REPORT

May 6, 2015

FOUNDATION INVESTIGATION AND DESIGN REPORT

CULVERT AT STATION 12+620, TOWNSHIP OF DENISON HIGHWAY 17 FOUR-LANING EXTENSION FROM 20.5 KM WEST OF HIGHWAY 144, EASTERLY FOR 6.5 KM MINISTRY OF TRANSPORTATION, ONTARIO GWP 156-98-00

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PART A

FOUNDATION INVESTIGATION REPORT

CULVERT AT STATION 12+620, TOWNSHIP OF DENISON

HIGHWAY 17 FOUR LANING EXTENSION FROM 20.5 KM

WEST OF HIGHWAY 144, EASTERLY 6.5 KM

MINISTRY OF TRANSPORTATION, ONTARIO

GWP 156-98-00

1.0 INTRODUCTION

Golder Associates Ltd. (Golder) has been retained by D.M. Wills Associates Ltd. (DMW) on behalf of the Ministry of Transportation, Ontario (MTO) to provide foundation engineering services for the proposed culvert which will cross the future Highway 17 alignment at STA 12+620 in the Township of Denison. The proposed work is part of the four lane extension of the existing Highway 17 at the West Junction of Sudbury Municipal Road 55, from 20.5 km West of Highway 144, easterly for 6.5 km and includes a new interchange. The general location of the proposed culvert is shown on the Site Location Plan on Drawing 1.

The Terms of Reference and the Scope of Work for the foundation investigation are outlined in MTO's Request for Proposal (RFP), dated March 2011. Golder's proposal for the associated foundation engineering services is contained in Section 6.8 of DMW's Technical Proposal for this assignment. The work has been carried out in accordance with Golder's Supplementary Specialty Plan for foundation engineering services for this project, dated November 11, 2011. The base Plan showing the proposed horizontal alignment and a drawing showing the proposed vertical alignment for the Highway 17 four-lane extension were provided to Golder by DMW in January 2012 and the General Arrangement (GA) for the culvert was provided to Golder by DMW on November 8, 2013.

This report addresses the investigation carried out for the proposed culverts at Station 12+620 only. Separate reports address the foundation investigations for the remaining culverts, High Fill embankments over swamps, and bridge structures.

Preliminary subsurface information for this project is available and was supplied by MTO, in the reports and subsequent appendices titled:

- Planning, Preliminary Design, and Environmental Assessment Report, Highway 17, Town of Walden, GWP 156-98-00, dated August 2008 by Stantec Consulting Limited
  - Appendix N: Alternate Route Geotechnical Assessment Report, Highway 17, Town of Walden, GWP 156-98-00, Index No: 080FGR, PML Ref: 05TF059G dated July 29, 2008 by Peto MacCallum Ltd.
  - Appendix O: Alternate Route Foundation Assessment Report, Highway 17, Town of Walden, GWP 156-98-00, Index No: 072FFR, PML Ref: 05TF059F, dated May 20, 2008 by Peto MacCallum Ltd.
- Planning, Preliminary Design, and Environmental Supplementary Report, Highway 17, Town of Walden, GWP 156-98-00, dated March 2009 by Stantec Consulting Limited
  - Preliminary Geotechnical Investigation Report, Highway 17, Town of Walden, GWP 156-98-00, Index No: 102FGIR, PML Ref: 05TF059G1 dated March 3, 2009 by Peto MacCallum Ltd.

2.0 SITE DESCRIPTION

The overall project consists of the detail design for the four-lane extension of Highway 17 from the present four lane terminus at the west junction of Sudbury Municipal Road 55, approximately 20.5 km west of Highway 144, easterly for 6.5 km, including a new interchange. The proposed highway alignment is south of and approximately follows the existing east-west alignment of Highway 17 within the project limits. Two culverts are to be constructed under the new four lane extension at STA12+620 within the Township of Denison. The proposed culverts will be approximately 29.5 m long and 32.7 m long under the westbound lanes (WBL) and eastbound lanes (EBL), respectively.

In general, the topography is comprised of low-lying swamps with areas of standing water and various vegetation types and organic soils, with sparse to densely forested areas. The land use in the general area includes rural residential developments. The ground surface within the limits of the culvert alignments varies between about Elevation 257.7 m and Elevation 257.2 m. A detailed description of the subsurface conditions along the culvert alignments is presented in Section 4.0.

3.0 INVESTIGATION PROCEDURES

The investigation for the WBL and EBL culverts at STA 12+620 was carried out between February 25 and March 5, 2014, during which time a total of five (5) boreholes were advanced along to proposed culvert alignments. The locations of the boreholes are shown on Drawing 2 and are provided on the Record of Borehole sheets in Appendix A.

The field investigation was carried out using track-mounted CME-850 drill rig supplied and operated by Landcore Drilling (Landcore) of Sudbury, Ontario. The boreholes were advanced using 108 mm inner diameter hollow-stem augers. In general, soil samples were obtained at intervals of depth of about 0.75 m and 1.5 m, using a 50 mm outer diameter (O.D.) split-spoon sampler driven by an automatic hammer, in accordance with Standard Penetration Test (SPT) procedures (ASTM D1586, Standard Test Method for Standard Penetration Test and Split-Barrel Sampling of Soils). Field vane shear tests were conducted in cohesive soils for assessment of undrained shear strengths (ASTM D2573, Standard Test Method for Field Vane Shear Test) using MTO Standard ‘N’ size. All boreholes were backfilled upon completion in accordance with Ontario Regulation 903 Wells (as amended).

The culvert boreholes were advanced to depths ranging between 15.3 m and 15.8 m below existing ground surface.

The groundwater conditions and water levels in the open boreholes were observed during the drilling operations and are described on the Record of Borehole sheets provided in Appendix A. Groundwater elevations as encountered in the boreholes may not be representative of static groundwater levels since the groundwater levels in the boreholes may not have stabilized upon completion of drilling. Furthermore, groundwater elevations will vary depending on seasonal fluctuations, precipitation and local soil permeability.

The field work was observed by members of our engineering and technical staff, who located the boreholes, arranged for the clearance of underground services, observed the drilling, sampling and in situ testing operations, logged the boreholes and examined and cared for the soil samples. The samples were identified in the field, placed in appropriate containers, labelled and transported to our Sudbury geotechnical laboratory where the samples underwent further visual examination and laboratory testing. All of the laboratory tests were carried out to MTO and/or ASTM Standards, as appropriate. Classification testing (water content, Atterberg limits and grain size distribution) was carried out on selected representative samples. The results of the laboratory testing on samples from the culvert boreholes are included in Appendix B.

The proposed centreline of the new Highway 17 alignment and temporary benchmarks along the centrelines of the culverts were staked and surveyed in the field by exp. prior to drilling. The as-drilled borehole locations and ground surface elevations were referenced to the temporary benchmarks located along the centrelines of the culverts. The locations and elevations of the temporary benchmarks were then provided to Golder by exp. The borehole locations given in the Record of Borehole sheets and shown on Drawing 2 are positioned relative to MTM NAD 83 northing and easting coordinates and the ground surface elevations are referenced to Geodetic datum. The borehole locations, ground surface elevations and drilled depths are as follows:

Borehole	Location (MTM NAD 83)		Ground Surface Elevation (m)	Borehole Depth (m)
	Northing	Easting		
C2-1	5 136 822.9	276 753.9	257.2	15.8
C2-2	5 136 809.2	276 759.2	257.2	15.8
C2-3	5 136 791.7	276 765.9	257.2	15.8
C2-4	5 136 774.2	276 772.7	257.3	15.8
C2-5	5 136 757.5	276 779.1	257.7	15.3

4.0 SITE GEOLOGY AND SUBSURFACE CONDITIONS

4.1 Regional Geology

As delineated in the NOEGTS[1] Mapping, the ground terrain in this section of Highway 17 is comprised of bedrock knobs, outcrops and ridges with an undulating to rolling glaciolacustrine plain, alluvial plain and organic soil deposits. In the lower-lying glaciolacustrine plain and alluvial plain areas, the primary material consists of wet silts, sands and clays, and the organic terrain deposit primarily consists of peat. The surface water drainage in the area varies from dry to wet, corresponding to areas of moderate to low relief.

Based on geological mapping by the Ministry of Natural Resources (Map 2542)[2], the site is underlain by rocks of the Paleoproterozoic Era belonging to the Huronian Supergroup and Elliot Lake Group consisting of conglomerate, wacke, arkose, quartz arenite, argillite, limestone and dolostone. Areas of mafic and related intrusive rocks comprised of diabase sills, dykes and related granophyre are also present in the vicinity of the site. Based on geological mapping by the Ontario Department of Mines (Map 2170) [3] this site area is characterized by extensive faults from distinct time periods. The Murray Fault has been identified to run parallel to the proposed approximate alignment of Highway 17.

4.2 General Overview of Local Subsurface Conditions

The detailed subsurface soil and groundwater conditions as encountered in the borings advanced during this investigation together with the results of the laboratory tests carried out on selected soil samples are presented on the attached Record of Borehole sheets and the laboratory test figures provided in Appendices A and B, respectively. The results of the in situ field tests (i.e. SPT 'N'-values and undrained shear strengths from the field vanes) as presented on the Record of Borehole sheets and in Section 4.0 are uncorrected. The stratigraphic boundaries shown on the Record of Borehole sheets are inferred from non-continuous sampling, observations of drilling progress and the results of SPTs and in situ testing. These boundaries, therefore,

[1] Northern Ontario Engineering Geology Terrain Study. Ontario Geological Society Digital Map Reference Number 41ISW.

[2] Ministry of Natural Resources (1991). Bedrock Geology of Ontario – West Central Sheet, Ontario Geological Survey - Map 2542

[3] Ontario Department of Mines (1969). Sudbury Mining Area, Sudbury District, Map 2170.

represent transitions between soil types rather than exact planes of geological change. Further, subsurface conditions will vary between and beyond the borehole locations.

The inferred soils stratigraphy based on the result of the boreholes is shown in profile on Drawing 2. It should be noted that the orientation (i.e., north, south, east, west) stated in the text of the report is typically referenced to project north and therefore may differ from the Magnetic North shown on the drawings.

The stratigraphy encountered at the site generally consists of topsoil/organics or peat at the ground surface underlain by a clayey silt to silty clay deposit further underlain by a deposit of silt to silt and sand.

Detailed descriptions of the subsurface conditions encountered along the investigated culvert alignments are provided in the following sections of this report. Where relatively significant thicknesses of overburden were encountered, the various soil types are described in detail for each main deposit or stratum.

4.2.1 Silty Organics/Topsoil/Peat

An approximately 0.6 m to 0.8 m thick deposit of black, fibrous peat was encountered at the ground surface in Boreholes C2-2 to C2-4. In Borehole C2-5, a 0.3 m thick layer of topsoil was encountered at the ground surface. In Borehole C2-1, a 0.8 m thick layer of silty organics was encountered at the ground surface. The surface of the silty organics/peat/topsoil deposit varies between Elevation 257.7 m and 257.2 m.

The SPT ‘N’-values measured within the peat deposit were typically 1 blow per 0.3 m of penetration, suggesting a very soft consistency. One SPT ‘N’-value measured within the peat deposit was 10 blows per 0.3 m of penetration and is inferred to indicate frozen ground conditions.

The natural water content measured on one sample of the peat is about 209 per cent.

4.2.2 Clayey Silt to Silty Clay

In all of the boreholes, a cohesive deposit was encountered beneath the silty organics/peat/topsoil deposit. In general, the cohesive deposit consisted of an upper clayey silt zone, transitioning into varved silty clay. At depth, within the deposit in the majority of the boreholes, the deposit was observed to be varved consisting of irregular layers of clayey silt to silty clay and silty clay to clay. The top of the clayey silt to silty clay deposit was encountered between Elevations 257.4 m and 256.4 m and the thickness of the overall deposit ranged between 6.0 m and 6.9 m.

The SPT ‘N’-values measured within the clayey silt to silty clay deposit typically ranged from 0 blows (weight of hammer) to 3 blows per 0.3 m of penetration. One SPT ‘N’-value measured in Borehole C2-5 within the clayey silt to clay deposit was 30 blows per 0.3 m of penetration, possibly due to the presence of gravel or a cobble within the cohesive deposit. In situ field vane tests carried out within the deposit measured undrained shear strengths ranging from about 19 kPa to 57 kPa. The field vane tests results indicate that the clayey silt to silty clay deposit generally has a soft to stiff consistency.

The grain size distributions for five samples of the clayey silt to silty clay deposit are presented on Figure B1 in Appendix B.

Atterberg limits tests were carried out on nine samples of the clayey silt to silty clay deposit and indicate liquid limits ranging from about 30 per cent to 49 per cent, plastic limits ranging from about 19 per cent to 25 per cent and plasticity indices ranging from about 11 per cent to 24 per cent. The results of the Atterberg limits tests are shown on the plasticity chart on Figures B2 in Appendix B and indicate that the material is classified as clayey silt of low plasticity to silty clay of intermediate plasticity.

The natural water content measured on nine samples of this deposit range between about 31 per cent and 59 per cent.

4.2.3 Silt to Silt and Sand

Grey silt to silt and sand, trace to some clay was encountered beneath the clayey silt to silty clay deposit in all of the boreholes. The surface of this silt to silt and sand was encountered between Elevations 250.7 m to 249.8 m and all boreholes were terminated within this deposit after exploring for between 8.1 m and 9.2 m.

The SPT 'N'-values measured within this deposit range between 0 blows (weight of hammer) and 19 blows per 0.3 m of penetration, indicating a very loose to compact relative density. Split spoon refusal was encountered in Borehole C2-5 and recorded an SPT 'N'-value of 50 blows per 0.1 m prior to bouncing, likely indicative of cobbles/boulders or close proximity to the bedrock surface.

The grain size distributions of seven samples of this deposit are presented on Figures B3 in Appendix B. The results of Atterberg limits testing on two samples of the silt to silt and sand deposit indicated that the material is classified as non-plastic.

The natural water content measured on seven samples of this deposit range between about 22 per cent and 30 per cent.

4.2.4 Groundwater Conditions

In general, the samples taken in the boreholes were wet. The groundwater levels observed upon completion of drilling ranges from about Elevation 257.0 m to 253.9 m, measured between 0.2 m and 3.8 m below ground surface. It should be noted that the groundwater levels in the area fluctuate seasonally as well as during precipitation events and snowmelt.

5.0 CLOSURE

The field personnel supervising the drilling program were Messrs. Ed Savard and Matthew Thibeault, under the direction of Mr. Evan Childerhose, P.Eng. This report was prepared by Messrs. Adam Core and Matthew Thibeault and the technical aspects were reviewed by Ms. Sarah E. M. Poot, P.Eng., a senior geotechnical engineer and Associate of Golder. Mr. Jorge M. A. Costa, P.Eng., Golder's Designated MTO Contact for this project and Principal of Golder, conducted an independent quality control review of the report.

Report Signature Page

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PART B

FOUNDATION DESIGN REPORT

CULVERT AT STATION 12+620, TOWNSHIP OF DENISON

HIGHWAY 17 FOUR LANING EXTENSION FROM 20.5 KM WEST OF HIGHWAY 144, EASTERLY 6.5 KM

MINISTRY OF TRANSPORTATION, ONTARIO

GWP 156-98-00

6.0 DISCUSSION AND ENGINEERING RECOMMENDATIONS

This section of the report provides an interpretation of the geotechnical data obtained during the investigation and recommendations on the foundation aspects of design of the proposed works. The recommendations provided are intended for the guidance of the design engineer. Where comments are made on construction, they are provided to highlight aspects of construction that could affect the design of the project. Those requiring information on aspects of construction must make their own interpretation of the subsurface information provided as it affects their proposed construction methods, costs, equipment selection, scheduling and the like.

6.1 General

Golder was retained by DMW to provide foundation engineering services for the design of two proposed culverts at STA 12+620. The proposed box culverts under Highway 17 will be approximately 2.5 m wide by 0.75 m high. The culvert under the WBL will be 29.5 m long and the culvert under the EBL will be 32.7 m long. The proposed culvert inlets are at Elevation 257.0 m at the north end of the WBL and Elevation 257.5 m at the south end of the EBL, and the maximum proposed embankment at the culvert area is 1.8 m high.

This report presents an assessment of the stability and settlement of the embankment at the culvert locations and geotechnical resistances for design of the culverts. It provides recommendations for stable embankment geometry and embankment fill materials, and alternative mitigation measures that may be required as a means to reduce culvert settlements and to improve embankment stability (if necessary). The report also provides recommendations to addresses potential construction concerns and geotechnical problems associated with culvert and adjacent embankment construction, sub-excavating soft/organic materials and placement of new fill materials.

6.2 Culvert Types

The analyses and recommendations presented herein assume that the culvert sections will be concrete boxes having dimensions of 2.5 m wide by 0.75 m high. However, foundation design recommendations for a circular pipe culvert [i.e. concrete or Corrugated Steel Pipe (CSP)] are also provided in the event that an alternative culvert type is considered.

6.3 Culvert Construction Timing

In general, the foundation soils at the culvert crossing will undergo settlement as a result of loading from the new overlying embankment. Therefore, the timing of culvert construction is an essential factor in determining the preferred settlement mitigation option, if required. In areas where relatively small settlements are estimated to occur due to the presence of relatively thin, compressible foundation soils at the culvert location, as is the case at this site, culvert construction can commence concurrently with the proposed new embankment construction so long as any requirements for maintaining embankment stability are addressed, as discussed in Section 6.4. If required, the culvert design could include a camber to mitigate post-construction settlement.

Culverts which are constructed concurrently with the new embankments will experience settlement (both short-term and long-term), as well as lateral spreading (or horizontal strain in the longitudinal direction) as a result of the embankment loading. The analyses of embankment stability, embankment/culvert settlement and horizontal strain on the culvert are discussed in Sections 6.4.1, 6.4.2 and 6.4.3, respectively. If the culvert structure is capable of tolerating the estimated total and differential settlements and associated strains, the culvert could be constructed with a camber (if necessary), such that once the settlement has occurred, the hydraulic flow will be as originally designed. However, culverts designed to include a camber may have a relatively high risk of poor performance resulting in unfavourable drainage/surface water flow conditions at some locations. It is important to note that it is inherently difficult to predict settlements for the variable subsurface conditions along the culvert alignment with a sufficient degree of accuracy to allow an accurate camber design. If the actual settlements are smaller than predicted, the culvert may not achieve the design grade or slope, which could impede the flow of water. If actual settlements are larger than expected, the culvert may sag below the design invert elevation and as a result some sediments may be deposited inside the culvert reducing the flow of water. Expansion joints may also be included along the length of the culvert to accommodate horizontal strain which would occur in conjunction with the vertical settlement.

Sub-excavation of all existing organic material is required prior to placement of any fill or culvert bedding material, as organic soils are highly compressible and can undergo significant secondary (creep) settlement, as discussed in Section 6.7.1.

6.4 Stability, Settlement and Horizontal Strain

The following sections summarize the methods utilized to carry out analyses of embankment stability and settlement of the culvert and methods utilized to evaluate horizontal strains along the culvert beneath the zone of influence of the proposed embankment loading.

6.4.1 Stability

The stability analysis carried out for the 1.8 m high granular fill embankment at the proposed culvert location using the commercially available program GeoStudio (Version 7.23), produced by Geo-Slope International, indicates that after completion of construction (including removal and replacement of the organic deposits), the embankment will have a Factor of Safety (FoS) greater than 1.3 for a deep-seated, global failure surface that would impact the operation of the highway. Therefore, stability mitigation is not required for the embankments at the culvert location at STA 12+620.

6.4.2 Settlement

The following sections outline the methods used to conduct the settlement analyses at the culvert location and the results of the analyses.

6.4.2.1 Methodology

To estimate the magnitude of the expected settlements, analyses were carried out along the culvert alignments using the commercially available program Settle3D (Version 2.013) produced by Rocscience Inc. The rate of settlement/consolidation of the cohesive foundation soils was assessed using Terzaghi's one-dimensional consolidation theory.

The sources of settlement at this site are:

- primary time-dependent consolidation of the cohesive deposits;
- secondary time-dependent (creep) consolidation of the cohesive deposits (long-term);
- immediate settlement of the native granular soils; and
- self-weight compression of the embankment fill materials beneath the culvert (where applicable).

The thickness of the native cohesive and non-cohesive foundation soils and the height of the embankment vary along the proposed culvert alignment and therefore the settlements along the length of the culvert will similarly vary. As such, settlements have been assessed at the culvert inlet, centerline and culvert outlet for each of the WBL and EBL culvert sections.

The settlement analyses assume that all organic soils (i.e., silty organics/peat/topsoil) beneath the culvert alignments will be removed prior to construction and that granular fill will be used for replacement of sub-excavated material (as discussed in Section 6.7.1). The piezometric condition required in the analyses is based on the groundwater level at about the level of the natural ground surface.

6.4.2.2 Parameter Selection

The immediate compression of the very loose to compact silt to sand and gravel deposit below the cohesive soils was modeled by estimating an elastic modulus of deformation based on the SPT 'N'-values and using correlations proposed by Bowles (1984) and Kulhawy and Mayne (1990). These estimated moduli values were compared with the typical range of expected values for similar soil types, as outlined in Canadian Highway Bridge Design Code and Commentary, (CHBDC, 2006) and adjusted, if necessary.

The consolidation settlement of the cohesive deposit was assessed using the results of the laboratory index tests and in situ field vane tests in the boreholes and the results of consolidation tests on cohesive deposits present in other areas of the project where culverts are required to estimate the stress history and deformation parameters for the cohesive deposits at this culvert location. Estimates of deformation parameters (i.e., recompression and compression indices) were obtained using empirical correlations proposed in literature by Koppula (1986), Terzaghi and Peck (1967), Kulhawy and Mayne (1990) and Azzouz et al. (1976). The correlations by Terzaghi and Peck (1967) and Koppula (1986) relating the natural water content and liquid limit to the compression index was found to be the most consistent with the results of laboratory consolidation tests for the clayey soils in the high fill and culvert areas of the project, and as such were used to represent the deformation properties at this location.

The following correlation relating in situ undrained shear strength to preconsolidation stress proposed by Mesri (1975) was employed:

$$\sigma'_p = \frac{s_{u(mob)}}{0.22}$$

where:

$s_{u(mob)}$ = $\mu s_{u(FV)}$
σ'_p = preconsolidation stress (kPa)
$s_{u(mob)}$ = average mobilized undrained shear strength (kPa)
$s_{u(FV)}$ = undrained shear strength from field vane test (kPa)
μ = Bjerrum's (1973) correction factor based on Plasticity Index

The coefficient of consolidation, c_v (cm^2/s), required in the settlement time-rate analysis was estimated from the U.S. Navy (1986) correlation with liquid limits assuming normally-consolidated soils from laboratory consolidation test data from elsewhere within the project limits.

The simplified stratigraphy together with the associated strength and unit weight values assigned to the different native soil types at the culvert location are summarized below.

Stratigraphic Unit	γ' (kN/m^3)	σ_p' (kPa)	e_o	C_c	C_r	E' (MPa)	c_v[2] (cm^2/s)
Silty Organics/ Peat/Topsoil[1]	12	-	-	-	-	-	-
Clayey Silt to Silty Clay	17	110	1.2	0.4	0.04	-	$1.25x10^{-2}$
Silt to Silt and Sand	18	-	-	-	-	6	-

Notes:

1. The peat/topsoil is to be removed prior to culvert/embankment construction.
2. In the overconsolidated range.

6.4.2.3 Results of Analysis

For the WBL and EBL culvert, the estimated total settlement at the centreline of each culvert is estimated to be about 105 mm (comprised of 40 mm of immediate settlement due to compression of the cohesionless deposits and about 65 mm of consolidation settlement of the cohesive deposit). The estimated total settlement comprised of immediate and post-construction settlement, at the north and south end of each culvert is about 50 mm. The differential settlement between the centre of the culvert and the ends is therefore up to about 55 mm and will occur after culvert installation.

6.4.3 Horizontal Strain

The following sections outline the methods used to estimate the horizontal strain along the culverts and the results of the analysis.

6.4.3.1 Parameter Selection

As a result of the two dimensional nature of the proposed embankment geometry in the immediate area of the culvert, shear stresses will be mobilized in the foundation soils upon completion of embankment construction causing lateral spreading of the foundation soils and new embankment fill. This, in conjunction with the non-uniform vertical settlement of the foundation soils along the proposed alignment of the culvert sections, will generate horizontal straining along the newly constructed culverts. In order to maintain the structural integrity of the culvert sections, the culvert design must incorporate a suitable allowance for extension at the joints/couplings of the culvert segments to prevent the culvert from cracking and/or failing in tension.

The research work by Rutledge and Gould (1973) on the movements of articulated conduits under earth dams on compressible foundations can be used to estimate the magnitude of the horizontal strain likely to occur as a result of the proposed embankment construction at culvert sites. The following equations have been used to obtain a relationship between vertical settlement, vertical strain, horizontal strain and maximum joint opening as a result of settlement of the foundation soils:

$$\varepsilon_v = \frac{\delta_v}{d}$$

$$\varepsilon_h = \varepsilon_v \frac{\varepsilon_h}{\varepsilon_v}$$

$$\Delta L = \varepsilon_h L$$

where :

ΔL = maximum joint opening (m)

ε_v = maximum vertical strain

ε_h = maximum horizontal strain

$\frac{\varepsilon_h}{\varepsilon_v}$ = estimated ratio of maximum horizontal strain to maximum vertical strain from Figure 2 in Rutledge and Gould, 1973)

L = length of culvert (m)

δ_v = maximum vertical settlement of culvert as a result of immediate and post-construction settlement of foundation soils and granular fill / bedding material (m)

d = thickness of compressible foundation deposits at culvert location (m)

6.4.3.2 Results of Analysis

The settlement analysis of the WBL culvert indicates that the total post-construction settlement of the foundation soils along the culvert section will be about 105 mm at the centreline and 50 mm at the inlet/outlet, with an estimated differential settlement of about 55 mm. Therefore, the maximum post-construction horizontal strain along the 27.5 m long culvert is estimated to be about 0.5 per cent of the culvert length, resulting in an estimated total joint opening of about 140 mm along the length of the culvert section.

The settlement analysis of the EBL culvert indicates that the total post-construction settlement of the foundation soils along the culvert section will be about 105 mm at the centreline and 50 mm at the inlet/outlet, with an estimated differential settlement of about 55 mm. Therefore, the maximum post-construction horizontal strain along the 32.7 m long culvert is estimated to be about 0.58 per cent of the culvert length, resulting in an estimated total joint opening of about 180 mm along the length of the culvert section.

To mitigate the horizontal strain along the culvert, consideration could be given to preloading the embankment prior to construction of the culverts or the culvert could be constructed with a camber if such a horizontal strain can be accommodated in the design. Preloading to eliminate the immediate settlement of the cohesionless deposits could be carried out applying the final embankment height for one month prior to construction of the permanent culvert to reduce the post-culvert construction settlement to 65 mm (i.e. just consolidation settlement). In this case, the total joint opening would be reduced to about 90 mm at each of the WBL and EBL culverts. Additional reduction in strain would require additional preloading. Assuming a c_v of 1.25×10^{-2} cm^2/s for the clayey sit to silty clay deposit and a thickness of 6.9 m, the time for 90 per cent consolidation is approximately 3 months. Preloading is only required if the strain indicated above cannot be tolerated by the final type of culvert chosen for this site.

6.5 Geotechnical Resistance

For the 2.5 m wide permanent box culvert proposed for this site, the culvert should be designed using a factored geotechnical axial resistance at Ultimate Limit States (ULS) of 75 kPa and a geotechnical reaction at Serviceability Limit States (SLS) of 40 kPa (for 25 mm of settlement), based on the culverts being founded on a properly prepared subgrade/granular bedding (as discussed in Section 6.7.1). The geotechnical resistances noted above are applicable for loads that will be applied perpendicular to the base of the culvert. Where loads are not applied perpendicular to the base of the culvert, inclination of the loads should be taken into account in accordance with Section 6.7.4 and Section C6.7.4 of the CHBDC and its Commentary.

The loading on the foundation soils below the culvert and the associated total settlement at the culvert locations will be governed by the design height of the overlying and adjacent embankment fills. As such, it is recommended that the structural engineer exercise caution when utilizing the values of the geotechnical axial resistance at SLS in the design of the culvert. Where the culverts are constructed following completion of all foundation soil due to the loading of the embankment fill, the SLS value as provided above may be used for the culvert design for 25 mm of settlement.

6.5.1 Frost Protection

The estimated frost penetration depth for the Highway 17 area is 2.0 m as per OPSD 3090.100 (Foundation Frost Penetration Depths for Northern Ontario).

Box culverts are typically not provided with frost protection where water flows year-round through the culvert. Where the creek freezes in winter and frost penetration may extend to 2.0 m below the invert, it would be prudent and it is recommended that the subsoils from below the proposed culvert alignment be sub-excavated to a depth of 2.0 m below the culvert invert and replaced with non-frost susceptible OPSS.PROV 1010 (Aggregates) Granular 'B' Type II material.

6.5.2 Resistance to Lateral Loads/Sliding Resistance

Resistance to lateral forces/sliding resistance between the base of the box culverts and the granular fill/bedding placed following sub-excavation of organic deposits should be calculated in accordance with Section 6.7.5 of the CHBDC. The following summarizes the unfactored values of coefficient of friction for the interface materials.

Interface Materials	Coefficient of Friction
Precast Concrete Box Culvert on Compacted Granular 'A'	tan δ = 0.45
Cast-in-Place Concrete Box Culvert on Compacted Granular 'A'	tan δ = 0.55

6.6 Lateral Earth Pressures

The lateral earth pressures acting on the walls of the culverts will depend on the type and method of placement of backfill materials, the nature of the soils/embankment fill behind the backfill, the magnitude of surcharge including construction loadings, the freedom of lateral movement of the structure, and the drainage conditions behind the walls.

The following recommendations are made concerning the design of the culvert walls. It should be noted that these design recommendations and parameters are for level backfill and ground surface behind the walls. Where there is sloping ground behind the walls, the coefficient of lateral earth pressure must be adjusted to account for the slope.

- Select, free draining granular fill meeting the specifications of OPSS PROV. 1010 (Aggregates) Granular 'A' or Granular 'B' Type II but with less than 5 per cent passing the No. 200 (0.075 mm) sieve should be used as backfill behind the culvert walls, and on top of the culvert for a thickness of up to 300 mm. Backfill should be placed in a maximum of 200 mm loose lift thickness and nominally compacted. Weep holes should be installed in the walls to provide positive drainage of the granular backfill. Compaction (including type of equipment, target densities, etc.) should be carried out in accordance with OPSS 501 and SP105S21 (Compacting).
- For a box culvert, granular fill (where utilized) should be placed in a zone with the width up to 300 mm behind the back of the culvert. The pressures are based on the proposed embankment fill materials and the following parameters (unfactored) may be used:

Fill Type	Unit Weight	Coefficients of Static Lateral Earth Pressure	
		At-Rest, K_o	Active, K_a
Granular 'A'	22 kN/m^3	0.43	0.27
Granular 'B' Type II	21 kN/m^3	0.43	0.27

If the culvert structure allows for lateral yielding, active earth pressures may be used in the foundation design. If the culvert structure does not allow lateral yielding, at-rest earth pressures should be assumed for foundation design. The movement to allow active pressures to develop within the backfill, and thereby assume a restrained structure, may be taken as per Table C6.6 of the Commentary to the CHBDC.

6.7 Culvert Construction Considerations

6.7.1 Excavation and Backfill Below Culvert

Prior to the placement of any bedding material or granular fill, all organic soils should be stripped from the plan limits of the proposed works. Considering the design invert elevations of the proposed culvert (Elevations 257.0 m and 257.5 m at the north end of the WBL and the south end of the EBL, respectively) and assuming the organic materials (i.e. silty organics/peat/topsoil) will be removed, the excavation will extend up to at least 0.8 m below existing ground surface. As the organic deposit is relatively thin at the proposed culvert locations, it is recommended that OPSS.PROV 1010 (Aggregates) Granular 'A' or Granular 'B' Type II fill be used to backfill the excavation up to the underside of the culverts.

All excavations should be carried out in accordance with OPSS 902 (Excavating and Backfilling – Structures) and must be carried out in accordance with Ontario Regulation 213 Ontario Occupational Health and Safety Act for Construction Projects (as amended).

6.7.2 Culvert Bedding and Backfill

6.7.2.1 Precast Culvert

The bedding, levelling pad and granular backfill requirements for a precast culvert should be in accordance with OPSS 422 (Precast Reinforced Concrete Box Culverts). The bedding should be placed in lifts not exceeding 200 mm in loose thickness, and compacted to at least 98 per cent of the Standard Proctor maximum dry density of the material as specified in OPSS 501 and SP105S21 (Compacting). In addition, a minimum 75 mm thick uncompacted levelling pad consisting of OPSS.PROV 1010 (Aggregates) Granular 'A' material or concrete fine aggregate (meeting the grading requirements specified in OPSS.PROV 1002 (Aggregates - Concrete) should be provided as shown on OPSD 803.010 (Backfill and Cover for Concrete Culverts) for culvert construction in dry conditions. Alternatively, the bedding material can be placed in wet conditions. In this regard, a 300 mm thick layer of OPSS.PROV 1010 (Aggregates) Granular 'B' Type II material should be placed as bedding and nominally compacted by the construction equipment. Further, as the native soil below the bedding is generally fine grained, it is recommended that a non-woven geotextile be placed between the native soil and the bottom of the bedding. The geotextile should meet the specifications for OPSS 1860 (Geotextiles) Class II, and have a fabric opening size (FOS) not greater than 212 µm.

6.7.2.2 Cast-in-Place Culvert

Should a cast-in-place culvert be preferred, the bedding and backfill requirements should be in accordance with OPSS 902 (Excavating and Backfilling – Structures). The box culvert should be provided with at least 300 mm of OPSS.PROV 1010 (Aggregates) Granular 'A' or 'B' Type II for bedding purposes and partial frost protection. The bedding should be placed in lifts not exceeding 200 mm in loose thickness, and compacted to at least 98 per cent of the Standard Proctor maximum dry density of the material as specified in OPSS 501 and SP105S21 (Compacting).

6.7.2.3 Circular Culvert

The bedding, levelling pad and backfill for a circular concrete pipe culvert should be in accordance with OPSD 802.034 (Rigid Pipe Bedding and Cover in Embankment) and culvert construction should be in accordance with OPSS 421 (Pipe Culvert Installation in Open Cut). It is important that the backfill at the haunches be well compacted. The circular culvert should be constructed on a minimum 300 mm thick layer of OPSS.PROV 1010 (Aggregates) Granular ‘A’ or Granular ‘B’ Type II material for bedding purposes.

6.7.2.4 General

Backfill behind the culvert walls, should consist of granular fill placed and compacted as recommended in Section 6.6. The fill should also be placed concurrently on both sides of the culvert walls, ensuring that the backfill depth on one side does not exceed the other side by more than 500 mm.

The backfill above the culvert should consist of OPSS.PROV 1010 (Aggregates) Granular ‘A’ or Granular ‘B’ Type II to minimize differential settlements along the highway embankment in the area of the permanent culvert.

The culvert should be designed for the full overburden stress and appropriate live loads, assuming a fill unit weight of 22 kN/m^3 for Granular ‘A’ and 21 kN/m^3 for Granular ‘B’ Type II placed above and surrounding the culvert.

Inspection and field density testing should be carried out by qualified geotechnical personnel during all engineered fill placement operations to ensure that appropriate materials are used, and that adequate levels of compaction have been achieved.

6.7.3 Erosion Protection

Provisions should be made for scour and erosion protection (suitable non-woven geotextiles and/or rip-rap) at the culvert location. In order to prevent surface water from flowing either beneath the culverts (potentially causing undermining and scouring) or around the culvert (creating seepage through the embankment fill, and potentially causing erosion and loss of fine soil particles), a concrete cut-off wall or clay seal should be provided at the upstream end of each culvert section. If a clay seal is adopted, the clay material should meet the requirements of OPSS 1205 (Clay Seal), and the seal should be a minimum 1 m thick if constructed of natural clay or soil-bentonite mix and extend from a depth of 1 m below the scour level to a minimum horizontal distance of 2 m on either side of each section of culvert inlet opening, and a minimum vertical height equivalent to the high water level, including along the upstream slope of the embankment. Alternatively, a 0.6 m thick clay blanket (if constructed of natural clay or a soil-bentonite mix) may be constructed, extending upstream three times the culvert height and along the adjacent slopes to a height of two times the culvert height or the high water level, whichever is greater.

The requirements for and design of erosion protection measures for the inlet and outlet of each culvert section should be assessed by the hydraulics design engineer. As a minimum, rip-rap treatment for the outlet of the culvert should be consistent with OPSD 810.010 (Rip-Rap Treatment for Sewer and Culvert Outlets). Erosion protection for the inlet of the culverts should follow the standard presented in OPSD 810.010 similar to the outlet. Rip-rap should be provided over the full extent of the clay blanket, including the side slopes and fill slope over the culverts.

6.7.4 Control of Groundwater and Surface Water

Excavation within the plan limits of the proposed culvert alignments will be required to remove organic overburden prior to placement of backfill, bedding material and the actual culvert structures. During excavation, groundwater flow into the excavation can be expected to occur due to the relatively high water levels. Therefore, control of surface water and groundwater will be necessary at the culvert location, as required, to allow for construction to be carried out in dry conditions.

Creek/ditch flows will need to be diverted/piped away from the excavation areas during the construction period. Surface water should be directed away from the excavation areas to prevent ponding of water that could result in disturbance and weakening of the foundation subgrade.

Given that the design invert is approximately at or above the existing ground surface and that the excavation required to remove the organic materials is relatively shallow, it is not anticipated that any specialized measures will be required to control groundwater and allow construction in the dry, apart from the diversion of the creek/ditch flows noted above. However, seasonal fluctuations may require pumping from properly filtered sumps to adequately control seepage. Surface water should be directed away from the excavations areas to prevent ponding of water.

7.0 CLOSURE

This report was prepared by Mr. Adam Core, EIT and the technical aspects were reviewed by Ms. Sarah E.M. Poot, P.Eng., a senior geotechnical engineer and Associate of Golder. Mr. Jorge M. A. Costa, P.Eng., Golder's Designated MTO Contact for this project and a Principal of Golder, conducted an independent quality control review of the report.

Report Signature Page

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AC/SEMP/JMAC/kp

N:\Active\2011\1190 Sudbury\1191\Temp folder 11-1191-0007\Report\Culverts\R05 - Culvert STA 12+620 Twp Denison (C2)\Final\11-1191-0007-05 RPT 15May01 FIDR Culvert 12+620 Denison.docx

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Stantec Consulting Limited. 2009. Planning, Preliminary Design, and Environmental Supplementary Report, Highway 17, Town of Walden, GWP 156-98-00, dated March 2009

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ASTM International:

ASTM D1586	Standard Test Method for Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils
ASTM D1587	Standard Practice for Thin-Walled Tube Sampling of Soils for Geotechnical Purposes
ASTM D2573	Standard Test Method for Field Vane Shear Test in Cohesive Soil

Commercial Software:

Settle3D (Version 2.013) by Rocscience Inc.

GeoStudio (Version 7.23) by Geo-Slope International Ltd.

Contract Design Estimating and Documentation (CDED):

Special Provision 105S21	Amendment to OPSS 501 - Compacting

Ontario Occupational Health and Safety Act:

Ontario Regulation 213	Construction Projects (as amended)

Ontario Provincial Standard Drawing:

OPSD 802.010	Flexible Pipe Embedment and Backfill Earth Excavation
OPSD 802.034	Rigid Pipe Bedding and Cover in Embankment, Original Ground: Earth or Rock
OPSD 803.010	Backfill and Cover for Concrete Culverts with Spans Less Than or Equal to 3.0m
OPSD 810.010	Rip-Rap Treatment for Sewer and Culvert Outlets
OPSD 3090.100	Foundation Frost Penetration Depths for Northern Ontario

Ontario Provincial Standard Specification:

OPSS 421	Construction Specification for Pipe Culvert Installation in Open Cut
OPSS 422	Construction Specification for Precast Reinforced Concrete Box Culverts and Box Sewers in Open Cut
OPSS 501	Construction Specification for Compacting
OPSS 517	Construction Specification for Dewatering of Pipeline, Utility and Associated Structure Excavation
OPSS 902	Construction Specification for Excavating and Backfilling – Structures
OPSS 1205	Material Specification for Clay Seal
OPSS 1860	Material Specification for Geotextiles
OPSS.PROV 1002	Material Specification for Aggregates Concrete
OPSS.PROV 1010	Material Specification for Aggregates (Base, Subbase, Select Subgrade and Backfill Material)

Ontario Water Resources Act:

Ontario Regulation 903 Wells (as amended)

MINISTRY OF TRANSPORTATION, ONTARIO

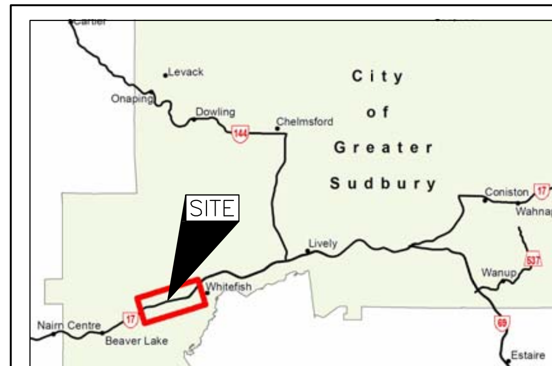
METRIC
DIMENSIONS ARE IN METRES AND/OR MILLIMETRES UNLESS OTHERWISE SHOWN. STATIONS IN KILOMETRES + METRES.

CONT No.
GWP No. 156–98–00

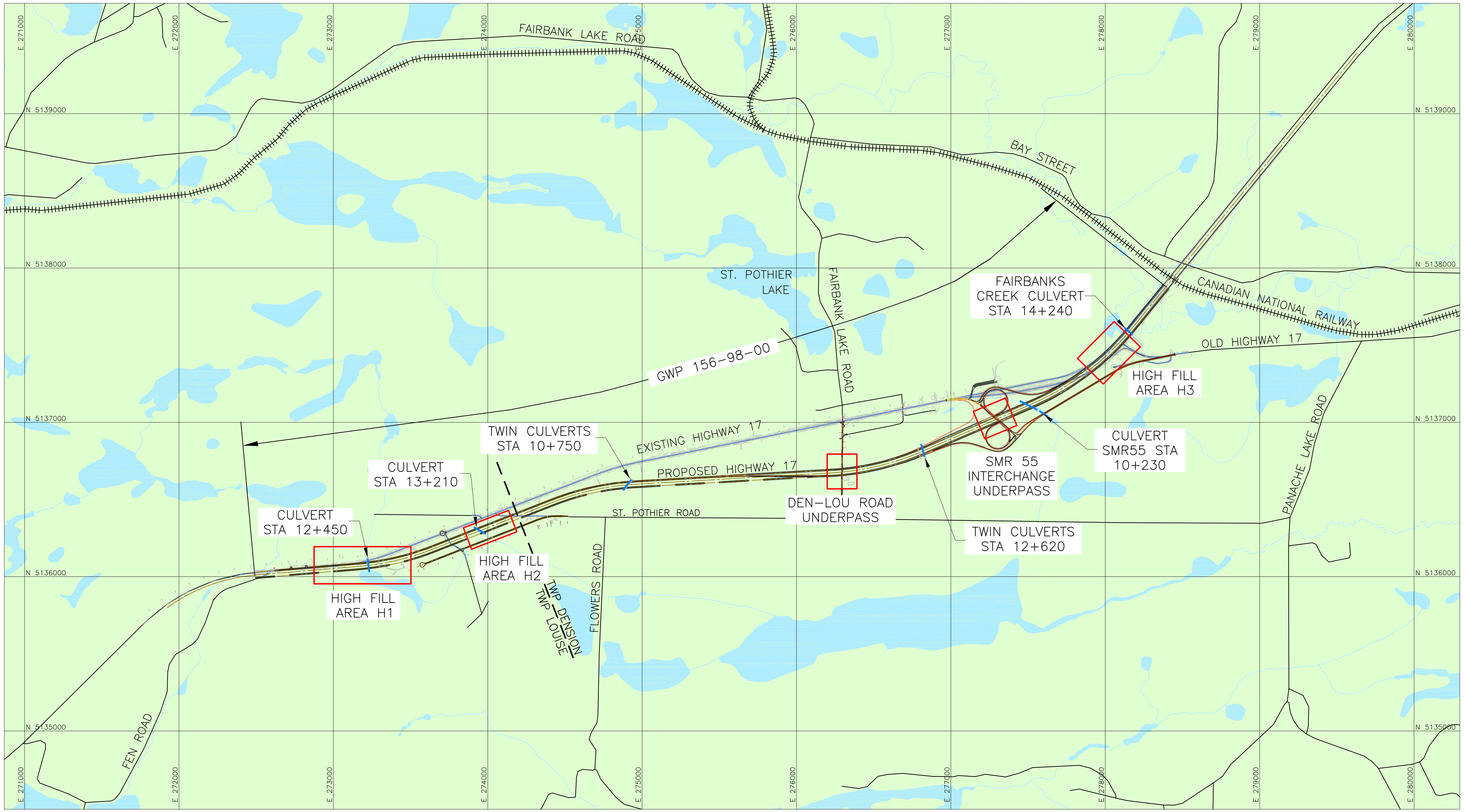
SHEET

HIGHWAY 17
SITE LOCATION PLAN

Golder Associates Ltd.
SUDBURY, ONTARIO, CANADA



KEY PLAN
10 0 10 20 km



PLAN

SCALE
300 0 300 600 m

REFERENCE

Base plans provided by Golder GIS and highway alignment provided in digital format by DM Wills, drawing file EBL & WBL PROFILES.dwg received Feb 28, 2013.

NO.	DATE	BY	REVISION

HWY. 17		PROJECT NO. 11–1191–0007	DIST.
SUBM'D. MT	CHKD.	DATE: APR 2015	SITE:
DRAWN: TB	CHKD. SEMP	APPD. JMAC	DWG. 1

PLOT DATE: April 16, 2015

MINISTRY OF TRANSPORTATION, ONTARIO

METRIC

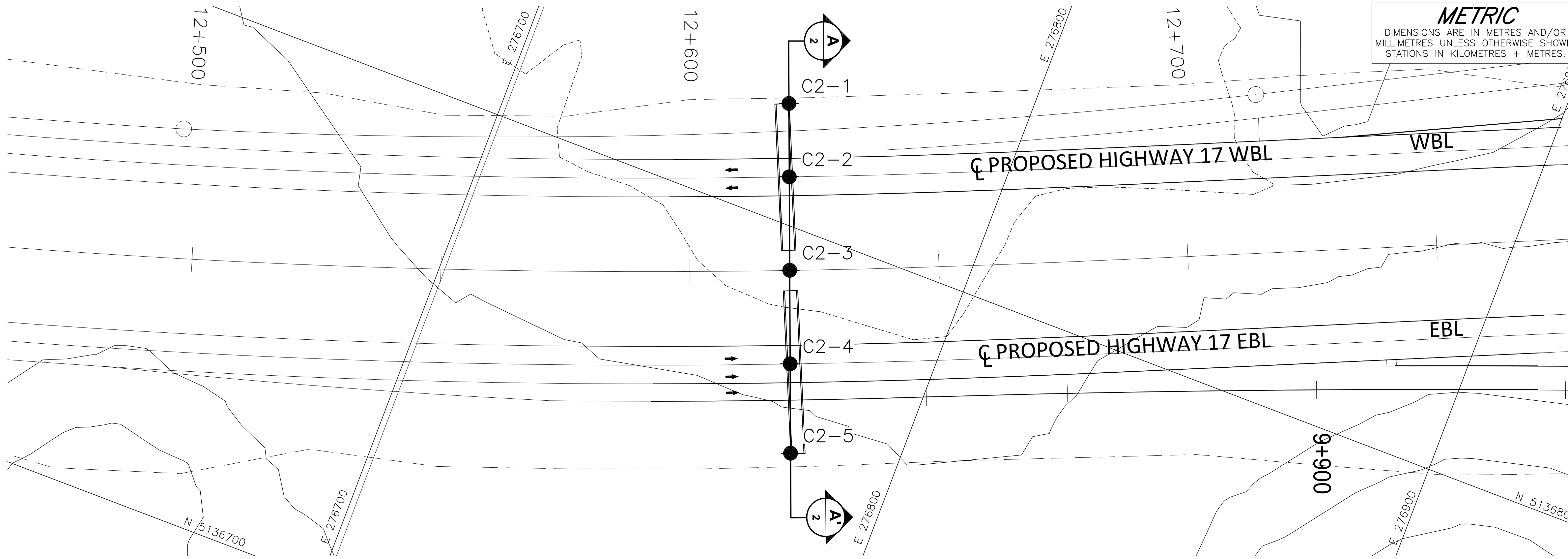
DIMENSIONS ARE IN METRES AND/OR MILLIMETRES UNLESS OTHERWISE SHOWN. STATIONS IN KILOMETRES + METRES.

CONT No.
GWP No. 156–98–00

SHEET

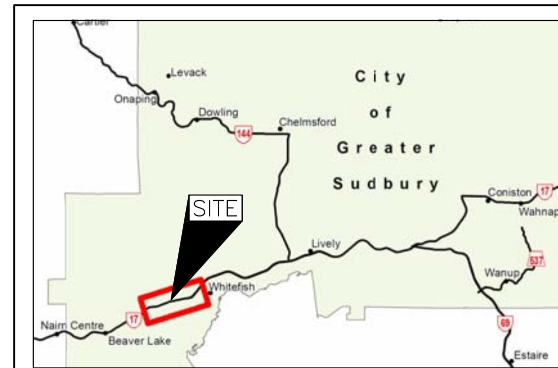
HIGHWAY 17 4 LANING
CULVERT – STA 12+620
BOREHOLE LOCATIONS AND SOIL STRATA

Golder Associates Ltd.
SUDBURY, ONTARIO, CANADA



PLAN

SCALE 10 0 10 20 m



KEY PLAN

10 0 10 20 km

LEGEND

●	Borehole – Current Investigation
N	Standard Penetration Test Value
16	Blows/0.3m unless otherwise stated (Std. Pen. Test, 475 j/blow)
▽	WL upon completion of drilling
R	Refusal

BOREHOLE CO-ORDINATES

No.	ELEVATION	NORTHING	EASTING
C2–1	257.2	5136822.9	276753.9
C2–2	257.2	5136809.2	276759.2
C2–3	257.2	5136791.7	276765.9
C2–4	257.3	5136774.2	276772.7
C2–5	257.7	5136757.5	276779.1

NOTES

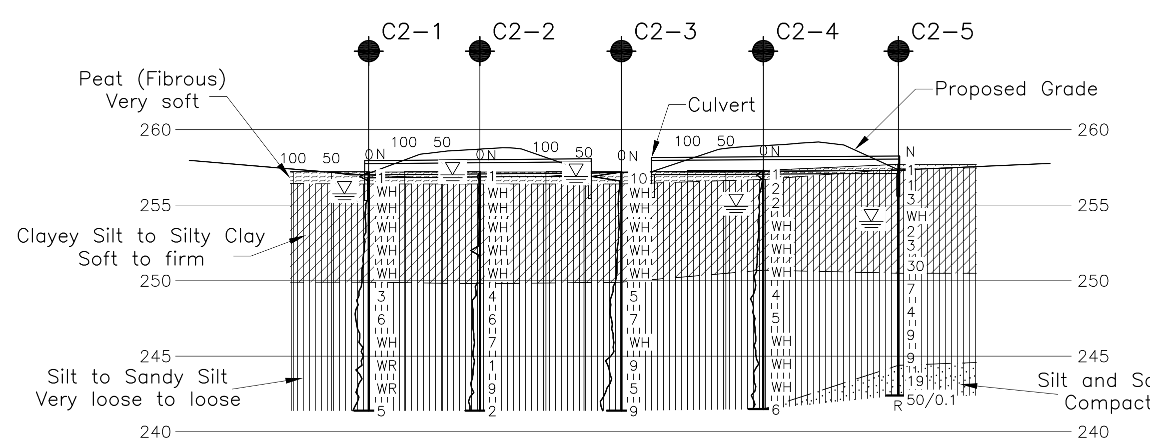
This drawing is for subsurface information only. The proposed details/works are shown for illustration purposes only and may not be consistent with the final design configuration as shown elsewhere in the Contracts Documents.

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

The complete Foundation Investigation and Design Report for this project and other related documents may be examined at the Materials Engineering and Research Office, Downsview. Information contained in this report and related documents is specifically excluded in accordance with Section GC 2.01 of OPS General Conditions.

REFERENCE

Base plans provided in digital format by DM Wills, drawing files 581_base.dwg, GWP156-98-00_B & C Plans.dwg and 581_contours.dwg received Jan 17, 12+620 –Geotech – 46-576 Structural Culvert.dwg provided in digital format by DM Wills received on April 15, 2014.



A–A' 2 CULVERT AT STA 12+620
HIGHWAY 17

HORIZONTAL SCALE 10 0 10 20 m
5 0 5 10 m VERTICAL SCALE

LICENSED PROFESSIONAL ENGINEER S.E.M. POOT 90471921 APR 15, 2015 PROVINCE OF ONTARIO

LICENSED PROFESSIONAL ENGINEER J.M.A.COSTA APR 15, 2015 PROVINCE OF ONTARIO

NO.	DATE	BY	REVISION

Geocres No. 41I–329

HWY. 17		PROJECT NO. 11–1191–0007	DIST.
SUBM'D. AC	CHKD.	DATE: APR 2015	SITE: 46–576
DRAWN: TB	CHKD. SEMP	APPD. JMAC	DWG. 2

PLOT DATE: April 15, 2015

APPENDIX A

Record of Boreholes

LIST OF SYMBOLS

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

I. GENERAL

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

II. STRESS AND STRAIN

γ	shear strain
Δ	change in, e.g. in stress: $\Delta\sigma$
ε	linear strain
ε_v	volumetric strain
η	coefficient of viscosity
υ	Poisson's ratio
σ	total stress
σ'	effective stress ($\sigma' = \sigma - u$)
σ'_{vo}	initial effective overburden stress
$\sigma_1, \sigma_2, \sigma_3$	principal stress (major, intermediate, minor)
σ_{oct}	mean stress or octahedral stress $= (\sigma_1 + \sigma_2 + \sigma_3)/3$
τ	shear stress
u	porewater pressure
E	modulus of deformation
G	shear modulus of deformation
K	bulk modulus of compressibility

III. SOIL PROPERTIES

(a) Index Properties

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

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

(a) Index Properties (continued)

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

(b) Hydraulic Properties

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

(c) Consolidation (one-dimensional)

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

(d) Shear Strength

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

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

LIST OF ABBREVIATIONS

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

I. SAMPLE TYPE

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

II. PENETRATION RESISTANCE

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

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

PH: Sampler advanced by hydraulic pressure
PM: Sampler advanced by manual pressure
WH: Sampler advanced by static weight of hammer
WR: Sampler advanced by weight of sampler and rod

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

III. SOIL DESCRIPTION

(a) Non-Cohesive (Cohesionless) Soils

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

(b) Cohesive Soils
Consistency

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

IV. SOIL TESTS

w	water content
w_p	plastic limit
w_l	liquid limit
C	consolidation (oedometer) test
CHEM	chemical analysis (refer to text)
CID	consolidated isotropically drained triaxial test[1]
CIU	consolidated isotropically undrained triaxial test with porewater pressure measurement[1]
D_R	relative density (specific gravity, G_s)
DS	direct shear test
M	sieve analysis for particle size
MH	combined sieve and hydrometer (H) analysis
MPC	Modified Proctor compaction test
SPC	Standard Proctor compaction test
OC	organic content test
SO_4	concentration of water-soluble sulphates
UC	unconfined compression test
UU	unconsolidated undrained triaxial test
V	field vane (LV-laboratory vane test)
γ	unit weight

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

V. MINOR SOIL CONSTITUENTS

Per cent by Weight	**Modifier**	**Example**
0 to 5	Trace	Trace sand
5 to 12	Trace to Some (or Little)	Trace to some sand
12 to 20	Some	Some sand
20 to 30	(ey) or (y)	Sandy
over 30	And (non-cohesive (cohesionless)) or With (cohesive)	Sand and Gravel Silty Clay with sand / Clayey Silt with sand

Golder Associates

RECORD OF BOREHOLE No C2-1

 METRIC

PROJECT 11-1191-0007			
G.W.P. 156-98-00	LOCATION N 5136822.9; E 276753.9		ORIGINATED BY EHS
DIST	HWY 17	BOREHOLE TYPE 108 mm I.D. Continuous Flight Hollow Stem Augers	COMPILED BY AC
DATUM GEODETIC	DATE February 25, 2014		CHECKED BY SEMP

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, × REMOULDED (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	GROUND WATER CONDITIONS	SHEAR STRENGTH (field vane, sensitivity)	UNIT WEIGHT	GR	SA	SI	CL
257.2	GROUND SURFACE										
0.0	Silty ORGANICS, trace sand, trace rootlets Very Loose Brown Frozen to 0.2 m, then wet	1	SS	1							
256.4 0.8	CLAYEY SILT to SILTY CLAY, trace rootlets in Sample 2 Soft to firm Brown to grey Wet	2	SS	WH	∇ (approx. El. 255.9)						
		3	SS	WH							
						+ (sensitivity 10)					
		4	SS	WH							
						+ (sensitivity 25)					
	Varved below 4.6 m depth.	5	SS	WH							
						+ (sensitivity 10)					
		6	SS	WH							
						+ (sensitivity 10)					
249.9 7.3	SILT to Sandy SILT, trace to some clay Very loose to loose Grey Wet	7	SS	3			NP	0	2	85	13
		8	SS	6							
		9	SS	WH							

Elevation scale: 257, 256, 255, 254, 253, 252, 251, 250, 249, 248, 247, 246

Continued Next Page

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

RECORD OF BOREHOLE No C2-1

 METRIC

PROJECT 11-1191-0007

G.W.P. 156-98-00

DIST ____ HWY 17

DATUM GEODETIC

LOCATION N 5136822.9; E 276753.9

BOREHOLE TYPE 108 mm I.D. Continuous Flight Hollow Stem Augers

DATE February 25, 2014

ORIGINATED BY EHS

COMPILED BY AC

CHECKED BY SEMP

--- CONTINUED FROM PREVIOUS PAGE ---

ELEV DEPTH	DESCRIPTION	NUMBER	TYPE	"N" VALUES	ELEVATION SCALE	WATER CONTENT (%)	GR	SA	SI	CL
	SILT to Sandy SILT, trace to some clay Very loose to loose Grey Wet				245					
		10	SS	WH		○	0	22	75	3
					244					
		11	SS	WH	243					
					242					
241.4		12	SS	5						
15.8	END OF BOREHOLE									

Note:

1. Water level at a depth of 1.4 m below ground surface (Elev. 255.8 m) upon completion of drilling.

2. Advanced DCPT 1.5 m south, 0.5 m east of borehole.

Legend: DYNAMIC CONE PENETRATION RESISTANCE PLOT (20, 40, 60, 80, 100); SHEAR STRENGTH kPa: ○ UNCONFINED, + FIELD VANE, ● QUICK TRIAXIAL, × REMOULDED (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 (%)

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

Golder Associates

RECORD OF BOREHOLE No C2-2

 METRIC

PROJECT 11-1191-0007
G.W.P. 156-98-00
LOCATION N 5136809.2; E 276759.2
ORIGINATED BY MT/EHS
DIST HWY 17
BOREHOLE TYPE 108 mm I.D. Continuous Flight Hollow Stem Augers
COMPILED BY AC
DATUM GEODETIC
DATE February 26 and 27, 2014
CHECKED BY SEMP

ELEV DEPTH	DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	ELEVATION SCALE	FIELD VANE (kPa) / Sensitivity	WATER CONTENT (%)	GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
257.2	GROUND SURFACE							
0.0	PEAT (Fibrous), Very Soft, Black, Wet	1	SS	1	257			
256.4 / 0.8	CLAYEY SILT to SILTY CLAY, Soft to firm, Grey, Wet	2	SS	WH	256			
		3	SS	WH			✓	0 0 50 50
					255	+ 4		
		4	TO	WH	254			
					253	+ 10		
		5	SS	WH	252		✓	
						+ 5		
	Varved below 6.1 m depth.	6	SS	WH	251			
					250	+ 4		
249.8 / 7.4	SILT, trace to some clay, trace to some sand, Very loose to loose, Grey, Wet	7	SS	4	249			
		8	SS	6	248		✓	0 3 91 6
					247			
		9	SS	7	246			

Ground water: ∇ at ground surface.

Continued Next Page

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

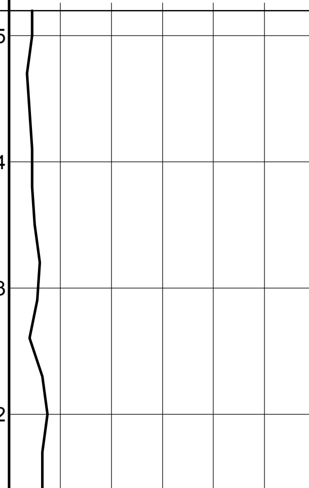
Golder Associates

RECORD OF BOREHOLE No C2-2

 METRIC

PROJECT 11-1191-0007
G.W.P. 156-98-00
LOCATION N 5136809.2; E 276759.2
ORIGINATED BY MT/EHS
DIST HWY 17
BOREHOLE TYPE 108 mm I.D. Continuous Flight Hollow Stem Augers
COMPILED BY AC
DATUM GEODETIC
DATE February 26 and 27, 2014
CHECKED BY SEMP

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, × REMOULDED) 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 ---										
	SILT, trace to some clay, trace to some sand Very loose to loose Grey Wet		10	SS	1		245				
							244				
			11	SS	9		243				
							242				
241.4			12	SS	2						
15.8	END OF BOREHOLE Note: 1. Water level 0.2 m below ground surface (Elev. 257.0 m) upon completion of drilling. 2. Advanced DCPT 1.5 m south, 1.0 m east of borehole.										



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

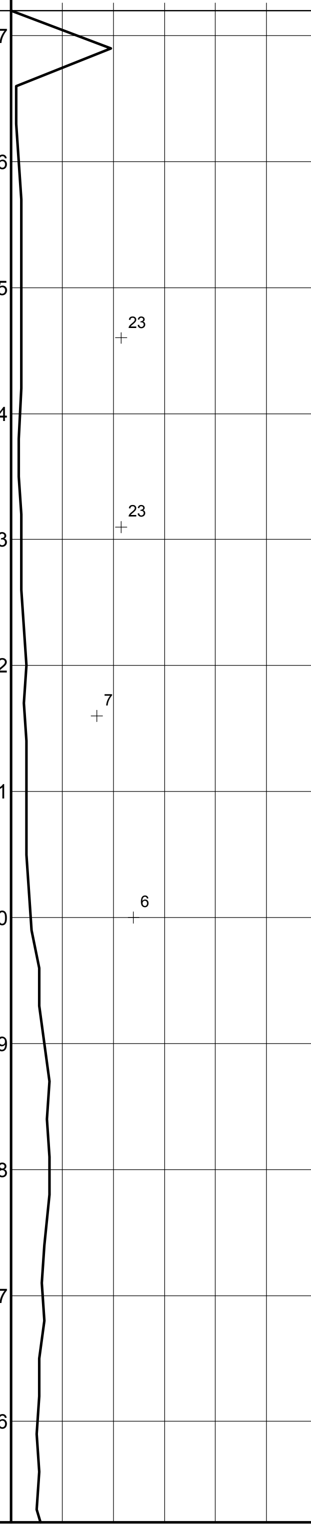
Golder Associates

RECORD OF BOREHOLE No C2-3

 METRIC

PROJECT 11-1191-0007			
G.W.P. 156-98-00	LOCATION N 5136791.7; E 276765.9		ORIGINATED BY EHS
DIST	HWY 17	BOREHOLE TYPE 108 mm I.D. Continuous Flight Hollow Stem Augers	COMPILED BY AC
DATUM GEODETIC	DATE March 3, 2014		CHECKED BY SEMP

ELEV DEPTH	DESCRIPTION (SOIL PROFILE)	SAMPLE NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	SHEAR STRENGTH kPa (+ FIELD VANE)	WATER CONTENT (%)	UNIT WEIGHT γ kN/m³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
257.2	GROUND SURFACE								
0.0	PEAT (Fibrous) Very Soft Black Frozen to 0.3 m, then wet	1	SS	10	∇		209.3		
256.4 0.8	CLAYEY SILT to SILTY CLAY, trace rootlets Firm Grey Wet	2	SS	WH					
		3	SS	WH					
						23			
		4	SS	WH			w_P–w_L range, w ≈ 58		0 0 39 61
						23			
		5	SS	WH					
						7			
		6	SS	WH					
						6			
249.9 7.3	SILT, trace to some clay, trace to some sand Very loose to loose Grey Wet	7	SS	5				NP	0 2 85 13
		8	SS	7					
		9	SS	WH					



Continued Next Page

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

SUD-MTO 001 1111910007 CULVERTS.GPJ GAL-MISS.GDT 27/10/14 DATA INPUT:

Golder Associates

RECORD OF BOREHOLE No C2-3

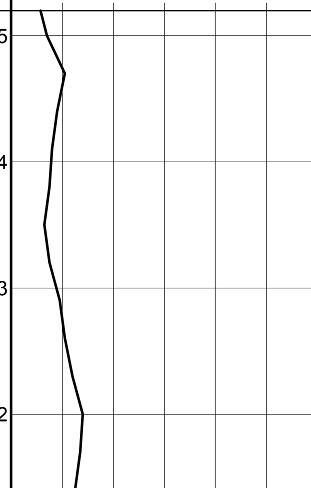
 METRIC

PROJECT 11-1191-0007			
G.W.P. 156-98-00	LOCATION N 5136791.7; E 276765.9		ORIGINATED BY EHS
DIST	HWY 17	BOREHOLE TYPE 108 mm I.D. Continuous Flight Hollow Stem Augers	COMPILED BY AC
DATUM GEODETIC		DATE March 3, 2014	CHECKED BY SEMP

--- CONTINUED FROM PREVIOUS PAGE ---

ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	WATER CONTENT (%)	UNIT WEIGHT γ kN/m³	GR	SA	SI	CL
	SILT, trace to some clay, trace to some sand Very loose to loose Grey Wet		10	SS	9		245						
							244						
			11	SS	5		243	○ (approx. 21)		0	18	79	3
							242						
241.4			12	SS	9								
15.8	END OF BOREHOLE Note: 1. Water level 0.3 m below ground surface (Elev. 256.9 m) upon completion of drilling. 2. Advanced DCPT 1.5 m south, 1.0 m east of borehole.												

DYNAMIC CONE PENETRATION RESISTANCE PLOT (20 40 60 80 100)



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

PLASTIC LIMIT W_P — NATURAL MOISTURE CONTENT W — LIQUID LIMIT W_L

REMARKS & GRAIN SIZE DISTRIBUTION (%)

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

Golder Associates

RECORD OF BOREHOLE No C2-4

 METRIC

PROJECT 11-1191-0007
G.W.P. 156-98-00
LOCATION N 5136774.2; E 276772.7
ORIGINATED BY EHS
DIST HWY 17
BOREHOLE TYPE 108 mm I.D. Continuous Flight Hollow Stem Augers
COMPILED BY AC
DATUM GEODETIC
DATE March 4, 2014
CHECKED BY SEMP

ELEV DEPTH	DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	SHEAR STRENGTH (FIELD VANE)	WATER CONTENT	GR	SA	SI	CL
257.3	GROUND SURFACE											
0.0	PEAT (Fibrous) Very Soft Black Frozen to 0.15 m, then wet	1	SS	1		257						
256.7 0.6	CLAYEY SILT to SILTY CLAY, trace rootlets in sample 2 Soft to firm Grey Wet	2	SS	2		256			0	0	58	42
	Varved below 2.0 m depth.	3	SS	2	▽	255	25					
		4	SS	WH		254	10					
		5	SS	WH		253 / 252	9					
		6	SS	WH		251						
250.7 6.6	SILT, trace to some clay, trace to some sand Very loose to loose Grey Wet					250						
		7	SS	4		249						
		8	SS	5		248			0	2	94	4
		9	SS	WH		247 / 246						

Continued Next Page

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

SUD-MTO 001 1111910007 CULVERTS.GPJ GAL-MISS.GDT 27/10/14 DATA INPUT:

RECORD OF BOREHOLE No C2-4

 METRIC

PROJECT 11-1191-0007			
G.W.P. 156-98-00	LOCATION N 5136774.2; E 276772.7		ORIGINATED BY EHS
DIST	HWY 17	BOREHOLE TYPE 108 mm I.D. Continuous Flight Hollow Stem Augers	COMPILED BY AC
DATUM GEODETIC	DATE March 4, 2014		CHECKED BY SEMP

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, × REMOULDED; 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 ---

ELEV DEPTH	DESCRIPTION	NUMBER	TYPE	"N" VALUES	ELEVATION SCALE
	SILT, trace to some clay, trace to some sand Very loose to loose Grey Wet	10	SS	WH	245
					244
		11	SS	WH	243
					242
241.5		12	SS	6	
15.8	END OF BOREHOLE				

Note:

1. Water level 2.4 m below ground surface (Elev. 254.9 m) upon completion of drilling.

2. Advanced DCPT 1.5 m east of borehole.

$+^3$, $\times^3$: Numbers refer to Sensitivity ○ 3% STRAIN AT FAILURE

Golder Associates

RECORD OF BOREHOLE No C2-5

 METRIC

PROJECT 11-1191-0007
G.W.P. 156-98-00
LOCATION N 5136757.5; E 276779.1
ORIGINATED BY EHS
DIST HWY 17
BOREHOLE TYPE 108 mm I.D. Continuous Flight Hollow Stem Augers
COMPILED BY AC
DATUM GEODETIC
DATE March 5, 2014
CHECKED BY SEMP

ELEV DEPTH	DESCRIPTION	NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
257.7	GROUND SURFACE						
0.0	TOPSOIL, Black, Frozen						
257.4 / 0.3	CLAYEY SILT to SILTY CLAY, trace rootlets in samples 1 and 2; Soft to firm; Grey; Wet	1	SS	1			
		2	SS	1		257	
		3	SS	3		256	0 6 61 33
	Varved below 2.6 m depth.					255	
		4	SS	WH			
					∇	254	
		5	SS	2			
		6	SS	3		253	0 1 54 45
						252	
	Possible cobble ancountered at 6.1 m depth.	7	SS	30		251	
250.5 / 7.2	SILT, trace to some clay, trace to some sand; Very loose to loose; Grey; Wet					250	
		8	SS	7		249	
		9	SS	4		248	
		10	SS	9		247	
						246	

Dynamic Cone Penetration Resistance Plot: 20 40 60 80 100
Shear Strength kPa: ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × REMOULDED; 20 40 60 80 100
Field vane result near elev. 252: + with sensitivity 3

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 ○ 3% STRAIN AT FAILURE

SUD-MTO 001 1111910007 CULVERTS.GPJ GAL-MISS.GDT 27/10/14 DATA INPUT:

RECORD OF BOREHOLE No C2-5

 METRIC

PROJECT 11-1191-0007

G.W.P. 156-98-00 LOCATION N 5136757.5; E 276779.1 ORIGINATED BY EHS

DIST HWY 17 BOREHOLE TYPE 108 mm I.D. Continuous Flight Hollow Stem Augers COMPILED BY AC

DATUM GEODETIC DATE March 5, 2014 CHECKED BY SEMP

--- CONTINUED FROM PREVIOUS PAGE ---

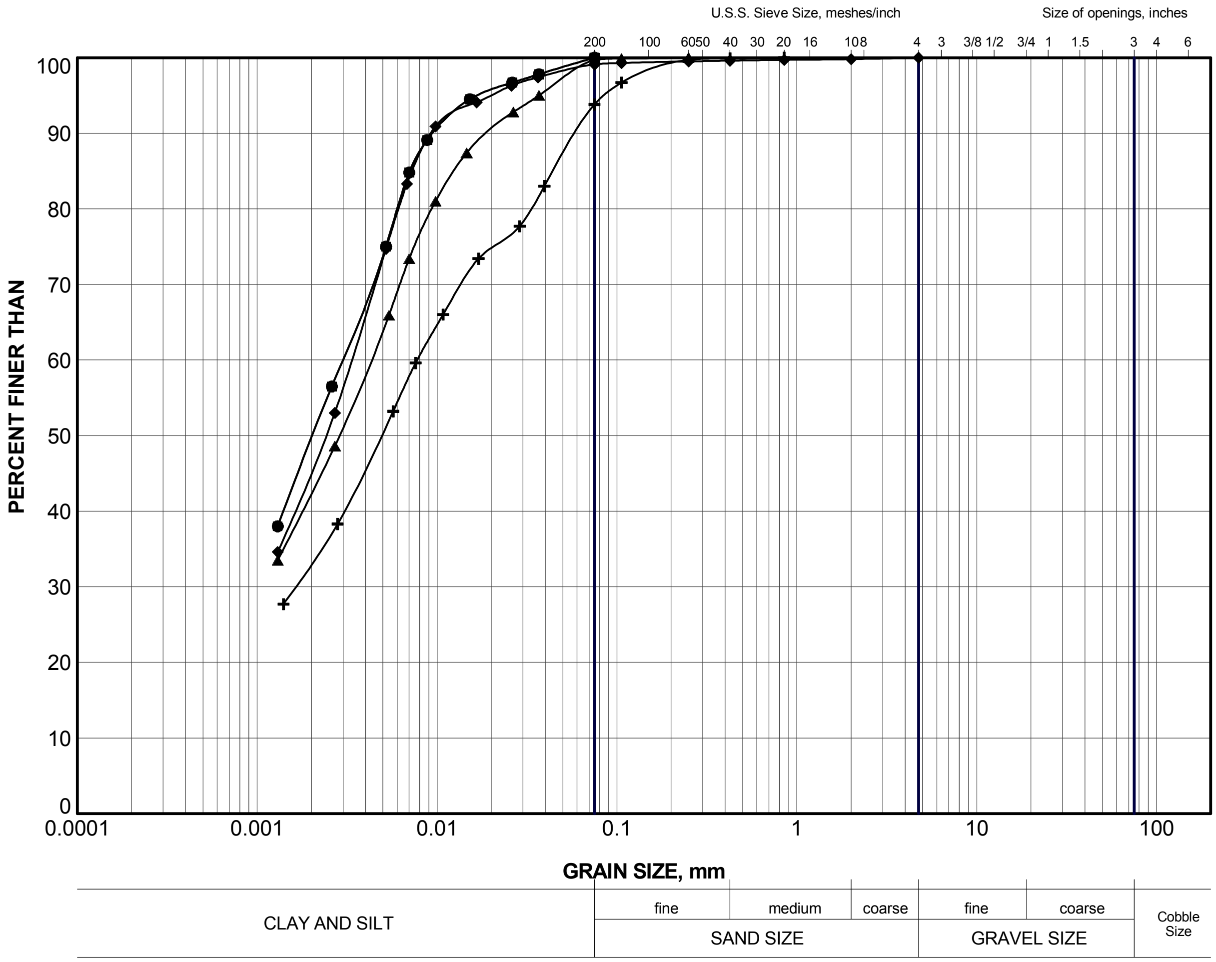
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT / SHEAR STRENGTH kPa	WATER CONTENT (%)	UNIT WEIGHT γ kN/m³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
	SILT, trace to some clay, trace to some sand Very loose to loose Grey Wet		11	SS	9		245				
244.4 13.3	SILT and SAND, trace gravel, trace clay Compact Grey Wet		12	SS	19		244		○		2 40 55 3
							243				
242.4 15.3	END OF BOREHOLE SPOON REFUSAL (HAMMER BOUNCING) Note: 1. Water level 3.8 m below ground surface (Elev. 253.9 m) upon completion of drilling.		13	SS	50/0.1						

Legend: DYNAMIC CONE PENETRATION RESISTANCE PLOT 20 40 60 80 100; SHEAR STRENGTH kPa: ○ UNCONFINED, + FIELD VANE, ● QUICK TRIAXIAL, × REMOULDED; 20 40 60 80 100. PLASTIC LIMIT W_P, NATURAL MOISTURE CONTENT W, LIQUID LIMIT W_L; WATER CONTENT (%) 20 40 60.

$+^3$, $\times^3$: Numbers refer to Sensitivity ○ 3% STRAIN AT FAILURE

APPENDIX B

Laboratory Test Results



LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEV (m)
●	C2-2	3	255.4
■	C2-3	4	253.9
▲	C2-4	2	256.2
✚	C2-5	3	255.9
◆	C2-5	6	252.8

PROJECT

HIGHWAY 17
CULVERT STA 12+620

TITLE

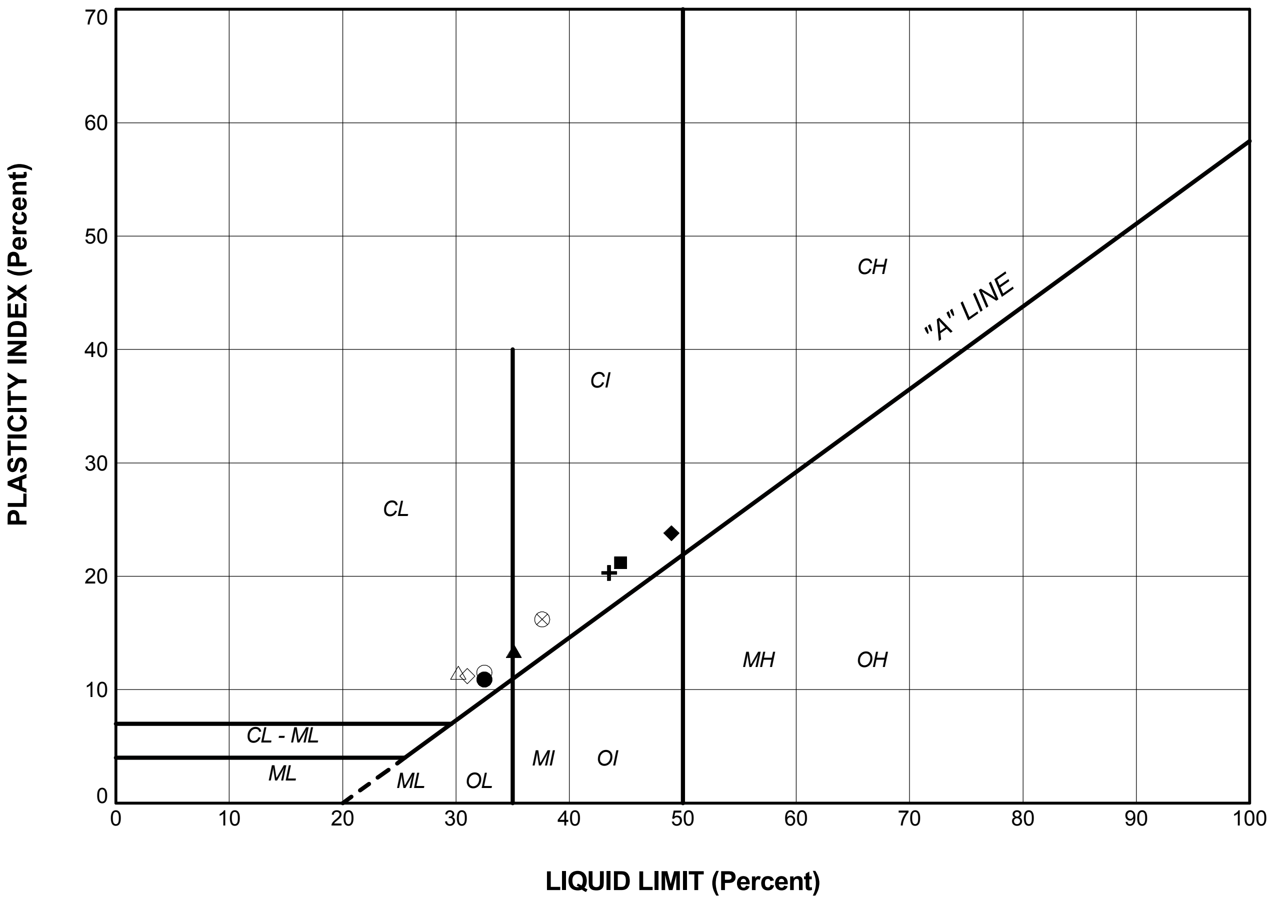
GRAIN SIZE DISTRIBUTION

CLAYEY SILT to SILTY CLAY

Golder Associates
SUDBURY, ONTARIO

PROJECT No.	11-1191-0007		FILE No. 1111910007 CULVERTS.GPJ
DRAWN	TB	Oct 2014	SCALE N/A REV.
CHECK	SEMP	Oct 2014	
APPR		Oct 2014	FIGURE B1

SUD-MTO GSD (NEW) GLDR_LDN.GDT



SOIL TYPE
C = Clay
M = Silt
O = Organic

PLASTICITY
L = Low
I = Intermediate
H = High

LEGEND

SYMBOL	BOREHOLE	SAMPLE	LL(%)	PL(%)	PI
●	C2-1	2	32.5	21.6	10.9
■	C2-1	5	44.5	23.3	21.2
▲	C2-2	3	35.1	21.7	13.4
✚	C2-2	5	43.5	23.2	20.3
◆	C2-3	4	49.0	25.2	23.8
◇	C2-4	2	31.0	19.8	11.2
○	C2-4	6	32.5	21.0	11.5
△	C2-5	3	30.2	18.7	11.5
⊗	C2-5	6	37.6	21.4	16.2

PROJECT

HIGHWAY 17
CULVERT STA 12+620

TITLE

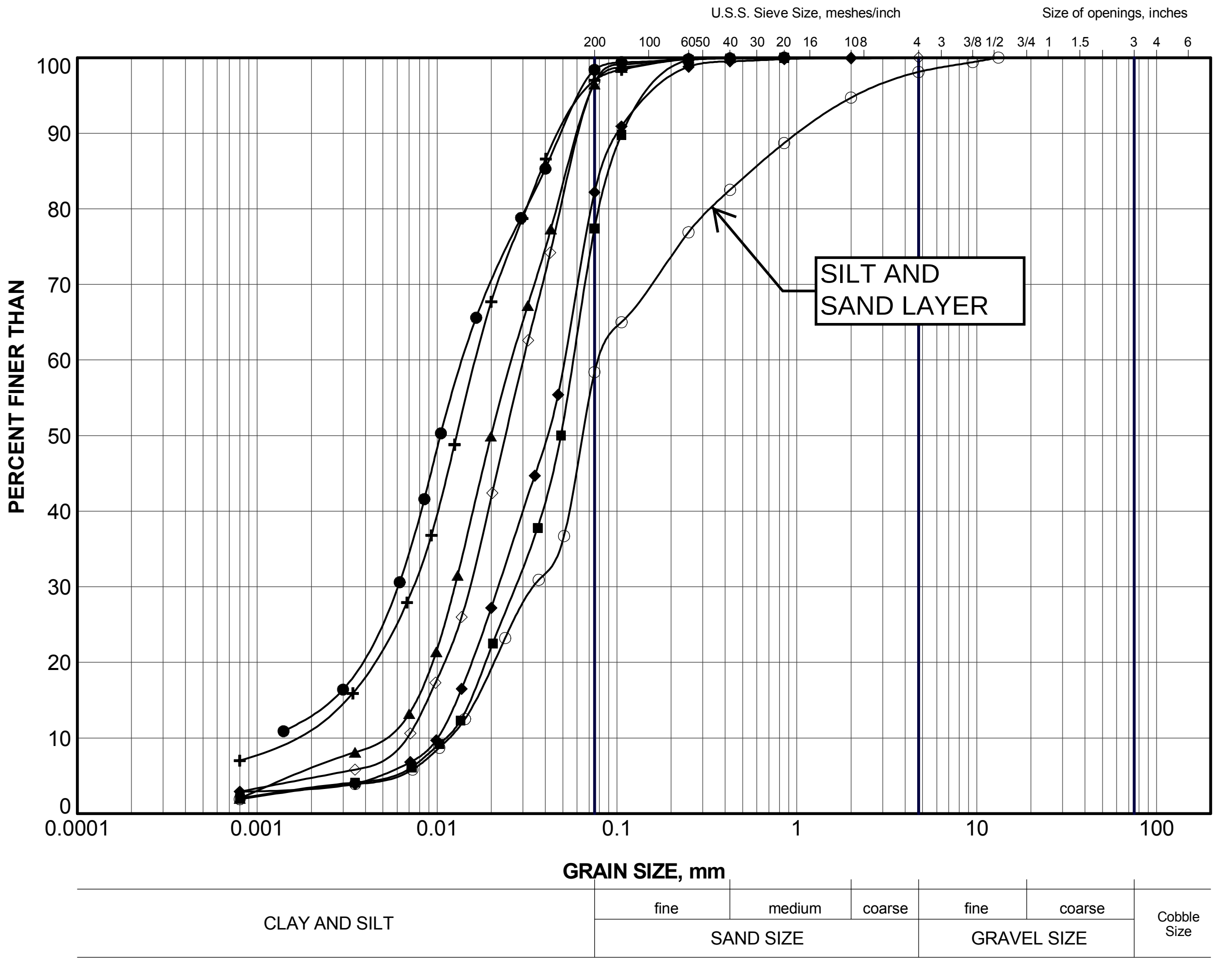
PLASTICITY CHART

CLAYEY SILT to SILTY CLAY

Golder Associates
SUDBURY, ONTARIO

PROJECT No.	11-1191-0007		FILE No. 111910007 CULVERTS.GPJ
DRAWN	TB	Oct 2014	SCALE N/A REV.
CHECK	SEMP	Oct 2014	**FIGURE B2**
APPR		Oct 2014	

SUD-MTO PL (NEW) GLDR_LDN.GDT



LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEV (m)
●	C2-1	7	249.3
■	C2-1	10	244.7
▲	C2-2	8	247.8
+	C2-3	7	249.3
◆	C2-3	11	243.2
◇	C2-4	8	247.9
○	C2-5	12	243.7

PROJECT

HIGHWAY 17
CULVERT STA 12+620

TITLE

GRAIN SIZE DISTRIBUTION

SILT to SILT and SAND

Golder Associates
SUDBURY, ONTARIO

PROJECT No.	11-1191-0007		FILE No. 1111910007 CULVERTS.GPJ
DRAWN	TB	Oct 2014	SCALE N/A REV.
CHECK	SEMP	Oct 2014	
APPR		Oct 2014	**FIGURE B3**

SUD-MTO GSD (NEW) GLDR_LDN.GDT

At Golder Associates we strive to be the most respected global company providing consulting, design, and construction services in earth, environment, and related areas of energy. Employee owned since our formation in 1960, our focus, unique culture and operating environment offer opportunities and the freedom to excel, which attracts the leading specialists in our fields. Golder professionals take the time to build an understanding of client needs and of the specific environments in which they operate. We continue to expand our technical capabilities and have experienced steady growth with employees who operate from offices located throughout Africa, Asia, Australasia, Europe, North America, and South America.

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