Golder Associates Ltd.

309 Exeter Road, Unit #1
London, Ontario, Canada N6L 1C1
Telephone: (519) 652-0099
Fax: (519) 652-6299

FOUNDATION INVESTIGATION AND DESIGN REPORT
STRUCTURAL CULVERT
SITE 6-407-C
HIGHWAY 3 WIDENING
GWP 315-98-00
MINISTRY OF TRANSPORTATION - SOUTHWESTERN REGION

Submitted to:

Delcan Corporation
1069 Wellington Road South, Suite 214
London, Ontario
N6E 2H6

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March 12, 2007

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PART A

FOUNDATION INVESTIGATION REPORT

STRUCTURAL CULVERT
SITE 6-407-C
HIGHWAY 3 WIDENING
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MINISTRY OF TRANSPORTATION - SOUTHWESTERN REGION

March 2007 06-1130-177-0-2

1.0 INTRODUCTION

Golder Associates Ltd. (Golder Associates) has been retained by Delcan Corporation (Delcan) on behalf of the Ministry of Transportation, Ontario (MTO) to carry out foundation investigations as part of the detail design work for GWP 315-98-00. The project involves the first phase of the reconstruction and widening of Highway 3 (Talbot Trail) between Windsor and Leamington. The project limits extend along Highway 3 from just west of Essex Road 34 (Talbot Street North) easterly to just east of Essex Road 8 (Maidstone Avenue West) in Essex County, Ontario.

In conjunction with the widening, the scope of work for this project includes:

- Rehabilitation or replacement of selected culverts within the project limits;
- Slotted left turn lanes at all intersections;
- Revision or upgrading of illumination at four intersections;
- Revision or upgrading of traffic signals at two intersections;
- Replacement or relocation of existing traffic counting stations;
- Drainage improvements; and
- Upgrading of existing signage.

It has been proposed to widen five structural culverts and four short span culverts and to replace two short span culverts.

This report addresses the foundation investigation for the extension of the south end of the structural culvert located on Highway 3 at Station 19+320, South Sandwich (Site 6-407-C). It has been proposed to extend this culvert by up to 21 metres.

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 P61-3113-1 dated August 17, 2006 and our letter dated November 14, 2006. The work was carried out in accordance with our Quality Control Plan for Foundations Engineering dated September 18, 2006.

Delcan provided Golder Associates with a base plan and profile for this project in digital format which included the top elevations of the culverts.

2.0 SITE DESCRIPTION

GWP 315-98-00 extends along Highway 3 from 0.5 kilometres west of Essex Road 34 (Talbot Street North) within the Town of Tecumseh easterly to 0.6 kilometres east of Essex Road 8 (Maidstone Avenue West) in the Town of Essex. West of Manning Road, Highway 3 is within South Sandwich Township. East of Manning Road, it is within Maidstone Township. The chainage equation at Manning Road is 20+981.675 South Sandwich (SS) = 10+000.000 Maidstone (M). The west project limit is located at Station 17+700 SS and the east project limit is situated at Station 13+600 M.

Culvert Site 6-407-C is located at Station 19+320 SS on Highway 3 approximately 40 metres east of Malden Road. This culvert conveys flows of the Malden Road East Drain from the right/south side of Highway 3 to the left/north side. The location of the project is shown on the Key Plan, Figure 1, and in the photograph in Appendix B.

The land use in the vicinity of the site is predominantly agricultural. The adjacent topography is generally flat to slightly rolling with ground surface elevations between 191 and 195 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 Plain.[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.

The available surficial geology mapping for the project area indicates that the predominant surficial soils are clayey silt till.[2] The till is reportedly underlain by limestone, dolomite and shale of the Middle Devonian era and by dolomite of the Upper Silurian era. The overburden thickness within the project area ranges from 27 to 41 metres.[3]

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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.

[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 work for this portion of the investigation was carried out on November 30 and December 1, 2006, at which time two boreholes were drilled in the area of the proposed culvert extension. Borehole 11 was advanced to a depth of 7.5 metres and borehole 12 to a depth of 8.2 metres.

The investigation was carried out using a Deidrich 50 track-mounted power auger supplied and operated by a specialist drilling contractor. Samples of the overburden were obtained at intervals of 0.75 metres up to a depth of 4.6 metres and at 1.5 metre intervals below this depth 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 piezometer was installed in borehole 11 to monitor the groundwater levels at this location. The boreholes were backfilled in accordance with current regulations, MTO recommended procedures and Ontario Regulation 128/03.

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 labeled 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 dimensions and the coordinates, ground surface elevations and depths of the boreholes.

BOREHOLE	LOCATION (m)		GROUND SURFACE ELEVATION	BOREHOLE DEPTH
	Northing	Easting	(m)	(m)
11	4 674 083.5	272 385.2	190.20	7.47
12	4 674 105.4	272 395.8	190.85	8.23

The existing culvert has the following characteristics:

DIMENSIONS (m)	TOP ELEVATION (m)		CONSTRUCTION
	(Lt)	(Rt)	
3.68 x 1.78 x 28.65	190.68	190.74	Concrete, non-rigid frame open footing

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 drilled in the area of the proposed culvert extension typically encountered topsoil and fill materials underlain by an extensive deposit of clayey silt till.

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 Topsoil and Fill

Topsoil was present at the ground surface at both borehole locations. The topsoil layer was 400 millimetres thick at borehole 11 and 80 millimetres thick at borehole 12.

The topsoil layer at borehole 12 was underlain by 1.3 metres of fill materials from elevation 190.8 metres. The fill materials consisted of a 0.6 metre thick layer of fine to medium sand over a 0.7 metre thick layer of clayey silt. The clayey silt fill was stiff with an N value of 11 blows per 0.3 metres.

4.1.2 Clayey Silt Till

Clayey silt till was encountered beneath the topsoil layer in borehole 11 from elevation 189.8 metres and beneath the fill layers in borehole 12 from elevation 189.5 metres. The results of grain size analyses conducted on three samples obtained from the standard penetration testing are shown in Figure A-1 in Appendix A.

The clayey silt till is stiff to hard with N values ranging from 10 blows to 57 blows per 0.3 metres. Water contents in the till ranged from 16 to 18 per cent. The clayey silt till is of low plasticity based on average plastic and liquid limits of 15 and 32 per cent, respectively, and an average plasticity index of 17 per cent. The results of the Atterberg limits testing are shown on the Plasticity Chart, Figure A-2.

Cobbles and boulders were not encountered in either of the boreholes for this investigation. However, the presence of cobbles and boulders should be anticipated in the clayey silt till.

4.2 Groundwater Conditions

Groundwater conditions were observed during and on completion of drilling and sampling. Both boreholes were dry during and upon completion of drilling.

A standpipe piezometer was installed in borehole 11 to monitor the groundwater conditions. On December 14, 2006, the groundwater level was measured at elevation 187.4 metres or at a depth of 2.8 metres below the ground surface. The most recent measurement was taken on February 26, 2007. On that date, the groundwater level was 1.52 metres below the existing ground surface or at elevation 188.7 metres.

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

The water level in the Malden Road East Drain was measured at elevation 189.96 metres on December 1, 2006.

5.0 MISCELLANEOUS

The investigation was carried out using equipment supplied and operated by London Soil Test Limited 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.

GOLDER ASSOCIATES LTD.

Dirka U. Prout, P. Eng.
Geotechnical Engineer

Philip R. Bedell, P. Eng.
Principal

Fintan J. Heffernan, P. Eng.
Designated MTO Contact

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PART B

FOUNDATION DESIGN REPORT

STRUCTURAL CULVERT
SITE 6-407-C
HIGHWAY 3 WIDENING
GWP 315-98-00
MINISTRY OF TRANSPORTATION - SOUTHWESTERN REGION

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 extension of the structural culvert (Site 6-407-C) situated in the project area on Highway 3 at Station 19+320 Sandwich South (SS). This culvert is a non-rigid frame, open footing (NRFO) structure.

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

A series of improvements is planned for Highway 3 from 0.5 kilometres west of Essex County Road 34 (Talbot Road) to 0.6 kilometres east of Essex County Road 8 (Maidstone Avenue West). The major improvement will be the widening of Highway 3 from 2 lanes to 4 lanes. This will require drainage improvements within the project limits including the extension of the right/inlet side of the culvert at Station 19+320 (SS).

The subsoils encountered in the boreholes advanced during the investigation typically consist of topsoil and surficial fills over stiff to hard clayey silt till. The groundwater level was measured at elevation 188.7 metres on February 26, 2007. The long-term groundwater table is inferred to be between 187 and 189 metres. The water level in the Malden Road East Drain was measured at elevation 190.0 metres on December 1, 2006.

The culvert extension 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. The approximate invert elevation at the inlet is 189.0 metres. Based on the soil conditions found at the boreholes locations, the culvert extension can be founded on spread footings at or below elevation 187.8 metres in the very stiff to hard clayey silt till. Minimal groundwater inflow into the excavation is anticipated.

The recommended factored geotechnical resistance at Ultimate Limit States (ULS) and the unfactored geotechnical resistance at Serviceability Limit States (SLS) are 500 kilopascals and 350 kilopascals, respectively, assuming a maximum allowable settlement of 25 millimetres and a 1.5 metre footing width for design of the culvert foundations. An unfactored coefficient of sliding of 0.53 may be used for design of cast-in-place concrete footings.

6.2.1 Frost Protection

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

6.3 Backfill

Backfill around the culvert extension should be carried out in accordance with Ontario Provincial Standard Drawing (OPSD) 3101.150. 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 III.

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 6.5, should be provided at the inlet.

6.4 Lateral Earth Pressures for Design

The lateral pressures acting on the proposed culvert extension will depend on the backfill soils and, where used, the type and method of placement of the backfill materials behind the wall, 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 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 OPSS 501.06.

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

Fill unit weight:	22 kN/m^3
Coefficients of lateral earth pressure:	
‘active’ or unrestrained, K_a	0.31
‘at rest’ or restrained, K_o	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 foundation 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 resistance to sliding, for a cast-in-place concrete culvert with a concrete working slab, may be based on an unfactored angle of friction of 28 degrees between the very stiff to hard clayey silt till and concrete interface. The factored horizontal geotechnical resistance, H_{ri}, should be based on CHBDC 6.7.5 as follows:

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

Where:

A'	-	effective contact area, square metres
c'	=	0
ϕ'	=	28 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 3.0.

6.5 Construction Considerations

The founding soils are sensitive to disturbance and softening due to water seepage and/or ponding. If cast-in-place culverts are to be constructed, placement of a working slab of lean concrete will be required at the base of the culvert excavations for the footing area. 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 that the working slab be placed immediately after footing inspection.

Inlet seals and outlet cutoffs and filters are not considered necessary as the likelihood of uplift or piping is low. The provision of camber in the culvert extension is not required due to the low cover (less than 1.5 metres), light loading and the presence of very stiff to hard clayey silt till at the foundation level.

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. In addition, sediment control such as silt fences and erosion control blankets may be required during construction and the diversion of the watercourse to mitigate migration of fine soil particles.

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

6.6 Excavations and Temporary Cut Slopes

Excavations for the culvert extensions will encounter surficial topsoil and fills and the very stiff to hard clayey silt till. The presence of cobbles and boulders which may be present in the clayey silt till should be anticipated. Excavations for the footings will likely encounter the groundwater table. However, the overall amount of groundwater inflow is expected to be minimal.

Surficial water seepage into the excavations should be expected and will be heavier during periods of sustained precipitation. In addition to diverting the existing drain flows, pumping from well filtered sumps located outside the foundation footprint at the base of the excavations may be required to provide groundwater control during foundation excavations. The consideration with respect to protection of the founding soils, however, as given in Section 6.5 under the heading Construction Considerations, must be recognized. Sumps should be maintained outside of the actual footing limits. 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.

Where space is restricted and will not permit open cuts, a temporary support system should be installed to support the sides of the excavation and permit the use of vertical cuts. 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.

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/m²; 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/m³
q = surcharge loads

In granular soils, such as backfill to the existing culvert, the unfactored rectangular earth pressure distribution (p' in kN/m²; constant with depth), can be calculated as follows:

$$p' = 0.65K_a [\gamma - \gamma_w) H + q]$$

where H = the height of the excavation
K = 0.3 for level ground behind excavation
γ = soil unit weight = 20 kN/m³
γ_w = unit weight of water = 9.8 kN/m³
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 very stiff to hard clayey soils may be taken as 2.8. The soil unit weight should be taken as 20 kN/m³ and the unit weight of water should be taken as 9.8 kN/m³. 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 SP 105S19.

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 as would any cohesionless materials below the groundwater level. The native clayey silt till materials would be classified as Type 2 soils. Temporary open cut slopes should be maintained no steeper than 1 horizontal to 1 vertical.

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.

GOLDER ASSOCIATES LTD.

Dirka U. Prout, P. Eng.
Geotechnical Engineer

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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
σ_1, σ_2, σ_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 (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 11

METRIC

PROJECT 06-1130-177

G.W.P. 315-98-00 LOCATION N 4674083.5 ;E 272385.2 ORIGINATED BY MA

DIST ____ HWY 3 BOREHOLE TYPE Power Auger, Solid Stem COMPILED BY LMK

DATUM GEODETIC DATE November 30, 2006 CHECKED BY ____

ELEV / DEPTH	DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	ELEVATION SCALE	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
190.20	GROUND SURFACE					
0.00	TOPSOIL, clayey Brown				190	
189.80 / 0.40	CLAYEY SILT, trace sand, trace gravel (TILL) Stiff to Hard Brown becoming Grey at about elev. 186.6m	1	SS	10		
					189	
		2	SS	15		
					188	
		3	SS	39		0 21 45 34
		4	SS	32	187	
		5	SS	25	186	
		6	SS	17		0 22 41 37
					185	
		7	SS	18	184	
182.73		8	SS	18	183	
7.47	END OF BOREHOLE					

Borehole dry during drilling November 30, 2006.

Water level measured in standpipe at elev. 187.40m Dec. 14, 2006.

Water level measured in standpipe at elev. 188.68m Feb. 26, 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

UNIT WEIGHT γ kN/m³

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

Golder Associates
London, Ontario

RECORD OF BOREHOLE No 12

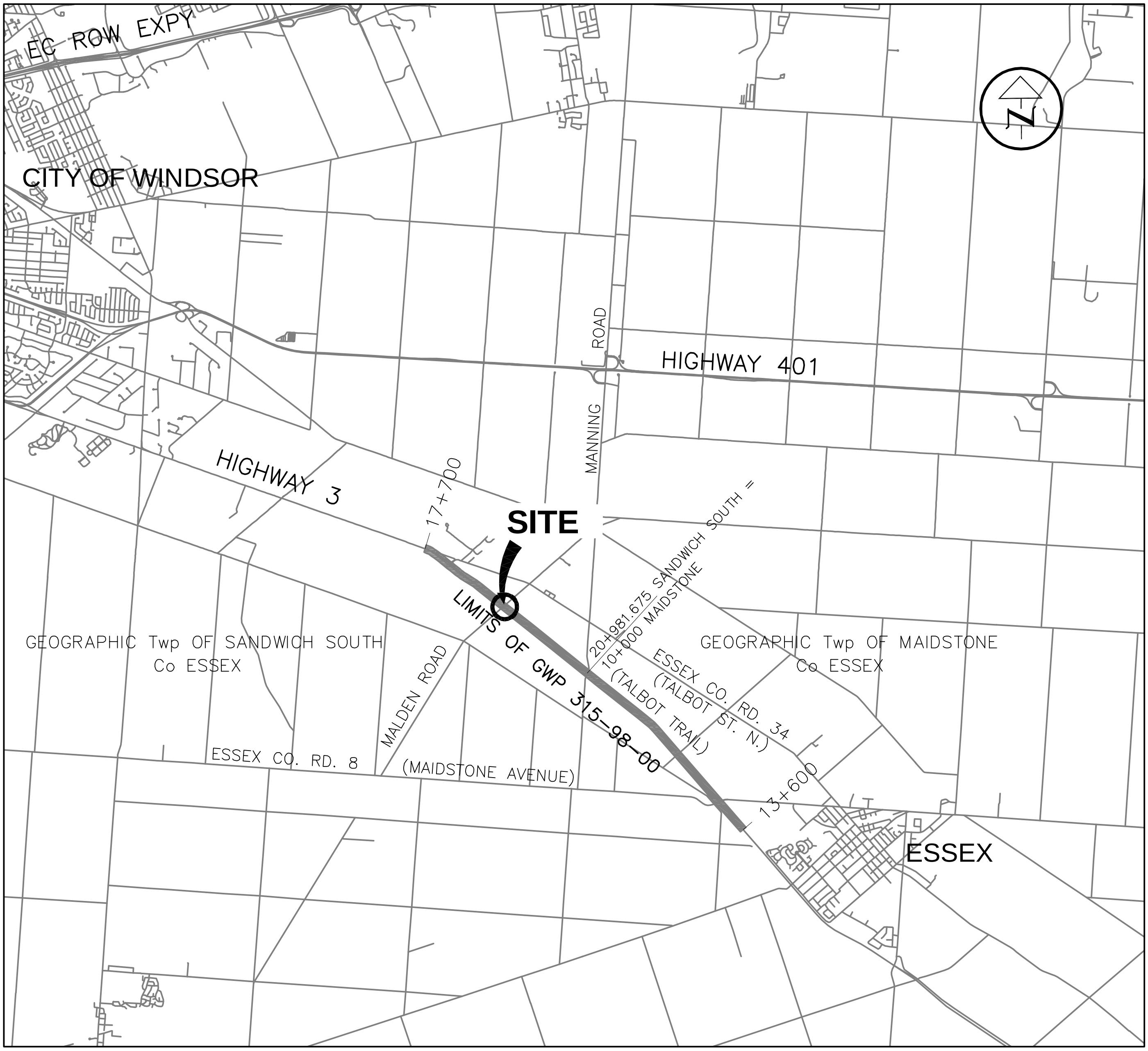
METRIC

PROJECT 06-1130-177
G.W.P. 315-98-00 LOCATION N 4674105.4 ;E 272395.8 ORIGINATED BY MA
DIST HWY 3 BOREHOLE TYPE Power Auger, Solid Stem COMPILED BY LMK
DATUM GEODETIC DATE December 1, 2006 CHECKED BY

ELEV / DEPTH	DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	ELEVATION SCALE	WATER CONTENT (%)	GR	SA	SI	CL
190.85	GROUND SURFACE									
0.08	TOPSOIL, clayey									
190.18 / 0.67	Brown FILL, fine to medium sand, trace gravel				190					
189.48 / 1.37	Brown FILL, clayey silt, trace sand, trace gravel, trace topsoil. Stiff	1	SS	11						
	Brown and Black CLAYEY SILT, trace sand, trace gravel (TILL). Stiff to Hard. Brown becoming Grey at about elev. 187.8m	2	SS	18	189					
		3	SS	53	188					
		4	SS	57	187					
		5	SS	32		w_P ≈ 14, w ≈ 16, w_L ≈ 31	0	22	42	36
		6	SS	30	186					
		7	SS	25	185, 184					
182.62 / 8.23		8	SS	15	183					
	END OF BOREHOLE. Borehole dry during drilling December 1, 2006.									

Column headings: SOIL PROFILE (ELEV DEPTH, DESCRIPTION, STRAT PLOT); SAMPLES (NUMBER, TYPE, "N" VALUES); GROUND WATER CONDITIONS; ELEVATION SCALE; DYNAMIC CONE PENETRATION RESISTANCE PLOT (20, 40, 60, 80, 100); SHEAR STRENGTH kPa (○ UNCONFINED, + FIELD VANE, ● QUICK TRIAXIAL, × 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 ○ 3% STRAIN AT FAILURE



NOTE

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

PROJECT	STRUCTURAL CULVERT - SITE 6-407-C HIGHWAY 3 WIDENING GWP 315-98-00
TITLE	**KEY PLAN**

Golder Associates
LONDON, ONTARIO

PROJECT No.	06-1130-177-0-2	FILE No.	061130177-BB001
		SCALE	AS SHOWN REV. 0
CADD	WDF	Dec. 13/06	
CHECK			**FIGURE 1**

DRAWING FILE: 061130177-BB001.DWG Plot Date: Mar 13, 2007 - 1:03pm

MINISTRY OF TRANSPORTATION, ONTARIO

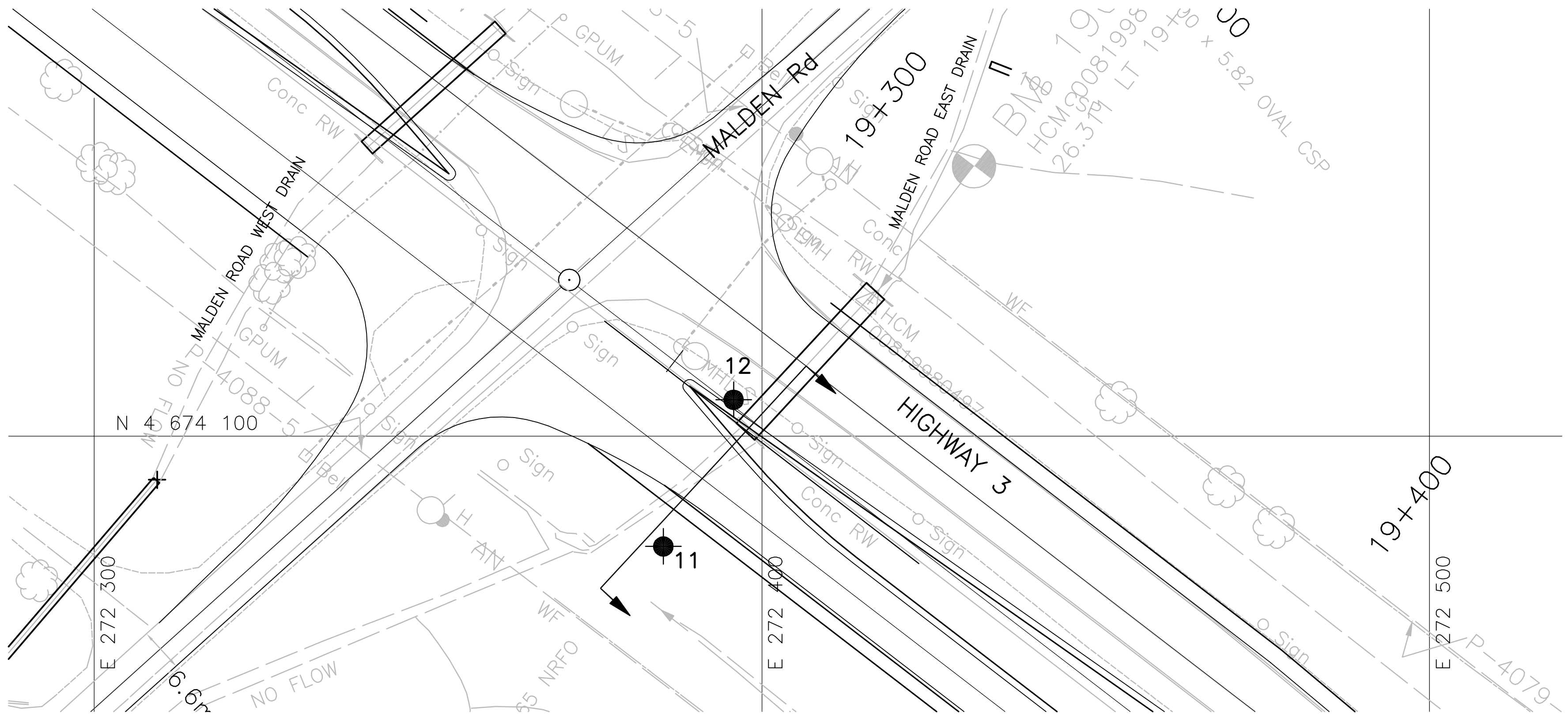
METRIC
DIMENSIONS ARE IN METRES AND/OR MILLIMETRES UNLESS OTHERWISE SHOWN. STATIONS IN KILOMETRES + METRES.

CONT No.
WP No. 315–98–00

SHEET

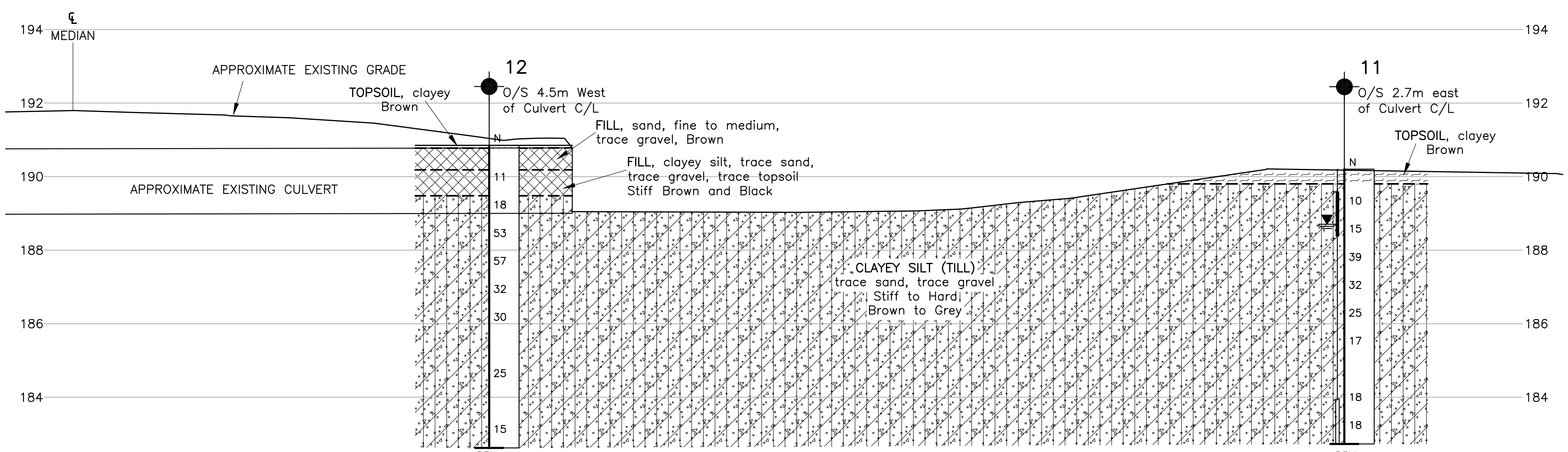
STRUCTURAL CULVERT
SITE 6–407–C
HIGHWAY 3 WIDENING
BORHOLE LOCATION AND SOIL STRATA

Golder Associates Ltd.
LONDON, ONTARIO, CANADA



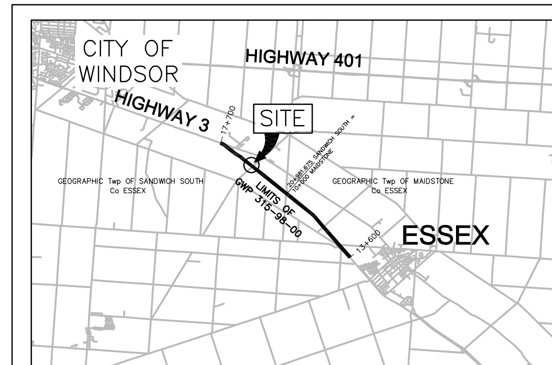
PLAN

SCALE 10 0 10 m



PROFILE ALONG C/L OF CULVERT

SCALE 1.5 0 1.5 m



KEY PLAN

SCALE 3000 0 3000m

LEGEND

- Borehole – Current Investigation
- N — Standard Penetration Test Value
- 16 — Blows/0.3m unless otherwise stated (Std. Pen. Test, 475 j/blow)
- Seal
- Standpipe
- WL in standpipe, measured on Feb. 26, 2007.
- DRY — Borehole dry during drilling

No.	ELEVATION	CO–ORDINATES (MTM Zone 11) NORTHING	EASTING
11	190.20	4 674 083.5	272 385.2
12	190.85	4 674 105.4	272 395.8

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 in digital format by DELCAN.

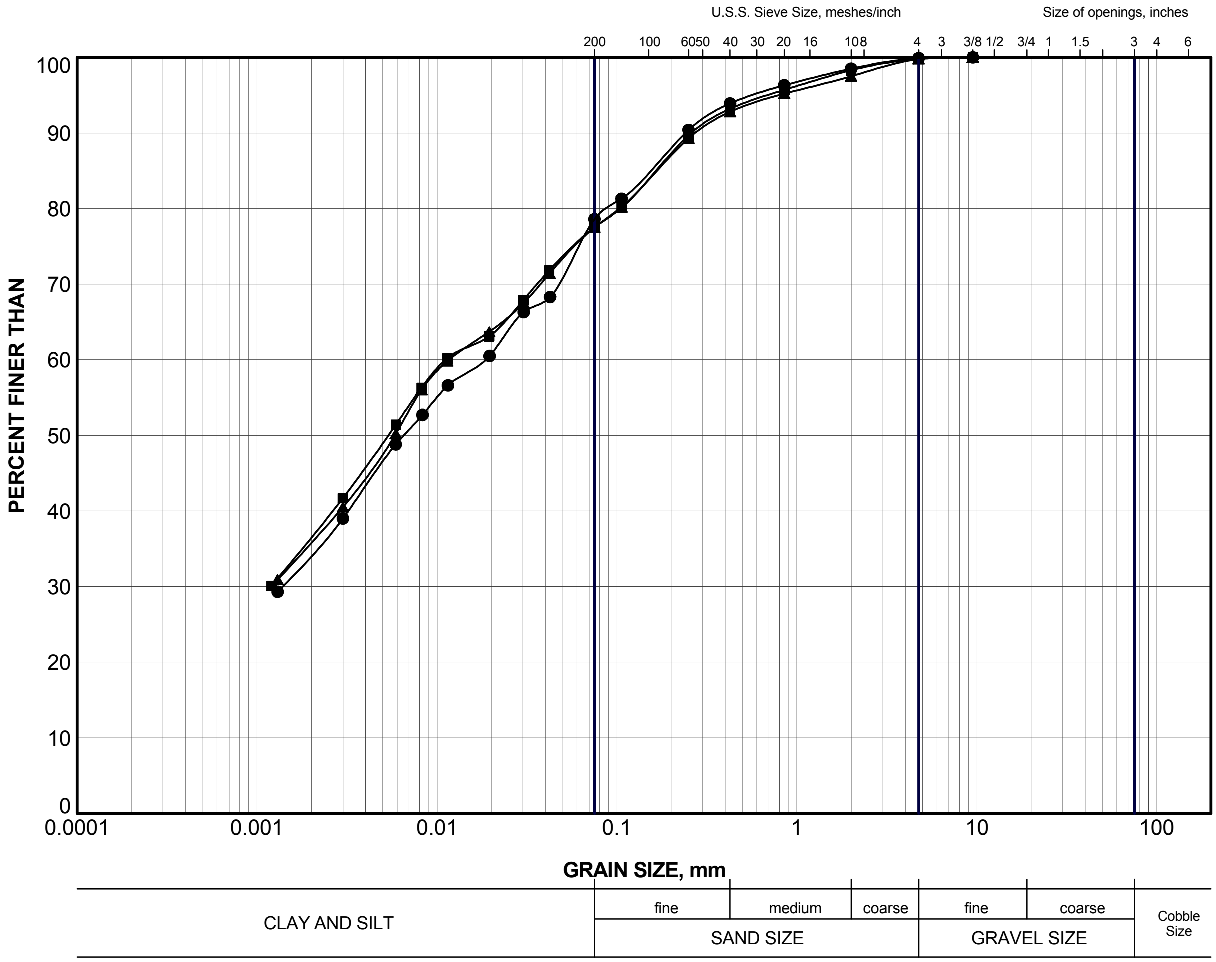
NO.	DATE	BY	REVISION

Geocres No. 40J2–89

HWY. 3		PROJECT NO. 06–1130–177–0–2	DIST.
SUBM'D. DUP	CHKD.	DATE: Dec. 19/06	SITE: 6–407–C
DRAWN: WDF	CHKD.	APPD.	DWG. 1

APPENDIX A

LABORATORY TEST DATA



LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEV (m)
●	11	3	187.7
■	11	6	185.4
▲	12	5	186.8

PROJECT

STRUCTURAL CULVERT - SITE 6-407-C
HIGHWAY 3 WIDENING
GWP 315-98-00

TITLE

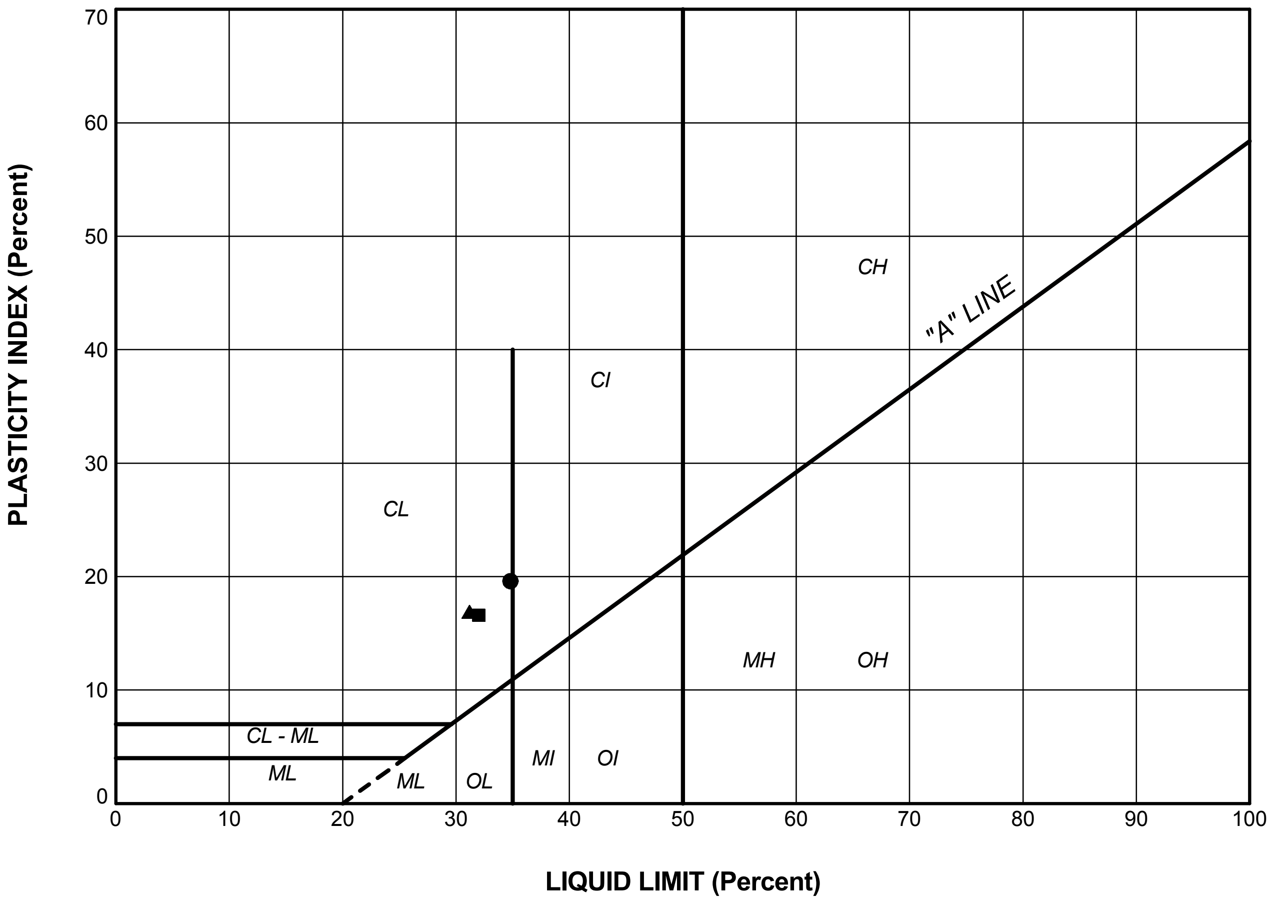
GRAIN SIZE DISTRIBUTION

CLAYEY SILT (TILL)

Golder Associates
LONDON, ONTARIO

PROJECT No.		06-1130-177	FILE No.	06-1130-177-BB.GPJ
			SCALE N/A	REV.
DRAWN	WDF	Dec 17/06	**FIGURE A-1**	
CHECK				

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
●	11	3	34.8	15.2	19.6
■	11	6	32.0	15.4	16.6
▲	12	5	31.2	14.3	16.9

PROJECT
STRUCTURAL CULVERT - SITE 6-407-C
HIGHWAY 3 WIDENING
GWP 315-98-00

TITLE
PLASTICITY CHART

Golder Associates
LONDON, ONTARIO

PROJECT No.		06-1130-177	FILE No. 06-1130-177-BB.GPJ	
			SCALE N/A	REV.
DRAWN	WDF	Dec 17/06	**FIGURE A-2**	
CHECK				

MTO_PI GLDR_LDN.GDT

APPENDIX B

PHOTOGRAPH

SITE PHOTOGRAPH

Photo 1: Culvert Site 6-407-C (Station 19+320 SS Highway 3). View of inlet looking north.