



FOUNDATION INVESTIGATION AND DESIGN REPORT PROPOSED RETAINING WALL AT GLENDALE AVENUE AND YORK ROAD INTERSECTION, TOWN OF NIAGARA- ON-THE-LAKE, NIAGARA REGION, ONTARIO

MINISTRY OF TRANSPORTATION ONTARIO

G.W.P 2423-15-00

GEOCRES NO. 30M3-315
DRAFT LAT: 43.160074°, LONG: -79.162193°

WSP PROJECT NO.: 18M-01021-12
DATE: DECEMBER 18, 2019

WSP CANADA INC.
2 INTERNATIONAL BOULEVARD
TORONTO, ON
CANADA, M9W 1A2

T: +1 416 679-9410
WSP.COM

TABLE OF CONTENTS

1	INTRODUCTION	1
2	BACKGROUND INFORMATION	1
3	FIELD AND LABORATORY INVESTIGATION	2
3.1	FIELD INVESTIGATIONS	2
3.2	LABORATORY INVESTIGATIONS	3
3.3	GROUNDWATER INVESTIGATIONS	4
4	SUBSURFACE CHARACTERIZATION	4
4.1	GENERAL	4
4.2	OVERVIEW	4
4.3	SUBSOIL CHARACTERIZATIONS	4
4.3.1	PAVEMENT STRUCTURE	4
4.3.2	FILL	4
4.3.3	UPPER CLAYEY SILT	5
4.3.4	SILTY CLAY TO CLAY	6
4.3.5	LOWER CLAYEY SILT	8
4.4	GROUNDWATER LEVEL OBSERVATIONS	9
4.5	CORROSIVITY AND WATER-SOLUBLE SULPHATE TESTING OF SOILS	9
5	DISCUSSION AND RECOMMENDATIONS	10
5.1	GENERAL	10
5.2	CONSEQUENCE AND SITE UNDERSTANDING CLASSIFICATION	10
5.3	GEOTECHNICAL MODEL	11
5.3.1	OVERVIEW OF SUB-SURFACE CONDITIONS	11
5.3.2	GROUND MOTION PARAMETERS	11
5.3.3	FROST DEPTH	11
5.4	DISCUSSION OF ALTERNATIVE WALL OPTIONS	11

5.4.1	MECHANISMS OF LATERAL SUPPORT IN RETAINING WALLS	11
5.4.2	RESISTANCE TO Lateral EARTH PRESSURES AND SLIDING	16
5.4.3	LATERAL EARTH PRESSURE - SEISMIC LOADING	16
5.4.4	FOUNDATIONS.....	17
5.4.5	STABILITY CONSIDERATIONS.....	18
5.4.6	SETTLEMENTS	19
5.4.7	BACKFILL AND DRAINAGE.....	19
5.5	CONSTRUCTION CONSIDERATIONS.....	20
5.5.1	SITE PREPARATION	20
5.5.2	EXCAVATIONS.....	20
5.5.3	EROSION / SCOUR PROTECTION.....	21
5.6	GROUNDWATER CONTROL	21
5.7	POTENTIAL FOR SULPHATE ATTACK/CORROSION ON BURIED CONCRETE AND STEEL	21
6	CLOSURE..... ERROR! BOOKMARK NOT DEFINED.	

TABLES

TABLE 3-1	SUMMARY OF BOREHOLE INFORMATION.....	3
TABLE 4-1	GRAIN SIZE DISTRIBUTION SUMMARY- SILTY CLAY FILL.....	5
TABLE 4-2	ATTERBERG LIMITS TEST RESULTS-SILTY CLAY FILL.....	5
TABLE 4-3	GRAIN SIZE DISTRIBUTION SUMMARY- CLAYEY SILT	6
TABLE 4-4	ATTERBERG LIMITS TEST RESULTS- CLAYEY SILT	6
TABLE 4-5	GRAIN SIZE DISTRIBUTION SUMMARY - SILTY CLAY TO CLAY	7
TABLE 4-6	ATTERBERG LIMITS TEST RESULTS-SILTY CLAY TO CLAY UPPER HORIZON	7
TABLE 4-7	ATTERBERG LIMITS TEST RESULTS-SILTY CLAY TO CLAY LOWER HORIZON.....	8
TABLE 4-8	GRAIN SIZE DISTRIBUTION SUMMARY- CLAYEY SILT TILL.....	8
TABLE 4-9	ATTERBERG LIMITS TEST RESULTS-SILTY CLAY TILL.....	9
TABLE 5-1:	COMPARISON OF RETAINING WALL ALTERNATIVES	14
TABLE 5-2	UNFACTORED STATIC EARTH PRESSURE COEFFICIENTS.....	16
TABLE 5-3	UNFACTORED SEISMIC EARTH PRESSURE COEFFICIENTS.....	17
TABLE 5-4:	FOUNDING ELEVATIONS.....	18
TABLE 5-5	GEOTECHNICAL RESISTANCES.....	18
TABLE 5-6	GEOTECHNICAL MODEL FOR SLOPE STABILITY	19
TABLE 5-6	GEOTECHNICAL MODEL FOR SETTLEMENT ANALYSIS	19
TABLE 5-7	RECOMMENDED UNFACTORED PARAMETERS FOR TEMPORARY SHORING DESIGN	20

DRAWINGS

BOREHOLE LOCATION PLAN AND SOIL STRATA

APPENDICES

- A RECORD OF BOREHOLE SHEETS
- B LABORATORY TEST RESULTS
- C SITE PHOTOGRAPHS
- D SLOPE STABILITY ANALYSES RESULTS
- E RESULTS OF SOIL CORROSIVITY ANALYSIS

PART A: FOUNDATION INVESTIGATION REPORT
PROPOSED RETAINING WALL AT GLENDALE AVENUE AND YORK ROAD ROUNDABOUT
TOWN OF NIAGARA-ON-THE-LAKE, ONTARIO
ASSIGNMENT NO. 2017-E-0018-12, G.W.P 2423-15-00
GEOCRES NO: 30M3-315

1 INTRODUCTION

WSP Canada Inc. (WSP) was retained by the Ministry of Transportation, Ontario (MTO) Central Region to conduct a peer review of the preliminary design plan, prepare a Design-Build Ready Package and assist MTO and Niagara Region during the Design Builder Procurement phase of the Queen Elizabeth Way (QEW) / Glendale Avenue interchange improvements project in the Town of Niagara-on-the-Lake, Ontario. This work is carried out under the MTO Central Region Mega 4 Retainer, Assignment No: 2017-E-0018 and forms Work Order No. 12.

As part of the preparation of the Design-Build Ready Package, foundation engineering services were required for the detail design of the following components:

- one 40 m long 2 m high Retaining Wall at Glendale Avenue and York Road Roundabout;
- one 30 m long 7 m high Retaining Wall for the Airport Road Structure;
- three 13 m long and 7 m high Retaining Walls for the Airport Road Structure;
- five Overhead Sign Support (OHS) Structures; and,
- nine High Mast Light Poles (HML).

This report addresses the foundation investigation carried out in support of the proposed Retaining Wall at the Glendale Avenue and York Road Roundabout. The retaining wall is part of the Diverging Diamond Interchange project at QEW and Glendale Avenue located in the Town of Niagara-On-The-Lake, Ontario. The purpose of the foundation investigation was to assess the subsurface and groundwater conditions at the site by means of boreholes, field and laboratory tests.

The Terms of Reference for the foundation engineering services are outlined in Work Order No. 12, dated March 1, 2019. The General Arrangement (GA) for proposed retaining wall was not available at the time of this report; a base drawing showing a general site plan and profile along the proposed wall was available at the time of preparation of this report.

Site photographs 1 to 3, taken on September 3, 2014 and contained in Appendix D, show the condition of the existing retaining wall at the Glendale Avenue and York Road Intersection. The existing retaining wall consists of a modular concrete block gravity wall and works as the culvert head and wing wall.

2 BACKGROUND INFORMATION

2.1 GEOLOGICAL SETTING

The project site is located within the physiographic region of Southern Ontario known as the Iroquois Plain, which lies between Lake Ontario and Niagara Escarpment. The Iroquois Plain was inundated by glacial Lake Iroquois in late Pleistocene times. The Iroquois Plain is flat with little relief and is covered by lacustrine deposits of sands, silt and silty-clays overlying glacial clayey silt (Halton Till). These deposits are underlain by red shale of the Queenston formation of the Upper Ordovician.

2.2 PREVIOUS GEOTECHNICAL INFORMATION

The following foundation report was available for review and provided information of subsoil information and foundation recommendations for the proposed culvert extensions and associated headwalls and wingwalls.

- “Foundation Investigation and Design Report, Culvert Extensions, QEW/Glendale Avenue Interchange Improvements, Niagara-On-The-Lake, GWP 2423-15-00, Assignment No. 2016-E-0029-002, Ontario,” by Golder Associates Ltd., dated April 17, 2019, GEOCREs No. 30M3-308. (Reference 1).

Geotechnical data and recommendations for extension of the culvert crossing under York Road (Culvert EX-05) have been reviewed and the relevant Record of Boreholes are included in Appendix B. The site investigation for the design of the proposed culvert (EX-05) extension was carried out on September 18 and November 27, 2018. The field investigation consisted of two (2) boreholes advanced to depths of 12.8 m (Elev. 99.2 m) and 10.4 m (Elev. 99.2 m).

Boreholes CV5 and CV6 were terminated within the stiff silty clay to clay deposit. Upon completion of drilling, groundwater was encountered at a depth of 10.7 m below ground surface (Elev. 101.5 m) in Borehole CV5 and at ground surface (Elev. 109.6 m) in Borehole CV6.

2.3 SITE DESCRIPTION

The proposed roundabout is to be located approximately 390 m north of the existing QEW and Glendale Avenue interchange. The existing Glendale Avenue is a four-lane undivided roadway running south-north and York Road is four lane divided roadway running east-west. The existing Glendale Avenue and York Road four-way intersection is proposed to be converted to a roundabout to facilitate smoother traffic movements. The key plan of the site is shown on Drawing No.1.

A retaining wall is currently present at the southeast corner of the York Road and Glendale Avenue intersection. The existing retaining wall consists of a concrete modular wall about 40 m long and up to 2.5 m high and serves as a culvert headwall and wingwall. No signs of erosion or settlement were noted during site reconnaissance and subsequent field investigation. In general, the existing retaining wall is in good condition and no performance concerns were noted.

To accommodate the proposed turning lane at the proposed roundabout, the existing intersection will be widened. The existing culvert will be extended south (addressed in GEOCREs Report No. 30M3-308) and consequently the existing retaining wall will need to be shifted south. Based on the base drawing provided, the proposed wall is 40 m in length and the wall height varies approximately between 1.0 m to 3.0 m.

The topography of the general project area is generally flat to gently undulating, except at the creek crossing. The surrounding area of the proposed York Road and Glendale Avenue intersection widening is vegetated at the northeast and southeast quadrants with trees, shrubs and bushes. The northwest and southwest quadrants are occupied by commercial developments. The proposed retaining wall site is a low-lying area and generally covered by bushes that have grown at the existing culvert outlet location on the southeast quadrant of the intersection.

3 FIELD AND LABORATORY INVESTIGATION

3.1 FIELD INVESTIGATIONS

The foundation scope in Table 2 of the Work Order indicated two (2) boreholes for the proposed retaining wall design. Upon review of the existing available information (GEOCREs No. 30M3-308), WSP proposed to eliminate one borehole and use two existing boreholes; the proposed change was approved by MTO.

The single borehole (Borehole RW1) was drilled at the southwest end of the proposed retaining wall to a depth of 15.8 m (Elev. 97.1 m). The borehole was drilled on July 12, 2019 using a track-mounted CME 55 (owned/operated by Pontil Drilling). The borehole was advanced using solid stem augers (150 mm diameter). Borehole RW1 was proposed to be drilled at the base of the existing embankment along the proposed retaining wall alignment; however, due to conflicts with underground

utilities, the borehole location had to be moved south. The presence of shrubs and trees, as well as a deep ditch prohibited access to the southern location; as such, the borehole was moved to Glendale Avenue road grade, which was the closest accessible location for access and to avoid underground utilities.

Prior to drilling operations, underground utilities were cleared at the borehole location by representatives of public, private companies and MTO.

The borehole locations were surveyed in the field using a Sokkia Archer Global Positioning System (GPS) unit, which has a horizontal and vertical accuracy of 3 mm and 5 mm, respectively. The borehole location is shown on Drawing 1, following the text of the report. A summary of the borehole information is given in Table 3-1.

Table 3-1 Summary of Borehole Information

Borehole	MTM NAD 1983, Zone 10		Ground Elevation (m)	Depth of Borehole (m)	Note
	Easting (m) (Latitude (°))	Northing (m) (Longitude (°))			
RW1	332,250.9 (43.160056)	4,780,078.5 (-79.162437)	113.0	15.8	Advanced from Glendale Avenue road surface

Soil samples in the borehole were taken at 0.75 m and 1.5 m intervals of depth by the Standard Penetration Test (SPT) spoon samples, in general accordance with ASTM D1586¹. The test consists of freely dropping a 63.5 kg hammer a vertical distance of 0.76 m to drive a 51 mm O.D. split barrel (SS-split-spoon) sampler into the ground. The number of blows of the hammer required to drive the sampler into the relatively undisturbed ground by a vertical distance of 0.30 m is recorded as the Standard Penetration Resistance (SPT) N-value of the soil. This is indicative of the compactness condition of non-cohesive soils (gravels and sands) or the consistency of cohesive soils (silty/ clayey soils).

In-situ shear vane tests (with a MTO 'N' vane) were carried out within the cohesive soils when the consistency of such soils allowed the in-situ measurement of the shear strength of the soil. Field vane shear tests were carried-out in accordance with ASTM D2573². In addition, a relatively undisturbed Shelby tube sample was retrieved in this borehole at depth of 9.7 m (Elev. 103.3 m) in accordance with ASTM D1587³.

The WSP borehole investigation was carried out under full-time supervision of WSP engineering staff who directed the drilling and sampling operation, logged borehole data in accordance with MTO Soils Classification System and soil samples retrieved for subsequent laboratory identification and testing. The recovered soil samples were placed in labelled moisture-proof bags, and returned to WSP's Galaxy laboratory for further assessment.

3.2 LABORATORY INVESTIGATIONS

A laboratory testing program, consisting of natural moisture contents, Atterberg Limits tests and grain size analyses, was performed on selected representative samples. In addition, conductivity / resistivity, pH, sulphate and chloride content testing was carried out on selected samples by a specialist analytical laboratory. The results of the laboratory tests are presented on the appropriate Record of Borehole Sheets in Appendix A and details of grain size distributions and Atterberg limits are provided in Appendix B.

¹ ASTM D1586 – Standard Test Method for Standard Penetration Tests and Split Barrel Sampling of Soils.

² ASTM D2573 - Standard Test Method for Field Vane Shear Test in Saturated Fine-Grained Soils.

³ ASTM D1587 - Standard Practice for Thin-Walled Tube Sampling of Fine-Grained Soils for Geotechnical Purposes.

3.3 GROUNDWATER INVESTIGATIONS

Groundwater conditions in the open borehole were observed during and on completion of drilling. The borehole was grouted using a cement/bentonite mixture as per MTO procedures and in accordance with Ontario Regulation 903 (amended to Ontario Regulation 372/07).

4 SUBSURFACE CHARACTERIZATION

4.1 GENERAL

The subsurface conditions encountered at the proposed retaining wall location are described in the following sections. For purposes of soil description, the Guideline for Foundation Engineering Services Version 1.0, dated May 2019 was followed.

A borehole location plan with a subsurface profile is shown on Drawing 1 at the end of the text. It should be noted that the subsurface conditions may vary in between and beyond the borehole locations. Drawing 1 that presents the inferred stratigraphic details at the proposed retaining wall location are based on the borehole advanced as part of the current investigation and on the two boreholes (Boreholes CV6 and CV5) relevant to this site from the previous investigation (GEOCRE No. 30M3-308).

The soil descriptions are based on visual and tactile observations, and complemented by the results of field and laboratory soil test results. It should be noted that the subsurface conditions and the fill thicknesses encountered may vary in between and beyond the borehole locations. The strata boundaries shown should not be interpreted as exact planes of geological change but rather as inferred transitions from one soil type to another.

An overview of subsurface conditions is first described below followed by detail descriptions of subsurface conditions. All depths quoted are below existing ground surface. It is to be noted that based on the borehole data, the elevations (Elev.) reported for strata boundaries are from the shallowest occurrence to the deepest occurrence.

4.2 OVERVIEW

In general terms, the stratigraphic sequence encountered can be described as topsoil/pavement structure underlain by fill (silty clay, clayey silt and sand and gravel) and native deposits. The underlying native deposits consist of an upper clayey silt and silty clay to clay followed by a lower clayey silt deposit.

4.3 SUBSOIL CHARACTERIZATIONS

4.3.1 PAVEMENT STRUCTURE

A pavement structure was encountered at the existing surface at Borehole RW1, which was advanced from the travelled lanes of Glendale Avenue. The pavement structure consisted of 260 mm of concrete over granular material consisting of sand and gravel. The SPT 'N'-value within the pavement granular was recorded as 6 blows per 300 mm of penetration, indicating a loose state of compactness.

4.3.2 FILL

Fill was encountered at ground surface in Boreholes CV5 and CV6 and below the pavement structure in Borehole RW1 at a depth of 0.6 m (Elev. 112.4 m). The fill was composed of silty topsoil, clayey silt and sand and gravel in Borehole CV5 which

extended to a depth of 0.8 m (Elev. 111.4 m). Underlying the upper fill material in Borehole CV5 and below the pavement structure in Borehole RW1 and from the ground surface in Borehole CV6, a silty clay fill material was encountered, and extended to depths ranging between 1.5 m to 3.5 m (Elev. 111.5 m to 107.8 m).

The grain size distribution of one (1) representative sample from the silty clay fill material reproduced from GEOCRE No. 30M3-308 is provided in Table 4-1:

Table 4-1 Grain Size Distribution Summary- Silty Clay Fill

SAMPLE TESTED	SIZE FRACTION	% PASSING BY WEIGHT	REMARKS
CV6 – SS1	Gravel	7	Shown as Figure B-2 , extracted from GEOCRE No. 30M3-308 appended in Appendix B and summarized on the relevant Record of Borehole Sheet
	Sand	11	
	Silt	40	
	Clay	42	

One Atterberg Limits test was performed on a representative sample from the silty clay fill material. The test results are summarized in Table 4-2.

Moisture content of this layer varied from 21% to 26%, which is wet of the plastic limit and is indicative of a moist condition.

The SPT 'N' values in this deposit ranged from 4 to 14 blows per 300 mm penetration, suggesting a firm to stiff consistency.

Table 4-2 Atterberg Limits Test Results-Silty Clay Fill

SAMPLE TESTED	ATTERBERG LIMITS	INDEX VALUES	REMARKS
CV6 – SS1	Liquid Limit	40	Shown as Figure B-1 , extracted from GEOCRE No. 30M3-308 appended in Appendix B and summarized on the relevant Record of Borehole Sheet
	Plastic Limit	19	
	Plasticity Index	21	

4.3.3 UPPER CLAYEY SILT

Borehole CV5 encountered a clayey silt deposit at a depth of 3.5 m (Elev. 108.7 m) below ground surface. The explored thickness of this deposit was 1.1 m.

The grain size distribution of one (1) representative sample from the clayey silt reproduced from GEOCRE No. 30M3-308 is provided in Table 4-3.

Table 4-3 Grain Size Distribution Summary-Clayey Silt

SAMPLE TESTED	SIZE FRACTION	% PASSING BY WEIGHT	REMARKS
CV5 – SS5	Gravel	0	Shown as Figure B-3 , extracted from GEOCRE No. 30M3-308 appended in Appendix B and summarized on the relevant Record of Borehole Sheet
	Sand	22	
	Silt	51	
	Clay	27	

One Atterberg Limits test results reproduced from GEOCRE No. 30M3-308 indicate the following index values (Table 4-4). Based on this, the soil is classified as clayey silt of low plasticity according to the MTO Soil Classification Manual.

Table 4-4 Atterberg Limits Test Results-Clayey Silt

SAMPLE TESTED	ATTERBERG LIMITS	INDEX VALUES	REMARKS
CV5 – SS5	Liquid Limit	33	Shown as Figure B-4 , extracted from GEOCRE No. 30M3-308 appended in Appendix B and summarized on the relevant Record of Borehole Sheet
	Plastic Limit	17	
	Plasticity Index	16	

Moisture content of this deposit was 18%, which is at about the plastic limit and is indicative of a moist condition (based on one (1) sample).

A SPT N-value of 13 blows per 300 mm penetration was obtained in this deposit, suggesting a stiff consistency (based on one (1) SPT value).

4.3.4 SILTY CLAY TO CLAY

Underneath the clayey silt deposit in Borehole CV5 and below the fill material in Boreholes CV6 and RW1, all boreholes encountered a firm to very stiff silty clay to clay deposit. The silty clay to clay deposit was contacted at depths of 1.5 m to 4.6 m (Elev. 111.5 m to 107.6 m). The explored depths of this deposit ranged between 10.4 m to 14.0 m (Elev. 99.4 m to Elev. 99.0 m). Boreholes CV5 and CV6 were terminated within this deposit.

The grain size distributions of two (2) samples from this deposit were determined in the laboratory and along with two (2) grain size distribution results from GEOCRE No. 30M3-308 are provided in Table 4-5:

Table 4-5 Grain Size Distribution Summary - Silty Clay to Clay

SAMPLE TESTED	SIZE FRACTION	% PASSING BY WEIGHT	REMARK
CV5 – SS9, CV6 – SS8, RW1 – SS5 and RW1 – SS11	Gravel	0 to 1	Shown as Figure B-6 , extracted from GEOCREs No. 30M3-308 and Figure B-6a appended in Appendix B and summarized on the relevant Record of Borehole Sheets
	Sand	2 to 3	
	Silt	23 to 33	
	Clay	63 to 75	

With respect to moisture content, Atterberg Limits, SPT 'N' values and undrained shear strengths based on the field shear vane (as discussed below), the existence of an upper horizon, i.e., a weathered crust and a less competent lower horizon within the silty clay deposit is noted, although no clear distinction was noted in the grain size distribution results given above.

Upper Horizon:

The upper silty clay to clay crust was encountered immediately below fill material in Boreholes RW1 and CV6, and below the clayey silt deposit in Borehole CV5, at depths of 1.5 m to 4.6 m (Elev. 107.6 m to Elev. 111.5 m). The cohesive crust was found to be in a stiff to very stiff consistency with measured SPT 'N' values ranging from 11 to 27 blows per 300 mm penetration. Moisture content of this portion of silty clay to clay deposit ranged between 22% and 30%, which is at or above the plastic limit, and is indicative of a moist to wet condition.

The Liquidity Index (LI) of soil samples, based on Atterberg Limits tests, for upper silty clay to clay crust ranged from 0.1 to 0.2, indicating the upper silty clay to clay deposit could be categorized as lower boundary of lightly over consolidated (LOC) clay.

Atterberg Limits tests were performed on representative samples from the upper silty clay to clay crust; the results from the current and previous investigation are summarized in Table 4-6. The results indicate that the deposit is classified as silty clay of intermediate plasticity to clay of high plasticity.

Table 4-6 Atterberg Limits Test Results-Silty Clay to Clay Upper Horizon

SAMPLE TESTED	ATTERBERG LIMITS	INDEX VALUES	REMARKS
CV5 – SS6, CV6 – SS3, RW1 – SS5	Liquid Limit	54 to 55	Shown as Figure B-5 , extracted from GEOCREs No. 30M3-308 and Figure B-5a appended in Appendix B and summarized on the relevant Record of Borehole Sheets
	Plastic Limit	22 to 23	
	Plasticity Index	32 to 33	

Lower Horizon:

The lower silty clay to clay horizon is inferred in all three boreholes at depths of 4.9 m to 6.7 m (Elev. 104.7 m to Elev. 106.3 m). The cohesive lower horizon was found to have a firm to stiff consistency, with measured SPT 'N' values ranging from 4 to 12 blows per 300 mm penetration. Moisture content of this portion of silty clay to clay deposit ranged between 22% and 38%, which is generally above the plastic limit and is indicative of a moist to wet condition.

The Liquidity Index (LI) of soil samples subjected to Atterberg Limits test for lower silty clay to clay ranged from 0.4 to 0.5, indicating the silty clay to clay deposit could be categorized as higher boundary of LOC clay.

Atterberg Limit tests was performed on representative samples from the lower silty clay to clay deposit, the results are summarized in Table 4-7. The test results indicated that the deposit can be classified as silty clay of intermediate plasticity to clay of high plasticity.

Table 4-7 Atterberg Limits Test Results-Silty Clay to Clay Lower Horizon

SAMPLE TESTED	ATTERBERG LIMITS	INDEX VALUES	REMARKS
CV5 – SS9, CV6 – SS8, RW1 – SS11 and RW1 – SS14	Liquid Limit	36 to 55	Shown as Figure B-5 , extracted from GEOCRESS No. 30M3-308 and Figure B-5a appended in Appendix B and summarized on the relevant Record of Borehole Sheets
	Plastic Limit	176 to 22	
	Plasticity Index	19 to 33	

Field vane tests were carried out in the lower silty clay to clay and yielded shear strength values ranging between 40 kPa and 93 kPa, with sensitivities ranging from 1.5 to 3.0, except for one value of greater than 144 kPa in Borehole CV5 at depth of 8.7 m (Elev. 113.5 m). Collectively, these indicate, the consistency of this deposit can be described as firm to very stiff.

A varved clay structure was observed in Shelby tube samples extracted within the silty clay to clay deposit at the Glendale Avenue and QEW Interchange during the current investigation and should be expected within this deposit.

4.3.5 LOWER CLAYEY SILT

Borehole RW1 encountered a clayey silt deposit underlying the silty clay to clay deposit below a depth of 13.7 m (Elev. 99.3 m). The explored thickness of this deposit was 1.9 m.

The grain size distribution of one (1) representative sample from this deposit was determined in the laboratory and the results are summarized in Table 4-8.

Table 4-8 Grain Size Distribution Summary-Clayey Silt Till

SAMPLE TESTED	SIZE FRACTION	% PASSING BY WEIGHT	REMARKS
RW1 – SS15	Gravel	3	Shown as Figure B-6a in Appendix B and summarized on the relevant Record of Borehole Sheet
	Sand	10	
	Silt	49	
	Clay	38	

An Atterberg Limits test was performed on a representative sample from the clayey silt deposit; the test results are summarized in Table 4-9. The results indicate that the deposit consists of a clayey silt of low plasticity.

Table 4-9 Atterberg Limits Test Results-Silty Clay Till

SAMPLE TESTED	ATTERBERG LIMITS	INDEX VALUES	REMARK
RW1 – SS15 and SS16	Liquid Limit	29 and 31	Shown as Figure B-5a in Appendix B and summarized on the relevant Record of Borehole Sheets
	Plastic Limit	16	
	Plasticity Index	13 and 15	

Moisture contents obtained from recovered samples of this deposit ranged from 18% to 30%, which is above the plastic limits and is indicative of a moist to wet condition.

One SPT 'N' value of 11 blows per 300 mm of penetration was measured within this deposit, which suggests a stiff consistency.

4.4 GROUNDWATER LEVEL OBSERVATIONS

Groundwater level in the open boreholes (Boreholes RW1 and CV5) was observed during the drilling and at the completion of the boring. The observed water level in the open borehole on completion was at a depth of 10.7 to 11.9 m below ground surface (Elev. 101.1 to 101.5 m). It should be noted that this water level had not stabilized. In addition, groundwater was observed at surface (same as creek water level, Elev. 109.6 m) in Borehole CV6 during that investigation.

Groundwater levels will be subject to seasonal fluctuations in response to major weather events. The groundwater levels observed at the site may also be influenced by the water level in the watercourse.

4.5 CORROSIVITY AND WATER-SOLUBLE SULPHATE TESTING OF SOILS

Two (2) soil samples (Borehole RW1/SS4 and Borehole CV5/SS2) were analyzed for corrosivity parameters, including the resistivity of the soil, pH, Electrical Conductivity and sulphide concentration for corrosion protection to the proposed retaining wall. The test results are summarized as follows:

- resistivity was measured at 671 and 1300 ohm cm;
- pH was measured at 7.62 and 8.15;
- Electrical Conductivity was measured at 762 and 1490 $\mu\text{mho}/\text{cm}$; and,
- sulphide concentration was measured at less than 0.05%.

The sulphate (SO_4) resistance of the concrete in contact with the soils was evaluated by performing water-soluble sulphate test on same soil sample taken from selected Boreholes RW1 and CV5 at depths from 1.5 to 2.9 m below grade. The tests revealed that the sulphate concentration in the tested soil samples were 390 and 971 smg/kg or 390 and 971 $\mu\text{g}/\text{g}$.

The test results are attached in Appendix F.

PART B: FOUNDATION DESIGN REPORT
PROPOSED RETAINING WALL AT GLENDALE AVENUE AND YORK ROAD ROUNDABOUT
TOWN OF NIAGARA-ON-THE-LAKE, ONTARIO
ASSIGNMENT NO. 2017-E-0018-12, G.W.P 2423-15-00
GEOCRES NO: 30M3-315

5 DISCUSSION AND RECOMMENDATIONS

5.1 GENERAL

This section of the report provides recommendations for the foundation aspects for the proposed retaining wall at the Glendale Avenue and York Road roundabout in the Town of Niagara-on-the-Lake, Ontario. The recommendations are based on our understanding of the project and on the interpretation of factual data compiled from both field and laboratory investigations carried out by WSP and others for this project.

The discussions and recommendations presented in this report are intended to assist the designers with sufficient information that would enable them to proceed with the design of the retaining wall.

Construction comments made herein are based on geotechnical considerations only and should not be relied upon without further independent assessment and qualification in the selection of means and methods for construction.

The existing Glendale Avenue is a four-lane undivided roadway running south-north and York Road is four lane divided roadway running east-west. The existing four-way intersection will be converted to a roundabout to facilitate smoother traffic movements. As part of the proposed roundabout construction, the York Road and Glendale Avenue intersection will be widened to the south and east, respectively. The existing retaining wall at southeast corner of intersection will be replaced to accommodate the proposed widening.

The General Arrangement (GA) for proposed retaining wall was not available at the time of this report; a base drawing showing a general site plan and profile along the proposed wall was available at the time of preparation of this report.

5.2 CONSEQUENCE AND SITE UNDERSTANDING CLASSIFICATION

The proposed retaining wall and its foundation systems are classified as having a “Typical Consequence Level” associated with exceeding limits states design, as per Section 6.5 of Canadian Highway Bridge Design Code and its Commentary (CHBDC, 2014).

Based on the level of foundation investigations completed to date at the proposed retaining wall in comparison to the degree of site understanding outlined in Section 6.5 of CHBDC (2014), a “Typical Degree of Site and Prediction Model Understanding” is considered appropriate for the proposed retaining wall.

The corresponding consequence factor(s), Ψ , and geotechnical resistance factors, ϕ_{gu} and ϕ_{gs} , from Tables 6.1 and 6.2 of the CHBDC (2014) have been used for the appropriate aspects of the foundation design.

5.3 GEOTECHNICAL MODEL

5.3.1 OVERVIEW OF SUB-SURFACE CONDITIONS

The stratigraphy at the site generally consists of a pavement structure or surficial fill underlain by native silty clay to clay further underlain by a clayey silt deposit. The upper portion of the silty clay to clay deposit has a stiff to very stiff consistency (weathered crust) and was approximately 4.9 m to 7.5 m thick, while the lower portion of the silty clay to clay deposit has a firm to stiff consistency.

The design groundwater level can be taken as the same as the water level in the creek, as was observed in Borehole CV6, i.e., at Elev. 109.6 m.

5.3.2 GROUND MOTION PARAMETERS

Based on the borehole information and our review of the general subsurface conditions in the area, the subject site for the proposed retaining wall can be classified as 'Site Class D' for seismic site response according to Table 4.1.8.4.A of National Building Code (NBC) 2015 and Table 4.1 of the Canadian Highway Bridge Design Code (CHBDC, 2014).

The Peak Ground Acceleration and Spectral (PGA and $S_a(0.2)$) for Site Class C at the proposed retaining wall location (Town of Niagara-On-The-Fall) as obtained from the Natural Resources Canada (NRC) website on September 9, 2019 (<http://earthquakescanada.nrcan.gc.ca/hazard-alea/interpolat/calc-en.php>), for the 2% in 50-year probability of exceedance, is 0.207g and 0.321, respectively. The values provided above are the reference ground condition Site Class C and must be modified in accordance with Section 4.4.3.3 of the CHBDC (2014) to a Site Class D. As per Section 4.4.3.3 of the CHBDC (2014), the adjusted PGA value from the reference Site Class C to Site Class D is 0.241g for a 2% in 50-year probability of exceedance (2,475 return period).

5.3.3 FROST DEPTH

The minimum earth cover required for a structure (strip or spread footing) subjected to frost action at the project site is 1.2 m in accordance with Ontario Provincial Standard Drawing (OPSD) 3090.101 (Foundation, Frost Penetration Depths for Southern Ontario).

The thickness of levelling pads for Retained Soil System (RSS) walls is designed by the proprietary RSS system and only partial frost protection is generally provided.

5.4 DISCUSSION OF ALTERNATIVE WALL OPTIONS

5.4.1 MECHANISMS OF LATERAL SUPPORT IN RETAINING WALLS

In addition to technical feasibility, the type of retaining wall is often selected based on multiple factors such as cost, aesthetics and environmental considerations. There is a wide variety of options available, ranging from simple concrete modular type walls to embedded retaining walls such as contiguous retaining walls. The following general retaining wall types are reviewed first:

- Gravity or Mass Retaining Walls: Resistance to failure mechanisms of sliding and overturning (toppling) primarily relies on the weight of the structures; concrete modular walls and armour stone walls belong to this category.
- Cantilever Walls: Lateral pressures of the retained soil are resisted by bending of the wall stem; weight of the retained soil acting on the footing slab base, which projects beneath the backfill, prevents sliding and overturning (gravity action).

- Retained Soil System (RSS) Walls (also known as Mechanically Stabilized Earth (MSE) Walls): These constructions at the global level can be treated as equivalent to gravity walls but at the local level as individually anchored wall units; instead of allowing the lateral pressures of the retained soil to be carried down to the foundation as bending stresses in the front wall, they are carried into the retained mass itself by the tensile forces induced in the reinforcement ties at various depths by the weight of the backfill; tension is always a more economical source of support than bending.
- Embedded Retaining Walls: The primary mechanism of resistance against the lateral earth pressures of the retained mass is the passive earth pressure of the soil in front of the wall, and possibly aided by props or tie-back anchors at one or more levels; typical examples in this category are sheet piled walls, soldier pile and lagging walls and contiguous caisson walls.

The first three retaining wall types can be described as back-filled walls where the retained height of the soil behind is created by building up, i.e., bottom up construction. For embedded retaining walls, the level difference is created by removing soil from in front of the wall, i.e., top to bottom construction, and are sometimes called excavated walls.

The existing retaining wall at Glendale Avenue and York Road is a concrete block type (modular) retaining wall. The main advantage of concrete block wall is ease of construction for a curved type wall and over another structure, such as a culvert. The construction a roundabout at the Glendale Avenue and York Road Interchange will necessitate the widening of the existing embankment to the south and a new retaining wall will be required. Based on the proposed embankment construction, the new retaining wall will be a back-filled wall, i.e., a bottom up construction. As such the following types of retaining walls are considered feasible:

- Concrete Cantilever Retaining Wall
- RSS Wall
- Gravity Wall

Irrespective of the back-filled type of retaining wall adopted, the lateral earth pressure and vertical gravity loads, i.e., the weight of the wall and immediate backfill, acting together will result in eccentric (due to the lateral force; and results in a reduced effective width of the footing and hence in an increase in the applied stress) and inclined loading (due to the combined action of vertical and lateral forces and results in reduced mobilisation of bearing resistance) conditions under the retaining wall footing. This will limit the effective footing area and the geotechnical resistance that will mobilize to resist the vertical loads. Therefore, as per Section 6.10.4 of the CHBDC (2014), the available geotechnical resistance will need to be reduced. These reductions can only be estimated once the footings are proportioned.

The new retaining wall should be designed to low appearance and medium performance requirements.

The following limit states need to be addressed: bearing resistance, sliding and overturning, settlements and global stability for the back-filled wall types under discussion. Provision of good drainage is key to sound retaining wall performance.

CONCRETE CANTILEVER RETAINING WALL OPTION

A concrete retaining wall consisting of a vertical stem and footing slab base is a common retaining wall option. Due to the reinforced concrete nature of the wall, which makes it less compliant for movement, relatively competent foundations, such as very stiff to hard clayey soil/compact to dense granular soil deposits are warranted, requiring more stringent site preparation than a RSS wall. At the proposed retaining wall site, excavations of up to 3.5 m may be required to found on the foundations on the stiff to very stiff silty clay to clay crust. Additionally, due to the presence of the culvert within the retaining wall footprint, temporary protection systems, cofferdams and / or dewatering may be required for the construction of the strip footings.

RSS WALL OPTION

This wall option has many of the drawbacks of a concrete cantilever retaining wall addressed above. Being a more movement tolerant wall system, it requires less stringent site preparation, use of precast elements negates issues with reinforcement fixing and in-situ concreting. Additionally, shallower excavation depths are required for an RSS wall, with associated reduction in dewatering requirements. Wall facings can address aesthetic requirements with ease. On the other hand, the quality of backfill and placement are more important as the principal load carrying mechanism of lateral earth pressures on the facing panels relies on the interaction of the backfill with the reinforcement strips. Also, the integrity of the connections between the reinforcing elements and the wall panels are critical. Environmental and chemical/electro-chemical

considerations are relevant and may vary between inextensible steel reinforcement systems and geosynthetic reinforcement systems. This wall option has been widely used in Southern Ontario with good performance (MTO RSS Guidelines, Engineering Standards Branch). It is understood that RSS walls near flowing water would require a site-specific design submission for review and approval by the MTO RSS Committee. As the new wall would be constructed in the immediate vicinity of the culvert, an RSS wall is not considered feasible at this site.

CONCRETE MODULAR WALL OPTION

The existing retaining wall at this site is comprised of a precast reinforced concrete block laid out at culvert outlet. Considering challenging geometry and existence of a culvert, a gravity modular style wall would provide a suitable alternative for this site, due to minimum site preparation and dewatering requirements.

The Gravity Type wall would be considerably less expensive and easier to construct, but would carry slightly more risk of slope erosion if the waterway should flood. The subgrade material can potentially migrate into the backfill material if it is not adequately separated from the native soils with a geotextile filter fabric (e.g., Terrafix 270R or better or similar) in accordance with Ontario Provincial Standard Specification (OPSS) 1860 (Material Specification for Geotextiles). The concrete modular wall is feasible and practicable at this site.

The Table 5-1 provides a summary of comparison different retaining wall options:

Table 5-1: Comparison of Retaining Wall Alternatives

ALTERNATIVE	FEASIBILITY	ADVANTAGES	DISADVANTAGES	RISKS / CONSEQUENCES	RELATIVE COST
Cantilever Cast-in-Place Concrete on Spread Footings	Feasible provided that, temporary protection systems, cofferdams and / or dewatering are used during construction due to proximity of existing culvert.	<ul style="list-style-type: none"> Longer service life than RSS walls. Superior appearance. Conventional construction and excavation. Suitable founding stratum encountered below frost depth. 	<ul style="list-style-type: none"> Footings would need to be founded below frost depth (1.2 m at this site). Requires excavations of up to 3.5 m through the existing fill and into the stiff to very stiff silty clay to clay crust. Adjacent to existing culvert which would necessitate use of protection systems, cofferdams, and / or dewatering during construction. Less tolerable to post-construction settlements. 	<ul style="list-style-type: none"> The retaining wall is adjacent to an existing culvert, increasing risk of dewatering issues. Deeper protections systems greater potential for groundwater control 	More expensive than all feasible types of walls.
RSS wall	Feasible however the RSS wall would be within the floodplain and near flowing water.	<ul style="list-style-type: none"> Fast and efficient design and construction. Can be founded at depths higher than frost depth if a suitable bearing stratum is encountered. More tolerable to post-construction settlements. 	<ul style="list-style-type: none"> Potential for loss of soil particles in flood conditions. Temporary protections systems would be required during construction. Potentially large construction footprint due to length of reinforcing strips. 	<ul style="list-style-type: none"> The general requirement of RSS wall performance and appearance should be followed to meet SSP 599S22. Excavation below groundwater table and backfilling may be required. Special approval from the MTO RSS Committee would be required. 	Less expensive than cantilever cast-in-place retaining walls.

			<ul style="list-style-type: none"> Excavations of up to 2 m would be required at some locations to remove the existing fill layer. 		
Concrete Modular Wall	Feasible and preferred alternative for this site.	<ul style="list-style-type: none"> Fast and efficient design and construction. Can be founded at depths higher than frost depth if a suitable bearing stratum is encountered. 	<ul style="list-style-type: none"> Requires tilt back of the wall. Mitigation and prevention measures would be considered to prevent migration of fine material into wall. Tolerable to post-construction settlements; however, the aesthetics of the wall may be compromised. Excavations of up to 2 m would be required to below the existing fill layer. 	<ul style="list-style-type: none"> Potential for loss of soil particles. Excavations below the groundwater table would be required. 	Less expensive than RSS and cast-in-place retaining walls.

RECOMMENDED RETAINING WALL OPTION

Based on the evaluation criterion outlined in Table 5-1, purpose and location of the wall as well as consideration of the proposed wall height between 1.5 and 3.0 m, a modular type retained soil system comprising of gabion baskets with or without wire mesh tie backs founded on granular pad placed on native stiff to very stiff clayey silt is the preferred alternative for the construction of the proposed retaining wall.

5.4.2 RESISTANCE TO LATERAL EARTH PRESSURES AND SLIDING

The lateral and sliding resistance of retaining wall should be controlled during design to resist unbalanced lateral earth pressure imposed by the backfill material adjacent to the wall. Computation of earth pressures should be in accordance with Section 6.12.2 of the CHBDC (2014). For design purposes, the following (Table 5-2) unfactored static earth pressure parameters can be used (assuming wall friction is neglected, the back wall is vertical and the ground surface is horizontal in front of the toe):

Table 5-2 Unfactored Static Earth Pressure Coefficients

Wall Movement Condition	Compacted Granular 'A' and Granular 'B' Type II Angle of Internal Friction, $\phi = 35^\circ$ Unit Weight = 22 kN/m ³ (Wall friction neglected)		Compacted Granular 'B' Type I Angle of Internal Friction, $\phi = 32^\circ$ Unit Weight = 21 kN/m ³ (Wall friction neglected)	
	Top Ground Surface Angle		Top Ground Surface Angle	
	Horizontal	2H:1V	Horizontal	2H:1V
Active Earth Pressure (K_a)	0.27	0.38	0.31	0.46
At-Rest Earth Pressure (K_o)	0.43	0.62	0.47	0.68
Passive Earth Pressure (K_p)	3.69	-	3.25	-

The effect of compaction pressure should be considered during the design in accordance with CHBDC (2014) Clause C6.12.3. the hydrostatic pressure would not be considered since free-draining granular material or rockfill should be used as backfill behind the wall.

A friction angle of 19 and 26 degrees shall be assumed at the interface of a pre-cast footing and native founding material (subgrade) and granular material consisting of compacted OPSS.PROV 1010 (Aggregates) Granular 'A' or Granular 'B' Type II for the calculation of sliding resistance, respectively. The designer shall use appropriate factors on the angle of internal friction and cohesion values provided on the table to check the sliding resistance. Foundation keys or dowels may be specified if adequate resistance from the subgrade cannot be mobilised. The recommended unfactored coefficient of friction, δ at the base of footing (assuming a pre-cast footing) can be taken as 0.35 and 0.5 for placing the footing on the founding material (subgrade) and granular material, respectively. Minimum backfill placement requirements should conform to CHBDC Figure C6.20.

5.4.3 LATERAL EARTH PRESSURE - SEISMIC LOADING

YIELDING WALLS:

Seismic (earthquake) loading should be taken into account in the design. These estimates are based on the Monobe-Okabe (M-O) pseudo-static method of analysis. The M-O method produces seismic loads that are more critical than the static loads that act prior to an earthquake.

The horizontal seismic coefficient, k_h , used in the calculation of the seismic active pressure coefficient, can be taken as, $k_h=0.5$ PGA as per CHBDC and Commentary Section 4.6.5 and Section C4.6.5. The seismic active earth pressure coefficient is also dependent on the vertical component of the earthquake acceleration coefficient, k_v , although the influence of k_v is estimated to be less than 10% on the seismic active earth pressure (Kramer, 1996) and can be neglected.

It should be noted that in the computation of seismic earth pressure coefficients, the wall back-face geometry, backfill slope and wall friction effects need to be addressed.

For design purposes, the following unfactored seismic lateral earth pressure parameters can be used (assuming wall friction is neglected, the back wall is vertical and the ground surface is horizontal in front of the toe):

Table 5-3 Unfactored Seismic Earth Pressure Coefficients

Wall Movement Condition	Compacted Granular 'A' and Granular 'B' Type II Angle of Internal Friction, $\phi = 35^\circ$ Unit Weight = 22 kN/m ³ (Wall friction neglected)		Compacted Granular 'B' Type I Angle of Internal Friction, $\phi = 32^\circ$ Unit Weight = 21 kN/m ³ (Wall friction neglected)	
	Top Ground Surface Angle		Top Ground Surface Angle	
	Horizontal	2H:1V	Horizontal	2H:1V
Seismic Active Earth Pressure (K_{AE})	0.29	0.43	0.32	0.52
Seismic Passive Earth Pressure (K_{PE})	NA	NA	NA	NA

NON-YIELDING WALLS:

When the wall movements are insufficient to mobilize the shear strength of the backfill soil, the limiting conditions of minimum active or maximum passive conditions cannot develop. The horizontal seismic coefficient, k_h , used in the calculation of the seismic pressure coefficient, should be taken as, $k_h=PGA$.

The exposed founding subgrade should be covered with a 100 mm thick concrete mud slab to further protect the subgrade from disturbance due to construction activities.

5.4.4 FOUNDATIONS

Strip footings are feasible for the support of the proposed retaining wall and should be founded below any topsoil, fill or softened surficial soils, at a minimum depth of 1.2 m below the adjacent final grade to provide adequate protection against frost penetration, in accordance with OPSS 3090.101 (Foundation, Frost Penetration Depths for Southern Ontario).

Concrete modular wall foundations do not need to be founded below frost depth; however, they should be founded below any topsoil, fill or softened surficial soils.

Based on the ground conditions encountered in the boreholes the proposed retaining wall location, strip footings for a concrete retaining wall, or concrete modular blocks, should be founded on the stiff to very stiff silty clay to clay deposit below the existing fill, which extends to between Elevation 111.5 m and 107.8 m (see Table 5-4 below). Alternatively, the sub-excavated area could be backfilled with compacted OPSS.PROV 1010 (Aggregates) Granular 'A' or Granular 'B' Type II that is placed and compacted in accordance with OPSS.PROV 501 (Compacting) to raise the subgrade to the proposed founding level. The granular backfill used for the subexcavation should be extended at least 0.5 m beyond the outside edge of the modular concrete section and backfill soil mass and then downward at a gradient of 1H:1V. OPSS.PROV 1010 (Aggregates) Granular 'B' Type I can be used for the remainder of the excavation, and the retaining wall backfill for cost saving measures or if OPSS.PROV 1010 (Aggregates) Granular 'A' or Granular 'B' Type II is not readily available. In subsequent section and in the slope stability analyses, the granular "pad" refers to the OPSS.PROV 1010 (Aggregates) Granular 'A' or Granular 'B' Type II material used to backfill the excavation and on which the retaining wall should be founded, while the granular "backfill" refers to the OPSS.PROV 1010 (Aggregates) Granular 'B' Type I the can be used for the retaining wall backfill material.

Table 5-4: Founding Elevations

REFERENCE BOREHOLE / LOCATION	HIGHEST FOOTING FOUNDATION ELEVATION (m)	APPROXIMATE EXCAVATION DEPTHS FROM EXISTING GROUND SURFACE AT PROPOSED RETAINING WALL ALIGNMENT (m)	FOUNDING CONDITIONS
RW1 / East End	111.5	-	Stiff to Very Stiff Silty Clay to Clay
CV6 / Center	107.8	1.5	Very Stiff Silty Clay to Clay
CV5 / West End	107.8	3.5	Stiff Clayey Silt/Silty Clay to Clay

The recommended factored ultimate geotechnical resistance and factored serviceability geotechnical resistance provided for footing with 1.5 and 3.0 m width (for 25 mm of settlement) for a footing placed on the properly prepared subgrade or granular pad (at or below the elevation mentioned in Table 5-5 and placing granular fill) are as follows:

Table 5-5 Geotechnical Resistances

FOUNDING CONDITIONS	FOOTING WIDTH (M)	FACTORED ULTIMATE GEOTECHNICAL RESISTANCE (kPa)	FACTORED SERVICEABILITY GEOTECHNICAL RESISTANCE (kPa) FOR 25 mm SETTLEMENT
Stiff to Very Stiff Silty Clay to Clay / Stiff Clayey Silt	1.5	185	125
	3.0	185	100
Granular 'A' or Granular 'B' Type II Pad	1.5	300	200
	3.0	450	125

The bearing resistance for inclined loads should be reduced in accordance with the requirements of Clause 6.10.4 of the CHBDC (2014). All footing subgrade should be inspected by qualified geotechnical personnel following excavation, in accordance with OPSS 902 (Excavating and Backfilling Structures) and Special Provision (SP)109S12 (Amendment to OPSS 902). The excavation depth required to reach an adequate subgrade for the proposed spread footing should be confirmed by design build contractor prior to construction of footing.

The design and specification of backfill material and drainage system requirement will be responsibility of supplier. The designer of the concrete modular wall should be responsible for the detail design of the structures and provide drawings to show pertinent information such as location, length, height, elevations, performance level, appearance, etc.

In case a concrete modular wall is adopted, it shall be constructed in accordance with OPSS.PROV 512 (Installation of Gabions). The modular blocks should be embedded a minimum of 0.5 m below final ground surface. The fines from the fill material may migrate through the concrete modular walls, especially when the drainage path is flooded. This may lead to erosion, bulging of the concrete modular walls or failure of embankment. In order to prevent loss of fines, a properly designed granular filter or non-woven Class II geotextile (with an FOS of 75 – 100 µm in accordance with OPSS.PROV 1860 (Geotextiles)) shall be placed behind the concrete modular wall.

5.4.5 STABILITY CONSIDERATIONS

The most critical cross section for the retaining wall which is considered to be the one closest to the creek (at approximate location of Borehole CV6) has been used in the stability analysis for the retaining wall with the subsurface profile simulating RW1 and CV6 conditions. The foundation granular pads were considered for the analysis. The stability of the proposed retaining wall was analysed

using the limit equilibrium methods and the Slide 2018 software developed by Rocscience Inc. The software analyses numerous potential failure surfaces (Morgenstern-Price finally adopted) and establishes the critical one with a minimum factor of safety. The soil parameter utilized from correlation with SPT 'N' value obtained from Canadian Foundation Engineering Manual (CFEM, 2006). Figures D1 and D2 in Appendix D show the stability analysis result and ground model parameter are summarized in Table 5-6.

Table 5-6 Geotechnical Model for Slope Stability

Soil Type	Unit Weight (kN/m ³)	Total Stress Parameters, Su (kPa)	EFFECTIVE STRESS PARAMETERS	
			c' (kPa)	Ø' (Degree)
Silty Clay Fill	19.5	70	0	26
Silty Clay to Clay	19.5	70	0	26
Granular Pad	22	N/A	0	35
Granular Backfill	21.5	N/A	0	32

The Factor of Safety for both the short term and long-term global stability of the retaining wall was greater than 1.5, which is considered the minimum acceptable FOS by MTO. Based on the above analysis no instability problems are anticipated for proposed retaining wall founded on a granular pad during and after construction.

5.4.6 SETTLEMENTS

Based on the findings of the boreholes, settlements of less than 25 mm are anticipated under the factored Serviceability Geotechnical Resistances noted in Table 5-5 in Section 5.4.4 at the retaining wall location. The parameters used in the settlement analysis are summarized in Table 5-7.

Table 5-7 Geotechnical Model for Settlement Analysis

Soil Type	Unit Weight (kN/m ³)	Elastic Modulus (MPa)	P _c ' (kPa)	e _o	C _c	C _r
Silty Clay to Clay Crust	19.5	25	425	0.75	0.47	0.025
Silty Clay to Clay	19.5	20	325	0.7	0.35	0.02

Any structural connection between the retaining wall and the culvert headwalls should be designed to tolerate some differential movements.

5.4.7 BACKFILL AND DRAINAGE

Positive drainage of the granular backfill should be provided with transverse drains whilst OPSD 3190.100 (Walls, Retaining and Abutment, Drainage) and OPSD 3121.150 (Walls Retaining, Backfill, Minimum Granular Requirement) requirements should be met with respect to backfill, sub-drains and frost taper. Selection of compaction equipment should be compliant with OPSS.PROV 501 (Compacting).

Backfill and frost taper to the concrete modular wall should consist of OPSS.PROV 1010 (Aggregates) Granular A or Granular B and placement should be in accordance with OPSS 902 (Excavating and Backfilling Structures).

5.5 CONSTRUCTION CONSIDERATIONS

5.5.1 SITE PREPARATION

It is recommended that all topsoil, organics loosened/softened and deleterious materials should be stripped from the proposed concrete modular footprint and backfilled area in accordance with OPSS 902 (Excavating and Backfilling Structures).

It is recommended that the existing wall be removed during the widening of the roadways so as not to create a hard point in the road surface, the existing fill should be re-graded and proper bonding (through benching) between the old and new fill (similar to a roadway widening recommendation). Also, to avoid any obstruction to future service installation along road corridor, the existing wall should be removed prior to installation of new wall.

5.5.2 EXCAVATIONS

All excavations, shoring and backfilling should be carried out in accordance with the Occupational Health and Safety Act (OHSA). Where space permits, and appropriate groundwater control measures are in place, temporary open cut excavations are anticipated through the cohesive fill material (Type 3) into cohesive native material (Type 2). The side slopes of no steeper than 2H:1V should be provided for open cut excavations. Excavations at steeper slopes or deeper than 1.2 m will require temporary shoring systems, as well as the following specifications.

In accordance with OHSA, the sub-soils intercepted can be classified as follows:

- Silty Clay/Clayey Silt Fill Material Type 3
- Clayey silt/Silty Clay Type 2, 2H: 1V above water level and Type 4 below water level

The above slopes are for short-term open excavations only and should be visually monitored, especially when people are working inside.

Excavations in the native soils should be possible using heavy equipment such as a hydraulic excavator and cobbles and boulders within the fill and native soils should be anticipated.

Should shoring be undertaken, such system should be designed by a Professional Engineer using the parameters provided in Table 5-8, experienced in this type of work and such work should conform to OPSS.PROV 539 (Temporary Protection Systems) and meet Performance Level 2. Use of sheet piles or soldier pile and lagging systems are considered suitable for the temporary excavation support at this site; the decision regarding the shoring type, method and design are the responsibility of the contractor.

For shoring design, assume groundwater to be at the creek water elevation (109.6 m).

Table 5-8 Recommended Unfactored Parameters for Temporary Shoring Design

Soil Type	Unfactored Parameters for Temporary Shoring Design			
	K_a	K_o	K_p	Bulk Unit Weight (kN/m ³)
Fill (Silty Clay/Clayey Silt)	0.39	0.56	2.56	19.5
Native Clayey Silt/Silty Clay	0.39	0.56	2.56	19.5

5.5.3 EROSION / SCOUR PROTECTION

The soils along the proposed retaining wall may be susceptible to erosion and scour depending on the design flood / flow velocities of the watercourse present to the east of the retaining wall. The requirements for design of erosion/scour protection should be assessed by the hydraulic design engineer. As a minimum, it is recommended that erosion protection (e.g. rip-rap or granular sheeting) be provided along the base of the proposed retaining wall. The erosion protection should be as per OPSS.PROV 511 (Rip-Rap, Rock Protection, and Granular Sheeting) and should be approved by the hydraulic design engineer.

5.6 GROUNDWATER CONTROL

Groundwater level at this site should be taken at the creek water level (Elev. 109.6 m). Construction should be carried out in the dry and the creek should be temporarily diverted using sandbags and clay puddle along with a bypass scheme. The seepage and runoff shall be directed away from open excavation and should not be allowed to pond into excavation pit. The taking of water for short-term construction dewatering and the control of water from the dewatering operations shall be performed in accordance with OPSS.PROV 517 (Dewatering) and NSSP FOUN0003.

The seepage should be able to be handled by gravity drainage and pumping from open sumps and on occasions more aggressive dewatering may be required (e.g. vacuum well points/ eductors). For excavations close to the creek, seepage through conducting seams can be expected depending on the time of the year (i.e., creek level). Intensity of seepage depends on the weather (i.e., precipitation), time of construction (i.e., snow melt) and construction methodology employed by the contractor.

The control of water during construction should be undertaken as per OPSS.PROV 517 (Construction Specification for Dewatering).

5.7 POTENTIAL FOR SULPHATE ATTACK/CORROSION ON BURIED CONCRETE AND STEEL

Laboratory testing carried out on two samples of soil obtained from Boreholes RW1 and CV5, the results are summarized in Section 4.5.

The Canadian Standards Association (CSA) recognizes four categories of potential sulphate attack of buried concrete based on per cent sulphate in soil. From 0 to 0.10 per cent the potential is negligible, from 0.10 to 0.20 per cent the potential is mild but positive, from 0.20 to 0.50 per cent the potential is considerable and 0.50 per cent and greater the potential is severe. Based on the above the soil sample is considered to have a negligible potential for sulphate attack on buried concrete.

Based on MTO Gravity Pipe Design Guideline (April 2014), subgrade soil corrosiveness categorized to four (4) groups in accordance to Table 3.2 from the MTO guideline. The soil resistivity for the sample tested at this site indicated resistivity are less than 2,000 ohm-cm, which categorized the subgrade soil as severe. Due to corrosiveness condition of subgrade soil protection measure should be provided for steel elements (reinforcing) imbedded within the subgrade soils.

6 CLOSURE

Thank you for the opportunity to be of service to you. Should you have any questions or require further clarification on any aspect of this report, please do not hesitate to contact this office.

SIGNATURES



Mansoor Khorsand, P.Eng.
Geotechnical Engineer



Nikol Kochmanová, Ph.D., P.Eng., PMP
Senior Geotechnical Engineer
MTO Foundations Designated Contact

REFERENCES

Canadian Highway Bridge Design Code (CHBDC) and Commentary on CAN/CSA S6-14. 2014. CSA Special Publication, S6.1 14. Canadian Standard Association.

Canadian Geotechnical Society, 2006. Canadian Foundation Engineering Manual, 4th Edition. The Canadian Geotechnical Society c/o BiTech Publisher Ltd, British Columbia.

MTO Gravity Pipe Design Guideline, (April 2014)

CAC/CSA A23.1-14/A23.2-14 Concrete Materials and Method of Concrete Construction

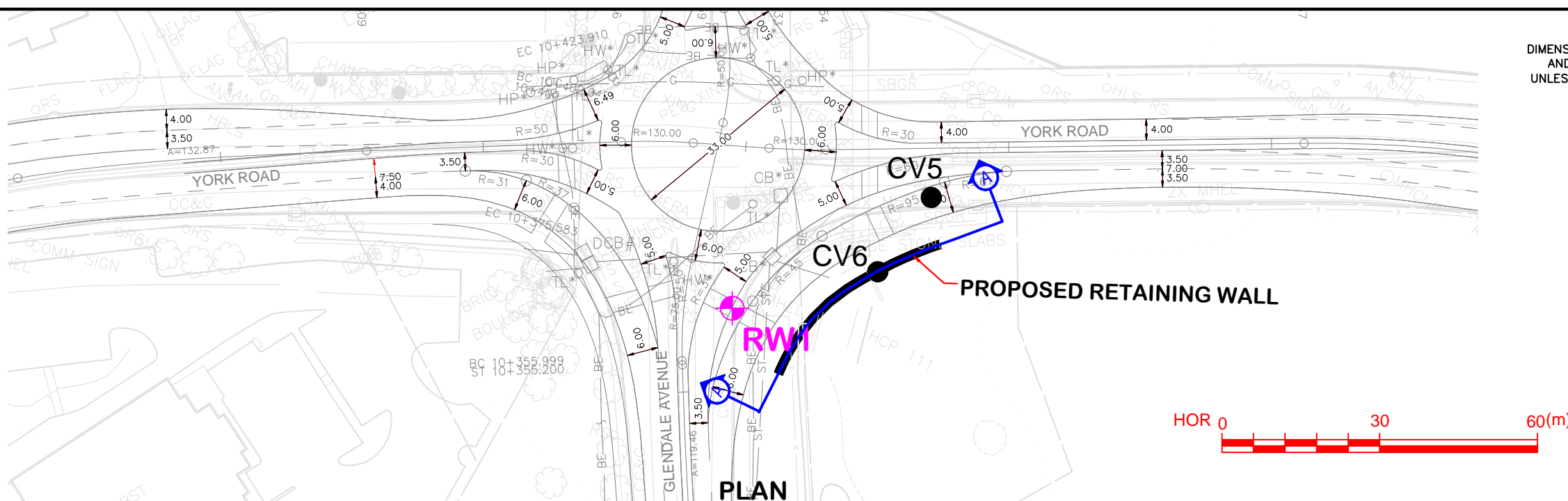
Ontario Provincial Standard Specifications (OPSS):

- OPSS.PROV 501: Construction Specification for Compacting
- OPSS.PROV 511: Construction Specification for Rip-Rap, Rock Protection, and Granular Sheeting
- OPSS.PROV 512: Construction Specification for Installation of Gabions
- OPSS.PROV 517: Construction Specification for Dewatering
- OPSS.PROV 539: Construction Specification for Temporary Protection Systems
- OPSS 902: Construction Specification for Excavating and Backfilling – Structures. (SP)109S12 (Amendment to OPSS 902)
- OPS.PROV 1010: Material Specification for Aggregates - Base, Subbase, Select Subgrade, and Backfill Material
- OPSS.PROV 1860: Material Specification for Geotextiles
- OPSD 3090.101: Foundation Frost Penetration Depths for Southern Ontario
- OPSD 3190.100: Walls Retaining and Abutment Wall Drain
- OPSD 3121.150: Walls Retaining, Backfill Minimum Granular Requirement

DRAWINGS

BOREHOLE LOCATION PLAN AND SOIL STRATIGRAPHY (DRAWING 1)





METRIC
DIMENSIONS ARE IN METRES
AND/OR MILLIMETRES
UNLESS OTHERWISE SHOWN

DIST
CONT
WP No: 2423-15-00

QEW/ GLENDALE AVENUE
INTERCHANGE
York Road Roundabout Retaining Wall
BOREHOLE LOCATIONS & SOIL STRATA

SHEET
S-1

2 International Blvd, Suite 201
Toronto, Ontario
M9W 1A2



KEY PLAN

SOIL STRATA SYMBOLS

Fill Silty Clay to Clay
 Sandy Clayey Silt Clayey Silt

SOIL STRATA SYMBOLS

Borehole - Current Investigation
 Borehole - Previous Investigation (Geocres No. 30M3-308)
N Blows/0.3m (Std Pen Test, 475 J/blow)
 Water Level (based on data available in Geocres Report Boreholes)

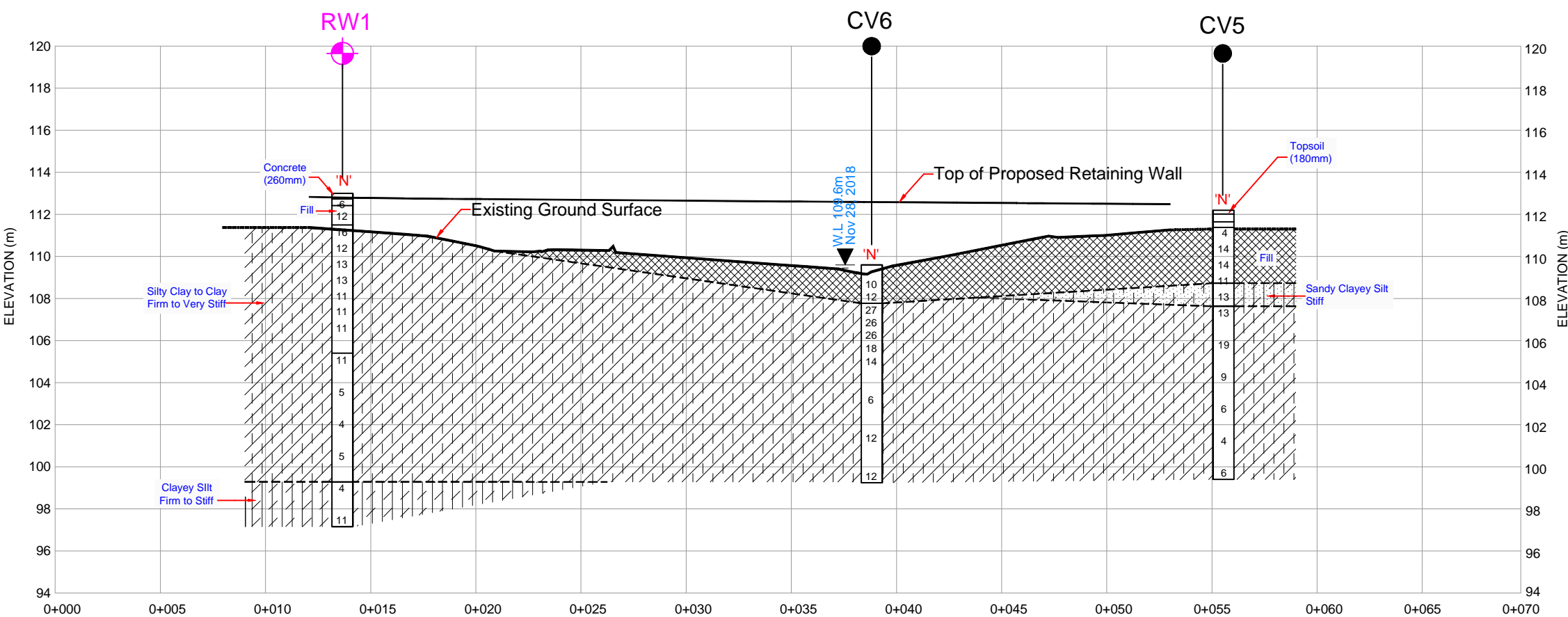
BH No.	APPROX. ELEV. (m)	MTM NAD83 ZONE 10 CO-ORDINATES	
		NORTH (m)	EAST (m)
CV5	112.2	4780080.4	332294.2
CV6	109.6	4780072.3	332278.8
RW1	113.0	4780078.5	332250.9

DRAFT LAT: 43.160074°, LONG: -79.162193°

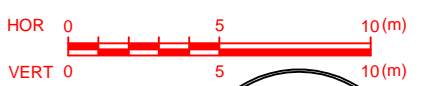
NOTES

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

WSP has reviewed the included foundation drawing prepared by Golder Associates Ltd. (Geocres Report 30M3-308 dated April 17, 2019), and conducted one additional borehole to satisfy MTO minimum exploration requirement for retaining walls.



CROSS SECTION A-A



REVISIONS		GEOCRES No : 30M3-315	
DATE	BY	DESCRIPTION	
Oct 10/19	ZMO	Submission for MTO review	
HWY No QEW		DIST	CENTRAL
SUBM'D	CHECKED MK	DATE	SITE
DRAWN	CHECKED MK	APPROVED	DWG

APPENDIX

A

RECORD OF BOREHOLE SHEETS

METRIC 1 OF 2

[illegible]

18M-01021-12

RECORD OF BOREHOLE No RW1

METRIC 2 OF 2

G.W.P. 2423-15-00 LOCATION LAT:43.160074°, LONG:-79.162193°, MTM NAD 1983 (Zone 10), E 332250.9, N 4780078.5 ORIGINATED BY FJ
DIST Central HWY QEW BOREHOLE TYPE Solid Stem Auger-152 mm O.D-CME 55 Track Mounted Drill Rig COMPILED BY SU
DATUM Geodetic DATE Jun/27/2019 CHECKED BY MK

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT NATURAL MOISTURE CONTENT LIQUID LIMIT			POCKET PEN. (C _u) (kPa)	NATURAL UNIT WT (kN/m ³)	REMARKS & GRAIN SIZE DISTRIBUTION (%)					
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa							W _p W W _L		GR	SA	SI	CL
								○ UNCONFINED	● QUICK TRIAXIAL	+ FIELD VANE	× LAB VANE	WATER CONTENT (%)								
	Continued							20	40	60	80	100								
	SILTY CLAY TO CLAY: trace sand, grey, moist, firm to stiff (<i>continued</i>)		12	SH																
11			13	SS	4		102													
12							101													
			14	SS	5															
13							100													
99.28																				
13.72	CLAYEY SILT: trace to some sand, trace gravel, grey, moist, firm to stiff		15		4		99										3	10	49	38
15							98													
			16	SS	11															
97.15																				
15.85	End of Borehole																			
	Note: 1) Water level was at a depth of 11.9 m below ground surface upon completion of drilling.																			

GROUNDWATER ELEVATIONS

Measurement 1st 2nd 3rd 4th

+ 3, × 3: Numbers refer to Sensitivity ○ 3% Strain at Failure

18M-01021-12

PROJECT 1671430 WQ2			RECORD OF BOREHOLE No CV5			SHEET 1 OF 2		METRIC			
G.W.P. 2423-15-00			LOCATION N 4780080.4; E 332294.2 MTM NAD 83 ZONE 10 (LAT. 43.160080; LONG. -79.161908)			ORIGINATED BY MA					
DIST Central HWY QEW			BOREHOLE TYPE 178 mm O.D. Hollow Stem Augers; CME 75 Track Mounted Drill Rig			COMPILED BY KG/EN					
DATUM Geodetic			DATE September 18, 2018			CHECKED BY					
SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	DYNAMIC CONE PENETRATION RESISTANCE PLOT			UNIT WEIGHT γ	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES		SHEAR STRENGTH kPa				
						20 40 60 80 100					
						○ UNCONFINED + FIELD VANE					
						● QUICK TRIAXIAL x REMOULDED					
						WATER CONTENT (%)					
						PLASTIC LIMIT W_p NATURAL MOISTURE CONTENT w LIQUID LIMIT W_L					
						10 20 30					
112.2	GROUND SURFACE										
0.0	Silty topsoil, some sand (FILL) Brown										
111.7	Clayey silt, some sand, trace gravel (FILL) Brown										
111.4	Sand and gravel, trace silt (FILL) Brown Moist		1	SS	4						
0.8	Clayey silt, trace sand, trace gravel, trace topsoil, trace wood fragments, trace rootlets (FILL) Soft to stiff Brown to black Moist		2	SS	14						
			3	SS	14						
			4	SS	11						
108.7	Sandy CLAYEY SILT, trace rootlets, silty sand seams at 3.8 m bgs Stiff Brown Moist		5	SS	13						
107.6	SILTY CLAY to CLAY, trace sand, trace gravel, some silt seams Soft to very stiff Brown to grey below 7.3 m Moist		6	SS	13						
4.6			7	SS	19						
			8	SS	9						
			9	SS	6						
			10	SS	4						
			11	SS	6						
99.4	END OF BOREHOLE										
12.8											

GTA-MTO 001 S:\CLIENTS\TOQEW-GLLENDALE\02_DATA\GINTOQEW-GLLENDALE.GPJ GAL-GTA.GDT 04/17/19

Continued Next Page

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

PROJECT <u>1671430 WO2</u>	RECORD OF BOREHOLE No CV5	SHEET 2 OF 2	METRIC
G.W.P. <u>2423-15-00</u>	LOCATION <u>N 4780080.4; E 332294.2 MTM NAD 83 ZONE 10 (LAT. 43.160080; LONG. -79.161908)</u>	ORIGINATED BY <u>MA</u>	
DIST <u>Central</u> HWY <u>QEW</u>	BOREHOLE TYPE <u>178 mm O.D. Hollow Stem Augers; CME 75 Track Mounted Drill Rig</u>	COMPILED BY <u>KG/EN</u>	
DATUM <u>Geodetic</u>	DATE <u>September 18, 2018</u>	CHECKED BY _____	

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT			PLASTIC LIMIT W _p	NATURAL MOISTURE CONTENT W	LIQUID LIMIT W _L	UNIT WEIGHT γ	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV. DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa							
	--- CONTINUED FROM PREVIOUS PAGE ---														
	NOTES: 1. Open borehole dry during drilling. 2. Borehole caved to 11.6 m on removal of augers. 3. Water level in open borehole at a depth of 10.7 m below ground surface (Elev. 101.5 m) on removal of augers.														

PROJECT 1671430 WO2

RECORD OF BOREHOLE No CV6

SHEET 1 OF 1

METRIC

G.W.P. 2423-15-00

LOCATION N 4780072.3; E 332278.8 MTM NAD 83 ZONE 10 (LAT. 43.160009; LONG. -79.162105) ORIGINATED BY SE

DIST Central HWY QEW

BOREHOLE TYPE Hilti PD 250E Portable Drill Rig, 63.5 mm Casing Wash Boring COMPILED BY EN

DATUM Geodetic

DATE November 27, 28, 2018 CHECKED BY MA

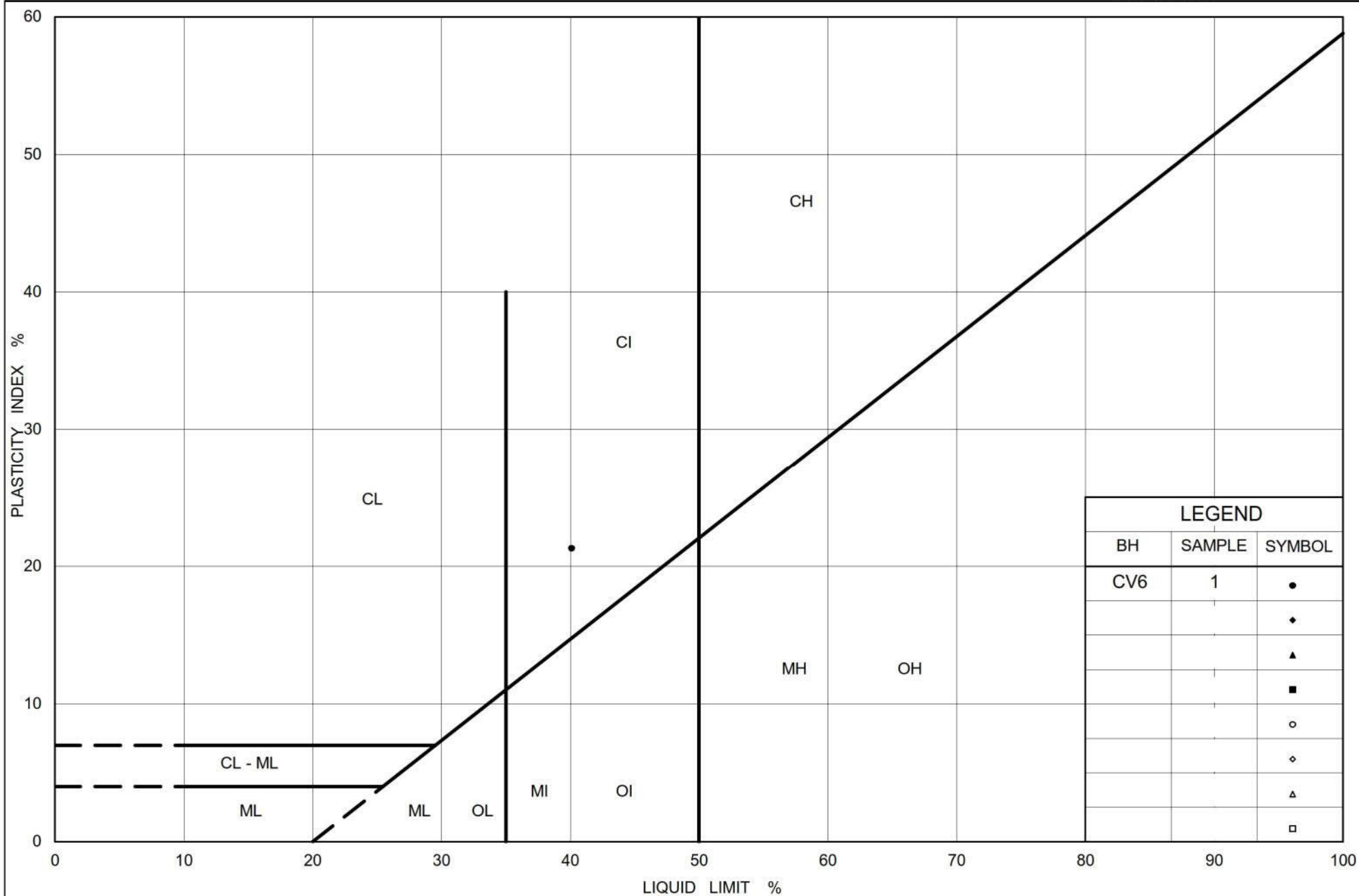
SOIL PROFILE		SAMPLES			GROUND WATER CONDITIONS	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT W _p	NATURAL MOISTURE CONTENT W	LIQUID LIMIT W _L	UNIT WEIGHT γ	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE		20 40 60 80 100	20 40 60 80 100					
109.6	GROUND SURFACE											
0.0	Silty clay, trace to some sand, trace to some gravel, some organics to 0.6 m (FILL) Stiff Brown Moist		1	SS	10							
			2	SS	12							
107.8	SILTY CLAY to CLAY, trace sand, trace gravel Firm to very stiff Brown becoming grey below 5.6 m Moist becoming wet below 3.0 m - No recovery in samples 4 and 6.		3	SS	27							
1.8			4	SS	26							
			5	SS	26							
			6	SS	18							
			7	SS	14							
			8	SS	6							
			9	SS	12							
			10	SS	12							
99.2	END OF BOREHOLE											
10.4	NOTE: 1. Water level in open borehole at ground surface (Elev. 109.6 m) on completion of drilling.											

APPENDIX

B

LABORATORY TEST RESULTS





Ministry of Transportation

Ontario

PLASTICITY CHART Silty Clay (Fill) (Culvert EX-05)

Figure No. B-1

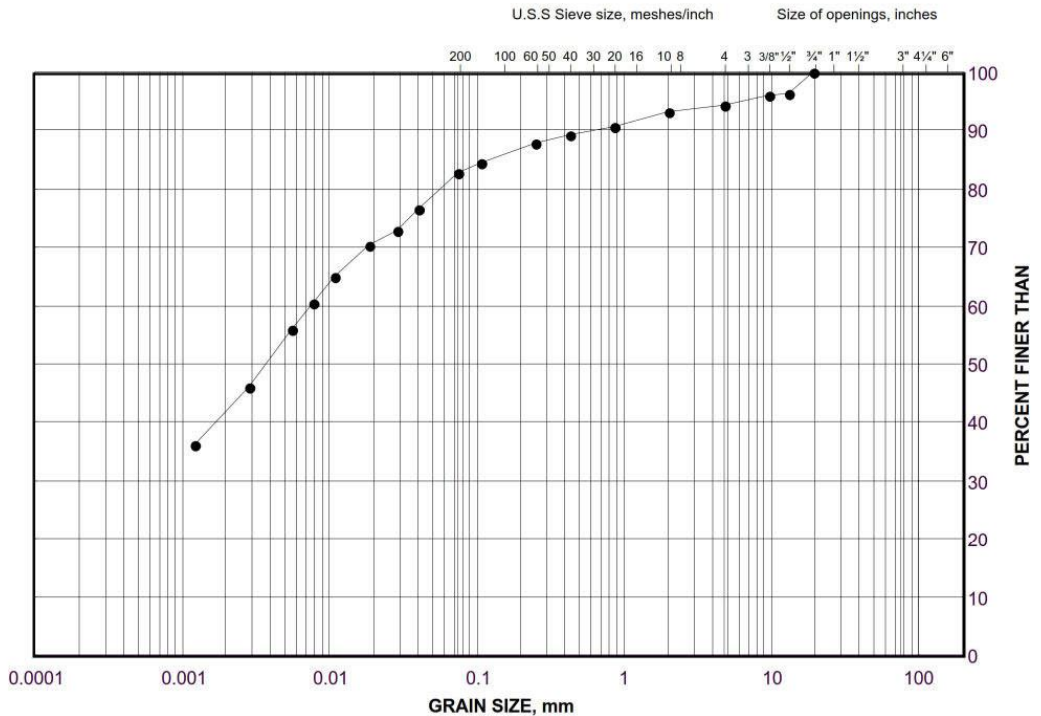
Project No. 1671430 (WO 002)

Checked By: MA

GRAIN SIZE DISTRIBUTION

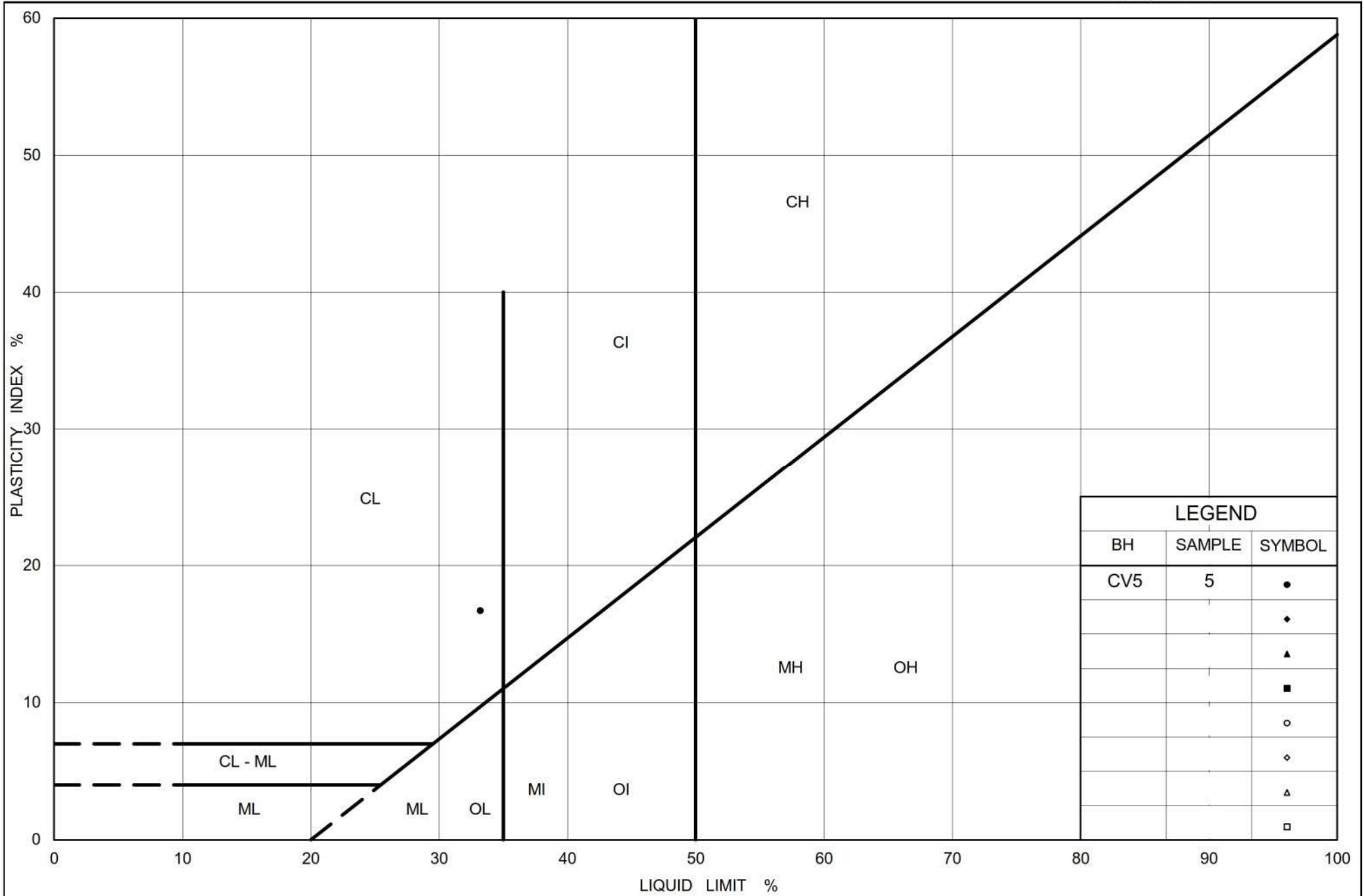
Silty Clay (Fill)
(Culvert EX-05)

FIGURE B-2



LEGEND

SYMBOL	Borehole	SAMPLE	ELEVATION(m)
•	CV6	1	108.7



Ministry of Transportation

Ontario

PLASTICITY CHART Clayey Silt (Culvert EX-05)

Figure No. B-3

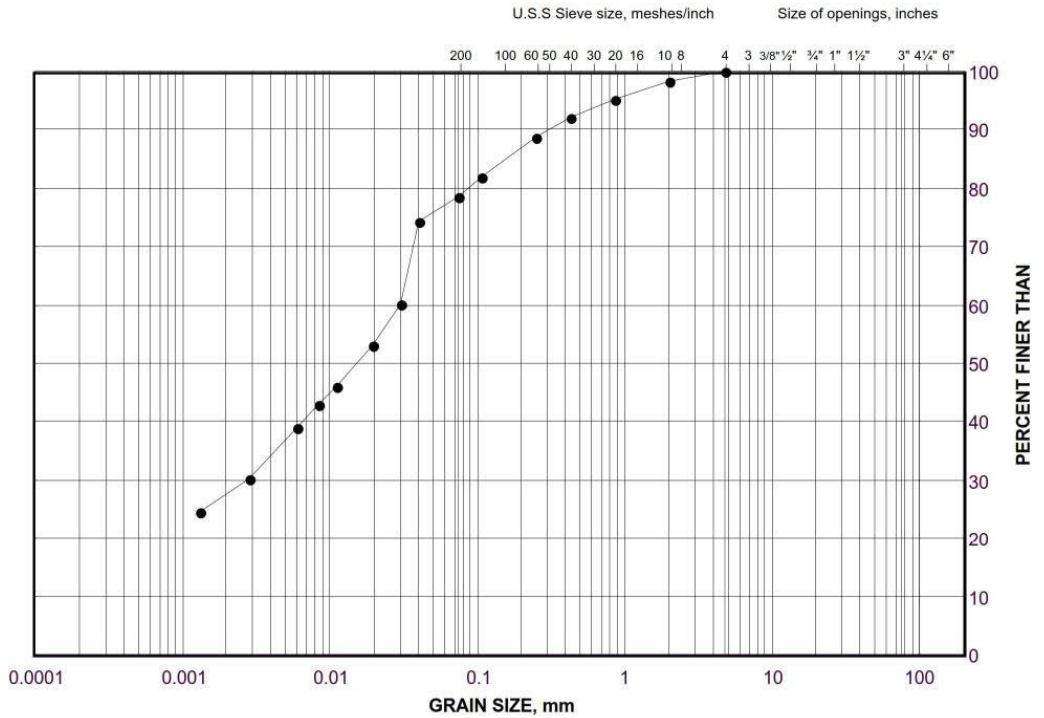
Project No. 1671430 (WO 002)

Checked By: MA

GRAIN SIZE DISTRIBUTION

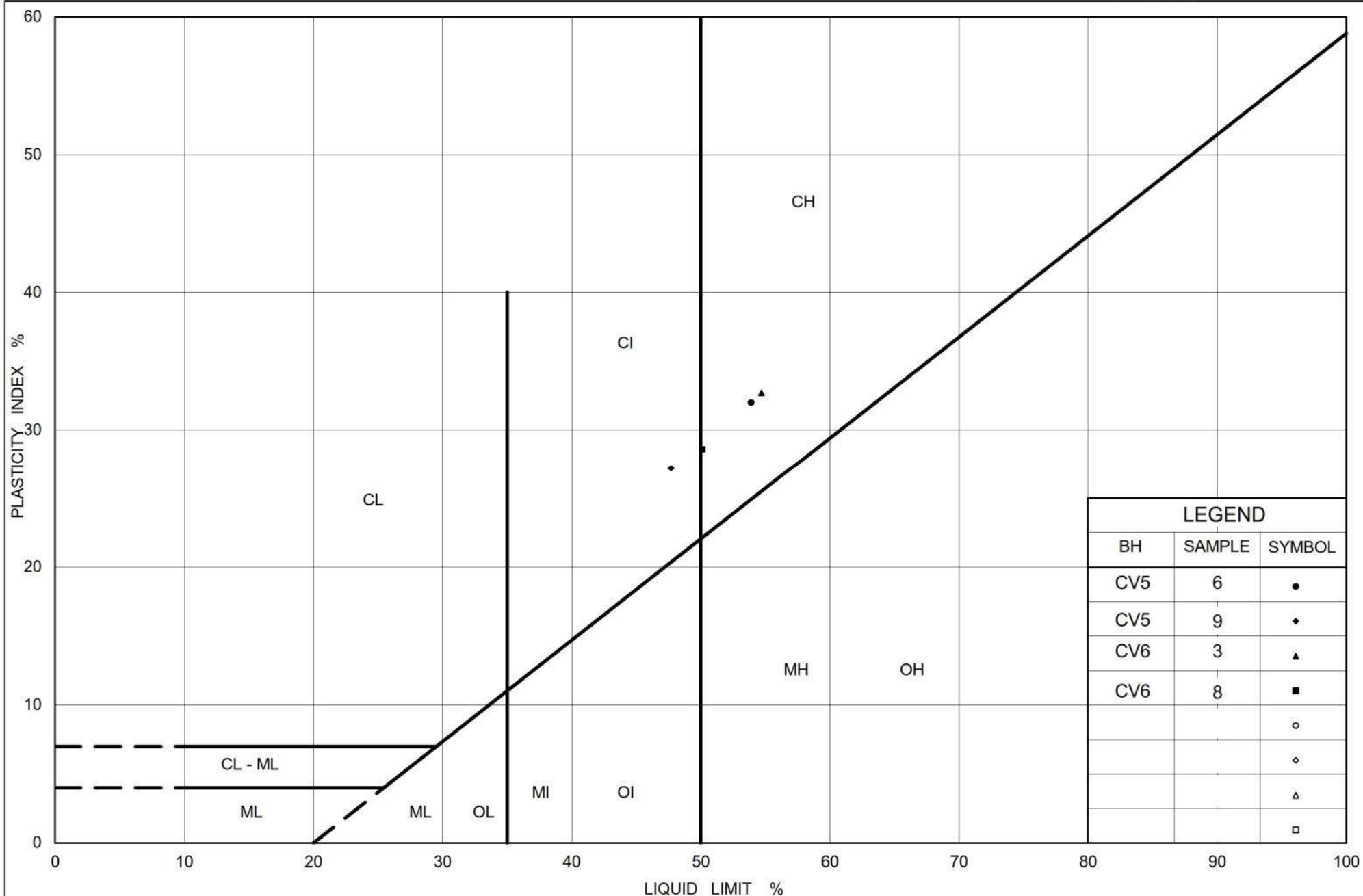
Clayey Silt
(Culvert EX-05)

FIGURE B-4



LEGEND

SYMBOL	Borehole	SAMPLE	ELEVATION(m)
•	CV5	5	108.1



Ministry of Transportation

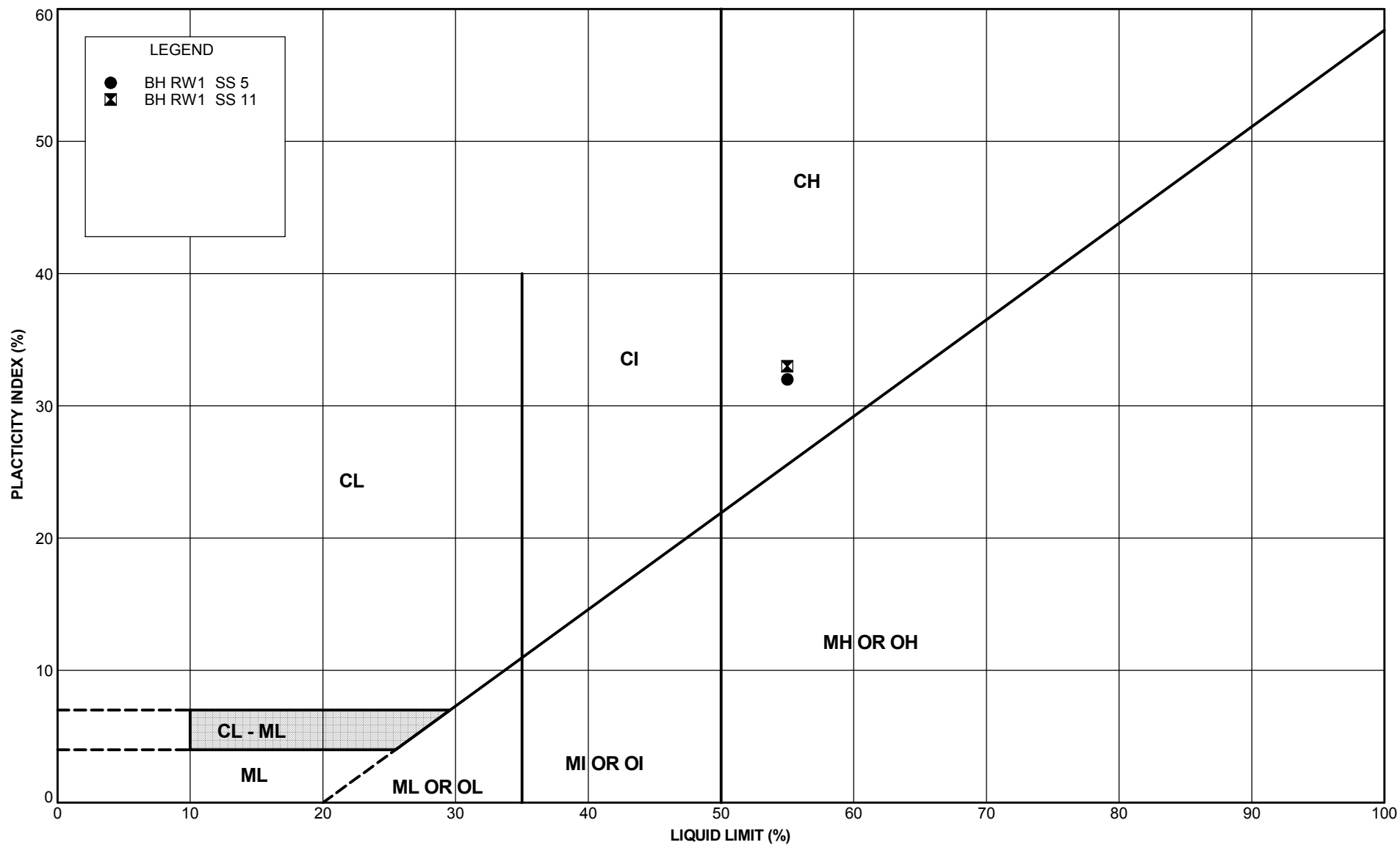
Ontario

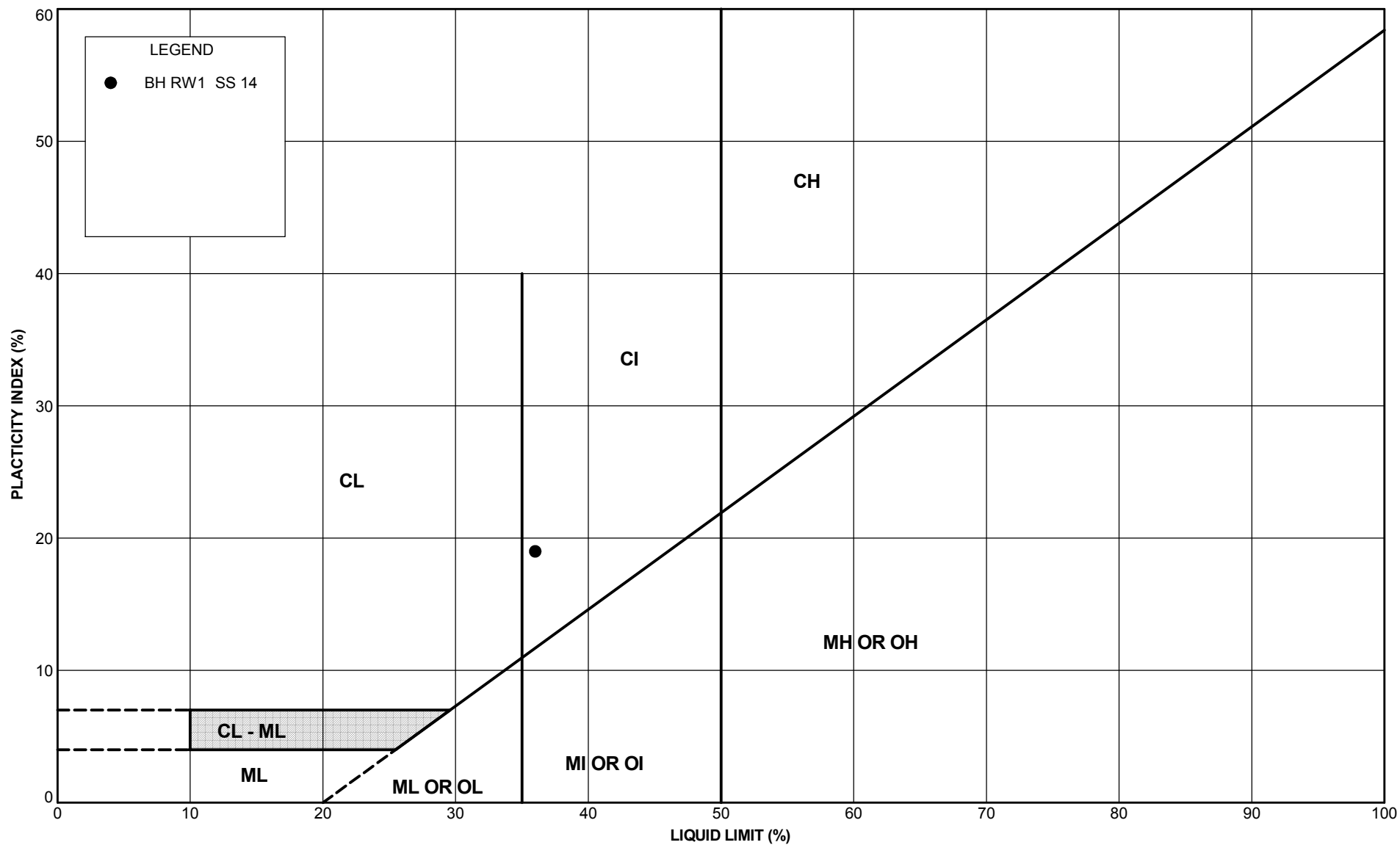
PLASTICITY CHART Silty Clay to Clay (Culvert EX-05)

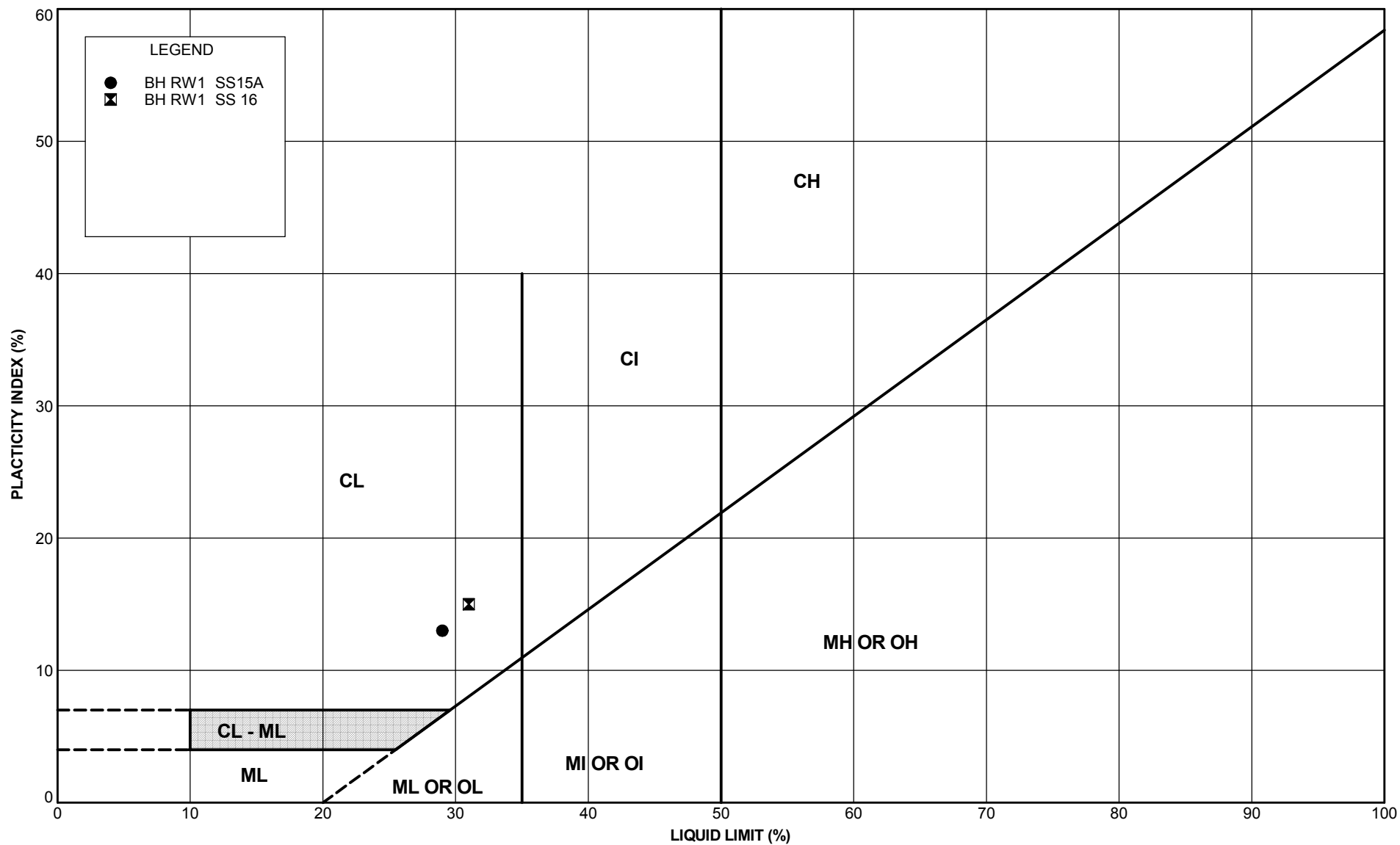
Figure No. B-5

Project No. 1671430 (WO 002)

Checked By: MA



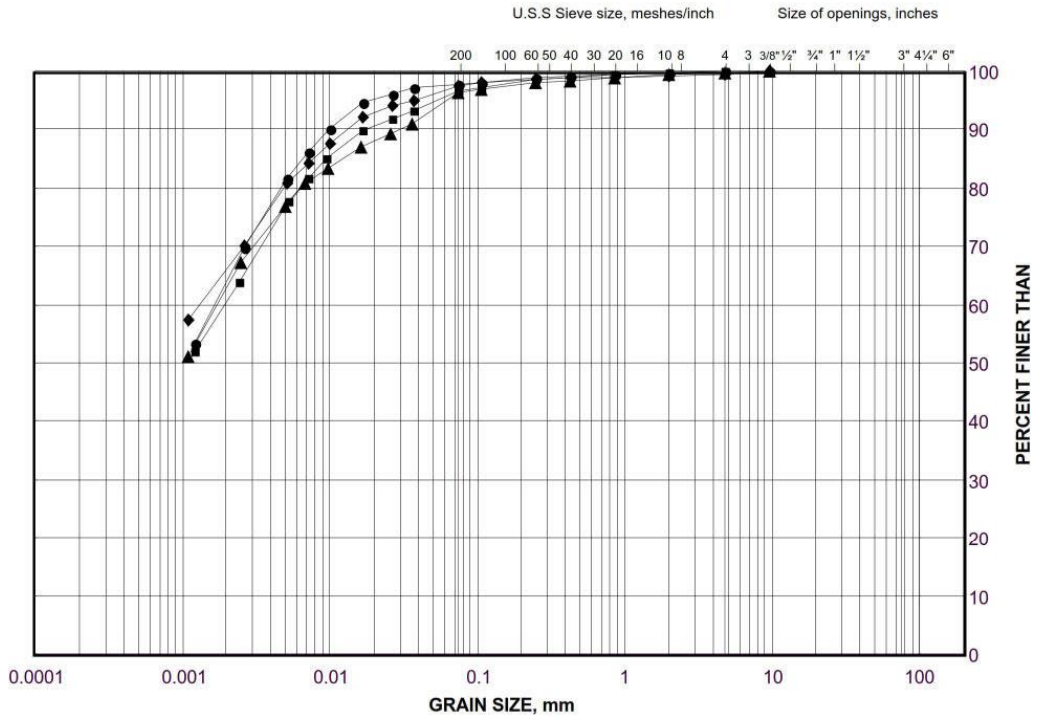




GRAIN SIZE DISTRIBUTION

Silty Clay to Clay
(Culvert EX-05)

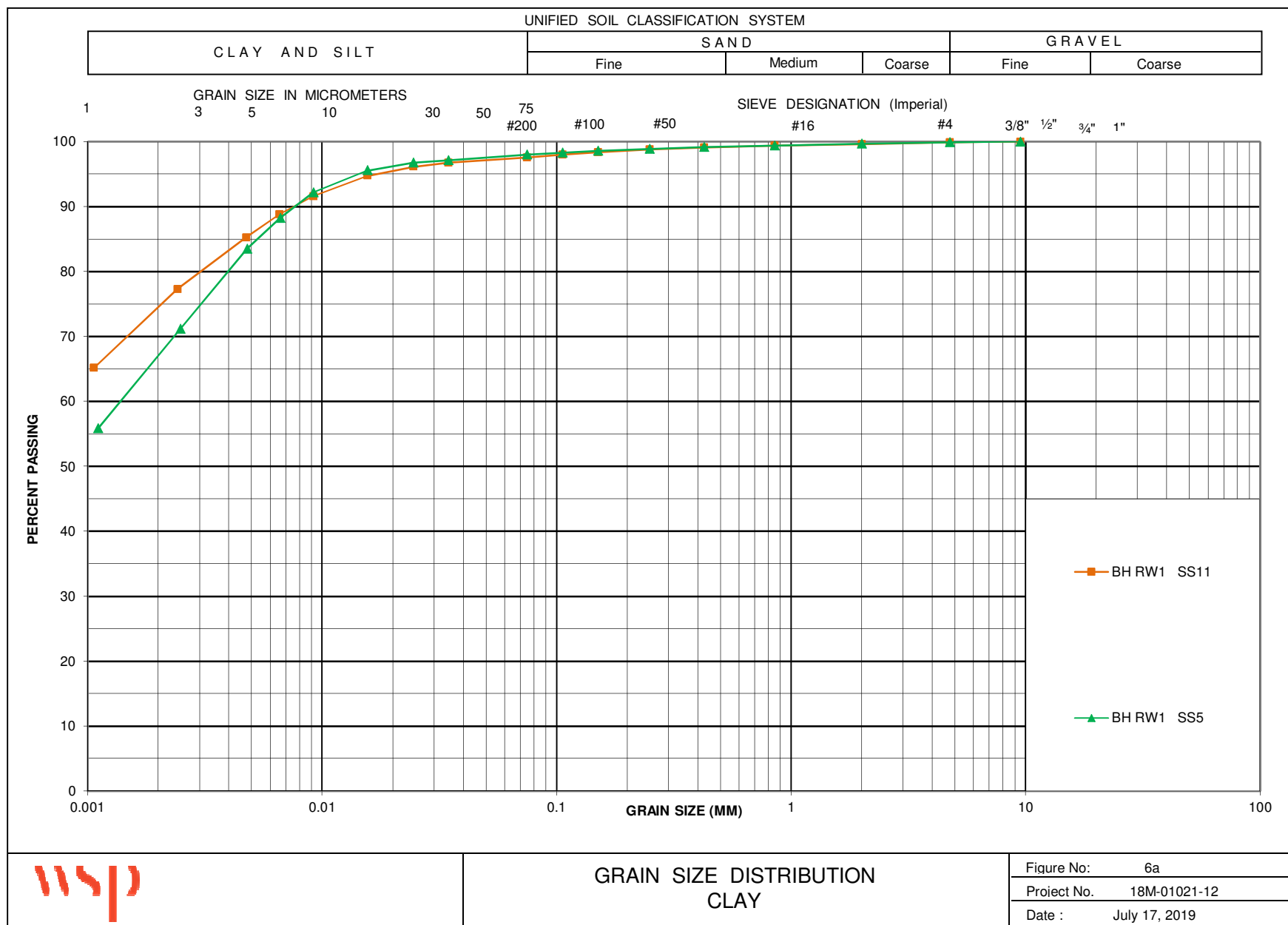
FIGURE B-6

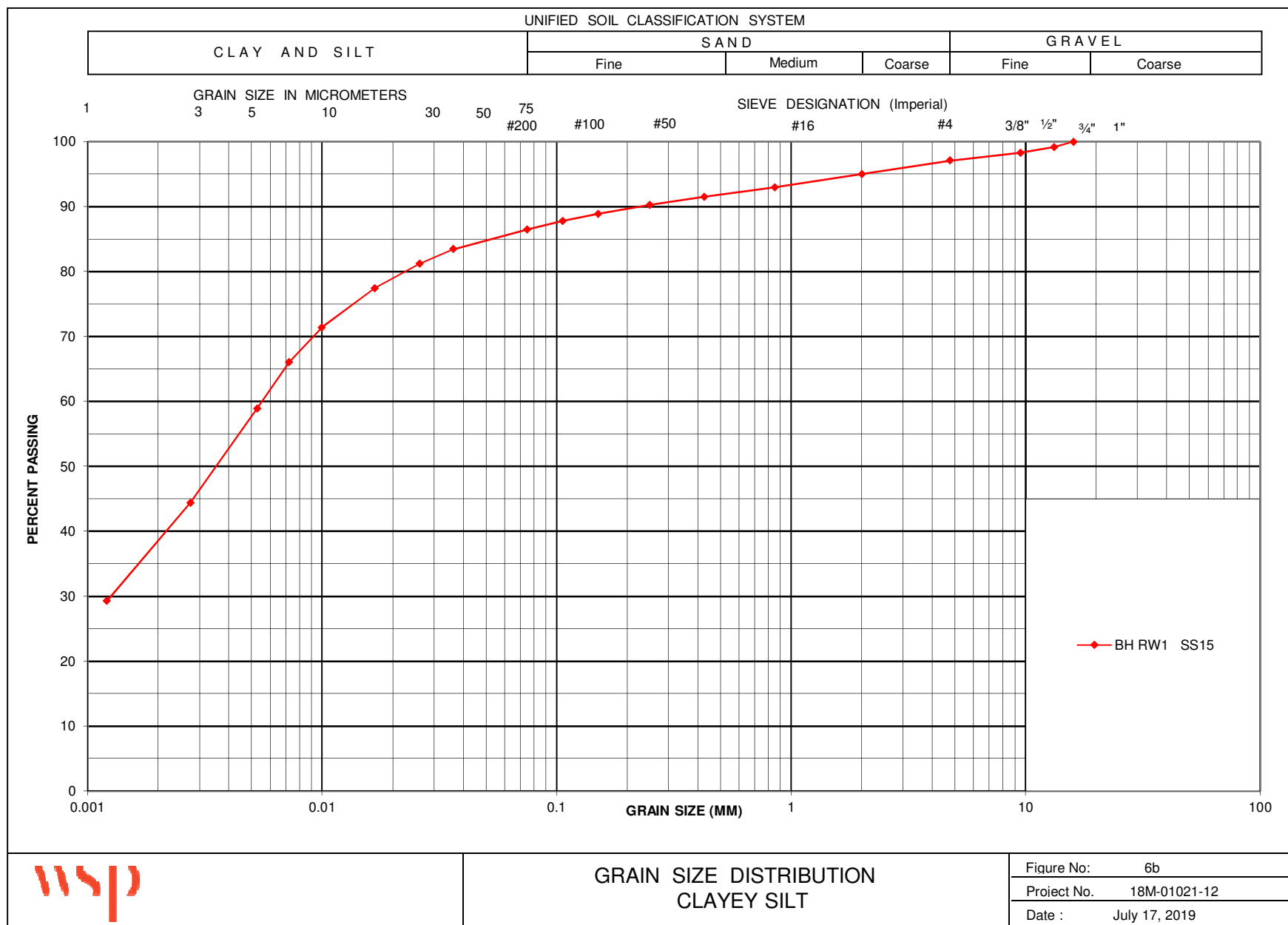


SILT AND CLAY SIZES	FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE
FINE GRAINED	SAND SIZE			GRAVEL SIZE		SIZE

LEGEND

SYMBOL	Borehole	SAMPLE	ELEVATION(m)
●	CV6	3	107.5
■	CV5	6	107.3
◆	CV6	8	103.2
▲	CV5	9	102.8





GRAIN SIZE DISTRIBUTION
CLAYEY SILT

Figure No: 6b

Project No. 18M-01021-12

Date : July 17, 2019

APPENDIX

C

SITE PHOTOGRAPHS





Photograph 1: Existing retaining wall structure looking south. The slope face at wall toe was covered with shrubs, sign of erosion on the slope face was not observed. (September 3, 2019)



Photograph 2: Existing retaining wall structure looking southeast. The wall is currently acting as the existing culvert headwall. (September 3, 2019)



Photograph 3: Existing retaining wall structure looking east. The slope face at wall toe was covered with shrubs, sign of erosion on the slope face was not observed. (September 3, 2019)



Photograph 4: Soil sample extracted at Glendale Avenue and QEW Interchange, the varved clay structure observed in clay material collected in borehole RSS2.

APPENDIX

D

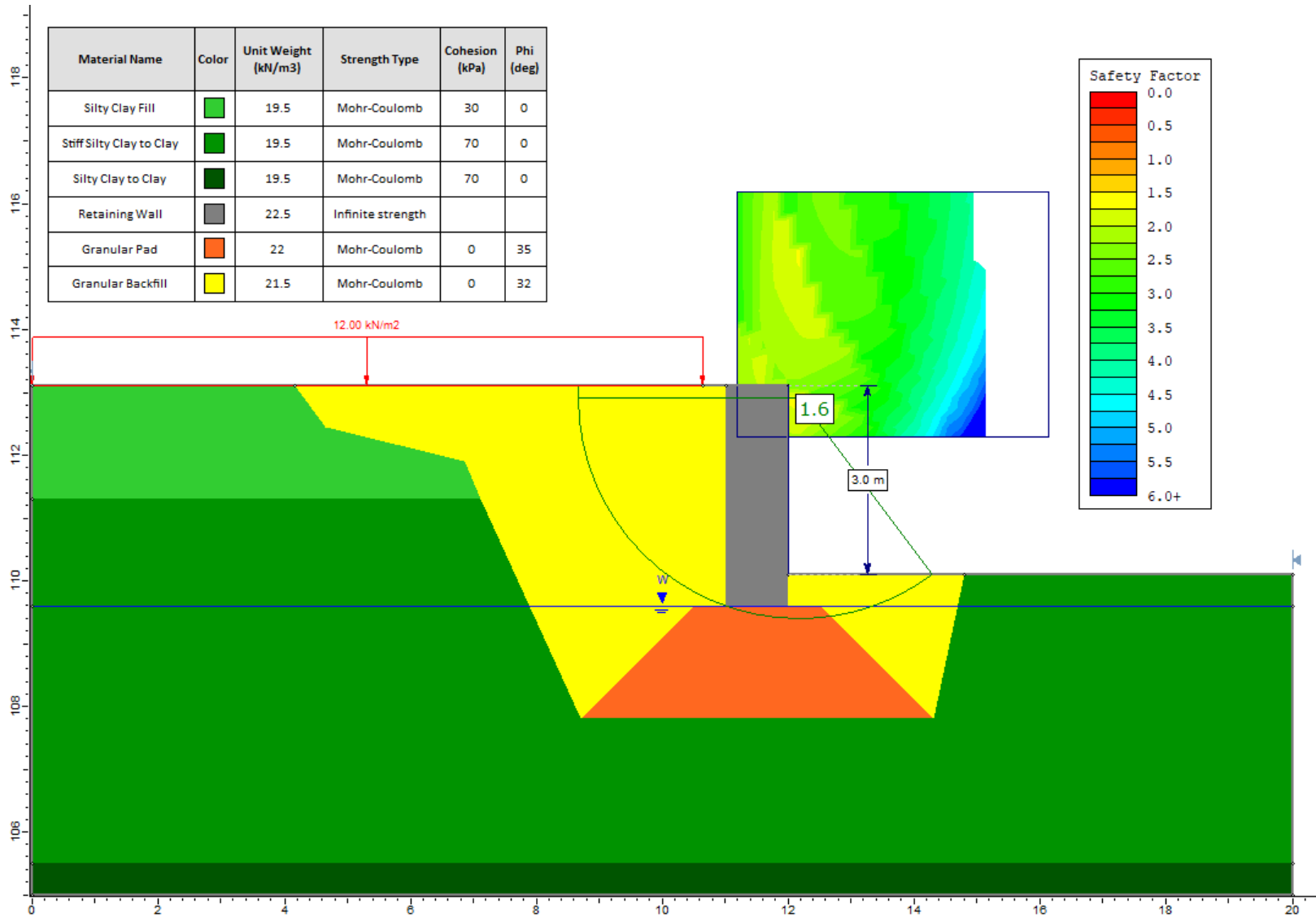
SLOPE STABILITY ANALYSES RESULTS



Retaining Wall at Glendale Avenue and York Road Roundabout

Static Global Stability Analysis – Short-Term (Undrained) Condition

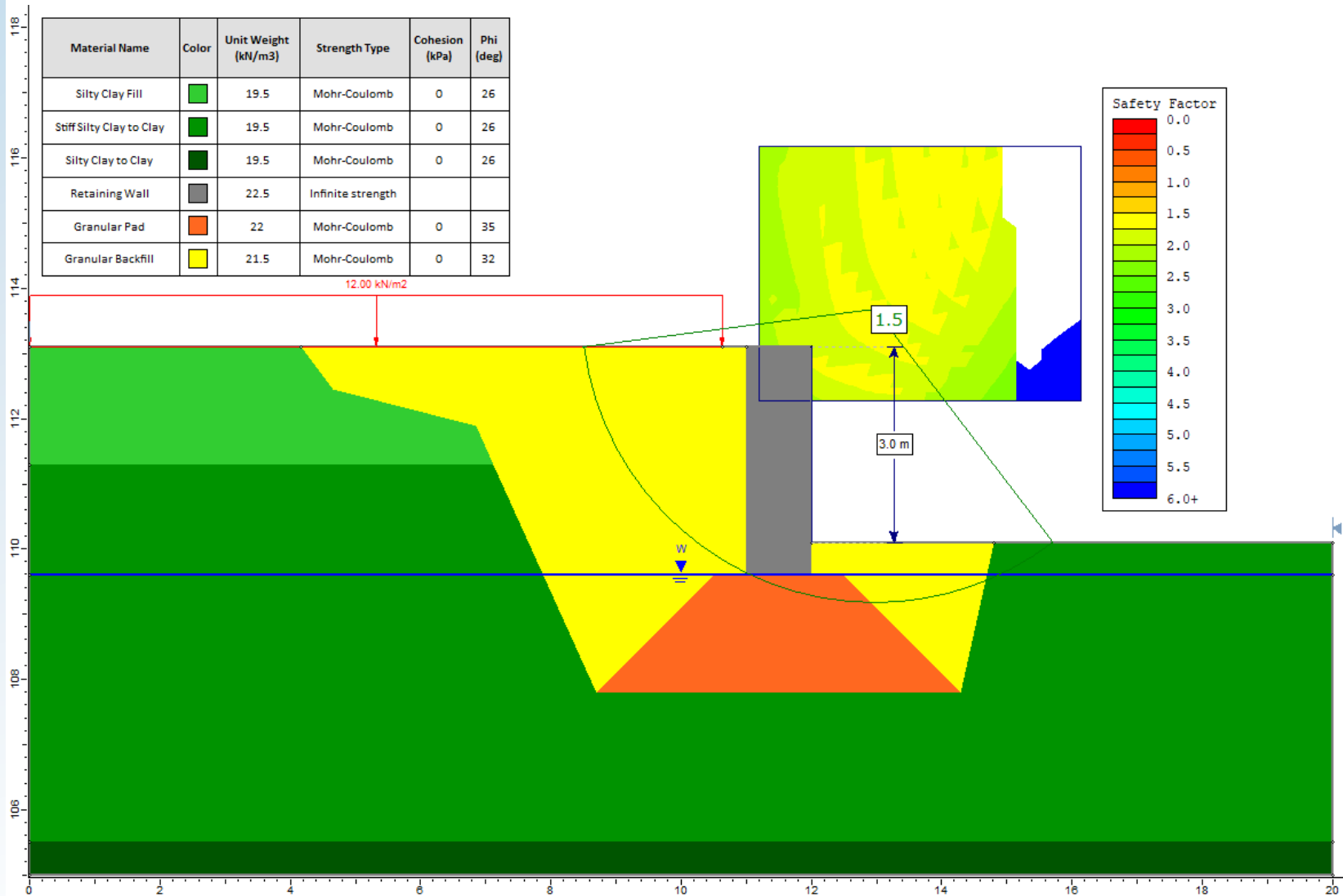
Figure D1



Retaining Wall at Glendale Avenue and York Road Roundabout

Static Global Stability Analysis - Long-Term (Drained) Condition

Figure D2



APPENDIX

E

RESULTS OF SOIL CORROSIVITY ANALYSIS



**CLIENT NAME: WSP CANADA INC.
51 CONSTELLATION COURT
TORONTO, ON M9W1K4
(416) 798-0065**

ATTENTION TO: Mike Wilson

PROJECT: 18M-01021-12

AGAT WORK ORDER: 19T509150

SOIL ANALYSIS REVIEWED BY: Yris Verastegui, Report Reviewer

DATE REPORTED: Sep 04, 2019

PAGES (INCLUDING COVER): 5

VERSION*: 1

Should you require any information regarding this analysis please contact your client services representative at (905) 712-5100

***NOTES**

All samples will be disposed of within 30 days following analysis. Please contact the lab if you require additional sample storage time.



Certificate of Analysis

AGAT WORK ORDER: 19T509150

PROJECT: 18M-01021-12

5835 COOPERS AVENUE
MISSISSAUGA, ONTARIO
CANADA L4Z 1Y2
TEL (905)712-5100
FAX (905)712-5122
<http://www.agatlabs.com>

CLIENT NAME: WSP CANADA INC.

SAMPLING SITE:

ATTENTION TO: Mike Wilson

SAMPLED BY:

Corrosivity Package

DATE RECEIVED: 2019-08-23

DATE REPORTED: 2019-09-04

		SAMPLE DESCRIPTION: BH RW1 SS4				BH RSS2 SS5		BH RSS4 SS9		BH OHS2-1 SS3		BH OHS4-2 SS9	
		SAMPLE TYPE: Soil				Soil		Soil		Soil		Soil	
		DATE SAMPLED: 2019-06-27				2019-06-27		2019-06-27		2019-06-27		2019-06-27	
Parameter	Unit	G / S	RDL	467503	RDL	467514	RDL	467515	467516	RDL	467517		
Chloride (2:1)	µg/g		4	308	2	21	4	59	47	8	287		
Sulphate (2:1)	µg/g		4	971	2	302	4	1420	845	8	1410		
pH (2:1)	pH Units		NA	8.15	NA	8.35	NA	8.21	8.15	NA	7.83		
Electrical Conductivity (2:1)	mS/cm		0.005	1.49	0.005	0.459	0.005	1.52	0.930	0.005	1.74		
Resistivity (2:1) (Calculated)	ohm.cm		1	671	1	2180	1	658	1080	1	575		
Redox Potential 1	mV		NA	57.9	NA	69.4	NA	-120.6	61.1	NA	63.8		
Redox Potential 2	mV		NA	65.2	NA	74.1	NA	-113.7	57.8	NA	60.9		
Redox Potential 3	mV		NA	63.8	NA	62.6	NA	-120.2	59.9	NA	61.2		

Comments: RDL - Reported Detection Limit; G / S - Guideline / Standard

467503 EC, pH, Chloride and Sulphate were determined on the extract obtained from the 2:1 leaching procedure (2 parts DI water: 1 part soil). Resistivity is a calculated parameter.
PI note: Redox Potential is not an accredited parameter.
Redox potential measured on as received sample. Due to the potential for rapid change in sample equilibrium chemistry with exposure to oxidative/reduction conditions laboratory results may differ from field measured results.

Elevated RDLs indicate the degree of sample dilutions prior to the analysis to keep analytes within the calibration range, reduce matrix interference and/or to avoid contaminating the instrument.

467514 EC, pH, Chloride and Sulphate were determined on the extract obtained from the 2:1 leaching procedure (2 parts DI water: 1 part soil). Resistivity is a calculated parameter.
PI note: Redox Potential is not an accredited parameter.
Redox potential measured on as received sample. Due to the potential for rapid change in sample equilibrium chemistry with exposure to oxidative/reduction conditions laboratory results may differ from field measured results.

467515 EC, pH, Chloride and Sulphate were determined on the extract obtained from the 2:1 leaching procedure (2 parts DI water: 1 part soil). Resistivity is a calculated parameter.
PI note: Redox Potential is not an accredited parameter.
Redox potential measured on as received sample. Due to the potential for rapid change in sample equilibrium chemistry with exposure to oxidative/reduction conditions laboratory results may differ from field measured results.
The negative value reported for Redox is possibly due to the presence of reducing agents in the sample.

Elevated RDLs indicate the degree of sample dilutions prior to the analysis to keep analytes within the calibration range, reduce matrix interference and/or to avoid contaminating the instrument.

467516-467517 EC, pH, Chloride and Sulphate were determined on the extract obtained from the 2:1 leaching procedure (2 parts DI water: 1 part soil). Resistivity is a calculated parameter.
PI note: Redox Potential is not an accredited parameter.
Redox potential measured on as received sample. Due to the potential for rapid change in sample equilibrium chemistry with exposure to oxidative/reduction conditions laboratory results may differ from field measured results.

Elevated RDLs indicate the degree of sample dilutions prior to the analysis to keep analytes within the calibration range, reduce matrix interference and/or to avoid contaminating the instrument.

Analysis performed at AGAT Toronto (unless marked by *)

Certified By:

José Verástegui

Quality Assurance

CLIENT NAME: WSP CANADA INC.

AGAT WORK ORDER: 19T509150

PROJECT: 18M-01021-12

ATTENTION TO: Mike Wilson

SAMPLING SITE:

SAMPLED BY:

Soil Analysis

RPT Date: Sep 04, 2019			DUPLICATE				REFERENCE MATERIAL			METHOD BLANK SPIKE			MATRIX SPIKE		
PARAMETER	Batch	Sample Id	Dup #1	Dup #2	RPD	Method Blank	Measured Value	Acceptable Limits		Recovery	Acceptable Limits		Recovery	Acceptable Limits	
								Lower	Upper		Lower	Upper		Lower	Upper

Corrosivity Package

Chloride (2:1)	467503	467503	308	307	0.3%	< 2	101%	80%	120%	104%	80%	120%	103%	70%	130%
Sulphate (2:1)	467503	467503	971	976	0.5%	< 2	101%	80%	120%	108%	80%	120%	110%	70%	130%
pH (2:1)	467503	467503	8.15	8.14	0.1%	NA	100%	90%	110%	NA			NA		
Electrical Conductivity (2:1)	467503	467503	1.49	1.52	2.0%	< 0.005	100%	90%	110%	NA			NA		

Comments: NA signifies Not Applicable.

Duplicate Qualifier: As the measured result approaches the RL, the uncertainty associated with the value increases dramatically, thus duplicate acceptance limits apply only where the average of the two duplicates is greater than five times the RL

pH duplicates QA acceptance criteria was met relative as stated in Table 5-15 of Analytical Protocol document.

Certified By:


Method Summary

CLIENT NAME: WSP CANADA INC.

PROJECT: 18M-01021-12

SAMPLING SITE:

AGAT WORK ORDER: 19T509150

ATTENTION TO: Mike Wilson

SAMPLED BY:

PARAMETER	AGAT S.O.P	LITERATURE REFERENCE	ANALYTICAL TECHNIQUE
Soil Analysis			
Chloride (2:1)	INOR-93-6004	McKeague 4.12 & SM 4110 B	ION CHROMATOGRAPH
Sulphate (2:1)	INOR-93-6004	McKeague 4.12 & SM 4110 B	ION CHROMATOGRAPH
pH (2:1)	INOR 93-6031	MSA part 3 & SM 4500-H+ B	PH METER
Electrical Conductivity (2:1)	INOR-93-6036	McKeague 4.12, SM 2510 B	EC METER
Resistivity (2:1) (Calculated)	INOR-93-6036	McKeague 4.12, SM 2510 B, SSA #5 Part 3	CALCULATION
Redox Potential 1	INOR-93-6066	G200-09, SM 2580 B	REDOX POTENTIAL ELECTRODE
Redox Potential 2	INOR-93-6066	G200-09, SM 2580 B	REDOX POTENTIAL ELECTRODE
Redox Potential 3	INOR-93-6066	G200-09, SM 2580 B	REDOX POTENTIAL ELECTRODE



Chain of Custody Record

If this is a Drinking Water sample, please use Drinking Water Chain of Custody Form (potable water consumed by humans)

Report Information:

Company: WSP Canada Inc.
Contact: Mike Wilson
Address: 51 Constellation court
Toronto, ON
Phone: 416-798-0065 Fax: 416-798-0518
Reports to be sent to:
1. Email: Michael.Wilson@wsp.com
2. Email: Sharif.Willah@wsp.com

Regulatory Requirements:

(Please check all applicable boxes)

☒ Regulation 153/04

Table Indicate One

☐ Ind/Com

☐ Res/Park

☐ Agriculture

Soil Texture (Check One)

☐ Coarse

☐ Fine

☐ Sewer Use

☐ Sanitary

☐ Storm

Region Indicate One

☐ MISA

☐ Regulation 558

☐ CCME

☐ Prov. Water Quality Objectives (PWQO)

☐ Other

Indicate One

Is this submission for a
Record of Site Condition?

☐ Yes

☐ No

**Report Guideline on
Certificate of Analysis**

☐ Yes

☐ No

Project Information:

Project: ISM-01021-12
Site Location: GEW/Glenade
Sampled By: _____
AGAT Quote #: _____ PO: _____

Please note: If quotation number is not provided, client will be billed full price for analysis.

Invoice Information:

Bill To Same: Yes ☒ No ☐

Company: _____
Contact: _____
Address: _____
Email: payables.ontario@wsp.com

Sample Identification	Date Sampled	Time Sampled	# of Containers	Sample Matrix	Comments/ Special Instructions	Y / N	Field Filtered - Metals, Hg, CrVI	Metals and Inorganics	0. Reg 153	Full Metals Scan	Regulation/Custom Metals	Nutrients:	Volatiles:	PHCs F1 - F4	ABNs	PAHs	PCBs:	Organochlorine Pesticides	TCLP:	Sewer Use	Potentially Hazardous or High Concentration (Y/N)
BH RW1 SS4	June 27	-	1	Soil				<input type="checkbox"/> All Metals <input type="checkbox"/> 153 Metals (excl. Hydrides)	<input type="checkbox"/> Hydride Metals <input type="checkbox"/> 153 Metals (incl. Hydrides)	<input type="checkbox"/> CN	<input type="checkbox"/> TP <input type="checkbox"/> NH ₄ ⁺ <input type="checkbox"/> TKN	<input type="checkbox"/> VOC <input type="checkbox"/> BTEX <input type="checkbox"/> THM									
BH RSS2 SS5	June 28	-	1	Soil				<input type="checkbox"/> B-HWS <input type="checkbox"/> Cl ⁻ <input type="checkbox"/> FOC <input type="checkbox"/> Hg	<input type="checkbox"/> EC <input type="checkbox"/> SAR	<input type="checkbox"/> pH	<input type="checkbox"/> NO ₃ <input type="checkbox"/> NO ₂ <input type="checkbox"/> NO ₃ +NO ₂	<input type="checkbox"/> VOC <input type="checkbox"/> BTEX <input type="checkbox"/> THM									
BH RSS4 SS9	June 28	-	1	Soil				<input type="checkbox"/> B-HWS <input type="checkbox"/> Cl ⁻ <input type="checkbox"/> FOC <input type="checkbox"/> Hg	<input type="checkbox"/> EC <input type="checkbox"/> SAR	<input type="checkbox"/> pH	<input type="checkbox"/> NO ₃ <input type="checkbox"/> NO ₂ <input type="checkbox"/> NO ₃ +NO ₂	<input type="checkbox"/> VOC <input type="checkbox"/> BTEX <input type="checkbox"/> THM									
BH OHS2-1 SS3	June 27	-	1	Soil				<input type="checkbox"/> B-HWS <input type="checkbox"/> Cl ⁻ <input type="checkbox"/> FOC <input type="checkbox"/> Hg	<input type="checkbox"/> EC <input type="checkbox"/> SAR	<input type="checkbox"/> pH	<input type="checkbox"/> NO ₃ <input type="checkbox"/> NO ₂ <input type="checkbox"/> NO ₃ +NO ₂	<input type="checkbox"/> VOC <input type="checkbox"/> BTEX <input type="checkbox"/> THM									
BH OHS4-2 SS5	June 27	-	1	Soil				<input type="checkbox"/> B-HWS <input type="checkbox"/> Cl ⁻ <input type="checkbox"/> FOC <input type="checkbox"/> Hg	<input type="checkbox"/> EC <input type="checkbox"/> SAR	<input type="checkbox"/> pH	<input type="checkbox"/> NO ₃ <input type="checkbox"/> NO ₂ <input type="checkbox"/> NO ₃ +NO ₂	<input type="checkbox"/> VOC <input type="checkbox"/> BTEX <input type="checkbox"/> THM									

Samples Relinquished By (Print Name and Sign): <u>Michael Wilson</u>	Date: <u>Aug 23, 2019</u>	Time: <u>3:07 PM</u>	Samples Received By (Print Name and Sign): <u>Simon Z</u>	Date: <u>19/8/23</u>	Time: <u>3:04</u>
Samples Relinquished By (Print Name and Sign):	Date:	Time:	Samples Received By (Print Name and Sign):	Date:	Time:
Samples Relinquished By (Print Name and Sign):	Date:	Time:	Samples Received By (Print Name and Sign):	Date:	Time:

Nº: **T 093250**

Laboratory Use Only

Work Order #: 19TS09150

Cooler Quantity: 96 94 98

Arrival Temperatures: _____

Custody Seal Intact: ☐ Yes ☐ No ☐ N/A

Notes: on ice

Turnaround Time (TAT) Required:

Regular TAT ☒ 5 to 7 Business Days

Rush TAT (Rush Surcharge Apply)

☐ 3 Business Days ☐ 2 Business Days ☐ Next Business Day

OR Date Required (Rush Surcharges May Apply):

Please provide prior notification for rush TAT
*TAT is exclusive of weekends and statutory holidays

For 'Same Day' analysis, please contact your AGAT CPM

**CLIENT NAME: WSP CANADA INC.
51 CONSTELLATION COURT
TORONTO, ON M9W1K4
(416) 798-0065**

ATTENTION TO: Mike Wilson

PROJECT: 19T509150

AGAT WORK ORDER: 19T511287

SOLID ANALYSIS REVIEWED BY: Sherin Moussa, Senior Technician

DATE REPORTED: Sep 04, 2019

PAGES (INCLUDING COVER): 5

Should you require any information regarding this analysis please contact your client services representative at (905) 501-9998

***NOTES**



AGAT Laboratories

Certificate of Analysis

AGAT WORK ORDER: 19T511287

PROJECT: 19T509150

5623 McADAM ROAD
MISSISSAUGA, ONTARIO
CANADA L4Z 1N9
TEL (905)501-9998
FAX (905)501-0589
<http://www.agatlabs.com>

CLIENT NAME: WSP CANADA INC.

ATTENTION TO: Mike Wilson

(201-042) Sulfide

DATE SAMPLED: Aug 28, 2019

DATE RECEIVED: Aug 29, 2019

DATE REPORTED: Sep 04, 2019

SAMPLE TYPE: Other

	Analyte:	Sulfide
	Unit:	%
Sample ID (AGAT ID)	RDL:	0.05
BH RW1 SS4 (481286)		<0.05
BH RSS2 SS5 (481287)		<0.05
BH RSS4 SS9 (481288)		0.14
BH OHS2-1 SS3 (481289)		<0.05
BH OHS4-2 SS9 (481290)		<0.05

Comments: RDL - Reported Detection Limit
Analysis performed at AGAT Toronto (unless marked by *)

Certified By:

Sherin Hoossaf



AGAT Laboratories

Quality Assurance - Replicate

AGAT WORK ORDER: 19T511287

PROJECT: 19T509150

5623 McADAM ROAD
MISSISSAUGA, ONTARIO
CANADA L4Z 1N9
TEL (905)501-9998
FAX (905)501-0589
<http://www.agatlabs.com>

CLIENT NAME: WSP CANADA INC.

ATTENTION TO: Mike Wilson

(201-042) Sulfide

REPLICATE #1															
Parameter	Sample ID	Original	Replicate	RPD											
S	481287	0.048	0.048	0.0%											
Sulfate	481287	< 0.01	<0.01	0.0%											
Sulfide	481287	< 0.05	<0.05	0.0%											



AGAT Laboratories

Quality Assurance - Certified Reference materials

AGAT WORK ORDER: 19T511287

PROJECT: 19T509150

5623 McADAM ROAD
MISSISSAUGA, ONTARIO
CANADA L4Z 1N9
TEL (905)501-9998
FAX (905)501-0589
<http://www.agatlabs.com>

CLIENT NAME: WSP CANADA INC.

ATTENTION TO: Mike Wilson

(201-042) Sulfide

CRM #1															
Parameter	Expect	Actual	Recovery	Limits											
S	0.8	0.81	101%	90% - 110%											
Sulfate	0.01	0.01	100%	90% - 110%											
Sulfide	0.8	0.8	100%	90% - 110%											

Method Summary

CLIENT NAME: WSP CANADA INC.

AGAT WORK ORDER: 19T511287

PROJECT: 19T509150

ATTENTION TO: Mike Wilson

SAMPLING SITE:

SAMPLED BY:

PARAMETER	AGAT S.O.P	LITERATURE REFERENCE	ANALYTICAL TECHNIQUE
Solid Analysis			
Sulfide	MIN-200-12037		LECO