February 10, 2016

FOUNDATION INVESTIGATION AND DESIGN REPORT

TRENCHLESS CROSSINGS
HIGHWAY 401 WIDENING FROM HIGHWAY 403/410 INTERCHANGE TO THE CREDIT RIVER
CITY OF MISSISSAUGA, REGION OF PEEL
G.W.P. 2150-01-00

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AECOM Canada Inc.
300 Water Street
Whitby, Ontario
L1N 9J2

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REPORT

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PART A

FOUNDATION INVESTIGATION REPORT
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HIGHWAY 403/410 INTERCHANGE TO THE CREDIT RIVER
CITY OF MISSISSAUGA, REGION OF PEEL
G.W.P. 2150-01-00

1.0 INTRODUCTION

Golder Associates Ltd. (Golder) has been retained by AECOM Canada Inc. (AECOM) on behalf of the Ministry of Transportation, Ontario (MTO) to provide foundation engineering services in support of the proposed culverts construction associated with the widening of Highway 401 from the Highway 403/410 Interchange to the Credit River in the City of Mississauga, Region of Peel, Ontario.

The terms of reference and scope of work for the foundation investigation are outlined in MTO's Request for Proposal (RFP) dated October 5, 2010 and subsequent clarifications, and specifically in Golder Associates Ltd.'s (Golder's) revised scope change letter (Scope Change No. 11) dated October 7, 2015.

The Foundation Investigation for the trenchless methods of culvert installation conducted by Golder involved the advancement of 9 new boreholes along Highway 401 near Mavis Road, supplemented with boreholes advanced for other foundation components of this project (i.e., G.W.P. 2150-01-00) and existing relevant borehole information collected from the MTO GEOCRES library. This report presents the subsurface conditions at the locations of seven culvert crossings.

2.0 SITE DESCRIPTION

The proposed trenchless crossing locations are located within the area at and around the existing Highway 401 and Mavis Road interchange. The west limit of the proposed new trenchless crossings is approximately 200 m west of Mavis Road, and the east limit is approximately 500 m east of Mavis Road.

The topography across the site adjacent to Highway 401 consists of gently undulating terrain which slopes downward to the west towards the Credit River. Vegetation within the right-of-way and the associated interchange loops is sparse, consisting of grass, small shrubs and occasional treed areas further east of the Mavis Road Interchange. Residential properties are present along the Highway 401 corridor west of Mavis Road and commercial facilities are located along Highway 401 east of Mavis Road.

Based on the information provided by AECOM, the proposed trenchless crossing locations are shown on Drawing 1.

3.0 INVESTIGATION PROCEDURES

3.1 Current Investigations

A total of nine boreholes (Boreholes TC15-1 to TC15-9) were drilled in November, 2015 as part of the site-specific geotechnical investigation program for the proposed trenchless crossing locations, using truck-mounted CME-75 and track-mounted CME-55 drill rigs supplied and operated Davis Drilling Inc. of Milton, Ontario. Use was also made of seven boreholes from earlier stages of Golder's investigation for the widening of Highway 401 (Boreholes BH-2014-8A, BH-2014-9A, BH-2014-10A, MR-1, MR-2, MR-3, MR-3A, and MR-4). The boreholes were generally advanced using 150 mm outside diameter solid stem augers or 108 mm inside diameter hollow stem augers, with soil samples 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 *(ASTM D1586-08a, Standard Test Method for Standard Penetration Test).* The specific auger type and diameter are indicated on the borehole records contained in Appendices A through G, organized by culvert location. The boreholes from the 2015 investigation were advanced to at least three tunnel diameters below the proposed culvert invert.

The groundwater conditions were observed in the open boreholes during and immediately following the drilling operations. Standpipe piezometers were installed in Boreholes TC15-1, TC15-4, TC15-6, TC15-9, MR-1, MR-4, and 2014-9A; the details of the piezometer installation are shown on the applicable borehole records. All of the open boreholes were backfilled with bentonite upon completion, in accordance with Ontario Regulation 903 (as amended), with an asphalt patch placed at the highway surface.

The field work was supervised on a full-time basis by members of Golder’s engineering staff who located the boreholes in the field, cleared all locations of underground utilities, directed the drilling, sampling and in situ testing operations, and logged the subsurface conditions. The soil samples were identified in the field, placed in labelled containers and transported to Golder’s laboratory in Mississauga for further examination and laboratory testing. Index and classification tests consisting of water content determinations, Atterberg limits and grain size distribution were carried out on selected soil samples. The results of the testing program are presented on the Record of Borehole sheets and shown on the laboratory test figures, in Appendices A through G, by crossing location.

3.2 Previous Investigations

Three boreholes (Boreholes 237-2, 237-4, 237-6) from a previous investigation by others have been used in the preparation of this report, as follows:

MTO GEOCRES No. 30M12-237: Report titled “Foundation Investigation Report for Highway 401 – Mavis Road Underpass, City of Mississauga, MTO W.P. 311-89-00; Site No. 24-736”, by Terraprobe, dated February 16, 1998

For this report, these three boreholes have been renamed to show the MTO GEOCRES 30M12-237 reference number followed by the original borehole designation. Therefore, the boreholes have been renamed as 237-X, where X is the original borehole number.

3.3 Borehole Locations

The borehole locations were recorded in the field by Golder personnel using a GPS-enabled Tablet connected to a Trimble GPS Booster device, with a horizontal accuracy of approximately 1.0 m. The borehole locations were further refined using local site features and by cross-referencing with the digital terrain models provided by AECOM. The ground surface elevation at each borehole location was estimated from the digital terrain model provided by AECOM. Due to recent construction activities on site, the provided digital terrain model was not considered valid for Boreholes TC15-3, TC15-4, and TC15-5. For these boreholes, the ground surface elevation at the borehole locations was surveyed using an auto-level and rod and tied into locations where the elevation could be estimated from the digital terrain model. The borehole locations (referenced to the MTM NAD83 co-ordinate system) and approximate ground surface elevations (referenced to Geodetic datum), as well as drilled depths, are provided on the Record of Borehole sheets and shown on Drawings 1 to 8, as summarized below.

Culvert No. (Station)	Drawing No.	Borehole No.	MTM NAD83 Northing (m)	MTM NAD83 Easting (m)	Ground Surface Elevation (m)	Drilled Depth (m)
3 (16+790)	2	TC15-4	4831055.8	287900.1	183.9	8.2
		2014-8A	4831083.8	287904.3	182.2	12.8
5 (11+274, Mavis Road)	3	2014-9A	4831109.3	288020.6	185.6	8.2
		2014-10A	4831175.3	288132.5	189.4	9.8
		MR-3	4831172.8	288079.3	194.6	18.3
		MR-3A	4831173.9	288078.3	194.6	30.9/32.6*
		MR-4	4831158.4	288051.0	195.4	31.1
6 (16+855)	4	TC15-2	4831179.8	287870.8	186.8	12.8
		2014-8A	4831083.8	287904.3	182.2	12.8
		237-2	4831216.8	287990.0	186.6	18.6
		237-4	4831198.6	288001.2	187.5	15.7
		237-6	4831177.4	288025.5	185.2	9.6
9 (17+446)	5	TC15-8	4831457.2	288444.0	189.6	8.2
		TC15-9	4831412.9	288452.3	189.6	8.2
10 (16+855)	6	TC15-1	4831248.9	287859.0	187.3	11.3
		TC15-3	4831238.8	287904.7	185.8	9.8
11A (11+456, Mavis Road)	7	TC15-3	4831238.8	287904.7	185.8	9.8
		TC15-5	4831301.4	288003.9	185.8	8.2
		MR-1	4831249.0	287997.7	194.7	25.2/26.5*
		MR-2	4831239.6	287971.8	195.1	37.2/39.0*
12 (17+145)	8	TC15-6	4831376.5	288156.4	188.4	8.2
		TC15-7	4831351.4	288147.9	189.9	11.3

*The greater depth represents the bottom of the DCPT (driven from the bottom of the borehole)

The locations of the boreholes from the previous investigation are shown on Drawings 1 and 4 and a copy of the borehole records are presented in Appendix C corresponding to Culvert No. 6.

4.0 SITE GEOLOGY AND SUBSURFACE CONDITIONS

4.1 Regional Geology

This section of Highway 401 is located within the Peel Plain physiographic region, as delineated in *The Physiography of Southern Ontario* (Chapman and Putnam, 1984)[1].

The Peel Plain physiographic region covers the central portions of the Regional Municipalities of York, Peel and Halton. The general topography of this region consists of level to gently rolling terrain, sloping down gradually

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

southward toward Lake Ontario. A surficial till sheet, which generally follows the surface topography, is present throughout much of this area. The till, which is mapped in this area as the Halton Till, typically consists of clayey silt to silty clay, with occasional sand to silt zones. Shallow, localized deposits of loose sand, silt and/or soft clay can overlie this uppermost till sheet, and these represent relatively recent deposits, formed in small glacial meltwater ponds scattered throughout the Peel Plain and concentrated near river valleys. The recent sand, silt and clay and uppermost till deposits in this area overlie and are interbedded with stratified deposits of sand, silt and clay. The study area, in the western portion of the Peel Plain, is underlain by grey shale of the Georgian Bay Formation which contains limestone layers.

4.2 Subsurface Conditions

The subsurface models at the trenchless crossing locations have been developed based on the results of nine boreholes drilled as part of the 2015 investigation, eight boreholes completed as part of 2012 and 2014 investigations by Golder for the same project, and three boreholes advanced as part of a previous study by others.

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 and laboratory test figures contained in Appendices B through G. These Appendices are organized by proposed crossing location, in order of culvert number.

The stratigraphic boundaries shown on the borehole records and on the interpreted stratigraphic profiles on Drawings 2 to 8 are inferred from observations of drilling progress and from non-continuous sampling and, therefore, represent transitions between soil types rather than exact planes of geological change. The subsurface conditions will vary between and beyond the borehole locations.

In general, the subsurface conditions at the proposed crossing locations consist of asphalt and sand and gravel to gravelly sand road base fill associated with the existing Highway 401 or ramp pavements, underlain by embankment fill materials of variable composition, in places underlain by a thin clayey silt to silty clay deposit. The fill materials and near surface cohesive deposits at each culvert alignment are underlain by a glacial till deposit, which is typically comprised of clayey silt, grading from a sandy clayey silt to a clayey silt with sand.

Although there was no indication of the presents of cobbles and/or boulders in most boreholes during drilling, glacial till deposits in southern Ontario typically contain such materials and should be expected within such glacial deposits, especially near the bedrock interface.

A more detailed description of the subsurface conditions encountered in the boreholes is provided in the following sections.

4.2.1 Culvert No. 3, Station 16+790

The proposed Culvert No. 3 is located on the Highway 401 to Mavis Road W-N/S Ramp at Station 16+790. The existing ground surface in the vicinity of the proposed culvert location is at about Elevation 183.9 m. Boreholes TC15-4 and BH-2014-8A were advanced at this location (see Drawing 2) to a depth of 8.2 m and 12.8 m below ground surface (Elevations 175.7 m and 169.4 m).

Based on Boreholes TC15-4 and BH-2014-8A, the subsoil conditions consist of: asphalt underlain by cohesive and non-cohesive fill; underlain by native clayey silt till.

A summary of the major stratigraphic units, including laboratory test results, are presented below. Record of Borehole sheets and laboratory test results are presented in Appendix A.

Boreholes TC15-4 and BH-2014-8A

Stratigraphic Unit (Consistency or Relative Density)	**Top Elevation - Bottom Elevation (m)**	**Thickness (m)**	**In Situ Testing Results**	**Laboratory Testing Results**				
			SPT 'N'-values*	**Moisture Content (%)**	**Atterberg Limits**			**Grain Size Distribution; and Atterberg Limits Figures**
					Plastic Limit (%)	**Liquid Limit (%)**	**Plasticity Index (%)**	
Asphalt	183.9-183.8	0.1	-	-	-	-	-	-
Non-Cohesive Fill (compact to dense)	183.8-181.5	0.7-0.8	11 and 43	-	-	-	-	-
Cohesive Fill (firm to very stiff)	183.0-180.2	2.6	8 to 16	13 to 14	15	30	15	A1; and A2
Silty Clay (firm to stiff)	181.5-180.0	1.5	7 and 10	16	-	-	-	-
Clayey Silt to Sandy Clayey Silt to Clayey Silt with Sand (Till) (stiff to hard)	180.2-169.4**	4.5**-10.6**	10 to 35	9 to 17	13 to 14	20 to 25	7 to 11	A3; and A4

*Blows per 0.3 m of penetration unless otherwise noted

** Deposit/layer information limited to the termination of borehole(s) within deposit/layer

4.2.2 Culvert No. 5, Station 11+274 (Mavis Road)

The proposed Culvert No. 5 is located on Mavis Road south of Highway 401 at Station 11+274. The existing ground surface in the vicinity of the proposed culvert location is at about Elevation 194.5 m. Boreholes BH-2014-9A, MR-4, MR-3, MR-3A, and BH-2014-10A were advanced at this location (see Drawing 3) to depths between 8.2 m and 32.6 m below ground surface (between Elevations 179.7 m and 162.0 m).

Based on Boreholes BH-2014-9A, MR-4, MR-3, MR-3A, and BH-2014-10A, the subsoil conditions consist of: asphalt underlain by cohesive fill; underlain by native clayey silt till. In Borehole MR-3 a boulder was cored through from a depth of 15.3 m to 15.9 m (Elevation 179.3 to 178.7 m) and the presence of cobbles is also inferred from auger grinding in Borehole MR-4.

A summary of the major stratigraphic units, including laboratory test results, are presented below. Record of Borehole sheets and laboratory test results are presented in Appendix B.

Boreholes BH-2014-9A, MR-4, MR-3, MR-3A, and BH-2014-10A

Stratigraphic Unit (Consistency or Relative Density)	**Top Elevation - Bottom Elevation (m)**	**Thickness (m)**	**In Situ Testing Results**	**Laboratory Testing Results**				
			SPT 'N'-values*	**Moisture Content (%)**	**Atterberg Limits**			**Grain Size Distribution; and Atterberg Limits Figures**
					Plastic Limit (%)	**Liquid Limit (%)**	**Plasticity Index (%)**	
Non-Cohesive Fill	195.2-194.6	0.6	-	-	-	-	-	-
Cohesive Fill Inferred Cobbles Present (soft to very stiff)	194.6-183.8	0.7-10.8	4 to 36	8 to 16	15 to 17	25 to 34	10 to 19	B1; and B2
Sandy Clayey Silt to Clayey Silt with Sand (Till) Boulder and Inferred Cobbles Present (stiff to hard)	188.7-162.0**	7.6**-19.5**	13 to 93	8 to 24	11 to 17	18 to 28	6 to 13	B3-A, B3-B; and B4-A, B4-B

*Blows per 0.3 m of penetration unless otherwise noted

** Deposit/layer information limited to the termination of borehole(s) within deposit/layer

4.2.3 Culvert No. 6, Station 16+855

The proposed Culver No. 6 is located on Highway 401 at Station 16+855. The existing ground surface in the vicinity of the proposed culvert location is at about Elevation 184.5 m. Boreholes TC15-2, BH-2014-8A, 237-2, 237-4, and 237-6 were advanced at this location (see Drawing 4) to depths between 9.6 m and 18.6 m below ground surface (between Elevations 187.5 and 182.2).

Based on Boreholes TC15-2, BH-2014-8A, 237-2, 237-4, 237-6, the subsoil conditions consist of: asphalt underlain by cohesive and non-cohesive fill; underlain by native clayey silt till.

A summary of the major stratigraphic units, including laboratory test results, are presented below. Record of Borehole sheets and laboratory test results are presented in Appendix C.

Boreholes TC15-2, BH-2014-8A, 237-2, 237-4, and 237-6

Stratigraphic Unit (Consistency or Relative Density)	**Top Elevation - Bottom Elevation (m)***	**Thickness (m)**	**In Situ Testing Results**	**Laboratory Testing Results**				
			SPT 'N'-values*	**Moisture Content (%)**	**Atterberg Limits**			**Grain Size Distribution; and Atterberg Limits Figures**
					Plastic Limit (%)	**Liquid Limit (%)**	**Plasticity Index (%)**	
Asphalt	187.5-187.3	0.2	-	-	-	-	-	-
Non-Cohesive Fill (compact to very dense)	187.3-181.5	0.2-2.5	11 and 34; and 50 blows per 0.05 m of penetration	***	-	-	-	-
Cohesive Fill (firm to very stiff)	186.9-180.0	1.5-4.6	8 to 20	10 to 18***	20 ***	38***	18***	C1; and C2
Silty Clay (very stiff)	181.5-180.0 and 178.0-176.5	1.5	19	16***	-	-	-	-
Silty Clay to Clayey Silt to Sandy Clayey Silt to Clayey Silt with Sand (Till) (stiff to hard)	185.4-168.0**	8.2**-16.1**	9 to 91; and 85 blows per 0.25 m of penetration to 85 blows per 0.2 m of penetration	11 to 12***	13 to 14***	21 to 25***	8 to 11***	C3; and C4

*Blows per 0.3 m of penetration unless otherwise noted

**Deposit/layer information limited to the termination of borehole(s) within deposit/layer

***Refer to Record of Boreholes in Appendix C for additional lab testing by others

4.2.4 Culvert No. 9, Station 17+446

The proposed Culvert No. 9 is located on Highway 401 at Station 17+446. The existing ground surface in the vicinity of the proposed culvert location is at about Elevation 189.6 m. Boreholes TC15-8 and TC15-9 were advanced at this location (see Drawing 5) to a depth of 8.2 m below ground surface (Elevations 181.3 m and 181.4 m).

Based on Boreholes TC15-8 and TC15-9, the subsoil conditions consist of: asphalt underlain by non-cohesive and cohesive fill; underlain by native clayey silt till.

A summary of the major stratigraphic units, including laboratory test results, are presented below. Record of Borehole sheets and laboratory test results are presented in Appendix D.

Boreholes TC15-8 and TC15-9

Stratigraphic Unit (Consistency or Relative Density)	**Top Elevation - Bottom Elevation (m)**	**Thickness (m)**	**In Situ Testing Results**	**Laboratory Testing Results**				
			SPT 'N'-values*	**Moisture Content (%)**	**Atterberg Limits**			**Grain Size Distribution; and Atterberg Limits Figures**
					Plastic Limit (%)	**Liquid Limit (%)**	**Plasticity Index (%)**	
Asphalt	189.6-189.5	0.1	-	-	-	-	-	-
Non-Cohesive Fill (loose to dense)	189.5-188.7	0.8	26 and 42	4	-	-	-	D1
Cohesive Fill (firm to stiff)	188.7-186.6	1.3-2.1	6 to 12	15-19	15 to 18	32 to 38	16 to 20	D2; and D3
Sandy Clayey Silt to Clayey Silt with Sand Till (stiff to hard)	187.3-181.4**	5.2**-6.0**	11 to 40	9-14	13 to 15	20 to 25	7 to 10	D4; and D5

*Blows per 0.3 m of penetration unless otherwise noted

** Deposit/layer information limited to the termination of borehole(s) within deposit/layer

4.2.5 Culvert No. 10, Station 16+855

The proposed Culvert No. 10 is located on the Mavis Road to Highway 401 N-W Ramp at Station 16+855. The existing ground surface in the vicinity of the proposed culvert location is at about Elevation 187.3 m. Boreholes TC15-1 and TC15-3 were advanced at this location (see Drawing 6) to a depth of 11.3 m and 9.8 m below ground surface (Elevations 176.0 m).

Based on Boreholes TC15-1 and TC15-3, the subsoil conditions consist of: asphalt underlain by non-cohesive and cohesive fill; underlain by native clayey silt till.

A summary of the major stratigraphic units, including laboratory test results, are presented below. Record of Borehole sheets and laboratory test results are presented in Appendix E.

Boreholes TC15-1 and TC15-3

Stratigraphic Unit (Consistency or Relative Density)	**Top Elevation - Bottom Elevation (m)***	**Thickness (m)**	**In Situ Testing Results**	**Laboratory Testing Results**				
					Atterberg Limits			
			SPT 'N'-values*	**Moisture Content (%)**	**Plastic Limit (%)**	**Liquid Limit (%)**	**Plasticity Index (%)**	**Grain Size Distribution; and Atterberg Limits Figures**
Asphalt	187.3-187.2	0.1	-	-	-	-	-	-
Non-Cohesive Fill (dense)	187.2-186.5	0.7	35	-	-	-	-	-
Cohesive Fill (firm to very stiff)	186.5-181.2	4.5-5.3	7 to 26	9 to 13	15 to 18	29 to 30	11 to 14	E1; and E2
Sandy Clayey Silt to Clayey Silt with Sand Till (firm to very stiff)	181.3-176.0**	5.2**-5.3**	8 to 26	11 to 12	13 to 16	20 to 26	7 to 10	E3; and E4

*Blows per 0.3 m of penetration unless otherwise noted

** Deposit/layer information limited to the termination of borehole(s) within deposit/layer

4.2.6 Culvert No. 11A, Station 11+456 (Mavis Road)

The proposed Culvert No. 11A is located on Mavis Road north of Highway 401 at Station 11+456. The existing ground surface in the vicinity of the proposed culvert location is at about Elevation 192.5 m. Boreholes TC15-3, TC15-5, MR-1, and MR-2 were advanced near this location (see Drawing 7) to depths between 8.2 m and 39.0 m below ground surface (Elevations 177.6 and 156.1 m).

Based on Boreholes TC15-3, TC15-5, MR-1, and MR-2, the subsoil conditions consist of: asphalt underlain by non-cohesive and cohesive fill; underlain by a layer of silty clay to clayey silt in places; clayey silt till; and layers of silty clay, silty sand and gravel, sand and silt till, and sand and gravel.

A summary of the major stratigraphic units, including laboratory test results, are presented below. Record of Borehole sheets and laboratory test results are presented in Appendix F.

Boreholes TC15-3, TC15-5, MR-1, and MR-2

Stratigraphic Unit (Consistency or Relative Density)	**Top Elevation - Bottom Elevation (m)**	**Thickness (m)**	**In Situ Testing Results**	**Laboratory Testing Results**				
					Atterberg Limits			
			SPT 'N'-values*	**Moisture Content (%)**	**Plastic Limit (%)**	**Liquid Limit (%)**	**Plasticity Index (%)**	**Grain Size Distribution; and Atterberg Limits Figures**
Asphalt	195.1-194.5	0.2	-	-	-	-	-	-
Non-Cohesive Fill (loose to dense)	194.9-193.9	0.6	-	-	-	-	-	-
Cohesive Fill (firm to hard)	194.3-181.3	2.1-9.9	6 to 45	7 to 17	15 to 20	26 to 35	11 to 16	F1; and F2
Clayey Silt to Silty Clay (stiff to very stiff)	184.4-183.1	0.9	14 and 22	13 and 18	18	43	25	F3; and F4
Sandy Clayey Silt to Clayey Silt with Sand Till (firm to hard)	183.6-168.0	5.3**-15.5	8 to 116; and 89 blows per 0.23 m of penetration	8 to 12	11 to 16	20 to 30	7 to 14	F5; F6-A, and F6-B
Silty Clay (hard)	168.0-167.4	0.6	39	27	-	-	-	-
Silty Sand and Gravel (dense)	167.4-166.4	1.0	39	-	-	-	-	-
Sand and Silt Till (compact to very dense)	166.4-159.1	7.3	29 to 64	9	13	17	4	F7; and F8
Sand and Gravel (compact)	159.1-156.1**	3.0**	11	6	-	-	-	F9

*Blows per 0.3 m of penetration unless otherwise noted

** Deposit/layer information limited to the termination of borehole(s) within deposit/layer and includes 1.8 m of DCPT.

4.2.7 Culvert No. 12, Station 17+145

The proposed Culvert No. 12 is located on the Highway 401 to Mavis Road E-N/S Ramp at Station 17+145. The existing ground surface in the vicinity of the proposed culvert location is at about Elevation 189.6 m. Boreholes TC15-6 and TC15-7 were advanced at this location (see Drawing 8) to a depth of 8.2 m and 11.3 m below ground surface (Elevations 180.2 and 178.6 m).

Based on Boreholes TC15-6 and TC15-7, the subsoil conditions consist of: asphalt underlain by non-cohesive and cohesive fill; underlain by native clayey silt till.

A summary of the major stratigraphic units, including laboratory test results, are presented below. Record of Borehole sheets and laboratory test results are presented in Appendix G.

Boreholes TC15-6 and TC15-7

Stratigraphic Unit (Consistency or Relative Density)	**Top Elevation - Bottom Elevation (m)**	**Thickness (m)**	**In Situ Testing Results**	**Laboratory Testing Results**				
			SPT 'N'-values*	**Moisture Content (%)**	**Atterberg Limits**			**Grain Size Distribution; and Atterberg Limits Figures**
					Plastic Limit (%)	**Liquid Limit (%)**	**Plasticity Index (%)**	
Asphalt	189.9-189.7	0.2	-	-	-	-	-	-
Non-Cohesive Fill (compact)	189.7-189.1	0.6	23	4	-	-	-	-
Cohesive Fill (firm to stiff)	189.1-186.9	0.6-2.2	7-13	14	16	32	16	G1; and G2
Clayey Silt to Sandy Clayey Silt Till (stiff to hard)	187.7-178.6***	7.5**-8.3**	11-59	10 to 13	13 to 15	21 to 28	8 to 13	G3; and G4

*Blows per 0.3 m of penetration unless otherwise noted

** Deposit/layer information limited to the termination of borehole(s) within deposit/layer

4.3 Groundwater Conditions

The water levels were observed in the open boreholes immediately following completion of drilling, and the depth to water level measurements are recorded on the borehole records contained in Appendices A through G. Additionally, piezometers were installed in Boreholes TC15-1, TC15-4, TC15-6, TC15-9, MR-1, MR-4, 2014-9A, and 237-2 from the previous investigation, the details of which are presented in the corresponding Record of Borehole sheets. It should be noted that details of the piezometer installation in Borehole 237-2 is not provided on the Record of Borehole sheet or the report but the water level information is provided and is included in the summary below.

The water levels immediately following the completion of drilling and as measured in the piezometers at a later date, is summarized below.

Culvert No. (Station)	Borehole No.	Ground Surface Elevation (m)	Borehole Depth (m)	Depth to Water Level Below Ground Surface (m)	Water Level Elevation (m)	Date
3 (16+790)	TC15-4	183.9	8.2	Dry* 2.6** 2.7**	- 181.3 181.2**	- Nov. 19, 2015 Dec. 16, 2015
	2014-8A	182.2	12.8	Dry*	-	Dec. 15, 2015
5 (11+274, Mavis Road)	2014-9A	185.6	8.2	7.2* 0.8** 1.4**	178.4 184.8** 184.2**	Dec. 16, 2014 June 30, 2015 Dec. 16, 2015
	2014-10A	189.4	9.8	9.4*	180*	Dec. 15, 2014
	MR-3	194.6	18.3	Dry to 15.3m***	-	May 30, 2012
	MR-3A	194.6	30.9	***	-	-
	MR-4	195.4	31.1	21.3* 18.6 to 18.3**	174.1 176.8 to177.1**	May 28, 2012 May 30 to Nov. 5, 2012
6 (16+835)	TC15-2	186.8	12.8	Dry*	-	Nov. 9, 2015
	2014-8A	182.2	12.8	Dry*	-	Dec. 15, 2015
	237-2	186.6	18.6	8.5* 9.8**	178.1* 176.8**	Dec. 18, 1997 Jan. 8, 1998
	237-4	187.5	15.7	Dry*	-	Dec. 16, 1997
	237-6	185.2	9.6	8.6*	176.6*	Dec. 15, 1997
9 (17+446)	TC15-8	189.5	8.2	Dry*	-	Nov. 4, 2015
	TC15-9	189.6	8.2	Dry* 5.5** 2.2**	- 184.1** 187.4**	Nov. 2, 2015 Nov. 19, 2015 Dec. 16, 2015
10 (16+855)	TC15-1	187.3	11.3	10.4* 5.4** 5.3**	176.9* 181.9** 182.0**	Nov. 4, 2015 Nov. 19, 2015 Dec. 15, 2015
	TC15-3	185.8	9.8	Dry*	-	Nov. 9, 2015
11A (11+456, Mavis Road)	TC15-3	185.8	9.8	Dry*	-	Nov. 9, 2015
	TC15-5	185.8	8.2	Dry*	-	Nov. 9, 2015
	MR-1	194.7	25.2	Dry to 18.0 m*** 10.4 m to 10.1 m**	- 184.3 to 184.6**	June 7, 2012 Aug. 10 to Nov. 5, 2012
	MR-2	195.1	37.2	19.8***	175.3	May 22, 2015
12 (17+145)	TC15-6	188.4	8.2	Dry* 3.4**	- 185**	Nov. 5, 2015 Nov. 19, 2015
	TC15-7	189.9	11.3	Dry*	-	Nov. 5, 2015

* *Water level was obtained upon completion of drilling, water level measured at start of work day.*

*** Water level was obtained from piezometer reading.*

****Water level was not recorded upon completion of drilling*

Groundwater levels provided from measurements taken during or immediately after completion of drilling operations may not represent the stabilized groundwater levels at the site(s).

Groundwater levels in the area are subject to seasonal fluctuations and variations due to precipitation events. Although typically not encountered during drilling and generally not indicated on the existing borehole records prepared by others, "perched" groundwater conditions are expected within the fill soils, above the cohesive till.

5.0 CLOSURE

This Foundation Investigation Report was prepared by Mr. Alex Szot, EIT, and reviewed by Mr. Kevin Bentley, P.Eng., a geotechnical engineer and Associate of Golder. Mr. Jorge M. A. Costa, P.Eng., a Principal of Golder and a Designated MTO Foundations Contact for Golder, conducted an independent review of this report.

GOLDER ASSOCIATES LTD.

LICENSED PROFESSIONAL ENGINEER
K. J. BENTLEY
FEB. 10, 2016
PROVINCE OF ONTARIO

Alex Szot, EIT
Geotechnical Engineer In Training

Kevin J. Bentley, P.Eng.
Geotechnical Engineer, Associate

LICENSED PROFESSIONAL ENGINEER
J. M. A. COSTA
Feb 10/2016
PROVINCE OF ONTARIO

Jorge M.A. Costa, P.Eng.
Designated MTO Foundations Contact, Principal

AJS/KJB/JMAC/SJB/sm

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PART B

FOUNDATION DESIGN REPORT
TRENCHLESS CROSSINGS
HIGHWAY 401 WIDENING FROM
HIGHWAY 403/410 INTERCHANGE TO THE CREDIT RIVER
CITY OF MISSISSAUGA, REGION OF PEEL
G.W.P. 2150-01-00

February 10, 2016
Report No. 10-1111-0211-12

6.0 DISCUSSION AND ENGINEERING RECOMMENDATIONS

6.1 General

This section of the report provides geotechnical recommendations for the installation of culverts crossing under the Highway 401 mainline, Mavis Road and associated ramps using trenchless methods. The recommendations are based on interpretation of the factual data obtained from the boreholes advanced in the vicinity of each crossing location. The discussion and recommendations presented are intended to provide the designers with sufficient information to assess the feasible trenchless installation methods and to design the crossings.

Where comments are made on construction, they are provided 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 such interpretation may affect equipment selection, proposed construction methods, scheduling and the like.

It is understood that the new culverts will range in diameter from 0.8 to 1.5 m and will be installed at invert levels between about 2.3 m and 11.1 m below ground/roadway surface thus providing for between about 1.3 m and 9.9 m of cover on the liner/casing. All culvert construction/installation in non-open cut construction should be carried out consistent with the Non Standard Special Provision (NSSP) titled “Pipe Installation by Trenchless Methods, included in Appendix H.

6.2 Pipe Materials

Installation of the culverts by either conventional jack and bore or pipe ramming methods will require that a steel casing be installed during boring or ramming. The steel casing would remain in place, with a smaller diameter sewer or culvert pipe installed within the casing. It is recommended that grout be injected into the annular space between the culvert pipe and the steel casing, as discussed further in Section 6.7. It has been assumed that the steel casing will, as a minimum, be sufficiently large in diameter as compared to the proposed culvert pipe outside diameter to allow for final adjustment of the final pipe invert alignment since construction tolerances and misalignment during installation of the steel casing could otherwise jeopardize proper gravity-flow of the culvert.

If micro-tunnelling methods are selected for this project, it is likely that the culvert pipe will be jacked into place behind the micro-tunnelling cutter head. Different pipe materials could be used from interlocking steel pipe to glass-fibre reinforced concrete (mortar) pipe specially made for micro-tunnelling. In such cases, the jacking pipe may be used for the final culvert pipe, depending on materials and installed diameter. It will be essential to specify appropriate hydraulic, joint integrity and long-term abrasion resistance performance requirements in the event that alternative pipe materials are proposed by the trenchless contractor.

The pipe must be selected to withstand the overburden and highway loads, hydrostatic pressures (if present), and the installation forces and grouting pressure. The overburden pressure may be calculated using a unit weight of 21 kN/m^3. The unit weight of water may be taken as 9.8kN/m^3.

6.3 Culvert Tunnel Alignment

Tables 1 and 2 following the text of this report provides a summary of the proposed culvert and estimated casing pipe diameter, invert elevations, the cover thickness at the highway/ramp shoulders, and the corresponding estimated range of overburden cover expressed as a function of the tunnel diameter (i.e., the number of tunnel diameters between the crown of the tunnel and the overlying/highway ground surface). Table 2 also provides a summary of the subsurface conditions encountered in the boreholes at and above the depth through which the culvert crossings are to be advanced. Plan and interpreted stratigraphic profiles for each crossing location are provided on Drawings 1 to 8 (Sections A-A' to G-G'), and the borehole records and geotechnical laboratory test results specific to each crossing location are provided in the corresponding Appendices A to G.

For tunnels under 400-series highways, MTO typically requires that the minimum overburden cover shall not be less than 1.5 m or generally two tunnel diameters, whichever is greater, at any point along the entire length of the tunnel crossing. The minimum 1.5 m cover requirement is met at all but one of the culvert locations, and four of the proposed crossing locations have less than two tunnel diameters of cover thickness.

For the proposed Culvert Nos. 6 and 9 liner/casing pipe diameters of 1.4 m and 1.2 m, respectively, the estimated obvert is more than 1.5 m below the lowest ground/highway surface point along the alignment but provides less than 2 tunnel diameters equivalent cover thickness. The proposed pipe invert for these two culverts is also at or just below the approximate interface of the fill and native material and suggests that the carrier pipe alignment may be deflected at this interface because of the different character of these two materials which could lead to reduced overburden cover. Typically it is recommended that the tunnel obvert be a minimum of 0.5 m below the fill/native interface so that the tunnel horizon is primarily within the native soil deposits; however, it is understood that other constraints, such as elevations required to achieve proper drainage between ditches and storm water ponds and vertical road alignments, may not allow the depth of cover to be increased at these locations. Based on the proposed vertical alignment of Culvert Nos. 6 and 9, trenchless methods are considered of comparatively higher risk of ground losses for most trenchless construction methods, which will require strict controls and a diligent monitoring program. Alternatively, these culverts could be installed using open cut methods; however, permission from MTO would be required to reconsider standard restrictions and allow for lane closures for work performed on the highway.

For the proposed Culvert Nos. 3 and 12 estimated liner/casing pipe diameters of 1.8 m and 1.0 m, respectively, the estimated obvert is more than 1.5 m below the lowest ground/Ramp surface point along the alignment except at the right shoulder of Culvert No. 12 where the cover thickness is about 1.3 m. Based on the vertical alignment drawings provided by AECOM, the estimated tunnel obvert is less than 2 tunnel diameters equivalent cover thickness at both culvert alignments. Typically, it would be recommended that the tunnel invert be lowered to at least meet the minimum 1.5 m thickness of cover requirement at culvert No. 12; however, as noted above, hydraulic constraints do not allow for this lowering of the invert at this location. Alternatively, twin smaller diameter pipes could be used at these locations to provide at least 1.5 m of cover and preferably provide cover of a thickness that is at least two tunnel diameters.

Typically, trenchless construction (and tunnelling) is undertaken in the direction of increasing elevation to allow for gravity drainage of groundwater seepage. Therefore the entry shafts would be located at the lower elevation end and the exit shafts would be located at the higher elevation end. It will be necessary that where the base of the shafts is below the anticipated groundwater level the shaft be dewatered to maintain stability of the excavation base, as discussed in Section 6.6.

6.4 Pipe Installation Methods

For typical MTO construction contracts, the Contractor is responsible for choosing the method and equipment for culvert installation unless specific methods are otherwise prohibited. Ground behaviour will be, in part, dependent on the installation method adopted and this report provides guidance on the influence of ground behaviour on some possible culvert installation methods. While in general, it should not be construed that the Contractor is restricted to the particular methods considered herein, this report does recommend that some trenchless construction methods be specifically prohibited or mandated at select locations. For any construction method, the Contractor must make his own interpretation of the anticipated ground behaviour, based on the factual information provided in Part A, Foundation Investigation Report.

Based on the culvert profiles provided by AECOM, it is understood that it is preferable that the culverts be installed using trenchless methods under Highway 401, Mavis Road, and the associated ramps. Trenchless methods commonly available in the Ontario construction industry include: conventional “jacking and boring”, pipe ramming, mirco-tunnel boring machine (MTBM) and horizontal directional drilling (HDD).

HDD uses drilling fluid under pressure to create the pilot hole and is typically used for smaller diameter crossings below embankments or rivers, where the installed pipe is not dependant on gravity drainage as is the case for culverts. Furthermore, HDD would typically require greater amounts of cover than are present at the majority of the culvert locations to minimize the risk of hydraulic fracturing of the ground and loss of drilling fluid to the surface (“frac-out”). Therefore the HDD method is not considered suitable for any of these crossings and is not considered further within this report.

The following sections of this report present and address the geotechnical design recommendations and construction issues for the four main types of construction: jack and bore, pipe ramming, MTBM and open-face shield tunnelling. As noted in Section 6.1, construction of the culverts should adhere to the NSSP “Pipe Installation by Trenchless Method”, included in Appendix H. Given the subsurface conditions, planned pipe diameters and limited thickness of cover between the top of any carrier or jacked pipe, the risk of unacceptable ground losses during trenchless construction are relatively high at Culvert Nos. 3, 6, 9 and 12 as described below. Therefore, although a relatively common NSSP may be used for the trenchless installations, the contract should specifically prohibit / discourage the use of all other trenchless methods of construction considered except pipe ramming at these locations. An “Operational Constraint” or “Notice to Contractor” should be incorporated into the Contract Documents to alert the Contractor of the limited trenchless methods to be considered at Culvert Nos. 3, 6, 9 and 12; an example “Operational Constraint” is provided in Appendix I.

6.4.1 Jack and Bore

Conventional “jack and bore” is a method of forming a near horizontal bore from a jacking/drive (i.e., entry) pit. Boring is undertaken with a rotating cutter head mounted at the lead end of a continuous-flight auger system and a continuous welded casing is jacked through reaction against a thrust block located within the jacking pit. Spoil from the tunnel excavation is transported to the jacking pit along helical auger flights and the new pipe is then installed within the casing. The casing may be lubricated to reduce the frictional forces between casing and the surrounding soil. The jack and bore method is generally suitable for penetrating cohesive soils (silt and clay) and unsaturated granular soils that are well-graded (i.e., broadly graded) and not “dry” or otherwise subject to running or flowing conditions. Jack and bore methods can lead to excessive ground losses, settlement and development of sinkholes extending to the surface when passing through saturated (flowing) or dry (running) sand, silt and/or gravel. The presence of boulders and cobbles can obstruct augering operations, damage the equipment and require manual interventions that slow progress. The removal of obstructions may also result in loss of ground at the face and ground settlement at the ground surface, depending on the soil conditions. Difficulties may also be encountered in maintaining alignment control of the tunnel as it advances due to the presence of stiffer or more compact/dense soils ahead of the face, cobbles or boulders at the face or due to mixed face conditions. Because the steel casing is jacked from the rear, there is little opportunity to adjust the alignment if deviations begin to occur as a result of obstructions or variability in the ground conditions at the tunnel face.

The size of the jacking pit is controlled by the equipment size and the length of the casing sections which are being installed. Typically, a work area of about 10 m long by about 3 m to 5 m wide is required to accommodate the jacking/drive pit for jack and bore operations. The receiving pit is typically about 3 m in dimension on each side.

6.4.2 Pipe Ramming

Pipe ramming involves the use of a percussive hammer to advance a steel casing with a cutting shoe attached at the front end of the casing. The casing is generally advanced open-ended and the soil within the casing is typically removed after the casing has been driven the entire length of the installation, thereby reducing the potential for ground loss into the casing during driving. As each casing length is installed the rammer is removed, the next casing is welded in place and the rammer replaced and restarted. On completion of the bore, compressed air or water, pressure jetting or augering is used to remove the spoils from within the casing. In some cases, depending on the ground conditions and length of the pipe, soil can be removed periodically from within the pipe to reduce the total mass being driven and the resistance to driving.

Pipe ramming is best suited for soft to firm clays and very loose to compact sands above the water table. Pipe ramming methods are also better suited for penetrating through/displacing potential obstructions such as cobbles and boulders in comparison to jack and bore installation method, though this method can still be obstructed by cobbles and boulders depending on their size and number. Difficulties in maintaining alignment control of the tunnel as it advances can still occur if cobbles and boulders are encountered. Vibrations from the pipe ramming operations may result in settlement of loose materials in the immediate vicinity of the installation. Furthermore, a “plug” of soil may form at the head of the casing inducing surficial heave as the pipe is advanced. This can be controlled by stopping the operation and removing spoil from within the pipe before advancing further. Compared to the jack and bore method the single most important advantage of pipe ramming is that the soil is typically removed from the pipe only after the pipe has fully passed beneath overlying infrastructure. Another advantage of pipe ramming is there is no need for a thrust block in the driving pit, therefore a smaller pit size is required for pipe ramming.

6.4.3 Micro-Tunnel Boring Machine (MTBM)

Micro-tunnel boring machines (MTBM) typically use pressurized bentonite slurry to counterbalance the earth and water pressures acting at the tunnel face and to transport the cuttings to the surface. A remotely-controlled rotating cutterhead is used to excavate soil in a controlled manner at the face and together with the pressurized slurry these act to minimize loss of ground during tunnel advance. The slurry is circulated back through the tunnel to transport cuttings to a settling tank as well as cyclone and screen separators. The MTBM can also be specified and equipped to cut and/or crush cobbles and boulders that are anticipated along the proposed tunnel alignment. While many MTBMs are stated as capable of cutting or crushing cobbles and boulders, these machines can still be “choked” if there are a sufficient number of cobbles and progress can still be obstructed if boulders cannot be efficiently cut by the face tools or they move around at the face in loose soils rather than being cut. Given the machine’s ability to control soil and water pressures at the face, dewatering of granular soils along the tunnel alignment is seldom necessary with this tunnelling method.

Micro-tunnelling, as described above, is typically considered to be the method that minimizes the risk of loss of ground and ground surface settlement. However, it is relatively expensive to mobilize this type of machine and the availability of machines with the suitable diameter bore and the mobilization costs for such equipment may constrain their use on this project.

In the greater Toronto area, some trenchless contractors use “small boring units” (SBUs) and present this system as “micro-tunnelling”. In general, the small boring units often consist of a rotating cutter head system that is temporarily welded to the lead end of a steel casing. The ground is cut using a variety of face tools (similar to MTBMs described above), but the spoil is transported to the surface using an auger system, much like conventional jack and bore systems. Face openings on the small boring units are typically much smaller than the auger opening on conventional jack and bore systems and the risk of uncontrolled ingress of ground into the lead end of the casing is lower for this system as compared to jack and bore methods. These systems do not, however, provide consistent and positive support to the ground at all face openings with any slurry or cuttings, unlike the slurry-based MTBMs described above. Therefore, while the small boring units are more suitable and advantageous for cutting through stiff to hard cohesive glacial till and weathered rock materials, they should only be used with caution if granular soils may be encountered along the alignment.

6.4.4 Open Face Shield Tunnelling

Open face shield tunnelling involves excavating the soils using a hydraulic excavator arm, working within a full-circumference tunnelling shield. Alternatively, hand mining (i.e., manual and mechanically-assisted excavation) within the tunnelling shield could be carried out whereby the soil would be excavated using manual equipment with workers at the face. Typically, the liner would consist of a solid steel casing, jacked in sections from the launching shaft. Unlike auger jack and bore, this method allows personnel to enter the tunnel to allow more control over the operations such as for removal of obstructions or control of groundwater seepage or localized instabilities. Similar to jack and bore, however, groundwater lowering is necessary to control granular soils below the groundwater level. Manual or machine-assisted excavation generally requires a tunnel diameter of about 1.2 m or more.

6.5 Anticipated Soil Behaviour and Feasibility of Tunnelling Methods

The anticipated soil and groundwater conditions within the proposed tunnel horizons are summarized in Table 2. The feasibility for installing the various culverts using the jack and bore, pipe ramming, MTBM or open shield method is summarized in Table 3. A summary comparison of the advantages, disadvantages, relative costs and risks associated with the culvert installation methods, including a conventional open cut option, is presented in Table 4.

Based on the fines content of the soil deposits along and above the trenchless/tunnelling horizon, the coefficient of uniformity[2] and the SPT 'N' values, the soil has been classified according to the Tunnelman's Ground Classification System by Terzaghi as reported in Heuer (1974). This system is commonly used to describe the expected behaviour of an unsupported tunnel face during excavation and uses qualitative "stand-up time" criteria to classify the ground at and above the tunnel face into the following principal categories: firm, slowly ravelling, fast ravelling, cohesive-running, running and flowing.

The behaviour of the soil conditions within the tunnel horizon have been classified in Table 3 and generally range from "running" to "cohesive running" to "fast raveling" to "firm" to "slow ravelling". Soils that are classified as "running" are not considered suitable for the jack and bore method or the open face shield method because of the risk for uncontrolled inflows into the casing that would lead to increased settlement (and potentially sink holes) at the ground surface. These methods can be utilized if the sand and silt deposits are dewatered/depressurized such that the groundwater level is lowered to below the tunnel invert along the full alignment. In a moist, depressurized condition, the sands and silts would behave as ravelling to cohesive running ground, providing the ability to advance with minimal ground losses providing excavation is undertaken on a continuous controlled basis. Pipe ramming is suitable through the majority of the soil conditions, with the exception of very stiff to hard clayey tills, as resistance will build up rapidly and it will be difficult to impossible to displace cobbles and boulders encountered in such soils.

6.5.1 Jack and Bore Considerations

Jack and bore operations can be carried out below the groundwater table in soils that have a high fines content and exhibit suitable "stand-up" time; however, under such conditions the specifications should require that a plug of spoil material remain in the lead end of the casing at all times. This can be achieved by maintaining the cutting head at the appropriate distance behind the leading edge of the casing or retracting it into the casing during the jacking operations through such soils. The objective is to restrict the potential for uncontrolled inflow of material into the casing, with a plug of soil at the front of the casing to minimize ground loss and consequent settlement. Once started, the jack and bore operation should continue without interruption until complete. Jack and bore installation is feasible at some of the culvert crossings proposed at this site, but is discouraged at four sites due to low soil cover thickness.

If obstructions, such as a boulder or a nest of cobbles, are encountered, it would be necessary to remove the augers and soil plug. Depending on the soil conditions at the location of the obstructions, this may result in loss of ground at the face and ground settlement at the ground surface. Typically the till deposits and native cohesive deposits will have a greater "stand-up time" compared to the granular soil and fill. For granular soil above the water table, depending in the "fines content" (proportion of soil passing the 0.075 mm sieve opening size) and how broadly the soil is graded the stand-up time might be sufficient to permit obstruction removal without significant ground settlement. In the event the obstructions are encountered below the groundwater table in granular soils, then the risk of large ground settlements occurring is greatly increased. The contractor should have a contingency plan for such an event that includes highway / ramp closure to protect the travelling public.

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[2] The coefficient of uniformity is an indicator of the degree to which the soil is well graded, and is expressed as the ratio of the particle size at which 60 per cent of the particles are finer divided by the particle size at which 10 per cent are finer.

The stiff to hard native cohesive soils, including glacial till soils as encountered at this site, will likely be difficult to penetrate using only jacking forces and the lead end of the casing. In such cases, contractors frequently prefer to have the lead end of the auger at or ahead of the lead edge of the casing. While in some well-known cohesive soil ground conditions this may be acceptable, this practice could lead to excessive ground losses if native saturated or dry granular soils, granular embankment fill or pavement sub-base and base course materials are encountered.

Difficulties may also be encountered in maintaining alignment control of the tunnel as it advances due to the "mixed-face" soil conditions (specifically till / fill interface which is present at many of the proposed trenchless locations) and presence of cobbles/boulders and/or stiffer or more compact/dense soils ahead of the face. Ground movements should be monitored during pipe installation to measure ground surface movements (i.e. settlement/heave) as compared to specified tolerances (see Section 6.6).

6.5.2 Pipe Ramming Considerations

Pipe ramming should be feasible at most of the culvert crossing locations at this site depending on contractor equipment and the length of the installation. Pipe ramming also includes risks to roadway performance at locations where at least 1.5 m of cover will not exist; however, such risks are generally less severe in consequence as compared to those described above for conventional jack and bore methods at this site. Alignment control is a concern at many sites due to the mixed face conditions and difficulties may be experienced when ramming through the very stiff to hard cohesive soils and cohesive tills within the tunnel horizon as significant resistance to pipe advance can be expected and will increase as the pipe is advanced. Also, when the pipe is not being advanced (during welding of casing extensions) the stresses around the circumference of the pipe may increase which will further increase the friction around the pipe, making it more difficult to advance the pipe. The casing may be lubricated to reduce the frictional forces between casing and the surrounding soil and/or the Contractor may utilize a higher energy hammer and thicker wall pipe in such conditions.

As with the jack and bore method, tunnel alignment may be difficult to control due to the mixed face conditions and/or presence of cobbles/boulders. There is an increased risk of difficulty with alignment control for longer tunnelled portions, such as expected at Culvert No. 5 and 11A (i.e. below Mavis Road). Consideration could be given to temporary cutting into the Mavis Road embankment slopes to shorten the pipe run and increase tolerance levels. If cobbles and boulders are encountered, the casing may be cleaned out, allowing access for equipment to break up the obstructions. Cleaning out the spoils from inside the casing may result in the loss of ground at the face of the casing. As discussed in Section 6.5, the till and cohesive soils will have a longer "stand-up time", compared to the granular soil and fills.

Ground movements should be monitored during pipe installation to measure ground surface movements (i.e., settlement/heave) as compared to specified tolerances (see Section 6.6). To the degree possible, the volumes or weights of ground extracted during installation should be periodically measured (e.g., on a per-pipe section basis) and compared to the theoretical cut volume or weight of the soil as another measure to warn of potential excess excavation.

6.5.3 MTBM Considerations

The MTBM methods commonly use viscous bentonite slurry to counterbalance the earth and water pressures acting at the tunnel face; many systems are, however, loosely referred to as “micro-tunnelling”. Systems that do not utilize bentonite slurry support for support of the cut face and transport of the cuttings should not generally be considered “micro-tunnelling” for the purposes of this report and the project specifications. If the slurry pressure at the face is allowed to become too high and/or the slurry is not sufficiently viscous (e.g. when low viscosity polymer-water mixes are used), hydraulic fracture (typically referred to as “frac-out”) of the ground can occur, allowing bentonite slurry to exit at ground surface. “Frac-out” can then result in a sudden drop in face pressure, creating face instability if tunnelling through granular soils below the groundwater table. To minimize the risk of “frac-out” the MTBM method should not be used for culvert crossing locations on this project with cover of less than 2.5 m as is the case at Culvert Nos. 3, 6, 9 and 12. Further, to both properly support ground at the cutting face and along the pipe if an over-cut is used, slurries should have a Marsh funnel viscosity of not less than about 70 seconds.

An advantage of the MTBM is that lowering of the groundwater level in granular soils is not typically required. Another advantage is the MTBM can also be specified to have the capability to cut stones (i.e. cobbles and boulders) and, in some cases, crush larger particles (cut rock, gravel, etc.) that are anticipated along the proposed tunnel alignments. For tunnelling in the anticipated ground conditions on this project, MTBMs should be specified to include rock disc cutters and/or roller bit cutters as well as soft-ground excavation tools on the MTBM face. Typical drag bits or carbide cutting teeth are often broken from the face of tunnel boring machines when encountering boulders in the tills or shale/limestone fragments (i.e. encountered in the Mavis Road embankment fill).

In some cases, the term micro-tunnelling is used to describe a “small boring unit” that includes a rotating TBM-like cutter head that is welded to the lead end of a steel casing, where the cuttings are conveyed to the jacking pit using an internal continuous flight auger system. This type of system should not be used where there is a risk that saturated or dry granular soils (native or highway and pavement fill materials) might be encountered. While the small boring units are often highly effective in penetrating glacial till, the openings in the cutting head are not well protected against uncontrolled ingress of running or flowing ground.

Ground movements should be monitored during pipe installation to measure ground surface movements (i.e., settlement/heave) as compared to specified tolerances (see Section 6.6). To the degree possible, the volumes or weights of ground extracted during installation should be periodically measured (e.g., on a per-pipe section basis) and compared to the theoretical cut volume or weight of the soil as another measure to warn of potential excess excavation.

This project includes pipe design diameters ranging from about 0.8 m to about 1.5 m. For this size range, many MTBM systems are available. Given the numbers of pipes to be installed, one or two MTBM sizes may be selected to minimize the equipment and operational costs. Consideration could be given during construction to adapting the final pipe diameter to better match proposed equipment sizes and pipe materials.

6.5.4 Open Face Shield Tunnelling Considerations

If the open face shield tunnelling method is selected, the contractor should have a means to readily secure the face if inward ground deformation is encountered or if unanticipated work stoppages are necessary (pre-fabricated breasting boards, etc.). Further, the tunnelling work should be continuous from start to finish (24 hours per day, 7 days per week). If it is necessary to stop the tunnelling operations, the contractor should be prepared to immediately support the face. Filling of the annular space between the liner and native ground should be carried out as soon as the liner is installed (bentonitic grout/lubricant in the case of jacked pipes, with cementitious grout provided at the completion of construction).

Ground movements should be monitored during pipeline installation to measure ground surface movements (i.e. settlement/heave) as related to specified tolerances (see Section 6.6). To the degree possible, the volumes or weights of ground extracted during installation should be periodically measured (e.g., on a per-pipe section basis) and compared to the theoretical cut volume or weight of the soil as another measure to warn of potential excess excavation.

6.6 Instrumentation and Monitoring

An instrumentation and monitoring program is recommended at trenchless crossing locations to:

- document the effects of the culvert installation on the overlying roadways, adjacent structures or services lines/pipes;
- identify adverse movement trends;
- measure the Contractor’s compliance with the settlement limits specified in the Contract; and
- provide information to support adaptation of the culvert installation methods to observed behaviour and ground conditions toward compliance with the settlement limits.

Monitoring of settlement instruments on this project is constrained by the continuous and high traffic volume and the limited periods during which access to Highway 401, the Ramps and Mavis Road can be obtained. By necessity, settlement points on the road must be read remotely and the use of electromagnetic distance measuring equipment reading reflectors installed on the highway or “reflectorless” precision surveying using robotic/automated scanning systems is recommended. A specialist surveying firm should be retained to confirm the set-up and to carry out the settlement monitoring during construction; their equipment and procedures must be capable of surveying the settlement point elevation to within ± 2 mm of the actual elevation.

In addition, the installation of in-ground settlement points, consisting of a sleeved iron bar, set 0.3 m above the tunnel obvert elevation at each crossing at accessible locations (e.g. highway/roadway shoulders) should be also considered. The elevation of the top of the bar would be read using conventional precision levelling equipment. The in-ground monitoring points provide the best measure of the ground settlement effects of tunnelling as tunnelling progress, as they are unaffected by frost heave, thaw settlement or the bridging action of the pavement structure.

All monitoring points should be read at least three times (on three consecutive/separate days) before the start of culvert installation to establish a pre-construction baseline. All points behind the face of the excavation and those within 10 m of the front of the face should be read every 4 hours over the duration of the tunnel drives, including any delay/stop/wait periods and non-work days. The effectiveness of this monitoring method could be impacted by night work and weather conditions if the work is undertaken during the winter months.

A settlement monitoring plan consistent with the requirements in the “Appendix: Settlement Monitoring Guideline – Tunnelling” of MTO’s “Guideline for Foundation Engineering – Tunnelling Speciality for Corridor Encroachment Permit Application”, should be established as part of the Contract Administration for construction.

Where concrete pavements exist, these may temporarily bridge over and mask underlying ground losses or settlements. High traffic volumes and the need to preserve the integrity of pavements further inhibit installation of monitoring points through concrete pavements. Therefore, to the extent practicable and possible, it will be important to measure the volume of ground removed from beneath paved areas as compared to the theoretical cut hole volume on a frequency of at least once per 6 m section of pipe installed. Measuring excavated ground volumes will be difficult because of bulking that occurs when excavating soils and the spoil discharge systems on some systems are not readily conducive to such measurements (e.g., jack and bore, MTBM). However, on-site observation of construction operations and measurement of grout and/or lubricant volumes should assist in identifying atypical conditions that could be indicative of unacceptable ground losses.

6.7 Grouting

After the permanent culvert pipe is installed within the jacked or rammed casing, post installation grout to fill the annular space between the pipes should be carried out, as required in the NSSP provided in Appendix H for culvert installation via trenchless methods.

For any installations at which the settlement monitoring indicates that pavement settlement has occurred, or where signs of ground loss have been noted, provision should be made for a program of compensation grouting above the pipe and/or repair of the pavements.

7.0 CLOSURE

This Foundation Design Report was prepared by My. Alex Szot, EIT, with technical input from Mr. Kevin Bentley, P.Eng., a geotechnical engineer and Associate of Golder, and reviewed by Mr. Storer Boone, P.Eng., Principal who is certified in MTO's RAQS system for high complexity tunnelling assignments. Mr. Jorge M. A. Costa, P.Eng., a Designated MTO Foundations Contact for Golder and Principal of Golder, conducted an independent review of this report.

GOLDER ASSOCIATES LTD.

LICENSED PROFESSIONAL ENGINEER
FEB.10.2016
K. J. BENTLEY
PROVINCE OF ONTARIO

Alex Szot, EIT
Geotechnical Engineer In Training

Kevin J. Bentley, P.Eng.
Geotechnical Engineer, Associate

LICENSED PROFESSIONAL ENGINEER
Feb. 10, 2016
S. J. BOONE
90559733
PROVINCE OF ONTARIO

Storer J. Boone, Ph.D. P.Eng
Senior Geotechnical Engineer, Principal
(Designated MTO Foundations Contact- Tunnelling Specialty)

Jorge M.A. Costa, P.Eng.
Designated MTO Foundations Contact, Principal

AJS/KJB/JMAC/SJB/sm

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REFERENCES

Heuer, Ronald E., 1974 “Important Ground Parameters in Soft Ground Tunneling”, Proceedings Specialty Conference on Subsurface Explorations for Underground Excavations and Heavy Construction, ASCE, NY.

Table 1: Summary of Proposed Trenchless Installations

Trenchless Crossing	Approximate Station	Drawing/ Section and Appendix	Borehole Nos.	Proposed Culvert Diameter (m)	Estimated Liner/Casing Pipe Min. Diameter (D) (m)	Existing Pavement / Shoulder Crest Elevation (m)		Proposed Culvert Invert Elevation (m)		Estimated Liner/Casing Pipe Obvert Elevation (m)		Estimated Cover Thickness on Liner/Casing (m)		Approx. Minimum Cover Thickness on Liner/Casing	Trenchless options to be evaluated further [2]
						Left Shoulder	**Right Shoulder**	***Left* Shoulder**	***Right* Shoulder**	**Left Shoulder**	**Right Shoulder**	**Left Shoulder**	**Right Shoulder**		
Culvert No. 3	16+790 (W-N/S Ramp)	2 - A-A' A	TC15-4 2014-8A	1.5	1.8	184.2	183.9	180.3	180.2	182.1	182.0	2.1	1.9	1.1D	YES[3,4]
Culvert No. 5	11+274 (Mavis Road)	3 - B-B' B	2014-9A 2014-10A MR-3 MR-3A MR-4	1.0	1.2	195.0	194.2	183.9	184.2	185.1	185.4	9.9	8.8	7.3D	YES
Culvert No. 6	16+855 (Hwy 401 Median)	4 - C-C' C	TC15-2 237-2 237-4 237-6 2014-8A	1.2	1.4	184.7	[1]184.5	181.2	180.8	182.6	182.2	2.1	2.3	1.5D	YES[4]
Culvert No. 9	17+446 (Hwy 401 Median)	5 - D-D' D	TC15-8 TC15-9	0.9	1.2	[1]189.3	189.5	186.3	185.0	187.5	186.2	1.8	3.3	1.5D	YES[4]
Culvert No. 10	16+855 (N-W Ramp)	6 - E-E' E	TC15-1 TC15-3	0.8	1.0	187.0	187.8	182.0	181.8	183.0	182.8	4.0	5.0	4.0D	YES
Culvert No. 11A	11+456 (Mavis Road)	7 - F-F' F	TC15-3 TC15-5 MR-1 MR-2	0.8	1.0	193.2	192.5	183.2	183.5	184.2	184.5	9.0	8.0	8.0D	YES
Culvert No. 12	17+145 (E-N/S Ramp)	8 - G-G' G	TC15-6 TC15-7	0.8	1.0	190.1	189.3	186.7	187.0	187.7	188.0	2.4	1.3	1.3D	YES[3,4]

[1] Elevation at low point at median centreline is equal to or higher than crest elevation at shoulder (i.e. minimum cover thickness has been accounted for within limits of trenchless crossing assessment)

[2] For tunnels under 400-series highways, MTO requires that the minimum overburden cover shall not be less than 1.5 m or typically two liner diameters, whichever is greater, at any point along the entire length of the trenchless crossing.

[3] These locations are below ramps leading to/from Mavis Road to Highway 401 (i.e. not specifically 400-series highways) and will ultimately be re-aligned and re-surfaced, thus, further consideration could be given to evaluating trenchless options at these locations despite low cover thickness.

[4] Trenchless options at this culvert location are to be limited given that less than two diameters equivalent cover thickness is available. High level of care and monitoring required at these sites.

Table 2: Summary of Anticipated Subsurface Conditions

Trenchless Crossing	Approximate Station	Drawing/ Profile and Appendix	Borehole Nos.	Anticipated Subsurface Conditions at Culvert Alignment	[1]Groundwater Elevation (m)	Distance between Groundwater and Invert of Culvert (m)	
						Left Shoulder	*Right* Shoulder
Culvert No. 3	16+790 (W-N/S Ramp)	2 - A-A' (A)	TC15-4 2014-8A	■ Stiff to very stiff clayey silt with sand fill ■ Stiff to hard sandy clayey silt till	181.2	0.9 m above invert	1.0 m above invert
Culvert No. 5	11+274 (Mavis Road)	3 - B-B' (B)	2014-9A 2014-10A MR-3 MR-3A MR-4	■ Firm to hard clayey silt fill ■ Stiff to hard sandy clayey silt till to clayey silt with sand till	184.2	0.3 above invert	At invert
Culvert No. 6	16+855 (Hwy 401 Median)	4 - C-C' (C)	TC15-2 237-2 237-4 237-6 2014-8A	■ Stiff to very stiff silty clay fill ■ Compact silty sand and gravel fill ■ Firm to stiff silty clay ■ Stiff to very stiff silty clay to clayey silt till / sandy clayey silt till / clayey silt with sand till	181.0	0.2 m below invert	0.2 m above invert
Culvert No. 9	17+446 (Hwy 401 Median)	5 - D-D' (D)	TC15-8 TC15-9	■ Firm to stiff silty clay to clayey silt to sandy clayey silt fill ■ Very stiff to hard sandy clayey silt till to claye silt with sand till	187.4	1.1 m above invert	2.4 m above invert
Culvert No. 10	16+855 (N-W Ramp)	6 - E-E' (E)	TC15-1 TC15-3	■ Stiff to very stiff clayey silt to sandy clayey silt to sandy clayey silt with gravel fill ■ Stiff to very stiff sandy clayey silt till	182.0	At invert	0.2 m above invert
Culvert No. 11A	11+456 (Mavis Road)	7 - F-F' (F)	TC15-3 TC15-5 MR-1 MR-2	■ Firm to very stiff silty clay to clayey silt to sandy clayey silt to sandy clayey silt with gravel fill ■ Stiff to very stiff silty clay to clayey silt ■ Very stiff to hard sandy clayey silt till to clayey silt with sand till	184.6	1.4 m above invert	1.1 m above invert
Culvert No. 12	17+145 (E-N/S Ramp)	8 - G-G' (G)	TC15-6 TC15-7	■ Firm to stiff clayey silt to sandy clayey silt fill ■ Very stiff to hard sandy clayey silt till to clayey silt with sand till	185.0	1.7 m below invert	2.0 m below invert

[1] Highest measured groundwater elevation in closest piezometer (subject to fluctuation).

Table 3: Feasibility of Jack and Bore, Pipe Ramming, MTBM, and Open Face Shield Tunnelling

Trenchless Crossing Location	**Approximate Station**	**Borehole Nos.**	**Soil Conditions[1] (ground surface to invert)**	**Fines Content[2] (%)**	**SPT 'N' Values (ground surface to invert) (per 0.3 m)**	**[3]Coefficient of Uniformity**	**Behaviour**	**Feasibility of Jack and Bore**	**Feasibility of Pipe Ramming**	**Feasibility of MTBM**	**Feasibility Of Open Face Shield**
Culvert No. 3	16+790 (W-N/S Ramp)	TC15-4	■ Compact to dense sand and gravel (fill) ■ **Stiff to very stiff clayey silt with sand (fill)** ■ **Stiff to hard sandy clayey silt (till)**	- 62 76	43, 10 8, 16, 15 35	- 117 37	Running **Firm to Fast Raveling** **Slow Raveling**	Questionable (low cover thickness)	Feasible	Not Feasible (less than 2.5 m cover)	Questionable (low cover thickness – less than two diameters)
		2014-8A	■ Compact silty sand and gravel (fill) ■ **Firm to stiff silty clay** ■ **Stiff to very stiff clayey silt to clayey silt with sand (till)**	- - 62, 48	11 7, 10 10	- - 140, 133	Running **Slow Raveling to Firm** **Slow Raveling**				
Culvert No. 5	11+274 (Mavis Road)	2014-9A	■ Firm clayey silt (fill) ■ **Stiff to very stiff sandy clayey silt to clayey silt with sand (till)**	- 67, 57	7 19, 25, 22	- 83, 100	Firm to Slow Raveling **Slow Raveling**	Feasible	Feasible	Feasible	Questionable (diameter less than 1.2 m)
		2014-10A	■ Soft clayey silt (fill) ■ **Stiff to hard sandy clayey silt to clayey silt with sand (till)**	- 65, 70	4 25, 36, 23, 25, 22, 14	- 100, 50	Firm to Slow Raveling **Slow Raveling**				
		MR-3	■ **Firm to hard clayey silt to clayey silt with gravel (fill)** ■ **Very stiff clayey silt with sand (till)**	- 61	24, 5, 12, 8, 6, 10, 11, 17, 29, 33 20	- 114	**Firm to Fast to Slow Raveling** **Slow Raveling**				
		MR-4	■ Sand and gravel (fill) ■ **Stiff to hard clayey silt to clayey silt with sand (fill)** ■ **Very stiff to hard clayey silt with sand (till)**	- 61 61, 78, 49, 66	- 11, 10, 10, 14, 14, 17, 80, 9, 28, 36 30	- 117 117, 33, 166	Running **Firm to Slow Raveling** **Slow Raveling**				
Culvert No. 6	16+855 (Hwy 401 Median)	TC15-2	■ **Stiff to very stiff sandy silty clay to clayey silt with sand (fill)** ■ **Stiff to very stiff sandy clayey silt (till)**	49, 76 65	15, 20, 12, 13, 8 16, 20	500, 72 53	Firm to Slow Raveling Slow Raveling	Not feasible (low cover thickness)	Feasible (with controls and monitoring)	Feasible (using specialized methods)	Not feasible (low cover thickness)
		2014-8A	■ **Compact silty sand and gravel (fill)** ■ **Firm to stiff silty clay** ■ Stiff to very stiff clayey silt to clayey silt with sand (till)	- - 62, 48	11 7, 10 10	- - 140, 133	**Running** **Slow Raveling to Firm** Slow Raveling				
		237-2[4]	■ **Loose/compact shale pieces and silt (fill)** ■ **Very stiff to hard silty clay to sandy clayey silt (till)**	- 79, 66	50/0.05 41, 35	- 23, 233	**Cohesive Running** **Slow Raveling**				
		237-4[4]	■ Compact road granulars (fill) ■ **Stiff to very stiff silty clay (fill)** ■ **Very stiff sandy clayey silt (till)**	- 87 53	34 12, 20 22, 26, 26	- 18 530	Running **Firm to Slow Raveling** **Slow Raveling**				
		237-6[4]	■ **Very stiff to hard sandy clayey silt (inferred till)**	-	6, 28, 85, 26, 24, 21	-	**Slow Raveling**				

Trenchless Crossing Location	Approximate Station	Borehole Nos.	Soil Conditions[1] (ground surface to invert)	Fines Content[2] (%)	SPT 'N' Values (ground surface to invert) (per 0.3 m)	[3]Coefficient of Uniformity	Behaviour	Feasibility of Jack and Bore	Feasibility of Pipe Ramming	Feasibility of MTBM	Feasibility Of Open Face Shield
Culvert No. 9	17+446 (Hwy 401 Median)	TC15-8	■ Compact to dense sand and gravel (fill) ■ **Stiff sandy clayey silt (fill)** ■ **Stiff to hard sandy clayey silt to clayey silt with sand (till)**	- 77 70, 62	42 11, 12 22, 28, 40	- 140 100, 110	Running **Firm to Fast Running** **Slow Raveling**	Not feasible (low cover thickness)	Feasible (with controls and monitoring)	Feasible (using specialized methods)	Not feasible (low cover thickness)
		TC15-9	■ Compact sand and gravel (fill) ■ **Firm to stiff clayey silt to silty clay (fill)** ■ **Stiff to hard sandy clayey silt (till)**	15 - 62, 64	26 9, 6, 10 22, 34, 31	100 - 175, 120	Running **Firm to Slow Raveling** **Slow Raveling**				
Culvert No. 10	16+855 (N-W Ramp)	TC15-1	■ Dense sand and gravel (fill) ■ **Stiff to very stiff clayey silt with gravel to sandy clayey silt with gravel (fill)**	- 33, 42	35 11, 17, 12, 13, 14, 26	- >1,000	Running **Rapid to Slow Raveling**	Feasible	Feasible	Feasible	Questionable (diameter less than 1.2 m)
		TC 15-3	■ **Firm to very stiff sandy clayey silt to sandy clayey silt with gravel (fill)**	40, 65	12, 7, 8, 17, 17	>1,000	**Rapid to Slow Raveling**				
Culvert No. 11A	11+456 (Mavis Road)	TC15-3	■ **Firm to very stiff sandy clayey silt to sandy clayey silt with gravel (fill)**	40, 65	12, 7, 8, 17	>1,000	**Rapid to Slow Raveling**	Feasible	Feasible	Feasible	Questionable (diameter less than 1.2 m)
		TC15-5	■ **Firm to very stiff clayey silt (fill)** ■ **Stiff to very stiff sandy clayey silt (till)**	88 59	6, 11, 18, 26	20 117	**Firm to Slow Raveling** **Slow Raveling**				
		MR-1	■ Sand and gravel (fill) ■ **Stiff to hard clayey silt (fill)** ■ **Very stiff clayey silt** ■ **Stiff to hard clayey silt with sand (till)**	- - 71 68, 59	- 15,10,9,11,45,11,18,11,16 22 38	- - 70 71, 70	Running **Rapid to Slow Raveling** **Firm** **Slow Raveling**				
		MR-2	■ Sand and gravel (fill) ■ **Clayey silt to silty clay with gravel (fill)** ■ **Stiff silty clay** ■ **Stiff to hard clayey silt with sand (till)**	- 44 - 62, 60, 41	- 10,9,7,14,16,18,12,20,11 14 35	- 75 - 105, 104, 462	Running **Firm to Slow Raveling** **Firm** **Rapid to Slow Raveling**				
Culvert No. 12	17+145 (E-N/S Ramp)	TC15-6	■ **Firm clayey silt (fill)** ■ **Stiff to hard sandy clayey silt to clayey silt with sand (till)**	- 70, 62, 59	7 31	- 75, 100, 114	**Firm to Slow Raveling** **Slow Raveling**	Questionable (low cover thickness)	Feasible	Not Feasible (less than 2.5 m cover)	Questionable (diameter less than 1.2 m)
		TC15-7	■ Compact sand and gravel (fill) ■ **Firm to stiff sandy clayey silt (fill)** ■ **Very stiff to hard sandy clayey silt to clayey silt with sand (till)**	- 71 68, 56	23 7, 12, 13 21	- 187 94, 111	Running **Firm to Slow Raveling** **Slow Raveling**				

Notes:

1. Soil conditions from ground surface to invert, **bold** soil condition indicates soil conditions at tunnel horizon.
2. Fines content is the percentage by weight passing the number 200 sieve (0.075 mm).
3. In calculating coefficient of uniformity, grain size curves were extrapolated to estimate the per cent at which 10% are fines, if applicable.
4. Pavement holes drilled along existing Hwy 401 in this area for the current project encountered asphalt, concrete, and granular fills up to about 0.9 m below road surface.

Table 4: Evaluation of Culvert Installation Methods

Installation Method	Advantages	Disadvantages	Estimated Cost/m of Culvert Installation	Risk/Consequences
Open Cut	■ Ease of construction at locations where excavation depths are relatively shallow (typically less than 4 m below road grade) at Culvert Nos. 6, 9, and 12 ■ Fully exposed installation, does not require settlement monitoring program	■ Road closures / night work on Highway 401 and associated ramps ■ Temporary excavation support systems may be required ■ Likely requires disposal of soils excavated and replacement with properly compacted granular fill.	■ $600/m to $900/m (not including costs for traffic control, inefficiencies due to time restrictions and night work)	■ Traffic delays and risk of extended highway / ramp closure times if problems encountered. ■ Impacts to construction schedule and requirement for traffic control measures that will have direct impact on total cost. ■ Weather could cause significant delays.
Trenchless - Jack and Bore Installation	■ Culverts can be installed without lane closures thus minimizing traffic disruption.	■ Large work area required for jacking pit. ■ Mixed face or obstructions (e.g., cobbles and boulders) may deflect and/or halt bore; greatest risk of ground subsidence of highway/roadway particularly if obstructions that slow installation procedures or if unanticipated granular and wet soils encountered. ■ May require groundwater lowering. ■ Requires settlement monitoring program to assess for ground loss along the alignment	■ $900/m to $1,800/m	■ Risk of encountering refusal on obstructions within native deposits, particularly till, where man entry to remove obstructions is not possible. ■ Mixed face and/or obstructions can result in deflection of the casing resulting in misalignment of culvert. ■ Potential for loss of ground into casing particularly if granular and wet materials (e.g. pockets in the fills and perched groundwater) are encountered. ■ Risk of ground surface subsidence increases with decreasing cover.
Trenchless - Pipe Ramming Installation	■ Minimal traffic disruption. ■ Less risk of subsidence above culvert alignment than jack and bore installation methods. ■ Better suited for penetrating through potential obstructions such as cobbles and boulders than jack and bore methods.	■ Large work area required for ramming pit. ■ Mixed face and/or large obstructions can deflect casing. Potential for heaving at ground surface. May require groundwater lowering. ■ Potential noise objections in urban areas. ■ Requires settlement monitoring program to assess for ground loss or heave along the alignment	$1,800/m to $3,600/m	■ Mixed face and/or obstructions can cause deflection of casing resulting in misalignment of culvert. ■ Nests of cobbles and/or boulders can stop penetration of casing requiring hand mining. ■ Vibration from pipe ramming may be experienced by the users of the highway.
Trenchless - MTBM	■ Minimal traffic disruption. ■ Typically does not require groundwater lowering except for use of “small boring units” without slurry face pressure and cuttings transport systems. ■ Slurry machines able to counterbalance earth and water pressures in a controlled manner, thereby reducing the risk of ground losses during tunneling. ■ Machine can also be specified to have the capability to cut and crush boulders.	■ Relatively expensive. High mobilization cost for short crossings. ■ Slurry processing systems required along with additional working area at shaft/pit locations for some systems. ■ “Small boring unit” systems are not capable of fully controlling saturated granular soils. ■ Susceptible to hydraulic fracture depending on slurry viscosity and pressure. ■ Requires settlement monitoring program to assess for ground loss along the alignment	$7,500/m	■ Hydraulic fracture is possible at culvert locations with cover less than 2.5 m and any slurry exiting onto the pavements could be a significant hazard to traffic. ■ Use of small boring units or low viscosity slurries could contribute to excessive ground losses when cutting through granular soils that result in pavement damage and a significant hazard to traffic.
Trenchless - Open Face Shield Tunnelling	■ Minimal traffic disruption. ■ Better suited for penetrating through potential obstructions such as cobbles and boulders than jack and bore methods.	■ Risk of ground subsidence of highway but more control than jack and bore methods. ■ Requires groundwater lowering if saturated granular soils might be encountered. ■ Requires diameter sufficient for person entry (>1.2 m) ■ Requires settlement monitoring program to assess for ground loss along the alignment. ■ Additional health and safety concerns	$1,800/m to $3,600/m	■ Potential for loss of ground into shield particularly if granular materials are encountered. ■ Risk of ground surface subsidence increases with decreasing cover.

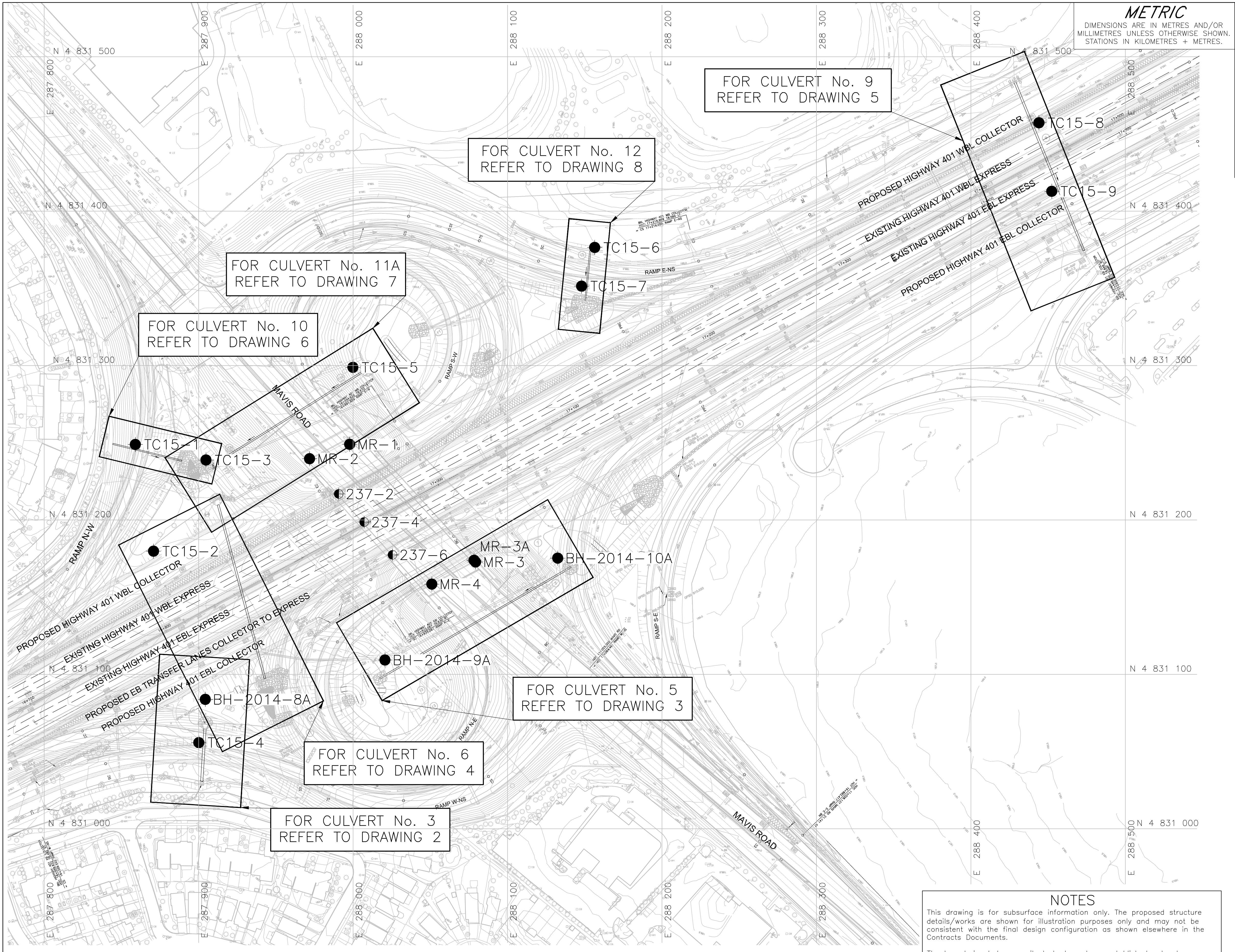
METRIC
DIMENSIONS ARE IN METRES AND/OR MILLIMETRES UNLESS OTHERWISE SHOWN. STATIONS IN KILOMETRES + METRES.

CONT No.
GWP No. 2150-01-00

HIGHWAY 401
CULVERTS
INDEX PLAN

SHEET

Golder Associates



PLAN
SCALE
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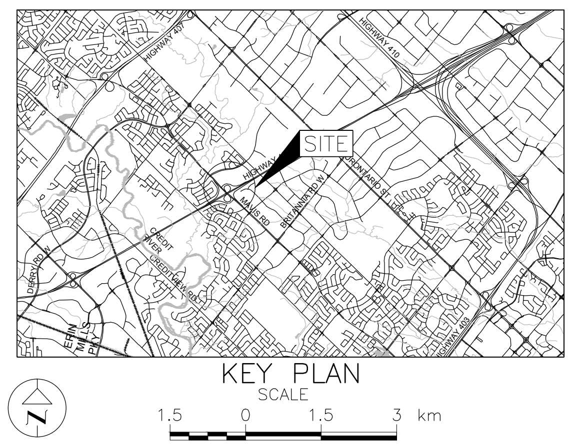

KEY PLAN
SCALE

LEGEND

●	Borehole – Current Investigation
◐	Borehole – Previous Investigation (Terraprobe, 1998)

BOREHOLE CO-ORDINATES

No.	ELEVATION	NORTHING	EASTING
237-2	186.6	4831216.8	287990.7
237-4	187.5	4831198.6	288007.2
237-6	185.2	4831177.4	288025.5
BH-2014-8A	182.2	4831083.8	287904.3
BH-2014-9A	185.6	4831109.3	288020.6
BH-2014-10A	189.4	4831175.3	288132.5
MR-1	194.7	4831249.0	287997.7
MR-2	195.1	4831239.6	287971.8
MR-3	194.6	4831172.8	288079.3
MR-3A	194.6	4831173.9	288078.3
MR-4	195.4	4831158.4	288051.0
TC15-1	187.3	4831248.9	287859.0
TC15-2	186.8	4831179.8	287870.8
TC15-3	185.8	4831238.8	287904.7
TC15-4	183.9	4831055.8	287900.1
TC15-5	185.8	4831298.8	287999.8
TC15-6	188.4	4831376.5	288156.4
TC15-7	189.9	4831351.4	288147.9
TC15-8	189.6	4831457.2	288444.0
TC15-9	189.6	4831412.9	288452.3

NOTES

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REFERENCE

Base plans provided in digital format by AECOM, drawing file nos. X-60213979-C-BA-HWY401_MAVIS.dwg, X-60213979-C-DE-HWY401_MAVIS_Add1.dwg, received December 1, 2015, 10cmContours.dwg, received December 21, 2015 and X-60213979-C-DE-HWY401_MAVIS_Add4.dwg, received January 19, 2016.

NO.	DATE	BY	REVISION

Geocres No. 30M12-394

HWY. 401		PROJECT NO. 10-1111-0211	DIST.
SUBM'D. AJS	CHKD. AJS	DATE: Jan. 2016	SITE:
DRAWN: JFC	CHKD. KJB	APPD. JMAC	DWG. 1

PLOT DATE: February 11, 2016
FILENAME: T:\Projects\2010\10-1111-0211 (AECOM, Mississauga)\-SA- Trenchless Crossing\1011110211SA001.dwg

MINISTRY OF TRANSPORTATION, ONTARIO

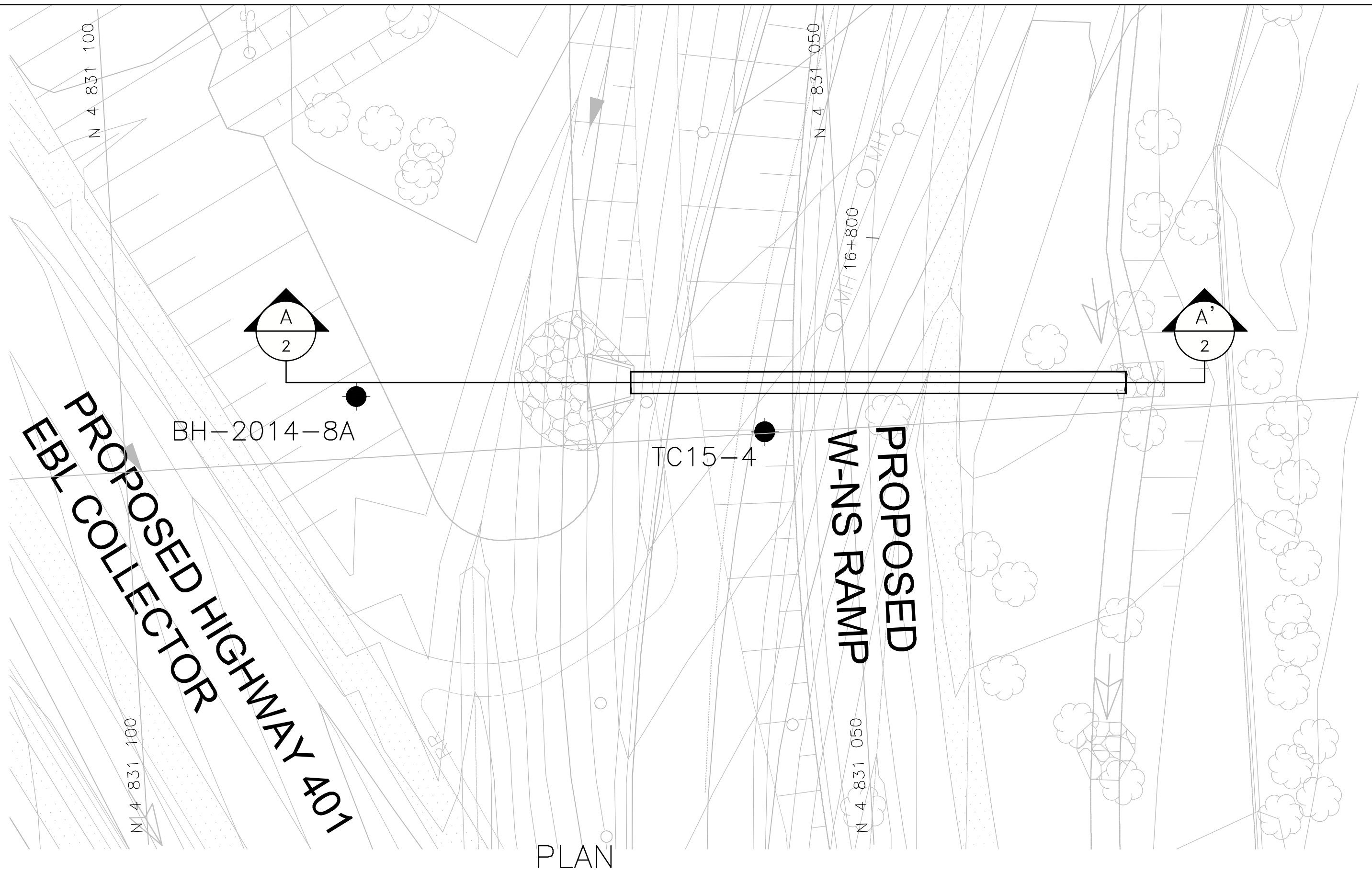
METRIC
DIMENSIONS ARE IN METRES AND/OR MILLIMETRES UNLESS OTHERWISE SHOWN. STATIONS IN KILOMETRES + METRES.

CONT No.
GWP No. 2150-01-00

SHEET

HIGHWAY 401
CULVERT NO. 3
BOREHOLE LOCATIONS AND SOIL STRATA

Golder Associates



PLAN
SCALE
5 0 5 10 m

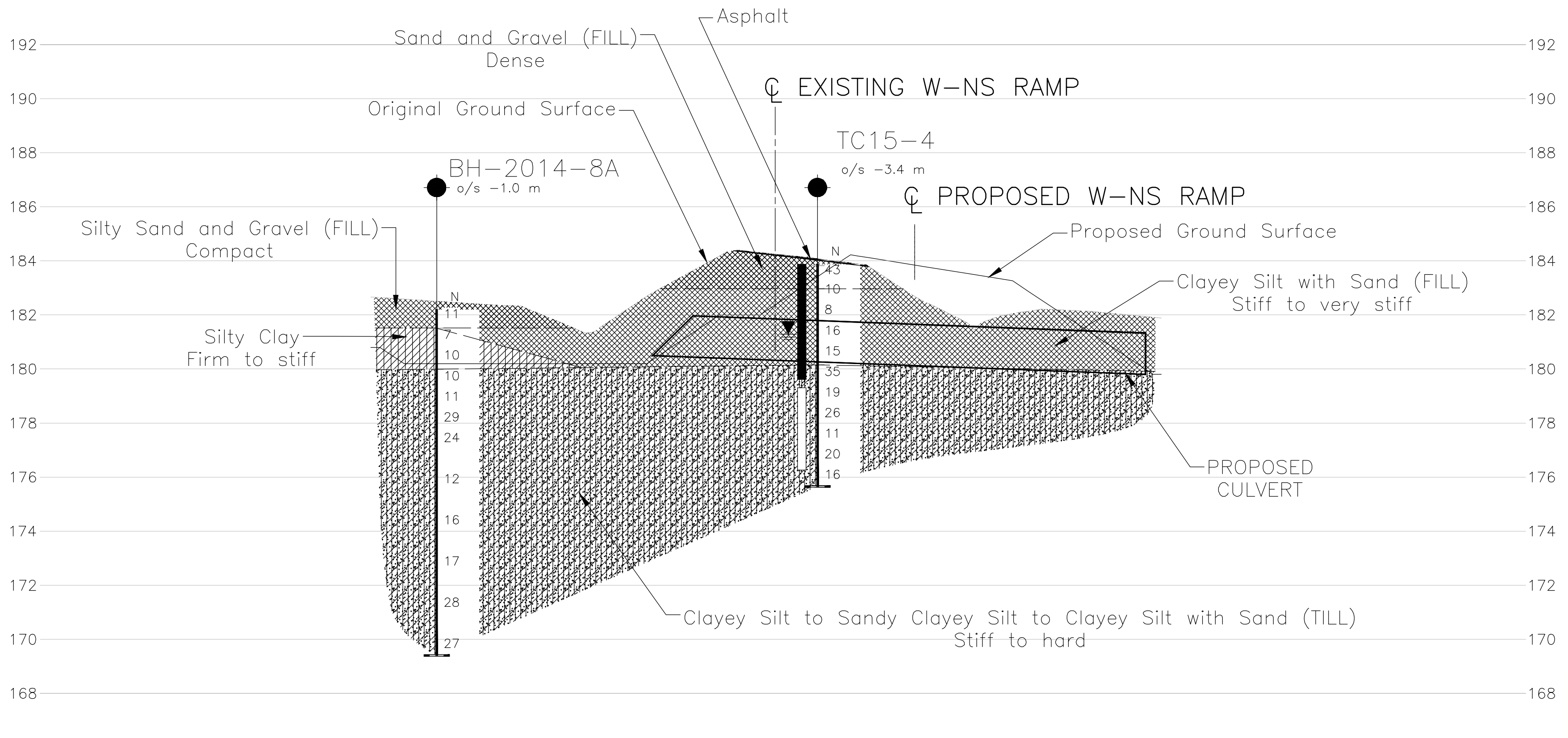
KEY PLAN
SCALE
1.5 0 1.5 3 km

LEGEND

●	Borehole – Current Investigation
▮	Seal
▯	Piezometer
N	Standard Penetration Test Value
16	Blows/0.3m unless otherwise stated (Std. Pen. Test, 475 j/blow)
▼	WL in piezometer, measured on December 16, 2015

BOREHOLE CO-ORDINATES

No.	ELEVATION	NORTHING	EASTING
BH-2014-8A	182.2	4831083.8	287904.3
TC15-4	183.9	4831055.8	287900.1



A-A
2
CULVERT No. 3 PROFILE
STATION 16+790

VERTICAL SCALE
2.5 0 2.5 5 m

HORIZONTAL SCALE
5 0 5 10 m

NOTES

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REFERENCE

Base plans provided in digital format by AECOM, drawing file nos. X-60213979-C-BA-HWY401_MAVIS.dwg, X-60213979-C-DE-HWY401_MAVIS_Add1.dwg and 60213979_CT-SMP-MAVIS401-RT-1.dwg received December 1, 2015 and 10cmContours.dwg, received December 21, 2015.

J.M.A. COSTA
Feb. 11, 2016

K. J. BENTLEY
Feb. 11, 2016

NO.	DATE	BY	REVISION

Geocres No. 30M12-394

HWY. 401		PROJECT NO. 10-1111-0211	DIST.
SUBM'D. AJS	CHKD. AJS	DATE: Jan. 2016	SITE:
DRAWN: JFC	CHKD. KJB	APPD. JMAC	DWG. 2

PLOT DATE: February 11, 2016
FILENAME: T:\Projects\2010\10-1111-0211 (AECOM, Mississauga)\-SA- Trenchless Crossing\10111102115A02.dwg

MINISTRY OF TRANSPORTATION, ONTARIO

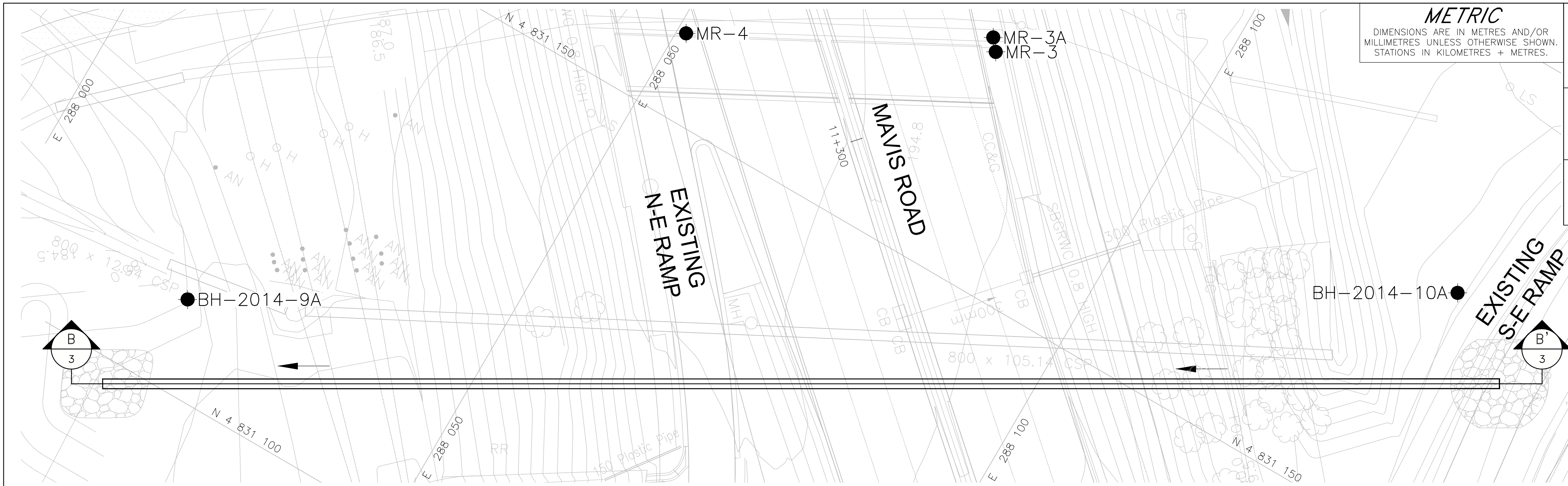
METRIC
DIMENSIONS ARE IN METRES AND/OR MILLIMETRES UNLESS OTHERWISE SHOWN. STATIONS IN KILOMETRES + METRES.

CONT No.
GWP No. 2150-01-00

HIGHWAY 401
CULVERT NO. 5
BOREHOLE LOCATIONS AND SOIL STRATA

SHEET

Golder Associates



PLAN
SCALE
5 0 5 10 m

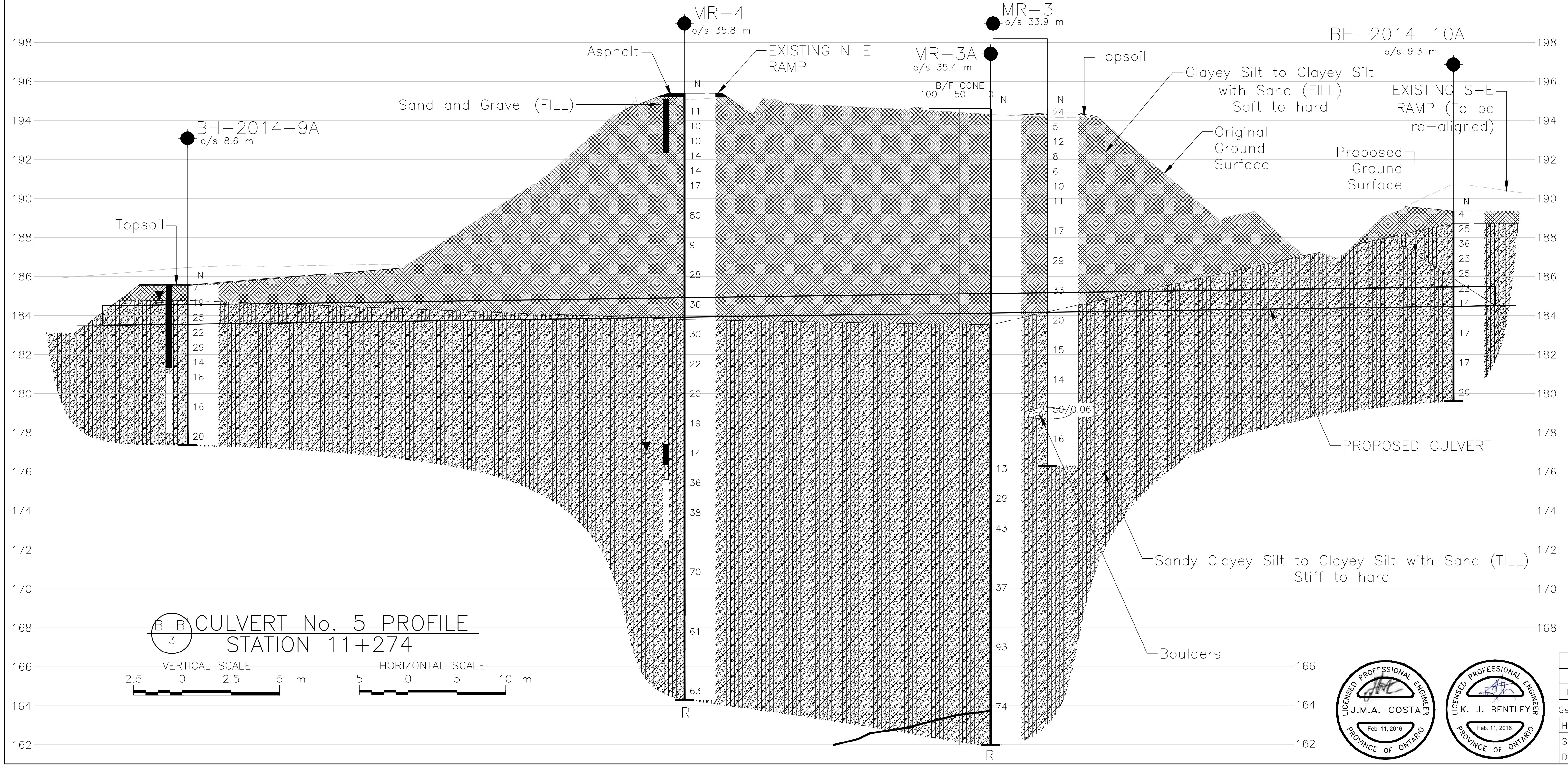
KEY PLAN
SCALE
1.5 0 1.5 3 km

LEGEND

●	Borehole – Current Investigation
▮	Seal
▯	Piezometer
N	Standard Penetration Test Value
16	Blows/0.3m unless otherwise stated (Std. Pen. Test, 475 j/blow)
▼	WL in piezometer, measured on December 16, 2015 and November 5, 2012
▽	WL upon completion of drilling
R	Refusal to Further Penetration

BOREHOLE CO-ORDINATES

No.	ELEVATION	NORTHING	EASTING
BH-2014-9A	185.6	4831109.3	288020.6
BH-2014-10A	189.4	4831175.3	288132.5
MR-3	194.6	4831172.8	288079.3
MR-3A	194.6	4831173.9	288078.3
MR-4	195.4	4831158.4	288051.0



B-B
3
CULVERT No. 5 PROFILE
STATION 11+274

VERTICAL SCALE
2.5 0 2.5 5 m

HORIZONTAL SCALE
5 0 5 10 m

NOTES

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REFERENCE

Base plans provided in digital format by AECOM, drawing file nos.
X-60213979-C-BA-HWY401_MAVIS.dwg,
X-60213979-C-DE-HWY401_MAVIS_Add1.dwg,
60213979_CT-SMP-MAVIS401-LT-1.dwg and
60213979_CT-SMP-MAVIS401-LT-2.dwg, received December 1, 2015 and
10cmContours.dwg, received December 21, 2015.

J.M.A. COSTA
Feb. 11, 2016

K. J. BENTLEY
Feb. 11, 2016

NO.	DATE	BY	REVISION
.	.	.	.

Geocres No. 30M12-394

HWY. 401		PROJECT NO. 10-1111-0211	DIST.
SUBM'D. AJS	CHKD. AJS	DATE: Jan. 2016	SITE:
DRAWN: JFC	CHKD. KJB	APPD. JMAC	DWG. 3

PLOT DATE: February 11, 2016
FILENAME: T:\Projects\2010\10-1111-0211 (AECOM, Mississauga)\-5A- Trenchless Crossing\1011110211SA003.dwg

MINISTRY OF TRANSPORTATION, ONTARIO

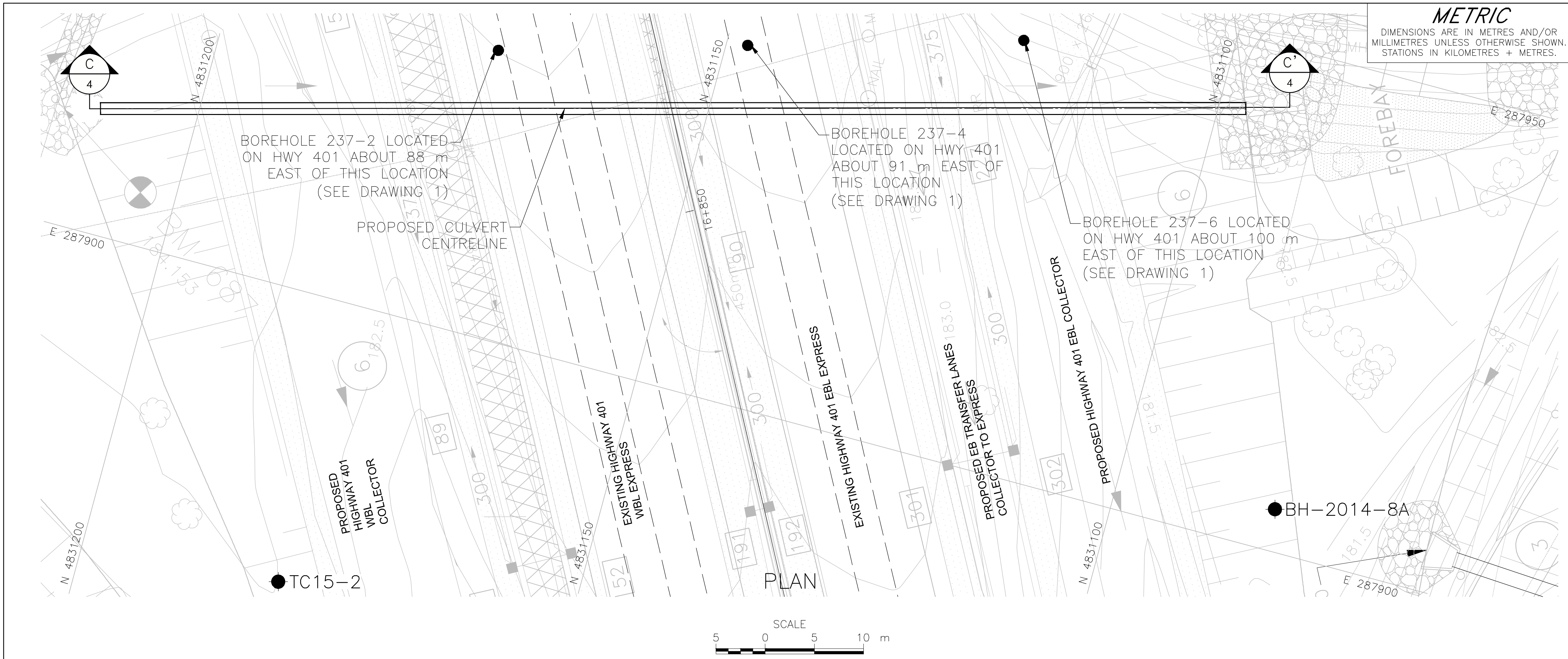
METRIC
DIMENSIONS ARE IN METRES AND/OR MILLIMETRES UNLESS OTHERWISE SHOWN. STATIONS IN KILOMETRES + METRES.

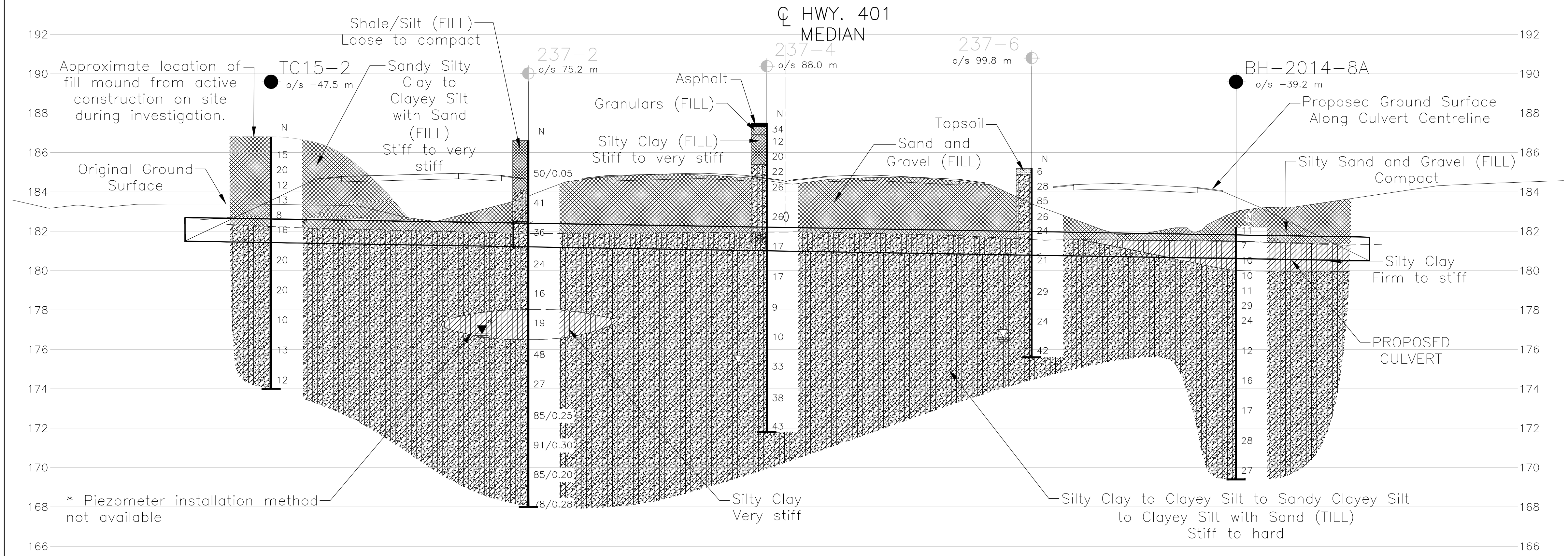
CONT No.
GWP No. 2150-01-00

HIGHWAY 401
CULVERT NO. 6
BORHOLE LOCATIONS AND SOIL STRATA

SHEET

Golder Associates



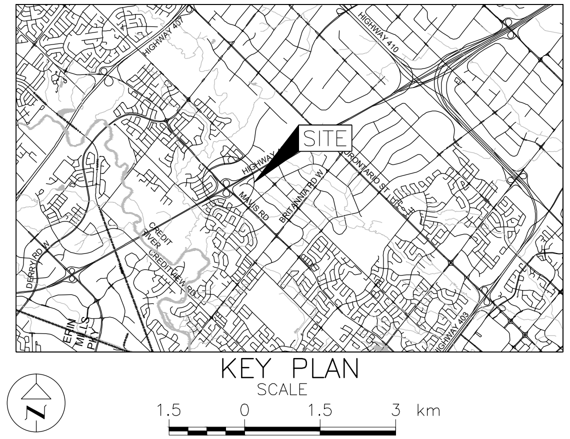


CULVERT No. 6 PROFILE
STATION 16+855

C-C
4

VERTICAL SCALE
2.5 0 2.5 5 m

HORIZONTAL SCALE
5 0 5 10 m



LEGEND

●	Borehole – Current Investigation
◐	Borehole – Previous Investigation (Terraprobe, 1998)
▮	Seal
▯	Piezometer
N	Standard Penetration Test Value
16	Blows/0.3m unless otherwise stated (Std. Pen. Test, 475 j/blow)
▽	WL upon completion of drilling
▼	WL in piezometer, measured on January 8, 1998

BOREHOLE CO-ORDINATES

No.	ELEVATION	NORTHING	EASTING
237-2	186.6	4831216.8	287990.7
237-4	187.5	4831198.6	288007.2
237-6	185.2	4831177.4	288025.5
BH-2014-8A	182.2	4831083.8	287904.3
TC15-2	186.8	4831179.8	287870.8

NOTES

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REFERENCE

Base plans provided in digital format by AECOM, drawing file nos. X-60213979-C-BA-HWY401_MAVIS.dwg, X-60213979-C-DE-HWY401_MAVIS_Add1.dwg, received December 1, 2015 and 2015-12-09-401 MavisTrenchless_5 6 9_60213979.dwg, received December 9, 2015 and 10cmContours.dwg, received December 21, 2015 and X-60213979-C-DE-HWY401_MAVIS_Add4.dwg, 2016-01-19-Updated culvert sections-60213979.dwg, received January 19, 2015.

J.M.A. COSTA
Feb. 11, 2016

K. J. BENTLEY
Feb. 11, 2016

NO.	DATE	BY	REVISION
.	.	.	.

Geocres No. 30M12-394

HWY. 401		PROJECT NO. 10-1111-0211	DIST.
SUBM'D. AJS	CHKD. AJS	DATE: Jan. 2016	SITE:
DRAWN: JFC	CHKD. KJB	APPD. JMAC	DWG. 4

PLOT DATE: February 11, 2016
FILENAME: T:\Projects\2010\10-1111-0211 (AECOM, Mississauga)\-SA- Trenchless Crossing\10111102115A004.dwg

MINISTRY OF TRANSPORTATION, ONTARIO

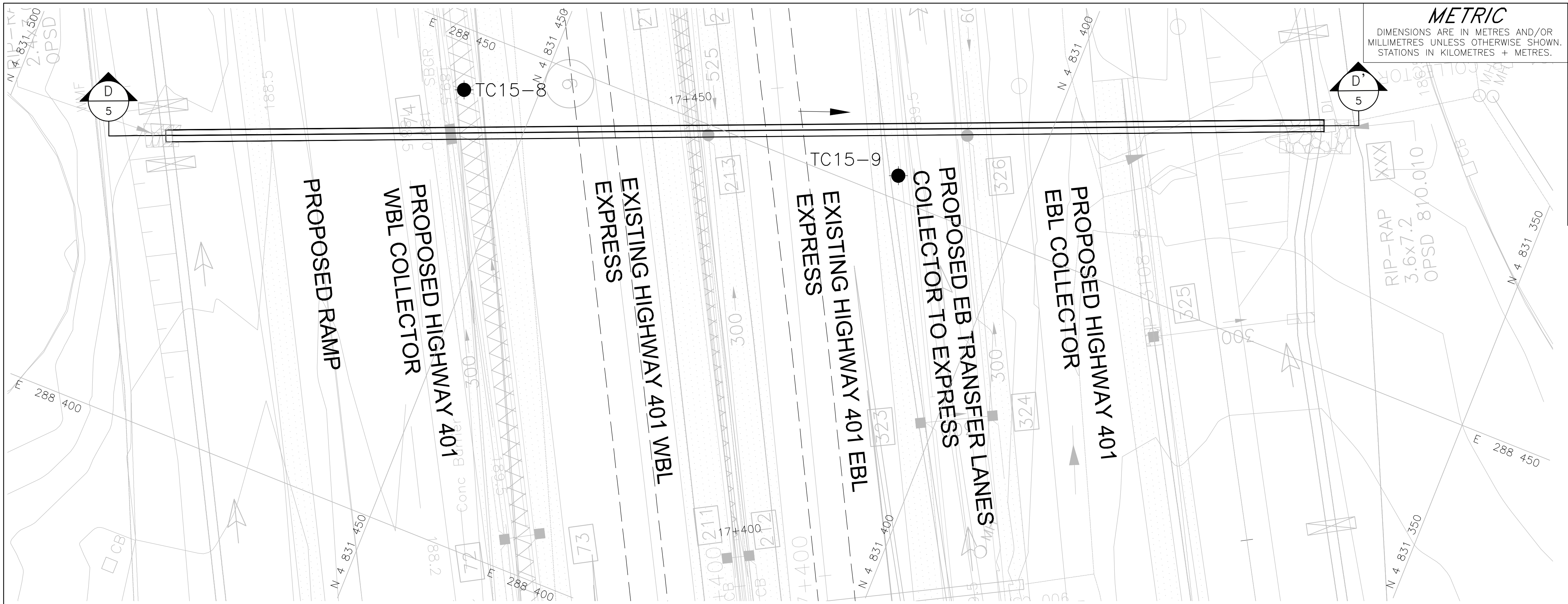
METRIC
DIMENSIONS ARE IN METRES AND/OR MILLIMETRES UNLESS OTHERWISE SHOWN. STATIONS IN KILOMETRES + METRES.

CONT No.
GWP No. 2150-01-00

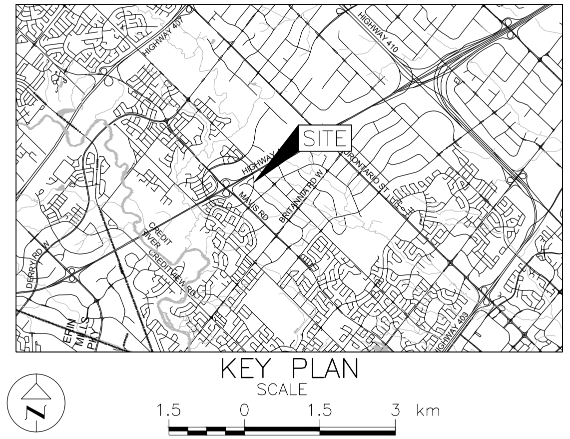
HIGHWAY 401
CULVERT NO. 9
BOREHOLE LOCATIONS AND SOIL STRATA

SHEET

Golder Associates



PLAN
SCALE
5 0 5 10 m



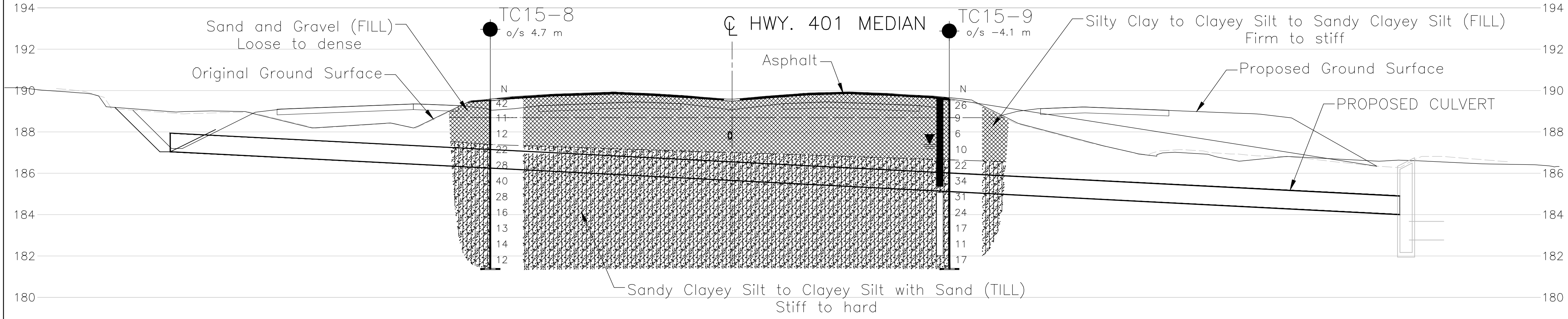
KEY PLAN
SCALE
1.5 0 1.5 3 km

LEGEND

●	Borehole – Current Investigation
▮	Seal
▯	Piezometer
N	Standard Penetration Test Value
16	Blows/0.3m unless otherwise stated (Std. Pen. Test, 475 j/blow)
▼	WL in piezometer, measured on December 16, 2015

BOREHOLE CO-ORDINATES

No.	ELEVATION	NORTHING	EASTING
TC15-8	189.6	4831457.2	288444.0
TC15-9	189.6	4831412.9	288452.3



D-D' 5 CULVERT No. 9 PROFILE
STATION 17+446

VERTICAL SCALE
2.5 0 2.5 5 m

HORIZONTAL SCALE
5 0 5 10 m

NOTES

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REFERENCE

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J.M.A. COSTA
Feb. 11, 2016

K. J. BENTLEY
Feb. 11, 2016

NO.	DATE	BY	REVISION
.	.	.	.

Geocres No. 30M12-394

HWY. 401		PROJECT NO. 10-1111-0211	DIST.
SUBM'D. AJS	CHKD. AJS	DATE: Jan. 2016	SITE:
DRAWN: JFC	CHKD. KJB	APPD. JMAC	DWG. 5

PLOT DATE: February 11, 2016
FILENAME: T:\Projects\2010\10-1111-0211 (AECOM, Mississauga)\-SA- Trenchless Crossing\1011110211SA005.dwg

MINISTRY OF TRANSPORTATION, ONTARIO

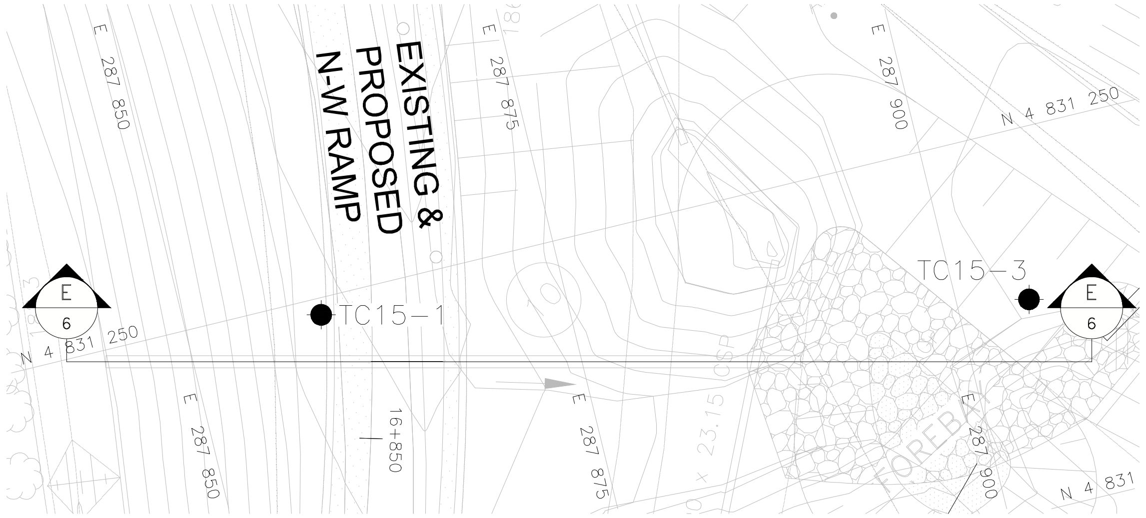
METRIC
DIMENSIONS ARE IN METRES AND/OR MILLIMETRES UNLESS OTHERWISE SHOWN. STATIONS IN KILOMETRES + METRES.

CONT No.
GWP No. 2150-01-00

SHEET

HIGHWAY 401
CULVERT NO. 10
BOREHOLE LOCATIONS AND SOIL STRATA

Golder Associates



PLAN
SCALE
5 0 5 10 m

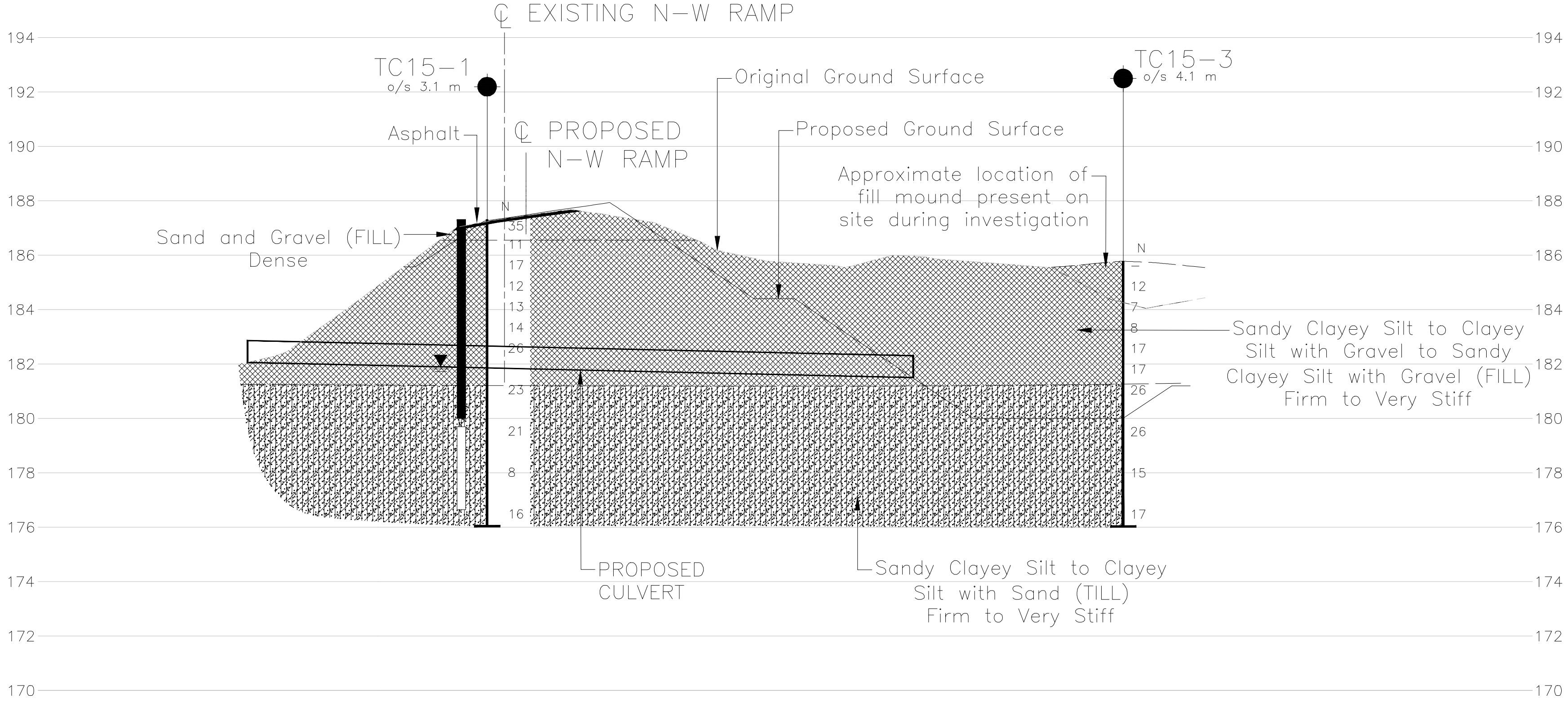
KEY PLAN
SCALE
1.5 0 1.5 3 km

LEGEND

- ● Borehole – Current Investigation
- ▮ Seal
- ▯ Piezometer
- N Standard Penetration Test Value
- 16 Blows/0.3m unless otherwise stated (Std. Pen. Test, 475 j/blow)
- ▼ WL in piezometer, measured on Dec. 16, 2015

BOREHOLE CO-ORDINATES

No.	ELEVATION	NORTHING	EASTING
TC15-1	187.3	4831248.9	287859.0
TC15-3	185.8	4831238.8	287904.7



E-E / 6 CULVERT No. 10 PROFILE
STATION 16+855

VERTICAL SCALE
2.5 0 2.5 5 m

HORIZONTAL SCALE
5 0 5 10 m

NOTES

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REFERENCE

Base plans provided in digital format by AECOM, drawing file nos. X-60213979-C-BA-HWY401_MAVIS.dwg, X-60213979-C-DE-HWY401_MAVIS_Add1.dwg and 60213979_CT-SMP-MAVIS401-LT-1.dwg received December 1, 2015 and 10cmContours.dwg, received December 21, 2015.

J.M.A. COSTA
Feb. 11, 2016

K. J. BENTLEY
Feb. 11, 2016

NO.	DATE	BY	REVISION

Geocres No. 30M12-394

HWY. 401		PROJECT NO. 10-1111-0211	DIST.
SUBM'D. AJS	CHKD. AJS	DATE: Jan. 2016	SITE:
DRAWN: JFC	CHKD. KJB	APPD. JMAC	DWG. 6

PLOT DATE: February 11, 2016
FILENAME: T:\Projects\2010\10-1111-0211 (AECOM, Mississauga)\-SA- Trenchless Crossing\1011110211SA006.dwg

MINISTRY OF TRANSPORTATION, ONTARIO

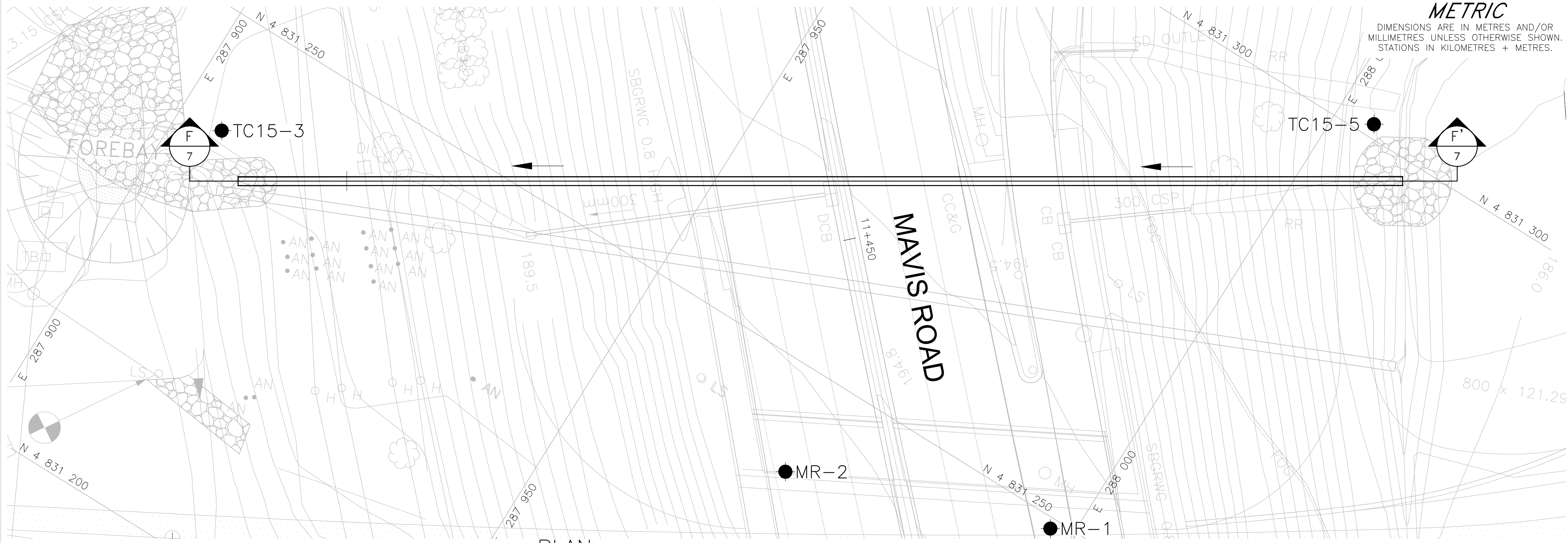
CONT No.
GWP No. 2150-01-00

HIGHWAY 401
CULVERT NO. 11A
BOREHOLE LOCATIONS AND SOIL STRATA

SHEET

Golder Associates

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



PLAN
SCALE
5 0 5 10 m

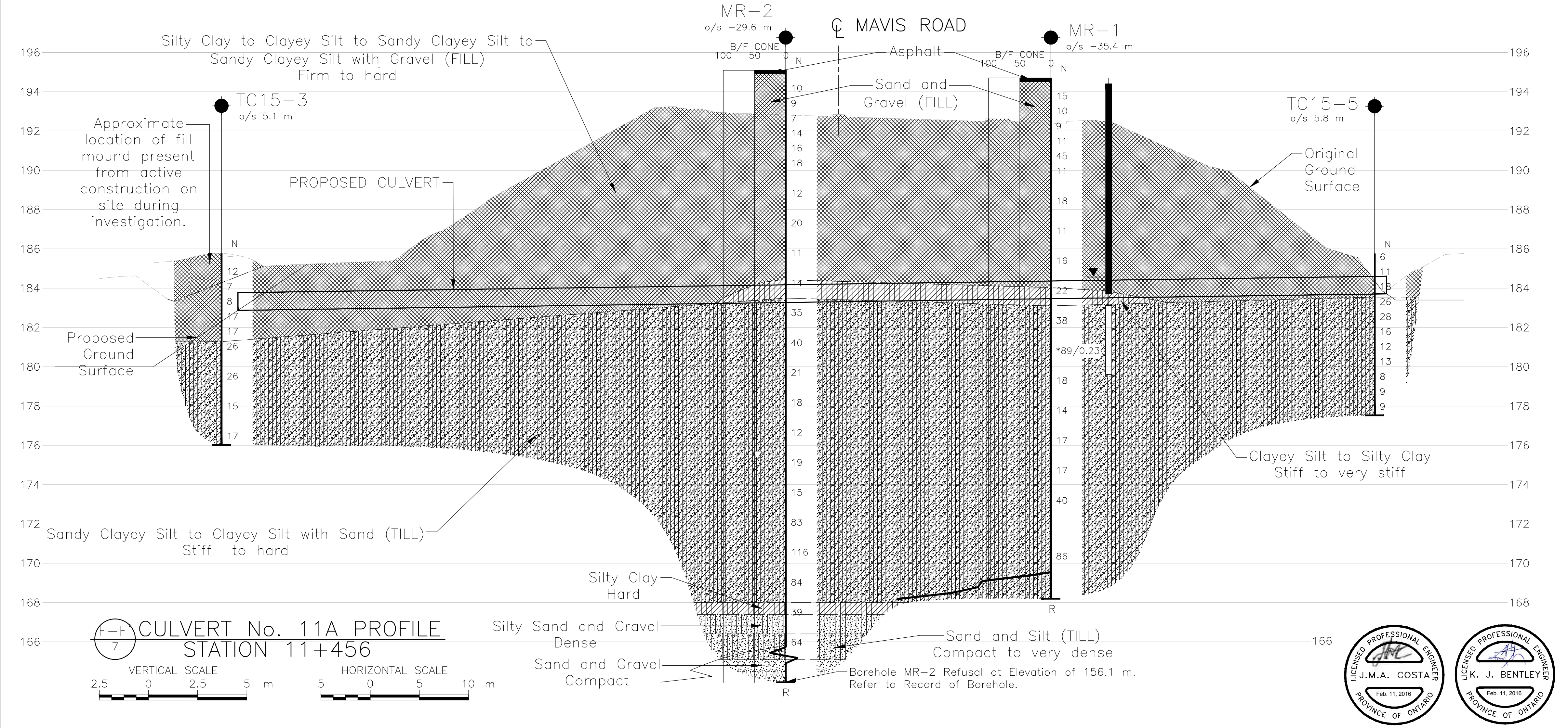
KEY PLAN
SCALE
1.5 0 1.5 3 km

LEGEND

●	Borehole – Current Investigation
▮	Seal
▯	Piezometer
N	Standard Penetration Test Value
16	Blows/0.3m unless otherwise stated (Std. Pen. Test, 475 j/blow)
▼	WL in piezometer, measured on November 5, 2012
▽	WL upon completion of drilling
R	Refusal to Further Penetration

BOREHOLE CO-ORDINATES

No.	ELEVATION	NORTHING	EASTING
MR-1	194.7	4831249.0	287997.7
MR-2	195.1	4831239.6	287971.8
TC15-3	185.8	4831238.8	287904.7
TC15-5	185.8	4831301.4	288003.9



F-F
7
CULVERT No. 11A PROFILE
STATION 11+456

VERTICAL SCALE
2.5 0 2.5 5 m

HORIZONTAL SCALE
5 0 5 10 m

J.M.A. COSTA
Feb. 11, 2016

K. J. BENTLEY
Feb. 11, 2016

NOTES

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REFERENCE

Base plans provided in digital format by AECOM, drawing file nos.
X-60213979-C-BA-HWY401_MAVIS.dwg,
X-60213979-C-DE-HWY401_MAVIS_Add1.dwg,
60213979_CT-SMP-MAVIS401-LT-1.dwg and
60213979_CT-SMP-MAVIS401-LT-2.dwg, received December 1, 2015 and
10cmContours.dwg, received December 21, 2015.

NO.	DATE	BY	REVISION
.	.	.	.

Geocres No. 30M12-394

HWY. 401	PROJECT NO. 10-1111-0211	DIST.
SUBM'D. AJS	CHKD. AJS	DATE: Jan. 2016	SITE:
DRAWN: JFC	CHKD. KJB	APPD. JMAC	DWG. 7

PLOT DATE: February 11, 2016
FILENAME: T:\Projects\2010\10-1111-0211 (AECOM, Mississauga)\-SA- Trenchless Crossing\10111102115A007.dwg

MINISTRY OF TRANSPORTATION, ONTARIO

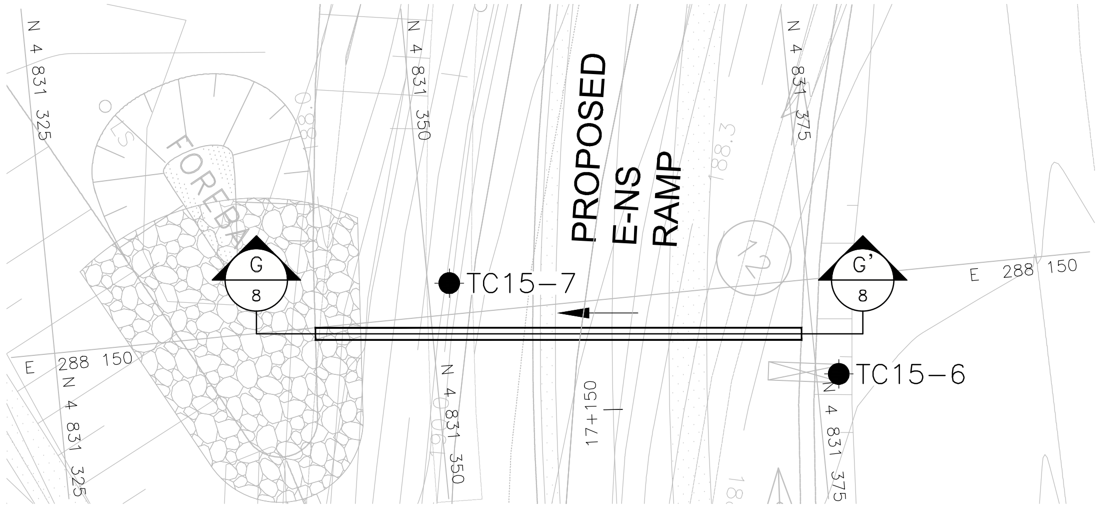
METRIC
DIMENSIONS ARE IN METRES AND/OR MILLIMETRES UNLESS OTHERWISE SHOWN. STATIONS IN KILOMETRES + METRES.

CONT No.
GWP No. 2150-01-00

HIGHWAY 401
CULVERT NO. 12
BOREHOLE LOCATIONS AND SOIL STRATA

SHEET

Golder Associates



PLAN
SCALE
5 0 5 10 m

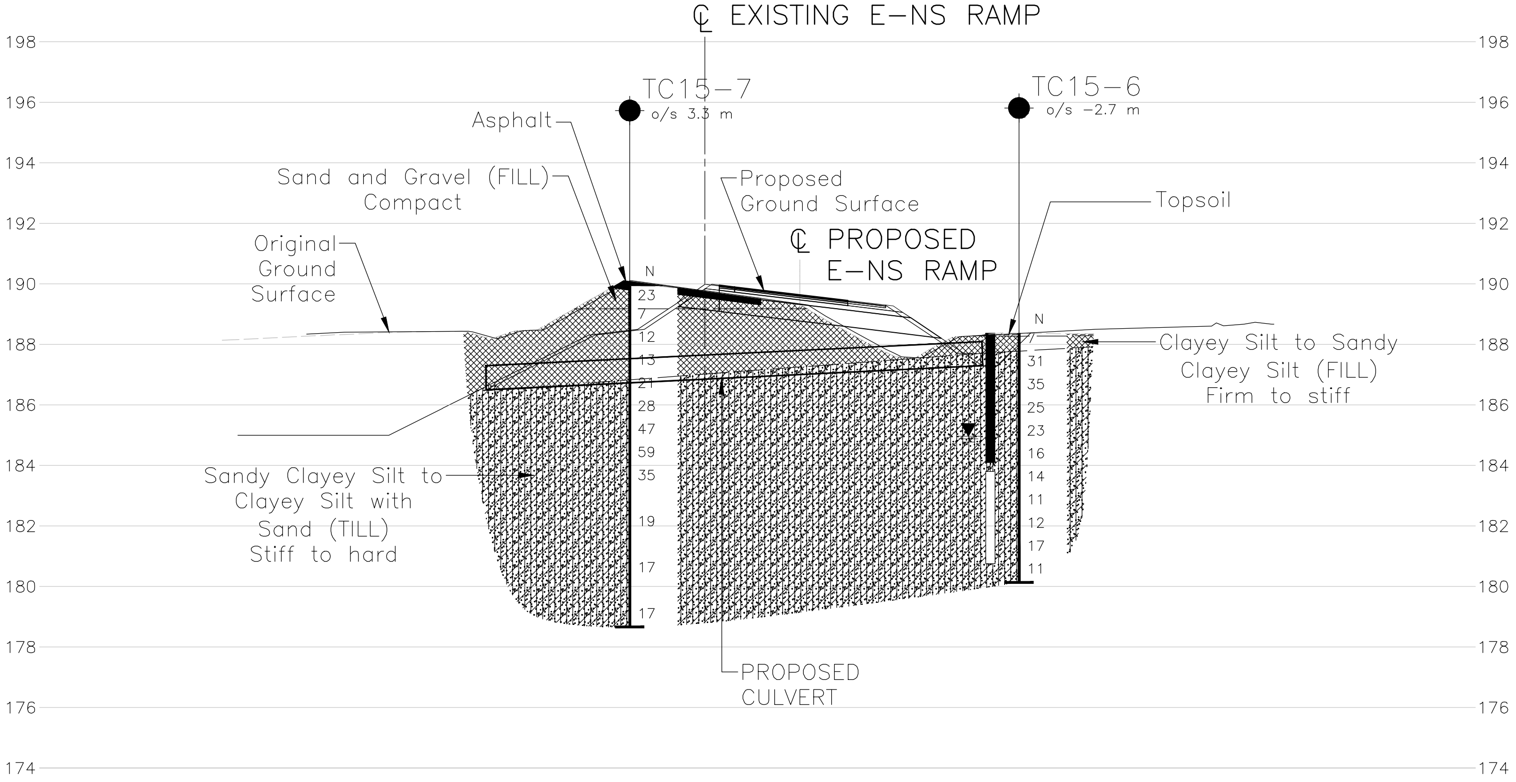
KEY PLAN
SCALE
5 0 5 10 m

LEGEND

●	Borehole – Current Investigation
▮	Seal
▯	Piezometer
N	Standard Penetration Test Value
16	Blows/0.3m unless otherwise stated (Std. Pen. Test, 475 j/blow)
▼	WL in piezometer, measured on Dec. 16, 2015

BOREHOLE CO-ORDINATES

No.	ELEVATION	NORTHING	EASTING
TC15-6	188.4	4831376.5	288156.4
TC15-7	189.9	4831351.4	288147.9



G-G
8
CULVERT No. 12 PROFILE
STATION 17+145

VERTICAL SCALE
2.5 0 2.5 5 m
HORIZONTAL SCALE
5 0 5 10 m

NOTES

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REFERENCE

Base plans provided in digital format by AECOM, drawing file nos.
X-60213979-C-BA-HWY401_MAVIS.dwg,
X-60213979-C-DE-HWY401_MAVIS_Add1.dwg and
60213979_CT-SMP-MAVIS401-LT-2.dwg received December 1, 2015 and
10cmContours.dwg, received December 21, 2015 and
X-60213979-C-DE-HWY401_MAVIS_Add4.dwg, 2016-01-19-Updated
culvert sections-60213979.dwg, received January 19, 2015.

J.M.A. COSTA
Feb. 11, 2016

K. J. BENTLEY
Feb. 11, 2016

NO.	DATE	BY	REVISION
.	.	.	.

Geocres No. 30M12-394

HWY. 401		PROJECT NO. 10-1111-0211	DIST.
SUBM'D. AJS	CHKD. AJS	DATE: Jan. 2016	SITE:
DRAWN: JFC	CHKD. KJB	APPD. JMAC	DWG. 8

PLOT DATE: February 11, 2016
FILENAME: T:\Projects\2010\10-1111-0211 (AECOM, Mississauga)\-5A- Trenchless Crossing\1011110211SA008.dwg

LIST OF SYMBOLS

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

I. GENERAL

π	3.1416
ln x,	natural logarithm of x
$\log_{10}$	x or log x, logarithm of x to base 10
g	acceleration due to gravity
t	time
FoS	factor of safety

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
υ	Poisson's ratio
σ	total stress
σ'	effective stress ($\sigma' = \sigma - u$)
σ'_{vo}	initial effective overburden stress
σ_1, σ_2, σ_3	principal stress (major, intermediate, minor)
σ_{oct}	mean stress or octahedral stress $= (\sigma_1 + \sigma_2 + \sigma_3)/3$
τ	shear stress
u	porewater pressure
E	modulus of deformation
G	shear modulus of deformation
K	bulk modulus of compressibility

III. SOIL PROPERTIES

(a) Index Properties

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

(a) Index Properties (continued)

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

(b) Hydraulic Properties

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

(c) Consolidation (one-dimensional)

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

(d) Shear Strength

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

Notes:
1 $\tau = c' + \sigma' \tan \phi'$
2 shear strength = (compressive strength)/2

---

* Density symbol is ρ. Unit weight symbol is γ where $\gamma = \rho g$ (i.e. mass density multiplied by acceleration due to gravity)

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
DS	Denison type sample
FS	Foil sample
RC	Rock core
SC	Soil core
SS	Split-spoon
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, 60º cone attached to “A” size drill rods for a distance of 300 mm (12 in.).

PH: Sampler advanced by hydraulic pressure
PM: Sampler advanced by manual pressure
WH: Sampler advanced by static weight of hammer
WR: Sampler advanced by weight of sampler and rod

Piezo-Cone Penetration Test (CPT)

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

III. SOIL DESCRIPTION

(a) Non-Cohesive (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.

V. MINOR SOIL CONSTITUENTS

Per cent by Weight	**Modifier**	**Example**
0 to 5	Trace	Trace sand
5 to 12	Trace to Some (or Little)	Trace to some sand
12 to 20	Some	Some sand
20 to 30	(ey) or (y)	Sandy
over 30	And (non-cohesive (cohesionless)) or	Sand and Gravel
	With (cohesive)	Silty Clay with sand / Clayey Silt with sand

APPENDIX A

Borehole Records and Laboratory Test Results
Culvert No. 3, Station 16+790
BH-2014-8A, TC15-4
Figure A1 to Figure A4

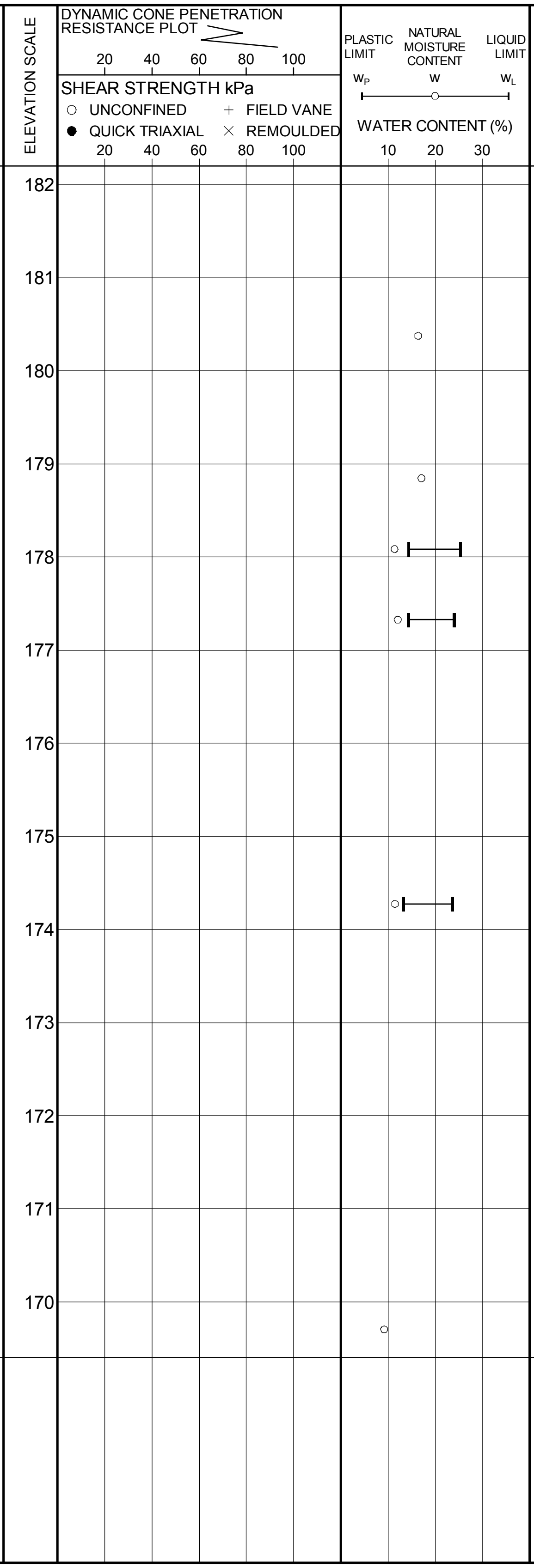
RECORD OF BOREHOLE No BH-2014-8A

SHEET 1 OF 1

METRIC

PROJECT 10-1111-0211
G.W.P. 2150-01-00
DIST Central HWY 401
DATUM GEODETIC
LOCATION N 4831083.8 ;E 287904.3
BOREHOLE TYPE 150 mm O.D. Solid Stem Augers
DATE Dec. 15, 2014
ORIGINATED BY AJS
COMPILED BY MP
CHECKED BY KJB

SOIL PROFILE		SAMPLES			GROUND WATER CONDITIONS	UNIT WEIGHT γ kN/m³	REMARKS & GRAIN SIZE DISTRIBUTION (%)			
ELEV DEPTH	DESCRIPTION	NUMBER	TYPE	"N" VALUES			GR	SA	SI	CL
182.2	GROUND SURFACE									
0.0	Silty sand and gravel, some asphalt fragments (FILL) Compact Brown Moist	1	SS	11						
181.5 0.7	SILTY CLAY, trace to some sand, trace to some gravel Firm to stiff Brown Moist	2	SS	7						
		3	SS	10						
180.0 2.2	CLAYEY SILT, some sand to CLAYEY SILT with SAND, trace to some gravel, pocket of sandy silt from 3.7 m to 5.2 m depth (TILL) Stiff to very stiff Brown becoming mottled brown and grey at about 3.7 m depth Moist	4	SS	10						
		5	SS	11						
		6	SS	29			3	35	44	18
		7	SS	24			9	43	32	16
		8	SS	12						
		9	SS	16						
		10	SS	17						
		11	SS	28						
		12	SS	27						
169.4 12.8	END OF BOREHOLE NOTE: 1. Open borehole dry upon completion of drilling.									



+3, ×3: Numbers refer to Sensitivity

○3% STRAIN AT FAILURE

RECORD OF BOREHOLE No TC15-4

SHEET 1 OF 1

METRIC

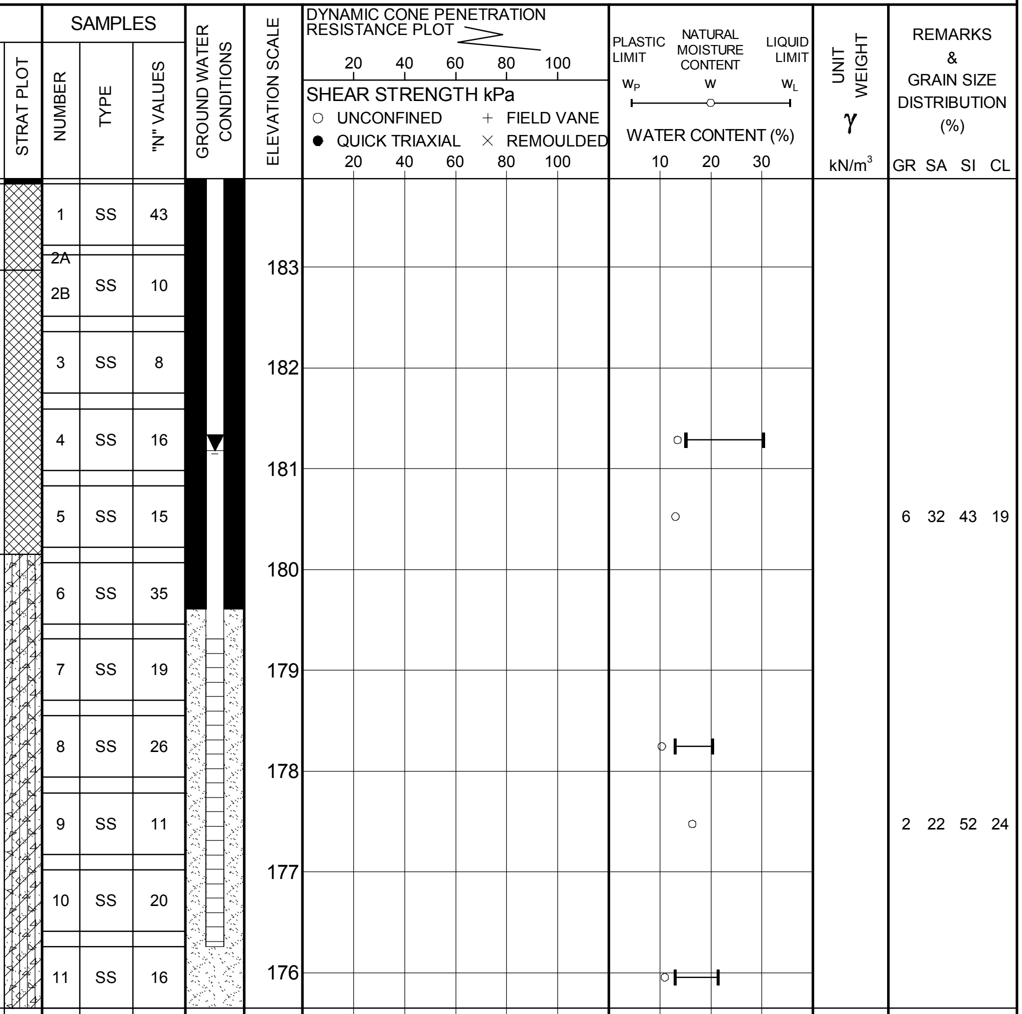
PROJECT 10-1111-0211			
G.W.P. 2150-01-00	LOCATION N 4831055.8 ;E 287900.1	ORIGINATED BY QC	
DIST Central HWY 401	BOREHOLE TYPE 150 mm O.D. Hollow Stem Augers	COMPILED BY AJS	
DATUM GEODETIC	DATE November 3, 2015	CHECKED BY KJB	

SOIL PROFILE

ELEV DEPTH	DESCRIPTION
183.9	GROUND SURFACE
0.0 0.1	ASPHALT
	Sand and gravel (FILL) Compact Brown Moist
183.0 0.9	Clayey silt with sand, trace to some gravel, contains silt pockets, oxidation staining (FILL) Stiff to very stiff Mottled brown Moist
180.2 3.7	Sandy CLAYEY SILT, trace to some gravel (TILL) Stiff to hard Brown to grey Moist
175.7 8.2	END OF BOREHOLE

SAMPLES

NUMBER	TYPE	"N" VALUES	GR	SA	SI	CL
1	SS	43				
2A 2B	SS	10				
3	SS	8				
4	SS	16				
5	SS	15	6	32	43	19
6	SS	35				
7	SS	19				
8	SS	26				
9	SS	11	2	22	52	24
10	SS	20				
11	SS	16				



NOTES:

1. Borehole dry upon completion of drilling.

2. Water level measured in piezometer:

Date	Depth (m)	Elev. (m)
11/19/15	2.6	181.3
12/16/15	2.7	181.2

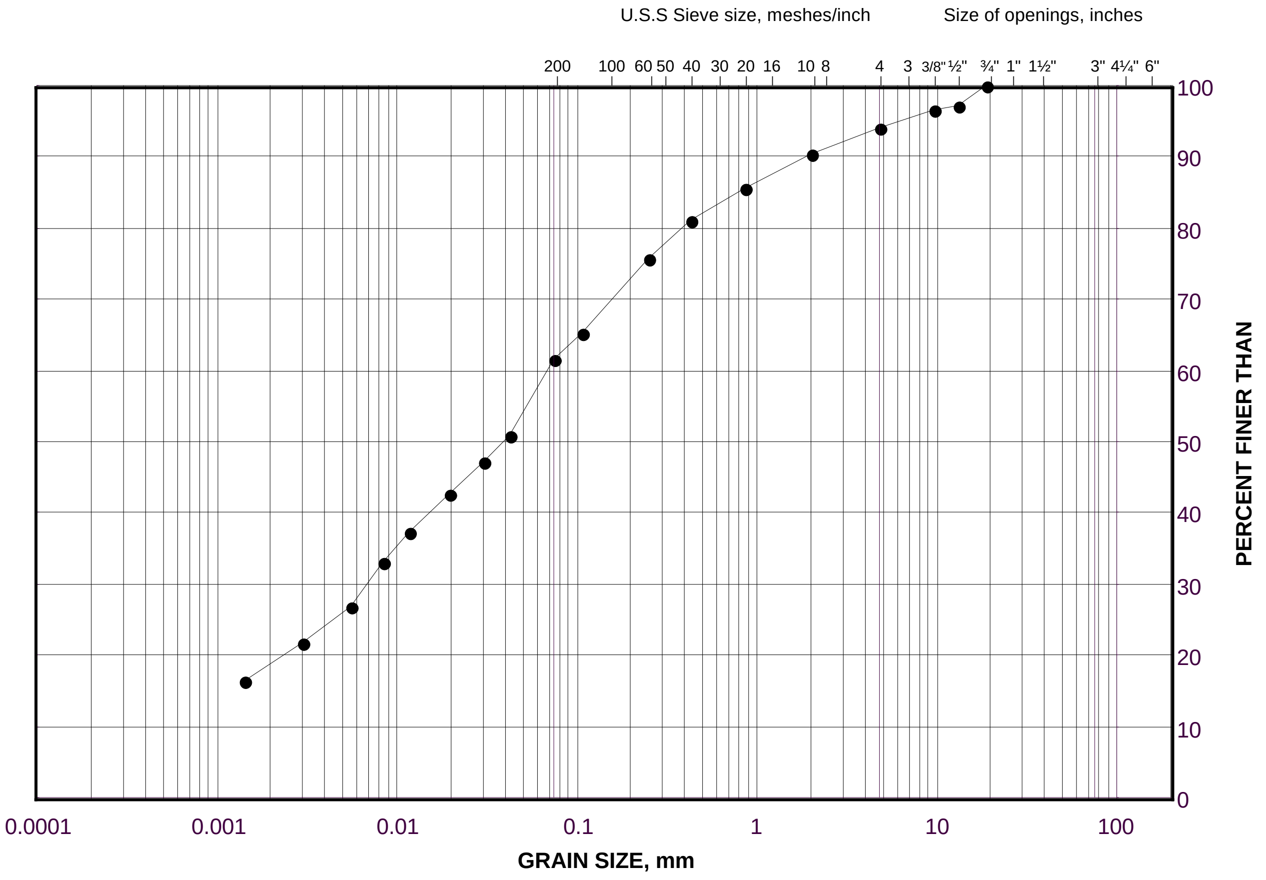
$+^3, \times^3$: Numbers refer to Sensitivity

$\bigcirc^{3\%}$ STRAIN AT FAILURE

GRAIN SIZE DISTRIBUTION

Clayey Silt with Sand (Fill)

FIGURE A1



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

LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	TC15-4	5	180.6

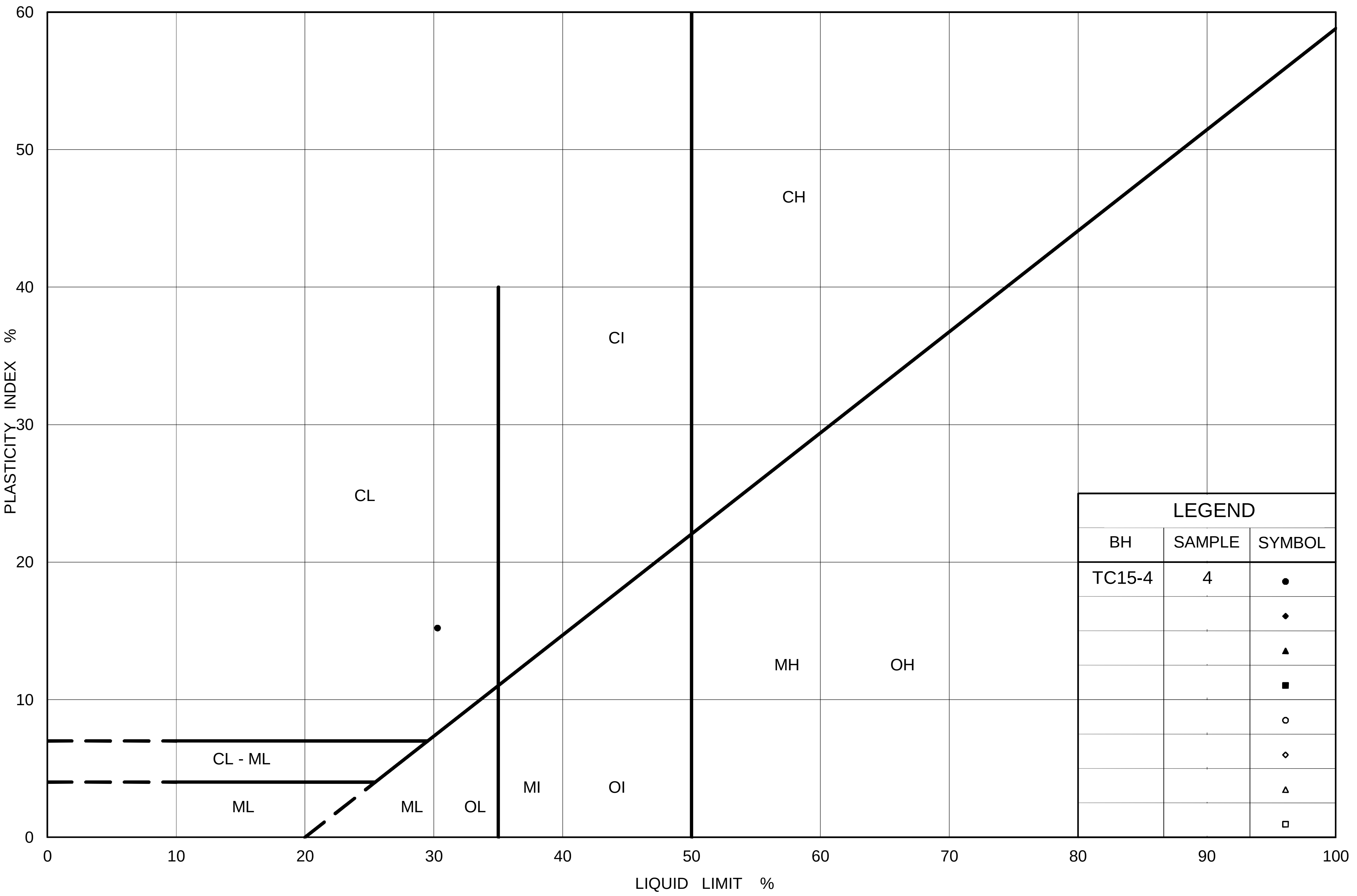
Project Number: 10-1111-0211

Checked By: KJB

Golder Associates

Date: 05-Jan-16

Oct 75, FF-S-21



Ministry of Transportation

Ontario

PLASTICITY CHART
Clayey Silt with Sand (Fill)

Figure No. A2

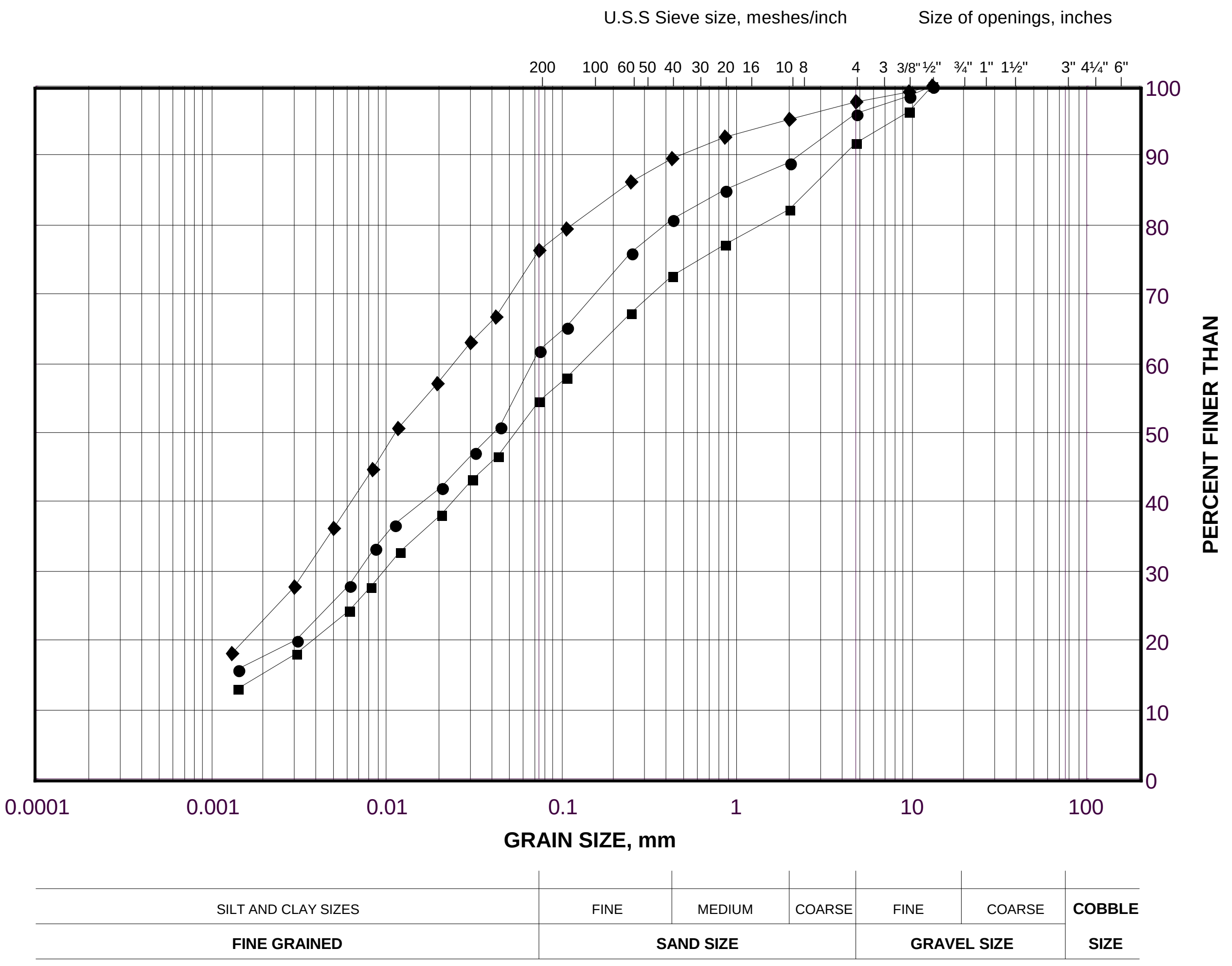
Project No. 10-1111-0211

Checked By: KJB

GRAIN SIZE DISTRIBUTION

Sandy Clayey Silt to Clayey Silt with Sand (Till)

FIGURE A3



LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	2014-8A	6	178.1
■	2014-8A	7	177.3
◆	TC15-4	9	177.6

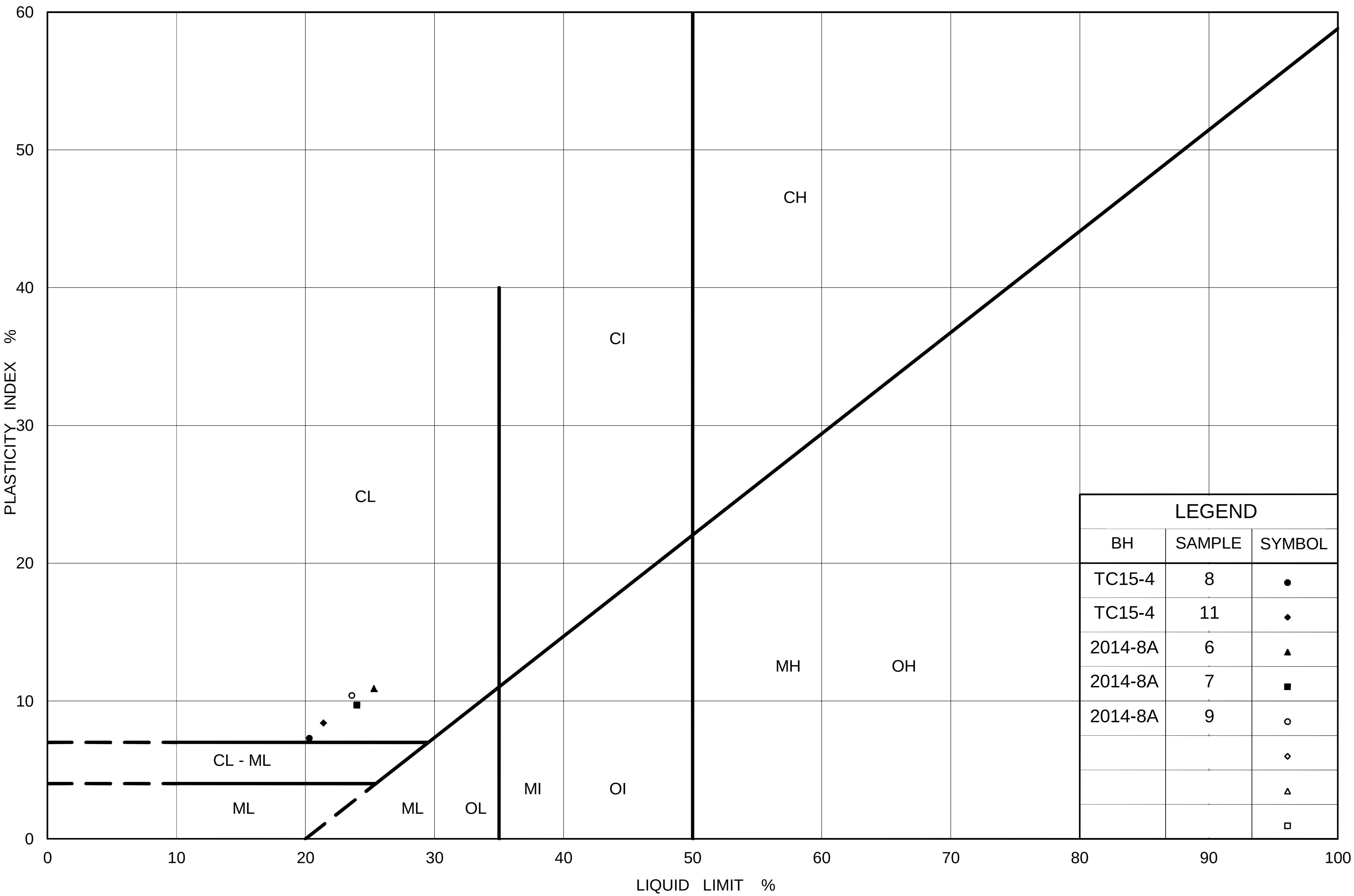
Project Number: 10-1111-0211

Checked By: KJB

Golder Associates

Date: 05-Jan-16

Oct 75, FF-S-21



LEGEND

BH	SAMPLE	SYMBOL
TC15-4	8	●
TC15-4	11	◆
2014-8A	6	▲
2014-8A	7	■
2014-8A	9	○
		◇
		△
		□

Ministry of Transportation

Ontario

PLASTICITY CHART
Sandy Clayey Silt to Clayey Silt with Sand (Till)

Figure No. A4

Project No. 10-1111-0211

Checked By: KJB

APPENDIX B

Borehole Records and Laboratory Test Results
Culvert No. 5, Station 11+274
BH-2014-9A, BH-2014-10A, MR-3, MR-3A, MR-4
Figure B1 to Figure B4-B

Golder Associates

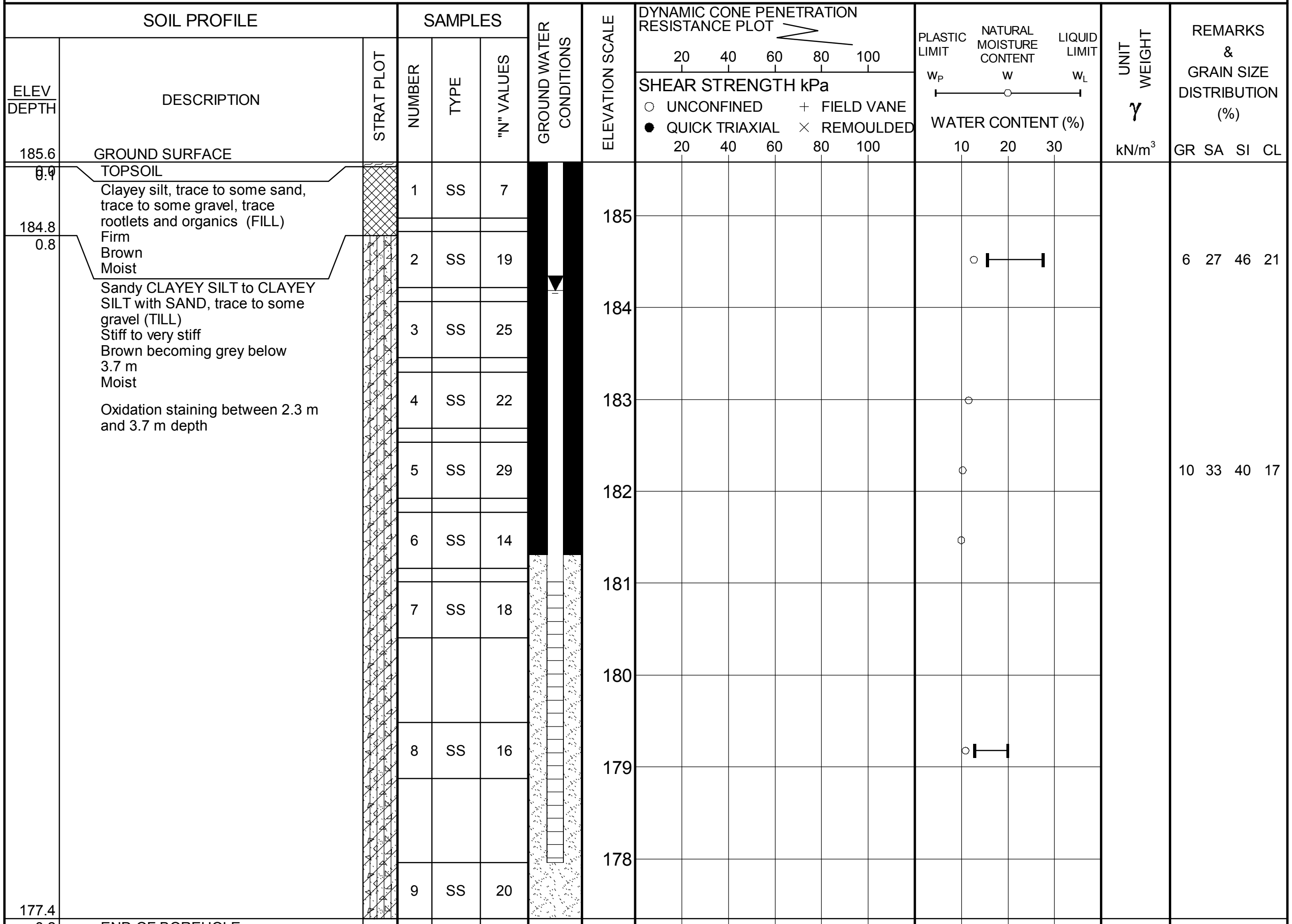
Foundation Design

RECORD OF BOREHOLE No BH-2014-9A

SHEET 1 OF 1

METRIC

PROJECT 10-1111-0211			
G.W.P. 2150-01-00	LOCATION N 4831109.3 ;E 288020.6		ORIGINATED BY QC
DIST Central HWY 401	BOREHOLE TYPE 150 mm O.D. Solid Stem Augers		COMPILED BY MP
DATUM GEODETIC	DATE Dec. 16, 2014		CHECKED BY KJB



ELEV DEPTH	DESCRIPTION
185.6	GROUND SURFACE
0.0	TOPSOIL
0.1	Clayey silt, trace to some sand, trace to some gravel, trace rootlets and organics (FILL) Firm Brown Moist
184.8 0.8	Sandy CLAYEY SILT to CLAYEY SILT with SAND, trace to some gravel (TILL) Stiff to very stiff Brown becoming grey below 3.7 m Moist Oxidation staining between 2.3 m and 3.7 m depth
177.4 8.2	END OF BOREHOLE

NUMBER	TYPE	"N" VALUES	GR	SA	SI	CL
1	SS	7				
2	SS	19	6	27	46	21
3	SS	25				
4	SS	22				
5	SS	29	10	33	40	17
6	SS	14				
7	SS	18				
8	SS	16				
9	SS	20				

REMARKS & GRAIN SIZE DISTRIBUTION (%)

NOTES:

1. Water level in open borehole measured at a depth of 7.2 m below ground surface (Elev. 178.4 m) upon completion of drilling.

2. Water level measured in piezometer:

Date	Depth (m)	Elev. (m)
06/30/15	0.8	184.8
12/16/15	1.4	184.2

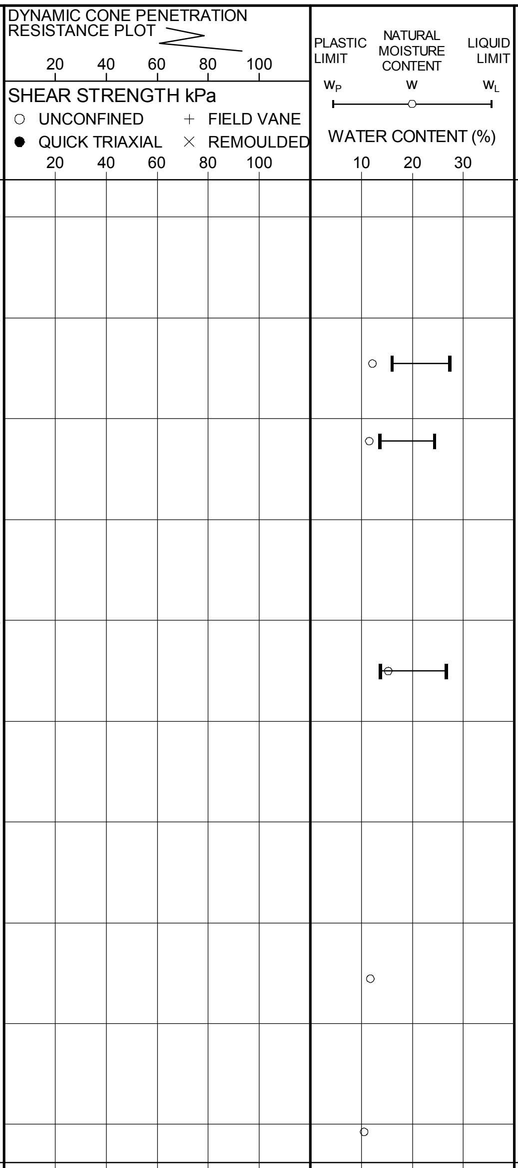
$+^3, \times^3$: Numbers refer to Sensitivity ○ $^{3\%}$ STRAIN AT FAILURE

Foundation Design

RECORD OF BOREHOLE No BH-2014-10A SHEET 1 OF 1 METRIC

PROJECT 10-1111-0211
G.W.P. 2150-01-00
LOCATION N 4831175.3 ;E 288132.5
ORIGINATED BY QC
DIST Central HWY 401
BOREHOLE TYPE 150 mm O.D. Solid Stem Augers
COMPILED BY MP
DATUM GEODETIC
DATE Dec. 15, 2014
CHECKED BY KJB

SOIL PROFILE		SAMPLES					REMARKS & GRAIN SIZE DISTRIBUTION (%)			
ELEV DEPTH	DESCRIPTION	NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	GR	SA	SI	CL
189.4	GROUND SURFACE									
0.0	Clayey silt, trace sand, trace gravel, trace rootlets and organics (FILL) Soft Black brown Moist	1	SS	4		189				
188.7 0.7	Sandy CLAYEY SILT to CLAYEY SILT with SAND, trace to some gravel (TILL) Stiff to hard Brown becoming grey below a depth of 6.1 m Moist	2	SS	25		188				
		3	SS	36						
		4	SS	23		187	5	30	43	22
		5	SS	25		186				
		6	SS	22		185				
	Oxidation staining from depth of 4.6 m to 5.2 m	7	SS	14			4	26	43	27
						184				
	Pockets of sandy silt from depth of 6.1 m to 6.7 m	8	SS	17		183				
						182				
		9	SS	17						
						181				
		10	SS	20	∇	180				
179.7 9.8	END OF BOREHOLE NOTE: 1. Water level in open borehole measured at a depth of 9.4 m below ground surface (Elev. 180.0 m) upon completion of drilling.									



UNIT WEIGHT γ kN/m³

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

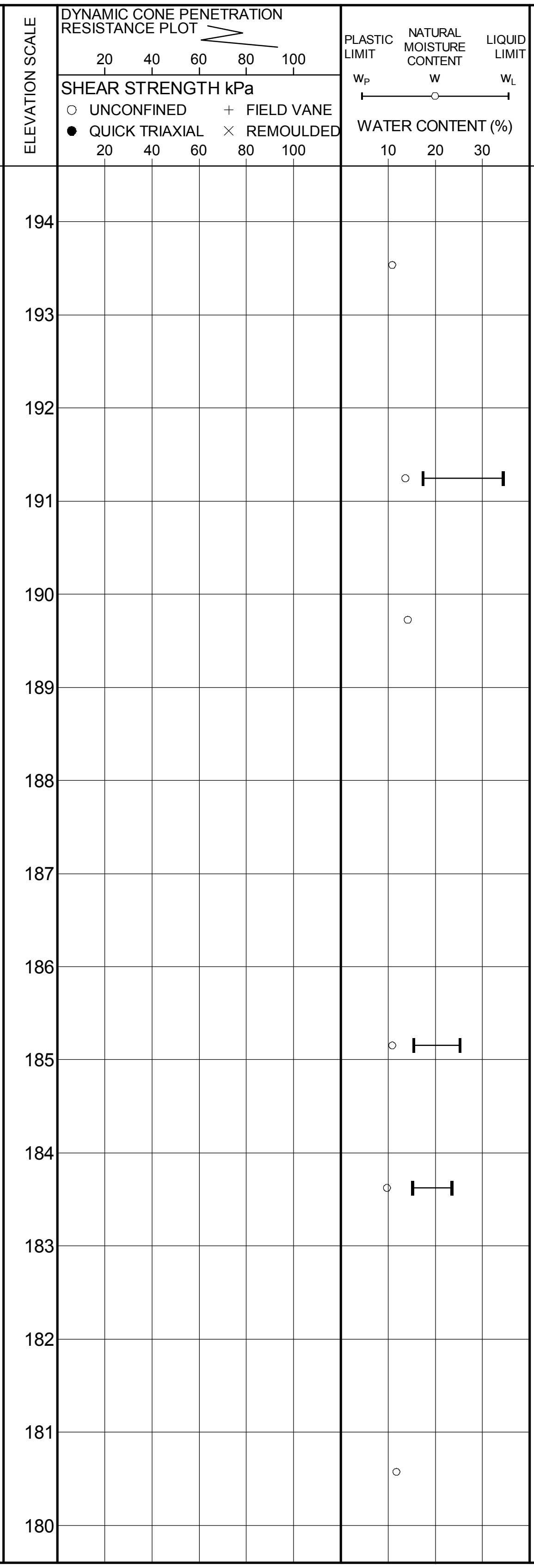
RECORD OF BOREHOLE No MR-3

SHEET 1 OF 2

METRIC

PROJECT 10-1111-0211
G.W.P. 2150-01-00
DIST Central HWY 401
DATUM GEODETIC
LOCATION N 4831172.8 ;E 288079.3
BOREHOLE TYPE 108 mm I.D. Hollow Stem Augers, NW Casing with Tricone
DATE May 29 to 30, 2012
ORIGINATED BY SB
COMPILED BY CC/TVA
CHECKED BY KJB

SOIL PROFILE		SAMPLES			REMARKS & GRAIN SIZE DISTRIBUTION (%)			
ELEV DEPTH	DESCRIPTION	NUMBER	TYPE	"N" VALUES	GR	SA	SI	CL
194.6	GROUND SURFACE							
0.0	TOPSOIL							
0.2	Clayey silt, some sand, trace to some gravel, containing rootlets, organics, asphalt and shale fragments to a depth of 6.7 m (FILL) Firm to hard Brown to grey Moist	1	SS	24				
		2	SS	5				
		3	SS	12				
		4	SS	8				
		5	SS	6				
	with gravel	6	SS	10				
		7	SS	11				
		8	SS	17				
		9	SS	29				
		10	SS	33				
184.2 10.4	CLAYEY SILT with SAND, trace to some gravel (TILL) Stiff to very stiff Grey Moist							
		11	SS	20	7	32	42	19
		12	SS	15				
		13	SS	14				



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$+^3, \times^3$: Numbers refer to Sensitivity

$\bigcirc^{3\%}$ STRAIN AT FAILURE

RECORD OF BOREHOLE No MR-3

SHEET 2 OF 2

METRIC

PROJECT 10-1111-0211

G.W.P. 2150-01-00

DIST Central HWY 401

DATUM GEODETIC

LOCATION N 4831172.8 ;E 288079.3

BOREHOLE TYPE 108 mm I.D. Hollow Stem Augers, NW Casing with Tricone

DATE May 29 to 30, 2012

ORIGINATED BY SB

COMPILED BY CC/TVA

CHECKED BY KJB

ELEV DEPTH	DESCRIPTION	NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT / SHEAR STRENGTH kPa	WATER CONTENT (%)	UNIT WEIGHT γ kN/m³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
	--- CONTINUED FROM PREVIOUS PAGE ---									
179.3		14	SS	50/0.06						
15.3	BOULDER Grey and black					179				
178.7 15.9	CLAYEY SILT with SAND, trace to some gravel (TILL) Very stiff Grey Wet					178				
		15	SS	16		177				
176.3 18.3	END OF BOREHOLE CASING REFUSAL									

NOTES:

1. Casing refusal on boulder at 15.3 m depth, cored through boulder using NQ size core barrel and continued sampling using NW Casing & Tricone.

2. Unable to advance borehole beyond a depth of 18.3 m due to casing refusal. Backfilled borehole, moved drilling 1.5 m north, and advanced Borehole MR-3A and continued sampling below 18.3 m depth.

3. Borehole dry (inside augers) at start of work day on May 30, 2012.

Legend: ○ UNCONFINED; + FIELD VANE; ● QUICK TRIAXIAL; × REMOULDED; PLASTIC LIMIT W_P; NATURAL MOISTURE CONTENT W; LIQUID LIMIT W_L

$+^3, \times^3$: Numbers refer to Sensitivity

$\bigcirc^{3\%}$ STRAIN AT FAILURE

RECORD OF BOREHOLE No MR-3A

SHEET 1 OF 3

METRIC

PROJECT 10-1111-0211
G.W.P. 2150-01-00
LOCATION N 4831173.9 ;E 288078.3
ORIGINATED BY SB
DIST Central HWY 401
BOREHOLE TYPE 108 mm I.D. Hollow Stem Augers
COMPILED BY CC/TVA
DATUM GEODETIC
DATE May 31 and June 4, 2012
CHECKED BY KJB

SOIL PROFILE			SAMPLES					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
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE				
194.6	GROUND SURFACE										
0.0	Refer to Record of Borehole MR-3 for subsurface conditions within these elevations.										
							194				
							193				
							192				
							191				
							190				
							189				
							188				
							187				
							186				
							185				
							184				
							183				
							182				
							181				
							180				

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Continued Next Page

$+^3$, $\times^3$: Numbers refer to Sensitivity

$\bigcirc^{3\%}$ STRAIN AT FAILURE

RECORD OF BOREHOLE No MR-3A

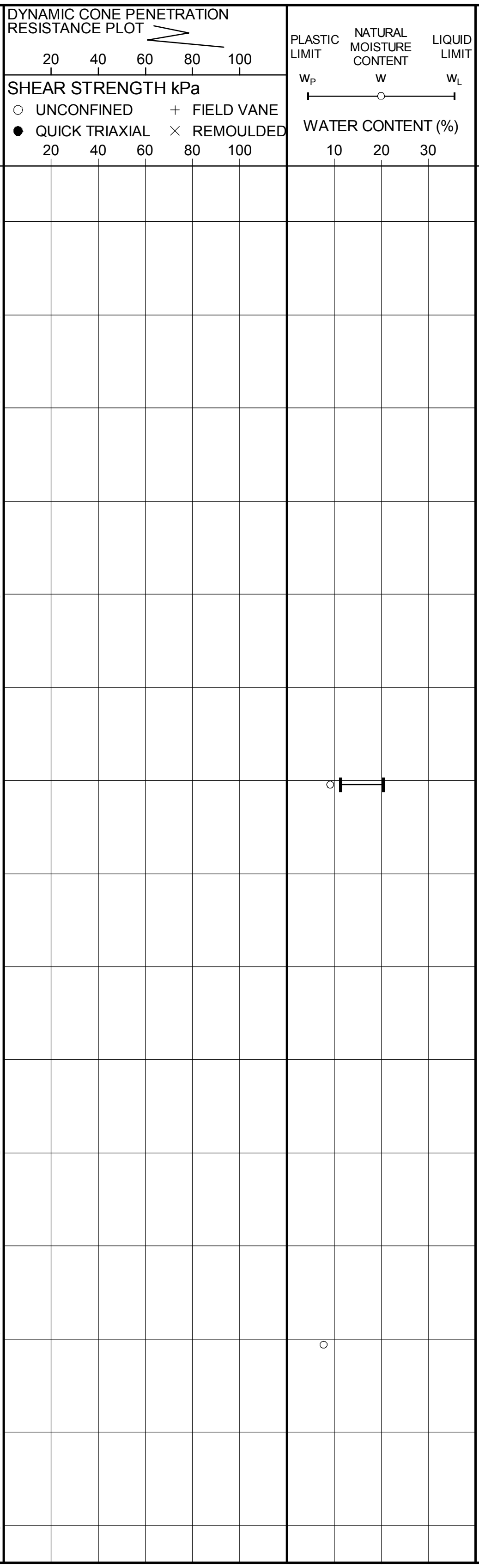
SHEET 2 OF 3

METRIC

PROJECT 10-1111-0211
G.W.P. 2150-01-00
LOCATION N 4831173.9 ;E 288078.3
ORIGINATED BY SB
DIST Central HWY 401
BOREHOLE TYPE 108 mm I.D. Hollow Stem Augers
COMPILED BY CC/TVA
DATUM GEODETIC
DATE May 31 and June 4, 2012
CHECKED BY KJB

--- CONTINUED FROM PREVIOUS PAGE ---

SOIL PROFILE			SAMPLES						REMARKS & GRAIN SIZE DISTRIBUTION (%)			
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	UNIT WEIGHT γ kN/m³	GR	SA	SI	CL
	Refer to Record of Borehole MR-3 for subsurface conditions within these elevations.						179					
							178					
							177					
176.3 18.3	CLAYEY SILT with SAND, trace to some gravel (TILL) Stiff to hard Grey Moist		16	SS	13		176					
							175					
			17	SS	29							
							174					
			18	SS	43		173		18	29	39	14
							172					
							171					
			19	SS	37		170					
							169					
							168					
			20	SS	93		167					
							166					
							165					



Continued Next Page

+3, ×3: Numbers refer to Sensitivity

○3% STRAIN AT FAILURE

PROJECT 10-1111-0211

RECORD OF BOREHOLE No MR-3A

SHEET 3 OF 3

METRIC

G.W.P. 2150-01-00

LOCATION N 4831173.9 ;E 288078.3

ORIGINATED BY SB

DIST Central HWY 401

BOREHOLE TYPE 108 mm I.D. Hollow Stem Augers

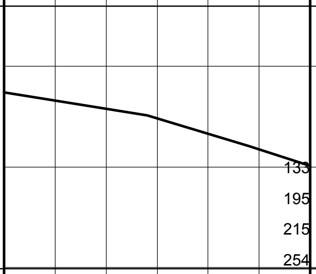
COMPILED BY CC/TVA

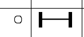
DATUM GEODETIC

DATE May 31 and June 4, 2012

CHECKED BY KJB

SOIL PROFILE			SAMPLES			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 (%)			
ELEV DEPTH	DESCRIPTION --- *CONTINUED FROM PREVIOUS PAGE* ---	STRAT PLOT	NUMBER	TYPE	"N" VALUES						GR	SA	SI	CL
163.7	CLAYEY SILT with SAND, trace to some gravel (TILL) Stiff to hard Grey Moist		21	SS	74		164				7	38	40	15
30.9 162.0	END OF BOREHOLE Dynamic Cone Penetration Test (DCPT)						163							
32.6	END OF DCPT Refusal to Further Penetration (254 Blows / 0.3 m) NOTE: 1. Groundwater conditions were not recorded upon completion of drilling, refer to Borehole MR-3.						162							





+3, ×3: Numbers refer to Sensitivity

○3% STRAIN AT FAILURE

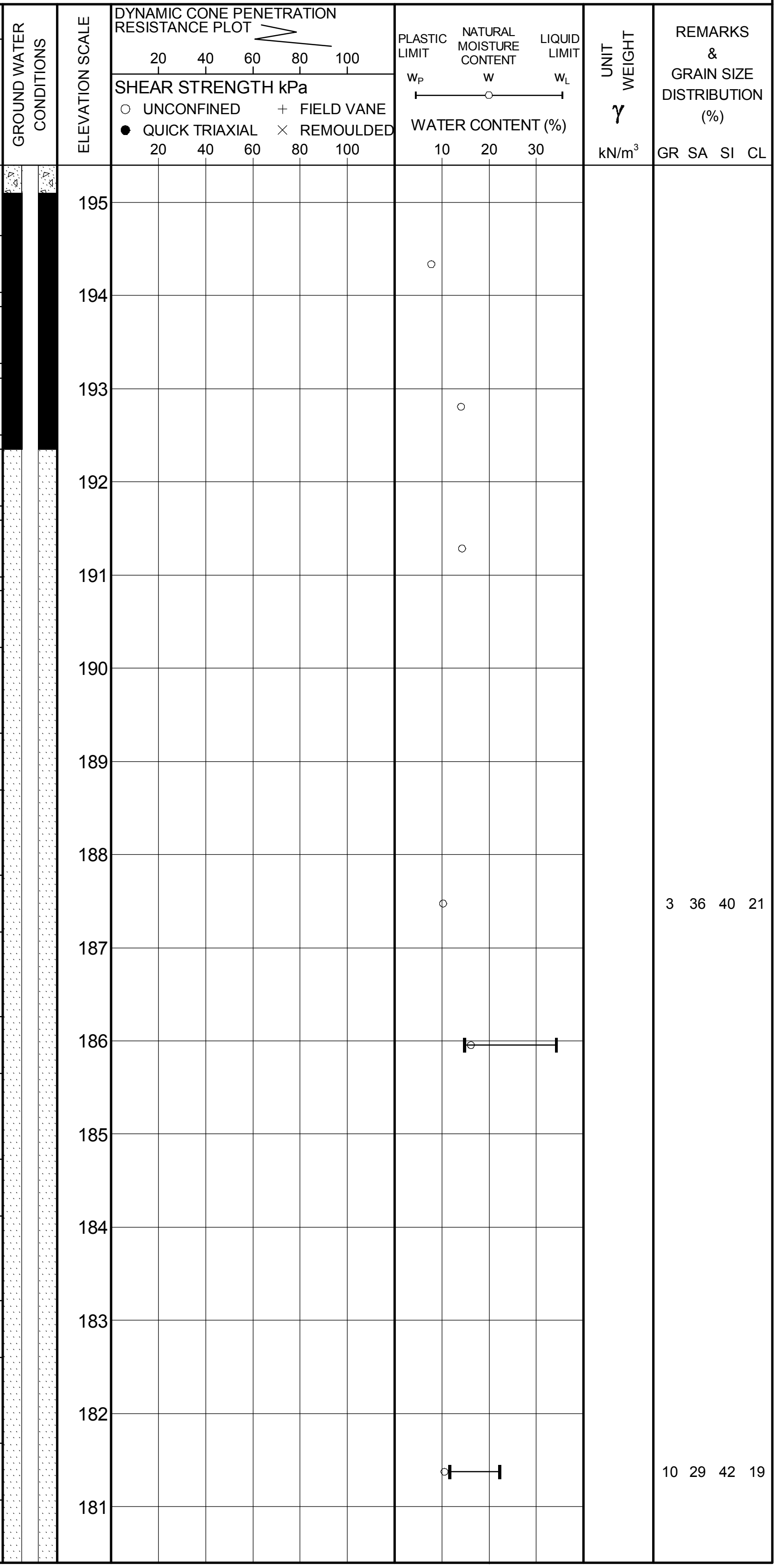
RECORD OF BOREHOLE No MR-4

SHEET 1 OF 3

METRIC

PROJECT 10-1111-0211			
G.W.P. 2150-01-00	LOCATION N 4831158.4 ;E 288051.0		ORIGINATED BY SB/CC
DIST Central HWY 401	BOREHOLE TYPE 108 mm I.D. Hollow Stem Augers		COMPILED BY CC/TVA
DATUM GEODETIC	DATE May 24 to 28, 2012		CHECKED BY KJB

ELEV DEPTH	DESCRIPTION	NUMBER	TYPE	"N" VALUES	GR	SA	SI	CL
195.4	GROUND SURFACE							
0.0	ASPHALT							
194.6 0.2	Sand and gravel, (FILL) Brown Moist							
0.8	Clayey silt, trace to some sand, trace gravel, containing wood fragments, (FILL) Stiff to hard Brown Moist	1	SS	11				
		2	SS	10				
		3	SS	10				
		4	SS	14				
		5	SS	14				
		6	SS	17				
	inferred cobbles	7	SS	80				
	with sand	8	SS	9	3	36	40	21
		9	SS	28				
		10	SS	36				
183.8 11.6	CLAYEY SILT with SAND, trace to some gravel, (TILL) Very stiff to hard Brown to grey Moist	11	SS	30				
		12	SS	22	10	29	42	19



Continued Next Page

+3, ×3: Numbers refer to Sensitivity

○3% STRAIN AT FAILURE

RECORD OF BOREHOLE No MR-4

SHEET 2 OF 3

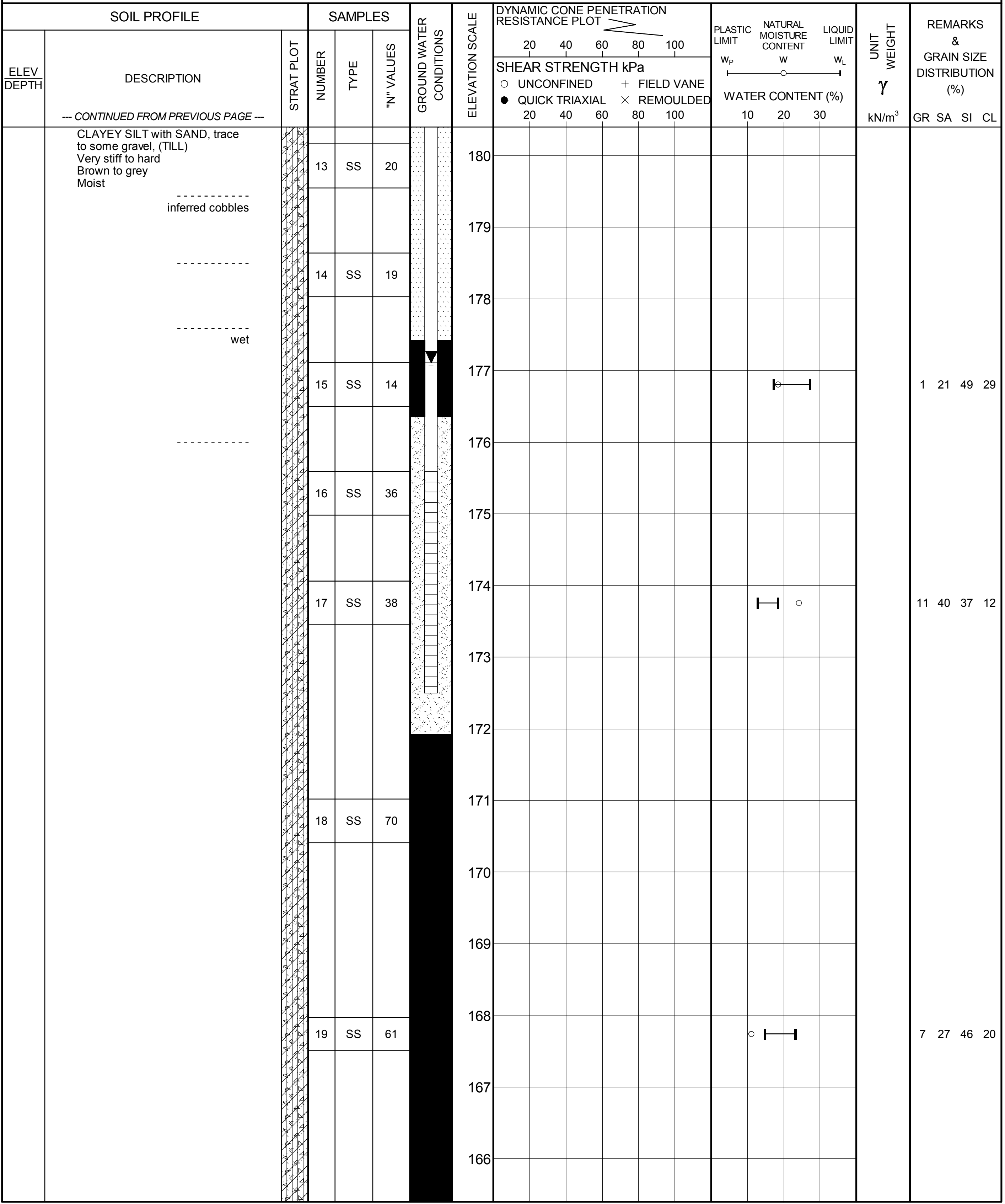
METRIC

PROJECT 10-1111-0211
G.W.P. 2150-01-00
DIST Central HWY 401
DATUM GEODETIC
LOCATION N 4831158.4 ;E 288051.0
BOREHOLE TYPE 108 mm I.D. Hollow Stem Augers
DATE May 24 to 28, 2012
ORIGINATED BY SB/CC
COMPILED BY CC/TVA
CHECKED BY KJB

--- CONTINUED FROM PREVIOUS PAGE ---

SOIL PROFILE

CLAYEY SILT with SAND, trace to some gravel, (TILL)
Very stiff to hard
Brown to grey
Moist
inferred cobbles
wet



NUMBER	TYPE	"N" VALUES	GR	SA	SI	CL
13	SS	20				
14	SS	19				
15	SS	14	1	21	49	29
16	SS	36				
17	SS	38	11	40	37	12
18	SS	70				
19	SS	61	7	27	46	20

Continued Next Page

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

RECORD OF BOREHOLE No MR-4

SHEET 3 OF 3

METRIC

PROJECT 10-1111-0211

G.W.P. 2150-01-00

DIST Central HWY 401

DATUM GEODETIC

LOCATION N 4831158.4 ;E 288051.0

BOREHOLE TYPE 108 mm I.D. Hollow Stem Augers

DATE May 24 to 28, 2012

ORIGINATED BY SB/CC

COMPILED BY CC/TVA

CHECKED BY KJB

SOIL PROFILE			SAMPLES			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
ELEV DEPTH	DESCRIPTION --- CONTINUED FROM PREVIOUS PAGE ---	STRAT PLOT	NUMBER	TYPE	"N" VALUES						
	CLAYEY SILT with SAND, trace to some gravel, (TILL) Very stiff to hard Brown to grey Moist						165				
164.3 31.1	- - - - - - - - - - - containing shale fragments		20	SS	63						
	END OF BOREHOLE										

NOTES:

1. Difficulties advancing auger was observed between depths of 15.2 m and 16.8 m (Elev. 180.2 m and 178.6 m) below ground surface.

2. Water level inside augers at a depth of 0.9 m below ground surface (Elev. 194.5 m), measured at start of work day on May 25, 2012.

3. Water level inside augers at a depth of 21.3 m below ground surface (Elev. 174.1 m) upon completion of sampling on May 28, 2012.

4. Piezometer installation consists of 50 mm diameter PVC pipe with a 3.0 m slotted screen.

Water Level Readings

Date	Depth (m)	Elev. (m)
05/28/12	18.3	177.1
05/30/12	18.6	176.8
08/10/12	18.4	177.0
10/09/12	18.4	177.0
11/05/12	18.3	177.1

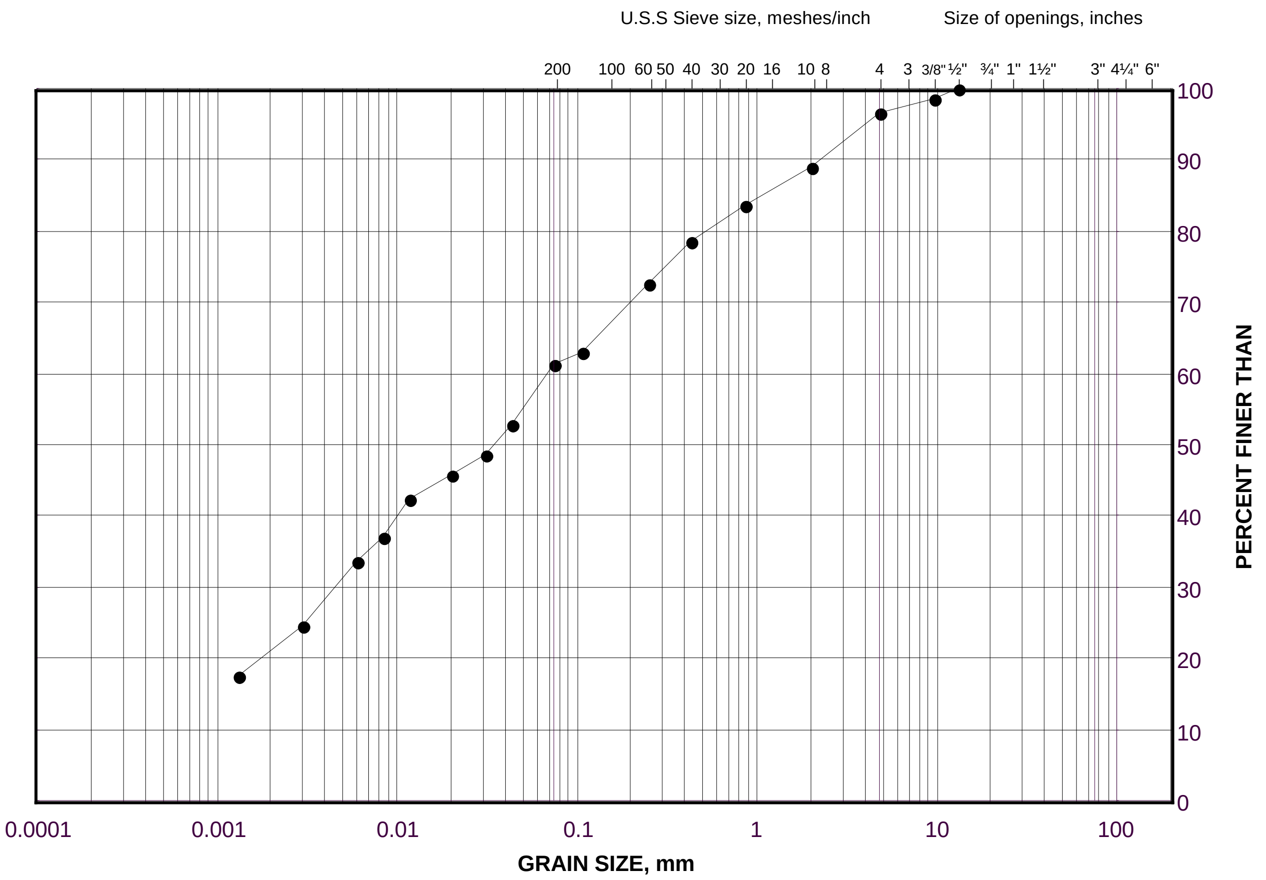
$+^3, \times^3$: Numbers refer to Sensitivity

$\bigcirc^{3\%}$ STRAIN AT FAILURE

GRAIN SIZE DISTRIBUTION

Clayey Silt with Sand (Fill)

FIGURE B1



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

LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	MR-4	8	187.5

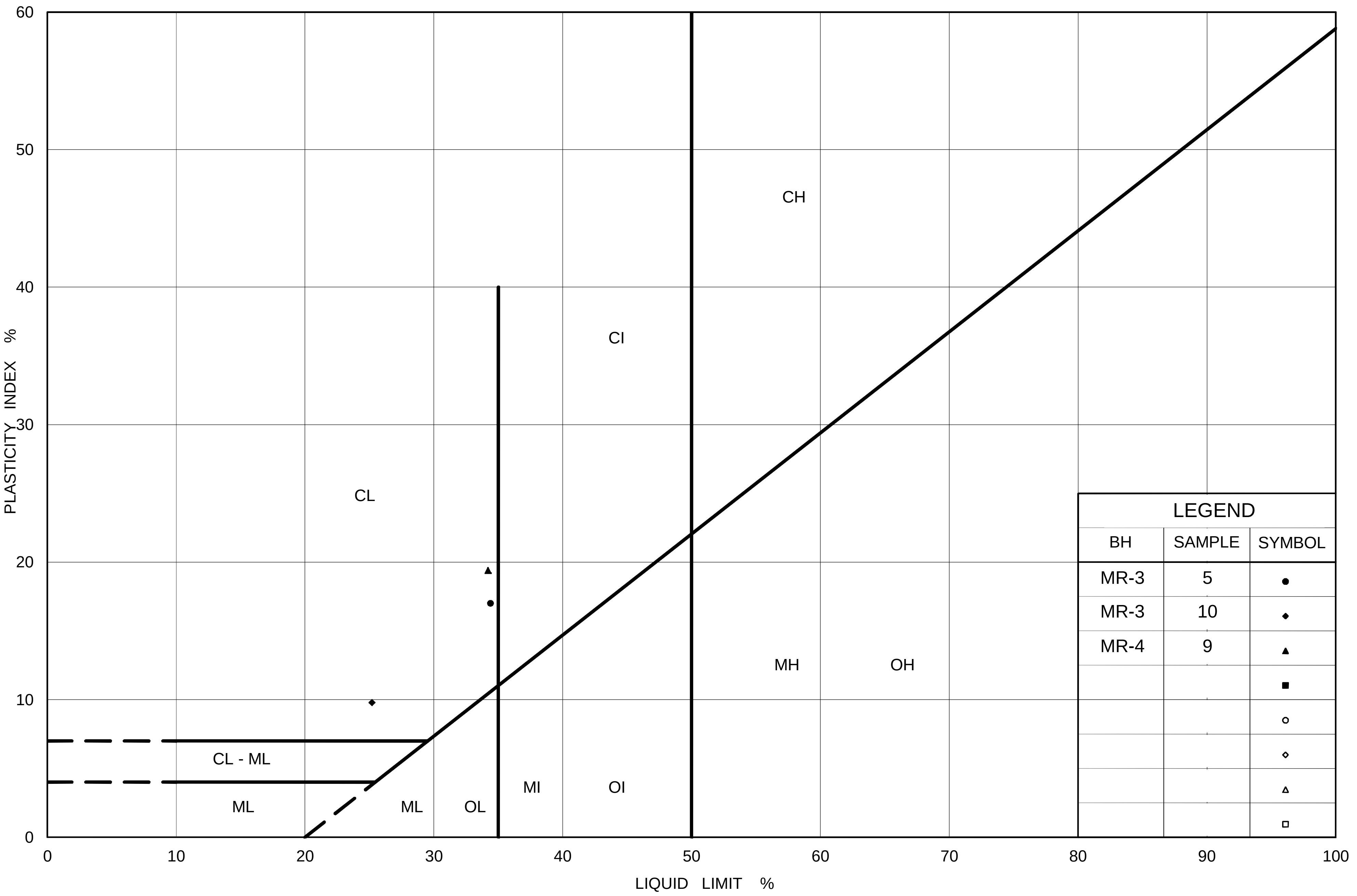
Project Number: 10-1111-0211

Checked By: KJB

Golder Associates

Date: 05-Jan-16

Oct 75, FF-S-21



LEGEND

BH	SAMPLE	SYMBOL
MR-3	5	●
MR-3	10	◆
MR-4	9	▲
		■
		○
		◇
		△
		□

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PLASTICITY CHART
Clayey Silt (Fill)

Figure No. B2

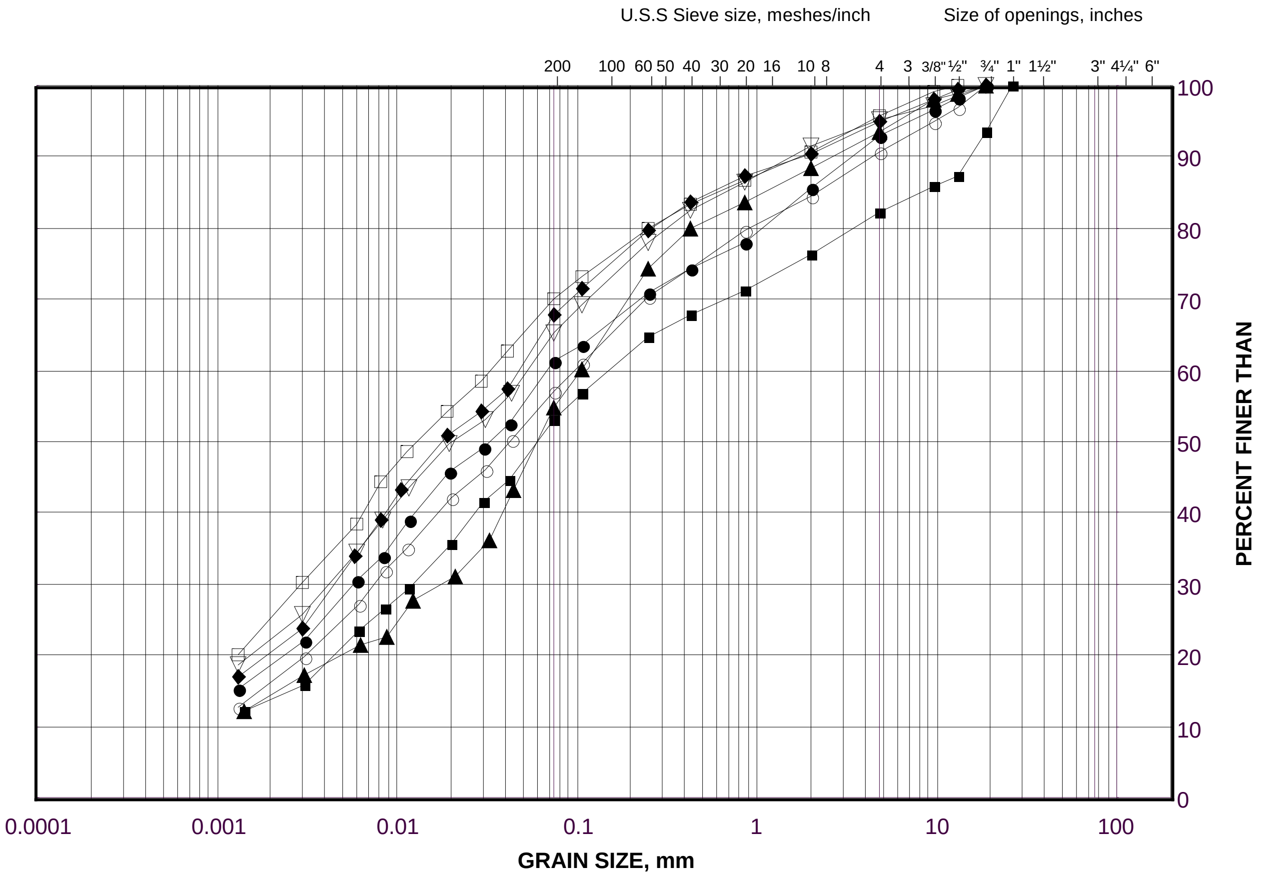
Project No. 10-1111-0211

Checked By: KJB

GRAIN SIZE DISTRIBUTION

Sandy Clayey Silt to Clayey Silt with Sand (Till)

FIGURE B3-A



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

LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	MR-3	11	183.6
■	MR-3A	18	172.9
◆	2014-9A	2	184.5
▲	MR-3A	21	163.8
▽	2014-10A	4	186.8
❍	2014-9A	5	182.2
□	2014-10A	7	184.6

Project Number: 10-1111-0211

Checked By: KJB

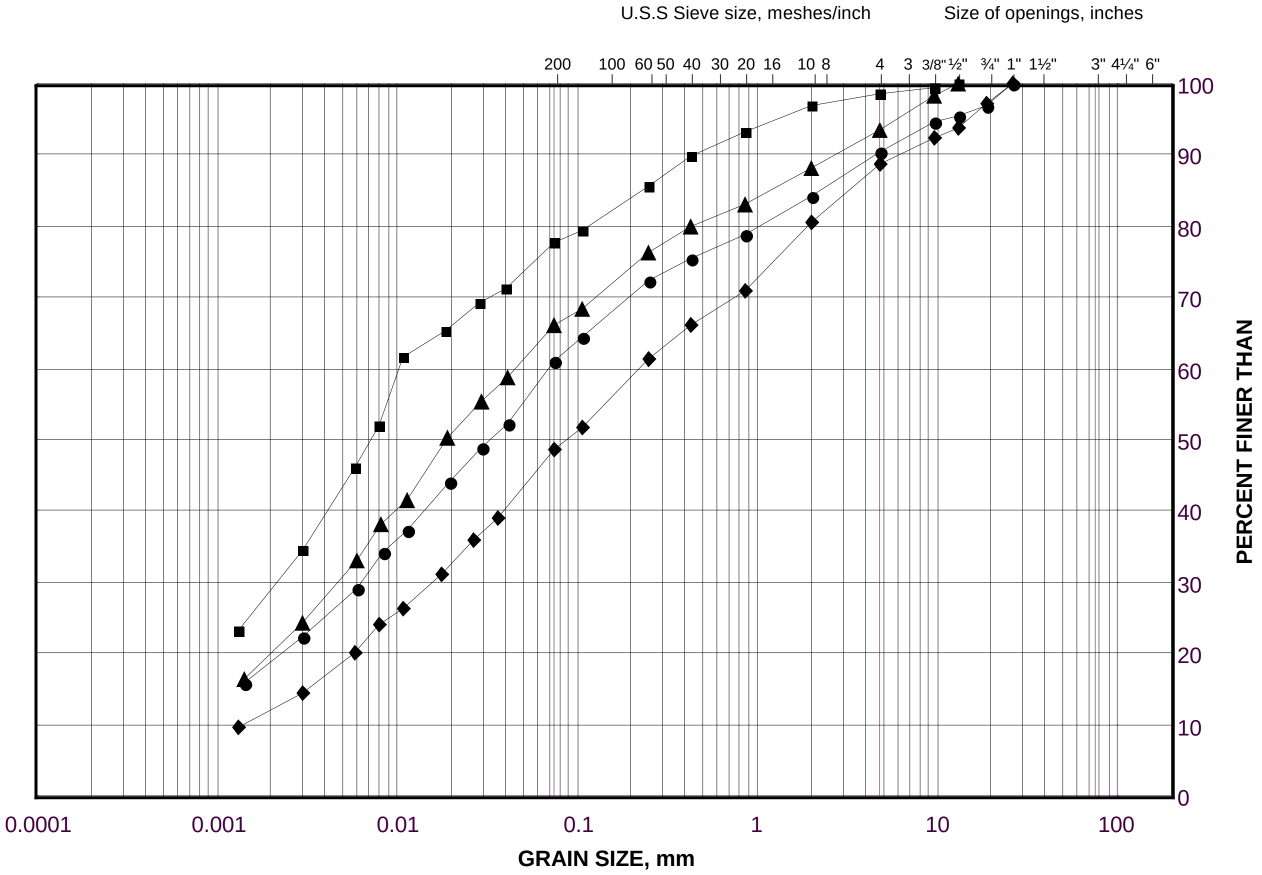
Golder Associates

Date: 05-Jan-16

GRAIN SIZE DISTRIBUTION

Sandy Clayey Silt to Clayey Silt with Sand (Till)

FIGURE B3-B



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

LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	MR-4	12	181.4
■	MR-4	15	176.8
◆	MR-4	17	173.7
▲	MR-4	19	167.7

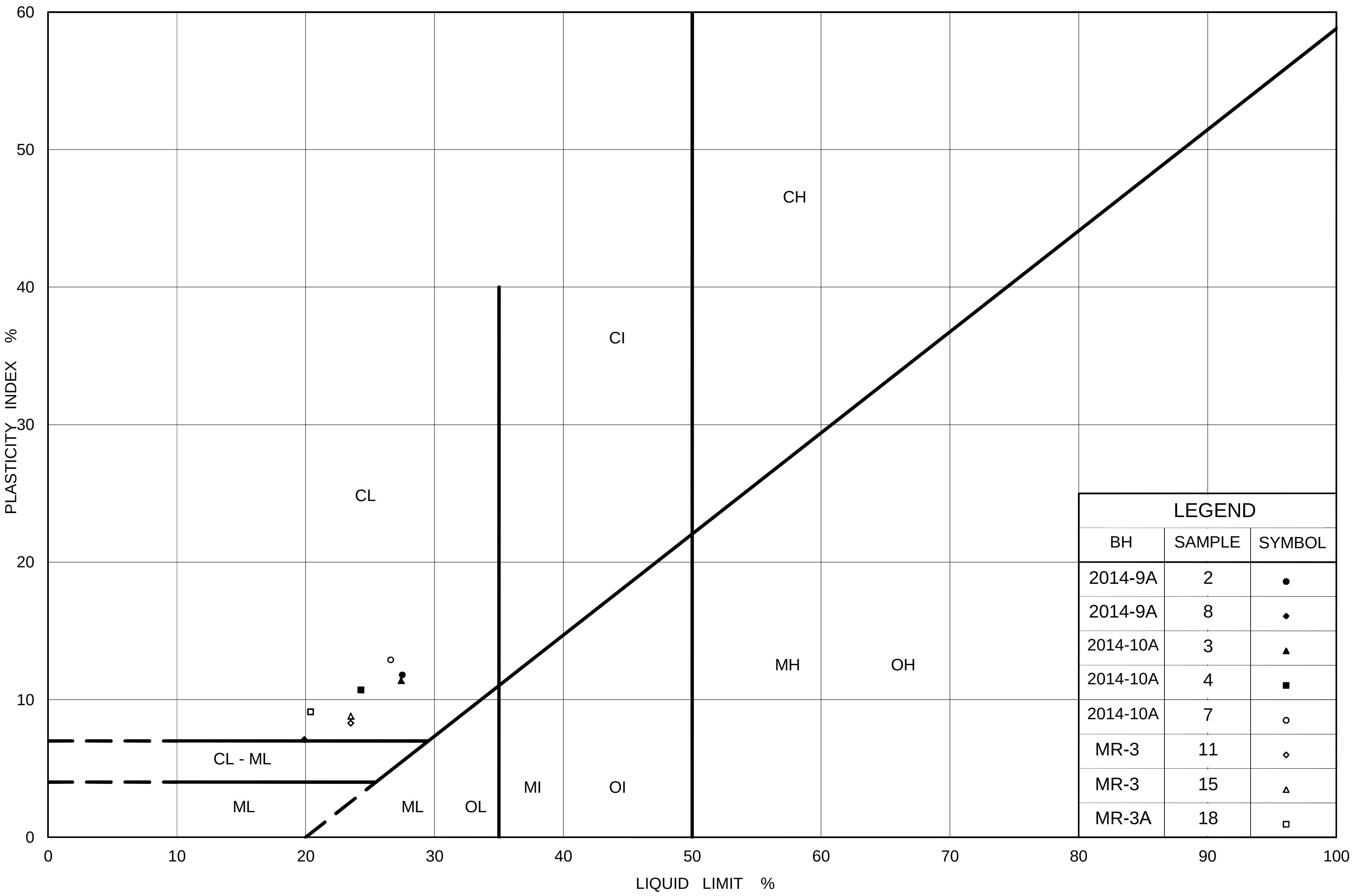
Project Number: 10-1111-0211

Checked By: KJB

Golder Associates

Date: 05-Jan-16

Oct 75, FF-S-21



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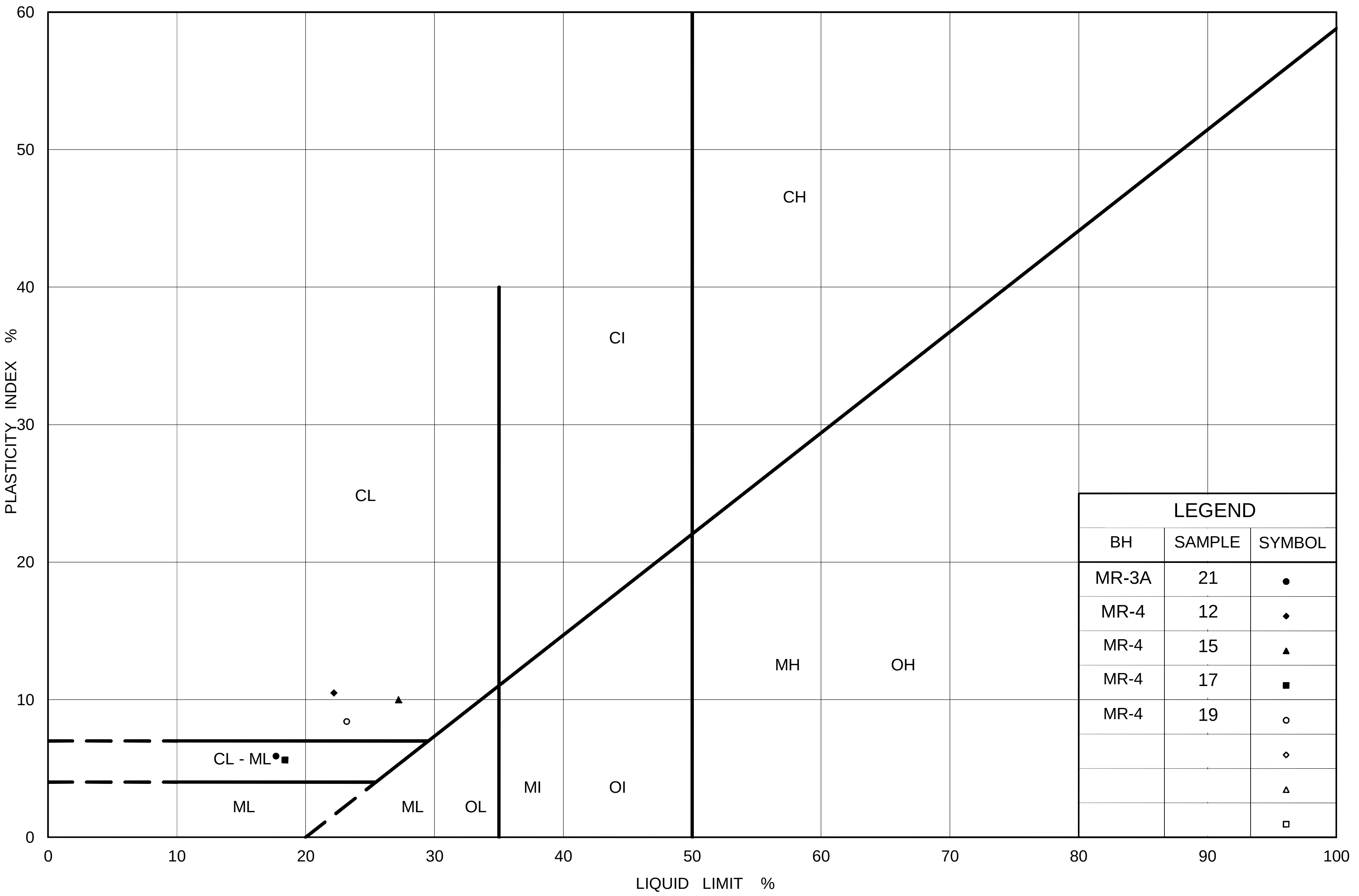
PLASTICITY CHART
Sandy Clayey Silt to Clayey Silt with Sand (Till)

Figure No. B4-A

Project No. 10-1111-0211

Checked By: KJB

Oct 75, FF-S-21



BH	SAMPLE	SYMBOL
MR-3A	21	●
MR-4	12	◆
MR-4	15	▲
MR-4	17	■
MR-4	19	○
		◇
		△
		□

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PLASTICITY CHART
Sandy Clayey Silt to Clayey Silt with Sand (Till)

Figure No. B4-B

Project No. 10-1111-0211

Checked By: KJB

APPENDIX C

Borehole Records and Laboratory Test Results
Culvert No. 6, Station 16+855
BH-2014-8A, TC15-2, 237-2, 237-4, 237-6
Figure C1 to Figure C4

Golder Associates

RECORD OF BOREHOLE No BH-2014-8A

SHEET 1 OF 1

METRIC

PROJECT 10-1111-0211
G.W.P. 2150-01-00
DIST Central HWY 401
DATUM GEODETIC

LOCATION N 4831083.8 ;E 287904.3
BOREHOLE TYPE 150 mm O.D. Solid Stem Augers
DATE Dec. 15, 2014

ORIGINATED BY AJS
COMPILED BY MP
CHECKED BY KJB

SOIL PROFILE

ELEV DEPTH	DESCRIPTION
182.2	GROUND SURFACE
0.0	Silty sand and gravel, some asphalt fragments (FILL) Compact Brown Moist
181.5 0.7	SILTY CLAY, trace to some sand, trace to some gravel Firm to stiff Brown Moist
180.0 2.2	CLAYEY SILT, some sand to CLAYEY SILT with SAND, trace to some gravel, pocket of sandy silt from 3.7 m to 5.2 m depth (TILL) Stiff to very stiff Brown becoming mottled brown and grey at about 3.7 m depth Moist
169.4 12.8	END OF BOREHOLE NOTE: 1. Open borehole dry upon completion of drilling.

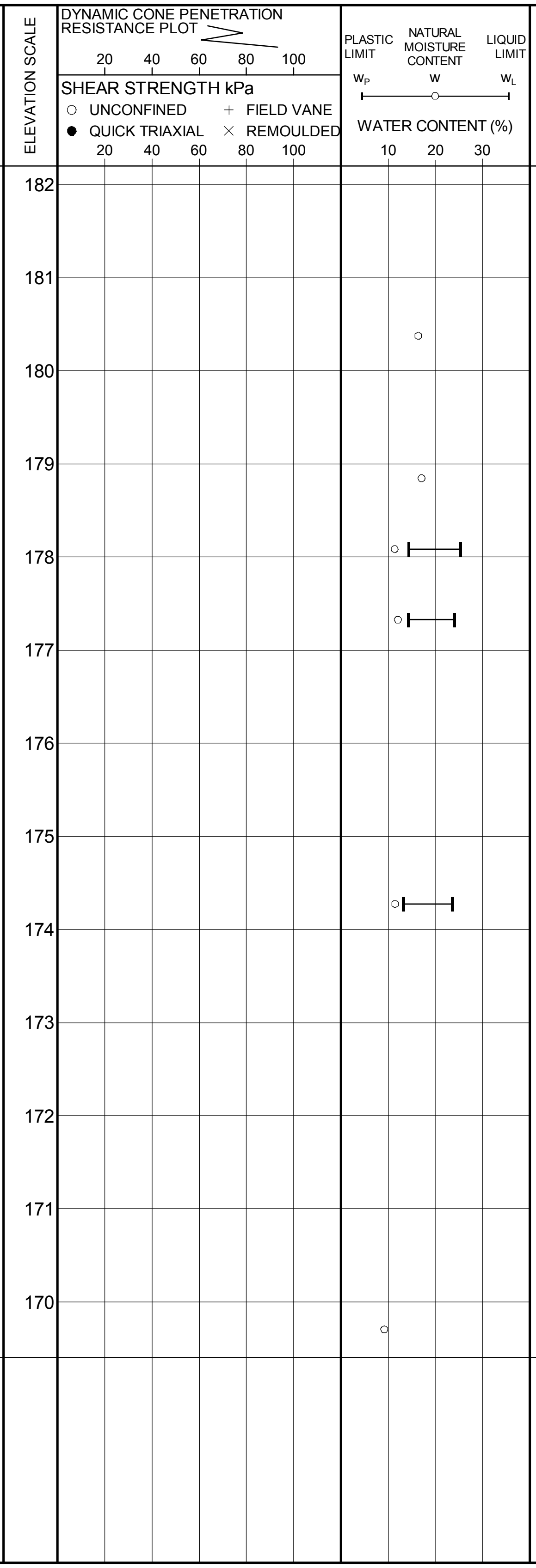
SAMPLES

NUMBER	TYPE	"N" VALUES	GR	SA	SI	CL
1	SS	11				
2	SS	7				
3	SS	10				
4	SS	10				
5	SS	11				
6	SS	29	3	35	44	18
7	SS	24	9	43	32	16
8	SS	12				
9	SS	16				
10	SS	17				
11	SS	28				
12	SS	27				

GROUND WATER CONDITIONS

UNIT WEIGHT γ kN/m³

REMARKS & GRAIN SIZE DISTRIBUTION (%)



+3, ×3: Numbers refer to Sensitivity

○3% STRAIN AT FAILURE

Golder Associates

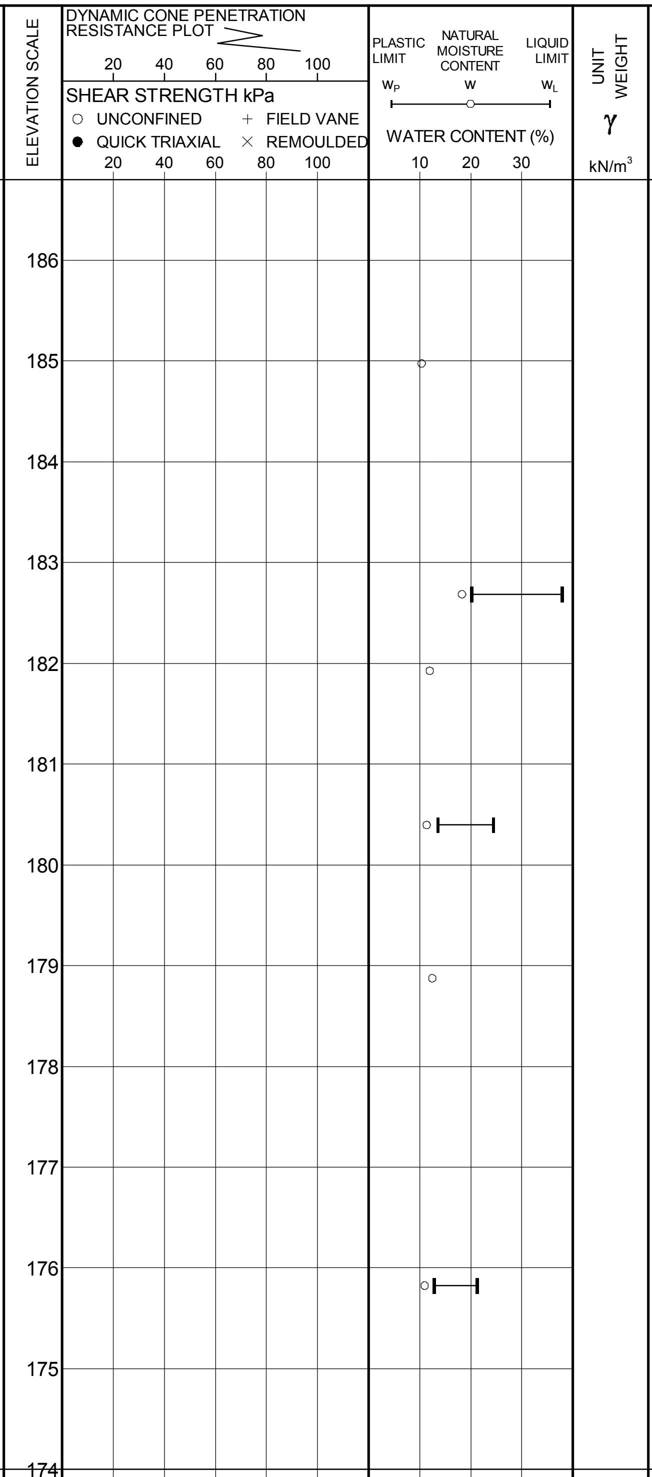
RECORD OF BOREHOLE No TC15-2

SHEET 1 OF 1

METRIC

PROJECT 10-1111-0211			
G.W.P. 2150-01-00	LOCATION N 4831179.8 ;E 287870.8		ORIGINATED BY QC
DIST Central	HWY 401	BOREHOLE TYPE 150 mm O.D. Hollow Stem Augers	COMPILED BY AJS
DATUM GEODETIC		DATE November 9, 2015	CHECKED BY KJB

ELEV DEPTH	SOIL PROFILE DESCRIPTION	SAMPLES NUMBER	TYPE	"N" VALUES	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR	SA	SI	CL
186.8	GROUND SURFACE							
0.0	Sandy silty clay to clayey silt with sand, trace to some gravel (FILL) Stiff to very stiff Mottled dark brown Moist							
		1	SS	15				
		2	SS	20	12	39	31	18
		3	SS	12				
		4	SS	13				
		5	SS	8	4	20	56	20
182.2 4.6	Sandy CLAYEY SILT, trace to some gravel, some silt and sand pockets (TILL) Stiff to very stiff Brown becoming grey below 7.2 m depth Moist	6	SS	16				
		7	SS	20				
	Oxidation staining between 7.6 m and 8.2 m depth	8	SS	20	10	25	48	17
		9	SS	10				
		10	SS	13				
174.0		11	SS	12				
12.8	END OF BOREHOLE NOTE: 1. Borehole dry upon completion of drilling.							



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

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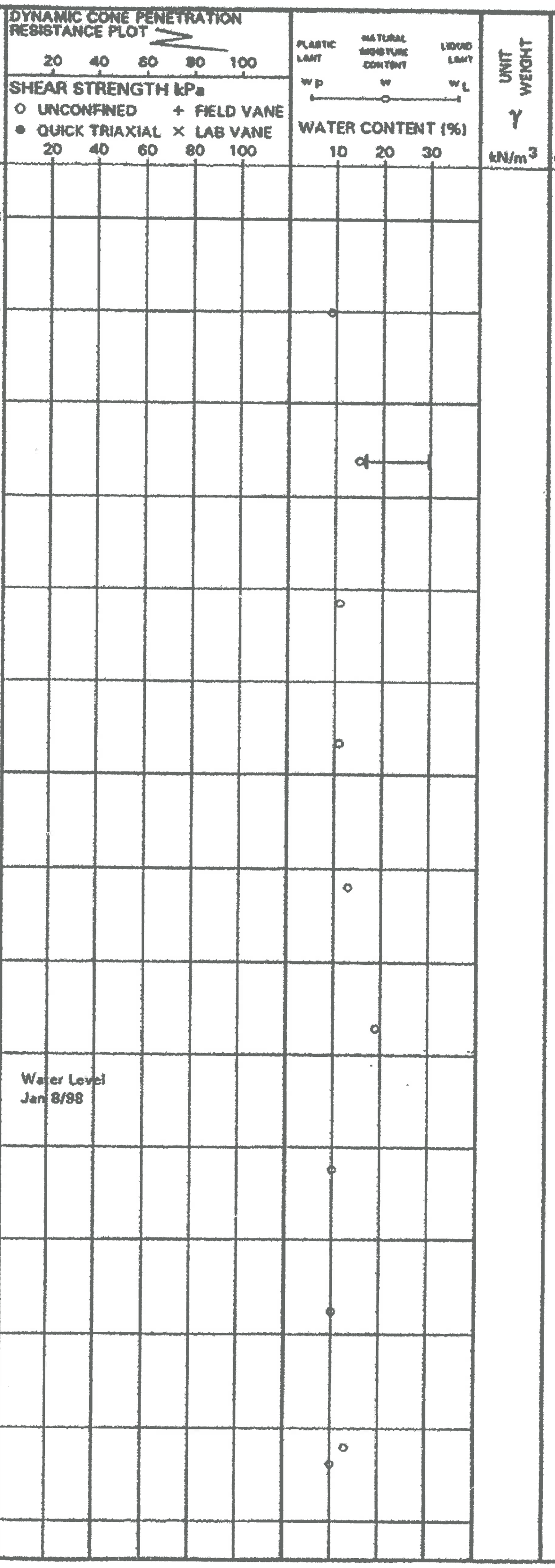
RECORD OF BOREHOLE No ~~97-2~~ 237-2 1 OF 2 METRIC

W.P. 311-89-00
DIST 6 HWY 401
DATUM Geodetic
LOCATION Co-ordinates 4 830 334.4 N; 604 208.7 E.
BOREHOLE TYPE 100mm diameter Solid Stem Auger
DATE 12.18.97 - 12.18.97
ORIGINATED BY TR
COMPILED BY JB
CHECKED BY IC

ELEV DEPTH	SOIL PROFILE DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	GR	SA	SI	CL
186.6	Ground Level									
0.0	Fill - mixture of shale fragments and silt Loose/Compact Grey					186				
		1	SS	50/ 5cm		185				
184.0 2.5	Silty Clay, some sand, trace of gravel (Till) Hard Brown/Grey					184				
		2	SS	41		183	3	18	37	42
182.5 4.1	Sandy Clayey Silt, traces of gravel (Till) Brown Grey Very Stiff to Hard					182				
		3	SS	36		181	4	30	40	26
		4	SS	24		180				
		5	SS	16		179				
178.0 8.6	Silty Clay, some sand, traces of gravel Very Stiff Grey				∇	178				
		6	SS	19	▼	177				
176.5 10.1	Sandy Clayey Silt, (T.11) traces of gravel Very Stiff to Hard Grey					176				
		7	SS	48		175				
		8	SS	27		174				
		9	SS	85/ 25cm		173				
						172				



REMARKS & GRAIN SIZE DISTRIBUTION (%)

Continued Next Page

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

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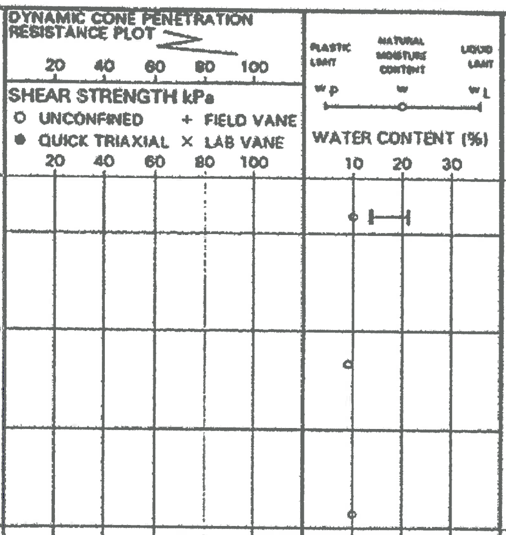
RECORD OF BOREHOLE No ~~97-2~~ 237-2 2 OF 2 METRIC

W.P. 311-89-00
LOCATION Co-ordinates 4 830 334.4 N; 604 208.7 E.
ORIGINATED BY TR
DIST 6 HWY 401
BOREHOLE TYPE 100mm diameter Solid Stem Auger
COMPILED BY JB
DATUM Geodetic
DATE 12.18.97 - 12.18.97
CHECKED BY IC

SOIL PROFILE			SAMPLES								REMARKS & GRAIN SIZE DISTRIBUTION (%)			
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT / SHEAR STRENGTH kPa	WATER CONTENT (%)	UNIT WEIGHT γ kN/m³	GR	SA	SI	CL
	Sandy Clayey Silt, (T.11) traces of gravel		10	SS	81/ 30cm		171				11	32	35	22
	Hard Grey						170							
			11	SS	85/ 28cm		169							
168.0 18.6			12	SS	79/ 28cm		168							
	End of Borehole													



Groundwater measured at 8.53m below ground surface upon completion of drilling.

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

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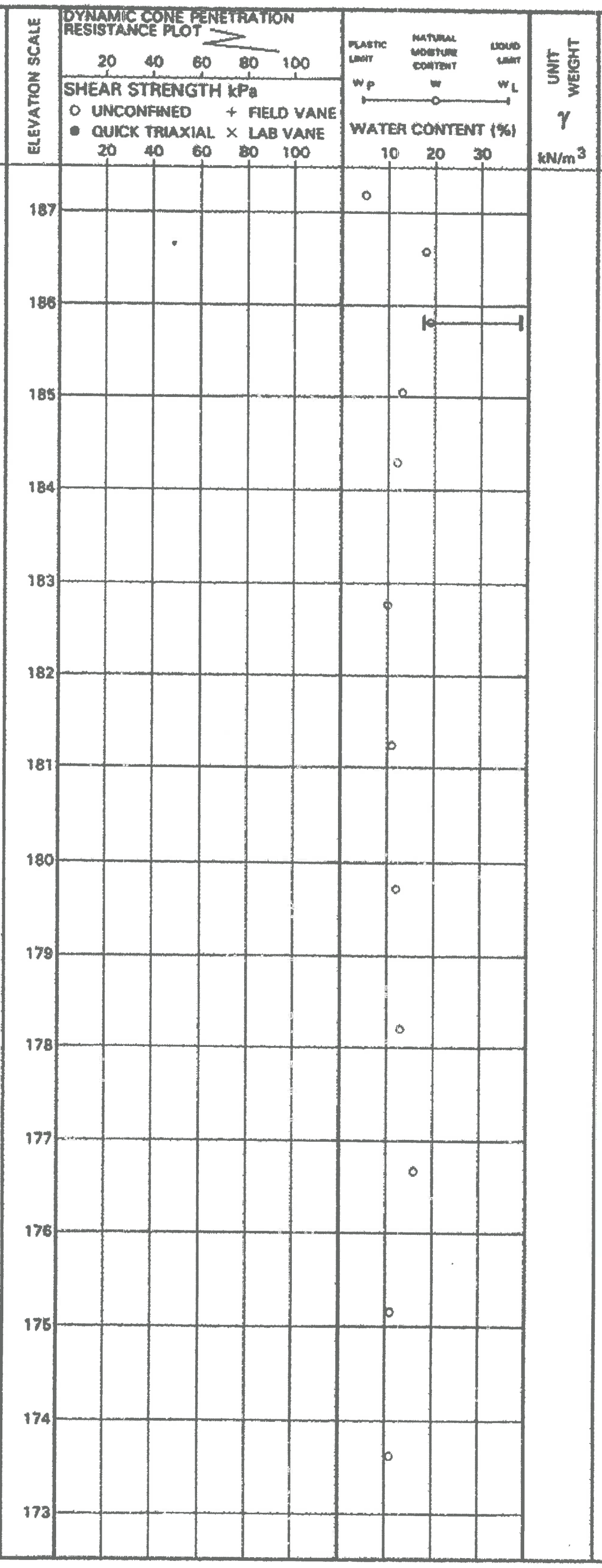
RECORD OF BOREHOLE No ~~97-4~~ 237-4

1 OF 2 **METRIC**

W.P. 311-89-00	LOCATION Co-ordinates 4 830 316.5 N; 604 225.5 E.		ORIGINATED BY TR
DIST 6	HWY 401	BOREHOLE TYPE 100mm diameter Solid Stem Auger	COMPILED BY JB
DATUM Geodetic	DATE 12.16.97 -		CHECKED BY IC

SOIL PROFILE		SAMPLES			GROUND WATER CONDITIONS	REMARKS & GRAIN SIZE DISTRIBUTION (%)			
ELEV DEPTH	DESCRIPTION	NUMBER	TYPE	"N" VALUES		GR	SA	SI	CL
187.5	Ground Level								
187.3 0.2	Asphalt								
186.9 0.6	Granular	1	SS	34					
	Fill - Silty Clay, some sand traces of gravel	2	SS	12					
185.4 2.1	Stiff to Very Stiff, Brown & Grey	3	SS	20		2	11	34	53
	Sandy Clayey Silt, traces of gravel (Till)	4	SS	22					
	Very Stiff, Brown	5	SS	26					
	……………… Grey	6	SS	26					
		7	SS	17		8	39	31	22
178.9 8.6		8	SS	17					
	Silty Clay, some sand, traces of gravel (Till) Stiff, Grey	9	SS	9					
176.1 11.4		10	SS	10					
	Sandy Clayey Silt, traces of gravel (Till) Hard, Grey	11	SS	33	∇				
		12	SS	38					



Continued Next Page

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

RECORD OF BOREHOLE No ~~97-4~~ 237-4

2 OF 2 **METRIC**

W.P. 311-89-00
LOCATION Co-ordinates 4 830 316.5 N; 604 225.5 E.
ORIGINATED BY TR
DIST 6 HWY 401
BOREHOLE TYPE 100mm diameter Solid Stem Auger
COMPILED BY JB
DATUM Geodetic
DATE 12.16.97 -
CHECKED BY IC

SOIL PROFILE			SAMPLES					DYNAMIC CONE PENETRATION RESISTANCE PLOT 20 40 60 80 100 SHEAR STRENGTH kPa ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × LAB VANE 20 40 60 80 100	PLASTIC LIMIT w_P NATURAL MOISTURE CONTENT w LIQUID LIMIT w_L WATER CONTENT (%) 10 20 30	UNIT WEIGHT γ kN/m³	REMARKS & GRAIN SIZE DISTRIBUTION (%)			
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE				GR	SA	SI	CL
	Sandy Clayey Silt, trace of gravel (Till)		13	SS	43		172		○					
171.8 15.7	End of Borehole													
	Borehole dry upon completion of drilling.													

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

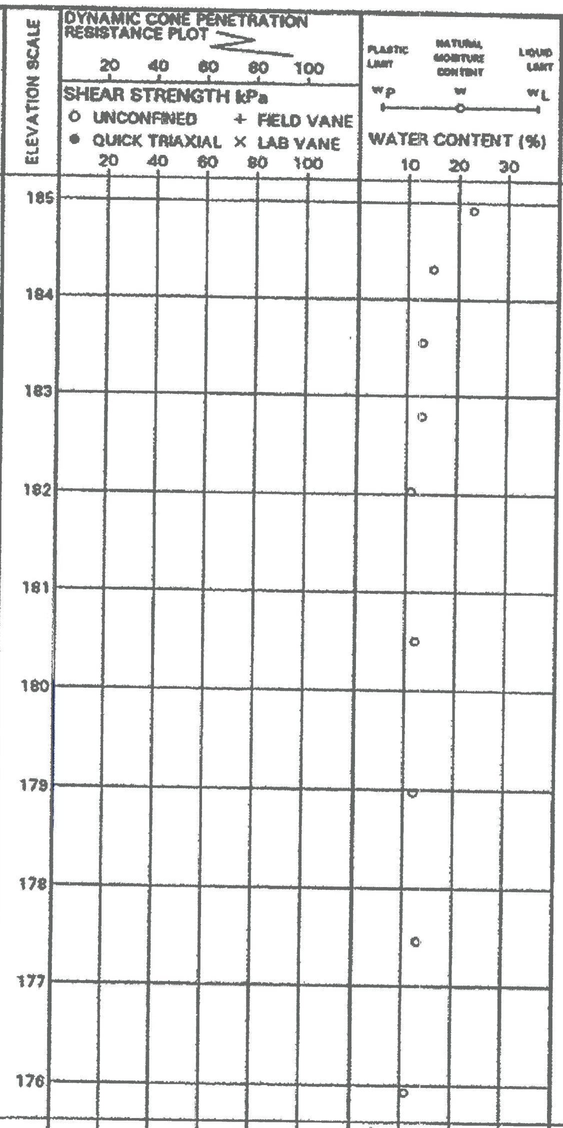
RECORD OF BOREHOLE No ~~97-6~~ 237-6

1 OF 1

METRIC

W.P. 311-89-00
LOCATION Co-ordinates 4 830 295.7 N; 604 244.2 E.
ORIGINATED BY TR
DIST 6 HWY 401
BOREHOLE TYPE 100mm diameter Solid Stem Auger
COMPILED BY JB
DATUM Geodetic
DATE 12.15.97 - 12.15.97
CHECKED BY IC

SOIL PROFILE		SAMPLES			
ELEV / DEPTH	DESCRIPTION	NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS
185.2	Ground Level				
184.9 / 0.0	Topsoil				
0.3	Sandy Clayey Silt, traces of gravel (Till) Very Stiff to Hard Brown	1	SS	6	
		2	SS	28	
		3	SS	85	
		4	SS	26	
		5	SS	24	
	Grey				
		6	SS	21	
		7	SS	29	
		8	SS	24	
176.7 / 8.5	Sandy Clayey Silt, traces of gravel (Till) Hard Grey				▽
		9	SS	42	
175.6 / 9.6	End of Borehole				



UNIT WEIGHT γ kN/m³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL

Groundwater measured at 8.57m below ground surface upon completion of drilling.

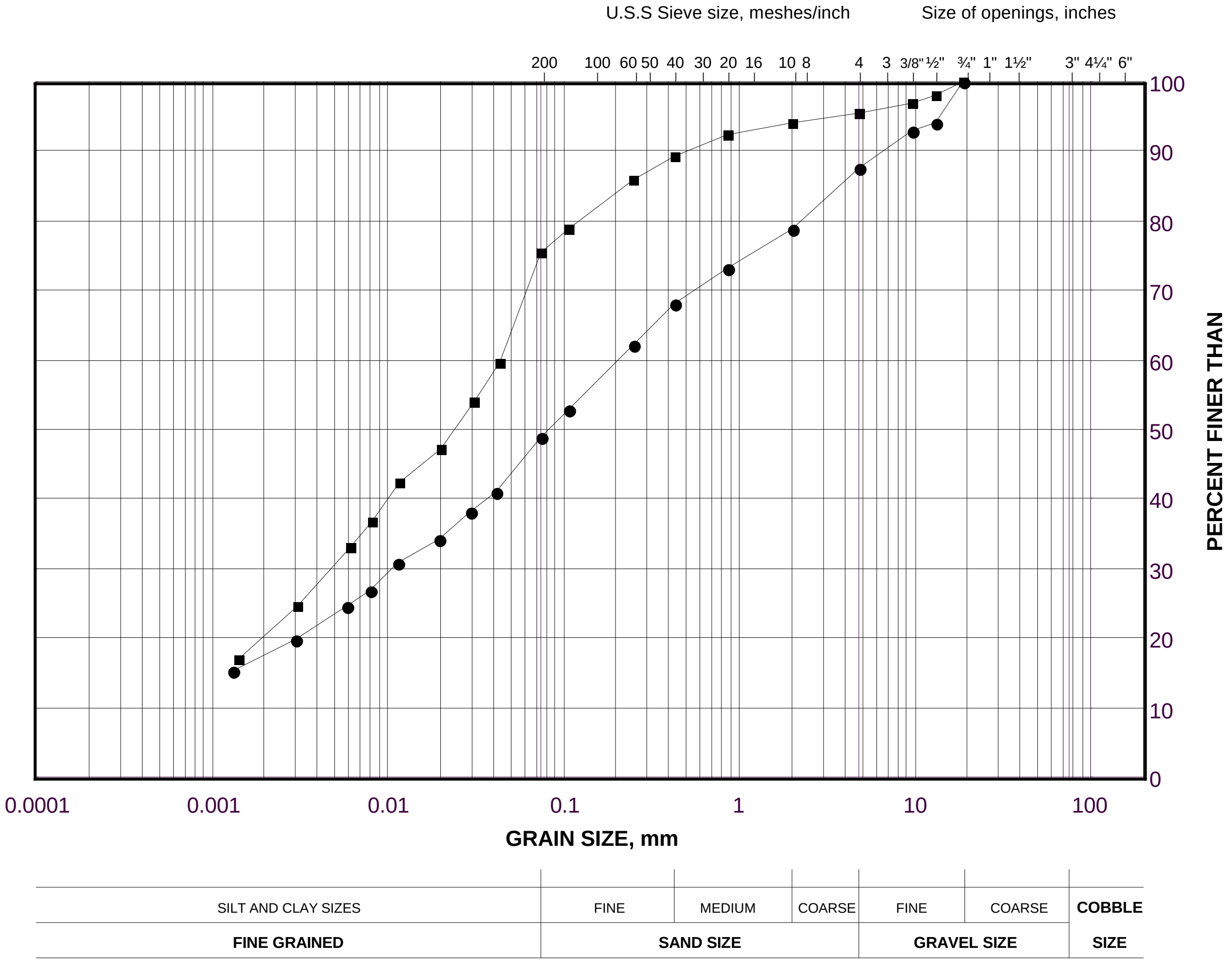
+³, ×³: Numbers refer to Sensitivity

○³% STRAIN AT FAILURE

GRAIN SIZE DISTRIBUTION

Clayey Silt with Sand to Sandy Silty Clay (Fill)

FIGURE C1



LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	TC15-2	2	185.0
■	TC15-2	5	182.7

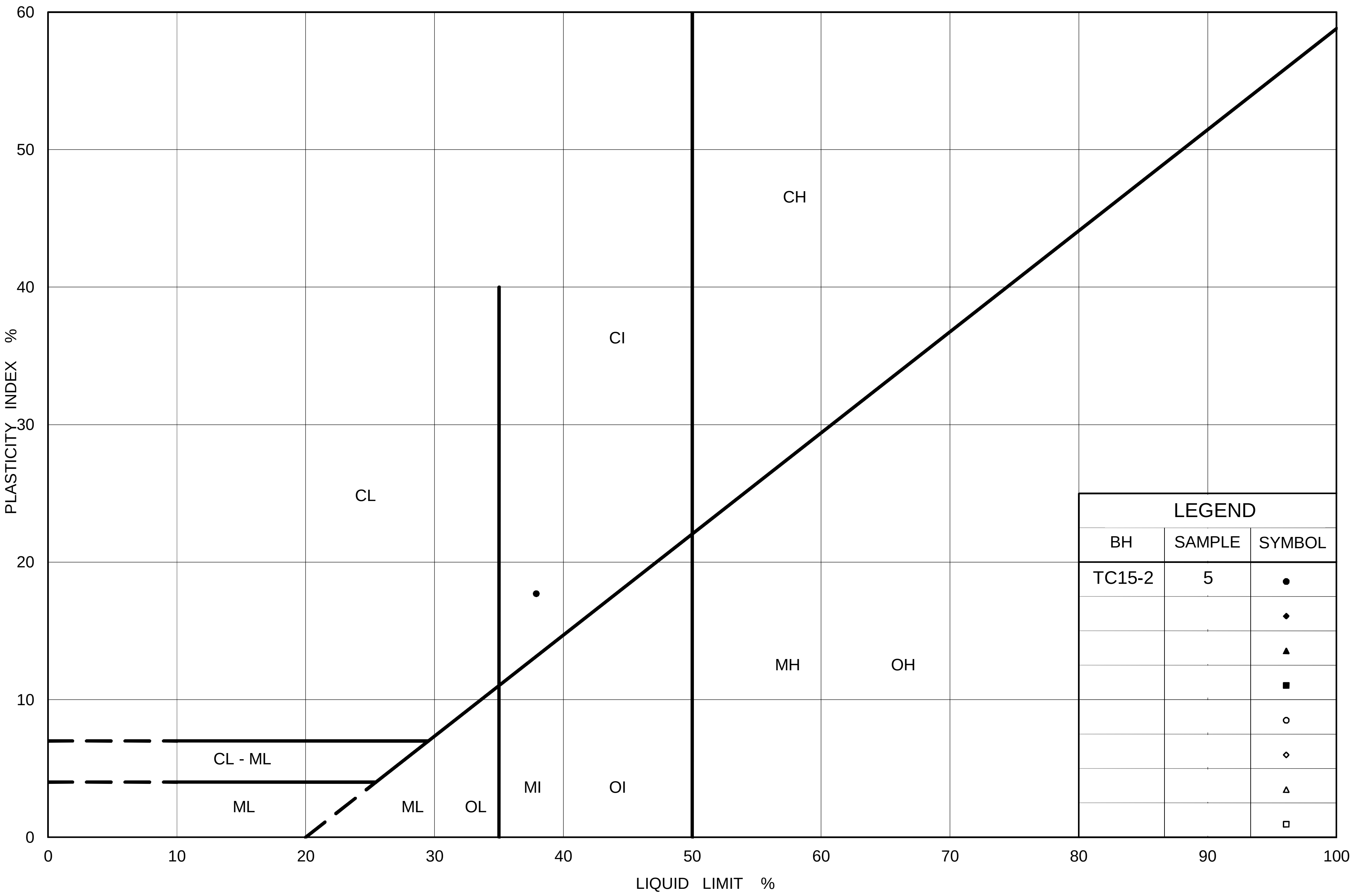
Project Number: 10-1111-0211

Checked By: KJB

Golder Associates

Date: 05-Jan-16

Oct 75, FF-S-21



Ministry of Transportation

Ontario

PLASTICITY CHART
Sandy Silty Clay (Fill)

Figure No. C2

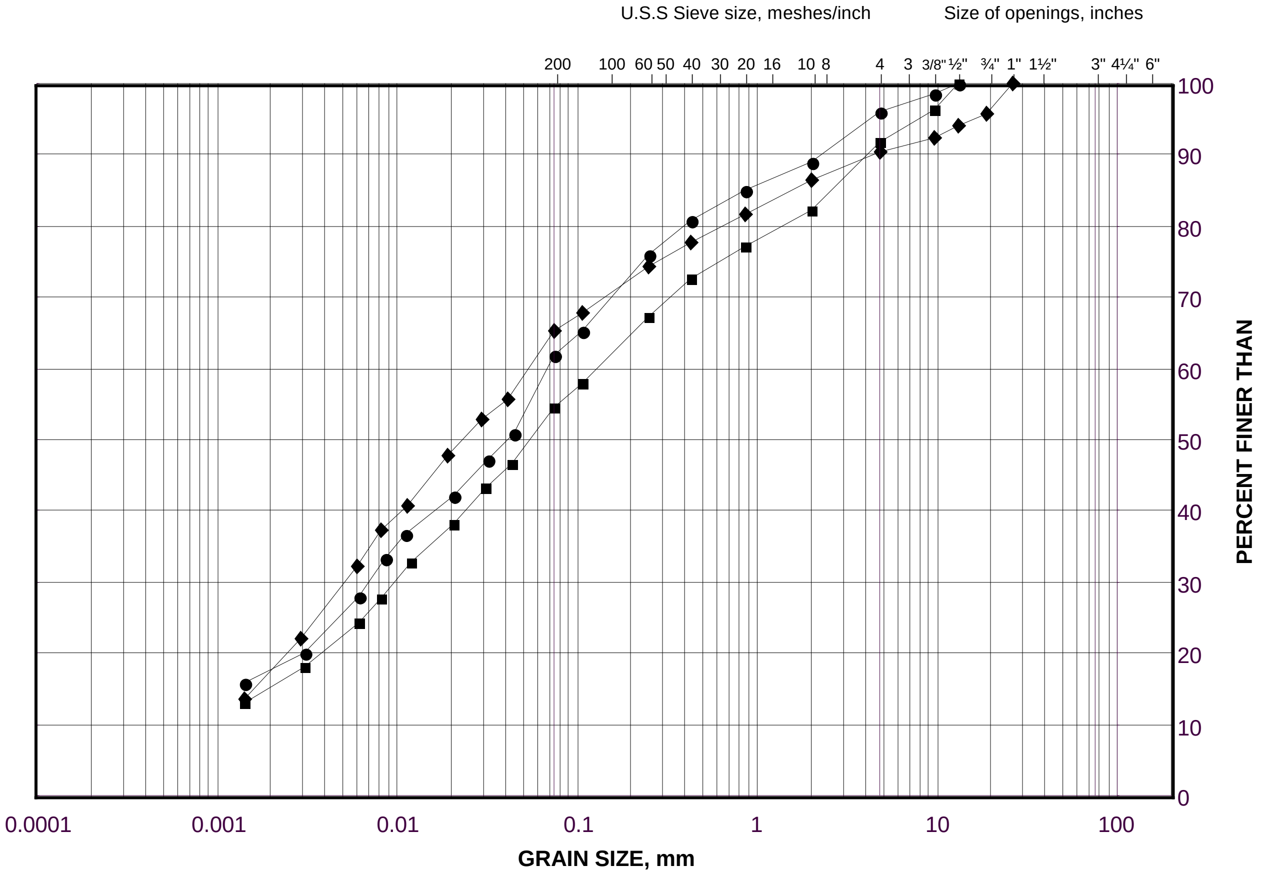
Project No. 10-1111-0211

Checked By: KJB

GRAIN SIZE DISTRIBUTION

Sandy Clayey Silt to Clayey Silt with Sand (Till)

FIGURE C3



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

LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	2014-8A	6	178.1
■	2014-8A	7	177.3
◆	TC15-2	8	178.9

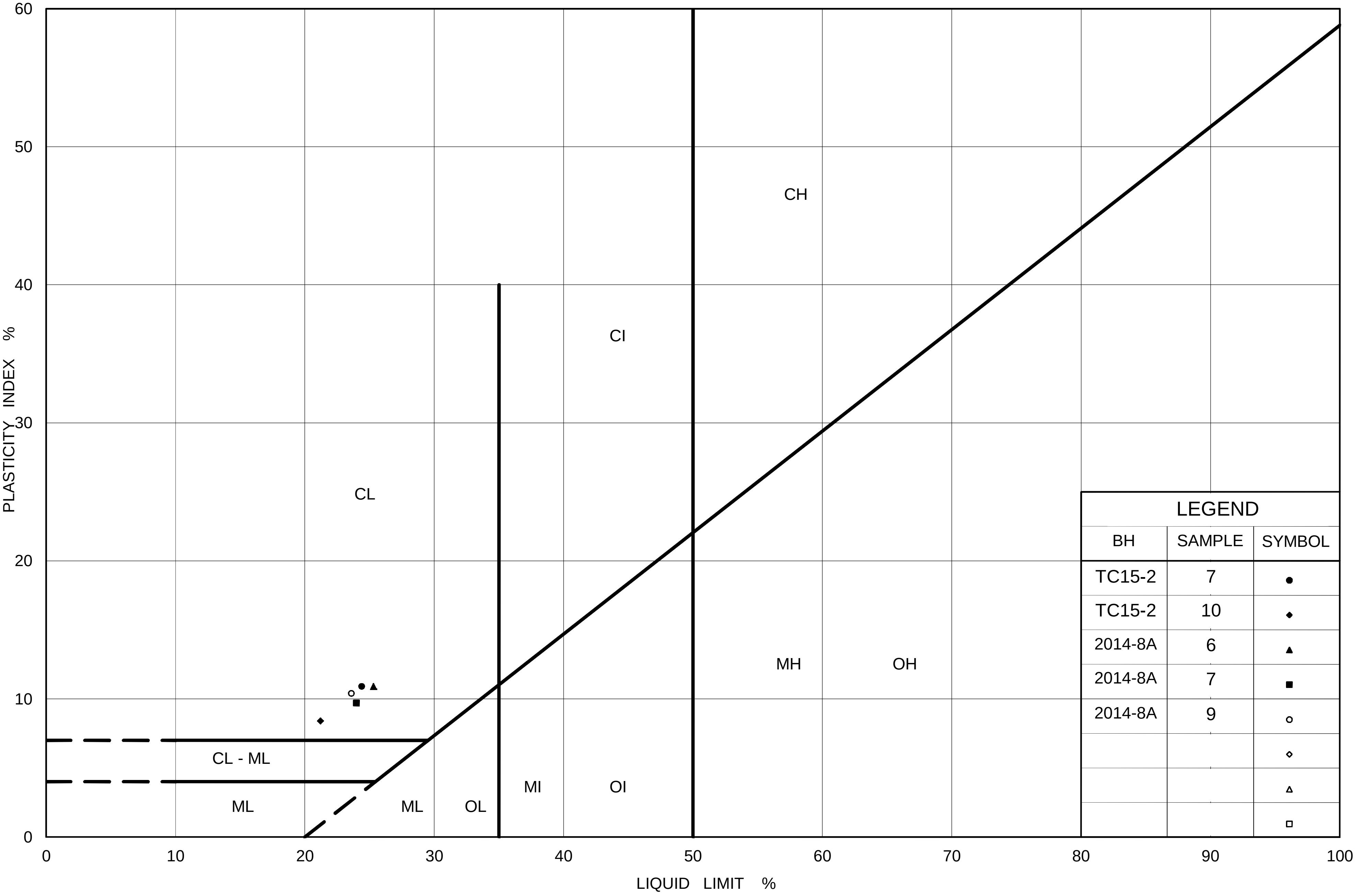
Project Number: 10-1111-0211

Checked By: KJB

Golder Associates

Date: 05-Jan-16

Oct 75, FF-S-21



LEGEND

BH	SAMPLE	SYMBOL
TC15-2	7	●
TC15-2	10	◆
2014-8A	6	▲
2014-8A	7	■
2014-8A	9	○
		◇
		△
		□

Ministry of Transportation

Ontario

PLASTICITY CHART
Sandy Clayey Silt to Clayey Silt with Sand (Till)

Figure No. C4

Project No. 10-1111-0211

Checked By: KJB

APPENDIX D

Borehole Records and Laboratory Test Results
Culvert No. 9, Station 17+446
TC15-8, TC15-9
Figure D1 to Figure D5

RECORD OF BOREHOLE No TC15-8

SHEET 1 OF 1

METRIC

PROJECT 10-1111-0211			
G.W.P. 2150-01-00	LOCATION N 4831457.2 ;E 288444.0	ORIGINATED BY QC	
DIST Central HWY 401	BOREHOLE TYPE 150 mm O.D. Hollow Stem Augers	COMPILED BY AJS	
DATUM GEODETIC	DATE November 4, 2015	CHECKED BY KJB	

ELEV DEPTH	SOIL PROFILE — DESCRIPTION	STRAT PLOT	SAMPLES NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR	SA	SI	CL
189.6	GROUND SURFACE									
0.0	ASPHALT									
0.1	Sand and gravel, trace silt (FILL) Compact to dense Brown Moist		1	SS	42					
188.7 0.9	Clayey silt, some sand to sandy clayey silt, trace to some gravel, some silt seams (FILL) Stiff Dark brown Moist		2	SS	11					
			3	SS	12		2	21	51	26
187.4 2.2	Sandy CLAYEY SILT to CLAYEY SILT with SAND, trace to some gravel, some silt seams, oxidation staining to a depth of 5.3 m (TILL) Stiff to hard Brown becoming grey below 4.4 m depth Moist		4	SS	22		4	26	50	20
			5	SS	28					
			6	SS	40					
			7	SS	28					
			8	SS	16		3	35	46	16
			9	SS	13					
			10	SS	14					
			11	SS	12					
181.4 8.2	END OF BOREHOLE NOTE: 1. Borehole dry upon completion of drilling.									

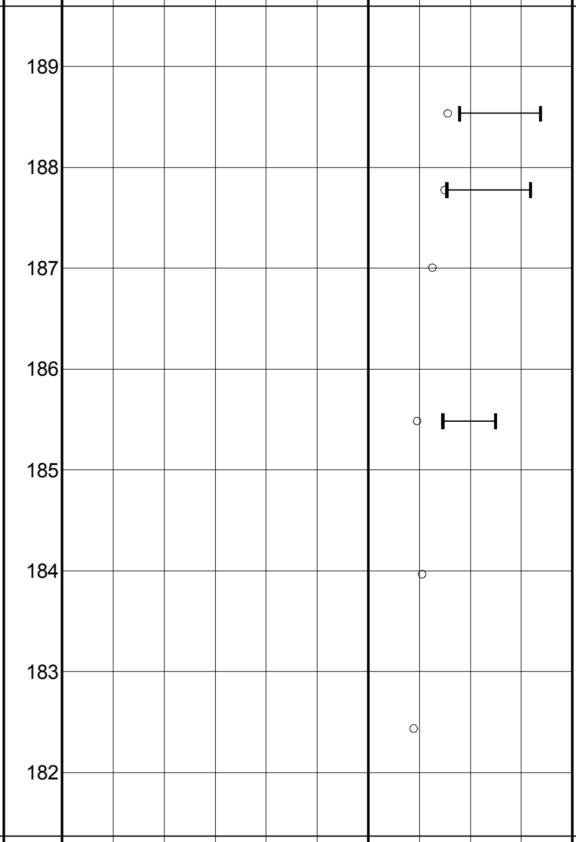
DYNAMIC CONE PENETRATION RESISTANCE PLOT 20 40 60 80 100

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



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

Golder Associates

Foundation Design

RECORD OF BOREHOLE No TC15-9

SHEET 1 OF 1

METRIC

PROJECT 10-1111-0211
G.W.P. 2150-01-00
DIST Central HWY 401
DATUM GEODETIC
LOCATION N 4831412.9 ;E 288452.3
BOREHOLE TYPE 150 mm O.D. Hollow Stem Augers
DATE November 2, 2015
ORIGINATED BY QC
COMPILED BY AJS
CHECKED BY KJB

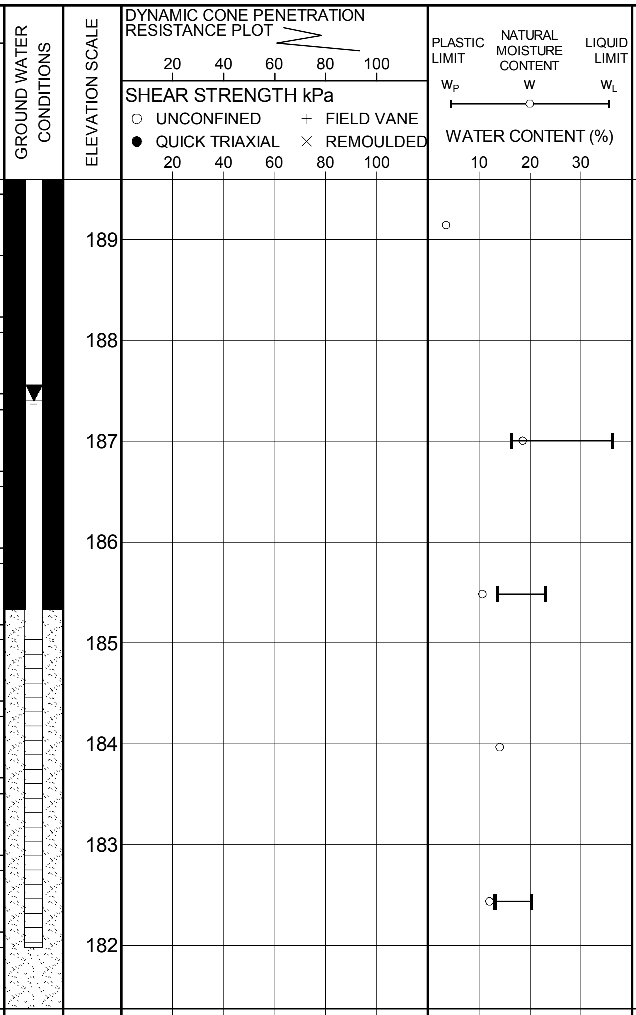
SOIL PROFILE

ELEV / DEPTH	DESCRIPTION
189.6	GROUND SURFACE
0.0	ASPHALT
0.1	Sand and gravel, some silt (FILL) Compact Brown Moist
188.7 0.9	Clayey silt to silty clay, trace to some sand, trace to some gravel (FILL) Firm to stiff Brown Moist
186.6 3.0	Sandy CLAYEY SILT, some gravel (TILL) Stiff to hard Brown Moist
181.4 8.2	END OF BOREHOLE

SAMPLES

NUMBER	TYPE	"N" VALUES	UNIT WEIGHT γ kN/m³	GR	SA	SI	CL
1	SS	26		40	45	13	2
2	SS	9					
3	SS	6					
4	SS	10					
5	SS	22					
6	SS	34		9	29	45	17
7	SS	31					
8	SS	24					
9	SS	17					
10	SS	11		9	27	44	20
11	SS	17					

REMARKS & GRAIN SIZE DISTRIBUTION (%)



END OF BOREHOLE

NOTES:

1. Borehole dry upon completion of drilling.

2. Water level measured in piezometer:

Date	Depth (m)	Elev. (m)
11/19/15	5.5	184.1
12/16/15	2.2	187.4

+ 3, × 3: Numbers refer to Sensitivity

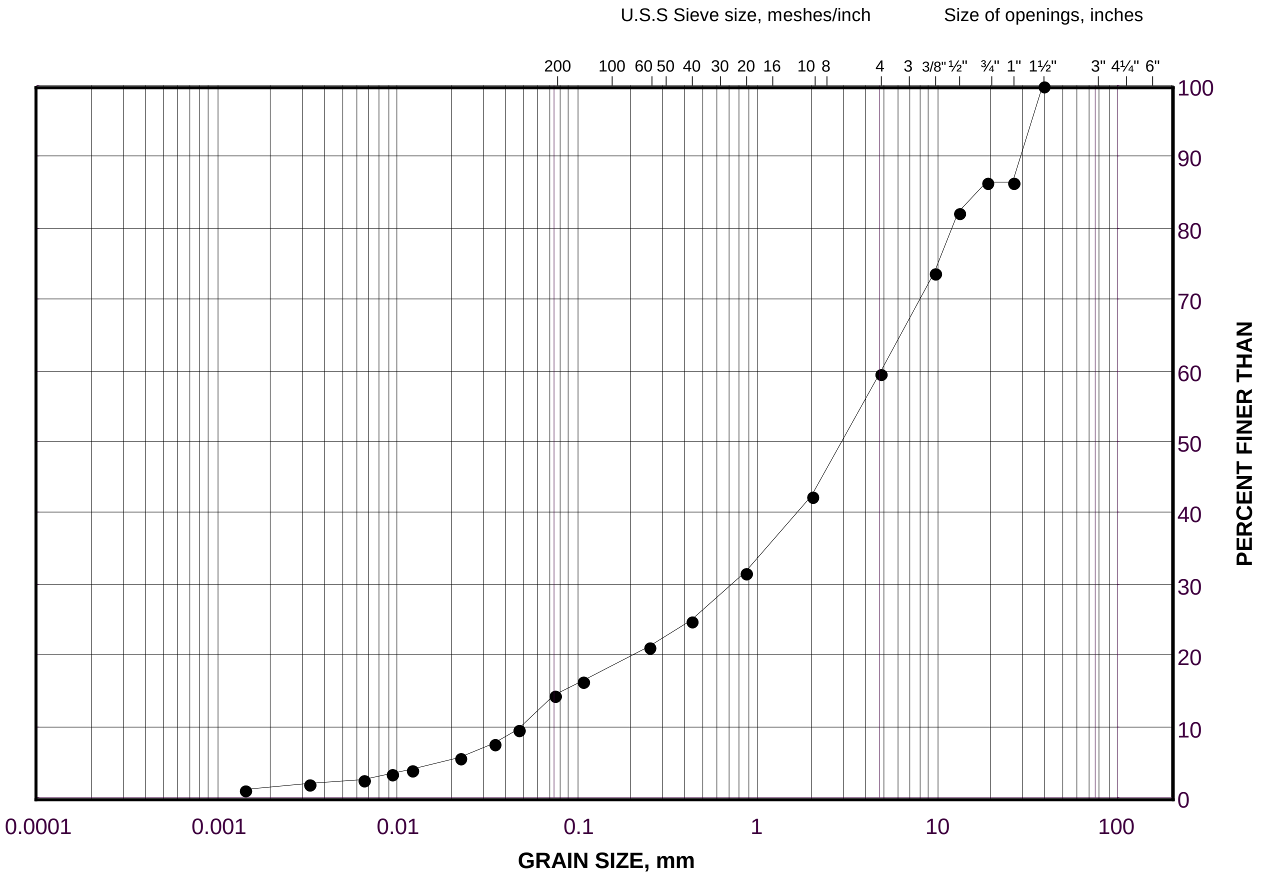
○ 3% STRAIN AT FAILURE

GTA-MTO 001 T:\PROJECTS\2010\10-1111-0211 (AECOM, MISSISSAUGA)\LOG\1011110211.GPJ GAL-GTA.GDT 01/21/16

GRAIN SIZE DISTRIBUTION

Sand and Gravel (Fill)

FIGURE D1



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

LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	TC15-9	1	189.1

Project Number: 10-1111-0211

Checked By: KJB

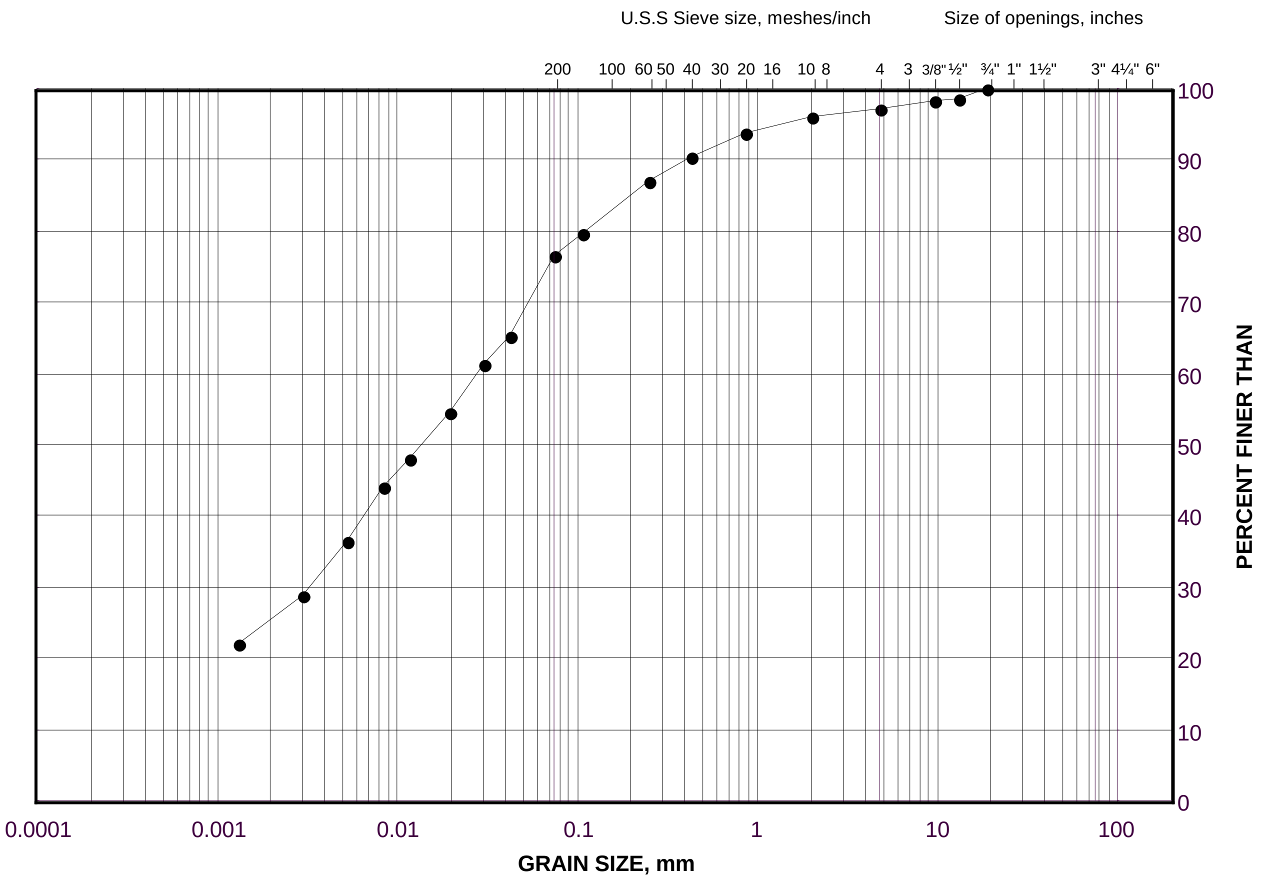
Golder Associates

Date: 05-Jan-16

GRAIN SIZE DISTRIBUTION

Sandy Clayey Silt (Fill)

FIGURE D2



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

LEGEND

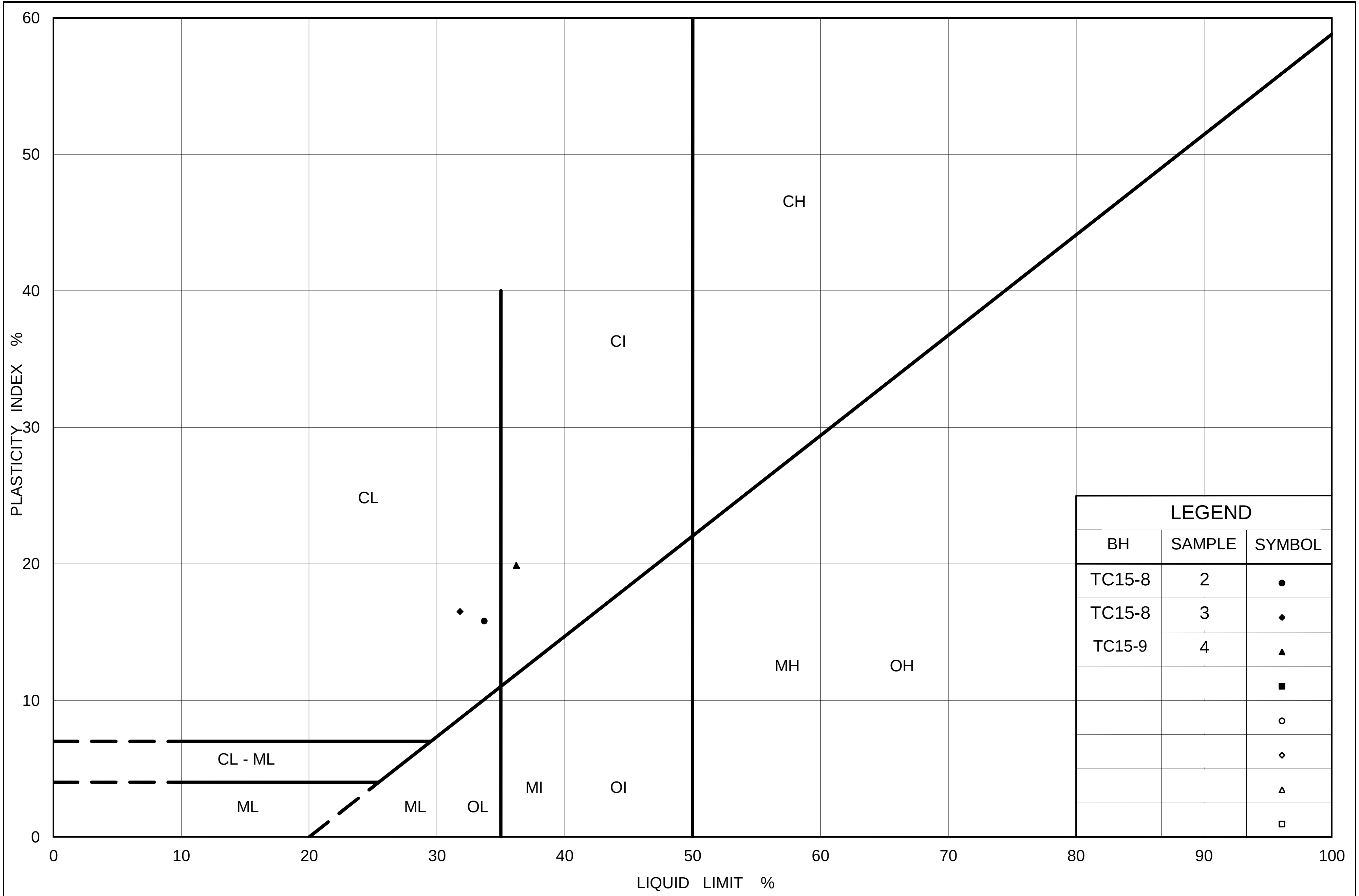
SYMBOL	BOREHOLE	SAMPLE	DEPTH(m)
●	TC15-8	3	187.8

Project Number: 10-1111-0211

Checked By: KJB

Golder Associates

Date: 05-Jan-16



Ministry of Transportation

Ontario

PLASTICITY CHART
Sandy Clayey Silt to Silty Clay (Fill)

Figure No. D3

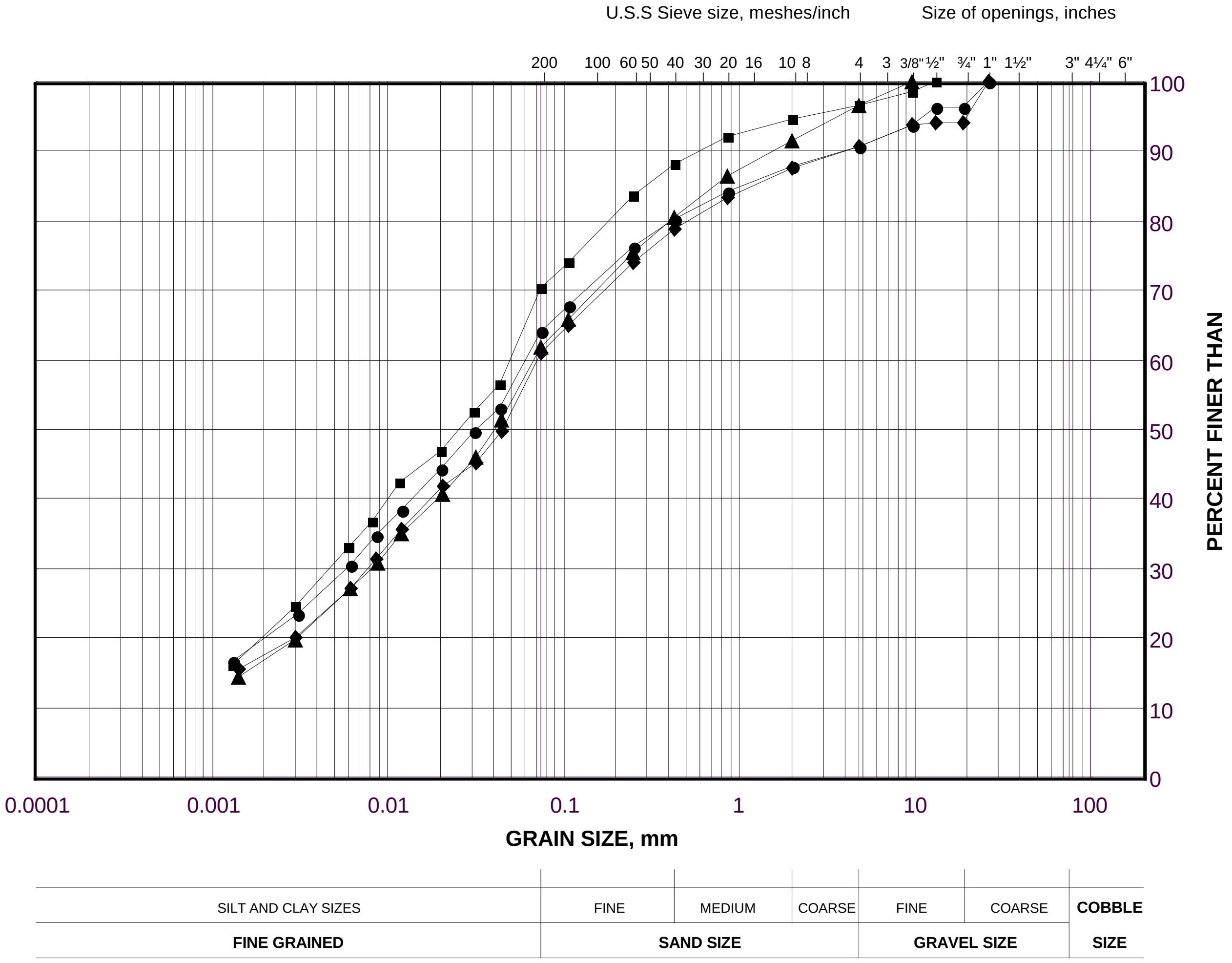
Project No. 10-1111-0211

Checked By: KJB

GRAIN SIZE DISTRIBUTION

Sandy Clayey Silt to Clayey Silt with Sand (Till)

FIGURE D4



LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	TC15-9	10	182.4
■	TC15-8	4	186.9
◆	TC15-9	6	185.5
▲	TC15-8	8	183.9

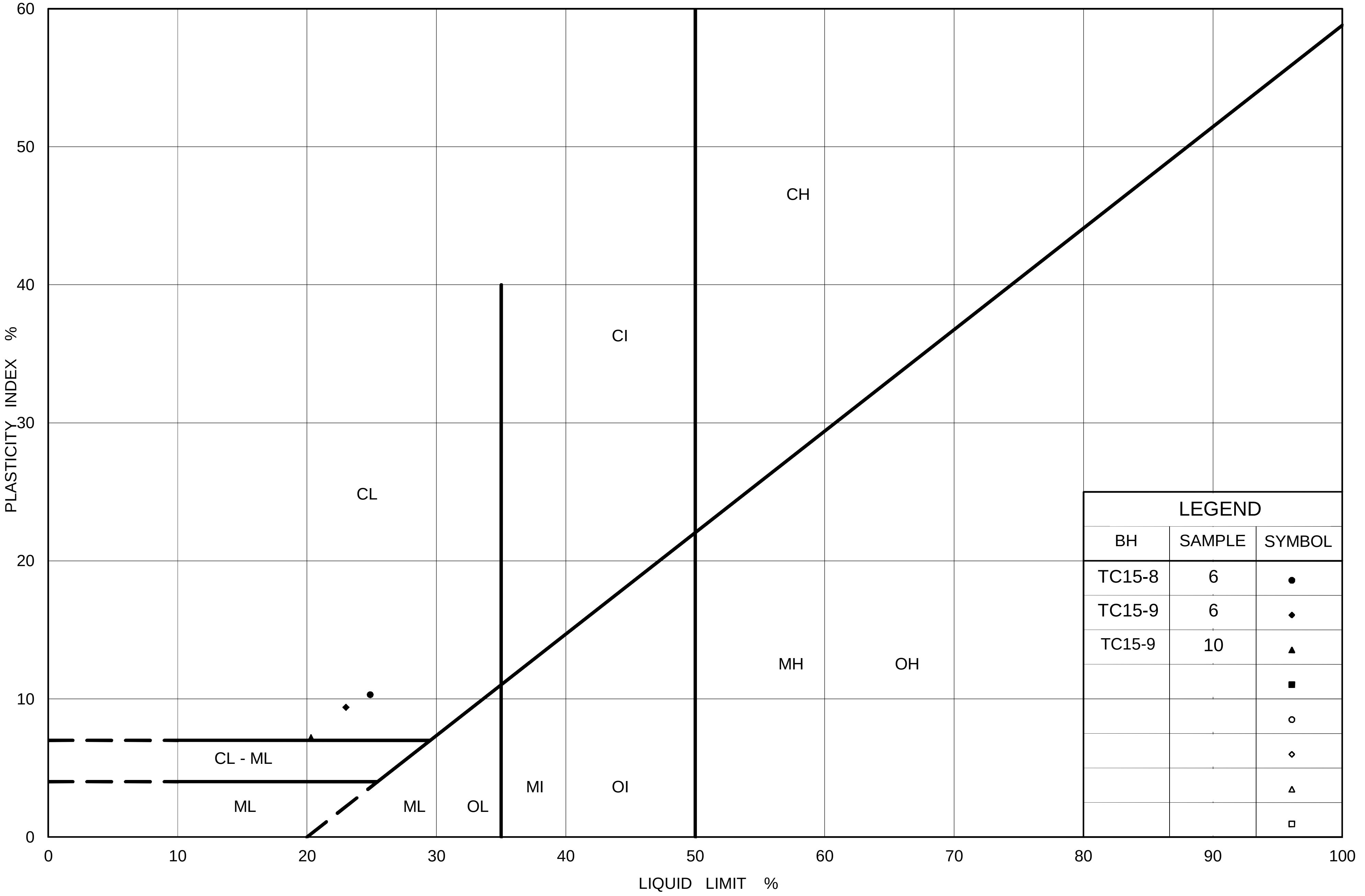
Project Number: 10-1111-0211

Checked By: KJB

Golder Associates

Date: 05-Jan-16

Oct 75, FF-S-21



Ministry of Transportation

Ontario

PLASTICITY CHART
Sandy Clayey Silt to Clayey Silt with Sand (Till)

Figure No. D5

Project No. 10-1111-0211

Checked By: KJB

APPENDIX E

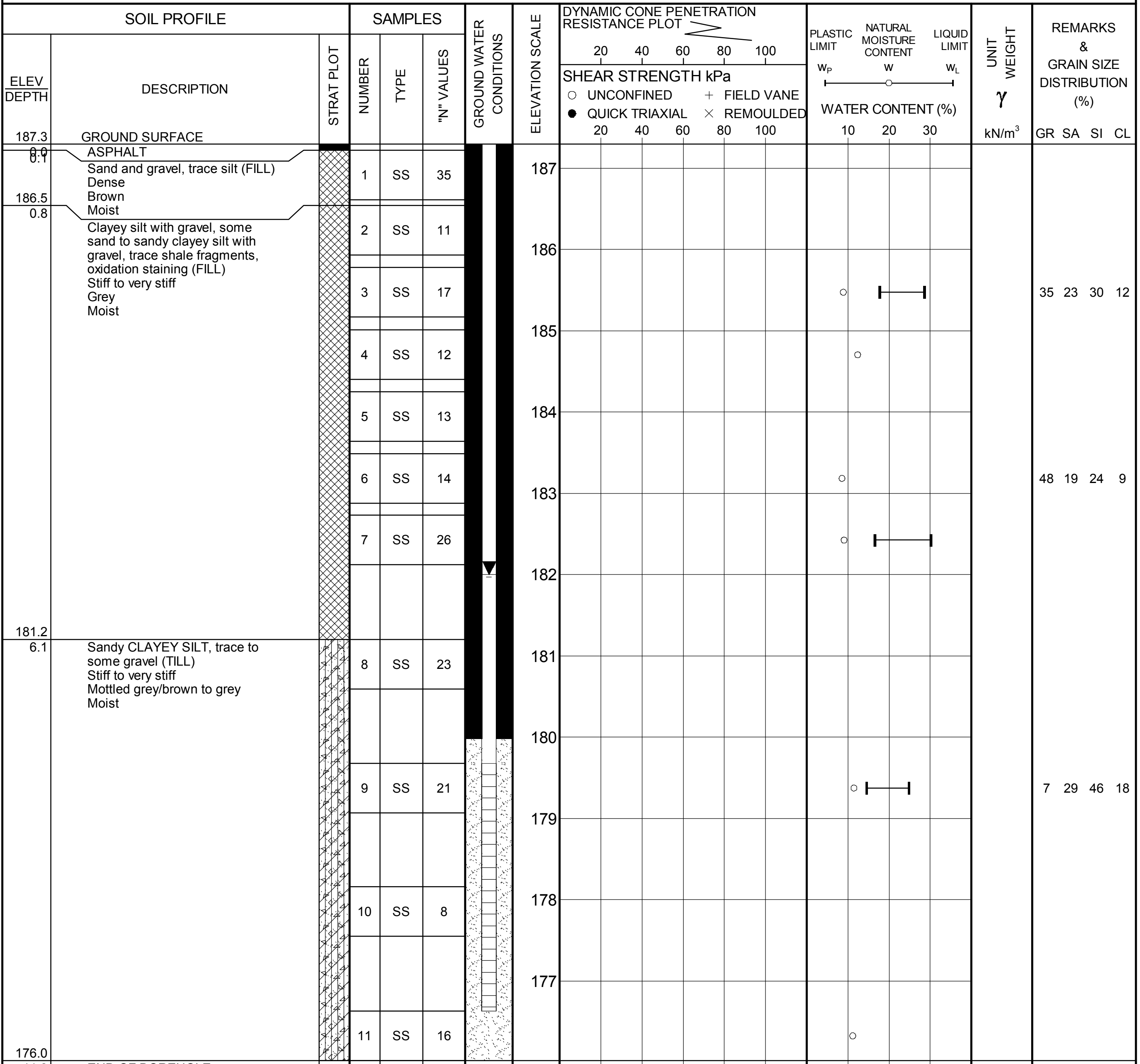
Borehole Records and Laboratory Test Results
Culvert No. 10, Station 16+855
TC15-1, TC15-3
Figure E1 to Figure E4

RECORD OF BOREHOLE No TC15-1

SHEET 1 OF 1

METRIC

PROJECT 10-1111-0211
G.W.P. 2150-01-00
DIST Central HWY 401
DATUM GEODETIC
LOCATION N 4831248.9 ;E 287859.0
BOREHOLE TYPE 150 mm O.D. Hollow Stem Augers
DATE November 4, 2015
ORIGINATED BY QC
COMPILED BY AJS
CHECKED BY KJB



ELEV DEPTH	DESCRIPTION	NUMBER	TYPE	"N" VALUES	UNIT WEIGHT γ kN/m³	GR	SA	SI	CL
187.3	GROUND SURFACE								
0.0	ASPHALT								
0.1	Sand and gravel, trace silt (FILL) Dense Brown Moist	1	SS	35					
186.5 0.8	Clayey silt with gravel, some sand to sandy clayey silt with gravel, trace shale fragments, oxidation staining (FILL) Stiff to very stiff Grey Moist	2	SS	11					
		3	SS	17		35	23	30	12
		4	SS	12					
		5	SS	13					
		6	SS	14		48	19	24	9
		7	SS	26					
181.2 6.1	Sandy CLAYEY SILT, trace to some gravel (TILL) Stiff to very stiff Mottled grey/brown to grey Moist	8	SS	23					
		9	SS	21		7	29	46	18
		10	SS	8					
		11	SS	16					
176.0 11.3	END OF BOREHOLE								

NOTES:

1. Water level at a depth of 10.4 m (Elev. 176.9 m) upon completion of drilling.

2. Water level measured in piezometer:

Date	Depth (m)	Elev. (m)
11/19/15	5.4	181.9
12/15/15	5.3	182.0

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

RECORD OF BOREHOLE No TC15-3

SHEET 1 OF 1

METRIC

PROJECT 10-1111-0211

G.W.P. 2150-01-00

LOCATION N 4831238.8 ;E 287904.7

ORIGINATED BY QC

DIST Central HWY 401

BOREHOLE TYPE 150 mm O.D. Solid Stem Augers

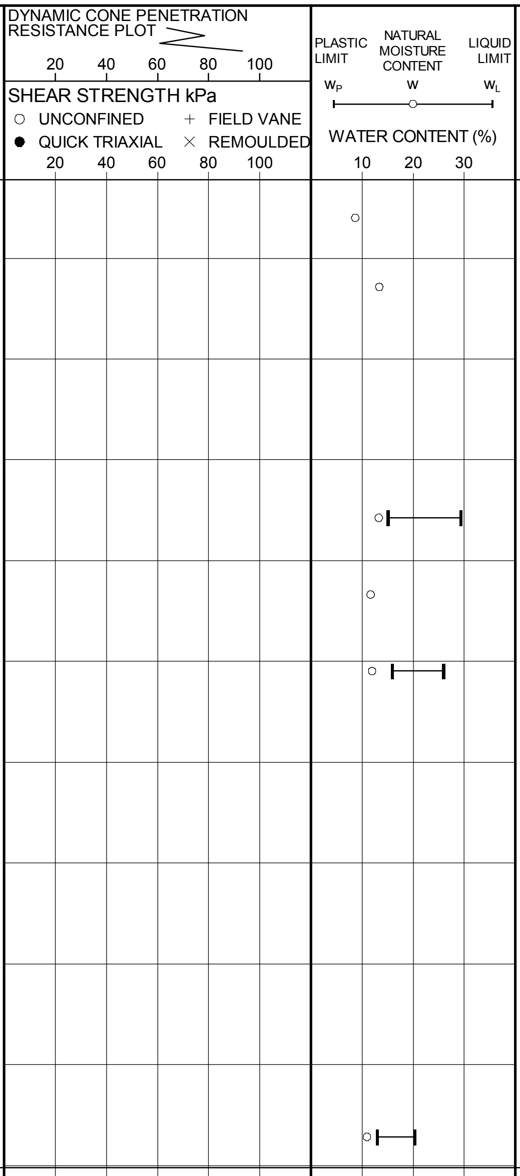
COMPILED BY AJS

DATUM GEODETIC

DATE November 9, 2015

CHECKED BY KJB

ELEV DEPTH	DESCRIPTION	NUMBER	TYPE	"N" VALUES	GR	SA	SI	CL
185.8	GROUND SURFACE							
0.0	Sandy clayey silt, trace to some gravel to sandy clayey silt with gravel, some silt pockets, oxidation staining (FILL) Firm to very stiff Brown to grey Moist	1	AS	-				
		2	SS	12	35	25	26	14
		3	SS	7				
		4	SS	8				
		5	SS	17				
181.3		6	SS	17	8	27	46	19
4.5	CLAYEY SILT with SAND, trace to some gravel (TILL) Very stiff Brown becoming grey below 6.4 m depth Moist	7	SS	26				
		8	SS	26				
		9	SS	15				
176.0		10	SS	17	10	33	39	18
9.8	END OF BOREHOLE NOTE: 1. Borehole dry upon completion of drilling.							



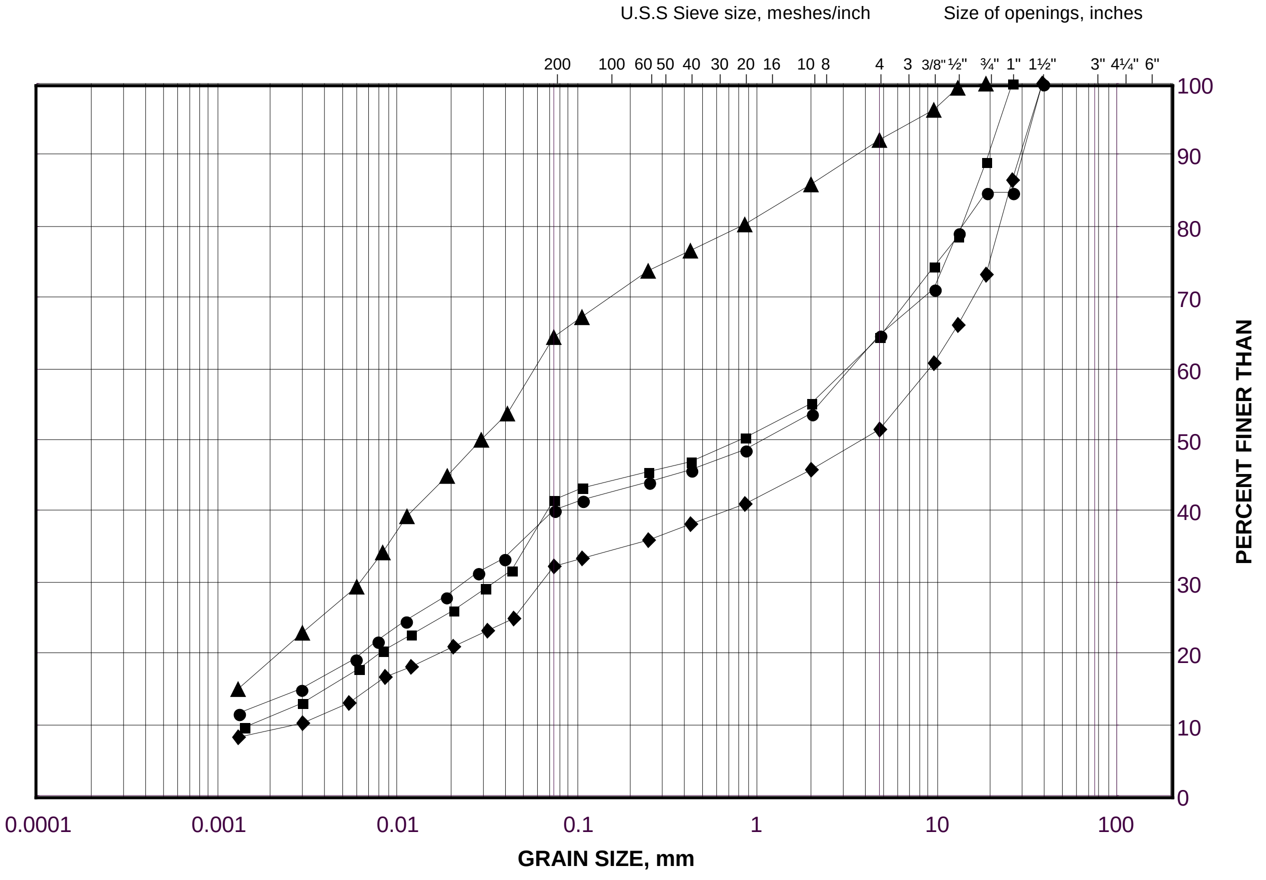
SOIL PROFILE · SAMPLES · STRAT PLOT · GROUND WATER CONDITIONS · ELEVATION SCALE · UNIT WEIGHT γ kN/m³ · REMARKS & GRAIN SIZE DISTRIBUTION (%)

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

GRAIN SIZE DISTRIBUTION

Sandy Clayey Silt to Clayey Silt with Gravel (Fill)

FIGURE E1



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

LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	TC15-3	2	184.7
■	TC15-1	3	185.8
◆	TC15-1	6	183.6
▲	TC15-3	6	181.7

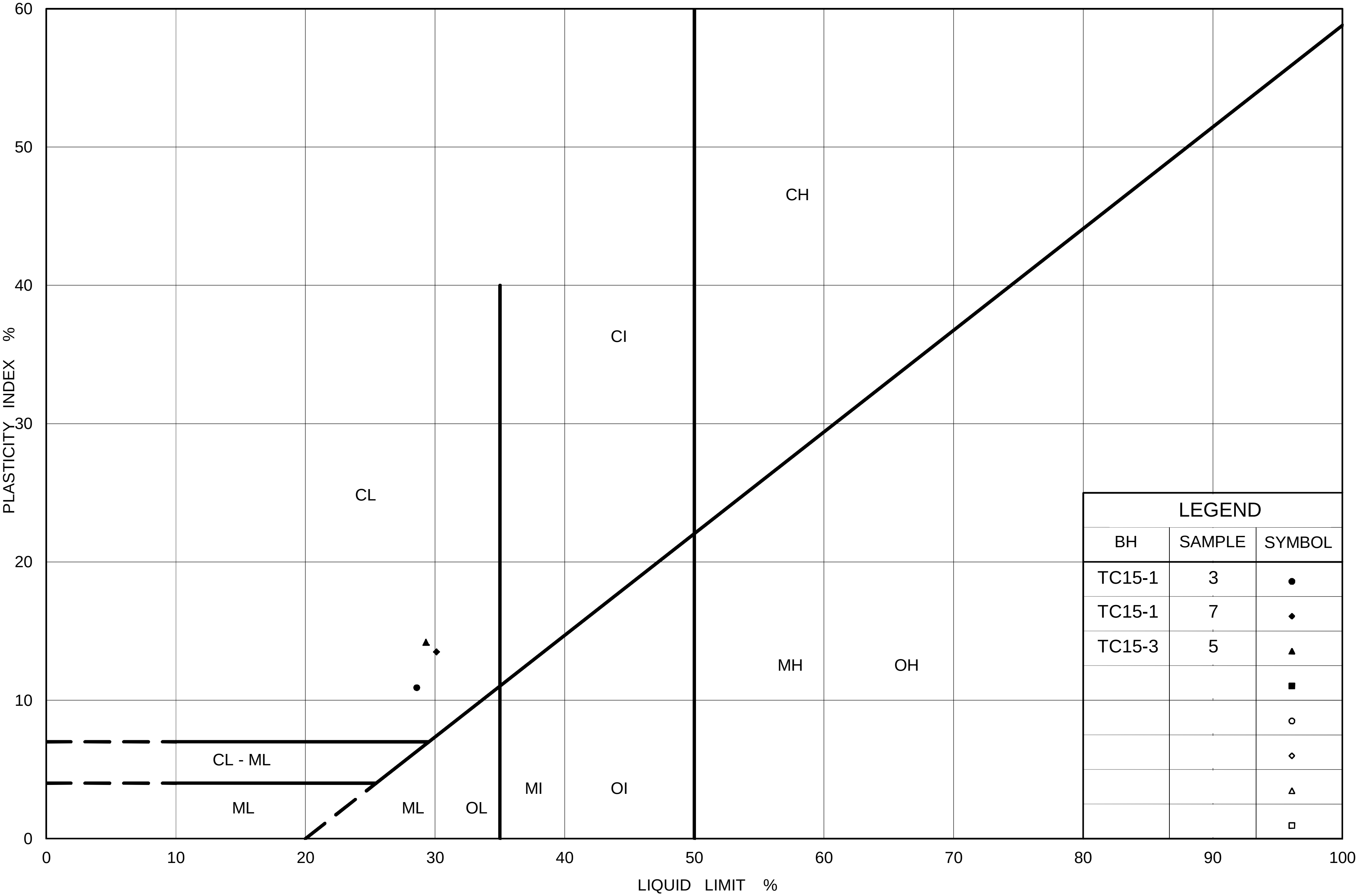
Project Number: 10-1111-0211

Checked By: KJB

Golder Associates

Date: 05-Jan-16

Oct 75, FF-S-21



Ministry of Transportation

Ontario

PLASTICITY CHART

Sandy Clayey Silt to Clayey Silt with Gravel (Fill)

Figure No. E2

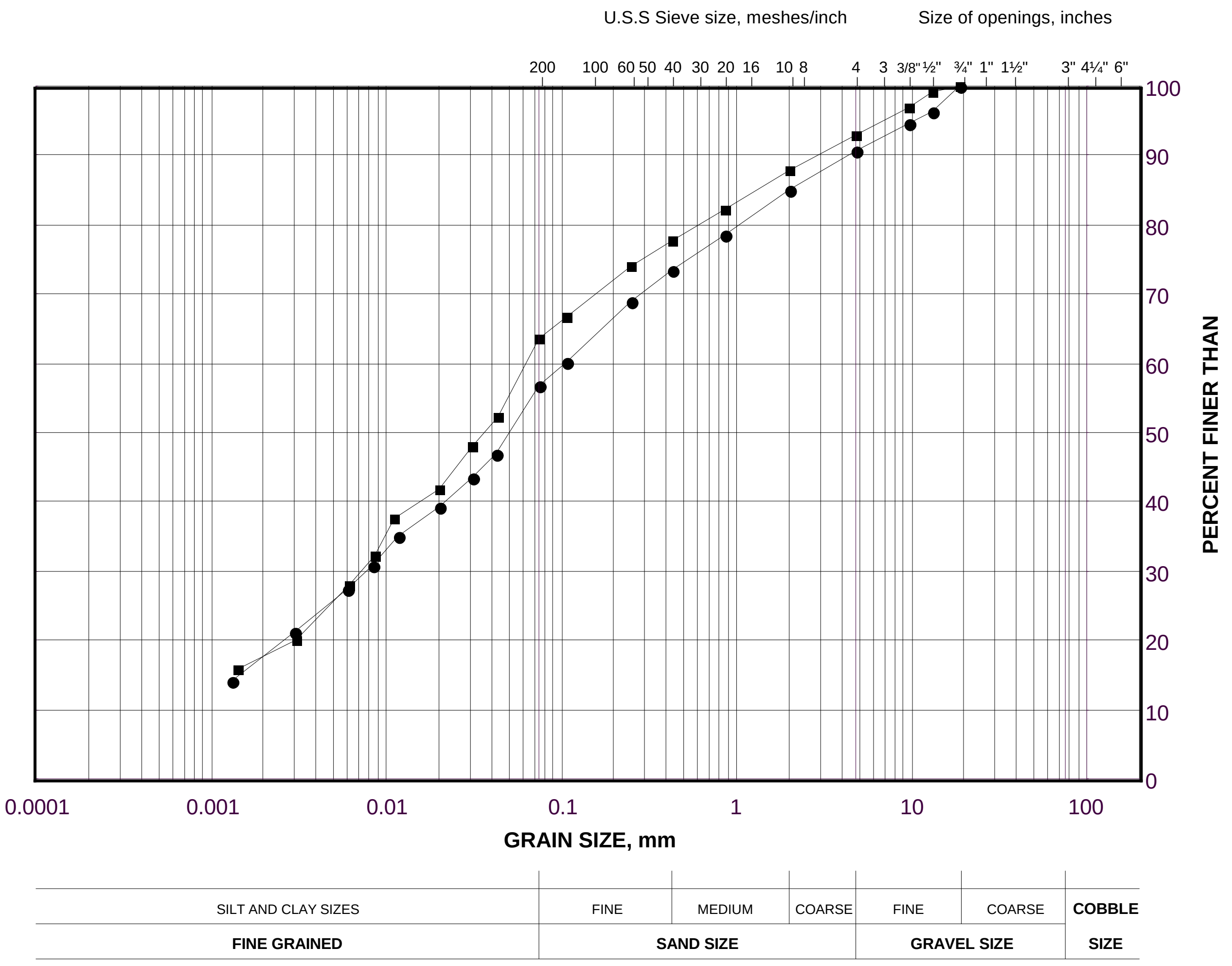
Project No. 10-1111-0211

Checked By: KJB

GRAIN SIZE DISTRIBUTION

Sandy Clayey Silt to Clayey Silt with Sand (Till)

FIGURE E3



LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	TC15-3	10	176.4
■	TC15-1	9	179.8

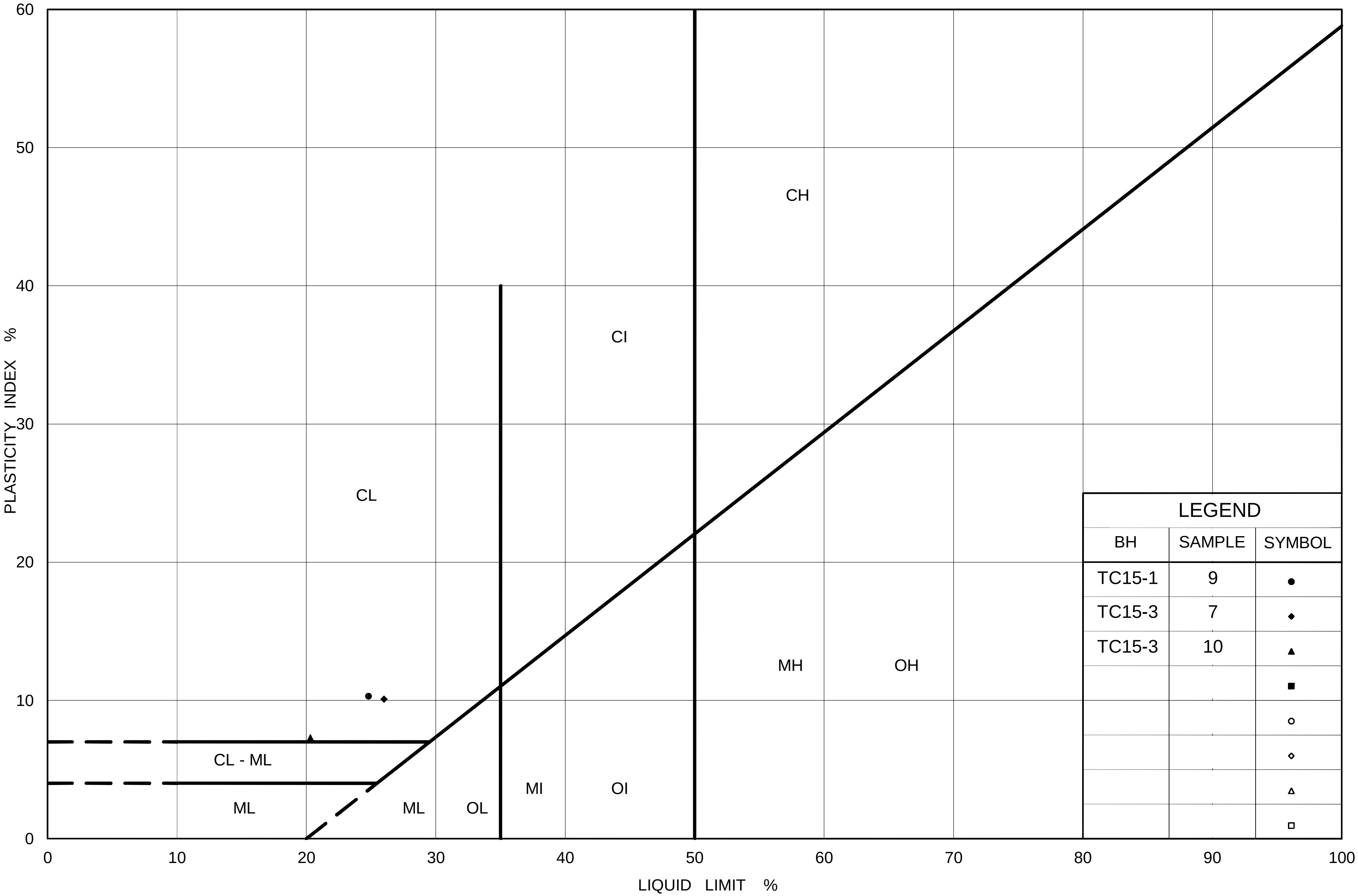
Project Number: 10-1111-0211

Checked By: KJB

Golder Associates

Date: 05-Jan-16

Oct 75, FF-S-21



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Ontario

PLASTICITY CHART

Sandy Clayey Silt to Clayey Silt with Sand (Till)

Figure No. E4

Project No. 10-1111-0211

Checked By: KJB

APPENDIX F

Borehole Records and Laboratory Test Results
Culvert No. 11A, Station 11+456
TC15-3, TC15-5, MR-1, MR-2
Figure F1 to Figure F9

RECORD OF BOREHOLE No TC15-3

SHEET 1 OF 1

METRIC

PROJECT 10-1111-0211

G.W.P. 2150-01-00

DIST Central HWY 401

DATUM GEODETIC

LOCATION N 4831238.8 ;E 287904.7

BOREHOLE TYPE 150 mm O.D. Solid Stem Augers

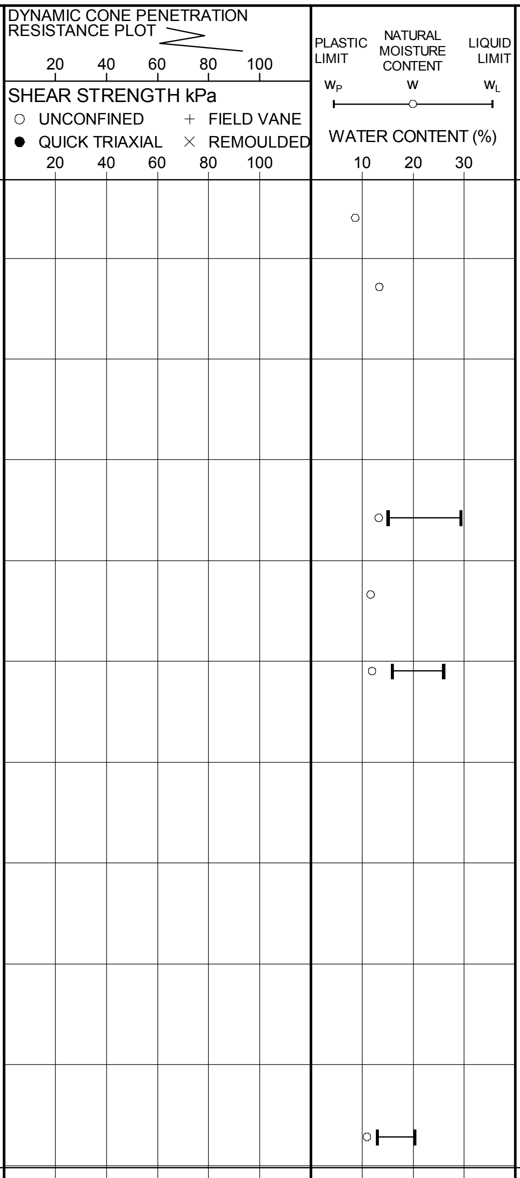
DATE November 9, 2015

ORIGINATED BY QC

COMPILED BY AJS

CHECKED BY KJB

ELEV DEPTH	DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	GR	SA	SI	CL
185.8	GROUND SURFACE							
0.0	Sandy clayey silt, trace to some gravel to sandy clayey silt with gravel, some silt pockets, oxidation staining (FILL) Firm to very stiff Brown to grey Moist	1	AS	-				
		2	SS	12	35	25	26	14
		3	SS	7				
		4	SS	8				
		5	SS	17				
		6	SS	17	8	27	46	19
181.3 4.5	CLAYEY SILT with SAND, trace to some gravel (TILL) Very stiff Brown becoming grey below 6.4 m depth Moist	7	SS	26				
		8	SS	26				
		9	SS	15				
		10	SS	17	10	33	39	18
176.0 9.8	END OF BOREHOLE NOTE: 1. Borehole dry upon completion of drilling.							



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

Golder Associates

Foundation Design

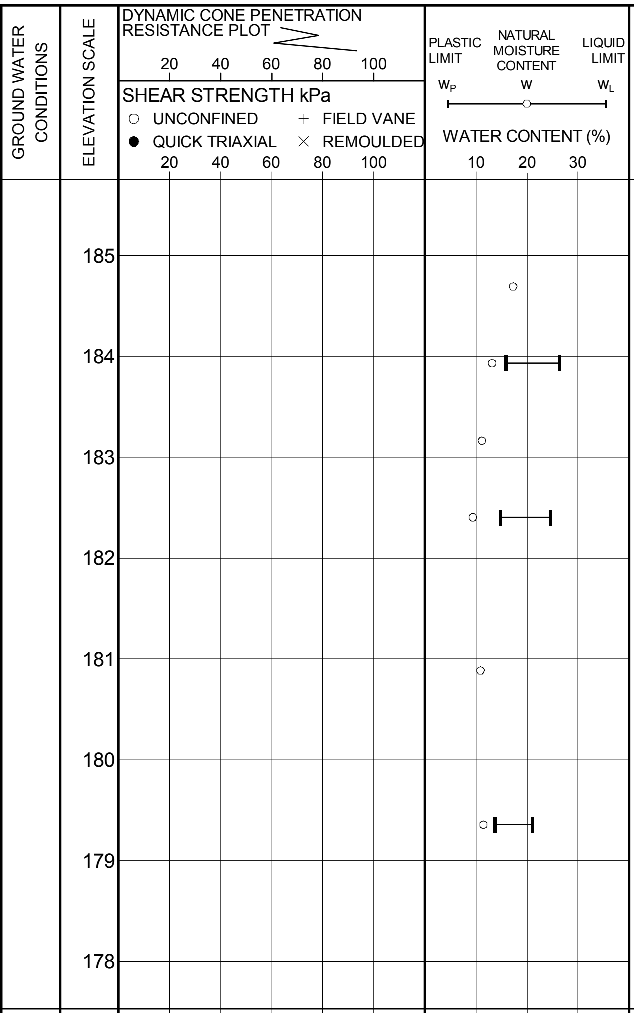
RECORD OF BOREHOLE No TC15-5

SHEET 1 OF 1

METRIC

PROJECT 10-1111-0211			
G.W.P. 2150-01-00	LOCATION N 4831301.4 ;E 288003.9	ORIGINATED BY QC	
DIST Central HWY 401	BOREHOLE TYPE 150 mm O.D. Solid Stem Augers	COMPILED BY AJS	
DATUM GEODETIC	DATE November 9, 2015	CHECKED BY KJB	

SOIL PROFILE			SAMPLES			UNIT WEIGHT γ kN/m³	REMARKS & GRAIN SIZE DISTRIBUTION (%)			
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES		GR	SA	SI	CL
185.8	GROUND SURFACE									
0.0	TOPSOIL									
0.1	Clayey silt, some sand, trace to some gravel, contains silt pockets (FILL) Firm to very stiff Mottled grey and brown Moist		1	SS	6					
			2	SS	11		2	10	48	40
			3	SS	18					
183.6 2.2	Sandy CLAYEY SILT, some gravel (TILL) Stiff to very stiff Brown becoming grey below 4.0 m depth Moist		4	SS	26		12	29	43	16
			5	SS	28					
			6	SS	16					
			7	SS	12					
			8	SS	13					
			9	SS	8					
			10	SS	9					
			11	SS	9					
177.6 8.2	END OF BOREHOLE NOTE: 1. Borehole dry upon completion of drilling.									



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

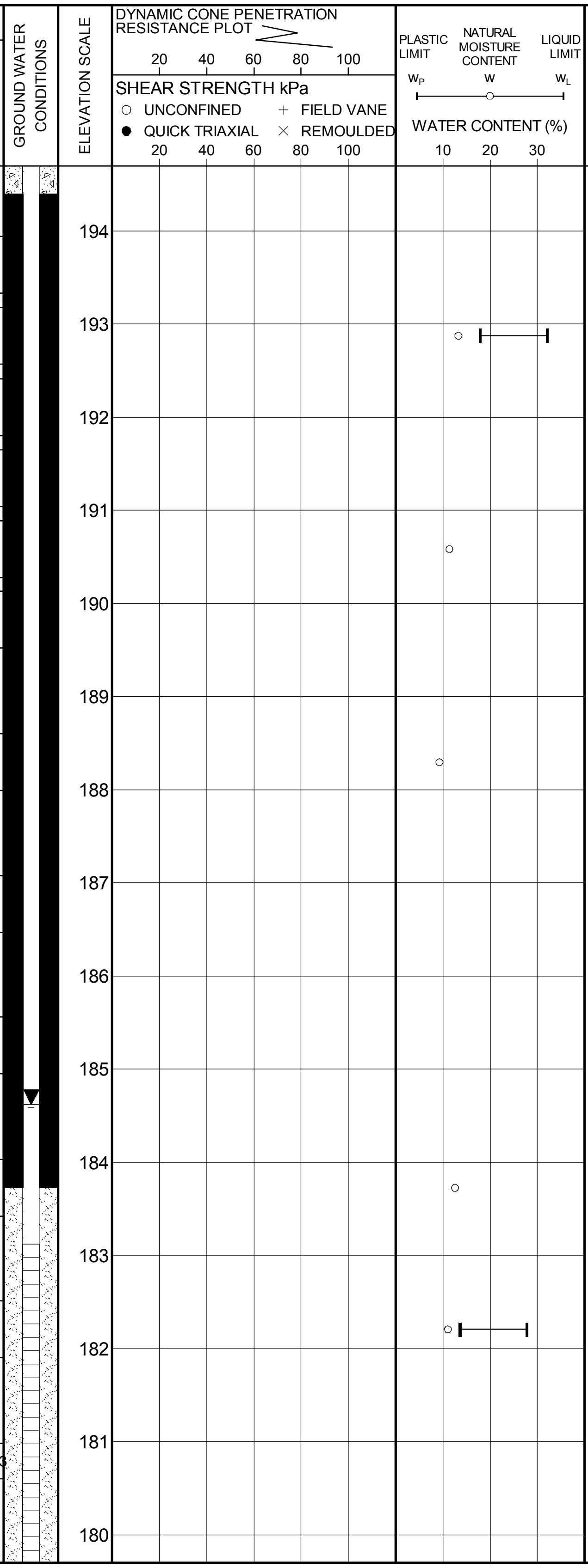
RECORD OF BOREHOLE No MR-1

SHEET 1 OF 3

METRIC

PROJECT 10-1111-0211			
G.W.P. 2150-01-00	LOCATION N 4831249.0 ;E 287997.7	ORIGINATED BY SB	
DIST Central	HWY 401	BOREHOLE TYPE 108 mm I.D. Hollow Stem Augers	COMPILED BY CC/TVA
DATUM GEODETIC	DATE June 6 and 7, 2012	CHECKED BY KJB	

ELEV DEPTH	SOIL PROFILE DESCRIPTION	SAMPLES NUMBER	TYPE	"N" VALUES	UNIT WEIGHT γ kN/m³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR	SA	SI	CL
194.7	GROUND SURFACE								
0.0	ASPHALT								
0.2	Sand and gravel (FILL) Brown Moist								
193.9 0.8	Clayey silt, some sand, some gravel, (FILL) Stiff to hard Grey Moist	1	SS	15					
		2	SS	10					
	Containing wood fragments between depths of 2.2 m to 3.0 m	3	SS	9					
		4	SS	11					
		5	SS	45					
		6	SS	11					
		7	SS	18					
		8	SS	11					
		9	SS	16					
184.0 10.7	CLAYEY SILT, some sand, trace to some gravel Very stiff Brown Moist	10	SS	22		6	23	46	25
183.1 11.6	CLAYEY SILT with SAND, trace to some gravel (TILL) Stiff to hard Brown Moist	11	SS	38		7	25	46	22
		12	SS	*89/0.23					
	Grey below a depth of 14.0 m								



Continued Next Page

+3, ×3: Numbers refer to Sensitivity

○3% STRAIN AT FAILURE

RECORD OF BOREHOLE No MR-1

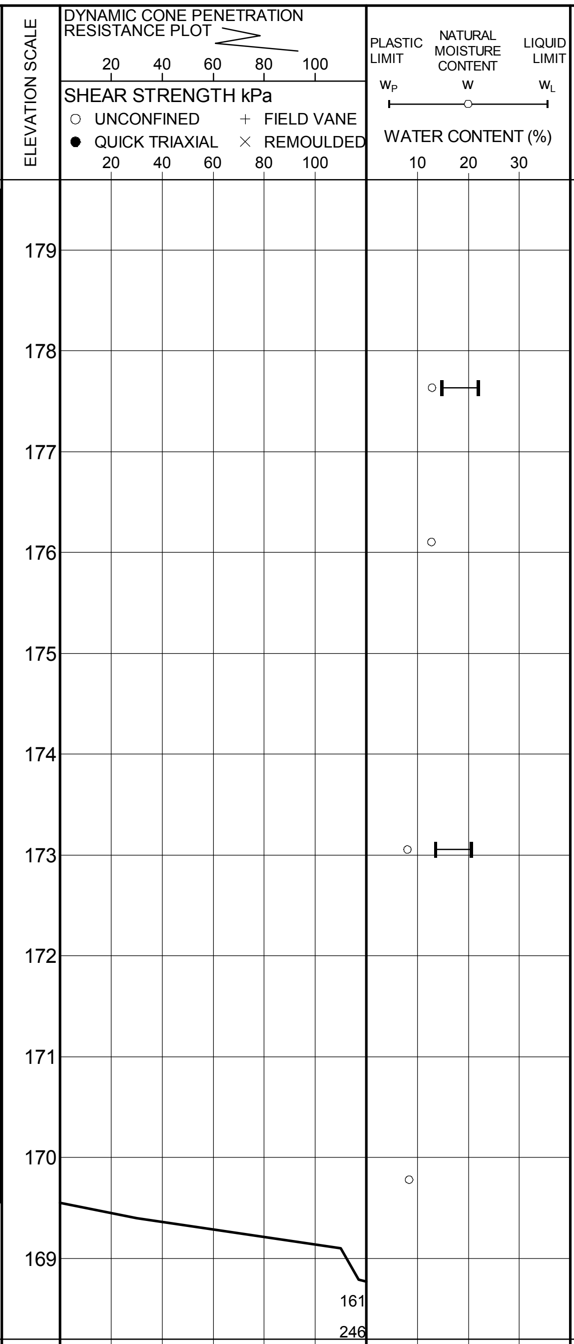
SHEET 2 OF 3

METRIC

PROJECT 10-1111-0211
G.W.P. 2150-01-00
DIST Central HWY 401
DATUM GEODETIC
LOCATION N 4831249.0 ;E 287997.7
BOREHOLE TYPE 108 mm I.D. Hollow Stem Augers
DATE June 6 and 7, 2012
ORIGINATED BY SB
COMPILED BY CC/TVA
CHECKED BY KJB

--- CONTINUED FROM PREVIOUS PAGE ---

ELEV DEPTH	DESCRIPTION	NUMBER	TYPE	"N" VALUES	GR	SA	SI	CL
	CLAYEY SILT with SAND, trace to some gravel (TILL) Stiff to hard Brown Moist	13	SS	18				
		14	SS	14				
		15	SS	17				
		16	SS	17				
		17	SS	40	9	32	42	17
169.6		18	SS	86				
25.2	END OF BOREHOLE Dynamic Cone Penetration Test (DCPT)							
168.2 26.5	END OF DCPT Refusal to Further Penetration (246 Blows / 0.3 m)							



Continued Next Page

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

RECORD OF BOREHOLE No MR-1

SHEET 3 OF 3

METRIC

PROJECT 10-1111-0211
G.W.P. 2150-01-00
DIST Central HWY 401
DATUM GEODETIC

LOCATION N 4831249.0 ;E 287997.7
BOREHOLE TYPE 108 mm I.D. Hollow Stem Augers
DATE June 6 and 7, 2012

ORIGINATED BY SB
COMPILED BY CC/TVA
CHECKED BY KJB

SOIL PROFILE			SAMPLES					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/m^3	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
ELEV DEPTH	DESCRIPTION --- CONTINUED FROM PREVIOUS PAGE ---	STRAT PLOT	NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE				
	NOTES: (see below)										

NOTES:

* Split-Spoon bouncing on possible cobbles/boulders.

1. A piece of cobble was observed at top of split-spoon upon completion of sampling No. 18.

2. Water level inside augers at a depth of 18.0 m below ground surface (Elev. 176.7 m), measured at start of work day on June 7, 2012.

3. Piezometer installation consists of 50 mm diameter PVC pipe with a 3.0 m slotted screen.

Water Level Readings

Date	Depth (m)	Elev. (m)
06/07/12	Dry	-
08/10/12	10.4	184.3
10/09/12	10.2	184.5
11/05/12	10.1	184.6

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

RECORD OF BOREHOLE No MR-2

SHEET 1 OF 3

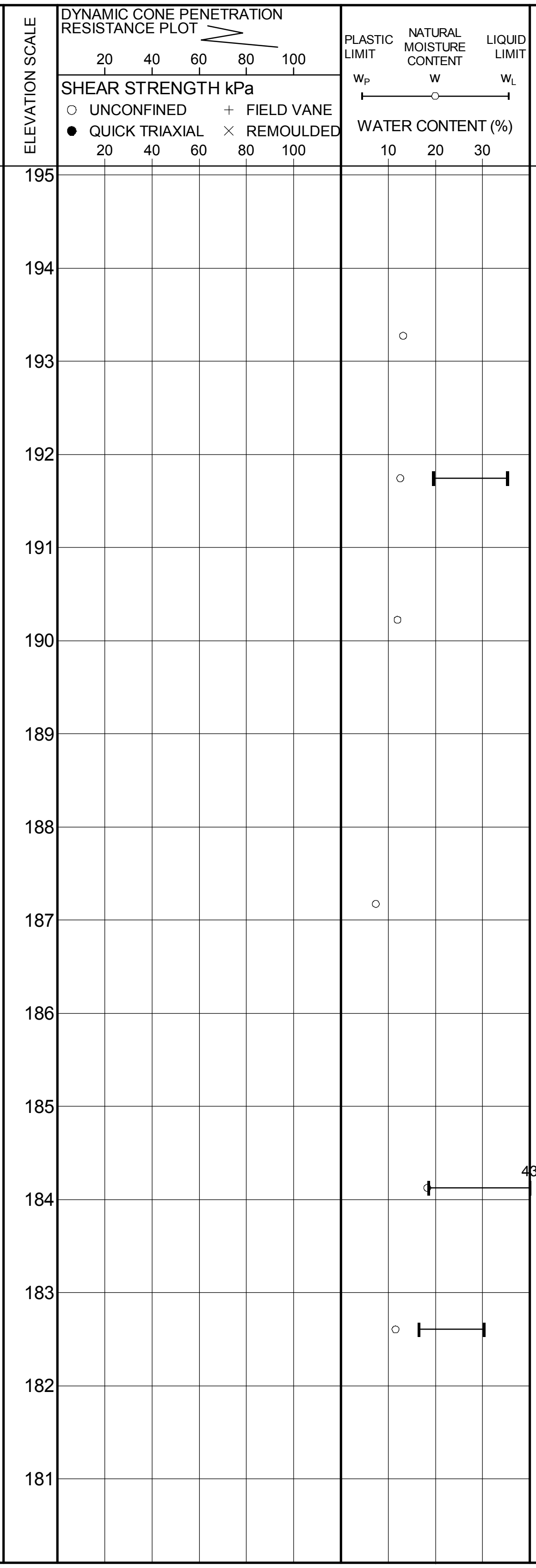
METRIC

PROJECT 10-1111-0211
G.W.P. 2150-01-00
DIST Central HWY 401
DATUM GEODETIC

LOCATION N 4831239.6 ;E 287971.8
BOREHOLE TYPE 108 mm I.D. Hollow Stem Augers
DATE May 22 to 23, 2012

ORIGINATED BY SB
COMPILED BY CC/TVA
CHECKED BY KJB

ELEV DEPTH	DESCRIPTION	NUMBER	TYPE	"N" VALUES	GR SA SI CL
195.1	GROUND SURFACE				
0.0	ASPHALT				
0.2	Sand and gravel (FILL) Brown Moist				
194.3 0.8	Clayey silt to silty clay, trace to some sand, trace to some gravel, containing organic and wood fragments to a depth of 5.2 m (FILL) Firm to very stiff Grey Moist	1	SS	10	
		2	SS	9	
		3	SS	7	
	with gravel	4	SS	14	40 16 29 15
		5	SS	16	
		6	SS	18	
		7	SS	12	
	with gravel	8	SS	20	
		9	SS	11	
184.4 10.7	SILTY CLAY, trace sand, trace gravel Stiff Brown Moist	10	SS	14	
183.5 11.6	CLAYEY SILT with SAND, trace to some gravel (TILL) Stiff to hard Brown Moist	11	SS	35	11 27 42 20
	containing sand seams and cobbles	12	SS	40	



UNIT WEIGHT γ kN/m³

REMARKS & GRAIN SIZE DISTRIBUTION (%)

Continued Next Page

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

Golder Associates

Foundation Design

RECORD OF BOREHOLE No MR-2

SHEET 2 OF 3

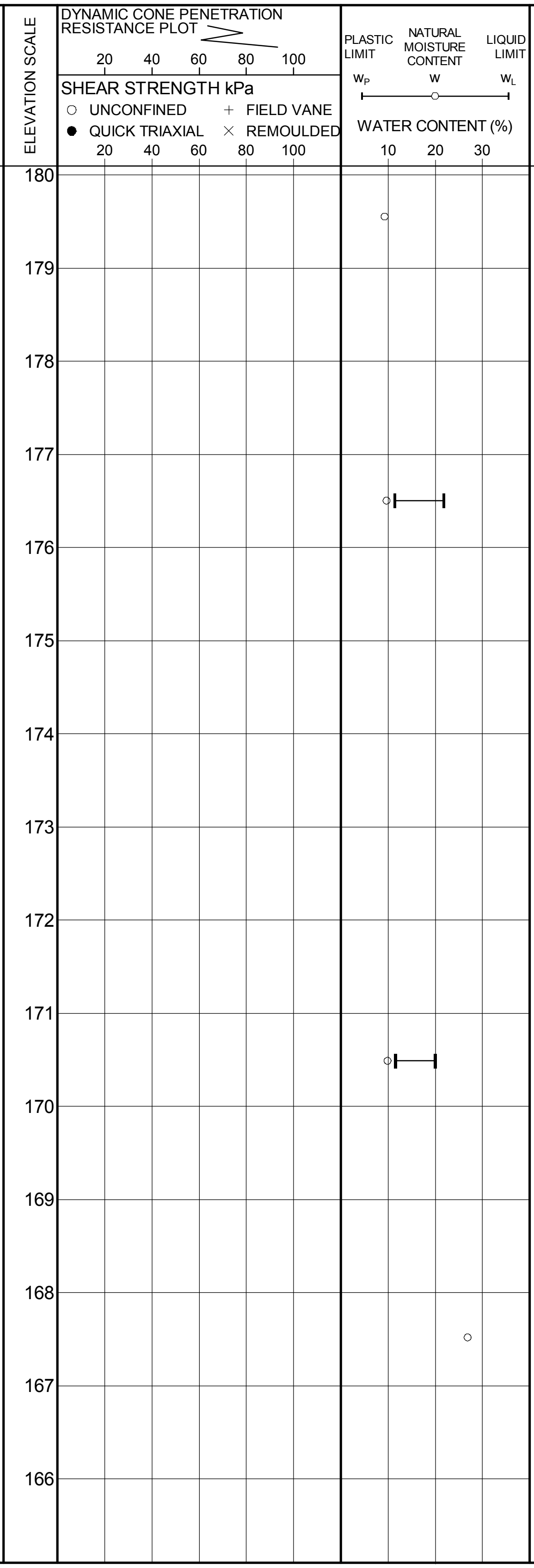
METRIC

PROJECT 10-1111-0211
G.W.P. 2150-01-00
LOCATION N 4831239.6 ;E 287971.8
ORIGINATED BY SB
DIST Central HWY 401
BOREHOLE TYPE 108 mm I.D. Hollow Stem Augers
COMPILED BY CC/TVA
DATUM GEODETIC
DATE May 22 to 23, 2012
CHECKED BY KJB

--- CONTINUED FROM PREVIOUS PAGE ---

ELEV DEPTH	DESCRIPTION	NUMBER	TYPE	"N" VALUES	GR	SA	SI	CL
	CLAYEY SILT with SAND, trace to some gravel (TILL) Stiff to hard Brown Moist	13	SS	21				
		14	SS	18				
		15	SS	12	10	30	43	17
		16	SS	19				
		17	SS	15				
		18	SS	83				
		19	SS	116	13	46	29	12
		20	SS	84				
168.0 27.1	SILTY CLAY, trace sand, trace gravel Hard Grey Wet	21A	SS	39				
167.4 27.7	Silty SAND and GRAVEL, trace clay Dense Grey Wet	21B						
166.4 28.7	SAND and SILT, trace to some gravel, trace to some clay (TILL) Compact to very dense Grey Wet	22	SS	64				

GROUND WATER CONDITIONS: ∇ at approx. elevation 175.6



UNIT WEIGHT γ kN/m³

REMARKS & GRAIN SIZE DISTRIBUTION (%)

Continued Next Page

+3, ×3: Numbers refer to Sensitivity

○3% STRAIN AT FAILURE

PROJECT 10-1111-0211

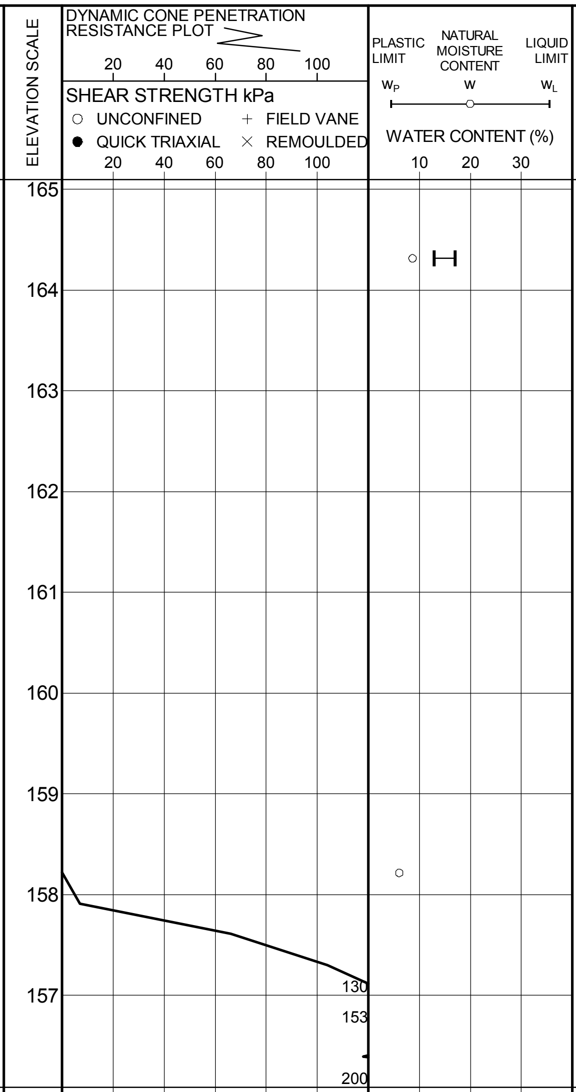
RECORD OF BOREHOLE No MR-2

SHEET 3 OF 3

METRIC

G.W.P. 2150-01-00
LOCATION N 4831239.6 ;E 287971.8
ORIGINATED BY SB
DIST Central HWY 401
BOREHOLE TYPE 108 mm I.D. Hollow Stem Augers
COMPILED BY CC/TVA
DATUM GEODETIC
DATE May 22 to 23, 2012
CHECKED BY KJB

ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	GR	SA	SI	CL
	--- CONTINUED FROM PREVIOUS PAGE ---									
	SAND and SILT, trace to some gravel, trace to some clay (TILL) Compact to very dense Grey Wet Frequent shale fragment inclusions below a depth of 30.5 m		23	SS	61		9	38	43	10
			24	SS	29					
159.1 36.0	SAND and GRAVEL, some silt, trace clay Compact Grey Wet		25	SS	11		32	51	15	2
157.9 37.2	END OF BOREHOLE Dynamic Cone Penetration Test (DCPT)									
156.1 39.0	END OF DCPT Refusal to Further Penetration (200 Blows / 0.15 m) NOTE: 1. Water level inside augers at a depth of 19.8 m below ground surface (Elev. 175.3 m), measured at the start of work day on May 22, 2012.									



UNIT WEIGHT γ kN/m³

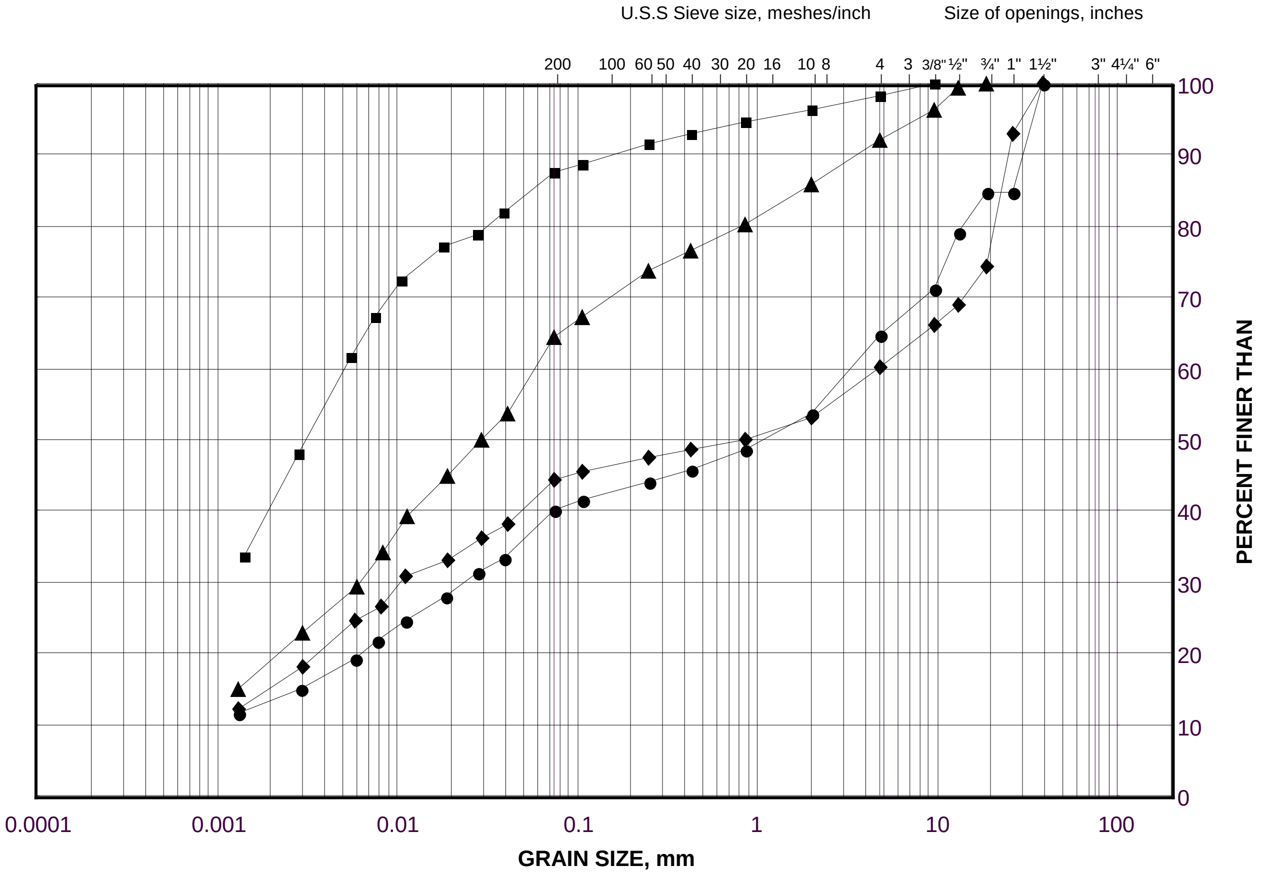
REMARKS & GRAIN SIZE DISTRIBUTION (%)

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

GRAIN SIZE DISTRIBUTION

Silty Clay with Gravel to Clayey Silt to Sandy Clayey Silt to Sandy Clayey Silt with Gravel (Fill)

FIGURE F1



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

LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	TC15-3	2	184.7
■	TC15-5	2	184.7
◆	MR-2	4	191.7
▲	TC15-3	6	181.7

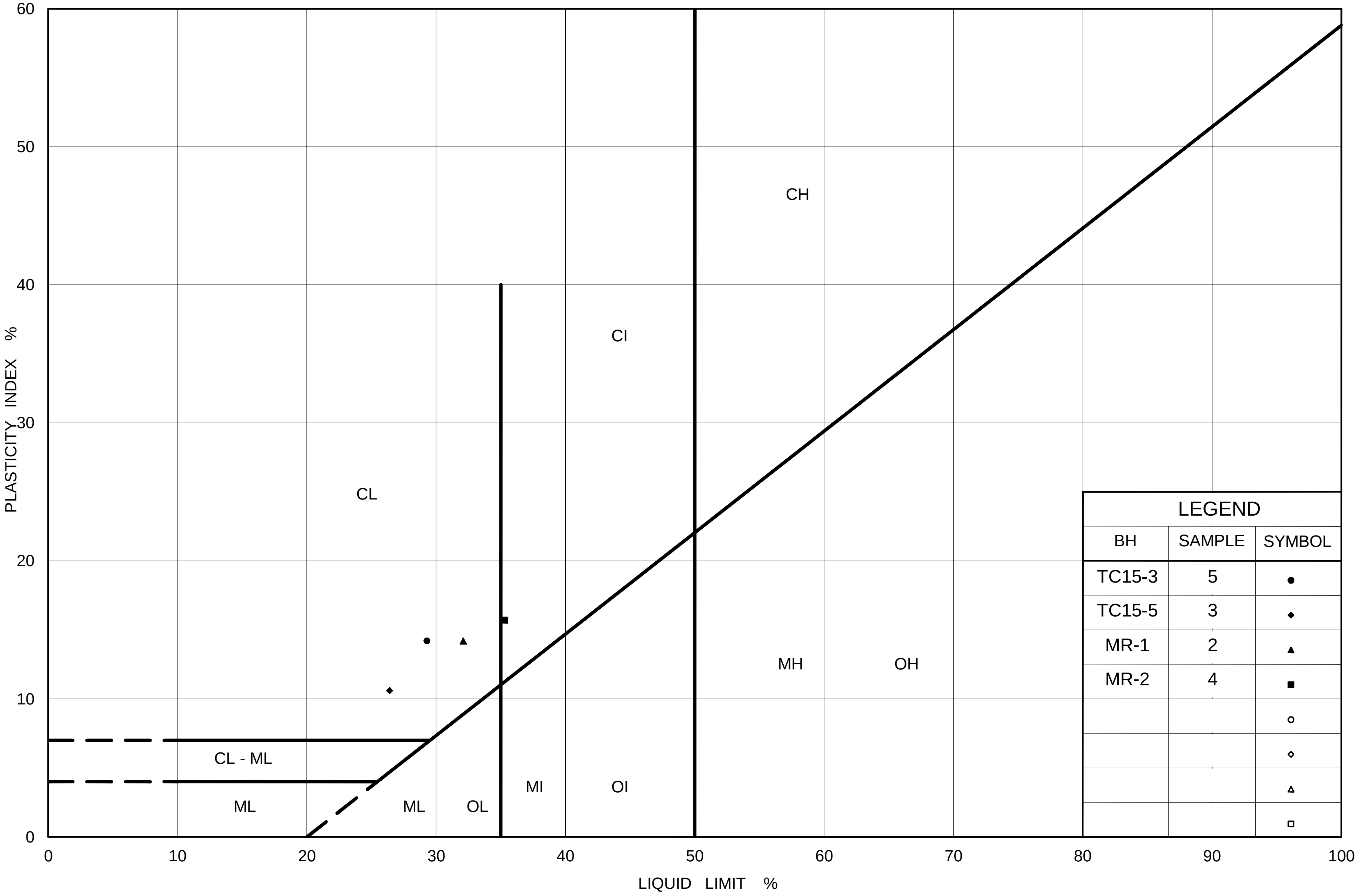
Project Number: 10-1111-0211

Checked By: KJB

Golder Associates

Date: 05-Jan-16

Oct 75, FF-S-21



LEGEND

BH	SAMPLE	SYMBOL
TC15-3	5	●
TC15-5	3	◆
MR-1	2	▲
MR-2	4	■
		○
		◇
		△
		□

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PLASTICITY CHART
Silty Clay with Gravel to Clayey Silt to Sandy Clayey Silt (Fill)

Figure No. F2

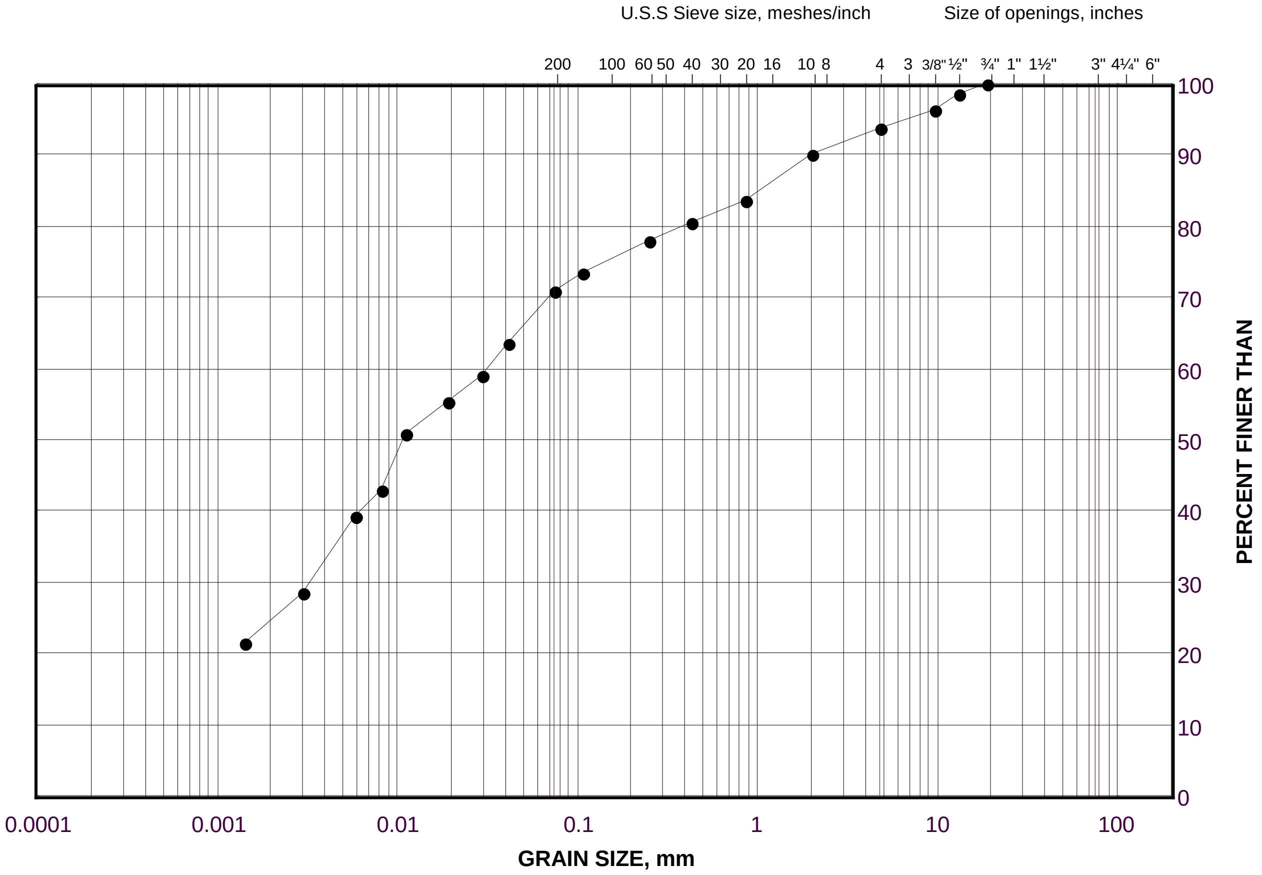
Project No. 10-1111-0211

Checked By: KJB

GRAIN SIZE DISTRIBUTION

Clayey Silt

FIGURE F3



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

LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	MR-1	10	183.7

Project Number: 10-1111-0211

Checked By: KJB

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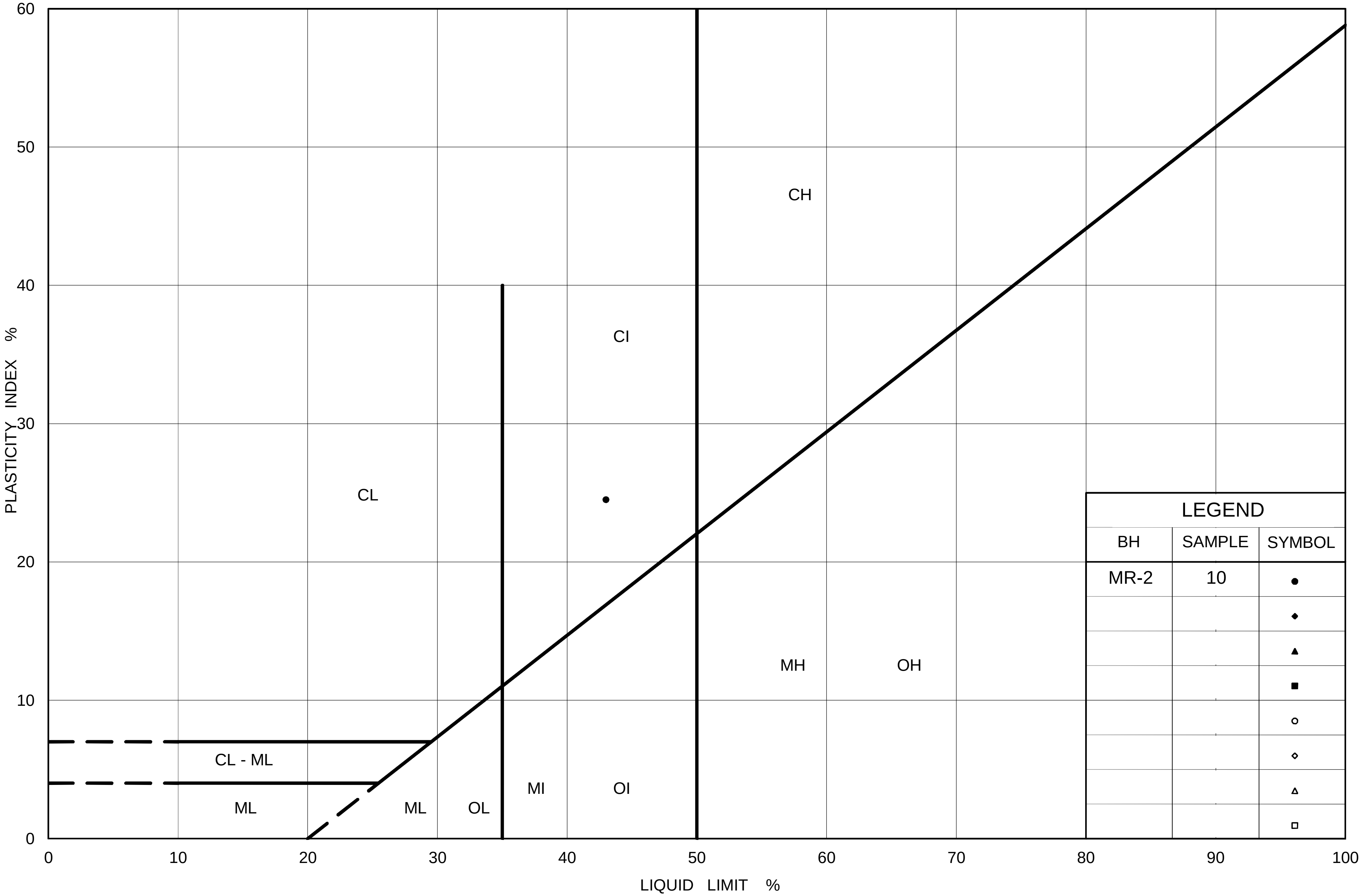
Date: 05-Jan-16

Oct 75, FF-S-21



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PLASTICITY CHART
Silty Clay

Figure No. F4

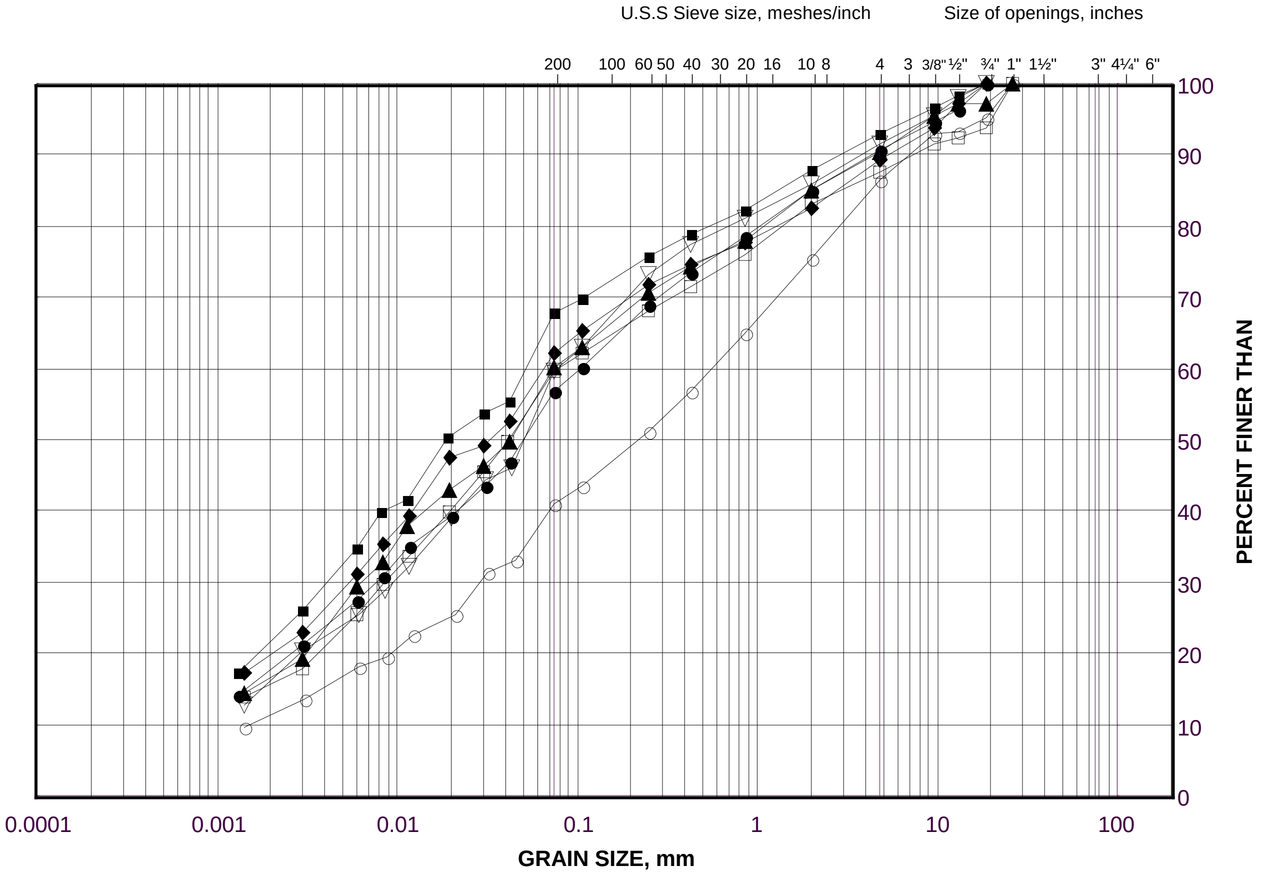
Project No. 10-1111-0211

Checked By: KJB

GRAIN SIZE DISTRIBUTION

Sandy Clayey Silt to Clayey Silt with Sand (Till)

FIGURE F5



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

LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	TC15-3	10	176.4
■	MR-1	11	182.2
◆	MR-2	11	182.6
▲	MR-2	15	176.5
▽	MR-1	17	173.1
❍	MR-2	19	170.5
□	TC15-5	4	183.2

Project Number: 10-1111-0211

Checked By: KJB

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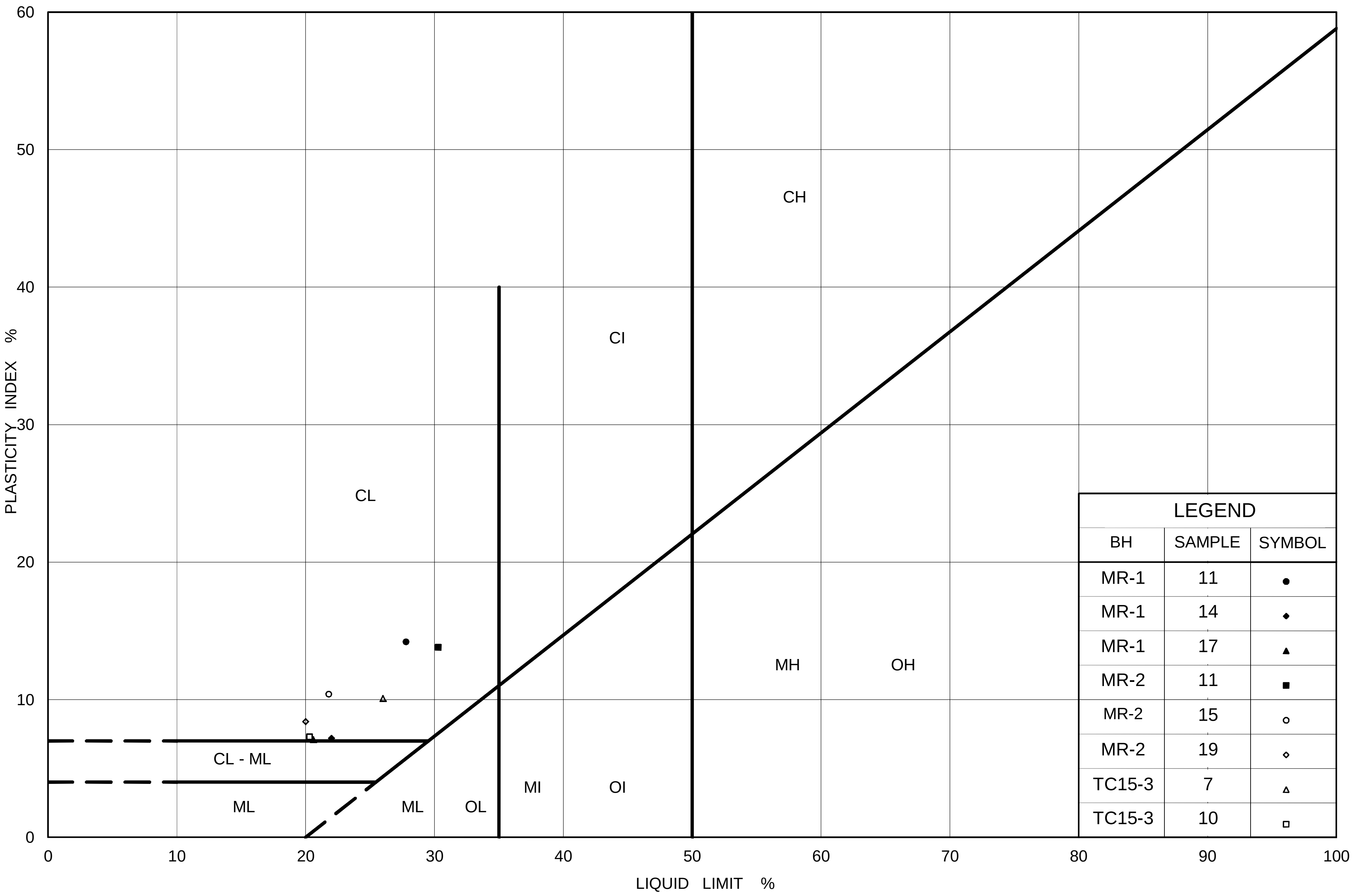
Date: 05-Jan-16

Oct 75, FF-S-21



LEGEND

BH	SAMPLE	SYMBOL
MR-1	11	●
MR-1	14	◆
MR-1	17	▲
MR-2	11	■
MR-2	15	○
MR-2	19	◇
TC15-3	7	△
TC15-3	10	□

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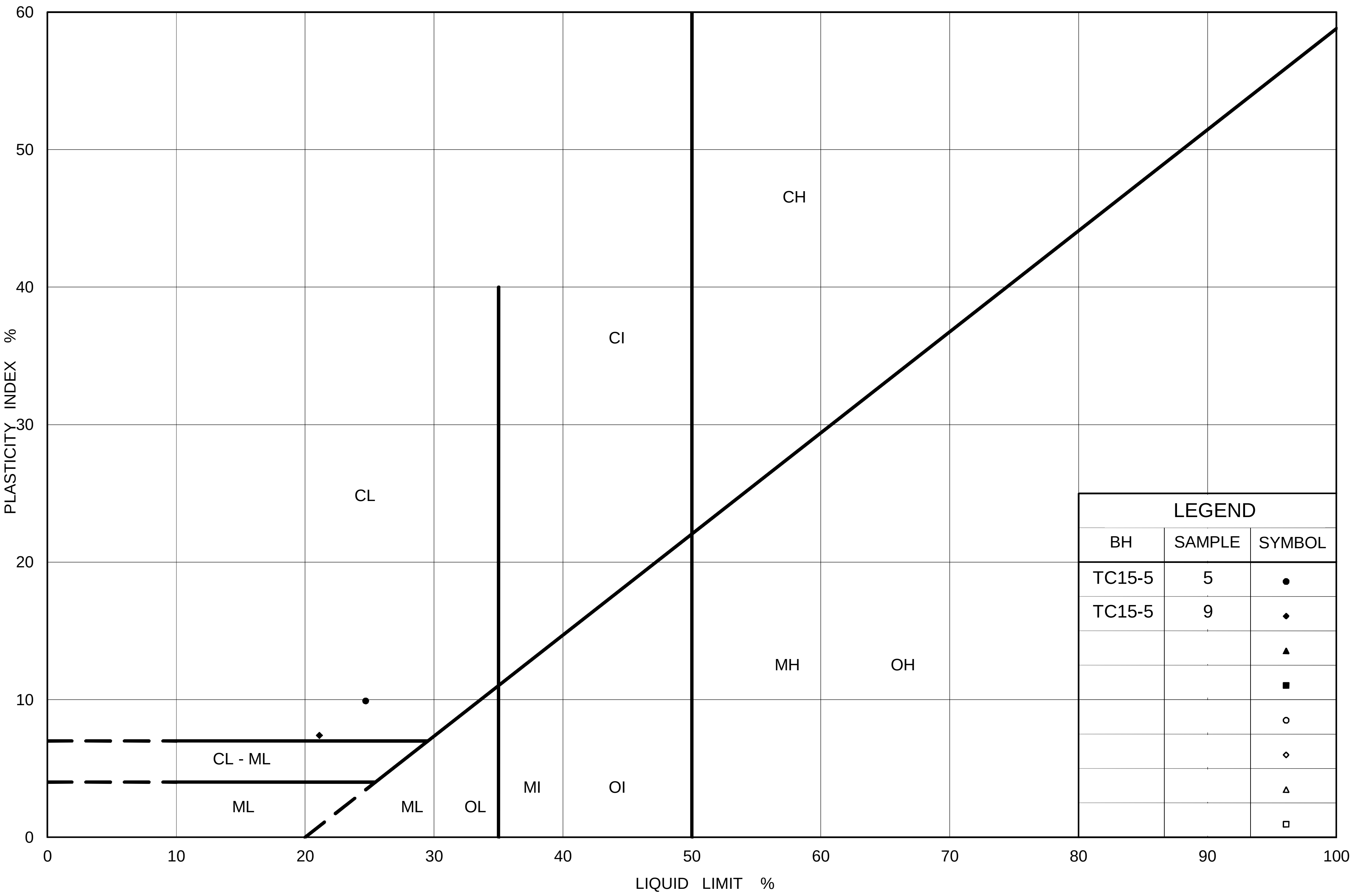
PLASTICITY CHART
Sandy Clayey Silt to Clayey Silt with Sand (Till)

Figure No. F6-A

Project No. 10-1111-0211

Checked By: KJB

Oct 75, FF-S-21



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PLASTICITY CHART
Sandy Clayey Silt (Till)

Figure No. F6-B

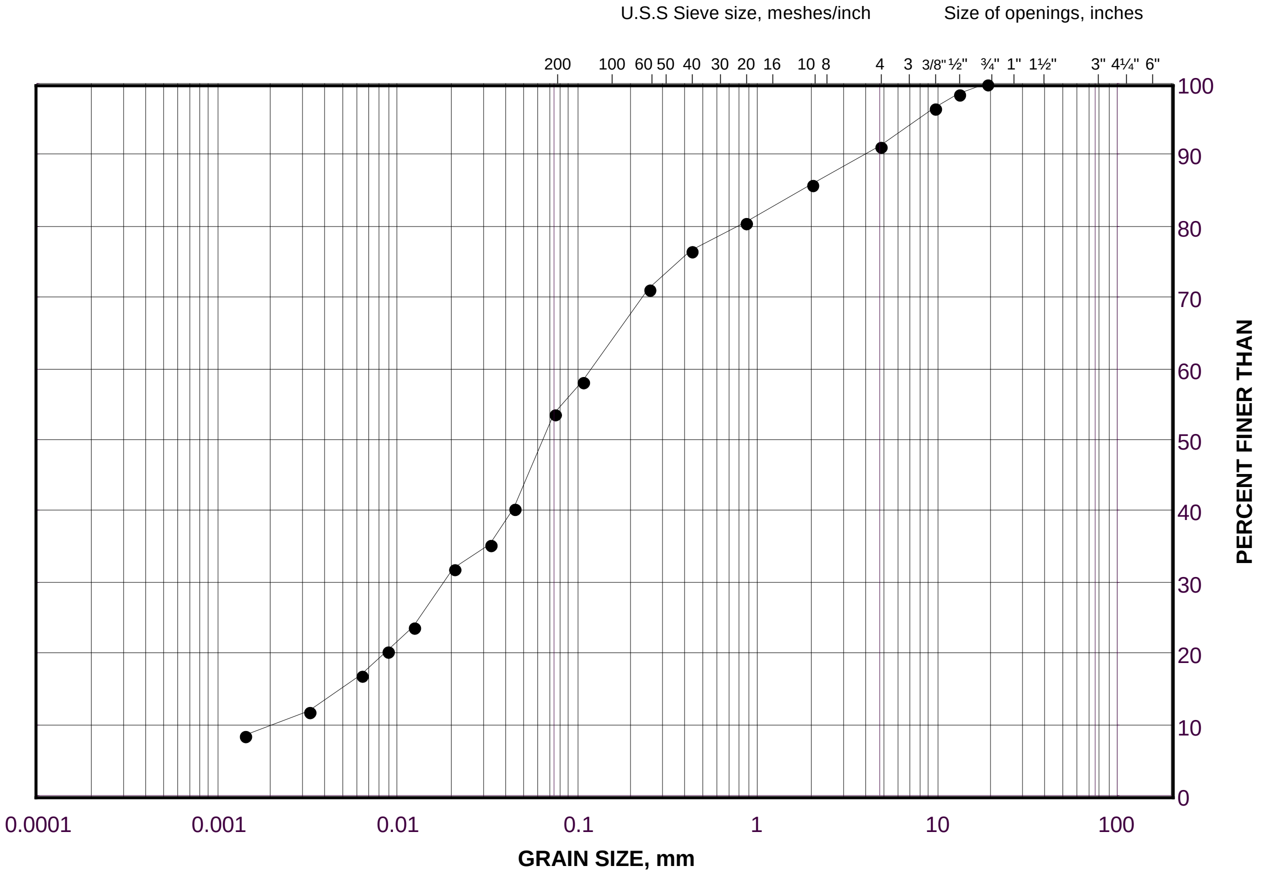
Project No. 10-1111-0211

Checked By: KJB

GRAIN SIZE DISTRIBUTION

Sand and Silt (Till)

FIGURE F7



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

LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	MR-2	23	164.3

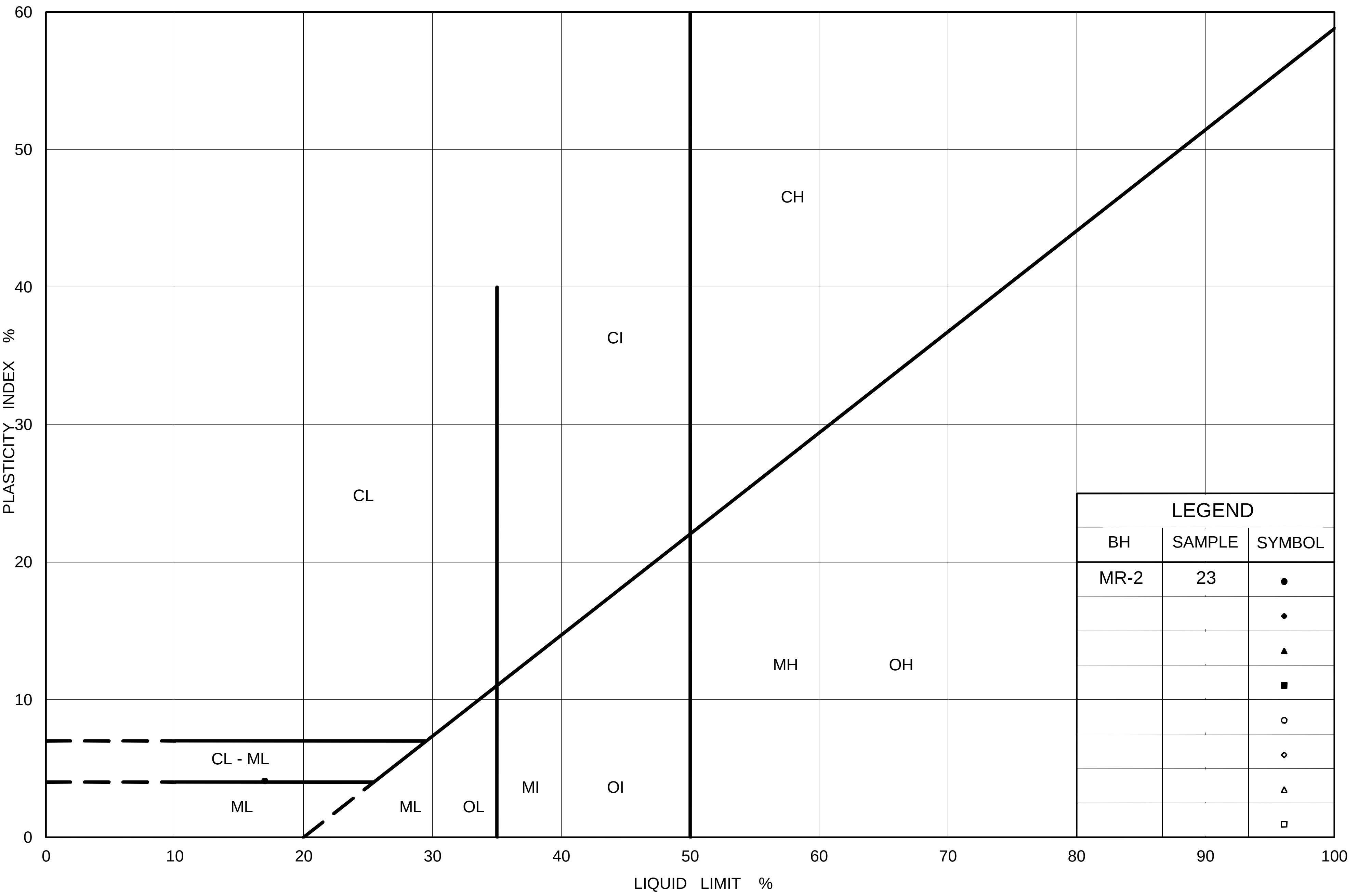
Project Number: 10-1111-0211

Checked By: KJB

Golder Associates

Date: 05-Jan-16

Oct 75, FF-S-21



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PLASTICITY CHART
Sand and Silt (Till)

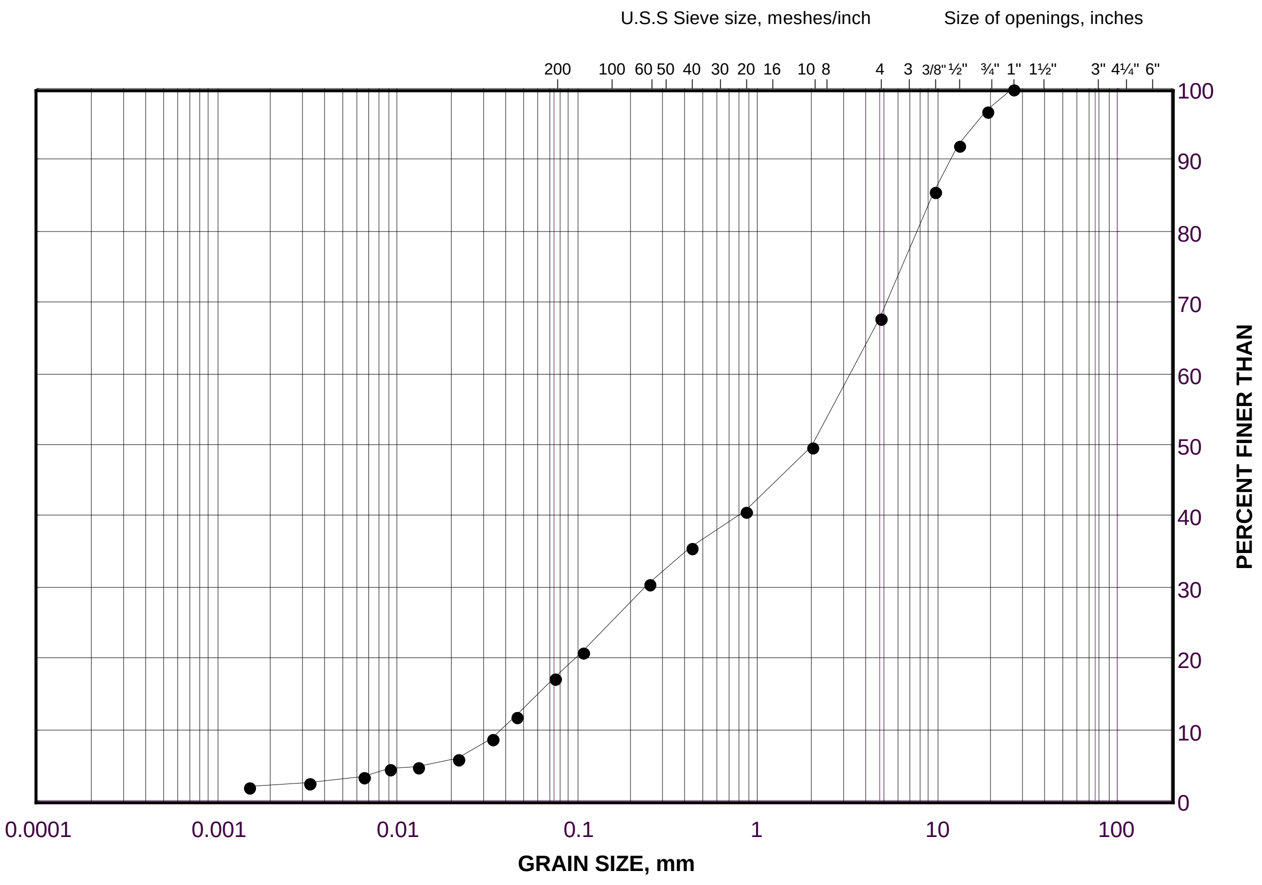
Figure No. F8

Project No. 10-1111-0211

Checked By: KJB

GRAIN SIZE DISTRIBUTION
Sand and Gravel

FIGURE F9



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

LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	MR-2	25	158.2

Project Number: 10-1111-0211

Checked By: KJB

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Date: 05-Jan-16

APPENDIX G

Borehole Records and Laboratory Test Results
Culvert No. 12, Station 17+145
TC15-6, TC15-7
Figure G1 to Figure G4

RECORD OF BOREHOLE No TC15-6

SHEET 1 OF 1

METRIC

PROJECT 10-1111-0211

G.W.P. 2150-01-00

DIST Central HWY 401

DATUM GEODETIC

LOCATION N 4831376.5 ;E 288156.4

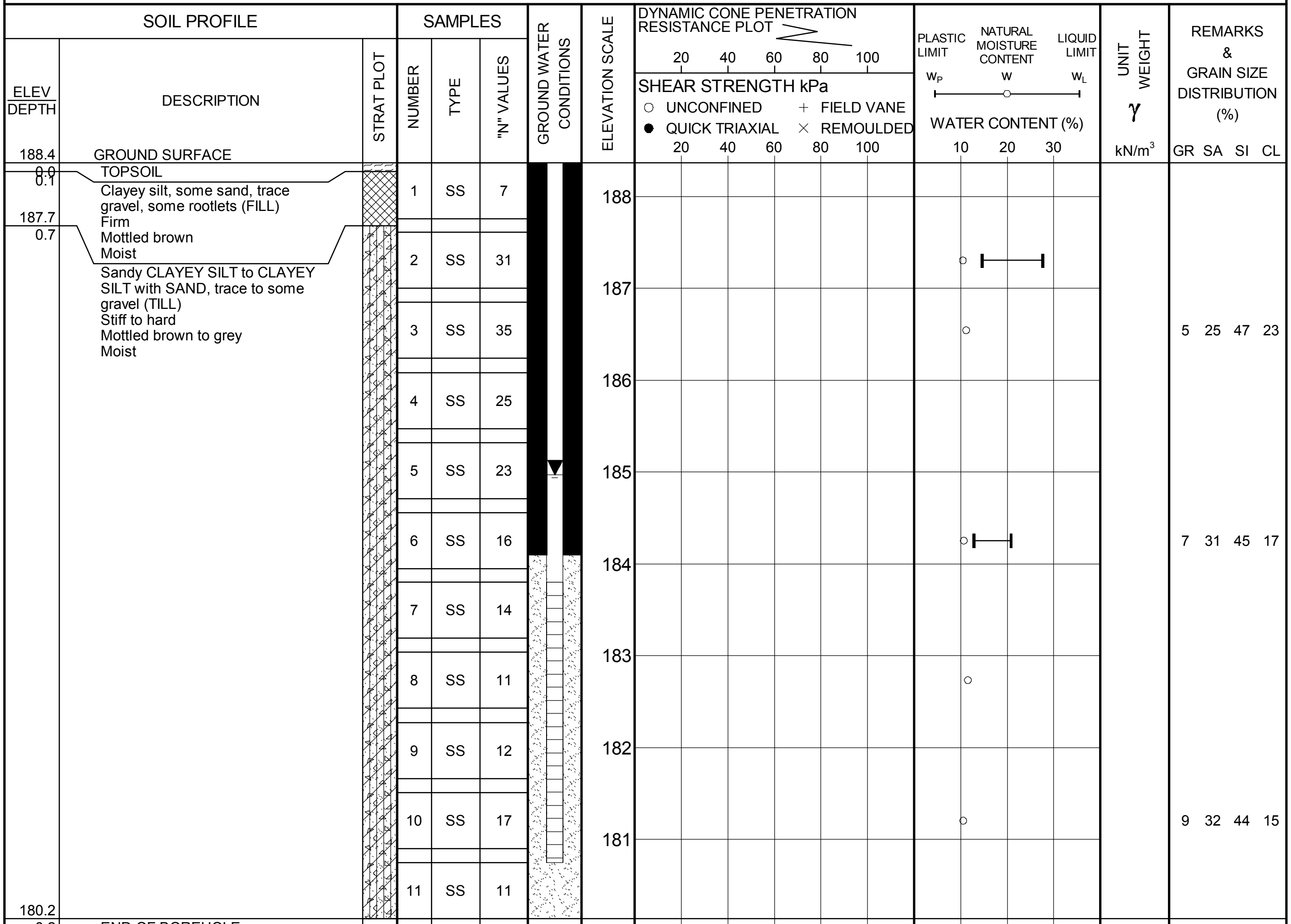
BOREHOLE TYPE 150 mm O.D. Solid Stem Augers

DATE November 5, 2015

ORIGINATED BY QC

COMPILED BY AJS

CHECKED BY KJB



ELEV DEPTH	DESCRIPTION	NUMBER	TYPE	"N" VALUES	GR	SA	SI	CL
188.4	GROUND SURFACE							
0.0 0.1	TOPSOIL							
	Clayey silt, some sand, trace gravel, some rootlets (FILL) Firm Mottled brown Moist	1	SS	7				
187.7 0.7	Sandy CLAYEY SILT to CLAYEY SILT with SAND, trace to some gravel (TILL) Stiff to hard Mottled brown to grey Moist	2	SS	31				
		3	SS	35	5	25	47	23
		4	SS	25				
		5	SS	23				
		6	SS	16	7	31	45	17
		7	SS	14				
		8	SS	11				
		9	SS	12				
		10	SS	17	9	32	44	15
		11	SS	11				
180.2 8.2	END OF BOREHOLE							

NOTES:

1. Borehole dry upon completion of drilling.

2. Water level measured in piezometer:

Date	Depth (m)	Elev. (m)
11/19/15	3.4	185.0

+ 3, × 3: Numbers refer to Sensitivity

○ 3% STRAIN AT FAILURE

Golder Associates

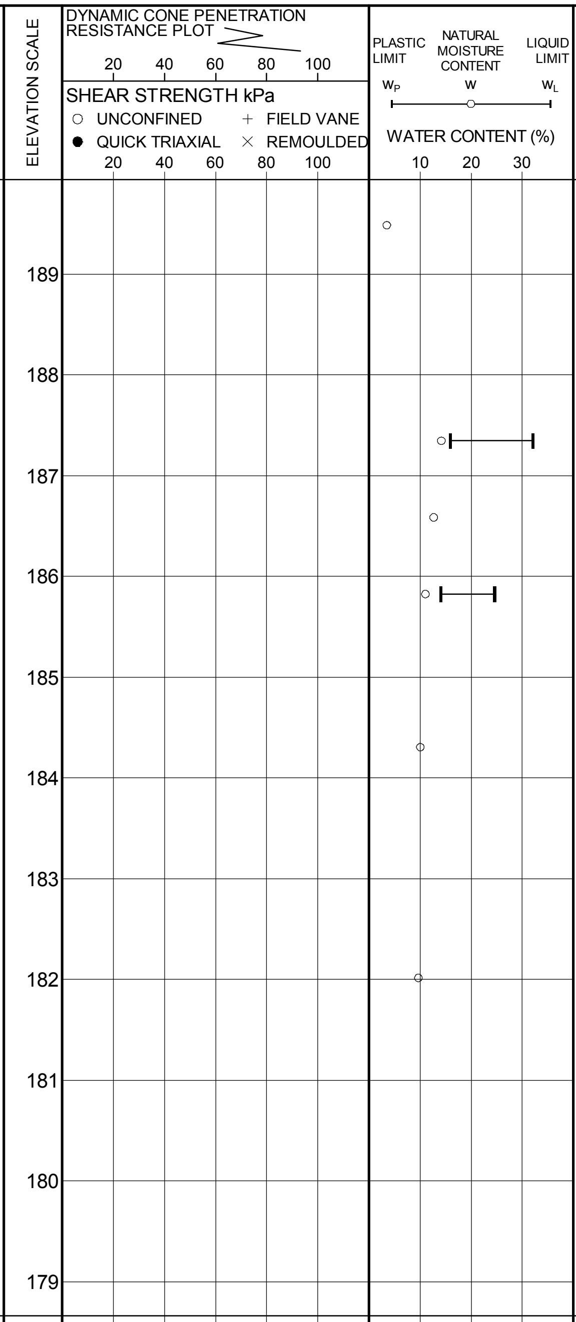
RECORD OF BOREHOLE No TC15-7

SHEET 1 OF 1

METRIC

PROJECT 10-1111-0211
G.W.P. 2150-01-00
DIST Central HWY 401
DATUM GEODETIC
LOCATION N 4831351.4 ;E 288147.9
BOREHOLE TYPE 150 mm O.D. Hollow Stem Augers
DATE November 5, 2015
ORIGINATED BY QC
COMPILED BY AJS
CHECKED BY KJB

ELEV DEPTH	DESCRIPTION	NUMBER	TYPE	"N" VALUES	GR	SA	SI	CL
189.9	GROUND SURFACE							
0.0	ASPHALT							
0.2	Sand and gravel (FILL) Compact Brown Moist	1	SS	23				
189.1 0.8	Sandy clayey silt, trace to some gravel, containing silt seams and pockets, oxidation staining (FILL) Firm to stiff Mottled brown	2	SS	7				
		3	SS	12				
		4	SS	13	5	24	47	24
186.9 3.0	Sandy CLAYEY SILT to CLAYEY SILT with SAND, some gravel, oxidation staining to a depth of 8.2 m (TILL) Very stiff to hard Mottled grey to brown becoming grey below 6.1 m depth Moist	5	SS	21				
		6	SS	28	4	28	49	19
		7	SS	47				
		8	SS	59				
		9	SS	35				
		10	SS	19	8	36	41	15
		11	SS	17				
		12	SS	17				
178.6 11.3	END OF BOREHOLE NOTE: 1. Borehole dry upon completion of drilling.							



UNIT WEIGHT γ kN/m³

REMARKS & GRAIN SIZE DISTRIBUTION (%)

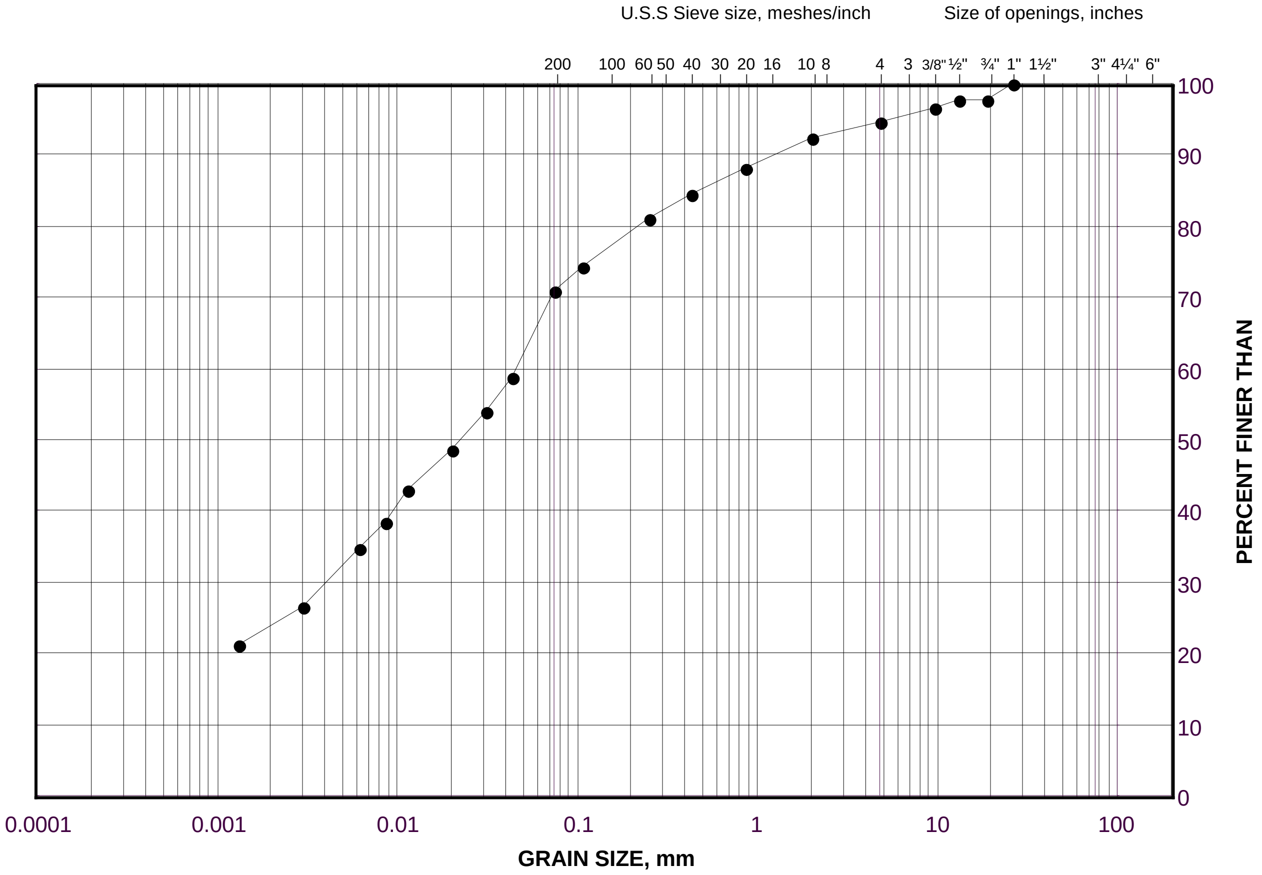
GTA-MTO 001 T:\PROJECTS\2010\10-1111-0211 (AECOM, MISSISSAUGA)\LOG\1011110211.GPJ GAL-GTA.GDT 01/21/16

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

GRAIN SIZE DISTRIBUTION

Sandy Clayey Silt (Fill)

FIGURE G1



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

LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	TC15-7	4	187.3

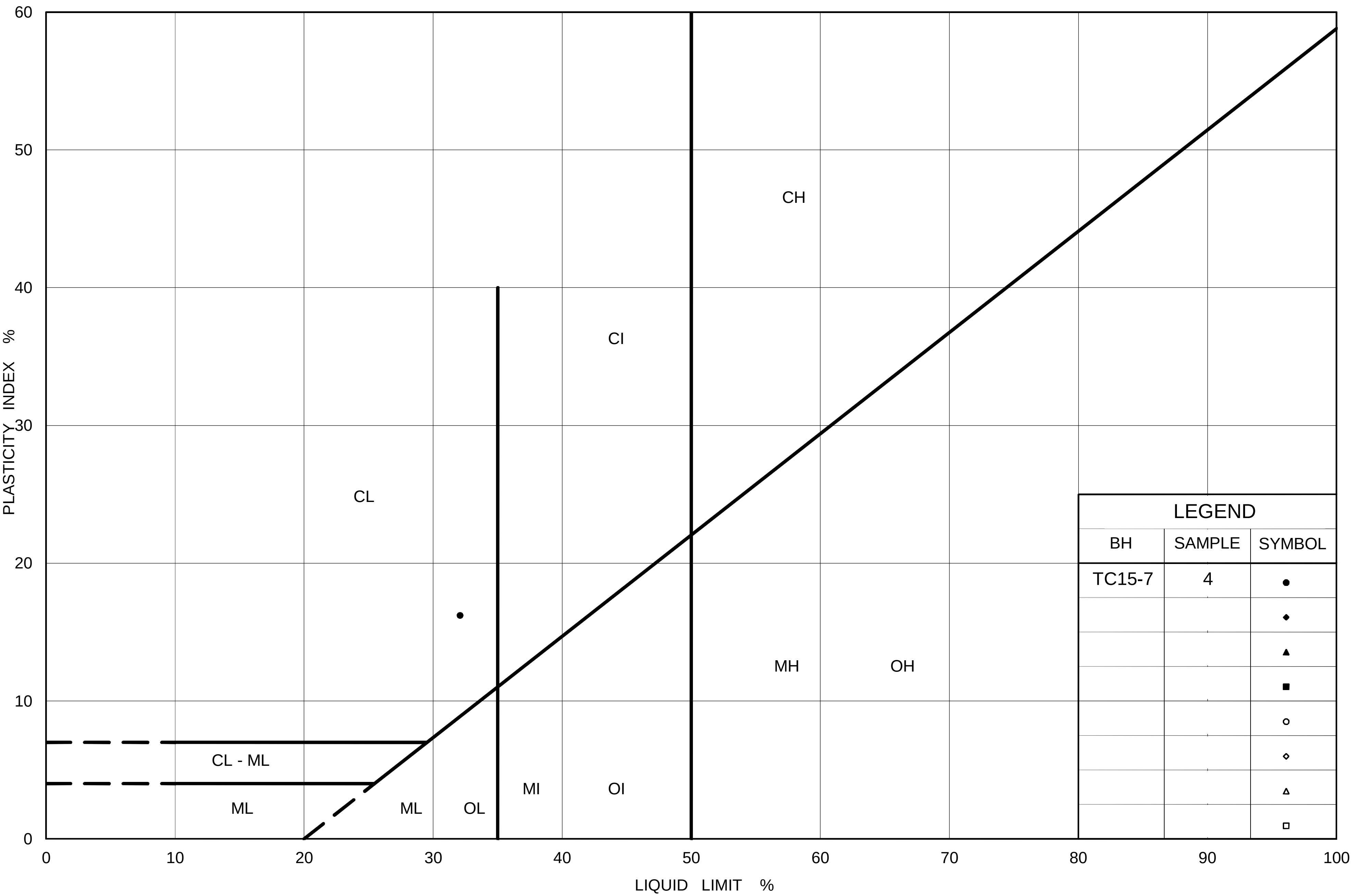
Project Number: 10-1111-0211

Checked By: KJB

Golder Associates

Date: 05-Jan-16

Oct 75, FF-S-21



Ministry of Transportation

Ontario

PLASTICITY CHART
Sandy Clayey Silt (Fill)

Figure No. G2

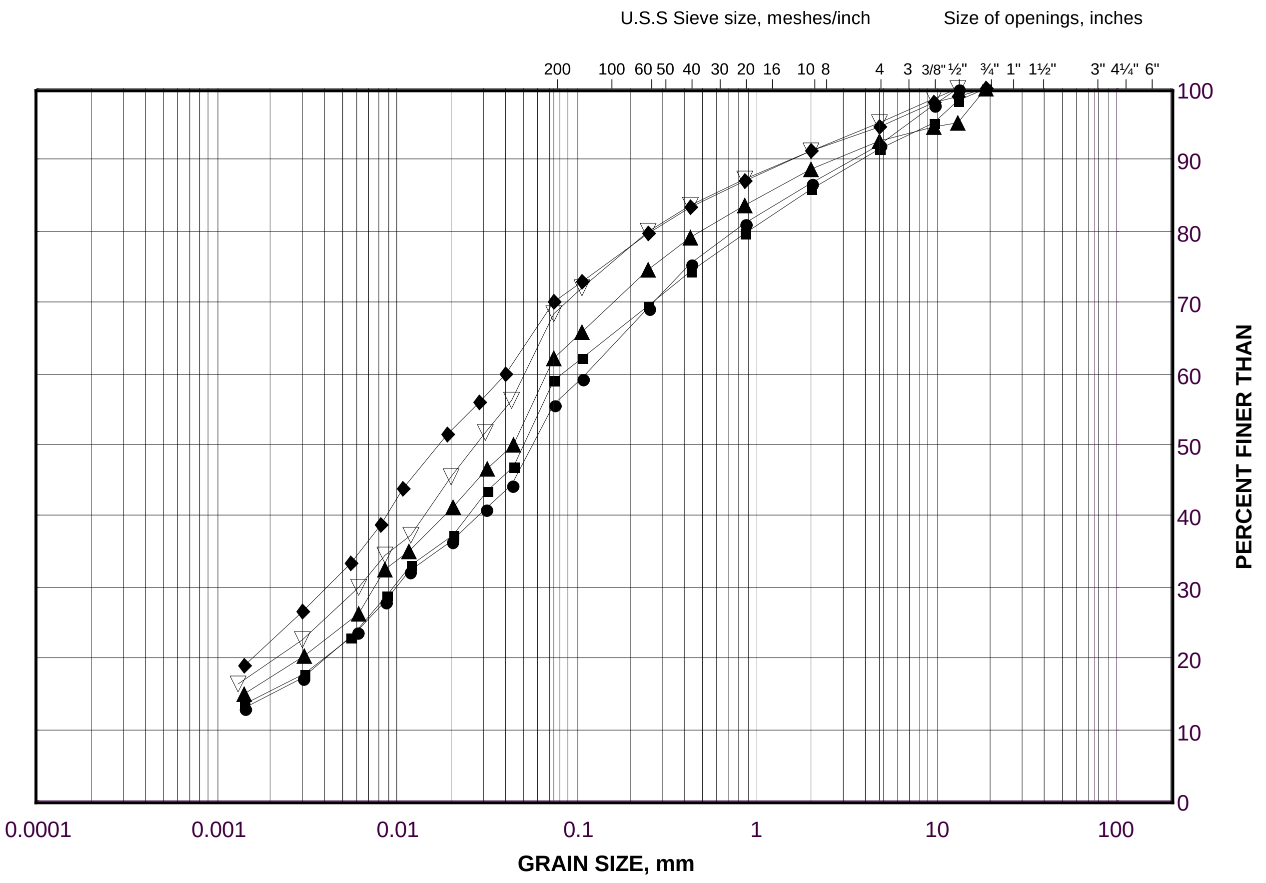
Project No. 10-1111-0211

Checked By: KJB

GRAIN SIZE DISTRIBUTION

Sandy Clayey Silt to Clayey Silt with Sand (Till)

FIGURE G3



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

LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	TC15-7	10	182.0
■	TC15-6	10	181.1
◆	TC15-6	3	186.5
▲	TC15-6	6	184.2
▽	TC15-7	6	185.8

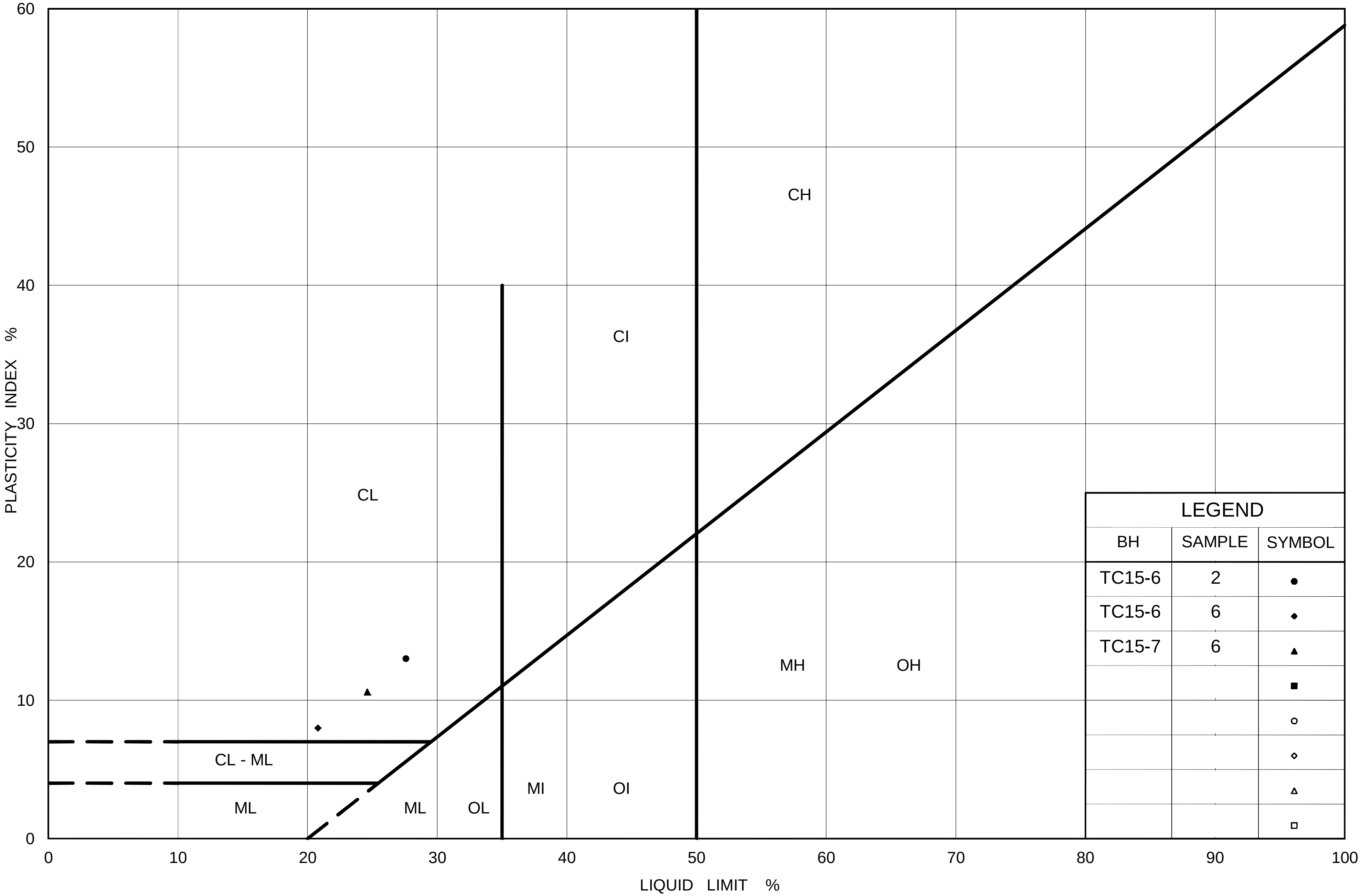
Project Number: 10-1111-0211

Checked By: KJB

Golder Associates

Date: 05-Jan-16

Oct 75, FF-S-21



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Ontario

PLASTICITY CHART
Sandy Clayey Silt to Clayey Silt with Sand (Till)

Figure No. G4

Project No. 10-1111-0211

Checked By: KJB

APPENDIX H

Non-Standard Special Provisions

PIPE INSTALLATION BY TRENCHLESS METHOD – Item No.

Special Provision

1. SCOPE

This specification covers the general requirements for the installation of pipes by trenchless methods, including Jack & Bore, Pipe Ramming, Directional Drilling, and Tunnelling. The Contractor shall determine the most appropriate method of installation for each of the crossing locations.

This specification shall supersede OPSS 415 (Construction Specification for Pipeline Installation by Tunneling), OPSS 416 (Construction Specification for Pipeline and Utility Installation by Jacking and Boring) and OPSS 450 (Construction Specification for Pipeline and Utility Installation in Soil by Horizontal Directional Drilling).

2. REFERENCES

This specification refers to the following standards, specifications, or publications:

Ontario Provincial Standard Specifications, General

OPSS 180	Management and Disposal of Excess Materials

Ontario Provincial Standard Specifications, Construction

OPSS 401	Trenching, Backfilling, and Compacting
OPSS 404	Support Systems
OPSS 491	Preservation, Protection, and Reconstruction of Existing Facilities
OPSS 492	Site Restoration Following Installation of Pipelines, Utilities and Associated Structures
OPSS 517	Dewatering of Pipeline, Utility, and Associated Structure Excavation
OPSS.PROV 539	Temporary Protection Systems

Ontario Provincial Standard Specifications, Material

OPSS.PROV 1004	Aggregates - Miscellaneous
OPSS.PROV 1350	Concrete - Materials and Production
OPSS.PROV 1440	Steel Reinforcement for Concrete
OPSS 1802	Smooth Walled Steel Pipe
OPSS.PROV 1820	Circular and Elliptical Concrete Pipe
OPSS 1840	Non-Pressure Polyethylene (PE) Plastic Pipe Products

American Society for Testing and Materials (ASTM) International Standards

ASTM A252-93	Welding and Seamless Steel Pipe Piles
ASTM D2657-03	Standard Practice for Heat Fusion Joining of Polyelofin Pipe and Fittings
ASTM D3350	Standard Specification for Polyethylene Plastics Pipe and Fittings Materials
ASTM F894	Polyethylene Large Diameter Profile Wall Sewer and Drain Pipe

Canadian Standards Association Standards:

CSA B182.6	Profile Polyethylene Sewer Pipe and Fittings.
CAN/CSA A5-93	Portland Cement
CSA W59	Welded Steel Construction (Metal Arc Welding)

3. DEFINITIONS

For the purpose of this specification, the following definitions apply:

Auger Jack & Bore: a method of forming a horizontal bore in the subsurface by essentially simultaneously jacking ahead and rotating a cutter head, followed by removal of material from inside the bore by using an auger.

Backreamer: a cutting head suitably designed for the subsurface conditions that is attached to the end of a drill string to enlarge the pilot bore during a pullback operation.

Bore Path: a drilled path according to the grade and alignment tolerances specified in the Contract Documents.

Design Engineer: means the Engineer retained by the Contractor who produces the original design and working drawings. The design engineer shall be licensed to practice in the Province of Ontario.

Design Checking Engineer: means the Engineer retained by the Contractor who checks the original design and working drawings. The design checking engineer shall be licensed to practice in the Province of Ontario.

Digger Shield/Hand Mining: a method of forming a horizontal bore in the subsurface by essentially simultaneously jacking ahead while tunnelling advances using hand–mining (man-entry operation or "Jack and Mine) or a "digger" type shield with a hydraulic excavator arm to remove materials from inside the liner pipe.

Drilling Fluids: a mixture of water and additives, such as bentonite, polymers, surfactants, and soda ash, designed to block the pore space on a bore wall, reduce friction in the bore, and to suspend and carry cuttings to the surface.

Drilling Fluid Fracture or Frac Out: a condition where the drilling fluid's pressure in the bore is sufficient to overcome the in situ confining stress, thereby fracturing the soil and/or rock materials and allowing the drilling fluids to migrate to the surface at an unplanned location.

Engineer: a Professional Engineer licensed by the Professional Engineers of Ontario to practice in the Province of Ontario.

Excavation: includes all materials encountered regardless of type and extent. Excavation shall include removal of natural soil, large boulders, cobbles, wood and fill regardless of means necessary to break consolidated materials for removal.

Environmentally Sensitive Area (ESA): areas adjacent to construction that are off limits to the Contractor as specified elsewhere in the Contract.

Fill: man-made mixture of previously placed/handled materials such as sand, clay, silt, gravel, broken rock, sometimes containing organic and/or deleterious materials, placed in an excavation or other area to raise the surface elevation.

Grouting: injection of grout into voids.

Guidance System: an electronic system capable of locating the position, depth and orientation of the drill head during the directional drilling process.

Directional Drilling (DD): directional boring or guided boring.

HDPE: high density polyethylene.

Inadvertent Returns: the flow of unexpected fluids, saturated materials (or running soil) towards the drilling rig that typically originated from an artesian aquifer encountered during the drilling process.

Loss of Circulation: the discontinuation of the flow of drilling fluid in the bore back to the entry or exit point or other planned recovery points.

Pilot Bore: the initial bore to set directional controlled horizontal and vertical alignment between the connecting points.

Pipe Jacking: a method for installing steel casing or concrete pipe in the subsurface utilizing hydraulically operated jacks of adequate number and capacity to ensure smooth and uniform advancement without overstressing the liner/pipe.

Pipe Ramming: a method for installing steel casings utilizing the energy from a percussion hammer to advance a steel casing with a cutting shoe attached at the front end of the casing.

Primary Liner (Support): system installed prior to or concurrent with excavation, to maintain stability of an excavation and to support earth or rock and any structure utilities or other facilities in or on the supported earth or rock mass, until the excavation is completed.

Product: pipe culverts, pipe sewers, watermain pipe and sanitary pipe.

Pullback: that part of the DD method in which the drill string is pulled back through the bore path to the entry point.

Quality Verification Engineer (QVE): an Engineer who has a minimum of five (5) years experience in the field of pipe installation using trenchless methods or alternatively has demonstrated expertise by providing satisfactory quality verification services for the work at a minimum of two (2) projects of similar scope to the contract. The Quality Verification Engineer shall be retained by the Contractor to certify that the work is in general conformance with the contract documents and to issue Certificate(s) of Conformance.

Reaming: a process for pulling a tool attached to the end of the drill string through the bore path to enlarge the bore and mix the cuttings with the drilling fluid. This typically includes multiple passes.

Rock: natural beds or massive fragments, or the hard, stable, cemented part of the earth's crust, igneous, metamorphic, or sedimentary in origin, which may or may not be weathered and includes boulders having a size equivalent to 0.3 m in diameter or greater.

Secondary Liner: concrete pipe, HDPE pipe or un-reinforced cast-in-place concrete, installed subsequent to tunnel excavation.

Shaft: vertically sided excavation used as entry and/or exit points from which the trenchless method is initiated or directed for the installation of product.

Strike Alert: a system that is intended to alert and protect the operator in the case of inadvertent drilling into an electrical utility cable. The strike alert system consists of a sensor and an alarm connected to the drill rig and a grounding stake. The alarm may be audio or visual or both.

Slurry: a mixture of soil and/or rock cuttings, and drilling fluid.

Soil: all materials except those defined as rock, and excludes stone masonry, concrete, and other manufactured materials; includes rock fragments having an equivalent size less than 0.3 m in diameter.

Trenchless Installation: an underground method of constructing a passage open at both ends that involves installing a pipe. For the purpose of this specification, the pipe may be installed by any of the various methods defined herein such as Auger Jack & Boring, Pipe Jacking, Pipe Ramming, Directional Drilling, or using a tunnelling machine or hand mining methods.

Tunnelling: An underground method of constructing a passage using a tunnel boring machine (TBM), a microtunnel boring machine (MTBM) or hand mining using a shield to support the opening.

4. DESIGN AND SUBMISSION REQUIREMENTS

4.01 General

The Contractor's documentation, submission requirements and installation methods shall specifically consider and address the subsurface conditions at each pipe crossing as identified in the Foundation Investigation Report or elsewhere in the Contract Documents.

4.02 Working Drawings

Three copies of stamped working drawings for portal or shaft construction, primary liner, excavation, secondary lining, dewatering and groundwater control and grouting shall be submitted to the Contract Administrator (CA) at least one week prior to the commencement of the work for information purposes. All submissions shall bear the seal and signature of the Design Engineer and Design Checking Engineer. The Contractor shall have a copy of the stamped working drawings at the site during construction.

As a minimum, working drawings/details pertaining to the tunnel design and construction shall include the following (as appropriate):

a) Plans, Elevations and Details:

- A work plan outlining the materials, procedures, methods and schedule to be used to execute the work;
- A list of personnel, including backup personnel, and their qualifications and experience;
- A safety plan including the company safety manual and emergency procedures;
- The work area layout;
- An erosion and sediment control plan that includes a contingency plan in the event the erosion and sediment control measures fail;
- A drilling fluid management plan, if applicable, that addresses control of frac-out pressures, any potential environmental impacts and includes a contingency plan detailing emergency procedures in the event that the fluid management plan fails;

- Lighting, ventilation and fire safety details as may be required by applicable occupational health and safety regulations; and
- Excavated materials disposal plan.

b) Design Criteria:

- Primary liner design details, if applicable;
- Design assumption and material data when materials other than those specified are proposed for use; and
- Drill path design, details of alignment and alignment control, maximum curvature and reaming stages.

c) Materials:

- Certification from the manufacturer that the product furnished on the contract meets the specifications cited in the manufacturer's product specification and that the materials supplied are suitable for the application; and
- Material mixture for filling voids and installation procedures.

d) Upstream/Downstream Portal Installation Procedure:

- The access shaft or entry/exit pit details designed and stamped/signed by the Design Engineer, as applicable; and
- Face support and other temporary support details, if applicable.

e) Primary Liner/Secondary Liner Installation and Grouting Procedure:

- Excavation and pipe installation procedures, including methods to handle obstructions and prevent soil cave-in; and
- Details of tunnelling equipment/methods to be used for the works.

f) Excavation and Dewatering:

- Ground control/dewatering details, as applicable, describing the proposed method for control, handling, treatment, and disposal of water.

g) Monitoring Method:

- The methods to be employed to monitor and maintain the alignment of the installation.

4.03 Site Survey

Prior to commencing the work, the Contractor shall, at each pipe location, lay-out the alignment and install settlement monitoring points.

4.04 Certificate of Conformance

The Contractor shall submit details of the sequence and method of construction to the Quality Verification Engineer for review, prepared and stamped by the Design Engineer. The Contractor shall submit to the Contract Administrator a Certificate of Conformance sealed and signed by the Quality Verification Engineer a minimum of one week prior to commencement of work under this item. The Certificate shall state that the construction procedures are in conformance with the requirements and specifications of the contract documents.

The Contractor shall submit to the Contract Administrator a Certificate of Conformance sealed and signed by the Quality Verification Engineer upon completion of each of the following operations and prior to commencement of each subsequent operation for each pipe installation:

Site Surveying (as noted in Section 4.02)
Excavation for pits including dewatering of excavations
Jacking/Ramming/Directional Drilling of Casing/Liner
Installation of the Product
Grouting Operations

Each Certificate of Conformance shall state that the work has been carried out in general conformance with the contract documents, specifications and/or stamped working drawings.

In addition, upon completion of the installation of the pipe at each location, the Contractor shall submit to the Contract Administrator a final Certificate of Conformance sealed and signed by the Quality Verification Engineer. The Certificate shall state that the pipe has been installed in general conformance with the Contractor's Submission and Design Requirements, stamped working drawings and contract documents.

The Design Engineer will not be permitted to carry out the work of the Quality Verification Engineer.

5. MATERIALS

5.01 Product

The product shall be concrete pipe or high density polyethylene pipe as specified.

5.02 Concrete

Concrete shall be according to OPSS.PROV 1350. The concrete strength shall be as specified in the Contractor's design submission.

5.03 Concrete Reinforcement

Steel reinforcing for concrete work shall be according to OPSS.PROV 1440.

5.04 Timber

Timber shall be sound, straight, and free from cracks, shakes and large or loose knots.

5.05 Grout

The Contractor shall submit the proposed grout mix design for grouts to be used for lubricating jacking pipe and for filling of voids and annular spaces. Purging grout shall consist of a mixture of one part Portland cement conforming to the requirements of CAN/CSA A5-93 and two parts mortar sand conforming to OPSS.PROV 1004 wetted with only sufficient water to make the mixture plastic.

5.06 Auger Jack & Bore Materials

5.06.01 Pipe Materials

Steel pipe shall conform with ASTM A252-93 welded joints suitable for jacking operations. The Contractor shall select pipe class for pipe jacking.

Concrete pipe as per OPSS.PROV 1820.

Fittings shall be suitable for and compatible with the class and type of pipe with which they will be used.

5.07 Pipe Ramming Materials

5.07.01 Pipe Materials

Steel pipe shall conform with ASTM A 252-93 welded joints.

New steel casing when specified shall be smooth wall carbon steel pipe according to ASTM A252-93 Grade 2.

Used steel casing can be used provided that the steel casing can resist the applicable static and dynamic loadings.

Pipe wall thickness shall be determined by the Contractor based on static and dynamic loads from traffic loading and anticipated ramming forces for selected pipe and driven pipe lengths. The wall thickness shall be increased as required to ensure the casing is not damaged during handling and installation. The pipe minimum wall thickness shall be as per Table 1 of OPSS 1802.

Pipe segments shall be determined by the Contractor.

Steel pipe joints shall be pressure fit type or welded.

All steel casing pipe shall be square cut.

Steel casing pipe shall have roundness such that the difference between the major and minor outside diameters shall not exceed 1% of the specified nominal outside diameter or 6 mm, whichever is less.

Steel casing pipe shall have a minimum allowable straightness of 1.5 mm maximum per metre of length.

5.07.02 Mill Certificates

For permanent casing, the Contractor shall submit to the Contract Administrator at the time of delivery one copy of the mill certificate, indicating that the steel meets the requirements for the appropriate standards for casings.

Where mill test certificates originate from a mill outside Canada or the United States of America the Contractor shall have the information on the mill certificate verified by testing by a Canadian laboratory. The laboratory shall be accredited by a Canadian National Accreditation Body to comply with the requirements of ISO/IEC Guide 25 for the specific tests or type of tests required by the material standard specified on the mill test certificate. The mill test certificates shall be stamped with the name of the Canadian testing laboratory and appropriate wording stating that the material conforms to the specified material requirements. The stamp shall include the appropriate material specification number, the date and the signature of an authorized officer of the Canadian testing laboratory.

5.08 Directional Drilling Materials

5.08.01 Drilling Fluids

The drilling fluids shall be mixed according to the manufacturer's recommendations and be appropriate for the anticipated subsurface conditions.

5.08.02 Pipe Materials

High Density Polyethylene (HDPE) pipe as per OPSS 1840 shall be used in accordance with ASTM D3350.

The requirements for fittings shall be suitable for and compatible with the class and type of pipe with which they will be used and in according to CAN/CSA-B182.6 or ASTM F894.

The Contractor shall determine the required dimensional ratio (DR) of the HDPE pipe to support all subsurface conditions and hydrostatic pressures, and to withstand the grouting pressure and installation forces. The Contractor shall identify these forces in his submission requirements.

The Contractor's submission shall demonstrate, in conjunction with the manufacturer's specifications, that the heat resistance of the pipe material is sufficient to tolerate without damage the heat of hydration generated by grout curing.

Fittings shall be suitable for and compatible with the class and type of pipe with which they will be used.

Jointing of HDPE piping shall be completed by thermal butt fusion in accordance with manufacturer's recommended procedures and as outlined in the latest revision of ASTM D2657. All manufacturer's recommendations and procedures shall be followed during the jointing process.

Jointing of HDPE piping to other piping materials or appurtenances shall be completed using flanged connections.

5.09 Tunnelling Materials

5.09.01 Primary Liner

Tunnelling methods will require installation of a primary liner. The primary liner shall be designed by the Contractor and the design/drawings shall be stamped/signed by the Design Engineer. The design shall be submitted to the Contract Administrator as specified herein.

5.09.02 Secondary Liner

Concrete or High Density Polyethylene Pipe shall be used according to the following requirements.

5.09.02.01 Concrete Pipe

Concrete pipe as per OPSS.PROV 1820 shall be used. The Contractor shall select the pipe class to withstand grouting pressure and installation forces. The Contractor shall identify these forces in his submission requirements.

Fittings shall be suitable for and compatible with the class and type of pipe with which they will be used.

5.09.02.02 High Density Polyethylene (HDPE)

High Density Polyethylene (HDPE) pipe as per OPSS 1840 shall be used in accordance with ASTM D3350.

The requirements for fittings shall be according to CAN/CSA-B182.6 or ASTM F894.

The Contractor shall determine the required dimensional ratio (DR) to withstand the grouting pressure and installation forces. The Contractor shall identify these forces in his submission requirements.

Fittings shall be suitable for and compatible with the class and type of pipe with which they will be used.

Jointing of HDPE piping shall be completed by thermal butt fusion in accordance with manufacturer's recommended procedures and as outlined in the latest revision of ASTM D2657. All manufacturer's recommendations and procedures shall be followed during the jointing process.

Jointing of HDPE piping to other piping materials shall be completed using flanged connections.

6. EQUIPMENT

6.01 Auger Jack & Bore Equipment

Pipe auger jack & bore equipment shall be determined by the Contractor and shall be identified in the submission requirements specified herein.

Specific details of the manner in which rock or boulders will be broken and removed from the face and the face will be protected to prevent soil loss into the liner shall be submitted to the Contract Administrator for information purposes prior to proceeding with the works.

6.02 Pipe Ramming Equipment

Pipe ramming equipment shall be determined by the Contractor and shall be identified in the submission requirements specified herein.

The pipe ramming hammer(s) shall be capable of driving the pipe casing from the drive pit through the existing subsurface conditions at the site.

Specific details of the manner in which rock or boulders will be broken and removed from the face and the face will be protected to prevent soil loss into the pipe shall be submitted to the Contract Administrator for information purposes prior to proceeding with the works.

6.03 Directional Drilling Equipment

6.03.01 General

The directional drilling equipment shall consist of a directional drilling rig and a drilling fluid mixing and delivery system of sufficient capacity to successfully complete the product installation without exceeding the maximum tensile strength of the product being installed.

6.03.02 Drilling Rig

The directional drilling rig shall:

- consist of a leak free hydraulically powered boring system to rotate, push, and pull hollow drill pipe into the ground at a variable angle while delivering a pressurized fluid mixture to a guidable drill head;
- contain a guidance system to accurately guide boring operations;
- be anchored to the ground to withstand the rotating, pushing, and pulling forces required to complete the product installation; and
- be grounded during all operations unless otherwise specified by the drilling rig manufacturer.

6.03.03 Drill Head

The drill head shall be steerable by changing its rotation, be equipped with the necessary cutting surfaces and drilling fluid jets, and be of the type for the anticipated subsurface conditions,

6.03.04 Guidance System

The guidance system shall be setup, installed, and operated by trained and experienced personnel. The operator shall be aware of any magnetic or electromagnetic anomalies and shall consider such influences in the operation of the guidance system when a magnetic or electromagnetic system is used.

6.03.05 Drilling Fluid Mixing System

The drilling fluid mixing system shall be of sufficient size to thoroughly and uniformly mix the required drilling fluid.

6.03.06 Drilling Fluid Delivery System

The delivery system shall have a means of measuring and controlling fluid pressures and be of sufficient flow capacity to ensure that all slurry volumes are adequate for the length and diameter of the final bore and the anticipated subsurface conditions. Connections between the delivery pump and drill pipe shall be leak-free.

6.04 Tunnelling Equipment

Tunnelling equipment shall be determined by the Contractor and shall be identified in the submission requirements specified herein.

Specific details of the manner in which rock or boulders will be broken and removed from the tunnel face shall be submitted to the Contract Administrator information purposes. Use of rock fracturing chemicals shall only be considered subject to a field demonstration satisfactory to the Ministry prior to its use.
Use of explosives is prohibited.

7. CONSTRUCTION

7.01 General

The Contractor shall notify the Contract Administrator at least 48 hours in advance of starting work. The proposed method of pipe installation to be used by the Contractor shall be submitted to the Contract

Administrator for information purposes prior to commencing the work and shall be subject to the limitations presented in the following subsections.

7.01.01 Layout, Alignment and Depth Control

The location of the installation shall be established from the lines, elevations and tolerances specified in the Contract Documents. The pipe installation shall be to the horizontal and vertical alignments specified in the Contract Drawings. Deviations from location, alignment, grades and/or invert levels shall be corrected by the Contractor at no cost to the Ministry.

All reference points necessary to construct the pipe installation and appurtenances shall be laid out.

The Contractor shall calibrate tracking and locating equipment at the beginning of each work day, and shall monitor and record the alignment and depth readings provided by the tracking system at every 5 m in normal conditions and every 2 m where precise alignment control is necessary;

The Contract Administrator shall be provided with the assistance and access necessary to check the layout of the pipe installation and associated appurtenances.

All excavations shall be carried out in accordance with the Occupational Health and Safety Act (OHSA) of Ontario.

For directional drilling, the contractor shall ensure that during pilot hole drilling the maximum degree of deviation or “dog-leg” shall be 2.5 degrees per 9m drill pipe length. Any deviation exceeding 2.5 degrees will necessitate a pull-back and straightening of the alignment at the Contractor’s sole expense. The pilot hole exit location shall be within 0.5m of the target location.

7.01.02 Construction Shafts

Construction shafts shall be specified in the Contractor's submission. The boundaries and protection of these shall be as required to contain all disturbances to areas outside of the ESA limits.

Shafts shall be maintained in a drained condition.

A minimum 2.4 m high secure fence shall be installed around the perimeter of the construction shaft area with gates and truck entrances. The fence shall be removed on completion of the work.

7.01.03 Protection Systems

The construction of all protection systems shall be according to OPSS.PROV 539. Where the stability, safety, or function of an existing roadway, watercourse, other works, proposed works or ESA’s may be impaired due to the method of operation, protection shall be provided. Protection may include sheathing, shoring, and piles where necessary to prevent damage to such works or proposed works.

7.01.04 Settlement or Heave

Any disturbance to the ground surface (settlement or heave) as a result of the pipe installation shall be immediately corrected by the Contract, at no additional cost to the Ministry.

7.01.05 Stability of Excavation

The construction methods, plant, procedures, and precautions employed shall ensure that excavations are stable, free from disturbance, and maintained in a drained condition.

The construction methods, plant, and materials employed shall prevent the migration of soil and/or rock material into the excavation from adjacent ground.

7.01.06 Preservation and Protection of Existing Facilities

Preservation and protection of existing facilities shall be according to OPSS 491.

Minimum horizontal and vertical clearances to existing facilities as specified in the Contract Documents shall be maintained. Clearances shall be measured from the nearest edge of the largest cut diameter required to the nearest edge of the facility being paralleled or crossed.

Existing underground facilities shall be exposed to verify its horizontal and vertical locations when the outlet pipe path comes within 1.0 m horizontally or vertically of the existing facility. Existing facilities shall be exposed by non-destructive methods. The number of exposures required to monitor work progress shall be as specified in the Contract Documents.

7.01.07 Transporting, Unloading, Storing and Handling Materials

Manufacturer’s handling and storage recommendations shall be followed.

7.01.08 Trenching, Backfilling and Compacting

Trenching, backfilling, and compacting for entry and exit points or other locations along the pipe path shall be according to OPSS 401.

7.01.09 Support Systems

Support systems shall be according to OPSS 404.

If any open excavation will encroach into the highway embankment the protection system shall satisfy the requirements for Performance Level 2 as specified in OPSS.PROV 539.

7.01.10 Dewatering

The work of this Section includes control, handling, treatment, and disposal of groundwater. The Contractor shall review the foundation investigation report for reference to soil and groundwater conditions on the project site and plan a dewatering scheme accordingly.

The Contractor shall control groundwater inflows to excavations to maintain stability of surrounding ground, to prevent erosion of soil, to prevent softening of ground exposed in the excavation, and to avoid interfering with execution of the work.

The Contractor shall maintain excavations free of standing water at all times during excavation, including while concrete is curing.

Should water enter the excavation in amounts that could adversely affect the performance of the work or could cause loss of ground, the Contractor shall take immediate steps to control the inflow.

The Contractor is alerted that seepage zones of perched water within fill materials should be expected, particularly where granular materials are excavated.

Dewatering shall be according to OPSS 517.

7.01.11 Removal of Boulders

The Contractor is alerted that cobbles and boulders should be anticipated in the soil deposits. Accordingly, the Contractor shall address the removal of cobbles and boulders in the proposed method of construction. The Contractor shall immediately inform the Contract Administrator of any obstruction encountered.

7.01.12 Record Keeping

Verification record requirements of the alignment and depth of the installation shall be as specified in the Contract Documents. A copy of the verification records shall be given to the Contract Administrator at the completion of the installation.

7.01.13 Testing

Testing of the product installation shall consist of verifying the specified grade between the two ends of the pipe and passing of water from the inlet end of the pipe to the outlet end to confirm gravity flow conditions.

7.01.14 Management and Disposal of Excess Material

Management and disposal of excess material shall be according to OPSS 180. Satisfactory re-usable excavated material required for backfill shall be separated from unsuitable excavated material.

7.01.15 Site Restoration

Site restoration shall be according to OPSS 492.

7.01.16 Supervision

A qualified individual, who is experienced in the pipe installation by trenchless methods shall supervise the work at all times.

7.02 Auger Jack & Bore Installation

7.02.01 Method of Installation Procedure

The installation procedure to be used shall be subject to the following limitations:

- Hydraulically operated jacks of adequate number and capacity shall be provided to ensure smooth and uniform advancement without over-stressing of the pipe.
- A suitably padded jacking head or collar shall be provided to transfer and distribute jacking pressure uniformly over the entire end bearing area of the pipe.
- The jacking pipe shall be fully supported in the jacking pit at the specified line and grade.

- Selection of the excavation method and jacking equipment shall take into consideration the conditions at each pipe crossing.

7.02.02 Pipe Installation

Concrete pipe joints shall be water tight and according to OPSS.PROV 1820 and must withstand jacking forces, determined by the Contractor.

During the jacking of the liner the space between the liner and the wall of the excavation shall be kept filled with bentonite slurry. Upon completion of jacking, the space between the liner and the wall of the excavation shall be filled with grout.

The annular space between the liner and the product shall be fully grouted with a water tight, expandable and stable grout.

7.03 Pipe Ramming Installation

For pipe ramming installation the following requirements apply:

Only smooth walled steel pipe shall be used. But welding of pipe joints shall conform to CAS W59.

Ramming equipment of adequate capacity shall be provided to ensure smooth and uniform advancement without overstressing of the pipe. Delays shall be avoided between ramming operations.

A ramming head shall be provided to transfer and distribute jacking pressure uniformly over the entire end bearing area of the pipe.

Two or more lubricated guide rails or sills shall be provided of sufficient length to fully support the pipe at the specified line and grade in the ramming pit. Pipe shall be installed to the line and grade specified.

Following installation of the liner pipe, all material shall be removed from the pipe to the satisfaction of the Contract Administrator. Any voids remaining between the pipe and the excavation wall shall be grouted as soon as the pipe is rammed. The annular space between the liner pipe and the product shall be fully grouted with a water tight, expandable and stable grout.

7.04 Directional Drilling Installation

7.04.01 General

When strike alerts are provided on a drilling rig, they shall be activated during drilling and maintained at all times.

7.04.02 Site Preparation

The work site shall be graded or filled to provide a level working area for the drilling rig. No alterations beyond what is required for DD operations are to be made. All activities shall be confined to designated work areas.

7.04.03 Pilot Bore

The pilot bore shall be drilled along the bore path in accordance with the grade, alignment, and tolerances as indicated on the Contractor's submitted drilling plan to ensure that the product is installed to the line and grade shown on the Contract Drawings. The Contractor's methods shall take into consideration the conditions at each crossing within the pipe alignment and shall be suitable to advance through such obstructions such as cobbles and boulders and address the potential for deflection off these obstruction and/or soil conditions.

In the event the pilot bore deviates from the submitted path, the Contract Administrator shall be notified. The Contract Administrator may require the Contractor to pullback and re-drill from the location along the bore path before the deviation.

In the event that a drilling fluid fracture, inadvertent returns, or loss of circulation occurs during pilot bore drilling operations, the Contract Administrator shall be advised of the event and action shall be taken in accordance with the Contractor's submitted contingency plan.

At the entry and exit points, there is potential for ravelling of the existing soil, fill and or weathered rock areas along the alignment. This is conventionally addressed by the use of drilling fluid. However, casing may be required. The Contractor's methods shall take into consideration the potential need to install sections of casing to manage ravelling at or near ground surface.

If a drill hole beneath the highway must be abandoned, the hole shall be backfilled with grout or bentonite to prevent future subsidence.

The Contractor shall maintain drilling fluid pressure and circulation throughout the DD process, including during the initial pilot bore and during the reaming process.

The Contractor shall at all times and for the entire length of the installation alignment be able to demonstrate the horizontal and vertical position of the alignment, the fluid volume used, return rates and pressures.

7.04.04 Drilling Fluid Fracture (Frac-Out)

In order to reduce the potential for hydraulic fracturing of the hole during directional drilling, a minimum depth of cover of 5m is normally maintained between the pipe and the ground surface. Sections of the pipe close to the exit pit with less than 5m cover shall be cased. The Contractor shall ensure that drilling fluid pressures are properly set and controlled to prevent frac-out, for the depth of cover available between the bottom of the pavement structure (bottom of the subbase material) and the top of the bore.

Since fluid loss normally occurs in fault zones, fracture zones, or seams of coarse material, fluid migration does not always gravitate to the surface, thus making detection difficult. Once a fluid loss is detected, the Contractor shall halt operations immediately and conduct a detailed examination of the drill path and implement measures to mitigate fluid loss. If no surface migration is evident, resume operation while paying particular attention to fluid monitoring.

In the event of a fluid migration to the surface occurring, the Contractor shall halt all operations immediately, isolate the migration site, and recover fluids. Once the fracture is controlled, continue drilling operations with the operator paying particular attention to the fracture points

7.04.05 Reaming

The bore shall be reamed using the appropriate tools to a diameter at least 50% greater than the outside diameter of the product.

7.04.06 Product Installation

7.04.06.0 General

The product shall be jointed according to manufacturer's recommendations. The length of the product to be pulled shall be jointed as one length before commencement of the continuous pulling operation.

The product shall be protected from damage during the pullback operation.

The minimum allowable bending radius for the product shall not be exceeded.

Product shall be allowed to recover before connections to new or existing facility are made. Product recovery time shall be according to manufacturers recommendations.

7.04.06.02 Pullback and Grouting

After successfully reaming the bore to the required diameter, the product shall be pulled through the bore path. Once the pullback operation has commenced, it shall continue without interruption until the product is completely pulled into bore unless otherwise approved by the Contract Administrator.

A swivel shall be used between the reamer and the product being installed to prevent rotational forces from being transferred to the product. When specified in the Contract Documents, a weak link or breakaway connector shall be used to prevent excess pulling force from damaging the product.

The product shall be inspected for damage where visible at excavation pits and where it exits the bore. Any damage noted shall be rectified to the satisfaction of the Contract Administrator,

The pull back and reaming operations shall not exceed the fluid circulation rate capabilities. Reaming and back pulling operations shall be planned to insure that, once started, all reaming and back pulling operations are completed without stopping and within the permitted work hours.

The space between the pipe and the excavation walls shall be filled with grout.

7. 05 Tunnelling Installation

7.05.01 General

The method of tunnelling shall be selected by the Contractor and shall be submitted to the Contract Administrator prior to commencement of the work for information purposes.

Excavation of native soil and fill shall be done in a manner to control groundwater inflow to the excavation and to prevent loss of ground into the excavation.

Methods of excavating the tunnel shall be capable of fully supporting the face and shall accommodate the removal of boulders and other oversize objects from the face. Continuous ground support shall be maintained during excavation.

As the excavation progresses, the Contractor shall continuously monitor (every 2 m) indications of support distress, such as cracking, deflection or failure of support system and subsidence of ground near the excavation.

The Contractor shall advance the ventilation system as a regular part of the normal excavation cycle.

The Contractor shall provide lighting in accordance with OHSA requirements for the entire length of the tunnel.

The tunnel is to be kept sufficiently dry at all times to permit work to be performed in a safe and satisfactory manner.

The Contractor shall maintain clean working conditions at all times in tunnels.

In the event that excavation threatens to endanger personnel, the Work, or adjacent property, the Contractor shall cease excavation. The Contractor shall then evaluate methods of construction and revise as necessary to ensure the safe continuation of the work.

The Contractor shall maintain tunnel excavation line and grade to provide for construction of final lining within specified tolerances.

7.05.01 Tunnelling Method

The tunnelling method shall be suitable to provide face support in changing ground conditions that may be encountered during the progress of the work. The selection of the tunnelling method should consider the soil conditions at each pipe crossing and the presence of obstructions, such as cobbles and boulders, with respect to the tunnel alignment.

7.05.02 Primary Liner (Support System)

Primary support systems shall prevent deterioration, loosening, or unravelling of ground surfaces exposed by excavation.

The primary liner support system shall be designed and installed to achieve the intended performance requirements.

Primary liner support system shall maintain the safety of personnel, minimize ground movement into the excavation, ensure stability and maintain strength of ground surrounding the excavation.

The primary liner shall be designed to support all subsurface conditions and hydrostatic pressures and to withstand any additional loads caused by installation and grouting, and shall ensure that no ground loading or other loading will be placed on the new work until after design strength has been reached.

The primary liner shall be installed so that the exterior is as tight as possible to the excavated surface of the tunnel and allows the placement of the full design thickness of the secondary lining.

Primary support systems shall be compatible with the encountered ground conditions, with the method of excavation, with methods for control of water, and with placement of the permanent lining.

All voids between the primary lining and the surface of the excavation shall be filled with cement grout. If an unexpanded liner is used, the space outside the liner plates shall be grouted at least daily.

7.05.03 Secondary Liner

7.05.03.01 Placing of Grout

The void outside the finished secondary liner shall be filled with cement grout according to the Contractor's submission.

Grout shall not be placed until the lining has achieved 85% of its specified strength or 30 MPa. Grouting shall be limited to such sequences and programs as are necessary to avoid damaging any part of the works or any other structure or property.

7.06 Instrumentation Monitoring

The work specified in this Section includes furnishing and installing instruments for monitoring of settlement and ground stability.

Surface settlement markers for monitoring ground stability shall be installed at the pavement/ground surface level on the shoulder, side slope and pavement at not greater than 5 m intervals along the tunnel alignment and as an array of three in-ground (1.5 m depth) measurement points on the shoulder of the highway perpendicular to the alignment. The equipment and procedures used for settlement monitoring during construction must be capable of surveying the settlement point elevations to within ± 1 mm of the actual elevation.

Surface settlement markers shall be hardened steel markers treated or coated to resist corrosion, with an exposed convex head having a minimum diameter of 12 mm and similar to surveyor's PK nails. Markers shall be rigidly affixed so as not to move relative to the surface to which it is attached. Traffic shall be managed by the contractor using short-term lane closures in accordance with the Ontario Traffic Manual (OTM).

In general, settlement monitoring points shall be 12-18 mm rebar encased in a 50-70 mm, SCH40 PVC pipe, set to a depth of 1.5 m below ground surface. The assembly shall be placed in a drill hole and backfilled with uniform sand.

The Contractor shall install all surface settlement instruments a minimum of one week prior to the start of works.

The surface settlement instruments shall be clearly labelled for easy identification.

The Contractor shall submit to the Contract Administrator a site plan showing the locations of the monitoring points, a geodetic survey of the settlement monitoring points including station, offset and elevation recorded at the following time intervals:

- Three consecutive readings at least one week prior to commencement of the work (Baseline Reading);
- Once per shift during tunnelling operations period; and
- Weekly after completion of the work for one month, or until such time at which all parties agree that further movement has stopped.

All readings shall be submitted to the Contract Administrative for information purposes on a weekly basis. Each report shall include all survey data collected in tabular and graphical format as plots of time versus settlement in comparison to survey data collected prior to commencement of the work.

7.07 Criteria for Assessment of Roadway Subsidence/Heave

Based on the monitoring of ground movement as specified in Subsections 4.02 and 7.06, the following represents trigger levels that define magnitude of movement and corresponding action:

- Review Level: If a maximum value of 10 mm relative to the baseline readings is reached, the Contractor shall review or modify the method, rate or sequence of construction or ground stabilization measures to mitigate further ground displacement. If this Review Level is exceeded, the Contractor shall immediately notify the CA and review and discuss response actions. The Contractor shall submit a plan of action to prevent Alert Levels from being reached. All construction work shall be continued such that the Alert Level is not reached.
- Alert Level: If a maximum value of 15 mm relative to the baseline readings is reached, the Contractor shall cease construction operations, inform the Contract Administrator and execute pre-planned measures to secure the site, to mitigate further movements and to assure safety of public and maintain traffic. No construction shall take place until all of the following conditions are satisfied:
    - ▪ The cause of the settlement has been identified.
    - ▪ The Contractor submits a corrective/preventive plan.
    - ▪ Any corrective and/or preventive measure deemed necessary by the Contractor is implemented.
    - ▪ The CA deems it is safe to proceed.

The Contractor shall avoid damaging instrumentation during construction. Instrumentation that is damaged as a result of the Contractor's operation shall be repaired or replaced by the Contractor within one business day. The costs for replacement/repair shall be borne by the Contractor.

At the completion of the job, the Contractor shall abandon all instrumentations installed during the course of the Work.

9. MEASUREMENT FOR PAYMENT

Measurement shall be by Plan Quantity Payment as may be revised by Adjusted Plan Quantity Payment in metres, following along the centre line of the pipes from centre to centre of maintenance holes or chambers (catch basins) or from/to the end of the pipe where no maintenance hole or chamber is installed, of the actual length of pipe installed by trenchless methods.

10. BASIS OF PAYMENT

Payment at the contract price shall be full compensation for all labour, equipment and materials required for excavation (regardless of material encountered), dewatering, sheathing and shoring, supply and installation of pipe liners, settlement instrumentation and monitoring, site restoration, and all other work necessary to complete the installation as specified.

Payment for the rigid or flexible pipe conduits installed inside the pipe liners shall be paid separately under the appropriate tender items.

Where a protection system is made necessary because of the Contractor's operations (e.g. choice of trenchless installation method), the cost shall be included in this item and shall be full compensation for all labour, equipment and materials required to carry out the work including subsequently removing the temporary protection system and performing any necessary restoration work.

Payment for connecting intercepted drains and service connections shall be made on the following basis:

(a) Where such drains and service connections are shown on the contract drawings the cost of connections shall be included in the contract price for pipe installation.

(b) Where such drains and service connections are not shown on the contract drawings, the cost of connections will be considered an allowable extra to the contract.

Payment for removal of boulders/obstructions greater than an equivalent 0.3 m in diameter shall be on a time and materials basis. The Contractor shall inform the Contract Administrator when boulders/obstructions are encountered and prior to removal to allow for proper and accurate tracking of time and material charges.

APPENDIX I

Operational Constraint

OPERATIONAL CONSTRAINT – Pipe Installation by Trenchless Method

Special Provision

The Contractor shall determine the most appropriate method of installation for each of the culvert crossing locations identified on the Contract Drawings. Where trenchless options are indicated at Culvert Nos. 3, 5, 6, 9, 10, 11A and 12, the Contractor shall determine the most appropriate method of installation for each of the crossing locations in accordance with the NSSP titled "Pipe Installation by Trenchless Method" with the following exceptions.

- Trenchless installations using Horizontal Directional Drilling methods will not be permitted for any of the crossings at Culvert Nos. 3, 5, 6, 9, 10, 11A and 12.

- Trenchless installations using Jack and Bore, Open Face Shield Tunnelling or conventional Microtunnelling methods will not be permitted at the crossings at Culvert Nos. 3, 6, 9, and 12.

The Contractor is alerted that the following soil conditions exist at the majority of the trenchless crossing sites:

- Mixed face conditions (fill soils and native soils) will be encountered along the proposed pipe alignments. The Contractor shall select equipment that is capable of excavating the different material types while minimizing loss of ground and maintaining alignment control.

- The clayey silt till deposit may contain cobbles and boulders and the fill soils may contain shale fragments.

- Low cover thickness (less than two tunnel diameters) is present at locations of Culvert Nos. 3, 6, 9 and 12 and strict controls and a diligent monitoring program are required.

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For more information, visit golder.com

Africa	+ 27 11 254 4800
Asia	+ 86 21 6258 5522
Australasia	+ 61 3 8862 3500
Europe	+ 44 1628 851851
North America	+ 1 800 275 3281
South America	+ 56 2 2616 2000

solutions@golder.com
www.golder.com

Golder Associates Ltd.
6925 Century Avenue, Suite #100
Mississauga, Ontario, L5N 7K2
Canada
T: +1 (905) 567 4444