown to grey in color, and moist to wet. SPT “N” values range from 6 to 42 blows per 300 mm, classifying this silty sand fill as loose to dense in compactness condition.

Laboratory testing performed on selected samples consisted of moisture content and grain size distribution tests. The test results are as follows:

Moisture Content:

- 5.8% to 20.2%

Grain Size Distribution:

- 51% to 82% sand; and

- 18% to 49% silt

The results of the moisture content and grain size distribution tests are provided on the record of borehole sheet in Appendix C. The results of the grain size distribution tests are also provided on Figures 3 and 4 in Appendix D.

#### 1.4.3.4 Sandy Silt

Beneath the fill material, a native sandy silt deposit was encountered in all boreholes drilled within the highway embankment along the existing culvert. This sandy silt layer has a thickness ranging from about 4.7 m to 10.8 m. It extends to depths between 6.1 m and 23.3 m, corresponding to approximate elevations of 277.8 and 275.4 m, respectively. All boreholes were terminated in this layer.

The deposit consists of silt and sand, and some organics. The layer is brown to grey in color, and moist to wet. SPT “N” values range from 5 to 27 blows per 300 mm, classifying the sand as loose to compact in compactness condition.

Laboratory testing performed on selected samples of the sandy silt consisted of moisture content and grain size distribution tests. The test results are as follows:

Moisture Content:

- 11.3% to 26.6%

Grain Size Distribution:

- 15% to 42% sand; and
- 58% to 85% silt

The results of the moisture content and grain size distribution tests are provided on the record of borehole sheet in Appendix C. The results of the grain size distribution tests are also provided on Figures 5 and 6 in Appendix D.

#### 1.4.4 Subsurface Conditions within Highway Embankment along the Proposed Culvert

BH-7, BH-8 and BH-9 were drilled through the highway embankment along the proposed culvert alignment. Likewise along the existing culvert, the subsurface conditions within the highway embankment along the proposed alignment consist of a surficial layer of sand and gravel fill underlain by silty sand fill, and then followed by native sandy silt deposits.

##### 1.4.4.1 Sand and Gravel Fill

Sand and gravel fill was encountered at the ground surface in BH-9 drilled at the NBL embankment crest along the proposed alignment. The thickness of the sand and gravel fill is 0.9 m. It extends from elevation of about 295.7 m to 294.9 m.

The composition of this layer is sand and gravel. It is brown in color, and moist. SPT “N” value is 26 blows per 300 mm penetration, classifying the material as compact in compactness condition.

The moisture content of a sand and gravel fill sample is around 5.1%. The result of the moisture content is provided on the record of borehole sheet in Appendix C.

#### 1.4.4.2 Silty Sand Fill

Silty sand fill was encountered in all boreholes drilled through the highway embankment along the proposed alignments. At locations of BH-7 and BH-8 this layer was found at the ground surface, while at BH-9 it was encountered below the sand and gravel fill. Along the proposed alignment the silty sand fill layer has a thickness ranging from about 12.2 m to 15.2 m. It extends to depths between 12.2 m and 15.2 m, corresponding to approximate elevations between 282.4 and 282.6 m.

The fill consists of silt and sand, brown in color, and moist to wet. SPT “N” values range from 6 to 41 blows per 300 mm, classifying the sand as loose to dense in compactness condition.

Laboratory testing performed on selected samples consisted of moisture content and grain size distribution tests. The test results are as follows:

Moisture Content:

- 5.8% to 22.9%

Grain Size Distribution:

- 42% to 66% sand; and
- 34% to 58% silt

The results of the moisture content and grain size distribution tests are provided on the record of borehole sheet in Appendix C. The results of the grain size distribution tests are also provided on Figure 7 in Appendix D.

#### 1.4.4.3 Sandy Silt

Beneath the fill material, a native soil material of sandy silt was encountered in all boreholes drilled through the highway embankment along the proposed culvert alignment. At these locations, the sandy silt layer has a thickness ranging from about 5.6 m to 8.1 m. It extends to depths between 20.3 m and 23.3 m, corresponding to approximate elevations of 274.3 and 274.5 m, respectively. All boreholes were terminated in this layer.

The deposit consists of silt and sand, which is grey in color and wet. SPT “N” values range from 7 to 24 blows per 300 mm, classifying the sand as loose to compact in compactness condition.

Laboratory testing performed on selected samples consisted of moisture content and grain size distribution tests. The test results are as follows:

**Moisture Content:**

- 17.5% to 23.0%

**Grain Size Distribution:**

- 14% to 44% sand; and
- 56% to 86% silt

The results of the moisture content and grain size distribution tests are provided on the record of borehole sheet in Appendix C. The results of the grain size distribution tests are also provided on Figure 8 in Appendix D.

## 1.5 Soil and Water Chemical Quality

Soil samples from BH-1, BH-5 and BH-6 were selected for pH, chloride, sulphate and electrical conductivity testing. The same chemical tests were performed on the water samples collected at the inlet and outlet of the existing culvert. The test results are shown on Table 1.1 below.

*Table 1.1 Summary of chemical analyses*

Sample Type	Sample Location	Chloride (mg/L)	Sulphate (mg/L)	pH	Electrical Resistivity (ohm-cm)
Soil	BH-1; SS2	167.9	60.3	6.30	2193
	BH-5, SS4	439.9	66.5	5.28	987
	BH-6, SS2	503.9	88.7	4.55	844
Surface Water	Inlet	65.4	20.2	6.53	22222
	Outlet	634.9	29.1	6.25	7692

The following indicates some acceptable/permissible levels:

- Chlorides primarily attack exposed metal, whether it be steel pipe or reinforcing steel in concrete pipe. The maximum permissible levels of chlorides in water for galvanized steel and aluminized type 2 steel culverts are 150 mg/L and 193 mg/L, respectively, according to the Canadian Performance Guideline for CSP Culverts (CSA G401).
- Sulphates are typically more damaging to the concrete culvert, although high sulphate concentrations can lower pH and can be a concern to metal culverts (AASHTO 2000).

According to AASHTO, concrete pipe is normally sufficient to withstand sulphate concentrations to 1000 mg/L or less. The sulphate concentrations up to 150 mg/L are considered negligible for sulphate corrosion.

- Soil that are extremely acidic (pH less than 5.5) or very strongly alkaline (pH greater than 8.5) are generally associated with significant corrosion rates (AASHTO 2000). Therefore, according to AASHTO (2000) soil and water pH levels between 5.5 and 8.5 are considered to be non-corrosive.
- According to the Canadian Performance Guideline for CSP Culverts (CSA G401), the minimum permissible levels of resistivity for galvanized steel and aluminized type 2 steel culverts are 2000 ohm-cm and 1500 ohm-cm, respectively. Generally, if the soil resistivity is less than 2000 ohm-cm, the soil corrosiveness is considered as severe (MTO Gravity Pipe Design Guidelines, pg. 25).

## 1.6 Groundwater Conditions

The groundwater levels at the site were measured in open holes upon completion of drilling operations. The ground water levels encountered in the boreholes are shown in Table 1.2 and on the borehole logs in Appendix C. It should be noted that the groundwater level is subject to seasonal fluctuations.

Table 1.2 Groundwater levels at the site

Borehole No.	Date of Drilling	Water Level	
		Depth (m)	Elevation (m)
BH-1	May/11/2011	0.6	281.9
BH-2	May/25/2011	14.6	284.1
BH-3	May/27/2011	10.0	282.9
BH-4	May/19/2011	13.6	283.0
BH-5	May/17/2011	1.1	281.9
BH-6	May/12/2011	0.6	279.6
BH-7	May/30/2011	14.3	283.5
BH-8	May/20/2011	10.8	283.8
BH-9	May/24/2011	13.4	282.3
BH-10	May/13/2011	2.4	281.5

## Part II: FOUNDATION DESIGN REPORT

### 2.1 Introduction

The following subsections address geotechnical design and construction considerations for replacement of the existing Highway 11 centreline culvert located 750 m south of Alpine Ranch Road in MacAulay Township, Huntsville Area. The existing culvert consists of two parts: (i) a concrete box structure lined with 900 mm ID smooth wall plastic pipe, and (ii) a 1.8 m diameter Corrugated Steel Pipe (CSP). The concrete box culvert is approximately 70 m long and it goes through the SBL highway embankment. The CSP culvert has three sections – 15 m, 23 m and 93 m in length going under the NBL highway embankment. The existing culvert is experiencing distress and bracing has been installed to control movement. Exp understands that replacement of the existing culvert is recommended due to these structural deteriorations as identified in photographs accompanying the Terms of Reference provided by MTO. The Request for Quotation from February 13, 2011 originally suggested that the recommendations for the culvert replacement should be based on an assumed pipe diameter of 1.2 m. However, the Draft Drainage and Hydrology report, prepared by Stantec and dated June 2011, indicates that a minimum 1.5 m diameter circular pipe is required at the site in order to meet MTO drainage criteria. Two alignments, the current and a proposed more direct alignment, were suggested in the Request for Quotation dated February 23, 2011. The site plan showing both alignments is included in Appendix B, Drawing 1. The proposed inlet and outlet are to be placed at approximately the same locations as those of the existing culvert.

The field program to identify and characterize the subsurface and groundwater conditions along these two alignments was carried out, and the results are presented in **Part I-Foundation Investigation Report**. The program included geo-environmental testing to identify the main corrosion indicators affecting pipe material service life. The recommendations for the culvert replacement were initially based on factual data along the existing culvert alignment and proposed culvert alignment covered in Part I-Foundation Investigation Report and an assumed pipe diameter of 1.2 m. This has been reassessed afterwards to reflect the larger pipe indicated in the Draft Drainage and Hydrology report and the outcome of the reassessment is presented in this report.

This report addresses the geotechnical design of the foundation for the proposed culvert by providing geotechnical design parameters at the Ultimate Limit State (ULS) and Serviceability Limit States (SLS) as well as other geotechnical parameters that may be required in accordance with the latest edition of the *Canadian Highway Bridge Design Code (CHBDC)* (November 2006), the *Canadian Foundation Engineering Manual (CFEM)* (2006), MTO Gravity Pipe Design Guidelines (May 2007) and good practice. Pertinent construction issues from a geotechnical standpoint are examined in general accordance with the Terms of Reference from MTO letter dated February 23, 2011. The interpretations provided are intended to assist designers in their assessments. Contractors or others should make their own interpretation of the factual information and how it might impact the schedule, equipment and costs. The assessments involve review of options for replacement along the existing as well as the new proposed alignment with a final selection based on the optimum solution. To permit relative cost

assessment, a table of approximate cost per linear meter for a typical 1.8 m diameter soft ground trenchless installation, using a range of technologies, is presented below (Table 2.1).

*Table 2.1 Approximate estimate of mining rates for 1.8 m diameter soft ground tunnel (assuming mixed face soil and groundwater at or near crown)*

Tunnel Installation Method	Number of Passes	Cost in \$ per m
Jack and Auger Bore	2	13,000
TBM with Jacking	2	18,000
EPB TBM	1	21,000
Micro-tunnelling	1	17,000
Face Shield	2	13,000

*Notes: One pass – a permanent liner installed directly*

*Two passes – a temporary liner (i.e., ribs and lagging) first, and then a permanent (i.e., cast-in-place) liner installed*

## 2.2 Culvert Replacement along the Existing Culvert Alignment

### 2.2.1 Expected Ground Conditions

The geotechnical investigation and its findings pertaining to the subsurface soil characteristics have been covered in the Part I-Foundation Investigation Report which contains details of the field and laboratory aspects of the investigation. According to results of current foundation investigation, the following ground conditions along the existing culvert alignment are evident:

- The highway embankments consist of a surficial layer of 0.6 to 0.9 m thick sand and gravel fill underlain by silty sand fill.
- The total thickness of the embankment fill along the existing culvert alignment ranged from 1.4 m (along the east toe of the NBL embankment) to 16.8 m (SBL) at the tested locations.
- The foundation soil at the invert of the new proposed culvert is anticipated to be native sandy silt located at elevations between 279.4 m and 282.6 m. It is expected that the invert of the new culvert will be placed at approximately the same level as the existing culvert.
- The groundwater levels in the boreholes on the embankment crest were recorded approximately 1.0 m to 2.0 m above the existing culvert invert.
- Sinkholes were observed at the east embankment.
- Chloride and resistivity values of surrounding soil and surface water at the outlet side of the existing culvert indicate significant corrosive potential.



Based on SPT “N” values measured in the boreholes on the embankment crest (5 to 27 blows per 300 mm) and results of dynamic cone penetration testing in the boreholes at the embankment toe, the sandy silt within the limits of the existing culvert is classified as loose to compact. For the proposed culvert founded on the native sandy silt material, not extended beyond the limits of the existing culvert ends, Factored Bearing Resistances at ULS of 400 kPa and SLS of 140 kPa are recommended in accordance with the Canadian Highway Bridge Design Code (C.H.B.D.C.), Section 6.7. For any proposed culverts that will extend beyond the existing culvert limits, Factored Bearing Resistances at ULS of 250 kPa and SLS of 100 kPa may be used. The anticipated maximum total settlements for the proposed culvert are not expected to exceed 25 mm for construction done in accordance with these design parameters and assuming good construction practice.

### 2.2.2 Construction Options

For the proposed culvert replacement at the location of the existing culvert five options were considered as possible alternatives for new culvert installation methods: open cut method; jack and auger bore; pipe ramming; TBM tunneling; and interior replacement. The selection of appropriate construction methods for this culvert considered culvert zone soil conditions, diameter and length of the culvert. The only approach that would allow new construction on the exact existing alignment is a cut and cover method. This will involve removals of the existing sections prior to replacement. The other (trenchless) approaches involve construction adjacent to the current alignment with the need to make good and/or decommission the existing culvert sections. Sufficient separation (i.e at least 3 tunnel diameter) will be required. Further, even though cobbles and boulders were not encountered at drilled locations, an appropriate equipment and construction method shall be selected based on ability to accommodate these obstructions. The following table summarizes advantages and disadvantages of suggested methods.

*Table 2.2 Installation methods for culvert replacement along the existing culvert alignment*

Installation Method	Advantages	Disadvantages	Ranking
Open Cut	<ul style="list-style-type: none"> <li>• Straightforward construction</li> <li>• Phased excavation possible including accessing CSP section first (NBL)</li> <li>• Short mobilization time</li> <li>• Low capital investment</li> <li>• Adaptable to changing ground</li> <li>• Experienced contractors</li> <li>• Possible existing culvert's concrete box section condition assessment</li> <li>• Existing sections incorporated or decommissioned</li> <li>• Likely relatively less expensive than trenchless methods , however the shoring can be costly and traffic interruption will occur</li> </ul>	<ul style="list-style-type: none"> <li>• Excavation in the high embankments (~17 m)- shoring required</li> <li>• Traffic interruption, detour route required</li> <li>• Dewatering required</li> <li>• Risk of cost overrun and inability to finish job: low to moderate</li> </ul>	1

Installation Method	Advantages	Disadvantages	Ranking
Jack and Auger Bore  (Non-entry method)	<ul style="list-style-type: none"> <li>• Short mobilization time</li> <li>• Best applied in uniform soil</li> <li>• No requirement for detour route</li> <li>• Applicable for relatively short culvert; a center shaft can be installed between the two bound lanes and the installation of the culvert can progress towards east and west from the center shaft</li> <li>• Suitable for steel pipes up to 1.8 m in diameter</li> <li>• Likely relatively less expensive than TBM tunneling, however requires the center shaft and it is difficult to steer</li> </ul>	<ul style="list-style-type: none"> <li>• Some traffic interruption-likely require single lane closures to access entry pits</li> <li>• Pipe can be difficult to steer/direct</li> <li>• Settlement of existing embankment due to loss of ground during jack and bore operations. Short and long term settlement.</li> <li>• Presence of existing culvert in the vicinity can create instabilities and deformations and impedance, existing sections need to be decommissioned (grouted and made good)</li> <li>• Relatively long culvert (~125 m from BH1 to BH 5) for this method to be installed without the centre shaft or an intermediate jacking station</li> <li>• Large bore pit size</li> <li>• Excavation and shoring required to achieve starting grade</li> <li>• Fluid to support annular space</li> <li>• Groundwater level in the embankment above the invert level- requires groundwater control (dewatering or grouting) for face control</li> <li>• Risk of cost overrun and inability to finish job: moderate to high</li> </ul>	3
Pipe Ramming  (Non-entry Method)	<ul style="list-style-type: none"> <li>• Best applied in uniform soil</li> <li>• No requirement for detour route</li> <li>• Suitable for steel pipes up to 1.8 m in diameter and up to 90 m long; a center shaft can be installed between the two bound lanes and the installation of the culvert can progress towards east and west from the centre shaft</li> <li>• Accommodates obstruction well</li> <li>• Little surface settlement</li> <li>• Not very sensitive to ground conditions</li> <li>• Likely relatively less expensive than TBM tunneling, however requires the center shaft and it is difficult to steer and slower than jack and bore method</li> </ul>	<ul style="list-style-type: none"> <li>• Some traffic interruption-likely require single lane closures to access entry pits</li> <li>• Pipe can be difficult to steer/direct</li> <li>• Presence of existing culvert in the vicinity can create instabilities and deformations and impedance, existing sections need to be decommissioned( grouted and made good)</li> <li>• Relatively long culvert (~125 m from BH 1 and BH 5) for this method to be installed without the centre shaft or an intermediate jacking station</li> <li>• Excavation and shoring required to achieve starting grade</li> <li>• Large entry pit size</li> <li>• Ground heave</li> <li>• Vibrations</li> <li>• Slower than other techniques</li> <li>• Groundwater level in the embankment above the culvert invert level- for face control dewatering or grouting required</li> <li>• Risk of cost overrun and inability to finish job: moderate to high</li> </ul>	4

Installation Method	Advantages	Disadvantages	Ranking
TBM Tunneling  (Man-entry Method)	<ul style="list-style-type: none"> <li>• Good control of settlement</li> <li>• Ability to access obstructions during tunneling</li> <li>• Experienced contractor is available</li> <li>• Cost may be reduced if and where existing contractor's suitable TBM</li> </ul>	<ul style="list-style-type: none"> <li>• High capital investment</li> <li>• Not practical for small diameter pipe (min ~1.8 m diameter)</li> <li>• Requires decommissioning of old culvert, including grouting and sealing</li> <li>• Groundwater level in the embankment above the invert level- for face control (ground stabilization) dewatering or grouting required</li> <li>• Possible negative interfering with the existing culvert</li> <li>• Not entirely rational relative to TBM use in diagonal approach (the new proposed alignment)</li> <li>• Likely relatively more expensive than open cut and jack and auger bore methods</li> <li>• Risk of cost overrun and inability to finish job: low to moderate</li> </ul>	2
Interior Replacement	<ul style="list-style-type: none"> <li>• Short mobilization time</li> <li>• No excavation required</li> <li>• No traffic interruption and requirement for detour route</li> </ul>	<ul style="list-style-type: none"> <li>• Reduction in culvert capacity</li> <li>• Deteriorated condition of the existing CSP and its structural instability make this option as an unviable option</li> <li>• Invert grouting performed in spring 2011 definitely eliminate this option as viable</li> </ul>	Not Applicable

Based on the above list of advantages and disadvantages of the possible construction methods, cut and cover might be considered as the most viable method for culvert replacement along the existing culvert alignment if disruption of traffic is allowed. However, if the Regional Traffic office requires replacing the culvert without disrupting traffic, than trenchless installation methods are more viable. Two trenchless methods considered in the table above, jack and auger bore and pipe ramming, will likely require single lane closures to access entry pits resulting in some traffic interruptions. Further, these two methods are generally limited to lengths of 60 to 90 m which is less than the distance from one side of the embankment to the other (~125 m from BH1 to BH 5). To mitigate this disadvantage, a 17 m deep centre shaft between two bound lanes will be likely required. This can significantly improve site access, but the construction of the shaft must be supported by a temporary shoring system and space may be limited. The disadvantage of these trenchless installation methods is the need to make good and/or decommission the existing culvert sections. Maintenance of surface water flow is required. Both methods are difficult to steer which can be problematic because of proximity of the existing culvert. TBM tunneling is also ranked as one of the most viable method. However, it may not be rational relative to a TBM approach on a new direct alignment. The new culvert must be at least 3 pipe diameter spaced from the existing culvert (toward south). Again the existing abandoned culvert must be properly decommissioned.

Therefore, based on site conditions and method's characteristics elaborated above the following options of the construction methods for the culvert at the existing alignment are discussed in the following sections:

- Open cut (Section 2.2.3)
- Trenchless installation: Jack and auger bore (Section 2.2.4), and
- TBM tunneling (Section 2.3.3)

### 2.2.3 Culvert Installation by Open Cut Method

The open cut method appears to be the best viable installation method for culvert replacement along the existing culvert alignment if interruption of traffic on Hwy 11 is acceptable. With this approach, grouting and sealing of the existing culvert will be eliminated. This method will involve removals of the existing sections prior to replacement. Alternatively, after excavation of existing culvert and assessment of its condition, it might be possible to keep the 70 m long concrete box structure and replace only the deteriorated CSP culvert. In that case, compatibility between sections and appropriate joint control must be incorporated in the design. Further, a new pipe might be installed beside the repaired existing culvert allowing a multiple culvert installation approach. The pipe must be designed to meet MTO drainage criteria with a minimum spacing allowed between two pipes as specified in OPSS 421. However, disadvantages of open cut approach are traffic interruption and expensive shoring system required due to the significant height of embankment. With this method a detour route must be constructed to provide continuous uninterrupted highway operation. Further, provision must be made to maintain water flow to the outlet.

#### 2.2.3.1 Excavations

All excavations must be conducted in accordance with the Occupational Health and Safety Act and Regulations for Construction (OHSARC). The sand/gravel and silt sand fill and native sandy silt material may be classified as Type 3 soil above the groundwater table and a Type 4 soil below the groundwater table, in conformance with the OHSARC. Excavations are expected to be below the groundwater levels measured in the boreholes on the embankment crest during this investigation. To avoid disturbance of the founding subgrade and to allow placement of backfill in dry conditions, groundwater must be controlled to below the proposed excavation levels prior to digging to final levels.

Temporary excavations side slopes for Type 3 soil should not exceed 1H:1V. Temporary excavation side slopes for Type 4 soils should not exceed 3H:1V. There is a potential for sloughing to occur if the trench remains open for an extended period of time (i.e. 24-48 hours) or during a rainfall event. Groundwater will be suitably controlled. Therefore, it is recommended that excavations be supported by a trench box if they are to be open for an extended period of time or for rain events.

Since the excavation in the road embankment is relatively high (~17 m), it is expected that temporary shoring will be used as a protection system. Systems such as steel sheet piles or steel "I" beam piles with timber lagging (soldier piles and lagging) can be employed for temporary excavations. Given the

setting, the most likely bracing would be internal and the impact on excavation operations must be accommodated. It will be the Contractor's responsibility to design a suitable temporary support system for the MTO review prior to installation. The Contractor is to follow OPSS 538 and SP No. 902S01, regarding excavations for structures, and OPSS 539 and SP No. 105S19, regarding temporary protection systems (e.g. braced sheet piles, or some other form of bracing such as a soldier pile and lagging system).

The Contractor shall be responsible for the complete design, construction, monitoring and removal of the installed protection system. Due to nature of this application it is expected that much of temporary shoring will be decommissioned in place noting the high cost for removal. Decommissioning must be consistent good practice and effected in manner to avoid interference with highway systems and utilities. The protection system shall be designed to provide protection for excavations as required by the occupational Health and Safety Act, at locations specified in the contract, and at any locations where the stability, safety or function of an existing structure and/or utility may be impaired by construction work. The protection system should be designed for the Performance Level 1a or 1b (for small less important sections). The minimum requirements for monitoring shall include the survey measurements of 6 m apart scaled targets attached to the shoring wall at the elevations specified. If movement approaches the allowable limit of 5 mm (Performance level 1a) or 10 mm (Performance level 1b), suitable measures should be taken to ensure stability of the protection system and to ensure that the movement does not exceed the performance level specified.

Shoring scheme can likely include two main forms:

OPTION A: Provide roadway protection parallel to the highway between the north bound and south bound sections, and then divert traffic and undertake open cut. It is suggested to do the north bound section first. The roadway protection can take the form of reversible shoring using steel sheeting tiebacks. Stability assessment indicates that open cut slope of 2H:1V or flatter would be stable. Flatter slope might be required for practical reasons. The results of slope stability assessment are presented in Appendix F (Figure F1). Where the cut extends below prevailing groundwater a suitable control/system is required. Once the north bound section is completed the ties can be reversed and the south bound section constructed in similar fashion. The sheeting would likely be decommissioned in place.

OPTION B: Provide braced sheeting perpendicular to the highway (or angled for the new alignment) with bulkheads for face protection and to allow culvert construction. Excavation in this case would have to accommodate the necessary cross-bracing.

Option A is more economical. Assuming about 1000 \$/m<sup>2</sup> for up to 2H:1V slope for the 18 m height indicates an estimated cost for the shoring only in the range of \$ 1.2 to 1.5 million. Related earth work costs are not included. This approach will be more disruptive to the highway embankment.

Option B will disrupt less of the embankment but would cost more, i.e. about 180% of the roadside shoring option (Option A). Excavation and backfilling operations will also be more challenging with

Option B. The above approaches can be applied to both alignments noting that the decommissioning of the existing culvert is required as a separate item on the new alignment scheme.

As mentioned before, the Contractor is responsible for temporary shoring work and designs that should accommodate all relevant conditions including local and global stability for all stages of installation.

### 2.2.3.2 Lateral Earth Pressure

Culvert walls at the outlet and inlet, and temporary shoring that may be required for excavation should be designed to resist lateral earth pressure. The expression for calculating lateral earth pressure is given by:

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

where

$P$  = earth pressure intensity at depth  $h$ , kPa

$K$  = earth pressure coefficient

$\gamma$  = unit weight of retained soil, kN/m<sup>3</sup>

$q$  = surcharge near wall, kPa

$h$  = depth to point of interest, m

The above expression does not take into account hydrostatic pressure, which must be included for the groundwater levels measured on the site.

Table 2.3 below lists various earth pressure properties for given materials.

Table 2.3 Material types and earth pressure properties

Material	Friction Angle $\phi'$ (unfactored)	Coefficient of Active Earth Pressure ( $K_a$ )	Coefficient of Passive Earth Pressure ( $K_p$ )	Coefficient of Earth Pressure at Rest ( $K_o$ )	Unit Weight $\gamma$ (kN/m <sup>3</sup> )
Granular A	35°	0.27	3.69	0.43	22
Granular B Type I	30°	0.33	3.00	0.50	21
Granular B Type II	35°	0.27	3.69	0.43	21
Gravel and Sand Fill	30°	0.33	3.00	0.50	21
Silty Sand	29°	0.35	2.88	0.52	20
Sandy Silt	27°	0.38	2.66	0.55	19

Note: Values given for horizontal earth pressures are for horizontal backfill. For sloping backfill, the design requirements outline in Sec C6.91(c) of the Canadian Highway Bridge Design Code should be used. A unit weight of  $\gamma = 21 \text{ kN/m}^3$  is based on well graded granular fill.

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

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

It is likely that bracing for the temporary support system will be required at a maximum interval of 5 m. For multiple support systems refer to Canadian Foundation Engineering Manual (CFEM) for apparent earth pressure distributions (CFEM, Section 26.10.3, Figure 26.8)

#### 2.2.3.3 Maximum Fill Height

Pipe selections for new culvert must conform to maximum height restrictions as outlined in OPSD Standards (OPSDs 807.030, 807.040, 805.010, 806.020, 806.021, 806.040, 806.060).

#### 2.2.3.4 Culvert Bedding

OPSDs 802.010, 802.031 and 802.032 which are included in Appendix E provide the bedding, embedment, cover and backfill standards for the different pipe material. According to these standards the culvert bedding should consist of Granular "A" (OPSS 1010) with thickness of 300 mm beneath the culvert and extend a minimum of 500 mm horizontally on either side of the culvert edge. The bedding material should be placed in layers not exceeding 200 mm in thickness, loose measurement, and compacted to at least 95% of the Standard Proctor Maximum Dry Density (SPMDD) before a subsequent layer is placed in accordance with OPSS 514. Bedding material placed in the haunches must be compacted prior to continued placement of cover material. Bedding on each side of the pipe shall be completed simultaneously. At no time shall the levels on each side differ more than the 200 mm uncompacted layers.

Prior to placing any fill material, the exposed native subgrade should be inspected according to OPSS 902. A non-woven geotextile separator is to be placed between the approved subgrade and the compacted fill to assist in material placement and maintain the integrity of the founding soil along the entire length of the culvert. The geotextile separator is to be a Class II non-woven material with an equivalent opening size of 75-150  $\mu\text{m}$ .

For the Township of MacAulay, a frost penetration depth of approximately 1.6 m can occur in open, unheated areas without snow cover. At the culvert inlet and outlet, and beneath the proposed culvert, the native soils consist of a sandy silt material. The sandy silt material has highly frost susceptibility based upon the MTO Frost Classification guideline of percent particles between 5 to 75  $\mu\text{m}$ . Therefore, non-frost susceptible materials such as sand and gravel (Granular "A") need to be provided to the limit of frost penetration beneath the inlet and outlet of the culvert. However, considering that cold air blowing



through the culvert during the winter season will freeze soil next to the culvert, a minimum 500 mm thick layer of non-susceptible material should be considered to be placed as a bedding along the entire culvert length.

#### 2.2.3.5 Culvert Backfill

The culvert backfill should consist of Granular “B”, Type I or Granular “A” (OPSS 1010) placed in layers not exceeding 300 mm in thickness for the full width of the trench and each layer shall be compacted to 95% of the Standard Proctor Maximum Dry Density before a subsequent layer is placed, according to OPSS 514.

The culvert should be encased with a minimum of 300 mm of compacted material. Typical backfill diagrams are presented in Appendix E, OPSS 802.010, 802.031 and 802.032. The minimum height of fill cover above the crown of the pipe before power operated tractors or rolling equipment shall be 900 mm, unless otherwise noted by the structural engineer.

#### 2.2.3.6 Clay Seal

If it is decided that the concrete box culvert is to be extended instead of replaced, a clay seal should be placed at the joint of the concrete box culvert and proposed extension to prevent the migration of material along the face of the culvert, the formation of flow paths, and any potential internal erosion (OPSD 802.095, Appendix E). OPSS 1205 specifies that material used for clay seals shall be natural clay, clay mixture (1 part Bentonite powder and 3.5 parts Granular “A”) or a geosynthetic clay liner (GCL). The coefficient of permeability shall not exceed  $1 \times 10^{-6}$  cm/s.

The following outlines the installation procedures and minimum material requirement of the clay seal:

- The clay seal should be placed along the sides and top of the culvert a minimum of 1.0 m along the side of the culvert and extending out laterally 1.0 m from the culvert.
- The clay seal should be placed from the top of the culvert footings and extend along the side and the top of the culvert. The clay must not be placed below the culvert.
- The clay should have a Liquid Limit greater than 40% and a Plasticity Index greater than  $0.73 \times (\text{Liquid Limit} - 20\%)$ .
- The clay seal is to be placed in maximum 150 mm thick lifts and compacted to 95% SPMDD within 2% of the optimum moisture content.

If the geosynthetic clay liner is used as a clay seal its material specifications containing the physical, mechanical and hydraulic properties shall be obtained from the manufacture. It is estimated that an approximately 12 mm thick GCL should be installed a minimum 1.0 m along the side of the culvert.



### 2.2.3.7 Dewatering

The soils encountered below the groundwater table and within potential excavation depths consist of silty sand fill and native sandy silt. The materials are highly susceptible to disturbance from groundwater and traffic. The groundwater level needs to be controlled to at least the excavation level to avoid disturbance, and any surface or groundwater seepage should be removed from within the excavation prior to the culvert bedding material placement of granular backfill in the dry. During the construction the upstream flow of the existing culvert (west side of Highway 11) should be directed away from the culvert. An appropriate diversion scheme must be developed by the Contractor.

It is the responsibility of the Contractor to propose a suitable dewatering system based on the time of construction and groundwater levels and creek flow conditions for prior approval of the MTO. The method used should not undermine the existing road.

Erosion and sediment control during culvert construction should be as per the MTC Drainage Manual, Volume 2. Silt fences and other sediment control measures should be included to protect the downstream environment from the construction activities.

### 2.2.4 Culvert Installation by Trenchless Method

If interruption of traffic is not acceptable and a trenchless installation method such as jacking and auger boring is selected, the procedures should conform to all relevant OPPS standards (in this case OPSS 416) and industrial standards. According to OPSS 421, the minimum spacing allowed between culverts when placing two pipes in multiple culvert installation is a 0.5 pipe diameter. However, since the existing pipe has experienced distress and instability and has to be decommissioned, it is recommended that the new alignment has to be at least 3 pipe diameter (min. 4.5 m) offset in the south direction, relative to the existing culvert. The existing abandoned culvert must be properly decommissioned including grouting and sealing. As noted above, provision for maintenance of water flow is required.

It is anticipated that the new invert levels will be also set into natural sandy silt, and excavation will be greatly through compact silt sand fill. Pipe jack and auger bore method involves jacking a pipe through the soil with a hydraulic ram and removal of soil with an auger. A cutting head is fixed to the leading edge of the pipe. The pipe should follow closely behind the cutting head. The auger transports spoils from the cutting head back to the bore pit.

Jack and bore method is considered feasible for this highway crossing, however, there are several items that must be addressed when considering this method. First, the problem associated with this method is deviation from the alignment, if not executed properly. The installation of the new alignment must not interfere with the existing abandoned culvert. Therefore, driving of the pipe has to be very accurate. Second, this method is generally applicable to relatively short tunnels. Successful drives in excess of 100 m have been performed. However, the proposed culvert length (~125 m) is somewhat longer than the common limit of this technique. This disadvantage can be mitigated by construction of a shaft in the centre between the two bound lanes and progress with pipe installation toward east and west from the shaft. This approach greatly improves site access and eliminates the construction of an access ramp at

the steep east slope of the embankment.

Due to presence of groundwater in the embankment at and above the culvert crown, control of the face of excavation by dewatering or grouting will be required during jacking and boring. Groundwater control for tunnelling is addressed in Section 2.3.3.3 of this report. If ground stabilization is not effectively done the pipe will have to be advanced ahead without soil removal to allow a soil plug at least three diameter to mitigate the possible ground loss.

### 2.2.5 Centre Shaft Construction

As mentioned before, a construction of a 17 m deep shaft at the centre of Hwy 11 between the two bound lanes is considered to allow installation of culvert using viable trenchless technologies. Appropriate excavation methods for the centre shaft shall be selected and designed by the Contractor. The Contractor is responsible to select shaft construction methodologies which should address all soil and groundwater issues such as seepage and stability. It is expected that the shaft can be excavated using heavy-duty hydraulic equipment. Considering the depth of the shaft the sides of the excavation will have to be shored.

Shoring should be designed using the state-of-the-practice information presented in the fourth edition of the Canadian Foundation Engineering Manual (CFEM). Geotechnical parameters that are considered to be appropriate are as follows:

Earth Pressure Coefficient       $K_a = 0.27$  where small movements permissible ( $\phi=35^\circ$ )

Soil unit weight       $\gamma = 20 \text{ KN/m}^3$  for the sandy silt/sand

It should be recognized that the final shoring design will be prepared by the shoring contractor. It is not possible to comment further on specific design details until this design is completed.

Unless otherwise advised, support of excavation walls, ground adjacent to anticipated construction activity, and structures adjacent to the construction, must be provided by the Contractor.

The shoring system must be designed for the worst condition that may apply during all stages of construction. This is not necessarily when excavation is completed.

The foregoing comments are for general guidance only. It is recommended that the shoring construction is inspected continuously by qualified personnel.

A small amount of groundwater flow is anticipated to enter the shaft during its construction which could be managed by a sump and pump method. However, it is the responsibility of the Contractor to propose a suitable dewatering system based on the time of construction and groundwater levels prior approval of the MTO. Dewatering shall conform to OPSS 517. The method used should not undermine the existing road.

Recommendations for backfilling work required at the shaft to return site condition to pre-construction grades is addressed in Section 2.3.3.6 of this report.

## **2.3 Culvert Replacement along the New Proposed Culvert Alignment**

### **2.3.1 Expected Ground Conditions**

The following ground conditions along the new proposed culvert alignment are evident from the investigation data:

- a. The highway embankments consist of sand and gravel fill and sity sand fill.
- b. The fill is underlain by native sandy silt.
- c. The thickness of the embankment fills is between 13.1 m to 16.1 m at investigated locations.
- d. At the level of the proposed culvert alignment the sity sand fill was found to be in compact conditions (SPT “N” values between 10 and 22).
- e. The foundation soil at the invert of the new proposed culvert is anticipated to be native sandy silt located at elevations between 279.4 m and 282.6 m.
- f. The sandy silt is described as loose to compact, based on SPT “N” values ranging from 7 to 24.
- g. The water table in the embankment fill is expected to be at Elev. 283.6 m, which is approximately 2.0 – 3.0 m above the invert of the proposed culvert.
- h. High chloride levels and resistivity values measured in soil and water samples collected at the outlet side indicate severe corrosion potential.

Based on investigation data, for the new culvert located at the new proposed alignment and founded on the native sandy silt material, not extended beyond the limits of the existing culvert ends, a Factored Bearing Resistances at ULS of 400 kPa and SLS of 140 kPa is recommended in accordance with the Canadian Highway Bridge Design Code (C.H.B.D.C.), Section 6.7. For any proposed culverts that will extend beyond the existing culvert limits, a Factored Bearing Resistance at ULS of 250 kPa and SLS of 100 kPa may be used. Again, the anticipated maximum total settlements for the new proposed culvert are not expected to exceed 25 mm for construction done in accordance with these design parameters and assuming good construction practice.

### **2.3.2 Construction Options**

Given the soil and groundwater conditions and dimensions (diameter of min 1.5 m and length of ~150 m) of the proposed new culvert, several construction methods were selected as possible. In addition, the selection of the appropriate excavation method along the new culvert alignment for this project must also consider: (i) excavation in a mixed ground condition (the culvert face might be partially in silty sand fill and partially in native sandy silt) and (ii) the groundwater table above the invert level. Therefore, Table 2.4 lists possible options considered, and summarizes their advantages and disadvantages.

**Table 2.4 Installation methods for culvert replacement along the new proposed culvert alignment**

Installation Method	Advantages	Disadvantages	Ranking
Open Cut	<ul style="list-style-type: none"> <li>• Straightforward construction</li> <li>• Short mobilization time</li> <li>• Low capital investment</li> <li>• Adaptable to changing ground</li> <li>• Experienced contractors</li> <li>• Likely relatively less expensive than trenchless methods, however the shoring can be costly and traffic interruption will occur</li> </ul>	<ul style="list-style-type: none"> <li>• Excavation in the high embankments (~16 m) –shoring required. High cost of shoring system</li> <li>• Traffic interruption, detour required</li> <li>• Dewatering required</li> <li>• Required decommissioning of existing culvert and repairing of sinkholes as a separate operation</li> <li>• Risk of cost overrun and inability to finish job: low to moderate</li> </ul>	5
Jack and Auger Bore (Non-entry Method)	<ul style="list-style-type: none"> <li>• Common use in Ontario</li> <li>• Relatively simple operation</li> <li>• Short mobilization time</li> <li>• Best applied in uniform soil with no free water present</li> <li>• No requirement for detour route</li> <li>• Applicable for relatively short culvert; a center shaft can be installed between the two bound lanes and the installation of the culvert can progress towards east and west from the central shaft</li> <li>• Suitable for steel pipes up to 1.8 m in diameter</li> <li>• Likely relatively less expensive than TBM tunneling, however requires the center shaft and it is difficult to steer and not suitable for mixed ground condition</li> </ul>	<ul style="list-style-type: none"> <li>• At the upper limit of application (required- min 1.5 m diameter pipe)</li> <li>• Some traffic interruption-likely require single lane closures to access entry pits</li> <li>• Pipe can be difficult to steer/direct</li> <li>• Settlement of existing embankment due to loss of ground during jack and bore operations. Short and long term settlement</li> <li>• Requires decommissioning of old culvert, including grouting and sealing</li> <li>• Requires decommissioning of old culvert, including grouting and sealing</li> <li>• Relatively long culvert (~150 m) for this method to be installed without the central shaft or an intermediate jacking station</li> <li>• Large entry pit size</li> <li>• Excavation and shoring required to achieve starting grade</li> <li>• Fluid to support annular space</li> <li>• Groundwater level in the embankment above the invert level- requires dewatering or grouting for face control</li> <li>• Risk of cost overrun and instability to finish job: moderate to high</li> </ul>	3
Pipe Ramming (Non-entry Method)	<ul style="list-style-type: none"> <li>• Not very sensitive to ground condition</li> <li>• Best applied in uniform soil</li> <li>• No traffic interruption and requirement for detour route</li> <li>• Suitable for steel pipes up to 1.8 m in diameter and best up to 30 m long</li> <li>• A center shaft can be installed between the two bound lanes and the installation of the culvert can progress towards east and west from the central shaft</li> <li>• Accommodates obstructions well</li> <li>• Little surface settlement</li> <li>• Soil removed after pipe in place</li> </ul>	<ul style="list-style-type: none"> <li>• Some traffic interruption-likely require single lane closures to access entry pits</li> <li>• Pipe can be difficult to steer/direct</li> <li>• Requires decommissioning of old culvert, including grouting and sealing</li> <li>• Relatively long culvert (~150 m) for this method to be installed without the central shaft or an intermediate jacking station</li> <li>• Excavation and shoring required to achieve starting grade</li> <li>• Large entry pit size</li> <li>• Ground heave</li> <li>• Vibrations</li> <li>• Slower than other techniques</li> </ul>	4

Installation Method	Advantages	Disadvantages	Ranking
	<ul style="list-style-type: none"> <li>Likely relatively less expensive than TBM tunneling, however requires the center shaft and it is difficult to steer and not suitable for mixed ground condition</li> </ul>	<ul style="list-style-type: none"> <li>Groundwater level in the embankment above the invert level- requires dewatering or grouting for face control</li> <li>Risk of cost overrun and instability to finish job: moderate to high</li> </ul>	
TBM Tunneling  (Man-entry Method)	<ul style="list-style-type: none"> <li>Good control of settlement</li> <li>Safe to use in mixed ground condition</li> <li>Ability to access obstructions during tunneling</li> <li>Experienced contractors are available</li> <li>Cost may be reduced if and where existing contractor's suitable TBM</li> </ul>	<ul style="list-style-type: none"> <li>High capital investment</li> <li>Not practical for small diameter pipe (min 1.8 m diameter)</li> <li>Requires dewatering or permeation grouting for ground stabilization</li> <li>A structural framework constructed above ground might be required at the launch pit to resist the jack reaction (if required)</li> <li>Requires decommissioning of old culvert, including grouting and sealing</li> <li>Likely relatively more expensive than open cut and jack and auger bore methods</li> <li>Risk of cost overrun and instability to finish job: low to moderate</li> </ul>	1
Micro-tunneling  (Non-entry Method)	<ul style="list-style-type: none"> <li>Handles wide variety of ground conditions</li> <li>Ability to control excavation face stability</li> <li>No dewatering</li> <li>Minimum surface disruption</li> <li>Very accurate</li> <li>Slightly less expensive than TBM tunneling, however it is obstruction problematic</li> </ul>	<ul style="list-style-type: none"> <li>High construction cost</li> <li>Obstruction problematic</li> <li>Requires decommissioning of old culvert, including grouting and sealing.</li> <li>Excavation and shoring required to achieve starting grade or thrust wall</li> <li>Requires large area for jacking shaft and support equipment</li> <li>Not suitable for short drive</li> <li>Risk of cost overrun and instability to finish job: moderate to high</li> </ul>	2
Horizontal Directional Drilling (HDD)  (Non-entry Method)	<ul style="list-style-type: none"> <li>No traffic interruption and requirement for detour route</li> <li>Short mobilization time</li> <li>Handles wide variety of ground conditions, but best applied in uniform overburden material</li> <li>No access pit required</li> <li>Steerable both horizontally and vertically to maintain and adjust alignment</li> <li>Suitable for installation of pipe up to 1.2 m in diameter and longer length</li> <li>No dewatering</li> <li>Rapid drilling</li> <li>Small settlement, if fluid well controlled</li> </ul>	<ul style="list-style-type: none"> <li>Size limitation to ~1300 mm</li> <li>Delays due to inability to deal with boulders, if any</li> <li>Escape of drilling mud might be problem</li> <li>Requires decommissioning of old culvert, including grouting and sealing.</li> <li>Annular space filling (gel of fluid or grouting)</li> </ul>	Not Applicable

Based on the above discussion of the construction methods, it is recommended that the following options be considered for further evaluation:

- TBM tunneling
- Micro-tunneling
- Pipe jack and auger bore
- Pipe ramming
- Open cut

### 2.3.2.1 TBM Tunneling

TBM tunnelling is a man-entry tunnelling method and encompasses the use of a tunnel boring machine (TBM). This method utilizes laser-guided targeting that achieves a very accurate line and grade to the pipe being installed. Given the compact nature of the silty sand fill and native sandy silt at the site and presence of groundwater along the embankment, this construction method can be successfully employed either using dewatering or grouting for groundwater control or using a “close face” machine (Earth Pressure Balance (EPB) or Slurry Support TBM).

To control ground movement behind the TBM a primary liner must be installed. TBM can employ single pass or two pass system. In the two pass system the temporary liner can be ribs and lagging with the permanent liner cast-in-place afterwards. The primary liner can be provided by either steel, cast iron or precast concrete liner plates. The space on the outside of the liner plates should be grouted as soon as possible, to reduce ground loss and ground settlement. Primary support can be also provided by jacking a pipe from a jacking station behind the boring machine. Pipes may be made of various materials (concrete, steel, fibreglass, etc). Selected pipe must conform to OPS requirements for embankment depth. The launch pit and jacking station should be constructed at the outlet side. If there is no sufficient depth to construct a trust wall for jacking, the jack reaction can be resisted by means of a structural framework constructed above ground having adequate restraint provided by means of piles, ground anchors or other such methods for transferring horizontal loads. TBM tunnelling with pipe jacking method is limited by the jacking force available. Even though it is not expected to be required at this site, excavation of an additional intermediate shaft to reduce the jacking forces is possible. This shaft can be also used as a rescue shaft if necessary. Given the diameter of culvert (min. 1.5 m) required, this method would require oversizing of pipe to minimum 1.8 m.

### 2.3.2.2 Micro-tunneling

Micro-tunnelling is a non-entry, remotely controlled, guided pipe-jacking process. This technique provides the ability to control excavation face stability by applying fluid pressure to counterbalance the earth pressure using either of two basic modes, slurry shield or earth pressure balance. Usually a pipe is jacked into place behind the cutting head with hydraulics. In order to minimize the resistance along the pipe exterior, a bentonite grout lubricant can be injected behind the cutting face. Steel, concrete or fibreglass pipes can be installed with this method. The method is suitable for the required pipe size of min. 1.5 m and length of approximate 150 m.

Micro-tunnelling is a laser-guided process, where the machine operator controls the machine from a control cabin located on the ground. Given its remote feature, whereby there is no personnel presence required in the tunnel or launch pit, this method is well suited for application in soft clays or saturated sand deposits, below water table, which is case at this project. Major disadvantages of micro-tunneling for this project are considered to be the relatively high cost of mobilization and lack of locally skilled contractors.

This option may become more attractive if potential bidders have available equipment in house.

#### 2.3.2.3 Pipe Jack and Auger Bore

Pipe jack and auger bore method is addressed in Section 2.2.4 of this report.

#### 2.3.2.4 Pipe Ramming

Pipe ramming is a trenchless method for installation of steel pipes over distances usually up to 30 m long and up to 1.8 m in diameter. The method uses pneumatic percussive blows to drive the pipe into ground. It typically requires excavation of two pits, but the ramming can be launched without an insertion pit if the ram is design to start at the side of a slope. However, since the required length of the proposed culvert in this project exceeds the limitation of the method, the launch pit (centre shaft) can be constructed in the middle between the bound lanes. As mentioned before, it requires a temporary shoring system. The method is the most useful for shallow installations under roads where other trenchless methods could cause surface settlement or heave, which is not case in this project. Spoil removal from the pipe can be done by auger. Installation is very noisy and difficult to steer.

#### 2.3.2.5 Open Cut Method

Open cut trenching is addressed in Section 2.2.3 of this report.

### 2.3.3 Culvert Installation by Tunneling Method

If the tunnelling method such as TBM tunnelling is selected, the procedures should conform to all relevant OPSS standards including OPPS 415 and common industrial standards.

#### 2.3.3.1 Tunneling Construction Considerations

It is anticipated that the invert level of the proposed culvert will be set into the natural sandy silt, so tunneling will be greatly through that soil or/and compact silty sand fill above. Boreholes BH 1 and BH 6 drilled at the inlet and outlet of the existing culvert, respectively, show that groundwater is present in the sandy silt at approximately 0.6 m below grade. Boreholes drilled on the embankment crest registered the groundwater levels in the silty sand fill, approximately 0.6 to 1.4 m above the native sandy silt layer. However, it must be noted that seasonal variations in the water table should be expected, with higher levels occurring during wetter periods of the year (such as spring thaw and late fall) and lower levels during drier periods. Some mounding on the embankment would be anticipated. Therefore, it is estimated that the groundwater level will be approximately 2.0 to 3.0 m above the invert of the proposed



culvert. Based on soil and groundwater conditions at the site, it is projected that the culvert excavation will be carried out through “mixed face” soil conditions with the groundwater table at and above the crown level. Cobbles and boulders were not encountered on the site during the fieldwork, however it can be expected that they might be present in the embankment fill.

A small to medium amount of groundwater seepage into the tunnel should be expected in the zone of tunnelling. Special construction techniques can be employed for the construction of the culvert in these materials. Possible construction methods include:

1. Lowering of the groundwater table to below tunnel invert. This will involve large-scale construction dewatering, and could adversely affect existing domestic wells, structures, roads and utilities, if any, in the neighbourhood.
2. Soil stabilization in the tunnel zone using chemical grouting such as permeation grouting. The soils must be grouted ahead of the tunnel, either from ground surface or from the tunnel face. It has been successfully applied in similar projects in Ontario.
3. Excavate the tunnel using an Earth Pressure Balance (EPB) tunnel boring machine to provide continuous support to the tunnel face by balancing the earth and water pressure against the thrust pressure of the machine. In general, this method is considered more effective in finer grained soils.
4. Excavate the tunnel using a tunnel boring machine with a slurry shield to provide continuous support to the tunnel face by balancing earth and water pressure in the in-situ soil with pressurized bentonite slurry. This method shows better effectiveness in coarse grained soils.

All these methods should be designed and installed by specialist contractors. Further input should be obtained from these contractors at the detailed design phase of the project.

#### 2.3.3.2 Tunnel Excavation Method

Given the soil conditions and the diameter and length of the proposed culvert, the tunnelling construction method could be either an open-face tunnelling boring machine (TBM) with dewatering or grouting, or an Earth Pressure Balance (EPB)/Slurry Support TBM. The culvert excavation should be carried out under the protection of a shield after the soils have been stabilized by dewatering or grouting. The open-face TBM is considered suitable for mixed ground tunnelling. Alternatively, an EPB TBM or a Slurry Support TBM can also be used in the saturated silty sand fill.

#### 2.3.3.3 Groundwater Control

For the culvert installation by tunnelling under dry conditions selecting dewatering as a mean of soil stabilization, it is estimated that groundwater levels in the embankment have to be lowered approximately by 3 to 4 m from the static water levels. To ensure dry working conditions and to stabilize the excavation, a water level drawdown to at least 1 m below the base of the excavation is required. The rate of dewatering will depend on the horizontal and vertical distribution and the amount of finer



particles present in the sandy fill. It is expected that a well point system will be required to manage the dewatering rates and required drawdown amount. However it is possible that tight spacing of the wells will be required for extensive dewatering. Technical specifications must ensure that the Contractor submits a groundwater and surface water control plan describing the proposed method for control. Dewatering shall conform to OPSS 517.

If chemical grouting is selected as primary method of groundwater control it can be performed from ground surface by extending the treatment zone approximately one pipe diameter above the crown and externally at the spring lines. The detail design of grouting works is the prerogative of the speciality contractors, and it should be based on empirical considerations, taking into account the specific subsurface conditions at the site.

#### 2.3.3.4 Ground Settlement

Settlement around the culvert is a combination of ground loss or “immediate” settlement caused by tunneling, and consolidation settlement. The immediate settlement is a direct result of the overcut and movement of ground at the heading during tunneling. The factors that influence the immediate settlement include the soil strength and the method of tunneling. Based on soil characteristics of the site, an experienced Contractor should be able to keep the settlement under the MTO’s required limit of 10 mm. Technical specifications should ensure that:

- The use of over-cutters (excavating to a diameter greater than the pipe diameter) is kept under 10 mm;
- The overcut area is grouted in a timely manner (if a man-entry tunnel is constructed grout should be injected immediately after support is installed); and,
- The program of instrumentation is carried out as per MTO guidelines.

Before the construction of the new culvert gets started, the existing culvert must be decommissioned and sinkholes made good by filling and/or grouting.

#### 2.3.3.5 Excavation of Pits

The launch and exit pits for the tunneling equipment are expected to be located at the outlet and inlet of the existing culvert, respectively. The bases of the pits are expected to be set at about 0.5 to 1 m depth. Excavations for these pits will extend through any surficial fill and/or topsoil deposits and into the underlying sandy silt deposit. In order to provide the required excavation geometry for the drilling (vertical front face for tunnel entry and a vertical rear face with a ballast system to act as a reaction force), the sides of the excavation will have to be shored. Recommendations for shoring are addressed in Section 2.2.5 of this report.

Boreholes BH 1 and BH 6 drilled at the inlet and outlet of the existing culvert, respectively, show that groundwater is present at approximately 0.6 m below grade. Boreholes BH 7, BH 8 and BH 9 drilled on the embankment crest registered the groundwater levels approximately 0.6 to 1.4 m above the native

sandy silt layer. However, as previously mentioned, seasonal variations in the water table should be expected, with higher levels occurring during wetter periods of the year and lower levels during drier periods.

For the shallow depth excavations anticipated, a small amount of groundwater flow should enter the underground works. It is expected that this amount of water could be managed by a sump and pump method. The water flow of the existing creek has to be conveyed away from the exit pit using the existing culvert. Technical specifications must ensure that the Contractor submits a groundwater and surface water control plan describing the proposed method for control.

#### 2.3.3.6 Backfilling

It is anticipated that backfilling work will be required at the launch and exit pits to return site condition to pre-construction grades. The following comments and recommendations are provided for backfilling such excavations.

The on-site excavated soils (silty sand and sandy silt) can be used as backfill, provided the material is within 3 percent of optimum moisture as determined in the standard proctor test. All excavations should be backfilled with inorganic on-site soils placed in maximum 300 mm thick lifts and compacted to at least 95 % of the Standard Proctor Maximum Dry Density (SPMDD). Any organic, excessively wet, or otherwise deleterious material should not be used for backfilling purposes. Any shortfall of suitable on-site excavated material can be made up with imported and approved materials.

All backfill and compaction operations should be monitored by qualified geotechnical personnel to approve material, to evaluate placement operations, and to verify that the specified degree of compaction is being achieved throughout the fill.

#### 2.3.3.7 Protection Systems

Depending on the tunneling method chosen for this project and the excavations that will be required to implement them, protection system(s) may be required for the existing roadway. The need for these systems will depend on the proposed geometry of the required excavations and their proximity to the existing highway structure. If required, protection systems (design, materials, construction, maintenance, monitoring and removal) will be required to meet the specifications set out in OPSS 539 and Special Provision No. 105S19. The protection systems are discussed in detail in Section 2.2.3.1.

#### 2.3.3.8 Monitoring and Contingency Plan

Regardless of the method of tunnelling selected for this project, it is recommended that the contractor develop a contingency plan incorporating appropriate monitoring to address loss of material from outside the pipe during the tunnelling operation. This plan should include at a minimum the following items:

- a) an "Alert" level(s), eg. The percent of soil in excess of 100% of the displaced soil, at which the plan would be implemented;
- b) a means to close the tunnel, and preferably to pressurize the pipe; and

- c) an emergency personnel/agency contact list.

Settlements should be monitored during construction to ensure compliance with MTO guidelines and the contract requirements. The instrumentation program should adequately verify effects of tunneling on the overlying highway and obtain advance warning of ground movements. The scope and layout of settlement instruments should be in general accordance with the MTO guidelines (Appendix: Settlement Monitoring Guideline – Tunneling). This should include a series of surface monitoring points placed at a maximum spacing of 5 m along the entire length of the proposed culvert. All monitoring points located in the unpaved portion of the right-of-way are to be founded below the frost penetration depth, which is typically 1.6 m in this area.

A reading schedule should be as follows:

- A minimum one set of readings prior to construction.
- A minimum three sets of readings during construction provided the movements are within the anticipated limits. Otherwise, the reading frequency may have to be increased.
- A minimum of two sets of readings on a weekly basis after completion of the work.

Instrumentation plans should be finalized once the Contractor is selected and when his construction methods are known.

Control of ground settlement on this project depends on the behaviour of soil at the tunnel face and on the tunneling methodology employed by the Contractor. Therefore, it is recommended that the inspection of the tunnel face by a geotechnical engineer be made twice a day to verify that the ground conditions are consistent with those encountered in the investigation boreholes. Furthermore, it is recommended that the volume of the material removed from the tunnel be monitored and continuously compared to the rate of tunnel advance. This would provide an indication if any over-excavation was taking place.

The criteria for evaluation of settlement should be based on the following action levels:

1. *Review Level:* If a maximum value of 10 mm relative to the baseline readings is reached, the method, rate or sequence of construction, or ground stabilization measures shall be reviewed or modified to mitigate further ground displacements.
2. *Alert Level:* If a maximum of 15 mm relative to the baseline readings is reached, the Contractor shall be required to cease construction operation or to execute pre-planned measures to secure the site to mitigate further unacceptable settlement and to assure safety of public.

## 2.4 Inlet and Outlet

### 2.4.1 Erosion Protection at Outlet

Rip-rap protection should be provided where the culvert discharges into the open creek. The rip-rap should extend approximately 5 m beyond the ends of the culvert and line the embankment slope to the spring line of the culvert. The size of the rip-rap is a function of the creeks hydrology. As a rule of thumb the thickness of the rip-rap should be a minimum of twice the median particle size, and 300 mm thick as a minimum. The rip-rap configuration at the creek bed should generally follow the OPSD 810.010, which is included in Appendix E of this report. Rip-rap placed at 1V:1H will be stable.

### 2.4.2 Stream Bed Rip-Rap

The stream bed rip-rap thickness is to be twice the median particle size, and/or 300 mm thick as a minimum as outlined by OPSD 810.010 included in Appendix E of this report.

### 2.4.3 Frost Protection

As noted before in Section 2.2.3.4, a frost penetration depth of approximately 1.6 m can occur in open, unheated areas of the Township of MacAulay without snow cover. At the culvert inlet and outlet, and beneath the proposed culvert, the native soils consist of a sandy silt material. The sandy silt material has a high frost susceptibility based upon the MTO Frost Classification guideline of percent particles between 5 to 75  $\mu\text{m}$ . Therefore, non-frost susceptible materials such as sand and gravel (Granular "A") need to be provided as outlined in Section 2.2.3.4.

## 2.5 Geo-environmental Assessment

The current geotechnical investigation program included geo-environmental testing (i.e. pH, electrical resistivity, and chloride and sulphate concentration levels) of the surrounding soil and water to assist in the design procedure of appropriate pipe material following the MTO Gravity Pipe Design Guidelines 2007 (The Guidelines) for culvert durability. The results of this testing are presented in Section 1.5 of this report. According to the Guidelines the pipe design process should be used with caution for extreme environmental conditions such as contact with soil or water with  $\text{pH} < 4$ ,  $\text{pH} > 10$  and/or  $R < 300$  ohm-cm (MTO Gravity Pipe Design Guidelines 2007, pg. 7).

Generally, soil or water pH levels between 5.5 and 8.5 are not considered to be detrimental to culvert durability (AASHTO, 2000). The measured levels of soil and water pH were between 6.30 and 6.53 at the inlet side and between 4.55 and 6.25 at the outlet side. According to these results, all surrounding soil and water samples tested meet the requirements except a soil sample collected at the culvert outlet location. This suggests that soils at that location are more acidic increasing potential for pipe corrosion. Table 7.1 in the Guidelines specifies that pipe materials such as concrete, steel and HDPE are susceptible to acid corrosion, so in the pipe design process it has to be taken into consideration.

According to Table 3.2 in the Guidelines the soil corrosiveness is considered as severe if the soil resistivity is less than 2000 ohm-cm. AASHTO (2000) states that soil resistivity values in excess of 5000

ohm-cm are considered to present limited corrosion potential. The results of the resistivity tests carried out on soil at the pipe structure location show that the resistivity of the soil in the vicinity of the culvert inlet is around 2200 ohm-cm, while the resistivity of the soil at the outlet side is much lower having a value of around 900 ohm-cm. The water samples collected at the inlet and outlet locations measured the resistivity of 22222 ohm-cm and 7692 ohm-cm, respectively. Since the soil resistivities at the outlet side are below the recommended levels, some level of pipe protection, depending upon the corresponding pH level and pipe material might be required.

Chloride ion corrosion also has to be considered during the pipe design process since chlorides primarily attack exposed metal, whether it be steel pipe or reinforcing steel in concrete pipe. The maximum permissible levels of chlorides in soil and water depend on corresponding pH level and pipe material type. The Canadian Performance Guideline for CSP Culverts (CSA G401) limits the maximum permissible levels of chlorides in water for galvanized steel and aluminized type 2 steel culverts to 150 mg/L and 193 mg/L, respectively. However, generally the level above 250 mg/L is considered corrosive. The measured levels of chlorides in the soil and water samples collected at the inlet location are 167.9 mg/L and 65.4 mg/L, respectively. In contrary, the levels of chlorides in both, soil and water, collected at the outlet location are much higher ranging from 439.9 to 634.9 mg/L. Therefore, if reinforced concrete pipe or steel pipes are selected they have to be adequately protected. Pre-cast concrete, HDPE and PVC pipes are generally not subject of significant chloride corrosion.

Concrete pipes are more susceptible to sulphate ion corrosion. According to Table 7.2 in the Guidelines the sulphate concentrations up to 150 mg/L are considered negligible for sulphate corrosion. Chemical analyses of soil and water samples indicate that both soil and water in the areas of interest have negligible amount of sulphate (between 20.2 mg/L and 88.7 mg/L).

## **2.6 Possible Causes of the Sinkholes**

It is reported by MTO that sinkholes have occurred in the east embankment adjacent to the NBL coinciding in location with the 45 degree bend in the CSP culvert in 2008 and 2010. According to the MTO report, these sinkholes have since been filled. However, a sinkhole was noted in the east embankment slope during this field work. Photo 5 in Appendix A shows the sinkhole.

It is also reported that two sections of the CSP culvert experienced distress and were braced in 12 locations to prevent further movement. A third section of the CSP culvert is also showing signs of distress.

The cause of the sinkhole that has developed in the east slope of the road embankment above the culvert is not clear. However, based on the CSP culvert condition it is most likely that appearances of these sinkholes are the results of the road embankment fill eroding and piping through loose backfill around the culvert, or even through holes in the culvert created by corrosion or abrasion or through holes at the separation of the sections. It is evident that the CSP culvert distresses leading to exposure of backfill material, piping and ground loss. Piping further lessened the soil pressure accelerating the failure process causing depression or sinkholes in the embankment fill.

The sinkholes in the east embankment slope above the CSP culvert section should be overexcavated in order to check its depth and extend and to investigate whether or not it was caused by embankment soil piping into the culvert via a hole or separation of the culvert.

The sinkholes must be repaired by filling and/or grouting before construction.

## 2.7 Temporary Construction Access Ramp

If required, a temporary access ramp shall be constructed along the northbound line of Hwy 11 where it is appropriate to allow necessary approach to the outlet. The existing east embankment at this location is approximately 16 m high and consists of an approximately 2H:1V side slope. The ramp has to be designed and constructed to such a manner as to allow safe traffic of the construction equipment. A slope stability assessment has been performed to assess the impact of the access ramp on the stability of the existing embankment. The following assumptions have been assumed for the analysis:

- The fill material for the access ramp will extend approximately 3.5 m from the shoulder of the existing roadway at a suitable location south of the culvert outlet and will go down along the east side of Hwy 11 having the slope of max 10%.
- The ramp embankment will have a side slope of 2.5H:1V or flatter.
- The traffic surcharge of 30 kPa will be applied

The results of these analyses are presented in Appendix F (Figures F2A to F2D). They show that the embankment slope should be stable during the construction stage if the slope of the fill is minimum 2.5H:1V.

The specific proposal for ramp construction by the selected contractor must be analyzed for stability prior to start the work.

## 2.8 Concluding Remarks

Repair/replacement of the deteriorated culvert can be on the existing alignment or more direct line angled across the highway embankment to directly connect the inlet and outlet points. For the existing alignment, if disruption of traffic is allowed, the most viable option appears to be open cut, although the required temporary shoring will be expensive. This approach may permit phased construction with replacement of deteriorated section of CSP in the north bound zone done first. The concrete section in the south bound can be further evaluated for feasibility of refurbishment and incorporation. If it is required to replace the culvert without disrupting traffic, TBM tunnelling is assessed as a preferred trenchless approach. However, the TBM approach may not be rational relative to its application on a new direct alignment.

Assessment of construction along the new alignment indicates that five options are feasible with TBM tunnelling method as the likely preferred approach. All options will require separate decommissioning of the existing culvert and sinkhole repairs. The trenchless approaches are less disruptive to highway operations.



## 2.9 Closure

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

This Foundation Investigation and Design Report has been prepared by Silvana Micic, Ph.D., P.Eng and Africa Geremew, Ph.D., and reviewed by Stan E. Gonsalves, M.Eng., P.Eng., Designated MTO Foundation Contact. The field investigation was conducted by Craig StAmant.

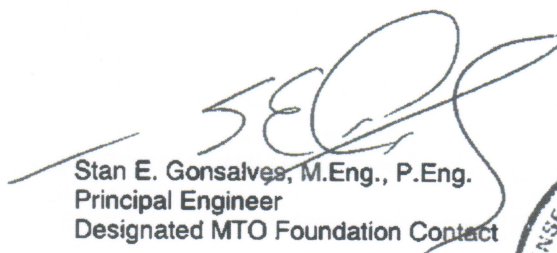
We trust that these comments provide you with sufficient information to proceed with design. Should you have any questions, please do not hesitate to contact this office.

Yours truly,

**exp Services Inc.**

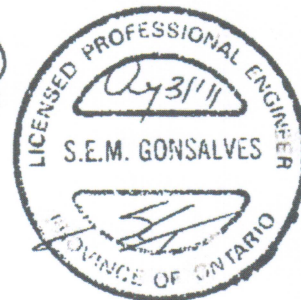


Silvana Micic, Ph.D, P.Eng.  
Senior Geotechnical Engineer



Stan E. Gonsalves, M.Eng., P.Eng.  
Principal Engineer  
Designated MTO Foundation Contact

Encl.



## **Appendix A – Photographs**





Photo 1. Inlet of the existing culvert (west side of HWY 11)



Photo 2. Inlet of the existing culvert (facing west)





Photo 3. East side of HWY 11 (facing north)



Photo 4. Outlet of the existing culvert (facing east)



Photo 5. Sinkhole in the east embankment

## **Appendix B – Drawings**



METRIC

DIMENSION ARE IN METERS AND/OR  
MILLIMETERS UNLESS OTHERWISE SHOWN.  
STATIONS ARE IN KILOMETERS+METERS.

CONT No.  
GWP 322-00-00

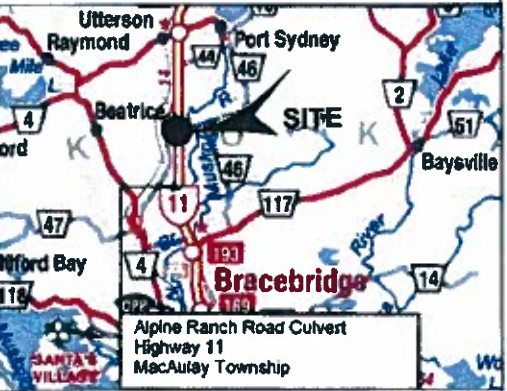
HWY 11 CENTRELINE CULVERT  
MACAULAY TOWNSHIP  
PLAN



SHEET

1

exp. EXP Services Inc.  
The new identity of Trow Associates



KEY MAP  
not to scale

LEGEND

Approx. Borehole Location (Current Investigation)

BH No.	ELEV.	CO-ORDINATES	
		NORTH	EAST
1	282.5	4 997 654	319 602
2	298.7	4 997 657	319 636
3	292.9	4 997 664	319 657
4	296.6	4 997 656	319 685
5	283.0	4 997 652	319 720
6	280.2	4 997 545	319 724
7	297.8	4 997 612	319 633
8	294.6	4 997 574	319 673
9	295.7	4 997 558	319 687
10	283.9	4 997 615	319 716

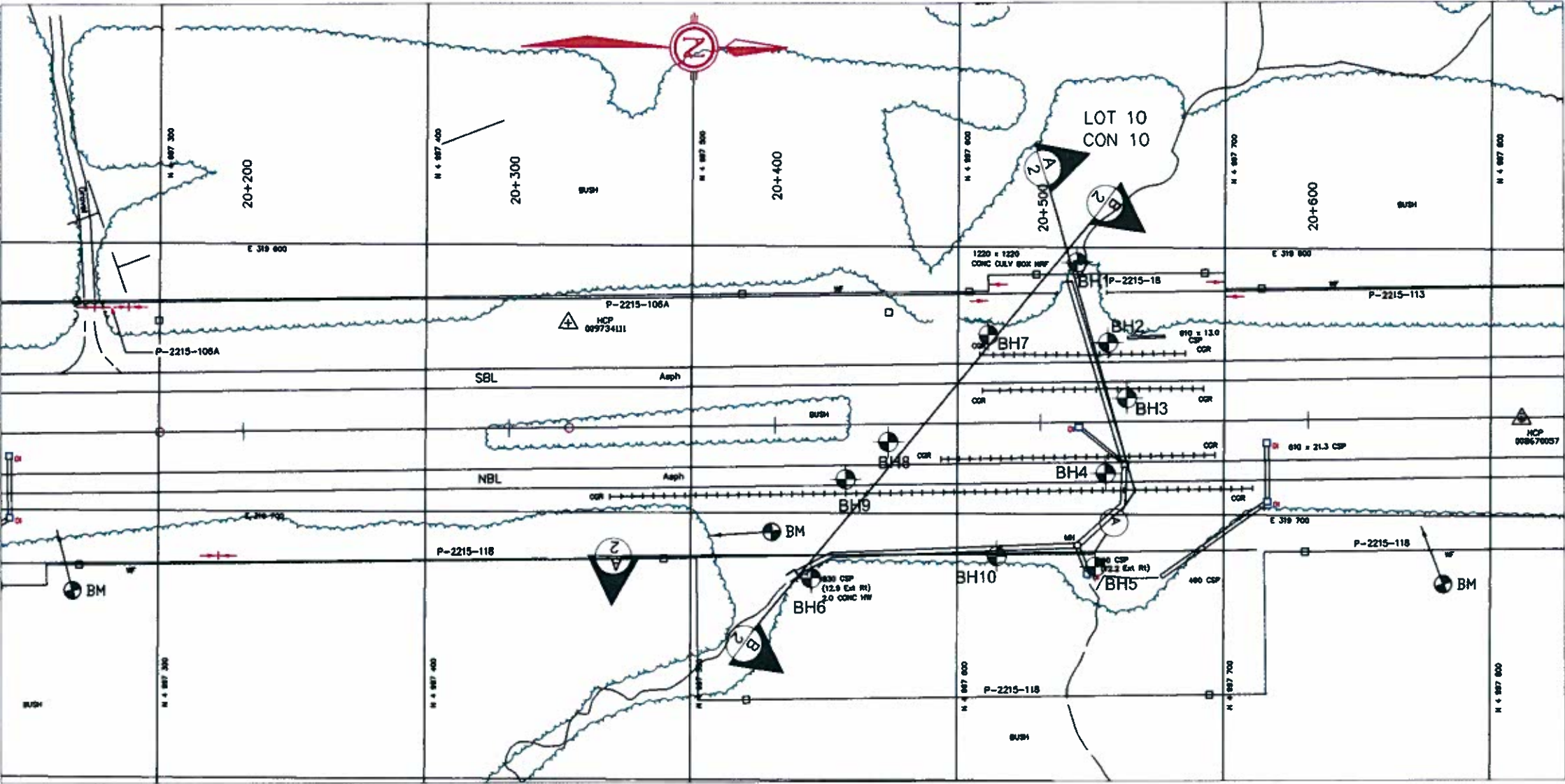
NOTE

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 complete foundation investigation and design report for this project and other related documents may be examined at the Materials Engineering and Research Office, Downsview. Information contained in this report and related documents are specifically excluded in accordance with the conditions of Section GC 2.01 of OPS Gen. Cond.

REV. No.	DATE	BY	DESCRIPTION
1	14/06/2011	SM	

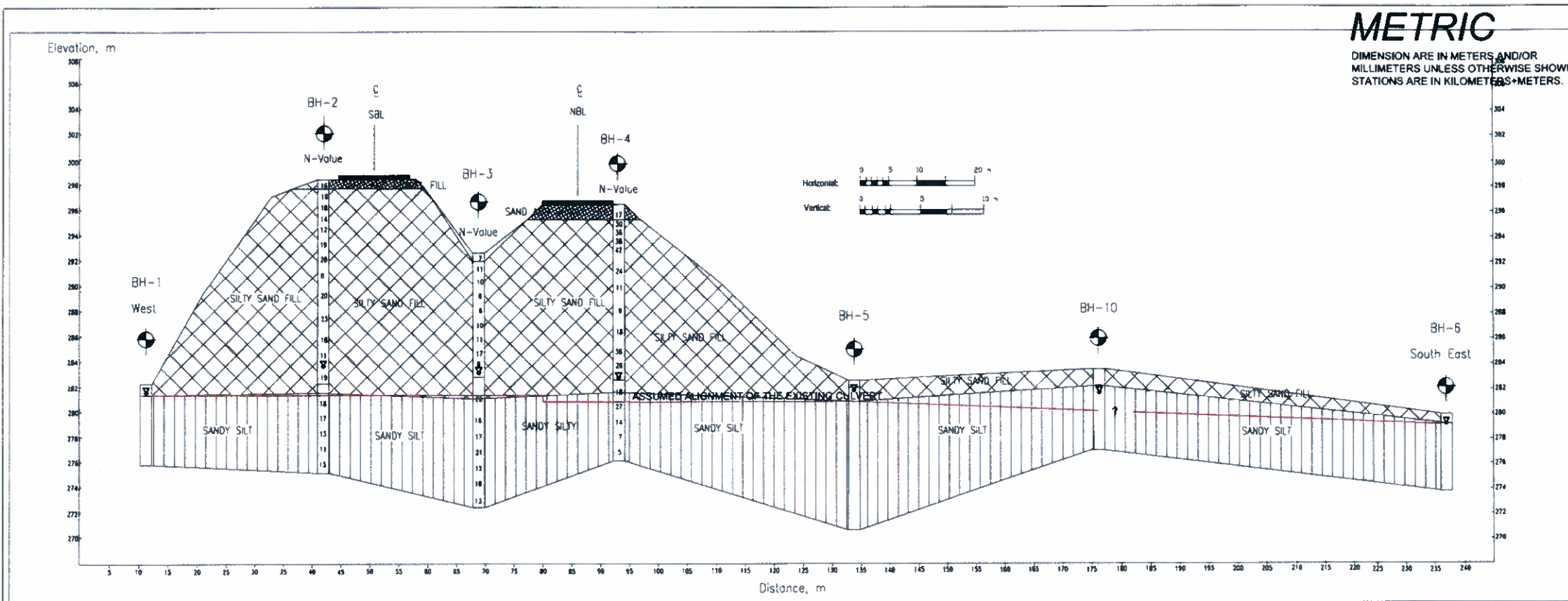
Geocres No. 31E-311	Project No. ADM 00200887-A0	DIST MUSKOKA
HWY No. 11	CHECKED: SG	DATE: JUNE 2011
SUBM'D: SM	CHECKED: SM	APPROVED: SG
DRAWN: AG	CHECKED: SM	APPROVED: SG
DWG. 01		



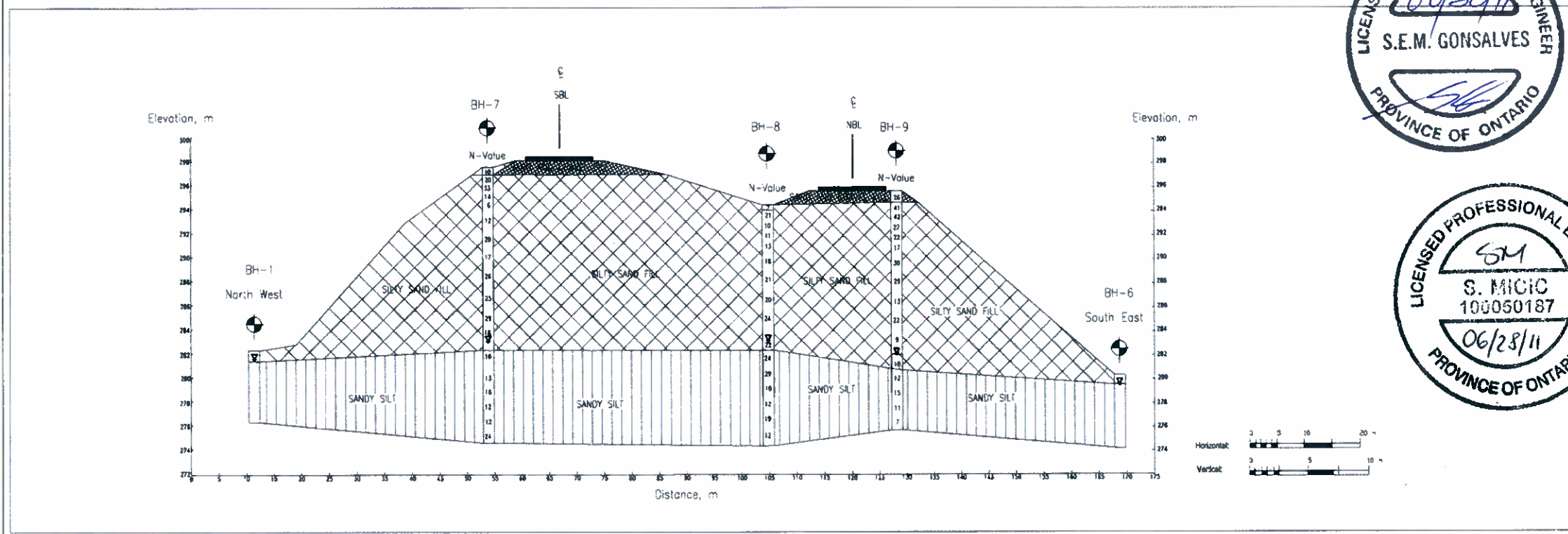
PLAN







**A-A**  
**SECTION 1**



**B-B**  
**SECTION 1**

**METRIC**

DIMENSION ARE IN METERS AND/OR MILLIMETERS UNLESS OTHERWISE SHOWN. STATIONS ARE IN KILOMETERS + METERS.

CONT No. <b>GWP 322-00-00</b>	 <b>SHEET</b> <b>2</b>
HWY 11 CENTRELINE CULVERT MACAULAY TOWNSHIP SECITON A-A and B-B	

**exp. EXP Services Inc.**  
The new identity of Trow Associates

**KEY MAP**  
not to scale

- LEGEND**
- Approx. Borehole Location (Current Investigation)
  - Water Level
  - Pavement
  - 'N' Blow/0.3 m
  - CULVERT

BH No.	ELEV.	CO-ORDINATES	
		NORTH	EAST
1	282.5	4 997 654	319 602
2	298.7	4 997 657	319 636
3	292.9	4 997 664	319 657
4	296.6	4 997 656	319 685
5	283.0	4 997 652	319 720
6	280.2	4 997 545	319 724
7	297.8	4 997 612	319 633
8	294.6	4 997 574	319 673
9	295.7	4 997 558	319 687
10	283.9	4 997 615	319 716

**=NOTE=**  
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 complete foundation investigation and design report for this project and other related documents may be examined at the Materials Engineering and Research Office, Downsview. Information contained in this report and related documents are specifically excluded in accordance with the conditions of Section GC 2.01 of OPS Gen. Cond.

REV. No.	DATE	BY	DESCRIPTION
1	14/06/2011	SM	

Geocres No. 31E-311

HWY No.11	Project No. ADM 00200887-A0	DIST. MUSKOKA
SUBM'D: SM	CHECKED: SG	DATE: JUNE 2011 SITE:
DRAWN: AG	CHECKED: SM	APPROVED: SG DWG. 02



## **Appendix C – Borehole Logs**



## EXPLANATION OF TERMS USED IN REPORT

**N-VALUE:** THE STANDARD PENETRATION TEST (SPT) N-VALUE IS THE NUMBER OF BLOWS REQUIRED TO CAUSE A STANDARD 51mm O.D SPLIT BARREL SAMPLER TO PENETRATE 0.3m INTO UNDISTURBED GROUND IN A BOREHOLE WHEN DRIVEN BY A HAMMER WITH A MASS OF 63.5kg, FALLING FREELY A DISTANCE OF 0.76m. FOR PENETRATIONS OF LESS THAN 0.3m N-VALUES ARE INDICATED AS THE NUMBER OF BLOWS FOR THE PENETRATION ACHIEVED. AVERAGE N-VALUE IS DENOTED THUS  $\bar{N}$ .

**DYNAMIC CONE PENETRATION TEST:** CONTINUOUS PENETRATION OF A CONICAL STEEL POINT (51mm O.D. 60° CONE ANGLE) DRIVEN BY 475J IMPACT ENERGY ON 'A' SIZE DRILL RODS. THE RESISTANCE TO CONE PENETRATION IS MEASURED AS THE NUMBER OF BLOWS FOR EACH 0.3m ADVANCE OF THE CONICAL POINT INTO THE UNDISTURBED GROUND.

SOILS ARE DESCRIBED BY THEIR COMPOSITION AND CONSISTENCY OR DENSENESS.

**CONSISTENCY:** COHESIVE SOILS ARE DESCRIBED ON THE BASIS OF THEIR UNDRAINED SHEAR STRENGTH ( $c_u$ ) AS FOLLOWS:

$C_u$ (kPa)	0 – 12	12 – 25	25 – 50	50 – 100	100 – 200	>200
	VERY SOFT	SOFT	FIRM	STIFF	VERY STIFF	HARD

**DENSENESS:** COHESIONLESS SOILS ARE DESCRIBED ON THE BASIS OF DENSENESS AS INDICATED BY SPT N VALUES AS FOLLOWS:

N (BLOWS/0.3m)	0 – 5	5 – 10	10 – 30	30 – 50	>50
	VERY LOOSE	LOOSE	COMPACT	DENSE	VERY DENSE

ROCKS ARE DESCRIBED BY THEIR COMPOSITION AND STRUCTURAL FEATURES AND/OR STRENGTH.

**RECOVERY:** SUM OF ALL RECOVERED ROCK CORE PIECES FROM A CORING RUN EXPRESSED AS A PERCENT OF THE TOTAL LENGTH OF THE CORING RUN.

**MODIFIED RECOVERY:** SUM OF THOSE INTACT CORE PIECES, 100mm+ IN LENGTH EXPRESSED AS A PERCENT OF THE LENGTH OF THE CORING RUN. THE ROCK QUALITY DESIGNATION (RQD), FOR MODIFIED RECOVERY IS:

RQD (%)	0 – 25	25 – 50	50 – 75	75 – 90	90 – 100
	VERY POOR	POOR	FAIR	GOOD	EXCELLENT

**JOINT AND BEDDING:**

SPACING	50mm	50 – 300mm	0.3m – 1m	1m – 3m	>3m
JOINTING	VERY CLOSE	CLOSE	MOD. CLOSE	WIDE	VERY WIDE
BEDDING	VERY THIN	THIN	MEDIUM	THICK	VERY THICK

## ABBREVIATIONS AND SYMBOLS

### FIELD SAMPLING

SS	SPLIT SPOON	TP	THINWALL PISTON
WS	WASH SAMPLE	OS	OSTERBERG SAMPLE
ST	SLOTTED TUBE SAMPLE	RC	ROCK CORE
BS	BLOCK SAMPLE	PH	TW ADVANCED HYDRAULICALLY
CS	CHUNK SAMPLE	PM	TW ADVANCED MANUALLY
TW	THINWALL OPEN	FS	FOIL SAMPLE

### STRESS AND STRAIN

$u_w$	kPa	PORE WATER PRESSURE
$r_u$	1	PORE PRESSURE RATIO
$\sigma$	kPa	TOTAL NORMAL STRESS
$\sigma'$	kPa	EFFECTIVE NORMAL STRESS
$\tau$	kPa	SHEAR STRESS
$\sigma_1, \sigma_2, \sigma_3$	kPa	PRINCIPAL STRESSES
$\epsilon$	%	LINEAR STRAIN
$\epsilon_1, \epsilon_2, \epsilon_3$	%	PRINCIPAL STRAINS
$E$	kPa	MODULUS OF LINEAR DEFORMATION
$G$	kPa	MODULUS OF SHEAR DEFORMATION
$\mu$	1	COEFFICIENT OF FRICTION

### MECHANICAL PROPERTIES OF SOIL

$m_v$	$\text{kPa}^{-1}$	COEFFICIENT OF VOLUME CHANGE
$c_c$	1	COMPRESSION INDEX
$c_s$	1	SWELLING INDEX
$c_a$	1	RATE OF SECONDARY CONSOLIDATION
$c_v$	$\text{m}^2/\text{s}$	COEFFICIENT OF CONSOLIDATION
$H$	m	DRAINAGE PATH
$T_v$	1	TIME FACTOR
$U$	%	DEGREE OF CONSOLIDATION
$\sigma'_{vo}$	kPa	EFFECTIVE OVERBURDEN PRESSURE
$\sigma'_p$	kPa	PRECONSOLIDATION PRESSURE
$\tau_f$	kPa	SHEAR STRENGTH
$c'$	kPa	EFFECTIVE COHESION INTERCEPT
$\phi'$	°	EFFECTIVE ANGLE OF INTERNAL FRICTION
$c_u$	kPa	APPARENT COHESION INTERCEPT
$\phi_u$	°	APPARENT ANGLE OF INTERNAL FRICTION
$\tau_R$	kPa	RESIDUAL SHEAR STRENGTH
$\tau_r$	kPa	REMOULDED SHEAR STRENGTH
$S_i$	1	SENSITIVITY = $c_u / \tau_r$

## PHYSICAL PROPERTIES OF SOIL

$P_s$	$\text{kg}/\text{m}^3$	DENSITY OF SOLID PARTICLES	$e$	1, %	VOID RATIO	$e_{\text{min}}$	1, %	VOID RATIO IN DENSEST STATE
$\gamma_s$	$\text{kN}/\text{m}^3$	UNIT WEIGHT OF SOLID PARTICLES	$n$	1, %	POROSITY	$I_D$	1	DENSITY INDEX = $\frac{e_{\text{max}} - e}{e_{\text{max}} - e_{\text{min}}}$
$P_w$	$\text{kg}/\text{m}^3$	DENSITY OF WATER	$w$	1, %	WATER CONTENT	$D$	mm	GRAIN DIAMETER
$\gamma_w$	$\text{kN}/\text{m}^3$	UNIT WEIGHT OF WATER	$s_r$	%	DEGREE OF SATURATION	$D_n$	mm	N PERCENT – DIAMETER
$P$	$\text{kg}/\text{m}^3$	DENSITY OF SOIL	$w_L$	%	LIQUID LIMIT	$C_u$	1	UNIFORMITY COEFFICIENT
$\gamma'$	$\text{kN}/\text{m}^3$	UNIT WEIGHT OF SOIL	$w_p$	%	PLASTIC LIMIT	$h$	m	HYDRAULIC HEAD OR POTENTIAL
$P_d$	$\text{kg}/\text{m}^3$	DENSITY OF DRY SOIL	$w_s$	%	SHRINKAGE LIMIT	$q$	$\text{m}^3/\text{s}$	RATE OF DISCHARGE
$\gamma_d$	$\text{kN}/\text{m}^3$	UNIT WEIGHT OF DRY SOIL	$I_p$	%	PLASTICITY INDEX = $(w_L - w_p)$	$v$	$\text{m}/\text{s}$	DISCHARGE VELOCITY
$P_{\text{sat}}$	$\text{kg}/\text{m}^3$	DENSITY OF SATURATED SOIL	$I_L$	1	LIQUIDITY INDEX = $(w - w_p) / I_p$	$i$	1	HYDRAULIC GRADIENT
$\gamma_{\text{sat}}$	$\text{kN}/\text{m}^3$	UNIT WEIGHT OF SATURATED SOIL	$I_C$	1	CONSISTENCY INDEX = $(w_L - w) / I_p$	$k$	$\text{m}/\text{s}$	HYDRAULIC CONDUCTIVITY
$P'$	$\text{kg}/\text{m}^3$	DENSITY OF SUBMERGED SOIL	$e_{\text{max}}$	1, %	VOID RATIO IN LOOSEST STATE	$j$	$\text{kN}/\text{m}^2$	SEEPAGE FORCE
$\gamma'$	$\text{kN}/\text{m}^3$	UNIT WEIGHT OF SUBMERGED SOIL						

# RECORD OF BOREHOLE No BH-01

1 OF 1

METRIC

W.P. GWP 322-00-00 LOCATION N 4997654; E 319602 ORIGINATED BY RL  
DIST Muskoka HWY 11 BOREHOLE TYPE Hand Drilling COMPILED BY AG  
DATUM Geodetic - MTO BM 294.67 DATE 05.11.11 - 05.11.11 CHECKED BY SM

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								WATER CONTENT (%)		
								○ UNCONFINED	+	FIELD VANE								
282.5	Ground Surface						● QUICK TRIAXIAL	×	LAB VANE									
0.0	SILTY SAND FILL (SM), trace organics, root fibers, dark brown, wet, very loose		1	SS		▽									0 71 29 0			
281.7																		
0.8	SANDY SILT (ML), trace clay, brown, wet, very loose		2	SS														
			3	SS														
	- becomes grey, loose		4	SS														
			5	SS														
	- seams and particles of top soils		6	SS														
			7	SS												0 19 81 0		
			8	SS														
276.4																		
6.1	END OF BOREHOLE																	
	NOTES: 1. Borehole advanced by hand drilling/sampling equipment. 2. Ground water level measured in the open hole upon completion of drilling operation. 3. This drawing is to be read with the subject report and project number as presented above. 4. Interpretation assistance by exp. is required before use by others.																	

ONTARIO MTO - TROW APPENDIX C - BOREHOLE LOGS - VERSION 5.GPJ ONTARIO MOT.GDT 06/14/11

# RECORD OF BOREHOLE No BH-02

1 OF 2

METRIC

W.P. GWP 322-00-00 LOCATION N 4997657; E 319636 ORIGINATED BY RL  
DIST Muskoka HWY 11 BOREHOLE TYPE CME Hollow Stem Auger COMPILED BY AG  
DATUM Geodetic - MTO BM 294.67 DATE 05.25.11 - 05.25.11 CHECKED BY SM

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							WATER CONTENT (%)	
								○ UNCONFINED	+ FIELD VANE							
								● QUICK TRIAXIAL	× LAB VANE							
298.7	Ground Surface							20 40 60 80 100								
298.0	ASPHALT (20 mm)															
298.1	SAND and GRAVEL FILL (SW), brown, moist, compact		1	SS	16		298			○						
0.6	SILTY SAND FILL (SM), brown, moist, compact		2	SS	16					○						
			3	SS	18		297			○						
			4	SS	14		296			○						
			5	SS	12		295			○						
			6	SS	19		294			○						
			7	SS	20		293			○						
			8	SS	8		292			○						
			9	SS	20		291			○						
			10	SS	23		290			○						
			11	SS	18		289			○						
							288			○						
					287			○								
					286			○								
					285			○								

ONTARIO MTO - TROW APPENDIX C - BOREHOLE LOGS - VERSION 5.GPJ ONTARIO MOT.GDT 06/14/11

Continued Next Page

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

# RECORD OF BOREHOLE No BH-02

2 OF 2

METRIC

W.P. GWP 322-00-00 LOCATION N 4997657; E 319636 ORIGINATED BY RL  
DIST Muskoka HWY 11 BOREHOLE TYPE CME Hollow Stem Auger COMPILED BY AG  
DATUM Geodetic - MTO BM 294.67 DATE 05.25.11 - 05.25.11 CHECKED BY SM

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								WATER CONTENT (%)		
								○ UNCONFINED ● QUICK TRIAXIAL	+ FIELD VANE × LAB VANE									
	- compact SILTY SAND FILL (SM), brown, moist, compact (continued)		12	SS	11													
			13	SS	19													
281.9																		
16.8	SANDY SILT (ML), brown to greyish brown, wet, compact			14	SS		18									0 22 78 0		
				15	SS		17											
	- compact			16	SS		13									0 22 78 0		
			17	SS	11													
275.4			18	SS	13													
23.3	END OF BOREHOLE																	
	NOTES: 1. Borehole advanced with continues flight hollow stem auger. 2. Ground water level measured in the open hole upon completion of drilling operation. 3. This drawing is to be read with the subject report and project number as presented above. 4. Interpretation assistance by exp. is required before use by others.																	

ONTARIO MTO - TROW APPENDIX C - BOREHOLE LOGS - VERSION 5.GPJ ONTARIO MOT.GDT 06/14/11

# RECORD OF BOREHOLE No BH-03

1 OF 2

METRIC

W.P. GWP 322-00-00 LOCATION N 4997664; E 319657 ORIGINATED BY RL  
DIST Muskoka HWY 11 BOREHOLE TYPE CME Hollow Stem Auger COMPILED BY AG  
DATUM Geodetic - MTO BM 294.67 DATE 05.27.11 - 05.27.11 CHECKED BY SM

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT w <sub>p</sub>	NATURAL MOISTURE CONTENT w	LIQUID LIMIT w <sub>L</sub>	UNIT WEIGHT γ kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%)					
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa							WATER CONTENT (%)				
292.9	Ground Surface							20	40	60	80	100							
0.0	SILTY SAND FILL (SM), brown, moist, loose		1	SS	7		292												
	- compact		2	SS	11		291												
	- occasional bands of top soils, moist, compact		3	SS	10		290												
			4	SS	8		289												
	- decayed wood pieces, dark brown, moist - loose		5	SS	6		288												
	- compact		6	SS	10		287												
			7	SS	11		286												
	- compact		8	SS	17		285												
	- loose	9	SS	8	284														
282.2																			
10.7	SANDY SILT (ML), root fibers, brown, wet, compact		10	SS	20		282												
							281												
	- compact		11	SS	16	280													
							279												

Continued Next Page

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

ONTARIO MTO - TROW APPENDIX C - BOREHOLE LOGS - VERSION 5.GPJ ONTARIO MOT.GDT 06/14/11

## 2 OF 2

METRIC

W.P.	<u>GWP 322-00-00</u>	LOCATION	<u>N 4997664; E 319657</u>	ORIGINATED BY	<u>RL</u>
DIST	<u>Muskoka</u> HWY <u>11</u>	BOREHOLE TYPE	<u>CME Hollow Stem Auger</u>	COMPILED BY	<u>AG</u>
DATUM	<u>Geodetic - MTO BM 294.67</u>	DATE	<u>05.27.11 - 05.27.11</u>	CHECKED BY	<u>SM</u>

[illegible]

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

ONTARIO MTO - TROW APPENDIX C - BOREHOLE LOGS - VERSION 5.GPJ ONTARIO MOT.GDT 06/14/11

# RECORD OF BOREHOLE No BH-04

1 OF 2

METRIC

W.P. GWP 322-00-00 LOCATION N 4997656; E 319685 ORIGINATED BY RL  
DIST Muskoka HWY 11 BOREHOLE TYPE CME Hollow Stem Auger COMPILED BY AG  
DATUM Geodetic - MTO BM 294.67 DATE 05.19.11 - 05.19.11 CHECKED BY SM

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>
296.6	Ground Surface						20 40 60 80 100										
0.0	SAND and GRAVEL FILL (SW), brown, moist, compact		1	SS	17		296										
295.7	SILTY SAND FILL (SM), brown, moist to very moist, dense		2	SS	30		295										
0.9	- dense		3	SS	36		294										
	- occasional bands of topsoil, moist		4	SS	38		293										
	- trace gravel		5	SS	42		292										
	- dense		6	SS	24		291										
	- compact		7	SS	11		290										
	- loose		8	SS	9		289										
	- occasional bands of top soil, occasional saturated silt seams, compact		9	SS	18		288										
	- dense		10	SS	38		287										
	- compact		11	SS	26		286										
	282.9						285										
	13.7						284										
						283											

ONTARIO MTO - TROW APPENDIX C - BOREHOLE LOGS - VERSION 5.GPJ ONTARIO MOT.GDT 06/14/11

Continued Next Page

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



## 2 OF 2

METRIC

W.P.	<u>GWP 322-00-00</u>	LOCATION	<u>N 4997656; E 319685</u>	ORIGINATED BY	<u>RL</u>
DIST	<u>Muskoka</u> HWY <u>11</u>	BOREHOLE TYPE	<u>CME Hollow Stem Auger</u>	COMPILED BY	<u>AG</u>
DATUM	<u>Geodetic - MTO BM 294.67</u>	DATE	<u>05.19.11 - 05.19.11</u>	CHECKED BY	<u>SM</u>

[illegible]

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

# RECORD OF BOREHOLE No BH-05

1 OF 2

METRIC

W.P. GWP 322-00-00 LOCATION N 4997652; E 319720 ORIGINATED BY RL  
DIST Muskoka HWY 11 BOREHOLE TYPE Hand Drilling COMPILED BY AG  
DATUM Geodetic - MTO BM 294.67 DATE 05.16.11 - 05.17.11 CHECKED BY SM

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								
								○ UNCONFINED	+ FIELD VANE							
								● QUICK TRIAXIAL	× LAB VANE							
283.0	Ground Surface						20 40 60 80 100									
0.0	SILTY SAND FILL (SM), dark brown, moist to very moist, loose		1	SS		▽	282					○			0 76 24 0	
			2	SS			281					○				
281.6	- seams of top soil						280					○				
1.4	SANDY SILT (ML) brown, wet, loose		3	SS			279					○				
			4	SS			278					○				
			5	SS			277					○				
	- becomes grey		6	SS			276					○				
			7	SS			275					○				
			8	SS			274					○				
			9	SS			273					○				
			10	SS			272					○				
			11	SS			271					○				
			12	SS								○				
	- compact		13	SS								○				
			14	SS								○				
			15	SS								○				
	- compact		16	SS							○					
270.8	END OF BOREHOLE															
12.2	NOTES: 1. Borehole advanced by hand drilling/sampling equipment. 2. Ground water level measured in the open hole upon completion of drilling operation. 3. This drawing is to be read with the subject report and project number as presented above.															

ONTARIO MTO - TROW APPENDIX C - BOREHOLE LOGS - VERSION 5.GPJ ONTARIO MOT.GDT 06/14/11

Continued Next Page

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

# RECORD OF BOREHOLE No BH-05

2 OF 2

METRIC

W.P. GWP 322-00-00 LOCATION N 4997652; E 319720 ORIGINATED BY RL  
DIST Muskoka HWY 11 BOREHOLE TYPE Hand Drilling COMPILED BY AG  
DATUM Geodetic - MTO BM 294.67 DATE 05.16.11 - 05.17.11 CHECKED BY SM

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 (%) GR SA SI CL
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			20	40	60	80	100	W <sub>p</sub>	W	W <sub>L</sub>		
	4. Interpretation assistance by exp. is required before use by others.																

ONTARIO MTO - TROW APPENDIX C - BOREHOLE LOGS - VERSION 5.GPJ ONTARIO MOT.GDT 06/14/11

# RECORD OF BOREHOLE No BH-06

1 OF 1

METRIC

W.P. GWP 322-00-00 LOCATION N 4997545; E 319724 ORIGINATED BY RL  
DIST Muskoka HWY 11 BOREHOLE TYPE Hand Drilling COMPILED BY AG  
DATUM Geodetic - MTO BM 294.67 DATE 05.12.11 - 05.12.11 CHECKED BY SM

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT	NATURAL MOISTURE CONTENT	LIQUID LIMIT	UNIT WEIGHT  γ  kN/m³	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa						
								20 40 60 80 100						
								○ UNCONFINED + FIELD VANE						
								● QUICK TRIAXIAL × LAB VANE						
280.2	Ground Surface													
0.0	SILTY SAND FILL (SM), dark brown, wet, very loose		1	SS										
279.4														
0.8	SANDY SILT (ML), trace clay, brown, wet, very loose - trace gravel		2	SS										
			3	SS										0 58 42 0
	- occasional root fibers, becomes grey, loose		4	SS										
			5	SS										0 37 63 0
			6	SS										
	- loose		7	SS										
			8	SS										
274.1	END OF BOREHOLE													
6.1	NOTES: 1. Borehole advanced by hand drilling/sampling equipment. 2. Ground water level measured in the open hole upon completion of drilling operation. 3. This drawing is to be read with the subject report and project number as presented above. 4. Interpretation assistance by exp. is required before use by others.													

ONTARIO MTO - TROW APPENDIX C - BOREHOLE LOGS - VERSION 5.GPJ ONTARIO MOT.GDT 06/14/11

# RECORD OF BOREHOLE No BH-07

1 OF 2

METRIC

W.P. GWP 322-00-00 LOCATION N 4997612; E 319633 ORIGINATED BY RL  
DIST Muskoka HWY 11 BOREHOLE TYPE CME Hollow Stem Auger COMPILED BY AG  
DATUM Geodetic - MTO BM 294.67 DATE 05.30.11 - 05.30.11 CHECKED BY SM

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							WATER CONTENT (%)
○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × LAB VANE															
297.8	Ground Surface														
0.0	SILTY SAND FILL (SM), dark brown, moist, loose														
	- compact			1	SS	10		297							
	- dense			2	SS	20		296							
	- compact			3	SS	33		295							
	- loose			4	SS	14		294							
				5	SS	6		293							
	- compact			6	SS	12		292							
				7	SS	20		291							0 42 58 0
				8	SS	17		290							
	- compact			9	SS	26		289							
				10	SS	25		288							
			11	SS	29		287							0 66 34 0	
							286								
							285								
							284								

Continued Next Page

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

ONTARIO MTO - TROW APPENDIX C - BOREHOLE LOGS - VERSION 5.GPJ ONTARIO MOT.GDT 06/14/11

## 2 OF 2

METRIC

W.P.	<u>GWP 322-00-00</u>	LOCATION	<u>N 4997612; E 319633</u>	ORIGINATED BY	<u>RL</u>
DIST	<u>Muskoka</u> HWY <u>11</u>	BOREHOLE TYPE	<u>CME Hollow Stem Auger</u>	COMPILED BY	<u>AG</u>
DATUM	<u>Geodetic - MTO BM 294.67</u>	DATE	<u>05.30.11 - 05.30.11</u>	CHECKED BY	<u>SM</u>

[illegible]

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

ONTARIO MTO - TROW APPENDIX C - BOREHOLE LOGS - VERSION 5.GPJ ONTARIO MOT.GDT 06/14/11

# RECORD OF BOREHOLE No BH-08

1 OF 2

METRIC

W.P. GWP 322-00-00 LOCATION N 4997574; E 319673 ORIGINATED BY RL  
DIST Muskoka HWY 11 BOREHOLE TYPE CME Hollow Stem Auger COMPILED BY AG  
DATUM Geodetic - MTO BM 294.67 DATE 05.20.11 - 05.20.11 CHECKED BY SM

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							WATER CONTENT (%)	
								○ UNCONFINED	+ FIELD VANE							
								● QUICK TRIAXIAL	× LAB VANE							
294.6	Ground Surface															
0.0	SILTY SAND FILL (SM), trace root fibers, dark brown, moist, loose		1	SS	7		294									
	- compact		2	SS	21											
			3	SS	10		293									
	- moist, compact		4	SS	11		292									
			5	SS	13		291									
	- compact		6	SS	18		290									
							289									
			7	SS	21		288							0 62 38 0		
							287									
	- silt seams, compact		8	SS	20		286									
							285									
			9	SS	24		284									
							283									
			10	SS	22		282							0 44 56 0		
282.4	SANDY SILT (ML), grey, wet, compact		11	SS	24		281									

Continued Next Page

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

ONTARIO MTO - TROW APPENDIX C - BOREHOLE LOGS - VERSION 5.GPJ ONTARIO MOT.GDT 06/14/11



# RECORD OF BOREHOLE No BH-08

2 OF 2

METRIC

W.P. GWP 322-00-00 LOCATION N 4997574; E 319673 ORIGINATED BY RL  
DIST Muskoka HWY 11 BOREHOLE TYPE CME Hollow Stem Auger COMPILED BY AG  
DATUM Geodetic - MTO BM 294.67 DATE 05.20.11 - 05.20.11 CHECKED BY SM

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 ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × LAB VANE						
	SANDY SILT (ML), grey, wet, compact ( <i>continued</i> )		12	SS	29									
	- compact						280							
			13	SS	10		279							0 21 79 0
							278							
			14	SS	12		277							
	- compact						276							
			15	SS	19		275							
274.3														
20.3	END OF BOREHOLE													
	NOTES: 1. Borehole advanced with continues flight hollow stem auger. 2. Ground water level measured in the open hole upon completion of drilling operation. 3. This drawing is to be read with the subject report and project number as presented above. 4. Interpretation assistance by exp. is required before use by others.													

ONTARIO MTO - TROW APPENDIX C - BOREHOLE LOGS - VERSION 5.GPJ ONTARIO MOT.GDT 06/14/11

# RECORD OF BOREHOLE No BH-09

1 OF 2

METRIC

W.P. GWP 322-00-00 LOCATION N 4997558; E 319687 ORIGINATED BY RL  
DIST Muskoka HWY 11 BOREHOLE TYPE CME Hollow Stem Auger COMPILED BY AG  
DATUM Geodetic - MTO BM 294.67 DATE 05.24.11 - 05.24.11 CHECKED BY SM

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										
								○ UNCONFINED + FIELD VANE										
								● QUICK TRIAXIAL × LAB VANE										
							20 40 60 80 100				20 40 60 80 100				WATER CONTENT (%)			
295.7	Ground Surface																	
0.0	SAND and GRAVEL FILL (SW), brown, moist		1	SS	26		295											
294.9	SILTY SAND FILL (SM), brown, moist, dense		2	SS	41		294											
0.9	- compact		3	SS	42		293											
			4	SS	27		292											
			5	SS	22		291											
			6	SS	17		290											
			7	SS	30		289											
	- dense		8	SS	29		288											
			9	SS	13		287											
			10	SS	22		286											
	- compact		11	SS	9		285											
							284											
	- loose						283											
						282												

Continued Next Page

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

ONTARIO MTO - TROW APPENDIX C - BOREHOLE LOGS - VERSION 5.GPJ ONTARIO MOT.GDT 06/14/11

# RECORD OF BOREHOLE No BH-09

2 OF 2

METRIC

W.P. GWP 322-00-00 LOCATION N 4997558; E 319687 ORIGINATED BY RL  
DIST Muskoka HWY 11 BOREHOLE TYPE CME Hollow Stem Auger COMPILED BY AG  
DATUM Geodetic - MTO BM 294.67 DATE 05.24.11 - 05.24.11 CHECKED BY SM

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								WATER CONTENT (%)		
								○ UNCONFINED	+	FIELD VANE								
							● QUICK TRIAXIAL	×	LAB VANE									
281.0	SILTY SAND FILL (SM), brown, moist, dense (continued)		12	SS	10									0 14 86 0				
14.7	SANDY SILT (ML), grey, wet, compact						281											
			13	SS	12		280											
							279											
	- compact		14	SS	15		278											
							277											
			15	SS	11		276											
275.4																		
20.3	END OF BOREHOLE		16	SS	7													
<div>NOTES: 1. Borehole advanced with continues flight hollow stem auger. 2. Ground water level measured in the open hole upon completion of drilling operation. 3. This drawing is to be read with the subject report and project number as presented above. 4. Interpretation assistance by exp. is required before use by others.</div>																		

ONTARIO MTO - TROW APPENDIX C - BOREHOLE LOGS - VERSION 5.GPJ ONTARIO MOT.GDT 06/14/11

# RECORD OF BOREHOLE No BH-10

1 OF 1

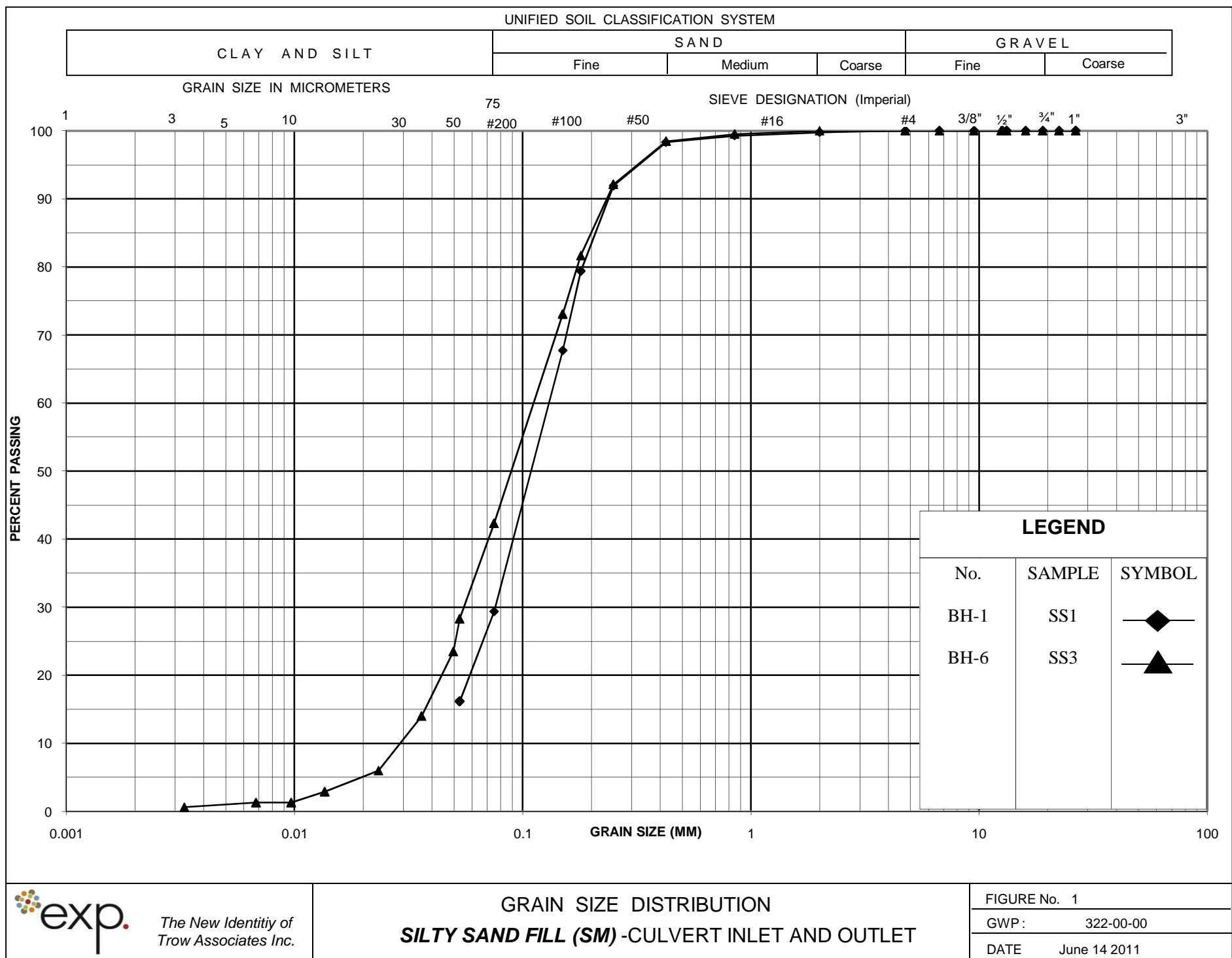
METRIC

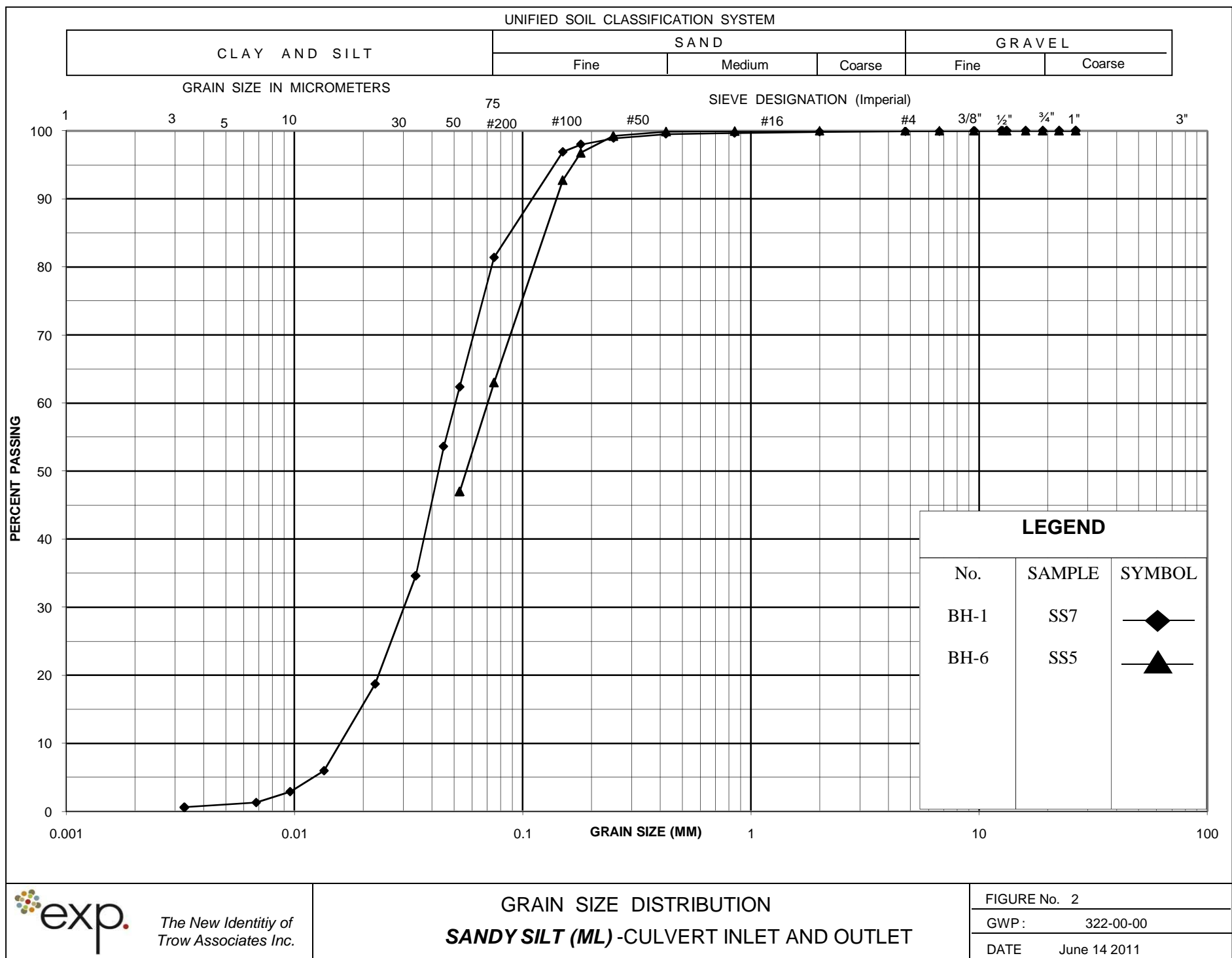
W.P. GWP 322-00-00 LOCATION N 4997615; E 319716 ORIGINATED BY RL  
DIST Muskoka HWY 11 BOREHOLE TYPE Hand Drilling COMPILED BY AG  
DATUM Geodetic - MTO BM 294.67 DATE 05.13.11 - 05.13.11 CHECKED BY SM

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								WATER CONTENT (%)		
								○ UNCONFINED ● QUICK TRIAXIAL	+ FIELD VANE × LAB VANE									
283.9	Ground Surface																	
0.0	SILTY SAND FILL (SM), trace organics, root fibers, dark brown, wet, very loose		1	SS			283											
282.5		2	SS															
1.4	SANDY SILT (ML), brown, moist, loose - dark brown, very loose - very loose	3	SS		282										0 39 61 0			
	- loose	4	SS		281													
		5	SS		280										0 33 67 0			
	- loose - grey, compact	6	SS		279													
	- compact	7	SS															
	- compact	8	SS		278													
277.8	END OF BOREHOLE																	
6.1	NOTES: 1. Borehole advanced by hand drilling/sampling equipment. 2. Ground water level measured in the open hole upon completion of drilling operation. 3. This drawing is to be read with the subject report and project number as presented above. 4. Interpretation assistance by exp. is required before use by others.																	

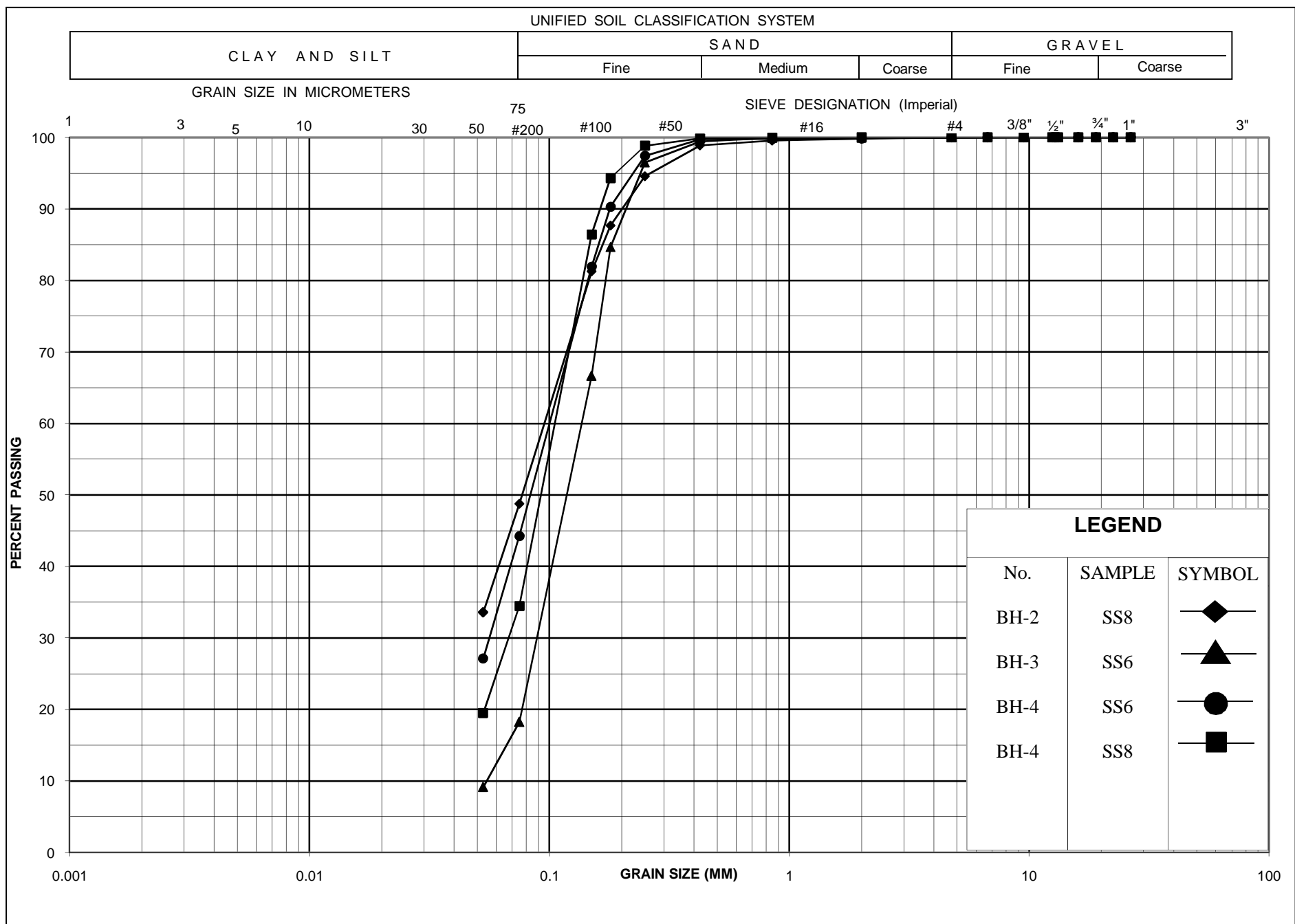
ONTARIO MTO - TROW APPENDIX C - BOREHOLE LOGS - VERSION 5.GPJ ONTARIO MOT.GDT 06/14/11

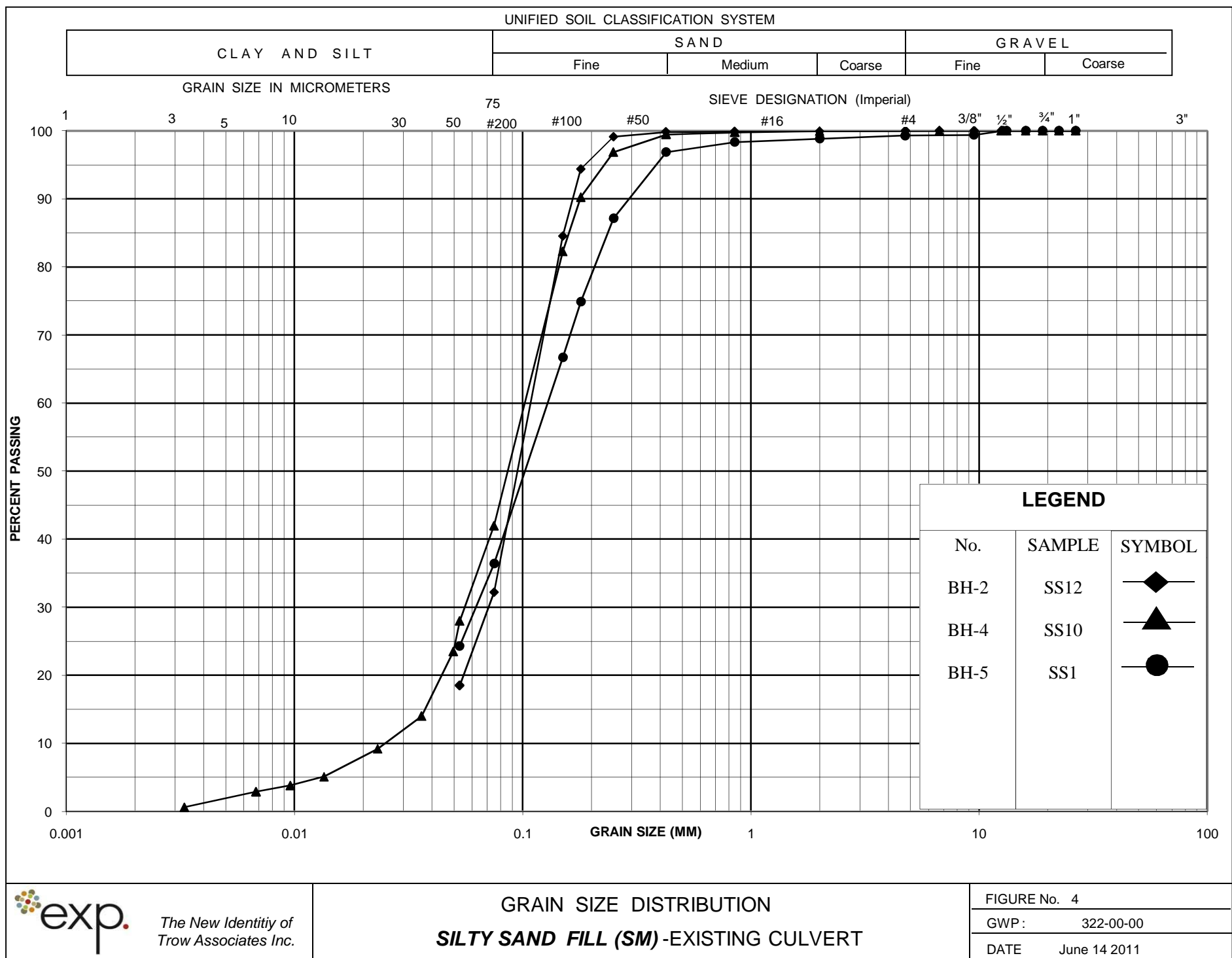
## Appendix D – Laboratory Data

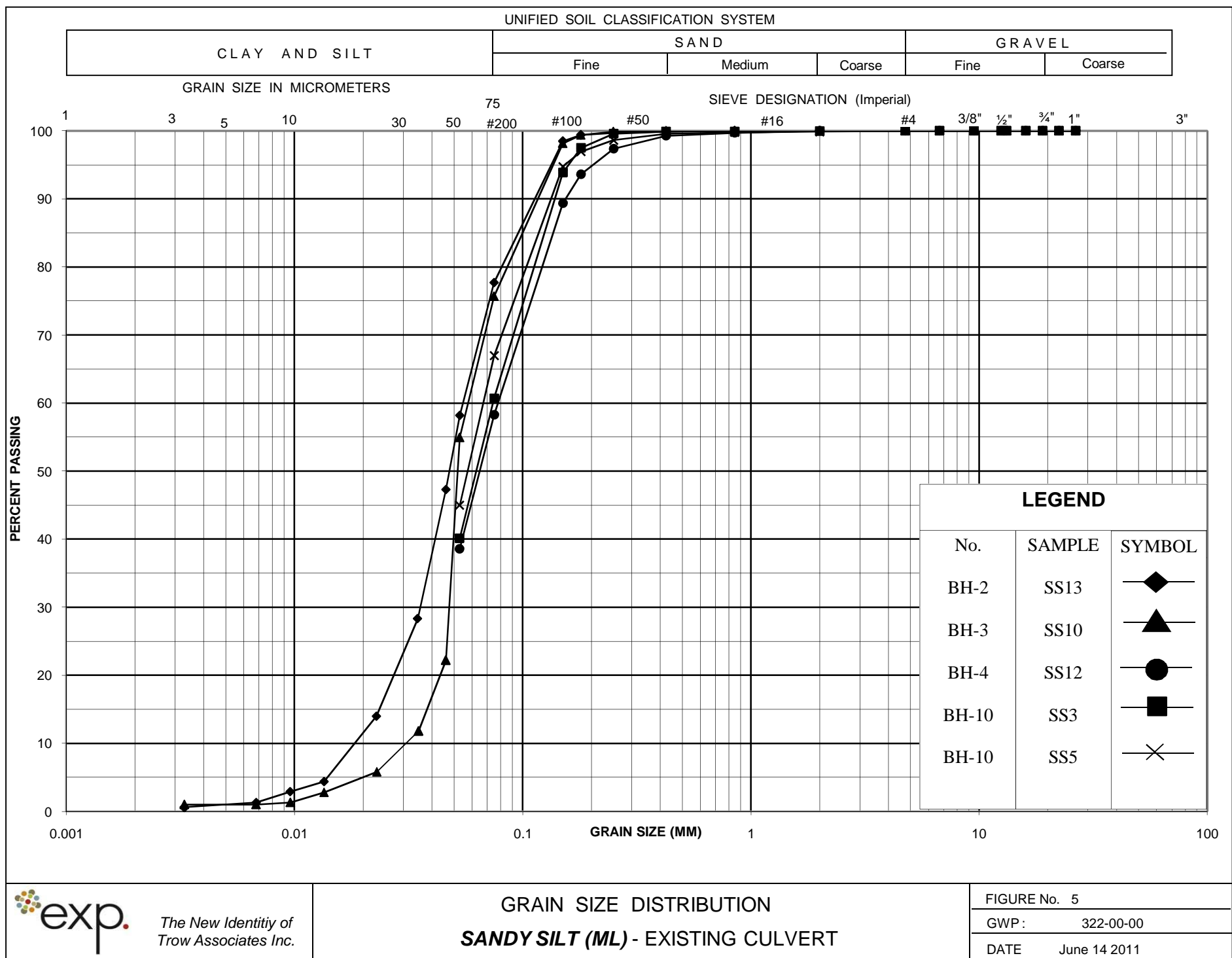


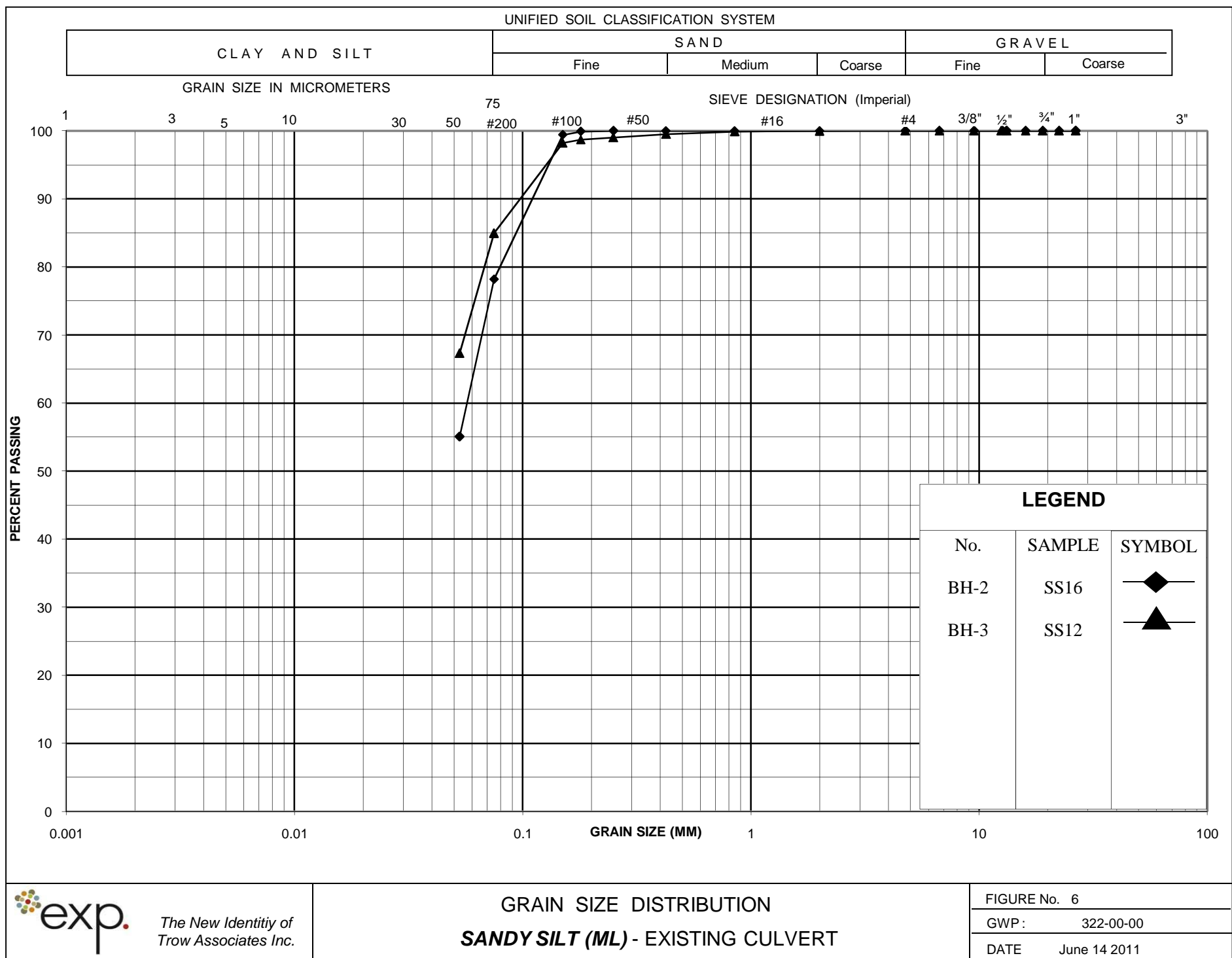


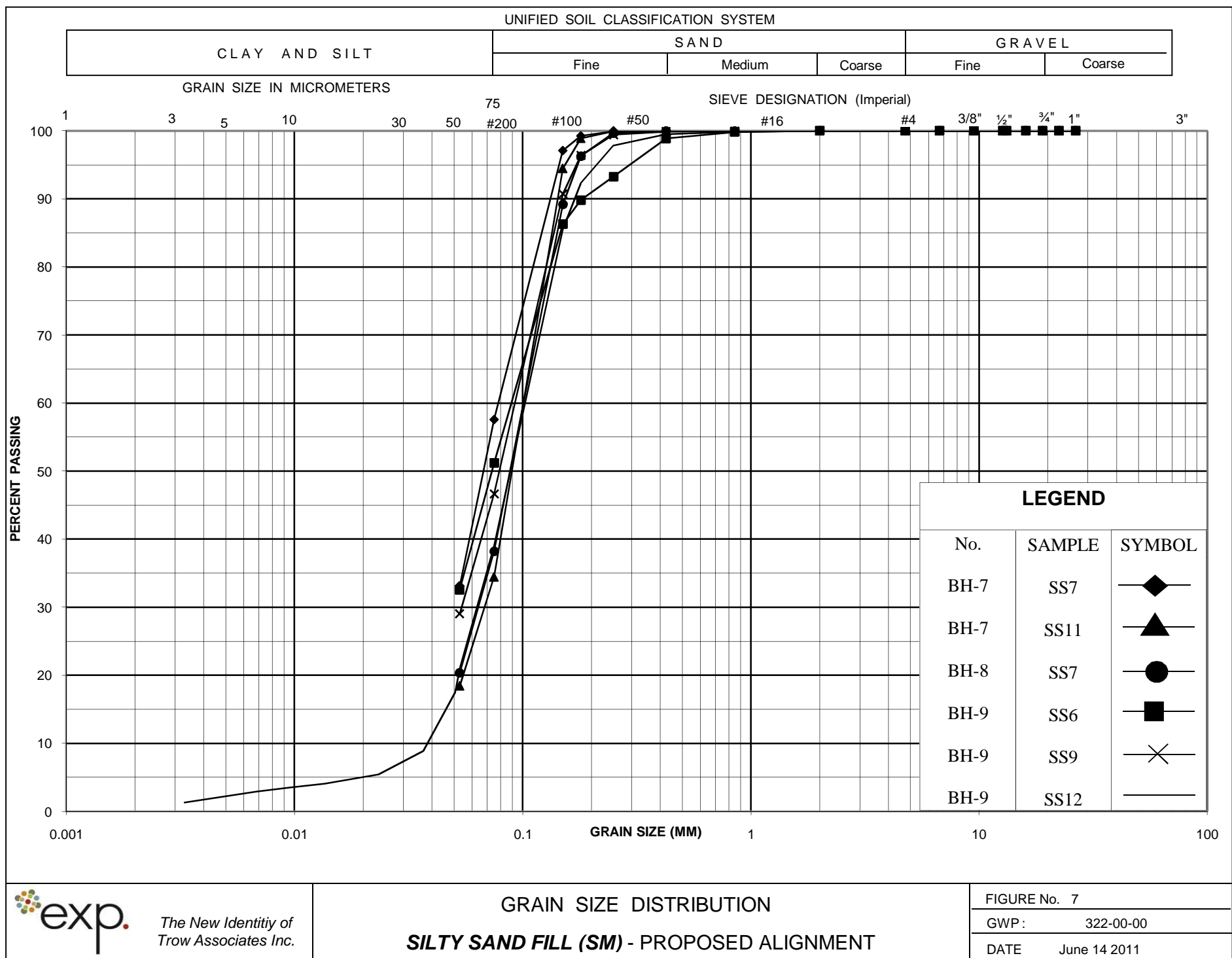




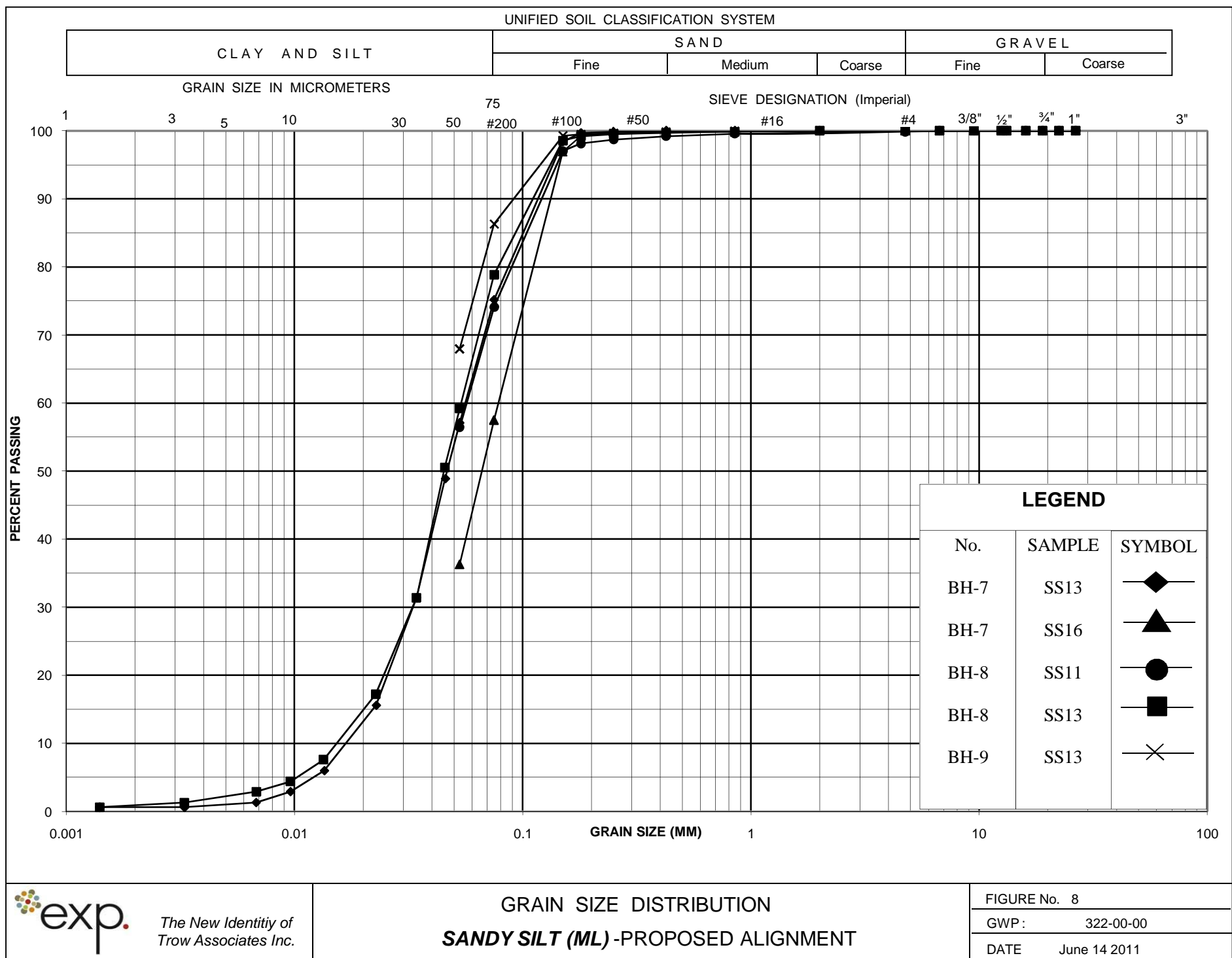




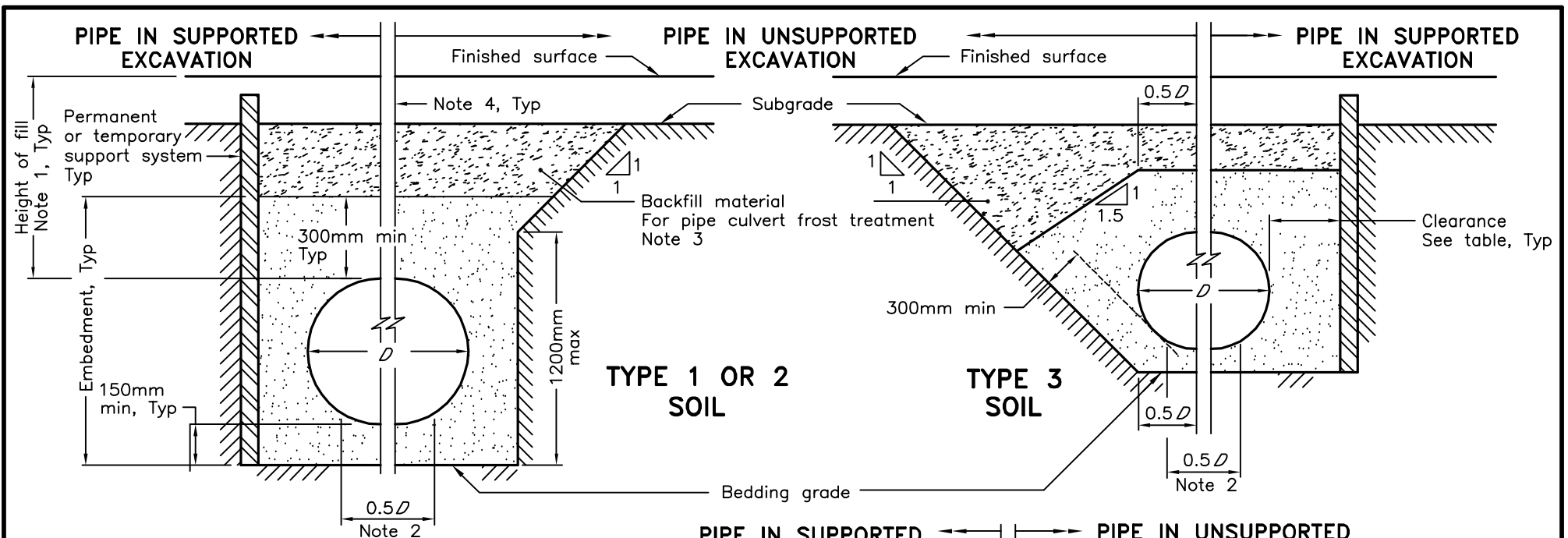




The New Identity of  
Trow Associates Inc.



## Appendix E – OPSD

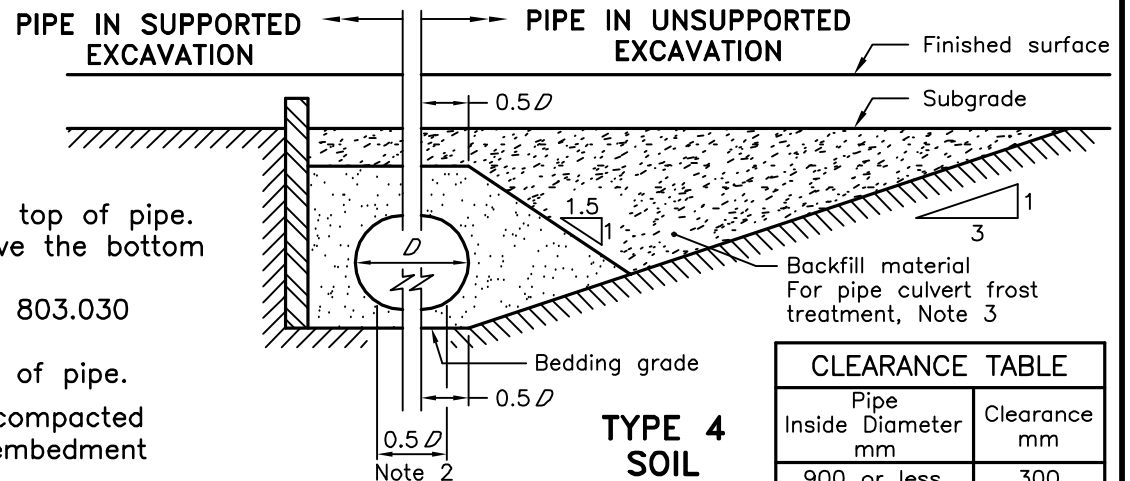


#### LEGEND:

$D$  - Inside diameter

#### NOTES:

- 1 Height of fill is measured from the finished surface to top of pipe.
  - 2 The pipe bed shall be compacted and shaped to receive the bottom of the pipe.
  - 3 Pipe culvert frost treatment shall be according to OPSD 803.030 and 803.031.
  - 4 Condition of excavation is symmetrical about centreline of pipe.
- A Granular material placed in the haunch area shall be compacted prior to placing and compacting the remainder of the embedment material.
- B Soil types as defined in the Occupational Health and Safety Act and Regulations for Construction Projects.
- C All dimensions are in metres unless otherwise shown.



CLEARANCE TABLE	
Pipe Inside Diameter mm	Clearance mm
900 or less	300
Over 900	500

ONTARIO PROVINCIAL STANDARD DRAWING

Nov 2010

Rev 2

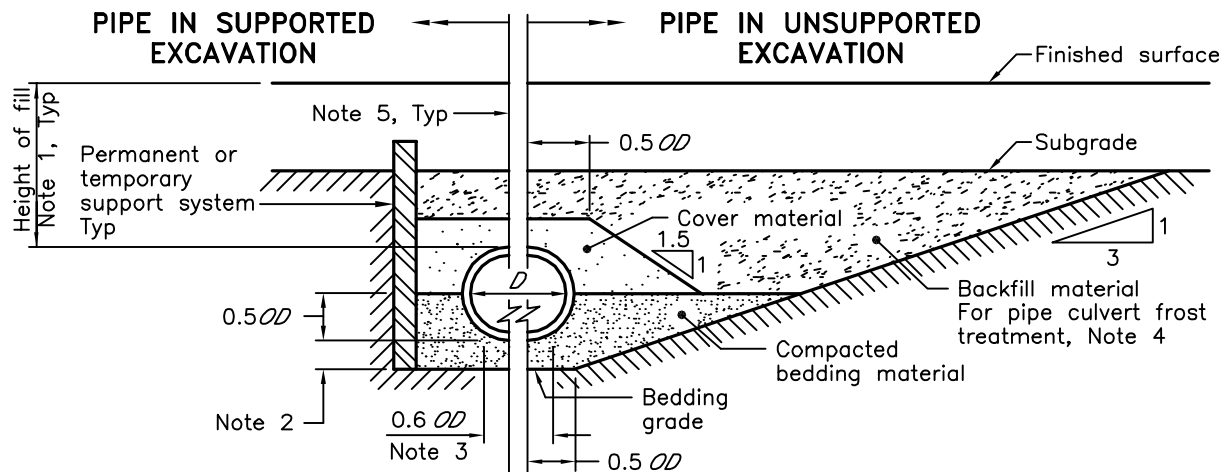
FLEXIBLE PIPE  
EMBEDMENT AND BACKFILL  
EARTH EXCAVATION

OPSD 802.010

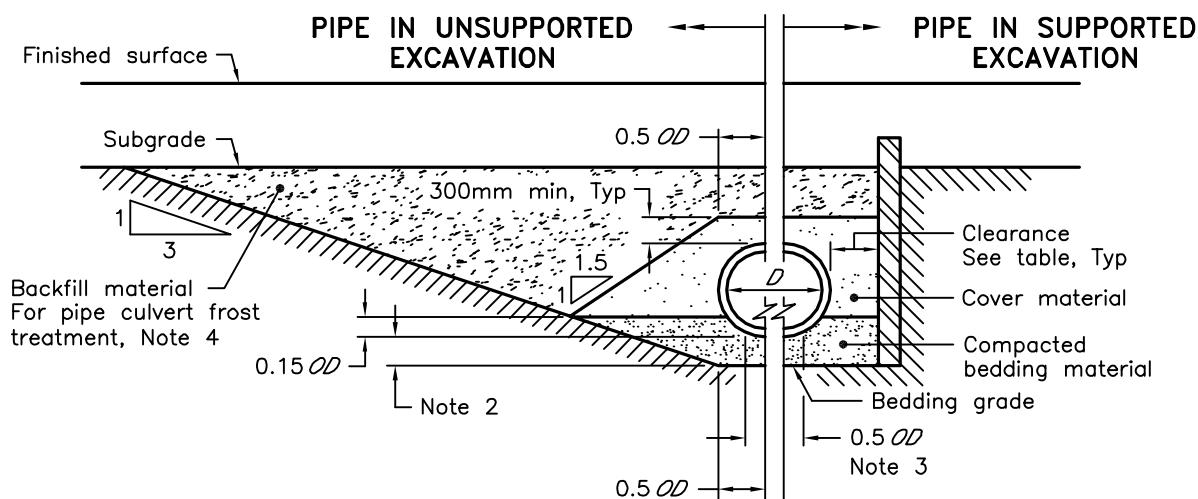








### CLASS B BEDDING



### CLASS C BEDDING

#### LEGEND:

$D$  – Inside diameter  
 $OD$  – Outside diameter

#### NOTES:

- 1 Height of fill is measured from the finished surface to top of pipe.
  - 2 The minimum bedding depth below the pipe shall be  $0.15D$ .  
 In no case shall this dimension be less than 150mm or greater than 300mm.
  - 3 The pipe bed shall be compacted and shaped to receive the bottom of the pipe.
  - 4 Pipe culvert frost treatment shall be according to OPSD 803.030 and 803.031.
  - 5 Condition of excavation is symmetrical about centreline of pipe.
- A Soil types as defined in the Occupational Health and Safety Act and Regulations for Construction Projects.
- B All dimensions are in metres unless otherwise shown.

CLEARANCE TABLE	
Pipe Inside Diameter mm	Clearance mm
900 or less	300
Over 900	500

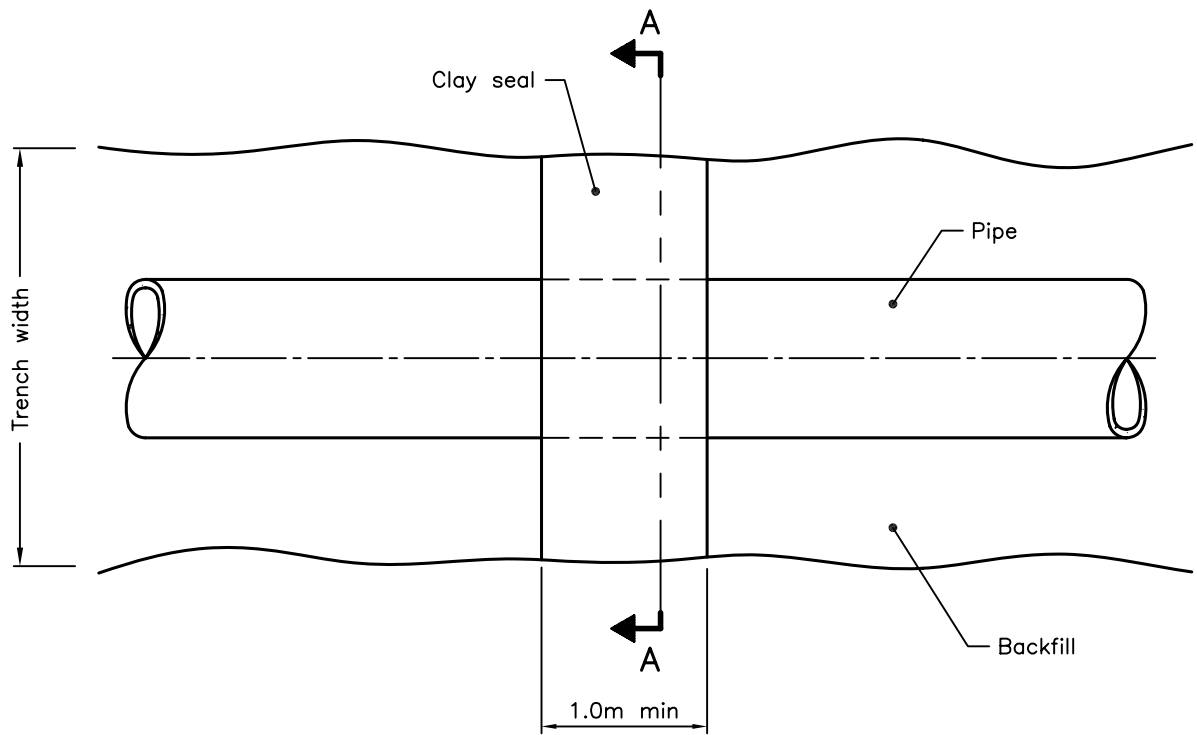
ONTARIO PROVINCIAL STANDARD DRAWING

Nov 2010 Rev 2

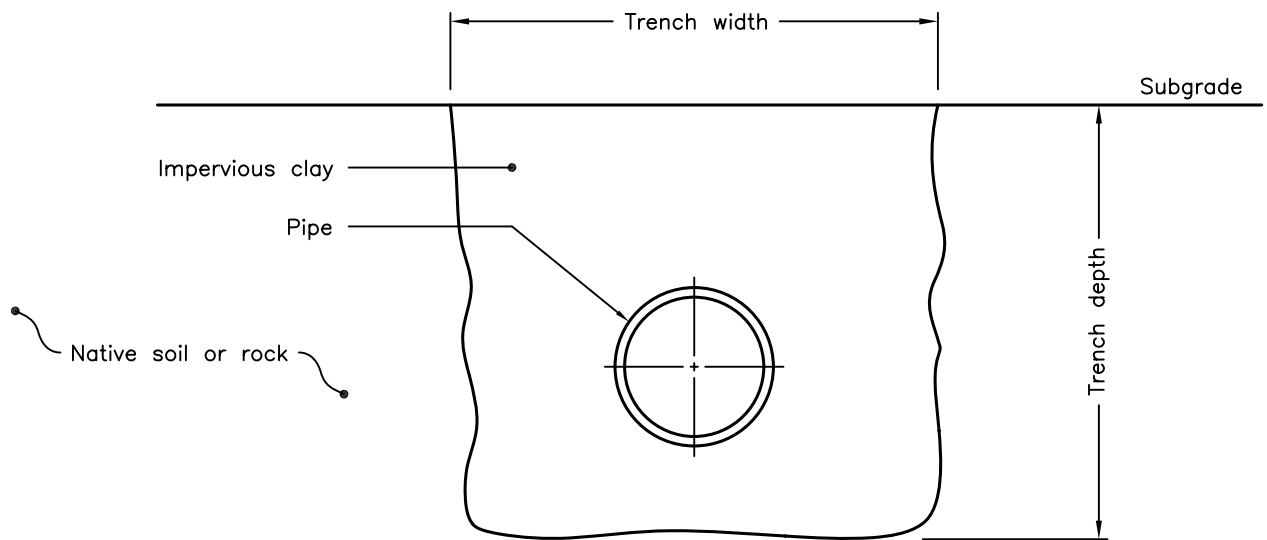
**RIGID PIPE BEDDING,  
 COVER, AND BACKFILL  
 TYPE 4 SOIL – EARTH EXCAVATION**

**OPSD 802.032**





PLAN



SECTION A-A

NOTES:

- A Clay seal to extend from bottom of trench excavation to the subgrade.
- B Clay seal to be located so that no pipe joints are within the clay seal material.
- C All dimensions are in metres unless otherwise shown.

ONTARIO PROVINCIAL STANDARD DRAWING

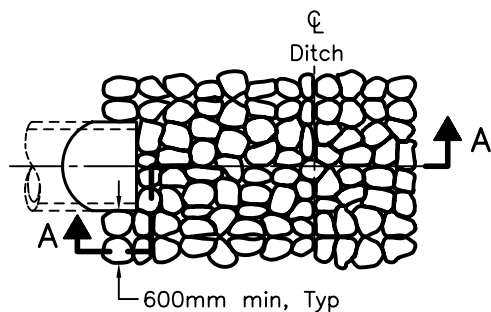
Nov 2006

Rev 0

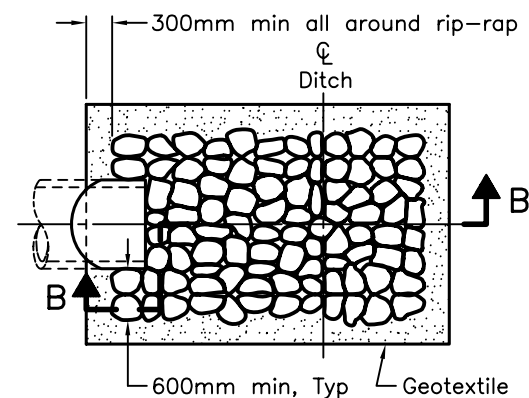
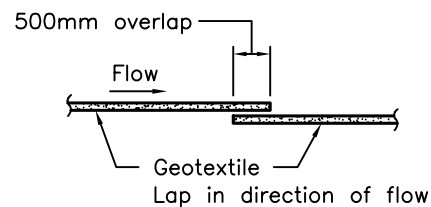
CLAY SEAL FOR PIPE TRENCHES



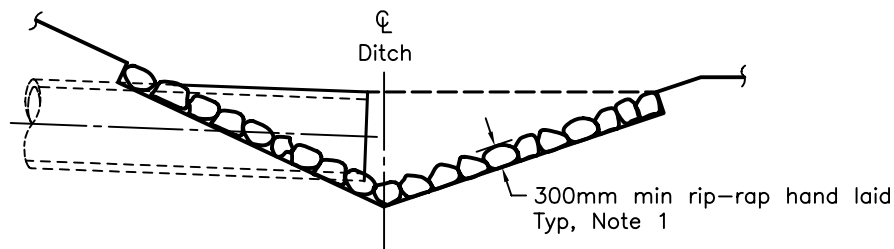
OPSD 802.095



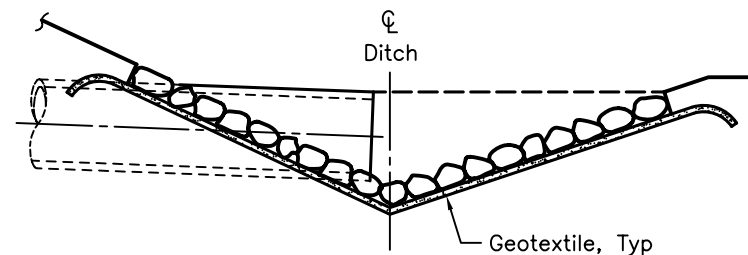
PLAN  
CUT OR FILL



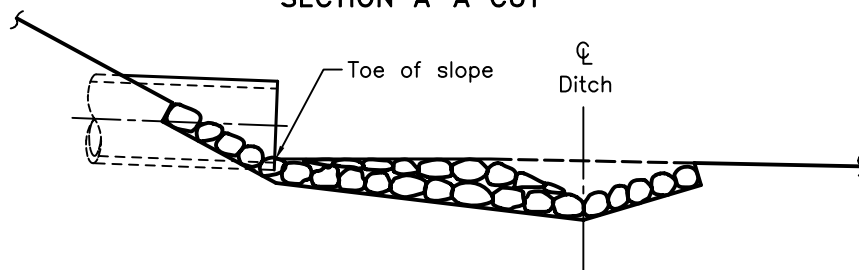
PLAN  
CUT OR FILL



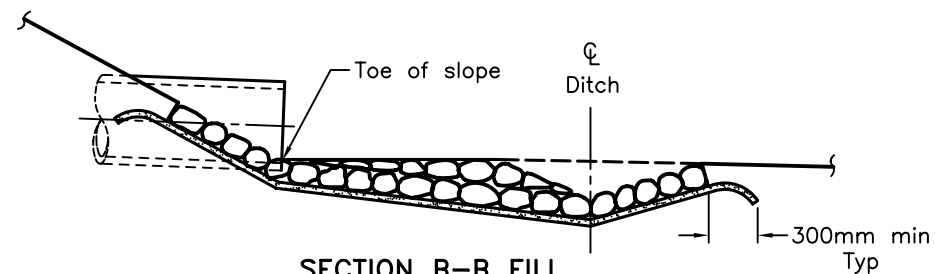
SECTION A-A CUT



SECTION B-B CUT



SECTION A-A FILL  
TYPE A – WITHOUT GEOTEXTILE



SECTION B-B FILL  
TYPE B – WITH GEOTEXTILE

# NOTES:

1 The thickness of the rip-rap layer shall be at least 1.5 times the rip-rap mean diameter.

A All dimensions are in millimetres unless otherwise shown.

ONTARIO PROVINCIAL STANDARD DRAWING

Nov 2007

Rev 1

## RIP-RAP TREATMENT FOR SEWER AND CULVERT OUTLETS

OPSD 810.010



## **Appendix F – Results of Slope Stability Analyses**

Figure F1. Results of Slope Stability Analyses\_Open Cut Construction Method\_Highway 11\_East Side Slope

Project No.: ADM00200887-A0  
Highway 11 Centreline Culvert Project  
Drained Condition

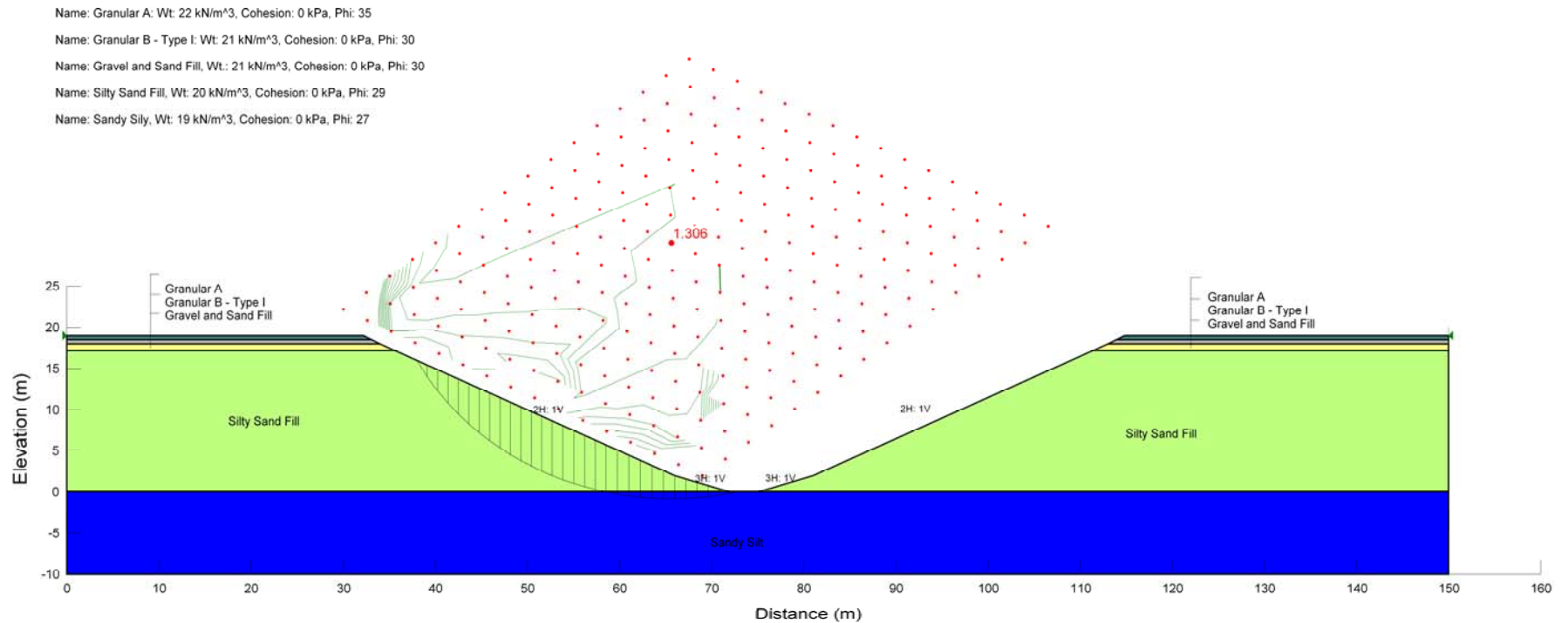


Figure F 1. Results of stability analyses for the open cut installation method

Figure F2-A. Results of Slope Stability Analyses on Construction Access Ramp with 3H:IV Slope\_Highway 11\_East Side Slope

Project No.: ADM00200887-A0  
 Highway 11 Centreline Culvert Project  
 Drained Condition

Name: Granular A, Wt: 22 kN/m<sup>3</sup>, Cohesion: 0 kPa, Phi: 35

Name: Granular B - Type I, Wt: 21 kN/m<sup>3</sup>, Cohesion: 0 kPa, Phi: 30

Name: Gravel and Sand Fill, Wt: 21 kN/m<sup>3</sup>, Cohesion: 0 kPa, Phi: 30

Name: Silty Sand Fill, Wt: 20 kN/m<sup>3</sup>, Cohesion: 0 kPa, Phi: 29

Name: Sandy Silt, Wt: 19 kN/m<sup>3</sup>, Cohesion: 0 kPa, Phi: 27

Name: Engineered Fill, Wt: 21 kN/m<sup>3</sup>, Cohesion: 0 kPa, Phi: 32

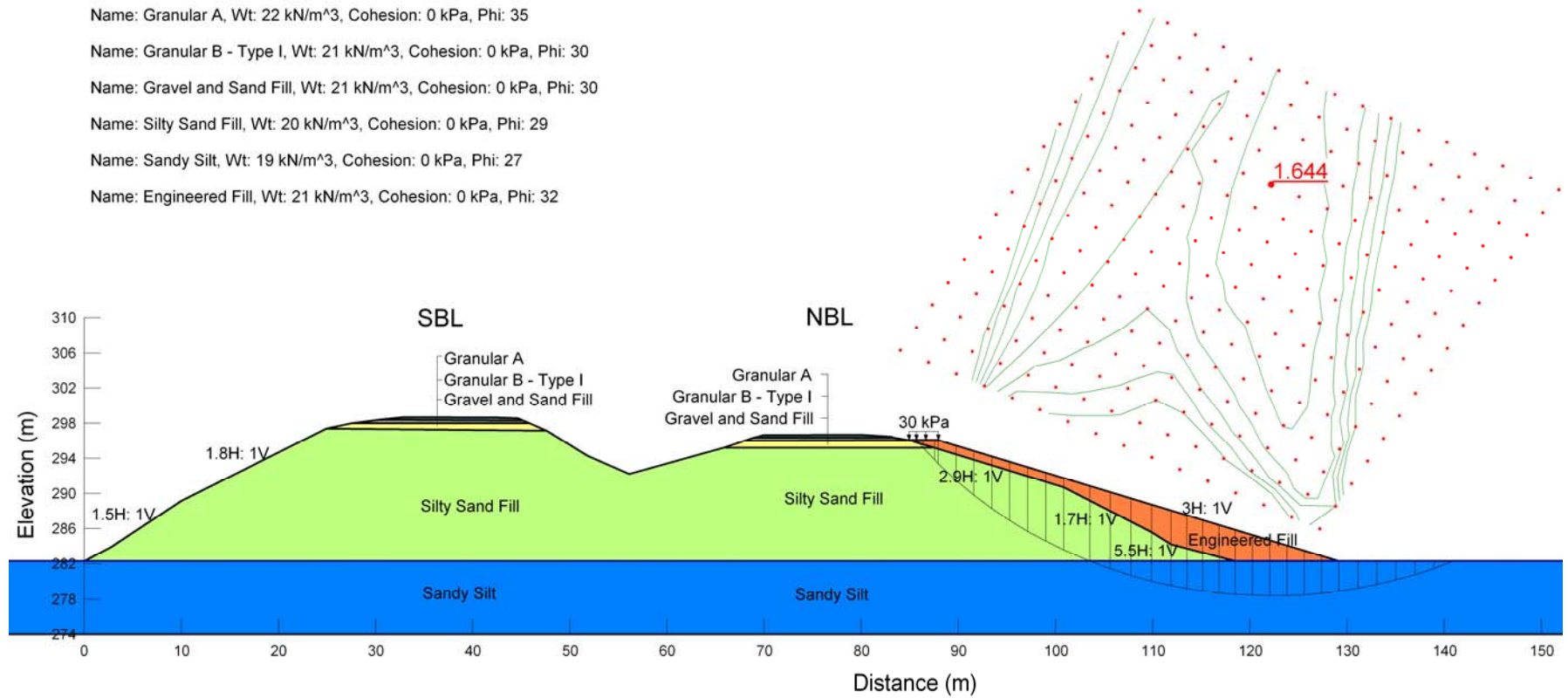


Figure F2-B. Results of Slope Stability Analyses on Construction Access Ramp with 3H:1V Slope\_Highway 11\_East Side Slope

Project No.: ADM00200887-A0  
 Highway 11 Centreline Culvert Project  
 Drained Condition

Name: Granular A, Wt: 22 kN/m<sup>3</sup>, Cohesion: 0 kPa, Phi: 35  
 Name: Granular B - Type I, Wt: 21 kN/m<sup>3</sup>, Cohesion: 0 kPa, Phi: 30  
 Name: Gravel and Sand Fill, Wt: 21 kN/m<sup>3</sup>, Cohesion: 0 kPa, Phi: 30  
 Name: Silty Sand Fill, Wt: 20 kN/m<sup>3</sup>, Cohesion: 0 kPa, Phi: 29  
 Name: Sandy Silt, Wt: 19 kN/m<sup>3</sup>, Cohesion: 0 kPa, Phi: 27  
 Name: Engineered Fill, Wt: 21 kN/m<sup>3</sup>, Cohesion: 0 kPa, Phi: 32

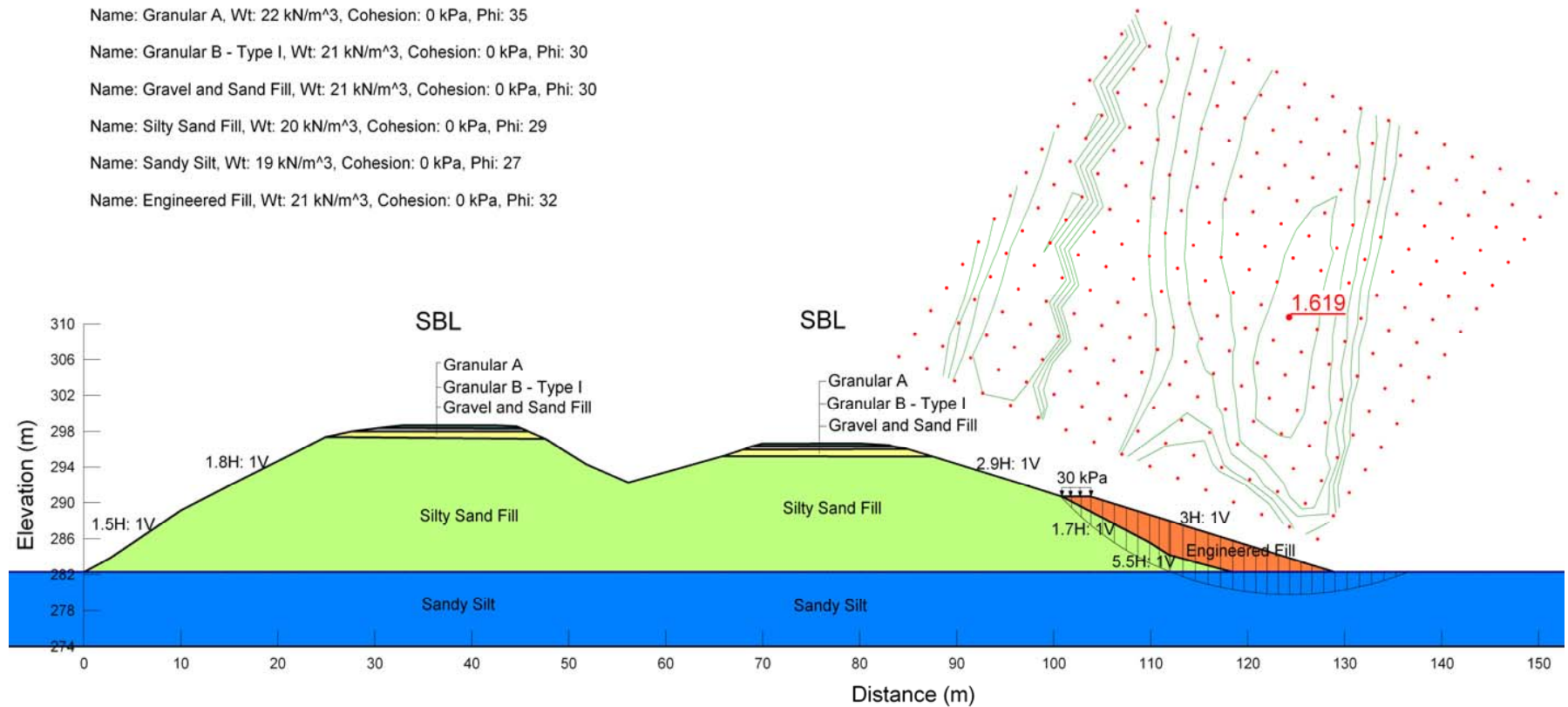




Figure 2F-C. Results of Slope Stability Analyses on Construction Access Ramp with 2.5H:1V Slope\_Highway 11\_East Side Slope

Project No.: ADM00200887-A0  
 Highway 11 Centreline Culvert Project  
 Drained Condition

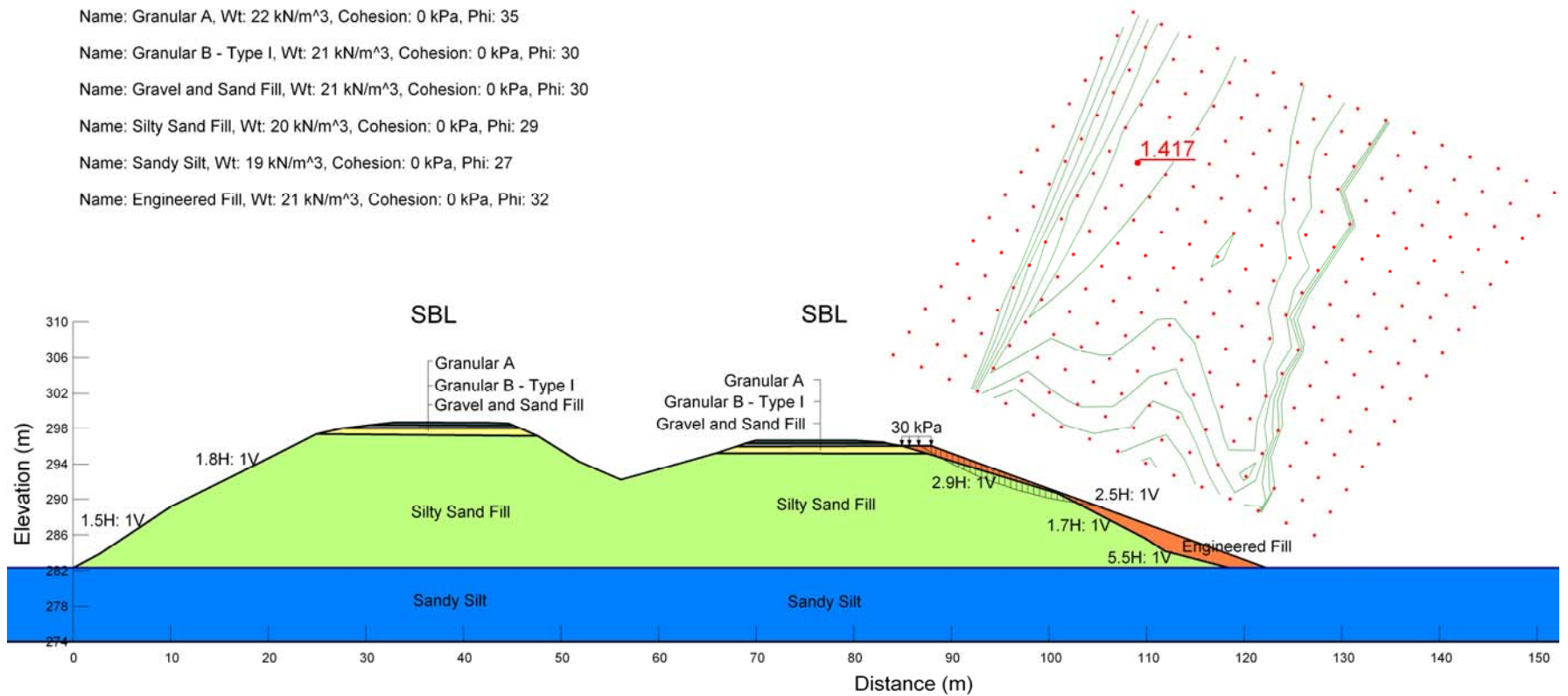


Figure 2F-D. Results of Slope Stability Analyses on Construction Access Ramp with 2.5H:1V\_Highway 11\_ East Side Slope

Project No.: ADM00200887-A0  
 Highway 11 Centreline Culvert Project  
 Drained Condition

Name: Granular A, Wt: 22 kN/m<sup>3</sup>, Cohesion: 0 kPa, Phi: 35

Name: Granular B - Type I, Wt: 21 kN/m<sup>3</sup>, Cohesion: 0 kPa, Phi: 30

Name: Gravel and Sand Fill, Wt: 21 kN/m<sup>3</sup>, Cohesion: 0 kPa, Phi: 30

Name: Silty Sand Fill, Wt: 20 kN/m<sup>3</sup>, Cohesion: 0 kPa, Phi: 29

Name: Sandy Silt, Wt: 19 kN/m<sup>3</sup>, Cohesion: 0 kPa, Phi: 27

Name: Engineered Fill, Wt: 21 kN/m<sup>3</sup>, Cohesion: 0 kPa, Phi: 32

