



**THURBER** ENGINEERING LTD.

**PRELIMINARY  
FOUNDATION INVESTIGATION AND DESIGN REPORT  
HIGHWAY 17 TWINNING, RENFREW AREA  
CULVERTS 1 AND 1N  
STA. 15+840, HORTON TOWNSHIP  
WP 4068-09-00 / ASSIGNMENT NO. 4018-E-0009**

Geocres No.: 31F10-001

Report to:

**Ministry of Transportation Ontario**

Latitude: 45.520085°  
Longitude: -76.684104°

December 2024  
Thurber File No.: 24726



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**PART 1. FACTUAL INFORMATION**

## **1 INTRODUCTION**

Thurber Engineering Ltd. (Thurber) has been engaged by the Ministry of Transportation Ontario (MTO) to carry out Foundation Investigations to support the design of the Highway 17 Twinning Project which extends from Scheel Drive westerly to 3 km west of Bruce Street within the County of Renfrew, Ontario. Thurber carried out the investigation under Ministry of Transportation (MTO) Assignment No. 4018-E-0009.

This report addresses the culvert crossing under Highway 17 located near Station 15+840 on Highway 17 in Horton Township within Renfrew County, Ontario. The existing Highway 17 alignment will become the future Highway 17 westbound lanes and new eastbound lanes will be constructed to the south of the existing alignment at this location. The existing culvert will be replaced, and a new culvert is required to convey an unnamed tributary of Little Halliday Creek below the embankment supporting the proposed Highway 17 eastbound lanes.

This section of the report presents the factual findings obtained from the foundation investigation conducted by Thurber as part of the current study.

The purpose of this investigation was to explore the subsurface conditions at the site and, based on the data obtained, to provide a borehole location plan, records of boreholes, stratigraphic profile, laboratory test results and a written description of the subsurface conditions.

It should be noted that the use of and reliance on Part 1 of the Report is governed by and limited to the terms and conditions set out in the Report and a reliance letter. The Preferred Proponent remains responsible to assess the need for additional investigations and to complete that work.

## **2 SITE DESCRIPTION**

### **2.1 General**

For project purposes, Highway 17 is herein described as oriented east-west, and the culvert is described as oriented north-south. The culvert crosses Highway 17 approximately 1.6 km east of the Highway 17 intersection with Pinnacle Rd and Storyland Rd in Horton Township, just west of Renfrew, Ontario.



In the area of the culvert, the existing Highway 17 is an undivided highway with two travelled lanes and an eastbound passing lane, gravel shoulders, and a posted speed limit of 90 km/hr. The road surface near the culvert is at approximate elevation 160.7 m. Steel cable guide rail on wooden posts is present along the eastbound shoulder. Traffic volumes for this section of Highway 17 is understood to have been 12,300 AADT in 2016.

The existing culvert is 1,000 mm diameter, 38.5 m long, high-density polyethylene (HDPE) pipe culvert oriented approximately perpendicular to the highway alignment. The culvert has an approximate gradient of approximately 1.5 % with the invert of the culvert near elevations 157.3 and 156.7 m at the inlet and outlet, respectively. The cover above the existing culvert is approximately 2.5 m at the highway centerline. The ditch drainage flows through the culvert under the highway embankment from north to south. The depth of standing water inside the inlet and outlet was measured as 100 mm and 300 mm, respectively, on July 25, 2024. The water elevation in the creek was determined to be 157.0 m on the same date.

Embankment side slopes, in the vicinity of the culvert, are inclined at approximately 3.8H:1V on the north side and 3.2H:1V on the south side. The existing embankment side slopes at the culvert site did not show any visible signs of global instability at the time of the investigation.

The site is in a rural setting, and the terrain along the ditch line is relatively flat in the vicinity of the culvert site. The area directly adjacent to the culvert is mostly farmland with some deciduous trees and shrubs.

Photographs of the project area are included in Appendix D. These photographs show the existing condition of the highway embankment and the culvert at the time of the field investigation.

## 2.2 Site Geology

Under the same MTO Assignment a hydrogeological investigation was conducted by Thurber in several locations along the Highway 17 twining project boundaries. The available information was reviewed prior to this investigation and can be found in the Geocres Library under Geocres Number 31F-245. Boreholes NS21-01 and NS21-02 from that investigation are relevant to the present report and has been included in Appendix B.

According to Crins et al. 2009<sup>1</sup>, the project area is described as Ecoregion 6E (Lake Simcoe-Rideau Ecoregion) within the Mixedwood Plains Ecozone. According to Wester et al. 2018<sup>2</sup>, the ecoregion is subdivided into Ecodistrict 6E-16 (Pembroke Ecodistrict). The area is characterized by glaciolacustrine dominated landscape overlying a mix of Paleozoic to Precambrian bedrock.

Based on published geological information in *The Physiography of Southern Ontario* by Chapman and Putnam (1984), the site lies within the physiographic region known as the Ottawa Valley Clay Plains. The Ottawa Valley Clay Plains are characterized primarily by clay plains deposited by the Champlain Sea (Leda Clay) interrupted by ridges of rock or sand.

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<sup>1</sup> <https://files.ontario.ca/mnrf-ecosystemspart1-accessible-july2018-en-2020-01-16.pdf>

<sup>2</sup> <https://files.ontario.ca/ecosystems-ontario-part2-03262019.pdf>



Ontario Geological Survey Maps P.2366<sup>3</sup> suggests for the site area the presence of marine deeper water deposits of clay, silty clay and clayey silt.

Ontario Geological Survey Map 2460<sup>4</sup> suggests the bedrock comprises calcitic carbonate metasedimentary bedrock including calcitic and siliceous marble.

### 3 SITE INVESTIGATION AND FIELD TESTING

Boreholes NS21-01 and NS21-02 were drilled off-road on November 9 and 10, 2021 using a Diedrich 50 track mounted drill equipped with hollow stem augers (HSA).

The foundation investigation and field-testing program was augmented between February 13 and March 13, 2024, and consisted of one on-road borehole identified as SC1-3 and three off-road boreholes identified as SC1-1, SC1-2 and SC1-4. The on-road borehole was advanced with a CME 75 truck mounted drill rig utilizing HSA. The off-road Boreholes were advanced with a CME 55 track mounted drill rig utilizing HSA. Prior to commencement of drilling, utility clearances were obtained in the vicinity of the borehole locations.

A summary of the borehole coordinates, elevations, and termination depths is provided in Table 3-1. The locations and elevations of the boreholes were surveyed by Thurber with a Trimble Catalyst DA1 antenna with centimeter accuracy and were measured relative to BM HCP 102 (Elevation 129.023 m), HCP118 (Elevation 139.303 m) and HCP138 (Elevation 170.618 m). Horizontal locations were measured by Thurber relative to existing site features. The elevations and borehole coordinates were reviewed and referenced to the survey data provided by the MTO. The borehole coordinates and elevations are shown on the Borehole Location and Soil Strata drawing included in Appendix A and on the individual Record of Borehole sheets included in Appendix B. The borehole coordinates are referenced to MTM Zone 9.

**Table 3-1: Borehole Summary**

<b>Borehole No.</b>	<b>Drilled Location</b>	<b>Northing (Latitude)</b>	<b>Easting (Longitude)</b>	<b>Ground Surface Elevation (m)</b>	<b>Termination Depth (m)</b>
SC1-1	Proposed EBL Near Outlet	5 042 208.8 (45.519649)	290 371.8 (-76.684686)	156.2	12.8
SC1-2	Existing Outlet	5 042 228.1 (45.519822)	290 399.9 (-76.684327)	156.9	15.8
SC1-3	Existing Westbound Shoulder	5 042 257.2 (45.520085)	290 417.3 (-76.684104)	160.7	17.4
SC1-4	Existing Inlet	5 042 254.4 (45.520061)	290 434.8 (-76.683881)	157.6	12.8
NS21-01	Proposed EBL Near Inlet	5 042 225.0 (45.519794)	290 394.7 (-76.684392)	156.8	6.7

<sup>3</sup> <https://www.geologyontario.mndm.gov.on.ca/mndmfiles/pub/data/imaging/P2366/P2366.pDf>

<sup>4</sup> [https://www.geologyontario.mndm.gov.on.ca/mndmaccess/mndm\\_dir.asp?type=pub&id=M2460](https://www.geologyontario.mndm.gov.on.ca/mndmaccess/mndm_dir.asp?type=pub&id=M2460)



Borehole No.	Drilled Location	Northing (Latitude)	Easting (Longitude)	Ground Surface Elevation (m)	Termination Depth (m)
NS21-02	Proposed EBL	5 042 217.7 (45.519729)	290 386.4 (-76.684498)	156.6	6.7

Soil samples were obtained at selected intervals using a split spoon sampler in conjunction with Standard Penetration Testing (SPT) in general accordance with ASTM D 1586. In-situ shear vane testing was carried out within the cohesive layers, where possible, using an MTO 'N' sized vane in general accordance with ASTM D 2573. A Thin-Walled (Shelby) Tube sampler was pushed and retrieved in Boreholes SC1-1, SC1-2 and SC1-4 to obtain a relatively undisturbed cohesive soil sample for further laboratory testing.

A 50 mm diameter well was installed in Boreholes NS21-01, NS21-02, and SC1-4 to allow for measurements of the groundwater level after drilling. The details for the wells are illustrated on the respective Record of Borehole sheets provided in Appendix B. The monitoring wells installed as part of the current investigation will be decommissioned by Thurber, as outlined in the Hydrogeological Investigation and Design Report

Boreholes SC1-1, SC1-2, and SC1-3 were backfilled in accordance with MOE requirements (O.Reg 903, as amended).

The drilling and sampling operations were supervised on a full-time basis by a member of Thurber's technical staff. The drilling supervisor logged the boreholes and processed the recovered soil and rock samples for transport to Thurber's Ottawa laboratory for further examination and testing.

#### 4 LABORATORY TESTING

Laboratory testing was selected in accordance with the current MTO Guideline for Foundation Engineering Services, Section 5. Geotechnical laboratory testing consisted of natural moisture content determination and visual identification of all retained soil samples. At least 25% of the recovered soil samples were subjected to testing for grain size distribution analysis and, where appropriate, Atterberg Limits in accordance with MTO and ASTM standards. Chemical analysis for determination of pH, conductivity, resistivity, sulphide, sulphate and chloride was carried out on two samples of the soil.

The results of the geotechnical tests are summarized on the Record of Borehole sheets included in Appendix B and all laboratory results are presented on the figures included in Appendix C.

#### 5 GENERAL DESCRIPTION OF SUBSURFACE CONDITIONS

Details of the encountered soil stratigraphy are presented on the Record of Borehole sheets included in Appendix B and the Borehole Location and Soil Strata Drawing included in Appendix A. A general description of the stratigraphy based on the conditions encountered in the boreholes is given in the following sections. However, the factual data presented on the Borehole Records takes precedence over the Soil Strata Drawing and the general description. It must be recognized



that the soil and groundwater conditions may vary between and beyond borehole locations. Soil classification is in accordance with the MTO Guideline for Foundation Engineering Services (GFES) Manual (April 2022) and the 4<sup>th</sup> Edition of the Canadian Foundation Engineering Manual.

In general, the encountered stratigraphy consists of peat over a native deposit of silty clay to clayey silt containing sand seams. A thin, native interbedded layer of silty sand was observed within the silty clay to clayey silt deposit. Silty sand with gravel to clayey silty sand fill was encountered within the embankment footprint.

## **5.1 Embankment Fill**

### **5.1.1 Silty Sand Fill**

A fill layer consisting of silty sand with some gravel was encountered at ground surface in on-road Borehole SC1-3. The thickness of the layer was 3.8 m (base elevation at 156.9 m). The SPT N values ranged from 8 to 45 blows, indicating a loose to dense relative density.

The moisture content of the samples tested ranged from 5% and 13%. The results of grain size analyses conducted on two samples of this fill material are summarized in the table below and are illustrated on Figure C1 in Appendix C.

**Summary of Grain Size Distribution Testing – Silty Sand Fill**

<b>Soil Particle</b>	<b>Percentage (%)</b>
Gravel	12 – 16
Sand	56 – 58
Silt & Clay	26 – 32

### **5.1.2 Clayey Silty Sand Fill**

A fill layer consisting of clayey silty sand containing some organics was encountered at the ground surface in Boreholes SC1-2 and SC1-4. The thickness of the layer was 0.8 m (base elevation at 156.8 to 156.1 m). The layer consistency is described as very loose based on tactile evaluations of strength.

The moisture content of the samples tested ranged from 26% and 46%.

## **5.2 Peat**

A 200 to 300 mm thick layer of peat was encountered at the ground surface in Boreholes NS21-01, NS21-02 and SC1-1. The peat in Boreholes SC-1, NS21-01 and NS21-02 was amorphous and very soft.

### 5.3 Silty Clay to Clayey Silt (CI to CL-ML)

A native deposit of silty clay to clayey silt was encountered below the fill in Boreholes SC1-2, SC1-3 and SC1-4 and below the peat in Boreholes NS21-01, NS21-02 and SC1-1. Varying amounts of sand were noted in the layer. Sand seams were encountered throughout the layer and were noted to be more frequent with depth. The layer was not fully penetrated in the boreholes but was proven to be at least 12.0 to 15.0 m thick and extend to depths ranging from 12.8 to 17.4 m (base elev. 144.8 to 141.1 m).

Where SPT were conducted within the layer, the N-values typically ranged from 1 to 6 blows. N-values as high as 8 to 11 blows were noted in the layer in Boreholes NS21-01, SC1-3 and SC1-4 but may be attributed to the presence of sand to silty sand pockets. Field vane tests were performed within this layer where possible. Undrained shear strengths were obtained and were greater than 118 kPa. The layer can be generally described as stiff to very stiff in consistency based on N-values, undrained shear strength measurements, and tactile evaluations of strength.

The moisture content of the samples tested ranged from 21 to 52%. The results of grain size analysis tests conducted on fourteen samples of this material are summarized in the table below and are illustrated on Figures C2 to C4 in Appendix C.

**Summary of Grain Size Distribution Testing – Silty Clay to Clayey Silt**

Soil Particle	Percentage (%)
Gravel	0
Sand	2 – 35
Silt	44 – 59
Clay	17 – 51

The results of Atterberg Limits testing carried out on fourteen samples of this material are summarized below and are illustrated on Figure C5 to C7 in Appendix C. The laboratory results indicate that the silty clay and clayey silt is of intermediate to low plasticity (CI to CL-ML). One result indicates non-plastic behavior but may be attributed to the high content of sand and silt. It is noted that the presence of the sand seams within the split spoon sampler complicates the interpretation of Atterberg Limit test results; the plasticity index values may be biased low.

#### Summary of Atterberg Limit Testing – Silty Clay to Clayey Silt

Parameter	Value
Liquid Limit	18 – 49
Plastic Limit	14 – 23
Plasticity Index	4 – 26

#### 5.4 Silty Sand (SM) Interbed

A native deposit of silty sand (SM), which is believed to be an interbedded layer, was encountered within the silty clay to clayey silty layer in Borehole SC1-4 and at the end of boreholes NS21-01, NS21-02. The layer was not fully penetrated in the boreholes NS21-01, NS21-02 but was proven to be at least 0.3 to 0.6 m thick and extend to a depth of 6.7 m (base elev. 150.1 to 149.9 m). In borehole SC1-4 the thickness of the layer was 0.7 m (base elevation at 150.0 m). The SPT N-values ranged from 11 to 22 blows, indicating a compact relative density.

The moisture content of the samples tested ranged from 18 to 20%. The results of grain size analysis tests conducted on two samples of this material are summarized in the table below and are illustrated on Figure C8 in Appendix C.

#### Summary of Grain Size Distribution Testing – Silty Sand

Soil Particle	Percentage (%)
Gravel	0
Sand	56 – 75
Silt	20 – 35
Clay	5 – 9

One Atterberg Limits testing was carried out on a sample of this material and the results indicate non-plastic behavior.

#### 5.5 Groundwater

Monitoring wells with diameter of 50 mm were installed in Boreholes SC1-4, NS21-01, and NS21-02. Groundwater levels recorded in the wells are presented in Table 5-1.

**Table 5-1: Summary of Groundwater Levels**

Borehole No.	Bottom of Screen Elevation (m)	Groundwater Depth <sup>(a)</sup> (m)	Groundwater Elevation (m)	Date of Measurement
SC1-4	148.5	-0.1	157.7	March 05, 2024
		-0.2	157.8	March 22, 2024
		-0.2	157.8	April 10, 2024
		-0.1	157.7	April 25, 2024
		-0.2	157.8	June 04, 2024
		-0.3	157.9	June 25, 2024
		0.0	157.6	July 12, 2024
		0.3	157.3	August 30, 2024
NS21-01	150.7	0.1	156.7	December 15, 2021
		0.0 <sup>(b)</sup>	156.8	January 18, 2022
		0.1	156.7	March 09, 2022
		0 <sup>(c)</sup>	156.8	April 25, 2024
		0.4 <sup>(c)</sup>	156.4	August 30, 2024
NS21-02	150.3	0.1	156.5	December 15, 2021
		0.0 <sup>(b)</sup>	156.6	January 18, 2022
		0.2	156.4	March 09, 2022
		0.1 <sup>(c)</sup>	156.5	April 25, 2024
		0.6 <sup>(c)</sup>	156.0	August 30, 2024

Notes: <sup>(a)</sup> negative ground water depths indicate artesian conditions

<sup>(b)</sup> piezometer water was frozen at the time of measurements

<sup>(c)</sup> water level taken after borehole log was finalized

The depth of standing water near the inlet and outlet was measured as 100 mm and 300 mm, respectively, on July 25, 2024. The water elevation in the creek was approximately 157.0 m on the same date.

These observations are considered short term as they were recorded at discrete times, and it should be noted that the creek level groundwater level at the time of construction may be different and seasonal fluctuations of the groundwater level are to be expected. In particular, the water levels may be at a higher elevation after periods of significant and/or prolonged precipitation.

## 5.6 Analytical Testing

One sample of the native silty clay to clayey silt and one sample of the clayey silty sand fill were submitted to Paracel Laboratories in Ottawa, Ontario for analysis of pH, water soluble sulphate, sulphide and chloride concentrations, resistivity, and conductivity. The analysis results are summarized in Table 5-2. Copies of the test results are provided in Appendix C.



**Table 5-2: Results of Chemical Analysis**

Borehole	Sample	Depth (m)	Chloride (µg/g)	Sulphate (µg/g)	Sulphide (%)	pH (-)	Resistivity (Ohm-cm)
SC1-1	SS3	1.5 – 2.1	188	27	<0.01	7.37	1,860
SC1-4	GS1	0 – 0.6	16	21	0.04	7.57	5,810

## 6 MISCELLANEOUS

The borehole locations reflect existing site features and access constraints. The as-drilled locations and ground surface elevation were measured by Thurber following completion of the field program. George Downing Estate Drilling Ltd. of Hawkesbury, Ontario, supplied and operated the drill rigs used to drill, test, sample, and decommission the boreholes. Traffic control was performed in accordance with Ontario Book 7 and was provided by T.G. Carroll Cartage of Ottawa, Ontario. The field investigation was supervised on a full-time basis by Mr. R. Howarth, Geotechnical Technician, and Mr. D. Amorim Pereira, Geotechnical Technician. Overall supervision of the field investigation program was provided by Mr. J. Gray, P.Eng.

Routine geotechnical laboratory testing were completed by Thurber's laboratory in Ottawa. Analytical testing was completed by Paracel Laboratories Ltd. in Ottawa.

Interpretation of the factual data and preparation of this report was completed by D. Amorim Pereira, Geotechnical Technician. The report was reviewed by Dr. F. Griffiths, P.Eng., and Dr. P.K. Chatterji, P.Eng., a Designated Principal Contact for MTO Foundation Projects.



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**PART 2. ENGINEERING DISCUSSION AND RECOMMENDATIONS**

## **7 INTRODUCTION**

Part 2 of the report provides an interpretation of the factual data from Part 1 and presents geotechnical recommendations to assist the project team in designing the foundations for a culvert crossing to be located at approximate Station 15+840 on existing Highway 17, approximately 1.6 km east of the Highway 17 intersection with Pinnacle Rd and Storyland Rd in Horton Township, just west of Renfrew, Ontario and a new culvert crossing located at approximate Station 15+840 on the proposed new eastbound lanes of Highway 17. Thurber carried out the investigation under Ministry of Transportation (MTO) Assignment No. 4018-E-0009.

This preliminary foundation investigation and design report with the interpretation and recommendations are intended for the use of the Ministry of Transportation and shall not be used or relied upon for any other purposes or by any other parties including design-build contractors. It should be noted that the use of and reliance on Part 1 of the Report is governed by and limited to the terms and conditions set out in the Report and a reliance letter. The Preferred Proponent remains responsible to assess the need for additional investigations and to complete that work. The Preferred Proponent must make their own interpretation based on the factual data in Part 1 of the report. The information included in Part 2 is not to be relied upon for design purposes and foundation design is the sole responsibility of the Preferred Proponent. No use shall be made of Part 2 or any part thereof. The Preferred Proponent must make their own interpretation of the factual information provided as it may affect equipment selection, proposed construction methods and scheduling.

The following sections provide preliminary geotechnical recommendations for the construction of foundation elements for the proposed structures. The discussion and preliminary recommendations presented in this report are based on information provided by the MTO and the factual data obtained during the current field investigation.

### **7.1 Background Information**

For project purposes, Highway 17 is herein described as oriented east-west and the creek flows from north to south. The site is located on Highway 17, approximately 1.6 km east of the intersection with Pinnacle Rd and Storyland Rd in Horton Township.



The existing culvert (Culvert 1) is 1,000 mm diameter, 38.5m long, high-density polyethylene (HDPE) pipe culvert oriented approximately perpendicular to the existing highway alignment. The culvert has a gradient of approximately 1.5% with the invert of the culvert near elevations 157.3 and 156.7 m at the inlet and outlet, respectively. The cover above the existing culvert is approximately 2.5 m at the highway centerline. A tributary of Little Halliday Creek flows through the culvert under the highway embankment from north to south. The depth of standing water near the inlet and outlet was measured as 100 mm and 300 mm, respectively, on July 25, 2024. The water elevation in the creek was approximately 157.0 m on the same date.

The existing road is superelevated to the north with elevations at the existing culvert crossing ranging from 160.7 to 160.3 m.

The encountered stratigraphy consists of a thin layer of peat over a native deposit of very stiff silty clay to clayey silt containing sand seams. A thin, native interbedded layer of silty sand was observed within the silty clay to clayey silt deposit. Silty sand with gravel to clayey silty sand fill was encountered within the embankment footprint. It is noted that the ground water level in the monitoring well installed in Borehole SC1-4 was at elevation 157.9 m on June 25, 2024, a slightly artesian condition.

The available hydrogeological information for the area near the culvert was reviewed prior to this investigation and can be found in the Geocres Library under Geocres Number 31F-245.

## **7.2 Proposed Structure**

The existing Highway 17 alignment at this site will become the future Highway 17 westbound lanes and new eastbound lanes will be constructed approximately 32.5 m south (edge of pavement to edge of pavement) of the existing alignment at this location. The culvert currently present under the existing Highway 17 lanes (Culvert 1) will require replacement while a new culvert (Culvert 1N) will be required under the proposed eastbound lanes.

The Structure and Culvert List of February 23, 2022, for this project indicated that the replacement for Culvert 1 is to be a structural, closed-bottom concrete box culvert (CBC) with a length of 28.2 m, a span of 3.0 m, a rise of 2.1 m, and a 0.98% slope. It is assumed that the stream bed will be at approximately elevation 157 m at the embankment centreline to match the invert of the existing pipe. The finished grade of the highway for the westbound lanes is to remain unchanged from the existing highway at approximate elevation 160.7 m.

Similarly, the Structure and Culvert List of February 23, 2022, for this project indicated that Culvert 1N is to be a structural, closed-bottom concrete box culvert (CBC) with a length of 26.8 m, a span of 3.0 m, a rise of 2.1 m, and a 0.98% slope. It is assumed that the stream bed will be at approximately elevation 156 m at the embankment centreline to match the current underside of the peat layer observed in the area. As per the preliminary MTO drawings the finished grade of the embankment for the new eastbound lanes is to be at approximate elevation 160.3 m. The proposed embankment has a height of approximately 4.3 m above the underside of the peat layer observed in the area.

Based on preliminary information provided by MTO, no retaining walls or headwalls are proposed at the culverts.





**The preliminary recommendations presented herein must be reassessed once the type, configuration, location, elevation, and orientation of the proposed works are established.**

### **7.3 Applicable Codes and Design Considerations**

The geotechnical assessment presented herein has been prepared based on the available data regarding the proposed work, existing ground conditions document in Part 1 of this report, and in accordance with the Canadian Highway Bridge Design Code (CHBDC), version CSA S6-19.

In accordance with the CHBDC, the analysis and design of the structure takes into consideration the importance of the structure and the consequence associated with exceeding limit states. The importance category and consequence classification are defined by the Regulatory Authority which, in this case, is the Ministry of Transportation, Ontario (MTO).

It is understood that the new culvert structures are being designated as a “Major Route” importance category. As per Section 6.14.2.1.b and 6.14.2.3.b of the CHBDC, a Major-Route geotechnical system is required to have a seismic performance criterion that meets a return period of 475-years.

It is understood that the culverts have been assigned a Typical Consequence Classification, in accordance with Section 6.5.1 of the CHBDC. Accordingly, a consequence factor ( $\Psi$ ) of 1.0, as per Table 6.1 of the CHBDC, has been used in assessing factored geotechnical resistances. If the consequence classification changes, the geotechnical assessment and recommendations provided within this report may need to be reviewed and revised.

The degree of site and prediction model understanding for this site has been assessed to be typical understanding (Section 6.5.3 of CHBDC).

The frost penetration depth and associated recommendations are provided in Section 10.5.

## **8 SEISMIC CONSIDERATIONS**

### **8.1 Spectral and Peak Acceleration Hazard Values**

The seismic hazard data for the CHBDC is based on the fifth-generation seismic model developed by the Geological Survey of Canada (GSC)<sup>5</sup>. The GSC seismic hazard calculation data sheet for this site for the *reference* ground condition (Site Class C) is presented in Appendix E. The site coefficients used to determine the design spectral acceleration values are a function of the Site Class, PGA, and  $S_a$  (0.2). The PGA value at this site provided by GSC for a *reference* Site Class C with a 2% probability of exceedance in 50 years (2475-year event) is 0.232 g. This value is to be scaled by the  $F(PGA)$  based on the *site-specific* Site Class, as discussed in Section 8.3.

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<sup>5</sup> <https://earthquakescanada.nrcan.gc.ca/hazard-alea/interpolat/calc-en.php>



## 8.2 Seismic Liquefaction Potential

Based on the assessment using the SPT data following the simplified method for cohesionless soil as outlined in Boulanger and Idriss (2014)<sup>6</sup>, the soils are not considered susceptible to liquefaction during a 1 in 2475yr design earthquake.

The susceptibility of the cohesive soils at this site to experience liquefaction/cyclic softening was first assessed following the Boulanger and Idriss (2007)<sup>7</sup> criteria which utilizes the measured undrained shear strengths. It is noted that sand seams were encountered throughout the layer and were noted to be more frequent with depth. As noted in Section 5.3, the interpretation of Atterberg test results is more difficult when sand seams are present and can skew the results to a lower Plasticity Index. The assessment of susceptibility to liquefaction or cyclic mobility for this interbedded layer has been made based on the results of testing on samples from the upper portions of the layer where fewer sand seams were noted. Based on the results of the analysis the cohesive materials at this site are not susceptible to liquefaction or cyclic mobility under the design earthquake.

## 8.3 CHBDC Seismic Site Classification and Performance Category

In accordance with Section 4.4.3.2 of the CHBDC, the selection of the seismic site classification is based on the nature of the soil deposits within the upper 30 m of the stratigraphy. As per Table 4.1 within Section 4.4.3.2 of the CHBDC, the site has been classified as a Seismic Site Class D.

The  $F(PGA)$ , as per Table 4.8 within Section 4.4.3.3 of the CHBDC, is equal to 1.13 for this site yielding a scaled *site-specific* Site Class D PGA of 0.262 g.

As per Section 4.4.4 of the CHBDC, the Seismic Performance Category is assigned based on the fundamental period, the importance category, and the spectral accelerations scaled to the site class. The  $F(0.2)$  and  $F(1.0)$ , as per Tables 4.2 and 4.4 within Section 4.4.3.3 of the CHBDC, is equal to 1.11 and 1.41 for this site, yielding a scaled *site-specific*  $S_a(0.2)$  of 0.400 and  $S_a(1.0)$  of 0.140. A Seismic Performance Category of 3 is applicable to this site based on Table 4.10 of the CHBDC. The seismic performance category should be confirmed by the structural engineer.

# 9 DESIGN OPTIONS

## 9.1 Culvert Type and Foundation Alternatives

Selection of the culvert type must consider the proposed construction procedures, staging requirements, geotechnical resistance available in the foundation soils, depth to suitable bearing

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<sup>6</sup> Boulanger, R. W., and Idriss, I. M. (2014). *CPT and SPT based liquefaction triggering procedures*, Report No. UCD/CGM-14/01, Center for Geotechnical Modeling, Department of Civil and Environmental Engineering, University of California, Davis, CA, 134 pp.

<sup>7</sup> Boulanger, R. W. and Idriss, I. M. (2007). *Evaluation of cyclic softening in silts and clays*, ASCE, *Journal of Geotechnical and Geoenvironmental Engineering*, 133(6), 641-652.

stratum and post-construction settlement criteria. From a geotechnical perspective, the following culvert types were considered:

- Circular Pipes (Concrete, HDPE, Steel)

Although, from a foundation engineering perspective, a pipe culvert is a technically feasible alternative, the proposed pipe must meet the required flow capacity, navigation and hydraulic requirements as well as provide passage for mammals.

- Open-Bottom Culvert (Box, Arch)

The construction of an open-bottom culvert will have greater construction concerns due to the high water table and requirement for greater excavation depths to construct the culvert footings to satisfy frost depth requirements. The use of an open bottom culvert would require greater dewatering efforts and has the potential for larger settlement following construction when compared to other culvert options.

- Closed-Bottom Culvert (Box)

A pre-cast, segmental, closed-bottom, box culvert is considered a feasible option from a foundation engineering perspective. Precast sections, rather than cast-in-place construction, can be installed expediently with less potential for disturbance of the subgrade during installation, require less excavation depth than open bottom culverts, and allow for more manageable dewatering efforts.

A comparison of these alternatives, based on their respective advantages and disadvantages, is included in Appendix F. It is not considered to be economical or practical to support a culvert on deep foundations at this site and therefore this option is not presented in this report.

## **9.2 Construction Methodology Alternatives**

At the time of the field investigation, ponded water was observed with surface elevations at approximately 158.2 m and 157.0 m, near the inlet and outlet of Culvert 1, respectively. Water depths ranged from 0.1 to 0.3 m. Water levels were measured to be at approximate elevation 157.8 m in the monitoring well installed in Borehole SC1-4. Excavations to install the culvert are anticipated to extend to as deep as elevation 156.1 m which is below the water level of the creek. An adequate and effective dewatering plan including surface water management, cofferdams, creek diversion and excavation dewatering will be required to enable excavation to the required founding elevation and construction of the foundations in the dry (see Section 11.3).

It is noted that the preliminary profile for the new eastbound lanes includes an embankment approximately 4.3 m above underside of the peat layer observed in the area. Settlement in the underlying soils is anticipated, and a mitigation program is required. Additional discussion is provided in Section 10.7.

At the time of preparation of this report, a construction staging plan has not yet been developed. The foundation recommendations presented herein have been prepared based on the assumption that construction of the new culvert and the new eastbound embankment will be

carried out while traffic remains on the existing alignment. Upon completion of the construction of the new lanes, all traffic would be temporarily directed onto those new lanes to allow culvert replacement for the westbound lanes to be constructed under a road closure of the existing alignment.

### **9.3 Recommended Approach for Culvert Replacement**

From a geotechnical perspective, closed-bottom, precast box culverts are recommended at this site. A pipe culvert would also be considered a feasible alternative. Construction staging for the pipe culvert would be similar to that for the closed bottom box culvert option.

Mitigation of the settlement induced by the new westbound embankment will require a structure designed to accommodate the movements.

## **10 FOUNDATION DESIGN RECOMMENDATIONS**

From a foundation engineering perspective, concrete box culverts are recommended. The following bullets summarize the relevant elevations near each culvert:

### **Existing Highway 17 / Proposed Westbound Lanes – Culvert 1**

- |   |          |
|---|----------|
| • Existing top of pavement                      | 160.7 m  |
| • Culvert invert at centreline                  | 157.0 m  |
| • Groundwater elevation June 25, 2024           | 157.9 m  |
| • Underside elevation of Silty Clay/Clayey Silt | <141.1 m |

### **Proposed Highway 17 Eastbound Lanes – Culvert 1N**

- |   |          |
|---|----------|
| • Top of pavement                               | 160.3 m  |
| • Culvert invert at centreline                  | 156.0 m  |
| • Groundwater elevation March 9, 2022           | 156.7 m  |
| • Underside elevation of Silty Clay/Clayey Silt | <141.1 m |

### **10.1 Concrete Pipe Culvert Foundation**

It is anticipated that all existing fill materials will be removed from beneath the culvert and the base of the excavation for the replacement culvert (Culvert 1) will be within the silty clay to clayey silt layer. Similarly, the existing peat will be removed from the footprint of the new embankment and the base of the excavation for the new culvert (Culvert 1N) under the new eastbound lanes will be within the silty clay to clayey silt layer. Bearing resistance values are not required for pipe culverts. The culverts should be founded on a granular bedding layer (see Section 10.3). Subgrade preparation should follow the recommendations provided in Section 10.3 to provide a suitable subgrade for the bedding. Surface water diversion and dewatering will be required to place the bedding material and install the culvert in the dry (see Section 11.3).



If a concrete pipe is selected, resistance to lateral forces/sliding resistance between concrete and the underlying granular 'A' bedding (see Section 10.3) should be evaluated based on the recommendations in Section 10.3.

## 10.2 Closed Box Concrete Culvert

The subgrade for Culverts 1 and 1N should be prepared as described in Section 10.3.

The recommended geotechnical resistances for a 3.6 m wide (outside) pre-cast, closed-bottom, box culvert with the culvert base at or below approximate elevation 156.6 m for Culvert 1 and 155.6 for Culvert 1N, installed on a bedding layer with a minimum thickness of 0.3 m placed on an undisturbed native silty clay to clayey silt subgrade are as follows:

- Factored Geotechnical Resistance at ULS of 225 kPa for both Culverts
- Factored Geotechnical Resistance at SLS of 150 kPa for both Culverts (provided settlement mitigation is included for Culvert 1N – see Section 10.7)

It is anticipated that the subgrade soils within the culvert footprint under the eastbound lane will be subjected to the additional loads from the proposed embankment. Further discussion on the potential settlement of the subgrade soils is provided in Section 10.7.

The factored geotechnical resistances include the following factors:

- Consequence factor ( $\Psi$ ) of 1.0 (as per CHBDC Table 6.1)
- Geotechnical resistance factors (as per CHBDC Table 6.2):
  - $\phi_{gu} = 0.5$  (static analysis; typical degree of understanding)
  - $\phi_{gs} = 0.8$  (static analysis; typical degree of understanding)

The bearing resistance values are for vertical, concentric loading. In the case of eccentric or inclined loading, the bearing resistance must be reduced in accordance with CHBDC Clause 6.10.2. Foundation settlement, based on the supplied SLS resistance, is expected to be less than 25 mm for Culvert 1 if constructed on subgrades prepared with good workmanship and in accordance with Sections 10.3 and 10.7. Foundation settlement, based on the supplied SLS resistance, is expected to be approximately 145 mm for Culvert 1N, see further discussion in Section 10.7.3.

Resistance to lateral forces/sliding resistance between the precast concrete and underlying Granular A bedding (Section 10.3) should be evaluated in accordance with the CHBDC assuming an unfactored coefficient of friction of 0.45. A resistance factor of 0.8 (as per CHBDC Table 6.2) should be used to estimate the sliding resistance between the culvert and Granular A. An unfactored coefficient of friction of 0.35 can be assumed for the interface between the Granular 'A' and the clayey silt. A reduction factor of 0.6 (as per CHBDC Table 6.2) should be used to estimate the sliding resistance between the Granular A and the clayey silt subgrade.

Surface water diversion and dewatering will be required to place the bedding material and install the culvert in the dry (Section 11.3).



### 10.3 Subgrade Preparation, Bedding and Backfilling

Granular A" in this section refer to OPSS Granular A meeting the specifications of OPSS.PROV 1010 and SP 110S06. "Granular A" is further defined as "Quarry-Source Granular A" unless specifically described as "Pit-Source Granular A". Fills should be placed and compacted as per OPSS.PROV 501 and OPSS.PROV 206.

The culvert should be constructed following OPSS.PROV 401 and either OPSS.PROV 421 (pipe culvert) or OPSS.PROV 422 (box culvert).

Subgrade preparation for the culvert replacement should include excavation and removal of the existing culvert if replaced along the same alignment. If the replacement culvert is placed on a new alignment, the existing culvert may be decommissioned in place (see Section 10.7.3 for further details).

A layer of fill extending to an elevation as low as 156.1 m was encountered in the area of Culvert 1. The fill was observed to contain organic material and must be removed from beneath the culvert.

A layer of peat with a thickness of approximately 0.2 to 0.3 m was encountered in the area of Culvert 1N during the drilling investigation and must be removed from beneath the culvert and the eastbound embankment footprint. The bearing resistances provided above assume that organic material and very soft to soft clay deposits, where encountered at the subgrade level within the culvert footprint are removed.

For a pipe culvert, at the founding level any existing fill, soft/loose soils (including topsoil and organic silt), disturbed soils, or otherwise deleterious materials encountered will need to be removed down to competent inorganic soils. Granular A should be used in dewatered excavations to backfill any sub-excavations required for subgrade improvement. Foundation preparation for a pipe culvert should be as per OPSD 802.031 and OPSD 803.031 with bedding extending to at least 300 mm below the pipe. It is recommended that culvert cover and bedding materials consist of OPSS.PROV 1010 Granular A.

The closed box culvert will be founded on existing clayey silt soils, the foundation subgrade should be prepared as per OPSS.PROV 902 using Granular A material as backfill of over-excavated areas, where required.

The culvert should be placed on a granular bedding with a minimum thickness of 0.3 m consisting of Granular A material. The top of the Granular A bedding must extend to 0.5 m beyond the outside edge of all sides of the culvert and sloped away from the footing at 1H:1V, or flatter. The granular bedding shall be compacted as per OPSS.PROV 501.

Given the sensitive subgrade clayey silt soils anticipated at the founding level of the culvert, construction equipment should not be permitted to travel on the exposed subgrade. The compaction of granular directly above the subgrade may result in disturbance of the material with pumping of fines into the granular and difficulty achieving the specified degree of compaction. After inspection and approval of the subgrade, protection of the subgrade should include installation of a Class II, non-woven geotextile with a maximum FOS of 150  $\mu$ m





(OPSS.PROV 1860) installed beneath the Granular A material. The geotextile should be placed as soon as possible after preparation of the final subgrade level and the excavation should be backfilled to the top of the bedding elevation to protect the subgrade from disturbance from both construction traffic and weather. Alternatively, 150 mm of granular bedding could be placed above a 200 mm thick, concrete working slab placed on the prepared subgrade. The working slab should extend at least 0.5 m beyond the outside dimensions of the culvert. An NSSP is provided in Appendix H to include in the contract documents to alert the Contractor of the sensitive nature of the foundation soils.

Backfill and cover for concrete box culverts should be as per OPSS 803.010 with cover material consisting of OPSS.PROV 1010 Granular A. Backfill above the granular cover material for a box or rigid pipe culvert should be in accordance with OPSS.PROV 902 and consist of materials meeting the requirements of OPSS Select Subgrade Material (SSM) or better.

Heavy compaction equipment, used adjacent to or directly above the culvert, must be restricted in accordance with OPSS.PROV 501 to protect the culvert from damage.

It is noted that construction will extend below the observed water level. Dewatering will be required to place the granular bedding and/or concrete in the dry. Please review Section 11.3 for additional comments on groundwater and surface water control.

#### **10.4 Backfill and Lateral Earth Pressures**

Structural backfill material should consist of Granular A or Granular B Type II meeting the OPSS.PROV 1010 and SP110S06 specifications. Large scale direct shear box testing on samples of Granular A and Granular B Type II from several nearby aggregate sources was completed for this project. The results indicate that for design of structural backfill for this project, an internal angle of friction of 40 degrees and 42 degrees can be used for quarry-sourced Granular A and Granular B Type II, respectively, generated within this area provided the effective vertical pressure on the material is less than 150 kPa (Geocres Memorandum 31F-213). An Operational Constraint will be required in the contract restricting the source of Granular A to quarries. Throughout this report, the term "Granular A" is defined as "Quarry-Source Granular A" unless specifically described as "Pit-Source Granular A".

The backfill must be in accordance with OPSS.PROV 902 and placed to the extents shown on OPSS 3101.150 for the culvert and wingwalls/headwalls. Structural backfill should consist of Granular A or Granular B Type II placed and compacted in accordance with OPSS.PROV 501. Heavy compaction equipment used adjacent to the walls must be restricted in accordance with OPSS.PROV 501.07.02a). The design of the retaining walls/headwalls, where required, must incorporate a subdrain as shown in OPSS 3101.150.

Lateral earth pressure parameters provided in Table 10-1 and Table 10-2 in the sections below are based on the assumptions that the wall is vertical and the backfill is fully drained so that there are no unbalanced hydrostatic pressures above the permanent groundwater level. If adequate drainage cannot be confirmed, the potential for buildup of hydrostatic pressures should be considered in design.



Where back slopes are horizontal, the corresponding coefficients provided in Table 10-1 and Table 10-2 should be used. For other backfill and wall geometries, Thurber will need to calculate the appropriate earth pressure coefficients once the final geometry is confirmed.

#### 10.4.1 Static Lateral Earth Pressure

Lateral earth pressures acting on structures should be computed in accordance with the CHBDC. Under drained conditions the lateral earth pressure is generally given by the following expression:

$$\sigma_h = K * (\gamma h + q)$$

where:

$\sigma_h$	=	horizontal pressure on the wall at depth h (kPa)
K	=	earth pressure coefficient (see table below) ( $K_A$ for unrestrained walls, $K_0$ for restrained walls)
$\gamma$	=	unit weight of retained soil (see table below), use submerged unit weight below groundwater level
h	=	depth below top of fill where pressure is computed (m)
q	=	value of any surcharge (kPa)

A lateral earth pressure due to backfill compaction should be added to the calculated lateral earth pressure in accordance with Clause 6.12.3 of the CHBDC. Typical earth pressure coefficients for OPSS Granular A and OPSS Granular B Type II backfill are shown in Table 10-1.

**Table 10-1: Static Earth Pressure Coefficients**

Condition	Pit Sourced OPSS Granular A $\phi = 35^\circ, \gamma = 22.8 \text{ kN/m}^3$	Quarry Sourced OPSS Granular A $\phi = 40^\circ, \gamma = 22.8 \text{ kN/m}^3$	Quarry Sourced OPSS Granular B Type II $\phi = 42^\circ, \gamma = 22.8 \text{ kN/m}^3$
Coefficient of at Rest Earth Pressure, $K_0$ (Restrained Wall)	0.43	0.36	0.33
Coefficient of Active Earth Pressure, $K_A$ (Unrestrained Wall)	0.27	0.22	0.20
Coefficient of Passive Earth Pressure, $K_P$ (Movement toward soil)	3.7	4.6	5.0

The parameters in Table 10-1 correspond to full mobilization of active and passive earth pressures and require certain relative movements between the wall and adjacent soil to produce these conditions. The movement required can be assessed from Table C6.12 of the Commentary to the CHBDC. Active earth pressures should be used for unrestrained walls. For rigid structures, at-rest horizontal earth pressures would apply for design.



## 10.4.2 Combined Static and Seismic Lateral Earth Pressure

In accordance with Clause 6.14 of the CHBDC, retaining structures should be designed using dynamic earth pressure coefficients that incorporate the effects of earthquake loading. The following recommendations are per Section C6.14 of the Commentary of the CHBDC which states that seismically induced lateral soil pressures may be calculated using Mononobe Okabe Method with:

- $k_h = \frac{1}{2} * F(PGA) * PGA$ , for structures that allow 25 to 50 mm of movement, and
- $k_h = F(PGA) * PGA$ , for restrained walls

The coefficients of horizontal earth pressure for seismic loading presented in Table 10-2 may be used for vertical walls. The provided earth pressure coefficients are based on a Seismic Site Class D. Please see Section 8.3 for the respective PGA and F(PGA) values.

**Table 10-2: Combined Static and Seismic Earth Pressure Coefficients – Site Class D (2,475-year)**

Condition	Pit Sourced OPSS Granular A $\phi = 35^\circ, \gamma = 22.8 \text{ kN/m}^3$	Quarry Sourced OPSS Granular A $\phi = 40^\circ, \gamma = 22.8 \text{ kN/m}^3$	Quarry Sourced OPSS Granular B Type II $\phi = 42^\circ, \gamma = 22.8 \text{ kN/m}^3$
Coefficient of Active Earth Pressure, $K_{AE}$ (Restrained Wall)	0.44	0.37	0.34
Coefficient of Active Earth Pressure, $K_{AE}$ (Unrestrained Wall)	0.35	0.28	0.26

The total pressure due to combined static and seismic loads acting at a specific depth below the top of the wall/soil may be determined using the following equation that includes consideration of material properties and the soils profile.

$$\sigma_{hAE} = K * \gamma * d + (K_{AE} - K_A) * \gamma * (H - d)$$

where:

$\sigma_{hAE}$	=	combined static and seismic lateral earth pressure on wall at depth d (kPa)
d	=	depth below the top of the wall where pressure is computed (m)
K	=	static earth pressure coefficient ( $K_A$ for unrestrained walls, $K_0$ for restrained walls)
$\gamma$	=	unit weight of retained soil, adjusted below water level
$K_{AE}$	=	combined static and seismic earth pressure coefficient
H	=	total height of the wall (m)



## **10.5 Frost Penetration Depth**

The depth of frost penetration at this site is estimated to be 1.9 m (as per OPSD 3090.101); shallow foundations, if any, should be founded at or below this depth or provided with equivalent insulation. Closed-bottom box culverts are not typically provided with frost protection. The earth cover should be measured perpendicular to the ground surface. Thermally equivalent frost protection could be in the form of insulation provided it is placed *above* the high-water level. It should be noted that open graded materials, such as rock protection, do not have the same thermal protection as soils.

Please refer to the pavement design report for frost taper recommendations for the pavement.

## **10.6 Cement Type and Corrosion Potential**

Chemical analysis for determination of pH, water soluble sulphate, sulphides, chloride concentrations, resistivity and electrical conductivity was carried out on samples of the fill and native materials. The analysis results are summarized in Section 5.6 and a copy of the test results is provided in Appendix C.

The pH, resistivity and chloride concentration provide an indication of the degree of corrosiveness of the sub-surface environment. The test results provided in Section 5.6 were compared with Table 3.2 of the MTO Gravity Pipe Design Guideline and generally indicate a low to severe corrosive environment. Given the range of the results, additional testing should be considered during detailed design. The test results provided in Section 5.6 may be used to aid in the selection of coatings and corrosion protection systems for buried steel objects.

The concentration of soluble sulphate provides an indication of the degree of sulphate attack that is expected for concrete in contact with the soil and groundwater at the site. The sulphate results in were compared with Table 3 of Canadian Standards Association Standards A23.1-19 (CSA A23.1) and indicate a low degree of sulphate attack potential on concrete structures at this site.

The corrosive effects of road de-icing salts should also be considered.

## **10.7 Embankment Fill**

Embankments shall be constructed in accordance with OPSS.PROV 206. It is recommended that local marine clay should not be used as embankment fill.

### **10.7.1 Westbound Embankment Reinstatement**

The existing highway embankment side slopes are inclined at approximately 3.2H:1V on the south side and 3.8H:1V on the north side. The existing slopes did not show any visible signs of global instability at the time of the investigation.

It is understood that no grade raise or embankment widening is anticipated along the Highway 17 alignment. In fact, consideration is being given to reducing the overall highway width as the passing lane may be decommissioned.



Embankment reinstatement after construction of the replacement culvert should be carried out in accordance with OPSS.PROV 206 with materials similar to the existing. If constructed using Select Subgrade Material (SSM) or Granular B Type I, the embankment should be constructed with side slopes of 2H:1V (or flatter). The granular fill should be placed and compacted in accordance with OPSS.PROV 501.

Where newly placed embankment fill is placed against existing embankment slopes or on a sloping ground surface steeper than 3H:1V, benching of the existing slope should be carried out in accordance with OPSD 208.010.

### **10.7.2 Embankment Stability**

Embankment stability has been assessed perpendicular to the roadway alignment. Analyses were completed for both the eastbound and westbound embankments near Station 15+840.

The slope stability analyses were carried out using GeoStudio 2024 Slope/W software for limit equilibrium analysis. Input parameters, soil model and groundwater conditions for the analyses are based on the in situ testing and the results of laboratory testing and are shown on the stability analyses outputs provided in Appendix G.

The following additional parameters and assumptions were used in the analysis:

- The soil stratigraphy is based on the nearest boreholes.
- A maximum fill height of 4.3 m (eastbound lanes) and 4.6 m (westbound lanes).
- Eastbound embankment: options for construction at 2H:1V with SSM/Granular B Type I or 1.25H:1V with rockfill.
- Westbound embankment: reinstatement at 2H:1V with SSM/Granular B Type I.
- A site adjusted PGA value of 0.13g, equal to ½ of the site adjusted PGA value (0.262g), was used for seismic analysis, as per Section 4.4.3.3, of the CHBDC and outlined in Section 8.3.
- A traffic surcharge of 17 kPa has been applied as a temporary load.

Copies of the output from the stability analyses are provided in Appendix G. Each output figure shows the slope geometry, groundwater conditions, soil stratigraphy and soil strength parameters utilized in the analysis.

The stability analyses generated the following factor of safety values for the proposed eastbound embankment design:

**Table 10-3: Slope Stability Analysis Results for the new Eastbound Embankment, Sta. 15+840, near Culvert 1N**

Condition	Case	Factor of Safety	
		2H:1V [SSM/Granular B I]	1.25H:1V [Rockfill]
Temporary (traffic loading)	Short Term (Undrained)	2.4 (Fig G1-1)	2.3 (Fig G2-1)
Permanent (no traffic loading)	Long Term (Drained)	1.5 (Fig G1-2)	1.6 (Fig G2-2)
Temporary (includes seismic)	Pseudo-Static Seismic (Undrained)	1.9 (Fig G1-3)	2.0 (Fig G2-3)

The stability analyses generated the following factor of safety values for the proposed westbound embankment design:

**Table 10-4: Slope Stability Analysis Results for the Reinstatement of the Westbound Embankment, Sta. 15+840, near Culvert 1**

Condition	Case	Factor of Safety
		2H:1V [SSM/Granular B I]
Temporary (traffic loading)	Short Term (Undrained)	2.3 (Fig G3-1)
Permanent (no traffic loading)	Long Term (Drained)	1.5 (Fig G3-2)
Temporary (includes seismic)	Pseudo-Static Seismic (Undrained)	1.8 (Fig G3-3)

The geotechnical resistance factors provided in Table 6.2 of the CHBDC for embankment fills with a typical degree of understanding and a consequence factor ( $\Psi$ ) of 1.0 generates minimum target Factors of Safety of 1.5 and 1.3 for permanent and temporary conditions respectively. All the static results presented in Table 10-3 meet or exceed the target Factors of Safety.

Table 6.3 in Section 6.14.4.1 of the CHBDC indicates a minimum seismic resistance factor of 0.95 for force-based design and 1.0 for performance-based design. Based on these values and consequence factor ( $\Psi$ ) of 1.0, a target Factor of Safety of 1.1 is considered appropriate for the pseudo-static seismic analysis. However, it is noted that some displacement of the embankment can occur where the pseudo-static Factor of Safety is less than 1.3. The pseudo-static results, presented in Table 10-3 above, meet the target Factors of Safety for seismic design.

Should slope flattening of the rockfill embankments be used onsite with surplus excavated material, slope protection and drainage measures will be required to ensure the long-term surficial stability of the embankment slopes, see Section 11.4. Slope flattening should meet the requirements of OPSD 202.010 and OPSD 202.020. Slope flattening should not be applied near culvert installations to avoid increasing the culvert length.

### **10.7.3 Embankment Settlement**

Embankments must be overbuilt to compensate for the estimated settlements.

It is noted that the addition of a widened platform to accommodate future grade raises has not been included in the design assumptions. Similarly, the placement of slope flattening material on rock fill slopes has not been included in the analyses. Inclusion of these modifications to the cross-sections will affect the settlement magnitudes presented herein.

#### Westbound – Culvert 1

The reinstated westbound embankment will have a similar height and footprint to the existing. The proposed opening for the Culvert 1 replacement is greater than the existing, thus, the construction represents a net unloading. No additional settlement is expected along the existing alignment. If the existing culvert is to be decommissioned by filling it with grout or removed and backfilled, it is estimated that this would induce further settlement of less than 10 mm beneath the existing culvert alignment as a result of the increased load imposed by the grout/fill. Settlement should be reviewed if the embankment is widened or reinstated to design grades greater than the existing grades.

Self-settlement of the 4.6 m high embankment required to reinstate the eastbound lanes after installation of Culvert 1 will also occur. For an embankment constructed of compacted SSM material, approximately 25 mm of self settlement will occur with the majority of that complete during construction.

No special mitigation measures for settlement are anticipated for the replacement of Culvert 1.

Settlement of the westbound lanes due to the construction of the new eastbound embankment is expected to be negligible.

#### Eastbound – Culvert 1N

The proposed eastbound lanes will result in a fill height of approximately 4.3 m near the proposed Culvert 1N. Settlement of the future highway embankment needs to be considered not only in terms of pavement performance on the approaches but also in selection and design of the new culvert.

The loading imposed from the new fill will increase the effective stress in underlying soil deposits and induce consolidation settlement in the clayey silt layer and elastic settlement in the granular deposits at the site.

In accordance with MTO's document "Embankment Settlement Criteria for Design" (March 2, 2010), the criteria adopted for embankment design at this site is shown in Table 10-5.

**Table 10-5: Summary of MTO Settlement Criteria**

Distance from Structure	0-20 m	20-50 m	50-75 m	>75 m	Post Construction Settlement Period
Settlement Limits Freeway	25 mm	50 mm	75 mm	100 mm	20 years

Representative site stratigraphy was developed based on the Record of Borehole logs with material properties based on the results of in-situ field testing and laboratory testing. The consolidation settlement parameters were estimated based on five test results from similar soils at the High Fill A & Culvert 4/4N site which is located approximately 650 m southeast of Culverts 1 and 1N. It is noted that engineering judgment and experience was used to select the material properties based on the stress range anticipated due to loading. The soil parameters used in the models are summarized in Table 10-6, below.

**Table 10-6: Summary of Material Parameters**

Soil Type	Thickness (m)	Unit Weight (kN/m <sup>3</sup> )	Typical Settlement Parameters					
			P <sub>c</sub> ' (kPa)	e <sub>0</sub>	Primary			
					C <sub>c</sub>	C <sub>r</sub>	C <sub>v</sub> (cm <sup>2</sup> /s)	C <sub>vr</sub> (cm <sup>2</sup> /s)
Silty Clay to Clayey Silt	15	17.5	> 450	1.0	0.41	0.03	0.006	0.007
Silty Sand	5.0*	19.0	E <sub>s</sub> = 10 MPa					

Notes: (\*) assuming that the thickness of all silty sand seams represents 25% of the total soil profile.

Analyses were carried out to calculate the predicted settlement with time, considering SSM embankments and a unit weight of 21 kN/m<sup>3</sup>. Settlement in the underlying soils from rockfill (unit weight of 20 kN/m<sup>3</sup>) placement is expected to be slightly less than that generated from SSM fill.

The estimated settlement of the underlying native soils at Culvert 1N, assuming a total soil layer thickness of 20 m, is 145 mm (105 mm of recompression from the silty clay to clayey silt and 40 mm of elastic settlement in the silty sand). The settlement is expected to occur within 6 months following fill placement with 95% of the settlement occurring within 4 months.

It is recommended that Culvert 1N be designed with a camber or be over-sized to accommodate the anticipated settlement without compromising hydraulic capacity. In this case, the SLS geotechnical resistance provided in Section 10.2 is associated with a settlement of 145 mm. Further, the placement of asphalt should be delayed for several months.

Alternatively, the site could be preloaded to minimize post-construction settlement of the culvert. A preload period of 4 months should be sufficient. A temporary culvert will need to be placed to allow creek flow during the preload period.

In addition to the settlement described above, there will be self-settlement of the 4.3 m high embankment material itself. For embankments constructed with compacted rockfill the short term settlement will be approximately 25 mm (up to 1 year after completion of construction with 90% of this value occurring in the first six months). In addition, rockfill embankments will continue to settle after the first year with an estimate of an additional 5 mm. Similarly, an embankment constructed of compacted SSM material will undergo approximately 20 mm of self compression with the majority of that complete during construction.

## 11 CONSTRUCTION CONSIDERATIONS

### 11.1 Temporary Excavations

All temporary excavation must be conducted in accordance with the requirements of the Occupational Health & Safety Act & Regulations (OHSA) for Construction Projects. The peat may be classified as a Type 4 soil. The native silty clay to clayey silt and silt sand materials may be classified as Type 3 soil. **Side slopes for excavations through more than one soil type must be entirely based on the highest soil type number.**

Excavation should occur in a dewatered environment (see Section 11.3). Excavations must be planned and carried out in a manner that does not impact on the stability of existing roadway. Any temporary cut slopes may have to be protected from precipitation and runoff to avoid surficial instabilities. The duration of temporary open excavations and cut slopes should be minimized to reduce the likelihood of causing instability concerns. Embankment and cut slope stability is the responsibility of the Contractor.

Excavation should be carried out in accordance OPSS.PROV 902, OPSS.PROV 421 and OPSS.PROV 422. The management and disposal of excess material shall be in accordance with OPSS.PROV 180. Excavations will extend through existing fills and into the underlying native soil deposits.

Selection of the equipment and methodology to excavate and prepare the founding surface is the responsibility of the Contractor. Material stockpiling is a temporary construction measure, and the associated stability implications are the responsibility of the Contractor. The selection and placement of construction equipment (such as cranes) and construction of temporary construction access roads are also the Contractor's responsibility.

Although not anticipated, at locations where there are space restrictions or where a slope must be retained, the excavations could be carried out within a protection system. Further discussion on temporary protection systems (TPS) is presented in Section 11.2.

### 11.2 Temporary Protection Systems

Although not anticipated, Temporary Protection Systems may be required during various stages of construction and must be implemented in accordance with OPSS.PROV 539 as amended by SP 105S09. Performance Level 2 (maximum 25 mm horizontal deflection) is considered appropriate where the protection supports the existing roadway. More stringent performance levels may be required if the protection system is intended to support existing structures or utilities.



The pressure distribution acting on the shoring system is a function of the construction sequence and the relative flexibility of the wall, and these factors must be considered when designing the shoring system.

Steel sheet piles are considered a suitable option for roadway protection for this site; however, the selection and design of protection systems are the responsibility of the Contractor. All protection systems should be designed by a licensed Professional Engineer experienced in such designs and retained by the Contractor. The design of the roadway protection system must incorporate traffic loading and surcharge loading due to construction equipment and operations.

It is recommended that the protection systems installed within 3 m from the edges of the culvert should be left in place and cut off in accordance with OPSS.PROV 539.

The lateral earth pressure coefficients and undrained strengths for the existing soils are given in Table 11-1 for a vertical wall and a horizontal backslope. Note peat should be removed prior to installing TPS. Unit weights provided herein are to be adjusted for applications below the groundwater level. Unbalanced hydrostatic pressures should be considered in the design of the protection systems.

**Table 11-1: Static Earth Pressure Coefficients for Existing Soils**

<b>Material</b>	<b>Unit Weight<sup>(*)</sup> (kN/m<sup>3</sup>)</b>	<b>K<sub>A</sub></b>	<b>K<sub>P</sub></b>	<b>K<sub>0</sub></b>	<b>Su (kPa)</b>
Existing Fill	21	0.33	3.00	0.50	-
Native Peat	10	**	**	**	**
Native, Cohesive Silty Clay to Clayey Silt	17.5	-	-	-	100
Native Silty Sand	21	0.33	3.00	0.50	-

*Note: (\*) to be adjusted when below water level*

*(\*\*) considered negligible. Peat should be removed prior to installing TPS.*

When designing roadway protection systems, the Contractor should consider the potential for obstructions such as cobbles and boulders in existing embankment fill. Although not encountered in the on-road boreholes at this site, rockfill embankments have been noted along Highway 17 within the project limits. Lateral support can be enhanced by using bracing or rakers. Suggested wording for an NSSP for obstructions is included in Appendix H.

### **11.3 Surface and Groundwater Control**

Culvert subgrade preparation and placement and compaction of granular bedding/pads and culvert placement must be carried out in the dry. The Contractor must control groundwater, perched groundwater and surface water flow at the site with a flow passage system and a dewatering system to permit construction in a dry and stable excavation.





The temporary flow diversion pipe should be placed outside the construction area. The design of flow passage systems is the responsibility of the Contractor. Given the site conditions and anticipated works, the Designer Fill-In (Note 2) in SP 517F01 Table 1 for flow passage systems should be “No; the design Engineer and design-checking Engineer do not need a minimum of 5 years of experience in designing similar flow passage systems.

The design of dewatering systems is the responsibility of the Contractor. The Contract Documents must alert the Contractor to this responsibility and to design the system in accordance with SP 517F01 which amends OPSS.PROV 517. The contractor’s design should include an assessment of any adverse effects the dewatering method, construction layout and staging may have on adjacent structures, utilities and facilities. Given the site conditions (minor artesian conditions, potential for bottom heave from underlying silty sand seams) and anticipated works (excavating to more than 1.5 m below groundwater level), the Designer Fill-In (Note 2) in SP 517F01 Table 1 should be “Yes” for dewatering systems; the design Engineer and design-checking Engineer need a minimum of 5 years of experience in designing similar dewatering systems. A preconstruction survey is not recommended; thus, Designer Fill-In Note 4 in this SP should be “N/A”. Based on the groundwater elevation at the time of the investigation, it is anticipated that the site will require dewatering to lower the groundwater to below the final excavation or footing level; Note 5 of SP 517F01 Table 1 should be a minimum of 0.5 m below the underside of the planned excavation base prior to each stage of excavation.

The water level will fluctuate and the minimum design groundwater elevation for the site at the time of the excavation should be no lower than the highwater level in the creek generated by the return period flow estimates defined in SP 517F01.

The dewatering plan should be coordinated with TPS design. The dewatering system will be required to remain operational and effective until the temporary excavations are backfilled and then should be decommissioned and removed. It is anticipated that sump pumps will likely be sufficient to extract water from the excavation for the culverts. Pumping from within a sandbag cofferdam system is one option. More than one pump may be required. A sheet pile cofferdam enclosure driven into the foundation clayey silt may also be considered. The groundwater level within the work zone should be lowered by pumping from sumps to a minimum of 0.5 m below the underside of the planned excavation base prior to each stage of excavation.

Further assessment of dewatering requirements and the need for registration on the Environmental Activity and Sector Registry (EASR) or a Permit to take Water (PTTW) should be carried out by specialists experienced in this field.

Please refer to Hydrogeological Investigation and Design Report for additional discussion on dewatering with respect to this assignment.

#### **11.4 Erosion and Scour Control**

The Contractor should provide silt fences and erosion control blankets as per OPSS.PROV 805 and OPSD 219.110 throughout the duration of construction to prevent transport of silt/sediment.



Particle size analysis on samples of the existing native materials indicate that the soils have a low to medium potential for soil erodibility (Wischmeier Nomograph factor, K).

Slope protection and drainage measures will be required to ensure the long-term surficial stability of the new embankment slopes. A vegetation cover should be established on exposed earth surfaces to protect against surficial erosion in general accordance with OPSS.PROV 803 and OPSS.PROV 804. Slope vegetation should be established as soon as possible after completion of construction in order to limit surficial erosion and water should be prevented from running down an unprotected slope.

Scour and erosion protection must be provided for the culvert inlet and outlet areas. Effective scour and erosion protection should be provided along the waterline and ditches. Design of the erosion protection measures must consider hydrologic and hydraulic factors and shall be carried out by specialists experienced in this field. Typically, rock protection should be provided over all earth surfaces subjected to flowing water in accordance with OPSS.PROV 511. Treatment at the outlet should be in accordance with OPSD 810.010.

Liaison between the Foundations Consultant, Structural Engineer and Hydraulic/Drainage Engineer will be required in design to ensure that scour protection, if required, is adequately addressed.

## **12 DESIGN AND CONSTRUCTION CONCERNS**

The preliminary recommendations presented herein must be reassessed once the type, location, elevation, and orientation of the works are established

The pH, resistivity and chloride concentration provide an indication of the degree of corrosiveness of the sub-surface environment. The test results provided in Section 5.6 indicate a low to severe corrosive environment. Given the range of the results, additional testing should be considered during detailed design.

The seismic hazard data considered for the preliminary design recommendations provided in this report were obtained from the fifth-generation seismic model developed by the Geological Survey of Canada (GSC). Additional seismic analyses will be required to reflect the reference seismic hazard available at the time of detailed design.

**The DB Contractor must review the existing factual information and determine the extent of additional field investigations and laboratory testing required to support the foundation design of the proposed works. It is noted that preliminary drawings for the culverts are not available at the time of writing. The preliminary recommendations provided herein will need to be re-evaluated once the culvert invert elevations are confirmed.**

The planned construction methodology includes open cut excavations for the installation of foundation elements of a new culvert. Potential construction concerns may include, but are not necessarily limited to:

- Construction will extend below the water level in the creek. An adequate and effective surface water management and dewatering plan must be implemented to construct the foundations in the dry.
- Control of groundwater seepage during excavation. Minor artesian conditions were noted during groundwater measurements. The clayey silt/silty clay layers were noted to have sand seams. The potential for basal heave must be considered in the design of the dewatering system.
- The clayey silt which will be exposed beneath a culvert bedding layer or wing wall spread footings is sensitive and readily disturbed. A suggested Notice to Contractor is provided in Appendix H.
- The Contractor's selection of construction equipment and methodology must include assessment of the capability of the existing soils to support the proposed construction equipment and supplies.
- Mitigation of the settlement induced by the new westbound embankment will require that the Culvert 1N structure be designed to accommodate the movements.

The successful performance of the structure installations will depend largely upon good workmanship and quality control during construction. Observation of the excavation and backfilling operations will be required as per OPSS.PROV 902 during construction to confirm that the foundation recommendations are correctly implemented, and material specifications are met.

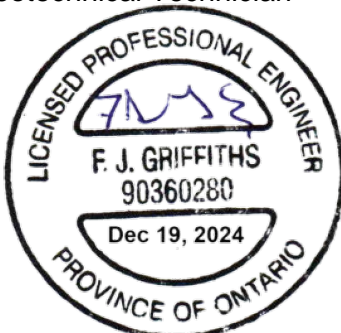


### 13 CLOSURE

Engineering analysis and preparation of this report was carried out by D. Amorim Pereira, Geotechnical Technician. The report was reviewed by Dr. F. Griffiths, P.Eng., and Dr. P.K. Chatterji, P.Eng., a Designated Principal Contact for MTO Foundation Projects.

Thurber Engineering Ltd.  
Report Prepared By:

Darlan Amorim Pereira, M.Sc.  
Geotechnical Technician



Dr. Fred Griffiths, P.Eng.  
Principal, Senior Geotechnical Engineer

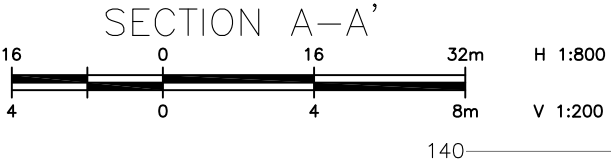
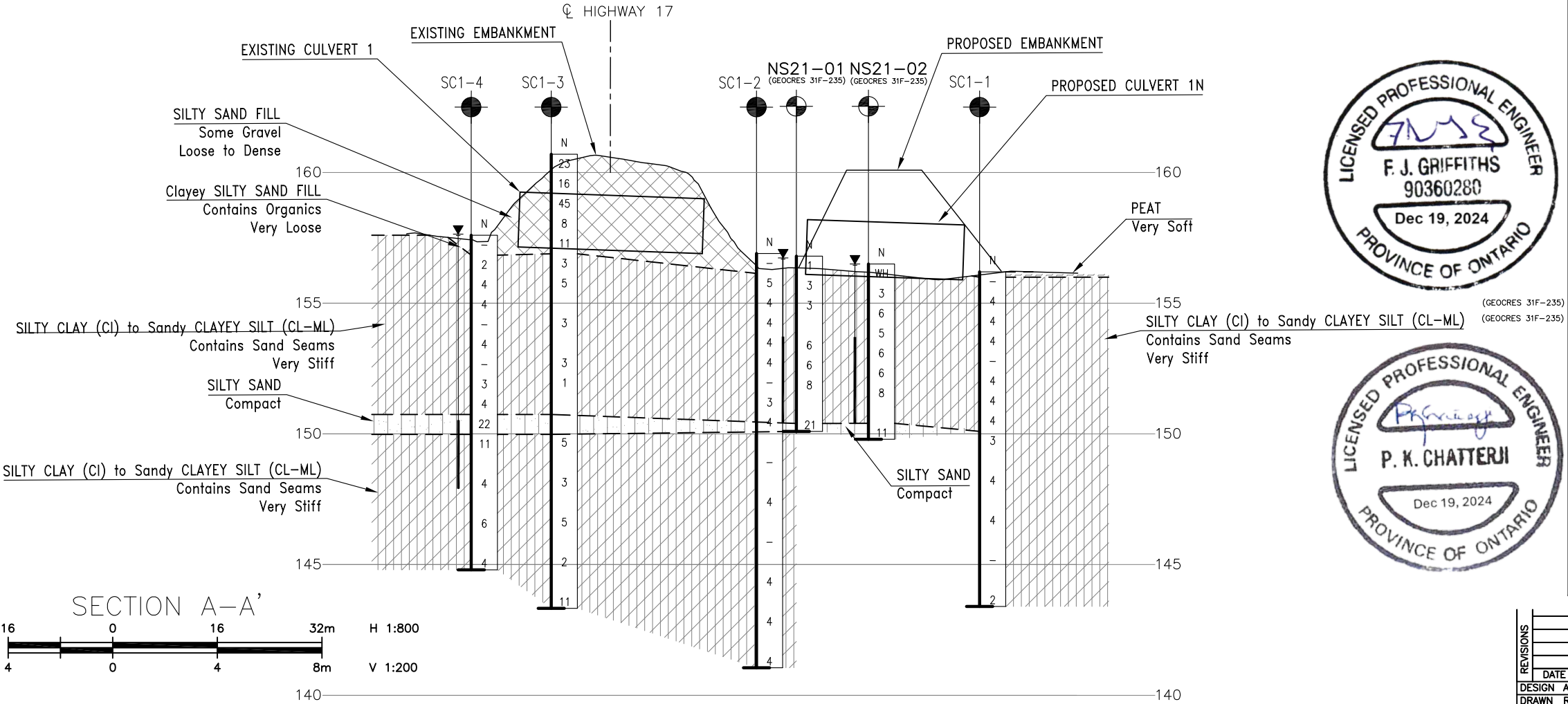
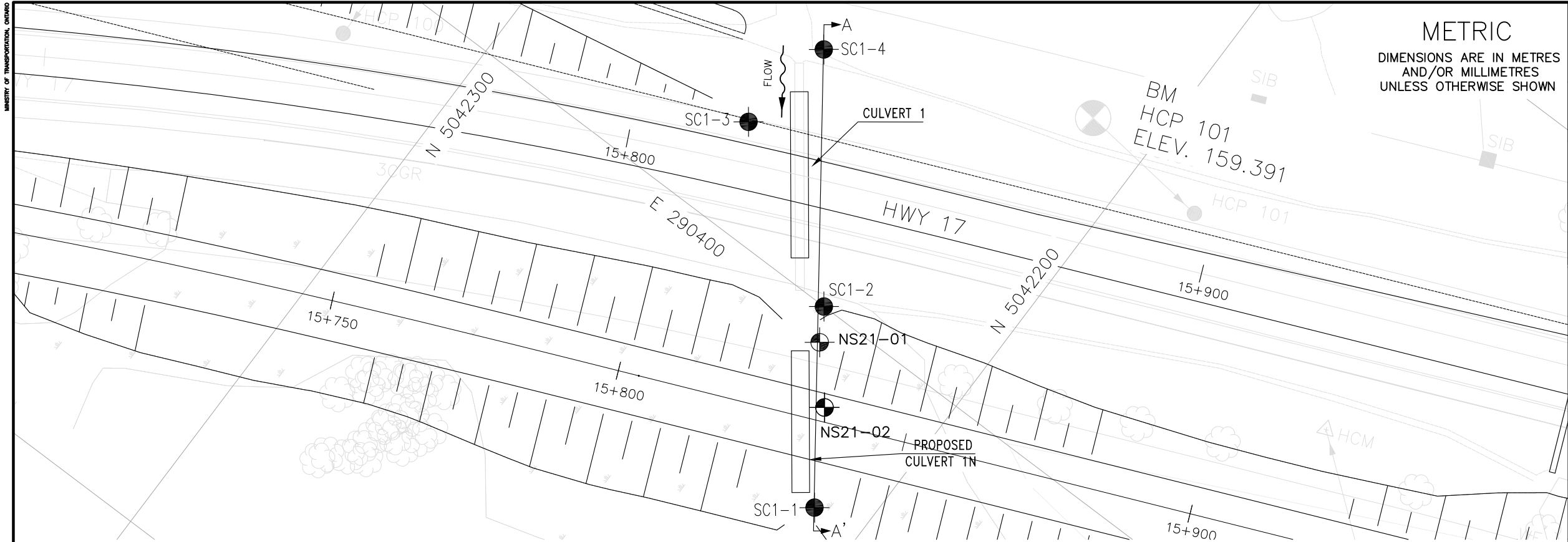


Dr. P.K. Chatterji, P.Eng.  
Designated Principal Contact,  
Principal, Senior Geotechnical Engineer



## **Appendix A.**

### **Borehole Location Plan and Stratigraphic Drawings**



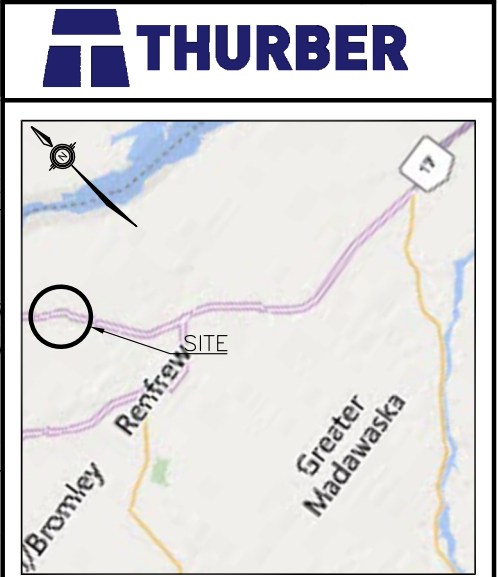
METRIC  
DIMENSIONS ARE IN METRES  
AND/OR MILLIMETRES  
UNLESS OTHERWISE SHOWN

CONT No  
GWP No 4068-09-00

HIGHWAY 17 TWINNING  
STA.15+840, HORTON TWP  
CULVERT 1/1N  
BOREHOLE LOCATION PLAN AND SOIL STRATA

Ontario

SHEET  
1



KEYPLAN			
LEGEND			
	Borehole		
	Historic Borehole		
N	Blows /0.3m (Std Pen Test, 475J/blow)		
CONE	Blows /0.3m (60° Cone, 475J/blow)		
PH	Pressure, Hydraulic		
	Water Level Upon Completion of Drilling		
	Water Level in Monitoring Well/Piezometer		
	Monitoring Well/Piezometer Screen		
90%	Rock Quality Designation (RQD)		
A/R	Auger Refusal		
NO	ELEVATION	NORTHING	EASTING
SC1-1	156.2	5 042 208.8	290 371.8
SC1-2	156.9	5 042 228.1	290 399.9
SC1-3	160.7	5 042 257.2	290 417.3
SC1-4	157.6	5 042 254.4	290 434.8
NS21-01	156.8	5 042 225.0	290 394.7
NS21-02	156.6	5 042 217.7	290 386.4



- NOTES-
- The boundaries between soil strata have been established only at Borehole locations. Between Boreholes the boundaries are assumed from geological evidence.
  - This drawing is for subsurface information only. Surface details and features are for conceptual illustration.
  - Coordinate system is MTM NAD 83 Zone 9.

GEOCRES No. 31F10-001			
REVISIONS			
DATE	BY	DESCRIPTION	
DESIGN AO	CHK -	CODE	LOAD
DRAWN RH	CHK FG	SITE	STRUCT
		DATE	NOV 2024
		DWG	1



## **Appendix B.**

### **Record of Borehole Sheets**



## SYMBOLS, ABBREVIATIONS AND TERMS USED ON TEST HOLE RECORDS

### TERMINOLOGY DESCRIBING COMMON SOIL GENESIS

Topsoil	mixture of soil and humus capable of supporting vegetative growth
Peat	mixture of fragments of decayed organic matter
Till	unstratified glacial deposit which may include particles ranging in sizes from clay to boulder
Fill	material below the surface identified as placed by humans (excluding buried services)

### TERMINOLOGY DESCRIBING SOIL STRUCTURE:

Desiccated	having visible signs of weathering by oxidization of clay materials, shrinkage cracks, etc.
Fissured	having cracks, and hence a blocky structure
Varved	composed of alternating layers of silt and clay
Stratified	composed of alternating successions of different soil types, e.g. silt and sand
Layer	> 75 mm in thickness
Seam	2 mm to 75 mm in thickness
Parting	< 2 mm in thickness

### RECOVERY:

For soil samples, the recovery is recorded as the length of the soil sample recovered.

### N-VALUE:

Numbers in this column are the field results of the Standard Penetration Test: the number of blows of a 63.5 kg hammer falling 0.76 m, required to drive a 50 mm O.D. split spoon sampler 0.3 m into undisturbed soil. For samples where insufficient penetration was achieved and N-value cannot be presented, the number of blows are reported over the sampler penetration in millimetres (e.g. 50/75).

### DYNAMIC CONE PENETRATION TEST (DCPT):

Dynamic cone penetration tests are performed using a standard 60 degree apex cone connected to an "A" size drill rods with the same standard fall height and weight as the Standard Penetration Test. The DCPT value is the number of blows of the hammer required to drive the cone 0.3 m into the soil. The DCPT is used as a probe to assess soil variability.





### STRATA PLOT:

Strata plots symbolize the soil and bedrock description. They are combinations of the following basic symbols. The dimensions within the strata symbols are not indicative of the particle size, layer thickness, etc.



Boulders  
Cobbles  
Gravel      Sand      Silt      Clay      Organics      Asphalt      Concrete      Fill      Bedrock

### TEXTURING CLASSIFICATION OF SOILS

Classification	Particle Size
Boulders	Greater than 200 mm
Cobbles	75 – 200 mm
Gravel	4.75 – 75 mm
Sand	0.075 – 4.75 mm
Silt	0.002 – 0.075 mm
Clay	Less than 0.002 mm

### TERMS DESCRIBING CONSISTENCY (COHESIVE SOILS ONLY)

Descriptive Term	Undrained Shear Strength (kPa)
Very Soft	12 or less
Soft	12 – 25
Firm	25 – 50
Stiff	50 – 100
Very Stiff	100 – 200
Hard	Greater than 200

NOTE: Clay sensitivity is defined as the ratio of the undisturbed strength over the remolded strength.

### SAMPLE TYPES

SS	Split spoon samples
ST	Shelby tube or thin wall tube
DP	Direct push sample
PS	Piston sample
BS	Bulk sample
WS	Wash sample
HQ, NQ, BQ etc.	Rock core sample obtained with the use of standard size diamond coring equipment

### TERMS DESCRIBING CONSISTENCY (COHESIONLESS SOILS ONLY)

Descriptive Term	SPT “N” Value
Very Loose	Less than 4
Loose	4 – 10
Compact	10 – 30
Dense	30 – 50
Very Dense	Greater than 50

### MODIFIED UNIFIED SOIL CLASSIFICATION

Major Divisions		Group Symbol	Typical Description
COARSE GRAINED SOIL	GRAVEL AND GRAVELLY SOILS	GW	Well-graded gravels or gravel-sand mixtures, little or no fines.
		GP	Poorly-graded gravels or gravel-sand mixtures, little or no fines.
		GM	Silty gravels, gravel-sand-silt mixtures.
		GC	Clayey gravels, gravel-sand-clay mixtures.
	SAND AND SANDY SOILS	SW	Well-graded sands or gravelly sands, little or no fines.
		SP	Poorly-graded sands or gravelly sands, little or no fines.
		SM	Silty sands, sand-silt mixtures.
		SC	Clayey sands, sand-clay mixtures.
FINE GRAINED SOILS	SILT AND CLAY SOILS $W_L < 35\%$	ML	Inorganic silts, very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity.
		CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.
		OL	Organic silts and organic silty-clays of low plasticity.
	SILT AND CLAY SOILS $35\% < W_L < 50\%$	MI	Inorganic compressible fine sandy silt with clay of medium plasticity, clayey silts.
		CI	Inorganic clays of medium plasticity, silty clays.
		OI	Organic silty clays of medium plasticity.
	SILT AND CLAY SOILS $W_L > 50\%$	MH	Inorganic silts, micaceous or diatomaceous fine sandy of silty soils, elastic silts.
		CH	Inorganic clays of high plasticity, fat clays.
		OH	Organic clays of high plasticity, organic silts.
HIGHLY ORGANIC SOILS		Pt	Peat and other organic soils.

Note -  $W_L$  = Liquid Limit



## EXPLANATION OF ROCK LOGGING TERMS

### ROCK WEATHERING CLASSIFICATION

Fresh (FR)	No visible signs of weathering.
Fresh Jointed (FJ)	Weathering limited to surface of major discontinuities.
Slightly Weathered (SW)	Penetrative weathering developed on open discontinuity surfaces, but only slight weathering of rock materials.
Moderately Weathered (MW)	Weathering extends throughout the rock mass, but the rock material is not friable.
Highly Weathered (HW)	Weathering extends throughout the rock mass and the rock is partly friable.
Completely Weathered (CW)	Rock is wholly decomposed and in a friable condition, but the rock texture and structures are preserved.

### TERMS

Total Core Recovery: (TCR)	Core recovered as a percentage of total core run length.
Solid Core Recovery: (SCR)	Percent ratio of solid core of full cylindrical shape recovered. Expressed with respect to the total length of core run.
Rock Quality Designation: (RQD)	Total length of sound core recovered in pieces 0.1 m in length or larger, as a percentage of total core length
Unconfined Compressive Strength: (UCS)	Axial stress required to break the specimen.
Fracture Index: (FI)	Frequency of natural fractures per 0.3 m of core run.

### DISCONTINUITY SPACING

Bedding	Bedding Plane Spacing
Very thickly bedded	Greater than 2 m
Thickly bedded	0.6 to 2 m
Medium bedded	0.2 to 0.6 m
Thinly bedded	60 mm to 0.2 m
Very thinly bedded	20 to 60 mm
Laminated	6 to 20 mm
Thinly laminated	Less than 6 mm

### STRENGTH CLASSIFICATION

Rock Strength	Approximate Uniaxial Compressive Strength (MPa)
Extremely Strong	Greater than 250
Very Strong	100 – 250
Strong	50 – 100
Medium Strong	25 – 50
Weak	5 – 25
Very Weak	1 – 5
Extremely Weak	0.25 – 1

RECORD OF BOREHOLE No SC1-1

1 OF 2

METRIC

WP# 4068-09-00 LOCATION Lat: 45.519649°, Long: -76.684686°  
Culvert 1/1N; Horton Township; MTM z9: N 5 042 208.8 E 290 371.8 ORIGINATED BY RH  
HWY 17 BOREHOLE TYPE CME 55 Trackmount / HSA COMPILED BY RH  
DATUM Geodetic DATE 2024.02.15 - 2024.02.15 CHECKED BY AO

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT				PLASTIC LIMIT NATURAL MOISTURE CONTENT LIQUID LIMIT			UNIT WEIGHT  γ  kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%)			
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa ○ UNCONFINED      + FIELD VANE ● QUICK TRIAXIAL    × LAB VANE				WATER CONTENT (%) w <sub>p</sub> w      w <sub>L</sub>				GR	SA	SI	CL
156.2	Ground Surface					▽													
0.0	AMORPHOUS PEAT																		
0.2	very soft, black		1	GS	-														
	SILTY CLAY (CI) to Sandy CLAYEY SILT (CL-ML) contains sand seams very stiff grey																		
			2	SS	4														
			3	SS	4														
			4	SS	4														
			5	PS	-														
			6	SS	4														
			7	SS	4														
	- becomes sandy		8	SS	4														
			9	SS	3														
						</													

Continued Next Page

+<sup>3</sup>, ×<sup>3</sup>: Numbers refer to  
Sensitivity

20  
15  
10

(%) STRAIN AT FAILURE

RECORD OF BOREHOLE No SC1-1

2 OF 2

METRIC

WP# 4068-09-00 LOCATION Lat: 45.519649°, Long: -76.684686°  
Culvert 1/1N; Horton Township; MTM z9: N 5 042 208.8 E 290 371.8 ORIGINATED BY RH  
HWY 17 BOREHOLE TYPE CME 55 Trackmount / HSA COMPILED BY RH  
DATUM Geodetic DATE 2024.02.15 - 2024.02.15 CHECKED BY AO

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												
	Continued From Previous Page						20 40 60 80 100													
143.4 12.8	SILTY CLAY (CI) to Sandy CLAYEY SILT (CL-ML) contains sand seams very stiff grey						146													
			12	ST	-		145													
			13	SS	2		144													
	End of Borehole																			
	Water level in open borehole at a depth of 0.6 m (elev. 155.6 m) upon completion of drilling.																			

RECORD OF BOREHOLE No SC1-2

1 OF 2

METRIC

WP# 4068-09-00 LOCATION Lat: 45.519822°, Long: -76.684327°  
Culvert 1/1N; Horton Township; MTM z9: N 5 042 228.1 E 290 399.9 ORIGINATED BY RH  
HWY 17 BOREHOLE TYPE CME 55 Trackmount / HSA COMPILED BY RH  
DATUM Geodetic DATE 2024.02.15 - 2024.02.16 CHECKED BY AO

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT      NATURAL MOISTURE CONTENT      LIQUID LIMIT			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 (%)				
156.9	Ground Surface							20 40 60 80 100						
0.0	Clayey SILTY SAND contains organics very loose brownish grey FILL		1	GS	-			○ UNCONFINED      + FIELD VANE						
156.1								● QUICK TRIAXIAL      × LAB VANE						
0.8	SILTY CLAY (CI) to Sandy CLAYEY SILT (CL-ML) contains sand seams very stiff grey		2	SS	5		156							
			3	SS	4		155							
			4	SS	4		154							0    4    54    42
			5	SS	4									
			6	SS	4		153							
			7	PS	-		152							
	- becomes sandy		8	SS	3		151							
			9	SS	4									
							150							
			10	SS	-		149							
							148							
			11	SS	4									0    23    58    19
							147							

Continued Next Page

+<sup>3</sup>, ×<sup>3</sup>: Numbers refer to  
Sensitivity 20  
15 10 5 (%) STRAIN AT FAILURE

## 2 OF 2

METRIC

[illegible]

DOUBLE LINE 24726 CULVERT 1.1N.GPJ 2012TEMPLATE(MTO).GDT 12-17-24

+<sup>3</sup>, ×<sup>3</sup>: Numbers refer to Sensitivity

RECORD OF BOREHOLE No SC1-3

1 OF 2

METRIC

WP# 4068-09-00 LOCATION Lat: 45.520085°, Long: -76.684104°  
Culvert 1/1N; Horton Township; MTM z9: N 5 042 257.2 E 290 417.3 ORIGINATED BY DAP  
HWY 17 BOREHOLE TYPE CME 75 Truckmount / HSA COMPILED BY RH  
DATUM Geodetic DATE 2024.03.13 - 2024.03.13 CHECKED BY AO

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					PLASTIC LIMIT NATURAL MOISTURE CONTENT LIQUID LIMIT			UNIT WEIGHT  kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%)			
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa					WATER CONTENT (%)				GR	SA	SI	CL
								20	40	60	80	100	W <sub>p</sub>	W	W <sub>L</sub>					
160.7	Ground Surface																			
0.0	SILTY SAND, some to with gravel loose to dense brown FILL		1	SS	23															
			2	SS	16													16 58 26 (SI+CL)		
			3	SS	45															
			4	SS	8															
			5	SS	11													12 56 32 (SI+CL)		
156.9																				
3.8	SILTY CLAY (CI) to Sandy CLAYEY SILT (CL-ML) contains sand seams very stiff grey		6	SS	3															
			7	SS	5															
			8	SS	3													0 2 53 45		
	- unable to push vane																			
			9	SS	3															
	- becomes sandy		10	SS	1															

Continued Next Page

+<sup>3</sup>, ×<sup>3</sup>: Numbers refer to  
Sensitivity

20  
15  
10  
(%) STRAIN AT FAILURE

DOUBLE LINE 24726 CULVERT 1.1N.GPJ 2012TEMPLATE(MTO).GDT 12-17-24



## METRIC

[illegible]

+<sup>3</sup>, ×<sup>3</sup>: Numbers refer to Sensitivity

RECORD OF BOREHOLE No SC1-4

1 OF 2

METRIC

WP# 4068-09-00 LOCATION Lat: 45.520061°, Long: -76.683881°  
Culvert 1/1N; Horton Township; MTM z9: N 5 042 254.4 E 290 434.8 ORIGINATED BY RH  
HWY 17 BOREHOLE TYPE CME 55 Trackmount / HSA COMPILED BY RH  
DATUM Geodetic DATE 2024.02.13 - 2024.02.13 CHECKED BY AO

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT				PLASTIC LIMIT NATURAL MOISTURE CONTENT LIQUID LIMIT			UNIT WEIGHT  kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%)						
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa ○ UNCONFINED      + FIELD VANE ● QUICK TRIAXIAL    × LAB VANE				WATER CONTENT (%) w <sub>p</sub> w      w <sub>L</sub>				GR	SA	SI	CL			
157.6	Ground Surface							20	40	60	80	100										
0.0	Clayey SILTY SAND contains organics very loose grey FILL		1	GS	-									○								
156.8							157															
0.8	SILTY CLAY (CI) to Sandy CLAYEY SILT (CL-ML) contains sand seams very stiff grey		2	SS	2										○							
			3	SS	4		156								○							
			4	SS	4		155							1	4			0	3	47	50	
			5	SS	-		154								○							
			6	SS	4		153								○							
			7	PS	-		152								○							
	- becomes sandy																					
			8	SS	3		151								○							
			9	SS	4		150								○							
150.7																						
6.9	SILTY SAND (SM), trace clay compact grey		10	SS	22		149								○				0	56	35	9
150.0																			Non-plastic			
7.6	SILTY CLAY (CI) to Sandy CLAYEY SILT (CL-ML) contains sand seams very stiff grey		11	SS	11		148								1	1			0	18	59	23
			12	SS	4										○							
															○							

Continued Next Page

+<sup>3</sup>, ×<sup>3</sup>: Numbers refer to  
Sensitivity

20  
15  
10  
(%) STRAIN AT FAILURE



DOUBLE LINE 24726 CULVERT 1.1N.GPJ 2012TEMPLATE(MTO).GDT 12-17-24

RECORD OF BOREHOLE No SC1-4

2 OF 2

METRIC

WP# 4068-09-00 LOCATION Lat: 45.520061°, Long: -76.683881°  
Culvert 1/1N; Horton Township; MTM z9: N 5 042 254.4 E 290 434.8 ORIGINATED BY RH  
HWY 17 BOREHOLE TYPE CME 55 Trackmount / HSA COMPILED BY RH  
DATUM Geodetic DATE 2024.02.13 - 2024.02.13 CHECKED BY AO

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																																
								20	40	60	80						100																							
Continued From Previous Page																																								
144.8 12.8	<b>SILTY CLAY (CI)</b> to Sandy <b>CLAYEY SILT (CL-ML)</b> contains sand seams very stiff grey  - unable to push vane						147									0 3 57 40																								
			13	SS	6																																			
			14	SS	4																																			
	<b>End of Borehole</b>  <b>Monitoring Well installed:</b> Schedule 40 PVC standpipe with 50-mm diameter and 3.0-m slotted screen. Stick-up cover installed at ground surface.  <b>Water Level Readings:</b> <table><tr><th>DATE</th><th>DEPTH (m)</th><th>ELEV. (m)</th></tr><tr><td>2024/03/05</td><td>-0.1</td><td>157.7</td></tr><tr><td>2024/03/22</td><td>-0.2</td><td>157.8</td></tr><tr><td>2024/04/10</td><td>-0.2</td><td>157.8</td></tr><tr><td>2024/04/25</td><td>-0.1</td><td>157.7</td></tr><tr><td>2024/06/04</td><td>-0.2</td><td>157.8</td></tr><tr><td>2024/06/25</td><td>-0.3</td><td>157.9</td></tr><tr><td>2024/07/12</td><td>0.0</td><td>157.6</td></tr><tr><td>2024/08/30</td><td>0.3</td><td>157.3</td></tr></table>	DATE	DEPTH (m)	ELEV. (m)	2024/03/05	-0.1	157.7	2024/03/22	-0.2	157.8	2024/04/10	-0.2	157.8	2024/04/25	-0.1	157.7	2024/06/04	-0.2	157.8	2024/06/25	-0.3	157.9	2024/07/12	0.0	157.6	2024/08/30	0.3	157.3												
DATE	DEPTH (m)	ELEV. (m)																																						
2024/03/05	-0.1	157.7																																						
2024/03/22	-0.2	157.8																																						
2024/04/10	-0.2	157.8																																						
2024/04/25	-0.1	157.7																																						
2024/06/04	-0.2	157.8																																						
2024/06/25	-0.3	157.9																																						
2024/07/12	0.0	157.6																																						
2024/08/30	0.3	157.3																																						

# RECORD OF BOREHOLE No NS21-01

1 OF 1

METRIC

WP# 4068-09-00 LOCATION Lat: 45.519794°, Long: -76.684392°  
Culvert 15+850 Horton N 5 042 225.0 E 290 394.7 ORIGINATED BY NW  
HWY 17 BOREHOLE TYPE Diedrich 50 (D-50) Trackmount / HSA COMPILED BY AO  
DATUM Geodetic DATE 2021.11.10 - 2021.11.10 CHECKED BY JG

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 P	W	W L	WATER CONTENT (%)				
156.8	Ground Surface																
0.0	AMORPHOUS PEAT																
156.5	very soft, black		1	SS	1												
0.3	SILTY CLAY (CI), trace sand																
	very stiff																
	grey		2	SS	3												
			3	SS	3												
			4	SS	6												
153.0																	
3.8	CLAYEY SILT (CL) with sand		5	SS	6												
	very stiff																
	grey		6	SS	8												
150.4			7	SS	21												
6.4	SILTY SAND, trace clay																
150.1	grey																
6.7	compact																
	End of Borehole																
	Monitoring well consists of 50 mm diameter Schedule 40 PVC pipe with a 3.0 m slotted screen																
	Water Level Readings:																
	DATE    DEPTH (m)    ELEV. (m)																
	2021/12/15    0.1    156.7																
	2022/01/18    0.0 (Frozen) 156.8																
	2022/03/09    0.1    156.7																

DOUBLE LINE 24726 CULVERT 1.1N.GPJ 2012TEMPLATE(MTO).GDT 11-20-24

+<sup>3</sup>, ×<sup>3</sup>: Numbers refer to  
Sensitivity 20  
15 10 5 0 (%) STRAIN AT FAILURE

# RECORD OF BOREHOLE No NS21-02

1 OF 1

METRIC

WP# 4068-09-00 LOCATION Lat: 45.519729°, Long: -76.684498°  
Culvert 15+850 Horton N 5 042 217.7 E 290 386.4 ORIGINATED BY NW  
HWY 17 BOREHOLE TYPE Diedrich 50 (D-50) Trackmount / HSA COMPILED BY AO  
DATUM Geodetic DATE 2021.11.09 - 2021.11.09 CHECKED BY JG

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					PLASTIC LIMIT W <sub>P</sub>	NATURAL MOISTURE CONTENT W	LIQUID LIMIT W <sub>L</sub>	UNIT WEIGHT γ  kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%)  GR SA SI CL
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa									
156.6	Ground Surface							20	40	60	80	100					
0.0	AMORPHOUS PEAT							20	40	60	80	100					
156.3	very soft, black		1	SS	WH												
0.3	SILTY CLAY (CI) very stiff grey																
			2	SS	3												
			3	SS	6												
			4	SS	5												
			5	SS	6												
			6	SS	6												
			7	SS	8												
150.5																	
6.1	SILTY SAND (SM) grey compact		8	SS	11												
149.9																	
6.7	End of Borehole																
	Monitoring well consists of 50 mm diameter Schedule 40 PVC pipe with a 3.0 m slotted screen																
	Water Level Readings: DATE    DEPTH (m)    ELEV. (m) 2021/12/15    0.1    156.5 2022/01/18    0.0 (Frozen) 156.6 2022/03/09    0.2    156.4																

DOUBLE LINE 24726 CULVERT 1.1N.GPJ 2012TEMPLATE(MTO).GDT 11-20-24

+<sup>3</sup>, ×<sup>3</sup>: Numbers refer to  
Sensitivity 20  
15 10 5 0  
(%) STRAIN AT FAILURE



## **Appendix C.**

### **Laboratory Testing**



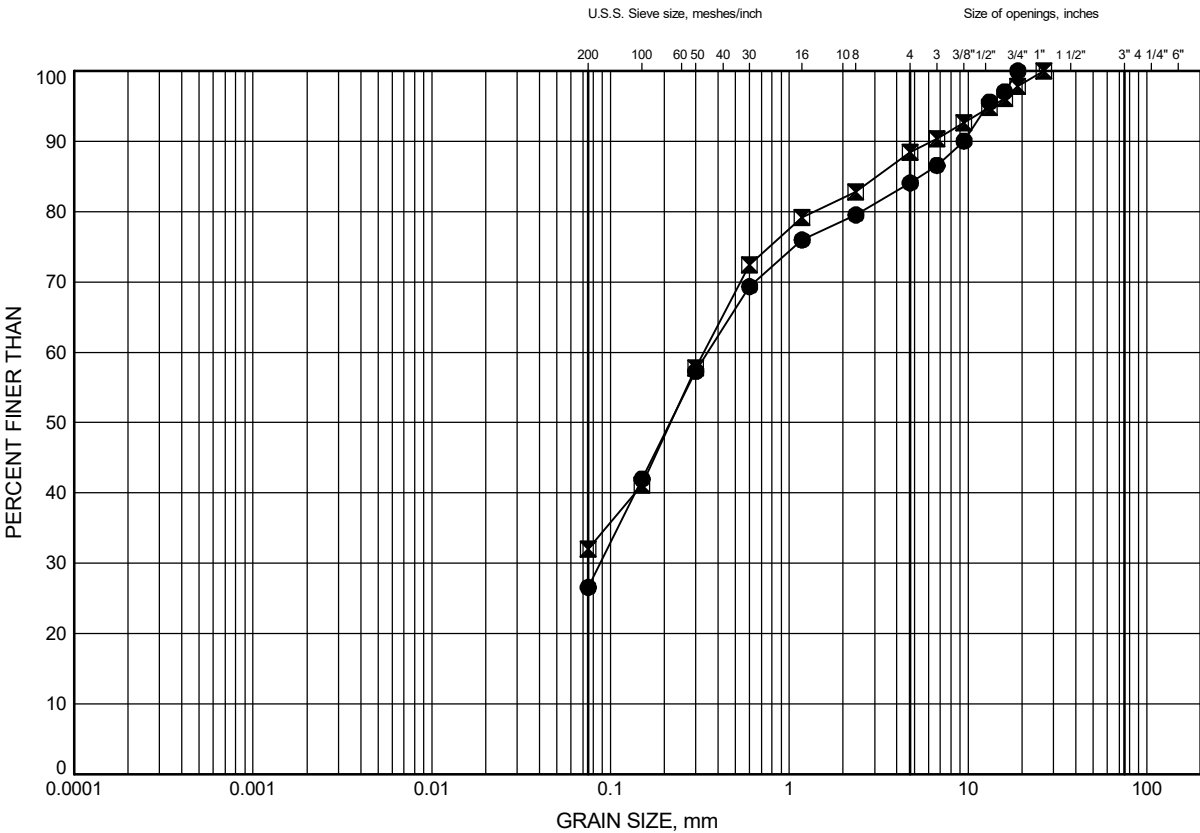
**Appendix C.1**  
**Particle Size Analysis Figures**  
**Atterberg Limit Test Results**

Highway 17 Twinning, Culvert 1/1N, Sta. 15+840

GRAIN SIZE DISTRIBUTION

FIGURE C1

FILL: Silty Sand



SILT and CLAY	FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE SIZE
FINE GRAINED	SAND			GRAVEL		

LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	SC1-3	1.1	159.6
⊠	SC1-3	3.4	157.3

GRAIN SIZE DISTRIBUTION - THURBER 24726 CULVERT 1.1N.GPJ 7-30-24

Date July 2024

WP# 4068-09-00



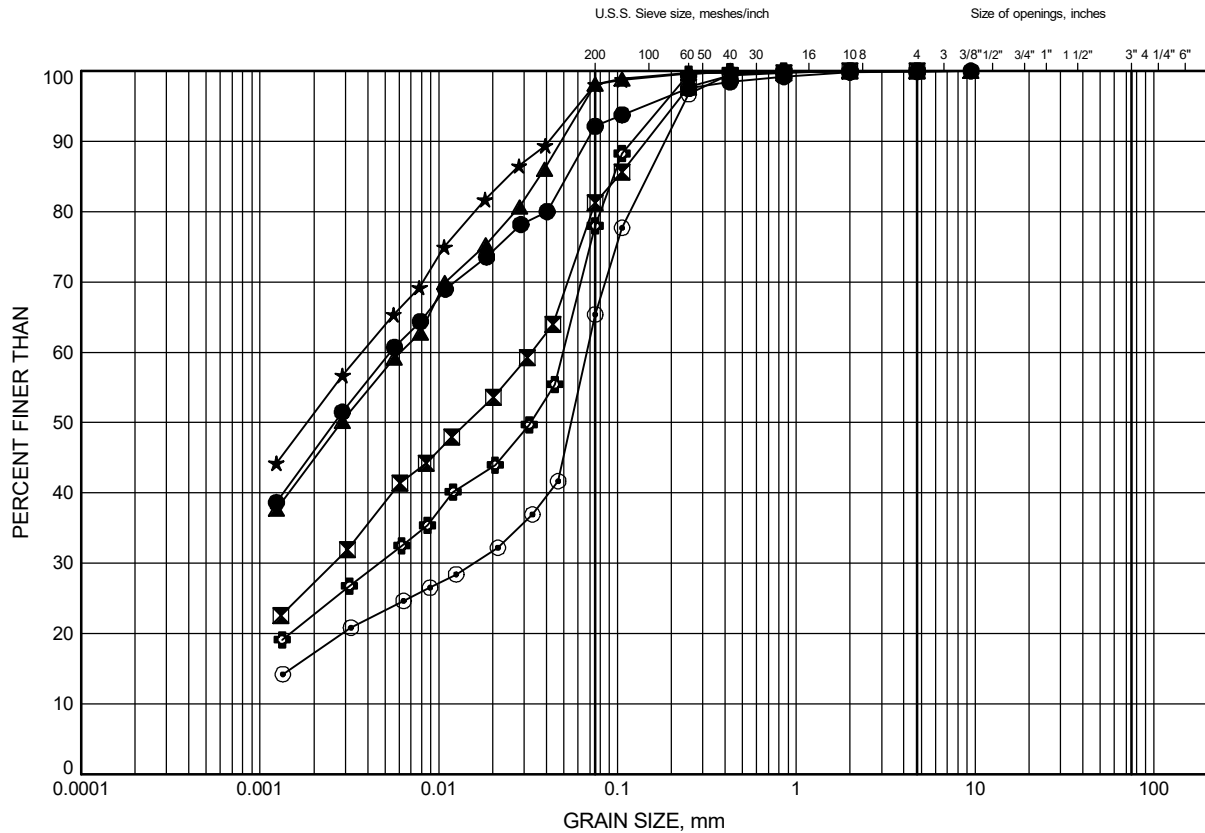
Prep'd RH

Chkd. AO



# GRAIN SIZE DISTRIBUTION

Silty Clay to Clayey Silt (CI to CL-ML)



SILT and CLAY	FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE SIZE
FINE GRAINED	SAND			GRAVEL		

## LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	NS21-01	1.8	155.0
⊠	NS21-01	4.9	151.9
▲	NS21-02	2.6	154.0
★	SC1-1	1.1	155.1
⊙	SC1-1	5.6	150.6
⊕	SC1-1	12.5	143.7

Date July 2024

WP# 4068-09-00

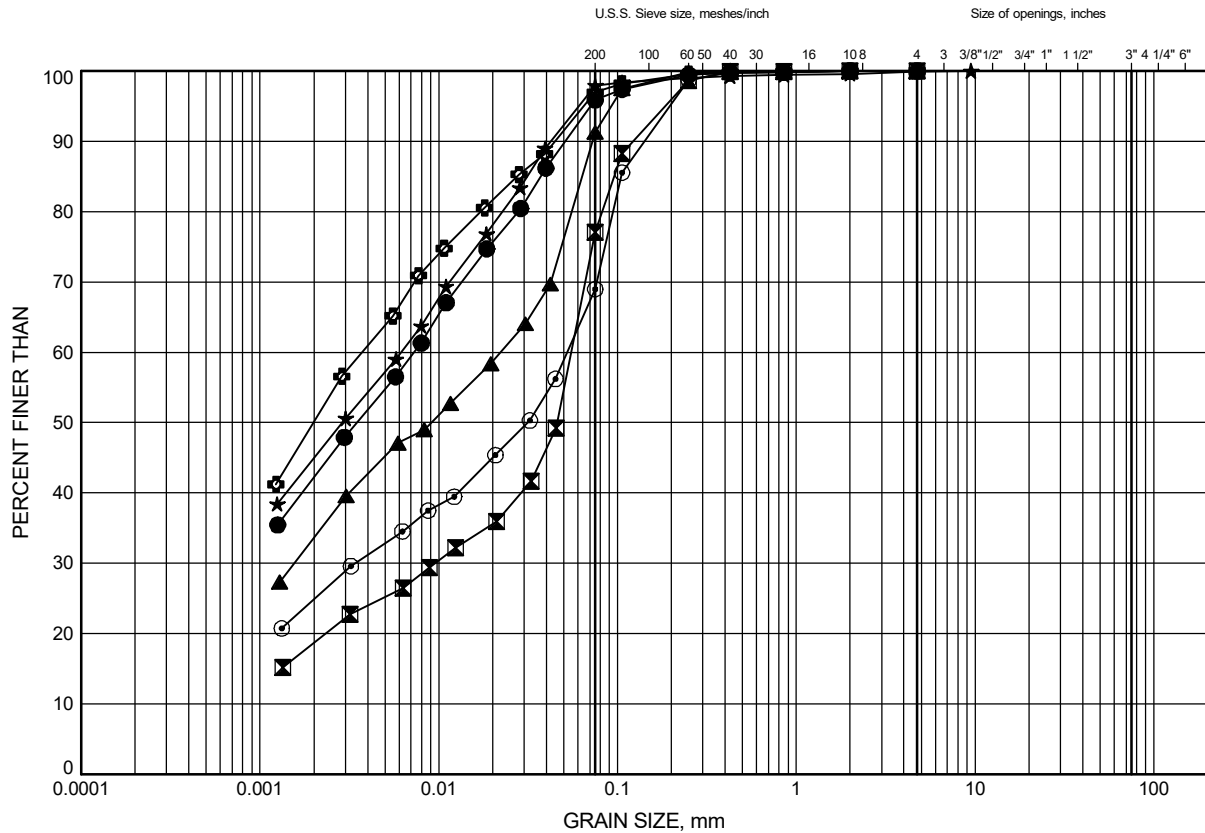


Prep'd RH

Chkd. AO

# GRAIN SIZE DISTRIBUTION

Silty Clay to Clayey Silt (CI to CL-ML)



SILT and CLAY	FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE SIZE
FINE GRAINED	SAND			GRAVEL		

## LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	SC1-2	2.6	154.3
⊠	SC1-2	9.4	147.5
▲	SC1-2	15.5	141.4
★	SC1-3	6.4	154.3
⊙	SC1-3	12.5	148.2
⊕	SC1-4	2.6	155.0

Date July 2024

WP# 4068-09-00



Prep'd RH

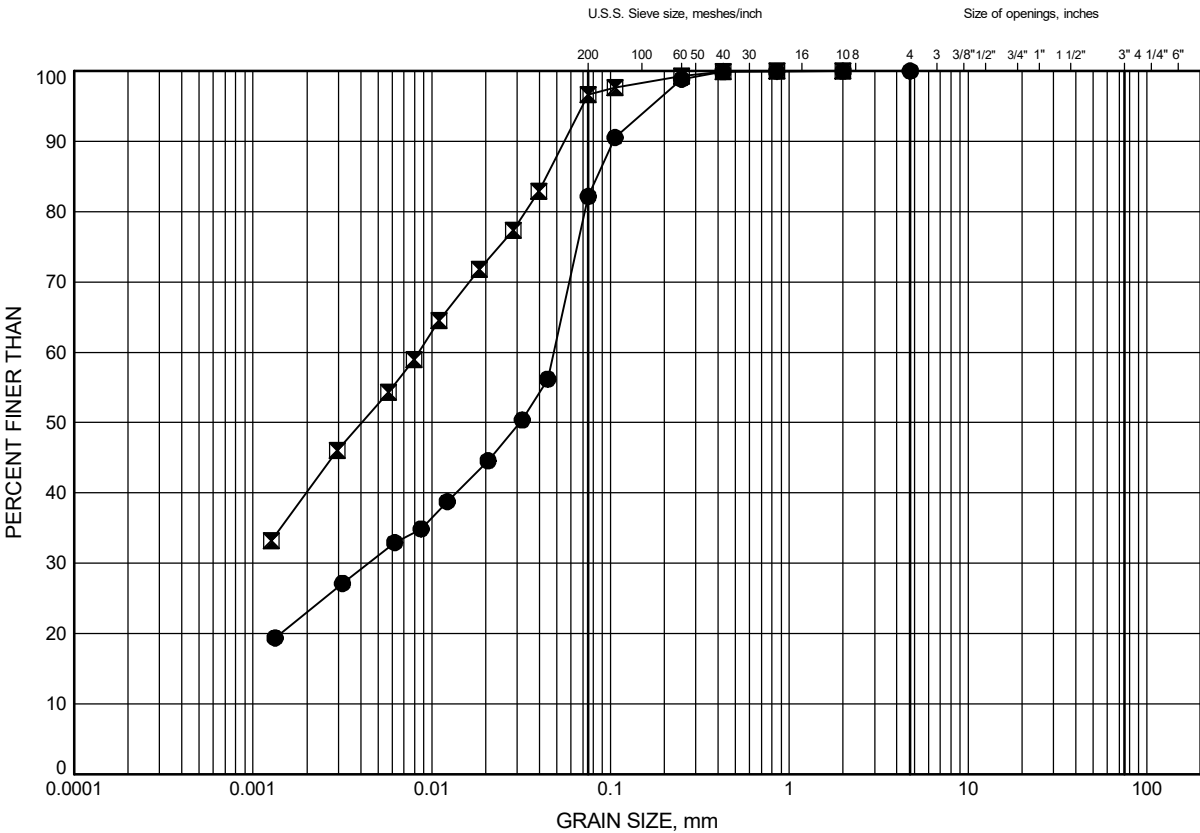
Chkd. AO

Highway 17 Twinning, Culvert 1/1N, Sta. 15+840

GRAIN SIZE DISTRIBUTION

FIGURE C4

Silty Clay to Clayey Silt (CI to CL-ML)



SILT and CLAY	FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE SIZE
FINE GRAINED	SAND			GRAVEL		

LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	SC1-4	7.9	149.7
⊠	SC1-4	11.0	146.6

GRAIN SIZE DISTRIBUTION - THURBER 24726 CULVERT 1.1N.GPJ 7-30-24

Date July 2024

WP# 4068-09-00



Prep'd RH

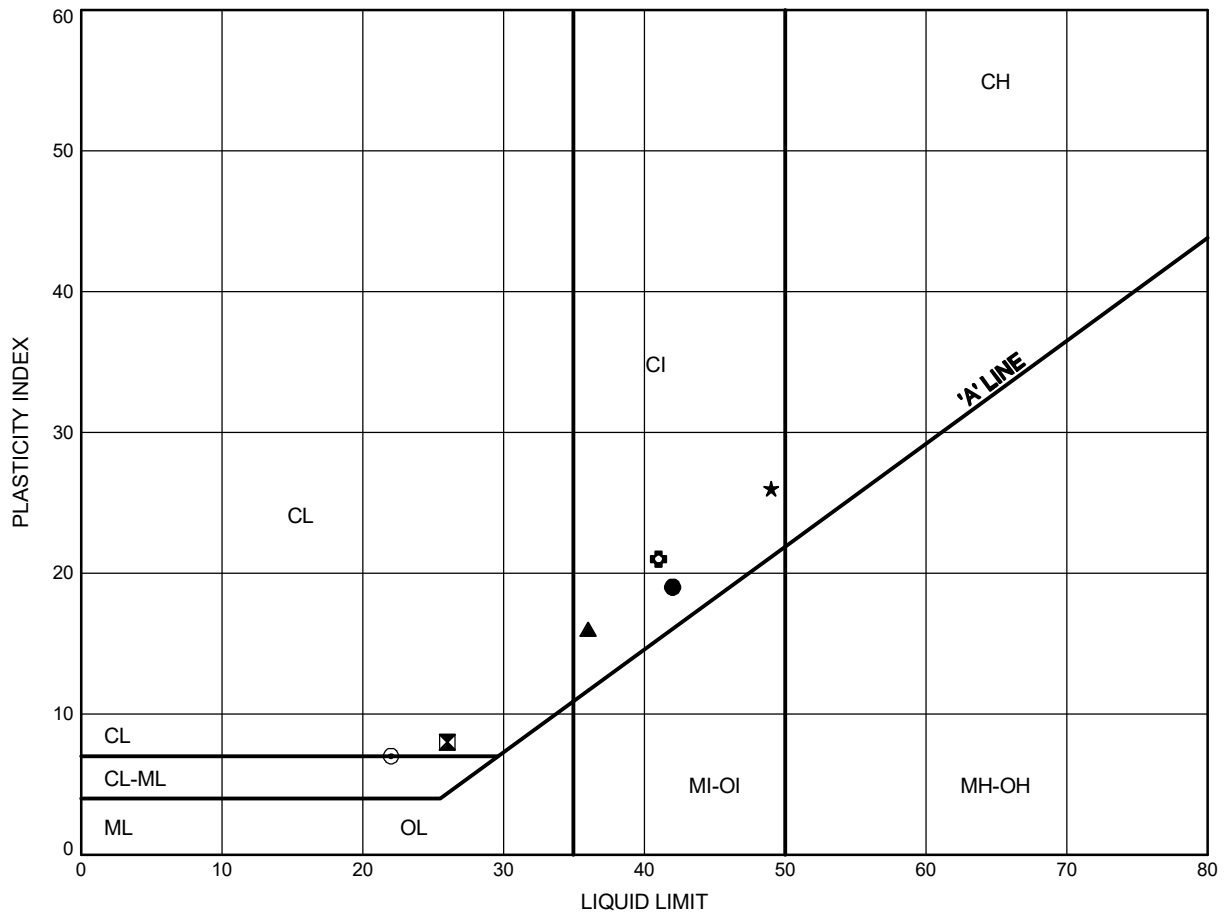
Chkd. AO

Highway 17 Twinning, Culvert 1/1N, Sta. 15+840

# ATTERBERG LIMITS TEST RESULTS

FIGURE C5

Silty Clay to Clayey Silt (CI to CL-ML)



## LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	NS21-01	1.8	155.0
⊠	NS21-01	4.9	151.9
▲	NS21-02	2.6	154.0
★	SC1-1	1.1	155.1
⊙	SC1-1	12.5	143.7
⊕	SC1-2	2.6	154.3

Date July 2024  
 WP# 4068-09-00



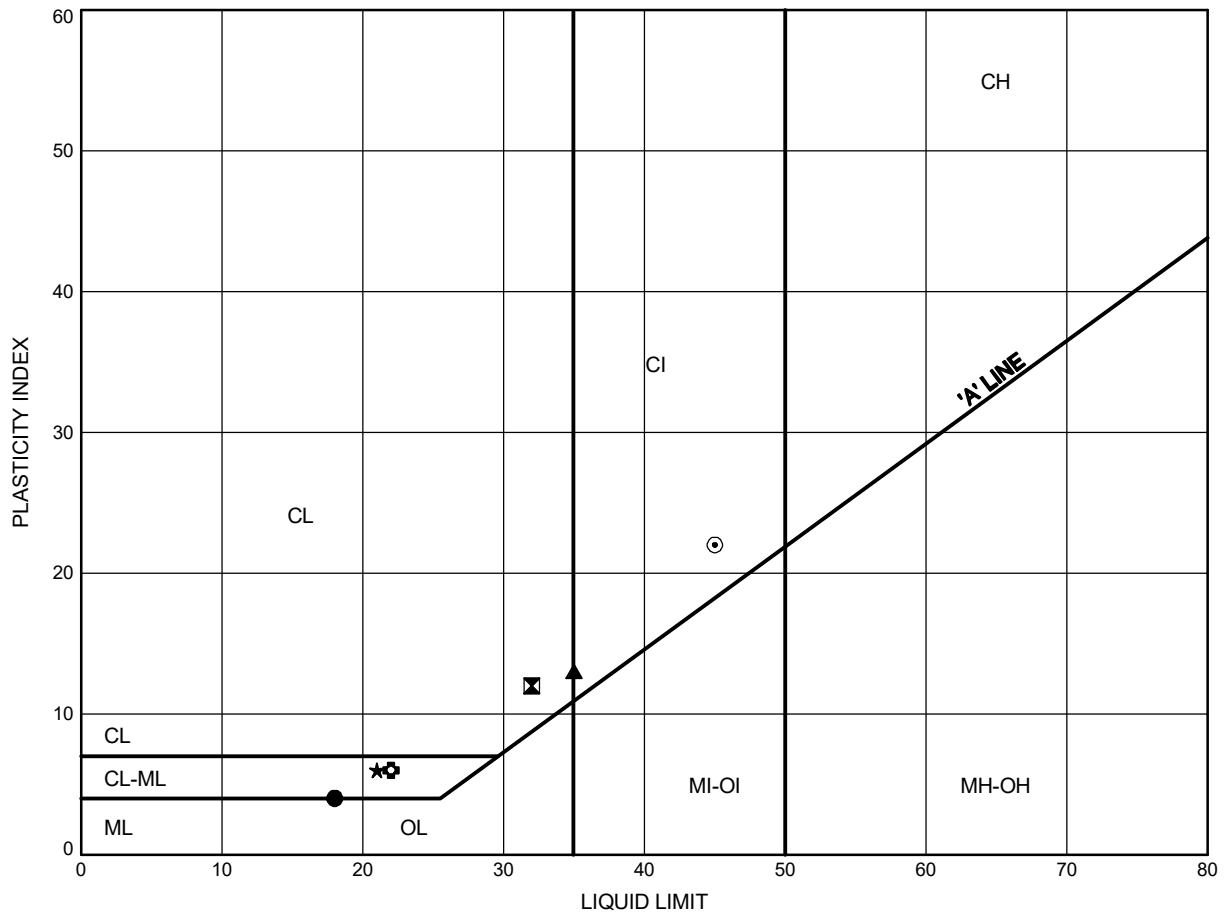
Prep'd RH  
 Chkd. AO

Highway 17 Twinning, Culvert 1/1N, Sta. 15+840

# ATTERBERG LIMITS TEST RESULTS

FIGURE C6

Silty Clay to Clayey Silt (CI to CL-ML)



## LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	SC1-2	9.4	147.5
⊠	SC1-2	15.5	141.4
▲	SC1-3	6.4	154.3
★	SC1-3	12.5	148.2
⊙	SC1-4	2.6	155.0
⊕	SC1-4	7.9	149.7

Date July 2024  
WP# 4068-09-00

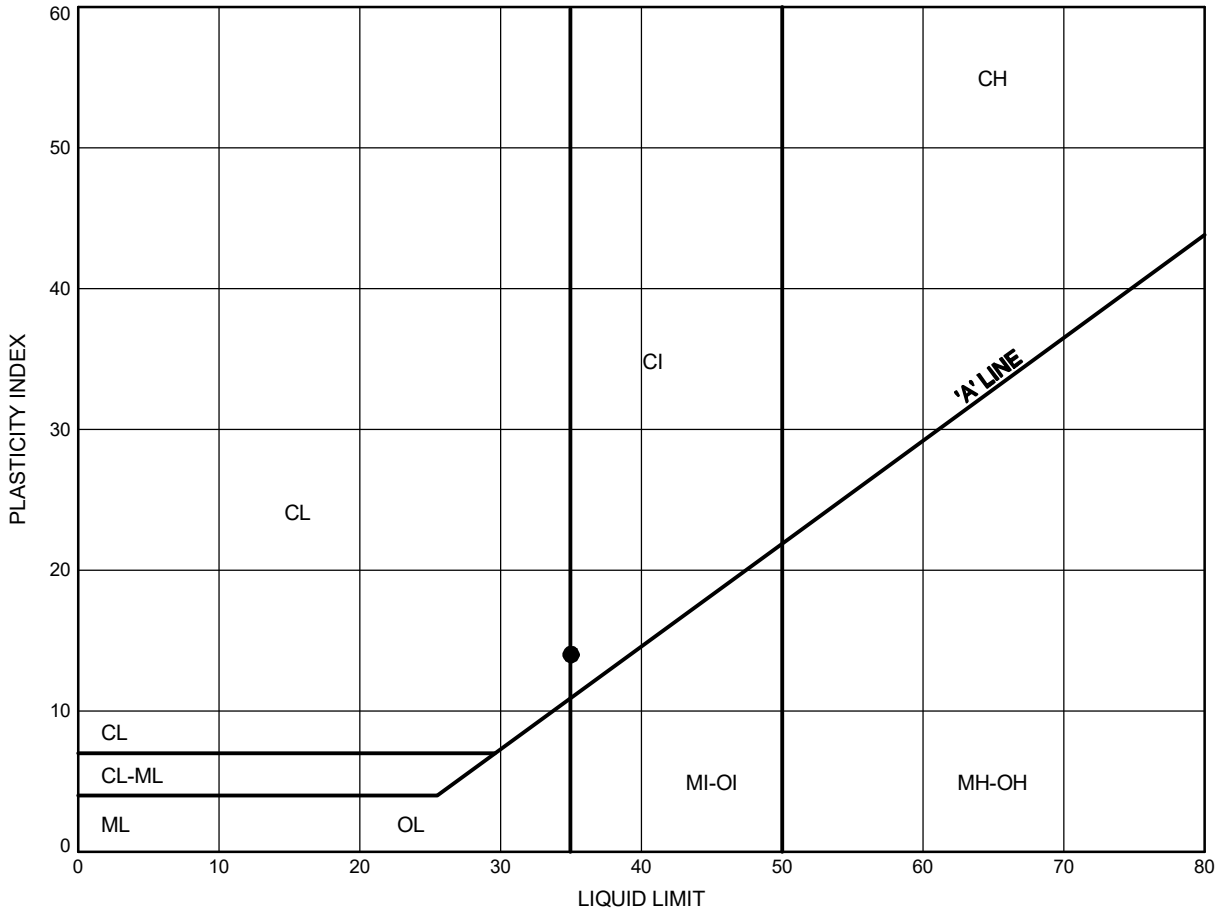


Prep'd RH  
Chkd. AO

Highway 17 Twinning, Culvert 1/1N, Sta. 15+840  
**ATTERBERG LIMITS TEST RESULTS**

FIGURE C7

Silty Clay to Clayey Silt (CI to CL-ML)



**LEGEND**

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	SC1-4	11.0	146.6

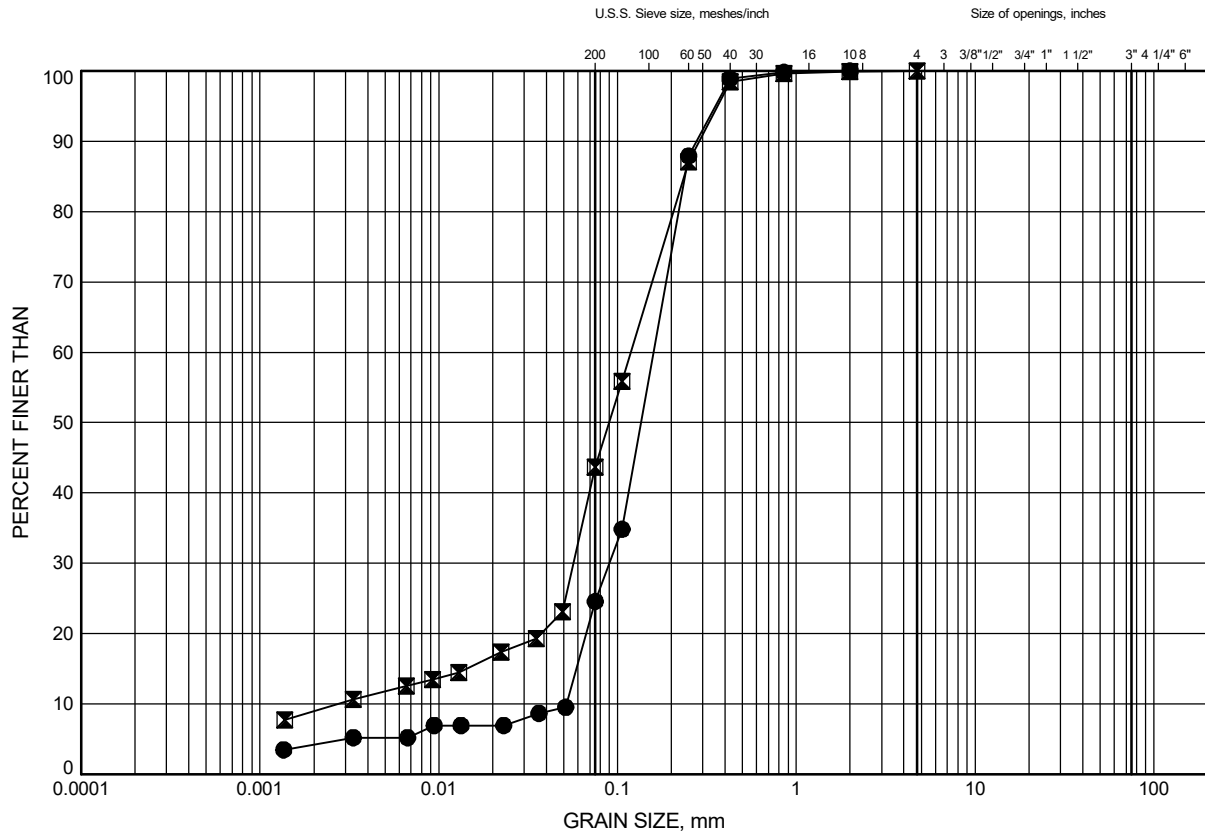
Date July 2024  
WP# 4068-09-00



Prep'd RH  
Chkd. AO

# GRAIN SIZE DISTRIBUTION

## Silty Sand (SM) Interbed



SILT and CLAY	FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE SIZE
FINE GRAINED	SAND			GRAVEL		

### LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	NS21-02	6.4	150.2
⊠	SC1-4	7.2	150.4

Date July 2024

WP# 4068-09-00



Prep'd RH

Chkd. AO



## **Appendix C.2**

### **Analytical Testing Results**



Certificate of Analysis

Report Date: 28-Feb-2024

Client: Thurber Engineering Ltd.

Order Date: 23-Feb-2024

Client PO: Culverts 1/1N and 4/4N

Project Description: 24726 Task 700.706a

<b>Client ID:</b>	SC1-1 SS#3 5'-7'	SC1-4 GS#1 0'-2'	1A GS#1 0'-2'	-	
<b>Sample Date:</b>	15-Feb-24 10:00	14-Feb-24 11:00	12-Feb-24 11:00	-	-
<b>Sample ID:</b>	2408372-01	2408372-02	2408372-03	-	
<b>Matrix:</b>	Soil	Soil	Soil	-	
<b>MDL/Units</b>					

**Physical Characteristics**

% Solids	0.1 % by Wt.	72.9	80.0	53.8	-	-	-
----------	--------------	------	------	------	---	---	---

**General Inorganics**

Conductivity	5 uS/cm	538	172	388	-	-	-
pH	0.05 pH Units	7.37	7.57	7.20	-	-	-
Resistivity	0.1 Ohm.m	18.6	58.1	25.8	-	-	-

**Anions**

Chloride	10 ug/g	188	16	115	-	-	-
Sulphate	10 ug/g	27	21	31	-	-	-

**SGS Canada Inc.**

P.O. Box 4300 - 185 Concession St.  
Lakefield - Ontario - K0L 2H0  
Phone: 705-652-2000 FAX: 705-652-6365

**Paracel Laboratories**

Attn : Dale Robertson

300-2319 St.Laurent Blvd.  
Ottawa, ON  
K1G 4K6, Canada

Phone: 613-731-9577  
Fax:613-731-9064

06-March-2024

**Date Rec. :** 27 February 2024

**LR Report:** CA15695-FEB24

**Reference:** Project#: 2408372

**Copy:** #1

## CERTIFICATE OF ANALYSIS

### Final Report

Analysis	1: Analysis Start Date	2: Analysis Start Time	3: Analysis Completed Date	4: Analysis Completed Time	5: RL	6: SC1-1 SS#3 5'-7'	7: SC1-4 GS#1 0'-2'	8: 1A GS#1 0'-2'
Sample Date & Time						15-Feb-24 10:00	14-Feb-24 11:00	12-Feb-24 11:00
Sulphide (Na <sub>2</sub> CO <sub>3</sub> ) [%]	06-Mar-24	06:37	06-Mar-24	09:27	0.02	< 0.01	0.04	0.02

RL - SGS Reporting Limit

### Method Descriptions

Parameter	Description	SGS Method Code	Reference Method Code
Sulphide (Na <sub>2</sub> CO <sub>3</sub> )	Sulphide by ECS	ME-CA-[ENV]ARD-LAK-AN-020	ASTM E1915-07A

**Patti Stark**  
Project Specialist,  
Environment, Health & Safety



## **Appendix D.**

### **Site Photographs**



**Photo 1. Looking northwest along culvert inlet (March 13, 2024)**



**Photo 2. Looking north along culvert inlet (March 05, 2024)**





**Photo 3. Looking southwest along westbound embankment (July 25, 2024)**



**Photo 4. Looking south along culvert outlet (July 25, 2024)**





**Photo 5. Looking southeast along eastbound embankment (July 25, 2024)**



**Photo 6. Looking northwest along Highway (July 25, 2024)**



## **Appendix E.**

### **GSC Seismic Hazard Calculation**

# 2015 National Building Code Seismic Hazard Calculation

INFORMATION: Eastern Canada English (613) 995-5548 français (613) 995-0600 Facsimile (613) 992-8836  
Western Canada English (250) 363-6500 Facsimile (250) 363-6565

Site: 45.520N 76.684W

User File Reference: CULVERT 1N - Highway 17 Sta. 15+840

2024-08-01 19:44 UT

Probability of exceedance per annum	0.000404	0.001	0.0021	0.01
Probability of exceedance in 50 years	2 %	5 %	10 %	40 %
Sa (0.05)	0.366	0.187	0.107	0.032
Sa (0.1)	0.432	0.232	0.139	0.045
Sa (0.2)	0.360	0.201	0.124	0.043
Sa (0.3)	0.273	0.156	0.099	0.035
Sa (0.5)	0.195	0.113	0.073	0.026
Sa (1.0)	0.099	0.059	0.038	0.013
Sa (2.0)	0.048	0.028	0.018	0.005
Sa (5.0)	0.013	0.007	0.004	0.001
Sa (10.0)	0.005	0.003	0.002	0.001
PGA (g)	0.232	0.127	0.077	0.025
PGV (m/s)	0.162	0.091	0.056	0.018

**Notes:** Spectral ( $S_a(T)$ , where  $T$  is the period in seconds) and peak ground acceleration (PGA) values are given in units of  $g$  ( $9.81 \text{ m/s}^2$ ). Peak ground velocity is given in  $\text{m/s}$ . Values are for "firm ground" (NBCC2015 Site Class C, average shear wave velocity  $450 \text{ m/s}$ ). NBCC2015 and CSAS6-14 values are highlighted in yellow. Three additional periods are provided - their use is discussed in the NBCC2015 Commentary. Only 2 significant figures are to be used. **These values have been interpolated from a 10-km-spaced grid of points. Depending on the gradient of the nearby points, values at this location calculated directly from the hazard program may vary. More than 95 percent of interpolated values are within 2 percent of the directly calculated values.**

## References

**National Building Code of Canada 2015 NRCC no. 56190;** Appendix C: Table C-3, Seismic Design Data for Selected Locations in Canada

**Structural Commentaries (User's Guide - NBC 2015: Part 4 of Division B)**  
**Commentary J:** Design for Seismic Effects

**Geological Survey of Canada Open File 7893** Fifth Generation Seismic Hazard Model for Canada: Grid values of mean hazard to be used with the 2015 National Building Code of Canada

See the websites [www.EarthquakesCanada.ca](http://www.EarthquakesCanada.ca) and [www.nationalcodes.ca](http://www.nationalcodes.ca) for more information



Natural Resources  
Canada

Ressources naturelles  
Canada

Canada





## **Appendix F.**

### **Foundation Comparison**



### COMPARISON OF ALTERNATIVE FOUNDATION TYPES

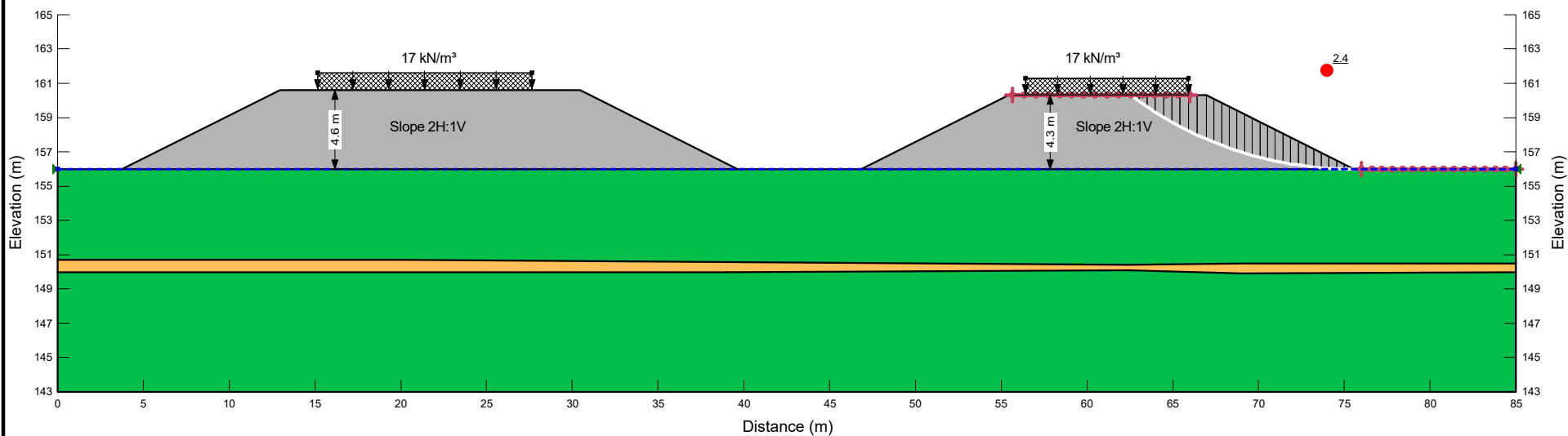
	Pipe Culverts	Open-Bottom Box Culverts	Closed-Bottom Box Culverts
<b>Advantages</b>	<p>Relatively expedient installation if precast units are used.</p> <p>Smaller magnitude of settlement than open footing culvert due to lower bearing stress on subgrade.</p>	<p>Readily encompasses natural substrate. Preferable from environmental perspective</p> <p>Possibility to maintain work zone to span the existing culvert; however, the replacement would need to be significantly wider than existing to allow for foundation excavation without conflict with existing pipe.</p>	<p>Relatively expedient installation if precast units are used.</p> <p>Smaller magnitude of settlement than open footing culvert due to lower bearing stress on subgrade.</p>
<b>Disadvantages</b>	<p>Requires a temporary by-pass to maintain waterflow</p> <p>Several parallel pipes may be required to provide hydraulic opening equivalent to box culvert</p> <p>Protection system may require bracing, anchors and/or rakers</p> <p>Difficult to include natural substrate.</p>	<p>May require protection system for construction of foundations.</p> <p>Deepest excavation increases quantities and dewatering concerns.</p> <p>Lower geotechnical resistances.</p> <p>Potential for post construction settlement.</p> <p>Less expedient installation as cast-in-place footings needed prior to placement of precast units</p>	<p>Requires a temporary by-pass to maintain waterflow</p> <p>Requires deeper concrete box with increased rise to include natural substrate.</p> <p>Protection system may require bracing, anchors and/or rakers</p>
<b>Risks/Consequences</b>	Some risk of basal instability during footing excavation due to depth of excavation below water table.	Increased risk of basal instability of footing excavation due to depth of excavation below water table.	Some risk of basal instability during footing excavation due to depth of excavation below water table.
<b>Relative Cost</b>	Low to Moderate	Moderate	Moderate
<b>Recommendation</b>	<b>Feasible</b>	<b>Not Recommended</b>	<b>Recommended</b>



## **Appendix G.**

### **Slope Stability Analysis Figures**

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Undrained Shear Strength (kPa)	Piezometric Surface	Effective Cohesion (kPa)	Effective Friction Angle (°)
■	a) Clayey Silt (Undrained)	Undrained (Phi=0)	17.5	100	1		
■	c) Silty Sand	Mohr-Coulomb	19		1	0	30
■	e) SSM	Mohr-Coulomb	21		1	0	32

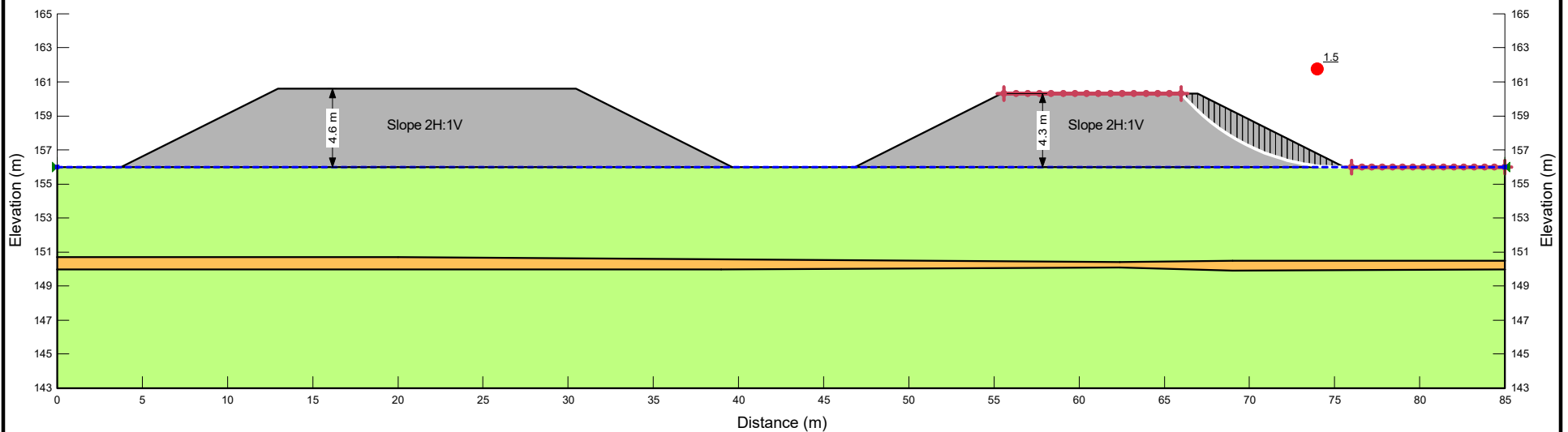


Project 24726 - Hwy 17, Sta 15+840, Culvert 1/1N		
Analysis a1) Temporary (traffic), short term, static, undrained		
Seismic Coefficient H: g, V: g	Last Run 2024-11-22, 08:50:40 AM	Scale 1:360

Additional Details  
 Name: a) 2.0H:1V SSM embankment  
 Comments:  
 Method: Morgenstern-Price, Half-Sine  
 Minimum Slip Surface Depth: 1.5 m  
 Entry: (62.554407, 160.3) m, Exit: (76, 156) m  
 Center: (75.498554, 177.60343) m, Radius: 21.609246 m

**Figure G1-1**

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Piezometric Surface
<span style="color: green;">■</span>	b) Clayey Silt (Drained)	Mohr-Coulomb	17.5	5	27	1
<span style="color: orange;">■</span>	c) Silty Sand	Mohr-Coulomb	19	0	30	1
<span style="color: gray;">■</span>	e) SSM	Mohr-Coulomb	21	0	32	1

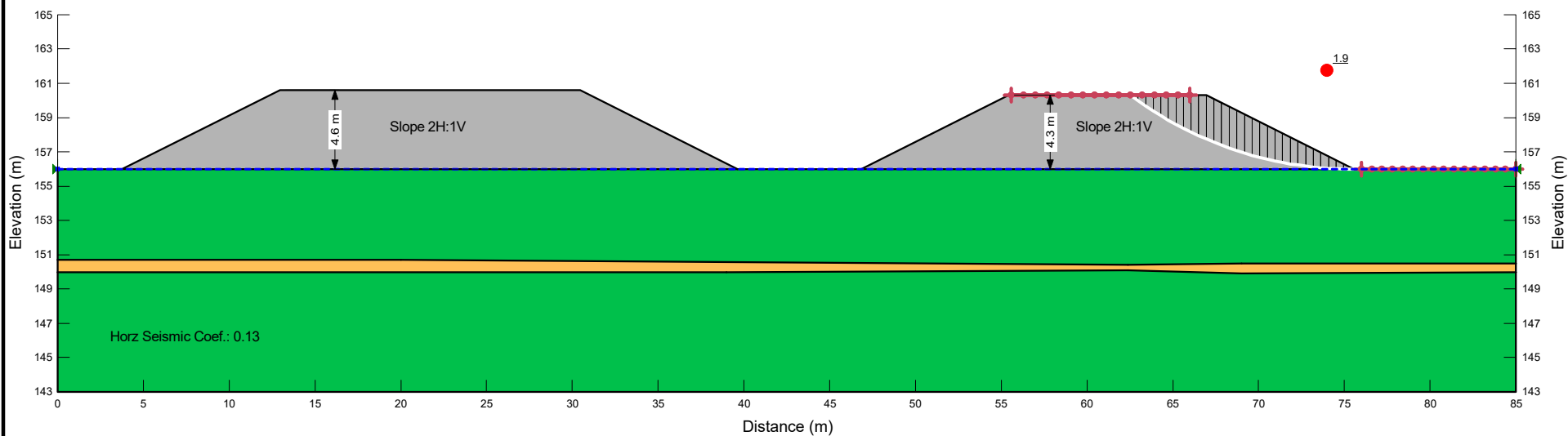


Project 24726 - Hwy 17, Sta 15+840, Culvert 1/1N		
Analysis a2) Permanent, long term, static, drained		
Seismic Coefficient H: g, V: g	Last Run 2024-11-21, 01:41:56 PM	Scale 1:360

Additional Details  
 Name: a) 2.0H:1V SSM embankment  
 Comments:  
 Method: Morgenstern-Price, Half-Sine  
 Minimum Slip Surface Depth: 1.5 m  
 Entry: (66, 160.3) m, Exit: (76, 156) m  
 Center: (75.416288, 168.42044) m, Radius: 12.434145 m

**Figure G1-2**

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Undrained Shear Strength (kPa)	Piezometric Surface	Effective Cohesion (kPa)	Effective Friction Angle (°)
<span style="color: green;">■</span>	a) Clayey Silt (Undrained)	Undrained (Phi=0)	17.5	100	1		
<span style="color: orange;">■</span>	c) Silty Sand	Mohr-Coulomb	19		1	0	30
<span style="color: gray;">■</span>	e) SSM	Mohr-Coulomb	21		1	0	32

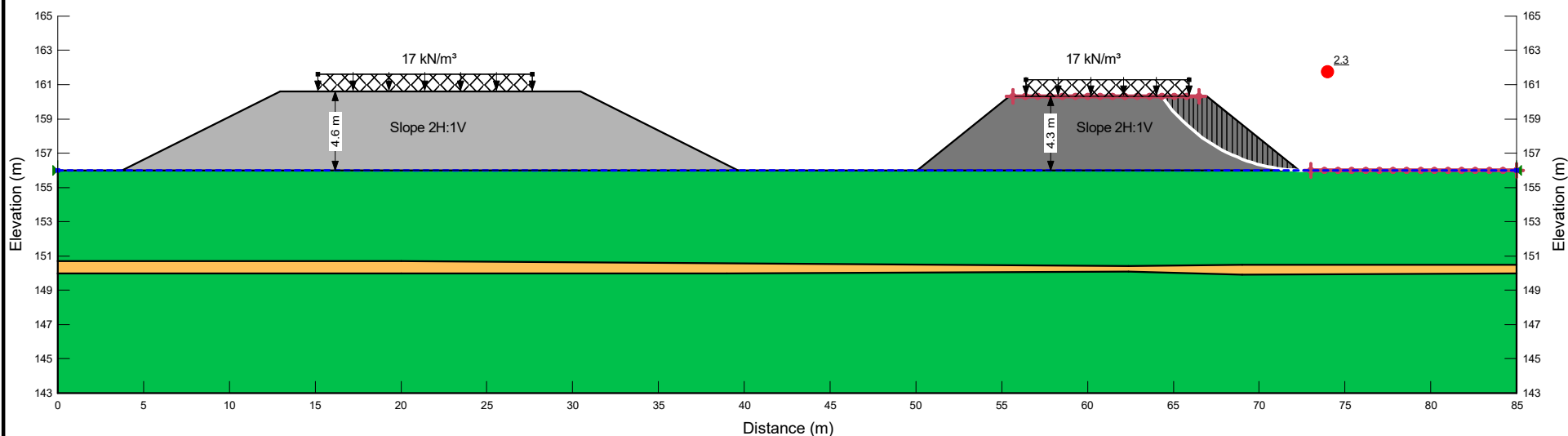


Project 24726 - Hwy 17, Sta 15+840, Culvert 1/1N		
Analysis a3) Temporary (seismic), pseudo-static, undrained		
Seismic Coefficient H: 0.13g, V: g	Last Run 2024-11-21, 01:48:41 PM	Scale 1:360

Additional Details  
 Name: a) 2.0H:1V SSM embankment  
 Comments:  
 Method: Morgenstern-Price, Half-Sine  
 Minimum Slip Surface Depth: 1.5 m  
 Entry: (62.533333, 160.3) m, Exit: (76, 156) m  
 Center: (75.484879, 177.62409) m, Radius: 21.630227 m

**Figure G1-3**

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Undrained Shear Strength (kPa)	Piezometric Surface	Effective Cohesion (kPa)	Effective Friction Angle (°)
<span style="color: green;">■</span>	a) Clayey Silt (Undrained)	Undrained (Phi=0)	17.5	100	1		
<span style="color: orange;">■</span>	c) Silty Sand	Mohr-Coulomb	19		1	0	30
<span style="color: gray;">■</span>	e) SSM	Mohr-Coulomb	21		1	0	32
<span style="color: darkgray;">■</span>	f) Rockfill	Mohr-Coulomb	20		1	0	42

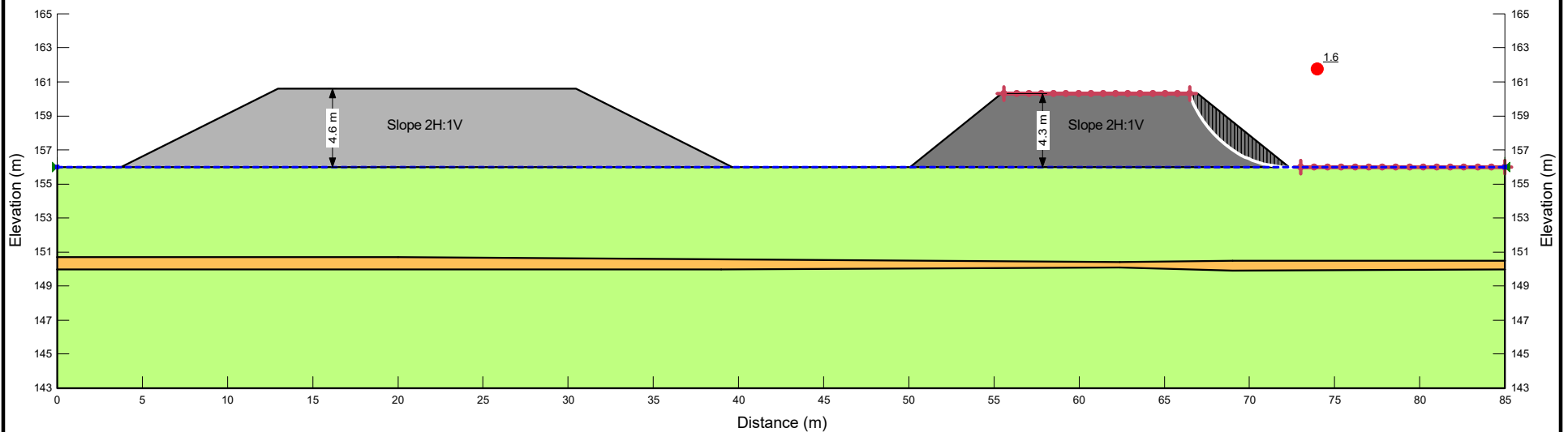


Project 24726 - Hwy 17, Sta 15+840, Culvert 1/1N		
Analysis b1) Temporary (traffic), short term, static, undrained		
Seismic Coefficient H: g, V: g	Last Run 2024-11-22, 08:50:41 AM	Scale 1:360

Additional Details  
 Name: b) 1.25H:1V Rockfill Embankment  
 Comments:  
 Method: Morgenstern-Price, Half-Sine  
 Minimum Slip Surface Depth: 1.5 m  
 Entry: (64.332644, 160.3) m, Exit: (73, 156) m  
 Center: (72.620651, 166.1206) m, Radius: 10.127706 m

**Figure G2-1**

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Piezometric Surface
<span style="color: green;">■</span>	b) Clayey Silt (Drained)	Mohr-Coulomb	17.5	5	27	1
<span style="color: orange;">■</span>	c) Silty Sand	Mohr-Coulomb	19	0	30	1
<span style="color: gray;">■</span>	e) SSM	Mohr-Coulomb	21	0	32	1
<span style="color: darkgray;">■</span>	f) Rockfill	Mohr-Coulomb	20	0	42	1



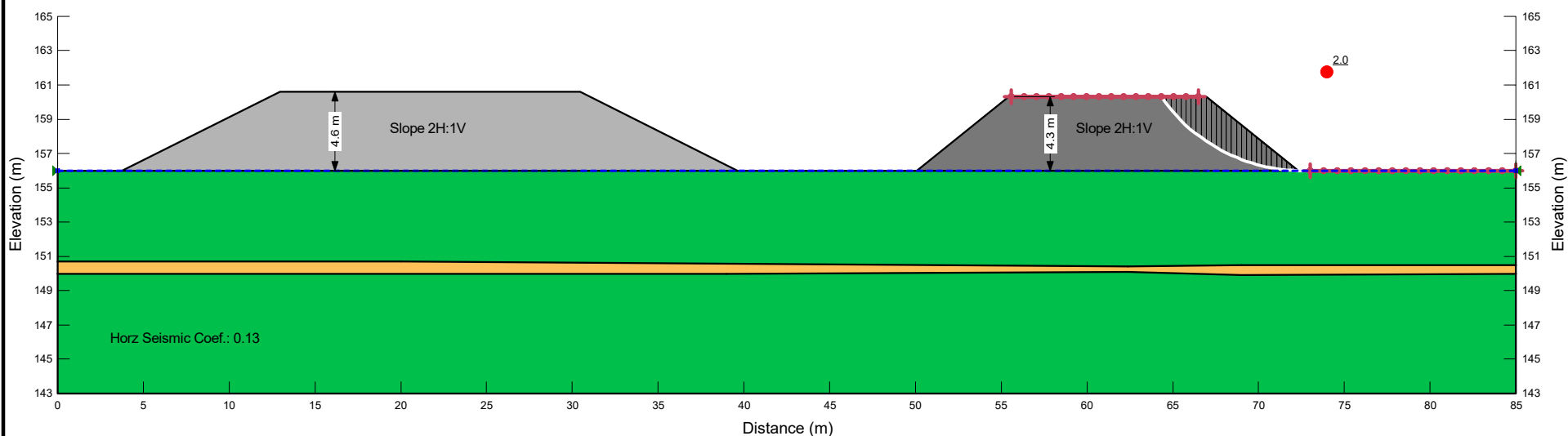
Project 24726 - Hwy 17, Sta 15+840, Culvert 1/1N		
Analysis b2) Permanent, long term, static, drained		
Seismic Coefficient H: g, V: g	Last Run 2024-11-21, 01:54:18 PM	Scale 1:360

Additional Details  
 Name: b) 1.25H:1V Rockfill Embankment  
 Comments:  
 Method: Morgenstern-Price, Half-Sine  
 Minimum Slip Surface Depth: 1.5 m  
 Entry: (66.5, 160.3) m, Exit: (73, 156) m  
 Center: (72.451506, 162.23367) m, Radius: 6.2577559 m

**Figure G2-2**



Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Undrained Shear Strength (kPa)	Piezometric Surface	Effective Cohesion (kPa)	Effective Friction Angle (°)
<span style="color: green;">■</span>	a) Clayey Silt (Undrained)	Undrained (Phi=0)	17.5	100	1		
<span style="color: orange;">■</span>	c) Silty Sand	Mohr-Coulomb	19		1	0	30
<span style="color: gray;">■</span>	e) SSM	Mohr-Coulomb	21		1	0	32
<span style="color: darkgray;">■</span>	f) Rockfill	Mohr-Coulomb	20		1	0	42

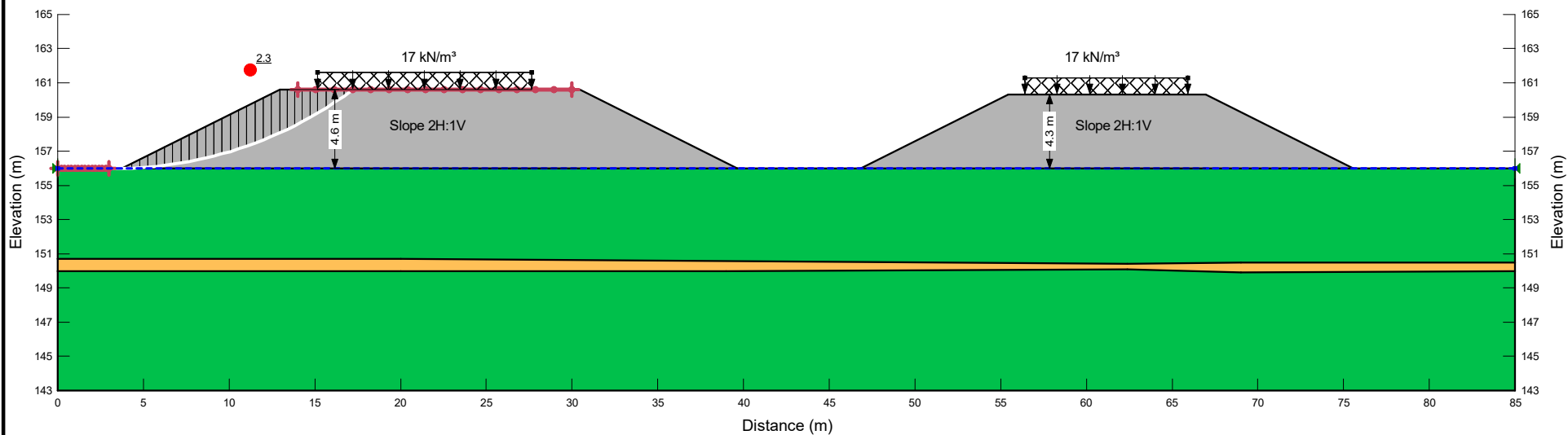


Project 24726 - Hwy 17, Sta 15+840, Culvert 1/1N		
Analysis b3) Temporary (seismic), pseudo-static, undrained		
Seismic Coefficient H: 0.13g, V: g	Last Run 2024-11-21, 01:54:19 PM	Scale 1:360

Additional Details  
 Name: b) 1.25H:1V Rockfill Embankment  
 Comments:  
 Method: Morgenstern-Price, Half-Sine  
 Minimum Slip Surface Depth: 1.5 m  
 Entry: (64.32, 160.3) m, Exit: (73, 156) m  
 Center: (72.611415, 166.12635) m, Radius: 10.133798 m

**Figure G2-3**

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Undrained Shear Strength (kPa)	Piezometric Surface	Effective Cohesion (kPa)	Effective Friction Angle (°)
<span style="color: green;">■</span>	a) Clayey Silt (Undrained)	Undrained (Phi=0)	17.5	100	1		
<span style="color: orange;">■</span>	c) Silty Sand	Mohr-Coulomb	19		1	0	30
<span style="color: gray;">■</span>	e) SSM	Mohr-Coulomb	21		1	0	32

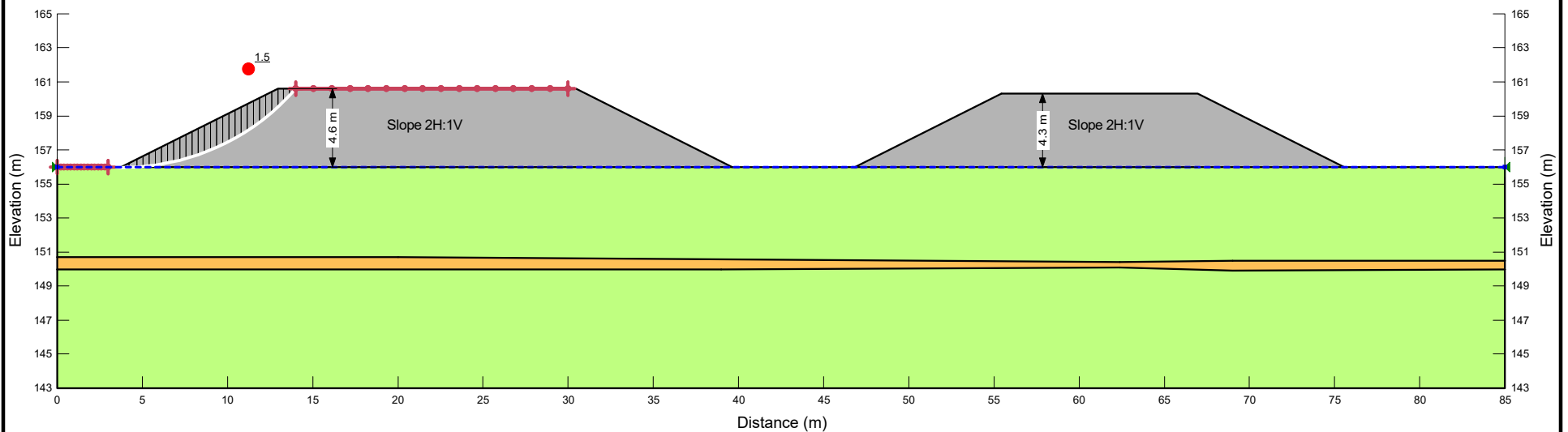


Project 24726 - Hwy 17, Sta 15+840, Culvert 1/1N		
Analysis c1) Temporary (traffic), short term, static, undrained		
Seismic Coefficient H: g, V: g	Last Run 2024-11-22, 08:50:46 AM	Scale 1:360

Additional Details  
 Name: c) 2.0H:1V SSM embankment  
 Comments:  
 Method: Morgenstern-Price, Half-Sine  
 Minimum Slip Surface Depth: 1.5 m  
 Entry: (3, 156) m, Exit: (17.2, 160.6) m  
 Center: (3.4168256, 178.93067) m, Radius: 22.934457 m

**Figure G3-1**

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Piezometric Surface
<span style="color: green;">■</span>	b) Clayey Silt (Drained)	Mohr-Coulomb	17.5	5	27	1
<span style="color: orange;">■</span>	c) Silty Sand	Mohr-Coulomb	19	0	30	1
<span style="color: gray;">■</span>	e) SSM	Mohr-Coulomb	21	0	32	1

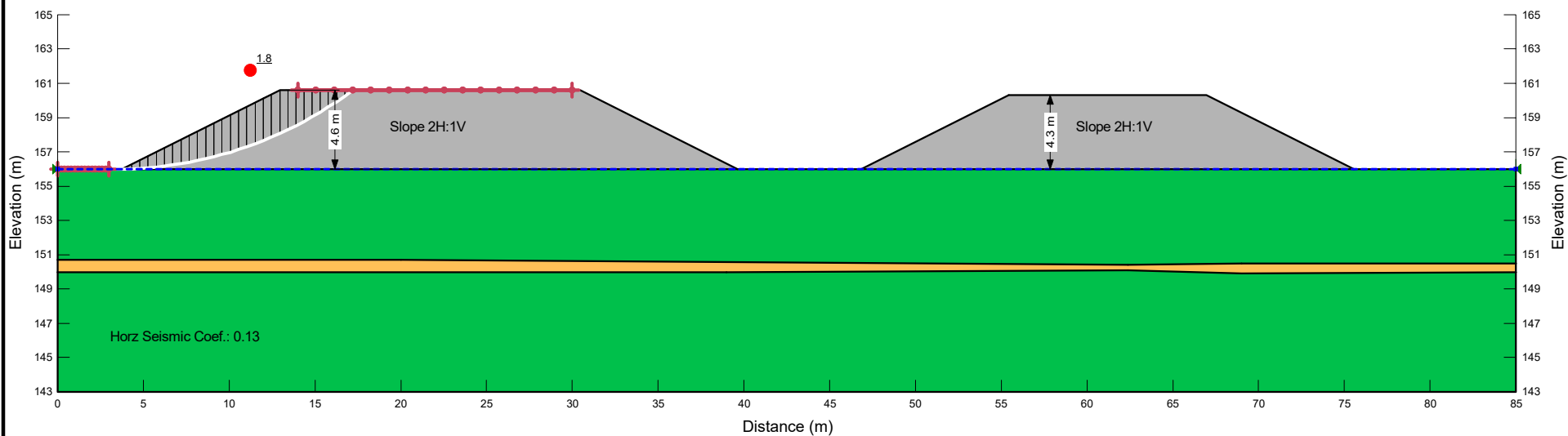


Project 24726 - Hwy 17, Sta 15+840, Culvert 1/1N		
Analysis c2) Permanent, long term, static, drained		
Seismic Coefficient H: g, V: g	Last Run 2024-11-21, 01:54:22 PM	Scale 1:360

Additional Details  
 Name: c) 2.0H:1V SSM embankment  
 Comments:  
 Method: Morgenstern-Price, Half-Sine  
 Minimum Slip Surface Depth: 1.5 m  
 Entry: (3, 156) m, Exit: (14, 160.6) m  
 Center: (3.8324909, 169.46143) m, Radius: 13.487152 m

**Figure G3-2**

Color	Name	Slope Stability Material Model	Unit Weight (kN/m³)	Undrained Shear Strength (kPa)	Piezometric Surface	Effective Cohesion (kPa)	Effective Friction Angle (°)
<span style="color: green;">■</span>	a) Clayey Silt (Undrained)	Undrained (Phi=0)	17.5	100	1		
<span style="color: orange;">■</span>	c) Silty Sand	Mohr-Coulomb	19		1	0	30
<span style="color: gray;">■</span>	e) SSM	Mohr-Coulomb	21		1	0	32



Project 24726 - Hwy 17, Sta 15+840, Culvert 1/1N		
Analysis c3) Temporary (seismic), pseudo-static, undrained		
Seismic Coefficient H: 0.13g, V: g	Last Run 2024-11-21, 01:54:23 PM	Scale 1:360

Additional Details  
 Name: c) 2.0H:1V SSM embankment  
 Comments:  
 Method: Morgenstern-Price, Half-Sine  
 Minimum Slip Surface Depth: 1.5 m  
 Entry: (3, 156) m, Exit: (17.2, 160.6) m  
 Center: (3.4168256, 178.93067) m, Radius: 22.934457 m

**Figure G3-3**



## **Appendix H.**

### **List of Referenced Specifications Non-Standard Special Provisions**



1. The following Special Provisions and OPSS Documents are referenced in this report:

OPSS.PROV 180	Management of Excess Materials
OPSS.PROV 206	Construction Specification for Grading
OPSS.PROV 401	Trenching, Backfilling, and Compacting
OPSS.PROV 421	Pipe Culvert Installation in Open Cut
OPSS.PROV 422	Precast Reinforced Concrete Box Culverts and Box Sewers in Open Cut
OPSS.PROV 501	Construction Specification for Compacting
OPSS.PROV 511	Construction Specification for Rip-Rap, Rock Protection, and Granular Sheetting
OPSS.PROV 517	Construction Specification for Dewatering
OPSS.PROV 539	Construction Specification for Temporary Protection Systems
OPSS.PROV 803	Vegetative Cover
OPSS.PROV 804	Construction Specification for Seed and Cover
OPSS.PROV 805	Construction Specification for Temporary Erosion and Sediment Control Measures
OPSS.PROV 902	Construction Specification for Excavating and Backfilling Structures
OPSS.PROV 1010	Material Specification for Aggregates Base, Subbase, Select Subgrade, and Backfill Material
OPSS.PROV 1860	Material Specification for Geotextiles
OPSD 202.010	Slope Flattening Using Surplus Excavated Material On Earth or Rock Embankment
OPSD 202.020	Drainage Gap for Slope Flattening on Rock or Granular Embankment
OPSD 208.010	Benching of Earth Slopes
OPSD 219.110	Light-Duty Silt Fence Barrier
OPSD 802.031	Rigid Pipe Bedding, Cover and Backfill, Type 3 Soil, Earth Excavation
OPSD 803.010	Backfill and Cover for Concrete Culverts with Spans Less than or Equal to 3.0M
OPSD 803.031	Frost Treatment - Pipe Culverts, Frost Penetration Line Between Top of Pipe and Bedding Grade
OPSD 810.010	General Rip-Rap Layout for Sewer and Culvert Outlets
OPSD 3090.101	Foundation Frost Depths for Southern Ontario
OPSD 3101.150	Walls Abutment, Backfill Minimum Granular Requirement
SP 105S09	Amendment to OPSS.PROV 539 - Construction Specification for Temporary Protection Systems



SP 110S06	Amendment to OPSS.PROV 1010 - Material Specification for Aggregates Base, Subbase, Select Subgrade, and Backfill Material
SP 517F01	Amendment to OPSS 517 - Construction Specification for Dewatering

2. Suggested wording for NSSPs

**“Protection of Sensitive Foundation Soils”**

The Contractor is advised that the native silty and clayey soils that will be exposed at the subgrade are moisture sensitive and may become disturbed or otherwise negatively impacted when subjected to construction or personnel traffic, freeze-thaw actions, ingress or ponding water. The Contractor shall be responsible for selecting appropriate granular compaction equipment, implementing adequate groundwater control measures and to minimize construction and personnel traffic on the founding subgrade.

**“Structural Backfill”**

Structural backfill for the culvert and retaining walls shall consist of OPSS Granular B Type II or Quarry Sourced OPSS Granular A material.

**“Notice to Contractor: Obstructions”**

Buried obstructions may be encountered during construction and interfere with excavations and installation of temporary protection/dewatering systems. Cobbles and boulders may be encountered within the fill layer. The Contractor must be prepared to dislodge or penetrate obstructions. Where obstructions are encountered near the surface, the Contractor may choose to remove such obstructions, provided it does not destabilize the existing embankment or temporary works.