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**FOUNDATION INVESTIGATION AND DESIGN REPORT
STRUCTURAL CULVERT, STATION 16+257
SITE 6-456-C, LEBO CREEK
HIGHWAY 77 REHABILITATION
GWP 139-98-00, AGREEMENT NO. 3006-E-0013
MINISTRY OF TRANSPORTATION - SOUTHWESTERN REGION**

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LIST OF ABBREVIATIONS

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PART A

FOUNDATION INVESTIGATION REPORT

STRUCTURAL CULVERT, STATION 16+257
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1.0 INTRODUCTION

Golder Associates Ltd. (Golder) 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 northerly 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 rehabilitation of the structural culvert located on Highway 77 at Station 16+257 (Site 6-456-C). The existing gabion walls at the culvert inlet will be replaced with cast-in-place retaining walls. The header walls at each end of the culvert will be raised 630 millimetres on the west side and 450 millimetres on the east side.

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's 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 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 south of Highway 3 northerly to Station 23+022 at the intersection with Essex County Road 8. The project also includes 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.

Culvert Site 6-456-C is located at Station 16+257 on Highway 77 and approximately 70 metres south of Mersea Township Road 7. At this location, Lebo Creek crosses under Highway 77 from west to east. The location of the project is shown on the Key Plan, Figure 1, and site photographs are provided in Appendix B.

In the vicinity of the culvert, Lebo Creek flows in a shallow channel with banks well vegetated with grasses and a few shrubs. The land use in the vicinity of the site is primarily rural residential with a greenhouse situated upstream of the culvert. The adjacent topography is generally flat to gently undulating with a ground surface elevation between 195 and 198 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.

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

The available surficial geology mapping for the project area indicates that the predominant surficial soil is medium sand of glaciolacustrine origin.² However, close to Mersea Township Road 7, there is an area of sandy silt to clayey silt till and glaciofluvial gravel or gravelly sand. The overburden thickness within the project area ranges from 33 to 37 metres.³ Immediately underlying the overburden is a medium brown microcrystalline limestone belonging to the Dundee Formation of the Hamilton group.

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 investigation at this site was carried out on November 19 and 21, 2007 at which time four boreholes, numbered 4, 5, 15 and 16, were drilled in the area of the proposed retaining walls. Boreholes 4 and 5 were advanced to a depth of 8.8 metres, borehole 15 to 2.9 metres and borehole 16 to 3.0 metres.

Boreholes 4 and 5 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. Boreholes 15 and 16 were drilled by staff from Golder using manual drilling equipment. The SPT testing in the manually drilled holes was conducted using a non-standard hammer weighing 31 kilograms. The SPT N values shown on the Record of Boreholes have been adjusted to approximate N values.

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 5 to monitor the groundwater level at this location. 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 labelled containers and transported to Golder's 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.

| <u>BOREHOLE</u> | <u>LOCATION (m)</u> | | <u>GROUND SURFACE ELEVATION</u> | <u>BOREHOLE DEPTH</u> |
|-----------------|---------------------|----------------|---|---------------------------|
| | <u>Northing</u> | <u>Easting</u> | (m) | (m) |
| 4 | 4663317.7 | 296866.4 | 195.22 | 8.84 |
| 5 | 4663306.7 | 296865.5 | 195.23 | 8.84 |
| 15 | 4663308.1 | 296859.0 | 193.62 | 2.90 |
| 16 | 4663316.1 | 296860.2 | 193.93 | 3.05 |

The existing culvert has the following characteristics:

| <u>DIMENSIONS (m)</u> | <u>OBVERT ELEVATION (m)</u> | | <u>CONSTRUCTION</u> |
|-----------------------|-----------------------------|--------|-----------------------------------|
| | (Lt) | (Rt) | |
| 3.05 x 1.52 x 17.44 | 194.35 | 194.35 | Rigid Frame Open Footing (RFO) |

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 granular roadbase in the shoulder areas and topsoil near the ditches. Layers of predominantly clayey fill were found beneath the roadbase and topsoil. The fill and topsoil were underlain by clayey silt deposits with minor layers of silty clay and sandy silt.

The locations of the boreholes are shown on the attached Drawing 1 together with a soil profile. 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

An approximately 0.3 to 0.5 metre thick layer of granular road base material was encountered at the ground surface in boreholes 4 and 5.

4.1.2 Topsoil and Fill

Topsoil layers 50 millimetres thick were encountered at the ground surface in boreholes 15 and 16, respectively.

In boreholes 4 and 5, fine to medium sand fill was found beneath the granular base to approximately elevation 194.8 and 194.7 metres, respectively. Beneath the sand fill in boreholes 4 and 5 and below the topsoil in boreholes 15 and 16, soft to stiff clayey silt fill was encountered from elevation 193.6 to 194.8 metres. The clayey silt fill had measured N values of 3 to 8 blows per 0.3 metres and water contents of 16 to 23 per cent. The clayey silt fill is of low plasticity based on a single Atterberg limits determination with plastic and liquid limits of 16 and 33 per cent, respectively, and a plasticity index of 17 per cent. The results of the Atterberg limits determinations are shown on Figure A-3. The results of grain size testing on a single sample of clayey silt fill are presented in Appendix A on Figure A-1.

4.1.3 Silty Clay

A layer of silty clay was encountered below the fill in borehole 15 at elevation 192.4 metres. The silty clay was hard with an N value of 31 blows per 0.3 metres. The water content of the silty clay was about 18 per cent.

4.1.4 Clayey Silt

Clayey silt was encountered beneath the fill in boreholes 4, 5 and 16 at elevations 192.0 to 192.9 metres and below the silty clay in borehole 15 at elevation 191.5 metres.

The clayey silt layer in borehole 5 was 5.4 metres thick. The remaining boreholes were terminated in the clayey silt. The clayey silt was stiff to very stiff with N values ranging from 10 to 24 blows per 0.3 metres. The water content of the clayey silt varied between 11 and 24 per cent. The clayey silt is of low plasticity based on average plastic and liquid limits of 16 and 30 per cent, respectively, and an average plasticity index of 14 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 clayey silt are shown in Figure A-2.

4.1.5 Sandy Silt

Borehole 5 was terminated in a layer of sandy silt which was encountered below the clayey silt at elevation 186.7 metres. The sandy silt was compact with an N value of 26 blows per 0.3 metres.

4.2 Groundwater Conditions

Groundwater conditions were observed during and on completion of drilling and sampling. Groundwater was encountered at a depth of 1.5 metres or at elevation 192.4 metres in borehole 16. Boreholes 4, 5 and 15 were dry during and upon completion of drilling.

A standpipe was installed in borehole 5 to monitor the groundwater conditions. The most recent groundwater reading was obtained on December 28, 2007 when the groundwater level was measured at elevation 193.0 metres or at a depth of 2.2 metres below the ground surface. A slightly higher groundwater level was measured on December 11, 2007 during a period of heavy rainfall.

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

| BOREHOLE | GROUND SURFACE ELEVATION (m) | ENCOUNTERED GROUNDWATER LEVEL | | INSTALLATION | MEASURED GROUNDWATER LEVEL | | | | | |
|----------|---------------------------------------|-------------------------------------|------------------|--------------|----------------------------|------------------|---------------|------------------|---------------|------------------|
| | | Depth (m) | Elevation (m) | | Nov. 28, 2007 | | Dec. 11, 2007 | | Dec. 28, 2007 | |
| | | | | | Depth (m) | Elevation (m) | Depth (m) | Elevation (m) | Depth (m) | Elevation (m) |
| 4 | 195.22 | Dry | Dry | - | - | - | - | - | - | - |
| 5 | 195.23 | Dry | Dry | Standpipe | 7.53 | 187.74 | 1.89 | 193.34 | 2.21 | 193.02 |
| 15 | 193.62 | Dry | Dry | - | - | - | - | - | - | - |
| 16 | 193.93 | 1.5 | 192.4 | - | - | - | - | - | - | - |

The water level in Lebo Creek was at elevation 192.91 metres on November 19, 2007.

Based on the encountered and measured groundwater levels, the long term groundwater level in the clayey silt and silty clay is inferred to be near elevation 193 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 and using manually operated equipment owned by Golder. The field operations were supervised by Mr. Mike Arthur and Mr. Dennis Verschoor under the direction of Mr. David J. Mitchell.

The laboratory testing was carried out at Golder's 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 16+257

SITE 6-456-C, LEBO CREEK

HIGHWAY 77 REHABILITATION

GWP 139-98-00, AGREEMENT NO. 3006-E-0013

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 rehabilitation of the structural culvert situated in the project area on Highway 77 at Station 16+257 (Site 6-456-C). The existing culvert is a 3.05 x 1.52 metre rigid frame open footing (RFO) structure with a length of 17.4 metres.

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 existing Lebo Creek culvert. The major improvements to the Lebo Creek structure are the removal of the existing gabion walls at the west end, raising of the header walls at the east end by 630 millimetres and at the west end by 450 millimetres and construction of two cast-in-place concrete retaining walls at the west/left end. The existing RFO culvert is to remain in place.

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 granular roadbase, topsoil and surficial fills over stiff to very stiff clayey silt. The groundwater level was estimated to be at about elevation 193 metres. The water level in Lebo Creek was measured at elevation 192.9 metres on November 19, 2007.

The new culvert retaining walls 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 192.8 metres, the culvert retaining walls can be founded on spread footings at or below elevation 191.6 metres in the stiff to very stiff clayey silt or hard silty clay.

For footings bearing directly on the native clayey silt or silty clay, the recommended factored geotechnical resistance at Ultimate Limit States (ULS) and the geotechnical resistance at Serviceability Limit States (SLS) are 250 kilopascals and 175 kilopascals, respectively, assuming a maximum allowable settlement of 25 millimetres and a 1.8 metre footing width. Unfactored coefficients of sliding of 0.4 for the silty clay and 0.5 for the clayey silt 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

Backfilling around the retaining walls and culvert should be carried out in accordance with Ontario Provincial Standard Drawings (OPSD's) 3101.150 and 3121.150. Backfill materials 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 retaining walls of the culvert. The height of backfill adjacent to the culvert retaining walls should be maintained as equal as possible on both sides of the walls during all stages of backfill placement. Adequate erosion protection, as recommended in Section 6.5, should be provided at the outlet.

6.4 Lateral Earth Pressures for Design

The lateral pressures acting on the proposed culvert retaining walls 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 current 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 SP 105S10.

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

| | <u>Granular A</u> | <u>Granular B Type III</u> |
|---|----------------------|----------------------------|
| Fill unit weight: | 22 kN/m ³ | 21kN/m3 |
| 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 a cast-in-place wall footing with a concrete working slab, may be based on unfactored angles of friction of 28 degrees between the stiff to very stiff clayey silt and concrete and 24 degrees between the hard 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 (silty clay) 28 degrees (clayey silt) |
| 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 and 3.0 based on unfactored effective angles of internal friction, ϕ' , of 26 and 30 degrees for the silty clay and clayey silt, respectively.

6.5 Construction Considerations

The founding soils are sensitive to disturbance and softening due to water seepage and/or ponding. Since a cast-in-place retaining wall is to be constructed, placement of a working slab of lean concrete will be required at the base of the excavations for the footing area. Exposure without the 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, outlet cutoffs and filters are not considered necessary as the potential for uplift and piping is low. The provision of camber for the culvert extension 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.

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.

6.6 Excavations and Temporary Cut Slopes

Excavations for the new retaining walls will encounter surficial topsoil and fills and the stiff to very stiff clayey silt and hard silty clay. The considerations with respect to protection of the founding soils, as given in Section 6.5 under the heading Construction Considerations, must be recognized.

Perched groundwater is to be expected in the granular fill which overlies the native cohesive soils. This groundwater can be controlled by pumping from properly filtered sumps located in the base of the excavation. Sumps should be maintained outside of the actual footing limits. Temporary open cut slopes should be maintained no steeper than 1 horizontal to 1 vertical. It may be necessary to use flatter slopes and/or blanket cut slopes with coarse free draining material in order to enhance the stability. Minimal groundwater flow is expected from the clayey silt and 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 existing gabion baskets at the west end (inlet) will be removed as well as the asphalt pavement from the concrete surface in the main lanes. Partial depth removal of the asphalt pavement in the shoulder areas will also be required. The proposed works will not require excavation of the road proper. However, for construction of the new retaining walls, if 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 excavation support system should be designed and constructed in accordance with MTO 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. The native clayey silt and silty clay materials would be classified as Type 2 or 3 soils depending on consistency.

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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SB/DUP/PRB/FJH/cr
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16+257 hwy 77.doc

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 |

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 |

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.)

Consistency

| | <u>kPa</u> | <u>psf</u> |
|------------|------------|----------------|
| 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 |

(b) Cohesive Soils

Dynamic Cone Penetration Resistance; N_d :

The number of blows by a 63.5 kg. (140 lb.) hammer dropped 760 mm (30 in.) to drive uncased a 50 mm (2 in.) diameter, 60° cone attached to "A" size drill rods for a distance of 300 mm (12 in.).

PH: Sampler advanced by hydraulic pressure

PM: Sampler advanced by manual pressure

WH: Sampler advanced by static weight of hammer

WR: Sampler advanced by weight of sampler and rod

Piezo-Cone Penetration Test (CPT)

A electronic cone penetrometer with a 60° conical tip and a project end area of 10 cm² pushed through ground at a penetration rate of 2 cm/s. Measurements of tip resistance (Q_t), porewater pressure (PWP) and friction along a sleeve are recorded electronically at 25 mm penetration intervals.

IV. SOIL TESTS

| | |
|----------|---|
| w | water content |
| w_p | plastic limit |
| w_l | liquid limit |
| C | consolidation (oedometer) test |
| CHEM | chemical analysis (refer to text) |
| CID | consolidated isotropically drained triaxial test ¹ |
| CIU | consolidated isotropically undrained triaxial test with porewater pressure measurement ¹ |
| D_R | relative density (specific gravity, G_s) |
| DS | direct shear test |
| M | sieve analysis for particle size |
| MH | combined sieve and hydrometer (H) analysis |
| MPC | Modified Proctor compaction test |
| SPC | Standard Proctor compaction test |
| OC | organic content test |
| SO_4 | concentration of water-soluble sulphates |
| UC | unconfined compression test |
| UU | unconsolidated undrained triaxial test |
| V | field vane (LV-laboratory vane test) |
| γ | unit weight |

Note: 1 Tests which are anisotropically consolidated prior to shear are shown as CAD, CAU.

LIST OF SYMBOLS

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

I. General

| | |
|-------------|---------------------------------------|
| π | 3.1416 |
| $\ln x$, | natural logarithm of x |
| \log_{10} | x or log x, logarithm of x to base 10 |
| g | acceleration due to gravity |
| t | time |
| F | factor of safety |
| V | volume |
| W | weight |

II. STRESS AND STRAIN

| | |
|--------------------------------|--|
| γ | shear strain |
| Δ | change in, e.g. in stress: $\Delta \sigma$ |
| ϵ | linear strain |
| ϵ_v | volumetric strain |
| η | coefficient of viscosity |
| ν | poisson's ratio |
| σ | total stress |
| σ' | effective stress ($\sigma' = \sigma - u$) |
| σ'_{vo} | initial effective overburden stress |
| $\sigma_1, \sigma_2, \sigma_3$ | principal stress (major, intermediate, minor) |
| σ_{oct} | mean stress or octahedral stress $= (\sigma_1 + \sigma_2 + \sigma_3)/3$ |
| τ | shear stress |
| u | porewater pressure |
| E | modulus of deformation |
| G | shear modulus of deformation |
| K | bulk modulus of compressibility |

III. SOIL PROPERTIES

(a) Index Properties

| | |
|--------------------|--|
| $\rho(\gamma)$ | bulk density (bulk unit weight*) |
| $\rho_d(\gamma_d)$ | dry density (dry unit weight) |
| $\rho_w(\gamma_w)$ | density (unit weight) of water |
| $\rho_s(\gamma_s)$ | density (unit weight) of solid particles |
| γ' | unit weight of submerged soil ($\gamma' = \gamma - \gamma_w$) |
| D_R | relative density (specific gravity) of solid particles ($D_R = \rho_s / \rho_w$) (formerly G_s) |
| e | void ratio |
| n | porosity |
| S | degree of saturation |

(a) Index Properties (continued)

| | |
|-----------|--|
| w | water content |
| w_l | liquid limit |
| w_p | plastic limit |
| I_p | plasticity index $= (w_l - w_p)$ |
| w_s | shrinkage limit |
| I_L | liquidity index $= (w - w_p) / I_p$ |
| I_C | consistency index $= (w_l - w) / I_p$ |
| e_{max} | void ratio in loosest state |
| e_{min} | void ratio in densest state |
| I_D | density index $= (e_{max} - e) / (e_{max} - e_{min})$ (formerly relative density) |

(b) Hydraulic Properties

| | |
|---|--|
| h | hydraulic head or potential |
| q | rate of flow |
| v | velocity of flow |
| i | hydraulic gradient |
| k | hydraulic conductivity (coefficient of permeability) |
| j | seepage force per unit volume |

(c) Consolidation (one-dimensional)

| | |
|-------------|---|
| C_c | compression index (normally consolidated range) |
| C_r | recompression index (over-consolidated range) |
| C_s | swelling index |
| C_a | coefficient of secondary consolidation |
| m_v | coefficient of volume change |
| c_v | coefficient of consolidation |
| T_v | time factor (vertical direction) |
| U | degree of consolidation |
| σ'_p | pre-consolidation pressure |
| OCR | over-consolidation ratio $= \sigma'_p / \sigma'_{vo}$ |

(d) Shear Strength

| | |
|------------------|--|
| τ_p, τ_r | peak and residual shear strength |
| ϕ' | effective angle of internal friction |
| δ | angle of interface friction |
| μ | coefficient of friction $= \tan \delta$ |
| c' | effective cohesion |
| c_u, s_u | undrained shear strength ($\phi = 0$ analysis) |
| p | mean total stress $(\sigma_1 + \sigma_3)/2$ |
| p' | mean effective stress $(\sigma'_1 + \sigma'_3)/2$ |
| q | $(\sigma_1 + \sigma_3)/2$ or $(\sigma'_1 + \sigma'_3)/2$ |
| q_u | compressive strength $(\sigma_1 + \sigma_3)$ |
| S_t | sensitivity |

- Notes:**
- 1 $\tau = c' + \sigma' \tan \phi'$
 - 2 shear strength = (compressive strength)/2
 - * density symbol is ρ . Unit weight symbol is γ where $\gamma = \rho g$ (i.e. mass density x acceleration due to gravity)

RECORD OF BOREHOLE No 4

1 OF 1

METRIC

PROJECT 06-1130-202-0-3

G.W.P. 139-98-00

LOCATION N 4663317.7 ; E 296866.4

ORIGINATED BY MA

DIST HWY 77

BOREHOLE TYPE POWER AUGER (SOLID STEM)

COMPILED BY LMK

DATUM GEODETIC

DATE November 19, 2007

CHECKED BY

| SOIL PROFILE | | | SAMPLES | | | GROUND WATER CONDITIONS | ELEVATION SCALE | DYNAMIC CONE PENETRATION RESISTANCE PLOT | | | | | PLASTIC LIMIT W _P | NATURAL MOISTURE CONTENT W | LIQUID LIMIT W _L | UNIT WEIGHT γ kN/m ³ | REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL |
|---------------|--|------------|---------|------|------------|----------------------------|-----------------|--|----|----|-----|--|------------------------------------|-------------------------------------|-----------------------------------|--|--|
| ELEV DEPTH | DESCRIPTION | STRAT PLOT | NUMBER | TYPE | "N" VALUES | | | SHEAR STRENGTH kPa | | | | | | | | | |
| | | | | | | | | ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × LAB VANE | | | | | | | | | |
| 195.22 | GROUND SURFACE | | | | | | 20 | 40 | 60 | 80 | 100 | | | | | | |
| 0.00 | FILL, sand and gravel, trace silt (crushed) | | | | | | | | | | | | | | | | |
| 194.88 | Brown | | | | | | | | | | | | | | | | |
| 0.43 | FILL, sand fine to medium, some gravel | | | | | | | | | | | | | | | | |
| | Brown | | 1 | SS | 5 | | | | | | | | | | | | |
| | FILL, clayey silt, trace to some sand, trace gravel, trace topsoil | | | | | | | | | | | | | | | | |
| | Firm to soft | | 2 | SS | 3 | | | | | | | | | | | | |
| | Brown and grey | | | | | | | | | | | | | | | | |
| 192.93 | | | | | | | | | | | | | | | | | |
| 2.29 | CLAYEY SILT, some sand, trace gravel | | 3 | SS | 15 | | | | | | | | | | | | |
| | Stiff to very stiff | | | | | | | | | | | | | | | | |
| | Brown becoming grey at about elev. 191.2m | | | 4 | SS | 19 | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |
| | | | | 5 | SS | 14 | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |
| | | | | 6 | SS | 12 | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |
| | | | | 7 | SS | 11 | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |
| | | | | 8 | SS | 11 | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |
| | | | 9 | SS | 12 | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |
| | | | 10 | SS | 14 | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |
| | | | 11 | SS | 10 | | | | | | | | | | | | |
| 186.38 | | | | | | | | | | | | | | | | | |
| 8.84 | END OF BOREHOLE | | | | | | | | | | | | | | | | |
| | Borehole dry during drilling on November 19, 2007. | | | | | | | | | | | | | | | | |

RECORD OF BOREHOLE No 5

1 OF 1

METRIC

PROJECT 06-1130-202-0-3
G.W.P. 139-98-00 LOCATION N 4663306.7 ; E 296865.5 ORIGINATED BY MA
DIST HWY 77 BOREHOLE TYPE POWER AUGER (SOLID STEM) COMPILED BY LMK
DATUM GEODETIC DATE November 19, 2007 CHECKED BY

| SOIL PROFILE | | | SAMPLES | | | GROUND WATER CONDITIONS | ELEVATION SCALE | DYNAMIC CONE PENETRATION RESISTANCE PLOT | | | PLASTIC LIMIT w _p | NATURAL MOISTURE CONTENT w | LIQUID LIMIT w _L | UNIT WEIGHT γ kN/m ³ | REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL | | | |
|---------------|--|------------|---------|------|------------|----------------------------|-----------------|---|--------------|----|------------------------------------|-------------------------------------|-----------------------------------|--|--|-------------------|--|--|
| ELEV DEPTH | DESCRIPTION | STRAT PLOT | NUMBER | TYPE | "N" VALUES | | | SHEAR STRENGTH kPa | | | | | | | | WATER CONTENT (%) | | |
| | | | | | | | | ○ UNCONFINED | + FIELD VANE | | | | | | | ○ | | |
| | | | | | | ● QUICK TRIAXIAL | × LAB VANE | | | | | | | | | | | |
| 195.23 | GROUND SURFACE | | | | | | | 20 | 40 | 60 | 80 | 100 | 10 | 20 | 30 | | | |
| 0.00 | FILL, sand and gravel, some silt (crushed) Grey | | | | | | | | | | | | | | | | | |
| 194.77 | | | | | | | | | | | | | | | | | | |
| 0.55 | FILL, sand fine to medium, some gravel, trace silt Brown | | 1 | SS | 4 | | | | | | | | | | | | | |
| | FILL, clayey silt, some sand, with sandy layers, trace gravel, trace topsoil Firm to soft Brown and grey | | 2 | SS | 4 | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | |
| | | | 3 | SS | 3 | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | |
| 192.03 | | | 4 | SS | 17 | | | | | | | | | | | | | |
| 3.20 | CLAYEY SILT, some sand, trace gravel Stiff to very stiff Grey | | | | | | | | | | | | | | | | | |
| | | | 5 | SS | 13 | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | |
| | | | 6 | SS | 11 | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | |
| | | | 7 | SS | 13 | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | |
| | | | 8 | SS | 12 | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | |
| | | | 9 | SS | 14 | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | |
| | | | 10 | SS | 12 | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | |
| 186.67 | | | | | | | | | | | | | | | | | | |
| 8.56 | SANDY SILT, some clay, trace gravel Compact Grey | | 11 | SS | 26 | | | | | | | | | | | | | |
| 8.84 | END OF BOREHOLE | | | | | | | | | | | | | | | | | |
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RECORD OF BOREHOLE No 15

1 OF 1

METRIC

PROJECT 06-1130-202-0-3
G.W.P. 139-98-00 LOCATION N 4663308.1 ; E 296859.0 ORIGINATED BY MA
DIST HWY 77 BOREHOLE TYPE MANUAL DRILLING COMPILED BY LMK
DATUM GEODETIC DATE November 21, 2007 CHECKED BY

| SOIL PROFILE | | | SAMPLES | | | GROUND WATER CONDITIONS | ELEVATION SCALE | DYNAMIC CONE PENETRATION RESISTANCE PLOT | | | | PLASTIC LIMIT w _p | NATURAL MOISTURE CONTENT w | LIQUID LIMIT w _L | UNIT WEIGHT γ kN/m ³ | REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL | |
|---------------|---|------------|---------|------|------------|----------------------------|-----------------|--|----|----|----|--|---|---------------------------------------|--|--|-------------------|
| ELEV DEPTH | DESCRIPTION | STRAT PLOT | NUMBER | TYPE | "N" VALUES | | | SHEAR STRENGTH kPa ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × LAB VANE | | | | | | | | | WATER CONTENT (%) |
| 193.62 | GROUND SURFACE | | | | | | | 20 | 40 | 60 | 80 | 100 | | | | | |
| 0.05 | TOPSOIL, silty Brown FILL, clayey silt, trace sand, trace gravel, trace topsoil Stiff Brown and grey | | | | | | 193 | | | | | | | | | | |
| 192.41 | | | 1 | SS | 8 | | | | | | | | | | | | |
| 1.21 | SILTY CLAY, some sand, trace gravel Hard Brown and grey | | | | | | 192 | | | | | | | | | | |
| 191.49 | | | 2 | SS | 31 | | | | | | | | | | | | |
| 2.13 | CLAYEY SILT, some sand, trace gravel Stiff Grey | | | | | | 191 | | | | | | | | | | |
| 190.72 | | | 3 | SS | 15 | | | | | | | | | | | | |
| 2.90 | END OF BOREHOLE | | | | | | | | | | | | | | | | |
| | Borehole dry during drilling on November 21, 2007. | | | | | | | | | | | | | | | | |

RECORD OF BOREHOLE No 16

1 OF 1

METRIC

PROJECT 06-1130-202-0-3

G.W.P. 139-98-00

LOCATION N 4663316.1 ; E 296860.2

ORIGINATED BY MA

DIST HWY 77




BOREHOLE TYPE MANUAL DRILLING

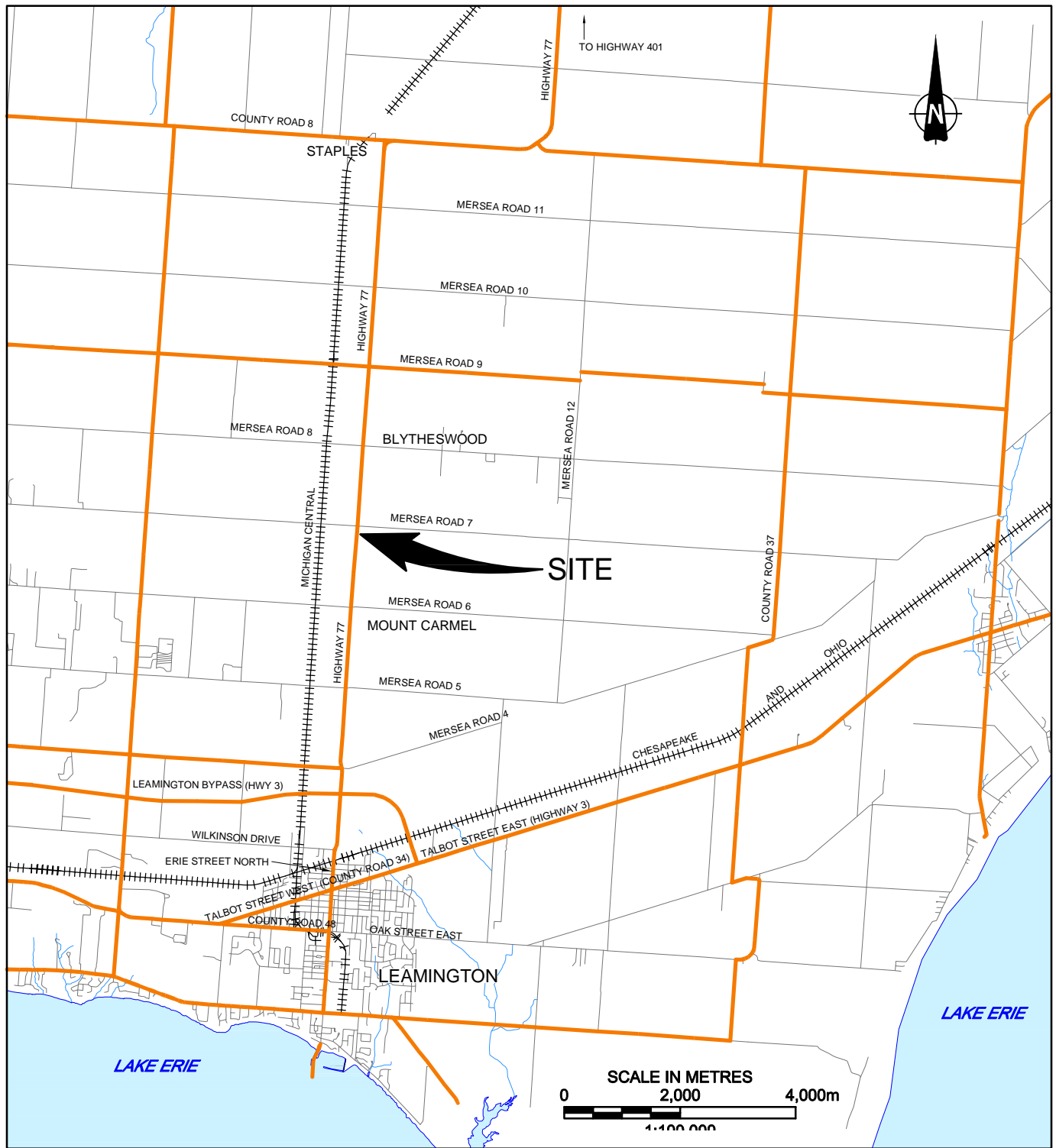
COMPILED BY LMK

DATUM GEODETIC

DATE November 21, 2007

CHECKED BY

| SOIL PROFILE | | | SAMPLES | | | GROUND WATER CONDITIONS | ELEVATION SCALE | DYNAMIC CONE PENETRATION RESISTANCE PLOT | | | PLASTIC LIMIT w _p | NATURAL MOISTURE CONTENT w | LIQUID LIMIT w _L | UNIT WEIGHT γ kN/m ³ | REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL |
|---------------|--|---|---------|------|------------|---|-----------------|--|--|--|------------------------------------|-------------------------------------|-----------------------------------|--|--|
| ELEV DEPTH | DESCRIPTION | STRAT PLOT | NUMBER | TYPE | "N" VALUES | | | SHEAR STRENGTH kPa ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL x LAB VANE | | | | | | | |
| 193.93 | GROUND SURFACE | | | | | | | | | | | | | | |
| 0.05 | TOPSOIL, silty Brown FILL, clayey silt, trace sand, trace gravel, trace topsoil Firm to stiff Brown |  | 1 | SS | 4 |  | 193 | | | | | | | | |
| 192.25 | | | | | | | | | | | | | | | |
| 1.68 | CLAYEY SILT, some sand, trace gravel Very stiff Brown becoming grey at about elev. 191.6m |  | 2 | SS | 22 | | 192 | | | | | | | | |
| | | | | | | | | | | | | | | | |
| | | | 3 | SS | 24 | | 191 | | | | | | | | |
| 190.88 | | | | | | | | | | | | | | | |
| 3.05 | END OF BOREHOLE | | | | | | | | | | | | | | |
| | Groundwater encountered at about elev. 192.4m during drilling on November 21, 2007. | | | | | | | | | | | | | | |



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

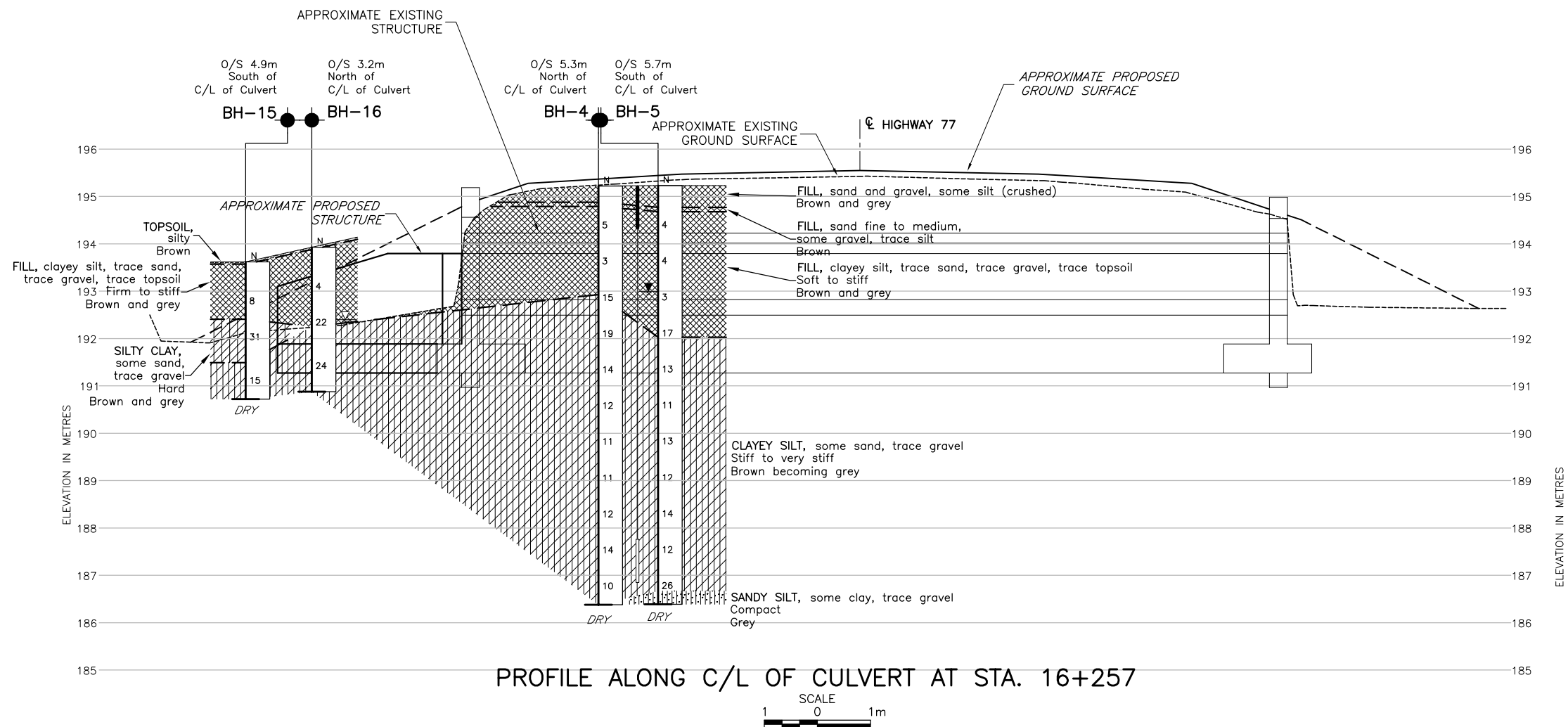
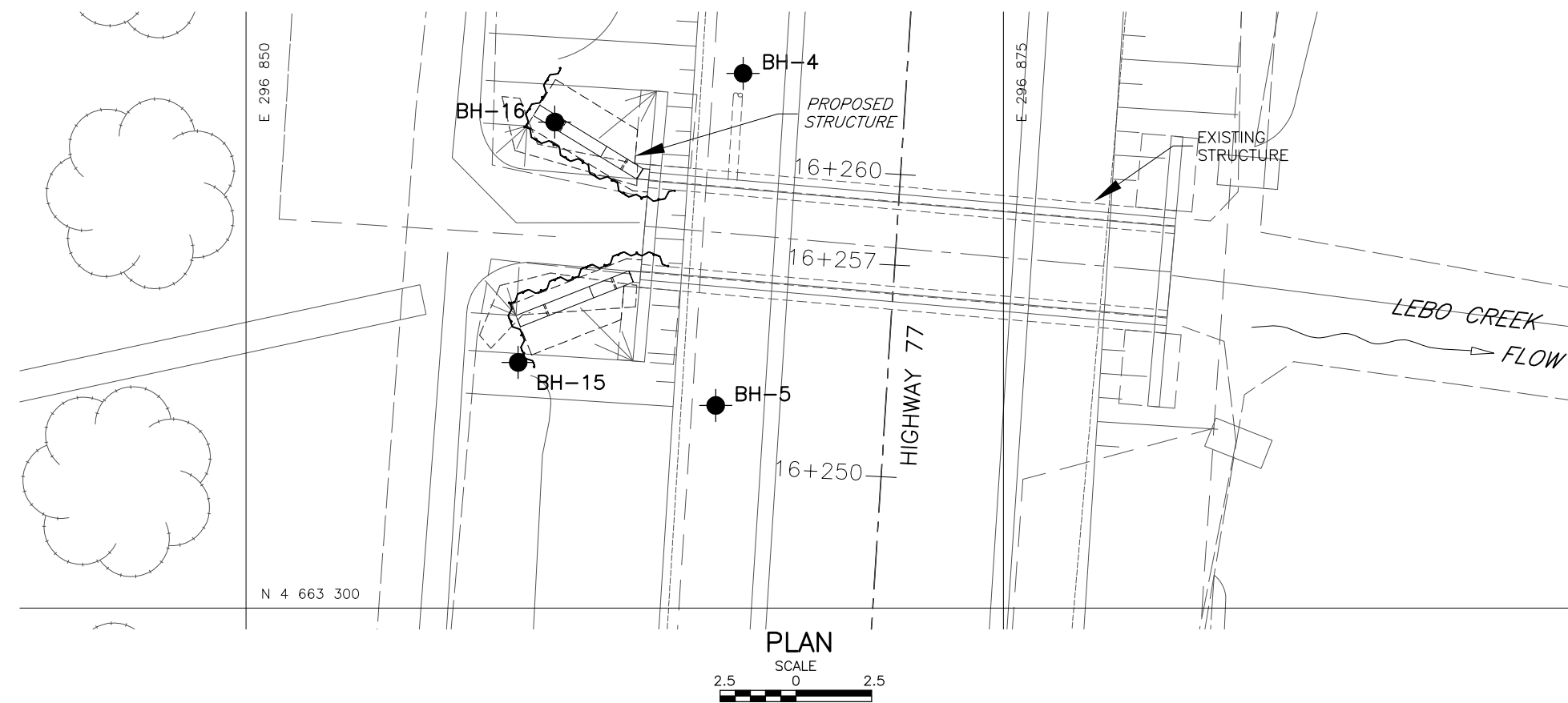
**STRUCTURAL CULVERT 16+257
HIGHWAY 77 REHABILITATION
GWP 139-98-00**

TITLE

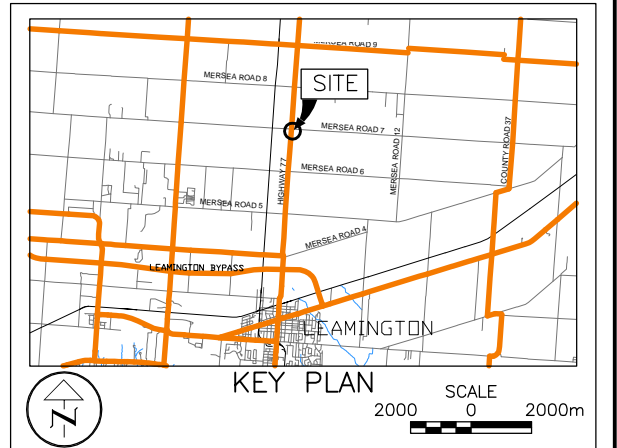
KEY PLAN



| | | | | |
|-------------------------|-----|-----------|------------------------------|----------|
| PROJECT No. 06-1130-202 | | | FILE No. 0611302020-3-F01001 | |
| CADD | DCH | Jan. 2/07 | SCALE | AS SHOWN |
| CHECK | | | REV. | |
| FIGURE 1 | | | | |

CONT No.
WP No. 139-98-00

SHEET

HIGHWAY 77 REHABILITATION
STRUCTURAL CULVERT 16+257
PROPOSED RETAINING WALLS
BOREHOLE LOCATION AND SOIL STRATA**Golder Associates Ltd.**
LONDON, ONTARIO, CANADA

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

| No. | ELEVATION | CO-ORDINATES (MTM Zone 11) | |
|-----|-----------|----------------------------|-----------|
| | | NORTHING | EASTING |
| 4 | 195.22 | 4 663 317.7 | 296 866.4 |
| 5 | 195.23 | 4 663 306.7 | 296 865.5 |
| 15 | 193.62 | 4 663 308.1 | 296 859.0 |
| 16 | 193.93 | 4 663 316.1 | 296 860.2 |

NOTES

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

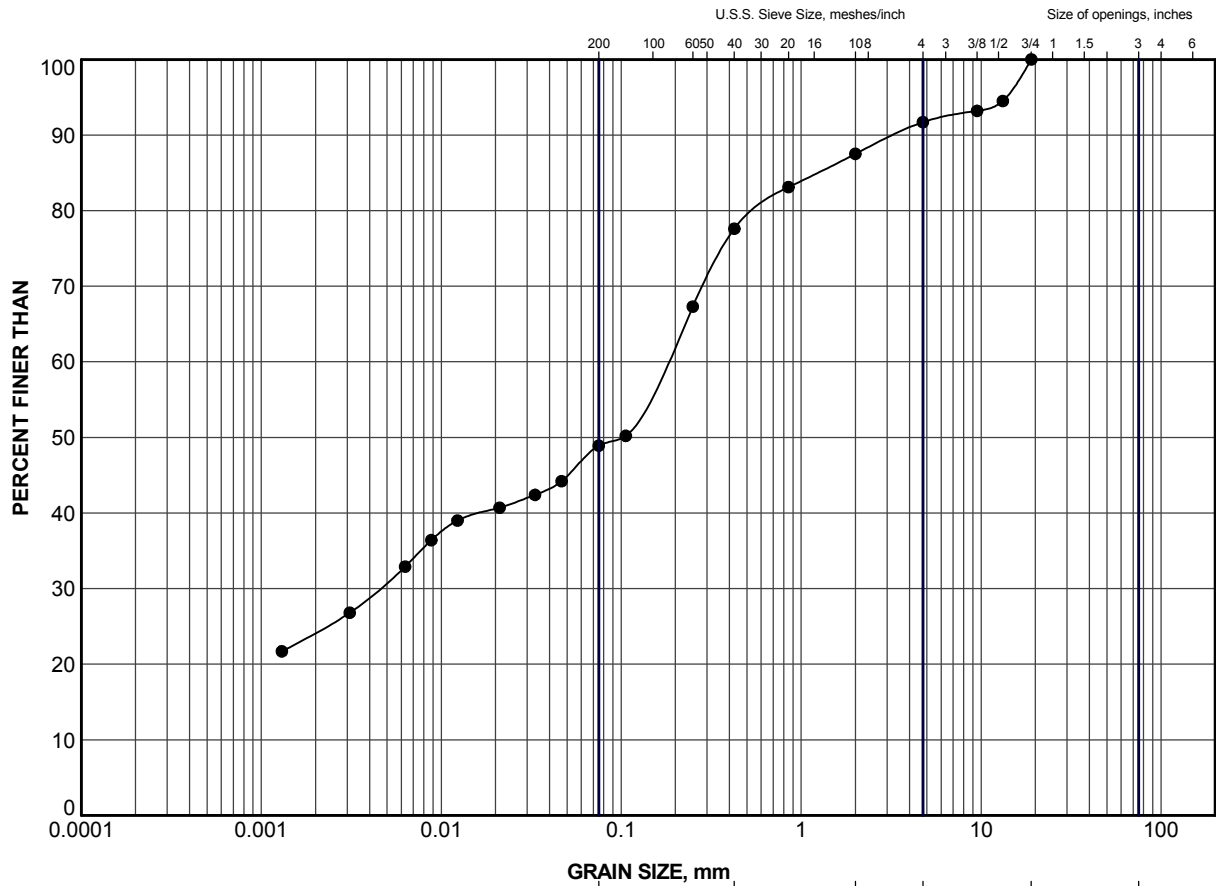
The boundaries between soil strata have been established only at borehole locations. Between boreholes the boundaries are assumed from geological evidence.

REFERENCE

Preliminary base plans provided in digital format by Dillon.

| NO. | DATE | BY | REVISION |
|-------------|-----------|-------------|-----------------|
| Geocres No. | 40J2-108 | | |
| HWY. | 77 | PROJECT NO. | 06-1130-202-0-3 |
| SUBM'D. | DUP | CHKD. | DUP |
| DATE: | Jan. 2/07 | DIST. | SITE: 6-456-C |
| DRAWN: | DCH | CHKD. | DUP |
| APPD. | | DWG. | 1 |

APPENDIX A
LABORATORY TEST DATA



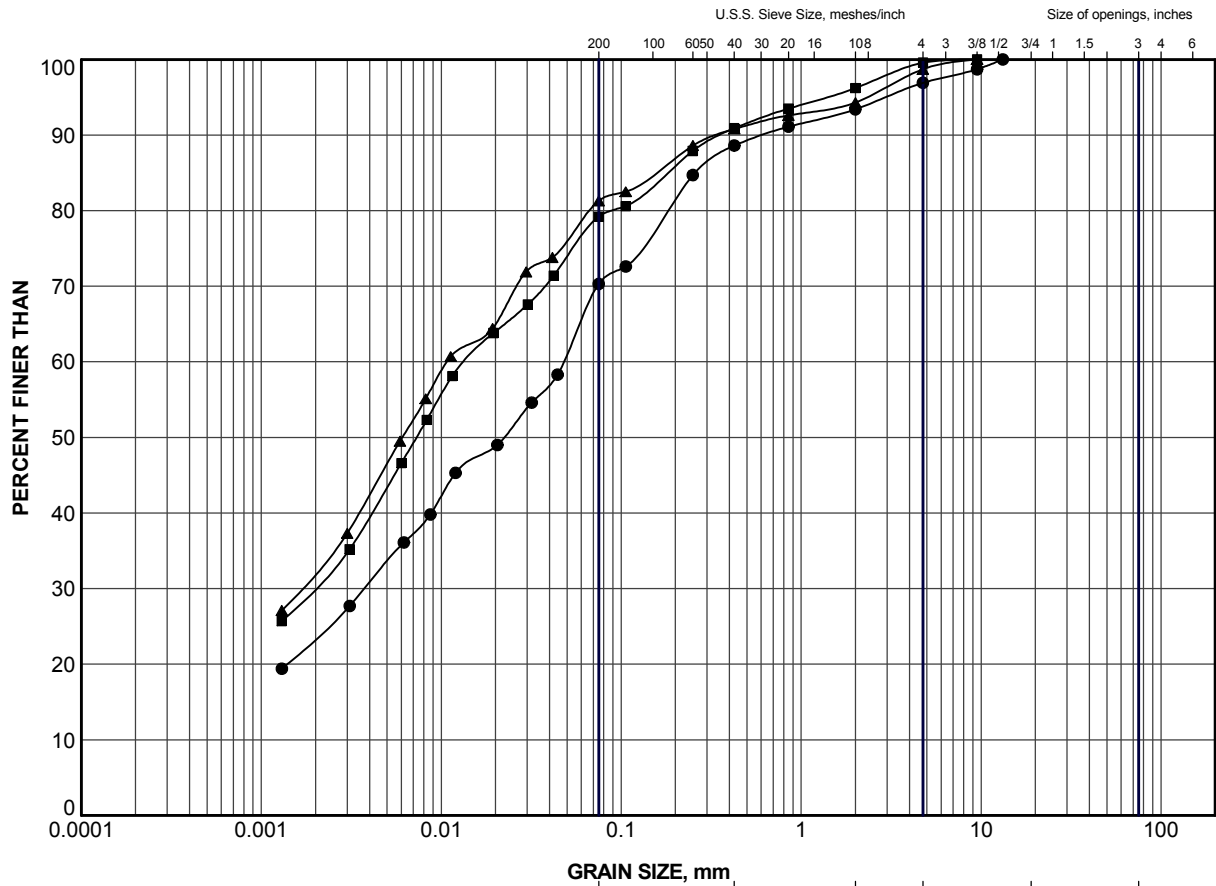
| | | | | | | |
|---------------|-----------|--------|--------|-------------|--------|----------------|
| CLAY AND SILT | fine | medium | coarse | fine | coarse | Cobble Size |
| | SAND SIZE | | | GRAVEL SIZE | | |

LEGEND

| SYMBOL | BOREHOLE | SAMPLE | ELEV (m) |
|--------|----------|--------|----------|
| ● | 5 | 3 | 192.7 |

| | | | | | |
|-----------------------------|--|---|--|------------|------|
| PROJECT | | STRUCTURAL CULVERT 16+257 HIGHWAY 77 REHABILITATION GWP 139-98-00 | | | |
| TITLE | | GRAIN SIZE DISTRIBUTION FILL (clayey silt) | | | |
| PROJECT No. 06-1130-202-0-3 | | FILE No. 0611302020-3-F010A1 | | | |
| DRAWN LMK | | Dec 19/07 | | SCALE N/A | REV. |
| CHECK | | | | FIGURE A-1 | |






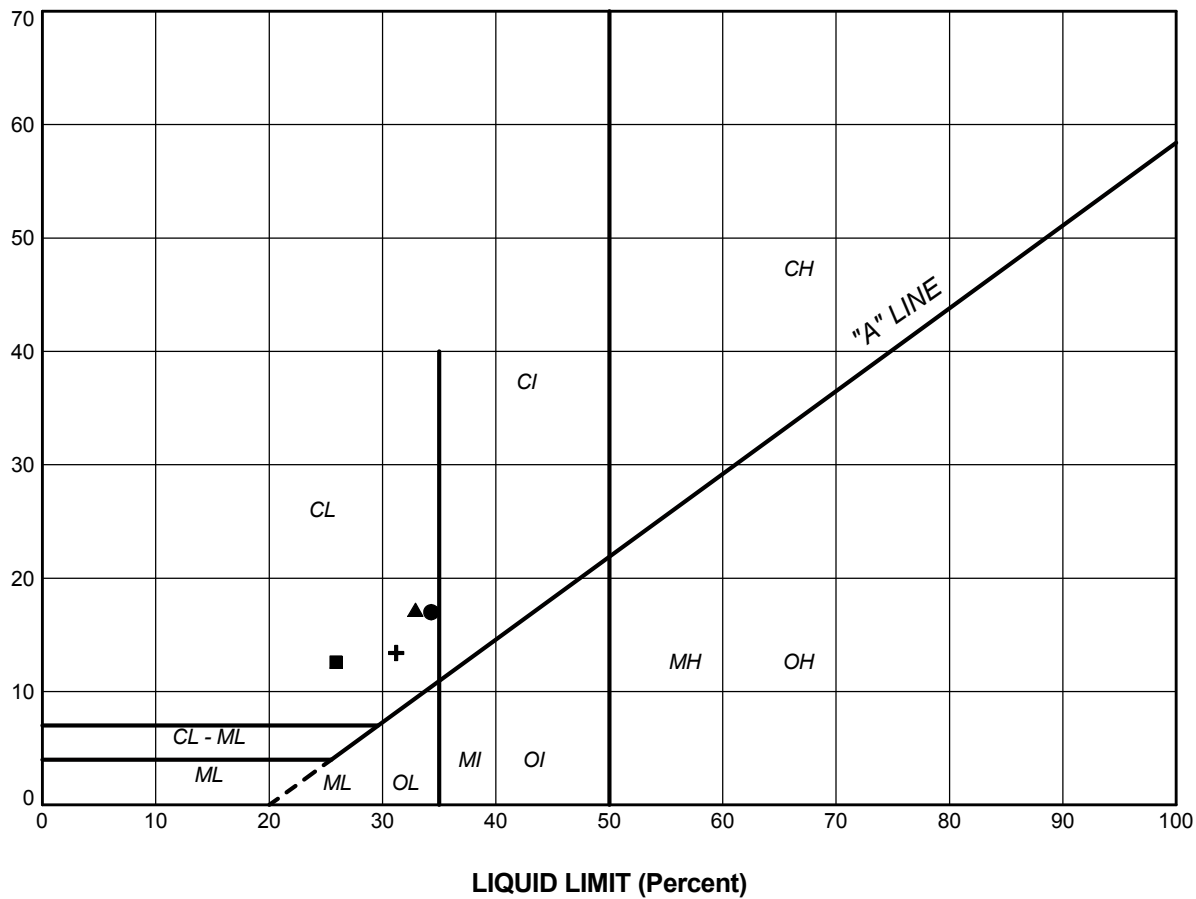
| | | | | | | |
|---------------|-----------|--------|--------|-------------|--------|----------------|
| CLAY AND SILT | fine | medium | coarse | fine | coarse | Cobble Size |
| | SAND SIZE | | | GRAVEL SIZE | | |

LEGEND

| SYMBOL | BOREHOLE | SAMPLE | ELEV (m) |
|--------|----------|--------|----------|
| ● | 4 | 6 | 190.4 |
| ■ | 4 | 8 | 188.9 |
| ▲ | 5 | 5 | 191.2 |

| | | | | |
|---|--|---|--|--|
| PROJECT | | STRUCTURAL CULVERT 16+257 HIGHWAY 77 REHABILITATION GWP 139-98-00 | | |
| TITLE | | GRAIN SIZE DISTRIBUTION CLAYEY SILT | | |
| PROJECT No. 06-1130-202-0-3 | | FILE No. 0611302020-3-F010A2 | | |
| DRAWN LMK | | Dec 19/07 | | |
| CHECK | | | | |
|  Golder Associates LONDON, ONTARIO | | FIGURE A-2 | | |

PLASTICITY INDEX (Percent)




SOIL TYPE
 C = Clay
 M = Silt
 O = Organic

PLASTICITY
 L = Low
 I = Intermediate
 H = High

LEGEND

| SYMBOL | BOREHOLE | SAMPLE | LL(%) | PL(%) | PI |
|-------------|----------|--------|-------|-------|------|
| CLAYEY SILT | | | | | |
| ● | 4 | 6 | 34.3 | 17.3 | 17.0 |
| ■ | 4 | 8 | 25.9 | 13.3 | 12.6 |
| + | 5 | 5 | 31.2 | 17.8 | 13.4 |
| FILL | | | | | |
| ▲ | 5 | 3 | 32.9 | 15.7 | 17.2 |

| | | | |
|---|-----|---|----------------|
| PROJECT | | STRUCTURAL CULVERT 16+257 HIGHWAY 77 REHABILITATION GWP 139-98-00 | |
| TITLE | | PLASTICITY CHART | |
| PROJECT No. 06-1130-202-0-3 | | FILE No. 0611302020-3-F0103A | |
| DRAWN | LMK | Dec 19/07 | SCALE N/A REV. |
| CHECK | | | |
|  Golder Associates LONDON, ONTARIO | | FIGURE A-3 | |

APPENDIX B
SITE PHOTOGRAPHS

SITE PHOTOGRAPHS



Photo 1: Station 16+257. West side (inlet) of Lebo Creek culvert.



Photo 2: Station 16+257. Lebo Creek culvert, looking east from outlet.