



November 17, 2011

FOUNDATION INVESTIGATION AND DESIGN REPORT

HIGHWAY 11 NBL CULVERT REPLACEMENT AT STATION 27+340
TOWNSHIP OF SOUTH HIMSWORTH, ONTARIO
MINISTRY OF TRANSPORTATION, ONTARIO
GWP 5416-00

Submitted to:

URS Canada Inc.
75 Commerce Valley Drive East
Markham, ON L3T 7N9



GEOCRE NO. 31L-146

REPORT

Report Number: 09-1191-0042-R04

Distribution:

5 Copies: Ministry of Transportation, Ontario, North Bay, Ontario (Northeastern Region)
1 Copy: Ministry of Transportation, Ontario, Downsview, Ontario (Foundations Section)
2 Copies: URS Canada Inc., Markham, Ontario
2 Copies: Golder Associates Ltd., Sudbury, Ontario





Table of Contents

PART A – FOUNDATION INVESTIGATION REPORT

1.0 INTRODUCTION.....	1
2.0 SITE DESCRIPTION.....	1
3.0 INVESTIGATION PROCEDURES	2
4.0 SITE GEOLOGY AND SUBSURFACE CONDITIONS	3
4.1 Regional Geology	3
4.2 Subsurface Conditions.....	3
4.2.1 Fill	4
4.2.2 Clayey Silt.....	4
4.2.3 Sand to Sand and Silt	5
4.2.4 Bedrock/ Refusal.....	5
4.2.5 Groundwater Conditions	5
5.0 CLOSURE.....	5

PART B – FOUNDATION DESIGN REPORT

6.0 DISCUSSION AND ENGINEERING RECOMMENDATIONS.....	8
6.1 General.....	8
6.2 Culvert Types	8
6.3 Culvert Construction Options	9
6.4 Stability, Settlement and Horizontal Strain.....	9
6.4.1 Stability	9
6.4.1.1 Methodology	9
6.4.1.2 Parameter Selection	10
6.4.1.3 Results of Analysis	10
6.4.2 Settlement.....	10
6.4.2.1 Methodology	11
6.4.2.2 Parameter Selection	11
6.4.2.3 Settlement of Embankment Fill	11
6.4.2.4 Results of Analysis	11



FOUNDATION REPORT - HIGHWAY 11 NBL STA 27+340 CULVERT REPLACEMENT

6.4.3	Horizontal Strain	12
6.4.3.1	Parameter Selection	12
6.4.3.2	Results of Analysis	13
6.5	Design Recommendations for Concrete Box Culvert.....	13
6.5.1	Geotechnical Resistance	13
6.5.2	Resistance to Lateral Loads/Sliding Resistance	13
6.5.3	Lateral Earth Pressures	14
6.6	Culvert Construction Considerations	14
6.6.1	Subgrade Preparation and Excavation.....	14
6.6.1.1	Removal of Organics	15
6.6.1.2	Replacement/Backfill below Base of Culvert	15
6.6.2	Bedding and Backfill above Base of Culvert	15
6.6.3	Erosion Protection.....	16
6.6.4	Control of Groundwater and Surface Water	16
6.6.5	Analytical Testing for Construction Materials	17
7.0	CLOSURE.....	17

DRAWINGS

Drawing 1 Borehole Locations and Soil Strata

APPENDICES

Appendix A Record of Boreholes

List of Symbols and Abbreviations

Record of Boreholes BH09-01 and BH09-07 to BH09-09

Appendix B Laboratory Test Results

Table B-1	Summary of Analytical Testing of Creek Water
Figure B-1	Grain Size Distribution – Sand and Gravel (Fill)
Figure B-2	Plasticity Chart – Clayey Silt
Figure B-3	Grain Size Distribution – Clayey Silt
Figure B-4	Grain Size Distribution – Sand to Sand and Silt



PART A

FOUNDATION INVESTIGATION REPORT

HIGHWAY 11 NBL CULVERT REPLACEMENT AT STATION 27+340

TOWNSHIP OF SOUTH HIMSWORTH, ONTARIO

MINISTRY OF TRANSPORTATION, ONTARIO

GWP 5416-06-00



1.0 INTRODUCTION

Golder Associates Ltd. (Golder) has been retained by URS Canada Inc. (URS) on behalf of Ministry of Transportation, Ontario (MTO) to provide foundation engineering services for the proposed rehabilitation of the Highway 11 Northbound Lanes (NBL), including the culvert replacement at Station 27+340. This project is part of the detail design for the rehabilitation of Highway 11 Northbound Lanes (NBL) and Southbound Lanes (SBL) from 1.5 km south of Highway 534, northerly 3.5 km and NBL only from 2.0 km north of Highway 534 northerly 9.5 km to 1.5 km south of Highway 654 in the Township of North Himsworth. The general location of this section of the Highway 11 alignment is shown on the Key Plan on Drawing 1 following the text of this report.

The terms of reference and scope of work for the foundation investigation are outlined in MTO's Request for Proposal dated July 23, 2009. Golder's proposal (P9-1191-0042, dated August 14, 2009) for foundation engineering services associated with the rehabilitation/replacement of culverts is contained in Section 6.8 of URS's Technical Proposal that forms part of the Consultant's Agreement (Purchase Order Number 5008-E-0061) for this project. The work was carried out in accordance with Golder's Supplemental Specialty Quality Control Plan for this project dated August 17, 2010.

This report addresses the investigation carried out for the replacement of the culvert on Highway 11 NBL at Station 27+340 only. Separate reports will be submitted detailing the foundation investigations for other culverts for this project, as well as for the wildlife crossing. The drawing for the culvert alignment was provided to Golder by URS on June 4, 2010 and cross-sections showing invert information were provided on August 25, 2010.

Based on the information from URS, the culvert at Station 27+340 will be concrete and will have an opening of about 1.2 m. The invert at both ends of the culvert will be Elevation 251.4 m. The embankment in the culvert area is about 3 m high and we understand that a 1 m grade raise and associated embankment widening (i.e. about 2 m on each side) will be required at this culvert location.

The purpose of this investigation is to establish the subsurface conditions at the location of the proposed culvert replacement by borehole drilling, in situ testing and laboratory testing on selected samples.

The culvert alignment was located in the field by Golder relative to stakes installed by Callon Dietz Inc. (Callon Dietz), a professional surveying company retained by URS, and referencing plan drawings provided by URS. The investigated area is shown in plan on Drawing 1 following the text of this report.

2.0 SITE DESCRIPTION

The replacement culvert will be located on the same alignment as the existing culvert in the Township of South Himsworth on Highway 11 approximately 0.9 km north of McCharles Line and Lindquist Line. In general, the topography in the area of the overall project limits is flat with numerous bedrock outcrops separated by swamps in low-lying areas or creeks.

The Preliminary Design Report (PDR) dated July 2009 indicates that the existing culvert at Station 27+340 is a 1,220 mm diameter and 25 m long Corrugated Steel Pipe (CSP) culvert and that the condition of the culvert is poor to fair.

The ground surface of the shoulder of the embankment is at Elevation 255 m and the creek water surface at the time of the investigation was about Elevation 251.9 m and Elevation 251.8 m on the east and west sides of the embankment, respectively.



3.0 INVESTIGATION PROCEDURES

The fieldwork for the investigation associated with the culvert replacement at Station 27+340 was carried out on May 3, 4, 10 and 11, 2010, during which time a total of four (4) Boreholes (BH09-01 and BH09-07 to BH09-09) and four (4) Dynamic Cone Penetration Tests (DCPTs) were advanced at the culvert location. The field investigation was carried out using a Track Mounted D-50 drilling rig supplied and operated by Walker Drilling Ltd. of Utopia, Ontario. The location of the boreholes is shown on Drawing 1 following the text of this report.

The boreholes were advanced through the overburden using 108 mm inside diameter hollow-stem augers. 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, performed in accordance with Standard Penetration Test (SPT) procedures (ASTM D1586-08a). The DCPTs were driven about 1 m north or south of each borehole, except at BH09-01 where the DCPT was advanced 6 m north of the borehole, to determine the depth to refusal. All boreholes were backfilled with bentonite upon completion in accordance with Ontario Regulation 903 (as amended by Ontario Regulation 372).

The boreholes were advanced to depths ranging between 7.2 m and 11.5 m below existing ground surface. The boreholes and DCPTs were terminated on refusal to further auger/casing advancement and cone penetration, respectively. These depths to refusal do not confirm bedrock surface elevations but may be inferred to indicate potential proximity to the bedrock 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 in Appendix A. It should be noted that 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 on completion of drilling. Furthermore, groundwater elevations will vary depending on seasonal fluctuations, precipitation and local soil permeability.

The fieldwork was supervised throughout by a member of our 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 soil samples. The results of the laboratory testing are included in Appendix B.

A sample of the creek water was obtained during the field investigation using appropriate sampling protocols and submitted to a specialist analytical laboratory under chain of custody procedures for testing for a suite of parameters. The results of the analytical testing are summarized in Table B-1 in Appendix B.

Survey stakes were installed near the NBL embankment east toe by Callon Dietz prior to drilling. The as-drilled borehole locations, in stations and offsets, were measured in reference to the stakes and were subsequently converted into MTM NAD 83 coordinates in AutoCAD. Borehole elevations were surveyed by a member of our technical staff in reference to the ground surface elevations at the horizontal control points along Highway 11. The borehole locations given on the Record of Borehole sheets and shown on Drawing 1 are positioned relative to MTM NAD 83 northing and easting coordinates and the ground surface elevations are referenced to Geodetic datum.



FOUNDATION REPORT - HIGHWAY 11 NBL STA 27+340 CULVERT REPLACEMENT

The as-drilled borehole locations, ground surface elevations at the drilled locations and borehole depths are summarized below.

Borehole	Location (m)		Ground Surface Elevation (m)	Borehole Depth (m)
	Northing	Easting		
09-01	5107941.1	315195.8	254.7	11.5
09-07	5107951.7	315182.2	254.9	11.0
09-08	5107954.7	315174.2	251.8	7.2
09-09	5107945.1	315204.3	252.0	7.7

4.0 SITE GEOLOGY AND SUBSURFACE CONDITIONS

4.1 Regional Geology

As delineated in *The Physiography of Southern Ontario* (Chapman and Putnam, 1984)¹, this section of Highway 11 lies within the physiographic region known as the Number 11 Strip, which extends along Highway 11 from Gravenhurst to North Bay. This part of the Number 11 Strip physiographic region is near the southwest shoreline of glacial Lake Algonquin. As a result, the streams entering Lake Algonquin deposited sand as delta features and silt and clay settled in deeper offshore water. Sand and gravel was also deposited as an esker which follows the strip from Bondfield to Gravenhurst.

The bedrock in the area consists typically of crystalline granite gneisses of the Powassan Domain of the Central Gneiss Belt, a subdivision of the Grenville Structural Province, as described in *Geology of Ontario, OGS Special Volume 4*².

4.2 Subsurface Conditions

The detailed subsurface soil and groundwater conditions as encountered in the boreholes advanced for this investigation, together with the results of the laboratory tests carried out on selected soil samples, are given on the attached Record of Borehole sheets in Appendix A. The results of the laboratory testing are provided in Appendix B. The inferred stratigraphy as encountered in the boreholes is shown on Drawing 1. The stratigraphic boundaries shown on the Record of Borehole sheets and in profile on Drawing 1 are inferred from non continuous sampling, observations of drilling progress and the results of SPTs and in situ testing. These boundaries, therefore, represent transitions between soil types rather than exact planes of geological change. Further, subsurface conditions will vary between and beyond the borehole locations.

¹ Chapman, L.J. and Putnam, D.F., 1984. *The Physiography of Southern Ontario*, Ontario Geological Survey, Special Volume 2, Third Edition. Accompanied by Map P.2715, Scale 1:600,000.

² *Geology of Ontario*, 1991. Ontario Geological Society Special Volume 4, Part 2. Ministry of Northern Development and Mines, Ontario.



FOUNDATION REPORT - HIGHWAY 11 NBL STA 27+340 CULVERT REPLACEMENT

It should be noted that the orientation (i.e. north, south, east and west) stated in the text of the report is typically referenced to project north (along the Highway 11 alignment) and therefore may differ from that shown on the drawing which represents magnetic north.

In general, the subsurface stratigraphy along the culvert alignment consists of a layer of fill at ground surface, underlain by a stratum of clayey silt and a deposit of sand to sand and silt. Refusal to further penetration on inferred bedrock was encountered at the bottom of the sand to sand and silt deposit.

The bottom of the creek was probed using a steel bar from the edge of the creek at the time of the field investigation and the depth to firm creek bottom was measured at 0.3 m below water surface on both sides of the existing embankment.

4.2.1 Fill

Boreholes BH09-01 and BH09-7 were advanced from the granular shoulder surface and penetrated through fill consisting of brown sand and gravel, trace to some silt. The fill contains cobbles and boulders in Borehole BH09-01. The thickness of the granular fill is 2.6 m in Borehole BH09-01 and 2.1 m in Borehole BH09-07. In Boreholes BH09-8 and BH09-09, advanced near the toes of the embankment, about 0.1 m and 0.15 m of organics was encountered at ground surface underlain by about 0.4 m and 0.15 m of sand and gravel fill, respectively.

The SPT 'N'-values measured within the sand and gravel fill are between 4 blows and 30 blows per 0.3 m of penetration, indicating a very loose to compact relative density.

The grain size distributions of two samples of the deposit are shown on Figure B-1 in Appendix B.

The measured water content on samples of this deposit varies between about 1 percent and 5 percent.

4.2.2 Clayey Silt

A deposit of grey and/or brown clayey silt, trace to some sand, was encountered underlying the fill in each of the boreholes. Trace to some organics was noted in the upper portion of the samples within the layer. The thickness of the stratum ranges from 0.9 m to 3.5 m and the top of the deposit was encountered between Elevation 252.8 m and 251.3 m.

The SPT 'N'-values measured within this deposit range from 2 blows to 17 blows per 0.3 m of penetration suggesting a soft to very stiff consistency.

Atterberg limits tests were carried out on four samples of the deposit and the test results indicate liquid limits ranging from 21 percent to 27 percent, plastic limits ranging from 14 percent and 16 percent and plasticity indices ranging from about 6 percent to 12 percent. The results of the Atterberg limits tests are shown on the plasticity chart on Figure B-2 in Appendix B and indicate that the material is classified as a clayey silt of low plasticity.

The grain size distributions of four samples of the clayey silt deposit are shown on Figure B-3 in Appendix B.

The natural water content measured on samples of the deposit ranges between 19 percent and 48 percent.

An organic content test on one sample of the clayey silt deposit indicates about 6 percent organics corresponding to the highest water content of the samples tested.



4.2.3 Sand to Sand and Silt

A deposit of grey sand to sand and silt, trace to some gravel and trace clay, was encountered underlying the clayey silt stratum in each of the boreholes. The top of the deposit was encountered between Elevation 250.9 m and 248.9 m and the thickness of the deposit ranges from 4.3 m to 7.7 m. The bottom of this deposit is defined by auger or casing refusal in each of the boreholes.

The SPT 'N'-values measured within this deposit range between 5 blows and 24 blows per 0.3 m of penetration, indicating a loose to compact relative density.

The grain size distributions of seven samples of this deposit are shown on Figure B-4 in Appendix B.

The natural water content measured on samples of this deposit varies between 11 percent and 28 percent.

4.2.4 Bedrock/ Refusal

In each of the boreholes and DCPTs, advanced 1 m to 6 m away from the boreholes, refusal to further auger or casing advancement or cone penetration was encountered at depths ranging between 7.2 m and 11.5 m below ground surface, between Elevation 244.6 m and 243.2 m. These depths to refusal, while they do not confirm bedrock elevations, may be inferred to indicate potential proximity to the bedrock interface.

4.2.5 Groundwater Conditions

In general, the samples taken in the boreholes were wet with free water noted in some samples of cohesionless material. Water levels observed in the boreholes upon completion of drilling range from 0.2 m to 7.6 m below existing ground surface, ranging between Elevation 253.2 m and 247.1 m. Groundwater/surface water levels in the area are subject to seasonal fluctuations and variations due to precipitation events.

5.0 CLOSURE

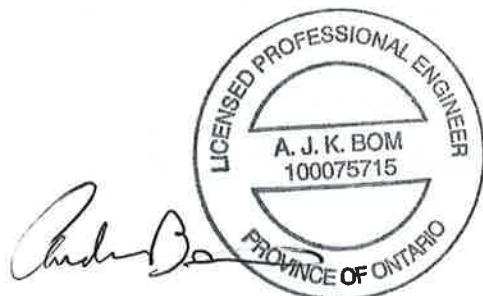
The field personnel supervising the drilling program were Mr. Ed Savard and Mr. Indulis Dumpis. This report was prepared by Mr. André Bom, P.Eng. The technical aspects were reviewed by Mr. Jorge M. A. Costa, P.Eng., Golder's Designated MTO Contact for this project, who also carried out a quality control review of the report.



FOUNDATION REPORT - HIGHWAY 11 NBL STA 27+340 CULVERT REPLACEMENT

Report Signature Page

GOLDER ASSOCIATES LTD.



André Bom, P.Eng.
Geotechnical Engineer



Jorge M. A. Costa, P.Eng.
Designated MTO Contact, Principal

AB/JMAC/lb

n:\active\2009\1190 sudbury\1191\09-1191-0042 urs hwy 11 culverts powassan\reporting\final\r04 - nbl 27+340\09-1191-0042-r04 final rpt 11nov17 hwy 11 nbl 27340 .docx



**FOUNDATION REPORT - HIGHWAY 11 NBL STA 27+340
CULVERT REPLACEMENT**

PART B

FOUNDATION DESIGN REPORT

HIGHWAY 11 NBL CULVERT REPLACEMENT AT STATION 27+340

TOWNSHIP OF SOUTH HIMSWORTH, ONTARIO

MINISTRY OF TRANSPORTATION, ONTARIO

GWP 5416-06-00



6.0 DISCUSSION AND ENGINEERING RECOMMENDATIONS

This section of the report provides an interpretation of the factual 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 such interpretation may affect their proposed construction methods, costs, equipment selection, scheduling and the like.

6.1 General

The overall project involves the rehabilitation of a 13.0 km section of Highway 11 SBL and/or NBL, which includes foundation investigation and design for the replacement of four (4) NBL culverts, three (3) SBL culverts, a new NBL and SBL wildlife crossing and the replacement of Windsor Creek NBL culvert.

This section of the report provides foundation design recommendations for the proposed culvert replacement on Highway 11 NBL at Station 27+340. The scope of work includes an assessment of stability and settlement of the embankment for the culvert replacement and providing recommendations on a preferred mitigation option that may be required as a means to minimize total and differential settlements (if applicable), geotechnical resistances (as applicable), and estimates of horizontal and vertical strains and maximum joint opening allowances along the culvert. The work also includes addressing foundation aspects for the final design and construction of head walls and wing walls associated with the culvert (where applicable), construction concerns and potential geotechnical problems associated with the culvert, including localized sub-excavation of soft / organic materials, placement of new fill and requirements for erosion protection and bedding materials.

We understand from URS that the replacement culvert to be constructed under the NBL embankment at Station 27+340 will be concrete and will have a diameter of 1.2 m. The new section of embankment at the replacement culvert location will be re-constructed to about 1 m above the existing embankment, approximately 4.0 m high, and the embankment will be widened by about 2 m (horizontal distance) on both sides of existing slope; however, the culvert length is such that head walls/wing walls will not be required. The new culvert will be about 25 m long and the inverts of the culvert will be Elevation 251.4 m.

The subsoils along the culvert alignment generally consist of embankment sand and gravel fill, underlain by a stratum of clayey silt and a deposit of sand to sand and silt. Refusal to further auger casing and/or split-spoon advancement, or cone penetration was encountered between Elevation 244.6 m and 243.2 m. Details of the subsurface conditions along this culvert are presented in Section 4.2 and shown in profile on Drawing 1 following the text of this report.

6.2 Culvert Types

The analysis and recommendations in this report assume that a concrete circular culvert will be installed at the site. However, foundation design recommendations for a concrete box culvert are also provided in the event that an alternative culvert type is considered.



6.3 Culvert Construction Options

In general, the foundation strata at the culvert crossing will undergo settlement as a result of the loading from the approximately 1 m grade raise and approximately 2 m widening. Therefore, the timing of culvert construction will be an essential factor in determining the preferred mitigation option for settlement. The following alternatives for culvert construction can be considered (where applicable, giving due consideration to the recommended foundation mitigation option for the embankment):

- concurrent with phased embankment construction between the two sides of the roadway; or
- following full sub-excavation of soft soils along the culvert alignment and concurrent with embankment construction.

At this site, where relatively small settlements are estimated to occur as a result of the embankment construction/raising, culvert construction may be carried out concurrently with the embankment. If required, the culvert design could include a camber.

At this site, the recommended construction alternative is to remove all organic materials as may be present beyond the existing culvert ends/toes of the embankment, backfill the sub-excavated area with MTO Special Provision (SP) 110S13 (Aggregates) Granular 'B' Type II material, place bedding and construct the culvert concurrent with embankment construction.

6.4 Stability, Settlement and Horizontal Strain

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

The analyses assume that all organic soils beneath the culvert alignment will be removed prior to construction as discussed in Section 6.6.1.1 and that granular fill (i.e. SP 110S13 (Aggregates) Granular 'B' Type II) will be used for replacement of sub-excavated material. The piezometric conditions required in the analyses were based on the groundwater levels observed during drilling.

6.4.1 Stability

The methodology used to evaluate embankment stability at the culvert location is described below and the results of the analyses are discussed in Section 6.4.1.3.

6.4.1.1 Methodology

Limit equilibrium slope stability analyses were performed using the commercially available program GeoStudio 2007 (Version 7.13), produced by Geo-Slope International Ltd., employing the Morgenstern-Price method of analysis. For all analyses, the Factor of Safety of numerous potential failure surfaces was computed in order to establish the minimum Factor of Safety. The Factor of Safety is defined as the ratio of the forces tending to



resist failure to the driving forces tending to cause failure. A target minimum Factor of Safety of 1.3 is normally adopted for the design of embankment slopes under static conditions. This Factor of Safety is considered adequate for the embankment at this site considering the design requirements and the field data available and is based on deep-seated, global failure surfaces that would affect the operation of the roadway. The stability analyses were performed to check that the target minimum Factor of Safety was achieved for the embankment height and geometry at the culvert location.

6.4.1.2 *Parameter Selection*

The embankment cross-section modelled in the analyses is assumed to be constructed of granular fill (such as SP 110S13 (Aggregates) Granular 'B' Type I or Type II), having a unit weight of 21 kN/m³ above the water level and 20 kN/m³ below the water level and an effective friction angle of 35° and is constructed with 2H:1V side slopes to 4 m high above the surrounding ground surface.

The subsoils encountered below the culvert alignment are generally composed of clayey silt underlain by a deposit of sand to sand and silt.

For the low plasticity clayey silt layer, the analysis were carried out for two cases, the first case assuming total stress parameters for the undrained condition and the second case using effective stress parameters for the drained condition. The total stress parameters (i.e. average mobilized undrained shear strength – s_u) and effective stress parameters (i.e. effective friction angle) for the clayey silt stratum were estimated from correlations with the SPT results and other laboratory test data. The clayey silt stratum modelled in the analysis is assumed to have a unit weight of 17 kN/m³, an undrained shear strength of 25 kPa for the undrained analysis and an effective friction angle of 28° for the drained analysis.

For the sand to sand and silt deposit, effective stress parameters were employed in the analyses assuming drained conditions and an effective friction angle of 30°. A unit weight of 20 kN/m³ was employed in the model for this material.

6.4.1.3 *Results of Analysis*

The stability analysis performed on the proposed embankment at the culvert location indicates that after completion of construction, including the proposed grade raise and widening, the embankment will have a Factor of Safety of 1.3 or greater for deep-seated, global failure surfaces that would impact the operation of the roadway.

6.4.2 *Settlement*

As indicated previously, settlement of the embankment can be expected as a result of the lading from the approximately 1 m grade raise and resulting approximately 2 m embankment widening (on each side) on the cohesive layer immediately below the proposed culvert invert and the cohesionless foundations soils at this site. The following sections outline the methods used to conduct the settlement analyses at the culvert. The results of the analyses for the culvert are discussed in Section 6.4.2.3.



6.4.2.1 *Methodology*

To estimate the magnitude of the expected settlements, analyses were carried out along the culvert alignment using hand calculations as per CFEM (2006) Section 11.3.4.

6.4.2.2 *Parameter Selection*

Below the existing embankment, the foundation soils are composed primarily of clayey silt and sand to sand and silt. Based on the proposed culvert invert elevation given in the General Arrangement drawing, about half of the clayey silt stratum will be sub-excavated in order to place the bedding material prior to culvert installation.

The clayey silt stratum will generally consolidate as fill is placed due to the low plasticity nature of the stratum and the relatively small thickness of this layer after sub-excavation for culvert installation. Pore pressures are expected to dissipate as filling progresses, such that the settlement is anticipated to be elastic and not time sensitive. Based on the characteristics of the clayey silt stratum, the stratum was assigned an Elastic Modulus (E') value of 3 MPa.

The immediate compression of the sand to sand and silt layer was modelled 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). The sand to sand and silt layer was assigned E' of 10 MPa.

6.4.2.3 *Settlement of Embankment Fill*

It is recommended that the embankment be reconstructed at the location of the culvert replacement using SP 110S13 (Aggregates) Granular 'B' Type I or Type II. Where granular fill will be placed below the water level, Granular 'B' Type II should be used. The material placed below the water level will compress/settle under its selfweight as additional fill is placed over it. The material placed above the water level should be compacted in accordance with OPSS 501 (Compacting). The magnitude of compression settlement from the fill placed below water and from properly compacted embankment fill above water is expected to occur during construction. It is recommended that the fines content of the Granular 'B' Type II fill used for embankment construction below the water be restricted to a maximum of 5 percent passing the No. 200 sieve, to reduce the potential for segregation of fines during placement and to reduce the potential post-construction settlement and associated maintenance needs.

6.4.2.4 *Results of Analysis*

The total immediate settlement of the native foundation soils along the culvert alignment due to the new embankment loading (after culvert construction) is estimated to range from about 15 mm below the east shoulder of the embankment and about 25 mm below the west edge of the embankment.

Based on these results, culvert construction concurrent with embankment construction can be carried out without the need for any additional foundation mitigation measures, as long as the structural design of the culvert can accommodate these estimated settlements.



6.4.3 Horizontal Strain

The following sections outline the method used to estimate the horizontal strain along the culvert.

If the expected settlements, vertical strain and horizontal strain resulting from the overlying embankment on the replacement culvert are relatively small, the preferred construction option is to typically construct the culvert concurrently with the embankment. Due to the variations of the subsurface conditions along the length of the culvert, the settlements and horizontal strains may differ at different points along the culvert and this should be considered when choosing an appropriate design and construction methodology to be employed.

6.4.3.1 Parameter Selection

As a result of the two-dimensional nature of the embankment geometry and embankment raising/widening construction, shear stresses will be mobilized in the foundation soils (upon completion of embankment construction or during the preload period) causing lateral spreading of the foundation soils and new embankment fill. This, in conjunction with the non-uniform vertical settlement of the culvert will generate horizontal straining along the newly constructed culvert. In order to maintain the structural integrity of the culvert, 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 on articulated conduits under earth dams constructed 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 the culvert location. 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:

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

$$\epsilon_h = \epsilon_v \left(\frac{\epsilon_h}{\epsilon_v} \right)$$

$$\Delta L = \epsilon_h L$$

where:

ΔL = maximum joint opening (m)

ϵ_v = maximum vertical strain

ϵ_h = maximum horizontal strain

$\left(\frac{\epsilon_h}{\epsilon_v} \right)$ = estimated ratio of maximum horizontal strain to maximum vertical strain (from Rutledge and Gould, 1973 - Figure 2)

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 under culvert backfill/bedding material (m)

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



6.4.3.2 Results of Analysis

The maximum horizontal strain along the 25 m long culvert associated with the estimated total settlement is calculated to be up to about 0.1 percent of the culvert length. As a result, culvert construction concurrent with embankment construction can be carried out without the need for any additional foundation mitigation measures, as long as the structural design of the culvert can accommodate the estimated horizontal strain.

Based on a culvert length of 25 m, the estimated maximum joint opening is 25 mm.

6.5 Design Recommendations for Concrete Box Culvert

6.5.1 Geotechnical Resistance

If a concrete box culvert is considered, a factored geotechnical axial resistance at Ultimate Limits States (ULS) of 200 kPa is recommended for design for an assumed 1.2 m wide box culvert founded on a properly prepared subgrade of granular fill overlying the soft to firm clayey silt. The geotechnical resistance given is for loads applied perpendicular to the surface of 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 *Canadian Highway Bridge Code (CHBDC)* and its *Commentary*.

It is noted that at this site, the loading on the foundation soils below the culvert and the associated total settlement at the culvert location will be governed by the design height of the overlying embankment fill. As such, it is recommended that the structural engineer exercise caution when utilizing the value of the geotechnical axial resistance at Serviceability Limit States (SLS) in the design of the culvert and that consideration be given to the sequence and staging of construction. Based on the above, the geotechnical resistance at SLS (for 25 mm settlement) for a 1.4 m wide box culvert constructed on the properly prepared Granular 'B' Type II subgrade overlying the soft to firm clayey silt may be taken as 100 kPa.

6.5.2 Resistance to Lateral Loads/Sliding Resistance

Resistance to lateral forces/sliding resistance between the base of a concrete box culvert and the granular fill/bedding placed following sub-excavation should be calculated in accordance with Section 6.7.5 of the *CHBDC*. The following summarizes the coefficient of friction for the interface materials for a precast and cast-in-place culvert.

Interface Materials	Coefficient of Friction
Precast Concrete Box Culvert on Compacted Granular 'A' or 'B' Type II	$\tan \delta = 0.45$
Cast-in-Place Concrete Box Culvert on Compacted Granular 'A' or 'B' Type II	$\tan \Phi' = 0.58$



6.5.3 Lateral Earth Pressures

The lateral earth pressures acting on the side walls of the culvert (head walls and/or wing walls will not be required) will depend on the type and method of placement of backfill materials, the nature of 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 culvert walls.

The following recommendations are made concerning the design of the box culvert.

- Select, free draining granular fill meeting the specifications of SP 110S13 (Aggregates) Granular 'A' or Granular 'B' Type II but with less than 5 percent passing the No. 200 (0.075 mm) sieve should be used as backfill behind the culvert. Compaction (including type of equipment, target densities, etc.) should be carried out in accordance with OPSS 501 (Compacting). Backfill should be placed with a maximum of 200 mm loose lift thickness. Other aspects of the granular backfill requirements for concrete culverts should be in accordance with OPSD 803.010 (Backfill and Cover for Concrete Culverts).
- A minimum compaction surcharge of 12 kPa should be included in the lateral earth pressures for the structural design of the culvert, in accordance with *CHBDC* Section 6.9.3 and Figure 6.6. Other surcharge loadings should be accounted for in the design, as required.
- For a box culvert, granular fill should be placed in a zone with the width equal to at least 2.0 m behind the back of the culvert (in accordance with Figure C6.20(a) of the *Commentary* to the *CHBDC*).
- For a box culvert, the pressures are based on the proposed embankment fill materials and the existing overburden soils and the following parameters (unfactored) may be used assuming the use of granular fill:

	Granular Fill
Soil unit weight:	21 kN/m ³
Coefficients of static lateral earth pressure:	
Active, K_a	0.31
At rest, K_o	0.47

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

6.6 Culvert Construction Considerations

6.6.1 Subgrade Preparation and Excavation

The following sections discuss general aspects of subgrade preparation and embankment construction at the culvert site, including removal of organic materials.



All excavations must be carried out in accordance with Ontario Regulation 213 Ontario Occupational Health and Safety Act for Construction Projects (as amended by Ontario Regulation 443) in Type 3 soil. In addition, provisions for traffic control measures should be included in the Contract Documents to maintain the safe operation of the existing Highway 11 and any associated side roads and detours during excavation operations, where applicable.

Where required, temporary excavation support systems should be designed and constructed in accordance with OPSS 539 (Temporary Protection Systems). Temporary excavation support systems should be designed to Performance Level 2 for any excavation adjacent to existing roadways and Performance Level 3 for excavations in other areas.

6.6.1.1 *Removal of Organics*

Based on the information from the boreholes advanced during the field investigation, the thickness of organic deposits (i.e. peat or organic silt) at the culvert location is up to about 0.2 m overlying the sand and gravel fill at the toe of the embankments, adjacent to the creek. Prior to the placement of any bedding material and fill for new construction, all organic soils should be stripped from the plan limits of the proposed works. Construction of the embankment section in sub-excavation areas should be in accordance with OPSD 203.010 (Embankments Over Swamp, New Construction).

6.6.1.2 *Replacement/Backfill below Base of Culvert*

For replacement of sub-excavated material below the water level along the culvert alignment, it is recommended that Granular 'B' Type II be used to backfill the excavation. In addition, in this instance (i.e. typically backfill below the water table), the granular fill should to be end-dumped simultaneously as the excavation advances in accordance with OPSS 209 (Embankments Over Swamps and Compressible Soils).

6.6.2 *Bedding and Backfill above Base of Culvert*

The bedding, levelling pad and backfill requirements for a circular concrete pipe culvert should be in accordance with OPSD 802.031 (Rigid Pipe, Bedding Cover and Backfill, Type 3 Soil - Earth Excavation) 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.

A precast box culvert, if used as an alternative to the circular concrete pipe culvert, should be constructed in accordance with OPSS 422 (Precast Reinforced Concrete Box Culverts). The box culvert should be constructed on a minimum 300 mm thick layer of SP 110S13 (Aggregates) Granular 'B' Type II material for bedding purposes and partial frost protection.

In dry conditions, the bedding should be placed in lifts not exceeding 200 mm in loose thickness, and compacted to at least 95 percent of the Standard Proctor maximum dry density (SPMDD) of the material as specified in OPSS 501 (Compacting). Where bedding material is placed in wet conditions, Granular 'B' Type II should be used. The structural design of the culvert should take into consideration the conditions for bedding placement and compaction in accordance with the requirements of Section 7.8.3.6 of the *CHBDC*. For culverts where the



invert level is located at or below the groundwater table, the structural design should assume that the bedding material will only achieve 90 percent of the SPMDD during placement.

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 backfill above and surrounding the culvert.

Inspection should be carried out by qualified geotechnical personnel during all engineered fill placement operations to ensure that appropriate materials are used, and that field density testing is carried out on fills placed above the water level to check that adequate levels of compaction have been achieved.

6.6.3 Erosion Protection

Provision 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 culvert (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 clay seal or concrete cut-off wall should be provided at the upstream end of the culvert. 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 the culvert inlet opening, and a minimum vertical height equivalent to the high water level including along the embankment slope. Alternatively, a 0.6 m thick clay blanket (if constructed of natural clay or a soil-bentonite mix) may be constructed, extending upstream three (3) times the culvert height and along the adjacent slopes to a height of two (2) 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 the culvert should be assessed by the hydraulics design engineer. As a minimum, rip-rap treatment for the outlet of the culvert should be consistent with the standard presented in 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 but with the rip-rap placed up to the toe of slope level, in combination with the cut-off measures noted above. Similarly, rip-rap should be provided over the full extent of the clay blanket, including the creek side slopes and fill slope over the culvert.

6.6.4 Control of Groundwater and Surface Water

Excavation within the plan limits of the proposed culvert alignment will be required to below the invert for placement of bedding material. Creek/ditch flows via the culvert at the time of construction of the replacement culvert will need to be diverted/piped away from the excavation area during the construction period. As a result of the excavation, groundwater flow into the excavation can be expected to occur due to the high groundwater levels observed at the culvert location even given the relatively low-permeable clayey silt subsoils. A precast concrete box culvert may be placed and the associated bedding materials constructed 'in-the-wet' and, as such, control of surface water and groundwater would not be required at this culvert location under such conditions.



6.6.5 Analytical Testing for Construction Materials

The analytical test results on a sample of creek water taken adjacent to the culvert site are presented in Table B-1. The suite of parameters tested is intended to allow the structural engineer to assess the requirements for the appropriate type of cement to be used in construction and the need for corrosion protection.

7.0 CLOSURE

This report was prepared by Mr. André Bom, P.Eng., a geotechnical engineer with Golder. Mr. Jorge M. A. Costa, P.Eng., Golder's Designated MTO Contact for this project and a Principal with Golder, reviewed the technical aspects of and conducted an independent quality control review of the report.



FOUNDATION REPORT - HIGHWAY 11 NBL STA 27+340 CULVERT REPLACEMENT

Report Signature Page

GOLDER ASSOCIATES LTD.



André Bom, P.Eng.
Geotechnical Engineer



Jorge M. A. Costa, P.Eng.
Designated MTO Contact, Principal

AB/JMAC/lb

Golder, Golder Associates and the GA globe design are trademarks of Golder Associates Corporation.

n:\active\2009\1190 sudbury\1191\09-1191-0042 urs hwy 11 culverts powassan\reporting\final\r04 - nbl 27+340\09-1191-0042-r04 final rpt 11nov17 hwy 11 nbl 27340 .docx



REFERENCES

- Bowles, J.E. 1984. Physical and Geotechnical Properties of Soils, Second Edition. McGraw Hill Book Company, New York.
- Canadian Geotechnical Society, 2006. Canadian Foundation Engineering Manual, Fourth Edition.
- Canadian Highway Bridge Design Code (CHBDC) and Commentary on CAN/CSA-S6-06. 2006. CSA Special Publication, S6.1-06. Canadian Standard Association.
- Chapman, L.J., and Putnam, D.F. 1984. The Physiography of Southern Ontario. Ontario Geological Survey, Special Volume 2, 3rd Edition. Ontario Ministry of Natural Resources.
- Geology of Ontario. 1991. Ontario Geological Society, Special Volume 4, Part 2. Eds. P.C. Thurston, H.R. Williams, R.H. Sutcliffe and G.M. Stott. Ministry of Northern Development and Mines, Ontario.
- Kulhawy, F.H. and Mayne, P.W. 1990. Manual on Estimating Soil Properties for Foundation Design. EL 6800, Research Project 1493 6. Prepared for Electric Power Research Institute, Palo Alto, California.
- Rutledge, P.C. and Gould, J.P. 1973. Movements of Articulated Conduits Under Earth Dams on Compressible Foundations, In: Embankment Dam Engineering – Casagrande Volume. Eds. Hirschfeld, R.C. and Poulos, S.J. John Wiley & Sons, New York.

STANDARDS:

ASTM International:

- | | |
|----------------|---|
| ASTM D1586-08a | Standard Test Method for Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils |
|----------------|---|

Contract Design Estimating and Documentation (CDED):

- | | |
|--------------------------|---|
| Special Provision 110S13 | Material Specification for Aggregates – Base, Subbase, Select Subgrade and Backfill Material. |
|--------------------------|---|

Ontario Occupational Health and Safety Act:

- | | |
|---------------------------|-------------------------------------|
| Ontario Regulation 213/91 | Construction Projects |
| Ontario Regulation 443/09 | Amendment to Ontario Regulation 213 |

Ontario Provincial Standard Drawing:

- | | |
|--------------|--|
| OPSD 203.010 | Embankments Over Swamp – New Construction. |
| OPSD 803.010 | Backfill and Cover for Concrete Culverts With Spans less than or equal to 3.0 m. |
| OPSD 810.010 | Rip-Rap Treatment for Sewer and Culvert Outlets. |



FOUNDATION REPORT - HIGHWAY 11 NBL STA 27+340 CULVERT REPLACEMENT

Ontario Provincial Standard Specification:

OPSS 209	Construction Specification for Embankments Over Swamps and Compressible Soils.
OPSS 422	Construction Specification for Precast Reinforced Concrete Box Culverts and Box Sewers in Open Cut.
OPSS 501	Construction Specification for Compacting.
OPSS 539	Construction Specification for Temporary Protection Systems.
OPSS 1002	Material Specification for Aggregates – Concrete.
OPSS 1205	Material Specification for Clay Seal.

Ontario Water Resources Act:

Ontario Regulation 372/97 Amendment to Ontario Regulation 903

NO.	DATE	BY	REVISION			
Geocres No. 31L-146						
HWY. 11			PROJECT NO. 09-1191-0042		DIST.	
SUBM'D. LG		CHKD. AB		DATE: NOV 2011		SITE:
DRAWN: JJJ		CHKD.		APPD. JMAC		DWG. 1





APPENDIX A

Record of Boreholes



LIST OF SYMBOLS

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

1. 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
V	volume
W	weight

II. STRESS AND STRAIN

γ	shear strain
Δ	change in, e.g. stress: $\Delta\sigma$
ε	linear strain
ε_v	volumetric strain
η	coefficient of viscosity
ν	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	liquid limit
w_p	plastic limit
I_p	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_a	coefficient of secondary consolidation
m_v	coefficient of volume change
c_v	coefficient of consolidation
T_v	time factor (vertical direction)
U	degree of consolidation
σ'_p	pre-consolidation pressure
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 $= \tan \delta$
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
SS	Split-spoon
DS	Denison type sample
FS	Foil sample
RC	Rock core
SC	Soil core
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, 60° 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 cm² 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.

V. MINOR SOIL CONSTITUENTS

Percent 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 (cohesionless) or With (cohesive)	Sand and Gravel Silty Clay with sand / Clayey Silt with sand

III. SOIL DESCRIPTION

(a) Cohesionless Soils

Density Index	N
Relative Density	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.

PROJECT		09-1191-0042		RECORD OF BOREHOLE No BH09-01		1 OF 1 METRIC												
W.P.		5416-06-00		LOCATION		N 5107941.1; E 315195.8												
DIST		HWY 11		BOREHOLE TYPE		108 mm I.D. Continuous Flight, Hollow Stem Augers, NW Casing, Wash Boring												
DATUM		Geodetic		DATE		May 3 and 4, 2010												
						ORIGINATED BY EHS												
						COMPILED BY AMW												
						CHECKED BY AB												
SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT W _p	NATURAL MOISTURE CONTENT W	LIQUID LIMIT W _L	UNIT WEIGHT γ	REMARKS & GRAIN SIZE DISTRIBUTION (%)				
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			20	40						60	80	100	20
254.7	GROUND SURFACE																	
0.0	Sand and gravel, trace silt, containing cobbles and boulders (FILL) Compact Brown Moist		1	SS	17													
			2	SS	21													55 39 (6)
	Auger refusal at 1.8 m depth. Switched to NW casing.		3	SS	30													
252.1			4	SS	3													
2.6	CLAYEY SILT, some sand, trace to some organics Firm Brown to black Wet		5	SS	4													0 15 70 15
250.9			6	SS	11													
3.8	SAND to SAND and SILT, trace to some gravel Compact Grey Wet		7	SS	14													0 93 (7)
			8	SS	24													
			9	SS	18													
			10	SS	10													
			11	SS	13													22 43 (35)
243.2	END OF BOREHOLE CASING REFUSAL																	
11.5	Notes: 1. Water level at a depth of 7.6 m below ground surface (Elev. 247.1 m) upon completion of drilling. 2. Advanced DCPT 6.0 m north of Borehole BH09-01. Refusal at a depth of 11.3 m (Elev. 243.4 m) (hammer bouncing).																	

SUD-MTO 001 09-1191-0042-4000.GPJ GAL-MISS.GDT 16/11/11 DATA INPUT:

PROJECT		09-1191-0042		RECORD OF BOREHOLE No BH09-07		1 OF 1 METRIC							
W.P.		5416-06-00		LOCATION		N 5107951.7; E 315182.2							
DIST		HWY 11		BOREHOLE TYPE		108 mm I.D. Continuous Flight, Hollow Stem Augers							
DATUM		Geodetic		DATE		May 10, 2010							
				ORIGINATED BY		ID							
				COMPILED BY		AMW							
				CHECKED BY		AB							
SOIL PROFILE			SAMPLES			DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT NATURAL MOISTURE CONTENT LIQUID LIMIT		UNIT WEIGHT		REMARKS & GRAIN SIZE DISTRIBUTION (%)	
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	20 40 60 80 100	W _p W W _L	WATER CONTENT (%)	γ	GR SA SI CL	
254.9	GROUND SURFACE												
0.0	Sand and gravel, trace to some silt (FILL) Loose to compact Brown Moist		1	SS	6		254						
			2	SS	9								
			3	SS	16		253					57 36 (7)	
252.8	CLAYEY SILT, trace sand, trace to some organics in upper 1.5 m Soft to very stiff Grey Wet		4	SS	5		252						
			5	SS	2		251				OC=5.9%		
			6	SS	17		250					0 24 50 26	
			7	SS	15		249						
249.3	SAND to SAND and SILT, trace gravel, trace clay Loose to compact Grey Wet		8	SS	17		248						
			9	SS	22		247						
			10	SS	8		246						
			11	SS	14/0.2		245						
243.9	END OF BOREHOLE SPOON AND AUGER REFUSAL						244					3 36 58 3	
11.0	Notes: 1. Water level at a depth of 1.7 m below ground surface (Elev. 253.2 m) upon completion of drilling. 2. Advanced DCPT 1.0 m north of Borehole BH09-07. Refusal at a depth of 11.3 m (Elev. 243.6 m) (hammer bouncing).												

PROJECT		09-1191-0042		RECORD OF BOREHOLE No BH09-08		1 OF 1 METRIC								
W.P.		5416-06-00		LOCATION		N 5107954.7; E 315174.2								
DIST		HWY 11		BOREHOLE TYPE		108 mm I.D. Continuous Flight, Hollow Stem Augers								
DATUM		Geodetic		DATE		May 11, 2010								
				ORIGINATED BY		ID								
				COMPILED BY		AMW								
				CHECKED BY		AB								
SOIL PROFILE			SAMPLES			DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT NATURAL MOISTURE CONTENT LIQUID LIMIT			UNIT WEIGHT		REMARKS & GRAIN SIZE DISTRIBUTION (%)	
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	SHEAR STRENGTH kPa		WATER CONTENT (%)		γ	GR SA SI CL	
							20 40 60 80 100	20 40 60 80 100	W _p W W _L	20 40 60				
251.8	GROUND SURFACE													
0.0	Organics (0.1 m) over sand and gravel (FILL)		1	SS	4									
251.3	Loose Brown Wet													
0.5	CLAYEY SILT, trace to some organics		2	SS	7		251							
	Soft to firm Grey Wet		3	SS	8		250							
			4	SS	2		249						0 13 60 27	
248.9	Sandy SILT, trace clay						248							
2.9	Loose to compact Grey Wet		5	SS	5									
			6	SS	8		247						0 23 69 8	
			7	SS	9		246							
			8	SS	13		245							
244.6	END OF BOREHOLE AUGER REFUSAL													
7.2	Notes: 1. Water level at a depth of 0.2 m below ground surface (Elev. 251.6 m) upon completion of drilling. 2. Advanced DCPT 1.5 m north of Borehole BH09-08. Refusal at a depth of 7.3 m (Elev. 244.5 m) (hammer bouncing). 3. Borehole advanced on south side of creek; water surface at Elev. 251.8 m. Creek bed measured at about 0.2 m below water surface and probed to firm bottom at about 0.3 m below water surface.													

SUD-MTO 001 09-1191-0042-4000.GPJ GAL-MISS.GDT 16/11/11 DATA INPUT:

PROJECT		09-1191-0042		RECORD OF BOREHOLE No BH09-09		1 OF 1 METRIC											
W.P.		5416-06-00		LOCATION		N 5107945.1; E 315204.3											
DIST		HWY 11		BOREHOLE TYPE		108 mm I.D. Continuous Flight, Hollow Stem Augers											
DATUM		Geodetic		DATE		May 11, 2010											
				ORIGINATED BY		ID											
				COMPILED BY		AMW											
				CHECKED BY		AB											
SOIL PROFILE			SAMPLES			DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT		NATURAL MOISTURE CONTENT		LIQUID LIMIT		UNIT WEIGHT		REMARKS & GRAIN SIZE DISTRIBUTION (%)	
ELEV	DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	SHEAR STRENGTH kPa		WATER CONTENT (%)		γ		GR SA SI CL		
252.0	0.0	GROUND SURFACE							20 40 60 80 100	20 40 60							
251.7	0.3	Organics (0.15 m) over sand and gravel (FILL) Brown Moist		1	SS	2			20 40 60 80 100	20 40 60							
250.8	1.2	CLAYEY SILT, some sand Soft to stiff Grey and brown Moist		2	SS	10		251	20 40 60 80 100	20 40 60	○				0 17 61 22		
		SAND to SAND and SILT, trace clay Loose to compact Grey Wet		3	SS	16		250	20 40 60 80 100	20 40 60	○				0 80 16 4		
				4	SS	13		249	20 40 60 80 100	20 40 60	○						
				5	SS	12		248	20 40 60 80 100	20 40 60	○						
				6	SS	12		247	20 40 60 80 100	20 40 60	○				0 95 (5)		
				7	SS	10		246	20 40 60 80 100	20 40 60	○				0 34 64 2		
				8	SS	5		245	20 40 60 80 100	20 40 60	○						
244.3	7.7	END OF BOREHOLE SPOON AND AUGER REFUSAL		9	SS	18/0.1			20 40 60 80 100	20 40 60	○						
		<p>Notes:</p> <p>1. Water level at a depth of 4.6 m below ground surface (Elev. 247.4 m) upon completion of drilling.</p> <p>2. Advanced DCPT 1.0 m south of Borehole BH09-09. Refusal at a depth of 7.5 m (Elev. 244.5 m) (hammer bouncing).</p> <p>3. Borehole advanced on north side of creek; water surface at Elev. 251.9 m. Creek bed measured at about 0.2 m below water surface and probed to firm bottom at about 0.3 m below water surface.</p>															

SUD-MTO 001 09-1191-0042-4000.GPJ GAL-MISS.GDT 16/11/11 DATA INPUT:



APPENDIX B

Laboratory Test Results



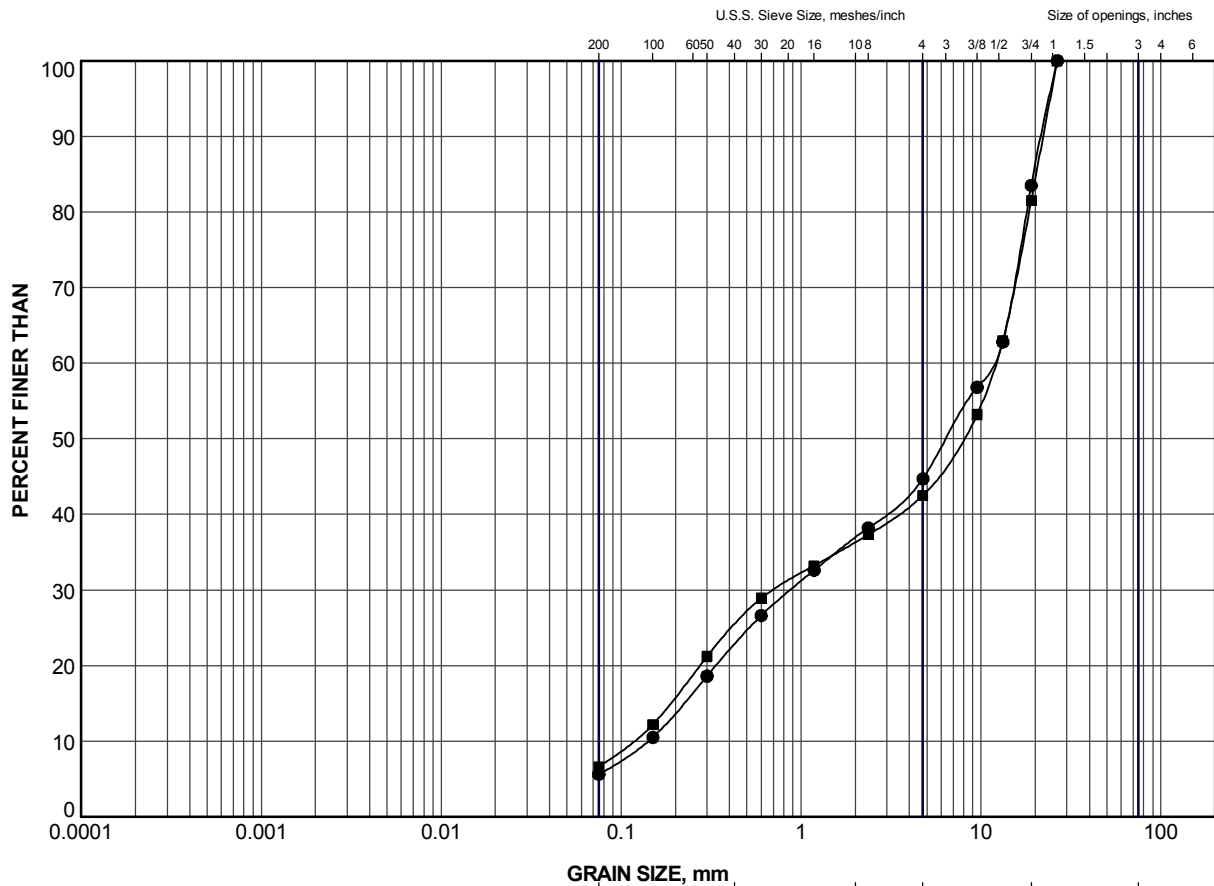
FOUNDATION REPORT - HIGHWAY 11 NBL STA 27+340 CULVERT REPLACEMENT

Table B-1 - Summary of Analytical Testing of Creek Water

Parameter	Units	Method Detection Limit	Result
Chloride	mg/L	0.2	6.53
Sulphate	mg/L	1	4.9
Conductivity	µS/cm	1	135
Resistivity	Mohm-cm	n/a	0.0074
pH	n/a	n/a	7.07

Notes: 1. Samples obtained May 17, 2010.
2. Analytical testing carried out by Testmark Laboratory Ltd.


Compiled by: AB
Checked by: LG

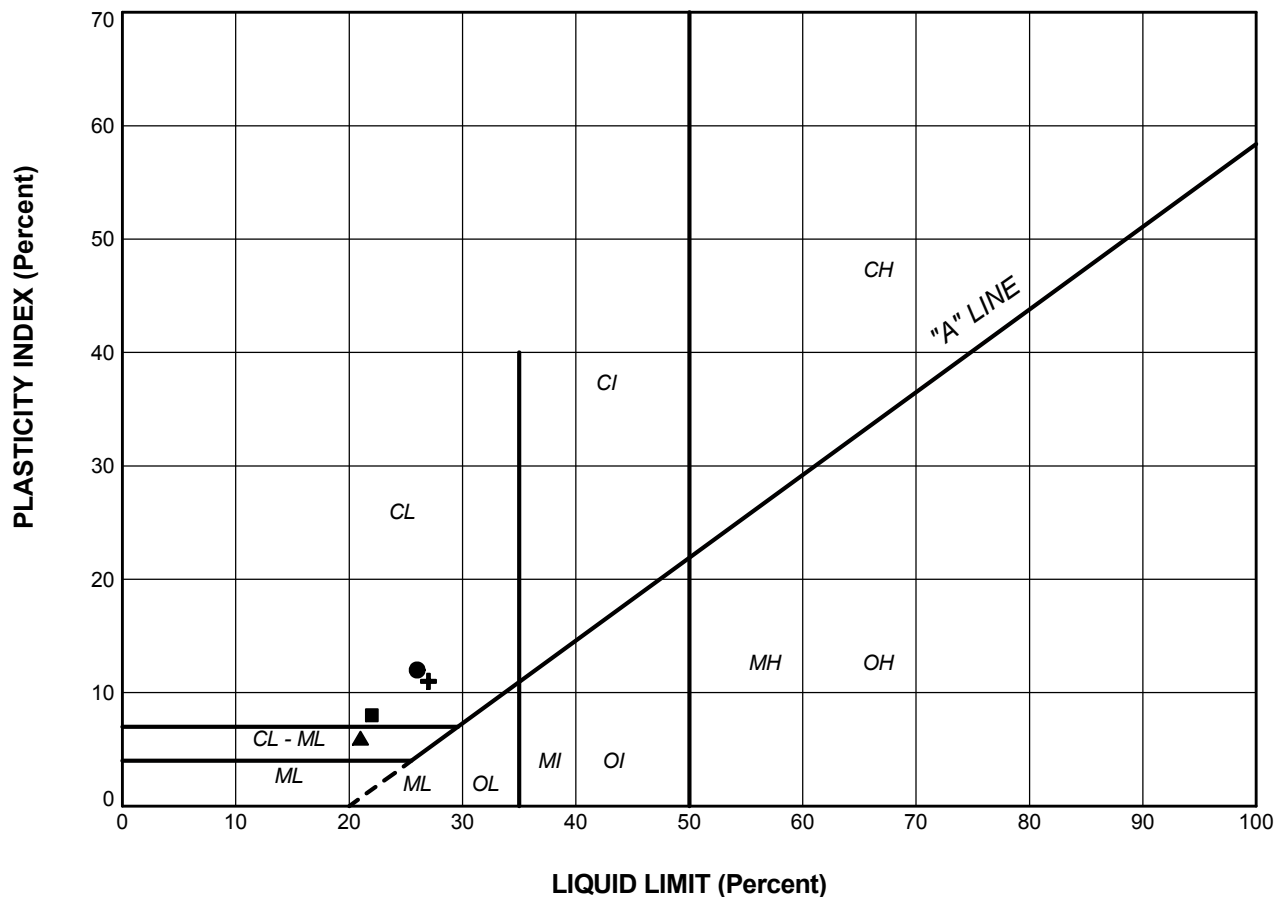


GRAVEL SIZE, mm							Cobble Size
CLAY AND SILT	fine	medium	coarse	fine	coarse		
	SAND SIZE			GRAVEL SIZE			

LEGEND


SYMBOL	BOREHOLE	SAMPLE	ELEV (m)
●	BH09-01	2	253.6
■	BH09-07	3	253.1

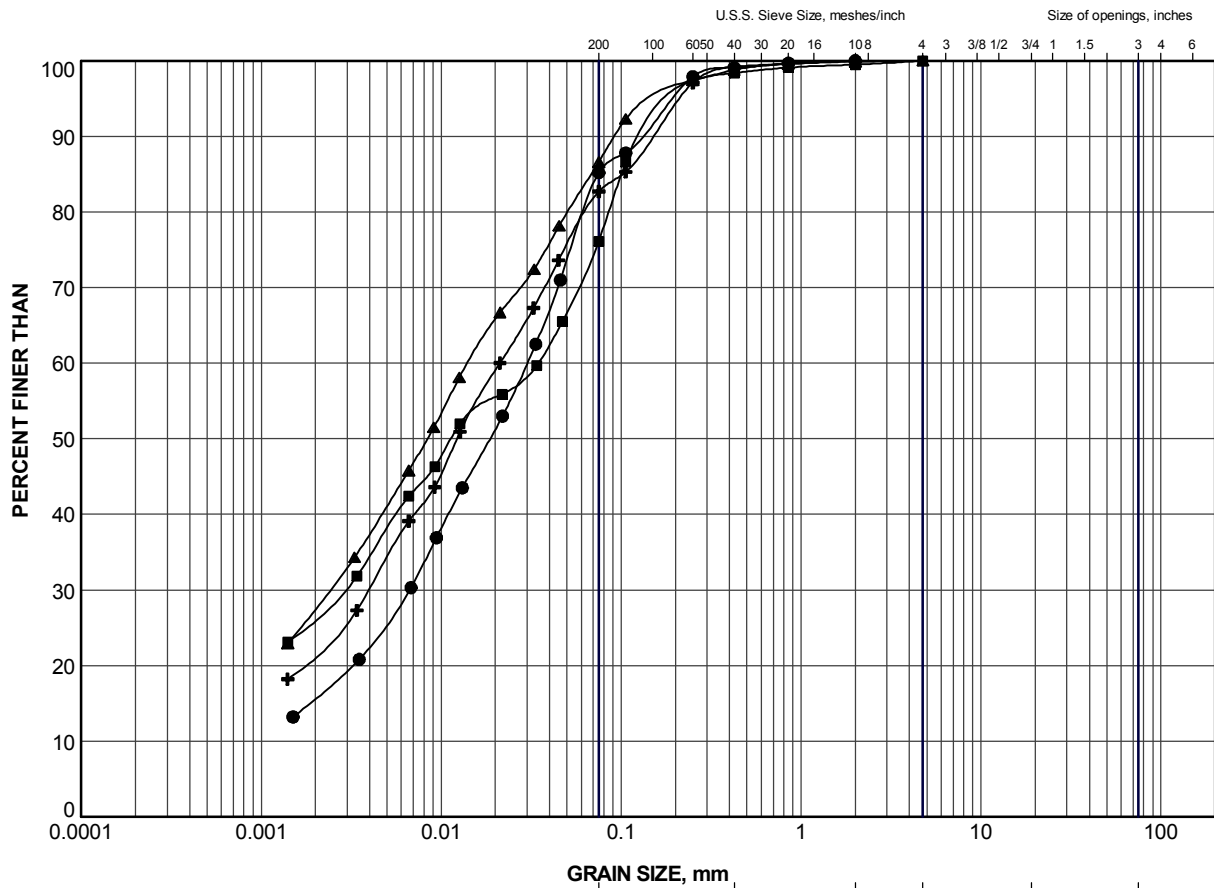
PROJECT				
HIGHWAY 11 NBL CULVERT 27+340				
TITLE				
GRAIN SIZE DISTRIBUTION				
SAND AND GRAVEL (FILL)				
PROJECT No.		09-1191-0042		FILE No. 09-1191-0042-4000.GPJ
DRAWN	JJL	Nov 2011	SCALE	N/A
CHECK	AB	Nov 2011	REV.	
APPR	JMAC	Nov 2011		
 Golder Associates SUDBURY, ONTARIO				FIGURE B-1



LEGEND

SYMBOL	BOREHOLE	SAMPLE	LL(%)	PL(%)	PI
●	BH09-07	7	26.0	14.0	12.0
■	BH09-08	2	22.0	14.0	8.0
▲	BH09-08	3	21.0	15.0	6.0
+	BH09-08	4	27.0	16.0	11.0


PROJECT				
HIGHWAY 11 NBL CULVERT 27+340				
TITLE				
PLASTICITY CHART				
CLAYEY SILT				
PROJECT No. 09-1191-0042		FILE No. 09-1191-0042-4000.GPJ		
DRAWN	JJL	Nov 2011	SCALE	N/A
CHECK	AB	Nov 2011	REV.	
APPR	JMAC	Nov 2011		
 Golder Associates SUDBURY, ONTARIO			FIGURE B-2	

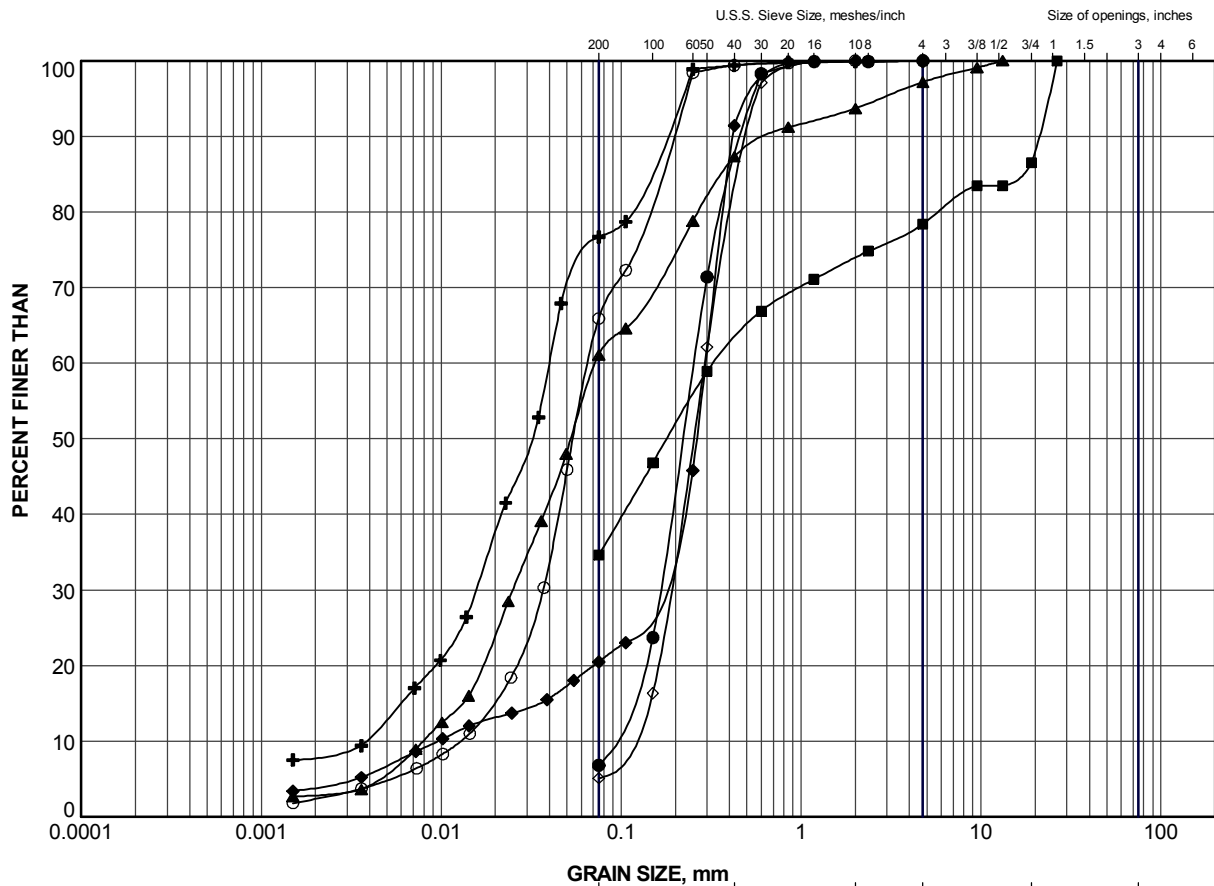


GRAVEL SIZE, mm						
CLAY AND SILT	fine	medium	coarse	fine	coarse	Cobble Size
	SAND SIZE			GRAVEL SIZE		

LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEV (m)
●	BH09-01	5	251.3
■	BH09-07	7	250.0
▲	BH09-08	4	249.2
+	BH09-09	2	250.9

PROJECT					
HIGHWAY 11 NBL CULVERT 27+340					
TITLE					
GRAIN SIZE DISTRIBUTION					
CLAYEY SILT					
PROJECT No.		09-1191-0042		FILE No. 09-1191-0042-4000.GPJ	
DRAWN	JJL	Nov 2011	SCALE	N/A	REV.
CHECK	AB	Nov 2011			
APPR	JMAC	Nov 2011			
 Golder Associates SUDBURY, ONTARIO			FIGURE B-3		



CLAY AND SILT	fine	medium	coarse	fine	coarse	Cobble Size
	SAND SIZE			GRAVEL SIZE		

LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEV (m)
●	BH09-01	7	249.8
■	BH09-01	11	243.6
▲	BH09-07	11	244.1
+	BH09-08	6	247.7
◆	BH09-09	4	249.4
◇	BH09-09	7	247.1
○	BH09-09	8	245.6

PROJECT

HIGHWAY 11 NBL CULVERT 27+340

TITLE

GRAIN SIZE DISTRIBUTION

SAND TO SAND AND SILT



Golder Associates
SUDBURY, ONTARIO

PROJECT No. 09-1191-0042		FILE No. 09-1191-0042-4000.GPJ	
DRAWN	JJL	Nov 2011	SCALE N/A
CHECK	AB	Nov 2011	REV.
APPR	JMAC	Nov 2011	

FIGURE B-4

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.

Africa	+ 27 11 254 4800
Asia	+ 86 21 6258 5522
Australasia	+ 61 3 8862 3500
Europe	+ 356 21 42 30 20
North America	+ 1 800 275 3281
South America	+ 55 21 3095 9500

solutions@golder.com
www.golder.com

Golder Associates Ltd.
1010 Lorne Street
Sudbury, Ontario, P3C 4R9
Canada
T: +1 (705) 524 6861

