October 2014

FOUNDATION INVESTIGATION AND DESIGN REPORT

Culvert Rehabilitation, Site No. 12-373/C
Station 14+361, Highway 4
Contract 2 Structure Replacements and Rehabilitation
GWP 3040-11-00
Ministry of Transportation, West Region

Submitted to:

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REPORT

Report Number: 12-1132-0163-2000-R09

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1.0 INTRODUCTION

Golder Associates Ltd. (Golder Associates) has been retained by Stantec Consulting Ltd. (Stantec) on behalf of the Ministry of Transportation, Ontario (MTO) to carry out foundation investigations as part of the detail design work for GWP 3040-11-00. The project involves the detail design of the replacement and rehabilitation of several structures along multiple highways in Southern Ontario. This report addresses the proposed rehabilitation of the culvert at Site 12-373/C at Station 14+361 on Highway 4 in the Geographic Township of Stephen in Huron County.

The purpose of the foundation investigation is to explore the subsurface conditions at the location of the proposed wingwall replacements to be carried out for the culvert rehabilitation by drilling boreholes and carrying out in situ testing and laboratory testing on selected samples. The terms of reference for the scope of work are outlined in the MTO's Request for Proposal and in Golder Associates' proposal P2-1132-0163 dated February 25, 2013. The work was carried out in accordance with our Quality Control Plan for Foundation Engineering dated March 26, 2013.

2.0 SITE DESCRIPTION

The subject culvert is situated at Station 14+361 on Highway 4, approximately 0.3 kilometres north of Crediton Road in the Township of Stephen in Huron County, Ontario. The town of Exeter is approximately 4.1 metres north of the site. The location of the culvert is shown on the Key Plan, Figure 1.

This section of Highway 4 is currently a two lane undivided highway with gravel shoulders. It is generally oriented north-south in the vicinity of the subject site. Prout Drain flows in the culvert from east to west beneath Highway 4. The existing culvert is a concrete rigid frame open footing (RFO) structure constructed in 1963 with the following characteristics:

Dimensions (m)	Obvert Elevation (m)		Construction
	Lt[1]	Rt[1]	
3.05 x 2.09 x 29.84	263.08	263.28	RFO

NOTE: 1. When facing the direction of increasing chainage, Lt and Rt are defined as Left and Right of centreline, respectively.

The banks of the Prout Drain channel immediately upstream and downstream of the culvert are grass covered with rock/rubble or sand bag slope protection on all four corners. The channel is concrete lined and trapezoidal in shape throughout the culvert and just beyond each end. Prout Drain flows through fields adjacent to Highway 4. Site photographs are provided in Appendix B.

The culvert is situated in a rural area with low relief. Ground surface elevations in the vicinity of the culvert range from about 263 to 266 metres.

2.1 Site Geology

The project area is located within the Horseshoe Moraines physiographic region. This region is characterized by morainic ridges composed of pale brown, hard, calcareous, fine-textured till with a moderate degree of stoniness.[1] The overburden in the area of the site generally consists of clayey to silty till called Rannoch Till.[2]

The geological mapping indicates that the underlying bedrock consists of medium brown microcrystalline limestone of the Dundee Formation of the Hamilton Group of Middle Devonian age.[3] The bedrock surface at the site is at about elevation 239.5 metres, with the overburden thickness being about 23.5 to 26 metres.[4]

[1] Chapman, L.J., and Putnam, D.F., 1984: Physiography of Southern Ontario; Ontario Geological Survey, Special Volume 2, 270p. Accompanied by Map. P.2715 (coloured), scale 1:600,000.

[2] Karrow, P.F and assistants. 1973: Quaternary Geology of the St. Mary's Area. Southern Ontario; Ontario Division of Mines Map 2366, scale 1:50,000.

[3] Sanford B.V., 1969: Geology Toronto-Windsor Area, Ontario; Ontario Geological Survey of Canada Map 1263A, Scale 1:250,000.

[4] Karrow, P.F. and Ferguson, A.J. 1975: Bedrock Topography of the St. Mary's Area, Southern Ontario. Ontario Div. of Mines Preliminary Map No.P.266, Scale 1:50,000.

3.0 INVESTIGATION PROCEDURES

The field work for the investigation was carried out on July 10, 2013, during which time 4 boreholes were drilled at the locations shown on the Borehole Location Plan, Drawing 1.

The boreholes were drilled using track-mounted CME 75 drilling equipment supplied and operated by a specialist drilling contractor. Samples of the overburden were typically obtained at depth intervals of 0.75 metres using 50 millimetre outside diameter split spoon sampling equipment in accordance with the Standard Penetration Test (SPT) procedures (ASTM D1586).

The recorded SPT N values are noted on the Record of Borehole sheets. The SPT resistance, or N value, is defined as the number of blows required by a 63.5 kilogram hammer dropped from a height of 760 millimetres to drive a split-spoon sampler a distance of 300 millimetres after an initial 150 millimetres of penetration. The results of the SPT testing as presented on the Record of Borehole sheets, Drawing 1 and in Section 4.0 of this report are unmodified (not standardized for hammer efficiency, borehole diameter, rod length, etc.). The samplers used in the investigation limit the maximum particle size that can be sampled and tested to about 40 millimetres. Therefore, particles or objects that may exist within the soils that are larger than this dimension will not be sampled or represented in the grain size distributions. Larger particle sizes, including cobbles and boulders, are known to be present in the clayey silt till as discussed in the text of this report.

Groundwater conditions in the boreholes were observed throughout the drilling operations and a standpipe was installed in borehole 216 as indicated on the corresponding Record of Borehole sheet. The boreholes were backfilled in accordance with current MTO procedures and Ontario Regulation 903 (as amended).

The field work was monitored on a full-time basis by experienced members of our staff who located the boreholes in the field, monitored the drilling, sampling and in situ testing operations and logged the boreholes. The samples were identified in the field, placed in labelled containers and transported to our London laboratory for further examination and testing. Index and classification tests, consisting of water content determinations, Atterberg limits, and grain size distribution analyses, were carried out on selected samples. The results of the testing are shown on the Record of Borehole sheets and in Appendix A.

The as-drilled borehole locations and ground surface elevations are shown on the Record of Borehole sheets and on Drawing 1. The table below summarizes the coordinates, ground surface elevations and depths of the boreholes.

Borehole	Location (m)		Ground Surface Elevation (m)	Borehole Depth (m)
	Northing	Easting		
216	4 797 141	388 095	262.84	6.55
217	4 797 145	388 121	265.08	8.08
218	4 797 134	388 123	265.07	8.08
219	4 797 130	388 094	262.72	6.55

4.0 SUBSURFACE CONDITIONS

4.1 Site Stratigraphy

The detailed subsurface soil and groundwater conditions encountered in the boreholes, together with the results of the in situ testing and the laboratory testing carried out on selected samples, are given on the attached Record of Borehole sheets following the text of this report and in Appendix A. The stratigraphic boundaries shown on the Record of Borehole sheets are inferred from non-continuous samples and observations of drilling resistance and, therefore, may represent transitions between soil types rather than exact planes of geological change. Further, the subsurface conditions will vary between and beyond the borehole locations.

The boreholes drilled at the site generally encountered the existing pavement granulars or topsoil overlying variable embankment fill materials then, in sequence, clayey silt till and silt.

The locations and elevations of the boreholes, together with the interpreted stratigraphic profile, are shown on Drawing 1. A detailed description of the subsurface conditions encountered in the boreholes is provided on the Record of Borehole sheets and is summarized in the following sections.

4.2 Soil Conditions

4.2.1 Pavement Structure

Pavement granular base materials were encountered at ground surface in borehole 217. The granular base materials were about 90 millimetres thick. Pavement granular subbase material was encountered beneath the granular base in borehole 217. The granular subbase material was about 1280 millimetres thick. The granular subbase had an N value of 8 blows per 0.3 metres and a water content of 9 per cent.

4.2.2 Topsoil

A layer of topsoil was encountered at the ground surface in boreholes 216, 218 and 219. The topsoil was 90 to 180 millimetres thick.

Materials designated as topsoil in this report were classified solely based on visual and textural evidence. Testing of organic content or for other nutrients was not carried out. Therefore, the use of materials classified as topsoil cannot be relied upon for support and growth of landscaping vegetation.

4.2.3 Fill

Clayey silt fill materials were encountered beneath the topsoil in boreholes 216 and 219 at elevations 262.7 and 262.6 metres, respectively, beneath the granular subbase in borehole 217 at elevation 263.7 metres and beneath the sandy silt fill in borehole 218 at elevation 261.4 metres. The cohesive fill ranged in thickness from 0.8 to 1.2 metres. The clayey silt fill material had measured N values of 9 to 15 blows per 0.3 metres and water contents of 12 and 19 per cent.

Granular fill materials were encountered beneath the topsoil in borehole 218 at elevation 265.0 metres and beneath the clayey silt fill in boreholes 217 at elevation 263.0 metres. The fill consisted of sand and gravel and sandy silt. The granular fill materials were 1.5 and 3.6 metres thick with standard penetration test N values of 8 to 15 blows per 0.3 metres. Samples of the granular fill had water contents of 4 to 20 per cent. The gradation of a sample of sandy silt fill is presented on Figure A-1 in Appendix A.

4.2.4 Clayey Silt Glacial Till

Layers of firm to hard clayey silt glacial till were encountered beneath the fill materials in boreholes 216 to 219 from elevations 260.7 to 261.5 metres. Boreholes 218 and 219 were terminated in the clayey silt till after exploring the layer for 3.7 and 5.2 metres, respectively. The clayey silt till was 4.0 and 5.2 metres thick where fully penetrated. Measured N values for the clayey silt till layers ranged from 5 to 33 blows per 0.3 metres. Water contents of the samples ranged from 10 to 24 per cent. Cobbles and boulders should be expected in the clayey silt till.

The clayey silt till is of low plasticity based on the Atterberg limits determinations carried out on samples obtained during standard penetration testing. The plastic limit ranged from 13 to 17 per cent, the liquid limit from 23 to 30 per cent, and the plasticity index from 10 to 14 per cent. The Atterberg limits data for the clayey silt till are presented on Figure A-4. Grain size distribution curves for samples of the clayey silt till are provided on Figure A-2.

4.2.5 Silt

Silt layers were encountered beneath the clayey silt till in boreholes 216 and 217 at elevations 256.4 and 257.5 metres, respectively. The silt layers were explored for 0.1 and 0.5 metres before being terminated. The dense silt had measured N values of 33 and 45 blows per 0.3 metres and water contents of 11 and 15 per cent. A grain size distribution curve for a sample of the silt is provided on Figure A-3.

4.3 Groundwater Conditions

Groundwater conditions were observed during and on completion of drilling and sampling and a groundwater observation standpipe was installed in borehole 216. Installation details are provided on the corresponding Record of Borehole sheet following the text of this report. Groundwater was encountered in boreholes 218 and 219 at depths of 6.1 and 7.6 metres, or at elevations 257.5 and 256.6 metres, respectively. The groundwater level in boreholes 216 and 217 was not established at the completion of drilling. A summary of the encountered and measured groundwater levels is provided in the table below.

Borehole	Ground Surface Elevation (m)	Encountered Groundwater Elevation (m)	Measured Groundwater Level Elevation (m)			
			July 10, 2013	Sept. 4, 2013	April 30, 2014	July 25, 2014
216	262.84	*	261.41	261.07	261.77	261.32
217	265.08	*	-	-	-	-
218	265.07	257.5	-	-	-	-
219	262.72	256.6	-	-	-	-

*Groundwater not observed

The above-noted encountered water levels are not considered to be representative of the long-term, stabilized groundwater conditions. The corresponding water level in the watercourse was measured at elevation 260.9 metres on July 10, 2013 and on April 30, 2014. On September 4, 2013 the water level in the standpipe installed in borehole 216 was about 1.8 metres below ground surface or at about elevation 261.1 metres. On April 30, 2014 the water level in the piezometer installed in borehole 216 was about 1.1 metres below the ground surface or at about elevation 261.8 metres. It should be noted that the April 2014 reading occurred after a period of heavy precipitation. On July 25, 2014 the water level in the standpipe installed in borehole 216 was about 1.5 metres below ground surface or at about elevation 261.3 metres.

Based on the observed groundwater levels, the surrounding topography, and water levels in the drain, the groundwater level is inferred to typically be at about elevation 261.5 metres. The groundwater levels are expected to fluctuate seasonally and are expected to be higher during periods of sustained precipitation or during spring snow melt conditions.

5.0 MISCELLANEOUS

The investigation was carried out using equipment supplied and operated by Aardvark Drilling Inc., an Ontario Ministry of Environment licensed well contractor. The field operations were supervised by Mr. Brett Thorner, E.I.T. under the direction of the Field Investigation Manager, Mr. David J. Mitchell. The laboratory testing was carried out at Golder Associates' London laboratory under the direction of Mr. Chris M. Sewell. The laboratory is an accredited participant in the MTO Soil and Aggregate Proficiency Program and is certified by the Canadian Council of Independent Laboratories for testing Types C and D aggregates. This report was prepared by Mr. Brett Thorner, E.I.T. under the direction of the Project Engineer Ms. Dirka U. Prout, P.Eng. and the Team Leader, Dr. Storer J. Boone, P.Eng. This report was reviewed by Mr. Azmi Hammoud, P.Eng., an Associate and a Geotechnical Engineer with Golder Associates. Mr. Fintan J. Heffernan, P.Eng., the Designated MTO Contact and Quality Control Auditor for this assignment conducted an independent quality review of the report.

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PART B

FOUNDATION DESIGN REPORT

CULVERT REHABILITATION, SITE NO. 12-373/C

STATION 14+361, HIGHWAY 4

CONTRACT 2 STRUCTURE REPLACEMENTS AND REHABILITATION

GWP 3040-11-00

MINISTRY OF TRANSPORTATION - WEST REGION

6.0 ENGINEERING RECOMMENDATIONS

6.1 General

This section of the report provides recommendations on the foundation aspects of the design of proposed retaining walls to be carried out as part of the major rehabilitation of Culvert Site 12-373/C at Station 14+361 on Highway 4 in the Township of Stephen in Huron County, Ontario.

The recommendations are based on interpretation of the factual data obtained from the boreholes advanced during the investigation at this site. The interpretation and recommendations are intended to provide the designers with sufficient information to design the proposed foundations. As such, where comments are made on construction, they are provided only in order to highlight those aspects which could affect the design of the project. Those requiring information on aspects of construction should make their own interpretation of the factual information provided as it may affect equipment selection, proposed construction methods, and scheduling.

The existing culvert is a 29.8 metre long concrete RFO structure with a 3.1 metre span and a 2.1 metre high opening with invert elevations of 261.2 and 261.0 metres at the inlet and outlet, respectively. The existing sand bag and rock/rubble slope protection segments are between about 1.0 and 1.5 metres long and are between about 0.5 and 1.8 metres in height. The 2006, 2008 and 2010 inspection reports prepared by MTO indicate that significant erosion has occurred at the outlet; however, this has not impacted the embankment stability. Based on information provided by Stantec, it is understood that new retaining walls may be added, particularly on the west (outlet) side as part of the major rehabilitation of the culvert. It has been indicated by Stantec that consideration is being given to constructing the retaining walls as gabion or reinforced soil system (RSS) walls. The retaining wall options are discussed below. Erosion protection in the form of a 450 millimetre thick rock protection mat to elevation 262.80 metres will be added in each quadrant.

6.2 Retaining Walls

6.2.1 Retaining Wall Options

Gabion Walls

Gabion walls do not require an embedment depth equivalent to the frost depth provided they are founded on a granular pad of 300 millimetres compacted thickness, and the foundations have adequate embedment to provide a stable structure. Advantages of gabion walls compared to more rigid structures include the ability to accommodate differential settlements, dissipation of the energy of flowing water, and they are free-draining provided an adequate filter is placed behind the wall. Gabion walls can be constructed relatively quickly with minimal equipment and materials.

RSS Walls

The height of the retaining walls will be relatively low. Therefore, a reinforced soil system wall utilizing an interlocking block system and geogrid reinforcement is a geotechnically feasible alternative. RSS walls are proprietary systems which are to be designed by the supplier and constructed in accordance with their specifications. The internal stability of the mechanically-reinforced soil walls should be verified by the RSS supplier/designer. If an RSS block system wall is selected, the geotechnical aspects of the global stability of the detailed retaining wall design should be reviewed prior to construction. Depending on the design approach selected, an embedment depth equivalent to the frost depth may not be required for foundations of an RSS block system wall. This wall type can be constructed relatively quickly and inexpensively using small equipment.

6.2.2 Foundations – Retaining Walls

Gabion walls may also be founded directly on a 300 millimetre thick compacted Granular A pad. If required, a granular levelling course approximately 75 millimetres in thickness may be placed on the founding strata for gabion walls. Non-woven geotextile is to be placed between the gabions and the backfill. The gabion wall is to be constructed in accordance with OPSS 512, OPSS 1860, and the manufacturer's specifications.

RSS walls may be designed such that the facing blocks are built on a levelling pad constructed with Granular A to a minimum thickness of 300 millimetres. Depending on the design selected by the RSS supplier, it may not be necessary to provide 1.4 metres of earth cover or thermal equivalent for frost protection. However the foundations must have adequate embedment to provide a stable structure. Typically the embedment depth, defined as the distance between the top of the levelling pad and the top of the adjoining finished grade, is a minimum of 500 millimetres.

All retaining wall foundations must be protected against scour as noted in the Canadian Highway Bridge Design Code (CHBDC) Section 1.9.5. It is recommended that the replacement retaining walls be founded on the native clayey silt till encountered between elevations 261.5 and 260.7 metres which may be below the water level in the creek, which at the time of the investigation in July 2013 was at elevation 260.9 metres.

If required, engineered fill used to backfill subexcavated areas should consist of Ontario Provincial Standard Specifications (OPSS) Granular B Type II and should be compacted to at least 95 per cent standard Proctor maximum dry density.

Based on the existing invert elevation of 261.2 metres, the replacement retaining walls may be founded on the native clayey silt till at the elevations noted in the following table.

Wall Type	Location	Maximum Founding Elevation (m)
Gabion Walls	NW, SW	261.4
	NE, SE	260.6
RSS Walls	NW, SW	261.4
	NE, SE	260.6

Retaining walls founded on the native clayey silt till may be designed using a factored geotechnical resistance at Ultimate Limit States (ULS) of 200 kilopascals and a geotechnical resistance at Serviceability Limit States (SLS) of 125 kilopascals. Retaining walls founded on at least one metre thick engineered fill placed and compacted as noted above may be designed using a factored geotechnical resistance at ULS of 150 kilopascals and a geotechnical resistance at SLS of 100 kilopascals. The SLS values correspond to 25 millimetres of settlement.

6.2.3 Resistance to Lateral Forces

The resistance to lateral forces/sliding resistance between the retaining walls and the subgrade soils should be calculated in accordance with Section 6.7.5 of the CHBDC. Each retaining wall shall be checked for overturning. Assuming that the founding soils are not loosened/disturbed during excavation and footing construction, the following angles of friction and corresponding unfactored coefficient of friction, tan δ, may be used for the interaction between the base of the wall and the founding soil:

Wall Type	Interaction	Angle of Interface Friction, δ (degrees)	Coefficient of Interface Friction, Tan δ
Gabion Wall	Gabion basket on Granular A leveling pad	30	0.58
RSS Block System Wall	Pre-cast concrete block facing units on Granular A levelling pad	30	0.58

6.2.4 Lateral Earth Pressures for Design

The lateral pressures acting on the proposed retaining walls will depend on the type and method of placement of the backfill materials, on the nature of the soil behind the backfill, on the magnitude of surcharge including construction loadings, on the freedom of lateral movement of the structure, and on the drainage conditions behind the walls.

The following recommendations are made concerning the design of the walls in accordance with the current CHBDC. It should be noted that these design recommendations and parameters assume 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 Granular A, Granular B Type II or Granular B Type III but with less than 5 per cent passing the 0.075 millimetre sieve should be used as backfill behind the walls. The fill should be compacted in loose lifts not greater than 200 millimetres in thickness. Longitudinal drains and weep holes should be installed to provide positive drainage of the granular backfill.
- A compaction surcharge equal to 12 kPa should be included in the lateral earth pressures for the structural design in accordance with CHBDC Figure 6.6.

- If the wall support does not allow lateral yielding, at-rest earth pressures should be assumed for geotechnical design. The granular fill should be placed in a zone with a width equal to at least 1.4 metres behind the walls (case (a) from commentary on CHBDC Figure C6.20).
- If the wall support allows lateral yielding (unrestrained structure, such as typically the case for retaining walls), active earth pressures may be used in the geotechnical design of the structure. The granular fill should be placed in a wedged shaped zone with a width equal to at least 1.4 metres at the footing level against a cut slope which begins at the footing level and extends upwards at a maximum inclination of 1 horizontal to 1 vertical (case (b) from commentary on CHBDC Figure C6.20).
- For walls backfilled using granular materials in accordance with Case (b), the unrestrained Case, the following parameters (unfactored) may be assumed:

	GRANULAR A	GRANULAR B TYPE II	GRANULAR B TYPE III
Fill unit weight:	22 kN/m^3	21 kN/m^3	21 kN/m^3
Coefficients of lateral earth pressure:			
'active' or unrestrained, K_a	0.27	0.27	0.31
'passive', K_p	3.7	3.7	3.3

6.3 Construction Considerations

6.3.1 General

Care should be taken during construction to avoid disturbance of the subgrades prior to constructing foundations for the replacement retaining walls. All existing fill and any topsoil, organics, and soft or loose soils should be stripped from the proposed founding areas prior to placement of base materials. Subgrade preparation should be performed and monitored in accordance with OPSS 902.

It is recommended that the footing excavations be carried out such that the final 0.5 metres of excavation is completed with a Quality Verification Engineer (QVE) experienced in geotechnical engineering on site. The prepared excavation bases should be inspected by the QVE and granular base materials should be placed immediately after inspection to protect the founding materials.

Sediment control such as silt fences and erosion control blankets may be required during construction. All retaining wall foundations must be protected against scour as noted in the CHBDC Section 1.9.5.

6.4 Excavations and Groundwater Control

Excavations will extend through the existing fill and topsoil to the underlying native clayey silt till. Depending on the wall type and selected foundation system, the excavation for the retaining walls may extend up to 1.2 metres below the inferred groundwater level of elevation 261.5 metres. Seepage volumes from the clayey silt till are anticipated to be such that groundwater control may be achieved by using properly constructed and filtered sumps. Sumps should be maintained outside of the actual wall footing limits. Some seepage from the granular fill layers should be expected particularly after the spring thaw or other periods of heavy precipitation.

Surficial water seepage into the excavations should be expected and will be heavier during periods of sustained precipitation. Surface water runoff should be directed away from the excavations at all times. The existing culvert flows may need to be diverted/piped during construction.

Temporary open cut slopes within the fill materials should be maintained no steeper than 1 horizontal to 1 vertical and localized sloughing and ground movements should be expected. All excavations should be carried out in accordance with the latest edition of the Ontario Occupational Health and Safety Act and Regulations for Construction Projects. The fill would be classified as a Type 3 soil and the native clayey silt till would be classified a Type 2 soil.

7.0 MISCELLANEOUS

This section of the report was prepared by Mr. Brett Thorner, E.I.T. under the direction of the Project Engineer Ms. Dirka U. Prout, P.Eng. and the Team Leader, Dr. Storer J. Boone, P.Eng. The report was reviewed by Mr. Azmi M. Hammoud, P.Eng., an Associate with Golder Associates. Mr. Fintan J. Heffernan, P.Eng., the Designated MTO Contact and Quality Control Auditor for this assignment, conducted an independent quality review of the report.

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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.) split spoon 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) 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	c_u,s_u 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.

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
F	factor of safety
V	volume
W	weight

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
v	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

(a) Index Properties (continued)

w	water content
w_l	liquid limit
w_p	plastic limit
l_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 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
* density symbol is ρ. Unit weight symbol is γ where $\gamma = \rho g$ (i.e. mass density x acceleration due to gravity)

Golder Associates
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RECORD OF BOREHOLE No 216

METRIC

PROJECT 12-1132-0163

W.P. 3040-11-00 | LOCATION N 4797140.6 , E 388094.8 | ORIGINATED BY BT

DIST ___ HWY 4 | BOREHOLE TYPE POWER AUGER, HOLLOW STEM | COMPILED BY AMG/LMK

DATUM GEODETIC | DATE July 10, 2013 | CHECKED BY ___

ELEV DEPTH	DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
262.84	GROUND SURFACE				
0.00	TOPSOIL, silty Brown				
0.18	FILL, clayey silt, some sand, trace gravel, trace topsoil Stiff Brown	1	SS	9	
261.47 1.37	CLAYEY SILT TILL, trace to some sand, trace gravel Compact to dense Brown becoming grey at about elev. 259.9m	2	SS	14	10 29 39 22
		3	SS	30	
		4	SS	22	
		5	SS	23	5 7 49 39
		6	SS	21	
		7	SS	33	
256.38 6.55	SILT, some sand, trace clay, trace gravel Dense Grey				
	END OF BOREHOLE				

Borehole dry during drilling on July 10, 2013.

Water level measured at elev. 261.41m on July 10, 2013.

Water level measured at elev. 261.07m on September 4, 2013.

Water level measured at elev. 261.77m on April 30, 2014.

Water level measured at elev. 261.32m on July 25, 2014.

Piezometer installation: Backfill; Granular Bentonite; Piezometer; Filter Sand.

Chart columns: DYNAMIC CONE PENETRATION RESISTANCE PLOT (20 40 60 80 100); SHEAR STRENGTH kPa (○ UNCONFINED, + FIELD VANE, ● QUICK TRIAXIAL, × LAB VANE; 20 40 60 80 100); PLASTIC LIMIT W_P, NATURAL MOISTURE CONTENT W, LIQUID LIMIT W_L; WATER CONTENT (%) 10 20 30; UNIT WEIGHT γ kN/m³; ELEVATION SCALE 262, 261, 260, 259, 258, 257.

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

Golder Associates
London, Ontario

RECORD OF BOREHOLE No 217

METRIC

PROJECT 12-1132-0163
W.P. 3040-11-00
LOCATION N 4797144.7 , E 388121.3
ORIGINATED BY BT
DIST ____ HWY 4
BOREHOLE TYPE POWER AUGER, HOLLOW STEM
COMPILED BY AMG/LMK
DATUM GEODETIC
DATE July 10, 2013
CHECKED BY ____

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	GR	SA	SI	CL
265.08	GROUND SURFACE						265							
0.09	FILL, granular base Brown													
	FILL, granular subbase Loose Brown		1	SS	8		264							
263.71 1.37	FILL, clayey silt, trace sand, trace gravel, trace topsoil Stiff Brown		2	SS	15									
262.95 2.13	FILL, silty sand, some topsoil, trace gravel Compact Dark brown to dark grey		3	SS	15		263							
			4	SS	14		262							
261.42 3.66	CLAYEY SILT TILL, trace sand, trace gravel Firm to stiff Grey		5	SS	5		261				7	8	50	35
			6	SS	13		260							
			7	SS	11						1	2	49	48
			8	SS	13		259							
							258							
257.46 7.62	SILT, some clay, trace fine sand Dense Grey		9	SS	45						0	8	76	16
257.00 8.08	END OF BOREHOLE Borehole dry during drilling on July 10, 2013.						257							

Dynamic cone penetration resistance plot scale: 20 40 60 80 100
Shear strength kPa: ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × LAB VANE; scale 20 40 60 80 100
PLASTIC LIMIT W_P — NATURAL MOISTURE CONTENT W — LIQUID LIMIT W_L; WATER CONTENT (%) scale 10 20 30
REMARKS & GRAIN SIZE DISTRIBUTION (%)

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

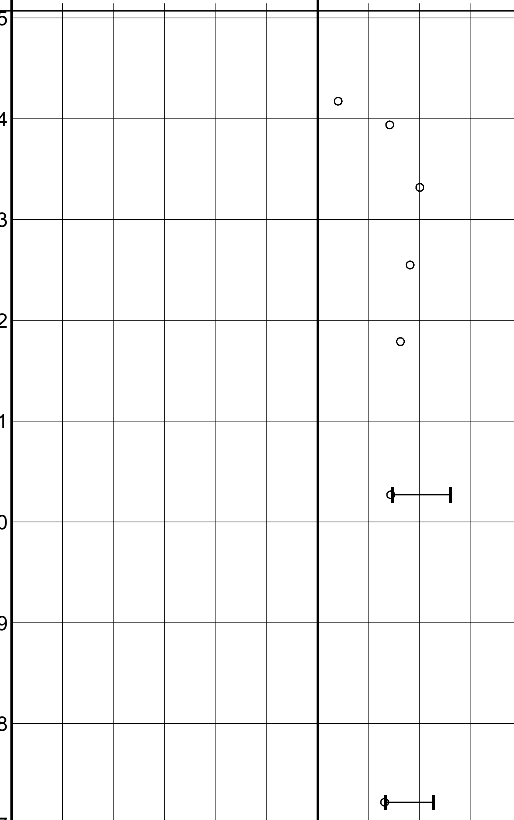
Golder Associates
London, Ontario

RECORD OF BOREHOLE No 218

METRIC

PROJECT 12-1132-0163
W.P. 3040-11-00
LOCATION N 4797134.4 , E 388123.3
ORIGINATED BY BT
DIST HWY 4
BOREHOLE TYPE POWER AUGER, HOLLOW STEM
COMPILED BY AMG/LMK
DATUM GEODETIC
DATE July 10, 2013
CHECKED BY

ELEV DEPTH (m)	DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	GR	SA	SI	CL
265.07	GROUND SURFACE								
0.09	TOPSOIL, silty; Brown								
	FILL, sand and gravel, trace silt, with cobbles; Loose; Brown	1	SS	8					
264.03 / 1.04	FILL, sandy silt, some clay, trace to some topsoil, trace gravel; Compact to loose; Brown to dark grey	2	SS	12					
		3	SS	8					
		4	SS	10		1	26	48	25
261.41 / 3.66	FILL, clayey silt, trace sand, trace topsoil, with wood fragments; Stiff; Grey	5	SS	9					
260.65 / 4.42	CLAYEY SILT TILL, trace to some sand, trace gravel, with cobbles; Stiff to very stiff; Grey	6	SS	14		1	4	55	40
		7	SS	14					
		8	SS	11					
		9	SS	19	∇ (elev. 257.5 m)	4	20	47	29
256.99 / 8.08	END OF BOREHOLE Groundwater encountered at elev. 257.5m during drilling on July 10, 2013.								



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

Golder Associates
London, Ontario

RECORD OF BOREHOLE No 219

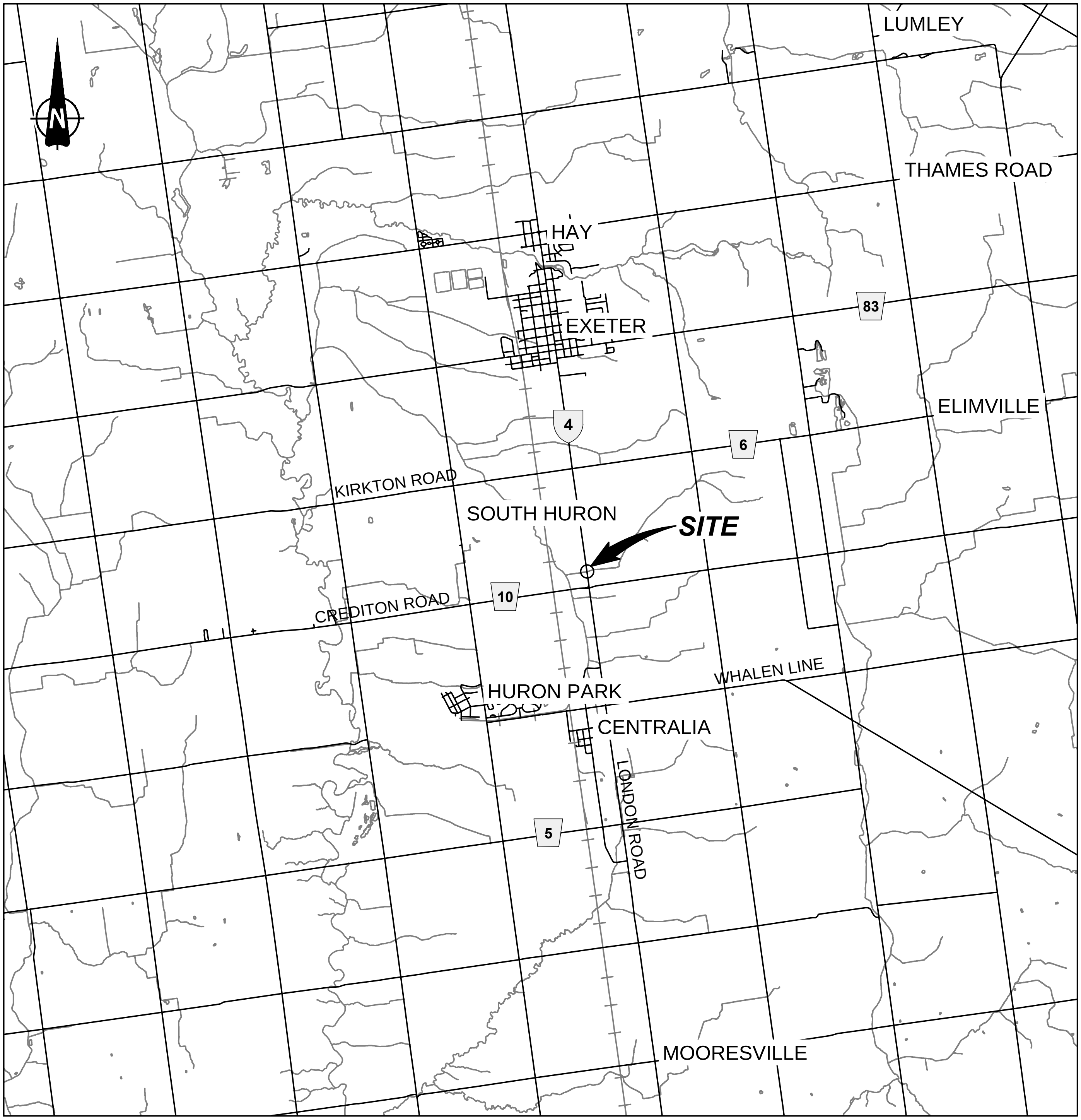
METRIC

PROJECT 12-1132-0163			
W.P. 3040-11-00	LOCATION N 4797129.7 , E 388094.4		ORIGINATED BY BT
DIST	HWY 4	BOREHOLE TYPE POWER AUGER, HOLLOW STEM	COMPILED BY AMG/LMK
DATUM GEODETIC	DATE July 10, 2013		CHECKED BY

ELEV / DEPTH	DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	WATER CONTENT (%)	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
262.72	GROUND SURFACE						
0.00	TOPSOIL, silty, Brown						
0.15	FILL, clayey silt, trace sand, trace gravel, trace topsoil. Stiff. Brown	1	SS	12			
261.35 / 1.37	CLAYEY SILT TILL, trace to some sand, trace gravel. Very stiff to hard. Brown becoming grey at about elev. 260.6m	2	SS	20			
		3	SS	21			1 9 54 36
		4	SS	22			
		5	SS	17			
		6	SS	32			5 15 43 37
		7	SS	22	▽		
256.17 / 6.55	END OF BOREHOLE. Groundwater encountered at elev. 256.6m during drilling on July 10, 2013.						

Column headings: SOIL PROFILE; STRAT PLOT; SAMPLES; ELEVATION SCALE (262, 261, 260, 259, 258, 257); DYNAMIC CONE PENETRATION RESISTANCE PLOT 20 40 60 80 100; SHEAR STRENGTH kPa ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × LAB VANE 20 40 60 80 100; PLASTIC LIMIT W_P, NATURAL MOISTURE CONTENT W, LIQUID LIMIT W_L; WATER CONTENT (%) 10 20 30; UNIT WEIGHT γ kN/m³

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



SCALE
0 2000 4000m
1:100,000

REFERENCE

PLAN BASED ON CANMAP STREETFILES V.2008.5.

NOTE

THIS DRAWING IS TO BE READ IN CONJUNCTION WITH ACCOMPANYING TEXT.

PROJECT

CULVERT REHABILITATION, SITE 12-373/C
STATION 14+361, HIGHWAY 4
GWP 3040-11-00

TITLE

KEY PLAN

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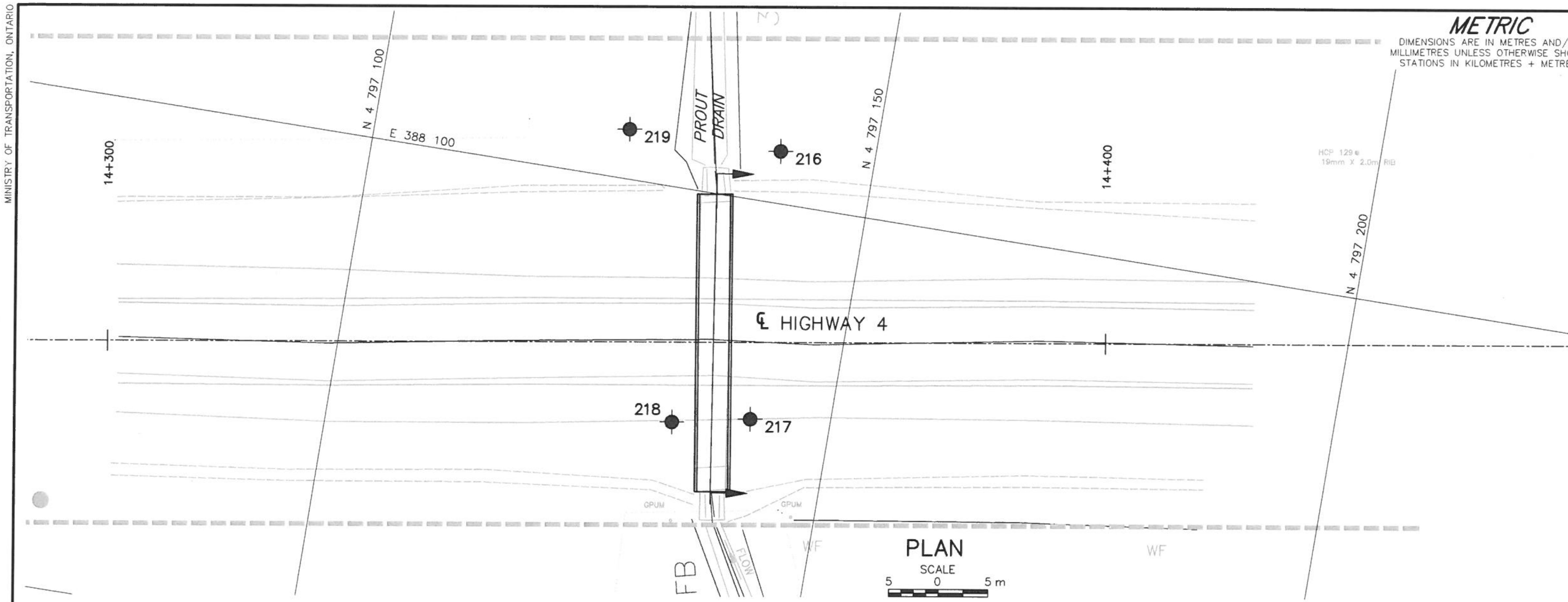
PROJECT No.		12-1132-0163	FILE No.	1211320163-2000-F09001
			SCALE AS SHOWN	REV. 0
CADD	LMK	Nov. 19/13	**FIGURE 1**	
CHECK				

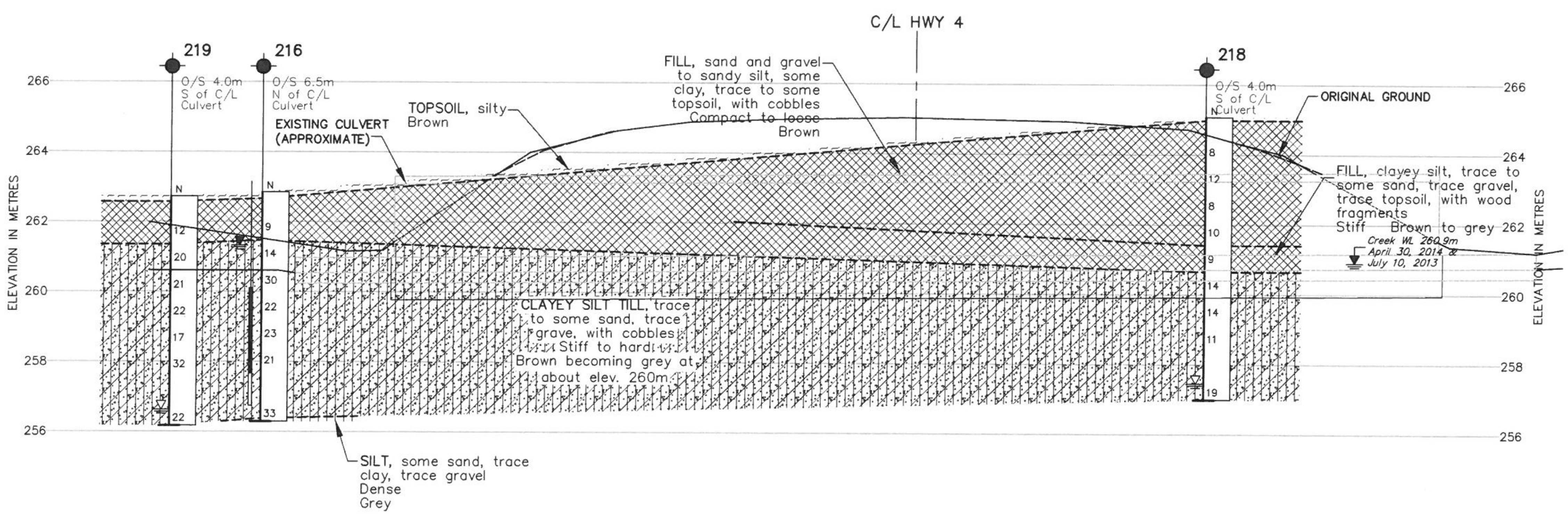
Drawing file: 1211320163-2000-F09001.dwg Aug 05, 2014 - 2:17pm

MINISTRY OF TRANSPORTATION, ONTARIO

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



PLAN
SCALE 5 0 5 m



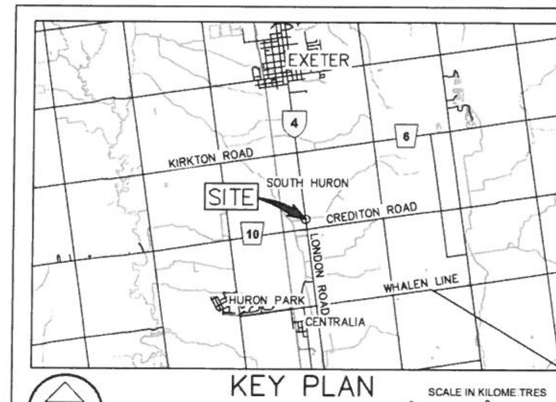
PROFILE ALONG ℄ CULVERT
HORIZONTAL SCALE 2 0 2 m
VERTICAL SCALE 2 0 2 m

CONT No.
WP No. 3040-11-00

SHEET

CULVERT REHABILITATION
STATION 14+361, HIGHWAY 4
STRUCTURE REPLACEMENTS AND REHABILITATION
BOREHOLE LOCATIONS AND SOIL STRATA

Golder Associates Ltd.
LONDON, ONTARIO, CANADA



KEY PLAN
SCALE IN KILOMETRES 0 2 4

LEGEND

- Borehole – Current Investigation
- Seal
- Standpipe
- N — Standard Penetration Test Value
- 16 — Blows/0.3m unless otherwise stated (Std. Pen. Test, 475 j/blow)
- WL measured on July 25, 2014
- WL encountered during drilling
- DRY — Water level not established

No.	ELEVATION	CO-ORDINATES (MTM NAD83 ZONE 11) NORTHING	EASTING
216	262.84	4 797 140.6	388 094.8
217	265.08	4 797 144.7	388 121.3
218	265.07	4 797 134.4	388 123.3
219	262.72	4 797 129.7	388 094.4

NOTES

This drawing is for subsurface information only. Surface details and features are for conceptual illustration.

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

REFERENCE

Base plans provided by Stantec.

LICENSED PROFESSIONAL ENGINEER D. J. PROUT PROVINCE OF ONTARIO
REGISTERED PROFESSIONAL ENGINEER F. J. HEFFERNAN PROVINCE OF ONTARIO

NO.	DATE	BY	REVISION

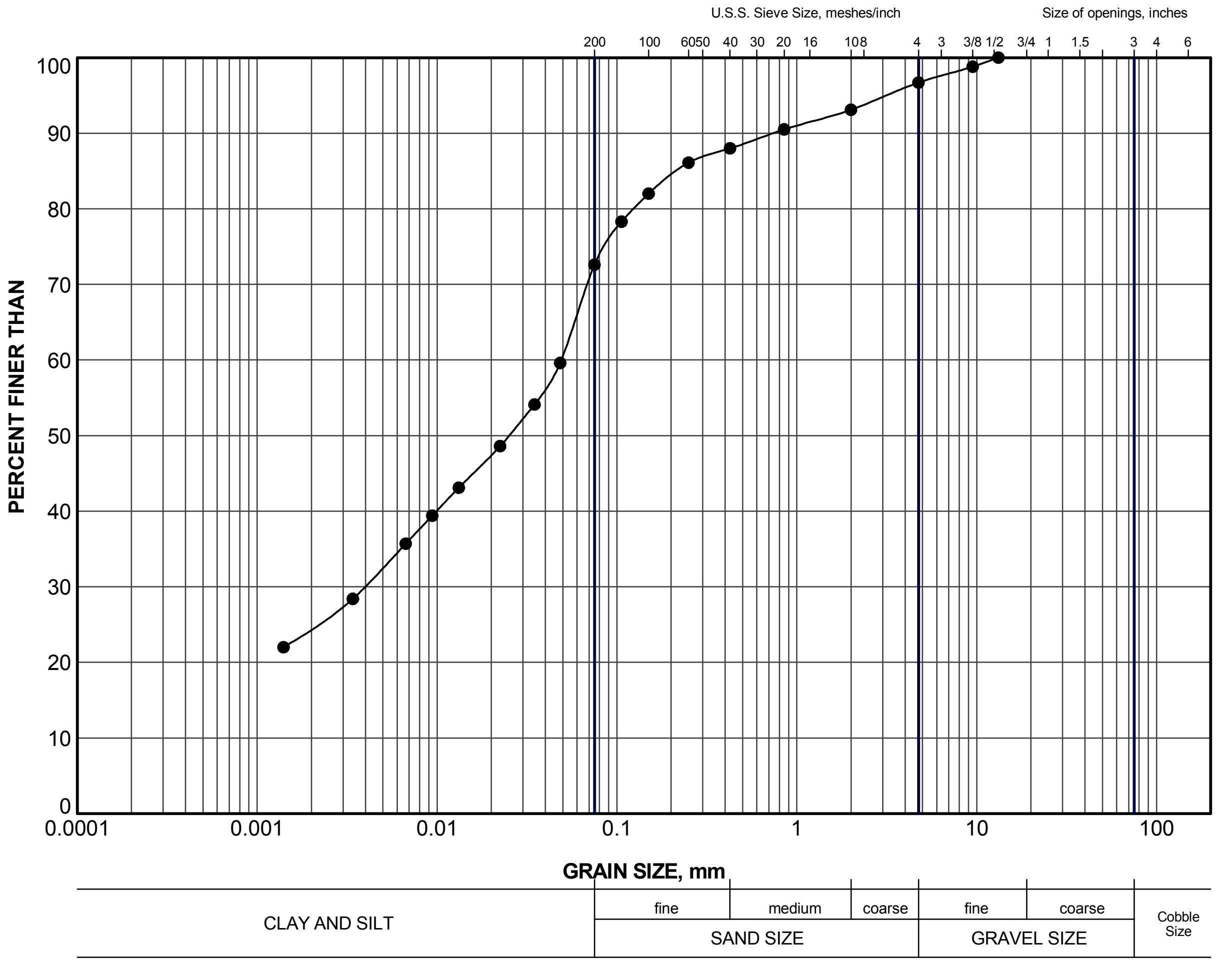
Geocres No. 40P6-30

HWY. 4		PROJECT NO. 12-1132-0163	DIST.
SUBM'D. BT	CHKD. BT	DATE: July 24/14	SITE: 12-373/C
DRAWN: LMK	CHKD. DUP	APPD. FJH	DWG. 1

PLOT DATE: October 10, 2014
FILENAME: N:\Active\2012\1132 - Geo\1132-0100\12-1132-0163 STANTEC-FDHS-MEGA CULVERTS-3011-E-0041\Drafting\AutoCAD files\1211320163-2000-00901.dwg

APPENDIX A

Laboratory Test Data



LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEV (m)
●	218	4	261.8

PROJECT

CULVERT REHABILITATION, SITE 12-373/C
STATION 14+361, HIGHWAY 4
GWP 3040-11-00

TITLE

GRAIN SIZE DISTRIBUTION
FILL

PROJECT No.	12-1132-0163	FILE No.	1211320163-2000-F090A1
		SCALE N/A	REV.
DRAWN	LMK	Aug 12/14	**FIGURE A-1**
CHECK			

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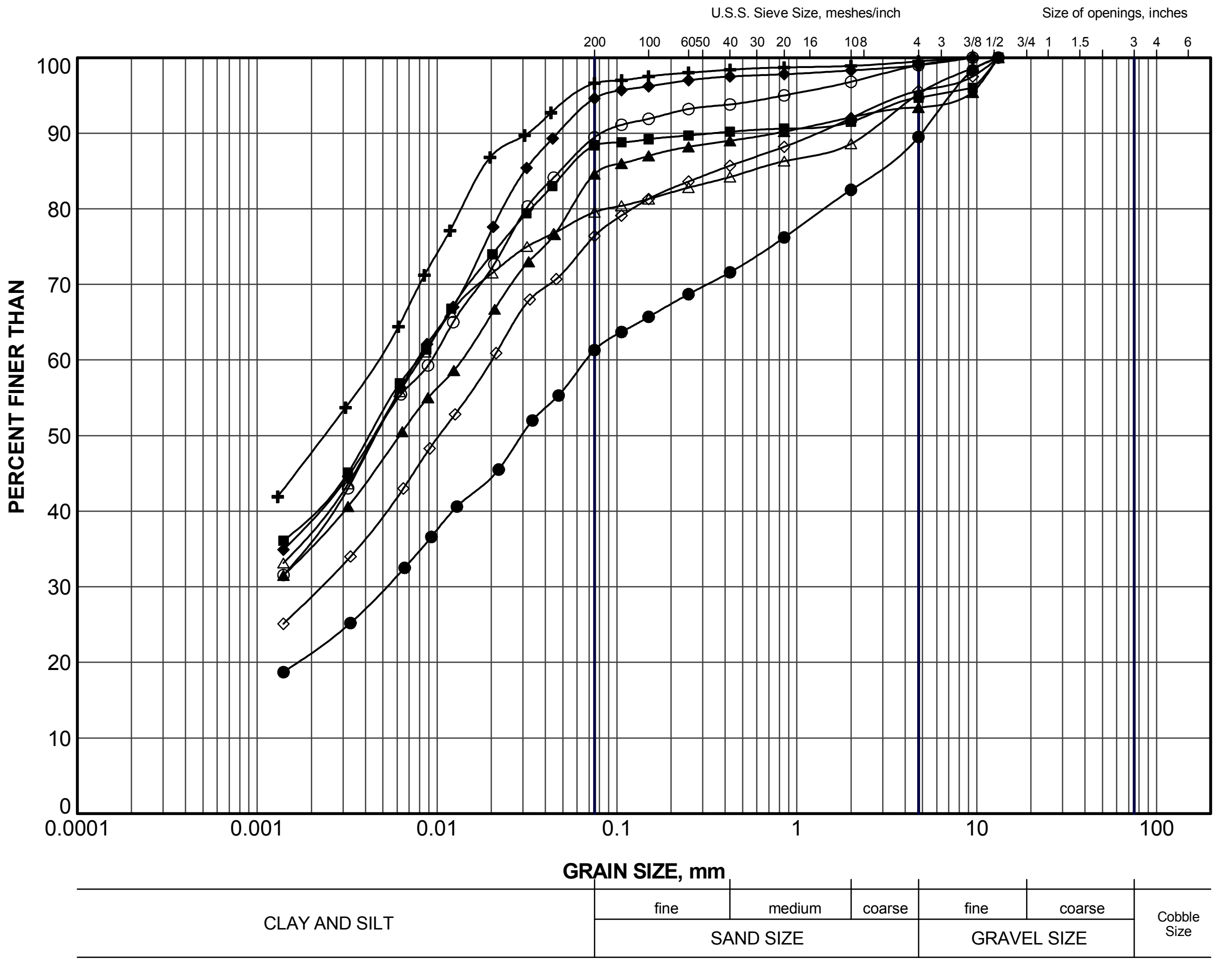
LDN_MTO_GSD GLDR_LDN.GDT 12/08/14



LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEV (m)
●	216	2	261.1
■	216	5	258.8
▲	217	5	261.0
✚	217	7	259.5
◆	218	6	260.3
◇	218	9	257.2
○	219	3	260.2
△	219	6	257.9

PROJECT

CULVERT REHABILITATION, SITE 12-373/C
STATION 14+361, HIGHWAY 4
GWP 3040-11-00

TITLE

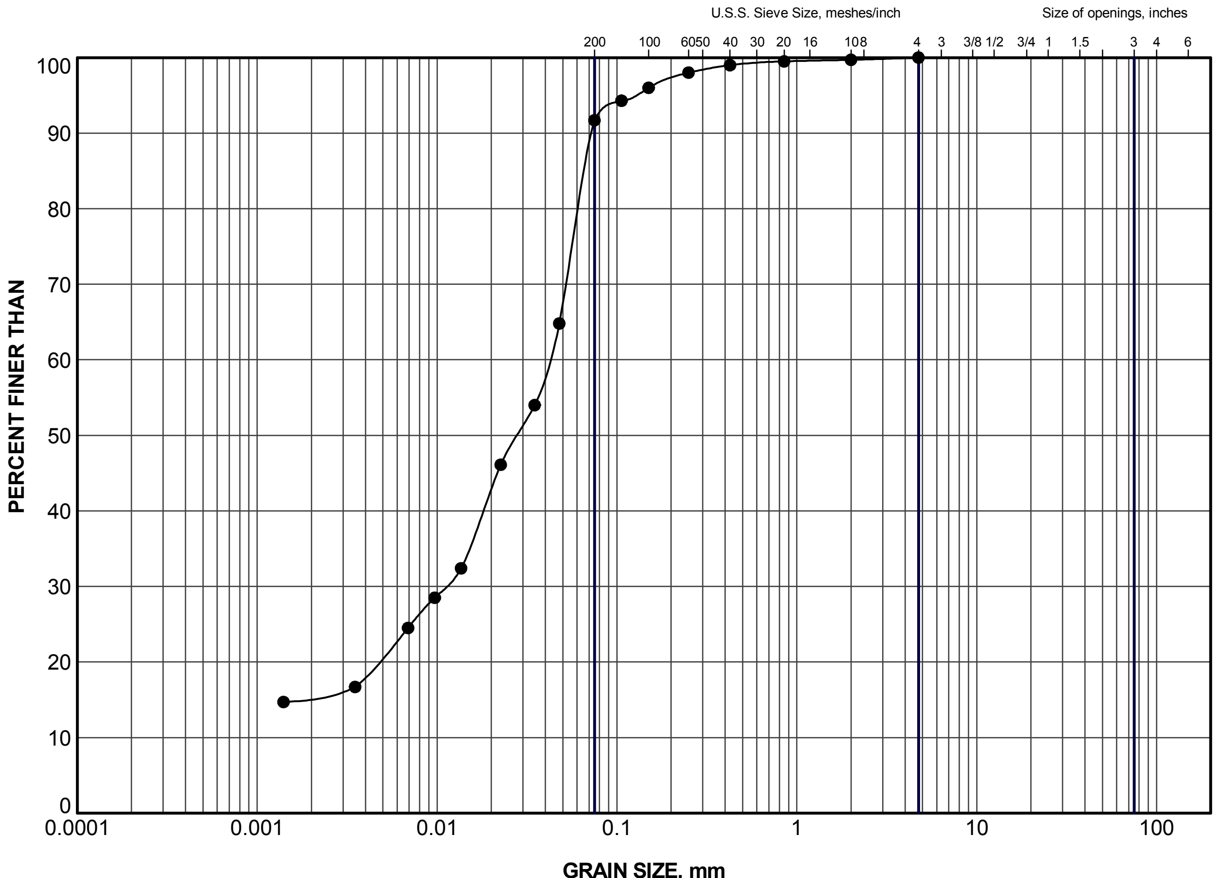
GRAIN SIZE DISTRIBUTION

CLAYEY SILT TILL

Golder Associates
LONDON, ONTARIO

PROJECT No.	12-1132-0163		FILE No. 1211320163-2000-F090A2	
			SCALE N/A	REV.
DRAWN	LMK	Aug 12/14	FIGURE A-2	
CHECK				

LDN_MTO_GSD GLDR_LDN.GDT 12/08/14



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

LEGEND

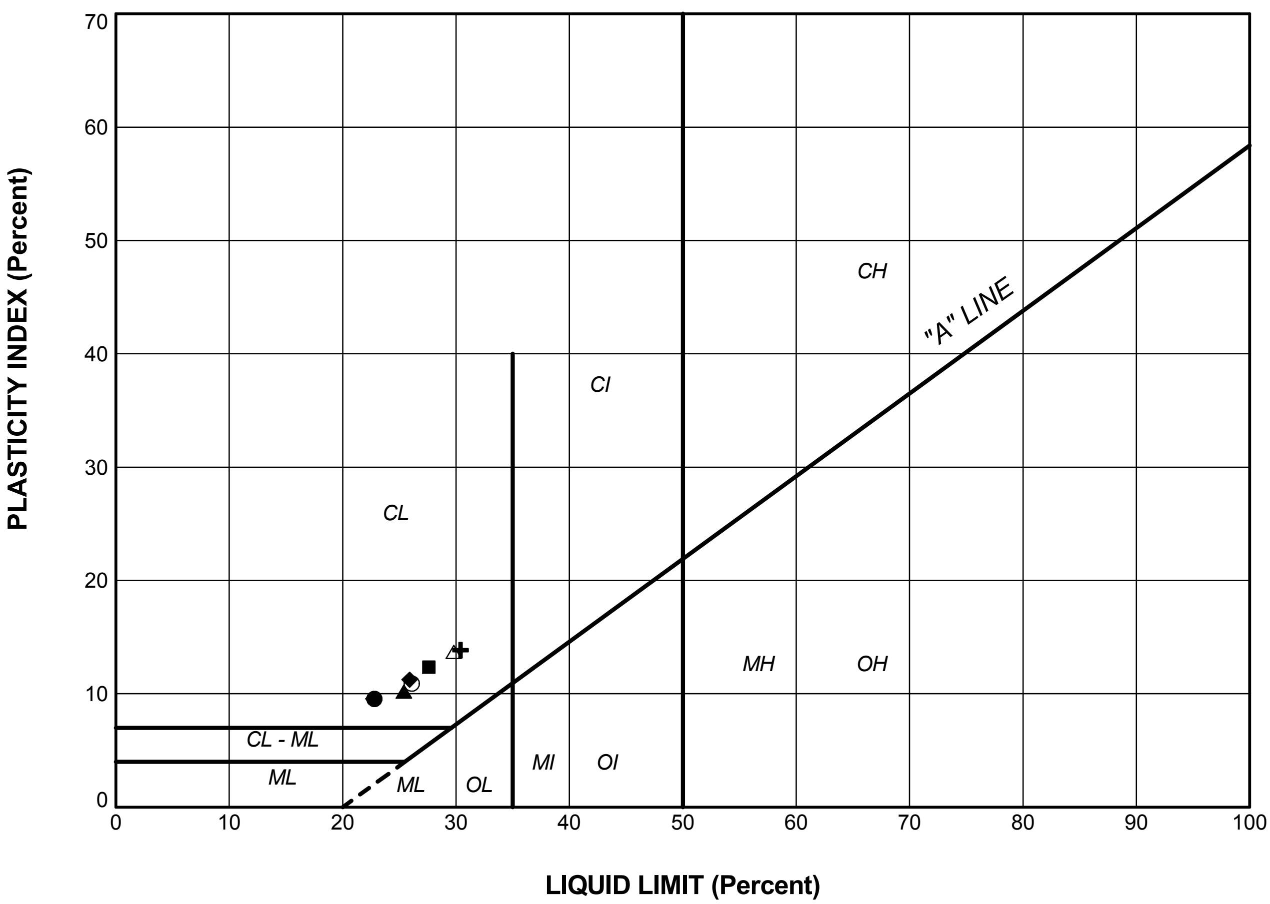
SYMBOL	BOREHOLE	SAMPLE	ELEV (m)
●	217	9	257.2

PROJECT
CULVERT REHABILITATION, SITE 12-373/C
STATION 14+361, HIGHWAY 4
GWP 3040-11-00

TITLE
GRAIN SIZE DISTRIBUTION
SILT

Golder Associates LONDON, ONTARIO	PROJECT No.	12-1132-0163	FILE No. 1211320163-2000-F090A3	
			SCALE N/A	REV.
	DRAWN LMK	Aug 12/14	**FIGURE A-3**	
	CHECK			

LDN_MTO_GSD GLDR_LDN.GDT 19/11/13



SOIL TYPE
C = Clay
M = Silt
O = Organic

PLASTICITY
L = Low
I = Intermediate
H = High

LEGEND

SYMBOL	BOREHOLE	SAMPLE	LL(%)	PL(%)	PI
●	216	2	22.8	13.3	9.6
■	216	5	27.6	15.3	12.4
▲	217	5	25.4	15.2	10.2
✚	217	7	30.4	16.6	13.9
◆	218	6	25.9	14.7	11.3
◇	218	9	22.7	13.2	9.6
○	219	3	26.1	15.2	10.9
△	219	6	29.8	16.1	13.7

PROJECT
CULVERT REHABILITATION, SITE 12-373/C
STATION 14+361, HIGHWAY 4
GWP 3040-11-00

TITLE

PLASTICITY CHART

Golder Associates
LONDON, ONTARIO

PROJECT No.	12-1132-0163	FILE No. 1211320163-2000-F090A4
		SCALE N/A REV.
DRAWN LMK	Aug 12/14	FIGURE A-4
CHECK		

LDN_MTO_PI GLDR_LDN.GDT 12/08/14

APPENDIX B

Site Photographs

Photograph 1: East elevation (inlet) of Culvert Site 12-373/C.

Photograph 2: West elevation (outlet).

Photograph 3: Highway 4 looking south from Culvert Site 12-373/C.

n:\active\2012\1132 - geo\1132-0100\12-1132-0163 stantec-fdns-mega culverts-3011-e-0041\ph 2000-gwp 3040-11-00\rpts\r09 - site 12-373\1211320163-2000-r09 oct 3 14 (final) app b - photos.docx

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North America	+ 1 800 275 3281
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