THURBER ENGINEERING LTD.

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PRELIMINARY FOUNDATION INVESTIGATION AND DESIGN REPORT
HIGHWAY 527 WABIKON CREEK CULVERT
6 KM NORTH OF ON-811, THUNDER BAY UNORGANIZED
SITE NO.: 48C-240/C
ASSIGNMENT NO. 6017-E-0013

G.W.P. 6829-14-00

Geocres No.: -

Report to:

Hatch Corporation

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Longitude: -89.352081°

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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 for the Wabikon Creek Culvert on Highway 527. The culvert is located approximately 6 km north of Tertiary Highway 811 within the Unorganized Thunder Bay District. Thurber Engineering Limited (Thurber) carried out the current investigation as a sub-consultant to Hatch Corporation (Hatch) under Assignment No. 6017-E-0013.

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 information was available for the subject culvert site within the online Geocres Library.

2 SITE DESCRIPTION

The existing culvert, conveying Wabikon Creek under Highway 527, is a twin cell timber culvert with an unknown construction date. A site survey plan from Hatch indicates that the culvert is approximately 3.9 m wide, 1.9 m high and approximately 17.3 m long. The culvert alignment is generally north to south with the flow through the culvert toward the north.

At the location of the culvert, Highway 527 is a two-lane highway with a rural cross-section and gravel shoulders. The embankment fill height above the culvert is approximately 0.6 m. The elevation of the road surface at the centreline is approximately 422.1 m. The existing embankment slopes are inclined between approximately 1.9H:1V and 2.3H:1V. The land adjacent to the highway and waters edge is undeveloped and densely vegetated with trees. Traffic volumes on this section of Highway 527 are understood to be 170 AADT (2016). A sign is present at the culvert site indicating an alternate name for the creek as Cheeseman Creek.

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.

The site investigation and field testing program was carried out between June 7th and June 11th, 2018. 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 15.

Table 3-1: Borehole Summary

Borehole No.	Drilled Location	Northing (m)	Easting (m)	Ground Surface Elevation (m)	Termination Depth (m)
18-401	East of culvert – NB Lane	5 474 122.2	351 844.3	422.1	8.3
18-402	West of culvert – SB Lane	5 474 121.0	351 830.4	422.2	7.6
18-403	South of culvert – culvert inlet	5 474 111.0	351 839.2	419.8	5.2
18-404	North of culvert – culvert outlet	5 474 136.8	351 838.4	419.5	5.0

The drilling was carried out using a truck mounted CME 75 drill rig for on-road Boreholes 18-401 and 18-402 and portable drilling equipment for off-road Boreholes 18-403 and 18-404. Both drills were equipped with NW casing

Soil samples were obtained at selected intervals using a split spoon sampler in conjunction with Standard Penetration Testing (SPT). Boreholes 18-403 and 18-104, which were drilled with portable equipment, also utilized a full-weight hammer for SPT testing. Bedrock was cored and collected in all boreholes using NQ coring equipment.

A 19 mm diameter standpipe piezometer was installed in Borehole 18-403 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. Boreholes advanced within paved areas were capped with granular fill followed by 150 mm of cold patch asphalt to reinstate the travelling surface. The piezometer installed during the investigation was decommissioned in accordance with Ontario MOE Regulation 903 on August 11, 2018.

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 and bedrock 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 testing was also carried out on selected samples to MTO and ASTM standards. All rock cores were photographed and their total core recovery (TCR), solid core recovery (SCR) and rock quality designation (RQD) were measured. Chemical analysis for determination of pH, conductivity, resistivity, sulphate, sulphide 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

Details of the encountered soil stratigraphy are presented on the Record of Borehole sheets included in Appendix B and the Borehole Locations and Soil Strata drawing included in Appendix A. A general description of the stratigraphy, based on the conditions encountered in the boreholes, is given in the following paragraphs. However, the factual data presented on the Record of Borehole sheets takes precedence over this general description for interpretation of the site conditions. It must be recognized that the soil and groundwater conditions may vary between and beyond borehole locations.

In general terms, the site was found to be underlain by a pavement structure and granular embankment fill overlying native gravel which is underlain by bedrock.

5.1 Embankment Fill

5.1.1 Asphalt

Boreholes 18-401 and 18-402 were drilled through the travelled lanes of Highway 527 and encountered a layer of asphalt with a thickness of 50 mm.

5.1.2 Fill: Silty Sand with Gravel

Below the asphalt pavement within the on-road boreholes was a layer of granular embankment fill consisting of silty sand with gravel. Occasional cobbles were encountered within this layer. The underside of the embankment fill ranged from 3.0 to 3.8 m below the existing roadway surface (elev. 418.4 to 419.1 m).

The SPT tests conducted in the fill gave N-values ranging from 29 blows for 300 mm of penetration to 100 blows for 175 mm of penetration, indicating a relative density of compact to very dense; however, the higher blow counts could represent the presence of a cobble rather than the state of packing of the soil matrix. Recorded moisture contents ranged from 6 to 10%.

Gradation analyses were completed on three samples of the granular fill. The grain size distribution curves for these samples are included in Figure C1 of Appendix C. The results of the tests are summarized in Table 5-1 below and are presented on the corresponding Record of Borehole sheets in Appendix B.

Table 5-1: Gradation Results for Embankment Fill

Soil Particle	Percentage (%)
Gravel	16 – 38
Sand	49 – 66
Silt and Clay	13 – 18

5.2 Organic Silt

A layer of organic silt was encountered from surface in off-road Boreholes 18-403 and 18-404. The underside depth of this layer ranged from 0.3 to 1.2 m below ground surface (elev. 418.3 to 419.5 m). Two SPT tests conducted in the organic silt gave N-values of 2 and 18 blows, recognizing that correlations between SPT blow counts and relative density /consistency are not intended for organic soils. One SPT conducted in the organic silt gave an N-Value of 100 blows for 150 mm of penetration; however, this represents refusal on an underlying cobble or boulder. Very poor sample recovery within the split spoon sampler was noted within this layer. The moisture content of the organic silt was measured to range from 69 to 110%.

5.3 Silty Sand to Silty Gravel with Cobbles and Boulders

A fluvial deposit of silty sand to silty gravel was encountered below the embankment fill in Boreholes 18-401 and 18-402, and below the organic silt in Boreholes 18-403 and 18-404. The composition of the deposit generally ranged from silty sand some gravel trace organics to silty gravel with sand. Occasional cobbles were encountered in this layer in Boreholes 18-401, 18-402, and 18-404. This layer consisted predominantly of cobbles and boulders in Borehole 18-403. The thickness of this layer ranged from 0.3 to 1.8 m with underside depths ranging from 1.8 to 4.4 m below ground surface (elev. 417.7 to 418.1 m).

The SPT tests conducted in this layer gave N-values ranging from 38 blows for 300 mm of penetration to 100 blows for 0 mm of penetration, indicating a dense to very dense relative density; however, the higher blow counts could represent the presence of a cobble rather than the state of packing of the soil matrix. The recorded moisture contents ranged from 8 to 32%.

A gradation analysis completed on one sample of the silty sand indicated 11% gravel, 72% sand and 17% fines. A gradation analyses completed on one sample of the silty gravel indicated 44% gravel, 27% sand and 29% fines. The gradation results are presented on the corresponding Record of Borehole sheets in Appendix B and the grain size distribution curves are included in Figures C2 and C3 of Appendix C.

5.4 Bedrock

Bedrock was proven by coring in all boreholes. Information on the confirmed bedrock surface is summarized in Table 5-2 below:

Table 5-2: Summary of Bedrock Elevation

Borehole No.	Depth to Bedrock (mbgs)	Bedrock Surface Elevation (m)
18-401	4.4	417.7
18-402	4.1	418.1
18-403	2.1	417.7
18-404	1.8	417.7

The bedrock encountered within all boreholes consisted of fresh fine to medium grained, dark grey to black basalt. The Total Core Recovery (TCR) measured on the recovered bedrock core ranged from 88 to 100%, the Solid Core Recovery (SCR) ranged from 18 to 100% and the Rock Quality Designation (RQD) ranged from 0 to 90%. Based on the measured RQD values, the bedrock quality is classified as very poor to excellent, but typically fair to good. The basalt bedrock is estimated to be very strong. Photographs of the bedrock core are provided in Appendix C.

5.5 Groundwater

The water level was measured in the piezometer installed in Borehole 18-403 and is presented in Table 5-3 below:

Table 5-3: Groundwater Level Observations

Borehole	Groundwater Level		Date of Measurement
	Depth (mbgs)	Elevation (m)	
18-403	0.1 0.0	419.7 419.8	June 14, 2018 August 11, 2018

The creek water level was also surveyed at the culvert inlet and outlet and the measured elevations are provided in Table 5-4 below:

Table 5-4: Creek Water Level Observations

Location	Surface Water Elevation (m)	Date of Measurement
Culvert Inlet	419.8	June 18, 2018
Culvert Outlet	419.6	June 18, 2018

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

5.6 Analytical Testing

One sample of soil was submitted to Paracel Laboratories in Ottawa, Ontario for analysis of pH, water soluble sulphate, sulphide and chloride concentrations, resistivity and conductivity. The analysis results are provided in Appendix C and are summarized in Table 5-5 below:

Table 5-5: Analytical Results Summary

Borehole	18-401
Sample	SS5
Depth (m)	3.1 – 3.7
Chloride (μg/g)	9
Sulphate (μg/g)	28
Sulphide (%)	< 0.02
pH (-)	7.56
Resistivity (Ohm-cm)	11,100
Conductivity (uS/cm)	90

6 MISCELLANEOUS

Borehole locations were selected in consultation with Hatch and the Ministry of Transportation relative to the existing culvert and the existing site features. The as-drilled locations and ground surface elevations for the boreholes were surveyed by Thurber.

George Downing Estate Drilling Ltd. of Hawkesbury, Ontario and OGS Drilling of Almonte, Ontario supplied and operated the drilling equipment for the on-road and off-road drilling, respectively, to carry out the drilling, soil sampling, in-situ testing, piezometer installation and borehole decommissioning. Traffic control was provided by NC Traffic Management Inc. of Kirkland Lake, Ontario. The field investigation was supervised on a full-time basis by Mr. Nick Weil and Mr. Sean O'Bryan, C.E.T., of Thurber. Overall supervision of the investigation program was conducted by Mr. Stephen Dunlop, P.Eng.

Routine geotechnical laboratory testing was completed by Thurber's laboratory 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 Ms. Allison Chow, E.I.T. and Mr. Stephen Dunlop, P.Eng. The report was reviewed by Dr. Fred Griffiths, P.Eng., a Designated Principal Contact for MTO Foundation Projects.

Allison Chow
Aug 24, 2018

Allison Chow, B.A.Sc., E.I.T.
Geotechnical Engineering Intern

Stephen Dunlop, M.A.Sc., P.Eng.
Senior Geotechnical Engineer

Dr. Fred Griffiths, P.Eng.
Senior Associate
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 project team in designing a suitable foundation for the proposed replacement of the existing Wabikon Creek culvert crossing Highway 527. The discussion and recommendations presented in this report are based on the information provided by Hatch 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, conveying Wabikon Creek under Highway 527, is a twin cell timber culvert with an unknown construction date. A site survey plan from Hatch indicates that the culvert is approximately 3.9 m wide, 1.9 m high and approximately 17.3 m long. The culvert alignment is generally north to south with the flow through the culvert toward the north.

Creek bottom elevations of 419.34 m and 419.29 m at the inlet and outlet, respectively, were surveyed by Thurber during the field investigation. The embankment fill height above the culvert is approximately 0.6 m. The elevation of the road surface at the centreline is approximately 422.1 m. The existing embankment slopes are inclined between approximately 1.9H:1V and 2.3H:1V.

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

7.1 Proposed Structure

At the time of preparation of the draft 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 as the existing culvert.

It was also anticipated that the culvert will be installed on the same alignment as the existing culvert and that the invert elevations would be similar to the existing 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 assumed that the proposed culvert structure has a consequence classification of *Typical Consequence*, in accordance with Section 6.5.1 of the CHBDC. Accordingly, a consequence factor (Ψ) of 1.0, as per Table 6.1 of the CHBDC, has been used in assessing factored geotechnical resistances for this structural culvert.

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 calculated 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). At this site, the PGA for a reference Site Class C with a 2% probability of exceedance in 50 years (2475-year event) is 0.039g. This value is to be scaled by the F(PGA) based on the site specific Site Class.

8.2 CHBDC Seismic Site Classification

In accordance with the CHBDC, the selection of the seismic site classification is based on the soil conditions encountered in the upper 30 m of the stratigraphy. This site has been classified as a Site Class C in accordance with Section 4.4.3.2 of the CHBDC (S6-14). It is considered likely that a more favourable site class (B) would apply to this site, however, this would need to be confirmed with site-specific shear wave velocity testing.

8.3 Seismic Liquefaction

The Seed and Idriss Simplified Method was used to assess the potential for liquefaction at this site. Based on the low reference PGA and the subsurface conditions encountered at the drilled locations at this site, the foundation soils at this site are considered not susceptible to liquefaction during a seismic event.

9 DESIGN OPTIONS

9.1 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, pipe culverts are a feasible culvert option. It is anticipated that a pipe with an internal diameter of 3.0 m or greater will be required to match the existing opening size. Since there is insufficient cover for such a large pipe with a similar invert elevation, multiple smaller diameter circular pipe culverts would likely be required.

- Closed Bottom Culvert (Box)

  A precast segmental box culvert in an open cut construction 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.

- Open Bottom Culvert (Box, Arch)

  Open bottom culverts are considered feasible for this site from a foundation engineering perspective but would require greater excavation (to the bedrock surface) and dewatering efforts. Given the highly permeable layer of gravel, cobbles and boulders, it may not be possible to maintain a dry excavation with conventional pumps due to excessive groundwater inflow (see Section 11.3). For this option, consideration may need to be given to excavating down to the bedrock in the wet and placing a layer of mass concrete below the water using tremie methods to a level that is higher than the drawn-down water level.

- Steel Sheet Pile Walls with Precast Concrete Slab

  A culvert consisting of two rows of parallel sheet pile walls supporting precast concrete slabs is not feasible at this site due to the shallow bedrock encountered during the site investigation.

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

9.2 Construction Methodology Alternative

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

- Open Cut with Full Road Closure and Temporary 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 ground/surface water control. However, it is

understood that an acceptable detour route is not available and therefore this option is not feasible.

- Open Cut with Temporary Modular Bridge Spanning Excavation

  It is anticipated that it will not be feasible at this site to complete a culvert replacement within a full width open cut excavation with a single lane temporary modular bridge (TMB) spanning the excavation since the fill heights are not high enough to allow working space below the TMB.

- 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. Site preparation work would include removal of the organic silt layer from within the footprint of the embankment widening. A review of the environmental acceptability for placing fill within the creek, the requirement for property acquisition, and alteration to highway geometry is needed to assess this option.

- Open Cut with Staged Replacement and Temporary Protection System

  The use of open cut techniques in conjunction with staged culvert replacement is a potentially feasible construction option from a geotechnical perspective. This option will require roadway protection, as discussed further in Section 11.2, installed along the embankment centerline to maintain a single lane of traffic flow along the current highway alignment. Installation of sheet piles will be difficult due to the presence of cobbles and boulders. The required height of soil to be retained by the roadway protection will require lateral support in the form of rakers, struts, or deadman/ bedrock anchors to reduce lateral deflections.

- Trenchless Techniques

  Tunneling would have the advantage of minimum disruption to traffic and would avoid a large excavation through the existing highway embankment. However, this option will be high risk due to the possibility of encountering obstructions. The low cover is also problematic and presents a significant risk to roadway settlement of heave. The anticipated size of replacement culvert will also limit the available installation methods. Construction of entry and exit pits would also be challenging at this site due to the water at the toe of the slope on the outlet side. A trenchless installation is not feasible at this site.

9.3 Recommended Approach for the Culvert Replacement

From a foundation engineering perspective, a set of circular pipes, a precast segmental box culvert and a cast-in-place open bottom box culvert, using open cut techniques, are all considered feasible culvert options, recognizing that that the open-bottom culvert option will require a deeper excavation including additional dewatering and excavating through soil that contains cobbles and boulders. Excavating in the wet and placing a mat of mass concrete using tremie methods may also be required for the open-bottom culvert option due to excessive groundwater inflow from the highly permeable layer of gravel, cobbles and boulders. Temporary protection systems (TPS) or a temporary widening would be needed to facilitate construction.

10 FOUNDATION DESIGN RECOMMENDATIONS

Foundation design aspects for the replacement culvert include subgrade conditions, geotechnical resistances, settlement of the founding soils, imposed loading pressures, erosion control, temporary protection system design, groundwater control and stability of stage construction. The culvert must be designed to resist loading 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.

10.1 Culvert Foundation Bearing Resistances

10.1.1 Box Culvert

A closed pre-cast box culvert may be founded on a bedding layer (see Section 10.2) in a dewatered temporary excavation overlying the existing dense native, undisturbed layers (e.g. silty sand to silty gravel) at or below the elevation of the existing culvert (invert at approximately 419.3 m). Assuming a base slab thickness of 0.3 m, the existing stratigraphy at the anticipated founding elevation of 419.0 m consists of dense to very dense silty sand to silty gravel. A closed box culvert would not need to be founded below the depth of frost (Section 10.3). For a box culvert up to 5.0 m wide, the design can be based on the factored geotechnical resistance values as follows.

- Factored Geotechnical Resistance at ULS of 500 kPa
- Factored Geotechnical Resistance at SLS of 300 kPa

The factored geotechnical resistances 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 supplied SLS resistance, is expected to be up to 25 mm.

Resistance to lateral forces/sliding resistance between concrete and native granular soil or the underlying Granular 'A' bedding (Section 10.2) should be evaluated in accordance with the CHBDC assuming an unfactored coefficient of 0.45 for precast concrete. A geotechnical resistance factor against sliding (Φ_{gu}) of 0.80 as per Table 6.2 of the CHBDC (static analysis – typical understanding) for frictional sliding of shallow foundations is to be applied to the calculated value.

It is noted that construction will extend below the observed creek water level. Water diversion and dewatering (Section 11.3) will be required to place the bedding material and install the culvert in the dry.

10.1.2 Open Bottom Culvert

From a geotechnical perspective, this option is technically feasible provided that the excavation is adequately dewatered, or constructing in the wet is considered acceptable. It

should be recognized that a deeper excavation will be required through a soil that contains cobbles and boulders. An open-bottom culvert will require frost protection, and the frost depth at this site is 2.6 m (see Section 10.3). The corresponding elevation of the founding level would be 416.7 m; however, the elevation of the bedrock, which is not frost susceptible, was noted to range from 417.7 to 418.1 m in the boreholes advanced at this site. Therefore, the existing overburden should be excavated, and the cast-in-place culvert footing should be founded directly on sound bedrock, or on a mat of mass concrete that extends to the bedrock surface.

Assuming that the bedrock subgrade is cleaned and inspected in accordance with the recommendations provided in Section 10.2, culvert footings founded on the bedrock, or a mat of mass concrete extending to the bedrock surface can be designed with a factored geotechnical resistance at ULS of 2,000 kPa. SLS will not govern design for a footing founded on bedrock. However, if constructing in the wet is required due to excessive groundwater inflow (see Section 11.3), it likely will not be possible to inspect the bedrock surface and some loose soil/rock may still be present on the subgrade surface. In that case, a geotechnical resistance at SLS of 500 kPa should be used. The horizontal resistance against sliding between cast-in-place concrete footings founded on bedrock can be computed using a friction factor of 0.70. A geotechnical resistance factor against sliding (Φ_{gu}) of 0.80 as per Table 6.2 of the CHBDC (static analysis – typical understanding) for frictional sliding of shallow foundations is to be applied to the calculated value. Appropriate resistance factors should be applied for the design. If greater lateral resistance is required, rock anchors/dowels could be utilized. Further geotechnical guidance in this regard can be provided, if required.

10.1.3 Pipe Culvert

Geotechnical resistance values are not required for pipe culverts.

10.2 Subgrade Preparation, Bedding and Backfilling

Subgrade preparation for the culvert replacement should include excavation and removal of the existing culvert and backfill materials. All organics, soft or loose deposits, disturbed soils, and deleterious materials must be removed from the footprint of the foundation to expose competent subgrade at or below the desired founding elevations. It should be noted that unsuitable organic silt was observed in off-road Boreholes 18-403 and 18-404 to as deep as elevation 418.3 m. These layers must be removed from below the culvert and replaced with compacted granular fill.

The exposed final subgrade must be inspected to confirm that the subgrade is suitable and uniformly competent. If the subgrade consists of soil, any soft or organic materials at the subgrade level should be sub-excavated and backfilled with granular fill consisting of OPSS.PROV 1010 Granular A material as soon as practical to protect the subgrade from disturbance during construction. The granular fill should be compacted as per OPSS.PROV 501.

If an open bottom culvert founded on bedrock is the preferred design, care must be taken to avoid fracturing or disturbing the bedrock below the footings. The exposed bedrock subgrade must be inspected, if dewatering is possible, to confirm that loose pieces have been removed and that the subgrade is suitable and uniformly competent. Mass concrete

can be used to fill any uneven bedrock surfaces to achieve the design founding level for the culvert. If the excavation cannot be dewatered due to excessive groundwater inflow (see Section 11.3), effort will need to be made to clean the bedrock of loose soil/rock mass; however, it may not be possible to visually inspect the subgrade surface in that case. The inspector would need to use engineering judgement to confirm that the subgrade has been prepared as best as possible. Mass concrete can could then be placed below the water using tremie methods to raise the founding level to a level that is higher than the drawn-down water level. If mass concrete is used, it should extend at least 300 mm beyond all edges of the footing.

The bedding and backfill requirements should be consistent with Section 7 of the CHBDC, OPSS.PROV 501, OPSS 902, and MTOD 803.021 (for precast box culverts). In order to provide a more uniform foundation subgrade condition for a circular pipe or closed box culvert, a minimum 300 mm thick layer of bedding material conforming to OPSS.PROV 1010 Granular A requirements should be placed on the undisturbed subgrade and compacted per OPSS.PROV 501. A 75 mm thick layer of uncompacted Granular A should be placed above the bedding layer as a levelling course to receive the placement of the culvert sections.

For the circular pipe and closed box culvert options, the silty subgrade may be disturbed when saturated and should be protected from disturbance from both construction traffic and weather. Construction equipment should not be permitted to travel on the exposed subgrade. The bedding should be placed as soon as possible after reaching the final subgrade level and receipt of written notice to proceed in accordance with SP109S12.

It is noted that construction will extend below the creek elevation. Water diversion and dewatering will be required. Refer to Section 11.3 for additional comments on groundwater and surface water control.

It is recommended that culvert cover be in accordance with OPSS 902 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 902 and consist of material meeting the requirements of OPSS Select Subgrade Material or Granular B Type I 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 the culvert must be restricted in accordance with OPSS.PROV 501.

10.3 Frost Depth

The depth of frost penetration at this site is estimated to be 2.6 m (OPSD 3090.100); however, foundations founded on bedrock are not required to be founded below frost depth. It is not necessary to found a closed box or pipe culvert at a depth below frost penetration. Frost taper treatment should be provided at this site as per OPSD 803.010 (box culvert) or OPSD 803.031 (pipe culvert).

10.4 Backfill and Earth Pressure

Lateral earth pressures parameters provided in Table 10-1 and Table 10-2 in the sections below are based on the assumptions that the wall is vertical and the backfill is fully drained so that there are no unbalanced hydrostatic pressures above the permanent groundwater level. If adequate drainage cannot be confirmed, the potential for buildup of hydrostatic pressures should be considered in design. Where ground surfaces are horizontal or sloped at 2H:1V (for head walls or wing walls) behind vertical walls, the corresponding coefficients provided in Tables 10-1 and 10-2 should be used. For other backfill and wall geometries, Thurber will need to calculate the appropriate earth pressure coefficients.

10.4.1 Static Lateral Earth Pressure

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

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

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), use submerged unit weight below groundwater level
h	=	depth below top of fill where pressure is computed (m)
q	=	value of any surcharge (kPa)

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

Table 10-1. Static 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		OPSS SSM and Existing Sand Fill $\phi = 30^o$, $\gamma = 21.0$ kN/m^3	
	Horizontal Surface Behind Wall	Sloping Surface Behind Wall (2H:1V)	Horizontal Surface Behind Wall	Sloping Surface Behind Wall (2H:1V)	Horizontal Surface Behind Wall	Sloping Surface Behind Wall (2H:1V)
Active, K_A (Yielding Wall)	0.27	0.39	0.31	0.47	0.33	0.54
At Rest, K_O (Non-Yielding Wall)	0.43	-	0.47	-	0.50	-
Passive, K_P (Movement towards Soil Mass)	3.7	-	3.3	-	3.0	-
Soil Group(*)	"medium dense sand"		"loose to medium dense sand"		"loose sand"	

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

The use of a material with a high friction angle and low earth pressure coefficients (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 10-1. Active earth pressures should be used for any head/wing walls or unrestrained walls. For rigid structures such as a concrete box culvert, at-rest horizontal earth pressures would apply for design.

10.4.2 Combined Static and Seismic Lateral Earth Pressure

In accordance with Clause 4.6.5 of the CHBDC (S6-14), retaining structures should be designed using dynamic earth pressure coefficients 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 the 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 10-2 may be used. The provided earth pressure coefficients are based on a Seismic Site Class C and a PGA with a 2% probability of exceedance in 50 years of 0.039g (Geological Survey of Canada – Fifth Generation) and a F(PGA) of 1.00 as per Table 4.8 of the CHBDC (S6-14 update No. 2, July 2017).

Table 10-2. 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	0.28	0.42	0.32	0.50
Active, K_{AE} Non-Yielding Wall	0.29	0.44	0.33	0.54

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.

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

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, use submerged unit weight below groundwater level
K_{AE} = combined static and seismic earth pressure coefficient
H = total height of the wall (m)

10.5 Embankment Design and Reinstatement

10.5.1 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 Select Subgrade Material (SSM) or Granular B Type I (OPSS.PROV 1010). The fill should be placed and compacted in accordance with OPSS.PROV 501.

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

10.5.2 Embankment Settlement and Stability

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.

It is understood that no grade raise or widening is anticipated along the alignment of Highway 527 and therefore negligible settlement of the underlying soils is expected to occur. Further assessment of stability and settlement should be carried out where construction staging dictates the requirement for additional loading or if a temporary alignment is constructed.

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.

10.6 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 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 test results provided in Section 5.6 may be used to aid in the selection of coatings and corrosion protection systems for buried steel objects. The corrosion effects of road de-icing salts should also be considered.

11 CONSTRUCTION CONSIDERATIONS

11.1 Excavation

All excavations must be carried out in accordance with the Occupational Health and Safety Act (OHSA). For the purposes of OHSA, the fill and native soils above the groundwater table may be classified as Type 3 soil. Below the water table (i.e., if the groundwater flow is not controlled), the soils would be classified as Type 4 soils.

Excavations for the culvert replacement must be carried out in accordance with OPSS 902 and will be carried out through the existing embankment fill and extend into the underlying native deposits (silty sand to silty gravel). Selection of the equipment and methodology to excavate and prepare the founding surface is the responsibility of the Contractor. Stockpiling or surface surcharge should not be allowed on the embankment or side slopes.

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) is presented in Section 11.2.

11.2 Temporary Protection Systems

Temporary Protection Systems may be required during various stages of 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.

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 10-1. The lateral earth pressure coefficient for the existing native non-cohesive soils are given below:

γ = 22 (kN/m^3, bulk unit weight of soil)
K_A = 0.31
K_P = 3.3

Submerged unit weight should be used below the groundwater level.

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.

It is recommended that an NSSP be included in the tender documents to alert the Contractor to the potential for cobbles and boulders and obstructions within the fill and native soils. Deadman or bedrock anchors, struts and/or raker supports may be required to achieve the specified performance level.

11.3 Surface and Groundwater Control

Culvert construction, subgrade preparation and placement and compaction of granular bedding should be carried out in the dry. The depth of excavations required to construct the culvert will extend below the creek level observed at the time of the investigation. Furthermore, groundwater and surface runoff will tend to seep into and accumulate into the excavations. The Contractor must make all reasonable efforts to control groundwater and creek/surface water flow at the site to permit the replacement of the culvert in a dry and stable excavation.

Subgrade preparation, placement and compaction of granular bedding, and culvert construction must be carried out with a properly designed dewatering system to control groundwater and creek/surface water and may include coffer dams, creek diversion, pumping etc. The dewatering system will be required to remain operational and effective until the temporary excavations are backfilled and then should be decommissioned and removed.

The design of dewatering systems is the responsibility of the Contractor. The Contract Documents must alert the Contractor to this responsibility and to design the system in accordance with SP No. FOUN0003 which amends OPSS 902. A preconstruction survey is not recommended, thus Designer Fill-In ** in this SP should be “NA”.

The groundwater level will fluctuate and the minimum groundwater elevation at the time of the proposed work should be taken as the creek water level of the design storm return period defined by the contract documents for the temporary dewatering system.

If circular pipes or a closed box option are used, it is anticipated that a water course diversion will be required and will be carried out with a cofferdam directing creek water through a temporary pipe culvert located to the north of the permanent alignment. The comments on installation and extraction of temporary protection systems are also relevant for cofferdams. The temporary pipe culvert should be supported with a bedding layer that is at least 300 mm in thickness.

If circular pipe culverts or a closed box culvert are used, it is anticipated that pumping from sumps will likely be sufficient to extract water from the excavation. Excavation below the creek level without prior dewatering is not recommended since the inflow of water will cause base heave/boiling and sloughing of the soil below the water level, making it difficult to maintain a dry, sound base on which to work. The groundwater level within the work zone should be lowered by pumping from sumps to a minimum of 500 mm below the underside of the planned excavation base prior to each stage of excavation.

However, if a deeper excavation is required to allow for an open bottom culvert, it is anticipated that the groundwater inflows through the layer of gravel, cobbles and boulders will be significant and it may not be possible to manage this inflow with conventional pumps. In that case, consideration could be given to carrying out the excavation to bedrock below the water level in the wet and constructing a layer of mass concrete using tremie methods up to a level that is higher than the drawn-down water level, which should be drawn down as much as possible. Footings for the open bottom culvert could then be constructed on the surface of the mass concrete.

Further assessment of dewatering requirements and the need for a PTTW should be carried out by specialists experienced in this field.

11.4 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 ensure 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.

Particle size analyses in conjunction with the Wischmeier Nomograph indicate that the granular fill and native soils encountered on site have a low erosion potential.

Scour and erosion protection should be provided for the culvert inlet and outlet areas. 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/or 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 clay seal should also extend below the bedding and scour level if a concrete cut-off wall is not also used. The material requirements for a clay seal should be in accordance with OPSS.PROV 1205. A geosynthetic clay liner may be used as a clay seal. A concrete cut-off wall should be constructed per OPSD 812.010 for CSP culverts.

12 CONSTRUCTION CONCERNS

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

- Disturbance of the soil subgrade. Where fine-grained soils (e.g. silt) are exposed at the culvert subgrade following excavation, these areas will be soft and moisture sensitive. Construction traffic must not be allowed on the final subgrade.
- Cobbles/boulders and/or buried obstructions may be encountered in the existing embankment fill and in the native soils at this site and could interfere with installation of the roadway protection system.
- Creek water levels will fluctuate. Excavation will involve lowering the water level below the excavation base to maintain a reasonably dry excavation and stable side slopes. The dewatering scheme will be critical for culvert construction at this site.
- 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 installation will depend largely upon good workmanship and quality control during construction. Subgrade examination should be carried out by qualified geotechnical personal during construction in accordance with SP109S12 to confirm that foundation recommendations are correctly implemented and material specifications are met.

13 CLOSURE

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

Thurber Engineering Ltd.
Report Prepared By:

Aug 24/18

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

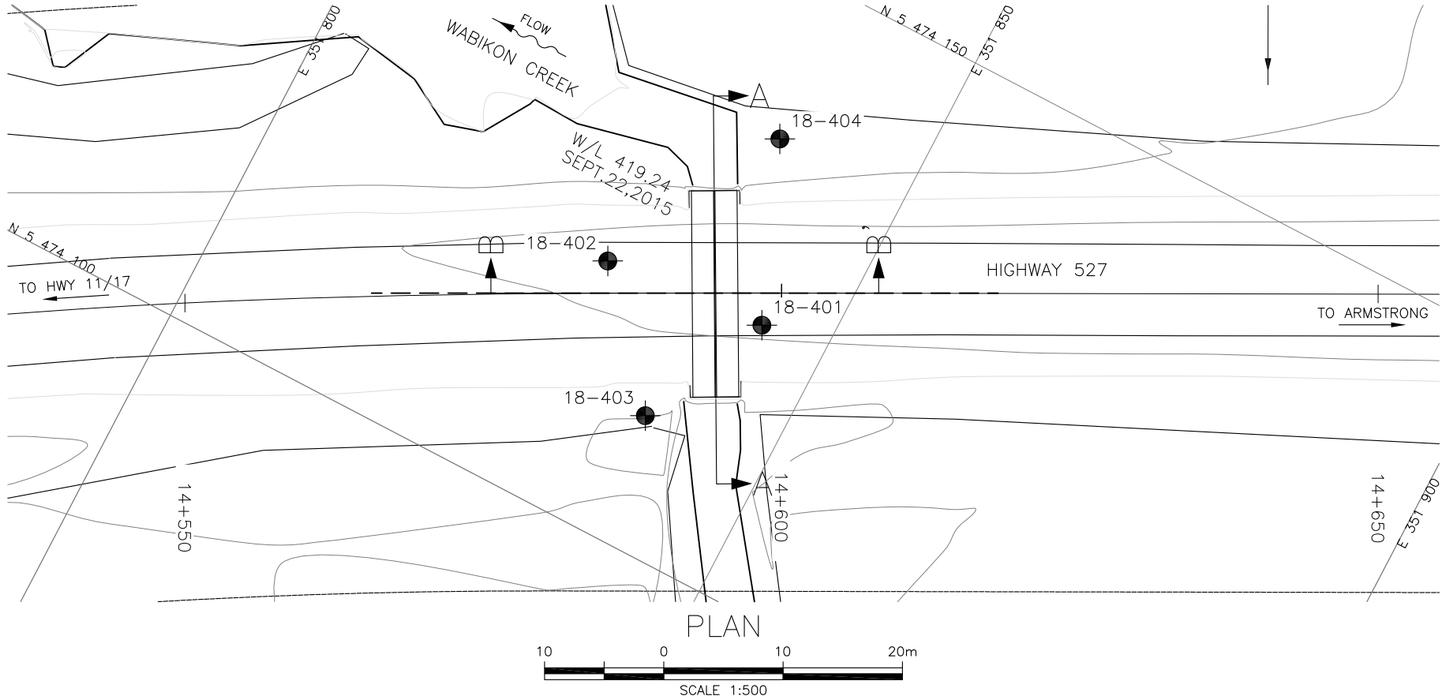
Stephen Dunlop, M.A.Sc., P.Eng.
Senior Geotechnical Engineer

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

Appendix A.

Borehole Location Plan and Stratigraphic Drawings

MINISTRY OF TRANSPORTATION, ONTARIO



PLAN

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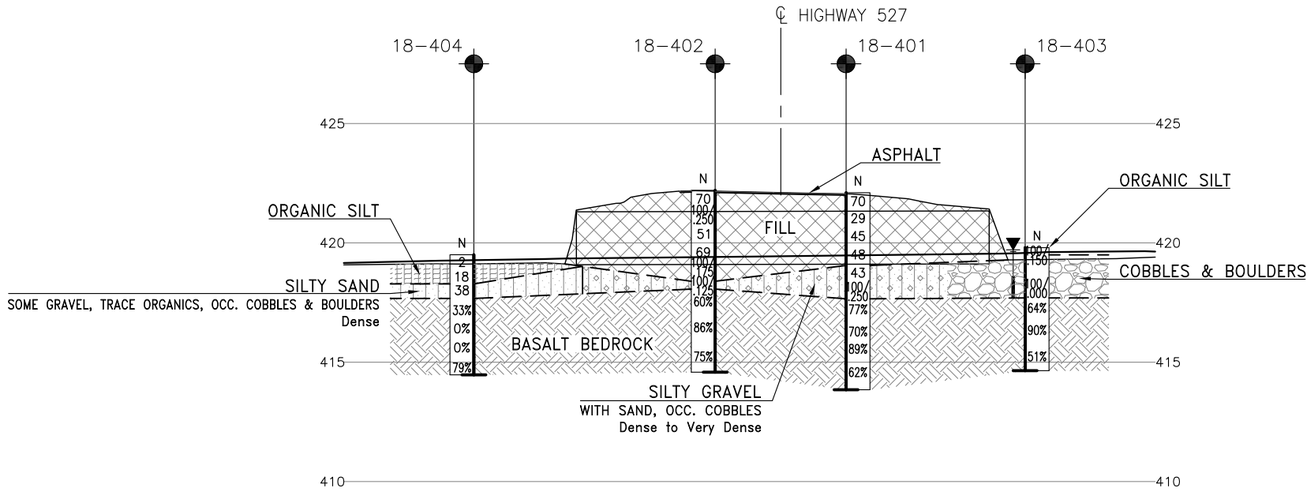

SECTION ALONG A–A'

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SCALE 1:250

METRIC

DIMENSIONS ARE IN METRES AND/OR MILLIMETRES UNLESS OTHERWISE SHOWN

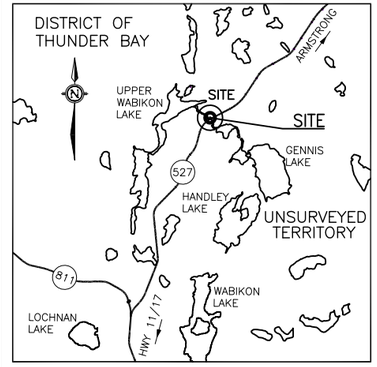
CONT No
GWP No 6829-14-00

SHEET

HIGHWAY 527
WABIKON CREEK CULVERT REPLACEMENT
BOREHOLE LOCATIONS AND SOIL STRATA

HATCH

THURBER ENGINEERING LTD.



KEYPLAN

LEGEND

⊕	Borehole
⊕	Borehole & 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
18-401	422.1	5 474 122.2	351 844.3
18-402	422.2	5 474 121.0	351 830.4
18-403	419.8	5 474 111.0	351 839.2
18-404	419.5	5 474 136.8	351 838.4

-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 15.

GEOCRES No.

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DESIGN DP	CHK SP	CODE	LOAD	DATE AUG 2018
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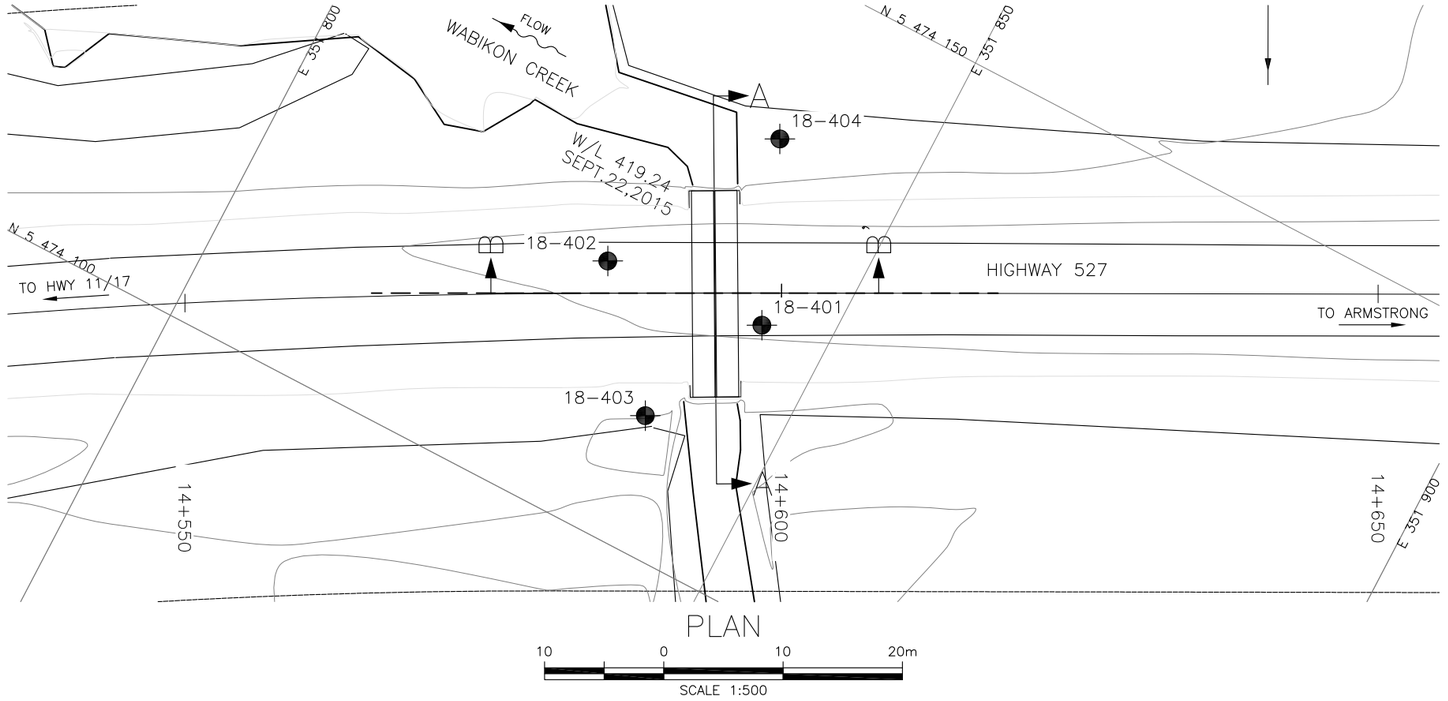
MINISTRY OF TRANSPORTATION, ONTARIO



PLAN

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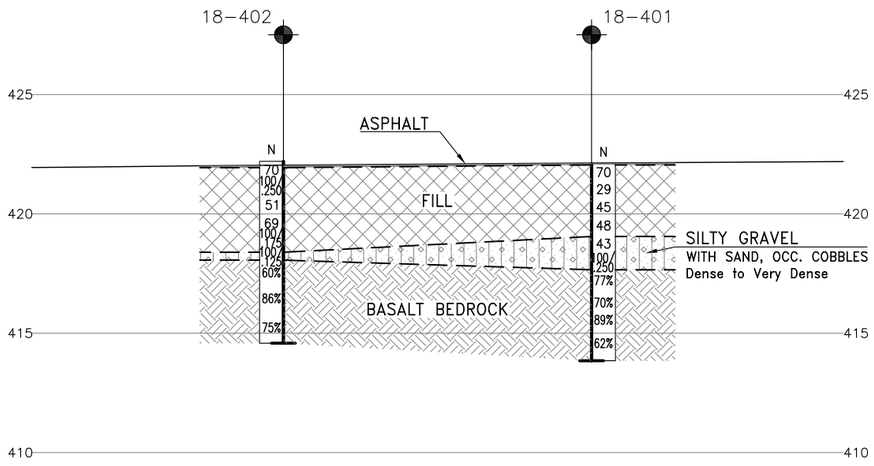

PROFILE ALONG B–B'

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SCALE 1:250

METRIC

DIMENSIONS ARE IN METRES AND/OR MILLIMETRES UNLESS OTHERWISE SHOWN

CONT No

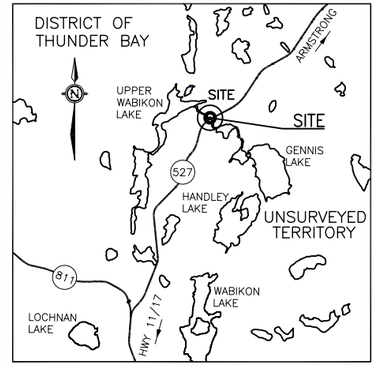
GWP No 6829-14-00

SHEET

HIGHWAY 527
WABIKON CREEK CULVERT REPLACEMENT
BOREHOLE LOCATIONS AND SOIL STRATA

HATCH

THURBER ENGINEERING LTD.



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LEGEND

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GEOCRES No.

REVISIONS			
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DESIGN DP	CHK SP	CODE	LOAD	DATE AUG 2018
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Appendix B.

Record of Borehole Sheets

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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:

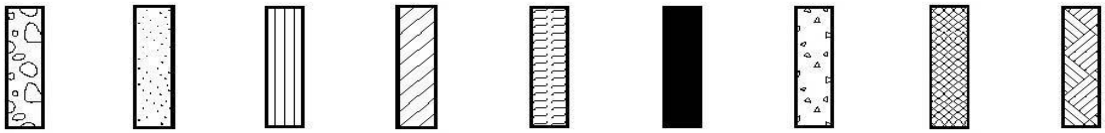
Numbers in this column are the field results of the Standard Penetration Test: the number of blows of a 63.5 kg hammer falling 0.76 m, required to drive a 50 mm O.D. split spoon sampler 0.3 m into undisturbed soil. For samples where insufficient penetration was achieved and N-value cannot be presented,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

TERMS DESCRIBING CONSISTENCY (COHESIVE SOILS ONLY)

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

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

SAMPLE TYPES

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

TERMS DESCRIBING CONSISTENCY (COHESIONLESS SOILS ONLY)

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

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

Ministry of Transportation
Ontario

THURBER

RECORD OF BOREHOLE No 18-401 1 OF 1 METRIC

GWP# 6829-14-00 LOCATION Lat: 49.4031877°, Long: -89.3517554° Wabikon Creek Culvert, MTM z15: N 5 474 122.2 E 351 844.3 ORIGINATED BY NW

HWY 527 BOREHOLE TYPE NW Casing / NQ Coring COMPILED BY SOB

DATUM Geodetic DATE 2018.06.07 - 2018.06.07 CHECKED BY SD

ELEV / DEPTH	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, ● QUICK TRIAXIAL, + FIELD VANE, × 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	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
422.1											
0.0 / 0.1	**50mm ASPHALT**						422				
	Silty SAND with Gravel, occasional Cobbles, **FILL** Compact to Very Dense Grey to Brown		1	SS	70				○		
			2	SS	29		421		○		
			3	SS	45				○		38 49 13 (SI+CL)
			4	SS	48		420		○		
419.1											
3.0	**Silty GRAVEL (GM)** with Sand, occasional Cobbles Dense to Very Dense Grey		5	SS	43		419		○		
			6	SS	100/ 250mm		418		○	FI	44 27 29 (SI+CL)
417.7											
4.4	**BASALT BEDROCK** Fresh Fine to Medium Grained Dark Grey to Black Very Strong		1	RUN						3 1 1 2	RUN #1 TCR=100% SCR=100% RQD=77%
			2	RUN			417			2 1	RUN #2 TCR=92% SCR=92% RQD=70%
			3	RUN			416			2 1 1	RUN #3 TCR=100% SCR=100% RQD=89%
			4	RUN			415			1 2 1	RUN #4 TCR=97% SCR=97% RQD=62%
413.8							414			2	
8.3	End of Borehole										

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

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

DOUBLE LINE 19773 WABIKON CREEK.GPJ 2012TEMPLATE(MTO).GDT 20/8/18

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Ministry of Transportation
Ontario

THURBER

RECORD OF BOREHOLE No 18-402 1 OF 1 METRIC

GWP# 6829-14-00 LOCATION Lat: 49.4031778°, Long: -89.3519475° Wabikon Creek Culvert, MTM z15: N 5 474 121.0 E 351 830.4 ORIGINATED BY NW

HWY 527 BOREHOLE TYPE NW Casing / NQ Coring COMPILED BY SOB

DATUM Geodetic DATE 2018.06.08 - 2018.06.08 CHECKED BY SD

ELEV / DEPTH	DESCRIPTION	STRAT PLOT	SAMPLES NUMBER	SAMPLES TYPE	SAMPLES "N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT / SHEAR STRENGTH kPa (○ UNCONFINED, ● QUICK TRIAXIAL, + FIELD VANE, × LAB VANE)	PLASTIC LIMIT w_P / NATURAL MOISTURE CONTENT w / LIQUID LIMIT w_L — WATER CONTENT (%)	UNIT WEIGHT γ kN/m^3	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
422.2								20 40 60 80 100	20 40 60		
0.0	**50mm ASPHALT**										
0.1	Silty SAND with Gravel, occasional Cobbles, **FILL** Very Dense Brown		1	SS	70		422		○		16 66 18 (SI+CL)
			2	SS	100/250mm				○		
							421				
			3	SS	51				○		31 55 14 (SI+CL)
							420				
			4	SS	69				○		
			5	SS	100/175mm		419		○		
418.4											
3.8	**Silty GRAVEL (GM)** with Sand, occasional Cobbles Very Dense Grey		6	SS	100/125mm				○	FI	
418.1							418			2	
4.1	**BASALT BEDROCK** Fresh Fine to Medium Grained Dark Grey to Black Very Strong		1	RUN						2 3 4	RUN #1 TCR=91% SCR=91% RQD=60%
							417			1	
			2	RUN						2 1	RUN #2 TCR=98% SCR=98% RQD=86%
							416			1	
			3	RUN						2 2	RUN #3 TCR=98% SCR=98% RQD=75%
							415			3	
414.6										0	
7.6	End of Borehole										

DRAFT

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

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

DOUBLE LINE 19773 WABIKON CREEK.GPJ 2012TEMPLATE(MTO).GDT 20/8/18

Ministry of Transportation
Ontario

THURBER

RECORD OF BOREHOLE No 18-403 1 OF 1 METRIC

GWP# 6829-14-00 LOCATION Lat: 49.403087°, Long: -89.3518276° Wabikon Creek Culvert, MTM z15: N 5 474 111.0 E 351 839.2 ORIGINATED BY SOB

HWY 527 BOREHOLE TYPE Portable / NW Casing / NQ Coring COMPILED BY SOB

DATUM Geodetic DATE 2018.06.10 - 2018.06.11 CHECKED BY SD

ELEV / DEPTH	DESCRIPTION	STRAT PLOT	SAMPLES: NUMBER	SAMPLES: TYPE	SAMPLES: "N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT / SHEAR STRENGTH kPa (○ UNCONFINED, ● QUICK TRIAXIAL, + FIELD VANE, × LAB VANE)	PLASTIC LIMIT w_P / NATURAL MOISTURE CONTENT w / LIQUID LIMIT w_L / WATER CONTENT (%)	UNIT WEIGHT γ kN/m^3	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
419.8								20 40 60 80 100	20 40 60		
0.0 / 419.5	**Organic SILT**		1	SS	100/ 150mm				o		
0.3	**COBBLES and BOULDERS**		2	NQ							
			3	NQ							
			4	NQ							
			5	NQ			419				
			6	NQ							
417.7			7	SS	100/ 0mm		418			FI	
2.1	**BASALT BEDROCK** Fresh Fine to Medium Grained Dark Grey to Black Very Strong		1	RUN						1 2 >5	RUN #1 TCR=100% SCR=94% RQD=64%
			2	RUN			417			0 2 1	RUN #2 TCR=98% SCR=98% RQD=90%
			3	RUN			416			2 >5 >5	RUN #3 TCR=100% SCR=77% RQD=51%
414.6							415			1	
5.2	End of Borehole Standpipe Readings: **DATE DEPTH (m) ELEV. (m)** 2018.06.14 0.1 419.7 2018.08.11 0.0 419.8										

+ ^{3}, × ^{3}: Numbers refer to Sensitivity

15 20 10 5 (%) STRAIN AT FAILURE

DOUBLE LINE 19773 WABIKON CREEK.GPJ 2012TEMPLATE(MTO).GDT 20/8/18

DRAFT

Ministry of Transportation
Ontario

THURBER

RECORD OF BOREHOLE No 18-404 1 OF 1 METRIC

GWP# 6829-14-00 LOCATION Lat: 49.4033188°, Long: -89.3518348° Wabikon Creek Culvert, MTM z15: N 5 474 136.8 E 351 838.4 ORIGINATED BY SOB

HWY 527 BOREHOLE TYPE Portable / NW Casing / NQ Coring COMPILED BY SOB

DATUM Geodetic DATE 2018.06.09 - 2018.06.10 CHECKED BY SD

ELEV / DEPTH	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 (20 40 60 80 100) ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × LAB VANE	PLASTIC LIMIT w_P / NATURAL MOISTURE CONTENT w / LIQUID LIMIT w_L WATER CONTENT (%) (20 40 60)	UNIT WEIGHT γ kN/m^3	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
419.5											
0.0	**Organic SILT**		1	SS	2		419				
			2	SS	18				110		
418.3											
1.2	**Silty SAND (SM)** some Gravel, trace Organics, occasional Cobbles and Boulders Dense Black		3	SS	38		418				11 72 17 (SI+CL)
417.7			4	NQ						FI	
1.8	**BASALT BEDROCK** Fresh Fine to Medium Grained Dark Grey to Black Very Strong		1	RUN						4	RUN #1 TCR=100% SCR=41% RQD=33%
							417			4	
			2	RUN						7	RUN #2 TCR=100% SCR=18% RQD=45%
										>5	
			3	RUN			416			>5	RUN #3 TCR=88% SCR=38% RQD=0%
										3	
										>5	
			4	RUN			415			2	RUN #4 TCR=100% SCR=100% RQD=79%
414.5										2	
5.0	End of Borehole										

DRAFT

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

$\frac{20}{15 \oplus 5}$ (%) STRAIN AT FAILURE

Appendix C.

Laboratory Testing

Appendix C.1

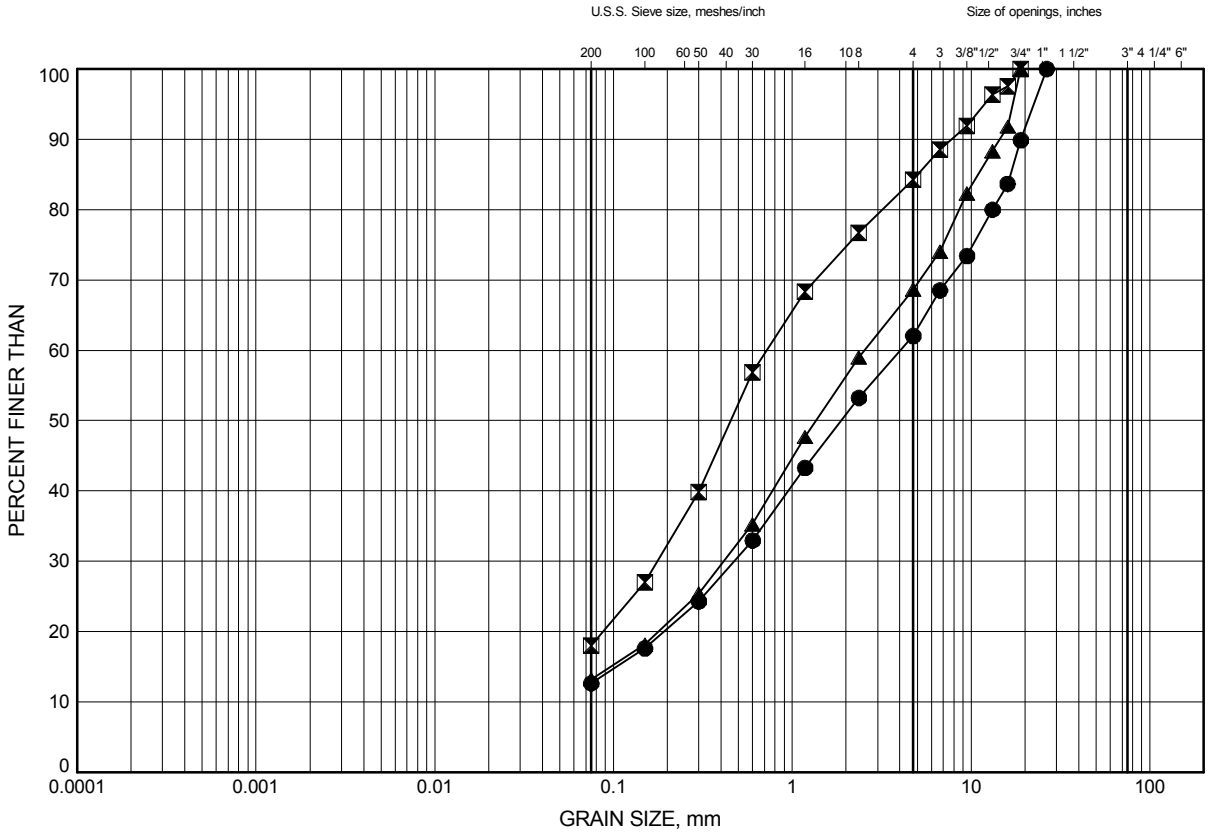
Particle Size Analysis Figures

Wabikon Creek Culvert

GRAIN SIZE DISTRIBUTION

FIGURE C1

Fill: Silty Sand with Gravel



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

LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	18-401	1.83	420.27
⊠	18-402	0.36	421.84
▲	18-402	1.83	420.37

Date August 2018

GWP# 6829-14-00

THURBER

Prep'd CM

Chkd. SD

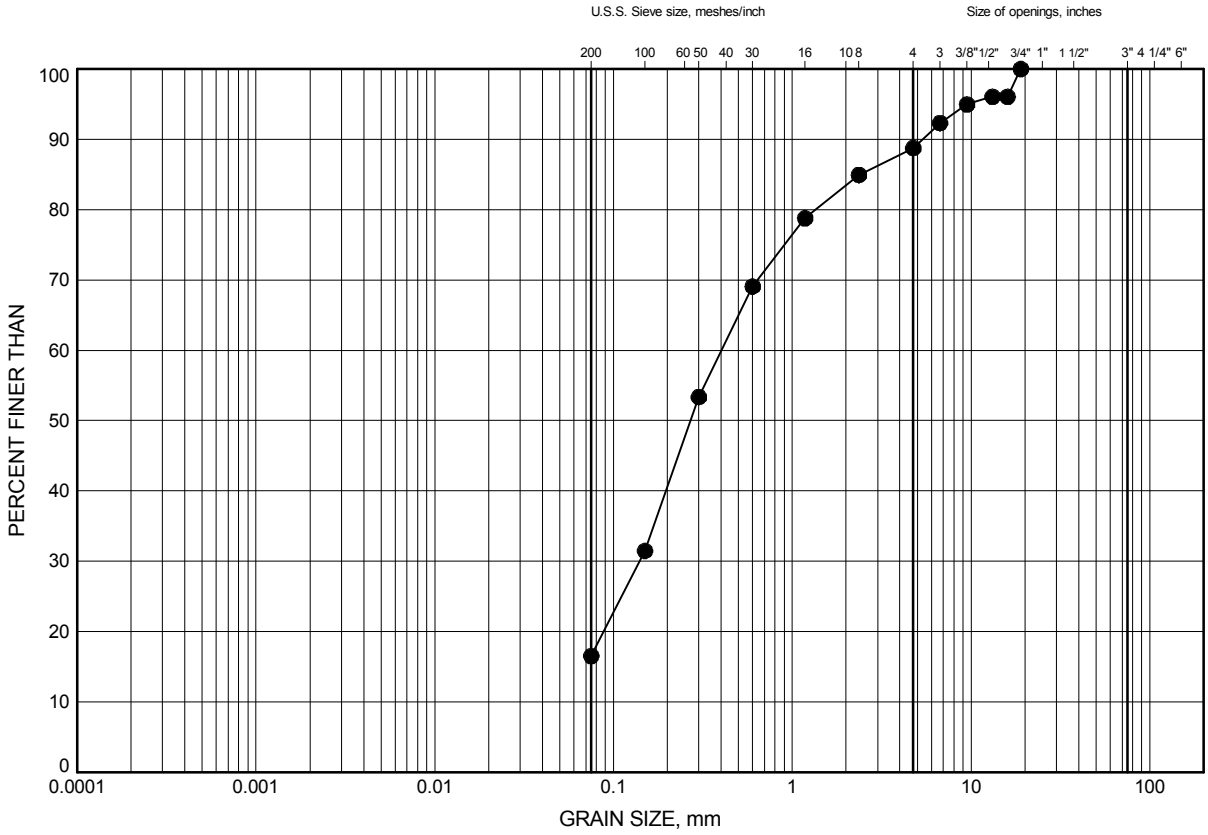
GRAIN SIZE DISTRIBUTION - THURBER 19773 WABIKON CREEK.GPJ 9/8/18

Wabikon Creek Culvert

GRAIN SIZE DISTRIBUTION

FIGURE C2

Silty Sand



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

LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	18-404	1.49	418.01

Date August 2018

GWP# 6829-14-00

THURBER

Prep'd CM

Chkd. SD

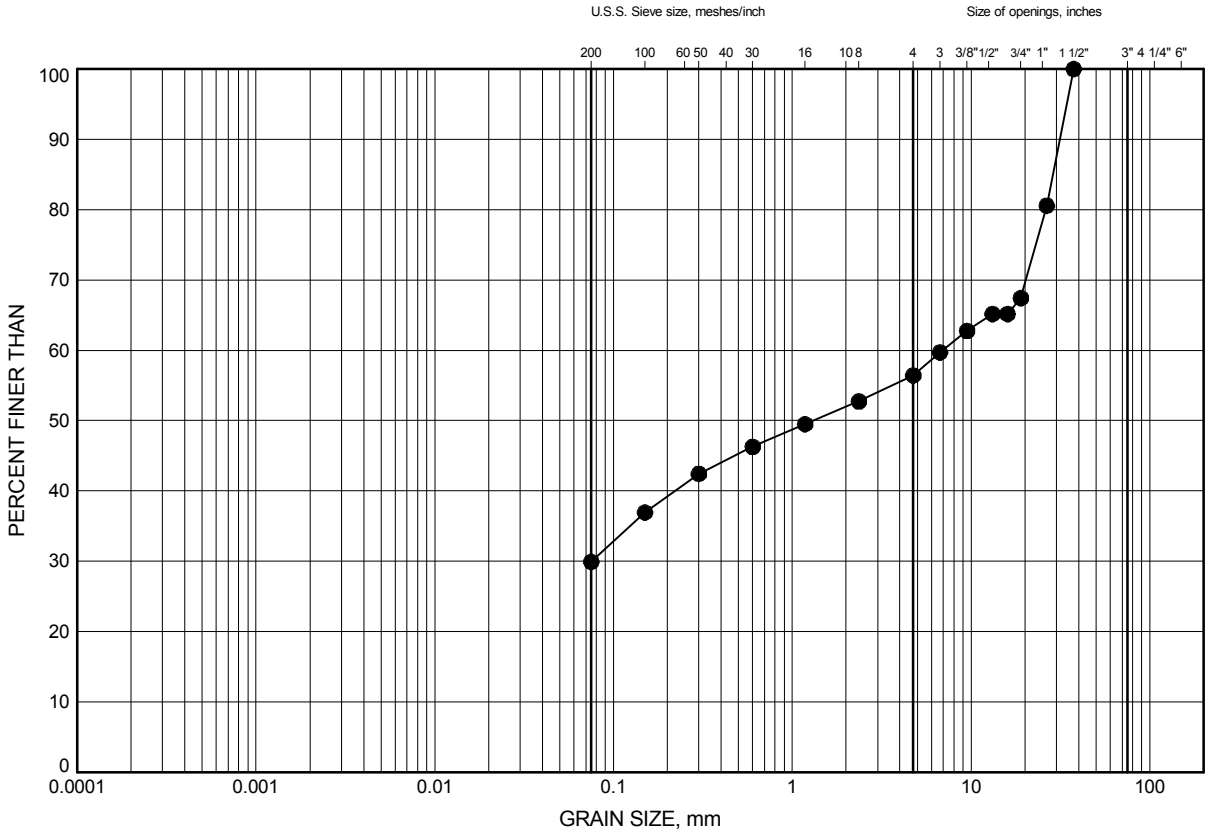
GRAIN SIZE DISTRIBUTION - THURBER 19773 WABIKON CREEK.GPJ 7/8/18

Wabikon Creek Culvert

GRAIN SIZE DISTRIBUTION

FIGURE C3

Silty Gravel with Sand



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

LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	18-401	4.01	418.09

Date August 2018

GWP# 6829-14-00

THURBER

Prep'd CM

Chkd. SD

GRAIN SIZE DISTRIBUTION - THURBER 19773 WABIKON CREEK.GPJ 7/8/18

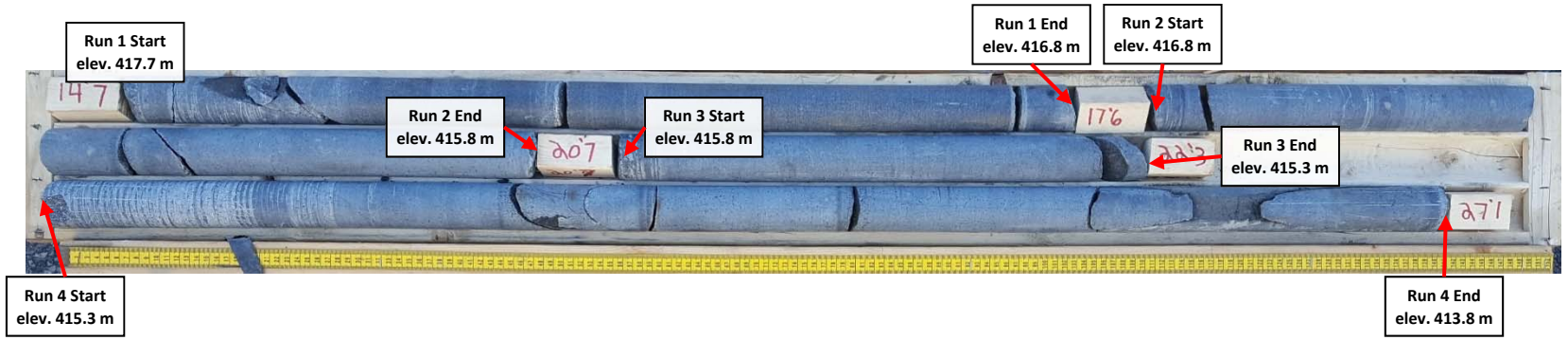
Appendix C.2

Rock Core Photos

Borehole 18-401

Run 1 to 4 (of 4)

Elevation 417.7 m to 413.8 m



THURBER ENGINEERING LTD.

Foundation Investigation
Wabikon Creek Culvert
Highway 527

GWP 6829-14-00

Project No.: 19773

Borehole 18-402

Run 1 to 3 (of 3)

Elevation 418.1 m to 414.6 m

THURBER ENGINEERING LTD.

Foundation Investigation
Wabikon Creek Culvert
Highway 527

GWP 6829-14-00

Project No.: 19773

Borehole 18-403

Run 1 to 3 (of 3)

Elevation 417.7 m to 414.6 m

THURBER ENGINEERING LTD.

Foundation Investigation
Wabikon Creek Culvert
Highway 527

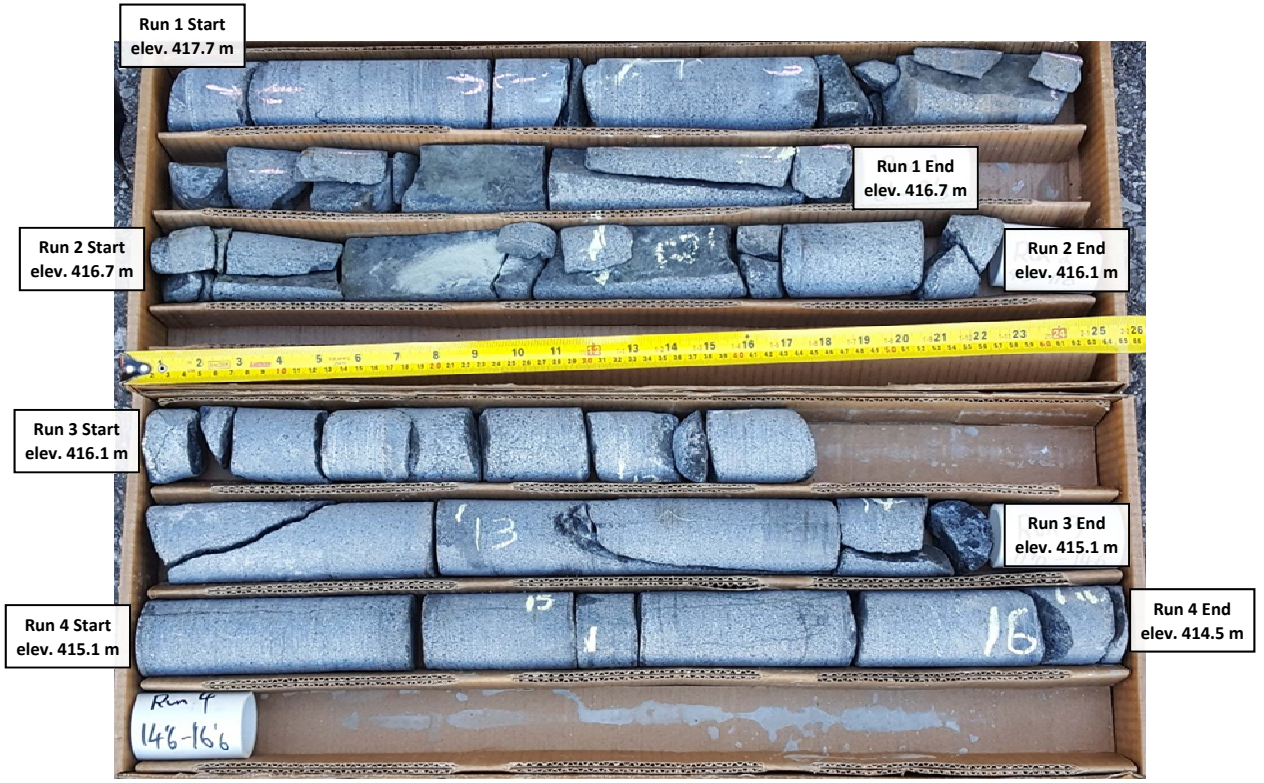
GWP 6829-14-00

Project No.: 19773

Borehole 18-404

Run 1 to 4 (of 4)

Elevation 417.7 m to 414.5 m



THURBER ENGINEERING LTD.

Foundation Investigation
Wabikon Creek Culvert
Highway 527

GWP 6829-14-00

Project No.: 19773

Appendix C.3

Analytical Testing Results

PARACEL LABORATORIES LTD.

Order #: 1825441

Certificate of Analysis

Client: Thurber Engineering Ltd.

Client PO:

Report Date: 26-Jun-2018

Order Date: 20-Jun-2018

Project Description: 19773

	Client ID:	18-101, SS6, 12'6"-14'6"	18-203, SS3, 5'10"-7'10"	18-204, SS4, 10'4"-12'4"	18-401, SS5, 10'-12'
	Sample Date:	05/30/2018 11:00	06/12/2018 14:30	06/13/2018 09:45	06/07/2018 13:30
	Sample ID:	1825441-01	1825441-02	1825441-03	1825441-04
	MDL/Units	Soil	Soil	Soil	Soil
Physical Characteristics					
% Solids	0.1 % by Wt.	80.0	88.0	89.3	92.4
General Inorganics					
Conductivity	5 uS/cm	135	156	98	90
pH	0.05 pH Units	7.81	7.76	7.76	7.56
Resistivity	0.10 Ohm.m	74.3	64.3	102	111
Anions					
Chloride	5 ug/g dry	9	25	29	9
Sulphate	5 ug/g dry	16	46	7	28

	Client ID:	18-502, SS8, 17'6"-19'6"	18-301, SS8A, 17'6"-19'4"	-	-
	Sample Date:	06/12/2018 11:15	06/05/2018 15:30	-	-
	Sample ID:	1825441-05	1825441-06	-	-
	MDL/Units	Soil	Soil	-	-
Physical Characteristics					
% Solids	0.1 % by Wt.	89.9	90.0	-	-
General Inorganics					
Conductivity	5 uS/cm	47	50	-	-
pH	0.05 pH Units	7.14	7.38	-	-
Resistivity	0.10 Ohm.m	213	198	-	-
Anions					
Chloride	5 ug/g dry	13	19	-	-
Sulphate	5 ug/g dry	10	6	-	-

SGS Canada Inc.
P.O. Box 4300 - 185 Concession St.
Lakefield - Ontario - KOL 2HO
Phone: 705-652-2000 FAX: 705-652-6365

28-June-2018

Paracel Laboratories
Attn : Dale Robertson

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

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

Date Rec. : 22 June 2018
LR Report: **CA12773-JUN18**
Reference: Project#:1825441

Copy: #1

CERTIFICATE OF ANALYSIS
Final Report

Sample ID	Sample Date & Time	Sulphide %
1: Analysis Start Date		28-Jun-18
2: Analysis Start Time		13:23
3: Analysis Completed Date		28-Jun-18
4: Analysis Completed Time		14:45
5: QC - Blank		< 0.02
6: QC - STD % Recovery		105%
7: QC - DUP % RPD		ND
8: RL		0.02
~~9: 18-101,SS6, 12'6"-14'16"~~	~~30-May-18~~	~~< 0.02~~
~~10: 18-204,SS4, 10'4"-12'4"~~	~~13-Jun-18~~	~~< 0.02~~
11: 18-401,SS5, 10'-12'	07-Jun-18	< 0.02
~~12: 18-502,SS8, 17'6"-19'6"~~	~~12-Jun-18~~	~~< 0.02~~
~~13: 18-301,SS8A, 17'6"-19'4"~~	~~05-Jun-18~~	~~< 0.02~~

RL - SGS Reporting Limit
ND - Not Detected

Kimberley Didsbury
Project Specialist
Environmental Services, Analytical

OnTuo LIMS

0001422899

Data reported represents the sample submitted to SGS. Reproduction of this analytical report in full or in part is prohibited without prior written approval. Please refer to SGS General Conditions of Services located at http://www.sgs.com/terms_and_conditions_service.htm. (Printed copies are available upon request.)
Test method information available upon request. "Temperature Upon Receipt" is representative of the whole shipment and may not reflect the temperature of individual samples.

Appendix D.

Site Photographs

Photo 1. Looking westward at north Highway 527 embankment slope (2018/06/03)

Photo 2. Looking eastward along Highway 527 over the culvert (2018/08/12)

Photo 3. Looking north downstream at culvert inlet (2018/08/12)

Photo 4. Looking south from BH 18-404 towards culvert outlet (2018/08/12)

Appendix E.

Foundation Comparison

COMPARISON OF ALTERNATIVE FOUNDATION TYPES

Type	Circular Pipe Culvert	Closed Box Culvert	Open Bottom Culvert	Precast Concrete Slab on Sheet Pile Culvert
Advantages	• Can tolerate larger magnitude of settlement than concrete (rigid frame) culverts. • Relatively expedient installation.	• Relatively expedient installation if precast units are used. • Typically smaller magnitude of settlement than open footing foundation due to lower bearing stress on subgrade. • Minimized differential settlement between culvert and approach fills.	• Limits disturbance to streambed. Typically favourable from an aquatic habitat perspective. • Relatively expedient installation if precast units are used. • Eliminates the need for a diversion channel.	• Minimized volume of excavation compared to other options. • Allows for winter construction. • Eliminates the need for a diversion channel.
Disadvantages	• Feasibility also depends on flow capacity and other hydraulic properties. May need multiple pipes. • Requires large excavation. • Roadway protection or temporary widening will be required. • Groundwater control is required.	• Requires large excavation. • Roadway protection or temporary widening will be required. • Groundwater control is required.	• Requires deeper excavation for footings, increasing excavation volume and dewatering efforts. • Roadway protection or temporary widening will be required.	• Quantity and cost of sheet piles. • Cannot penetrate obstructions. • Differential settlement will occur between non-yielding culvert and approach fills. A geogrid may be needed to strengthen the pavement structure.
Risks/ Consequences	• Groundwater inflow can disturb silty subgrade. • Cobbles, boulders and shallow bedrock present a challenge for installing roadway protection. Pre-drilling may be required to advance soldier piles, which may need to be socketed into the bedrock.	• Groundwater inflow can disturb silty subgrade. • Cobbles, boulders and shallow bedrock present a challenge for installing roadway protection. Pre-drilling may be required to advance soldier piles, which may need to be socketed into the bedrock.	• Groundwater inflow may be difficult to control through layer of gravel, cobbles and boulders. Construction in the wet may be needed. • Cobbles, boulders and shallow bedrock present a challenge for installing roadway protection. Pre-drilling may be required to advance soldier piles, which may need to be socketed into the bedrock.	• High risk of encountering obstructions and having inadequate lateral support due to a shallow refusal on bedrock.
Relative Cost	Low	Low	Moderate	Moderate to High
Recommendation	**Feasible**	**Recommended**	**Feasible**	**Not Recommended**

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

August 03, 2018

Site: 49.403 N, 89.352 W User File Reference: Wabikon Creek Culvert

Requested by: C.Murray, 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)**
0.053	0.072	**0.065**	0.052	**0.037**	**0.019**	**0.0080**	**0.0016**	**0.0008**	**0.039**	**0.026**

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)	0.0023	0.013	0.025
Sa(0.1)	0.0038	0.020	0.037
Sa(0.2)	0.0044	0.020	0.035
Sa(0.3)	0.0039	0.017	0.029
Sa(0.5)	0.0029	0.013	0.022
Sa(1.0)	0.0012	0.0059	0.011
Sa(2.0)	0.0005	0.0023	0.0043
Sa(5.0)	0.0002	0.0005	0.0009
Sa(10.0)	0.0002	0.0004	0.0005
PGA	0.0021	0.011	0.020
PGV	0.0014	0.0075	0.014

References

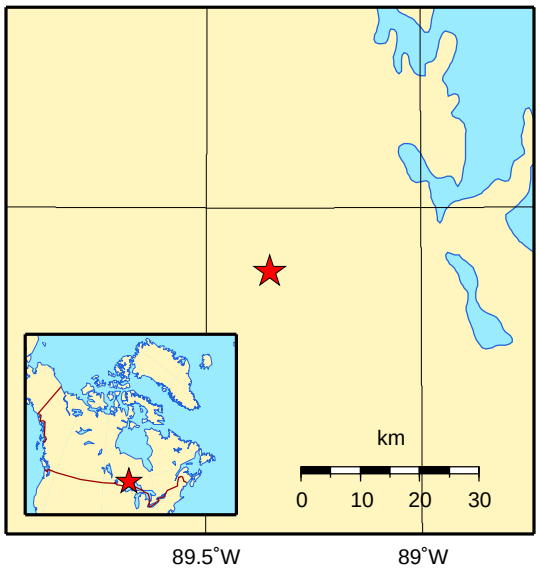
National Building Code of Canada 2015 NRCC no. 56190;
Appendix C: Table C-3, Seismic Design Data for Selected Locations in Canada

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



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Appendix G.

List of Special Provisions and 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 501	Construction Specification for Compacting
OPSS 511	Construction Specification for Rip-Rap, Rock Protection, and Granular Sheeting
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 902	Construction Specification for Excavating and Backfilling Structures
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
OPSD 208.010	Benching of Earth Slopes
OPSD 803.010	Backfill and Cover for Concrete Culverts with Span Less than or Equal to 3.0 m
MTOD 803.021	Bedding and Backfill for Precast Concrete Box Culverts
OPSD 803.031	Frost Treatment – Pipe Culverts Frost Penetration Line Between Top of Pipe and Bedding Grade
OPSD 810.010	General Rip-Rap Layout for Sewer and Culvert Outlets
OPSD 812.010	Cut Off Wall for Structural Plate Pipe Arch and Circular CSP
OPSD 3090.100	Foundation Frost Depths for Northern Ontario
SP109S12	Amendment to OPSS 902 - QVE, Backfilling Compaction, and Certificate of Conformance
SP517F01	Amendment to OPSS 517 - Dewatering System
SPFOUN0003	Amendment to OPSS 902 – Dewatering Structure Excavations

2. Suggested text for a NSSP on “Obstructions”

Obstructions such as cobbles and boulders may be encountered in the fill and native soils. These obstructions may also be present in the fill. Such obstructions may impede the progress of open-cut excavations, and/or installation of temporary protection systems. The contractor should use appropriate equipment and methodologies to penetrate the obstructions.