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FOUNDATION INVESTIGATION AND DESIGN REPORT
STRUCTURAL CULVERT, STATION 21+850 RT
11TH CONCESSION BRANCH OF REID DRAIN
HIGHWAY 77 REHABILITATION
GWP 139-98-00, AGREEMENT NO. 3006-E-0013
MINISTRY OF TRANSPORTATION - SOUTHWESTERN REGION

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FOUNDATION INVESTIGATION REPORT

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1.0 INTRODUCTION

Golder Associates Ltd. (Golder Associates) has been retained by Philips Engineering Ltd. (Philips) on behalf of the Ministry of Transportation, Ontario (MTO) to carry out foundation investigations as part of the detail design work for GWP 139-98-00. Highway 77 will be rehabilitated from its southern terminus in Leamington to Staples, approximately 11.7 kilometres. The southern project limit is just south of Highway 3 in Leamington and the northern limit is near the junction with Essex County Road 8 in Staples. The project also includes reconstruction and widening of an approximately 350 metre long section of Essex County Road 8 within the Highway 77/Essex County Road 8 interchange area. The scope of work for the proposed rehabilitation project includes:

- Pavement rehabilitation;
- Cross section revisions;
- Minor road widening and grade raise;
- Improvements to surface and subsurface drainage;
- Improvements to drainage structures;
- Intersection improvements, including turning lanes and illumination;
- Entrance upgrades;
- Guide rail replacement; and,
- Subsurface utility engineering.

The improvements to the drainage structures will include the replacement, extension or rehabilitation of five structural culverts. This report addresses the foundation investigation for the replacement of the structural culvert located on Highway 77 at Station 21+850 RT.

The purpose of the foundation investigation is to determine the subsurface conditions at the location of the proposed works 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, in Golder Associates' proposal P61-3143-1 dated September 14, 2006 and our letter dated November 8, 2007. The work was carried out in accordance with our Quality Control Plan for Foundations Engineering originally issued on December 13, 2006 and revised February 19, 2007.

Philips provided Golder Associates with a general arrangement drawing for the proposed structure and a base plan for this project in digital format as well as hard copies of the Contract Drawings for this project.

2.0 SITE DESCRIPTION

Along Highway 77, the project limits of GWP 139-98-00 extend from Station 11+652 on the south side of Highway 3 northerly to Station 23+022 at the intersection with Essex County Road 8. The project also includes the reconstruction of the Highway 77 S-E Ramp at the Essex County Road 8 intersection and reconstruction and some widening of Essex County Road 8 from Station 9+960 to Station 10+310. Approximately 11.4 kilometres of Highway 77 is entirely within the Municipality of Leamington. Within the Community of Staples, the remaining 0.3 kilometres runs along Essex County Road 8 which marks the border between the Municipality of Leamington and the Town of Lakeshore. Highway 77 is co-signed with Essex County Road 8 in the short east-west section which joins the northern leg to Highway 401 and the southern leg leading to Leamington.

The culvert is located at Station 10+012 on Mersea Township Road 11 east of Highway 77 at Station 21+850. At this location, the 11th Concession branch of the Reid Drain (Reid Drain) crosses beneath Mersea Township Road 11 from south to north. The location of the project is shown on the Key Plan, Figure 1, and a site photograph is provided in Appendix B.

In the vicinity of the culvert, Reid Drain flows in a channel which is well vegetated with grasses. The land use in the vicinity of the site is primarily agricultural. The adjacent topography is generally flat to gently undulating with a ground surface elevation near 189 metres.

2.1 Site Geology

The site is situated on the Essex Clay Plain, a subregion of the physiographic region of southern Ontario known as the St. Clair Clay Plains.[1] This subregion is described as a beveled till plain with little relief that has been locally smoothed by shallow deposits of lacustrine clay deposited in depressions in the till. The prevailing soil type is reported to be the Brookston clay loam. Near Leamington, there is a small morainic hill composed primarily of sand and gravel.

The available surficial geology mapping for the project area indicates that the predominant surficial soil is clayey silt till.[2] The overburden thickness within the project area is about 30

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[1] L.J. Chapman and D.F. Putnam, 1984. *The Physiography of Southern Ontario*. Third Edition. Ontario Geological Survey, Special Volume 2.

[2] Vagners, U. J., 1972. *Quaternary Geology of the Windsor-Essex Area, (Western and Eastern Parts) Southern Ontario*. Ontario Department of Mines and Northern Affairs, Preliminary Maps P. 749 and P.750, Geological Series.

metres.[3] Immediately underlying the overburden is a medium brown limestone followed by a brown and tan limestone containing quartz sand grains and chert belonging to the Dundee Formation of the Hamilton group.

[3] Vagners, U.J., Sado, E.V., and Yundt, S.E. 1973. *Drift Thickness of the Windsor-Essex Area (Western and Eastern Parts), Southern Ontario,* Ontario Division of Mines, Preliminary Maps P.814 and P.815, Drift Thickness Series.

3.0 INVESTIGATION PROCEDURES

The field investigation at this site was conducted on November 19, 2007 at which time three boreholes, numbered 1, 2 and 3, were drilled in the area of the proposed culvert replacement. All of the boreholes were advanced to depths of 8.8 metres.

The boreholes were advanced using a truck-mounted B57 power auger supplied and operated by a specialist drilling contractor. Samples of the overburden were obtained at intervals of 0.75 metres using 50 millimetre outside diameter split spoon sampling equipment in accordance with the standard penetration test (SPT) procedures.

Groundwater conditions in the boreholes were observed throughout the drilling operations and these observations are provided on the corresponding Record of Borehole sheets. A standpipe was installed in borehole 3 to monitor the groundwater levels at this location. The boreholes were backfilled in accordance with current regulations, MTO recommended procedures and Ontario Regulation 903.

The field work was supervised on a full-time basis by an experienced member of our engineering staff who arranged for utility locates, directed the drilling, sampling and in-situ testing operations, logged the boreholes and cared for the samples obtained. The soil samples were identified in the field, placed in labelled containers and transported to Golder Associates' London laboratory for further examination and testing. Index and classification tests consisting of water content determinations, grain size distribution analyses and Atterberg limits determinations were carried out on selected samples. The results of the field and laboratory testing are given on the Record of Borehole sheets and in Appendix A.

Temporary traffic control was carried out in accordance with the Ontario Traffic Manual, Temporary Conditions, Book 7, dated March 2001.

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 culvert location and the coordinates, ground surface elevations and depths of the associated boreholes.

BOREHOLE	LOCATION (m)		GROUND SURFACE ELEVATION	BOREHOLE DEPTH
	Northing	Easting	(m)	(m)
1	4668922	297177	188.25	8.84
2	4668898	297174	188.51	8.84
3	4668907	297186	188.48	8.84

The existing culvert has the following characteristics:

DIMENSIONS (m)	OBVERT ELEVATION (m)		CONSTRUCTION
	(Lt)	(Rt)	
2.40 x 1.40 x 7.3	188.33	188.41	Non-Rigid Frame Open Footing (NRFO)

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 and 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 sampling and observations of drilling resistance and represent transitions between soil types rather than exact planes of geological change. Subsurface conditions will vary between and beyond the borehole locations.

In general, the boreholes encountered surficial silty clay fill, asphalt and/or granular road base. The fill materials were underlain by silty clay deposits.

The locations of the boreholes are shown on the attached 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.

4.1.1 Pavement Structure

A 100 millimetre thick layer of asphalt was encountered at the ground surface in borehole 3. The asphalt was underlain by a 0.4 metre thick layer of granular road base material from elevation 188.4 metres. A 0.3 metre thick layer of granular road base was encountered at the ground surface in borehole 2.

4.1.2 Fill

A 100 millimetre thick layer of clayey silt fill was encountered at the ground surface in borehole 1. At boreholes 2 and 3, a 1.6 metre thick layer of silty clay fill was encountered beneath the granular road base from elevations 188.2 and 188.0 metres, respectively. The cohesive fill layers were firm to stiff with N values ranging from 4 to 8 blows per 0.3 metres. The silty clay fill had a water content of 21 per cent. The silty clay fill is of intermediate plasticity based on a sample with plastic and liquid limits of 17 and 40 per cent, respectively, and a plasticity index of 23 per cent. The results of the Atterberg limits determinations are shown on Figure A-3.

The results of a grain size analysis conducted on a sample of the silty clay fill obtained from the standard penetration testing are shown on Figure A-1.

Silty sand and gravel fill materials were encountered at elevation 188.2 metres beneath the clayey silt fill in borehole 1 and extended to elevation 188.0 metres.

4.1.3 Silty Clay

Silty clay was encountered beneath the granular fill in borehole 1 from elevation 188.0 metres and beneath the silty clay fill in boreholes 2 and 3 from elevations 186.6 and 186.4 metres, respectively.

The silty clay was firm to very stiff with N values ranging from 6 to 27 blows per 0.3 metres. The natural water contents of the silty clay varied between about 19 and 24 per cent. The silty clay is of intermediate plasticity based on average plastic and liquid limits of 18 and 39 per cent, respectively, and an average plasticity index of 21 per cent. The results of the Atterberg limits determinations are shown on Figure A-3.

The results of grain size analyses conducted on samples of the silty clay are shown on Figure A-2.

4.2 Groundwater Conditions

Boreholes 1, 2 and 3 remained dry during and upon completion of drilling.

A standpipe was installed in borehole 3 to monitor the groundwater conditions. The most recent groundwater level reading was obtained on December 28, 2007 where the groundwater level was measured at elevation 186.8 metres or at a depth of 1.7 metres below the ground surface.

Details of the groundwater conditions encountered and subsequently measured in the installations are provided on the Record of Borehole sheets and are summarized below.

		ENCOUNTERED GROUNDWATER LEVEL		MEASURED GROUNDWATER LEVEL					
				Nov. 28, 2007		Dec. 11, 2007		Dec. 28, 2007	
BOREHOLE	ELEVATION (m)	Depth (m)	Elevation (m)	Depth (m)	Elevation (m)	Depth (m)	Elevation (m)	Depth (m)	Elevation (m)
1	188.25	Dry	Dry	-	-	-	-	-	-
2	188.51	Dry	Dry	-	-	-	-	-	-
3	188.48	Dry	Dry	8.23	180.25	2.65	185.83	1.70	186.78

The water level in the Reid Drain was measured at elevation 186.11 metres on November 19, 2007.

The groundwater level at this site is inferred to be at elevation 187 metres.

The groundwater levels are expected to fluctuate seasonally and are likely to be higher during periods of sustained precipitation or spring melt.

5.0 MISCELLANEOUS

The investigation was carried out using power equipment supplied and operated by B.U.D. Environmental Services Ltd. which is an Ontario Ministry of Environment licensed well contractor. The field operations were supervised by Mr. Mike Arthur under the direction of 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 of Types C and D aggregates. This report was prepared by Ms. Dirka U. Prout, P. Eng. under the direction of the Project Manager, Mr. Philip R. Bedell, P. Eng. This report was reviewed by Mr. Fintan J. Heffernan, P. Eng., the Designated MTO Contact and Quality Control Auditor for this assignment.

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PART B

FOUNDATION DESIGN REPORT

STRUCTURAL CULVERT, STATION 21+850 RT
11TH CONCESSION BRANCH OF REID DRAIN
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6.0 ENGINEERING RECOMMENDATIONS

6.1 General

This section of the report provides our recommendations on the foundation aspects of the design of the proposed replacement of the structural culvert situated in the project area on Highway 77 at Station 21+850 RT. The existing culvert consists of a 2.4 metre span non-rigid frame open footing (NRFO) concrete culvert with a length of 7.3 metres and a 1.4 metre high opening.

Highway 77 is to be rehabilitated between Highway 3 in Leamington and Essex County Road 8 in Staples. The scope of work includes improvements to drainage structures including the replacement of the existing culvert at the 11th Concession Branch of the Reid Drain under Township of Mersea Road 11. The new culvert will be a 2.4 x 2.0 x 8.9 metre precast concrete box culvert with an invert at about elevation 186 metres. The existing concrete retaining walls are to be removed and replaced with new cast-in-place concrete retaining walls with guide rails.

It should be noted that the interpretation and recommendations are intended for use only by the design engineer. 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.

6.2 Foundations

The subsoils encountered in the boreholes advanced during the investigation typically consist of surficial clayey silt fill, asphalt and/or granular road base over silty clay fill overlying firm to very stiff silty clay. The groundwater level was estimated to be at about elevation 187 metres. The water level in the 11th Concession Branch of the Reid Drain was measured at elevation 186.1 metres on November 19, 2007.

The culvert replacement should be designed to withstand the appropriate weight of fill and traffic loading. Footing excavations should penetrate all existing fill and topsoil so that foundations bear directly on the native soils. Based on the soil conditions found at the borehole locations and the culvert invert at approximately elevation 186.0 metres, the new culvert can be founded at or below elevation 185.5 metres on a bedding layer bearing on the stiff to very stiff silty clay. The general arrangement drawings show the proposed underside of footing elevation for the cut-off walls and new retaining walls at approximately elevation 184.8 metres. Footings for the retaining walls can also be founded in the native silty clay at this depth.

For footings bearing directly on the native silty clay and for the pre-cast box section bearing on the granular bedding layer, the recommended factored geotechnical resistance at Ultimate Limit States (ULS) and the geotechnical resistance at Serviceability Limit States (SLS) are 275 kilopascals and 200 kilopascals, respectively, assuming a maximum allowable settlement of 25 millimetres and a 2.5 metre wide footing for the box section and a 1 metre wide footing for the retaining wall foundations. An unfactored coefficient of sliding of 0.4 may be used for design.

6.2.1 Frost Protection

All retaining wall footings should be provided with a minimum of 1.2 metres of earth cover or thermal equivalent for frost protection purposes.

Frost treatment in the form of a frost taper symmetrical about the culvert centreline must be provided in accordance with Ontario Provincial Standard Drawing (OPSD) 803.010. If the frost penetration depth of 1.2 metres results in a frost penetration line below the culvert bottom slab, then the frost taper should extend to the depth of the underside of the levelling pad. Otherwise, if the frost penetration line is above the base of culvert or slab, the frost taper must extend to the depth of the frost penetration line.

6.3 Bedding

Bedding is to be placed on a properly prepared subgrade from which all frozen, soft, uncompacted fill, organic materials or other deleterious materials have been removed. Bedding should consist of at least 150 millimetres of 19 millimetre clear stone placed in accordance with SP422S01. Any over excavation required for removal of existing fill or the existing culvert should be backfilled with clear stone.

6.4 Backfill

Backfill and cover for the culvert should be carried out in accordance with OPSD 803.010 and SP422S01. Culvert backfill material should consist of free-draining, non-frost susceptible granular materials such as Ontario Provincial Standard Specifications (OPSS) Granular A or Granular B, Type I.

Heavy compaction equipment should not be used immediately adjacent to the walls and roof of the culvert. The height of backfill adjacent to the culvert walls should be maintained equal on both sides of the structure during all stages of backfill placement. Adequate erosion protection as recommended in Section 6.6 should be provided at the outlet.

6.5 Lateral Earth Pressures for Design

The lateral pressures acting on the new culvert will depend on the backfill soils and, where used, the type and method of placement of the backfill materials behind the walls, as well as the subsequent lateral movement of the structure. The following recommendations are made concerning the design of the culvert walls in accordance with the Canadian Highway Bridge Design Code (CHBDC).

Backfill behind the culvert walls should consist of select, free-draining granular fill meeting the specifications of OPSS Granular A or Granular B, Type I but with less than 5 per cent passing the No. 200 sieve.

Where backfill soils are placed and compacted behind the walls, a compaction surcharge equal to 12 kilopascals should be included in the lateral earth pressures for structural design in accordance with the CHBDC. Compaction equipment should be used in accordance with SP105S10.

For walls backfilled using granular materials as noted above, the following parameters (unfactored) may be assumed:

	Granular A	Granular B Type I
Fill unit weight:	22 kN/m^3	20 kN/m^3
Coefficients of lateral earth pressure:		
‘active’ or unrestrained, K_a	0.27	0.31
‘at rest’ or restrained, K_o	0.43	0.47

If the wall support allows lateral yielding (unrestrained structure), active earth pressures may be used in the geotechnical design of the structure. The granular fill should be placed in a zone greater than 1.2 metres wide 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. If the culvert wall support does not allow lateral yielding (restrained structure), at-rest pressures should be assumed for geotechnical design. The granular fill should be placed in a zone with a width equal to at least 1.2 metres behind the culvert walls.

The resistance to sliding for the precast concrete box culvert and retaining walls may be based on an unfactored angle of interface friction of 24 degrees between the stiff to very stiff silty clay and concrete. The factored horizontal geotechnical resistance, H_{ri}, should be based on CHBDC 6.7.5 as follows:

$H_{ri} = 0.8A'c' + 0.8V\tan\delta > H_f$

Where:

A'	-	effective contact area, square metres
c'	=	0
δ	=	24 degrees
V	-	unfactored vertical force, kilonewtons
H_f	-	factored horizontal load, kilonewtons

The unfactored coefficient of passive pressure for the portion of the culvert wall and footing below the invert may be taken as 2.6 based on an unfactored effective angle of internal friction, ϕ', of 26 degrees.

6.6 Construction Considerations

The founding soils are sensitive to disturbance and softening due to water seepage and/or ponding. For the cast-in-place retaining walls, the placement of a working slab of lean concrete will be required at the base of the excavations for the footing areas for the retaining walls. Exposure without protection of the working slab will result in softening of the founding soils. The cleaned excavation base should be inspected by qualified geotechnical personnel prior to placing the working slab. It is recommended that the footing excavation be carried out such that the final 0.5 metres of excavation is completed with the geotechnical personnel on site and the working slab placed immediately after footing inspection.

Inlet seals and filters are not considered necessary as the potential for uplift and piping is low. The provision of camber for the culvert is not required since the height of the overlying fill is minimal and the stiff to very stiff foundation soils are such that excessive post-construction or differential settlements are not anticipated. However, cut-off walls must be provided at each end of the pre-cast box culvert in accordance with the CHBDC.

Erosion and scour protection for the culvert backfill should be provided, as appropriate. Consideration could be given to using suitable non-woven geotextile and rip rap, as required, to provide erosion protection based on hydraulic requirements. Rip-rap treatment at the culvert outlet should be provided in accordance with OPSD 810.010. In addition, sediment control such as silt fences and erosion control blankets may be required during construction and diversion of the watercourse to mitigate migration of fine soil particles.

Subgrade preparation should be performed and monitored in accordance with SP902S01.

6.7 Excavations and Temporary Cut Slopes

Excavations for the replacement culvert will encounter surficial clayey silt fill, asphalt and/or granular road base, silty clay fill and the firm to very stiff silty clay. The considerations with respect to protection of the founding soils, as given in Section 6.6 under the heading Construction Considerations, must be recognized.

Temporary open cut slopes should be maintained no steeper than 1 horizontal to 1 vertical. All excavations should be carried out in accordance with the current edition of the Ontario Occupational Health and Safety Act and Regulations For Construction Projects. The fill materials at this site would be classified as Type 3 soils. The native silty clay materials would be classified as Type 2 soils.

Excavations will extend below the inferred groundwater level of elevation 187 metres. However, minimal groundwater flow is expected from the silty clay.

The existing culvert flows will need to be diverted during construction. 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 appropriate Non Standard Special Provision (NSSP) should be included in the contract documents to alert the contractor about the need for adequate control of surface and groundwater flows.

The design drawings indicate that the removal of the existing culvert and construction of the replacement culvert will be done in two stages. In Stage 1, Mersea Township Road 11 will be closed east of Highway 77 and temporary traffic barriers and a protection system installed along the east side of Highway 77. The existing culvert and retaining wall will then be removed. The replacement culvert will be installed during Stage 2 and the new retaining walls constructed.

The temporary support system could consist of soldier piles and lagging where the H-piles would be driven to a suitable depth and horizontal lagging installed as the excavation proceeds. Support to the soldier pile and lagging wall system could be in the form of struts and walers in the case of footing excavations or rakers and anchors in the case of roadway protection excavations. Alternatively, sheet piling could be used.

The design of braced soldier pile and lagging walls should be based on a rectangular earth pressure distribution using the design parameters given below. Where the support to the wall is provided by anchors or rakers, the wall design should be based on a triangular earth pressure distribution using the design parameters given below. The raker/anchor support must be designed to accommodate the loads applied from pressures and surcharge pressures from area, line or point loads as well as the impact of sloping ground behind the system.

In the cohesive soils, the unfactored triangular earth pressure distribution (p in kN/m^2; increasing with depth), can be calculated as follows:

$$p = K_a (\gamma H + q)$$

where H = the height of the excavation at any point in metres
K_a = 0.4 for level ground behind excavation
γ = soil unit weight = 20 kN/m^3
q = surcharge loads

In granular soils, such as backfill to the existing culvert, the unfactored rectangular earth pressure distribution (p in kN/m^2; constant with depth), can be calculated as follows:

$$p = 0.65K_a (\gamma' H + q)$$

where H = the height of the excavation
K_a = 0.3 for level ground behind excavation
γ = soil unit weight = 21 kN/m^3
γ' = $\gamma - \gamma_w$ where γ_w = 9.8 kN/m^3
q = surcharge loads

Passive toe restraint to the soldier piles may be determined using a triangular pressure distribution acting over an equivalent width equal to three times the pile socket diameter. The coefficient of passive lateral earth pressure, K_p, for the socket within the stiff to very stiff soils may be taken as 2.6 for the silty clay. The soil unit weight should be taken as 20 kN/m^3 and the unit weight of water should be taken as 9.8 kN/m^3. A groundwater level at ground surface should be assumed for design.

The temporary excavation support system should be designed and constructed in accordance with MTO's Special Provision 105S19. The lateral movement of the temporary shoring system should meet Performance Level 2 as specified in SP105S19.

7.0 MISCELLANEOUS

This report was prepared by Ms. Dirka U. Prout, P.Eng. under the direction of the Project Manager, Mr. Philip R. Bedell, P. Eng. This report was reviewed by Mr. Fintan J. Heffernan, P.Eng., the Designated MTO Contact and Quality Control Auditor for this assignment.

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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
in 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 = σ'_p/σ'_{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 (ϕ = 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
London, Ontario

RECORD OF BOREHOLE No 1

METRIC

PROJECT 06-1130-202-0-5

G.W.P. 139-98-00 LOCATION N 4668922.4 ;E 297176.6 ORIGINATED BY MA

DIST ______ HWY 77 BOREHOLE TYPE POWER AUGER (SOLID STEM) COMPILED BY LMK

DATUM GEODETIC DATE November 19, 2007 CHECKED BY ______

ELEV DEPTH	SOIL PROFILE DESCRIPTION	STRAT PLOT	SAMPLE NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
188.25	GROUND SURFACE							
0.09	FILL, clayey silt, trace sand						188	
0.30	FILL, silty sand and gravel							
	SILTY CLAY, some sand, trace gravel Firm to very stiff Brown becoming grey at about elev. 185.3m		1	SS	6			
			2	SS	9		187	
			3	SS	27		186	
			4	SS	17		185	
			5	SS	9			1 13 43 43
			6	SS	10		184	
			7	SS	9		183	
			8	SS	8		182	0 12 41 47
			9	SS	12		181	
			10	SS	7		180	
179.41			11	SS	9			
8.84	END OF BOREHOLE Borehole dry during drilling on November 19, 2007.							

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

Sample 8 liquid limit: 41

UNIT WEIGHT γ kN/m³

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

Golder Associates
London, Ontario

RECORD OF BOREHOLE No 2

METRIC

PROJECT	06-1130-202-0-5				
G.W.P.	139-98-00	LOCATION	N 4668897.5 ;E 297173.5	ORIGINATED BY	MA
DIST		HWY 77	BOREHOLE TYPE POWER AUGER (SOLID STEM)	COMPILED BY	LMK
DATUM	GEODETIC	DATE	November 19, 2007	CHECKED BY	

ELEV / DEPTH	DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
188.51	GROUND SURFACE					
0.00	FILL, sand and gravel, trace silt (crushed)					
188.17 / 0.34	FILL, silty clay, some sand, trace gravel Firm Grey and brown	1	SS	6		
		2	SS	7		0 28 33 39
186.56 / 1.95	SILTY CLAY, some sand, trace gravel Firm to very stiff Brown becoming grey at about elev. 185.5m	3	SS	21		
		4	SS	20		
		5	SS	10		
		6	SS	8		
		7	SS	8		1 13 42 44
		8	SS	8		
		9	SS	7		
		10	SS	8		
		11	SS	8		
179.67 / 8.84	END OF BOREHOLE Borehole dry during drilling on November 19, 2007.					

Column headings: SOIL PROFILE; STRAT PLOT; SAMPLES; GROUND WATER CONDITIONS; ELEVATION SCALE (188–180); DYNAMIC CONE PENETRATION RESISTANCE PLOT 20 40 60 80 100; SHEAR STRENGTH kPa: O 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; REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL

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

LDN_MTO_01 0611302020-5.GPJ LDN_MTO.GDT 2/1/08

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London, Ontario

RECORD OF BOREHOLE No 3

METRIC

PROJECT 06-1130-202-0-5

G.W.P. 139-98-00 | LOCATION N 4668907.4 ;E 297186.1 | ORIGINATED BY MA

DIST | HWY 77 | BOREHOLE TYPE POWER AUGER (SOLID STEM) | COMPILED BY LMK

DATUM GEODETIC | DATE November 19, 2007 | CHECKED BY

ELEV / DEPTH	DESCRIPTION	NUMBER	TYPE	"N" VALUES	GR	SA	SI	CL
188.48	GROUND SURFACE							
0.10	ASPHALT							
187.99	FILL, sand and gravel, trace silt (crushed)							
0.49	FILL, silty clay, trace sand, trace gravel Firm to stiff Grey and brown	1	SS	8				
		2	SS	4				
186.35 2.13	SILTY CLAY, some sand, trace gravel Stiff to very stiff Brown becoming grey at about elev. 185.6m	3	SS	27				
		4	SS	23				
		5	SS	15	0	12	45	43
		6	SS	12				
		7	SS	10	1	12	43	44
		8	SS	10				
		9	SS	8				
		10	SS	10				
		11	SS	8				
179.64 8.84	END OF BOREHOLE							

Ground water conditions / installation: Asphalt; Cuttings; Bentonite; Cuttings; Filter sand

Elevation scale: 188, 187, 186, 185, 184, 183, 182, 181, 180

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

REMARKS & GRAIN SIZE DISTRIBUTION (%)

Borehole dry during drilling on November 19, 2007.

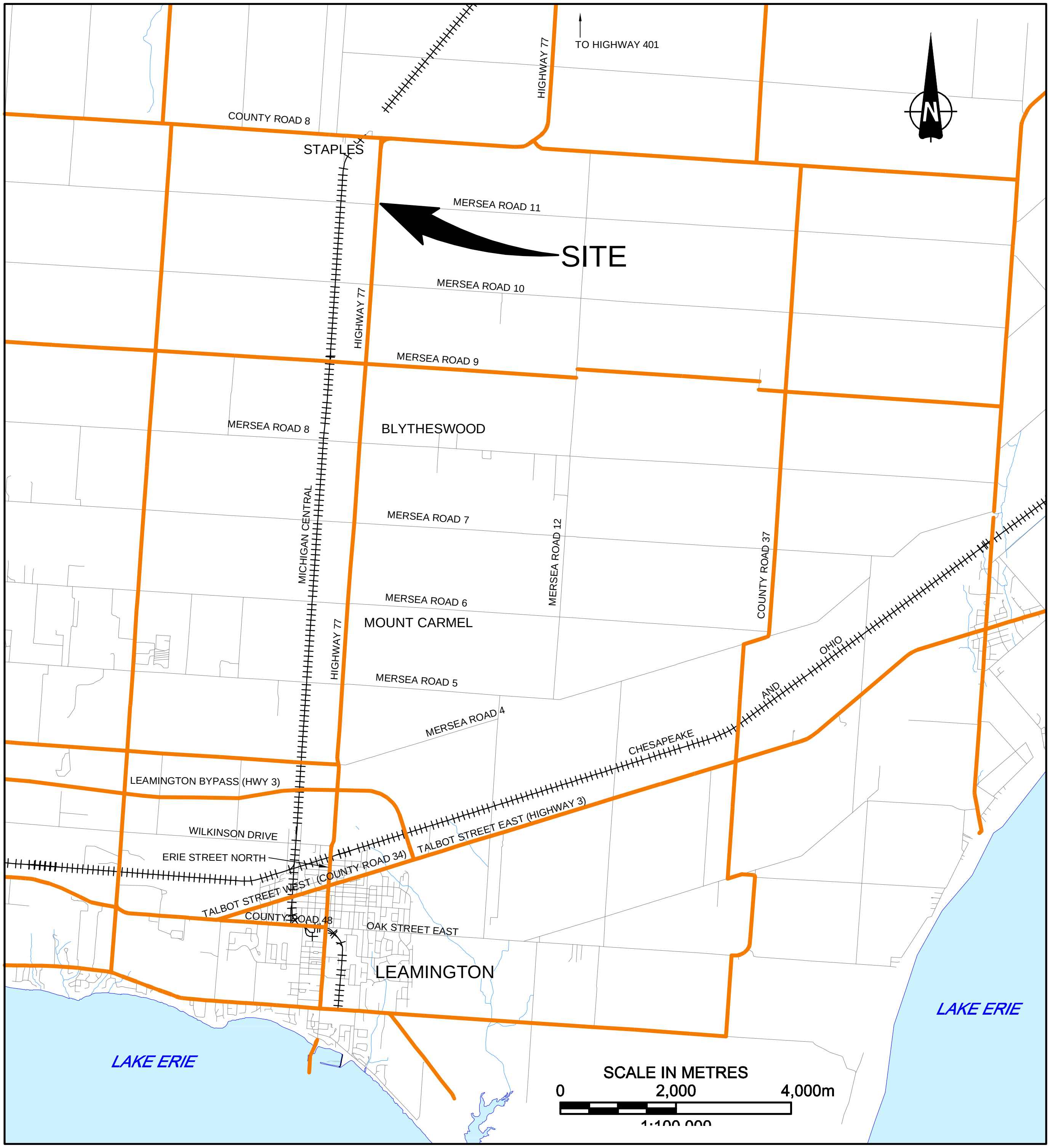
Water level measured at elev. 180.25m on November 28, 2007.

Water level measured at elev. 185.83m on December 11, 2007.

Water level measured at elev. 186.78m on December 28, 2007.

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

LDN_MTO_01 0611302020-5.GPJ LDN_MTO.GDT 2/1/08



REFERENCE

DRAWING BASED ON CANMAP STREETFILES V2005.4.

NOTES

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

ALL LOCATIONS ARE APPROXIMATE.

PROJECT

STRUCTURAL CULVERT 21+850 RT
HIGHWAY 77 REHABILITATION
GWP 139-98-00

TITLE

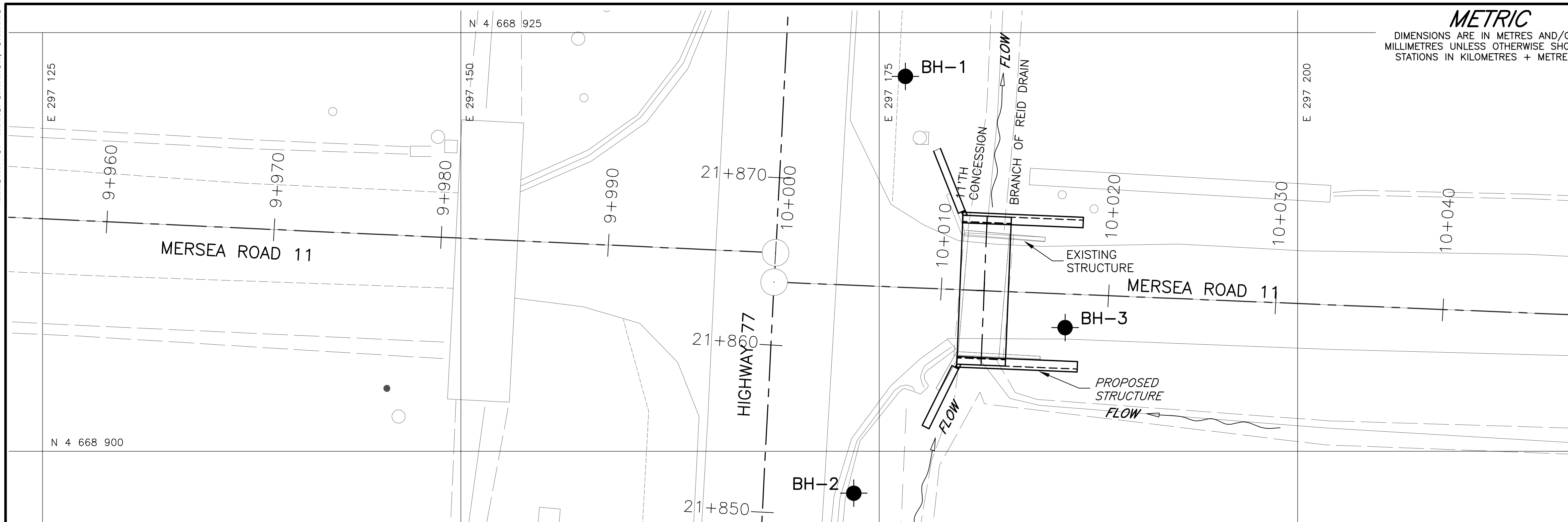
KEY PLAN

Golder Associates
LONDON, ONTARIO

PROJECT No.	06-1130-202	FILE No. 0611302020-5-F01001	
		SCALE AS SHOWN	REV.
CADD	DCH	Jan. 3/07	**FIGURE 1**
CHECK			

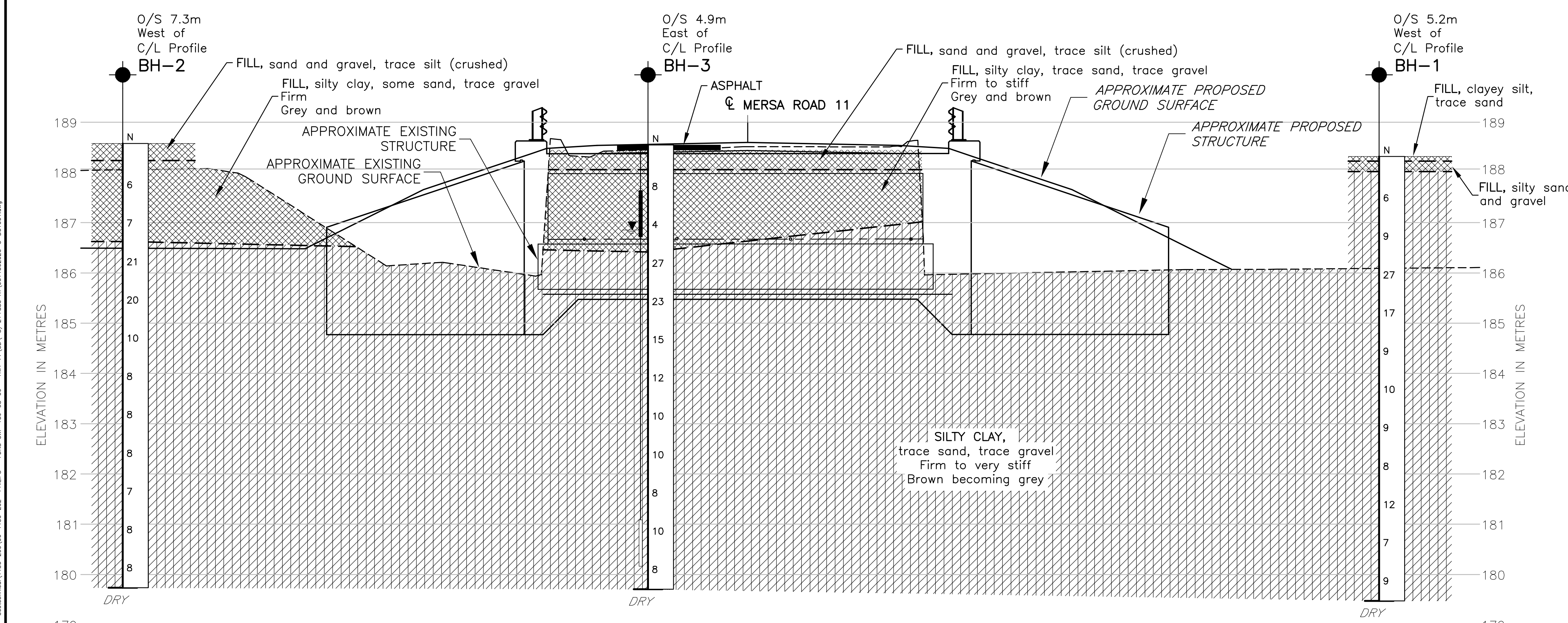
Drawing file: 0611302020-5-F01001.dwg Feb 01, 2008 - 1:26pm

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



PLAN

SCALE 5 0 5m



PROFILE ALONG C/L OF CULVERT AT STA. 21+850 RT

SCALE 1 0 1m

CONT No.
WP No. 139–98–00

SHEET

HIGHWAY 77 REHABILITATION
STRUCTURAL CULVERT 21+850 RT
CULVERT REPLACEMENT
BOREHOLE LOCATION AND SOIL STRATA

Golder Associates
Golder Associates Ltd.
LONDON, ONTARIO, CANADA

KEY PLAN

SCALE 2000 0 2000m

LEGEND

●	Borehole – Current Investigation
	Seal
	Piezometer
N	Standard Penetration Test Value
16	Blows/0.3m unless otherwise stated (Std. Pen. Test, 475 j/blow)
▼	WL in piezometer, measured on December 28, 2007
DRY	Borehole dry during drilling

No.	ELEVATION	CO–ORDINATES (MTM Zone 11) NORTHING	EASTING
1	188.25	4 668 922.4	297 176.6
2	188.51	4 668 897.5	297 173.5
3	188.48	4 668 907.4	297 186.1

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

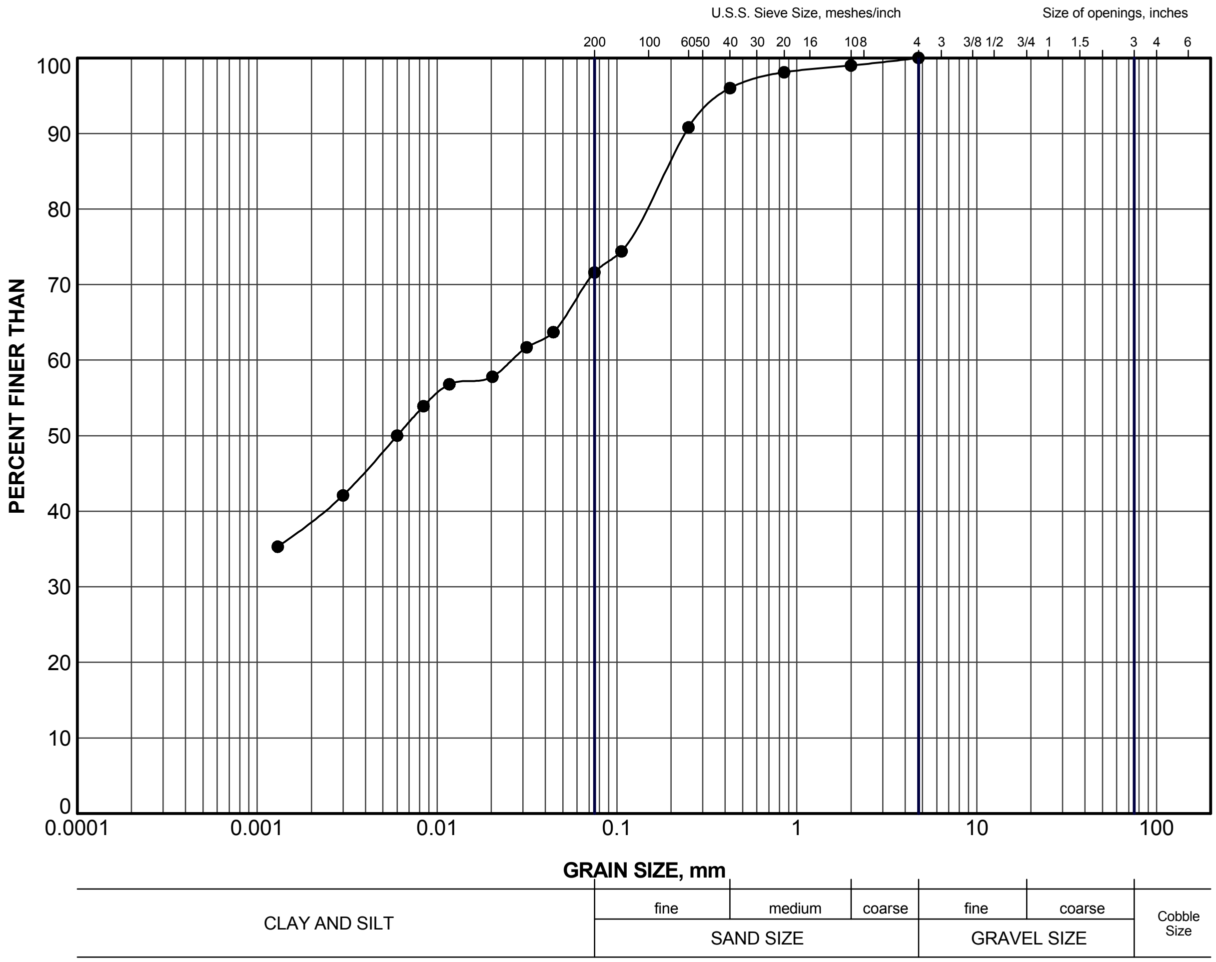
Preliminary base plans provided in digital format by Dillon.

NO.	DATE	BY	REVISION

Geocres No. 40J2–107			
HWY. 77		PROJECT NO. 06–1130–202–0–5	DIST.
SUBM'D. DUP	CHKD. DUP	DATE: Jan. 3/07	SITE:
DRAWN: DCH	CHKD. DUP	APPD.	DWG. 1

APPENDIX A

LABORATORY TEST DATA



LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEV (m)
●	2	2	186.8

PROJECT

STRUCTURAL CULVERT 21+850 RT
HIGHWAY 77 REHABILITATION
GWP 139-98-00

TITLE

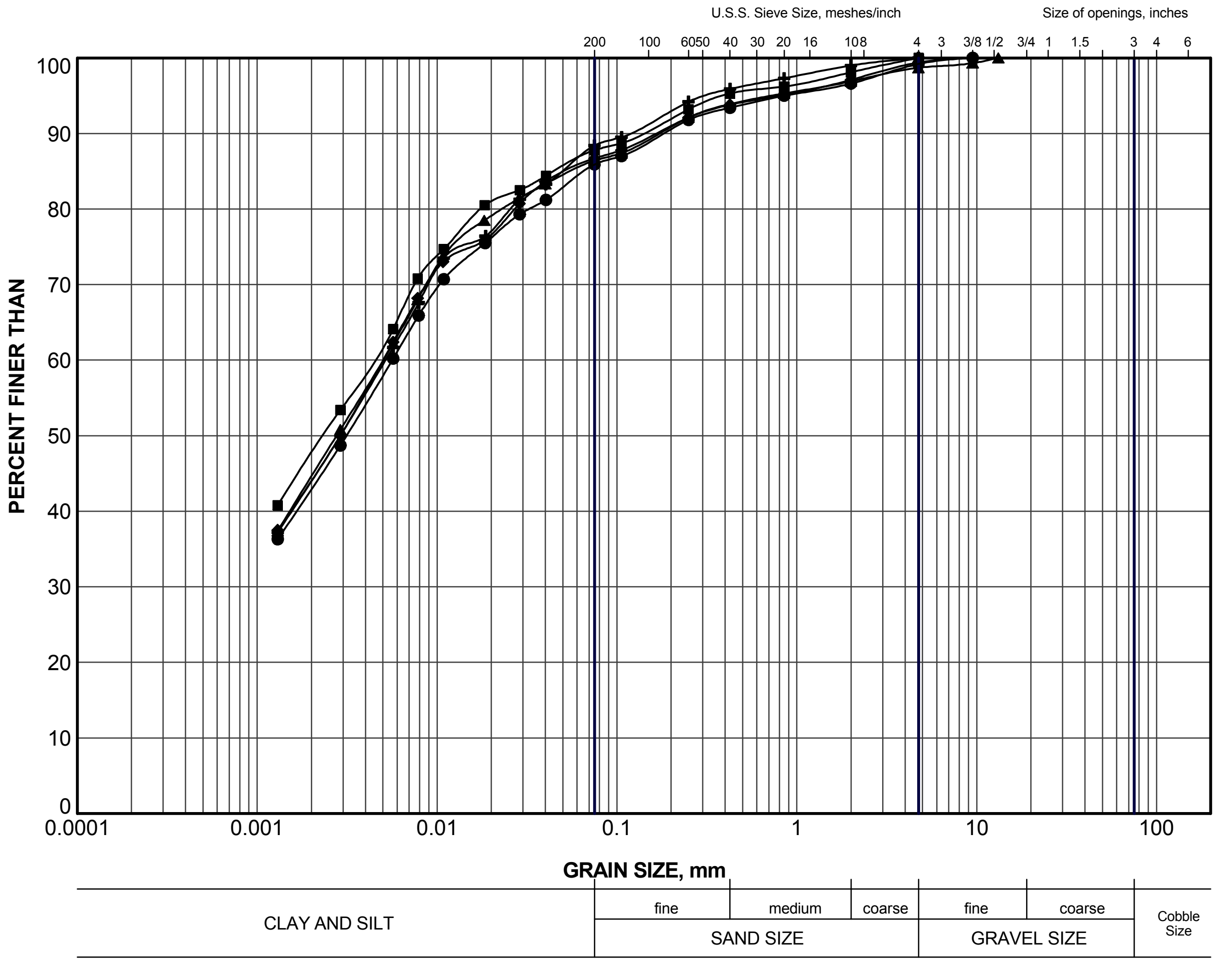
GRAIN SIZE DISTRIBUTION

FILL (silty clay)

Golder Associates
LONDON, ONTARIO

PROJECT No.		06-1130-202	FILE No. 0611302020-5-F010A1	
			SCALE N/A	REV.
DRAWN	LMK	Jan 8/08	FIGURE A-1	
CHECK				

LDN_MTO_NEW GLDR_LDN.GDT



LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEV (m)
●	1	5	184.2
■	1	8	181.9
▲	2	7	183.0
✚	3	5	184.4
◆	3	7	182.9

PROJECT

STRUCTURAL CULVERT 21+850 RT
HIGHWAY 77 REHABILITATION
GWP 139-98-00

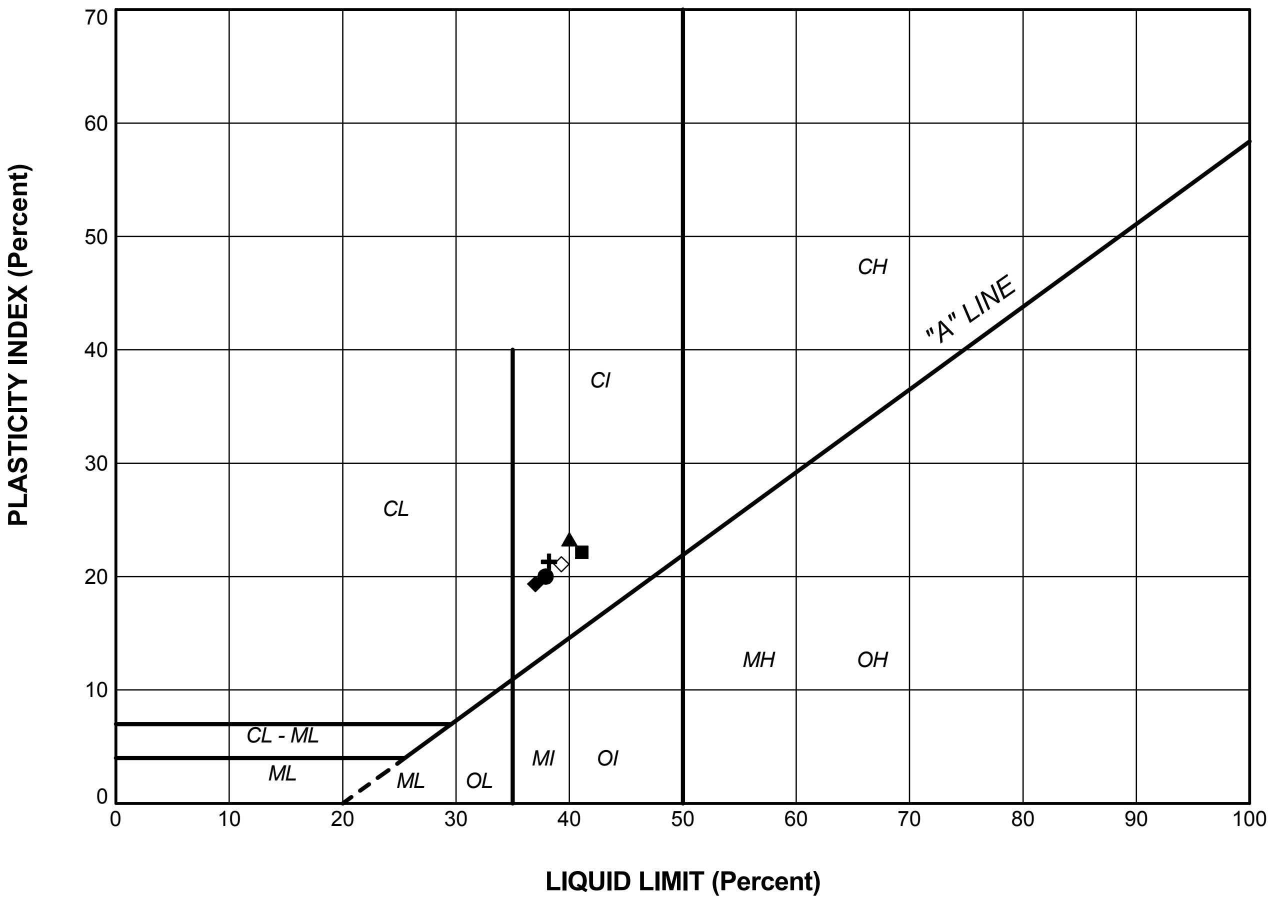
TITLE

GRAIN SIZE DISTRIBUTION
SILTY CLAY

Golder Associates
LONDON, ONTARIO

PROJECT No.	06-1130-202	FILE No.	0611302020-5-F010A2
		SCALE N/A	REV.
DRAWN LMK	Jan 8/07		
CHECK		FIGURE A-2	

LDN_MTO_NEW GLDR_LDN.GDT



SOIL TYPE
C = Clay
M = Silt
O = Organic

PLASTICITY
L = Low
I = Intermediate
H = High

LEGEND

SYMBOL	BOREHOLE	SAMPLE	LL(%)	PL(%)	PI
SILTY CLAY					
●	1	5	37.9	17.9	20.0
■	1	8	41.1	19.0	22.2
✚	2	7	38.2	16.9	21.3
◆	3	5	37.0	17.7	19.4
◇	3	7	39.3	18.2	21.1
SILTY CLAY (FILL)					
▲	2	2	40.0	16.7	23.3

PROJECT	STRUCTURAL CULVERT 21+850 RT HIGHWAY 77 REHABILITATION GWP 139-98-00				
TITLE	**PLASTICITY CHART**				
Golder Associates LONDON, ONTARIO	PROJECT No.	06-1130-202	FILE No. 0611302020-5-F010A3		
			SCALE	N/A	REV.
	DRAWN	BRS	Jan 11/08	**FIGURE A-3**	
	CHECK				

MTO_PI GLDR_LDN.GDT

APPENDIX B

SITE PHOTOGRAPH

SITE PHOTOGRAPH

Photo 1: Station 21+850 RT. North end of culvert.