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FOUNDATION INVESTIGATION AND DESIGN REPORT CULVERTS HIGHWAY 400 SBL BETWEEN HIGHWAY 11 AND COUNTY ROAD 11 (FORBES ROAD) SIMCOE COUNTY G.W.P. 167-99-00

Submitted to:

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April 2008 06-1111-011-3

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FOUNDATION INVESTIGATION REPORT
CULVERTS

HIGHWAY 400 SBL BETWEEN HIGHWAY 11
AND COUNTY ROAD 11 (FORBES ROAD)
SIMCOE COUNTY
G.W.P. 167-99-00

1.0 INTRODUCTION

Golder Associates Ltd. (Golder) has been retained by Transenco Limited (Transenco) on behalf of the Ministry of Transportation, Ontario (MTO) to provide foundation engineering services in support of the detailed design for the widening of Highway 400 between the Highway 400-11 interchange and County Road 11 (Forbes Road) in Simcoe County, Ontario.

This report addresses the extension or replacement of seven existing culverts located in Vespra Township within the project limits, at the following locations:

- Station 18+560;
- Station 21+150;
- Station 21+422;
- Station 21+754;
- Station 22+448;
- Station 24+103; and
- Station 24+920.

The terms of reference and scope of work for the foundation investigation are outlined in MTO's Terms of Reference dated September 12, 2007, and in Golder's Proposal No. 06-1111-011, dated September 18, 2007.

2.0 SITE DESCRIPTION

The seven culvert sites addressed in this report are located along Highway 400 between Highway 11 and County Road 11 (Forbes Road), in Simcoe County, Ontario. The location, dimensions and type, existing embankment height, and invert elevation for the existing culverts are summarized in the following table.

Culvert Location	*Existing Culvert Dimensions/Type*	*Approximate Embankment Height*	*Invert Elevation*
18+560	1.8 m diameter CSP	3.5 m to 4 m	230.0 m (west) 230.3 m (east)
21+150	1.27 m x 0.79 m CSPA	2.5 m	263.9 m (west) 263.7 m (east)
21+422	1.2 m x 1.2 m concrete box	3.5 m	264.2 m (west)
21+754	1.8 m x 1.5 m open footing	6 m	269.5 m (west)
22+448	1.2 m x 1.2 m concrete box	4 m	277.6 m (west)
24+103	1.8 m x 1.2 m open footing	3.5 m to 4 m	277.0 m (west)
24+920	1.2 m x 1.2 m concrete box	2.5 m to 3 m	278.1 m (west) 278.2 m (east)

In general, the terrain in the vicinity of each of the culvert sites is relatively flat and poorly drained. The natural ground surface in the project area rises toward the north, from about Elevation 230 m to 231 m at the Highway 400-11 interchange, to approximately Elevation 278 m near County Road 11 (Forbes Road). The Highway 400 embankment is approximately 2.5 m to 6 m in height relative to the natural ground surface at the culvert sites.

3.0 INVESTIGATION PROCEDURES

A borehole investigation was carried out in November and December 2007, during which time ten boreholes (Boreholes 2007-36 to 2007-45) were advanced to investigate the subsurface conditions at the culvert locations: in accordance with the Terms of Reference, two boreholes were advanced at each of the culverts at Stations 18+560, 21+150 and 24+920 (one at each end of the existing culvert); a single borehole was advanced at the west end of the four remaining culvert locations. The borehole locations are shown on Drawings 1 and 2.

The boreholes were drilled using truck-mounted, track-mounted and portable drill rigs, supplied and operated by Walker Drilling of Utopia, Ontario. The boreholes were advanced using hollow stem augers (except Borehole 07-44, which was advanced using portable drilling equipment), to depths ranging from 8.1 m to 13.7 m, to extend at least 10 m below the culvert invert or into "100-blow" soil. Soil samples were obtained at 0.75 m and 1.5 m intervals of depth, using a 50 mm outside diameter split-spoon sampler driven by an automatic hammer in accordance with the Standard Penetration Test (SPT) procedure.

The groundwater conditions in the open boreholes were observed during the drilling operations. The boreholes were backfilled to ground surface using bentonite pellets in accordance with Ontario Regulation 128 (amendment to Ontario Regulation 903).

The field work was supervised throughout by a member of Golder's technical staff, who located the boreholes in the field, arranged for the clearance of underground services, supervised the drilling, sampling and in situ testing operations, and logged the boreholes. The samples were identified in the field, placed in appropriate containers, labelled and transported to Golder's geotechnical laboratory in Mississauga, where the samples underwent further visual examination and geotechnical classification testing (water content, Atterberg limits, grain size distribution and organic content). All of the laboratory tests were carried out to MTO and/or ASTM standards as appropriate.

The borehole locations were measured in the field by a member of Golder's technical staff, relative to the existing culverts, and the ground surface elevations at the borehole locations were determined from the digital terrain model for the project. The borehole locations (MTM NAD83 coordinates) and ground surface elevations (referenced to geodetic datum) are summarized in the following table.

Culvert Location	*Borehole Number*	*MTM NAD83 Northing (m)*	*MTM NAD83 Easting (m)*	*Ground Surface Elevation (m)*
Station 18+560	2007-44	4,920,780.9	292,679.1	230.8
	2007-45	4,920,780.6	292,709.0	231.5
Station 21+150	2007-42	4,922,752.6	291,426.0	266.2
	2007-43	4,922,760.3	291,450.3	265.6
Station 21+422	2007-41	4,922,985.3	291,283.2	264.6
Station 21+754	2007-40	4,923,265.0	291,107.6	270.0
Station 22+448	2007-39	4,923,849.0	290,751.4	278.2
Station 24+103	2007-38	4,925,260.4	289,877.1	277.0
Station 24+920	2007-36	4,925,936.4	289,429.5	278.2
	2007-37	4,925,953.0	289,457.4	279.8

4.0 SITE GEOLOGY AND SUBSURFACE CONDITIONS

4.1 Regional Geology

This section of Highway 400 is located within the physiographic region known as the Simcoe Uplands, according to *The Physiography of Southern Ontario*[1].

The general topography within the Simcoe Uplands consists of sloping till (moraine) plains. The surficial soils in this region consist of sandy silt to sand and gravel, representing shoreline deposits of a former glacial lake that once flooded the area, overlying a glacial till deposit. Surficial deposits of clayey silt to silty clay are also present adjacent to current and former streams.

4.2 Subsurface Conditions

The detailed subsurface soil and groundwater conditions encountered in the boreholes and the results of in situ and laboratory testing are given on the borehole records; the results of laboratory testing are also presented on Figures 1 to 13. The stratigraphic boundaries shown on the borehole records, and on the interpreted stratigraphic sections on Drawing 3, are inferred from non-continuous sampling and, therefore, represent transitions between soil types rather than exact planes of geological change. The subsoil conditions will vary between and beyond the borehole locations.

A brief overview of the native soil conditions at each of the seven culverts sites is provided in the following table:

Culvert Location	*Boreholes*	*General Subsurface Conditions*
Station 18+560	2007-44 2007-45	The native soils at this culvert site consist of interlayered deposits of loose to dense silty sand to sandy silt. Interlayers of soft to firm clayey silt, approximately 1.2 m to 1.5 m in thickness, were encountered at shallow depth in both boreholes.
Station 21+150	2007-42 2007-43	The native soils at this culvert site consist of compact to very dense silty sand, to sand, to sand and gravel.
Station 21+422	2007-41	The native soils at this culvert site consist of a thin surficial deposit of very stiff clayey silt, overlying a deposit of dense to very dense sand and silt, underlain by hard clayey silt till and very dense silty sand till.
Station 21+754	2007-40	The native soils at this site consist of a thin surficial deposit of compact sand and gravel, overlying a hard clayey silt till deposit.

[1] Chapman, L.J. and D.F. Putnam. *The Physiography of Southern Ontario*, Ontario Geological Survey Special Volume 2, Third Edition, 1984. Accompanied by Map P.2715, Scale 1:600,000.

Culvert Location	*Boreholes*	*General Subsurface Conditions*
Station 22+448	2007-39	The native soils at this site consist of a thin surficial deposit of loose to compact sand, overlying a deposit of very stiff clayey silt till, in turn underlain by lower deposits of very dense sand and hard silty clay.
Station 24+103	2007-38	The native soils at this site consist of a surficial deposit of stiff to very stiff clayey silt, overlying a deposit of very stiff clayey silt till, in turn underlain by a lower deposit of very dense sand.
Station 24+920	2007-36 2007-37	The native soils at this site consist of surficial deposits of loose to dense silty sand to sand and gravel on the west side of the highway, and stiff to hard clayey silt and compact sand and gravel in the centre median area, all underlain by a deposit of very stiff to hard clayey silt till.

A more detailed description of the soil deposits encountered in the boreholes is provided below. The two southerly culvert sites (Stations 18+560 and 21+150), at which the soils consist predominantly of interlayered cohesionless soils, are addressed in Section 4.2.1. The five culvert sites north of Station 21+300 are addressed together in Section 4.2.2, based on the similarities in the stratigraphy at these sites (i.e., upper deposits of clayey silt and/or silty sand to sand and gravel, overlying a till deposit that is underlain by lower deposits of sand and silty clay).

4.2.1 Culverts at Stations 18+560 and 21+150

4.2.1.1 Topsoil

Approximately 300 mm of topsoil was encountered immediately below the existing ground surface in Borehole 2007-43, in the centre median of the highway at Station 21+150.

4.2.1.2 Fill

Approximately 0.8 m of moist silty sand fill was encountered immediately below the ground surface, extending down to Elevation 230.7 m, in Borehole 2007-45; this borehole was drilled at the embankment toe on the east side of Highway 400 SBL at Station 18+560. The encountered fill is loose, based on one measured SPT “N” value of 5 blows per 0.3 m of penetration.

Approximately 1.5 m and 1.7 m of clayey silt fill was encountered in Boreholes 2007-42 and 2007-43, respectively, which are located on the west and east sides of Highway 400 SBL at Station 21+150. The base of the fill was encountered at Elevations 264.7 m and 263.6 m in these boreholes. The fill at this location consists of moist clayey silt with sand, containing trace gravel; the result of a grain size distribution test completed on one selected sample is shown on Figure 1. Atterberg limits testing was completed on two samples of the cohesive fill; the results, which are plotted on a plasticity chart on Figure 2, confirm that this fill consists of clayey silt of low plasticity. The measured SPT “N” values within the clayey silt fill ranged from 5 to 45 blows per 0.3 m of penetration, indicative of a firm to hard consistency.

4.2.1.3 Sandy Silt to Sand and Gravel

Interlayered cohesionless soils were encountered at both culvert sites underlying the fill, topsoil, or ground surface. The surface of these native soils was encountered at Elevations 230.8 m and 230.7 m in Boreholes 2007-44 and 2007-45 at Station 18+560, and at Elevations 264.7 and 263.6 m in Boreholes 2007-42 and 2007-43 at Station 21+150. The boreholes were terminated within the interlayered cohesionless soils at depths of between 12.7 m and 13.7 m below the ground surface.

The interlayered cohesionless soils vary in composition from sand and gravel, to sand containing trace to some silt, to silty sand, to sand and silt, to sandy silt, typically containing trace gravel. The results of grain size distribution tests completed on ten selected samples of these interlayered cohesionless soils are presented on Figures 3A and 3B.

At Station 18+450, the measured SPT "N" values within the cohesionless soils ranged from 1 to 30 blows per 0.3 m of penetration, but were generally greater than 5 blows per 0.3 m of penetration, indicative of a loose to compact relative density. At Station 21+150, the measured SPT "N" values ranged from 27 to 122 blows per 0.3 m of penetration, indicative of a compact to very dense relative density; however, the majority of the deposit at this location is very dense.

4.2.1.4 Clayey Silt

Interlayers of clayey silt, 1.2 m to 1.5 m in thickness, were encountered in Boreholes 2007-44 and 2007-45 at Station 18+560. The surface of the clayey silt was encountered at a depth of 2.3 m (Elevation 228.5 m) in Borehole 2007-44 on the west side of Highway 400 SBL, and at depths of 2.3 m (Elevation 229.2 m) and 4.6 m (Elevation 226.9 m) in Borehole 2007-45 on the east side of Highway 400 SBL.

These interlayers consists of clayey silt containing trace to some sand; silty sand seams were observed within the sample recovered from the lower layer in Borehole 2007-45. The results of grain size distribution tests completed on two selected samples of these interlayers are shown on Figure 4. Atterberg limits testing was completed on three samples, and measured plastic limits of 13 to 15 per cent, liquid limits of 27 to 29 per cent, and plasticity indices of 12 to 16 per cent; these results, which are plotted on a plasticity chart on Figure 5, confirm that these interlayers consist of low plasticity clayey silt.

The measured SPT "N" values within the clayey silt interlayers ranged from 2 to 7 blows per 0.3 m of penetration, indicative of a soft to firm consistency.

4.2.2 Culverts North of Station 21+300

4.2.2.1 Topsoil

Approximately 100 to 200 mm of topsoil was encountered immediately below the existing ground surface in Boreholes 2007-36 (at Station 24+920) and 2007-39 (at Station 22+448).

4.2.2.2 Fill

Approximately 0.6 m to 1.5 m of fill was encountered in Boreholes 2007-37, 2007-38, 2007-40 and 2007-41, which were advanced near the west toe of the Highway 400 SBL embankment or within the centre median area. The base of the fill was encountered at the following depths and elevations:

Culvert Location	*Borehole No.*	*Depth of Base of Fill*	*Elevation of Base of Fill*
Station 21+422	2007-41	1.5 m	263.1 m
Station 21+754	2007-40	1.5 m	268.5 m
Station 24+103	2007-38	0.6 m	276.4 m
Station 24+920	2007-37	1.5 m	278.3 m

The encountered fill varied in composition from silty sand containing trace clay and trace to some gravel, to sand containing some silt, trace clay and trace gravel; cobbles and organics were observed at some of the borehole locations, as noted on the borehole records.

The measured SPT "N" values within the fill ranged from 6 to 18 blows per 0.3 m of penetration, indicative of a loose to compact relative density.

4.2.2.3 Upper Clayey Silt

An upper deposit of clayey silt, between 0.8 m and 2.5 m in thickness, was encountered immediately below the fill in Borehole 2007-37, 2007-38 and 2007-41. The surface of the upper clayey silt deposit was encountered at the following depths and elevations:

Culvert Location	*Borehole No.*	*Depth to Surface of Upper Clayey Silt*	*Elevation of Surface of Upper Clayey Silt*
Station 21+422	2007-41	1.5 m	263.1 m
Station 24+103	2007-38	0.6 m	276.4 m
Station 24+920	2007-37	1.5 m	278.3 m

This upper cohesive deposit consists of clayey silt containing trace to some sand and trace gravel; sand and silty sand seams were noted within this deposit in Boreholes 2007-37 and 2007-41, and trace quantities of organic matter were observed in some of the recovered samples. The results of grain size distribution tests carried out on three samples of the upper clayey silt deposit are shown on Figure 6. Atterberg limits testing was conducted on three selected samples of the upper clayey silt deposit and measured plastic limits of 11 to 18 per cent, liquid limits of 22 to 31 per cent, and plasticity indices of 11 to 14 per cent; Atterberg limits testing was also completed on one sample of a clayey silt interlayer within the upper silty sand to sand and gravel deposit (see Section 4.2.2.4) from Borehole 2007-41, and measured a plastic limit of 10 per cent, a liquid limit of 15 per cent, and a plasticity index of 5 per cent. These test results, which are plotted on a plasticity chart on Figure 7, confirm that the upper cohesive deposit and interlayer consist of clayey silt of low plasticity.

The measured SPT "N" values within the upper clayey silt deposit ranged from 9 to 37 blows per 0.3 m of penetration, indicative of a stiff to hard consistency.

4.2.2.4 Upper Sand and Silt to Sand and Gravel

An upper deposit of cohesionless soils was encountered below the topsoil, fill and/or upper clayey silt deposit at all the culvert sites north of Station 21+300, except at Station 24+103 (Borehole 2007-38). This upper deposit is between 0.8 m and 4.2 m in thickness. The surface of the upper cohesionless deposit was encountered at the following depths and elevations in the boreholes:

Culvert Location	*Borehole No.*	*Depth to Surface of Deposit*	*Elevation of Surface of Deposit*
Station 21+422	2007-41	2.3 m	262.3 m
Station 21+754	2007-40	1.5 m	268.5 m
Station 22+448	2007-39	0.2 m	278.0 m
Station 24+920	2007-36 2007-37	0.1 m 3.8 m	278.1 m 276.0 m

This upper deposit varies in composition from sand and silt, to silty sand to sand containing some silt and trace gravel, to sand and gravel containing trace to some silt. Seams or thin interlayers of clayey silt were observed in recovered samples from Boreholes 2007-36 and 2007-41, as noted on the borehole records. The results of grain size distribution tests carried out on six selected samples of the upper cohesionless deposit are shown on Figure 8. As discussed in Section 4.2.2.3, Atterberg limits testing was conducted on one sample of the clayey silt interlayer encountered within the sand and silt in Borehole 2007-41, and the result for this test is plotted on the plasticity chart on Figure 7.

The measured SPT "N" values within the upper sand and silt to sand and gravel deposit ranged from 5 to 57 blows per 0.3 m of penetration. The lowest SPT "N" values of 5 to 10 blows per 0.3 m of penetration were measured immediately below the topsoil in Boreholes 2007-36 and 2007-39, indicating that the upper portion of the deposit at these two locations has a loose relative density. In general, however, this upper deposit has a compact to dense relative density, except within the sand and silt in Borehole 2007-41 (Station 21+422), where the deposit has a dense to very dense relative density.

4.2.2.5 Clayey Silt Till to Silty Sand Till

A till deposit was encountered below the upper clayey silt and/or upper sand and silt to sand and gravel deposits in all of the boreholes at the five culvert sites north of Station 21+300. The till deposit was only fully penetrated in Borehole 2007-38 (at Station 24+103) and 2007-39 (at Station 22+448); the deposit is 3.0 m and 6.1 m in thickness, respectively, at these locations. All of the other boreholes were terminated within the till deposit, which had a thickness of at least 5.8 m to 8.1 m at these locations. The surface of the till deposit was encountered at the following depths and elevations in the boreholes:

Culvert Location	*Borehole No.*	*Depth to Surface of Till Deposit*	*Elevation of Surface of Till Deposit*
Station 21+422	2007-41	6.1 m	258.5 m
Station 21+754	2007-40	2.3 m	267. 7 m
Station 22+448	2007-39	1.5 m	276.7 m
Station 24+103	2007-38	3.1 m	274.0 m
Station 24+920	2007-36 2007-37	4.3 m 4.6 m	273.9 m 275.2 m

The till deposit generally consists of clayey silt with sand to some sand, and trace gravel; however, the lower portion of the till in Borehole 2007-41 grades to silty sand containing trace clay and gravel. The results of grain size distribution tests on five selected samples of the clayey silt till deposit, plus one selected sample of the silty sand till deposit from Borehole 2007-41, are shown on Figure 9. Atterberg limits testing was carried out on nine selected samples of the till deposit, and measured plastic limits of 9 to 15 per cent, liquid limits of 14 to 30 per cent, and plasticity indices of 5 to 17 per cent; these test results, which are plotted on a plasticity chart on Figure 10, confirm that the till generally consists of low plasticity clayey silt.

The measured SPT “N” values within the clayey silt till deposit ranged from 15 to greater than 100 blows per 0.3 m of penetration, indicative of a very stiff to hard (and generally hard) consistency. The measured SPT “N” values within the silty sand till in Borehole 2007-41 ranged from 51 to 88 blows per 0.3 m of penetration and 60 blows per 0.15 m of penetration, indicative of a very dense relative density.

4.2.2.6 Lower Sand

A lower sand deposit was encountered below the till deposit in Boreholes 2007-38 and 2007-39 (at Stations 22+448 and 24+103, respectively). The surface of the deposit was encountered at a depth of 6.1 m (Elevation 270.9 m) and 7.6 m (Elevation 270.6 m) in these boreholes, respectively. The lower sand was fully penetrated in Boreholes 2007-39, where the deposit is

3.1 m in thickness; Boreholes 2007-38 was terminated within the lower sand, which had a thickness of at least 6.4 m at this location.

The lower sand deposit contains trace to some silt, trace clay and trace gravel. The results of grain size distribution tests completed on two selected samples of the lower sand deposit are shown on Figure 11.

The measured SPT "N" values within the lower sand deposit were all greater than 100 blows per 0.3 m of penetration, indicative of a very dense relative density.

4.2.2.7 Lower Silty Clay

A lower silty clay deposit was encountered at a depth of 10.7 m (Elevation 267.5 m), below the lower sand deposit in Borehole 2007-39, which is located at Station 24+448. The borehole was terminated within this deposit, which has a thickness of at least 2.0 m.

The lower silty clay contains trace sand, as well as sand seams. The result of a grain size distribution test carried out on one selected sample of the lower silty clay deposit is shown on Figure 12. Atterberg limits testing was completed on one sample of the lower cohesive deposit, and measured a plastic limit of 16 per cent, a liquid limit of 39 per cent, and a plasticity index of 23 per cent; this result, which is plotted on a plasticity chart on Figure 13, confirms that the lower cohesive deposits consists of medium plasticity silty clay.

The measured SPT "N" values within the lower silty clay deposit were 62 and 138 blows per 0.3 m of penetration, indicative of a hard consistency.

4.2.3 Groundwater Conditions

Based on the observed soil moisture conditions, changes in colour from brown to grey, and the observed water levels in the open boreholes following completion of drilling, the estimated groundwater depths and elevations at the culvert sites are summarized as follows:

Culvert Location	*Borehole No(s).*	*Depth to Groundwater*	*Groundwater Elevation*
Station 18+560	2007-44 2007-45	0.0 m	230.8 m
Station 21+150	2007-42 2007-43	Approximately 4 m to 5 m below o.g.*	260.0 m*
Station 21+422	2007-41	5.6 m*	259.0 m*
Station 21+754	2007-40	1.2 m	268.8 m
Station 22+448	2007-39	1.2 m	277.0 m
Station 24+103	2007-38	-	-
Station 24+920	2007-36 2007-37	Approximately 1.5 m below o.g.	276.7 m

* Although the groundwater table is deeper at these culvert locations, shallow "perched" water conditions may be encountered on top of clayey silt layers, where present.

The groundwater level at the culvert will be subject to seasonal fluctuations, and will be higher during wet periods of the year (i.e. during spring conditions).

5.0 CLOSURE

This Foundation Investigation Report was prepared by Ms. Beng Lay Teh, and reviewed by Ms. Lisa Coyne, P.Eng., an Associate and geotechnical engineer with Golder. Mr. Fin Heffernan, P.Eng., a Designated MTO Contact for Golder, conducted an independent quality control review of the report.

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PART B

FOUNDATION DESIGN REPORT
CULVERTS

HIGHWAY 400 SBL BETWEEN HIGHWAY 11
AND COUNTY ROAD 11 (FORBES ROAD)
SIMCOE COUNTY
G.W.P. 167-99-00

6.0 DISCUSSION AND ENGINEERING RECOMMENDATIONS

6.1 General

This section of the report provides foundation design recommendations for the proposed extension or replacement of seven culverts located along the Highway 400 southbound lanes between Highway 11 and County Road 11 (Forbes Road). The recommendations are based on interpretation of the factual data obtained from the boreholes advanced during the subsurface investigation for these culvert sites. The interpretation and recommendations are intended to provide the designers with sufficient information to assess the feasible foundation alternatives and to design the foundations for the proposed culvert extensions or replacements. Where comments are made on construction, they are provided in order to highlight those aspects that could affect the design of the project, and for which special provisions or operational constraints may be required in the Contract Documents. 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, scheduling and the like.

Extension, or replacement, of seven existing culverts is proposed; details regarding each of these existing culverts and the proposed extensions or replacements are provided in the following table:

Culvert Location	*Existing Culvert Dimensions/Type*	*Approximate Embankment Height*	*Existing Culvert Invert Elevation*	*Proposed Extension*	*Proposed Replacement*
18+560	1.8 m diameter CSP	3.5 m to 4 m	230.0 m (west) 230.3 m (east)	3.0 m west 2.6 m east	-
21+150	1.27 m x 0.79 m CSPA	2.5 m	263.9 m (west) 263.7 m (east)	-	1.83 m x 0.91 m CSPA
21+422	1.2 m x 1.2 m concrete box	3.5 m	264.2 m (west)	3.0 m west	-
21+754	1.8 m x 1.5 m open footing	6 m	269.5 m (west)	6.0 m west	-
22+448	1.2 m x 1.2 m concrete box	4 m	277.6 m (west)	2.5 m west	-
24+103	1.8 m x 1.2 m open footing	3.5 m to 4 m	277.0 m (west)	3.5 m west	-
24+920	1.2 m x 1.2 m concrete box	2.5 m to 3 m	278.1 m (west) 278.2 m (east)	1.5 m west	1.2 m x 1.2 m

6.1.1 Foundation Options

Sections 6.2.1 to 6.8.1 discuss the foundation options for each of the proposed culvert extensions or replacements. In general, either open footing or box culvert extensions are feasible from a foundations perspective for all of the culvert sites, and the choice of foundation type for the extension or replacement can generally be determined on the basis of fisheries or structural requirements and compatibility with the existing culvert type. Deep foundations are not required for any of the culvert sites, since shallow foundations will provide sufficient bearing resistance and satisfactory settlement performance under the widened embankment loading.

6.1.2 Founding Elevations and Subexcavation Requirements

Sections 6.2.2 to 6.8.2 provide recommendations regarding founding elevations and subexcavation requirements for the proposed culvert extensions or replacements.

Strip footings for all open footing culvert extensions or for replacements, and for any associated wing walls/retaining walls, should be founded at a minimum depth of 1.6 m below the lowest surrounding grade, to provide adequate protection against frost penetration. If water will flow through the culvert year-round, frost protection for the culvert footings is not necessary; adequate frost protection for the wing wall/retaining wall footings would still be required.

Based on the subsoil conditions encountered in the boreholes, subexcavation is recommended for some of the culvert extension/replacement locations, in order to found the footings or base slab on suitable material. The width of the required subexcavation should be defined by lines extending from the outside edges of the culvert footing or base slab outward and downward at 1 horizontal to 1 vertical (1H:1V). Depending on the depth of subexcavation required relative to the base of the existing box culvert or footings, some temporary excavation support may be required to prevent loss of bedding material and/or native soils from below the existing culvert during subexcavation. The subgrade should be inspected following subexcavation to ensure that all existing fill, peat and surficial organic soils or other unsuitable material have been removed, then the subexcavated area should be backfilled with granular material meeting Ontario Provincial Standard Specification (OPSS) Granular A or Granular B Type II, that is placed and compacted in accordance with the requirements of MTO’s Special Provision SP105S10.

6.1.3 Geotechnical Resistance

Sections 6.2.3 to 6.8.3 provide recommendations regarding the factored geotechnical resistances at Ultimate Limit State (ULS) and the geotechnical resistances at Serviceability Limit State (SLS) for each of the culvert sites.

6.1.4 Resistance to Lateral Loads / Sliding Resistance

Sections 6.2.4 to 6.8.4 provide recommendations regarding the resistance to lateral loads / sliding resistance between cast-in-place concrete footings or pre-cast concrete box culvert sections and the subgrade soils or, where applicable, granular backfill placed following applicable subexcavation.

6.1.5 Settlement

Sections 6.2.5 to 6.8.5 provide discussion regarding the predicted settlement under the additional loading due to embankment widening at each of the culvert sites. In order to estimate the magnitude of settlement, analyses were carried out for each site using hand calculations and/or the commercially-available program Unisettle (V3.0).

6.2 Culvert at Station 18+560

6.2.1 Foundation Options

The existing culvert at Station 18+560 is a 1.8 m diameter corrugated steel pipe (CSP) that is to be extended approximately 3.0 m west and 2.3 m east. Both open footing culvert extensions and box culvert extensions are acceptable options from a geotechnical perspective. The use of open footing culvert extensions at this site would require some subexcavation and more groundwater control, but would allow the extensions to be founded below the relatively thin soft to firm clayey silt deposit; on the other hand, box culvert extensions would require less excavation and groundwater control, and would be able to tolerate the relatively limited predicted magnitude of settlement. Recommendations for box culvert and open footing foundation options are provided in Sections 6.2.2 to 6.2.5 below.

It is understood that CSP extensions (to match the existing culvert) may be preferred, in which case reference should be made to the discussion regarding groundwater control in Section 6.2.2, settlement under the embankment widening in Section 6.2.5, and the pipe manufacturer's requirements regarding bedding and backfill together with the recommendations presented in Section 6.9.

6.2.2 Founding Elevations, Subexcavation and Groundwater Control Requirements

Open Footing Culvert Extensions and Wing Walls/Retaining Walls

The invert/creek bed for the existing culvert is at approximately Elevation 230.0 m and 230.3 m at the west and east ends, respectively. To provide for a minimum of 1.6 m of soil cover for frost protection, strip footings would have to be founded at or below Elevation 228.4 m and 228.7 m at the west and east ends, respectively; however, the subsoils at this level consist of soft to firm clayey silt. The following subexcavation depths and founding elevations are recommended to found footings below the soft to firm clayey silt on the compact sand and silt; alternatively, following subexcavation to the recommended depth, the excavation can be backfilled with engineered fill and the footings constructed at the minimum depth for frost protection purposes.

Culvert Extension	*Culvert Invert*	*Depth of Subexcavation**	*Footing Founding Level*
West	230.0 m	2.7 m	227.3 m
East	230.3 m	2.6 m	227.7 m

* Below culvert invert level.

Box Culvert

A box culvert extension can be founded on the loose to compact silty sand to sandy silt deposit. Assuming that the base slab for box culvert extensions has a thickness of 400 mm, the following founding elevations would apply:

Culvert Extension	*Culvert Invert*	*Base Slab Founding Level*
West	230.0 m	229.6 m
East	230.3 m	229.9 m

Groundwater control will be required for excavation and construction of strip footings or box culverts for the culvert extensions at this site. As discussed further in Section 6.11 (Construction Considerations), it is recommended that a Non-Standard Special Provision (NSSP) be included in the Contract Documents to address groundwater control requirements for all of the culvert sites.

The sand and silt subgrade for the footings will be susceptible to loosening and degradation on exposure to water and construction traffic. As discussed further in Section 6.11 (Construction Considerations), it is recommended that a 100 mm thick layer of lean mix concrete or mass concrete be placed on the inspected and approved subgrade, to protect the subgrade from this degradation and form a working mat for construction of the culvert extensions. If box culvert extensions are adopted, it is recommended that a 75 mm thick levelling pad of Granular A or fine aggregate (meeting the gradation requirements set out in OPSS 1002) be provided on top of the lean concrete mat.

6.2.3 Geotechnical Resistance

The ULS and SLS resistances for open footing or box culvert extensions are dependent on the footing size, configuration and applied loads; the geotechnical resistances should, therefore, be reviewed if the selected footing width or founding elevation differ significantly from those given in this report.

Open Footing Culvert and Wing Walls/Retaining Walls

Assuming that the existing soils within the loading footprint are subexcavated as outlined in Sections 6.1.2 and 6.2.2, strip footings placed on the properly prepared subgrade should be designed based on a factored geotechnical resistance at ULS of 225 kPa, and a geotechnical resistance at SLS (for 25 mm of settlement) of 150 kPa. These recommendations are based on an assumed footing width of 0.6 m.

The geotechnical resistances provided are given under the assumption that the loads will be applied perpendicular to the surface of the footings. Where the load is not applied perpendicular to the surface of the footing, inclination of the load should be taken into account in accordance with the *Canadian Highway Bridge Design Code (CHBDC).*

Box Culvert

Box culvert extensions constructed on the prepared and approved subgrade at the founding elevations given in Section 6.2.2 should be designed based on a factored geotechnical resistance at ULS of 125 kPa, and a geotechnical resistance at SLS (for 25 mm of settlement) of 100 kPa. These recommendations are based on an assumed box culvert extension span of 1.8 m.

6.2.4 Resistance to Lateral Loads / Sliding Resistance

Resistance to lateral forces / sliding resistance between the concrete footings or base slab for the culvert extensions and the subgrade should be calculated in accordance with Section 6.7.5 of the *CHBDC*. For cast-in-place concrete footings founded on the compact sand and silt, the coefficient of friction, tan ϕ', should be taken as 0.5; for cast-in-place concrete footings founded on a compacted Granular A pad, the coefficient of friction should be taken as 0.6. For pre-cast concrete box culvert sections founded on the loose to compact silty sand to sandy silt, the coefficient of friction should be taken as 0.4. These values are unfactored; in accordance with the *CHBDC*, a factor of 0.8 is to be applied in calculating the horizontal resistance.

6.2.5 Settlement

The widening of the Highway 400 SBL embankment at this location will require placement of a thickness of approximately 0.5 m and 1 m of additional fill, respectively, on the existing west and east embankment side slopes. The settlement of the founding soils under this embankment widening has been estimated using the elastic deformation moduli and consolidation parameters given below, based on correlations with the SPT "N" values and Atterberg limits.

Soil Deposit	*Bulk Unit Weight*	*Elastic Modulus*	*Pc'*	*Cc/Cr*
Embankment fill	21 kN/m^3	-	-	-
Loose to compact upper cohesionless soils	19 kN/m^3	10 MPa	-	-
Soft to firm clayey silt	20 kN/m^3	-	40 kPa	0.2 / 0.02
Compact to dense lower cohesionless soils	20 kN/m^3	30 MPa	-	-

The settlement of the foundation soils under the 0.5 m to 1 m of additional fill that will be placed on the existing embankment side slopes is estimated to be approximately 30 mm to 35 mm, decreasing to approximately 10 mm under the shoulder of the existing embankment and at the toe of the widened embankment. The connection between the existing culvert and its extensions should be designed to accommodate this magnitude of settlement.

6.3 Culvert at Station 21+150

6.3.1 Foundation Options

The existing 1.27 m x 0.79 m corrugated steel pipe arch (CSPA) at Station 21+150 is to be replaced by a 1.83 m x 0.91 m CSPA. Geotechnical recommendations for strip footings to support a CSPA or concrete open footing culvert are provided in the following sections, along with recommendations for a box culvert replacement as an alternative to a CSPA replacement. Both options are feasible from a foundations perspective.

6.3.2 Founding Elevations, Subexcavation and Groundwater Control Requirements

Open Footing Culvert and Wing Walls/Retaining Walls

An open footing culvert replacement, and any associated wing walls/retaining walls, should be founded on strip footings extended below the existing embankment fill and any surficial organic materials, on the compact to very dense silty sand to sand and gravel. For design, strip footings should be founded at or below the following elevations; the footings may be stepped or sloped between the west and east ends.

Culvert Location	*Culvert Invert*	*Footing Founding Level*
West	263.9 m	262.3 m
East	263.7 m	262.1 m

If water is expected to flow through the culvert on a year-round basis, the footings can be founded higher, at or below Elevation 263.6 m on the west end and at or below Elevation 263.4 m on the east end, with the actual founding depth determined on the basis of creek flow and scour conditions as assessed by the structural and hydraulic engineers.

Box Culvert

A box culvert replacement should be founded below the existing fill and any surficial organic deposits, to be supported on the compact to very dense silty sand to sand and gravel deposit.

Assuming that the base slab for box culvert extensions has a thickness of 400 mm, the following founding elevations would apply:

Culvert Extension	*Culvert Invert*	*Base Slab Founding Level*
West	263.9 m	263.5 m
East	263.7 m	263.3 m

Groundwater control will be required for excavation and construction of strip footings or a box culvert for the culvert replacement at this site. As discussed further in Section 6.11 (Construction Considerations), it is recommended that a Non-Standard Special Provision (NSSP) be included in the Contract Documents to address groundwater control requirements for all of the culvert sites.

The silty sand portion of the subgrade will be susceptible to loosening and degradation on exposure to water and construction traffic. As discussed further in Section 6.11 (Construction Considerations), it is recommended that a 100 mm thick layer of lean mix concrete or mass concrete be placed on the inspected and approved subgrade, to protect the subgrade from this degradation and form a working mat for construction of the culvert replacement. If a box culvert replacement is adopted, it is recommended that a 75 mm thick levelling pad of Granular A or fine aggregate (meeting the gradation requirements set out in OPSS 1002) be provided on top of the lean concrete mat.

6.3.3 Geotechnical Resistance

The ULS resistance and settlement for open footing and box culvert replacements are dependent on the footing size, configuration and applied loads; the geotechnical resistances should, therefore, be reviewed if the selected footing width or founding elevation differs significantly from those given in the following sections.

Open Footing Culvert and Wing Walls/Retaining Walls

Strip footings placed on the properly prepared subgrade, at the elevations recommended in Section 6.3.2, should be designed based on a factored geotechnical resistance at ULS of 275 kPa, and a geotechnical resistance at SLS (for 25 mm of settlement) of 200 kPa. These recommendations are based on an assumed footing width of 0.6 m.

The geotechnical resistances provided are given under the assumption that the loads will be applied perpendicular to the surface of the footings. Where the load is not applied perpendicular to the surface of the footing, inclination of the load should be taken into account in accordance with the *CHBDC*.

Box Culvert

Box culvert extensions constructed on the prepared and approved subgrade at the founding elevations given in Section 6.3.2 should be designed based on a factored geotechnical resistance at ULS of 200 kPa, and a geotechnical resistance at SLS (for 25 mm of settlement) of 150 kPa. These recommendations are based on an assumed box culvert extension span of 1.8 m.

6.3.4 Resistance to Lateral Loads / Sliding Resistance

Resistance to lateral forces / sliding resistance between the concrete footings or base slab for the culvert extension or culvert replacement and the subgrade should be calculated in accordance with Section 6.7.5 of the *CHBDC*. For cast-in-place concrete footings founded on the compact to very dense silty sand to sand and gravel, the coefficient of friction, tan ϕ', can be taken as 0.55. For pre-cast concrete box culvert sections founded on the compact to very dense silty sand to sand and gravel, the coefficient of friction, tan δ, can be taken as 0.4. These values are unfactored; in accordance with the *CHBDC*, a factor of 0.8 is to be applied in calculating the horizontal resistance.

6.3.5 Settlement

No grade raise or embankment widening is planned at this culvert site; therefore, no additional settlement is predicted following the replacement of the existing culvert and restoration of the existing embankment.

6.4 Culvert at Station 21+422

6.4.1 Foundation Options

The existing 1.2 m wide x 1.2 m high concrete box culvert at Station 21+422 is to be extended approximately 4.0 m west. Although either an open footing or a box culvert extension is feasible from a geotechnical perspective, it is understood that a box culvert extension (to match the existing concrete box culvert) is preferred. Geotechnical recommendations for both open footing and box culvert extension options are provided in the following sections.

6.4.2 Founding Elevations, Subexcavation and Groundwater Control Requirements

Open Footing Culvert and Wing Walls/Retaining Walls

An open footing culvert extension, and any associated wing walls/retaining walls, should be founded on strip footings extended below the existing fill and any organic soils. The invert/creek bed of the existing culvert is at approximately Elevation 264.2 m at the west end of the existing culvert; footings for the west extension should, therefore, be founded at or below Elevation 262.6 m on the very stiff clayey silt, to provide adequate protection against frost penetration. If water will flow through the culvert year-round, the footings can be founded higher, at or below Elevation 263.1 m (to extend below the fill and organic soils), with the actual founding depth determined on the basis of creek flow and scour conditions as assessed by the structural and hydraulic engineers.

Box Culvert

A box culvert extension should be founded below any existing fill and surficial organic soils. Based on the invert/creek bed of the existing culvert at approximately Elevation 264.2 m, and assuming that the base slab for the extension would have a thickness of 400 mm, a box culvert extension would have to be founded at or below Elevation 263.8 m. However, since embankment fill was encountered in Borehole 2007-41 down to Elevation 263.1 m, it is recommended that subexcavation be carried out down to Elevation 263.1 m. The subexcavation can be replaced with a compacted Granular A or Granular B Type II pad prior to construction of the box culvert extension.

Groundwater control will be required for excavation and construction of strip footings or a box culvert for the westward culvert extension at this site. As discussed further in Section 6.11 (Construction Considerations), it is recommended that a Non-Standard Special Provision (NSSP) be included in the Contract Documents to address groundwater control requirements for all of the culvert sites.

The clayey silt subgrade will be susceptible to softening and degradation on exposure to water and construction traffic. As discussed further in Section 6.11 (Construction Considerations), it is recommended that a 100 mm thick layer of lean mix concrete or mass concrete be placed on the inspected and approved subgrade, to protect the subgrade from this degradation and form a working mat for construction of the culvert extension. If a box culvert extension is adopted, it is recommended that a 75 mm thick levelling pad of Granular A or fine aggregate (meeting the gradation requirements set out in OPSS 1002) be provided on top of the lean concrete mat.

6.4.3 Geotechnical Resistance

The ULS resistance and settlement for open footing and box culvert extensions are dependent on the footing size, configuration and applied loads; the geotechnical resistances should, therefore, be reviewed if the selected footing width or founding elevation differs significantly from those given in the following sections.

Open Footing Culvert and Wing Walls/Retaining Walls

Strip footings placed on the properly prepared subgrade, at the elevation recommended in Section 6.4.2, should be designed based on a factored geotechnical resistance at ULS of 200 kPa, and a geotechnical resistance at SLS (for 25 mm of settlement) of 150 kPa. These recommendations are based on an assumed footing width of 0.6 m.

The geotechnical resistances provided are given under the assumption that the loads will be applied perpendicular to the surface of the footings. Where the load is not applied perpendicular to the surface of the footing, inclination of the load should be taken into account in accordance with the *CHBDC*.

Box Culvert

Assuming that subexcavation and placement of engineered fill is completed as discussed in Sections 6.1.2 and 6.4.2, a box culvert extension at this site should be designed based on a factored geotechnical resistance at ULS of 175 kPa, and a geotechnical resistance at SLS (for 25 mm of settlement) of 125 kPa. These recommendations are based on an assumed box culvert extension span of 1.2 m.

6.4.4 Resistance to Lateral Loads / Sliding Resistance

Resistance to lateral forces / sliding resistance between the concrete footings or base slab for the culvert extension and the subgrade should be calculated in accordance with Section 6.7.5 of the *CHBDC*. For cast-in-place concrete footings founded on the very stiff clayey silt, the coefficient of friction, tan ϕ', can be taken as 0.5. For a pre-cast concrete box culvert section placed on a compacted Granular A or Granular B Type II pad following subexcavation as identified in Section 6.4.2, the coefficient of friction, tan δ, can also be taken as 0.5. These values are unfactored; in accordance with the *CHBDC*, a factor of 0.8 is to be applied in calculating the horizontal resistance.

6.4.5 Settlement

The widening of the Highway 400 SBL embankment at this location will require placement of a thickness of approximately 1 m of additional fill on the existing west embankment side slope. The settlement of the founding soils under this widening has been estimated using the elastic deformation moduli given below, based on correlations with the SPT "N" values.

Soil Deposit	*Bulk Unit Weight*	*Elastic Modulus*
Embankment fill	21 kN/m^3	-
Very stiff upper clayey silt	20 kN/m^3	20 MPa
Dense to very dense upper sand and silt	20 kN/m^3	20 MPa
Hard clayey silt till / Very dense silty sand till	21 kN/m^3	50 MPa

The settlement of the foundation soils under the approximately 1 m of additional fill that will be placed on the existing embankment side slope is estimated to be less than 10 mm under the main widening area, decreasing to less than 5 mm under the shoulder of the existing embankment and at the toe of the widened embankment. The connection between the existing culvert and its extension should be designed to accommodate this magnitude of settlement.

6.5 Culvert at Station 21+754

6.5.1 Foundation Options

The existing 1.5 m wide x 1.8 m high concrete open footing culvert at Station 21+754 is to be extended approximately 6.0 m west. Although either an open footing or a box culvert extension is feasible from a geotechnical perspective, it is understood that an open footing extension (to match the existing rigid frame, open footing culvert and to satisfy fisheries requirements) is preferred. Geotechnical recommendations for both open footing and concrete box extension options are provided in the following sections.

6.5.2 Founding Elevations, Subexcavation and Groundwater Control Requirements

Open Footing Culvert and Wing Walls/Retaining Walls

An open footing culvert extension, and any associated wing walls/retaining walls, should be founded on strip footings extended below the existing fill and any surficial organic soils. The invert/creek bed of the existing culvert, and that for the proposed westward extension, is at approximately Elevation 269.5 m; footings for the west extension should, therefore, be founded at or below Elevation 267.9 m on the compact sand and gravel (immediately above the hard clayey silt till) to provide adequate protection against frost penetration. If water will flow through the culvert year-round, the footings can be founded higher, at or below Elevation 268.5 m (to extend below the existing fill as encountered in Borehole 2007-40), with the actual founding depth determined on the basis of creek flow and scour conditions as assessed by the structural and hydraulic engineers.

Box Culvert

A box culvert extension should be founded below the existing fill and any surficial organic-containing soils. Based on the invert/creek bed of the existing culvert at approximately Elevation 269.5 m, and assuming that the base slab for the extension would have a thickness of 400 mm, a box culvert extension would have to be founded at or below Elevation 269.1 m. However, since embankment fill was encountered in Borehole 2007-40 down to Elevation 268.5 m, it is recommended that subexcavation be carried out down to Elevation 268.5 m. The subexcavation can be replaced with a compacted Granular A or Granular B Type II pad prior to construction of the box culvert extension.

Groundwater control will be required for excavation and construction of strip footings or a box culvert for the westward culvert extension at this site. As discussed further in Section 6.11 (Construction Considerations), it is recommended that a Non-Standard Special Provision (NSSP) be included in the Contract Documents to address groundwater control requirements for all of the culvert sites.

The sand and gravel/clayey silt till subgrade will be susceptible to disturbance and degradation on exposure to water and construction traffic. As discussed further in Section 6.11 (Construction Considerations), it is recommended that a 100 mm thick layer of lean mix concrete or mass concrete be placed on the inspected and approved subgrade, to protect the subgrade from this degradation and form a working mat for construction of the culvert extension. If a box culvert extension is adopted, it is recommended that a 75 mm thick levelling pad of Granular A or fine aggregate (meeting the gradation requirements set out in OPSS 1002) be provided on top of the lean concrete mat.

6.5.3 Geotechnical Resistance

The ULS resistance and settlement for open footing and box culvert extensions are dependent on the footing size, configuration and applied loads; the geotechnical resistances should, therefore, be reviewed if the selected footing width or founding elevation differs significantly from those given in the following sections.

Open Footing Culvert and Wing Walls/Retaining Walls

Strip footings placed on the properly prepared subgrade, at the elevation recommended in Section 6.5.2, should be designed based on a factored geotechnical resistance at ULS of 250 kPa, and a geotechnical resistance at SLS (for 25 mm of settlement) of 200 kPa. These recommendations are based on an assumed footing width of 0.6 m.

The geotechnical resistances provided are given under the assumption that the loads will be applied perpendicular to the surface of the footings. Where the load is not applied perpendicular to the surface of the footing, inclination of the load should be taken into account in accordance with the *CHBDC*.

Box Culvert

Assuming that subexcavation and placement of engineered fill is completed as discussed in Sections 6.1.2 and 6.5.2, a box culvert extension at this site should be designed based on a factored geotechnical resistance at ULS of 150 kPa, and a geotechnical resistance at SLS (for 25 mm of settlement) of 100 kPa. These recommendations are based on an assumed box culvert extension span of 1.5 m.

6.5.4 Resistance to Lateral Loads / Sliding Resistance

Resistance to lateral forces / sliding resistance between the concrete footings or base slab for the culvert extension and the subgrade should be calculated in accordance with Section 6.7.5 of the *CHBDC*. For cast-in-place concrete footings founded on the compact sand and gravel, the coefficient of friction, tan ϕ', can be taken as 0.5. For pre-cast concrete box culvert sections placed on a compacted Granular A or Granular B Type II pad following subexcavation as identified in Section 6.5.2, the coefficient of friction, tan δ, can also be taken as 0.5. These values are unfactored; in accordance with the *CHBDC*, a factor of 0.8 is to be applied in calculating the horizontal resistance.

6.5.5 Settlement

The widening of the Highway 400 SBL embankment at this culvert location will require placement of a maximum thickness of approximately 1.3 m of additional fill on the existing west embankment side slope. The settlement of the founding soils under this embankment widening has been estimated using the elastic deformation moduli given below, based on correlations with the SPT "N" values.

Soil Deposit	*Bulk Unit Weight*	*Elastic Modulus*
Embankment fill	21 kN/m^3	-
Compact sand and gravel	21 kN/m^3	15 MPa
Hard clayey silt till	21 kN/m^3	75 MPa

The settlement of the foundation soils under the maximum 1.3 m thickness of additional fill that will be placed on the existing west embankment side slope is estimated to be less than 10 mm under the main widening area, decreasing to less than 5 mm under the shoulder of the existing embankment and at the toe of the widened embankment. The connection between the existing culvert and its extension should be designed to accommodate this magnitude of settlement.

6.6 Culvert at Station 22+448

6.6.1 Foundation Options

The existing 1.2 m wide x 1.2 m high concrete box culvert at Station 22+448 is to be extended approximately 2.5 m west. Although either an open footing or a concrete box culvert extension is feasible from a geotechnical perspective, it is understood that a box culvert extension (to match the existing rigid frame box culvert) is preferred. Geotechnical recommendations for both options are provided in the following sections.

6.6.2 Founding Elevations, Subexcavation and Groundwater Control Requirements

Open Footing Culvert and Wing Walls/Retaining Walls

An open footing culvert extension, and any associated wing walls/retaining walls, should be founded on strip footings extended below the existing fill and any surficial organic soils. The invert/creek bed of the existing culvert, and that for the proposed westward extension, is at approximately Elevation 277.6 m; footings for the west extension should, therefore, be founded at or below Elevation 276.0 m on the very stiff clayey silt till. If water will flow through the culvert year-round, the footings can be founded higher, at or below Elevation 276.7 m, with the actual founding depth determined on the basis of creek flow and scour conditions as assessed by the structural and hydraulic engineers.

Box Culvert

A box culvert extension should be founded below the existing fill and any surficial organic-containing soils. Based on the invert/creek bed of the existing culvert at approximately Elevation 277.6 m, and assuming that the base slab for the extension would have a thickness of 400 mm, a box culvert extension would have to be founded at or below Elevation 277.2 m, on the compact upper sand deposit (just above the very stiff clayey silt till).

Groundwater control will be required for excavation and construction of strip footings or a box culvert for the westward culvert extension at this site. As discussed further in Section 6.11 (Construction Considerations), it is recommended that a Non-Standard Special Provision (NSSP) be included in the Contract Documents to address groundwater control requirements for all of the culvert sites.

The clayey silt till or sand subgrade will be susceptible to disturbance and degradation on exposure to water and construction traffic. As discussed further in Section 6.11 (Construction Considerations), it is recommended that a 100 mm thick layer of lean mix concrete or mass concrete be placed on the inspected and approved subgrade, to protect the subgrade from this degradation and form a working mat for construction of the culvert extension. If a box culvert extension is adopted, it is recommended that a 75 mm thick levelling pad of Granular A or fine aggregate (meeting the gradation requirements set out in OPSS 1002) be provided on top of the lean concrete mat.

6.6.3 Geotechnical Resistance

The ULS resistance and settlement for open footing and box culvert extensions are dependent on the footing size, configuration and applied loads; the geotechnical resistances should, therefore, be reviewed if the selected footing width or founding elevation differs significantly from those given in the following sections.

Open Footing Culvert and Wing Walls/Retaining Walls

Strip footings placed on the properly prepared subgrade, at the elevation recommended in Section 6.6.2, should be designed based on a factored geotechnical resistance at ULS of 200 kPa, and a geotechnical resistance at SLS (for 25 mm of settlement) of 150 kPa. These recommendations are based on an assumed footing width of 0.6 m.

The geotechnical resistances provided are given under the assumption that the loads will be applied perpendicular to the surface of the footings. Where the load is not applied perpendicular to the surface of the footing, inclination of the load should be taken into account in accordance with the *CHBDC*.

Box Culvert

A box culvert extension placed on the properly prepared subgrade, at or below the design elevation given in Section 6.6.2, should be designed based on a factored geotechnical resistance at ULS of 125 kPa, and a geotechnical resistance at SLS (for 25 mm of settlement) of 100 kPa. These recommendations are based on an assumed box culvert extension span of 1.2 m.

6.6.4 Resistance to Lateral Loads / Sliding Resistance

Resistance to lateral forces / sliding resistance between the concrete footings or base slab for the culvert extension and the subgrade should be calculated in accordance with Section 6.7.5 of the *CHBDC*. For cast-in-place concrete footings constructed on the very stiff clayey silt till, the coefficient of friction, tan ϕ', can be taken as 0.55. For pre-cast concrete box culvert sections placed on the compact sand, the coefficient of friction, tan δ, can be taken as 0.4. These values are unfactored; in accordance with the *CHBDC*, a factor of 0.8 is to be applied in calculating the horizontal resistance.

6.6.5 Settlement

The widening of the Highway 400 SBL embankment at this location will require placement of an approximately 0.5 m thickness of new fill on the existing west embankment side slope. The settlement of the founding soils under this widening has been estimated using the elastic deformation moduli given below, based on correlations with the SPT "N" values.

Soil Deposit	*Bulk Unit Weight*	*Elastic Modulus*
Embankment fill	21 kN/m^3	–
Compact upper sand	19 kN/m^3	10 MPa
Very stiff clayey silt till	21 kN/m^3	30 MPa
Very dense lower sand / Hard lower silty clay	20 kN/m^3	75 MPa

The settlement of the foundation soils under the approximately 0.5 m thickness of additional fill that will be placed on the existing west embankment side slope is estimated to be less than 10 mm under the main widening area, decreasing to less than 5 mm under the shoulder of the existing embankment and at the toe of the widened embankment. The connection between the existing culvert and its extension should be designed to accommodate this magnitude of settlement.

6.7 Culvert at Station 24+103

6.7.1 Foundation Options

The existing 1.8 m wide x 1.2 m high concrete open footing culvert at Station 24+103 is to be extended approximately 3.5 m west. Although either an open footing or box culvert extension is feasible from a geotechnical perspective, it is understood that an open footing extension (to match the existing rigid frame, open footing culvert and to satisfy fisheries requirements) is preferred. Geotechnical recommendations for both options are provided in the following sections.

6.7.2 Founding Elevations, Subexcavation and Groundwater Control Requirements

Open Footing Culvert and Wing Walls/Retaining Walls

An open footing culvert extension, and any associated wing walls/retaining walls, should be founded on strip footings extended below the existing fill and any surficial organic soils. The invert/creek bed of the existing culvert, and that for the proposed westward extension, is at approximately Elevation 277.0 m; footings for the west extension should, therefore, be founded at or below Elevation 275.4 m on the stiff to very stiff upper clayey silt. If water will flow through the culvert year-round, the footings can be founded higher, at or below Elevation 276.4 m, with the actual founding depth determined on the basis of creek flow and scour conditions as assessed by the structural and hydraulic engineers.

Box Culvert

A box culvert extension should be founded below the existing fill and any surficial organic-containing soils. Based on the invert/creek bed of the existing culvert at approximately Elevation 277.0 m, and assuming that the base slab for the extension would have a thickness of 400 mm, a box culvert extension would have to be founded at or below Elevation 276.6 m. However, since embankment fill was encountered in Borehole 2007-38 down to Elevation 276.4 m, it is recommended that subexcavation be carried out down to Elevation 276.4 m. The subexcavation can be replaced with a compacted Granular A or Granular B Type II pad prior to construction of the box culvert extension.

Groundwater control will be required for excavation and construction of strip footings or a box culvert for the westward culvert extension at this site. As discussed further in Section 6.11 (Construction Considerations), it is recommended that a Non-Standard Special Provision (NSSP) be included in the Contract Documents to address groundwater control requirements for all of the culvert sites.

The clayey silt subgrade will be susceptible to disturbance and degradation on exposure to water and construction traffic. As discussed further in Section 6.11 (Construction Considerations), it is recommended that a 100 mm thick layer of lean mix concrete or mass concrete be placed on the inspected and approved subgrade, to protect the subgrade from this degradation and form a working mat for construction of the culvert extension. If a box culvert extension is adopted, it is recommended that a 75 mm thick levelling pad of Granular A or fine aggregate (meeting the gradation requirements set out in OPSS 1002) be provided on top of the lean concrete mat.

6.7.3 Geotechnical Resistance

The ULS resistance and settlement for open footing and box culvert extensions are dependent on the footing size, configuration and applied loads; the geotechnical resistances should, therefore, be reviewed if the selected footing width or founding elevation differs significantly from those given in the following sections.

Open Footing Culvert and Wing Walls/Retaining Walls

Strip footings placed on the properly prepared subgrade, at or below the design elevation recommended in Section 6.7.2, should be designed based on a factored geotechnical resistance at ULS of 150 kPa, and a geotechnical resistance at SLS (for 25 mm of settlement) of 100 kPa. These recommendations are based on an assumed footing width of 0.6 m.

The geotechnical resistances provided are given under the assumption that the loads will be applied perpendicular to the surface of the footings. Where the load is not applied perpendicular to the surface of the footing, inclination of the load should be taken into account in accordance with the *CHBDC*.

Box Culvert

Assuming that subexcavation and placement of engineered fill is completed as discussed in Sections 6.1.2 and 6.7.2, a box culvert extension at this site should be designed based on a factored geotechnical resistance at ULS of 125 kPa, and a geotechnical resistance at SLS (for 25 mm of settlement) of 100 kPa. These recommendations are based on an assumed box culvert extension span of 1.8 m.

6.7.4 Resistance to Lateral Loads / Sliding Resistance

Resistance to lateral forces / sliding resistance between the concrete footings or base slab for the culvert extension and the subgrade should be calculated in accordance with Section 6.7.5 of the *CHBDC*. For cast-in-place concrete footings constructed directly on the stiff to very stiff clayey silt, the coefficient of friction, $\tan \phi'$, can be taken as 0.5. For pre-cast concrete box culvert sections placed on a compacted Granular A or Granular B Type II pad following subexcavation as identified in Section 6.7.2, the coefficient of friction, tan δ, can also be taken as 0.5. These values are unfactored; in accordance with the *CHBDC*, a factor of 0.8 is to be applied in calculating the horizontal resistance.

6.7.5 Settlement

The widening of the Highway 400 SBL embankment at this culvert site will require placement of a maximum thickness of approximately 1.2 m of additional fill on the existing west embankment side slope. The settlement of the founding soils under this additional loading has been estimated using the elastic deformation moduli given below, based on correlations with the SPT "N" values.

Soil Deposit	***Bulk Unit Weight***	***Elastic Modulus***
Embankment fill	21 kN/m^3	-
Compact silty sand	19 kN/m^3	12 MPa
Stiff to very stiff clayey silt	20 kN/m^3	15 MPa

The settlement of the foundation soils under the approximately 1.2 m maximum thickness of additional fill that will be placed on the existing west embankment side slope is estimated to be less than 10 mm under the main widening area, decreasing to less than 5 mm under the shoulder of the existing embankment and at the toe of the widened embankment. The connection between the existing culvert and its extension should be designed to accommodate this magnitude of settlement.

6.8 Culvert at Station 24+920

6.8.1 Foundation Options

The existing 1.2 m wide x 1.2 m high concrete box culvert at Station 24+920 is to be replaced, including an extension of approximately 1.5 m westward. Either an open footing or a box culvert replacement plus extension is feasible from a geotechnical perspective; however, a box culvert replacement/extension has a slight advantage over an open footing culvert in minimizing the depth of excavation and groundwater control requirements, and improved performance under differential settlement. Geotechnical recommendations for both options are provided in the following sections.

6.8.2 Founding Elevations, Subexcavation and Groundwater Control Requirements

Open Footing Culvert and Wing Walls/Retaining Walls

An open footing culvert replacement/extension, if adopted, and any associated wing walls/retaining walls, should be founded on strip footings extended below the existing fill, topsoil and any surficial organic-containing soil. The invert/creek bed of the existing and proposed culvert is at approximately Elevation 278.1 m at the west end and Elevation 278.2 m at the east end. The footings should be founded at or below Elevation 276.5 m on the compact to dense sand and gravel at the west end, and at or below Elevation 276.6 m on the hard clayey silt at the east end, to provide adequate protection against frost penetration. The footing may be sloped or stepped between the west and east ends.

Box Culvert

A box culvert extension should be founded below the existing fill and any surficial organic-containing soils. Based on the invert/creek bed of the existing and proposed culvert at approximately Elevation 278.1 m (west end) to 278.2 m (east end), assuming that the base slab for the extension would have a thickness of 400 mm, a box culvert extension would have to be founded at or below Elevation 277.7 m to 277.8 m m, on the compact silty sand over the western portion of the culvert replacement, and stiff to hard clayey silt over the eastern portion of the culvert replacement.

Groundwater control will be required for excavation and construction of strip footings or a box culvert for the culvert replacement and extension at this site. As discussed further in Section 6.11 (Construction Considerations), it is recommended that a Non-Standard Special Provision (NSSP) be included in the Contract Documents to address groundwater control requirements for all of the culvert sites.

The silty sand and clayey silt subgrade soils will be susceptible to disturbance and degradation on exposure to water and construction traffic. As discussed further in Section 6.11 (Construction Considerations), it is recommended that a 100 mm thick layer of lean mix concrete or mass concrete be placed on the inspected and approved subgrade, to protect the subgrade from this degradation and form a working mat for construction of the culvert replacement/extension. If a box culvert replacement/extension is adopted, it is recommended that a 75 mm thick levelling pad of Granular A or fine aggregate (meeting the gradation requirements set out in OPSS 1002) be provided on top of the lean concrete mat.

6.8.3 Geotechnical Resistance

The ULS and SLS resistances for an open footing or box culvert replacement/extension are dependent on the footing size, configuration and applied loads; the geotechnical resistances should, therefore, be reviewed if the selected footing width or founding elevation differs significantly from those given in the following sections.

Open Footing Culvert and Wing Walls/Retaining Walls

Strip footings placed on the properly prepared subgrade, at or below the design elevations recommended in Section 6.8.2, should be designed based on a factored geotechnical resistance at ULS of 150 kPa, and a geotechnical resistance at SLS (for 25 mm of settlement) of 100 kPa. These recommendations are based on an assumed footing width of 0.6 m.

The geotechnical resistances provided are given under the assumption that the loads will be applied perpendicular to the surface of the footings. Where the load is not applied perpendicular to the surface of the footing, inclination of the load should be taken into account in accordance with the *CHBDC*.

Box Culvert

A box culvert extension placed on the properly prepared subgrade, at or below the design elevations given in Section 6.8.2, should be designed based on a factored geotechnical resistance at ULS of 100 kPa, and a geotechnical resistance at SLS (for 25 mm of settlement) of 75 kPa. These recommendations are based on an assumed box culvert extension span of 1.2 m.

6.8.4 Resistance to Lateral Loads / Sliding Resistance

Resistance to lateral forces / sliding resistance between the concrete footings or base slab for the culvert extension or culvert replacement and the subgrade should be calculated in accordance with Section 6.7.5 of the *CHBDC*. For cast-in-place concrete footings constructed directly on the compact to dense sand and gravel or hard clayey silt, the coefficient of friction, tan ϕ', can be taken as 0.5. For pre-cast concrete box culvert sections placed on the compact silty sand or stiff clayey silt, the coefficient of friction, tan δ, can be taken as 0.4. These values are unfactored; in accordance with the *CHBDC*, a factor of 0.8 is to be applied in calculating the horizontal resistance.

6.8.5 Settlement

The widening of the Highway 400 SBL embankment at this culvert site will require placement of a maximum thickness of approximately 1 m of additional fill on the existing west embankment side slopes. The settlement of the founding soils under this embankment widening has been estimated using the elastic deformation moduli given below, based on correlations with the SPT "N" values.

Soil Deposit	***Bulk Unit Weight***	***Elastic Modulus***
Embankment fill	21 kN/m^3	-
Loose to compact silty sand	19 kN/m^3	5 MPa
Stiff to hard clayey silt	20 kN/m^3	20 MPa
Compact to dense sand and gravel	21 kN/m^3	25 MPa
Very stiff to hard clayey silt till	20 kN/m^3	50 MPa

The settlement of the foundation soils under the approximately 1 m maximum thickness of additional fill that will be placed on the existing west embankment side slope is estimated to be less than 10 mm under the main widening area, decreasing to less than 5 mm under the shoulder of the existing embankment and at the toe of the widened embankment. The connection between the existing culvert and its extension should be designed to accommodate this magnitude of settlement.

6.9 Culvert Bedding, Backfill and Erosion Protection

For box culvert extensions, the bedding levelling pad and backfill requirements should be in accordance with OPSS 422 for pre-cast rigid frame culverts. The box culvert extensions should be provided with at least 150 mm of OPSS Granular "A" material for bedding purposes.

Backfill to the culvert walls should consist of granular fill meeting the requirements of OPSS Granular A or Granular B Type II, but with less than 5 per cent passing the No. 200 sieve. The backfill should be placed and compacted in accordance with MTO's Special Provision SP105S10. The fill depth during placement should be maintained equal on both sides of the culvert walls, with one side not exceeding the other by more than 500 mm. The culvert extension should be designed for the full overburden pressure and live load, assuming an embankment fill unit weight of 22 kN/m^3 for Granular A, 21 kN/m^3 for Granular B Type II, and 21 kN/m^3 for earth backfill above and/or surrounding the culvert or its extension(s).

If the creek flow velocities are sufficiently high, provision should be made for scour and erosion protection (suitable non-woven geotextiles and/or rip-rap). In order to prevent surface water from flowing either beneath the culvert (potentially causing undermining and scouring) or around the culvert (creating seepage through the embankment fill, and potentially causing erosion and loss of fine soil particles), a clay seal or concrete cut-off wall should be provided at the upstream end of any culverts that are replaced or extended at the upstream end. If a clay seal is adopted, the clay material should meet the requirements of OPSS 1205, and the seal should extend from a depth of 1 m below the scour level to a minimum horizontal distance of 2 m on either side of the culvert inlet openings, and a minimum vertical height equivalent to the high water level including treatment of adjacent side slopes. Alternatively, a clay blanket may be constructed, extending upstream to a distance equal to three times the culvert height, and extending along the adjacent side slopes to a height of two times the culvert height or the high water level, whichever is higher.

The requirements for and design of erosion protection measures for the inlet and outlet of the culvert extensions/replacements should be assessed by the hydraulic design engineer. As a minimum, rip-rap treatment for the outlet of the culvert extensions should be consistent with the standard presented in OPSD 810.010 Rip-Rap Treatment Type A. Erosion protection for the inlet of the culvert extensions should follow the standard presented in OPSD 810.010, similar to Rip-Rap Treatment Type A with the rip-rap placed to above the high water level, in combination with the cut-off measures noted above. Similarly, rip-rap should be provided over the full extent of the clay blanket, including the creek side slopes and embankment fill slope adjacent to the culverts.

6.10 Lateral Earth Pressures for Design

The lateral earth pressures acting on the culvert walls and any associated wing walls/retaining walls will depend on the type and method of placement of the backfill materials, on the nature of the soils behind the backfill, on the magnitude of surcharge including construction loadings, on the freedom of lateral movement of the structure, and on the drainage conditions behind the walls.

The following recommendations are made concerning the design of the walls, assuming that the backfill to the culvert walls consists of free-draining granular fill meeting the requirements of OPSS Granular A or B Type II, placed and compacted in accordance with MTO's Special Provision SP105S10, with longitudinal drains and weep holes installed as necessary to provide positive drainage of the granular backfill.

- A minimum compaction surcharge of 12 kPa should be included in the lateral earth pressures for the structural design of the walls, in accordance with *CHBDC* Section 6.9.3 and Figure 6.9.3. Other surcharge loadings should be accounted for in the design, as required.

- The granular fill may be placed either in a zone with width equal to at least 1.6 m behind the back of the wall stem (Case I, Figure C6.20(a) of the *Commentary on CHBDC*) or within a wedge-shaped zone defined by a line drawn at 1.5 horizontal to 1 vertical (1.5H:1V) extending up and back from the rear face of the footing (Case II, Figure C6.20(b) of the *Commentary on CHBDC)*.

- For Case I, the pressures are based on the existing embankment fill materials and the following parameters (unfactored) may be used:

Soil unit weight:	20 kN/m^3
Coefficients of static lateral earth pressure:	
Active, K_a	0.33 (level ground)
	0.53 (2H:1V slope)
At rest, K_o	0.50 (level ground)
	0.80 (2H:1V slope)

- For Case II, the pressures are based on granular fill and the following parameters (unfactored) may be assumed:

	Granular A	**Granular B Type II**
Soil unit weight:	22 kN/m^3	21 kN/m^3

Coefficients of static lateral earth pressure:	
Active, K_a	0.27 (level ground)
	0.38 (2H:1V slope)
At rest, K_o	0.43 (level ground)
	0.61 (2H:1V slope)

- Where the wing wall/retaining support allows lateral yielding of the stem, active earth pressures should be used in the geotechnical design of the structure. Where the wall support does not allow lateral yielding (which typically applies to a culvert or rigid frame structure), at-rest earth pressures should be assumed for the geotechnical design. The movement to allow active pressures to develop within the backfill, and thereby assume an unrestrained structure, may be taken as follows:
  - Rotation of approximately 0.002 about the base of a vertical wall;
  - Horizontal translation of 0.001 times the height of the wall; or
  - A combination of both.

Seismic (earthquake) loading must also be taken into account in the design of the culvert walls and any associated wing walls/retaining walls, in accordance with Section 4.6 of the CHBDC. In this regard, the following should be included in the assessment of lateral earth pressures:

- Seismic loading will result in increased lateral earth pressures acting on the culvert walls and retaining walls. The walls should be designed to withstand the combined lateral loading for the appropriate static pressure conditions given above, plus the earthquake-induced dynamic earth pressure. According to Table A3.1.7 of the CHBDC, this site is located in Seismic Zone 1. The site-specific zonal acceleration ratio for the Barrie area is 0.05. Based on the subsurface conditions at the culvert sites, a 20 per cent amplification of the ground motion may occur, resulting in an increase in the ground surface acceleration from 0.05g to 0.06g. The seismic lateral earth pressure coefficients given below have been derived based on a design zonal acceleration ratio of A = 0.06.

- In accordance with Sections 4.6.4 and C.4.6.4 of the *CHBDC* and its *Commentary*, for structures which allow lateral yielding, the horizontal seismic coefficient, k_h, used in the calculation of the seismic active pressure coefficient, is taken as 0.5 times the zonal acceleration ratio (i.e. $k_h = 0.03$). For structures that do not allow lateral yielding, k_h is taken as 1.5 times the zonal acceleration ratio (i.e. $k_h = 0.09$). The seismic active earth pressure coefficient is also dependent on the vertical component of the earthquake acceleration, k_v. Three discrete values of vertical acceleration are typically selected for analysis, corresponding to $k_v = +2/3\ k_h$, $k_v = 0$, and $k_v = -2/3\ k_h$.

- The following seismic active pressure coefficients (K_{AE}) for the two cases (Case I and Case II) may be used in design; these coefficients reflect the maximum K_{AE} obtained using the k_h and three values of k_v as described above. It should be noted that these seismic earth pressure coefficients assume that the back of the wall is vertical and the ground surface behind the wall is flat.

SEISMIC ACTIVE PRESSURE COEFFICIENTS, K_{AE}

Wall Condition	Case I	Case II	
		Granular A	Granular B Type II
Yielding wall	0.32	0.26	0.26
Non-yielding wall	0.37	0.30	0.30

Note: These K_{AE} values include the effect of wall friction ($\delta = \phi'/2$) and are less than the static values of K_a and K_o reported above for the low zonal acceleration ratio for this site.

- The above K_{AE} values for yielding walls are applicable provided that the wall can move up to 250A (mm), where A is the design zonal acceleration ratio of 0.06. This corresponds to displacements of up to 15 mm at this site.

- The earthquake-induced dynamic pressure distribution, which is to be added to the static earth pressure distribution, is a linear distribution with maximum pressure at the top of the wall and minimum pressure at its toe (i.e. an inverted triangular pressure distribution). The total pressure distribution (static plus seismic) may be determined as follows:

$$P = K\,\gamma'\,d + (K_{AE} - K)\,\gamma'\,H$$

where
- K is either the static active earth pressure coefficient (K_a) or the static at rest earth pressure coefficient (K_o), as applicable;
- K_{AE} is the seismic active earth pressure coefficient;
- γ' is the effective unit weight of the soil (kN/m^3) taken as the soil unit weight given in previous sections for fill materials;
- d is the depth below the top of the wall (m); and
- H is the height of the wall above the toe (m).

6.11 Construction Considerations

6.11.1 Surface Water and Groundwater Control

Control of the surface water and groundwater will be necessary at the culvert extension or replacement sites to allow for excavation and foundation construction to be carried out in dry conditions.

Depending on the creek flow at the time of construction, the surface water flow could be passed through the culvert area by means of a temporary pipe, or diverted by pumping from behind a temporary cofferdam. Surface water should be directed away from the excavation areas, to prevent ponding of water that could result in disturbance and weakening of the foundation subgrades; further discussion on this aspect is provided in Section 6.11.3.

As discussed in Sections 6.2 to 6.8, groundwater control will be required at all of the culvert extension/replacement locations, as the foundation excavations are expected to extend below the groundwater level at most or all of the sites. Where the excavations will be advanced through existing fill and cohesive soils to terminate within cohesive soils (i.e. no excavation through water-bearing granular soils) or to terminate above the groundwater level at the site, seepage into the excavation should be adequately controlled by pumping from properly filtered sumps; based on the borehole results, this is anticipated to be the case for the culvert extensions at Station 21+150 (Boreholes 2007-41 and 2007-42), and for the culvert extension at Station 24+103 (Borehole 2007-38). For the remaining culvert sites, appropriate dewatering of the water-bearing granular soil deposits will be required to maintain the water level below the founding level for the culverts during excavation and construction.

6.11.2 Excavations and Temporary Roadway Protection

Temporary excavations for the culvert extensions or replacements will be made through the existing embankment fill, loose sands/silts, and soft to firm clayey silt soils, generally terminating in loose to dense sand to silty sand or stiff to hard clayey silt / clayey silt till soils. Excavation works must be carried out in accordance with the guidelines outlined in the Occupational Health and Safety Act and Regulations for Construction Projects. The existing fill and the weaker portions of the clayey silt or sand/silt soils would be classified as Type 3 soil, according to the OHSA, assuming that proper groundwater control is in place to dewater cohesionless soil deposits prior to excavation, where necessary. Where space permits, temporary open-cut excavations through these materials should be made with side slopes formed no steeper than 1H:1V.

Depending on the construction staging sequence and schedule, temporary roadway protection may be required to facilitate the culvert extension works; where full culvert replacements are adopted, temporary roadway protection is likely to be required. The temporary excavation support systems should be designed and constructed in accordance with MTO's Special Provision 105S19. The lateral movement of the temporary shoring system should meet Performance Level 2 as specified in SP105S19, provided that any adjacent utilities can tolerate this magnitude of deformation.

6.11.3 Subgrade Protection

Where clayey or silty soils are exposed at the footing subgrade level, they will be susceptible to disturbance from construction traffic and/or ponded water. In order to limit this degradation, it is recommended that a working mat of lean concrete be placed on the subgrade within four hours after preparation, inspection and approval of the footing subgrade. A sample NSSP to address this requirement is included in Appendix A.

7.0 CLOSURE

This Foundation Design Report was prepared by Ms. Beng Lay Teh, and reviewed by Ms. Lisa Coyne, P.Eng., an Associate and geotechnical engineer with Golder. Mr. Fin Heffernan, P.Eng., a Designated MTO Contact for Golder, conducted an independent quality control review of the report.

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LIST OF ABBREVIATIONS

The abbreviations commonly employed on Records of Boreholes, on figures and in the text of the report are as follows:

I. SAMPLE TYPE

AS	Auger sample
BS	Block sample
CS	Chunk sample
SS	Split-spoon
DS	Denison type sample
FS	Foil sample
RC	Rock core
SC	Soil core
ST	Slotted tube
TO	Thin-walled, open
TP	Thin-walled, piston
WS	Wash sample

II. PENETRATION RESISTANCE

Standard Penetration Resistance (SPT), N:
The number of blows by a 63.5 kg. (140 lb.) hammer dropped 760 mm (30 in.) required to drive a 50 mm (2 in.) drive open 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, 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 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
$\sigma_1, \sigma_2, \sigma_3$	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_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

RECORD OF BOREHOLE No 2007-36

 METRIC

PROJECT 06-1111-011
W.P. 167-99-00
DIST Central HWY 400
DATUM Geodetic

LOCATION N 4925936.4 ;E 289429.5
BOREHOLE TYPE 210 mm Diameter Hollow Stem Augers
DATE November 20, 2007

ORIGINATED BY PKS
COMPILED BY VO
CHECKED BY LCC

ELEV DEPTH (m)	SOIL PROFILE DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	WATER CONTENT (%)	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
278.2	GROUND SURFACE						
0.0	TOPSOIL						
0.1	Silty SAND, trace gravel, containing 75 mm thick clayey silt seam and rootlets Loose to compact Brown Moist	1	SS	5			
		2	SS	12		w plotted	
276.7 1.5	SAND and GRAVEL, trace silt Compact to dense Brown Wet	3	SS	32			
		4	SS	27		w plotted	31 60 6 3
		5	SS	22			
		6	SS	12		w plotted	32 61 4 3
273.9 4.3	CLAYEY SILT, some sand, trace gravel (TILL) Hard Grey Moist	7	SS	40		wp, w, wL plotted	
		8	SS	92			
		9	SS	54	∇ (El. 270.6)	wp, w, wL plotted	9 14 50 27
		10	SS	150			
	Wet below 10.7 m depth	11	SS	100/0.25			
265.8		12	SS	100/0.18			
12.4	END OF BOREHOLE						

ELEVATION SCALE: 278, 277, 276, 275, 274, 273, 272, 271, 270, 269, 268, 267, 266

DYNAMIC CONE PENETRATION RESISTANCE PLOT: 20 40 60 80 100

SHEAR STRENGTH kPa: O UNCONFINED, + FIELD VANE, ● QUICK TRIAXIAL, × REMOULDED; 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

NOTE:

1. Water level in open borehole at 7.6 m depth (Elevation 270.6 m) upon completion of drilling.

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

MIS-MTO 001 06-1111-011.GPJ GAL-MISS.GDT 2/19/08 DD

Golder Associates

RECORD OF BOREHOLE No 2007-37

 METRIC

PROJECT 06-1111-011
W.P. 167-99-00
LOCATION N 4925953.0 ;E 289457.4
ORIGINATED BY SB
DIST Central HWY 400
BOREHOLE TYPE 210 mm Diameter Hollow Stem Augers
COMPILED BY VO
DATUM Geodetic
DATE December 14, 2007
CHECKED BY LCC

ELEV DEPTH	DESCRIPTION	NUMBER	TYPE	"N" VALUES	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
279.8	GROUND SURFACE				
0.0	Silty sand, trace clay and gravel, containing rootlets and organics (FILL) Compact Black to brown Moist	1	SS	11	
		2	SS	18	
278.3 / 1.5	CLAYEY SILT, some sand, trace gravel, containing organics and silty sand seams Stiff to hard Brown to grey Moist	3	SS	11	OC = 4.2% 0 21 38 41
		4	SS	14	
		5	SS	37	
276.0 / 3.8	SAND and GRAVEL, trace to some silt, trace clay Compact Brown Wet	6	SS	16	39 48 9 4
275.2 / 4.6	CLAYEY SILT with sand to some sand, trace gravel, containing silty sand seams (TILL) Very stiff to hard Grey Moist to wet	7	SS	21	
		8	SS	24	
		9	SS	83	
		10	SS	80	
		11	SS	68/0.15	3 40 38 19
267.3		12	SS	75/0.15	
12.5	END OF BOREHOLE				

Ground water level symbol at approx. elevation 276.1.

Elevation scale: 279, 278, 277, 276, 275, 274, 273, 272, 271, 270, 269, 268

DYNAMIC CONE PENETRATION RESISTANCE PLOT: 20 40 60 80 100
SHEAR STRENGTH kPa: ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × REMOULDED — 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

NOTE:

1. Water level in open borehole at 3.7 m depth (Elevation 276.1 m) upon completion of drilling.

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

Golder Associates

RECORD OF BOREHOLE No 2007-38

 METRIC

PROJECT 06-1111-011			
W.P. 167-99-00	LOCATION N 4925260.4 ;E 289877.1		ORIGINATED BY PKS
DIST Central HWY 400	BOREHOLE TYPE 210 mm Diameter Hollow Stem Augers		COMPILED BY VO
DATUM Geodetic	DATE November 20 and 21, 2007		CHECKED BY LCC

ELEV DEPTH	DESCRIPTION	NUMBER	TYPE	"N" VALUES	ELEVATION SCALE	WATER CONTENT (%)	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
277.0	GROUND SURFACE						
0.0	Sand, some silt, trace clay and gravel, containing organics and rootlets (FILL) Loose Brown Moist	1	SS	8			
276.4 / 0.6	CLAYEY SILT, some sand, trace gravel Stiff to very stiff Brown Moist	2	SS	18	276		1 16 58 25
		3	SS	9	275		
		4	SS	15			0 12 76 12
274.0 / 3.1	CLAYEY SILT, some sand, trace gravel (TILL) Very stiff Brown Moist	5	SS	22	274		
		6	SS	16	273		
		7	SS	24	272		
270.9 / 6.1	SAND, trace silt, clay and gravel Very dense Brown Moist	8	SS	100/0.15	271		8 84 6 2
		9	SS	100/0.25	270, 269		
		10	SS	100/0.15	268		
		11	SS	100/0.15	267, 266		
264.6 / 12.5	END OF BOREHOLE	12	SS	100/0.25	265		

NOTE:

1. Borehole dry on completion of drilling operations.

Legend: DYNAMIC CONE PENETRATION RESISTANCE PLOT (20 40 60 80 100); SHEAR STRENGTH kPa: O UNCONFINED, + FIELD VANE, ● QUICK TRIAXIAL, × REMOULDED (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

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

Foundation Design

Golder Associates

RECORD OF BOREHOLE No 2007-39

 METRIC

PROJECT 06-1111-011
W.P. 167-99-00
DIST Central HWY 400
DATUM Geodetic
LOCATION N 4923849.0 ;E 290751.4
BOREHOLE TYPE 210 mm Diameter Hollow Stem Augers
DATE November 21, 2007
ORIGINATED BY PKS
COMPILED BY VO
CHECKED BY LCC

ELEV / DEPTH	DESCRIPTION	NUMBER	TYPE	"N" VALUES	WATER CONTENT (%)	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
278.2	GROUND SURFACE					
0.0	TOPSOIL					
0.2	SAND, some silt, trace clay, containing rootlets and organics; Loose to compact; Brown; Moist to wet	1	SS	6		
		2	SS	10	w	0 83 11 6
276.7 / 1.5	CLAYEY SILT with sand, trace gravel (TILL); Very stiff; Grey; Wet	3	SS	18	wP–w–wL	
		4	SS	20		
		5	SS	20		
		6	SS	19		
		7	SS	15	wP–w–wL	0 52 35 13
		8	SS	22		
270.6 / 7.6	SAND, some silt and gravel; Very dense; Brown; Wet	9	SS	100/0.15	w	12 69 17 2
		10	SS	100/0.25		
267.5 / 10.7	SILTY CLAY, trace sand, containing sand seams; Hard; Brown; Wet	11	SS	62	wP–w–wL	0 18 38 44
		12	SS	138		
265.6 / 12.7	END OF BOREHOLE					

NOTE:

1. Water encountered during drilling at depth of 1.5 m (Elevation 276.7 m).

DYNAMIC CONE PENETRATION RESISTANCE PLOT: 20 40 60 80 100
SHEAR STRENGTH kPa: O UNCONFINED, + FIELD VANE, ● QUICK TRIAXIAL, × REMOULDED: 20 40 60 80 100
PLASTIC LIMIT W_P, NATURAL MOISTURE CONTENT W, LIQUID LIMIT W_L; WATER CONTENT (%) 10 20 30
UNIT WEIGHT γ kN/m³
ELEVATION SCALE: 278 277 276 275 274 273 272 271 270 269 268 267 266

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

Golder Associates

RECORD OF BOREHOLE No 2007-40

 METRIC

PROJECT 06-1111-011
W.P. 167-99-00
LOCATION N 4923265.0 ;E 291107.6
ORIGINATED BY PKS
DIST Central HWY 400
BOREHOLE TYPE 210 mm Diameter Hollow Stem Augers
COMPILED BY VO
DATUM Geodetic
DATE November 21 and 23, 2007
CHECKED BY LCC

ELEV / DEPTH	DESCRIPTION	NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
270.0	GROUND SURFACE					
0.0	Silty sand, some gravel, trace clay, containing cobbles, organics and rootlets (FILL) Loose Brown Moist	1	SS	7		
		2	SS	6	▽	
268.5 / 1.5	SAND and GRAVEL, some silt, trace clay Compact Brown Wet	3	SS	14		32 46 15 7
267.7 / 2.3	CLAYEY SILT with sand to some sand, trace gravel (TILL) Hard Grey Wet	4	SS	36		
		5	SS	50		
		6	SS	73		1 25 41 32
		7	SS	100		
		8	SS	104		
		9	SS	102		
261.9 / 8.1	END OF BOREHOLE					

Elevation scale: 269, 268, 267, 266, 265, 264, 263, 262

DYNAMIC CONE PENETRATION RESISTANCE PLOT: 20 40 60 80 100

SHEAR STRENGTH kPa: ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × REMOULDED; 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

NOTE:

1. Water level in open borehole at a depth of 1.2 m (Elevation 268.8 m) upon completion of drilling operations.

+ 3, × 3: Numbers refer to Sensitivity

○ 3% STRAIN AT FAILURE

Golder Associates

RECORD OF BOREHOLE No 2007-41

 METRIC

PROJECT 06-1111-011			
W.P. 167-99-00	LOCATION N 4922985.3 ;E 291283.2		ORIGINATED BY PKS/SB
DIST Central HWY 400	BOREHOLE TYPE 210 mm Diameter Hollow Stem Augers		COMPILED BY VO
DATUM Geodetic	DATE November 23 and 26, 2007		CHECKED BY LCC

ELEV DEPTH	DESCRIPTION	NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
264.6	GROUND SURFACE					
0.0	Silty sand, some gravel, containing cobbles (FILL) Loose Brown Moist	1	AS	-		
		2	AS	-		
263.1 / 1.5	CLAYEY SILT, trace sand and gravel, containing sand partings Very stiff Brown Moist	3	SS	16		
262.3 / 2.3	SAND and SILT, trace clay and gravel, containing clayey silt interlayers in Sample 6 Dense to very dense Brown Moist	4	SS	57		
		5	SS	45		
		6	SS	37		6 49 34 11
		7	SS	34		
258.5 / 6.1	CLAYEY SILT with sand, trace gravel (TILL) Hard Brown Moist	8	SS	34	∇ (258.5)	3 46 38 13
257.0 / 7.6	Silty SAND, trace clay and gravel (TILL) Very dense Brown Wet	9	SS	75		
		10	SS	51		10 55 28 7
		11	SS	60/0.15		
		12	SS	88		
252.0 / 12.7	END OF BOREHOLE					

NOTE:

1. Water level in open borehole at a depth of 6.1 m (Elevation 258.5 m) upon completion of drilling operations.

Column headings: SOIL PROFILE; SAMPLES; STRAT PLOT; ELEVATION SCALE (264–252); DYNAMIC CONE PENETRATION RESISTANCE PLOT 20 40 60 80 100; SHEAR STRENGTH kPa: O UNCONFINED, + FIELD VANE, ● QUICK TRIAXIAL, × REMOULDED, 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 O 3% STRAIN AT FAILURE

Golder Associates

RECORD OF BOREHOLE No 2007-42

 METRIC

PROJECT 06-1111-011
W.P. 167-99-00
DIST Central HWY 400
DATUM Geodetic
LOCATION N 4922752.6 ;E 291426.0
BOREHOLE TYPE 210 mm Diameter Hollow Stem Augers
DATE November 26, 2007
ORIGINATED BY SB
COMPILED BY VO
CHECKED BY LCC

ELEV DEPTH	DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	WATER CONTENT (%)	GR	SA	SI	CL
266.2	GROUND SURFACE									
0.0	Clayey silt with sand, trace gravel (FILL) Firm to stiff Brown and black Moist	1	SS	5						
		2	SS	13		wp–w–wL plotted				
264.7 / 1.5	Silty SAND, trace gravel, trace clay Compact to very dense Moist Brown	3	SS	31		o	2	72	21	5
		4	SS	72						
		5	SS	67						
	Containing seams of clayey silt between 3.7 m and 4.3 m depth	6	SS	59		o	2	68	21	9
		7	SS	117						
		8	SS	83						
		9	SS	122						
	Wet below a depth of 9.1 m				∇					
		10	SS	27		o	0	75	24	1
		11	SS	88						
253.4		12	SS	60						
12.8	END OF BOREHOLE									

NOTE:

1. Samples were noted to be wet below a depth of 9.1 m (Elevation 257.1 m).

Legend: DYNAMIC CONE PENETRATION RESISTANCE PLOT (20, 40, 60, 80, 100); SHEAR STRENGTH kPa: O UNCONFINED, + FIELD VANE, ● QUICK TRIAXIAL, × REMOULDED (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. Elevation scale 266 to 254.

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

RECORD OF BOREHOLE No 2007-43

 METRIC

PROJECT 06-1111-011
W.P. 167-99-00
LOCATION N 4922760.3 ;E 291450.3
ORIGINATED BY SB
DIST Central HWY 400
BOREHOLE TYPE 210 mm Diameter Hollow Stem Augers
COMPILED BY VO
DATUM Geodetic
DATE December 14, 2007
CHECKED BY LCC

ELEV DEPTH	DESCRIPTION	NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	WATER CONTENT (%)	GR	SA	SI	CL
265.6	GROUND SURFACE										
0.0	TOPSOIL	1	SS	7		265					
265.3 / 0.3	Clayey silt with sand, trace gravel (FILL) Firm to hard Brown Moist	2	SS	8		264					
		3	SS	45			wP–wL plotted	2	30	39	29
263.6 / 2.0	SAND and GRAVEL, trace silt and clay Very dense Brown Moist	4	SS	69		263					
		5	SS	50/0.08		262	o	32	58	7	3
		6	SS	92		261					
261.0 / 4.6	Silty SAND to SAND, some silt, trace to some gravel, trace clay Very dense Brown Moist to wet	7	SS	75		260	o	0	74	25	1
		8	SS	97	▽ (259.5)	259	o				
		9	SS	70		258					
		10	SS	98		257, 256					
		11	SS	77		255, 254	o				
		12	SS	111		253					
253.0 / 12.7	END OF BOREHOLE NOTE: 1. Water level in open borehole at 6.1 m depth (Elevation 259.5 m) upon completion of drilling.										

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 × REMOULDED 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

RECORD OF BOREHOLE No 2007-44

 METRIC

PROJECT 06-1111-011			
W.P. 167-99-00	LOCATION N 4920780.9 ;E 292679.1		ORIGINATED BY SB
DIST Central HWY 400	BOREHOLE TYPE Portable Drilling Equipment with Half-Weight Hammer		COMPILED BY VO
DATUM Geodetic	DATE November 29, 2007		CHECKED BY LCC

Soil Profile

ELEV / DEPTH	DESCRIPTION
230.8	GROUND SURFACE
0.0	Silty SAND, containing fibrous peat, rootlets and organics Loose Grey Wet
228.5 / 2.3	CLAYEY SILT, trace sand Soft to firm Brown Wet
227.3 / 3.5	SAND and SILT, trace clay and gravel Compact Brown Wet
223.2 / 7.6	SAND, trace to some gravel, trace silt and clay Compact Brown Wet
221.7 / 9.1	Silty SAND, trace gravel and clay Compact to dense Brown to grey Wet
218.0 / 12.8	

Samples

NUMBER	TYPE	"N" VALUES	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
1	SS	1	
2	SS	7	
3	SS	4	
4	SS	2	0 3 67 30
5	SS	7	
6	SS	18	0 40 53 7
7	SS	22	
8	SS	12	
9	SS	20	10 75 8 7
10	SS	8*	
11	SS	7*	
12	SS	30	

Column headings: STRAT PLOT; GROUND WATER CONDITIONS; ELEVATION SCALE (230 to 218); DYNAMIC CONE PENETRATION RESISTANCE PLOT (20, 40, 60, 80, 100); SHEAR STRENGTH kPa: O UNCONFINED, + FIELD VANE, ● QUICK TRIAXIAL, × REMOULDED (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.

Continued Next Page

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

Golder Associates

RECORD OF BOREHOLE No 2007-44

 METRIC

PROJECT 06-1111-011			
W.P. 167-99-00	LOCATION N 4920780.9 ;E 292679.1		ORIGINATED BY SB
DIST Central HWY 400	BOREHOLE TYPE Portable Drilling Equipment with Half-Weight Hammer		COMPILED BY VO
DATUM Geodetic	DATE November 29, 2007		CHECKED BY LCC

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT (20, 40, 60, 80, 100); SHEAR STRENGTH kPa: O UNCONFINED, + FIELD VANE, ● QUICK TRIAXIAL, × REMOULDED (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
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES						
	--- CONTINUED FROM PREVIOUS PAGE ---										
	END OF BOREHOLE NOTES: 1. Borehole advanced using portable drilling equipment with a half-weight hammer. SPT "N" values shown have been adjusted to reflect values then would be obtained using a standard weight hammer. 2. Water level in open borehole was at ground surface (Elevation 230.8 m) upon completion of drilling. * SPT "N" values considered to have been affected by groundwater inflow to the borehole during sampling.										

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

RECORD OF BOREHOLE No 2007-45

 METRIC

PROJECT	06-1111-011				
W.P.	167-99-00	LOCATION	N 4920780.6 ;E 292709.0	ORIGINATED BY	PKS
DIST	Central HWY 400	BOREHOLE TYPE	210 mm Diameter Hollow Stem Augers	COMPILED BY	VO
DATUM	Geodetic	DATE	November 27, 2007	CHECKED BY	LCC

ELEV / DEPTH	DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
231.5	GROUND SURFACE					
0.0	Silty sand, trace clay (FILL) Loose Black Moist	1	SS	5		
230.7 / 0.8	Sandy SILT, trace clay, containing clayey silt seams Loose to compact Brown Moist becoming wet below 1.5 m depth	2	SS	8		
		3	SS	10		0 25 63 12
229.2 / 2.3	CLAYEY SILT, trace to some sand Soft Brown Wet	4	SS	3	▽ (228.5)	
		5	SS	4		
227.7 / 3.8	SAND and SILT, trace clay Compact Brown Wet	6	SS	13		0 55 41 4
226.9 / 4.6	CLAYEY SILT, trace sand, containing silty sand seams Firm Brown Wet	7	SS	5		0 14 53 33
225.4 / 6.1	SAND and SILT, trace gravel, trace clay Compact Brown Wet	8	SS	11		
		9	SS	21		
222.4 / 9.1	SAND, some silt, trace gravel and clay Compact Brown Wet	10	SS	17		0 85 13 2
220.8 / 10.7	Silty SAND, trace gravel and clay Compact Brown Wet	11	SS	14		
		12	SS	13		
217.8 / 13.7	END OF BOREHOLE					

NOTE:

1. Water level in open borehole at a depth of 3.0 m (Elevation 228.5 m) upon completion of drilling.

Chart columns: DYNAMIC CONE PENETRATION RESISTANCE PLOT (20 40 60 80 100); SHEAR STRENGTH kPa (O UNCONFINED, + FIELD VANE, ● QUICK TRIAXIAL, × REMOULDED; 20 40 60 80 100); PLASTIC LIMIT W_P, NATURAL MOISTURE CONTENT W, LIQUID LIMIT W_L; WATER CONTENT (%) 10 20 30; UNIT WEIGHT γ kN/m³. Elevation scale 231 to 218.

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

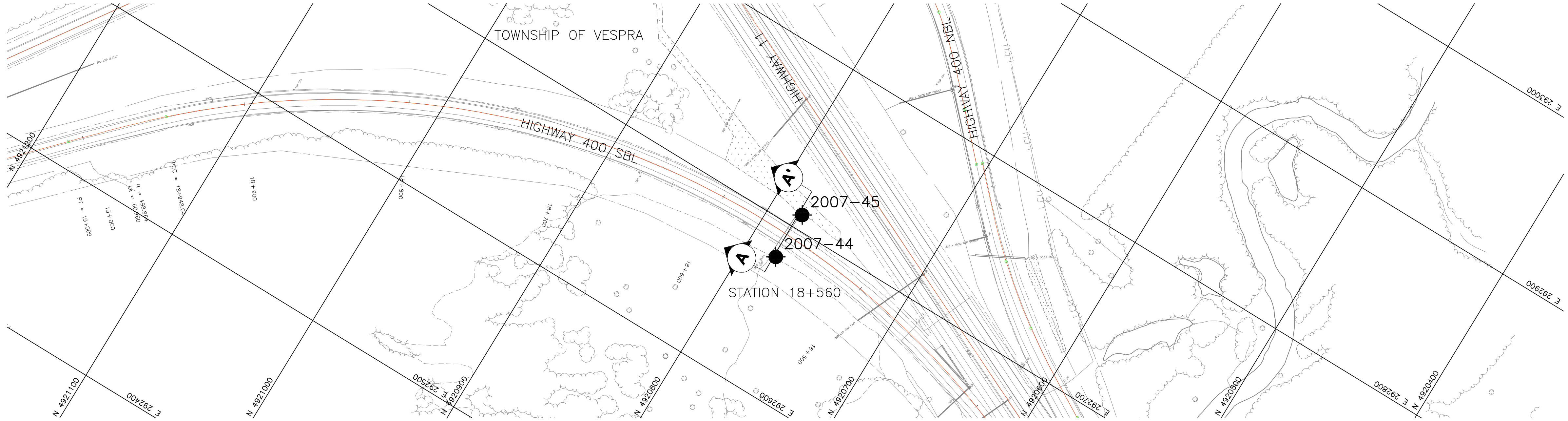
METRIC
DIMENSIONS ARE IN METRES AND/OR MILLIMETRES UNLESS OTHERWISE SHOWN. STATIONS IN KILOMETRES + METRES.

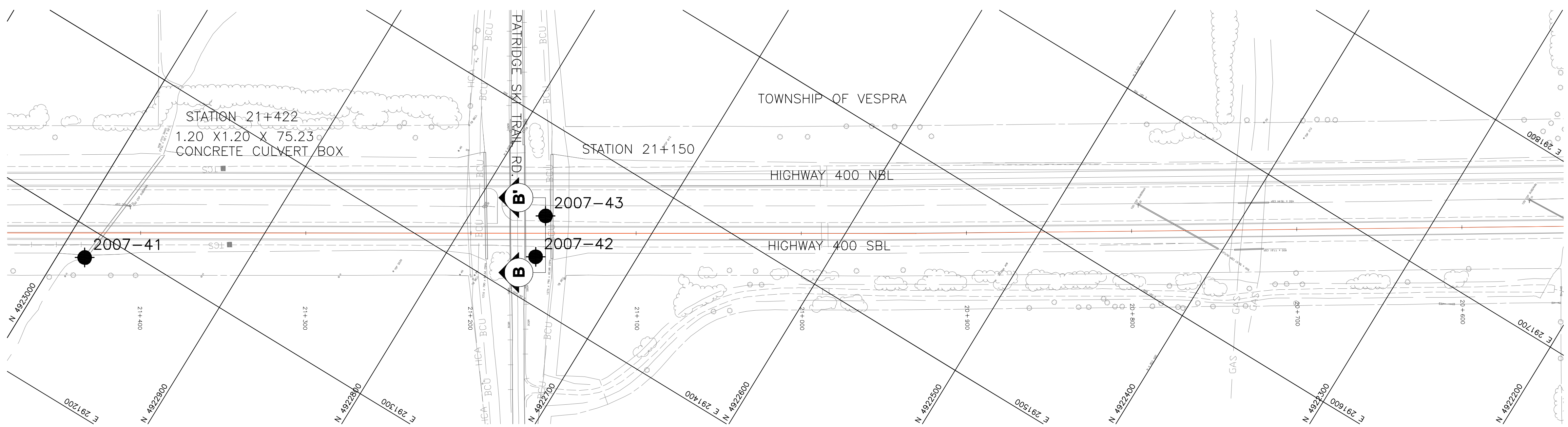
CONT No.
WP No.167–99–00

SHEET

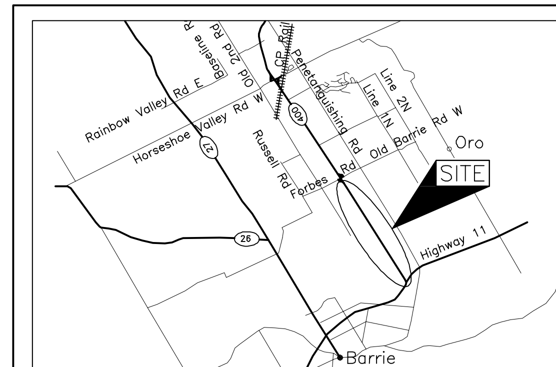
Highway 400 SBL
Culverts – Station 18+500 to 21+500
Borehole Locations

Golder Associates Ltd.
MISSISSAUGA, ONTARIO, CANADA





SCALE
30 0 30 60 m



KEY PLAN
SCALE
4 0 4 8 km

LEGEND

Borehole – Current Investigation

No.	ELEVATION	CO–ORDINATES NORTHING	CO–ORDINATES EASTING
2007–41	264.6	4922985.3	291283.2
2007–42	266.2	4922752.6	291426.0
2007–43	265.6	4922760.3	291450.3
2007–44	230.8	4920780.9	292679.1
2007–45	231.5	4920780.6	292709.0

NOTES

This drawing is for subsurface information only. The proposed structure details/works are shown for illustration purposes only and may not be consistent with the final design configuration as shown elsewhere in the Contracts Documents.

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

The complete foundation investigation and design report for this project and other related documents may be examined at the Materials Engineering and Research Office, Downsview. Information contained in this report and related documents is specifically excluded in accordance with Section GC 2.01 of OPS General Conditions.

REFERENCE

Base plans provided in digital format by Transenco Limited ("Hwy 400 Base Plan_1.dwg", and "Hwy 400 Base Plan_3.dwg" received on December 4, 2007).

NO.	DATE	BY	REVISION

Geocres No.

HWY. 400	PROJECT NO. 06–1111–011–3		DIST.
SUBM'D. VO	CHKD. PKS	DATE: 21/02/2008	SITE:
DRAWN: DD	CHKD. VO/BLT	APPD. LCC	DWG. 1

MINISTRY OF TRANSPORTATION, ONTARIO

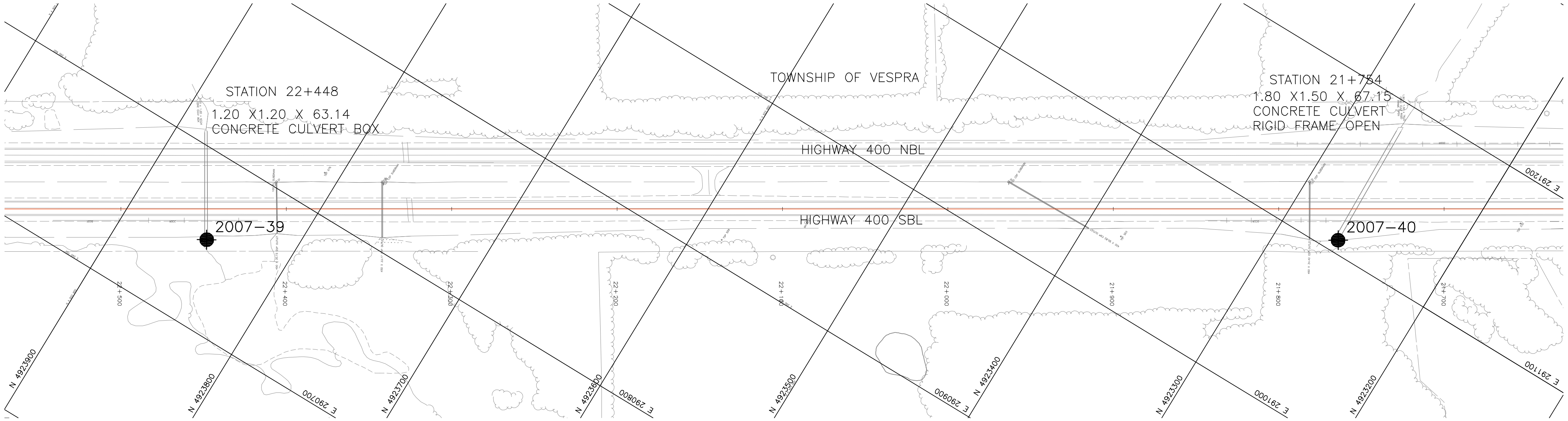
METRIC
DIMENSIONS ARE IN METRES AND/OR MILLIMETRES UNLESS OTHERWISE SHOWN. STATIONS IN KILOMETRES + METRES.

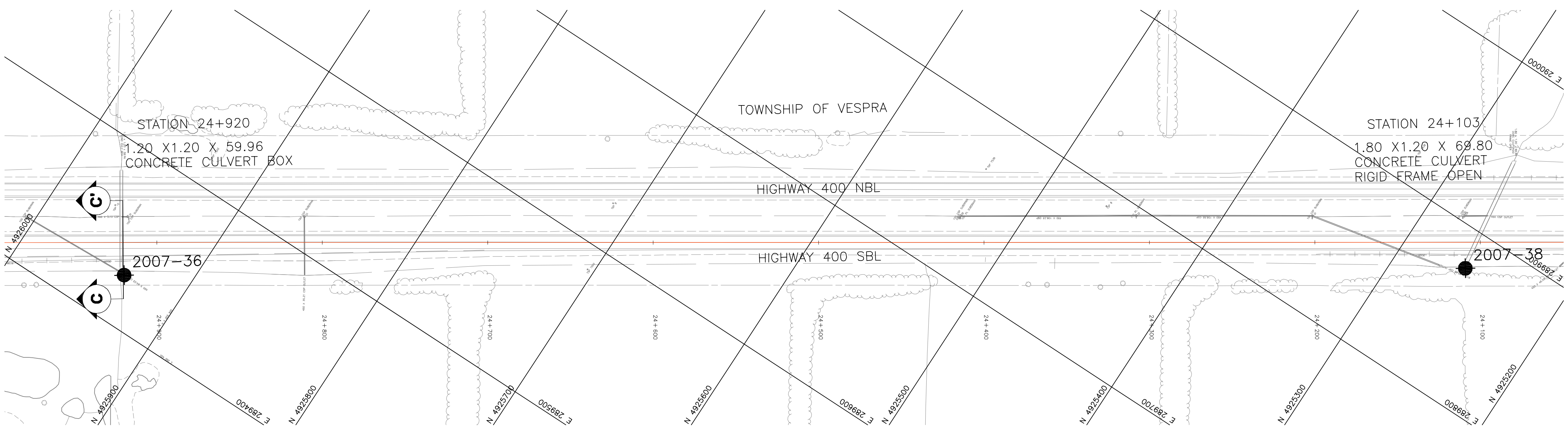
CONT No.
WP No.167–99–00

SHEET

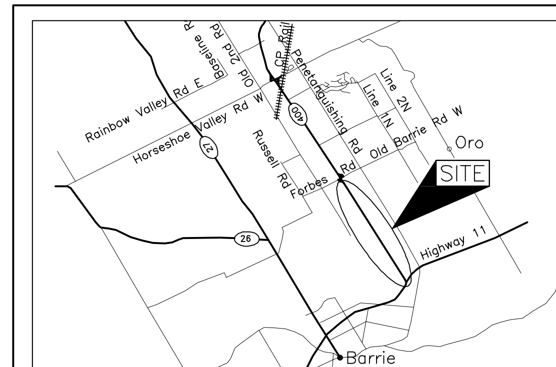
Highway 400 SBL
Culverts – Station 21+600 to 25+000
Borehole Locations

Golder Associates
Golder Associates Ltd.
MISSISSAUGA, ONTARIO, CANADA





SCALE
30 0 30 60 m



KEY PLAN
SCALE
4 0 4 8 km

LEGEND

Borehole – Current Investigation

No.	ELEVATION	CO–ORDINATES	
		NORTHING	EASTING
2007–36	278.2	4925936.4	289429.5
2007–37	279.8	4925953.0	289457.4
2007–38	277.0	4925260.4	289877.1
2007–39	278.2	4923849.0	290751.4
2007–40	270.0	4923265.0	291107.6

NOTES

This drawing is for subsurface information only. The proposed structure details/works are shown for illustration purposes only and may not be consistent with the final design configuration as shown elsewhere in the Contracts Documents.

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

The complete foundation investigation and design report for this project and other related documents may be examined at the Materials Engineering and Research Office, Downsview. Information contained in this report and related documents is specifically excluded in accordance with Section GC 2.01 of OPS General Conditions.

REFERENCE

Base plans provided in digital format by Transenco Limited ("Hwy 400 Base Plan_1.dwg", and "Hwy 400 Base Plan_3.dwg" received on December 4, 2007).

NO.	DATE	BY	REVISION

Geocres No.

HWY. 400	PROJECT NO. 06–1111–011–3		DIST.
SUBM'D. VO	CHKD. PKS	DATE: 21/02/2008	SITE:
DRAWN: DD	CHKD. VO/BLT	APPD. LCC	DWG. 2

PLOT DATE: February 21, 2008

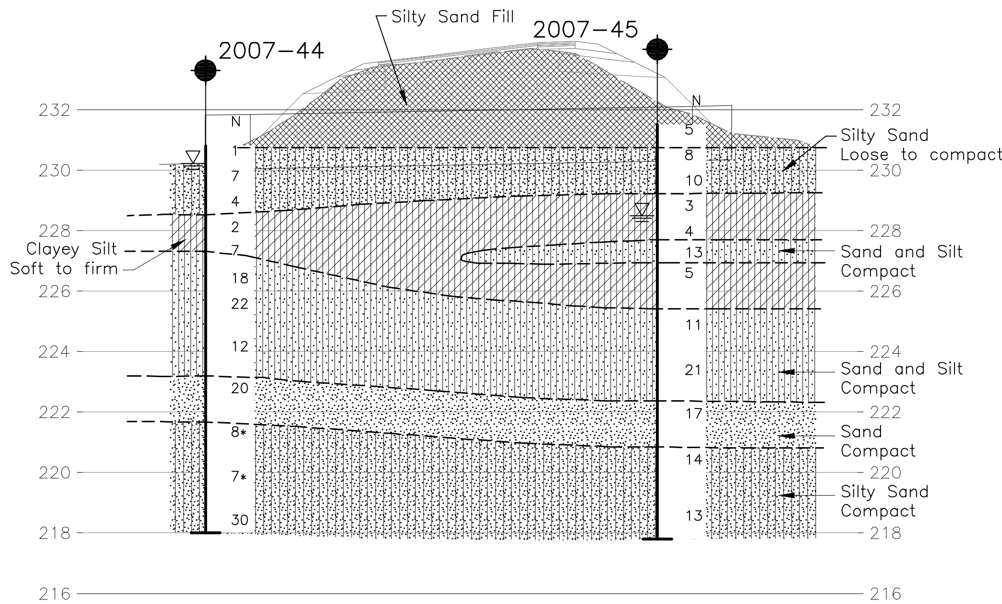
METRIC
DIMENSIONS ARE IN METRES AND/OR MILLIMETRES UNLESS OTHERWISE SHOWN. STATIONS IN KILOMETRES + METRES.

CONT No.
WP No. 167-99-00

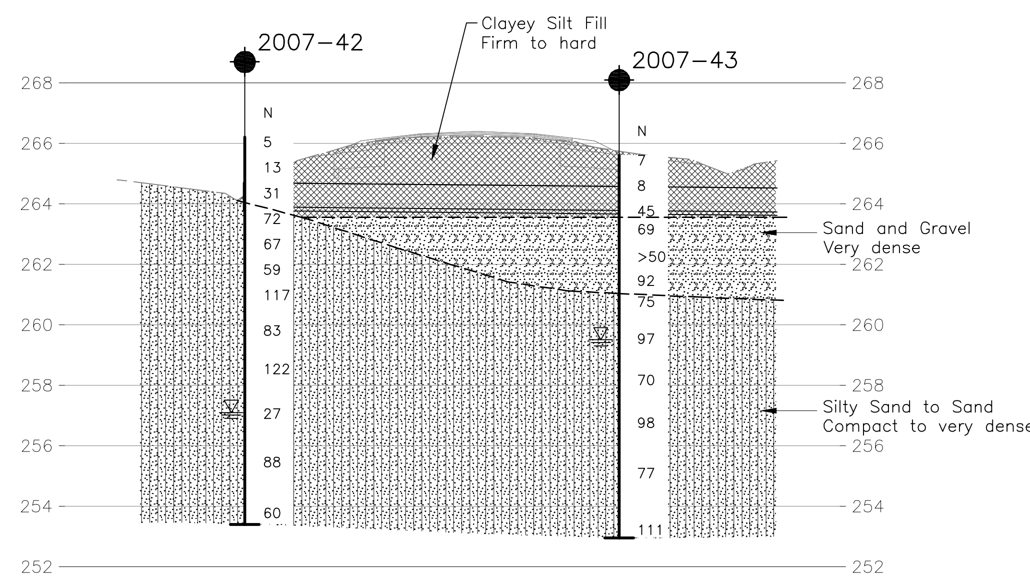
SHEET

Highway 400 SBL Culverts Soil Strata

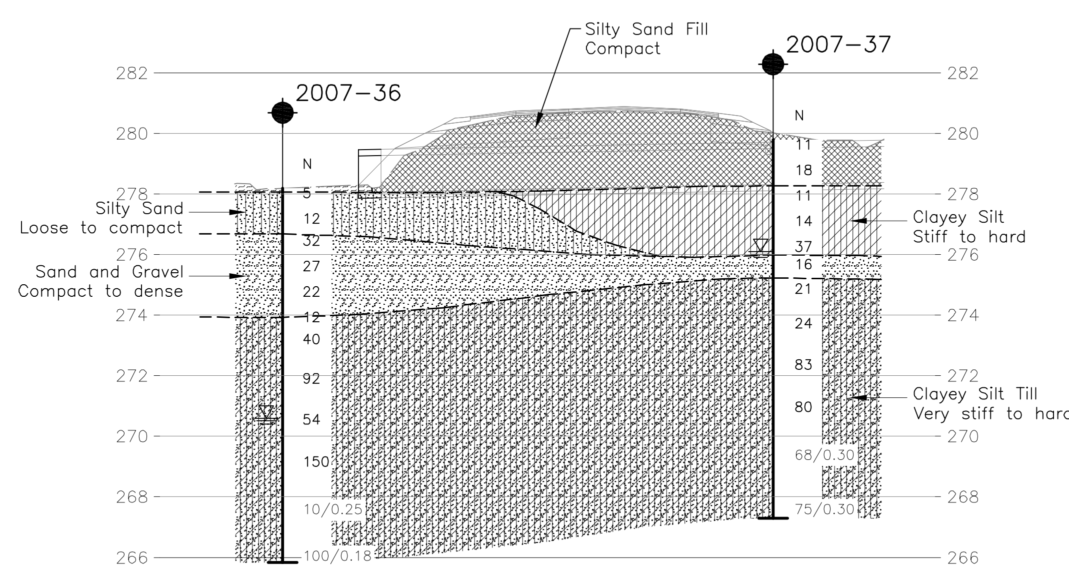
Golder Associates Ltd.
MISSISSAUGA, ONTARIO, CANADA



SECTION A – A'
CULVERT AT STATION 18+560



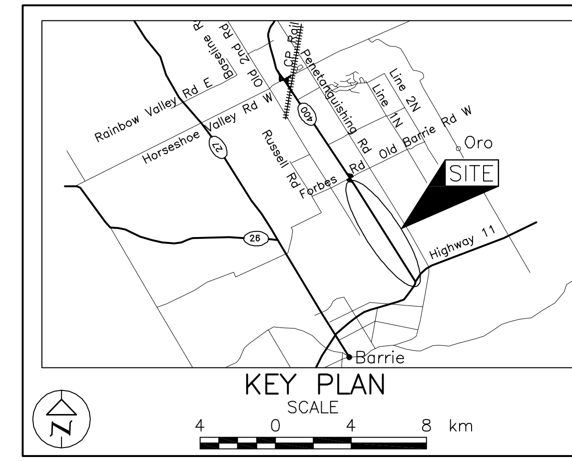
SECTION B – B'
CULVERT AT STATION 21+150



SECTION C – C'
CULVERT AT STATION 24+920

SCALE
HOR 5 0 5 10 m

SCALE
VERT 2.5 0 2.5 5 m



KEY PLAN
SCALE
4 0 4 8 km

LEGEND

- Borehole – Current Investigation
- WL upon completion of drilling
- N — Standard Penetration Test Value
- 16 — Blows/0.3m unless otherwise stated (Std. Pen. Test, 475 j/blow)

No.	ELEVATION	CO-ORDINATES NORTHING	CO-ORDINATES EASTING
2007-36	278.2	4925936.4	289429.5
2007-37	279.8	4925953.0	289457.4
2007-42	266.2	4922752.6	291426.0
2007-43	265.6	4922760.3	291450.3
2007-44	230.8	4920780.9	292679.1
2007-45	231.5	4920780.6	292709.0

NOTES

This drawing is for subsurface information only. The proposed structure details/works are shown for illustration purposes only and may not be consistent with the final design configuration as shown elsewhere in the Contracts Documents.

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

The complete foundation investigation and design report for this project and other related documents may be examined at the Materials Engineering and Research Office, Downsview. Information contained in this report and related documents is specifically excluded in accordance with Section GC 2.01 of OPS General Conditions.

REFERENCE

Base plans provided in digital format by Transenco Limited ("W_Golder Culverts.dwg" received on December 12, 2007).

NO.	DATE	BY	REVISION

Geocres No.

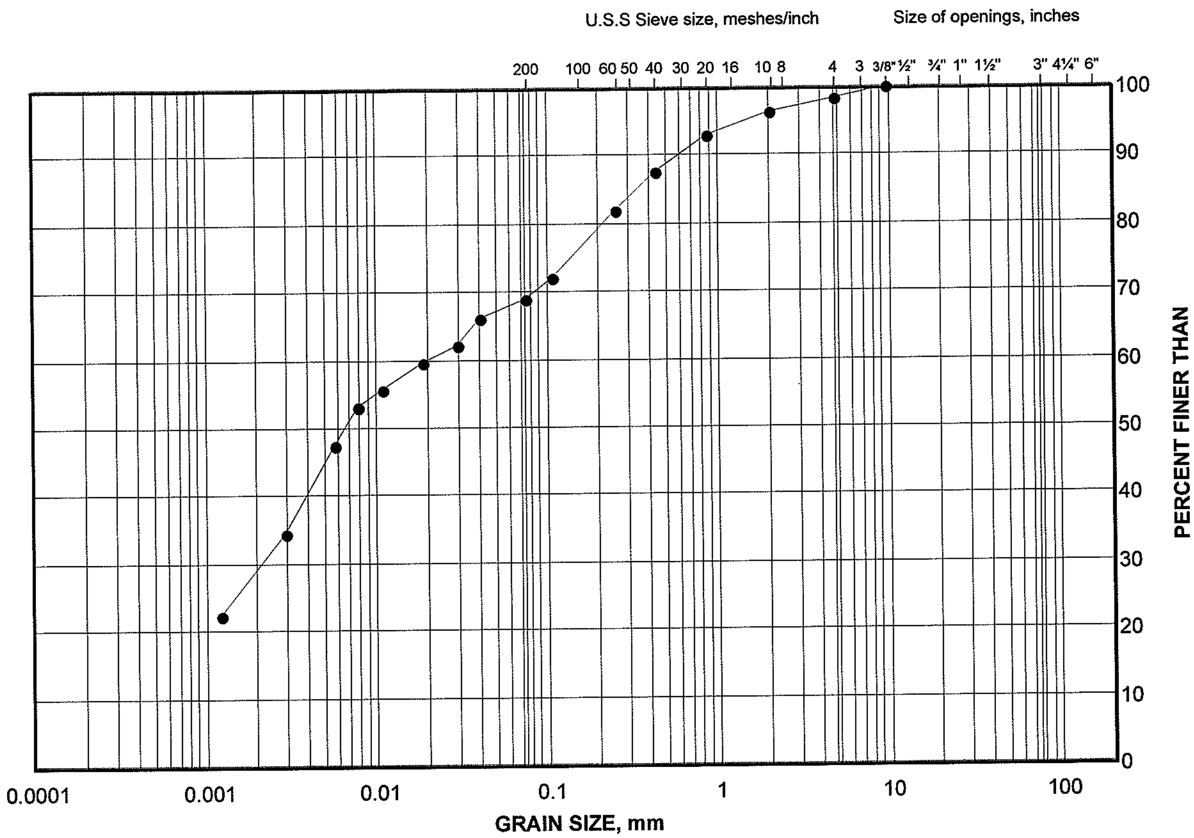
HWY. 400		PROJECT NO. 06-1111-011-3	DIST.
SUBM'D. VO	CHKD. PKS	DATE: 21/02/2008	SITE:
DRAWN: DD	CHKD. VO/BLT	APPD. LCC	DWG. 3

GRAIN SIZE DISTRIBUTION TEST RESULT

Clayey Silt Fill

Culvert at Station 21+150

FIGURE 1



SILT AND CLAY SIZES	FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE
FINE GRAINED	SAND SIZE			GRAVEL SIZE		SIZE

LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
•	2007-43	3A	263.8

Project Number: 06-1111-011

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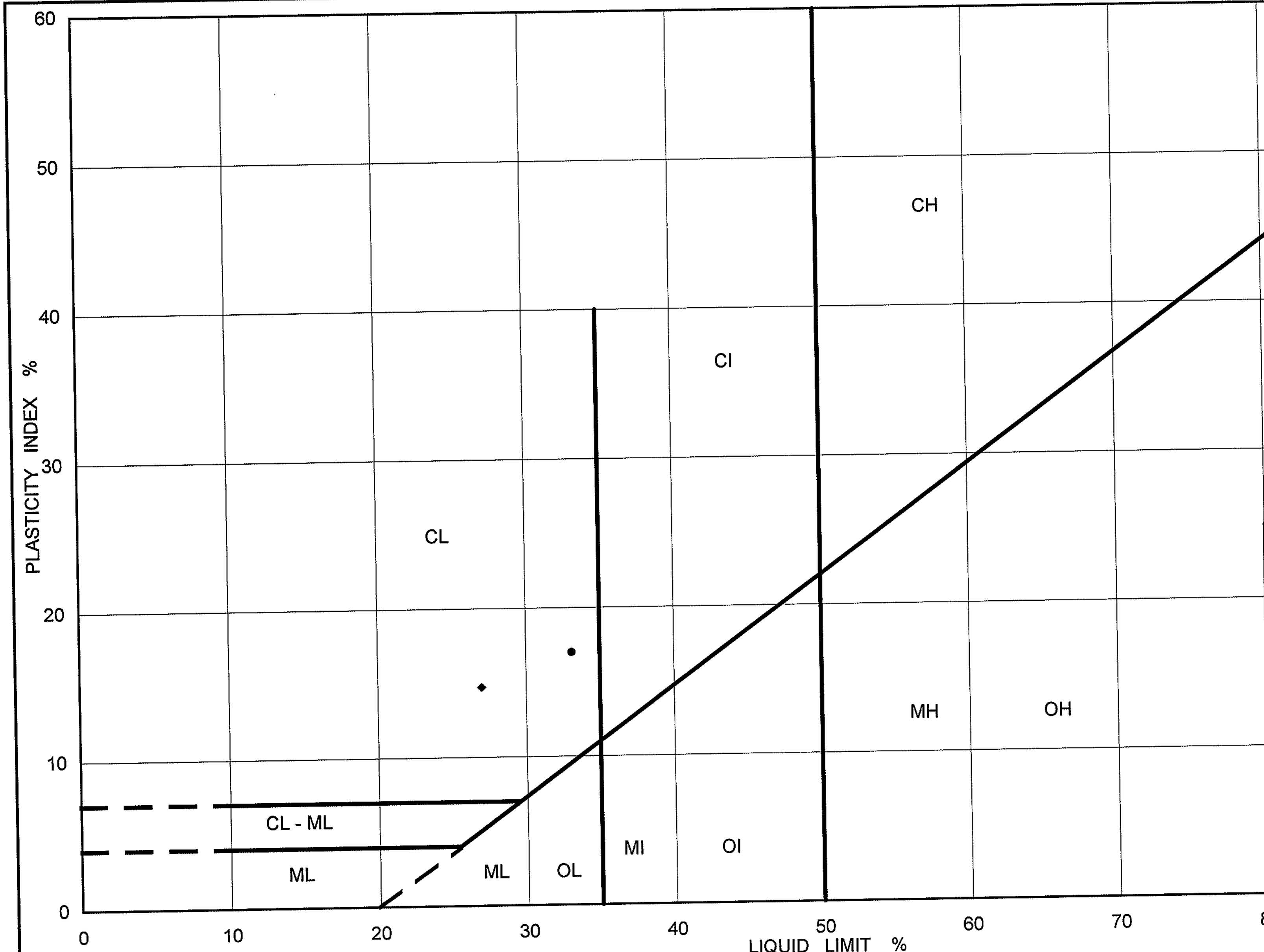
Golder Associates

Date: 20-Feb-08

Oct 75, FF-S-21



LEGEND		
BH	SAMPLE	SYMBOL
2007-42	2	●
2007-43	3A	◆
		▲
		■
		○
		◇
		△
		□

Ministry of Transportation

Ontario

PLASTICITY CHART
Clayey Silt Fill
Culvert at Station 21+150

Figure 2

Project No. 06-1111-011

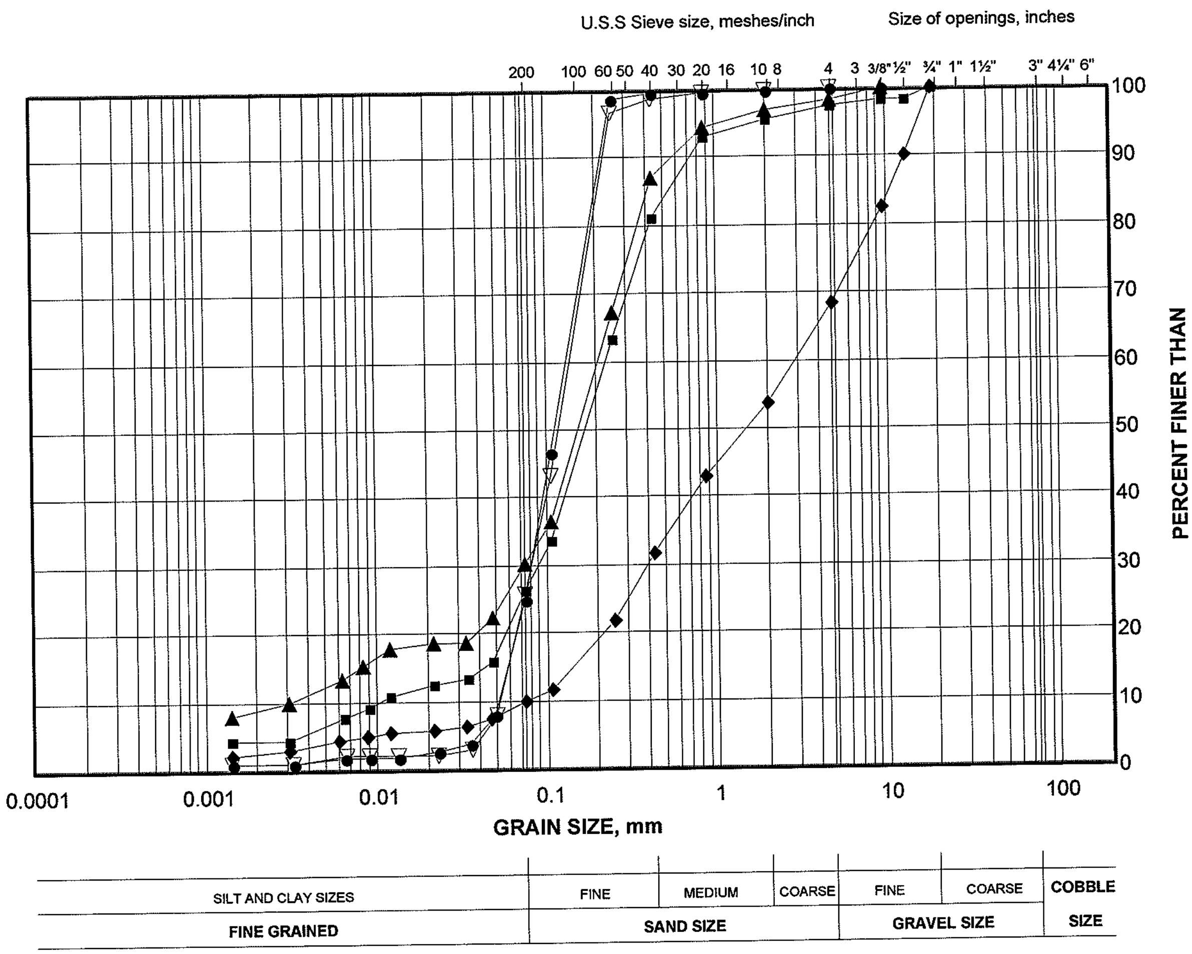
Checked By: [signature]

GRAIN SIZE DISTRIBUTION TEST RESULTS

Sandy Silt to Sand and Gravel

Culverts at Station 18+560 and 21+150

FIGURE 3A



LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	2007-42	10	256.8
■	2007-42	3	264.4
◆	2007-43	5	262.4
▲	2007-42	6	262.1
▽	2007-43	7	260.8

Project Number: 06-1111-011

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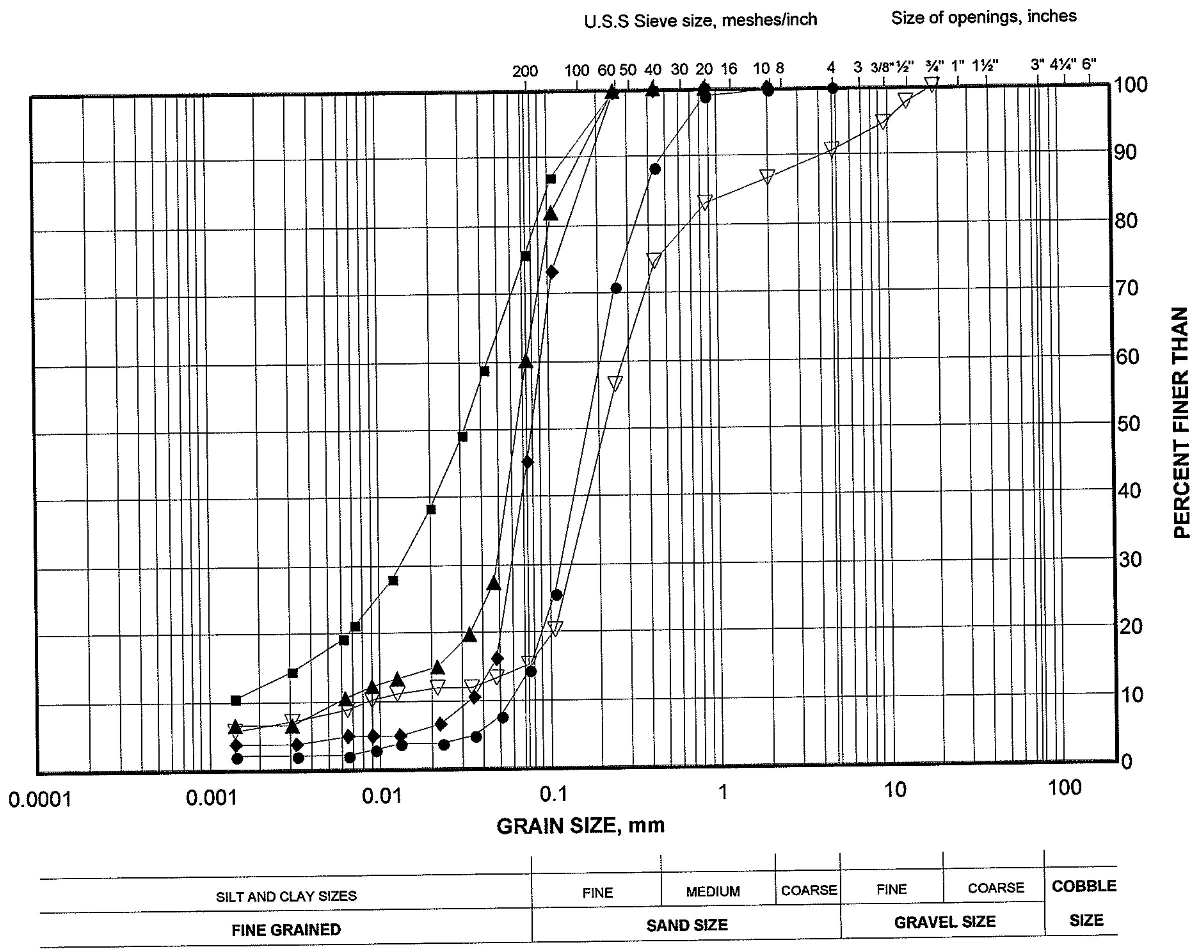
Date: 20-Feb-08

GRAIN SIZE DISTRIBUTION TEST RESULTS
Sandy Silt to Sand and Gravel
Culverts at Station 18+560 and 21+150

FIGURE 3B



LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	2007-45	10	222.1
■	2007-45	3	229.7
◆	2007-45	6	227.4
▲	2007-44	6	226.7
▽	2007-44	9	222.9

Project Number: 06-1111-011

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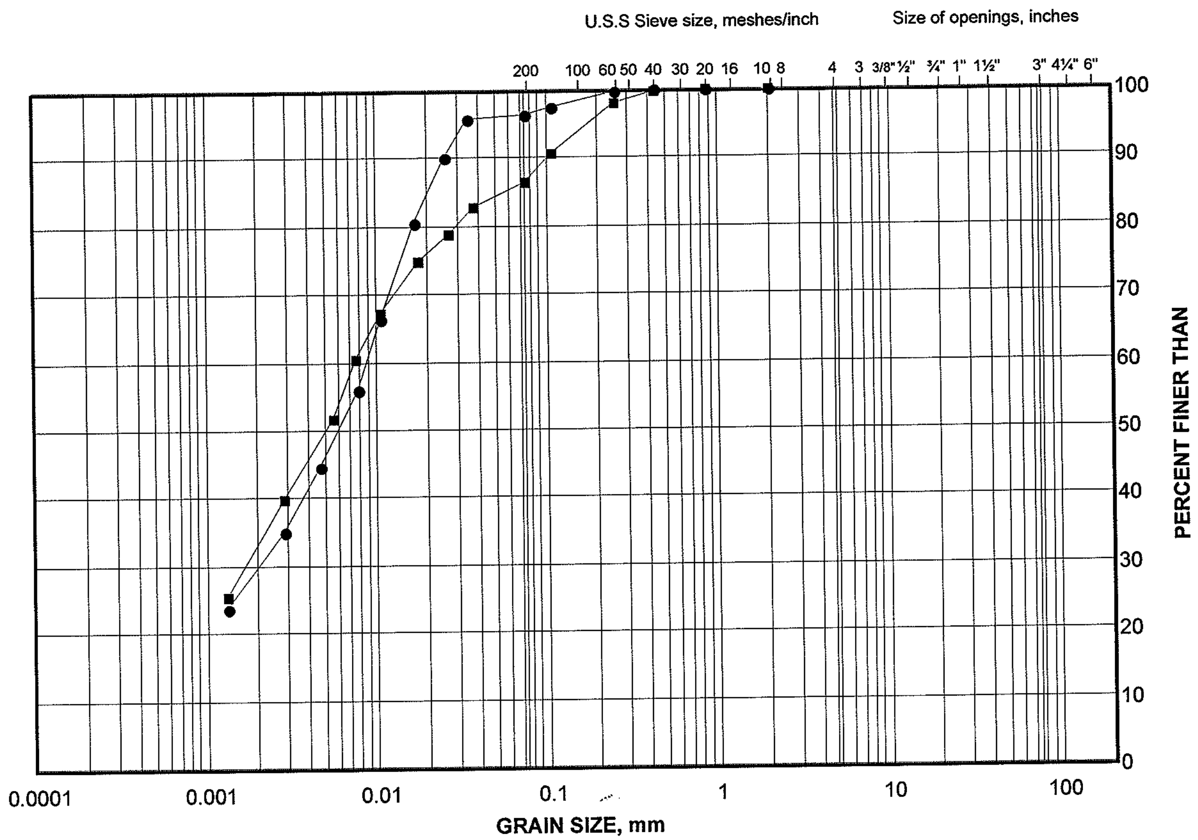
Date: 20-Feb-08

GRAIN SIZE DISTRIBUTION TEST RESULTS

Clayey Silt

Culvert at Station 18+560

FIGURE 4



SILT AND CLAY SIZES	FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE
FINE GRAINED	SAND SIZE			GRAVEL SIZE		SIZE

LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	2007-44	4	228.2
■	2007-45	7	226.6

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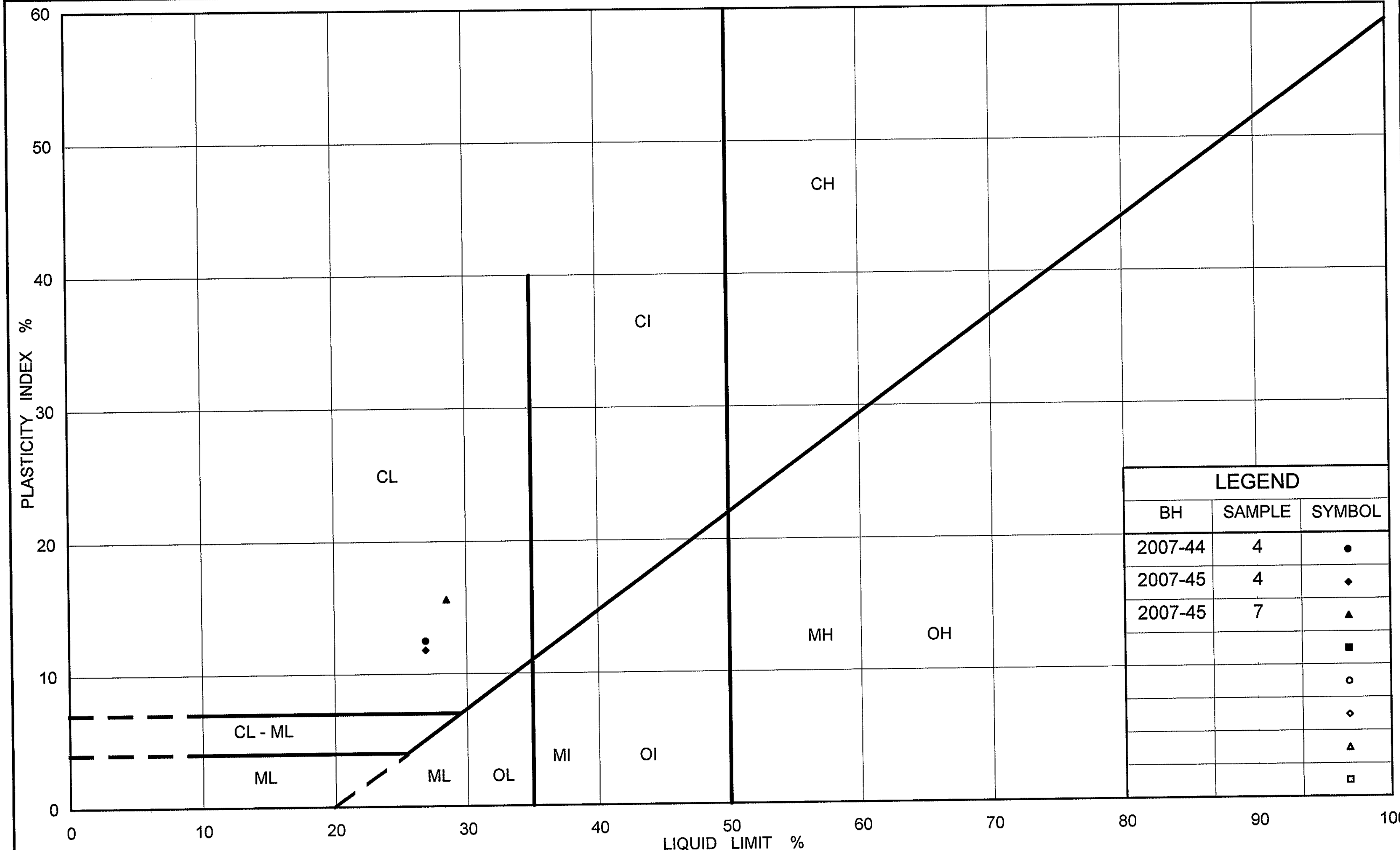
Date: 20-Feb-08

Oct 75, FF-S-21



LEGEND		
BH	SAMPLE	SYMBOL
2007-44	4	●
2007-45	4	◆
2007-45	7	▲
		■
		○
		◇
		△
		□

Ministry of Transportation

Ontario

PLASTICITY CHART
Clayey Silt
Culvert at Station 18+560

Figure 5

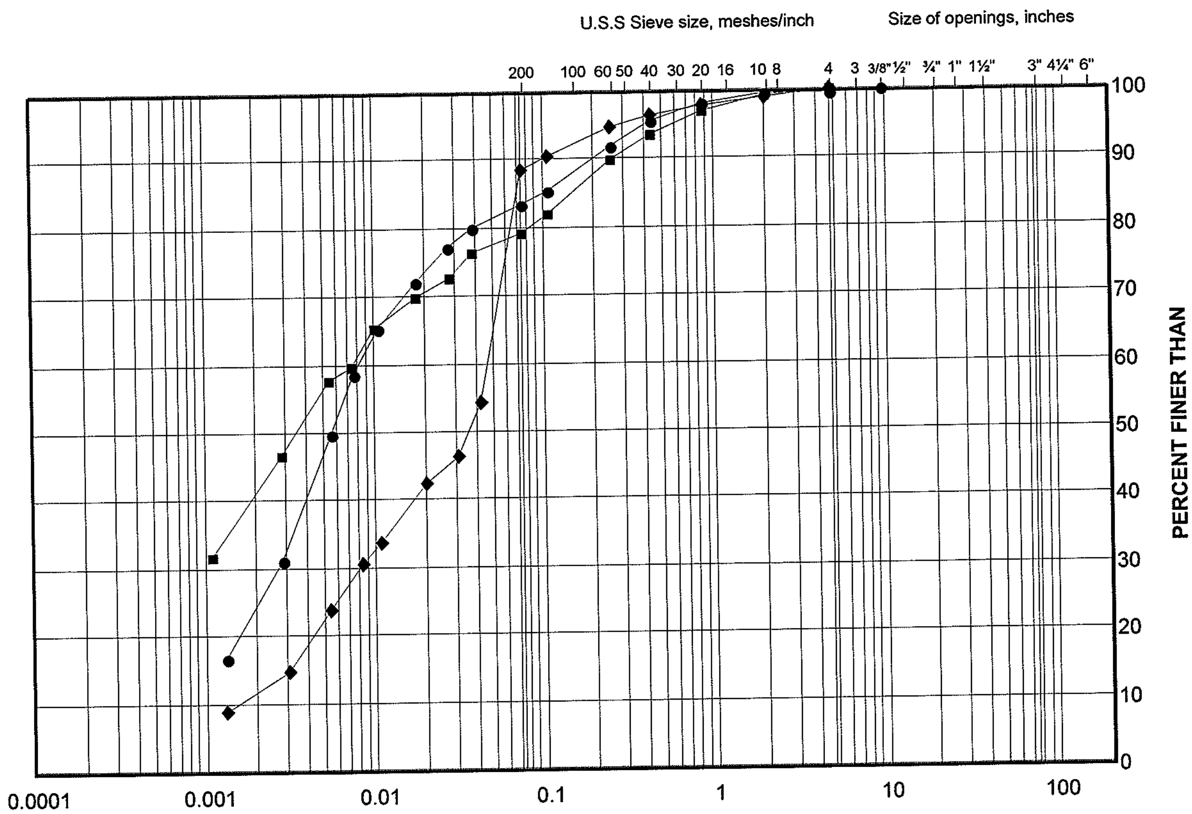
Project No. 06-1111-011

Checked By:

GRAIN SIZE DISTRIBUTION TEST RESULTS

Upper Clayey Silt
Culverts North of Station 21+300

FIGURE 6



SILT AND CLAY SIZES	FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE
FINE GRAINED	SAND SIZE			GRAVEL SIZE		SIZE

LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	2007-38	2	275.9
■	2007-37	3	278.0
◆	2007-38	4	274.4

Project Number: 06-1111-011

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Date: 20-Feb-08

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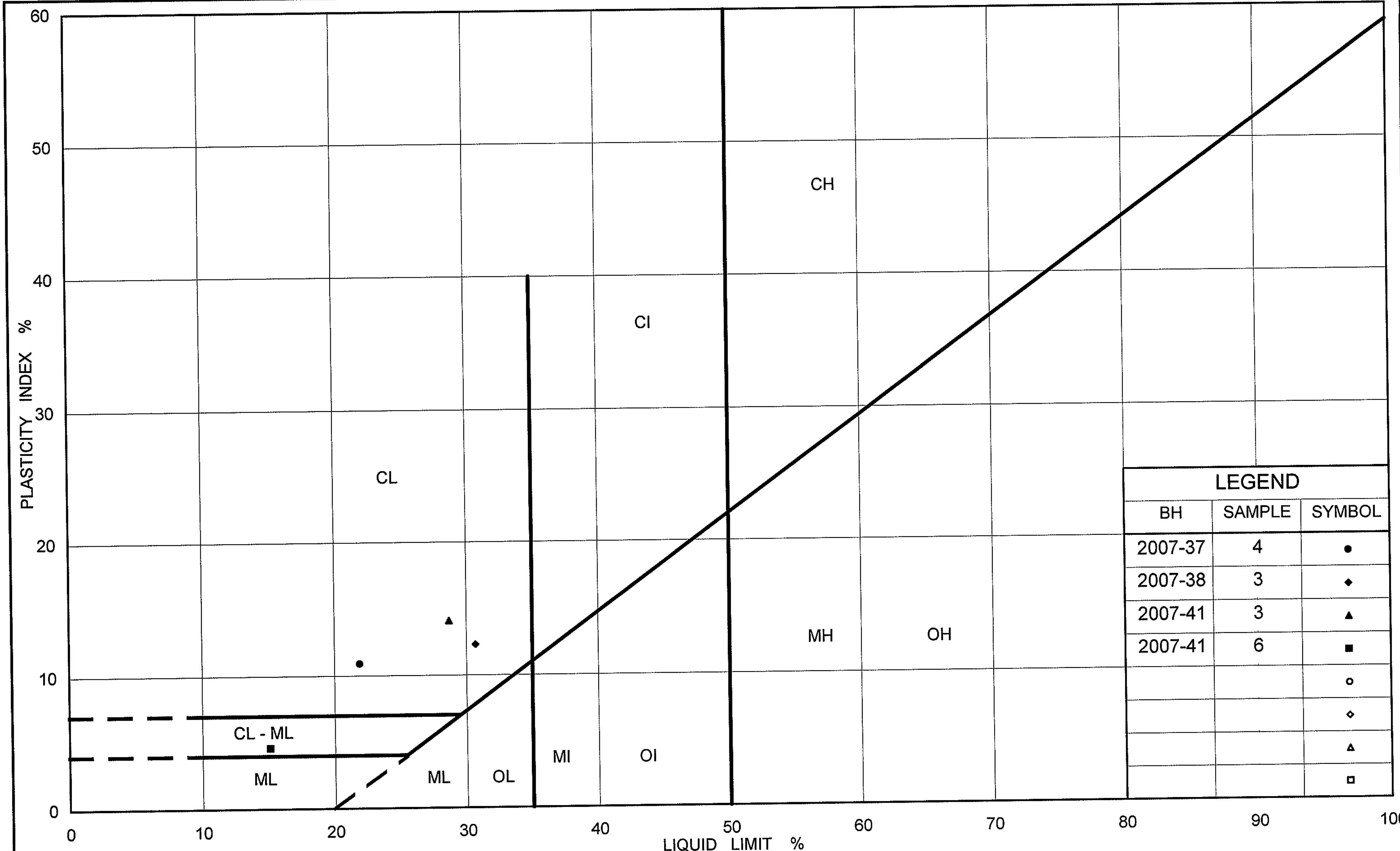
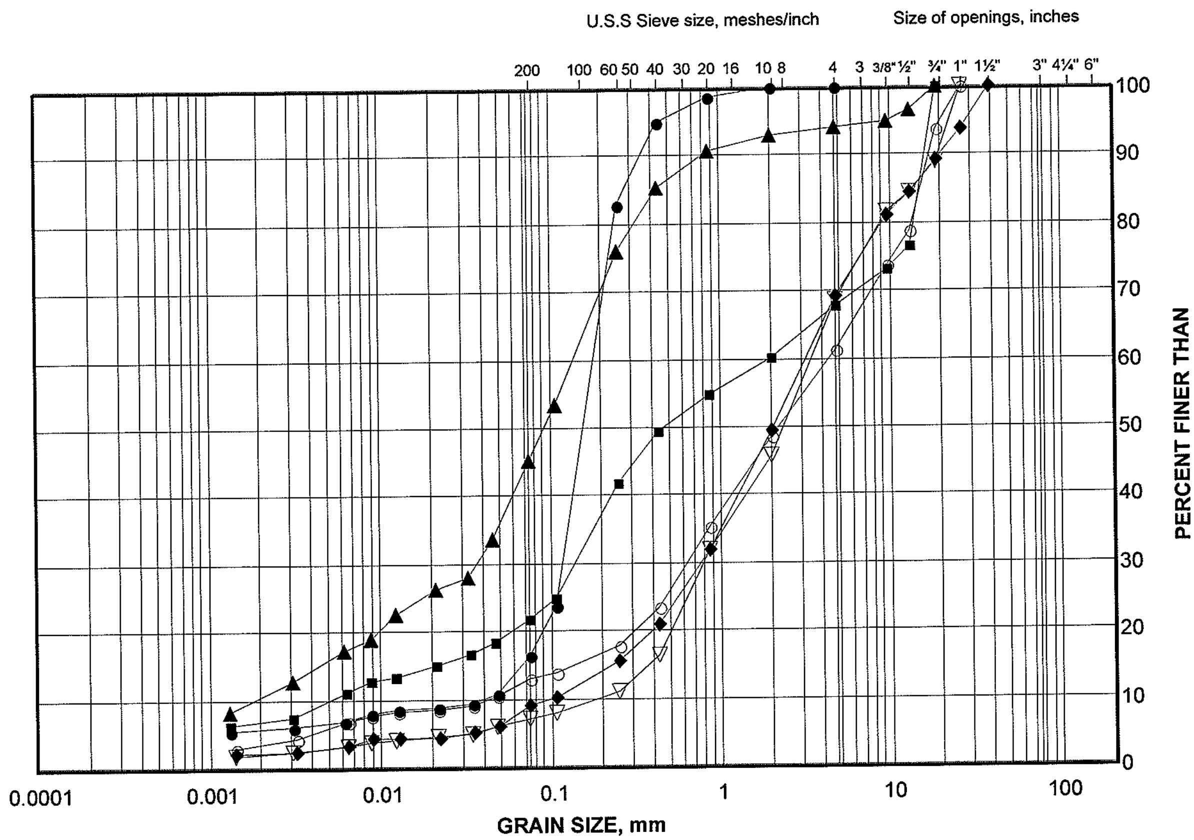


LEGEND		
BH	SAMPLE	SYMBOL
2007-37	4	●
2007-38	3	◆
2007-41	3	▲
2007-41	6	■
		○
		◇
		△
		□

Ministry of Transportation Ontario	**PLASTICITY CHART** Upper Clayey Silt Culverts North of Station 21+300	Figure 7 Project No. 06-1111-011 Checked By: [signature]

GRAIN SIZE DISTRIBUTION TEST RESULTS
Upper Silty Sand to Sand and Gravel
Culverts North of Station 21+300

FIGURE 8



SILT AND CLAY SIZES	FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE
FINE GRAINED	SAND SIZE			GRAVEL SIZE		SIZE

LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	2007-39	2	277.1
■	2007-40	3	268.2
◆	2007-36	4	275.6
▲	2007-41	6	260.5
▽	2007-36	6	274.1
○	2007-37	6	275.7

Project Number: 06-1111-011

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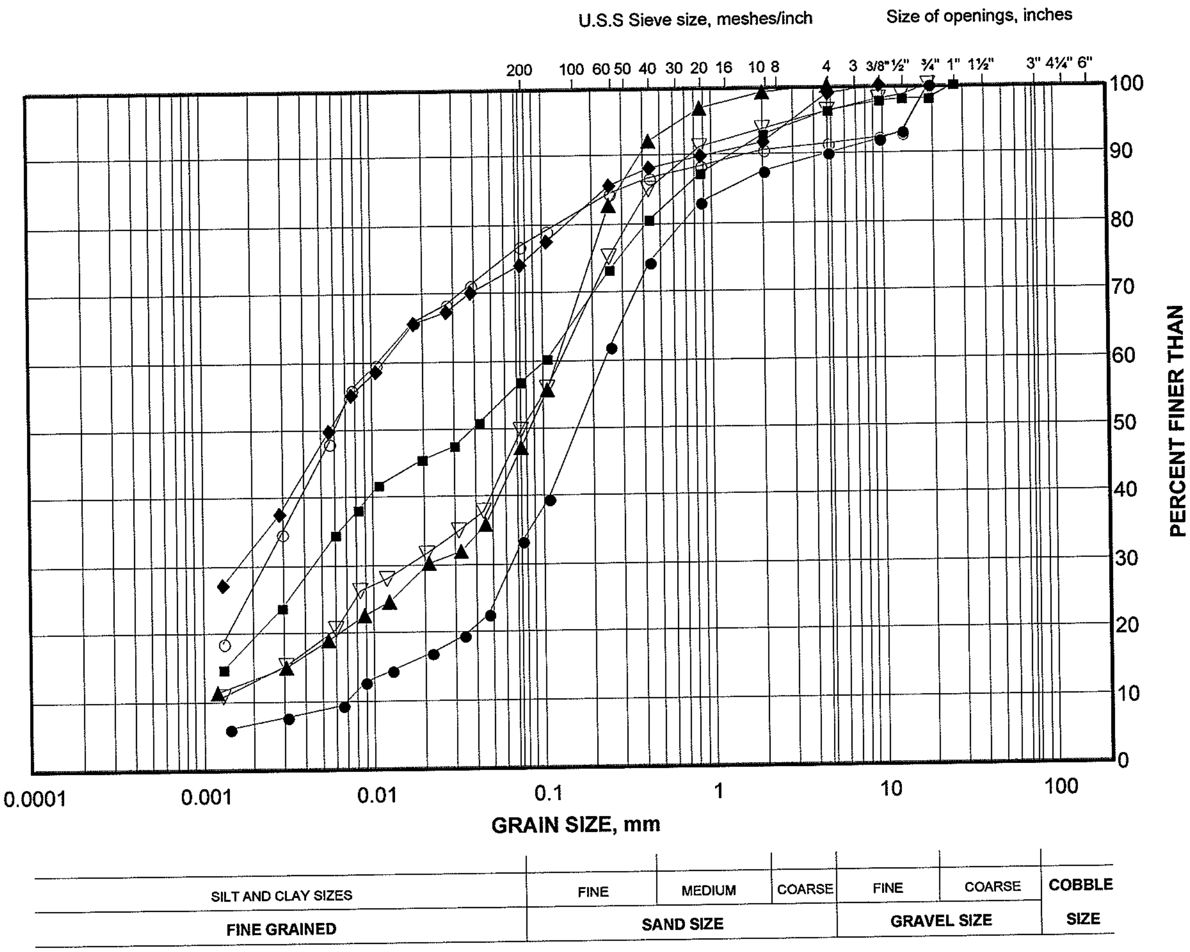
Date: 20-Feb-08

GRAIN SIZE DISTRIBUTION TEST RESULTS

Clayey Silt Till to Silty Sand Till
Culverts North of Station 21+300

FIGURE 9



LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	2007-41	10	255.2
■	2007-37	11	269.0
◆	2007-40	6	265.9
▲	2007-39	7	273.3
▽	2007-41	8	258.2
○	2007-36	9	270.3

Project Number: 06-1111-011

Checked By: [signature]

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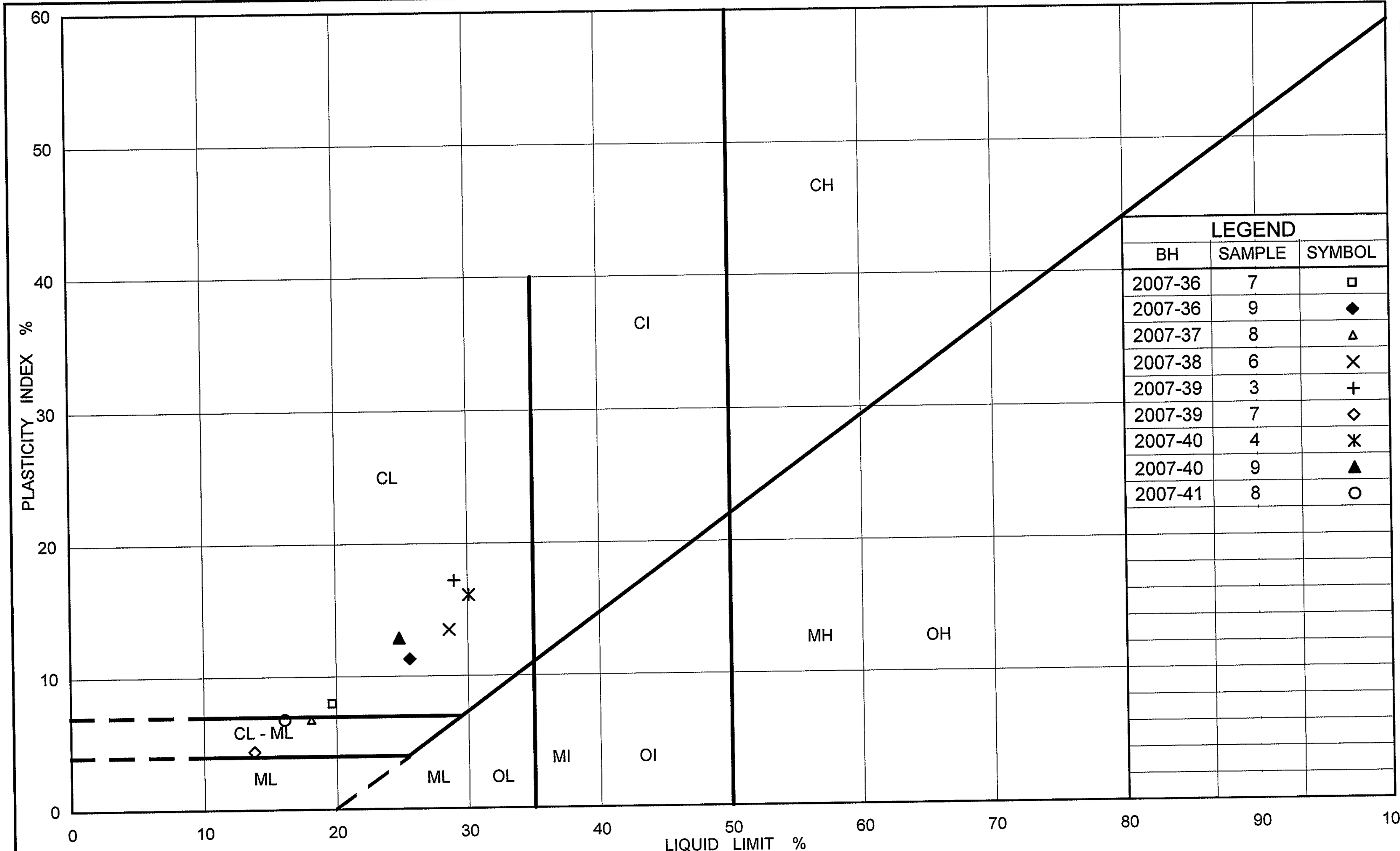
Date: 20-Feb-08

Oct 75, FF-S-21



BH	SAMPLE	SYMBOL
2007-36	7	□
2007-36	9	◆
2007-37	8	△
2007-38	6	×
2007-39	3	+
2007-39	7	◇
2007-40	4	✳
2007-40	9	▲
2007-41	8	○

Ministry of Transportation

Ontario

PLASTICITY CHART
Clayey Silt Till
Culverts North of Station 21+300

Figure 10

Project No. 06-1111-011

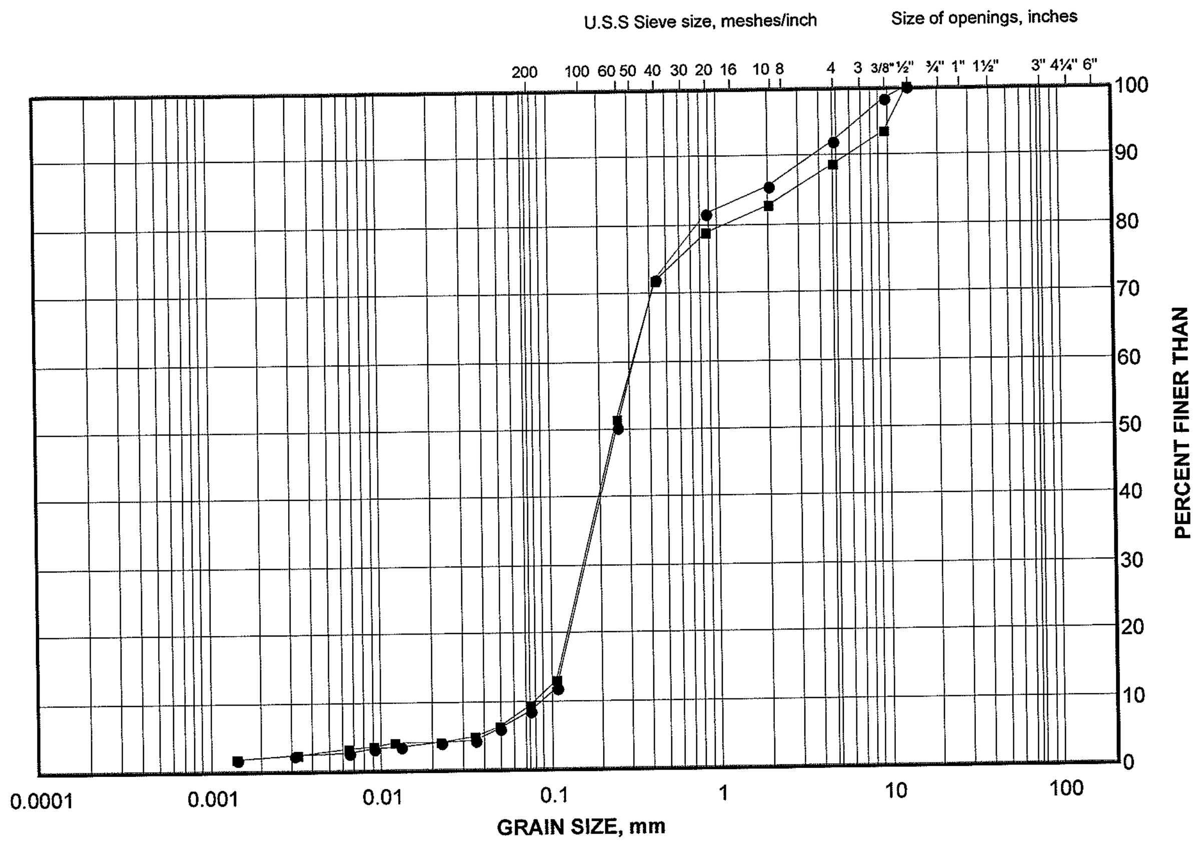
Checked By:

GRAIN SIZE DISTRIBUTION TEST RESULTS

Lower Sand

Culverts North of Station 21+300

FIGURE 11



SILT AND CLAY SIZES	FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE
FINE GRAINED	SAND SIZE			GRAVEL SIZE		SIZE

LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	2007-38	8	270.8
■	2007-39	9	270.5

Project Number: 06-1111-011

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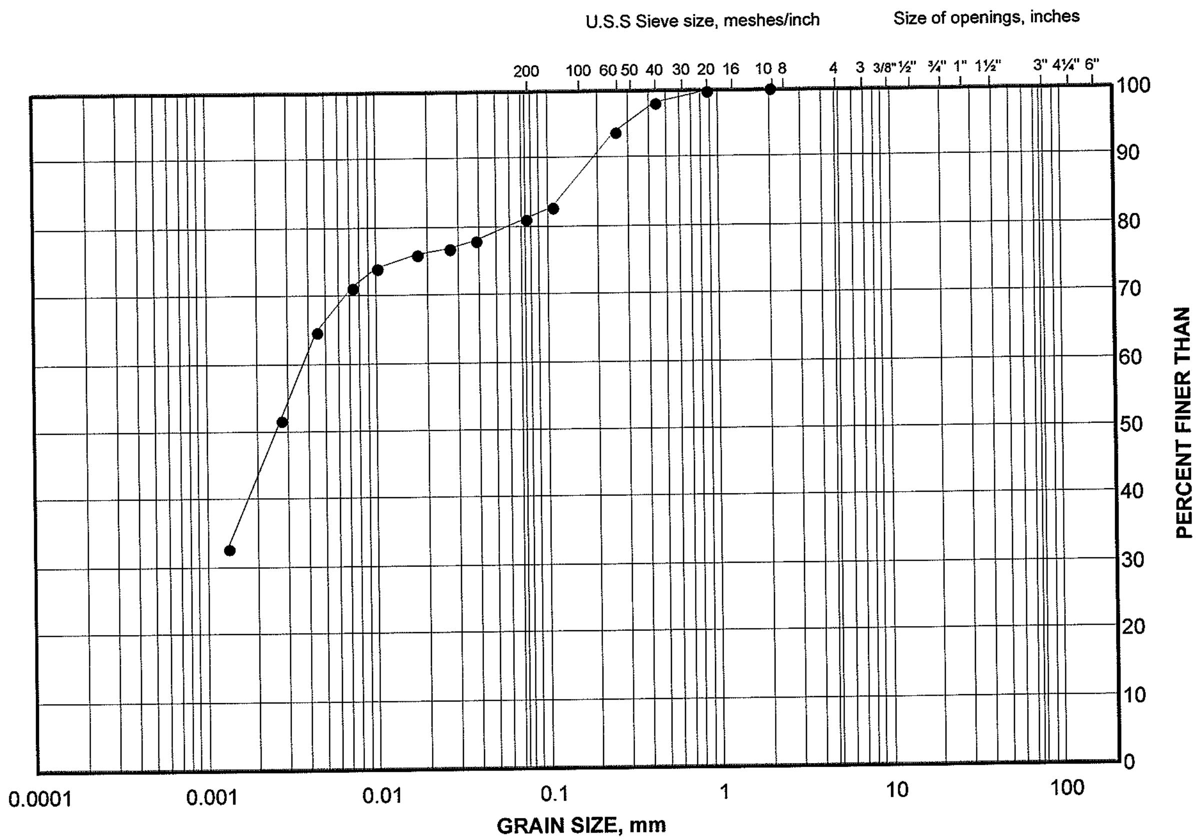
Date: 20-Feb-08

GRAIN SIZE DISTRIBUTION TEST RESULT

Lower Silty Clay

Culverts North of Station 21+300

FIGURE 12



SILT AND CLAY SIZES	FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE
FINE GRAINED	SAND SIZE			GRAVEL SIZE		SIZE

LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	2007-39	11	267.3

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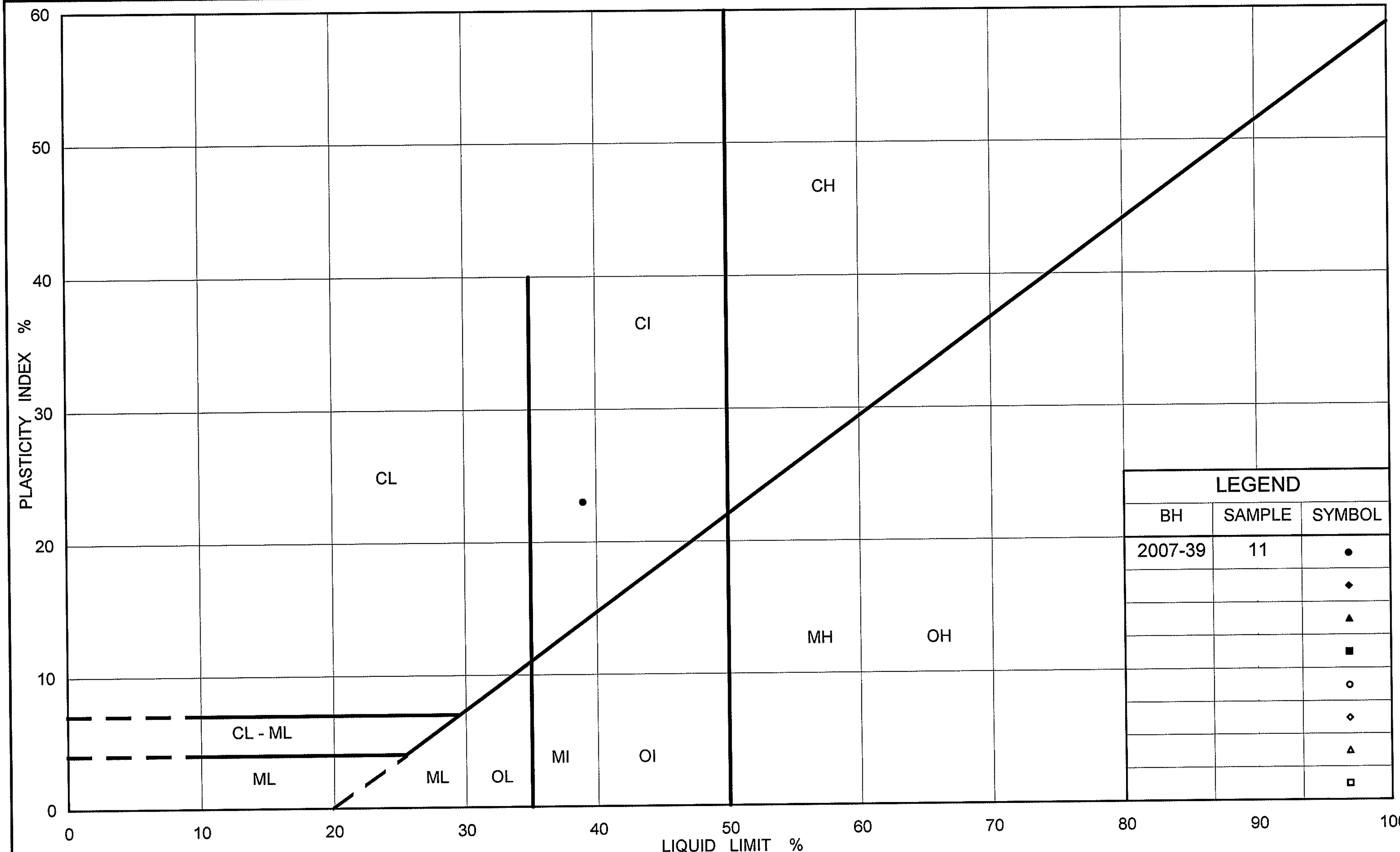
Date: 20-Feb-08



LEGEND

BH	SAMPLE	SYMBOL
2007-39	11	●
		◆
		▲
		■
		○
		◇
		△
		□

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Ontario

PLASTICITY CHART
Lower Silty Clay
Culvert North of Station 21+300

Figure 13

Project No. 06-1111-011

Checked By:

APPENDIX A

NON-STANDARD SPECIAL PROVISIONS

GROUNDWATER CONTROL – Item No.

Non-Standard Special Provision

Foundations for the new culverts or culvert extensions will require excavations to extend below the groundwater level at the sites. Cohesionless (sandy, silt or gravelly) soils that are present below the groundwater table will slough, run, boil or cave in to the excavation unless appropriate groundwater control is in place. The Contractor is to design and install an appropriate dewatering system for the culvert sites to enable construction in dry conditions, and prevent disturbance to the founding soils.

Basis of Payment

Payment at the contract price for the above tender item shall include full compensation for all labour and materials to complete the work.

END OF SECTION

SUBGRADE PROTECTION – Item No.

Non-Standard Special Provision

The subgrade soils for the culvert foundations or box culverts will be susceptible to disturbance and loosening from construction traffic and ponded water. If the concrete for the footings cannot be poured within four hours after inspection and approval of the prepared subgrade, a working mat of lean concrete or mass concrete, with minimum thickness of 100 mm, should be placed on the foundation subgrade.

Where pre-cast box culverts are used, if all the box segments are not placed on the prepared subgrade within four hours of its inspection and approval, a working mat of lean concrete or mass concrete, with minimum thickness of 100 mm, should be placed on the foundation subgrade. A levelling pad, consisting of a minimum thickness of 75 mm of Granular A or fine aggregate (meeting requirements set out in OPSS 1002) should be provided on top of the lean concrete mat.

Basis of Payment

Payment at the contract price for the above tender item shall include full compensation for all labour and materials to complete the work.