THURBER ENGINEERING LTD.

FINAL

FOUNDATION INVESTIGATION AND DESIGN REPORT
CULVERT REPLACEMENT AT STATION 17+230
HIGHWAY 17 – 0.1 KM EAST OF GOULAIS RIVER
VANKOUGHNET TOWNSHIP
G.W.P. 5181-13-00

5016-E-0040

Geocres No.: 41K-106

Report to:

Ministry of Transportation Ontario

Latitude: 46.729310°
Longitude: -84.348530°

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104, 2460 Lancaster Road, Ottawa ON K1B 4S5 T. 613 247 2121 F. 613 247 2185
thurber.ca

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PART 1. FACTUAL INFORMATION

1 INTRODUCTION

This section of the report presents the factual findings obtained from a foundation investigation completed at the Highway 17 culvert for an unnamed creek located approximately 0.1 km east of the Goulais River within the Township of Vankoughnet (Sta. 17+230). Thurber Engineering Limited (Thurber) carried out the current investigation under Agreement No. 5016-E-0040.

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. A model of the subsurface conditions influencing design and construction was developed in the course of the current investigation. No previous foundation investigation reports were available for the subject culvert site within the Geocres library.

2 SITE DESCRIPTION

The existing culvert is a corrugated steel pipe (CSP) culvert reported to have a diameter of 1,200 mm, a length of 39 m and invert elevations of 191.6 m upstream and 190.8 m downstream. The culvert has a generally east to west alignment with flow through the culvert to the west.

At the location of the culvert, Highway 17 is a two-lane highway with gravel shoulders. The Highway 17 fill height above the culvert is approximately 5.0 m with the centreline of the road surface at approximate elevation 197.6 m. The existing embankment slopes are inclined between approximately 1.5H:1V and 2H:1V. Steel cable guide rails are present on the east side of the embankment in the vicinity of the culvert. The land adjacent to the highway consists of occasional side roads with residential properties and is mainly vegetated with trees and shrubs. Traffic volumes on this section of Highway 17 are understood to be 3,700 AADT (2016).

Select photographs showing the existing conditions in the area of the culvert are included in Appendix D for reference.

3 SITE INVESTIGATION AND FIELD TESTING

Thurber contacted Ontario One Call in advance of the field investigation to obtain utility locate clearances in the vicinity of the intended boreholes. It is noted that fibreoptic lines are buried near the toe of slope on both sides of the highway.

The site investigation and field testing program was carried out between December 6th and December 11th, 2017. The northing, easting and elevation of the boreholes are shown on the Borehole Location and Soil Strata Drawing No. 1 in Appendix A and are summarized in Table 3-1. The site is within MTM Zone 13. The elevations were surveyed relative to the first order vertical benchmark tablet 0011969U391 provided by the ministry which has an elevation of 193.496 m.

Table 3-1: Borehole Summary

Borehole No.	Drilled Location	Approximate Northing (m)	Approximate Easting (m)	Ground Surface Elevation (m)	Sample Termination Depth (m)
17-14	West end – near culvert outlet	5 176 723.0	278 133.0	191.4	2.4
17-15	West shoulder – near culvert	5 176 707.0	278 150.0	197.1	15.8*
17-16	East shoulder – near culvert	5 176 705.0	278 169.0	197.1	16.5*
17-17	East end – near culvert inlet	5 176 688.0	278 183.0	193.0	11.3
17-18	West shoulder – north of culvert	5 176 737.0	278 143.0	196.4	15.8

* - Borehole was further advanced beyond sample termination depth by dynamic cone

The drilling was carried out using portable or manual equipment for off-road Boreholes 17-14 and 17-17, a track mounted CME 550 rig for Boreholes 17-16 and 17-18 and a truck mounted CME 75 drill rig for Borehole 17-15.

Soil samples were obtained at selected intervals using a split spoon sampler in conjunction with Standard Penetration Testing (SPT). Borehole 17-17 which was drilled with portable equipment, also utilized a full-weight hammer for SPT testing. Borehole 17-14 utilized a 40% weight hammer for SPT testing; the blow counts detailed within the borehole log have been adjusted accordingly. Undrained shear strength values were determined in-situ using an MTO-N sized vane

A 19 mm diameter standpipe piezometer was installed in Borehole 17-16 to allow for measurements of the groundwater level after completion of drilling. The piezometer installation details are illustrated on the respective Record of Borehole sheet provided in Appendix B. All other boreholes were backfilled with a low-permeability mixture of cuttings and bentonite pellets in accordance with Ontario MOE Regulation 903 as amended.

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

4 LABORATORY TESTING

Geotechnical laboratory testing consisted of natural moisture content determination and visual identification of all retained soil samples. Grain size distribution analyses testing was also carried out on selected samples to MTO and ASTM standards. Chemical analysis for determination of pH, conductivity, resistivity, soluble sulphate and chloride concentrations was carried out on one soil sample.

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 DESCRIPTION OF SUBSURFACE CONDITIONS

5.1 General

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. An overall description of the stratigraphy is given in the following paragraphs; however, the factual data presented in the Record of Boreholes governs any interpretation of the site conditions. It must be recognized that soil and groundwater conditions may vary between and beyond sampled locations.

The stratigraphy encountered through the embankment near the culvert is generally characterized by non-cohesive fill overlying native silt to sand overlying clay.

5.2 Topsoil

Boreholes 17-14, 17-16 and 17-17 encountered a layer of topsoil at ground surface ranging in thickness from 25 mm to 125 mm. The topsoil thickness may vary between boreholes and in other areas of the site.

5.3 Non-Cohesive Fill

Non-cohesive fill material classified as gravel with sand to silty sand with gravel to silt some sand was encountered from surface or beneath the topsoil in Boreholes 17-15, 17-16 and 17-18. Frequent cobbles and boulders were noted in the upper portion of the fill in Borehole 17-15. The underside of the fill ranged from 2.4 to 8.7 m below surface (elev. 188.4 to 194.1 m).

SPT tests conducted within the fill gave N-values ranging from 1 to 18 blows, indicating a very loose to compact relative density.

Moisture contents ranged from 1 to 37%. The results of grain size analyses conducted on five samples of the fill materials are summarized below and are illustrated on Figure C1 in Appendix C.

Table 5-1: Gradation Results for Non-Cohesive Fill

<table>
<tr><th>Soil Particle</th><th colspan="2">Percentage (%)</th></tr>
<tr><td>Gravel</td><td colspan="2">0 to 32</td></tr>
<tr><td>Sand</td><td colspan="2">10 to 91</td></tr>
<tr><td>Silt</td><td rowspan="2">4 to 45</td><td>81</td></tr>
<tr><td>Clay</td><td>9</td></tr>
</table>

Atterberg Limit testing on one sample of the fill indicated a non-plastic material.

5.4 Organic Silt to Sandy Silt with Organics

A thin layer ranging from organic silt to sandy silt with organics was encountered below the fill in Boreholes 17-15 and 17-16 and within the silt to sand deposit in Borehole 17-17. This layer had a thickness of 0.5 m (underside elev. 187.9 to 190.8 m).

SPT tests gave N-values ranging from 4 to 5 blows per 300 mm of penetration indicating a loose relative density. The moisture content ranged between 67 and 78%.

Organic content testing on two samples of the organic silt indicated an organic content ranging from 6.6 to 10.1%. Atterberg Limit testing on one sample of the sandy silt with organics indicated a non-plastic material. Gradation analysis was completed on one sample of sandy silt with organics. The results are summarized on the Record of Borehole sheets in Appendix B and the grain size distribution curve for this sample is included in Figure C2 of Appendix C. The results of the laboratory test are summarized as follows:

Table 5-2: Gradation Results for Sandy Silt with Organics

Soil Particle	Percentage (%)
Gravel	0
Sand	39
Silt	53
Clay	8

5.5 Silt to Sand

Beneath the materials noted above were deposits of cohesionless soils in all boreholes except Borehole 17-15 in which the cohesionless soils were encountered below a thin layer of high plastic clay as described in Section 5.6. The deposits varied from sandy silt to silt with sand to silty sand to sand trace silt. Boreholes 17-14 and 17-18 were terminated within the cohesionless deposits. The termination depths ranged from of 2.4 to 15.8 m (elev. 188.9 to 180.6 m). Where fully penetrated the silt and sand was found to have a thickness ranging from 0.8 to 7.1 m (underside elev. 184.3 to 186.9 m). A layer with organics was observed within the silt and sand in Borehole 17-17 and is described in Section 5.4 above.

SPT tests in the silt and sand unit gave N-values ranging from 0 to 40 blows per 300 mm of penetration indicating a very loose to dense relative density. The cohesionless deposit is generally in a very loose to loose state. The moisture content in the silt deposits typically ranged between 21 and 57% and the moisture content in the sand deposits typically ranged between 15 and 41%.

Atterberg Limit testing on five samples indicated a non-plastic material. Gradation analysis were completed on five silt samples and five sand samples. The results are summarized on the Record of Borehole sheets in Appendix B and the grain size distribution curves for these samples are included in Figure C3 and C4 of Appendix C. The results of the laboratory tests are summarized as follows:

Table 5-3: Gradation Results for Silt to Sand

<table>
<tr><th rowspan="2">Soil Particle</th><th colspan="2">Percentage (%)</th></tr>
<tr><th>Sands</th><th>Silts</th></tr>
<tr><td>Gravel</td><td>0 to 1</td><td>0</td></tr>
<tr><td>Sand</td><td>51 to 97</td><td>6 to 48</td></tr>
<tr><td>Silt</td><td rowspan="2">3 to 49</td><td>40 to 80</td></tr>
<tr><td>Clay</td><td>11 to 14</td></tr>
</table>

5.6 Clay (CH)

A thin layer of native high plastic clay was encountered in Borehole 17-15 just below the organic silt layer. This layer had a thickness of a thickness of 0.4 m (underside elev. 187.5 m).

The high plastic clay was also encountered below the silt to sand deposit in Boreholes 17-15, 17-16 and 17-17. Very thin silt interbeds were noted within the top 2.6 m of the clay deposit in Borehole 17-15. All three boreholes were terminated within this deposit at depths ranging from 11.3 to 16.5 m. Boreholes 17-15 and 17-16 were extended below termination depth by performing a dynamic cone penetration test (DCPT). The DCPT tests extended as deep as 31.4 m below ground surface (elev. 165.7 m) and was terminated on refusal. The SPT N-values ranged from weight of hammer to 9 blows per 300 mm penetration. Field vane tests performed within the deposit recorded undrained shear strengths ranging from 42 to greater than 106 kPa indicating a firm to very stiff consistency, but typically stiff. Remolded field vane testing indicates that the clay shows moderate sensitivity.

The moisture content of the samples tested ranged from 24 to 57%. The results of grain size analyses conducted on three samples of the clay are summarized below and are illustrated on Figure C5 in Appendix C.

Table 5-4: Gradation Results for Clay (CH)

Soil Particle	Percentage (%)
Gravel	0
Sand	1 to 4
Silt	26 to 37
Clay	60 to 70

Atterberg Limit testing was completed on three samples of the clay deposit. The results are summarized on the Record of Borehole sheets in Appendix B and the Atterberg Limit graphs are included in Figure C6 of Appendix C. The laboratory results are summarized below and indicate that the clay is of high plasticity (CH).

Table 5-5: Atterberg Limit Results for Clay (CH)

Parameter	Value
Liquid Limit	52 to 64
Plastic Limit	21 to 23
Plasticity Index	31 to 41

5.7 Groundwater

The water level was measured in the piezometer installed in Borehole 17-16 and is presented in the table below:

Table 5-6: Groundwater Level Observations

Borehole	Groundwater Level		Date of Measurement
	Depth (mbgs)	Elevation (m)	
17-16	8.5 8.2 8.2 8.1	188.6 188.9 188.9 189.0	December 7, 2017 December 9, 2017 December 10, 2017 December 11, 2017

It should be noted that Borehole 17-14 was uncased and caved in to surface, preventing a water level from being taken. Water was used to advance the drilling casing in Boreholes 17-15 and 17-17 which prevented reliable groundwater measurements on completion of drilling. Borehole 17-18 was dry within the hollow-stem augers on completion of drilling and the open borehole caved to 6 m below ground surface when the augers were pulled on completion of drilling, preventing a groundwater table measurement.

The creek water level was surveyed at the culvert inlet and outlet during the field investigation and the measured elevations are detailed in the below table:

Table 5-7: Creek Water Level Observations

Location	Surface Water Elevation (m)	Date of Measurement
Culvert Inlet	192.0	December 11, 2017
Culvert Outlet	191.4	December 11, 2017

These observations are considered short term and it should be noted that the groundwater level at the time of construction and seasonal fluctuations of the groundwater level are to be expected. In particular, the groundwater level may be at a higher elevation after periods of significant and/or prolonged precipitation events.

5.8 Analytical Testing

One sample of soil was submitted to Paracel Laboratories in Ottawa, Ontario for analysis of pH, water soluble sulphate and chloride concentrations, resistivity and conductivity. The analysis results are summarized in the table below:

Table 5-8: Analytical Results Summary

Borehole	Sample	Depth (m)	Sulphate (μg/g)	pH	Resistivity (Ohm-cm)	Conductivity (μS/cm)	Chloride (μg/g)
17-14	SS3A	1.2 – 1.4	88	6.20	1990	502	247

6 MISCELLANEOUS

Borehole locations were selected by Thurber relative to existing site features and the anticipated foundation locations. The as-drilled locations and ground surface elevation were measured by Thurber following completion of the field program.

George Downing Estate Drilling Ltd. of Hawksbury, Ontario supplied and operated the drilling equipment to conduct the drilling, soil sampling, in-situ testing, standpipe piezometer installation and borehole decommissioning. All work was performed within short duration TL-6 shoulder closures in conformance with the requirements set in Ontario Book 7; all signs and cones were provided by Thurber. The field investigation was supervised on a fulltime basis by Ms. Deanna Pizycki, E.I.T. and Ms. Katya Edney, P.Eng. of Thurber. Overall supervision of the investigation program was provided by Mr. Paul Carnaffan, P.Eng.

Routine geotechnical laboratory testing was completed by Thurber's laboratory in Ottawa, Ontario. Organic content tests were carried out by Stantec Limited in Ottawa, Ontario. Analytical testing was completed by Paracel Laboratories in Ottawa, Ontario. Interpretation of the factual data and preparation of this report were carried out by Mr. Christopher Murray, P.Eng. and Dr. Fred Griffiths, P.Eng.. The report was reviewed by Dr. P.K. Chatterji, P.Eng. a Designated Principal Contact for MTO Foundation Projects.

Christopher Murray, M.A.Sc., P.Eng.
Geotechnical Engineer

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

Dr. P.K. Chatterji, P.Eng.
Review Principal
Senior Geotechnical Engineer

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PART 2. ENGINEERING DISCUSSION AND RECOMMENDATIONS

7 INTRODUCTION

This section of the report provides an interpretation of the factual data from Part 1 of this report and presents geotechnical recommendations to assist the design team in designing a suitable replacement of the existing culvert crossing Highway 17 at an unnamed creek located approximately 0.1 km east of the Goulais River. The discussion and recommendations presented in this report are based on the information provided by the Ontario Ministry of Transportation (MTO) and on the factual data obtained during the course of the investigation.

This foundation investigation and design report with the interpretation and recommendations are intended for the use of the Ministry of Transportation, and shall not be used or relied upon for any other purposes or by any other parties including the construction or design-build contractor. The construction or design-build contractor must make their own interpretation based on the factual data in Part 1 of the report. Where comments are made on construction, they are provided only in order to highlight those aspects which could affect the design of the project. Contractors must make their own interpretation of the factual information provided as it may affect equipment selection, proposed construction methods and scheduling.

The existing culvert is a corrugated steel pipe (CSP) culvert reported to have a diameter of 1,200 mm, a length of 39 m and invert elevations of 191.6 m upstream and 190.8 m downstream. The culvert has a generally east to west alignment with flow through the culvert to the west. The Highway 17 fill height above the culvert is approximately 5.0 m with the centreline of the road surface at approximate elevation 197.6 m.

The stratigraphy encountered through the embankment near the culvert is generally characterized by non-cohesive fill overlying native silt to sand overlying native clay. It is noted that water level in the standpipe piezometer installed at the site was at 189.0 m on December 11th, 2017. The water level at the culvert inlet was recorded at elevation 192.0 m on December 11th, 2017.

No previous foundation investigation information for the subject culvert was available in the Geocres Library.

7.1 Proposed Structure

At the time of preparation of the final Foundation Investigation and Design Report, the size and type of the proposed replacement culvert had not been finalized, however it is assumed that the replacement culvert will have a similar cross-sectional area and alignment. It is also assumed the invert elevations will be similar to the exiting culvert and that no grade raise or permanent embankment widening is proposed at the culvert.

7.2 Applicable Codes and Design Considerations

The geotechnical assessment presented below has been prepared based on the available data regarding the proposed foundations and existing ground conditions and in accordance with the Canadian Highway Bridge Design Code (CHBDC), version CSA S6-14.

It is understood that a structural culvert replacement would have a consequence classification of *Typical Consequence*, in accordance with Section 6.5.1 of the CHBDC. The geotechnical resistance factor of 0.5 for bearing and 0.8 for settlement, both adopted for typical degree of understanding, were used to obtain the factored resistance values as per CHBDC 2014. If the consequence classification changes, the geotechnical assessment will need to be reviewed and revised.

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). The seismic hazard for this site has been obtained from the GSC calculator. The data includes a peak ground acceleration (PGA), peak ground velocity (PGV) and the 5% spectral response acceleration values (Sa(T)) for the *reference* ground condition (Site Class C) for a range of periods (T) and for a range of return periods including 475-year, 975-year and 2475-year events. The GSC seismic hazard calculation data sheet for this site is included in Appendix F.

The site coefficients used to determine the design spectral acceleration and displacement values are a function of the Site Class and the peak ground acceleration (PGA), which is 0.036g at this site.

8.2 CHBDC Seismic Site Classification

In accordance with the CHBDC, the selection of the seismic classification is based on the soil and rock within the upper 30 m of the stratigraphy. In accordance with Table 4.1, Section 4.4.3.2 of the CHBDC, and not taking cyclic softening potential into consideration, the site is classified as a Seismic Site Class E based on the soil conditions encountered.

8.3 Seismic Liquefaction

Based on the PGA value, the subsurface conditions encountered at the drilled locations at this site and using the Seed & Idriss Simplified Method for liquefaction assessment, the foundation soils are considered to be not susceptible to liquefaction during a seismic event.

8.4 Culvert Type and Foundation Alternatives

Selection of the culvert type must consider the proposed construction procedures, staging requirement, geotechnical resistance available in the foundation soils, the depth to suitable bearing stratum and post-construction settlement criteria. From a geotechnical perspective, the following culvert types were considered:

- Circular Pipes (Concrete, HDPE, Steel)
  From a foundation engineering perspective, a pipe culvert is a feasible alternative. The size of the replacement pipe will depend upon various design issues including flow capacity and hydraulic properties. Concrete pipes are less tolerant to settlements than alternative material types.

- Open Bottom Culvert (Box, Arch)
  Open bottom culvert is not recommended for this site from a foundation engineering perspective due to the low geotechnical resistance available in the native soils, possible settlement of the foundation soils and the requirement for greater excavation depths and dewatering effort during construction. Additionally, the size of culvert anticipated for this site would typically be too small for an open bottom culvert installation.

- Closed Bottom Culvert (Box)
  A precast segmental 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 founding soils during installation.

A comparison of these alternatives, based on their respective advantages and disadvantages, is included in Appendix E. 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.

8.5 Construction Methodology Alternatives

For the proposed culvert replacement, the following construction methods were considered.

- Open Cut with Full Road Closure and Detour
  Installation of a new culvert using open cut techniques and a full road closure would allow for an expedited construction schedule and could reduce costs associated with requiring roadway protection and water diversion. However, it is understood that an acceptable detour route is not available and therefore this option is not feasible.

- Open Cut with Staged Temporary Widening
  Widening of the existing highway and/or construction of a temporary detour embankment to accommodate traffic passage during construction is considered feasible from a geotechnical perspective. Settlement of the foundation soils under the existing and a temporary 0.5 to 4.5 m high detour embankment will occur but is anticipated to be less than 15 mm and 55 mm beneath the existing and widened embankments respectively. The impact the predicted settlement will have on the

existing buried utility lines needs to be considered. A review of the requirement for property acquisition and highway geometry is needed to fully assess this option.

- Open Cut with Staged Temporary Protection System

  The use of open cut techniques in conjunction with staged culvert replacement is a feasible construction staging option from a geotechnical perspective. This option will require roadway protection, as discussed further in Section 10.2, installed along the embankment centerline to maintain a single lane of traffic flow along the current highway alignment. The Contractor will need to consider the potential for cobbles/obstructions in the embankment fill while selecting the type of roadway protection. To reduce the lateral deflections of the protection systems installed to support a high embankment, the roadway protection may need to include a bracing system. Alternatively, a temporary modular bridge may be considered for maintaining traffic flow.

- Trenchless Techniques

  Trenchless techniques would have the advantage of minimum disruption to traffic and would avoid a large excavation through the existing highway embankment and are considered to be feasible at this site. However, consideration will have to be given to encountering a mixed soil face including saturated, loose, non-cohesive materials and the proximity of the nearby fibre optic cables located in the area of the culvert alignment entry and exit pits.

- Protection of Utilities

  The selected construction methodology should be such that it does not impact or damage buried utilities such as the fibre optic cables. Discussion with utility owners may be required prior to finalizing the construction methodology.

A comparison of these alternatives, based on their respective advantages and disadvantages, is included in Appendix E.

8.6 Recommended Approach for the Culvert Replacement

From a foundation engineering perspective, replacing the existing culvert with either a circular pipe culvert or a closed box culvert using open cut techniques is the recommended culvert replacement option. A temporary protection system (TPS) may be needed to facilitate construction. Design of the TPS will need to account for the lateral capacity available in the sand and clay foundation soils at this site and the potential need to brace the TPS.

9 FOUNDATIONS DESIGN RECOMMENDATIONS

Foundation design aspects for the replacement culvert includes subgrade conditions, geotechnical resistances, settlement of the founding soils, imposed loading pressures, erosion control, protection system design, groundwater control and stability of stage construction. The culvert must be designed to resist loadings including lateral earth pressures, hydrostatic pressure, weight of embankment fill, traffic loading and any surcharge due to construction equipment and activities under static and seismic conditions.

9.1 Culvert Foundation Bearing Resistances

Provided the replacement culvert is constructed on the same alignment as the existing culvert and the embankment is reconstructed with no grade raise or widening (temporary or permanent), it is anticipated that the subgrade soils within the culvert footprint will not be subjected to any significant additional loading.

A loose organic silt was encountered in Boreholes 17-15, 17-16 and 17-17 extending down to elevation 187.9 m. It is recommended that this material be sub-excavated beneath the replacement culvert, as described in Section 9.2 below.

9.1.1 Box Culvert

The recommended geotechnical resistances for a pre-cast box culvert with a base of less than 3 m width and installed at the founding elevation of the current culvert (approximate elev. 190.3 m assuming a 0.2 m culvert base slab thickness) on a prepared competent subgrade within the existing culvert footprint are as follows:

- Factored Geotechnical Resistance at ULS of 225 kPa
- Factored Geotechnical Resistance at SLS of 150 kPa

The factored geotechnical resistances provided above include the following factors:

- Consequence factor (Ψ) of 1.0 (as per CHBDC Table 6.1)
- Geotechnical resistance factors (as per CHBDC Table 6.2):
  - ϕ_{gu} = 0.5 (static analysis; typical degree of understanding)
  - ϕ_{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 6.10.3 and Clause 6.10.4. Foundation settlement, based on the above SLS resistance, is expected to be less than 25 mm.

Resistance to lateral forces/sliding resistance between the precast concrete and the underlying Granular ‘A’ bedding (Section 9.2) should be evaluated in accordance with the CHBDC assuming an ultimate coefficient of friction of 0.40.

As noted in Borehole 17-16, a layer of loose organic silt may be encountered at the proposed culvert subgrade. This organic layer must be completely removed down to inorganic native competent soils for the entire length of the culvert and replaced with well compacted granular fill. A geotextile layer should be provided between the native subgrade and the granular fill.

9.1.2 Pipe Culvert

Geotechnical resistance values are not required for pipe culverts. A modulus of subgrade reaction of 30 MN/m^3 can be used for a pipe culvert installed at this site. Subgrade preparation details for pipe culverts should follow the recommendations provided for box culverts.

9.2 Subgrade Preparation, Bedding and Backfilling

After excavation and removal of the exiting culvert and existing fill, all organics, soft or loose deposits, disturbed soils, alluvial deposits and deleterious materials must be stripped from the footprint of the foundation to expose competent subgrade material at or below the desired founding elevations. It is anticipated that the excavation will extend to as deep as elevation 187.9 m. The excavation should extend to 1 m beyond the length and width of the replacement culvert on all sides. Construction equipment should not be permitted to travel on the exposed subgrade.

The exposed subgrade must be inspected to confirm that the subgrade is suitable and uniformly competent. Any soft or organic materials at the subgrade level should be sub-excavated and backfilled and compacted as per OPSS.PROV 501 with granular fill consisting of OPSS.PROV 1010 Granular A material as soon as practical to protect the subgrade from disturbance during construction. In order to provide a more uniform foundation subgrade condition for the culvert, a minimum 300 mm thick layer of material conforming to OPSS.PROV 1010 Granular A requirements must be provided under the base of the culvert as per OPSS.PROV 421 and OPSD 802.010 (pipe culvert). If a box culvert is selected then a minimum 300 mm thick layer of Granular A is required as per OPSS 422 and OPSD 803.010, the uppermost 75 mm of this material should be considered the leveling pad.

Since the organic silt has been below the existing culvert since construction and has likely undergone consolidation, consideration may be given to leaving the buried organic silt layer in place below the replacement culvert footprint. The requirements for this option from a geotechnical perspective are as follows:

- The replacement culvert must be on an identical alignment to the existing culvert
- The replacement is a larger diameter than the existing culvert (preferably oversized)
- A minimum 500 mm thick layer of Granular A is placed below the replacement culvert
- The grade of Highway 17 remains at the existing grade or lower
- No permanent widening to the existing embankment is constructed

It is noted that even with the above requirements, this option could result in some settlement of the replacement culvert and require regrading and repairs to the highway platform and asphalt.

The compaction of granular bedding directly above the subgrade is likely to result in disturbance of the material with pumping of fines into the granular bedding and difficulty achieving the specified degree of compaction. Protection of the subgrade should include installation of a Class II non-woven geotextile with a maximum FOS of 150 μm (OPSS 1860) installed beneath the Granular A bedding layer. The geotextile should be placed as soon as possible after reaching the subgrade level. Proper handling, storage and installation of the geotextile should follow the recommendations of the manufacturer.

It is noted that construction will extend below the ditch elevation. Water diversion and dewatering will be required to prepare the subgrade in the dry depending on the water level at the time of construction. Please refer to Section 10.3 for additional comments on groundwater and surface water control.

It is recommended that culvert cover be in accordance with OPSS.PROV 401 and consist of free-draining, non-frost susceptible granular materials such as Granular A material meeting the requirements of OPSS.PROV 1010.

Culvert backfill above the granular cover should be in accordance with OPSS.PROV 401 and consist of material meeting the requirements of OPSS Granular A or Granular B Type II soils and should be compacted in regular lifts as per OPSS.PROV 501. Care must be exercised when compacting the fill adjacent to and above the culvert in order not to damage the culvert. Heavy compaction equipment, used adjacent to structure, must be restricted in accordance with OPSS.PROV 501.

Please refer to the pavement design report for recommendations on pavement reinstatement and frost tapers.

9.3 Frost Depth

The depth of frost penetration at this site is estimated to be 2.0 m based on OPSD 3090.100. It is not necessary to found a closed box or pipe culvert at a depth below frost penetration. The requirement for frost tapers should follow the recommendations within the Pavement Design Report.

9.4 Lateral Earth Pressure

Lateral earth pressures parameters provided in Table 9-1 and Table 9-2 in the sections below are based on the assumption that the backfill is fully drained so that there are no unbalanced hydrostatic pressures. If adequate drainage cannot be confirmed, the potential for buildup of hydrostatic pressures should be considered in design. For design purposes, the groundwater level should be assumed to be at elevation 192.0 m.

9.4.1 Static Lateral Earth Pressure Coefficients

Lateral earth pressures acting on structures should be computed in accordance with the CHBDC but generally are given by the following expression:

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

where:

p_h = horizontal pressure on the wall at depth h (kPa)
K = earth pressure coefficient (see table below)
(K_a for yielding walls, K_o for non-yielding walls)
γ = unit weight of retained soil (see table below), adjusted by subtracting 9.81 kN/m^3 for material below water 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 backfill are shown in Table 9-1.

Table 9-1. Earth Pressure Coefficients

<table>
<tr><th rowspan="3">Condition</th><th colspan="6">Earth Pressure Coefficient (K)</th></tr>
<tr><th colspan="2">OPSS Granular A or OPSS Granular B Type II
ϕ = 35°, γ = 22.8 kN/m^3</th><th colspan="2">OPSS Granular B Type I
ϕ = 32°, γ = 21.2 kN/m^3</th><th colspan="2">OPSS SSM and Existing Fill
ϕ = 30°, γ = 21.0 kN/m^3</th></tr>
<tr><th>Horizontal Surface Behind Wall</th><th>Sloping Surface Behind Wall (2H:1V)</th><th>Horizontal Surface Behind Wall</th><th>Sloping Surface Behind Wall (2H:1V)</th><th>Horizontal Surface Behind Wall</th><th>Sloping Surface Behind Wall (2H:1V)</th></tr>
<tr><td>Active, K_A (Yielding Wall)</td><td>0.27</td><td>0.40</td><td>0.31</td><td>0.48</td><td>0.33</td><td>0.54</td></tr>
<tr><td>At Rest, K_O (Non-Yielding Wall)</td><td>0.43</td><td>-</td><td>0.47</td><td>-</td><td>0.50</td><td>-</td></tr>
<tr><td>Passive, K_P (Movement towards Soil Mass)</td><td>3.7</td><td>-</td><td>3.3</td><td>-</td><td>3.0</td><td>-</td></tr>
<tr><td>Soil Group(*)</td><td colspan="2">“medium dense sand”</td><td colspan="2">“loose to medium dense sand”</td><td colspan="2">“loose sand”</td></tr>
</table>

Note: (*) Figure C6.16 of the Commentary to the CHBDC.

The use of a material with a high friction angle and low active pressure coefficient (Granular A or Granular B Type II) is preferred as it results in lower earth pressures acting on the culvert.

The parameters in the table 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 values to be used in design can be assessed from Figure C6.16 of the Commentary to the CHBDC using the soil group designation as outlined in Table 9-1. Active pressures should be used for any head walls or unrestrained walls. For rigid structures such as a concrete box culvert, it is recommended that at-rest horizontal earth pressures be used for design. Where ground surfaces are sloped behind the walls, the corresponding coefficients provided in the Table 9-1 should be used.

9.4.2 Combined Static and Seismic Lateral Earth Pressure Parameters

In accordance with Clause 4.6.5 of the CHBDC (S6-14), retaining structures should be designed using dynamic earth pressure coefficient that incorporate the effects of earthquake loading. The following recommendations are per Section C4.6.5 of the Commentary of the CHBDC which states that seismically induced lateral soil pressures may be calculated using Mononobe-Okabe Method with:

- k_h = ½ * F(PGA) * PGA, for structures that allow 25 to 50 mm of movement, and
- k_h = F(PGA) * PGA, for non-yielding walls

The ratio of wall movement to wall height required to mobilize the active conditions would be approximately 0.002 for a yielding structure with respect to the assessment of seismically induced lateral earth pressures.

The coefficients of horizontal earth pressure for seismic loading presented in Table 9-2 may be used. The provided earth pressure coefficients are based on a Seismic Site Class E, PGA with a 2% probability of exceedance in 50 years of 0.036g (Geological Survey of Canada – Fifth Generation) and a F(PGA) of 1.81 as per Table 4.8 of the CHBDC (S6-14 update No. 1, April 2016).

Table 9-2. Dynamic Earth Pressure Coefficients

Condition	Earth Pressure Coefficient (K)			
	OPSS Granular A or OPSS Granular B Type II $\phi = 35^o$, $\gamma = 22.8$ kN/m^3		OPSS Granular B Type I $\phi = 32^o$, $\gamma = 21.2$ kN/m^3	
	Horizontal Surface Behind Wall	Slope Surface Behind Wall (2H:1V)	Horizontal Surface Behind Wall	Slope Surface Behind Wall (2H:1V)
Active, K_{AE} Yielding Wall	0.31	0.44	0.33	0.53
Active, K_{AE} Non-Yielding Wall	0.29	0.49	0.35	0.61

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

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

where:

σ_h = lateral earth pressure at depth d (kPa)
d = depth below the top of the wall (m)
K = static earth pressure coefficient
(K_a for yielding walls, K_o for non-yielding walls)
γ = unit weight of retained soil, adjusted for water level by subtracting 9.81 kN/m^3
K_{AE} = combined static and seismic earth pressure coefficient
H = total height of the wall (m)

9.5 Embankment Design and Reinstatement

9.5.1 Embankment Reconstruction

Embankment reconstruction after culvert replacement should be carried out in accordance with OPSS.PROV 206. The embankment should be reinstated with side slopes of 2H:1V (or flatter) if constructed using Granular A, Granular B Type II or Granular B Type I material. The fill should be placed and compacted in accordance with OPSS.PROV 501.

Where new 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.

Provided the subgrade is prepared as outlined above and construction of the embankment is carried out in accordance with recommendations provided within this report, the embankment side slopes should remain stable and long-term stability issues are not anticipated.

It is understood that no grade raise or permanent embankment widening is anticipated along the alignment of Highway 17 and therefore negligible foundation settlement is expected to occur.

The magnitude of the embankment compression constructed with granular materials is in the order of 0.5% of the embankment height and is expected to occur following fill placement.

9.5.2 Temporary Widening

If a temporary widening is selected for construction staging, a temporary culvert extension should be provided on subgrade prepared as described in Section 9.2. The widening should be constructed with side slopes of 2H:1V (or flatter) if constructed using Granular B Type I. The fill should be placed and compacted in accordance with OPSS.PROV 501. A 1.5H:1V embankment slope could be used for temporary widening if it is constructed with rockfill, has a minimum top of embankment width of 3.0 m and is placed in accordance with OPSS 206.

Where new 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. The footprint of the widened embankment and the existing side slopes should be stripped of topsoil which was observed to range from 25 mm to 125 mm in thickness.

Providing the above recommendations are followed, global stability of the temporary widenings has been modeled and found to be satisfactory. Surficial stability of the temporary widenings will depend on following the recommendations presented in Section 10.4 although minor erosion is to be expected.

The magnitude of the settlement resulting from a widening on either side of Highway 17 is estimated to vary between 15 and 55 mm over the width of the widening from the current highway shoulder outward. Settlement will occur relatively rapidly with more than 50% occurring within 3 months of fill placement. The embankment widening for temporary detour should be periodically regraded to compensate for settlement. To remain effective, the temporary culvert extension should be oversized to allow for settlement of the temporary widening. The existing pavement adjacent to the widening is expected to settle as much as 15 mm and may require asphalt padding.

On completion of the culvert replacement the temporary widenings and culvert extensions should be removed and the 2H:1V highway embankment reinstated.

9.6 Cement Type and Corrosion Potential

Analytical tests were completed to determine the potential for degradation of the concrete in the presence of soluble sulphates and the potential for corrosion of exposed steel. The concentration of soluble sulphate provides an indication of the degree of sulphate attack that is expected for concrete in contact with soil and groundwater at the site. Soluble sulphate concentrations less than 1000 μg/g generally indicate that a low degree of sulphate attack is expected for concrete in contact with soil and groundwater. The class of concrete selected should consider the effects of road de-icing salts.

The pH, resistivity and chloride concentration provide an indication of the degree of corrosiveness of the sub-surface environment. The tests results provided in Section 5.8 may be used to aid in the selection of coatings and corrosion protection systems for buried steel objects. The corrosive effects of road de-icing salts should also be considered.

10 CONSTRUCTION CONSIDERATIONS

10.1 Excavation

All excavation must be carried out in accordance with the Occupational Health and Safety Act (OHSA). For the purposes of OHSA, the fill and native clays both above and below the water table may be classified as Type 3 soil. Cohesionless soils such as the native sand to silt below the groundwater level and alluvial deposits are classified as Type 4 soils.

Excavation for the culvert replacement must be carried out in accordance with OPSS.PROV 401 and will be carried out through the existing embankment fill and extend into the underlying silt/sand deposits. The sides of temporary excavations must be sloped in accordance with the requirement of the OHSA. Adjacent utilities including buried fibre optic cable will need to be taken into consideration when evaluating the excavation limits and whether the utilities need to be relocated or supported during construction.

At locations where there are space restrictions or where a slope has to be retained, the excavations will need to be carried out within a protection system. Further discussion on temporary protection systems (TPS) are presented in Section 10.2.

10.2 Temporary Protection Systems

Temporary Protection Systems may be required during construction and must be implemented in accordance with OPSS.PROV 539 and designed for Performance Level 2 (maximum 25 mm horizontal deflection). The actual 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.

The design of roadway protection is 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. Typical protection systems may include soldier piles and lagging or sheet piles. Cobbles and Boulders in the fill may impede sheet pile installation.

The protection system should be installed at a suitable distance away from the new culvert to limit the disturbance to the subgrade associated with removal of the protection system following completion of construction. Alternatively, the protection system near the culvert could be left in place and cut off in accordance with OPSS.PROV 539. Loose to very loose sand and silt deposits were observed in several boreholes. These materials could be adversely affected by vibration. It is recommended that the contract preclude the use of vibratory equipment during the installation and/or removal of protection systems. An NSSP to alert contractors to this has been included in Appendix G.

Lateral earth pressure coefficients, under fully mobilized conditions, that can be used in design of the protection system installed through the embankment fill and culvert backfill are provided in Table 9-1. The lateral earth pressure coefficients for the sand, silt and clay deposits are given below:

Native Sand / Silt

γ	=	19 kN/m^3	(must be adjusted for water table)
K_A	=	0.33	
K_P	=	3.0	

Native Clay

γ	=	18 kN/m^3	(must be adjusted for water table)
K_o	=	0.55	
K_A	=	0.38	
K_P	=	2.6	

10.3 Surface and Groundwater Control

Creek diversion may be required to ensure that culvert construction is carried out in the dry. Design of dewatering systems is the responsibility of the Contractor. The depth of excavation is expected to extend below the creek level observed at the time of the investigation. The Contractor must be prepared to control the groundwater and surface water flow at the site to permit construction in a dry and stable excavation. Water from either surface flow and/or groundwater must be diverted away from any excavation at all times. Groundwater perched within the embankment fill and, surface runoff will tend to seep into, and accumulate in excavations. It is anticipated that a sheet pile enclosure with groundwater control within the enclosure would be required to construct the culvert in the dry. For each excavation stage, groundwater should be lowered to below the planned base of the excavation. Groundwater should be lowered to 0.5 m below the final base of the excavation. Base instability of the excavation due to unbalanced hydrostatic forces is not anticipated. The comments provided in Section 10.2 are also applicable to sheet pile cofferdams.

The design of any dewatering system that may be required is the responsibility of the Contractor. The Contract Documents must alert them to this responsibility and the need to engage a dewatering specialist to design the system in accordance with OPSS.PROV 517 and MTO SP No. 517F01 Amendment to OPSS.PROV 517.

The Dewatering Systems Designer Fill-in information for SP No. 517F01 are as follows:

- * 46.729310°, -84.348530°
- ** Unnamed Creek Culvert Crossing of Highway 17 at Station 17+230
- ***** Yes
- ****** Within a 250 m radius around the culvert site

Temporary groundwater and surface water control measures will be required to remain operational during construction until the culvert is installed and backfilled.

10.4 Scour Protection and Erosion Control

The Contractor should provide silt fences and erosion control blankets as per OPSS 805 throughout the duration of construction to prevent transport of silt/sediment. Slope protection and drainage measures will be required to provide the long-term surficial stability of the embankment slopes. Slope vegetation should be established as soon as possible after completion of the embankment fills in order to limit surficial erosion.

Scour and erosion protection should be provided for both the culvert inlet and outlet areas. The embankment material consists of gravel with sand to silty sand and is considered to have a low to moderate erosion potential. The native sand is considered to have a moderate erosion potential, the native silty sand is considered to have a moderate erosion potential and the native silt is considered to be highly erodible. Design of the scour and erosion protection measures must consider hydrologic and hydraulic concerns and should 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 511. Treatment at the outlet should be in accordance with OPSD 810.010. A vegetation cover should be established on all other exposed earth surfaces to protect against surficial erosion in general accordance with OPSS.PROV 804.

It is recommended that a clay seal and a concrete cut-off wall be used to minimize the potential for piping and erosion around the inlet of the culvert. The clay seal must extend to approximately 300 mm above the high-water level and laterally for the width of the granular material, and have a minimum thickness of 500 mm. The material requirements should be in accordance with OPSS.PROV 1205. A geosynthetic clay liner may be used as a clay seal.

11 CONSTRUCTION CONCERNS

Potential construction concerns include, but are not necessarily limited to:

- Disturbance of the soil subgrade. Where fine-grained soils or loose silts and sands are exposed at the culvert subgrade following excavation, these areas will be soft and moisture sensitive. Construction traffic must not be allowed on the subgrade. The final subgrade should be protected with geotextile and bedding granular materials.
- An effective dewatering plan will be critical to construct the replacement culvert in the dry.
- Buried obstructions may be encountered during excavation in the embankment fill or interfere with driving of protection systems, or during tunnelling. A suitable bracing system may need to be included in the protection system to provide additional lateral support.
- Seasonal fluctuations of the groundwater and creek level are to be expected which may impact the construction.
- The Contractor's selection of construction equipment and methodology must include assessment of the capability of the existing embankment to support the proposed construction equipment and any temporary structure fill (i.e., as a pad for crane support).

The successful performance of the culvert will depend largely upon good workmanship and quality control during construction. Subgrade examination should be carried out by qualified geotechnical personal during construction to confirm that foundation recommendations are correctly implemented and material specifications are met.

12 CLOSURE

Engineering analysis and preparation of this report were carried out by Mr. Christopher Murray, P.Eng. and Dr. Fred Griffiths, P.Eng. The report was reviewed by Dr. P.K. Chatterji, P.Eng. a Designated Principal Contact for MTO Foundation Projects.

Thurber Engineering Ltd.
Report Prepared By:

Christopher Murray, M.A.Sc., P.Eng.
Geotechnical Engineer

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

Dr. P.K. Chatterji, P.Eng.
Review Principal
Senior Geotechnical Engineer

Appendix A.

Borehole Location Plan and Stratigraphic Drawings

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

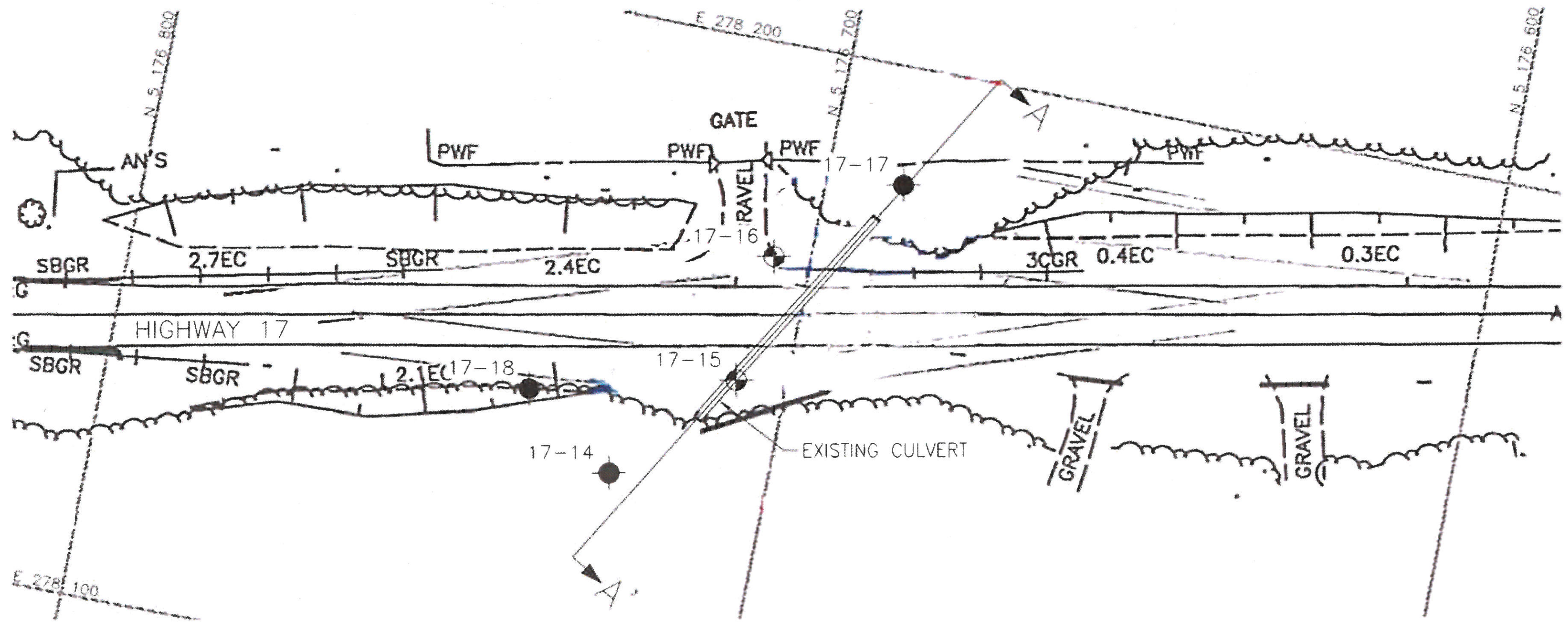
CONT No
GWP No 5181-13-00

HIGHWAY 17
CULVERT AT
STATION 17+230
BOREHOLE LOCATIONS AND SOIL STRATA

SHEET

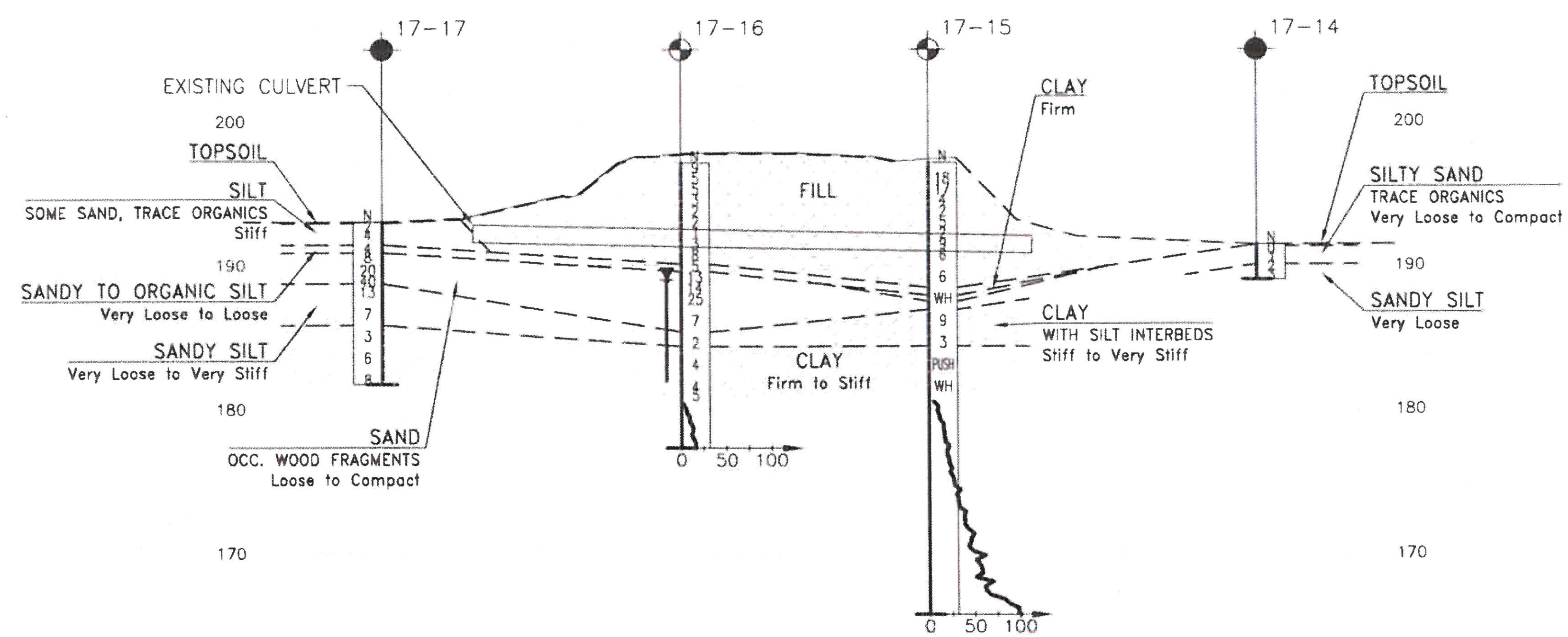
Ontario

THURBER ENGINEERING LTD



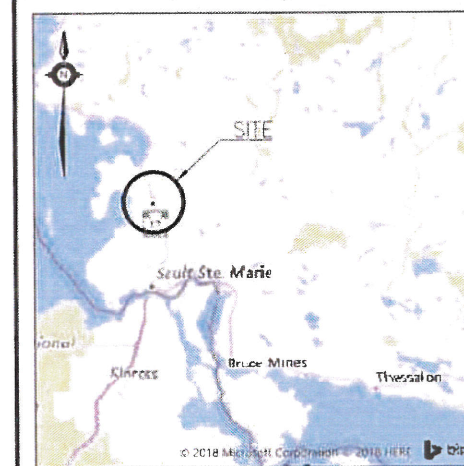
PLAN

20 0 20 40m
SCALE 1:1000



PROFILE

10 0 10 20m
SCALE 1:500



KEYPLAN

L E G E N D

●	Borehole
⊕	Borehole and Cone
N	Blows /0.3m (Std Pen Test, 475J/blow)
CONE	Blows /0.3m (60° Cone, 475J/blow)
PH	Pressure, Hydraulic
▽	Water Level
▼	Head Artesian Water
	Piezometer
90%	Rock Quality Designation (RQD)
A/R	Auger Refusal

NO	ELEVATION	NORTHING	EASTING
17-14	191.4000	5176723.0000	278133.0000
17-15	197.1000	5176707.0000	278150.0000
17-16	197.1000	5176705.0000	278169.0000
17-17	193.0000	5176688.0000	278183.0000
17-18	196.4000	5176737.0000	278143.0000

-NOTES-

1) The boundaries between soil strata have been established only at Borehole locations. Between Boreholes the boundaries are assumed from geological evidence.
2) This drawing is for subsurface information only. Surface details and features are for conceptual illustration.
3) Coordinate system is MTM NAD 83 Zone 13.

GEOCRES No. 41K-106

REVISIONS	DATE	BY	DESCRIPTION

DESIGN CM	CHK PK	CODE	LOAD	DATE MAY 2018
DRAWN MFA	CHK CM	SITE	STRUCT	DWG 1

FILENAME: H:\Drafting\17000\17848\TED-17848-Hwy17 Culvert.dwg
PLOTDATE: 5/29/2018 3:23 PM

Appendix B.

Record of Borehole Sheets

THURBER

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:

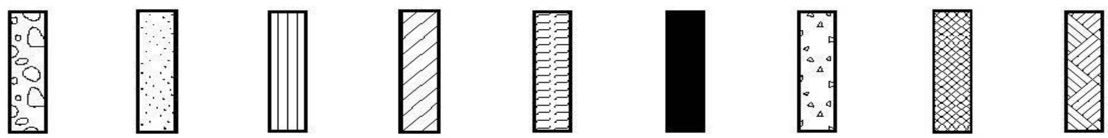
Numbers in this column are the field results of the Standard Penetration Test: the number of blows of a 63.5 kg hammer falling 0.76 m, required to drive a 50 mm O.D. split spoon sampler 0.3 m into undisturbed soil. For samples where insufficient penetration was achieved and N-value cannot be presented,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

THURBER

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

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 (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.

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

THURBER

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

THURBER

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 17-14

METRIC

GWP# 5181-13-00 | LOCATION Culvert at Station 17+230, MTM z13: N 5 176 723.0 E 278 133.0 | ORIGINATED BY DJP

HWY 17 | BOREHOLE TYPE Manual | COMPILED BY KE

DATUM Geodetic | DATE 2017.12.10 - 2017.12.10 | CHECKED BY FG

ELEV DEPTH	DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	ELEVATION SCALE	WATER CONTENT (%)	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
191.4							
0.0	**125 mm Topsoil**					159	
0.1	**Silty SAND (SM)** Very Loose Brown	1	SS	0	191		
		2	SS	1			0 72 28 (SI+CL)
190.0 / 1.4	**Sandy SILT (ML)** Very Loose Brown	3	SS	2	190		
		4	SS	3			
188.9 / 2.4	End of Borehole at 2.4 m due to cave in to surface				189		

Note: A 40% (25.6 kg) drop hammer was used to advance the splitspoon sampler. The "N" values presented above have been corrected to provide an estimate of the "N" value that would have been obtained with a standard 64 kg hammer

Column headings: SOIL PROFILE; STRAT PLOT; SAMPLES; GROUND WATER CONDITIONS; DYNAMIC CONE PENETRATION RESISTANCE PLOT 20 40 60 80 100; SHEAR STRENGTH kPa ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × LAB VANE 20 40 60 80 100; PLASTIC LIMIT w_P, NATURAL MOISTURE CONTENT w, LIQUID LIMIT w_L; WATER CONTENT (%) 20 40 60; UNIT WEIGHT γ kN/m^3

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

Ministry of Transportation Ontario

THURBER

RECORD OF BOREHOLE No 17-15

METRIC

GWP# 5181-13-00 | LOCATION Culvert at Station 17+230, MTM z13: N 5 176 707.0 E 278 150.0 | ORIGINATED BY KE

HWY 17 | BOREHOLE TYPE NW Casing | COMPILED BY KE

DATUM Geodetic | DATE 2017.12.09 - 2017.12.09 | CHECKED BY FG

ELEV / DEPTH	DESCRIPTION	NUMBER	TYPE	"N" VALUES	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
197.1					
0.0	GRAVEL with Sand, frequent Cobbles and Boulders **FILL** Compact Grey				
		1	SS	18	
195.6 / 1.5	Silty SAND with Gravel, frequent Cobbles and Boulders **FILL** Compact Brown	2	SS	17	32 47 21 (SI+CL)
195.0 / 2.1	SAND **FILL** Very Loose to Loose Brown	3	SS	4	
		4	SS	2	5 91 4 (SI+CL)
		5	SS	5	
		6	SS	2	
		7	SS	9	
		8	SS	6	
		9	SS	6	
188.4 / 8.7	**Organic SILT** Very Loose Grey-Black				organic content 6.6%
187.9 / 9.2	**CLAY (CH)** Firm Red-Grey	10	SS	WH	
187.5 / 9.6	**Silty SAND (SM)**, trace Organics				

Column headings also shown: STRAT PLOT; GROUND WATER CONDITIONS; ELEVATION SCALE (197, 196, 195, 194, 193, 192, 191, 190, 189, 188); DYNAMIC CONE PENETRATION RESISTANCE PLOT 20 40 60 80 100; SHEAR STRENGTH kPa ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × LAB VANE 20 40 60 80 100; PLASTIC LIMIT w_P, NATURAL MOISTURE CONTENT w, LIQUID LIMIT w_L, WATER CONTENT (%) 20 40 60; UNIT WEIGHT γ kN/m³.

Continued Next Page

+ ³, × ³: Numbers refer to Sensitivity

20 / 15 5 / 10 (%) STRAIN AT FAILURE

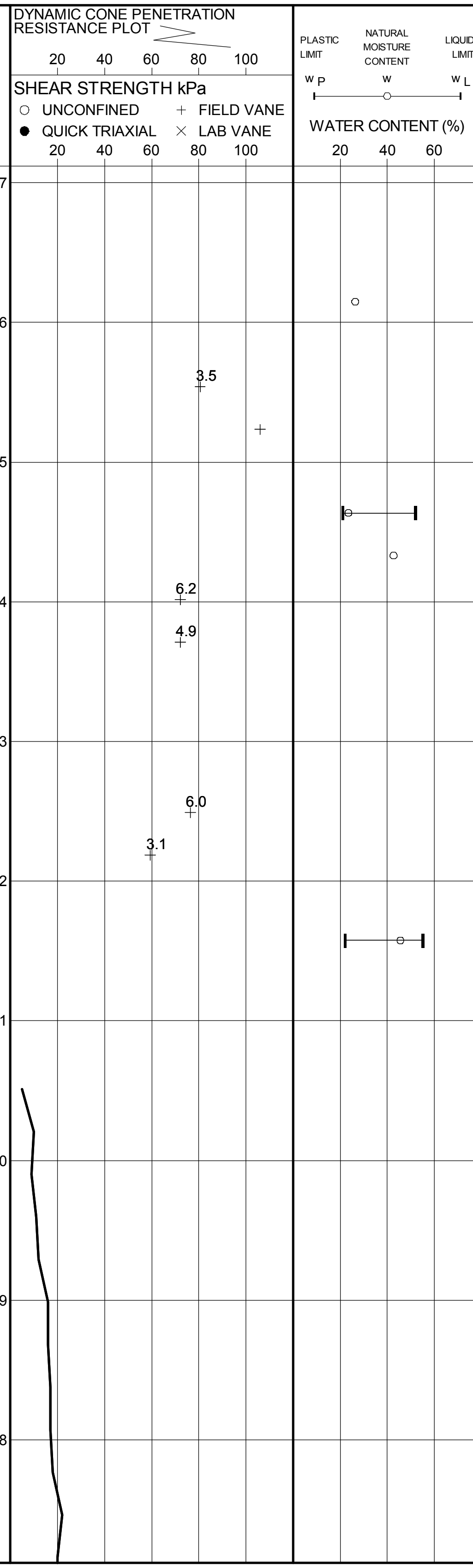
RECORD OF BOREHOLE No 17-15

METRIC

GWP# 5181-13-00	LOCATION Culvert at Station 17+230, MTM z13: N 5 176 707.0 E 278 150.0		ORIGINATED BY KE
HWY 17	BOREHOLE TYPE NW Casing		COMPILED BY KE
DATUM Geodetic	DATE 2017.12.09 - 2017.12.09		CHECKED BY FG

Continued From Previous Page

ELEV / DEPTH	DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	ELEVATION SCALE	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
186.9 / 10.2	Very Loose Grey-Black				187	
	CLAY (CH) with Silt Interbeds, Stiff to Very Stiff, Red-Grey	11	SS	9	186	
	- Shear Strength >106 kPa				185	
		12	SS	3		0 3 37 60
184.3 / 12.8	**CLAY (CH)** Stiff Red-Grey				184	
		13	TW	PUSH	183	
					182	
		14	SS	WH		0 1 34 65
181.3 / 15.8	End of Sampled Borehole. DCPT carried out from 15.8 to 31.4 m				181, 180, 179, 178	



UNIT WEIGHT γ kN/m³

Continued Next Page

+³, ×³: Numbers refer to Sensitivity

(%) STRAIN AT FAILURE

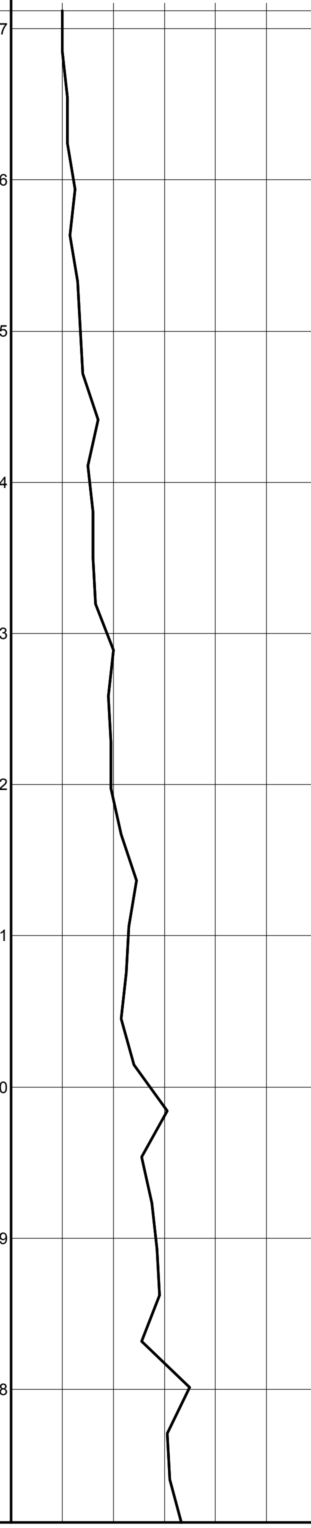
Ministry of Transportation
Ontario

THURBER

RECORD OF BOREHOLE No 17-15 METRIC

GWP# 5181-13-00	LOCATION Culvert at Station 17+230, MTM z13: N 5 176 707.0 E 278 150.0	ORIGINATED BY KE
HWY 17	BOREHOLE TYPE NW Casing	COMPILED BY KE
DATUM Geodetic	DATE 2017.12.09 - 2017.12.09	CHECKED BY FG

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT 20 40 60 80 100; SHEAR STRENGTH kPa ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × LAB VANE 20 40 60 80 100	PLASTIC LIMIT w_P — NATURAL MOISTURE CONTENT w — LIQUID LIMIT w_L; WATER CONTENT (%) 20 40 60	UNIT WEIGHT γ kN/m3	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES						
	Continued From Previous Page										
	DCPT continued						177				
							176				
							175				
							174				
							173				
							172				
							171				
							170				
							169				
							168				



Continued Next Page

+3, ×3: Numbers refer to Sensitivity

20 / 15 5 / 10 (%) STRAIN AT FAILURE

ONTMT4S 17848_CULVERT17+230.GPJ 2012TEMPLATE(MTO).GDT 3/7/18

Ministry of Transportation Ontario

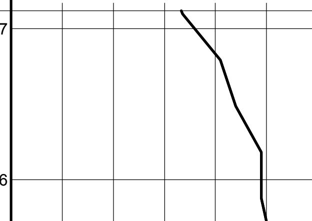
THURBER

RECORD OF BOREHOLE No 17-15

METRIC

GWP#	5181-13-00	LOCATION	Culvert at Station 17+230, MTM z13: N 5 176 707.0 E 278 150.0	ORIGINATED BY	KE
HWY	17	BOREHOLE TYPE	NW Casing	COMPILED BY	KE
DATUM	Geodetic	DATE	2017.12.09 - 2017.12.09	CHECKED BY	FG

ELEV DEPTH	SOIL PROFILE – DESCRIPTION	STRAT PLOT	SAMPLES – NUMBER	SAMPLES – TYPE	SAMPLES – "N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT (20, 40, 60, 80, 100) / SHEAR STRENGTH kPa (○ UNCONFINED, + FIELD VANE, ● QUICK TRIAXIAL, × LAB VANE) (20, 40, 60, 80, 100)	PLASTIC LIMIT w_P – NATURAL MOISTURE CONTENT w – LIQUID LIMIT w_L; WATER CONTENT (%) (20, 40, 60)	UNIT WEIGHT γ kN/m³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
	Continued From Previous Page										
	DCPT continued						167				
							166				
165.7 / 31.4	DCPT refusal at 31.4 m due to skin friction										



ONTMT4S 17848_CULVERT17+230.GPJ 2012TEMPLATE(MTO).GDT 3/7/18

+ 3, × 3: Numbers refer to Sensitivity

20 / 15 ⊕ 5 / 10 (%) STRAIN AT FAILURE

Ministry of Transportation
Ontario

THURBER

RECORD OF BOREHOLE No 17-16

METRIC

GWP# 5181-13-00	LOCATION Culvert at Station 17+230, MTM z13: N 5 176 705.0 E 278 169.0		ORIGINATED BY DJP
HWY 17	BOREHOLE TYPE Hollow Stem Auger		COMPILED BY KE
DATUM Geodetic	DATE 2017.12.06 - 2017.12.06		CHECKED BY FG

SOIL PROFILE

ELEV / DEPTH	DESCRIPTION
197.1	
0.0 / 0.1	**100 mm Topsoil**
	Silty SAND **FILL**, Loose, Brown
194.6 / 2.4	SILT some Sand **FILL**, Very Loose to Loose, Grey-Brown
190.5 / 6.6	Silty SAND **FILL**, Loose, Brown
190.1 / 7.0	**Organic SILT**, Loose, Grey
189.5 / 7.5	**Silty SAND (SM)**, Compact, Brown

SAMPLES

NUMBER	TYPE	"N" VALUES	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
1	SS	9	
2	SS	5	0 55 45 (SI+CL)
3	SS	5	
4	SS	3	
5	SS	2	
6	SS	2	
7	SS	1	0 10 81 9 non-plastic
8	SS	3	
9	SS	8	
10	SS	5	organic content 10.1%
11	SS	13	
12	SS	14	1 78 21 (SI+CL)
13	SS	25	

STRAT PLOT | GROUND WATER CONDITIONS | ELEVATION SCALE: 197, 196, 195, 194, 193, 192, 191, 190, 189, 188

DYNAMIC CONE PENETRATION RESISTANCE PLOT: 20 40 60 80 100

SHEAR STRENGTH kPa: ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × LAB VANE: 20 40 60 80 100

PLASTIC LIMIT w_P — NATURAL MOISTURE CONTENT w — LIQUID LIMIT w_L

WATER CONTENT (%): 20 40 60

UNIT WEIGHT γ kN/m3

Continued Next Page

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

Ministry of Transportation Ontario

THURBER

RECORD OF BOREHOLE No 17-16

METRIC

GWP# 5181-13-00 | LOCATION Culvert at Station 17+230, MTM z13: N 5 176 705.0 E 278 169.0 | ORIGINATED BY DJP

HWY 17 | BOREHOLE TYPE Hollow Stem Auger | COMPILED BY KE

DATUM Geodetic | DATE 2017.12.06 - 2017.12.06 | CHECKED BY FG

Continued From Previous Page

ELEV / DEPTH	DESCRIPTION	NUMBER	TYPE	"N" VALUES	ELEVATION SCALE	SHEAR STRENGTH kPa (FIELD VANE, sensitivity)	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
	Silty SAND (SM) Compact Brown				187		
		14	SS	7	186		
185.3 / 11.7	**Sandy SILT (ML)** Very Loose Grey				185		
		15	SS	2			0 44 42 14 non-plastic
184.3 / 12.7	**CLAY (CH)** Stiff Red-Brown				184	+ 2.3; + 2.6	
		16	SS	4	183		0 4 26 70
						+ 3.6; + 3.6	
		17	SS	4	182		
		18	SS	5	181		
180.6 / 16.5	End of Sampled Borehole DCPT carried out from 16.5 to 19.8 m				180, 179, 178		
177.3 / 19.8	End of DCPT at 19.8 m						

Continued Next Page

Column headings: SOIL PROFILE; STRAT PLOT; SAMPLES; GROUND WATER CONDITIONS; DYNAMIC CONE PENETRATION RESISTANCE PLOT 20 40 60 80 100; SHEAR STRENGTH kPa ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × LAB VANE 20 40 60 80 100; PLASTIC LIMIT w_P, NATURAL MOISTURE CONTENT w, LIQUID LIMIT w_L; WATER CONTENT (%) 20 40 60; UNIT WEIGHT γ kN/m³

+ 3, × 3: Numbers refer to Sensitivity

20 / 15 ⊕ 5 / 10 (%) STRAIN AT FAILURE

Ministry of Transportation Ontario

THURBER

RECORD OF BOREHOLE No 17-16

METRIC

GWP#	5181-13-00	LOCATION	Culvert at Station 17+230, MTM z13: N 5 176 705.0 E 278 169.0	ORIGINATED BY	DJP
HWY	17	BOREHOLE TYPE	Hollow Stem Auger	COMPILED BY	KE
DATUM	Geodetic	DATE	2017.12.06 - 2017.12.06	CHECKED BY	FG

ELEV DEPTH	SOIL PROFILE: DESCRIPTION	STRAT PLOT	SAMPLES: NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT (20 40 60 80 100); SHEAR STRENGTH kPa (○ UNCONFINED, + FIELD VANE, ● QUICK TRIAXIAL, × LAB VANE) 20 40 60 80 100	PLASTIC LIMIT w_P / NATURAL MOISTURE CONTENT w / LIQUID LIMIT w_L; WATER CONTENT (%) 20 40 60	UNIT WEIGHT γ kN/m³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
	Continued From Previous Page										
	Water Level in Standpipe 2017.12.07 8.46 mbgs 2017.12.09 8.22 mbgs 2017.12.10 8.16 mbgs 2017.12.11 8.12 mbgs										

+ 3, × 3: Numbers refer to Sensitivity

20 / 15 / 5 / 10 (%) STRAIN AT FAILURE

Ministry of Transportation
Ontario

THURBER

RECORD OF BOREHOLE No 17-17

METRIC

GWP# 5181-13-00
LOCATION Culvert at Station 17+230, MTM z13: N 5 176 688.0 E 278 183.0
ORIGINATED BY DJP

HWY 17
BOREHOLE TYPE Portable
COMPILED BY KE

DATUM Geodetic
DATE 2017.12.07 - 2017.12.07
CHECKED BY FG

ELEV DEPTH	DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	ELEVATION SCALE	SHEAR STRENGTH kPa (field vane)	WATER CONTENT (%) (approx.)	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
193.0								
0.0 / 0.1	25 mm Topsoil							
	SILT (ML) some Sand trace Organics, Very Loose to Loose, Brown-Grey	1	SS	2			~57	
		2	SS	4	192		~44	0 13 75 12 non-plastic
191.4 / 1.6	**Sandy SILT (ML)** with Organics, Loose, Grey	3	SS	4	191		~67	0 39 53 8 non-plastic
190.8 / 2.1	**SAND (SP)**, occasional Wood fragments, Loose to Compact, Brown	4	SS	8			~41	
		5	SS	20	190		~24	0 97 3 (SI+CL)
		6	SS	40	189		~27	
188.7 / 4.3	**Sandy SILT (ML)**, Compact to Loose, Grey	7	SS	13	188		~26	0 48 40 12 non-plastic
		8	SS	7	187 / 186		~46	
185.8 / 7.2	**CLAY (CH)**, Firm to Stiff, Red-Brown	9	SS	3	185	4.0 / 3.7	~57	
		10	SS	6	184 / 183		~57	

DYNAMIC CONE PENETRATION RESISTANCE PLOT: 20 40 60 80 100

SHEAR STRENGTH kPa: ○ UNCONFINED, + FIELD VANE, ● QUICK TRIAXIAL, × LAB VANE

PLASTIC LIMIT w_P, NATURAL MOISTURE CONTENT w, LIQUID LIMIT w_L

UNIT WEIGHT γ kN/m³

Continued Next Page

+ ³, × ³: Numbers refer to Sensitivity

20 / 15 ⊕ 5 / 10 (%) STRAIN AT FAILURE

ONTMT4S 17848_CULVERT17+230.GPJ 2012TEMPLATE(MTO).GDT 3/7/18

RECORD OF BOREHOLE No 17-17

METRIC

GWP# 5181-13-00 LOCATION Culvert at Station 17+230, MTM z13: N 5 176 688.0 E 278 183.0 ORIGINATED BY DJP

HWY 17 BOREHOLE TYPE Portable COMPILED BY KE

DATUM Geodetic DATE 2017.12.07 - 2017.12.07 CHECKED BY FG

ELEV / DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT (20 40 60 80 100) / SHEAR STRENGTH kPa (○ UNCONFINED, + FIELD VANE, ● QUICK TRIAXIAL, × LAB VANE) (20 40 60 80 100)	PLASTIC LIMIT w_P / NATURAL MOISTURE CONTENT w / LIQUID LIMIT w_L — WATER CONTENT (%) (20 40 60)	UNIT WEIGHT γ kN/m³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
	Continued From Previous Page										
	CLAY (CH) Firm to Stiff Red-Brown							+ 6.0; + 5.2			
			11	SS	8		182		○		
181.7 / 11.3	End of Borehole										

+ 3, × 3: Numbers refer to Sensitivity

20 / 15 5 / 10 (%) STRAIN AT FAILURE

Ministry of Transportation
Ontario

THURBER

RECORD OF BOREHOLE No 17-18

METRIC

GWP# 5181-13-00	LOCATION Culvert at Station 17+230, MTM z13: N 5 176 737.0 E 278 143.0		ORIGINATED BY DJP
HWY 17	BOREHOLE TYPE Hollow Stem Auger		COMPILED BY KE
DATUM Geodetic	DATE 2017.12.11 - 2017.12.11		CHECKED BY FG

SOIL PROFILE | SAMPLES | GROUND WATER CONDITIONS | ELEVATION SCALE | DYNAMIC CONE PENETRATION RESISTANCE PLOT (20 40 60 80 100) | SHEAR STRENGTH kPa (○ UNCONFINED, + FIELD VANE, ● QUICK TRIAXIAL, × LAB VANE; 20 40 60 80 100) | PLASTIC LIMIT w_P, NATURAL MOISTURE CONTENT w, LIQUID LIMIT w_L — WATER CONTENT (%) 20 40 60 | UNIT WEIGHT γ kN/m³ | REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL

ELEV DEPTH	DESCRIPTION	NUMBER	TYPE	"N" VALUES	REMARKS GR SA SI CL
196.4					
0.0	SAND with Silt, some Gravel **FILL** Compact Brown	1	SS	16	13 80 7 (SI+CL)
195.7 0.7	Silty SAND **FILL** Compact to Loose Brown-Grey	2	SS	10	
		3	SS	6	
194.1 2.4	**SILT (ML)** trace Sand Very Loose Grey	4	SS	1	
		5	SS	2	0 6 80 14 non-plastic
191.9 4.5	**Silty SAND (SM)** Compact to Loose Grey to Brown-Grey	6	SS	11	
		7	SS	8	
		8	SS	5	0 51 49 (SI+CL)
		9	SS	6	
		10	SS	8	
		11	SS	10	
187.6 8.8	**SAND (SP)** trace Silt Compact Red-Brown	12	SS	20	

Elevation scale: 196, 195, 194, 193, 192, 191, 190, 189, 188, 187

Continued Next Page

$+^3, \times^3$: Numbers refer to Sensitivity

20 / 15 5 / 10 (%) STRAIN AT FAILURE

Ministry of Transportation Ontario

THURBER

RECORD OF BOREHOLE No 17-18

METRIC

GWP# 5181-13-00 | LOCATION Culvert at Station 17+230, MTM z13: N 5 176 737.0 E 278 143.0 | ORIGINATED BY DJP

HWY 17 | BOREHOLE TYPE Hollow Stem Auger | COMPILED BY KE

DATUM Geodetic | DATE 2017.12.11 - 2017.12.11 | CHECKED BY FG

Continued From Previous Page

ELEV / DEPTH	DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	ELEVATION SCALE	WATER CONTENT	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
	SAND (SP) trace Silt Compact Red-Brown				186		
		13	SS	8		○	1 90 9 (SI+CL)
184.7					185		
11.7	**SILT (ML)** with Sand, occasional Clay interbeds Loose to Compact Red-Grey						
		14	SS	8	184	○	
					183		
		15	SS	5		○	0 24 65 11 non-plastic
					182		
		16	SS	14	181	○	
180.6 15.8	End of Borehole Borehole caved to 6.0 m B.G.S. when augers were pulled						

Column headings: SOIL PROFILE (ELEV DEPTH, DESCRIPTION, STRAT PLOT); SAMPLES (NUMBER, TYPE, "N" VALUES); GROUND WATER CONDITIONS; ELEVATION SCALE; DYNAMIC CONE PENETRATION RESISTANCE PLOT 20 40 60 80 100; SHEAR STRENGTH kPa ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × LAB VANE 20 40 60 80 100; PLASTIC LIMIT w_P, NATURAL MOISTURE CONTENT w, LIQUID LIMIT w_L, WATER CONTENT (%) 20 40 60; UNIT WEIGHT γ kN/m³; REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL

+³, ×³: Numbers refer to Sensitivity

20 / 15 ⊕ 5 / 10 (%) STRAIN AT FAILURE

Appendix C.

Laboratory Testing

Appendix C.1

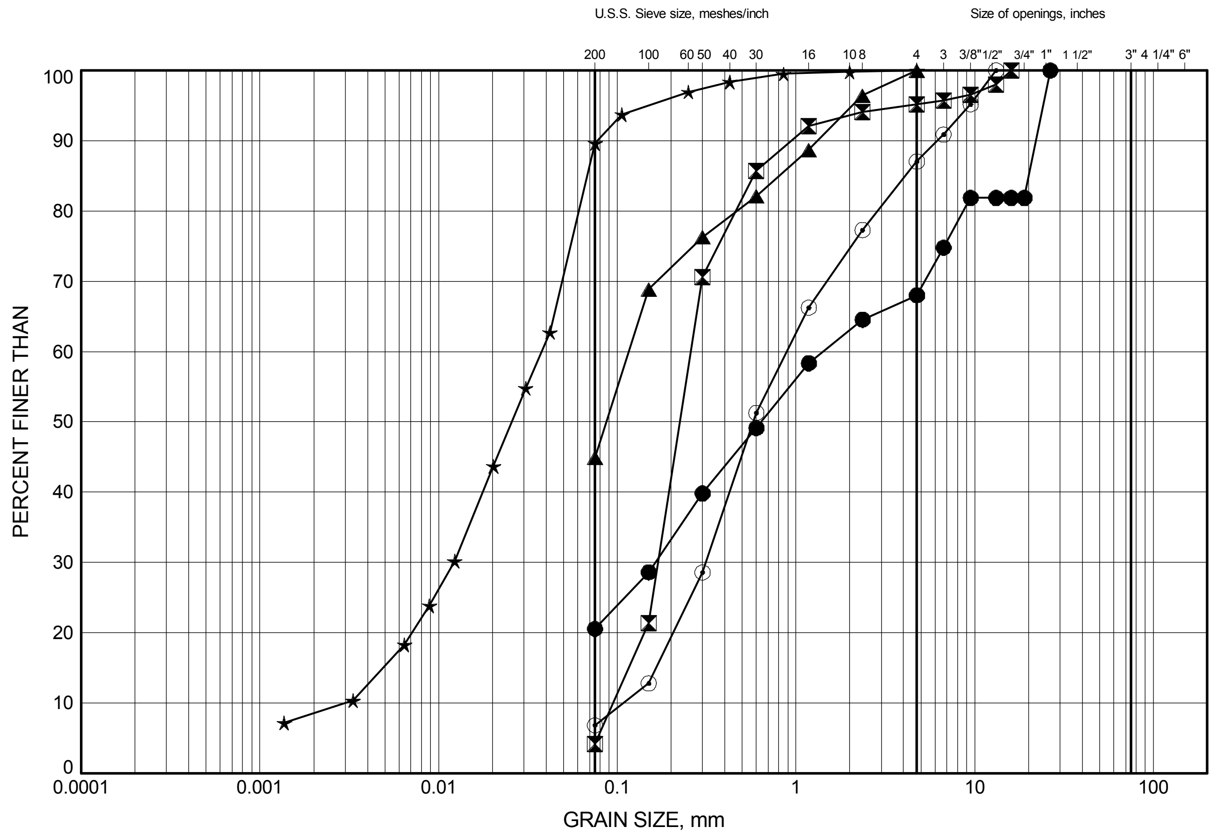
Particle Size Analysis Figures

Culvert at Station 17+230

GRAIN SIZE DISTRIBUTION

FIGURE C1

Non-Cohesive Fill



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

LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	17-15	1.83	195.29
⧗	17-15	3.35	193.77
▲	17-16	1.07	196.01
★	17-16	4.88	192.20
⊙	17-18	0.30	196.13

Date May 2018

GWP# 5181-13-00

THURBER

Prep'd CM

Chkd. FJG

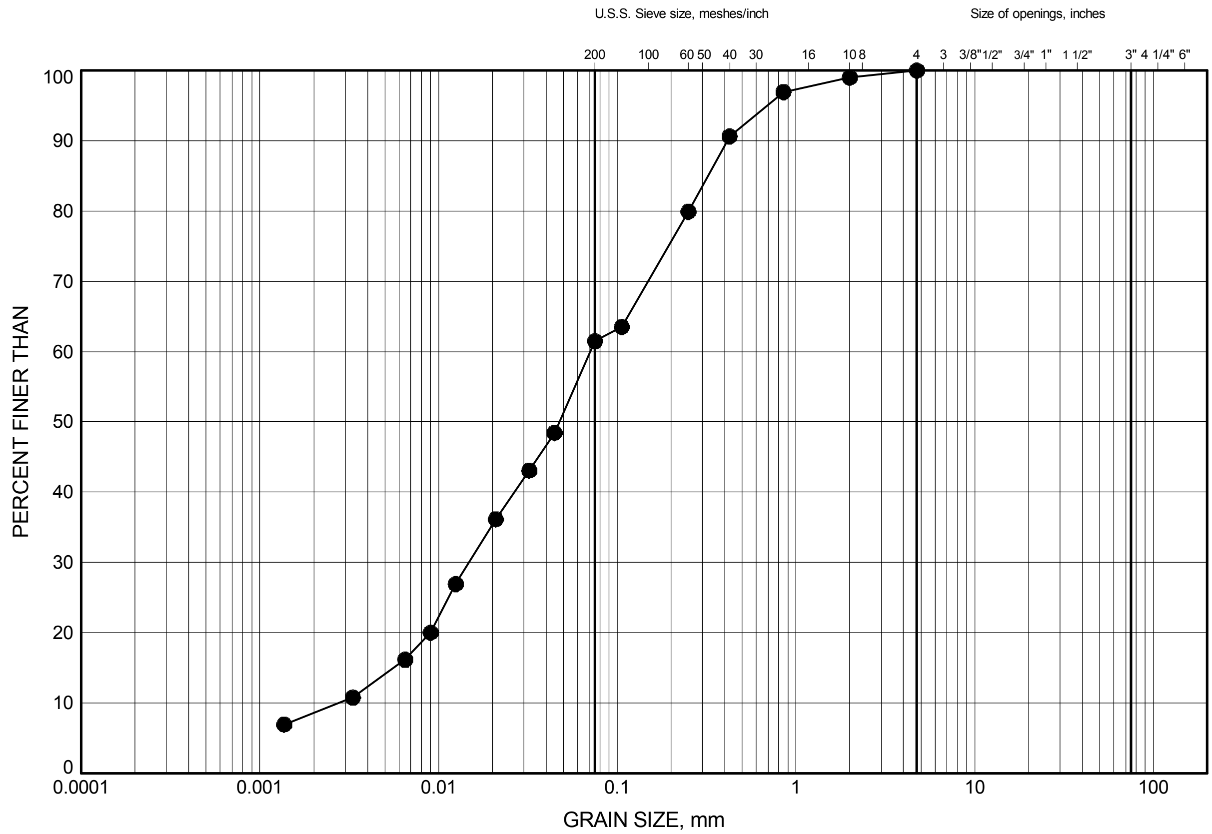
GRAIN SIZE DISTRIBUTION - THURBER 17848_CULVERT17+230.GPJ 29/5/18

Culvert at Station 17+230

GRAIN SIZE DISTRIBUTION

FIGURE C2

Sandy Silt with Organics



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

LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	17-17	1.83	191.15

Date May 2018

GWP# 5181-13-00

THURBER

Prep'd CM

Chkd. FJG

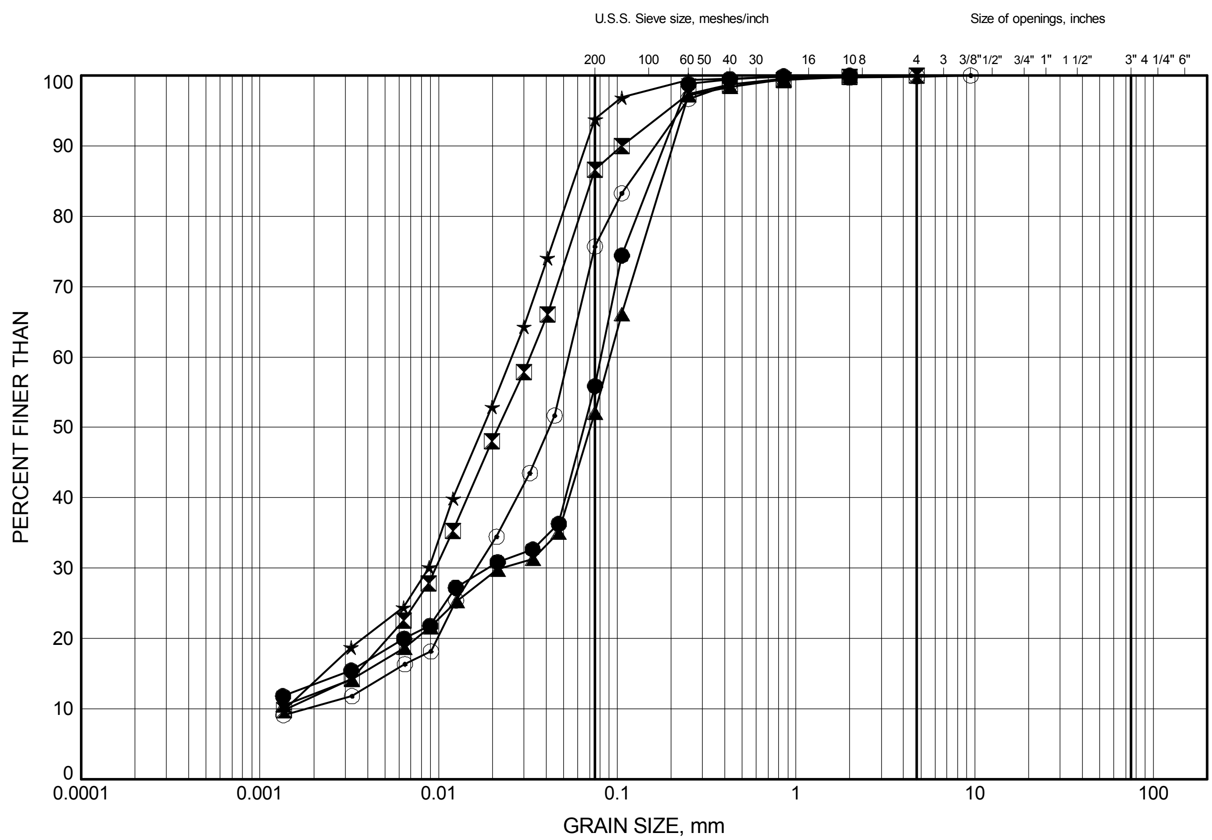
GRAIN SIZE DISTRIBUTION - THURBER 17848_CULVERT17+230.GPJ 29/5/18

Culvert at Station 17+230

GRAIN SIZE DISTRIBUTION

FIGURE C3

Silt



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

LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	17-16	12.50	184.58
⧗	17-17	0.91	192.07
▲	17-17	4.88	188.10
★	17-18	3.35	193.08
⊙	17-18	14.02	182.41

Date May 2018

GWP# 5181-13-00

THURBER

Prep'd CM

Chkd. FJG

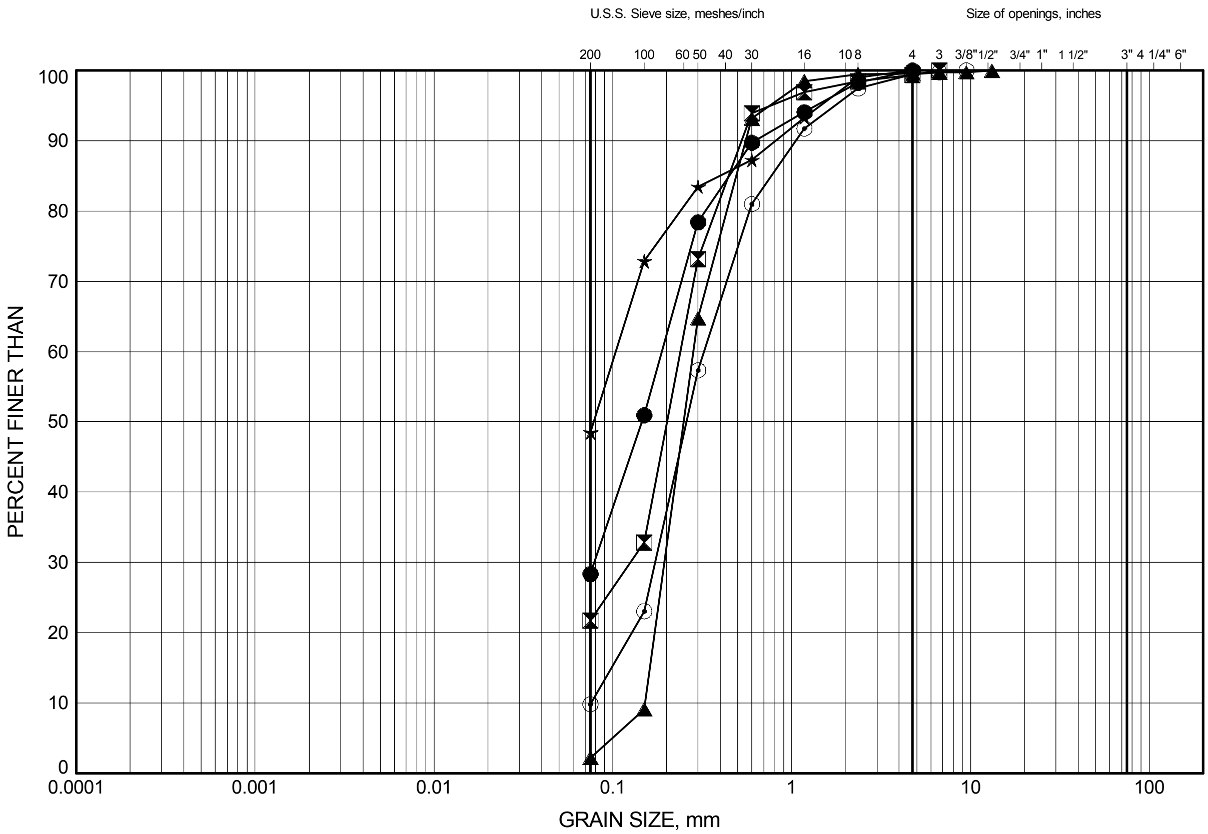
GRAIN SIZE DISTRIBUTION - THURBER 17848_CULVERT17+230.GPJ 29/5/18

Culvert at Station 17+230

GRAIN SIZE DISTRIBUTION

FIGURE C4

Sand



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

LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	17-14	0.91	190.44
⧗	17-16	8.69	188.39
▲	17-17	3.35	189.63
★	17-18	6.40	190.03
⊙	17-18	10.97	185.46

GRAIN SIZE DISTRIBUTION - THURBER 17848_CULVERT17+230.GPJ 29/5/18

Date May 2018

GWP# 5181-13-00

THURBER

Prep'd CM

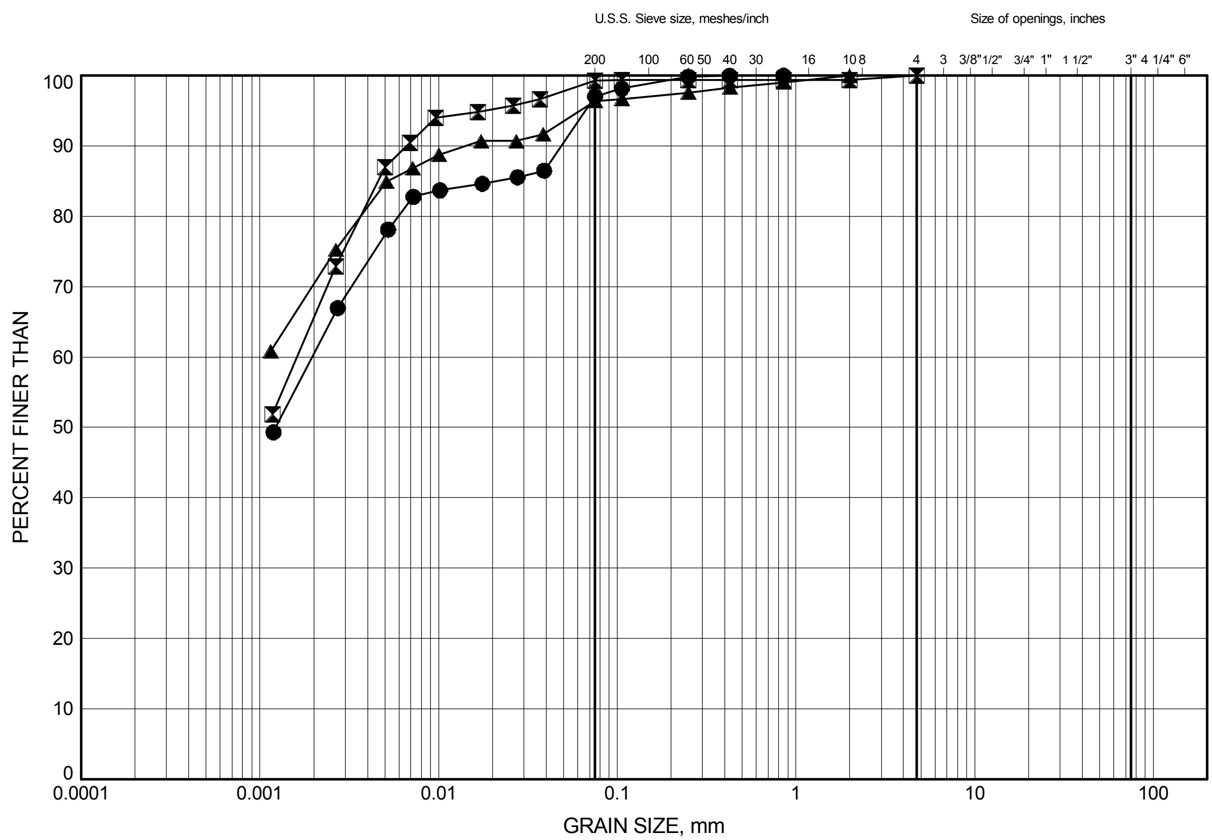
Chkd. FJG

Culvert at Station 17+230

GRAIN SIZE DISTRIBUTION

FIGURE C5

Clay



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

LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	17-15	12.48	184.64
⧗	17-15	15.54	181.58
▲	17-16	14.02	183.06

Date February 2018

GWP# 5181-13-00

THURBER

Prep'd CM

Chkd. FJG

GRAIN SIZE DISTRIBUTION - THURBER 17848_CULVERT17+230.GPJ 23/2/18

Appendix C.2

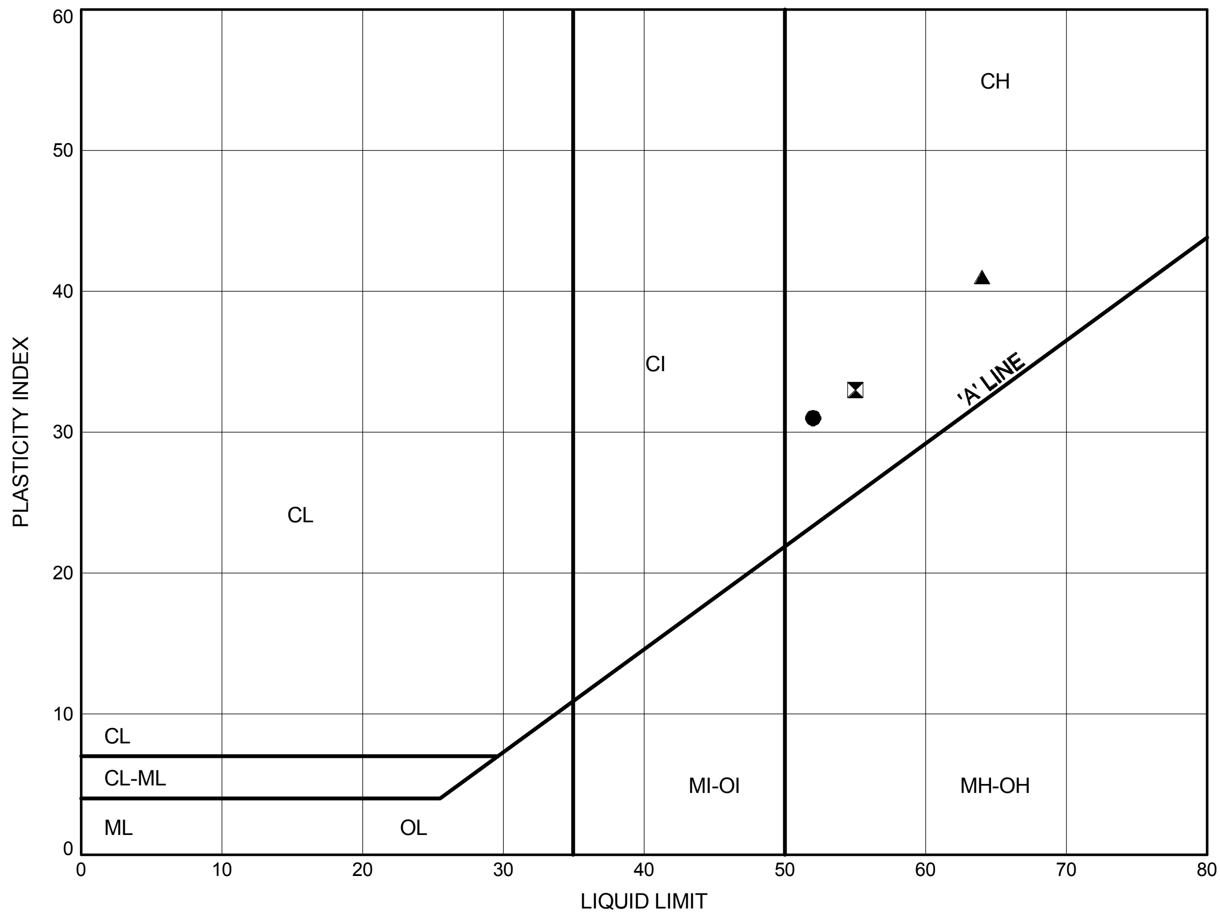
Atterberg Limit Analysis Figures

Culvert at Station 17+230

ATTERBERG LIMITS TEST RESULTS

FIGURE C6

Clay



LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	17-15	12.48	184.64
⧗	17-15	15.54	181.58
▲	17-16	14.02	183.06

THURBALT 17848_CULVERT17+230.GPJ 23/2/18

Date February 2018

GWP# 5181-13-00

THURBER

Prep'd CM

Chkd. FJG

Appendix C.3

Analytical Testing Results

PARACEL LABORATORIES LTD. TRUSTED. RESPONSIVE. RELIABLE.

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www.paracellabs.com

Certificate of Analysis

Thurber Engineering Ltd.

2460 Lancaster Rd, Suite 104
Ottawa, ON K1B 4S5
Attn: Katya Edney

Client PO:
Project: 17848 SSM to Goulais
Custody: 39588

Report Date: 29-Jan-2018
Order Date: 23-Jan-2018

Order #: 1804148

This Certificate of Analysis contains analytical data applicable to the following samples as submitted:

Paracel ID	Client ID
~~1804148-01~~	~~17-4 SS3 5-7'~~
~~1804148-02~~	~~17-6 SS2 2'6"-4'6"~~
~~1804148-03~~	~~17-10 SS2 2'6"-4'6"~~
1804148-04	17-14 SS 3A 4'-4'6"

Approved By: Mark Foto

Mark Foto, M.Sc.
Lab Supervisor

Analysis Summary Table

Analysis	Method Reference/Description	Extraction Date	Analysis Date
Anions	EPA 300.1 - IC, water extraction	25-Jan-18	25-Jan-18
Conductivity	MOE E3138 - probe @25 °C, water ext	25-Jan-18	25-Jan-18
pH, soil	EPA 150.1 - pH probe @ 25 °C, CaCl buffered ext.	23-Jan-18	24-Jan-18
Resistivity	EPA 120.1 - probe, water extraction	25-Jan-18	25-Jan-18
Solids, %	Gravimetric, calculation	26-Jan-18	29-Jan-18

Certificate of Analysis

Client: Thurber Engineering Ltd.

Client PO:

Report Date: 29-Jan-2018

Order Date: 23-Jan-2018

Project Description: 17848 SSM to Goulais

	Client ID:	17-4 SS3 5-7'	17-6 SS2 2'6"-4'6"	17-10 SS2 2'6"-4'6"	17-14 SS 3A 4'-4'6"
	Sample Date:	21-Nov-17	25-Nov-17	10-Dec-17	10-Dec-17
	Sample ID:	1804148-01	1804148-02	1804148-03	1804148-04
	MDL/Units	Soil	Soil	Soil	Soil
Physical Characteristics					
% Solids	0.1 % by Wt.	94.9	94.2	87.0	83.4
General Inorganics					
Conductivity	5 uS/cm	165	605	301	502
pH	0.05 pH Units	7.01	6.36	6.20	6.20
Resistivity	0.10 Ohm.m	60.7	16.5	33.2	19.9
Anions					
Chloride	5 ug/g dry	29 [1]	234 [1]	114 [1]	247 [1]
Sulphate	5 ug/g dry	103 [1]	230 [1]	69 [1]	88 [1]

Certificate of Analysis
Client: Thurber Engineering Ltd.
Client PO:

Report Date: 29-Jan-2018
Order Date: 23-Jan-2018
Project Description: 17848 SSM to Goulais

Method Quality Control: Blank

Analyte	Result	Reporting Limit	Units	Source Result	%REC	%REC Limit	RPD	RPD Limit	Notes
Anions									
Chloride	ND	5	ug/g						
Sulphate	ND	5	ug/g						
General Inorganics									
Conductivity	ND	5	uS/cm						
Resistivity	ND	0.10	Ohm.m						

Method Quality Control: Duplicate

Analyte	Result	Reporting Limit	Units	Source Result	%REC	%REC Limit	RPD	RPD Limit	Notes
Anions									
Chloride	85.2	5	ug/g dry	87.4			2.5	20	
Sulphate	47.3	5	ug/g dry	48.0			1.5	20	
General Inorganics									
Conductivity	1250	5	uS/cm	1250			0.2	6.2	
pH	7.61	0.05	pH Units	7.58			0.4	10	
Resistivity	7.99	0.10	Ohm.m	7.97			0.2	20	
Physical Characteristics									
% Solids	83.2	0.1	% by Wt.	83.4			0.3	25	

Certificate of Analysis
Client: Thurber Engineering Ltd.
Client PO:

Report Date: 29-Jan-2018
Order Date: 23-Jan-2018
Project Description: 17848 SSM to Goulais

Method Quality Control: Spike

Analyte	Result	Reporting Limit	Units	Source Result	%REC	%REC Limit	RPD	RPD Limit	Notes
Anions									
Chloride	187	5	ug/g	87.4	99.2	78-113			
Sulphate	153	5	ug/g	48.0	105	78-111			

Qualifier Notes:

Login Qualifiers :

Sample - One or more parameter received past hold time - pH, Chloride, Sulphate, and Conductivity.
Applies to samples: 17-4 SS3 5-7', 17-6 SS2 2'6''-4'6'', 17-10 SS2 2'6''-4'6'', 17-14 SS 3A 4'-4'6''

Sample Qualifiers :

1 : Holding time had been exceeded upon receipt of the sample at the laboratory.

Sample Data Revisions

None

Work Order Revisions / Comments:

None

Other Report Notes:

n/a: not applicable
ND: Not Detected
MDL: Method Detection Limit
Source Result: Data used as source for matrix and duplicate samples
%REC: Percent recovery.
RPD: Relative percent difference.

Soil results are reported on a dry weight basis when the units are denoted with 'dry'.
Where %Solids is reported, moisture loss includes the loss of volatile hydrocarbons.

Appendix D.

Site Photographs

Photo 1. Looking east (upstream) of Highway 17

Photo 2. Looking west (downstream) of Highway 17

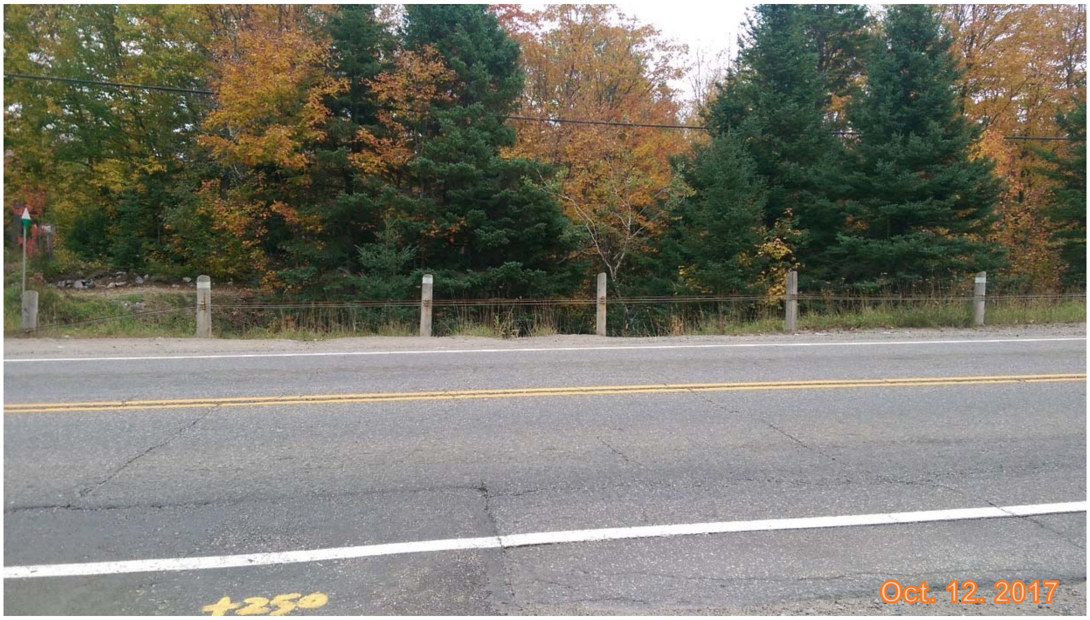


Photo 3. Looking east at Highway 17 over culvert alignment

Photo 4. Looking east at Culvert outlet

Photo 5. Looking west at Culvert inlet

Appendix E.

Foundation and Construction Methodology Comparison Tables

COMPARISON OF ALTERNATIVE FOUNDATION TYPES

Culvert Type	***Pipe Culvert or Closed Box Culvert***	***Circular Pipe Culvert (Trenchless Installation)***	***Open Bottom Culvert***
Advantages	- Typically the least costly culvert type - Relatively expedient installation if CSP sections or precast box culvert units are used. - Smaller magnitude of settlement than open footing culvert due to lower bearing stress on subgrade.	- Can tolerate larger magnitude of settlement than concrete (rigid frame) culverts. - Avoids open cut and large excavation quantity - Allows two lanes of traffic to be maintained throughout construction	- Relatively expedient installation if precast units are used. - Possibility to maintain work zone outside of existing waterway.
Disadvantages	- Requires large excavation and roadway protection. - Requires compacted granular pad on subgrade. - Requires waterflow realignment or installation of a temporary by-pass culvert to maintain existing waterflow alignment	- Requires construction of entry and exit pits and access to toes of slope. - Requires specialised construction equipment. - Feasibility also depends on flow capacity and other hydraulic properties.	- Requires deeper excavation increasing excavation volume and dewatering concern. - Potential for post construction settlement.
Risks/ Consequences	- Disruption to traffic - Concrete pipe or box culverts less tolerant of settlements	- Possibility of encountering cobbles or obstructions and mixed soils - Presence of saturated, loose, non-cohesive soils - Proximity of buried utilities may limit installation type and location of entry/exit pits	- Disruption to traffic - Increased risk of basal instability of footing excavation due to depth of excavation below water table.
Relative Cost	**Low to Medium**	**High**	**Medium**
Recommendation	**Recommended**	**Generally Feasible**	**Not Recommended**

COMPARISON OF CONSTRUCTION METHODOLOGY OPTIONS

Comment	Trenchless	Open Cut with Full Road Closure	Staged Construction, with Roadway Protection	Staged Construction with Platform Widening
Advantages	- Avoids open cut	- Allows for an expedited construction schedule - Reduces costs associated with roadway protection and water diversion	- Limits volume of earthwork compared to platform lowering/widening	- Avoids need for installation of protection systems through the roadway
Disadvantages	- Lane reductions may still be required for construction access - Buried fibreoptic cables present in the area of required entry/exit pits	- No acceptable detour route available	- Traffic impacts	- Potentially large volumes of earthwork required - Widened platform will cause settlement of the existing embankment
Risks/ Consequences	- Obstructions/delays - Encountering mixed soils -Presence of saturated, loose, non-cohesive soils			- Utility relocation/increase construction cost and schedule
Relative Cost	High	Low	Moderate	Moderate
	FEASIBLE	**NOT FEASIBLE**	**RECOMENDED**	**FEASIBLE**

Appendix F.

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

February 05, 2018

Site: 46.7293 N, 84.3485 W User File Reference: Culvert at Station 17 230

Requested by: , Thurber Engineering

National Building Code ground motions: 2% probability of exceedance in 50 years (0.000404 per annum)

Sa(0.05)	Sa(0.1)	**Sa(0.2)**	Sa(0.3)	**Sa(0.5)**	**Sa(1.0)**	**Sa(2.0)**	**Sa(5.0)**	**Sa(10.0)**	**PGA (g)**	**PGV (m/s)**
0.046	0.065	**0.062**	0.053	**0.045**	**0.028**	**0.014**	**0.0034**	**0.0015**	**0.036**	**0.034**

Notes. Spectral (Sa(T), where T is the period in seconds) and peak ground acceleration (PGA) values are given in units of g (9.81 m/s^2). Peak ground velocity is given in m/s. Values are for "firm ground" (NBCC 2015 Site Class C, average shear wave velocity 450 m/s). NBCC2015 and CSAS6-14 values are specified in **bold** font. 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.***

Ground motions for other probabilities:

Probability of exceedance per annum	0.010	0.0021	0.001
Probability of exceedance in 50 years	40%	10%	5%
Sa(0.05)	0.0040	0.014	0.024
Sa(0.1)	0.0068	0.022	0.035
Sa(0.2)	0.0084	0.025	0.037
Sa(0.3)	0.0078	0.023	0.034
Sa(0.5)	0.0062	0.020	0.029
Sa(1.0)	0.0032	0.012	0.018
Sa(2.0)	0.0012	0.0051	0.0087
Sa(5.0)	0.0004	0.0011	0.0019
Sa(10.0)	0.0003	0.0007	0.0010
PGA	0.0039	0.013	0.020
PGV	0.0035	0.013	0.021

References

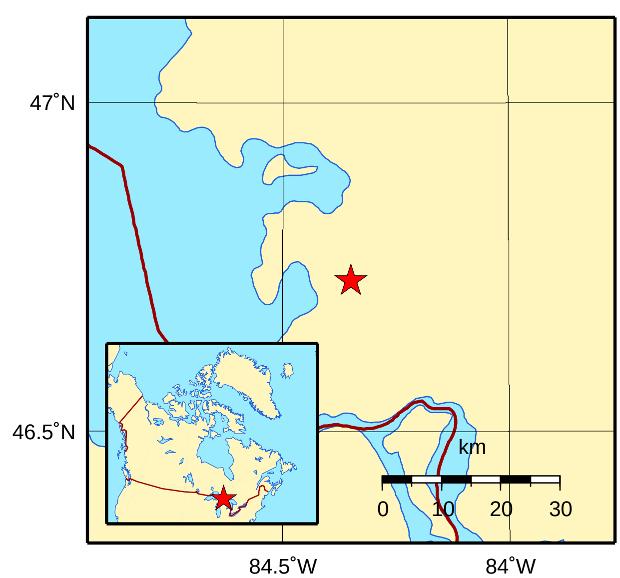
National Building Code of Canada 2015 NRCC no. 56190;
Appendix C: Table C-3, Seismic Design Data for Selected Locations in Canada

User's Guide - NBC 2015, Structural Commentaries NRCC no. xxxxxx (in preparation)
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* and *www.nationalcodes.ca* for more information

Aussi disponible en français



Appendix G.

List of Special Provisions
OPSS Documents Referenced in this Report

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

OPSS.PROV 206	Construction Specification for Grading
OPSS.PROV 401	Construction Specification for Trenching, Backfilling and Compacting
OPSS.PROV 421	Construction Specification for Pipe Culvert Installation in Open Cut
OPSS 422	Construction Specification for Precast Reinforced Concrete Box Culverts in Open Cuts
OPSS.PROV 501	Construction Specification for Compacting
OPSS 511	Construction Specification for Rip-Rap, Rock Protection, and Granular Sheeting
OPSS.PROV 517	Construction Specification for Dewatering of Pipeline, Utility and Associated Structure Excavation
OPSS.PROV 539	Construction Specification for Temporary Protection Systems
OPSS.PROV 804	Construction Specification for Seed and Cover
OPSS 805	Construction Specification for Temporary Erosion and Sediment Control Measures
OPSS.PROV 1010	Material Specification for Aggregates Base, Subbase, Select Subgrade, and Backfill Material
OPSS.PROV 1205	Material Specification for Clay Seal
OPSS 1860	Material Specification for Geotextile
SP No. 517F01	Amendment to OPSS 517 – Dewatering System and Temporary Flow Passage System
OPSD 208.010	Benching of Earth Slopes
OPSD 802.010	Flexible Pipe Embedment and Backfill Earth Excavation
OPSD 803.010	Backfill and Cover for Concrete Culverts with Span Less than or Equal to 3.0 m
OPSD 810.010	General Rip-Rap Layout for Sewer and Culvert Outlets

2. Suggested text for a NSSP on “Installation of Temporary Protection System”

Vibratory equipment is not permitted for installation or removal of temporary protection systems or cofferdams.

3. Suggested text for a NSSP on "Protection of Sensitive Foundation Soils"

The Contractor is advised that the native silt will that will be exposed at the subgrade following removal of existing culvert is 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 implementing adequate groundwater control measures and to minimize construction and personnel traffic on the founding subgrade.

The base of the excavation should be inspected by qualified geotechnical personnel that is experienced in geotechnical inspection to confirm that the exposed subgrade surface conforms to the design requirements. Once approved the subgrade should be protected with a non-woven geotextile placed between the native subgrade and granular bedding.