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 14-403-C
HIGHWAY 40 RECONSTRUCTION
GWP 760-91-00, AGREEMENT NO. 3005-E-0043
MINISTRY OF TRANSPORTATION - SOUTHWESTERN REGION

Submitted to:

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

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TABLE OF CONTENTS

PART A

FOUNDATION INVESTIGATION REPORT

STRUCTURAL CULVERT
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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 760-91-00. The project includes the reconstruction of 5.8 kilometres of Highway 40 from 0.1 kilometres south of Courtright Line (Lambton Road 80) northerly to 0.1 kilometres north of Rokeby Line in Lambton County, Ontario.

The scope of work for this project involves replacement of the existing composite pavement with a new flexible pavement and includes updating or replacement of features which do not meet current design standards and/or have reached the end of their life span. The roadway profile and alignment remain essentially unchanged. Elements which are scheduled to be replaced or updated include:

- Drainage elements, including culvert rehabilitation/replacement and ditch clean out;
- Guide rail;
- Signals and illumination; and
- Intersection geometrics, including turning lanes, where warranted.

This report addresses the foundation investigation for the extension of both ends of the structural culvert located at Station 18+460, Highway 40 (Site 14-403-C) at the intersection with Moore Line.

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 and in Golder Associates' proposal P61-3076 dated May 16, 2006. The work was carried out in accordance with our Quality Control Plan for Foundations Engineering dated July 11, 2006.

The centreline and stations of the alignment were surveyed by others prior to commencing the foundation investigation program. Delcan provided Golder Associates with preliminary drawings for this project in digital format.

2.0 SITE DESCRIPTION

GWP 760-91-00 extends along Highway 40 from 0.1 kilometres south of Courtright Line (Lambton Road 80), northerly to 0.1 kilometres north of Rokeby Line in the Township of Moore, Lambton County, Ontario. The culvert is located on Highway 40 on the north side of the intersection with Moore Line (Moore Township Road No. 5). The flow through the culvert is from east to west. The location of the project is shown on the Key Plan, Figure 1.

Land use in the vicinity of the site is typically agricultural with a few commercial properties to the west of Highway 40.

The adjacent topography is generally flat to slightly rolling with a ground surface elevation between 190 and 197 metres increasing to the north.

2.1 Site Geology

The project is located in the Lambton 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 till plain that has been locally smoothed by shallow deposits which settled in depressions in the till. The prevailing soil type is reported to be the Brookston clay or Caistor clay. The available surficial geology mapping for the project area indicates that the predominant surficial soils are clayey silt till.[2]

The bedrock surface lies between elevation 140 and 143 metres beneath 40 to 43 metres of overburden.[3] The subcropping bedrock is reported to be shale of the Dundee foundation.[4]

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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] Ontario Geological Survey (OGS), 1979. *Quaternary Geology, Sarnia-Brights Grove Area*. OGS, Preliminary Map P.2222.

[3] J.F. Caley and B.V. Sanford, 1991. *Preliminary Maps, Lambton County showing Drift-Thickness and Bedrock Contours*. Geological Survey of Canada, Paper 52-2.

[4] OGS, 1991. *Bedrock Geology of Ontario, Southern Sheet*. OGS, Map 2544.

3.0 INVESTIGATION PROCEDURES

The field work for this portion of the investigation was carried out on August 29, 2006, at which time four boreholes were drilled in the areas of the proposed extensions of the culvert.

The investigation for these four boreholes was carried out using a truck-mounted power auger supplied and operated by a specialist drilling contractor. Samples of the overburden were obtained at intervals of 0.75 metres 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. All of 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 location and coordinates, ground surface elevations and depths of the associated boreholes.

BOREHOLE	LOCATION (m)		GROUND SURFACE ELEVATION	BOREHOLE DEPTH
	Northing	Easting	(m)	(m)
101	4 744 361.4	311 680.8	192.92	9.60
102	4 744 363.2	311 675.4	193.03	9.60
103	4 744 361.5	311 653.5	193.10	9.60
104	4 744 359.8	311 645.8	192.88	9.60

The existing culvert has the following characteristics:

DIMENSIONS (m)	TOP ELEVATION (m)		CONSTRUCTION
	(Lt)	(Rt)	
3.05 x 1.83 x 27.93	191.84	191.83	Concrete, 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 at the proposed culvert extensions typically encountered topsoil and fill materials underlain by a deposit of silty clay till. The silty clay till deposit contained layers of silty clay with silt partings and 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 layers with an average thickness of 85 millimetres were encountered at ground surface in boreholes 101 and 104.

Layers of sand and gravel were encountered at ground surface in boreholes 102 and 103 with thicknesses of 0.2 metres and 1.4 metres, respectively. Below the sand and gravel fill in borehole 102, a 0.7 metre thick layer of silty sand fill was encountered at elevation 192.8 metres. The silty sand fill had a measured water content of about 14 percent. A 0.3 to 0.4 metre thick layer of silty clay fill was encountered below the silty sand fill at elevation 192.1 metres in borehole 102 and below the topsoil at elevation 192.9 metres in borehole 101. The silty clay fill had an N value of 6 blows per 0.3 metres and a measured water content of about 20 per cent.

4.1.2 Clayey Silt Till

Beneath the topsoil in borehole 104, a 1.3 metre thick layer of stiff clayey silt till was encountered at elevation 192.8 metres. The clayey silt till had an N value of 13 blows per 0.3 metres and a water content of about 18 percent.

4.1.3 Silty Clay Till

Beneath the fill materials in boreholes 101, 102 and 103, and beneath the clayey silt till in borehole 104, a stratum of firm to hard silty clay till was encountered at elevations ranging from 191.5 metres to 192.5 metres. Layers of silty clay with silt partings were found within the silty clay till in boreholes 101 and 102. The lower silty clay till in boreholes 101 and 102 were intercepted at about elevation 187.8 metres. The results of grain size testing on silty clay till samples recovered from the standard penetration testing are presented on Figure A-1 of Appendix A.

Above approximately elevation 188 metres, there is a crust of very stiff to hard silty clay till with N values in the range of 14 to 31 blows per 0.3 metres and an average of 23 blows per 0.3 metres. Beneath elevation 188 metres, the silty clay till is firm to very stiff with N values varying from 5 to 13 blows per 0.3 metres and averaging 10 blows per 0.3 metres. The estimated shear strength of the lower silty clay till is 115 to over 144 kilopascals based on in situ shear vane testing. The sensitivity ranges from 1.5 to 1.8 and averages 1.7.

The water contents of the silty clay till varied between 10 and 30 per cent and averaged 22 per cent. Natural water contents were generally less than 20 per cent in the desiccated silty clay till crust and were between 25 and 30 per cent in the lower silty clay till.

The silty clay till is of intermediate plasticity based on plastic limits ranging from 17 to 20 per cent with an average of 18 per cent, liquid limits ranging from 35 to 42 per cent with an average of 39 per cent, and a plasticity index ranging from 15 to 24 per cent with an average of 20 per cent. The Atterberg limits data are shown on the Plasticity Chart, Figure A-3.

Although not specifically encountered in the boreholes, the presence of cobbles and boulders in the till strata should be anticipated.

4.1.4 Silty Clay

Silty clay with silt partings was encountered between the silty clay till layers in boreholes 101 and 102 at approximately elevation 189.3 metres. The gradation of a sample of silty clay is shown on Figure A-2.

N values in the silty clay ranged from 15 to 20 blows per 0.3 metres and averaged 18 blows per 0.3 metres. The water content of the silty clay varied from 10 to 28 per cent with an average of 21 per cent. The silty clay is of intermediate plasticity based on a single sample with plastic and liquid limits of 19 and 42 per cent, respectively, and a plasticity index of 23 per cent. The results of the Atterberg limits testing are shown on Figure A-3.

4.2 Groundwater Conditions

Groundwater conditions were observed during and on completion of drilling and sampling. All of the boreholes remained dry during drilling.

Based on the change in colour and water contents of samples, the long term groundwater level estimated to be at approximately elevation 191 metres. The water level in the adjacent drain was measured at elevation 191.3 metres on August 29, 2006.

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 equipment supplied and operated by Aardvark Drilling Inc., 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 14-403-C
HIGHWAY 40 RECONSTRUCTION
GWP 760-91-00, AGREEMENT NO. 3005-E-0043
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 situated in the project area on Highway 40 at Station 18+460 (Site 14-403-C). This culvert is a rigid frame, open footing (RFO) 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

Highway 40, within the project limits, will be reconstructed to current standards with a minor grade raise of approximately 250 millimetres. Moore Line will also be reconstructed in order to tie into the proposed Highway 40 modifications.

The subsoils encountered in the boreholes advanced during the investigation typically consist of topsoil and surficial fills over stiff to hard becoming firm to stiff at depth silty clay till with layers of silty clay and clayey silt till. Groundwater was not encountered during the investigation; however, the long-term groundwater level was estimated to be at about elevation 191 metres. The water level in the adjacent channel was measured at elevation 191.3 metres on August 29, 2006.

The culvert extensions 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 boreholes locations and the culvert invert at elevation 190.0 metres, the culvert extensions can be founded on spread footings founded at or below elevation 189.7 metres in the very stiff to hard silty clay till or the very stiff silty clay layer which is present at the east end of the culvert at about elevation 189.3 metres. Minimal groundwater inflow into the excavations is anticipated.

The recommended factored geotechnical resistances at Ultimate Limit States (ULS) and at Serviceability Limit States (SLS) are 300 kilopascals and 200 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 0.5 may be used for design.

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 extensions should be carried out in accordance with Ontario Provincial Standard Drawing (OPSD) 803.010. 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.

Heavy compaction equipment should not be used immediately adjacent to the walls and roof of the culverts. The height of backfill adjacent to the culvert walls should be maintained equal on both sides of the structures during all stages of backfill placement. Adequate erosion protection, as recommended in Section 6.5, should be provided at the inlets and the outlets.

6.4 Lateral Earth Pressures for Design

The lateral pressures acting on the proposed culvert extensions 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.

The granular fill should be placed in a zone with a width equal to at least 1.2 metres behind the culvert walls. 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’, K_a (unrestrained case)	0.31
‘at rest’, K_o (restrained case)	0.47

If the wall support allows lateral yielding (unrestrained structure), active earth pressures may be used in the geotechnical design of the structure. If the culvert wall support does not allow lateral yielding (restrained structure), at-rest pressures should be assumed for geotechnical design. Resistance to sliding may be based on an angle of internal friction of 27 degrees. The unfactored coefficient of passive pressure for the portion of the culvert wall and footing below invert may be taken as 2.9.

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 the working slab be placed immediately after footing inspection. Subgrade preparation and monitoring should be in accordance with SP 902S01.

Inlet seals and outlet cutoffs and filters are not considered necessary. The provision of camber in the culvert extensions is not required.

Erosion and scour protection for the culvert backfill should be provided, as appropriate, consistent with OPSD 810.010. 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 diversion of the watercourse to mitigate migration of fine soil particles.

6.6 Excavations and Temporary Cut Slopes

Excavations for the culvert extensions will extend through the existing fills into firm to hard but generally very stiff to hard silty clay till. The presence of cobbles and boulders within the till layers should be anticipated when excavating or installing piles or anchors in these soils. Based on the subsurface conditions encountered in the boreholes, the base of the foundation excavations will be below the long-term groundwater level, at elevation 191 metres. Temporary open cut slopes should be maintained no steeper than 1 horizontal to 1 vertical.

Surficial water seepage into the excavations should be expected and will be heavier during periods of sustained precipitation. In addition to diverting the existing culvert flows, pumping from well filtered sumps located at the base of the excavations may be required to provide groundwater control during foundation excavations. However, the overall amount of groundwater inflow is expected to be minimal.

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/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 = 0.35 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 = 0.3 for level ground behind excavation
γ = soil unit weight = 20 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 3.5. 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 materials would be classified as Type 2 soils.

Subgrade preparation and monitoring should be in accordance with SP902S01.

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**	**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.

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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_1	liquid limit
w_p	plastic limit
l_p	plasticity index = $(w_1 - w_p)$
w_s	shrinkage limit
I_L	liquidity index = $(w - w_p)/I_p$
I_C	consistency index = $(w_1 - w)/I_p$
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)

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Golder Associates
London, Ontario

RECORD OF BOREHOLE No 101

METRIC

PROJECT 06-1130-132

G.W.P. 760-91-00

LOCATION N 4744361.4 ;E 311680.8

ORIGINATED BY M.A.

DIST ___ HWY 40

BOREHOLE TYPE HOLLOW STEM AUGER

COMPILED BY T.M.

DATUM GEODETIC

DATE August 29, 2006

CHECKED BY ___

ELEV DEPTH	DESCRIPTION	NUMBER	TYPE	"N" VALUES	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
192.92	GROUND SURFACE				
0.08	TOPSOIL, clayey Brown				
0.38	FILL, silty clay, trace sand, trace gravel Brown				
	SILTY CLAY, trace sand, trace gravel (TILL) Very Stiff Brown	1	SS	18	
		2	SS	21	
		3	SS	29	
		4	SS	23	0 12 46 42
189.26 / 3.66	SILTY CLAY, trace sand, trace gravel with silt partings Very Stiff Brown	5	SS	20	
		6	SS	15	
187.74 / 5.18	SILTY CLAY, trace sand, trace gravel (TILL) Firm to Very Stiff Grey	7	SS	11	0 9 41 50
		8	SS	9	
		9	SS	9	
		10	SS	7	
183.32 / 9.60	END OF BOREHOLE Borehole dry during drilling August 29, 2006				

Column headings: SOIL PROFILE (ELEV DEPTH, DESCRIPTION, STRAT PLOT); SAMPLES (NUMBER, TYPE, "N" VALUES); GROUND WATER CONDITIONS; ELEVATION SCALE (192 to 184); 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.

Plot annotations: 42; 1.8; 1.7; 126kPa

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

Golder Associates
London, Ontario

RECORD OF BOREHOLE No 102

METRIC

PROJECT 06-1130-132
G.W.P. 760-91-00
LOCATION N 4744363.2 ;E 311675.4
ORIGINATED BY M.A.
DIST HWY 40
BOREHOLE TYPE HOLLOW STEM AUGER
COMPILED BY T.M.
DATUM GEODETIC
DATE August 29, 2006
CHECKED BY

ELEV / DEPTH	DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	ELEVATION SCALE	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
193.03	GROUND SURFACE					
0.00	FILL, sand and gravel, some silt crushed Brown					
0.23	FILL, silty sand, some gravel Loose Brown	1	SS	6	192	
192.06 / 0.97	FILL, silty clay, trace sand, trace gravel Firm Grey					
191.66 / 1.37	SILTY CLAY, trace sand and gravel (TILL) Stiff to Very Stiff Brown	2	SS	14	191	
		3	SS	27	190	
		4	SS	25		
189.37 / 3.66	SILTY CLAY, trace sand, trace gravel with silt partings Very Stiff Grey	5	SS	18	189	0 4 40 56
		6	SS	17	188	
187.85 / 5.18	SILTY CLAY, trace sand, trace gravel (TILL) Stiff Grey	7	SS	9	187	
		8	SS	11	186	
		9	SS	11	185	0 8 45 47
		10	SS	9	184	
183.43 / 9.60	END OF BOREHOLE Borehole dry during drilling August 29, 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

Plot annotations: 42 (liquid limit, sample 5); 120.7 — 1.8; >143kPa — 1.6

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

Golder Associates
London, Ontario

RECORD OF BOREHOLE No 103

METRIC

PROJECT 06-1130-132

G.W.P. 760-91-00 | LOCATION N 4744361.5 ;E 311653.5 | ORIGINATED BY M.A.

DIST ___ HWY 40 | BOREHOLE TYPE HOLLOW STEM AUGER | COMPILED BY T.M.

DATUM GEODETIC | DATE August 29, 2006 | 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	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
193.10	GROUND SURFACE						193				
0.00	FILL, sand and gravel, some silt Brown										
			1	SS	9		192				
191.73 1.37	SILTY CLAY, trace sand, trace gravel (TILL) Firm to Very Stiff Brown becoming Grey at about elev 188.5m										
			2	SS	17		191				
			3	SS	27						0 11 56 33
			4	SS	29		190				
			5	SS	23		189				
			6	SS	14						0 5 49 46
			7	SS	10		188				
			8	SS	9		187				
							186	129.3 (1.6); >143kPa			
			9	SS	10		185				
			10	SS	5		184				
183.50 9.60	END OF BOREHOLE Borehole dry during drilling August 29, 2006										

Legend: 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

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

Golder Associates
London, Ontario

RECORD OF BOREHOLE No 104

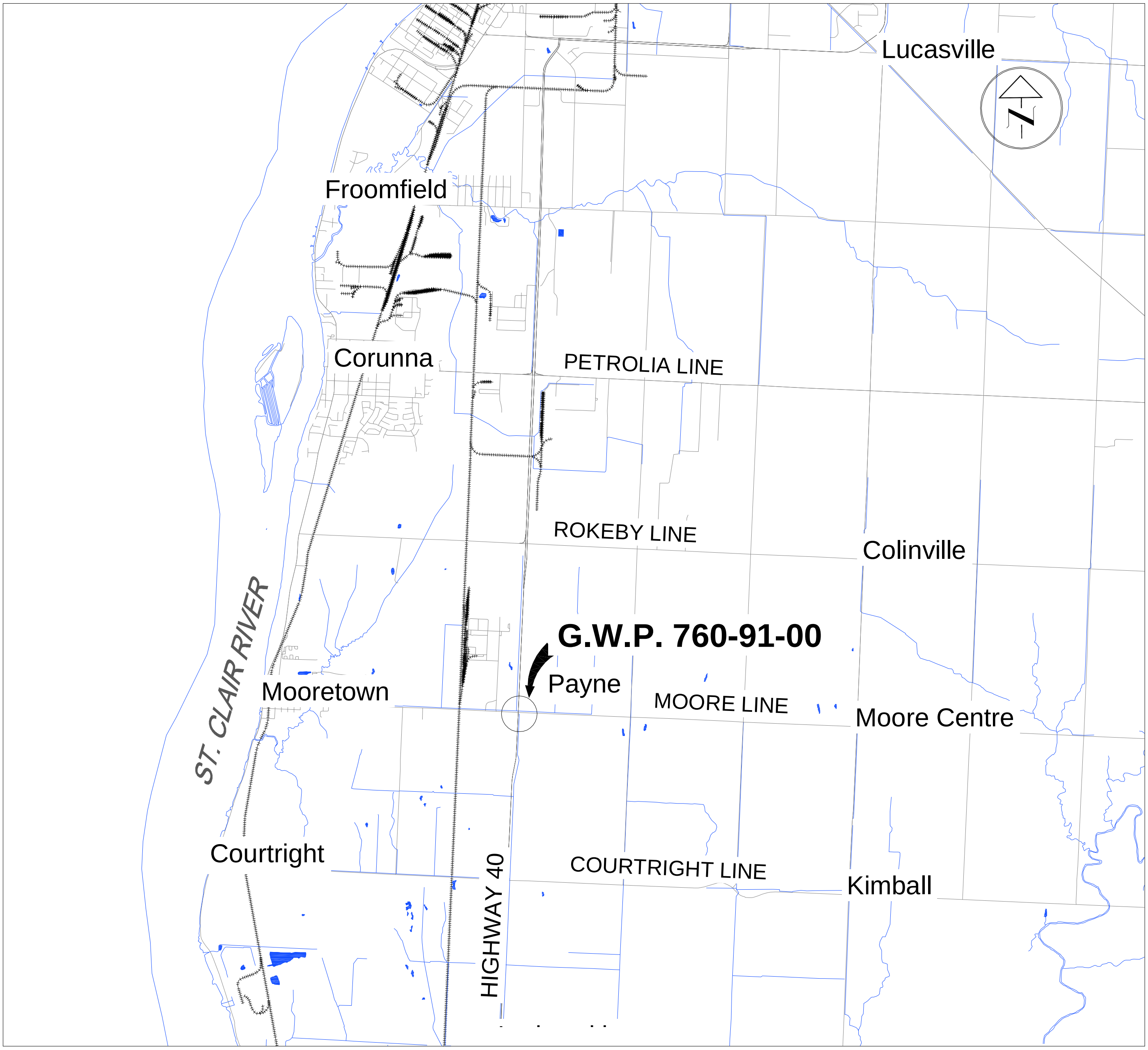
METRIC

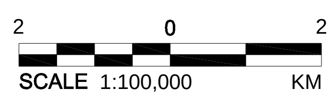
PROJECT 06-1130-132
G.W.P. 760-91-00
LOCATION N 4744359.8 ;E 311645.8
ORIGINATED BY M.A.
DIST HWY 40
BOREHOLE TYPE HOLLOW STEM AUGER
COMPILED BY T.M.
DATUM GEODETIC
DATE August 29, 2006
CHECKED BY

ELEV / DEPTH (m)	DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	ELEVATION SCALE	WATER CONTENT (%)	GR	SA	SI	CL
192.88	GROUND SURFACE									
0.09	TOPSOIL, clayey Brown CLAYEY SILT, trace sand, trace gravel (TILL) Stiff Brown and Grey				192					
		1	SS	13						
191.51 1.37	SILTY CLAY, trace sand, trace gravel (TILL) Stiff to Hard Brown becoming Grey at about elev. 189.2m									
		2	SS	26	191					
		3	SS	31	190					
		4	SS	27						
		5	SS	28	189		1	12	45	42
		6	SS	18	188					
		7	SS	13	187					
		8	SS	11		41	1	7	46	46
	Field vane: 1.7, 1.5, 126.4				186					
		9	SS	8	185					
					184					
		10	SS	10						
183.28 9.60	END OF BOREHOLE Borehole dry during drilling August 29, 2006									

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





DRAWING FILE: 051130132AA-001.DWG Plot Date: Dec 18, 2006 - 7:55pm

NOTE

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

PROJECT

STRUCTURAL CULVERT SITE 14-403-C
HIGHWAY 40 RECONSTRUCTION
G.W.P. 760-91-00

TITLE

KEY PLAN

Golder Associates
LONDON, ONTARIO

PROJECT No.	06-1130-132-0-2		FILE No.	051130132AA-001
			SCALE AS SHOWN	REV. 0
CADD	DCH	OCT. 26/06	FIGURE 1	
CHECK				

MINISTRY OF TRANSPORTATION, ONTARIO

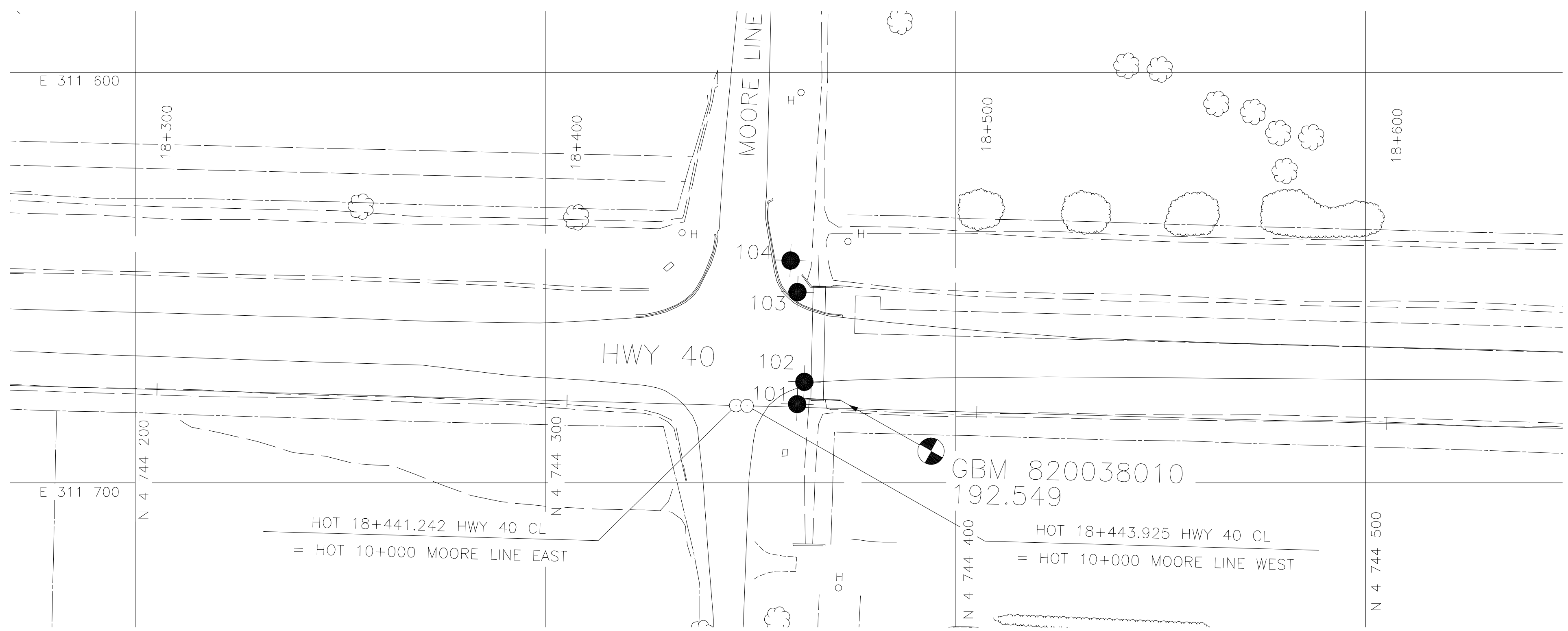
METRIC
DIMENSIONS ARE IN METRES AND/OR MILLIMETRES UNLESS OTHERWISE SHOWN. STATIONS IN KILOMETRES + METRES.

CONT No.
WP No. 760-91-00

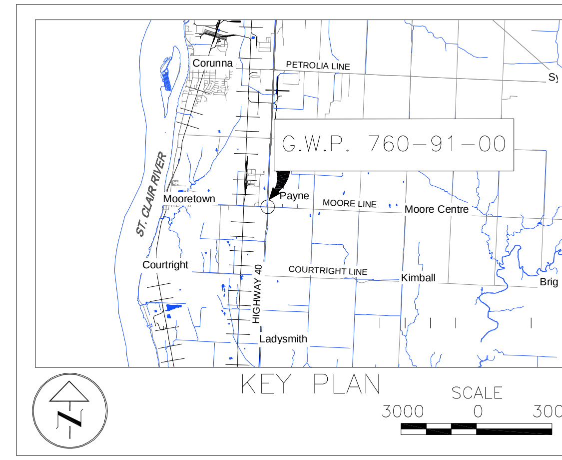
SHEET

STRUCTURAL CULVERT
SITE 14-403-C
HIGHWAY 40 RECONSTRUCTION
BOREHOLE LOCATION AND SOIL STRATA

Golder Associates Ltd.
LONDON, ONTARIO, CANADA



PLAN
SCALE
15 0 15 m

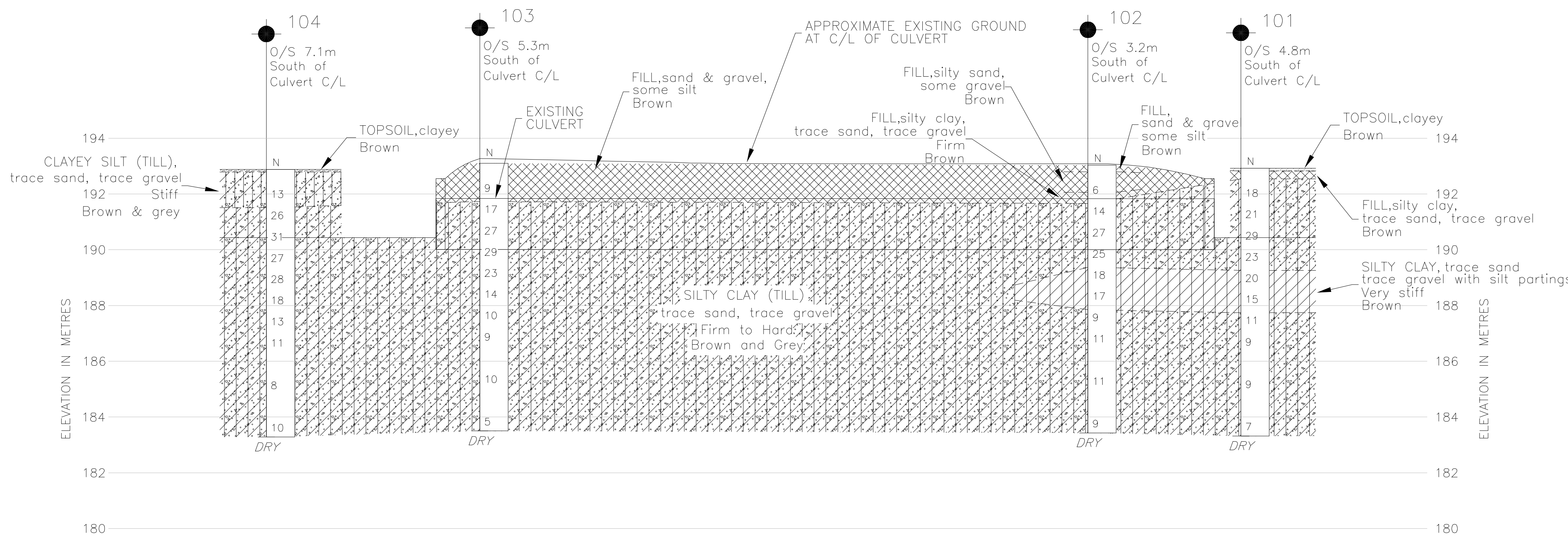


KEY PLAN
SCALE
3000 0 3000m

LEGEND

- ● Borehole – Current Investigation
- N Standard Penetration Test Value
- 16 Blows/0.3m unless otherwise stated (Std. Pen. Test, 475 j/blow)
- *DRY* Borehole dry during drilling

No.	ELEVATION	CO-ORDINATES (MTM Zone 11) NORTHING	EASTING
101	192.92	4 744 361.4	311 680.8
102	193.03	4 744 363.2	311 675.4
103	193.10	4 744 361.5	311 653.5
104	192.88	4 744 359.8	311 645.8



PROFILE ALONG C/L OF CULVERT
SCALE
2 0 2m

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 DILLON CONSULTING

NO.	DATE	BY	REVISION

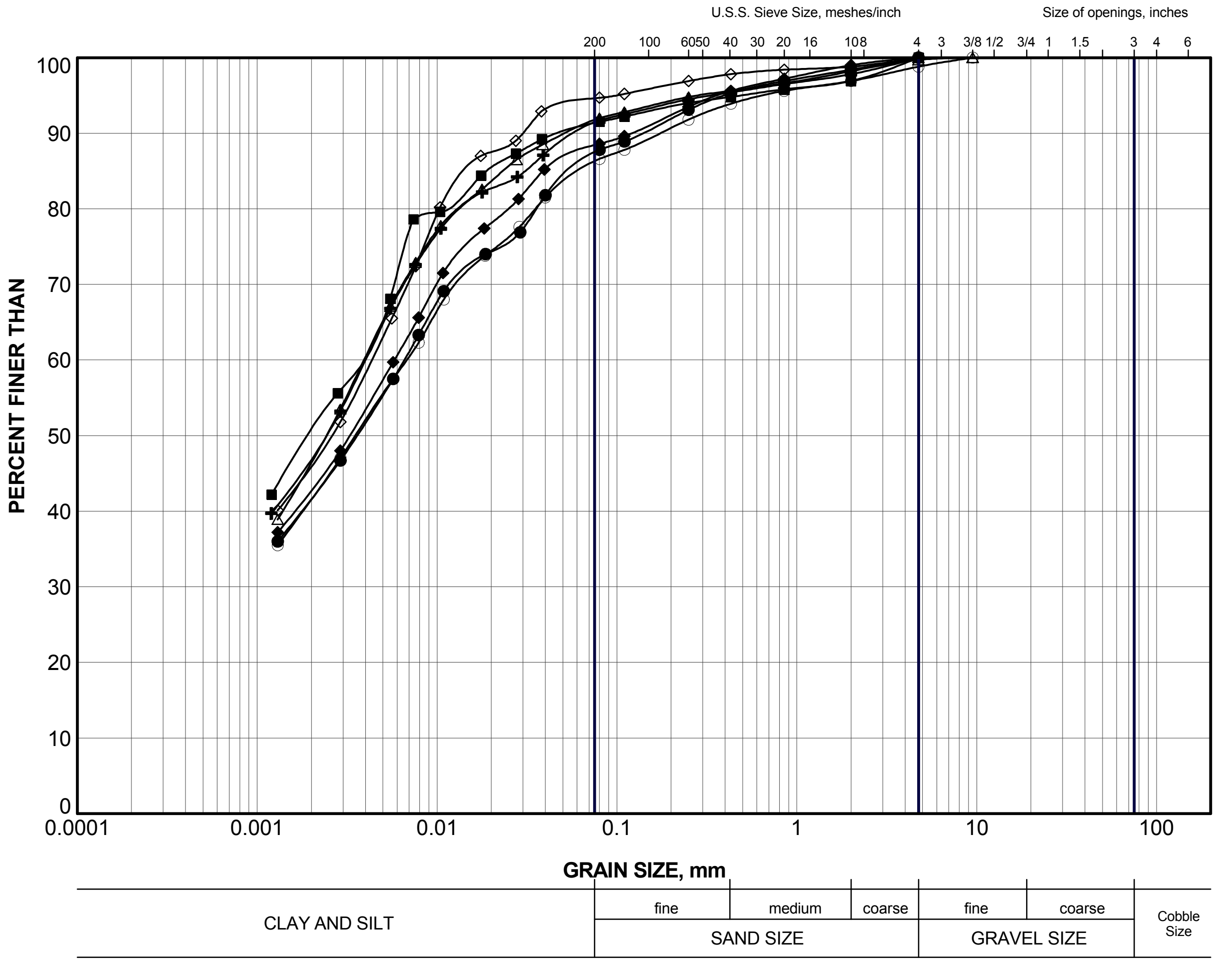
Geocres No. 40J16-77

HWY. 40		PROJECT NO. 06-1130-132-0-2	DIST.
SUBM'D. DUP	CHKD. DUP	DATE: Dec 12/06	SITE: 14-403-C
DRAWN: DCH	CHKD. DUP	APPD.	DWG. 1

PLOT DATE: December 18, 2006
FILENAME: N:\active\2006\1130 - Geotechnical\1130-100\06-1130-132 DELCAN - FDMS HWY 40 - SARNIA\Drafting\-MA- Structural Culvert\AutoCAD F\0611301 32MA-002.dwg

APPENDIX A

LABORATORY TEST DATA



LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEV (m)
●	101	4	189.6
■	101	7	187.3
✚	102	9	185.2
◆	103	3	190.6
◇	103	6	188.3
○	104	5	188.8
△	104	8	186.5

PROJECT

STRUCTURAL CULVERT
HWY 40 RECONSTRUCTION
GWP 760-91-00

TITLE

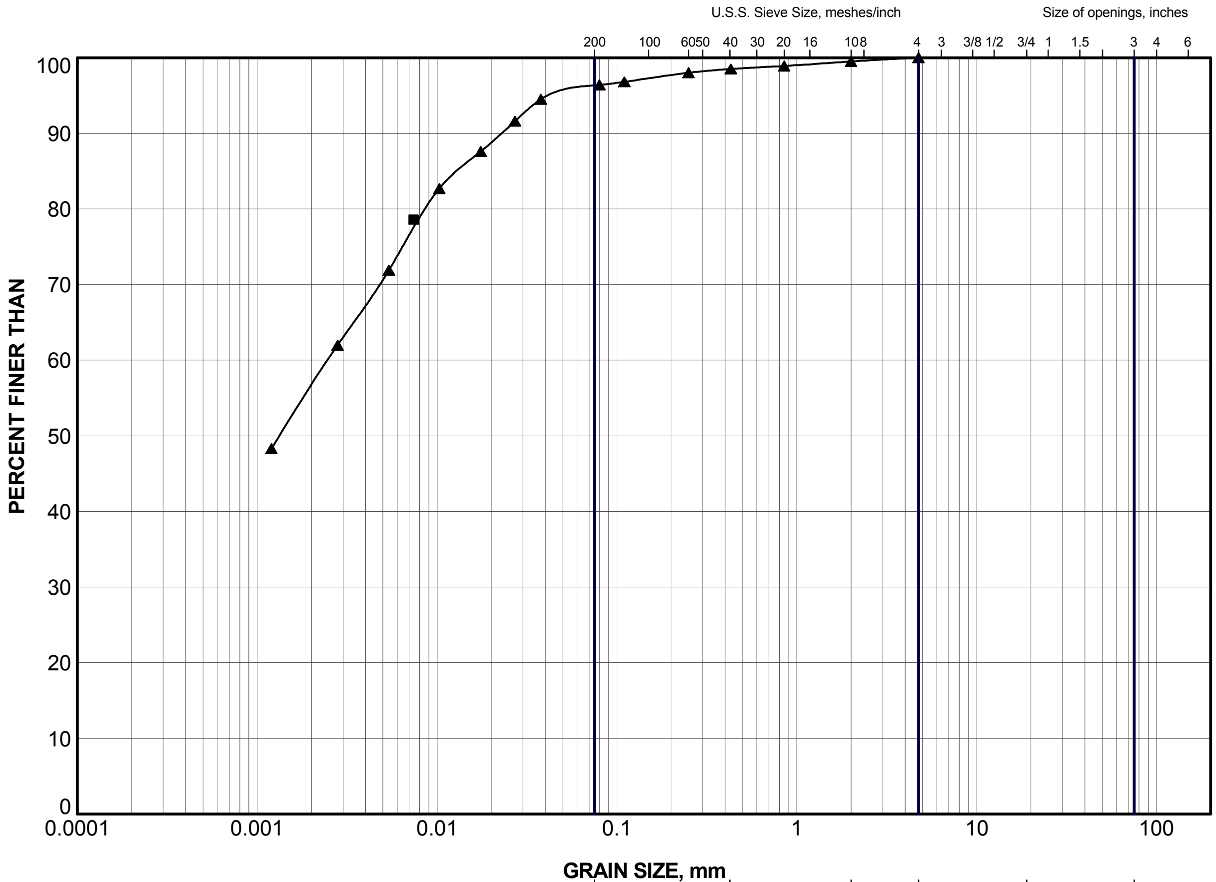
GRAIN SIZE DISTRIBUTION

SILTY CLAY TILL

Golder Associates
LONDON, ONTARIO

PROJECT No.	06-1130-132-2	FILE No.	06-1130-132-AA-.GPJ
		SCALE N/A	REV.
DRAWN WDF	Oct 26/06	**FIGURE A-1**	
CHECK			

LDN_MTO_NEW GLDR_LDN.GDT



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

LEGEND

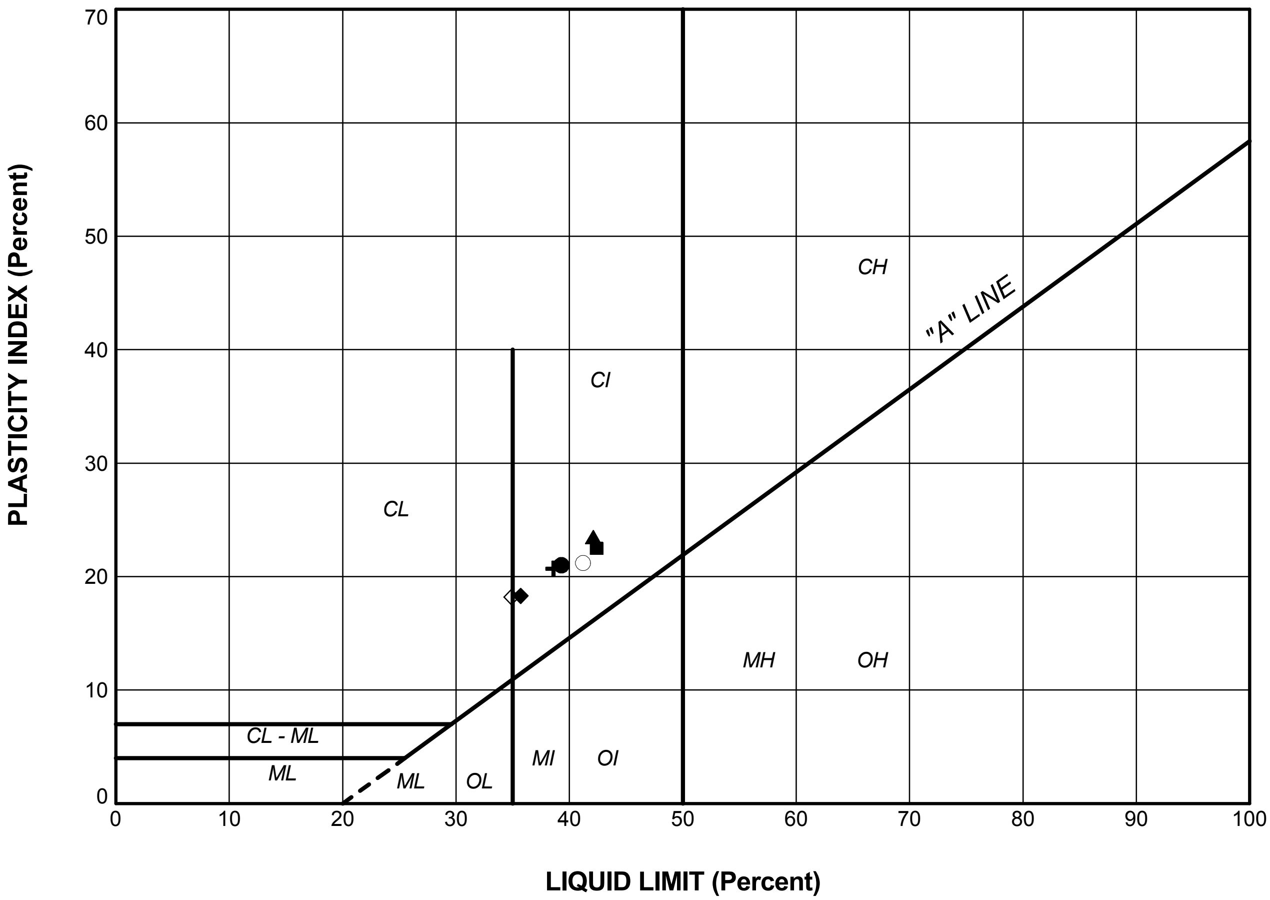
SYMBOL	BOREHOLE	SAMPLE	ELEV (m)
▲	102	5	189.0

PROJECT	STRUCTURAL CULVERT HWY 40 RECONSTRUCTION GWP 760-91-00
TITLE	**GRAIN SIZE DISTRIBUTION** **SILTY CLAY**

Golder Associates
LONDON, ONTARIO

PROJECT No.		06-1130-132-2	FILE No.	06-1130-132-AA-.GPJ
			SCALE N/A	REV.
DRAWN	WDF	Oct 26/06	**FIGURE A-2**	
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
SILTY CLAY					
▲	102	5	42.1	18.6	23.5
SILTY CLAY (TILL)					
●	101	4	39.3	18.3	21.0
■	101	7	42.4	19.9	22.5
✚	103	3	38.6	17.9	20.7
◆	103	6	35.7	17.4	18.3
◇	104	5	34.9	16.7	18.2
○	104	8	41.2	20.0	21.2

PROJECT	STRUCTURAL CULVERT HWY 40 RECONSTRUCTION GWP 760-91-00		
TITLE	**PLASTICITY CHART**		
Golder Associates LONDON, ONTARIO	PROJECT No. 06-1130-132-2	FILE No. 06-1130-132-AA-.GPJ	
		SCALE N/A	REV.
	DRAWN WDF Oct 26/06	**FIGURE A-3**	
	CHECK		

MTO_PI GLDR_LDN.GDT