



THURBER ENGINEERING LTD.

**FOUNDATION INVESTIGATION AND DESIGN REPORT
CULVERT REHABILITATION
HIGHWAY 406, NORTH OF PORT ROBINSON ROAD
CITY OF THOROLD, ONTARIO
G.W.P. 2063-17-00, SITE 34X-0294**

GEOCRES NO. 30M3-318

**Latitude: 43.041765°
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**Report
to
Ontario Ministry of Transportation**

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TABLE OF CONTENTS

PART 1: FACTUAL INFORMATION

1.0	INTRODUCTION	1
2.0	SITE DESCRIPTION	2
3.0	SITE INVESTIGATION AND FIELD TESTING.....	3
4.0	LABORATORY TESTING.....	5
5.0	DESCRIPTION OF SUBSURFACE CONDITIONS	6
5.1	Topsoil.....	6
5.2	Pavement Structure.....	7
5.3	Embankment Fill.....	7
5.4	Clayey Silt	8
5.5	Upper Silty Clay.....	9
5.6	Silt	12
5.7	Lower Silty Clay.....	13
5.8	Groundwater Conditions.....	14
6.0	CORROSIVITY AND SULPHATE TEST RESULTS.....	15
7.0	MISCELLANEOUS	15

PART 2: ENGINEERING DISCUSSION AND RECOMMENDATIONS

8.0	GENERAL.....	17
9.0	CULVERT FOUNDATIONS.....	18
9.1	Culvert Replacement Options	18
9.2	Foundation Design	20
9.3	Concrete Box Culvert	20
9.3.1	Subgrade Preparation	22
9.3.2	Settlement	22
9.3.3	Embankment Stability.....	24
9.3.4	Construction Considerations	25
10.0	CULVERT BACKFILL AND LATERAL EARTH PRESSURES	26
11.0	EMBANKMENT DESIGN AND CONSTRUCTION	27



12.0	SCOUR AND EROSION CONTROL	28
13.0	EXCAVATION AND GROUNDWATER CONTROL	28
14.0	SEISMIC CONSIDERATIONS.....	30
15.0	TEMPORARY PROECTION SYSTEMS	31
16.0	EXISTING CULVERT CONSIDERATIONS.....	32
17.0	SOIL CORROSION POTENTIAL	32
18.0	CONSTRUCTION CONCERNS	33
19.0	CLOSURE	34



Figure 1 – Borehole Location Plan (present and previous investigations)
Figure 2 – Summary of Subsurface Parameters
Figure 3 – Estimated settlement profile

Appendices

Appendix A	Record of Borehole Sheets – Present Investigation
Appendix B	Geotechnical and Analytical Laboratory Test Results – Present Investigation
Appendix B1	Grain Size Analysis and Atterberg Limit Test
Appendix B2	Analytical Laboratory Test Results for Corrosivity
Appendix B3	One-Dimension Consolidation Test Results
Appendix C	Cone Penetration Test (CPTu) Report
Appendix D	Record of Borehole Sheets and Geotechnical Laboratory Test Results – Previous Investigation
Appendix D1	Boreholes C10-1 to C10-3
Appendix D2	Borehole C11-3
Appendix D3	Borehole C12-3
Appendix D4	Boreholes PR-1, PR-5
Appendix E	Selected Site Photographs
Appendix F	Borehole Locations and Soil Strata Drawings
Appendix G	Foundation Comparison
Appendix H	Selected Slope Stability Outputs
Appendix I	List of OPSS Documents and NSSP Wordings



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PART 1: FACTUAL INFORMATION

1.0 INTRODUCTION

This report presents the factual findings obtained from a foundation investigation carried out by Thurber Engineering Ltd. (Thurber) for the proposed partial culvert replacement located on Highway 406 NBL, north of Port Robinson Road, at approximate Station 15+712, in Thorold, Ontario.

The purpose of this investigation was to explore the subsurface conditions at the culvert location and, based on the data obtained, to provide a borehole location plan, stratigraphic profile, records of boreholes, laboratory test results, and a written description of the subsurface conditions. A model of the subsurface conditions was developed for the site, based on the data obtained from the investigation, to describe the geotechnical conditions influencing design and construction of the replacement culvert.

Thurber was retained by The Ontario Ministry of Transportation (MTO) to carry out this foundation investigation under the MTO Assignment Number 2016-E-0076.

During the preparation of this report and in addition to the boreholes drilled, reference has been made to information on subsurface conditions contained in previous foundation reports prepared for nearby sites. The titles of these reports are listed as follows:

- Foundation Investigation Report for Culverts and Culvert Extensions, Highway 406 Twinning, Port Robinson Road to East Main Street, W.P. 280-99-00, GEOCRES No. 30M3-269, dated February 25, 2011, prepared by Terraprobe. (Reference 1).



- Foundation Investigation and Design Report for High Fills at Port Robinson, Highway 406 Twinning, Port Robinson Road to East Main Street, W.P. 280-99-00, GEOCRE No. 30M3-264, dated September 30, 2010, prepared by Terraprobe. (Reference 2).

2.0 SITE DESCRIPTION

The existing culvert is located approximately 170 m north of Port Robison Road, crossing under Highway 406 in Thorold, Ontario.

The culvert runs in a general northeast-southwest direction with its alignment in a skewed angle (55 degrees) to the centreline of the highway. The culvert allows the creek to flow in north-easterly direction beneath the highway. The lands surrounding the existing culvert consist of agricultural lands, with trees and bushes along the east and west sides of Highway 406. The terrain is generally flat.

Originally, an open footing culvert was built in 1968 and measured 3.65 m in width, 2.52 m in height and 56.6 m in length. As part of the Highway 406 twinning project, in 2013, the culvert was extended to the west by installing a new rigid frame box culvert. The culvert extension measured 35.5 m. Based on recent culvert inspection reports, the culvert appears to have experienced settlement, resulting in cracks at the mid-section. Scour has also been noted at some locations. The total length of the culvert is 92.1 m. The Highway 406 grade at the existing culvert is at approximate Elevation 182.0 m. The culvert inlet invert level is at approximate Elevation 176.5. The maximum height of the embankment fill at the culvert is approximately 5.3 m.

It is understood that the current project requirements involve replacement of the east portion of the existing open footing culvert, under Highway 406 northbound lane (NBL), with a concrete box culvert along the same alignment. The approximate length of the east culvert replacement is approximately 55.5 m.

Selected photographs of the culvert area are included in Appendix E for reference.

The site is situated within the physiographic region known as the Haldimand Clay Plain, which is characterized by glacio-lacustrine deposits laid down by the glacial Lake Warren during the Wisconsinian Age. These deposits consist of silts and clays and are generally underlain by a glacial till, which in turn overlies dolomitic limestone bedrock.



3.0 SITE INVESTIGATION AND FIELD TESTING

The present borehole investigation and field testing program for this site were carried out between October 28 to 31, 2019, and consisted of drilling and sampling four (4) boreholes, designated as Boreholes 19-01 to 19-04. All the boreholes were drilled from the east shoulder of Highway 406 SBL to the culvert outlet, which is located on the east side of Highway 406 NBL. Boreholes 19-01 and 19-02 were drilled from the Highway 406 platform and were terminated at 17.8 m depth (Elevations 163.7 and 164.2). Boreholes 19-03 and 19-04, were drilled within the outlet zone and terminated at 14.3 m depth (Elevations 162.4 and 164.3). The Records of Borehole sheets from the present investigation are provided in Appendix A.

A previous geotechnical investigation was carried out at this site between July 13 and July 14, 2010 (Reference 1) and consisted of advancing three boreholes (numbered C10-1, C10-2 and C10-3) near the existing culvert alignment. The boreholes were drilled and sampled to depths ranging from 12.7 m to 23.4 m (Elevations 158.3 to 164.4). The Record of Borehole sheets of the previous investigation at this site are included in Appendix D1.

The approximate locations of the boreholes from the present and previous investigations are shown on the Borehole Locations Plan and Soil Strata Drawing in Appendix F and in Figure 1 “Borehole Location Plan” following the report text.

The coordinates and elevations of the boreholes are given on this drawing and on the individual Record of Borehole Sheets in Appendices A and D1. Thurber surveyed the current boreholes in the field, and obtained the borehole coordinates and ground surface elevations. Coordinates of boreholes are related to MTM NAD 83 Zone 10. The survey equipment used was a Trimble R10 GNSS system, with a horizontal precision of 3 mm RMS, and a vertical precision of 3.5 mm RMS.

Lane closures and traffic control were implemented during drilling of the boreholes for the current investigation. Prior to commencement of drilling, utility clearances were obtained for all borehole locations.

The current boreholes were advanced using a track-mounted drill rig equipped with hollow stem augers. Soil samples were obtained at selected intervals using a 50 mm outside diameter split-spoon sampler driven in conjunction with the Standard Penetration Test (SPT). The SPT was performed in accordance with ASTM D1586.



In the cohesive deposits, the undrained shear strength of the material was measured in-situ by means of field vane tests (MTO N-Vane), and undisturbed soil samples were collected using thin-walled Shelby tube samplers.

In addition to the above field investigation, a Cone Penetration Test (CPTu) labelled CPT19-05, was conducted at the site on November 22, 2019. The CPTu was advanced to 29.2 m depth (Elevation 152.9). The piezocone penetrometer consists of a metal rod equipped with electronic sensors at its tip, which is statically pushed into the ground by a drill rig to continuously measure the tip resistance, sleeve friction, dynamic pore water pressure, temperature and cone inclination. The CPTu included pore pressure dissipation tests at selected depths in the silty clay in order to obtain horizontal coefficient of consolidation values. All CPTu testing was performed in accordance with the current ASTM D5778 standard. The approximate location of the CPTu is shown on the Borehole Location Plan and Stratigraphic Drawing in Appendix F. The inferred stratigraphy and results of the pore pressure dissipation tests are provided in ConeTec's report included in Appendix C.

The objectives of the CPTu and borehole drilling were to provide more detailed information about the subsurface stratigraphy and consolidation characteristics of the compressible cohesive (silty clay) soils, as well as to collect undisturbed soil samples for laboratory testing.

The field investigation was supervised on a full-time basis by a member of Thurber's technical staff who marked/staked the boreholes in the field, arranged for the clearance of subsurface utilities, supervised the drilling, sampling and in-situ testing operations, logged the boreholes and processed the recovered soil samples for transport to Thurber's laboratory for further examination and testing.

During the present investigation, groundwater conditions in the open boreholes were observed throughout the drilling operations. A standpipe piezometer (25 mm diameter) was installed and enclosed in filter sand columns in Borehole 19-04, to permit groundwater level monitoring. The details of the piezometer installation are shown in Table 3.1.

Table 3.1 – Piezometer Details

Borehole	Borehole Depth / Base Elevation (m)	Piezometer Tip Depth/ Elevation (m)	Completion Details
19-04	14.3/162.4	13.9/162.8	Piezometer with 3.0 m slotted screen installed with sand filter from 14.3 m to 10.2 m, bentonite holeplug from 10.2 m to 9.1 m, grout from 9.1 m to 1.5 m, bentonite from 1.5 m to 0.6 m, then sand to ground surface.

All remaining boreholes without piezometer installations were backfilled upon completion of drilling in general conformance with O.Reg. 903 as amended by O.Reg.128/03. The piezometer was decommissioned following groundwater monitoring in general conformance with O.Reg. 903. Asphalt was reinstated in Boreholes 19-01 and 19-02 drilled on the highway platform.

4.0 LABORATORY TESTING

All recovered soil samples were subjected to visual identification (VI) and to natural moisture content determination. Selected samples were subjected to grain size distribution analyses (sieve and/or hydrometer), Atterberg Limits testing and Specific Gravity. Geotechnical laboratory testing results of the present investigation are summarized on the Record of Borehole sheets included in Appendix A and are presented on the figures included in Appendix B1.

Laboratory test conducted during the previous investigation is presented in Appendix D.

During the present investigation, two selected soil samples were subjected to One-Dimension Consolidation Test from Boreholes 19-02 and 19-03. Consolidation tests were carried out in accordance with Standard Test Method for One-Dimensional Consolidation Properties of Soils, ASTM D 2435-11, method A. Each of the soil specimen in the current investigation was left to creep in one of the load steps. The results of these tests are included in Appendix B3.

Five One-dimension consolidation tests were performed on soil specimens retrieved from Boreholes C10-1, C11-3, C12-3, PR1 and PR5 drilled in the vicinity of the culvert during the previous investigations (References 1 and 2). The results of the consolidation tests from the previous investigations, are presented in Appendices D1 to D4. The borehole locations where



consolidation tests were conducted during the present and previous investigations are shown on Figure 1.

In order to assess the potential for sulphate attack on a concrete culvert, as well as the potential for metal corrosion associated with the structure, two samples of the native soils were collected and submitted to SGS Canada Inc., a CALA accredited analytical laboratory in Lakefield, Ontario, for analytical testing for corrosivity parameters and sulphate content. The results of the analytical testing are summarized in Section 6 and are presented in Appendix B2.

5.0 DESCRIPTION OF SUBSURFACE CONDITIONS

Details of the encountered soil stratigraphy are presented on the Record of Borehole sheets included in Appendices A and D1, and on the Borehole Locations and Soil Strata drawings in Appendix F. A general description of the stratigraphy is given in the following paragraphs. However, the factual data presented in the Record of Borehole Sheets governs any interpretation of the site conditions. It must be recognized and anticipated that soil conditions may vary between and beyond the borehole locations.

In general, the subsurface stratigraphy encountered on the highway grade consists of asphalt and concrete overlying compact gravelly sand and soft to very stiff silty clay embankment fill. Below and beyond the highway embankment, the native soils consist of topsoil overlying an extensive deposit of native upper silty clay. A layer of silt was contacted below the upper silty clay. The silt is underlain by a lower layer of silty clay. Groundwater levels are generally in the order of 0 to 1.5 m (Elevations 177.0 to 177.4) below original ground surface. A groundwater level was measured at 0.1 m (Elevation 176.8) above the ground surface in Borehole 19-04, drilled at the culvert outlet.

More detailed descriptions of the individual stratum are presented below.

5.1 Topsoil

Topsoil was encountered surficially in Boreholes 19-03, C10-1 and C10-3. The thickness of the topsoil was 75 mm in Borehole 19-03, and 230 mm in Boreholes C10-1 and C10-3.

The topsoil thickness may vary between and beyond the borehole locations, and the data is not intended for the purpose of estimating quantities.



5.2 Pavement Structure

Pavement structure consisting of approximately 125 mm of asphalt overlying granular (sand and gravel) road base was encountered in Boreholes 19-01 and 19-02 advanced through the Highway 406 platform. The granular fill ranged in thickness from 300 mm to 600 mm. A 300-mm thick layer of concrete was contacted below the asphalt in Borehole 19-02.

SPT 'N' values recorded in the granular road base were 9 and 35 blows per 0.3 m of penetration indicating loose to dense condition. The natural moisture contents measured on samples of the granular road base ranged from 3 percent to 25 percent.

5.3 Embankment Fill

The existing embankment fill consisted on layers of cohesionless and cohesive soils.

Cohesionless fill was contacted surficially in Boreholes 19-04 and C10-2, and consisted of reddish brown to brown sand and gravel, and gravelly sand containing some silt and trace clay. The thickness of the cohesionless fill varied from 100 mm to 700 mm.

Cohesive fill was contacted below the topsoil and/or pavement structure in Boreholes 19-01 to 19-03 and C10-3, and below the cohesionless fill in Boreholes 19-04 and C10-2. The cohesive fill consisted on reddish brown, brown and dark brown silty clay containing trace sand to sandy, trace gravel, occasional organics and grey silt lenses. The thickness of the silty clay fill ranged from 1.4 m to 4.9 m.

The depth to the base of the embankment fill ranged from 1.5 m to 5.6 m (Elevations 175.2 to 177.8).

An SPT 'N' value measured in the gravelly sand fill was 17 blows per 0.3 m of penetration, indicating a compact state. SPT 'N' values measured in the silty clay fill varied from 3 to 19 blows per 0.3 m of penetration, indicating a soft to very stiff consistency. The natural moisture contents measured on a sample of the cohesionless fill was 6 percent. Moisture contents measured on the silty clay fill samples ranged from 16 percent to 38 percent.

The results of grain size analyses conducted on samples of the silty clay fill during the present investigation, are provided on the Record of Borehole sheets in Appendix A, and illustrated on Figure B1 of Appendix B1. Grain size analyses results of the gravelly sand fill and silty clay fill



from the previous investigation, are presented in Figures B7-1 and B7-2 of Appendix D1. The results are summarized as follows:

Soil Particle	Silty Clay Fill (Percent)	Gravelly Sand Fill (Percent)
Gravel	0	26
Sand	3 to 19	56
Silt	38 to 59	14
Clay	28 to 43	4

The results of Atterberg Limits tests conducted on samples of the silty clay fill during the present investigation, are presented on the Record of Borehole sheets in Appendix A, and illustrated in Figure B5 of Appendix B1. The results of Atterberg Limits tests from the previous investigation are presented in Figure B7-3 of Appendix D1. The results are summarized as follows:

Index Property	Percentage (%)
Liquid Limit	37 to 44
Plasticity Index	17 to 22

The results of the Atterberg Limits testing indicate that the silty clay fill has a medium plasticity with a group symbol of CI.

5.4 Clayey Silt

An 800-mm thick layer of native brown to grey clayey silt containing trace sand, trace gravel and occasional organics and rootlets was contacted below the embankment fill in Boreholes 19-01 and 19-02.

The depth to the base of the clayey silt was at 4.5 m and 5.3 m (Elevations 177.0 and 176.7) in Boreholes 19-01 and 19-02, respectively

The SPT 'N' values recorded in the clayey silt were 9 blows per 0.3 m of penetration, indicating a stiff consistency. The natural moisture contents measured on samples of clayey silt were 22 percent and 26 percent.



5.5 Upper Silty Clay

An upper deposit of native brown to grey silty clay was encountered below the silty clay fill and clayey silt, at depths ranging from 1.5 m and 5.6 m (Elevations 175.2 to 177.0) in all the boreholes, except in Borehole C10-1, where it was encountered below the topsoil at 0.2 m (Elevation 176.9). The silty clay contained trace sand, trace gravel and thin silt lenses. The thickness of the upper silty clay ranged from 9.4 m to 12.5 m.

An over-consolidated weathered crust, extending to approximately 5.7 to 10 m depths (Elevations 171.0 to 173.0 m), was encountered in Boreholes 19-01 to 19-04, C10-1 and C10-2. Within this crust, SPT 'N' values typically ranged from 8 to 22 blows for 0.3 m of penetration indicating a stiff to very stiff consistency. Locally, in Borehole C10-3, the SPT 'N' values ranged up to 31 blows for 0.3 m of penetration, indicating a hard consistency.

Below the crust, a lightly over-consolidated silty clay zone was encountered below approximately Elevations 171.0 to 174.0 m, with depths of the base ranging from about 10.5 to 16.3 m. SPT 'N' values typically ranged between 0 and 6 blows per 0.3 m penetration within this zone. Vane shear tests (VST) conducted in the lightly over-consolidated silty clay measured in-situ undrained shear strength in the range of 55 kPa to 110 kPa, which corresponds to a stiff to very stiff consistency. An in-situ undrained shear strength of 48 kPa was measured in one borehole from the previous investigation, indicating a firm consistency.

Moisture contents measured on the upper silty clay samples ranged from 17 percent to 49 percent.

The results of grain size analyses conducted on samples of the upper silty clay during the present investigation, are provided on the Record of Borehole sheets in Appendix A, and illustrated on Figures B2 and B3 of Appendix B1. Grain size analyses results of the upper silty clay from the previous investigation, are presented in Figures B7-4 and B7-5 of Appendix D1. The results are summarized as follows:



Soil Particle	Upper Silty Clay (Percent)
Gravel	0 to 1
Sand	0 to 41
Silt	30 to 82
Clay	18 to 57

The results of Atterberg Limits tests conducted on samples of the upper silty clay during the present investigation, are presented on the Record of Borehole sheets in Appendix A, and illustrated in Figures B6 and B7 of Appendix B1. The results of Atterberg Limits tests from the previous investigation are presented in Figures B7-6 and B7-7 of Appendix D1. The results are summarized as follows:

Index Property	Percentage (%)
Liquid Limit	22 to 42
Plasticity Index	7 to 23

The results of the Atterberg Limits testing indicate that the upper silty clay has a low to medium plasticity with group symbols of CL and CI.

The results of two oedometer (one-dimensional consolidation) tests carried out on undisturbed silty clay samples of the present investigation, collected from depths ranging from 7.9 to 9.5 m, are summarized on the borehole logs and in Table 5.1 below. Two time-dependent creep tests were carried out for approximately 216 to 266 hours under constant loading stress for the measurement of coefficient of secondary consolidation (C_{α}). The detailed test results are also presented in Appendix B3.

Table 5.1 - Oedometer Test Results

Borehole	19-02	19-03
Sample No.	TW12	TW9
Depth (m)	9.45	7.9
Elevation (m)	172.6	170.7
Soil Type	Silty Clay	Silty Clay
Clay Content (%)	48	51
Moisture Content (%)	27	30
Liquid Limit (%)	39	39
Plasticity Index (%)	21	21
γ - Unit Weight (kN/m³)	18.9	18.6
G_s - Specific Gravity	2.74	2.79
e_o - Initial Void Ratio	0.884	0.98
P'₀ - In situ effective vertical stress (kPa)	120	131
P'_c - Preconsolidation Pressure (kPa)	242	230
OCR - Overconsolidation Ratio	2.02	1.75
C_c - Compression Index	0.327	0.399
C_r - Recompression Index	0.016	0.034
C_{α} - Secondary Compression Index	0.0080	0.0025
C_v - Coefficient of Consolidation in NC range (m²/yr)	4.87	3.88
C_{vr} - Coefficient of Consolidation in OC range (m²/yr)	15.11	11.86

Results of consolidation tests conducted during the previous investigations (References 1 and 2) and the associated borehole logs are included in Appendices D1 to D4.

The over-consolidation ratios (OCR) inferred from piezocone test show that this deposit is heavily over-consolidated with OCR values ranging from 10 to 4.1 from 4.5 m to 10.0 m depth, 6.2 to 2.3 from 10.0 m to 11.8 m and 2.9 to 1.1 from 11.8 m to 17.0 m. The behaviour observed from the pore pressure dissipation tests indicated that this deposit grades from over-consolidated to slightly over-consolidated.



In addition to the vertical coefficients of consolidation (C_v) obtained from the oedometer tests, the horizontal coefficients of consolidation (C_h) were measured at various depths in the Cone Penetration Test CPT19-05. Table 5.2 summarizes the results of the pore water dissipation tests.

Table 5.2 - Pore Pressure Dissipation Test Results

Piezocone (CPT19-05)	
Depth (m)	$C_h^{(1)}$ (cm ² /min)
6.4	-
9.4	1.4
13.1	1.2
17.7	27.0
22.9	0.5
29.175	-

⁽¹⁾ Houlsby and Teh, 1991

5.6 Silt

Brown to grey silt containing trace to some clay and trace sand was contacted below the upper silty clay at depth ranging from 10.5 m to 16.3 m (Elevations 162.7 to 166.6) in all the boreholes. The thickness of the silt was 3.0 m in Boreholes C10-2 and C10-3. The depth to the base of the silt was at 19.2 m and 16.2 m (Elevations 162.5 and 162.3) in Boreholes C10-2 and C10-3, respectively.

A 1.2-m thick layer of silt was encountered within the upper silty clay at 4.4 m depth (Elevation 172.7) in Borehole C10-1.

Boreholes 19-01 to 19-04 and C10-1 were terminated within the silt at depths ranging from 12.7 m and 17.8 m (Elevations 162.4 and 164.4).

Based on the SPT 'N' values ranging typically from 0 to 11 blows per 0.3 m of penetration, the silt is in a very loose to compact state. SPT 'N' values of 21 and 37 blows per 0.3 m of penetration, indicating a compact to dense state, were measured in Boreholes C10-1 and C10-3. Moisture contents measured in the silt ranged from 19 percent to 34 percent.



The results of grain size distribution analyses carried out on samples of the silt, during the present investigation, are presented on the Record of Borehole sheets included in Appendix A. Grain size distribution curves of the silt samples tested are presented on Figure B4 Appendix B1. Grain size analyses results of the silt samples from the previous investigation, are presented in Figure B7-8 of Appendix D1. The results are summarized as follows:

Soil Particle	Silt (Percent)
Gravel	0 to 1
Sand	0 to 4
Silt	77 to 92
Clay	7 to 19

5.7 Lower Silty Clay

A lower layer of brown silty clay containing sand was encountered below the silt at 19.2 m and 16.2 m depth (Elevations 162.5 and 162.3) in Boreholes C10-2 and C10-3.

Boreholes C10-2 and C10-3 were terminated within the lower silty clay at 23.4 m and 17.3 m depth (Elevations 158.3 and 161.2).

SPT 'N' values measured in the lower silty clay ranged from 8 to 33 blows per 0.3 m of penetration, indicating a stiff to hard consistency. Moisture contents measured in the lower silty clay samples ranged from 17 percent to 22 percent.

Grain size analyses results of the lower silty clay from the previous investigation, are presented in Figure B7-5 of Appendix D1. The results are summarized as follows:

Soil Particle	Silty Clay (Percent)
Gravel	0
Sand	7
Silt	74
Clay	19

The results of Atterberg Limits tests from the previous investigation are presented in Figure B7-7 of Appendix D1. The results are summarized as follows:



Index Property	Percentage (%)
Liquid Limit	24
Plasticity Index	8

The results of the Atterberg Limits testing indicate that the silty clay has a low plasticity with a group symbol of CL.

5.8 Groundwater Conditions

Groundwater levels in the boreholes were observed during the drilling operations and measured upon completion of drilling. Standpipe piezometers were installed in Borehole 19-04 during the present investigation, and in Boreholes C10-1 and C10-3 in the previous investigation, to permit monitoring of groundwater levels. Water levels measured in the installed piezometers and open boreholes are presented in Table 5.3 below.

Table 5.3 - Groundwater Level Measurements

Borehole	Date	Groundwater Level		Comments
		Depth (m)	Elev. (m)	
19-01	October 28, 2019	7.5	174.0	Borehole caved to 11.5 m Open borehole
19-03	October 30, 2019	13.3	165.3	Open borehole
19-04	October 31, 2019	0.4	176.3	Open borehole
	November 22, 2019	0.1 ⁽¹⁾	176.8	Piezometer
C10-1	July 13, 2010	7.3	169.8	Open borehole
	July 19, 2010	0.1	177.0	Piezometer
	August 6, 2010	0.0	177.1	Piezometer
	August 13, 2010	0.0	177.1	Piezometer
	August 23, 2010	0.0	177.1	Piezometer
C10-2	July 14, 2010	Dry	-	Open borehole
C10-3	July 14, 2010	8.5	170.0	Open borehole
	July 20, 2010	1.5	177.0	Piezometer
	July 27, 2010	1.1	177.4	Piezometer
	August 6, 2010	1.1	177.4	Piezometer

⁽¹⁾Groundwater measured above ground surface (Artesian condition)



Artesian conditions were noted in Borehole 19-04, where groundwater level was measured at 0.1 m (Elevation 176.8) above the ground surface

The values shown in Table 5.3 are short-term readings, and seasonal fluctuations of the groundwater level are to be expected. In particular, the groundwater level may be at a higher elevation after periods of significant or prolonged precipitation.

6.0 CORROSIVITY AND SULPHATE TEST RESULTS

Two selected soil samples were submitted for analytical testing of corrosivity parameters including sulphate content. The results of the analytical tests are shown in Table 6.1. The laboratory certificates of analysis are presented in Appendix B2.

Table 6.1 – Analytical Corrosivity Test Results

Sample ID	Depth (m)	Soil Sample Description	Sulphide (percent)	Chloride (µg/g)	Sulphate (µg/g)	pH	Resistivity (ohm.cm)	Redox Potential (mV)	Electrical Conductivity (µS/cm)
19-02 SS6	3.6 to 4.8	Silty clay fill	< 0.02	17	270	8.76	4650	252	215
19-03 SS5	3.0 to 3.6	Silty clay	< 0.02	590	15	8.92	3830	319	261

7.0 MISCELLANEOUS

Thurber staked and/or marked the borehole locations in the field and obtained utility clearances prior to drilling. Thurber surveyed the boreholes in the field and obtained the borehole coordinates and ground surface elevations.

Landshark Drilling from Brantford, Ontario supplied and operated the drilling and sampling equipment for the field program. ConeTec Investigations Ltd. supplied and operated the piezocone penetrometer equipment.



Full time supervision of the field activities was carried out by Mr. John Zoldy EIT and Ms. Eckie Siu of Thurber. Overall supervision of the field program was performed by Mr. Stephane Loranger, CET of Thurber.

Interpretation of the field data and preparation of the report were carried out by Ms. Rocio Palomeque Reyna. The report was reviewed by Mr. Matthew Boucher, P.Eng. and Dr. P.K. Chatterji, P.Eng., a Designated Principal Contact for MTO Foundations Projects.

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**FOUNDATION INVESTIGATION AND DESIGN REPORT
CULVERT REHABILITATION
HIGHWAY 406, NORTH OF PORT ROBINSON ROAD
CITY OF THOROLD, ONTARIO
G.W.P. 2063-17-00, SITE 34X-0294**

GEOCRES NO. 30M3-318

PART 2: ENGINEERING DISCUSSION AND RECOMMENDATIONS

8.0 GENERAL

This report presents interpretation of the geotechnical data in the factual report and provides foundation recommendations for the design of the partial replacement of the existing culvert located at Highway 406, approximately 170 m north of Port Robinson Road in Thorold, Ontario.

Available information of the existing culvert is provided below:

- The original culvert was built in 1968. This existing structure under Highway 406 NBL (east portion) is an open footing culvert, and measures 3.65 m in width and 2.52 m in height. The culvert invert levels at the inlet and outlet are at Elevations 176.1 and 175.9, respectively. The existing Highway 406 grade at the culvert location is at about Elevation 182.0, which indicates approximately 3.4 m to 3.6 m of fill above the culvert.
- In 2013, the culvert was extended to the west, as part of the Highway 406 twinning, by installing a new rigid frame box culvert. The culvert extension measured 35.5 m. After the culvert extension, the entire length of the culvert is 92.1 m.
- According to highway maintenance records, the existing culvert has experienced settlement, resulting in cracks at the mid-section. Scour has also been noted below the footings.



Based on a General Arrangement (GA) drawing (dated December 2019) provided by MTO, the project requirements involve replacement of the existing open footing culvert with a concrete box culvert. Only the east portion of the existing culvert will be replaced. The new culvert will be 3.6 m wide and 3.6 m high. The portion of the culvert that will be replaced is approximately 55.5 m long. The invert levels of the replacement culvert and the finished Highway 406 grade level will remain largely the same as for the existing culvert.

This foundation investigation and design report, with the interpretation and recommendations, is intended for the use of the Ministry of Transportation, and shall not be used or relied upon for any other purposes or by any other parties including the construction contractor. The contractors must make their own interpretation based on the factual data in Part 1 of the report. Where comments are made on construction, they are provided only in order to highlight those aspects, which could affect the design of the project. Contractors must make their own interpretation of the information provided as it may affect equipment selection, proposed construction methods and scheduling.

The discussion and recommendations presented in this report are based on the information provided by MTO and on the factual data obtained during the current and previous investigations.

9.0 CULVERT FOUNDATIONS

9.1 Culvert Replacement Options

This section presents discussions on available types of culverts for the proposed culvert replacement, and provides recommendations for feasible and/or preferred culvert options.

Several common culvert types that may be considered for the culvert replacement at this site are listed below:

- Concrete box (closed) culvert
- Concrete open footing culvert
- Circular Pipes (Concrete, Steel, HDPE)

A comparison of the technical advantages, disadvantages and relative risks and costs of each culvert alternative is presented in Appendix G. Discussions on feasible culvert alternatives are



presented in the following paragraphs. A preferred foundation scheme from a foundations perspective is then recommended.

Concrete open footing culvert

A concrete open footing culvert is feasible, however, from a foundation engineering perspective, the compressible silty clay subgrade will provide comparatively, lower geotechnical resistances and has potential scouring around and below the footings. Foundation recommendations for an open footing culvert has not been developed in this report.

Circular Pipes (Concrete, Steel, HDPE)

From a foundation engineering standpoint, concrete, steel and HDPE pipes are technically feasible alternatives provided that other design issues including flow capacity, hydraulic properties and durability can be satisfied. Multiple pipes may be required to provide adequate hydraulic capacity. It is understood that this option is not considered at this site and therefore foundation recommendations for pipe culverts are not further developed.

Concrete box (closed) culvert

Given the subsurface conditions and the anticipated construction sequencing and staging, precast concrete box culvert is the preferred culvert replacement option at this site. Precast sections, rather than cast-in-place construction, can be installed rapidly with less potential for disturbance of the founding soils during installation. A segmental box structure can accommodate some potential differential settlement along the culvert axis.

Due to the existing soil and groundwater conditions at this site, and from a foundation technical, constructability and cost-effectiveness perspective, the recommended culvert type for replacement is precast concrete box (closed) culvert. This report focuses on providing foundation recommendations for the design and construction of a concrete box culvert.

Staged open excavation is planned for this project. However, open cut construction would result in disruption to Highway 406 traffic flow amongst other logistics issues. Protection Systems (temporary shoring) will be required.



9.2 Foundation Design

In general, the subsurface stratigraphy encountered below the highway grade consists of pavement structure overlying compact gravelly sand and firm to very stiff silty clay embankment fill. The thickness of the embankment fill ranged from 1.4 m to 4.9 m. An 800-mm thick layer of clayey silt with occasional organics was contacted below the silty clay fill in two boreholes drilled on the highway platform. Below the fill, a deposit of native silty clay was contacted, grading from very stiff (crust) into firm consistency with depth. The thickness of the silty clay ranged from 9.4 m to 12.5 m. The silty clay is underlain by very loose to compact silt and a stiff to very stiff lower silty clay. The groundwater levels measured in the piezometers were at depths ranging from 0 m to 1.5 m (Elevations 177.0 to 177.4). In Borehole 19-04, drilled at the culvert outlet, groundwater level was measured at 0.1 m (Elevation 176.8) above the ground surface, indicating a slight artesian condition.

Foundation design aspects for the replacement culvert include subgrade conditions and preparation, geotechnical capacities, settlement of founding soils, lateral earth pressures, roadway protection system design, groundwater control, staged construction, and restoration of the roadway embankment.

9.3 Concrete Box Culvert

Replacement of the east portion of the culvert with precast concrete box culvert is considered a viable alternative for this site. Based on available information, it is anticipated that the proposed founding levels (bottom of bedding) of the culvert are at approximate Elevations 175.2 to 174.8, from the west end of the open footing culvert to the culvert outlet. From the borehole results, the subgrade soils at this elevation typically consist of stiff to very stiff silty clay.

In order to provide a uniform foundation subgrade, a 300 mm thick layer of bedding material conforming to OPSS PROV 1010 Granular A or Granular B Type II requirements should be provided under the base of the box culvert, similar to that shown on OPSD 803.010. The bedding material must be placed on the prepared subgrade as soon as practicable following its inspection and approval. The subgrade preparation, placement and compaction of the bedding material must be carried out in the dry. The surface prepared to support the box units should have a 75 mm minimum thickness top levelling course consisting of uncompacted Granular A as per OPSS 422 above the 300 mm bedding layer. Geotextile should be placed between the founding soils and the granular layer of bedding material. Construction equipment should not be



allowed to travel on the bedding or the prepared subgrade, which must be protected from disturbance during construction. It is understood that a layer of 600 mm thick compacted Granular A or approved compacted material as per OPPS 902 will be placed below the bedding to restore the areas of removed footings of the existing culvert.

The following geotechnical capacities may be used for design of the proposed box culvert founded at or below approximate Elevations 175.2 to 174.8, on a stiff to very stiff silty clay subgrade:

- Factored Geotechnical Resistance at ULS of 250 kPa
- Geotechnical Resistance at SLS (less than 25 mm settlement) of 150 kPa

A consequence factor of 1 was utilized in this design adopting the typical consequence level. The geotechnical resistance factor of 0.5 for bearing, and 0.8 for settlement, both adopted for typical degree of understanding, were used to obtain the above values, as per CHBDC 2014, Sec. 6.9.

The ULS resistance and settlement are dependent on the culvert size, configuration and applied loads; the geotechnical resistances should therefore be reviewed if the culvert width or founding/invert elevation differs significantly from that given above.

The geotechnical resistances are for vertical, concentric loads. Where eccentric or inclined loads are applied, the resistance used in design must be reduced in accordance with the CHBDC 2014, Clause 6.10.3 and Clause 6.10.4.

Resistance to lateral forces / sliding resistance between pre-cast concrete and the underlying Granular A or B Type II should be calculated assuming an ultimate coefficient of friction of 0.5.

It is recommended that the culvert be designed to resist external loadings including frost forces, lateral earth pressures, hydrostatic pressure, weight of the embankment fill, traffic loadings and surcharge due to construction equipment.

The estimated modulus of subgrade reaction (k_s) is 6,000 kN/m³ for this precast box culvert with each unit measuring 4.2 m in width and 2.5 m in length.



Recommendations regarding the existing west box culvert beneath Highway 406 SBL that will remain operational are presented in Section 16 of this report.

9.3.1 Subgrade Preparation

After the excavation reaches the design founding elevation, any remaining fill, topsoil, organic deposits, disturbed soils and any deleterious materials within the culvert replacement footprint must be sub-excavated to undisturbed native stiff to very stiff silty clay at or below the desired founding elevations, and replaced with well compacted granular fill consisting of OPSS.PROV 1010 Granular A or B Type II material compacted as per OPSS.PROV 501. It must be noted that Boreholes 19-01 and 19-02, located at the Highway 406 platform, encountered clayey silt with occasional organics. The presence of alluvial and organic deposits should also be expected in the vicinities of the creek and must be removed within the culvert footprint. The exposed surface must be inspected to confirm that the subgrade is suitable and uniformly competent.

Excavation and backfilling shall be as per OPSS 902 and MTO special provision SP109S12, amendment to OPSS 902. Site grading work shall be carried out as per OPSS 206. Subgrade preparation must be carried out in the dry. The dewatering scheme must be effective to lower the groundwater level to at least 0.5 m below the final subgrade level.

9.3.2 Settlement

It is understood that the compressible foundation soils underneath the culvert has undergone settlement over the years.

In addition, the performance of this culvert was assessed in 2009 in a report titled "Preliminary Design Report, Highway 406 Twinning, from 0.2 km North of Port Robinson Road to East Main Street" prepared by McCormick Rankin Corporation/Ecoplans Limited. MTO indicated that this open footing culvert had been slumping between 1979 and 2009, and the MTO maintenance department had added approximately a foot and a half of asphalt between 1999 and 2009. Based on the roadway pavement maintenance record and inspection report, the existing open footing culvert appears to have encountered settlement cracks likely due to ongoing scouring below the footings.

A settlement analysis was conducted to evaluate the foundation settlement since the original culvert construction, and also to estimate the settlement after culvert replacement.

The analysis was conducted assuming the following:

- Culvert under the existing Highway 406 NBL embankment was built in 1968.
- In 2013, the culvert was extended on the west end, and new fill of the Highway 406 SBL embankment was placed due to Highway 406 twining.
- The eastern portion of the existing culvert beneath the Highway 406 NBL will be removed and the existing open footing culvert will be replaced with a box culvert.
- The cohesive soils typically experience time-dependent settlements and will continue to settle over a long period of time.
- All organic deposits (i.e. topsoil and peat) will be removed prior to embankment construction therefore settlement of organic soils is not included.
- Highway embankment height is approximately 6.0 m.

Settlement analysis was performed using the commercially available software “Settle 3D” V4 by Rocscience to estimate the settlements due to the culvert replacement and new embankment construction. Stresses on the foundation soils imposed by the embankment fill and surcharge were calculated using the Boussinesq method.

The summary of the subsurface profile parameters based on relevant index tests, consolidation tests, CPT and field vane tests as well as the interpreted design values are shown in Figure 2, immediately after the text of the report.

The standard method was employed to calculate the secondary consolidation. Compression and recompression secondary coefficients of 0.0042 and 0.0013, respectively were assigned to the relevant soil materials.

The results of the settlement calculations are summarized in Table 9.1.

Table 9.1. Estimated Approximate Settlement of the Original Ground due to Highway Fill Height of 6 m

Year	Estimated Total Settlement
1968 to 2020	~175 mm
2020 to 2040	~25 mm



The remaining ground settlement in 20 years due to embankment loading is estimated to be approximately 25 mm.

The estimated remaining ground settlement profile is presented in Figure 3.

The effects of compression of the fill materials used to construct the embankment should be taken into account. The estimated compression of the embankment fill equal to 0.5% of the fill height is up to 30 mm at this site.

The culvert joint between the old box culvert and the new box culvert must be designed to accommodate a differential settlement of up to 15 mm.

The estimated differential settlement along the culvert has been provided in Figure 3. Accordingly, the precast sections should be designed to accommodate the anticipated differential settlement between the precast units.

9.3.3 Embankment Stability

The maximum height of the highway embankment at this site is approximately 5.3 m. No grade raise is anticipated at this site.

Global stability analyses were carried for the embankment at the culvert location. The analyses were carried out utilizing the commercially available slope stability analysis program Slope/W (Version 2019) of the GeoStudio software package developed by Geo-Slope International with the option for Morgenstern-Price method of slices for the limit equilibrium analyses. Analyses were completed for both static and seismic loading conditions.

The soil parameters used in the analyses were estimated from empirical correlations using the results of the in situ Standard Penetration Tests (SPTs), CPTu and geotechnical laboratory testing. The groundwater level in our analysis was based on readings obtained to date from standpipe piezometers.

The stability of the embankment was also checked under seismic loading assuming an acceleration of 0.22 g.



Results of the slope stability analyses are presented on Figures H1 to H4 in Appendix H. The results are also summarized in Table 9.2 below.

Table 9.2 - Computed Factors of Safety for Slope Stability

Condition	Factor of Safety	Figure (Appendix H)
Embankment height 5.3 m, Slope 2H:1V		
Static Drained	1.5	H1
Static Undrained	2.8	H2
Seismic = 0.22 g Drained	1.0	H3
Seismic = 0.22 g Undrained	1.9	H4

As per typical MTO requirements, a Factor of Safety (F.S.) of 1.3 is acceptable for short term conditions and for total stress (undrained) conditions. A F.S. of 1.5 is acceptable for long term (drained) conditions. Under the assumed seismic loading, the minimum acceptable factor of safety is 1.0. Accordingly, the computed factors of safety are considered to be acceptable for the Highway 406 reinstated embankment configuration at the culvert location.

Fill embankments for the highway should be stable at slope inclinations of 2H:1V or flatter, assuming the use of granular materials.

9.3.4 Construction Considerations

Staged open cutting will be employed to construct the replacement culvert at this site. The main foundation/geotechnical considerations are as follows:

- Traffic and water flow will be maintained at all times during construction.
- Unwatering methods such as temporary diversion of the creek and surface water using sandbags and/or sheetpile cofferdams enclosures may be required.
- Excavation and removal of the existing culvert, installation of the new culvert and backfilling will be carried out within the protection systems.
- Sump pumping will be required at all times.
- Roadway protection will be required during all stages of construction.



Protection systems (temporary shoring) such as the use of interlocking steel sheetpiles will be required. Foundation recommendations for design of such system are provided in Section 15 of this report.

10.0 CULVERT BACKFILL AND LATERAL EARTH PRESSURES

It is recommended that backfill to the culvert consists of free-draining, non-frost susceptible granular materials such as Granular A or B Type II conforming to the requirements of OPSS.PROV 1010. Reference should be made to the backfill arrangements stipulated in OPSD 803.01 as appropriate.

All fills must be placed in regular lifts and be compacted in accordance with OPSS.PROV 501. The backfill must be placed and compacted in simultaneous lifts on both sides of the culvert, and the difference of the top of backfill elevation on both sides of the culvert should be kept within 400 mm of each other at all times. Heavy compaction equipment must not be used adjacent to the culvert.

For a rigid structure such as concrete box culvert, it is recommended that at-rest horizontal earth pressures be used for design.

Earth pressures acting on the culvert walls may be assumed to impose a triangular distribution. For a fully drained backfill, the pressures should be computed in accordance with the CHBDC 2014 but are generally given by the expression:

$$p_h = K (\gamma h + q)$$

where	p_h	=	horizontal pressure on the wall at depth h (kPa)
	K	=	earth pressure coefficient (see table below)
	γ	=	bulk unit weight of retained soil (see table below)
	h	=	depth below top of fill where pressure is computed (m)
	q	=	value of any surcharge (kPa)



Earth pressure coefficients for backfill are dependent on the material used as backfill. Recommended unfactored values are shown in the following Table 10.1.

Table 10.1- Earth Pressure Coefficients (K)

Wall Condition	Earth Pressure Coefficient (K)			
	OPSS Granular A or OPSS Granular B Type II $\phi = 35^\circ$; $\gamma = 22.8 \text{ kN/m}^3$		OPSS Granular B Type I (modified) $\phi = 32^\circ$; $\gamma = 21.2 \text{ kN/m}^3$	
	Horizontal Surface Behind Wall	Sloping Surface Behind Wall (2H:1V)	Horizontal Surface Behind Wall	Sloping Surface Behind Wall (2H:1V)
Active (Unrestrained Wall)	0.27	0.40	0.31	0.48
At rest (Restrained Wall)	0.43	0.62	0.47	0.70
Passive (Movement Towards Soil Mass)	3.7	-	3.3	-

In accordance with Clause 6.12.3 of the CHBDC, a compaction surcharge should be added. The magnitude should be 12 kPa at the top of fill and decreasing to 0 kPa at a depth of 2.0 m for Granular A and Granular B Type II, or at a depth of 1.7 m for Granular B Type I. Compaction equipment to be used adjacent to the culvert walls should be restricted in accordance with OPSS.PROV 501.

11.0 EMBANKMENT DESIGN AND CONSTRUCTION

The existing highway embankment is up to 5.3 m in height at the culvert. It is understood that that there is no planned grade raise at this site.

Embankment reconstruction after culvert replacement should be carried out in accordance with OPSS 206. The embankment material should consist of imported Granular A or B Type II material.



Provided that the granular material is placed as recommended, it is anticipated that slope inclination of 2H:1V, should be stable. Where applicable, benching of the existing earth slope surface should be carried out as per OPSD 208.010 in order to enhance the keying in of the new fill.

In general, surface vegetation, peat, topsoil, organic deposits, disturbed material or otherwise loose/soft soils should be stripped from the areas around the culvert outlet, and within the embankment footprints. Inspection and approval of the foundation surfaces by qualified geotechnical personnel is recommended.

12.0 SCOUR AND EROSION CONTROL

Adequate scour and erosion protection should be provided at the culvert outlet area. Design of the scour and erosion protection measures must consider hydrologic and hydraulic factors and should be carried out by specialists experienced in this field. Scour and erosion protection should be conducted as per CHBDC 2014, Section 1.9.

Typically, rock protection should be provided over all surfaces with which creek water is likely to be in contact. Treatment at the outlets should be in accordance with OPSD 810.010. A vegetation cover should be established on all other exposed earth surfaces to protect against surficial erosion in general accordance with OPSS 804.

A concrete cut-off wall and a clay seal should be used to minimize the potential for erosion or piping around the culvert.

Geotextile must be placed at the precast culvert joints to prevent migration of soils into the culvert.

13.0 EXCAVATION AND GROUNDWATER CONTROL

All excavations must be carried out in accordance with the Occupational Health and Safety Act (OHSA). For the purposes of the OHSA, the embankment fill, and native silty clay at this site are classified as Type 3 soils. Surficial alluvial deposits that are anticipated in the outlet area are classified as Type 4 soils.



Excavation and backfilling for culvert construction must be carried out in accordance with OPSS 902. Excavated silty clay fill should not be reused as backfill and should be disposed of off-site.

Excavations for culvert replacement will typically be carried out through the existing embankment fill and extended into the native silty clay. The work will be carried out in association with a roadway protection system.

The groundwater levels measured in the piezometers were at depths ranging from 0 m to 1.5 m (Elevations 177.0 to 177.4). In Borehole 19-04, drilled at the culvert outlet, groundwater level was measured at 0.1 m (Elevation 176.8) above the ground surface, indicating a slight artesian condition. Groundwater perched within the embankment fill will seep into the excavations during culvert replacement. Surface runoff will also tend to accumulate in these excavations. The groundwater level is expected to be largely governed by the water level in the creek. As discussed in the previous section 9.3.4, a combination of the use of cofferdams at the outlet, creek water diversion, protection systems such as sheetpiled enclosures and pumping from filtered sumps may be required to maintain dry excavations during the course of staged construction. The dewatering system must be effective to maintain the water level at a minimum depth of 0.5 m below the final subgrade level throughout construction.

The design of an effective dewatering, unwatering, and temporary flow passage system is the responsibility of the Contractor. The Contract Documents must alert the Contractor to this responsibility and to design the system in accordance with Special Provision (SP) FOUN0003 which amends OPSS 902. SP FOUN0003 has been included in Appendix I.

In accordance with SP FOUN0003, the dewatering system is to be designed in accordance with OPSS.PROV 517. A preconstruction survey is required at this site, thus Designer Fill-In ** in SP FOUN0003 and SP 517F01 should be "Yes". It is recommended that a Professional Engineer with greater than 5 years of experience in designing dewatering systems be retained by the Contractor. The dewatering plan must be signed/sealed by the P.Eng.

Dewatering must remain operational and effective until the foundations are constructed. Suggesting wording for an NSSP in this regard is included in Appendix I.

Culvert replacement will need to be carried out in conjunction with temporary protection (shoring) which is discussed in more detail in Section 15.0

14.0 SEISMIC CONSIDERATIONS

In accordance with the CHBDC, the selection of the seismic site class is based on the soil conditions encountered in the upper 30 m of the stratigraphic profile. In general, the subsurface stratigraphy encountered at the site consists of topsoil or pavement structure overlying embankment fill underlain by layers of generally stiff to firm silty, silt and lower silty clay.

As per Table 4.1, Clause 4.4.3.2 of the CHBDC (2014), the site may be classified as Seismic Site Class D.

Based on the National Building Code of Canada (NBCC 2015), the peak horizontal ground acceleration (PGA), corresponding to a design earthquake having a 2 percent probability of being exceeded in 50 years (i.e. 2,475 year return period) is 0.22g at the site.

In accordance with Clause 4.6.5 of the CHBDC 2014, the abutments should be designed using active (K_{AE}) and passive (K_{PE}) earth pressure coefficients that incorporate the effects of earthquake loading. The coefficients of horizontal earth pressure for seismic loading presented in Table 14.1 may be used:

14.1 Earth Pressure Coefficients for Earthquake Loading

Condition	Earth Pressure Coefficient (K)	
	OPSS Granular A or Granular B Type II $\phi = 35^\circ, \gamma = 22.8 \text{ kN/m}^3$	OPSS Granular B Type I $\phi = 32^\circ, \gamma = 21.2 \text{ kN/m}^3$
Active (K_{AE})*	0.37	0.41
Passive (K_{PE})	3.4	2.9
At Rest (K_{OE})**	0.72	0.76

* After Mononobe and Okabe, passive case assumes a horizontal surface in front of the wall.

** After Woods

Based on review of the SPT and CPTu data, seismically-induced liquefaction of foundation soils is not anticipated under the design earthquake.



15.0 TEMPORARY PROTECTION SYSTEMS

Temporary protection (shoring) systems may be required to maintain live traffic lanes during partial replacement of the culvert.

An item titled "Temporary Protection System" as per OPSS.PROV 539 should be included in the contract documents. It is recommended that Performance Level 2 as per Clause 539.04.01.01 and the alignment of the temporary protection be specified on the contract drawings.

The selection and design of the temporary protection systems is the responsibility of the contractor. The design of such systems must incorporate traffic loading and surcharge loading due to the construction equipment and operations. It is anticipated that the protection system will need to be extended predominantly through the existing embankment, into the underlying native silty clay to develop the required toe resistance. Installation of roadway protection should consider that the existing embankment fill may contain obstructions.

For conceptual planning and costing purposes, a soldier pile and lagging wall or an interlocking sheetpile wall is considered suitable for temporary protection. These shoring walls may be designed using the geotechnical parameters given below:

γ	=	20 kN/m ³
γ_w	=	10 kN/m ³
K_a	=	0.33 (embankment fills)
	=	0.36 (native silty clay)
K_p	=	3.0 (embankment fills)
	=	2.8 (native silty clay)

Installation of the temporary protection system (e.g. driving of sheetpiles etc.) must be designed and carried out in order to minimize adverse impact on the existing box culvert under Highway 406 SBL.

It is recommended that lateral earth pressures acting on the wall be computed in accordance with the CHBDC 2014. The surcharge should include soil loadings above the top of the pile and other loadings adjacent to the wall. A properly designed and constructed soldier pile and lagging wall will be permeable and therefore water pressure acting on the retained height may be set to zero.



Full hydrostatic pressure will need to be incorporated for design of sheetpile walls if this type of protection system is used.

The actual pressure distribution acting on the shoring system is a function of the construction sequence, and the relative flexibility of the wall, and these factors must be considered when designing the shoring system. All shoring systems should be designed by a Professional Engineer experienced in such designs.

16.0 EXISTING CULVERT CONSIDERATIONS

It is understood that the west portion of the existing culvert under Highway 406 SBL was extended 35.5 m with a rigid frame culvert in 2013. This portion of the culvert will be maintained and kept operational during/after construction operations. Therefore, the existing west portion of the culvert must be protected from any damage and/or settlement during construction/replacement of the new east portion of the culvert. Care must be exercised during sub-excavation, removal of the existing culvert foundations, and construction/replacement of the east portion of the culvert.

Temporary protection system will be installed to protect the roadway traffic of Highway 406 SBL prior to commencing construction work for the new east replacement culvert. The Highway 406 SBL embankment roadway and the existing west portion of the culvert beneath the SBL embankment will remain operational and must be protected from any damage or adverse impact during installation and removal/extraction of the temporary protection system. Suggesting wording for an NSSP in this regard is included in Appendix I.

17.0 SOIL CORROSION POTENTIAL

The results of corrosivity and sulphate analytical tests conducted on two selected soils samples of the silty clay fill and silty clay are included in Appendix B2. Based on the test results, the following statements can be made:

- The potential for sulphate attack on concrete from the surrounding native soils is considered to be negligible due to the low concentration of sulphate and slightly alkaline pH values.



- The overall potential for corrosion on metal is considered moderate for the silty clay fill taken at depths ranging from 3.6 m to 4.8 m (Elevations 178.5 to 177.3) and silty clay taken at depths ranging from 3.0 m to 3.6 m (Elevations 175.6 to 175.0).
- The effects of road de-icing salts should also be considered when selecting the class of concrete and corrosion mitigation measures.

18.0 CONSTRUCTION CONCERNS

Potential construction concerns include, but are not necessarily limited to, the following:

- Potential differential settlement will occur over time at the joint between the new and old culverts.
- The existing fills may contain obstructions. The Contractor must be equipped and prepared to remove, penetrate or otherwise handle these obstructions during construction.
- Based on water levels measured in piezometers, excavations within the existing fill and native silty clay will be below the groundwater level. Slight artesian condition was also measured in one piezometer at the site. Seepage and perched groundwater will be encountered within the embankment fill. A dewatering specialist should be consulted to provide input on the required dewatering system.
- Daily visual inspection of the highway pavement surface must be carried out in the vicinity of the construction works. If cracks form in the pavement or settlement is observed to occur, these matters must immediately be brought to the attention of the CA for assessment if further action is required.
- The side embankment slopes should be inspected after construction. Where necessary, remedial measures such as re-vegetation and/or placement of gravel sheeting may be required.
- Removal of peat, organics, soft soils and alluvial deposits near creek channels particularly in the outlet area



- Confirmation that the culvert backfills and approach fills are adequately placed and compacted to specifications.
- Even though not encountered during the field investigation, buried obstructions may be encountered during excavation in the existing fill and may interfere with installation of the temporary roadway protection system. Suggested wording for an NSSP on obstructions is included in Appendix I.

19.0 CLOSURE

Engineering analysis and preparation of the foundation design report were carried out by Ms. R. Palomeque Reyna, P.Eng. and Mr. Matthew Boucher, P.Eng. The report was reviewed by Mr. Jason Lee, P.Eng and Dr. P.K. Chatterji, P.Eng., a Designated Principal Contact for MTO Foundations Projects.



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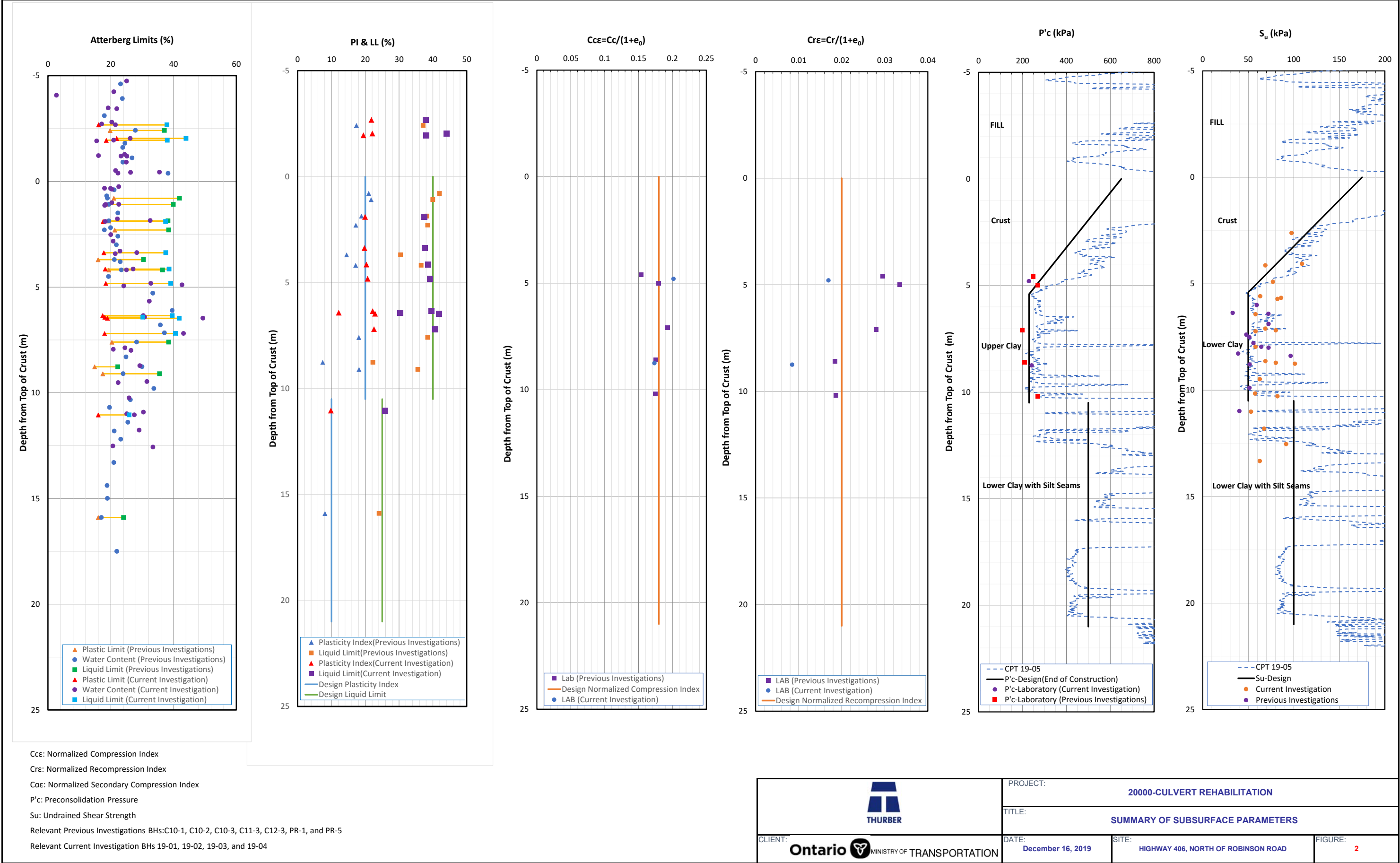
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Review Principal, Designated MTO Contact



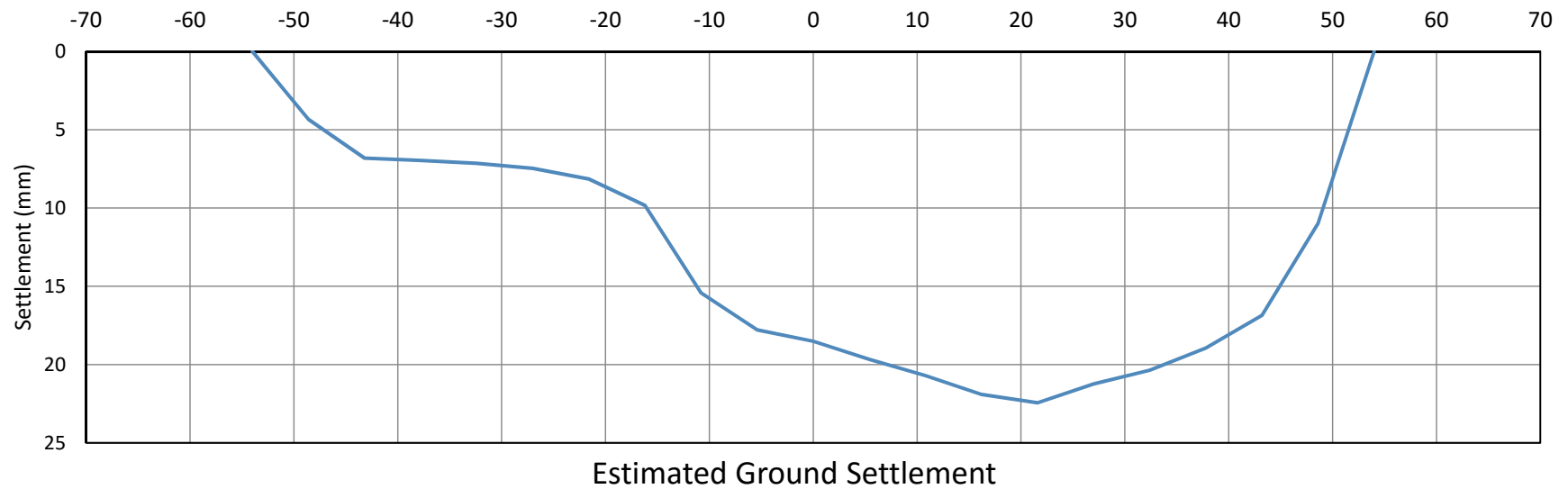
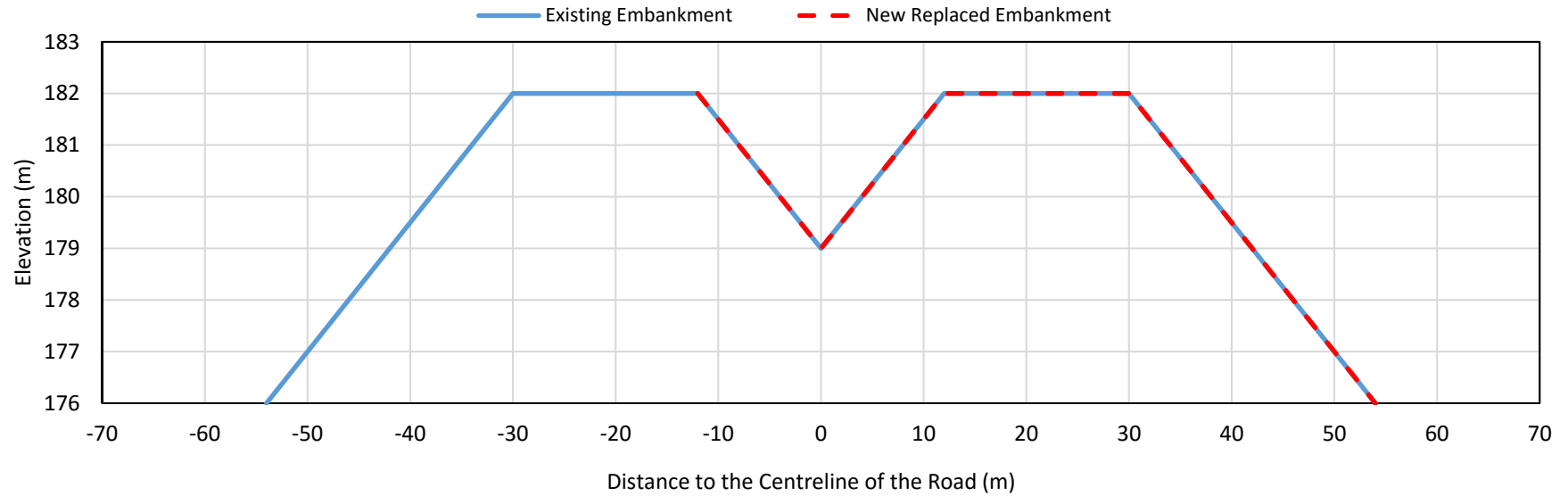
HIGHWAY 406 AND PORT ROBINSON ROAD
BOREHOLE LOCATION PLAN
(N.T.S. SCHEMATIC ONLY)

- BOREHOLES BY THURBER
- BOREHOLES BY TERRAPROBE (2011)
- CPT Location

FIGURE 1



Simplified Embankment Geometry





Appendix A
Record of Borehole Sheets
Present Investigation

SYMBOLS, ABBREVIATIONS AND TERMS USED ON RECORDS OF BOREHOLES

1. TEXTURAL CLASSIFICATION OF SOILS

CLASSIFICATION	PARTICLE SIZE	VISUAL IDENTIFICATION
Boulders	Greater than 200mm	same
Cobbles	75 to 200mm	same
Gravel	4.75 to 75mm	5 to 75mm
Sand	0.075 to 4.75mm	Not visible particles to 5mm
Silt	0.002 to 0.075mm	Non-plastic particles, not visible to the naked eye
Clay	Less than 0.002mm	Plastic particles, not visible to the naked eye

2. COARSE GRAIN SOIL DESCRIPTION (50% greater than 0.075mm)

TERMINOLOGY	PROPORTION
Trace or Occasional	Less than 10%
Some	10 to 20%
Adjective (e.g. silty or sandy)	20 to 35%
And (e.g. sand and gravel)	35 to 50%

3. TERMS DESCRIBING CONSISTENCY (COHESIVE SOILS ONLY)

DESCRIPTIVE TERM	UNDRAINED SHEAR STRENGTH (kPa)	APPROXIMATE SPT ⁽¹⁾ 'N' VALUE
Very Soft	12 or less	Less than 2
Soft	12 to 25	2 to 4
Firm	25 to 50	4 to 8
Stiff	50 to 100	8 to 15
Very Stiff	100 to 200	15 to 30
Hard	Greater than 200	Greater than 30

NOTE: Hierarchy of Soil Strength Prediction

- 1) Laboratory Triaxial Testing
- 2) Field Insitu Vane Testing
- 3) Laboratory Vane Testing
- 4) SPT value
- 5) Pocket Penetrometer



4. TERMS DESCRIBING DENSITY (COHESIONLESS SOILS ONLY)

DESCRIPTIVE TERM	SPT "N" VALUE
Very Loose	Less than 4
Loose	4 to 10
Compact	10 to 30
Dense	30 to 50
Very Dense	Greater than 50

5. LEGEND FOR RECORDS OF BOREHOLES

SYMBOLS AND ABBREVIATIONS FOR SAMPLE TYPE	SS Split Spoon Sample	WS Wash Sample	AS Auger (Grab) Sample
	TW Thin Wall Shelby Tube Sample	TP Thin Wall Piston Sample	
	PH Sampler Advanced by Hydraulic Pressure	PM Sampler Advanced by Manual Pressure	
	WH Sampler Advanced by Self Static Weight	RC Rock Core	SC Soil Core

$$\text{Sensitivity} = \frac{\text{Undisturbed Shear Strength}}{\text{Remoulded Shear Strength}}$$


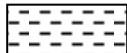



 Water Level
 Shear Strength Determination by Pocket Penetrometer

- (1) SPT 'N' Value Standard Penetration Test 'N' Value – refers to the number of blows from a 63.5kg hammer free falling a height of 0.76m to advance a standard 50 mm outside diameter split spoon sampler for 0.3 m depth into undisturbed ground.
- (2) DCPT Dynamic Cone Penetration Test – Continuous penetration of a 50 mm outside diameter, 60° conical steel point attached to "A" size rods driven by a 63.5 kg hammer free falling a height of 0.76 m. The resistance to cone penetration is the number of hammer blows required for each 0.3 m advance of the conical point into undisturbed ground.

UNIFIED SOILS CLASSIFICATION

MAJOR DIVISIONS		GROUP SYMBOL	TYPICAL DESCRIPTION
COARSE GRAINED SOILS	GRAVEL AND GRAVELLY SOILS	GW	Well-graded gravels or gravel-sand mixtures, little or no fines.
		GP	Poorly-graded gravels or gravel-sand mixtures, little or no fines.
		GM	Silty gravels, gravel-sand-silt mixtures.
		GC	Clayey gravels, gravel-sand-clay mixtures.
	SAND AND SANDY SOILS	SW	Well-graded sands or gravelly sands, little or no fines.
		SP	Poorly-graded sands or gravelly sands, little or no fines.
		SM	Silty sands, sand-silt mixtures.
		SC	Clayey sands, sand-clay mixtures.
FINE GRAINED SOILS	SILTS AND CLAYS $W_L < 50\%$	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity.
		CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays. ($W_L < 30\%$).
		CI	Inorganic clays of medium plasticity, silty clays. ($30\% < W_L < 50\%$).
		OL	Organic silts and organic silty-clays of low plasticity.
	SILTS AND CLAYS $W_L > 50\%$	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts.
		CH	Inorganic clays of high plasticity, fat clays.
		OH	Organic clays of medium to high plasticity, organic silts.
HIGHLY ORGANIC SOILS		Pt	Peat and other highly organic soils.
CLAY SHALE			
SANDSTONE			
SILTSTONE			
CLAYSTONE			
COAL			

EXPLANATION OF ROCK LOGGING TERMS

<u>ROCK WEATHERING CLASSIFICATION</u>		<u>SYMBOLS</u>	
Fresh (FR)	No visible signs of weathering.		
Fresh Jointed (FJ)	Weathering limited to the surface of major discontinuities.		CLAYSTONE
Slightly Weathered (SW)	Penetrative weathering developed on open discontinuity surfaces, but only slight weathering of rock material.		SILTSTONE
Moderately Weathered (MW)	Weathering extends throughout the rock mass, but the rock material is not friable.		SANDSTONE
Highly Weathered (HW)	Weathering extends throughout the rock mass and the rock is partly friable.		COAL
Completely Weathered (CW)	Rock is wholly decomposed and in a friable condition, but the rock texture and structure are preserved.		Bedrock (general)

<u>DISCONTINUITY SPACING</u>		<u>STRENGTH CLASSIFICATION</u>			
Bedding	Bedding Plane Spacing	Rock Strength	Approximate Uniaxial Compressive Strength		Field Estimation of Hardness*
			(MPa)	(psi)	
Very thickly bedded	Greater than 2m	Extremely Strong	Greater than 250	Greater than 36,000	Specimen can only be chipped with a geological hammer
Thickly bedded	0.6 to 2m				
Medium bedded	0.2 to 0.6m	Very Strong	100-250	15,000 to 36,000	Requires many blows of geological hammer to break
Thinly bedded	60mm to 0.2m	Strong	50-100	7,500 to 15,000	Requires more than one blow of geological hammer to break
Very thinly bedded	20 to 60mm				
Laminated	6 to 20mm	Medium Strong	25.0 to 50.0	3,500 to 7,500	Breaks under single blow of geological hammer.
Thinly Laminated	Less than 6mm				

<u>TERMS</u>					
Total Core Recovery: (TCR)	Core recovered as a percentage of total core run length.	Weak	5.0 to 25.0	750 to 3,500	Can be peeled by a pocket knife with difficulty
Solid Core Recovery: (SCR)	Percent Ratio of solid core of full cylindrical shape recovered. Expressed with respect to the total length of core run.	Very Weak	1.0 to 5.0	150 to 750	Can be peeled by a pocket knife, crumbles under firm blows of geological pick.
Rock Quality Designation: (RQD)	Total length of sound core recovered in pieces 0.1m in length or larger as a percentage of total core run length.	Extremely Weak (Rock)	0.25 to 1.0	35 to 150	Indented by thumbnail
Uniaxial Compressive Strength (UCS)	Axial stress required to break the specimen				
Fracture Index: (FI)	Frequency of natural fractures per 0.3m of core run.				

RECORD OF BOREHOLE No 19-01

1 OF 2

METRIC

W.P. 2063-17-00 LOCATION MTM NAD 83 Zone10: N 4 766 916.9 E 326 338.1 ORIGINATED BY JZ
DIST HWY 406 BOREHOLE TYPE Hollow Stem Augers COMPILED BY BH
DATUM Geodetic DATE 2019.10.28 - 2019.10.28 LATITUDE 43.041765 LONGITUDE -79.235657 CHECKED BY RPR

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT			UNIT WEIGHT γ kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			20 40 60 80 100	20 40 60 80 100	20 40 60 80 100		
181.5	GROUND SURFACE											
0.0	ASPHALT (125mm)											
0.1	SAND and GRAVEL, trace silt Dense Moist (FILL)		1	SS	35		181					
180.8												
0.7	Silty CLAY, some sand, trace gravel, grey silt lenses Stiff to Soft Reddish Brown to Brown Moist (FILL)		2	SS	10		180					
			3	SS	6							0 19 38 43
			4	SS	7		179					
			5	SS	4		178					
177.8												
3.7	Clayey SILT, trace sand, trace gravel, occasional organics, occasional rootlets Stiff Dark Brown to Grey Moist		6	SS	9		177					
177.0												
4.5	Silty CLAY, trace sand, trace gravel Very Stiff to Stiff Brown Moist		7	SS	14		176					
			8	SS	12							
			9	SS	16		175					1 8 50 41
							174					
	Grey silt lenses Brown to Grey		10	SS	9							
			11	TW	-		173					
	Firm Wet		12	SS	6		172					

Continued Next Page

+³, ×³: Numbers refer to
Sensitivity

20
15
10
(%) STRAIN AT FAILURE

RECORD OF BOREHOLE No 19-01

2 OF 2

METRIC

W.P. 2063-17-00 LOCATION MTM NAD 83 Zone10: N 4 766 916.9 E 326 338.1 ORIGINATED BY JZ
 DIST HWY 406 BOREHOLE TYPE Hollow Stem Augers COMPILED BY BH
 DATUM Geodetic DATE 2019.10.28 - 2019.10.28 LATITUDE 43.041765 LONGITUDE -79.235657 CHECKED BY RPR

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT			PLASTIC LIMIT NATURAL MOISTURE CONTENT LIQUID LIMIT			UNIT WEIGHT γ kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL	
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa			WATER CONTENT (%)					
								○ UNCONFINED + FIELD VANE								
								● QUICK TRIAXIAL × LAB VANE								
	Continued From Previous Page							20 40 60 80 100				W _p W W _L				
	Silty CLAY , trace sand, occasional silt layers Stiff Grey Wet						171									
			13	SS	4										0 4 42 54	
							170									
			14	TW	-											
							169									
	Stiff to Very Stiff						168									
			15	SS	3											
							167									
			16	SS	1		166								0 0 76 24	
165.2							165									
16.3	SILT , trace clay, trace sand Very Loose Brown Wet															
			17	SS	1		164									
163.7																
17.8	END OF BOREHOLE AT 17.8m. BOREHOLE CAVED-IN TO 11.5m WATER LEVEL AT 7.5m. BOREHOLE BACKFILLED WITH GROUT TO 4.5m, BENTONITE HOLEPLUG TO 0.2m, THEN COLD PATCH ASPHALT TO SURFACE.															

+³, ×³: Numbers refer to Sensitivity 20 15 10 5 0 (%) STRAIN AT FAILURE

RECORD OF BOREHOLE No 19-02

1 OF 2

METRIC

W.P. 2063-17-00 LOCATION MTM NAD 83 Zone10: N 4 766 904.1 E 326 359.2 ORIGINATED BY JZ
 DIST HWY 406 BOREHOLE TYPE Hollow Stem Augers COMPILED BY BH
 DATUM Geodetic DATE 2019.10.29 - 2019.10.29 LATITUDE 43.041649 LONGITUDE -79.235398 CHECKED BY RPR

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		UNIT WEIGHT γ kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION (%)	
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa				
182.1	GROUND SURFACE							20 40 60 80 100	PLASTIC LIMIT	NATURAL MOISTURE CONTENT	LIQUID LIMIT	GR SA SI CL
0.0	ASPHALT (125mm)							20 40 60 80 100	W _P	W	W _L	
0.1	CONCRETE (300mm)							20 40 60 80 100	WATER CONTENT (%)			
181.6								20 40 60 80 100				
0.4	SAND and GRAVEL, trace to some silt, trace clay		1	SS	9			20 40 60 80 100				
181.4	Loose Brown Moist (FILL)		2	SS	19			20 40 60 80 100				
0.7	Silty CLAY, trace sand Very Stiff to Stiff Dark Brown to Brown Moist (FILL)		3	SS	15			20 40 60 80 100				
			4	SS	13			20 40 60 80 100				
			5	SS	11			20 40 60 80 100				
			6	SS	11			20 40 60 80 100				
177.6								20 40 60 80 100				
4.5	Clayey SILT, trace sand, trace gravel, occasional organics, occasional rootlets		7	SS	9			20 40 60 80 100				
176.7	Stiff Grey Moist							20 40 60 80 100				
5.3	Silty CLAY, trace sand Very Stiff to Stiff Brown Moist		8	SS	19			20 40 60 80 100				
			10	SS	21			20 40 60 80 100				
								20 40 60 80 100				
			11	SS	12			20 40 60 80 100				
	Grey Moist to Wet							20 40 60 80 100				
								20 40 60 80 100				
			12	TW	-			20 40 60 80 100				
								20 40 60 80 100				

0 3 59 38

0 2 50 48

OED:
e₀=0.884
P_v=242 kPa

Continued Next Page

+³, ×³: Numbers refer to Sensitivity

20
15
10
(%) STRAIN AT FAILURE

OED:
e₀=0.884
P'_c=242 kPa

RECORD OF BOREHOLE No 19-02

2 OF 2

METRIC

W.P. 2063-17-00 LOCATION MTM NAD 83 Zone10: N 4 766 904.1 E 326 359.2 ORIGINATED BY JZ
 DIST HWY 406 BOREHOLE TYPE Hollow Stem Augers COMPILED BY BH
 DATUM Geodetic DATE 2019.10.29 - 2019.10.29 LATITUDE 43.041649 LONGITUDE -79.235398 CHECKED BY RPR

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT NATURAL MOISTURE CONTENT LIQUID LIMIT			UNIT WEIGHT γ kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa		WATER CONTENT (%)				
								○ UNCONFINED + FIELD VANE		W P W W L				
								● QUICK TRIAXIAL × LAB VANE						
	Continued From Previous Page							20 40 60 80 100		20 40 60			GR SA SI CL	
	Silty CLAY , trace sand Stiff Brown to Grey Moist to Wet						172						C _c =0.327 C _r =0.016 G _s =2.74	
			13	SS	2		171				○			
							170							
			14	SS	1							○	0 1 42 57	
							169							
			15	SS	3		168				○			
							167							
			16	TW	-						○			
							166							
165.7														
16.3	SILT , trace clay, trace sand Very Loose Brown Wet						165				○		0 1 92 7	
			17	SS	2									
164.2														
17.8	END OF BOREHOLE AT 17.8m. BOREHOLE CAVED-IN TO 12.8m. BOREHOLE BACKFILLED WITH GROUT TO 3.0m, HOLEPLUG TO 0.2m, THEN COLD PATCH ASPHALT TO SURFACE. Note: 1. Consolidation test was performed in TW12.													

+³, ×³: Numbers refer to
Sensitivity

20
15
10

(%) STRAIN AT FAILURE

RECORD OF BOREHOLE No 19-03

1 OF 2

METRIC

W.P. 2063-17-00 LOCATION MTM NAD 83 Zone10: N 4 766 947.8 E 326 381.1 ORIGINATED BY ES
DIST HWY 406 BOREHOLE TYPE Hollow Stem Augers COMPILED BY BH
DATUM Geodetic DATE 2019.10.30 - 2019.10.30 LATITUDE 43.042042 LONGITUDE -79.235127 CHECKED BY RPR

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					PLASTIC LIMIT NATURAL MOISTURE CONTENT LIQUID LIMIT			UNIT WEIGHT γ	REMARKS & GRAIN SIZE DISTRIBUTION (%)		
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa					WATER CONTENT (%)						
								○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × LAB VANE					w _p w w _L						
178.6	GROUND SURFACE						20	40	60	80	100	20	40	60	kN/m ³	GR	SA	SI	CL
0.0 0.1	TOPSOIL (75mm)		1	SS	5														
	Silty CLAY , some sand, occasional organics, occasional rootlets																		
	Firm																		
	Dark Brown																		
	Moist																		
	(FILL)		2	SS	6														
			3	SS	6														
			4	SS	7														
175.5			5	SS	12														
3.1	Silty CLAY , sand seams																		
	Stiff to Very Stiff																		
	Brown																		
	Moist		6	SS	12														
			7	SS	8														

Continued Next Page

+³, ×³: Numbers refer to
Sensitivity

20
15
10
(%) STRAIN AT FAILURE

RECORD OF BOREHOLE No 19-03

2 OF 2

METRIC

W.P. 2063-17-00 LOCATION MTM NAD 83 Zone10: N 4 766 947.8 E 326 381.1 ORIGINATED BY ES
DIST HWY 406 BOREHOLE TYPE Hollow Stem Augers COMPILED BY BH
DATUM Geodetic DATE 2019.10.30 - 2019.10.30 LATITUDE 43.042042 LONGITUDE -79.235127 CHECKED BY RPR

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT				PLASTIC LIMIT NATURAL MOISTURE CONTENT LIQUID LIMIT			UNIT WEIGHT γ kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa				WATER CONTENT (%)				
								20 40 60 80 100	○ UNCONFINED + FIELD VANE			w _p w w _L				
							● QUICK TRIAXIAL × LAB VANE									
	Continued From Previous Page															
	Silty CLAY , occasional silt seams Stiff Brown to Grey Wet						168									
			11	SS	3											
							167									
166.1			12	TW	-		166								0 0 78 22	
12.5	SILT , trace clay, trace sand Very Loose Brown Wet															
							165									
			13	SS	0											
164.3																
14.3	END OF BOREHOLE AT 14.3m. WATER LEVEL AT 13.3m UPON COMPLETION. BOREHOLE BACKFILLED WITH GROUT AND HOLEPLUG TO SURFACE. Note: 1. Consolidation test was performed in TW9.															

+³, ×³: Numbers refer to Sensitivity 20 15 10 5 0 (%) STRAIN AT FAILURE

RECORD OF BOREHOLE No 19-04

1 OF 2

METRIC

W.P. 2063-17-00 LOCATION MTM NAD 83 Zone10: N 4 766 930.0 E 326 383.2 ORIGINATED BY ES
DIST HWY 406 BOREHOLE TYPE Hollow Stem Augers COMPILED BY BH
DATUM Geodetic DATE 2019.10.30 - 2019.10.31 LATITUDE 43.041882 LONGITUDE -79.235102 CHECKED BY RPR

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						
176.7	GROUND SURFACE							20 40 60 80 100		20 40 60				
0.0	SAND and GRAVEL , some silt Brown Moist to Wet (FILL)		1	SS	6									
0.1														
	Silty CLAY , trace to some sand, trace gravel, occasional roots, and wood fibres Firm to Stiff Brown Wet (FILL)		2	SS	11									
175.2														
1.5	Silty CLAY , trace sand, occasional rootlets Stiff Reddish Brown Moist		3	SS	14									
			4	SS	12									
			5	SS	9									
			6	SS	6									
	Brown Wet													0 3 54 43
			7	TW	-									
			8	SS	3									
														0 1 68 31
			9	SS	1									
								</						

Continued Next Page

+³, ×³: Numbers refer to
Sensitivity 20
15 10 5 (%) STRAIN AT FAILURE

RECORD OF BOREHOLE No 19-04

2 OF 2

METRIC

W.P. 2063-17-00 LOCATION MTM NAD 83 Zone10: N 4 766 930.0 E 326 383.2 ORIGINATED BY ES
DIST HWY 406 BOREHOLE TYPE Hollow Stem Augers COMPILED BY BH
DATUM Geodetic DATE 2019.10.30 - 2019.10.31 LATITUDE 43.041882 LONGITUDE -79.235102 CHECKED BY RPR

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT				UNIT WEIGHT γ kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa					
	Continued From Previous Page							20 40 60 80 100					
								○ UNCONFINED + FIELD VANE					
								● QUICK TRIAXIAL × LAB VANE					
								WATER CONTENT (%)					
								PLASTIC LIMIT NATURAL MOISTURE CONTENT LIQUID LIMIT					
								W P W W L					
													</

ONTMT452 MTO-20000.GPJ 2017TEMPLATE(MTO).GDT 1/23/20

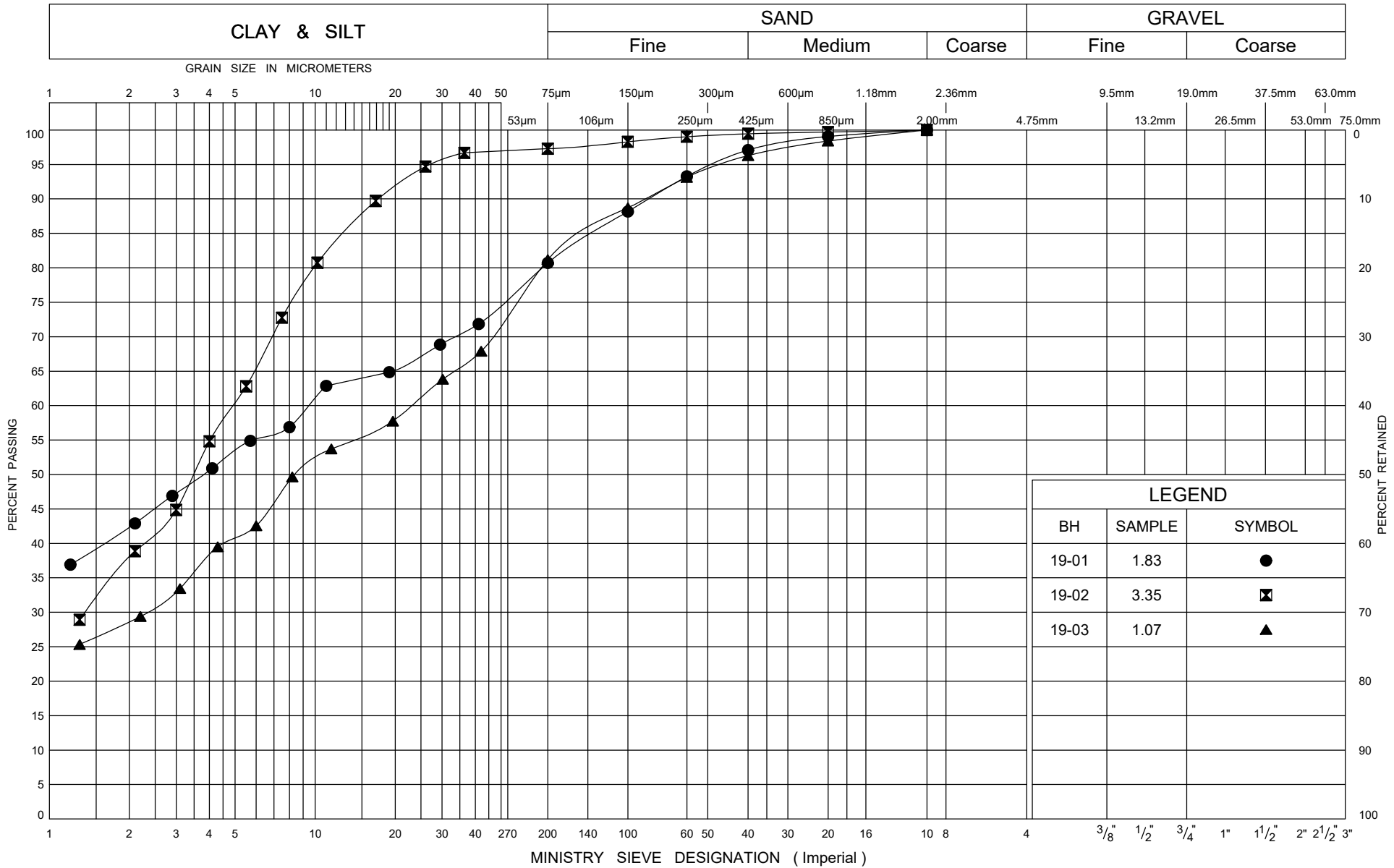


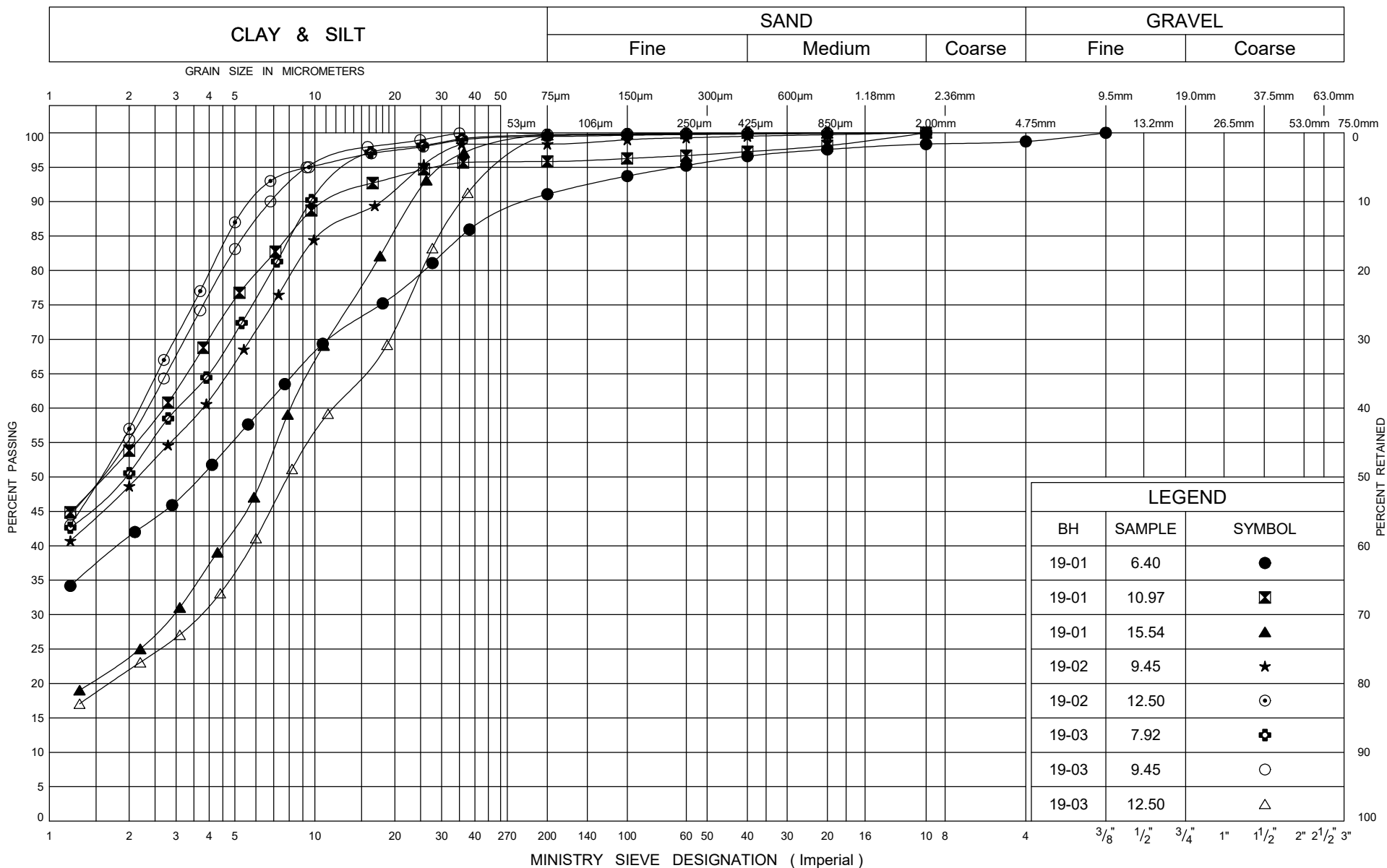
Appendix B

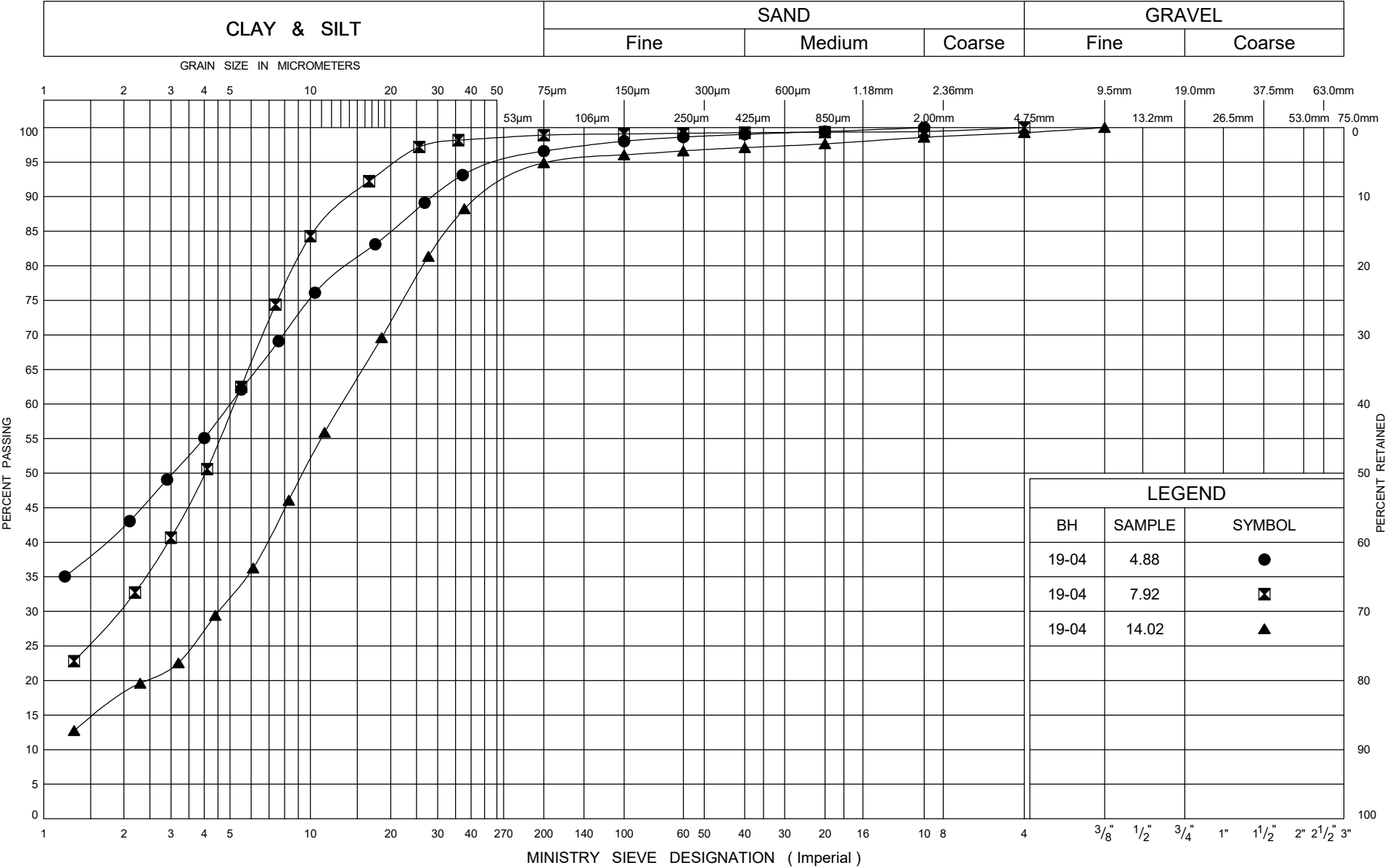
Geotechnical and Analytical Laboratory Test Results Present Investigation

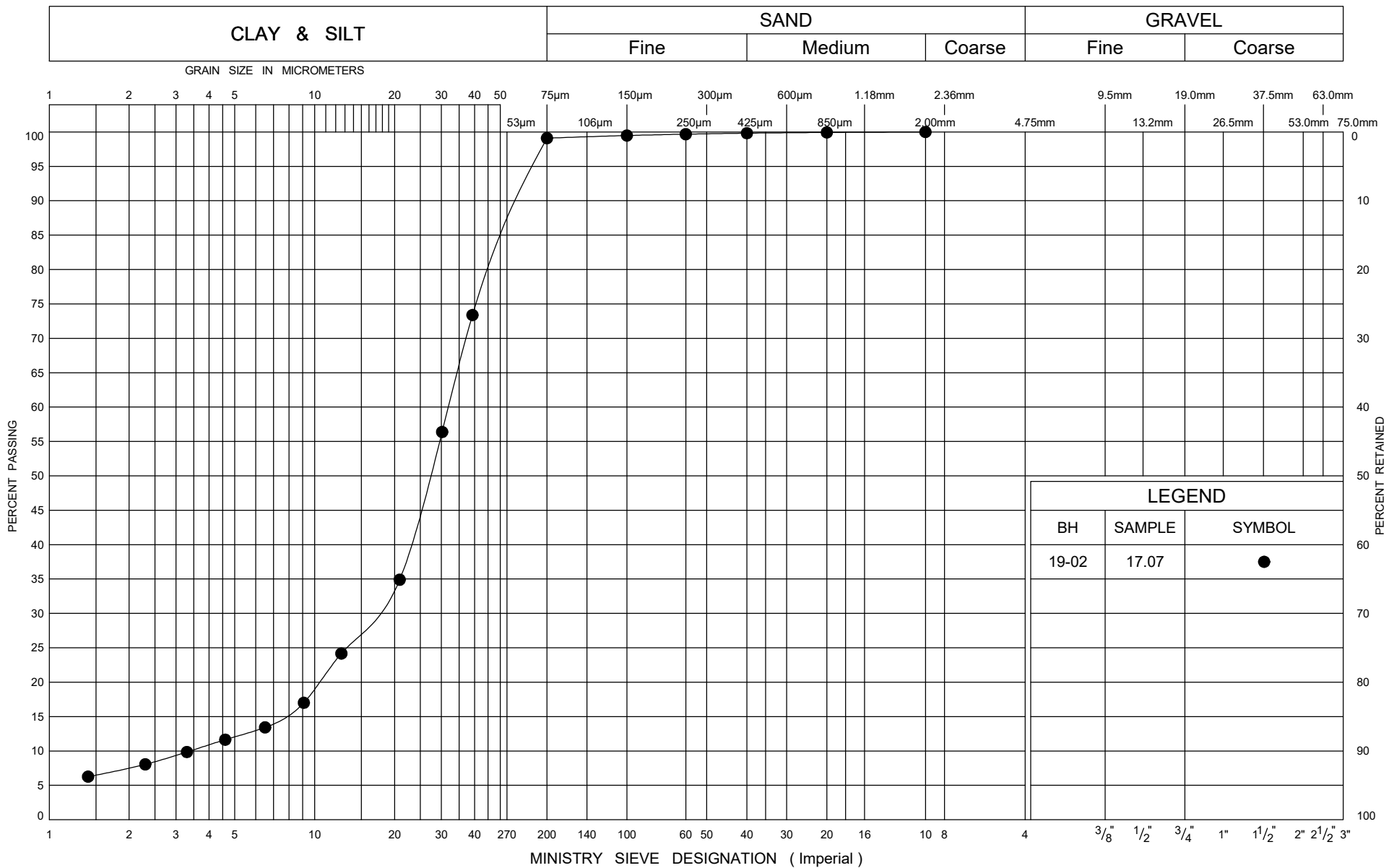


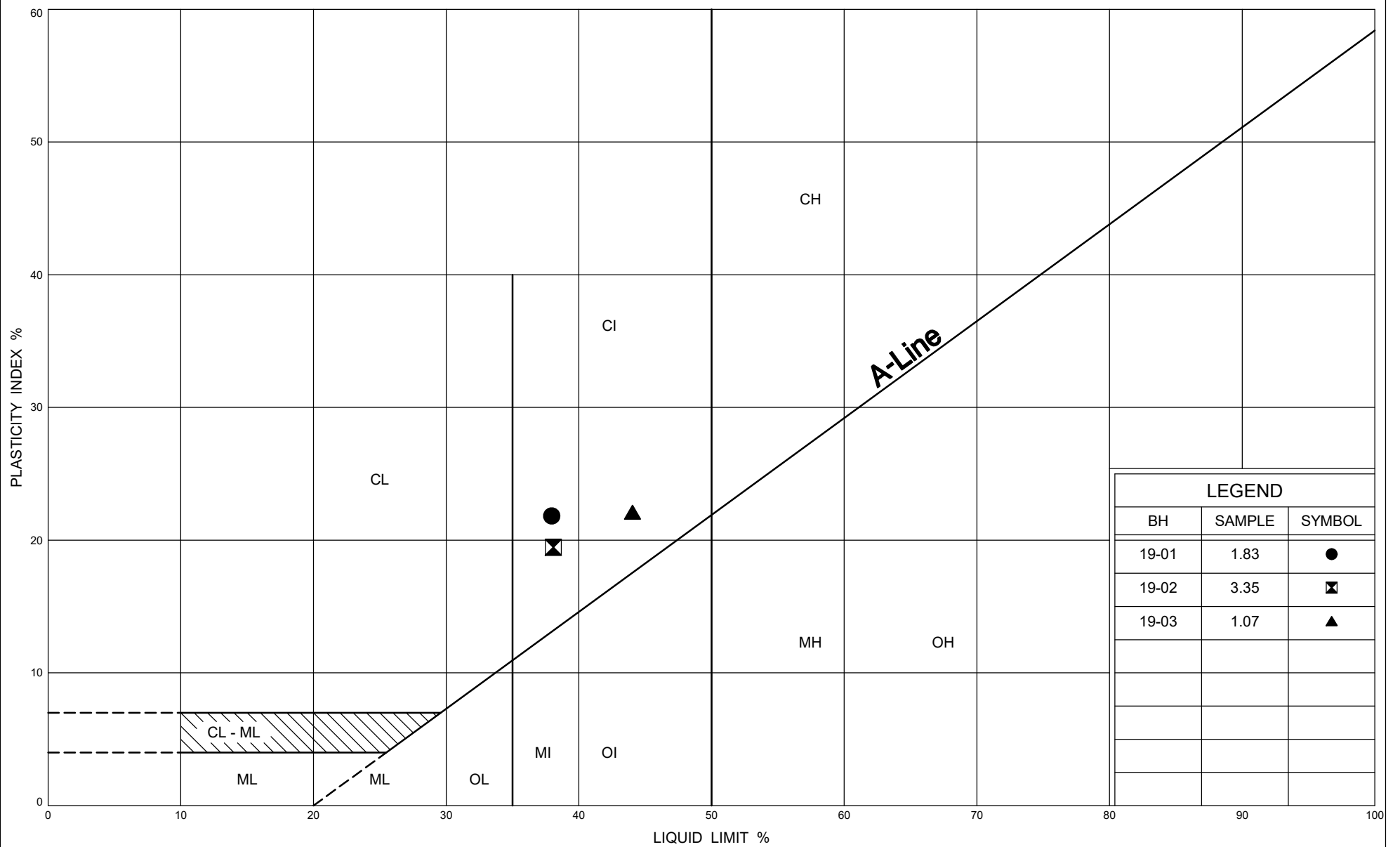
Appendix B1
Grain Size Analysis and Atterberg Limit Test

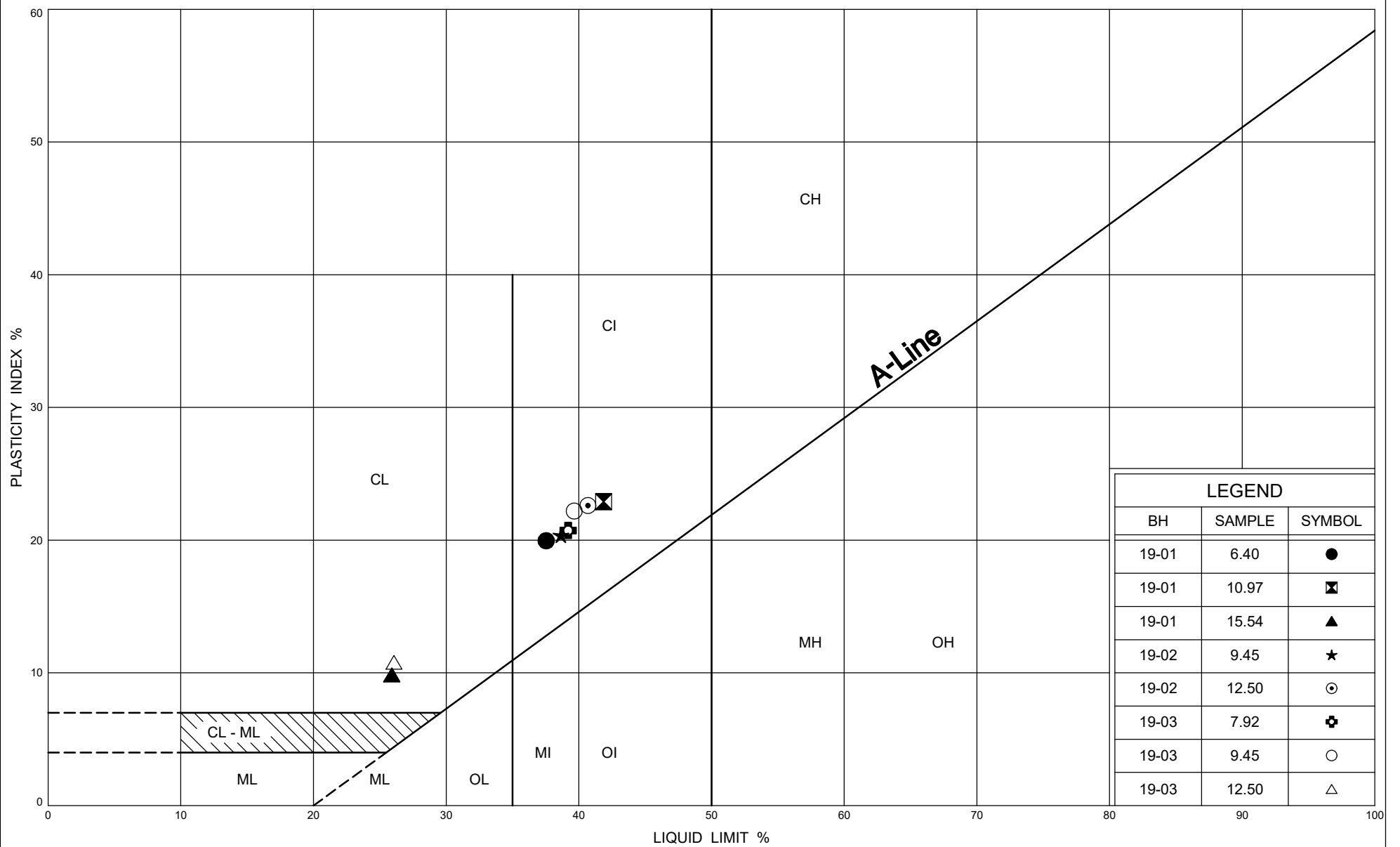












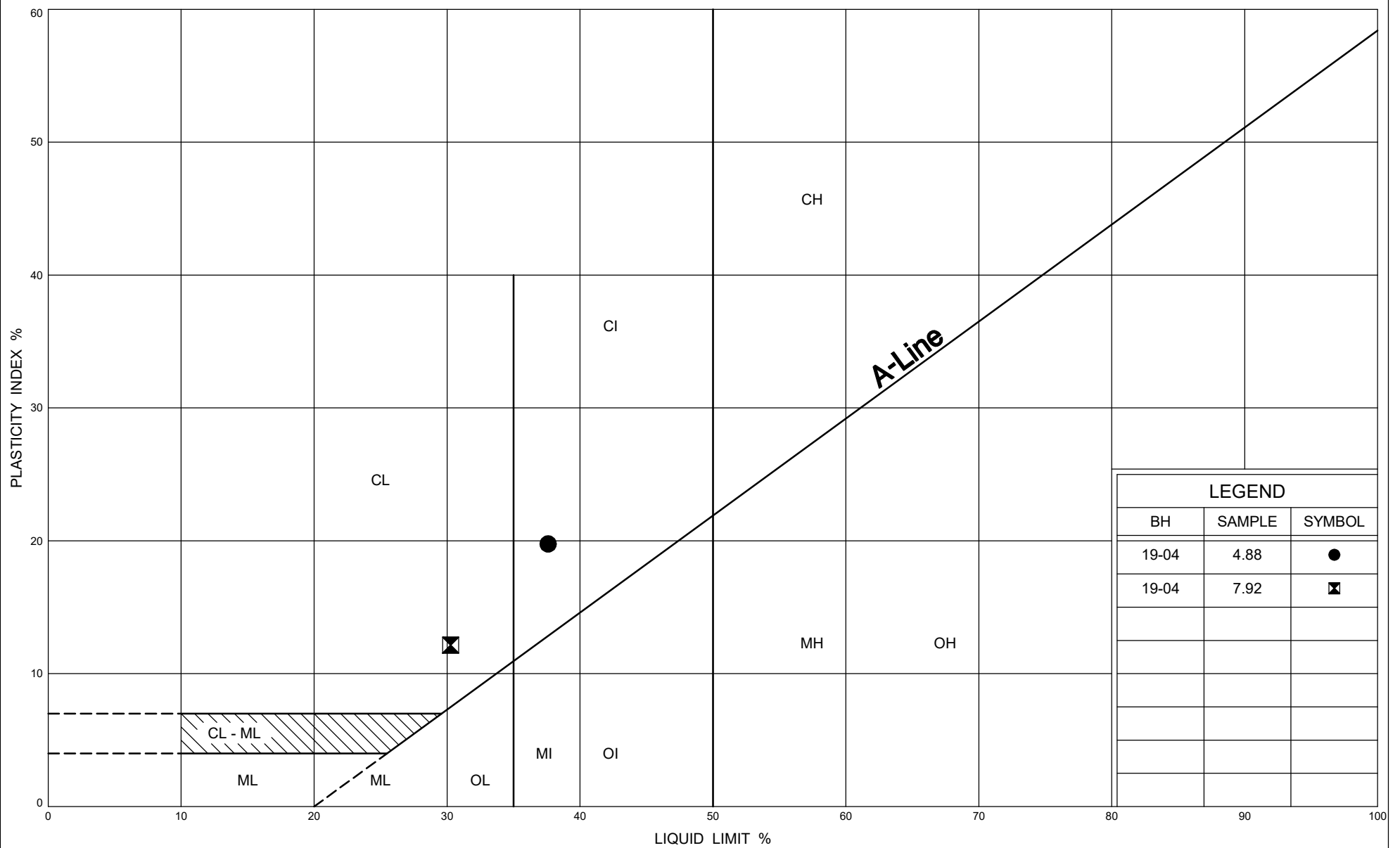
Ministry of
Transportation

PLASTICITY CHART

Silty CLAY

FIG No B6

W P 2063-17-00



LEGEND		
BH	SAMPLE	SYMBOL
19-04	4.88	●
19-04	7.92	☒



Ministry of
Transportation

PLASTICITY CHART

Silty CLAY

FIG No B7

W P 2063-17-00



Appendix B2
Analytical Laboratory Test Results for Corrosivity



FINAL REPORT

CA14210-NOV19 R1

Prepared for

Thurber Engineering Ltd.

First Page

CLIENT DETAILS

Client Thurber Engineering Ltd.

Address 103, 2010 Winston Park Drive
Oakville, ON
L6H 5R7, Canada

Contact Rocio Palomeque

Telephone 905-829-8666 x 263

Facsimile

Email rreyna@thurber.ca

Project

Order Number

Samples Soil (2)

LABORATORY DETAILS

Project Specialist Brad Moore Hon. B.Sc

Laboratory SGS Canada Inc.

Address 185 Concession St., Lakefield ON, K0L 2H0

Telephone 705-652-2143

Facsimile 705-652-6365

Email brad.moore@sgs.com

SGS Reference CA14210-NOV19

Received 11/07/2019

Approved 11/14/2019

Report Number CA14210-NOV19 R1

Date Reported 11/14/2019

COMMENTS

Temperature of Sample upon Receipt: 18 degrees C

Cooling Agent Present: Yes

Custody Seal Present: No

Chain of Custody Number: 002535

Corrosivity Index is based on the American Water Works Corrosivity Scale according to AWWA C-105. An index greater than 10 indicates the soil matrix may be corrosive to cast iron alloys.

SIGNATORIES

Brad Moore Hon. B.Sc

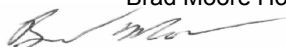




TABLE OF CONTENTS

First Page..... 1

Index..... 2

Results..... 3-4

QC Summary..... 5-6

Legend..... 7

Annexes..... 8



FINAL REPORT

CA14210-NOV19 R1

Client: Thurber Engineering Ltd.

Project:

Project Manager: Rocío Palomeque

Samplers: N/A

PACKAGE: - Corrosivity Index (SOIL)

Sample Number	5	6
Sample Name	19-02 SS6 12'-16"	19-03 SS5 10'-12'
Sample Matrix	Soil	Soil
Sample Date	29/10/2019	30/10/2019

Parameter	Units	RL		Result	Result
Corrosivity Index					
Corrosivity Index	none	1		4	4
Soil Redox Potential	mV	-		252	319
Sulphide	%	0.02		< 0.02	< 0.02
pH	pH Units	0.05		8.76	8.92
Resistivity (calculated)	ohms.cm	-9999		4650	3830

PACKAGE: - General Chemistry (SOIL)

Sample Number	5	6
Sample Name	19-02 SS6 12'-16"	19-03 SS5 10'-12'
Sample Matrix	Soil	Soil
Sample Date	29/10/2019	30/10/2019

Parameter	Units	RL		Result	Result
General Chemistry					
Conductivity	uS/cm	2		215	261

PACKAGE: - Metals and Inorganics (SOIL)

Sample Number	5	6
Sample Name	19-02 SS6 12'-16"	19-03 SS5 10'-12'
Sample Matrix	Soil	Soil
Sample Date	29/10/2019	30/10/2019

Parameter	Units	RL		Result	Result
Metals and Inorganics					
Moisture Content	%	0.1		21.6	17.3
Sulphate	µg/g	0.4		270	15



FINAL REPORT

CA14210-NOV19 R1

Client: Thurber Engineering Ltd.

Project:

Project Manager: Rocío Palomeque

Samplers: N/A

PACKAGE: - Other (ORP) (SOIL)

Sample Number	5	6
Sample Name	19-02 SS6 12'-16"	19-03 SS5 10'-12'
Sample Matrix	Soil	Soil
Sample Date	29/10/2019	30/10/2019

Parameter	Units	RL		Result	Result
Other (ORP)					
Chloride	µg/g	0.4		17	590



FINAL REPORT

CA14210-NOV19 R1

QC SUMMARY

Anions by IC
Method: EPA300/MA300-Ions1.3 | Internal ref.: ME-CA-IENVIIC-LAK-AN-001

Parameter	QC batch Reference	Units	RL	Method Blank	Duplicate		LCS/Spike Blank			Matrix Spike / Ref.		
					RPD	AC (%)	Spike Recovery (%)	Recovery Limits (%)		Spike Recovery (%)	Recovery Limits (%)	
								Low	High		Low	High
Chloride	DIO0141-NOV19	µg/g	0.4	<0.4	6	20	100	80	120	114	75	125
Sulphate	DIO0141-NOV19	µg/g	0.4	<0.4	2	20	97	80	120	91	75	125

Carbon/Sulphur
Method: ASTM E1915-07A | Internal ref.: ME-CA-IENVIARD-LAK-AN-020

Parameter	QC batch Reference	Units	RL	Method Blank	Duplicate		LCS/Spike Blank			Matrix Spike / Ref.		
					RPD	AC (%)	Spike Recovery (%)	Recovery Limits (%)		Spike Recovery (%)	Recovery Limits (%)	
								Low	High		Low	High
Sulphide	ECS0018-NOV19	%	0.02	<0.02	5	20	112	80	120			

Conductivity
Method: SM 2510 | Internal ref.: ME-CA-IENVIEWL-LAK-AN-006

Parameter	QC batch Reference	Units	RL	Method Blank	Duplicate		LCS/Spike Blank			Matrix Spike / Ref.		
					RPD	AC (%)	Spike Recovery (%)	Recovery Limits (%)		Spike Recovery (%)	Recovery Limits (%)	
								Low	High		Low	High
Conductivity	EWL0137-NOV19	uS/cm	2	< 2	3	10	101	90	110	NA		



QC SUMMARY

pH
Method: SM 4500 | Internal ref.: ME-CA-IENVIEWL-LAK-AN-001

Parameter	QC batch Reference	Units	RL	Method Blank	Duplicate		LCS/Spike Blank			Matrix Spike / Ref.		
					RPD	AC (%)	Spike Recovery (%)	Recovery Limits (%)		Spike Recovery (%)	Recovery Limits (%)	
								Low	High		Low	High
pH	EWL0137-NOV19	pH Units	0.05	NA	0		100			NA		

Method Blank: a blank matrix that is carried through the entire analytical procedure. Used to assess laboratory contamination.

Duplicate: Paired analysis of a separate portion of the same sample that is carried through the entire analytical procedure. Used to evaluate measurement precision.

LCS/Spike Blank: Laboratory control sample or spike blank refer to a blank matrix to which a known amount of analyte has been added. Used to evaluate analyte recovery and laboratory accuracy without sample matrix effects.

Matrix Spike: A sample to which a known amount of the analyte of interest has been added. Used to evaluate laboratory accuracy with sample matrix effects.

Reference Material: a material or substance matrix matched to the samples that contains a known amount of the analyte of interest. A reference material may be used in place of a matrix spike.

RL: Reporting limit

RPD: Relative percent difference

AC: Acceptance criteria

Multielement Scan Qualifier: as the number of analytes in a scan increases, so does the chance of a limit exceedance by random chance as opposed to a real method problem. Thus, in multielement scans, for the LCS and matrix spike, up to 10% of the analytes may exceed the quoted limits by up to 10% absolute and the spike is considered acceptable.

Duplicate Qualifier: for duplicates 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.

Matrix Spike Qualifier: for matrix spikes, as the concentration of the native analyte increases, the uncertainty of the matrix spike recovery increases. Thus, the matrix spike acceptance limits apply only when the concentration of the matrix spike is greater than or equal to the concentration of the native analyte.

LEGEND

FOOTNOTES

NSS Insufficient sample for analysis.

RL Reporting Limit.

↑ Reporting limit raised.

↓ Reporting limit lowered.

NA The sample was not analysed for this analyte

ND Non Detect

Samples analysed as received. Solid samples expressed on a dry weight basis. "Temperature Upon Receipt" is representative of the whole shipment and may not reflect the temperature of individual samples.

Analysis conducted on samples submitted pursuant to or as part of Reg. 153/04, are in accordance to the Protocol for Analytical Methods Used in the Assessment of Properties under Part XV.1 of the Environmental Protection Act" published by the Ministry and dated March 9, 2004 as amended.

SGS provides criteria information (such as regulatory or guideline limits and summary of limit exceedances) as a service. Every attempt is made to ensure the criteria information in this report is accurate and current, however, it is not guaranteed. Comparison to the most current criteria is the responsibility of the client and SGS assumes no responsibility for the accuracy of the criteria levels indicated. This document is issued, on the Client's behalf, by the Company under its General Conditions of Service available on request and accessible at http://www.sgs.com/terms_and_conditions.htm. The Client's attention is drawn to the limitation of liability, indemnification and jurisdiction issues defined therein. Any other holder of this document is advised that information contained hereon reflects the Company's findings at the time of its intervention only and within the limits of Client's instructions, if any. The Company's sole responsibility is to its Client and this document does not exonerate parties to a transaction from exercising all their rights and obligations under the transaction documents.

This report must not be reproduced, except in full. This report supersedes all previous versions.

-- End of Analytical Report --



Environment, Health & Safety - Lakefield: 185 Concession St., Lakefield, ON K0L 2H0 Phone: 705-652-2000 Fax: 705-652-6365 Web: www.sgs.com/environment
- London: 657 Consortium Court, London, ON, N6E 2S8 Phone: 519-672-4500 Toll Free: 877-848-8060 Fax: 519-672-0361

No: 002535
Page 1 of 1

Request for Laboratory Services and CHAIN OF CUSTODY

Laboratory Information Section - Lab use only

Received By: Amel A1-Monckton
Received Date (mm/dd/yyyy): 14-07-19 (mm/dd/yyyy)
Received Time: 14:15

Received By (signature): [Signature]
Custody Seal Present: Yes
Custody Seal Intact: Yes

Cooling Agent Present: Yes
Temperature Upon Receipt (°C): 18.0

LAB LIMS #: CA14210-NDU19

REPORT INFORMATION

Company: Thurber Engineering
Contact: Rocio Palomares
Address: 103-2010 Winston Park Drive

Phone: 905-824-9666 X260

Fax:

Email: reyana@thurber.ca

INVOICE INFORMATION

☒ (same as Report Information)

Company:

Contact:

Address:

Phone:

Email:

REGULATIONS

Regulation 153/04:

☐ Table 1 ☐ Res/Park ☐ Soil Texture: ☐ Coarse ☐ Medium ☐ Fine
☐ Table 2 ☐ Ind/Com ☐ Coarse ☐ Medium ☐ Fine
☐ Table 3 ☐ Agr/Other ☐ Coarse ☐ Medium ☐ Fine

Other Regulations:

☐ Reg 347/558 (3 Day min TAT)
☐ PWQO ☐ MMER
☐ CCME ☐ Other:
☐ MISA

Sewer By-Law:

☐ Sanitary ☐ Storm
☐ Municipality:

RECORD OF SITE CONDITION (RSC)

☐ YES ☐ NO

SAMPLE IDENTIFICATION

1	19-02	556	12'-6"	0.2/24/19	1	Soil
2						
3	19-03	555	10'-12'	0.2/30/19	1	Soil
4						
5						
6						
7						
8						
9						
10						
11						
12						

Field Filtered (Y/N)

Metals & Inorganics

PHC F1-F4 ☐ VOC ☐
BTEX ☐ BTEX/F1 ☐ F2-F4 ☐

PAH ☐ ABN ☐ SVOC(all) ☐

PCB Total ☐ Aroclor ☐

Pesticides OC ☐ OP ☐

TCLP M&I ☐ VOC ☐ PCB ☐
B(a)P ☐ ABN ☐ Ignit. ☐

Water Pkg Gen. ☐ Ext. ☐

Sewer Use:

Corrosivity

ANALYSIS REQUESTED

NOTE: DRINKING (POTABLE) WATER SAMPLES FOR HUMAN CONSUMPTION MUST BE SUBMITTED WITH SGS DRINKING WATER CHAIN OF CUSTODY

Specify Due Date:

Rush Confirmation ID:

Quotation #: P.O. #:

Project #: Site Location/ID:

TURNAROUND TIME (TAT) REQUIRED

☒ Regular TAT (5-7 days)

RUSH TAT (Additional Charges May Apply): ☐ 1 Day ☐ 2 Days ☐ 3 Days ☐ 4 Days

PLEASE CONFIRM RUSH FEASIBILITY WITH SGS REPRESENTATIVE PRIOR TO SUBMISSION

Observations/Comments/Special Instructions

Sampled By (NAME):

Signature:

Date: 14/07/19 (mm/dd/yyyy)

Pink Copy - Client

Relinquished by (NAME):

Signature:

Date: 14/07/19 (mm/dd/yyyy)

Yellow & White Copy - SGS



Appendix B3

One-Dimension Consolidation Test Results

Consolidation Test Report

CLIENT: MTO

FILE NUMBER: 20000

PROJECT: Highway 406 Culvert

REPORT DATE: December 6, 2019

TEST DATES: November 08, 2019 - November 26, 2019

SAMPLE: BH 19-02 TW12 30'-32'
Silty clay, trace sand, brown, moist.
LL=39, PL=18, $I_p = 21$.

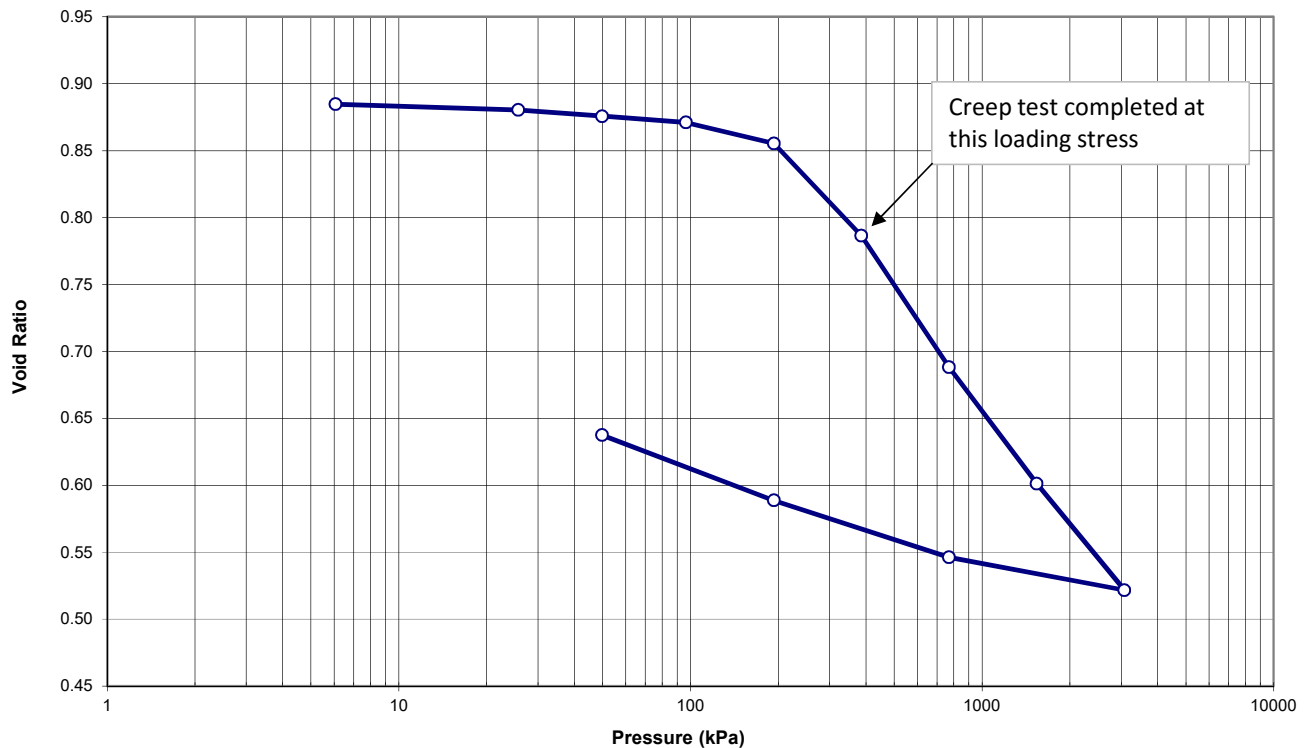
PROCEDURE: Test carried out in accordance with Standard Test Method for One-Dimensional Consolidation Properties of Soils, ASTM D 2435-11, method A

	Start of Test	End of Test
Wet Dens. (kg/m^3)	1928.1	2064.1
Dry Dens. (kg/m^3)	1456.4	1675.5
Moisture Cont. (%)	32.4	23.2
Void Ratio	0.884	0.638

Note: A Specific Gravity (Gs) of 2.74 was obtained for the void ratio and saturation calculations.

Void Ratio vs. Pressure

Project #: 20000
Client: MTO
Project Name: Highway 406 Culvert
Sample: BH 19-02 TW12 30'-32'



Consolidation Test Report

Highway 406 Culvert
20000

BH 19-02 TW12 30'-32'

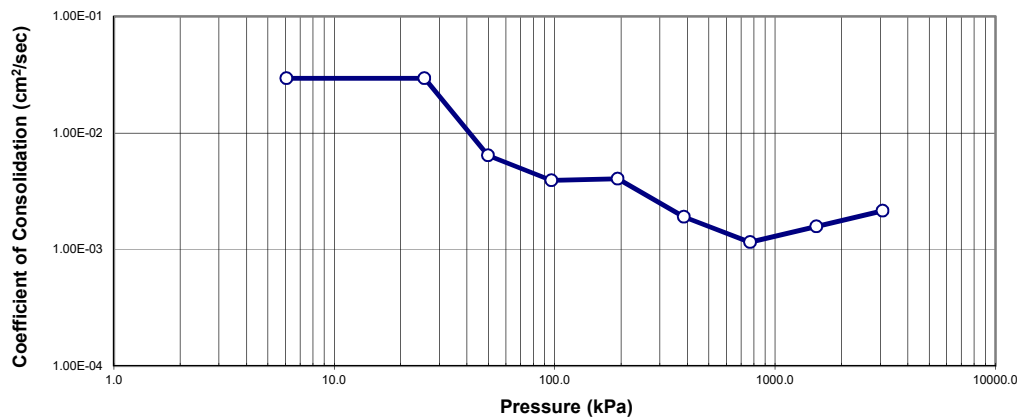
TRIMMING: The Specimen was manually trimmed to the size of consolidation ring, then mounted in a fixed ring consolidometer.

LOADING: A seating load of 6.1 kPa was applied and the consolidometer was flooded with distilled water. Sample was monitored to ensure no swelling effect occurred before the start of the test. Subsequent loads were applied after a constant load increment duration of 24 hours.

CALCULATIONS: Coefficients of Consolidation were calculated by the square root time method.

Pressure (kPa)	Corr. H. (mm)	Avg. H. (mm)	D ₉₀ (mm)	t ₉₀ (min)	c _v (cm ² /s)	Void Ratio	m _v (m ² /kN)	k (cm/s)
0.0	25.400					0.884		
6.1	25.409	25.405	-0.027	0.77	2.94E-02	0.885	-5.84E-05	-1.69E-07
25.7	25.351	25.380	-0.127	0.77	2.94E-02	0.880	1.16E-04	3.36E-07
49.9	25.287	25.319	-0.096	3.53	6.41E-03	0.876	1.04E-04	6.56E-08
96.6	25.225	25.256	-0.113	5.76	3.91E-03	0.871	5.24E-05	2.01E-08
193.2	25.013	25.119	-0.188	5.52	4.04E-03	0.855	8.70E-05	3.45E-08
385.7	24.083	24.548	-0.550	11.22	1.90E-03	0.786	1.93E-04	3.59E-08
770.7	22.759	23.421	-0.850	16.81	1.15E-03	0.688	1.43E-04	1.62E-08
1540.7	21.588	22.174	-0.830	11.02	1.58E-03	0.601	6.68E-05	1.03E-08
3081.4	20.515	21.052	-0.735	7.29	2.15E-03	0.522	3.23E-05	6.80E-09
770.7	20.846	20.681				0.546		
193.2	21.420	21.133				0.589		
49.9	22.078	21.749				0.638		

Coefficient of Consolidation vs. Pressure



Notes: C_v and k calculated using t₉₀ values

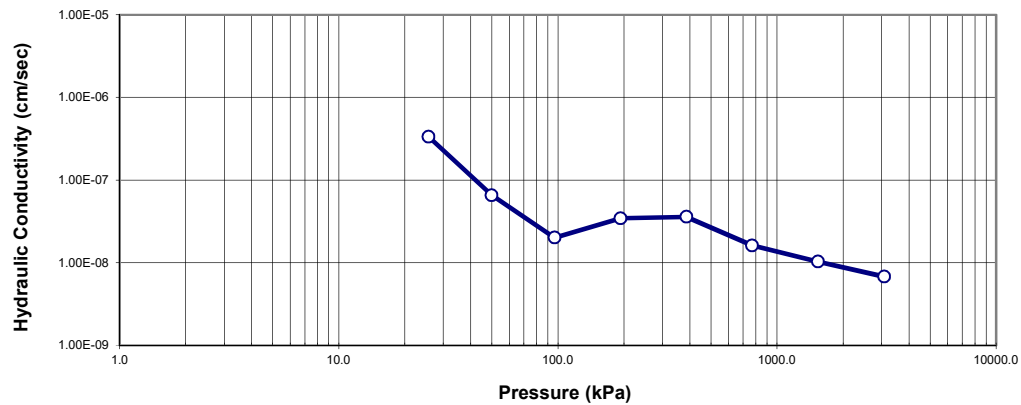
Consolidation Test Report

Highway 406 Culvert
20000

BH 19-02 TW12 30'-32'

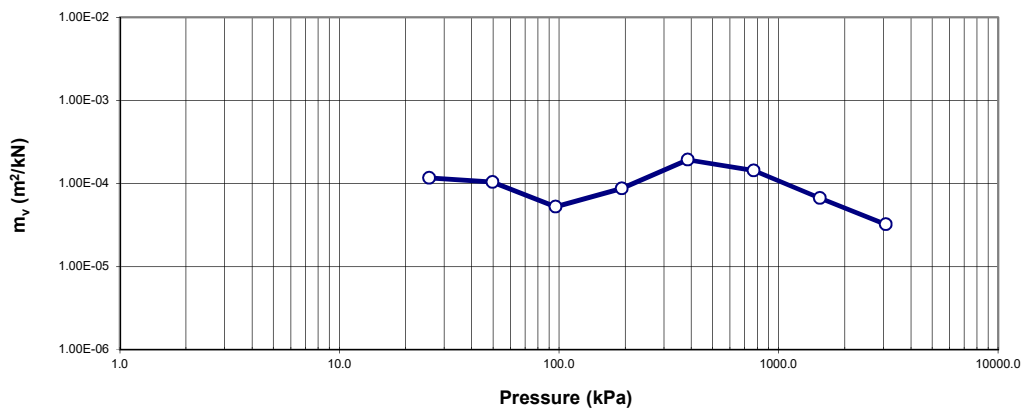
Hydraulic Conductivity vs. Pressure

Project #: 20000
Client: MTO
Project Name: Highway 406 Culvert
Sample: BH 19-02 TW12 30'-32'



m_v vs. Pressure

Project #: 20000
Client: MTO
Project Name: Highway 406 Culvert
Sample: BH 19-02 TW12 30'-32'



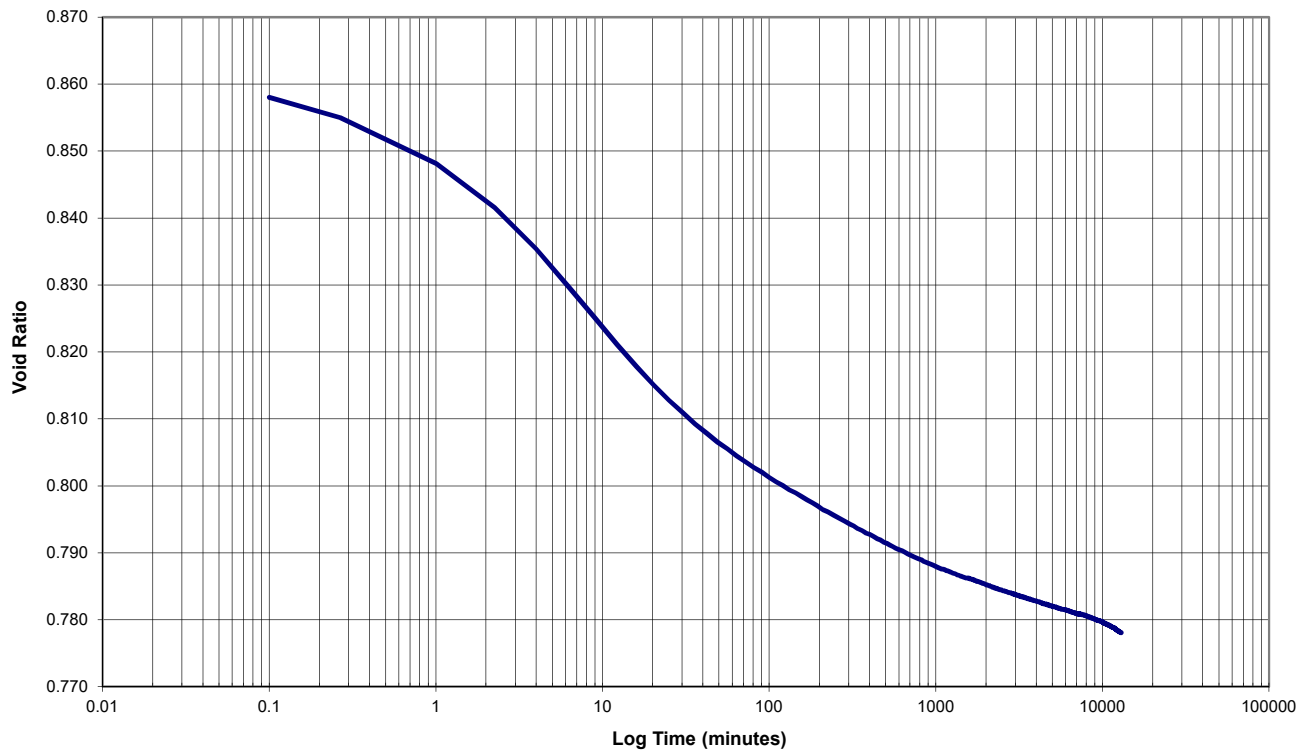
Consolidation Test Report

Highway 406 Culvert
20000

BH 19-02 TW12 30'-32'

Project #: 20000
Client: MTO
Project Name: Highway 406 Culvert
Sample: BH 19-02 TW12 30'-32'

Void Ratio vs. Log Time at 385.7 kPa - Creep Stage Duration of 9 Days



Consolidation Test Report

CLIENT: MTO

FILE NUMBER: 20000

PROJECT: Highway 406 Culvert

REPORT DATE: 6-Dec-2019

TEST DATES: November 07, 2019 - November 27, 2019

SAMPLE: BH 19-03 TW9 25'-27'
Silty clay, trace sand, brown, moist.
LL=39, PL=18, $I_p = 21$.

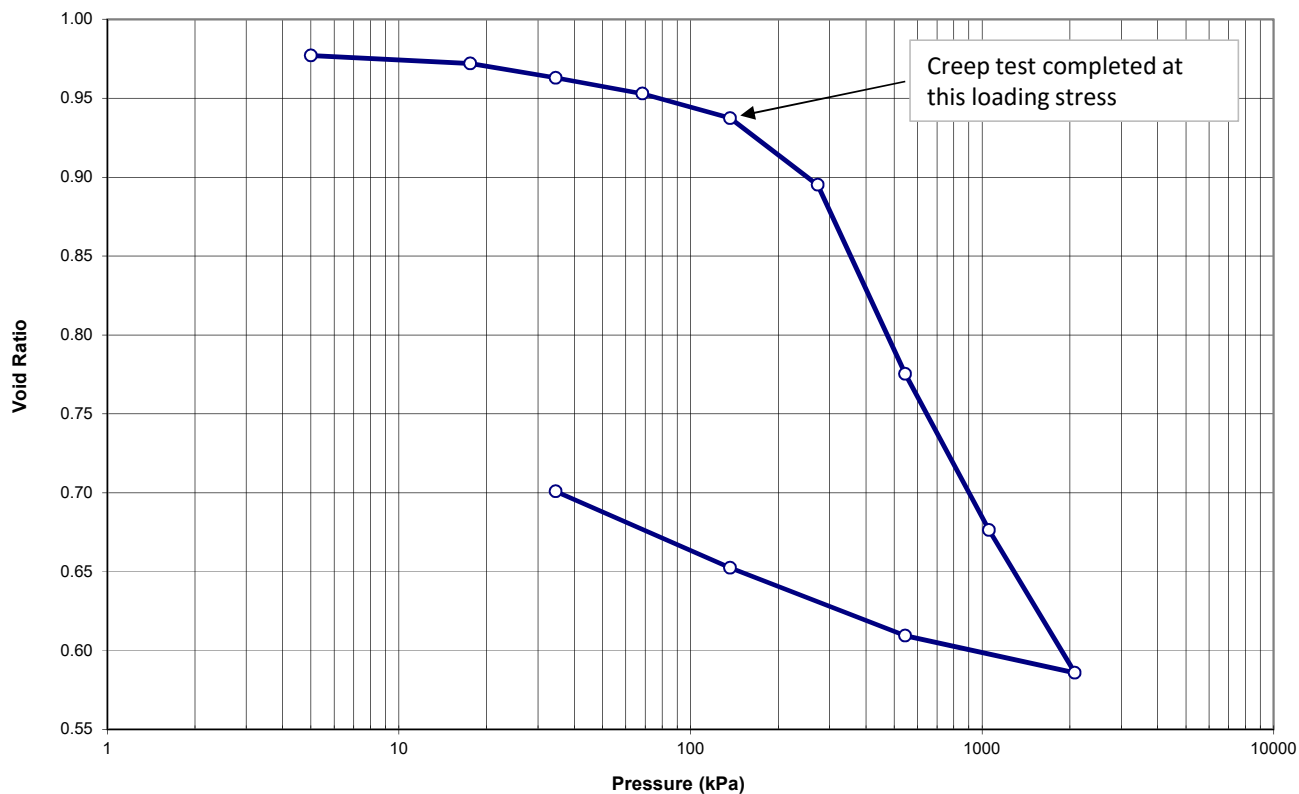
PROCEDURE: Test carried out in accordance with Standard Test Method for One-Dimensional Consolidation Properties of Soils, ASTM D 2435-11, method A

	Start of Test	End of Test
Wet Dens. (kg/m^3)	1894.6	2057.5
Dry Dens. (kg/m^3)	1406.9	1637.9
Moisture Cont. (%)	34.7	25.6
Void Ratio	0.980	0.701

Note: A Specific Gravity (Gs) of 2.79 was obtained for the void ratio and saturation calculations.

Project #: 20000
Client: MTO
Project Name: Highway 406 Culvert
Sample: BH 19-03 TW9 25'-27'

Void Ratio vs. Pressure



Consolidation Test Report

Highway 406 Culvert
20000

BH 19-03 TW9 25'-27'

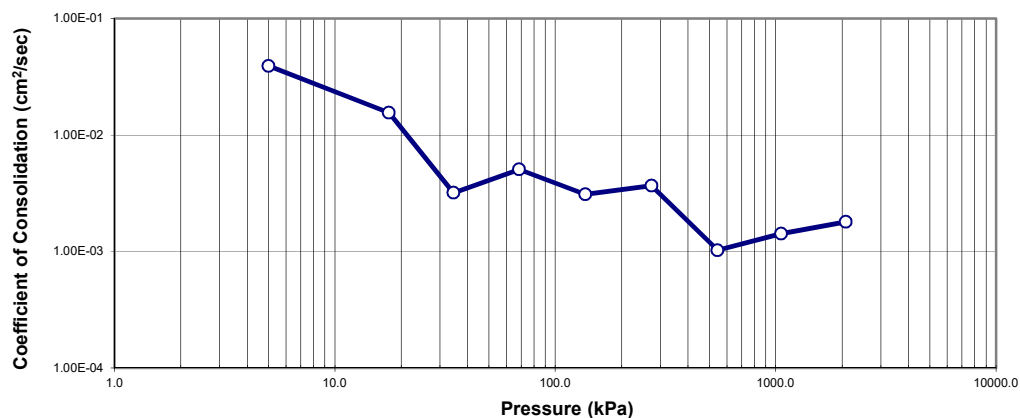
TRIMMING: The Specimen was manually trimmed to the size of consolidation ring, then mounted in a fixed ring consolidometer.

LOADING: A seating load of 5.0 kPa was applied and the consolidometer was flooded with distilled water. Sample was monitored to ensure no swelling effect occurred before the start of the test. Subsequent loads were applied after a constant load increment duration of 24 hours.

CALCULATIONS: Coefficients of Consolidation were calculated by the square root time method.

Pressure (kPa)	Corr. H. (mm)	Avg. H. (mm)	D ₉₀ (mm)	t ₉₀ (min)	c _v (cm ² /s)	Void Ratio	m _v (m ² /kN)	k (cm/s)
0.0	20.000					0.980		
5.0	19.970	19.985	-0.040	0.36	3.92E-02	0.977	3.00E-04	1.15E-06
17.6	19.919	19.945	-0.077	0.90	1.56E-02	0.972	2.03E-04	3.09E-07
34.5	19.827	19.873	-0.085	4.37	3.19E-03	0.963	2.73E-04	8.56E-08
68.5	19.726	19.777	-0.092	2.72	5.08E-03	0.953	1.50E-04	7.46E-08
136.9	19.569	19.648	-0.146	4.41	3.09E-03	0.937	1.16E-04	3.53E-08
273.2	19.142	19.356	-0.214	3.61	3.67E-03	0.895	1.60E-04	5.76E-08
545.5	17.932	18.537	-0.825	11.83	1.03E-03	0.775	2.32E-04	2.34E-08
1057.7	16.931	17.432	-0.680	7.56	1.42E-03	0.676	1.09E-04	1.52E-08
2080.1	16.018	16.475	-0.620	5.34	1.80E-03	0.586	5.27E-05	9.29E-09
545.5	16.255	16.137				0.609		
136.9	16.690	16.473				0.652		
34.5	17.179	16.935				0.701		

Coefficient of Consolidation vs. Pressure



Notes: C_v and k calculated using t₉₀ values

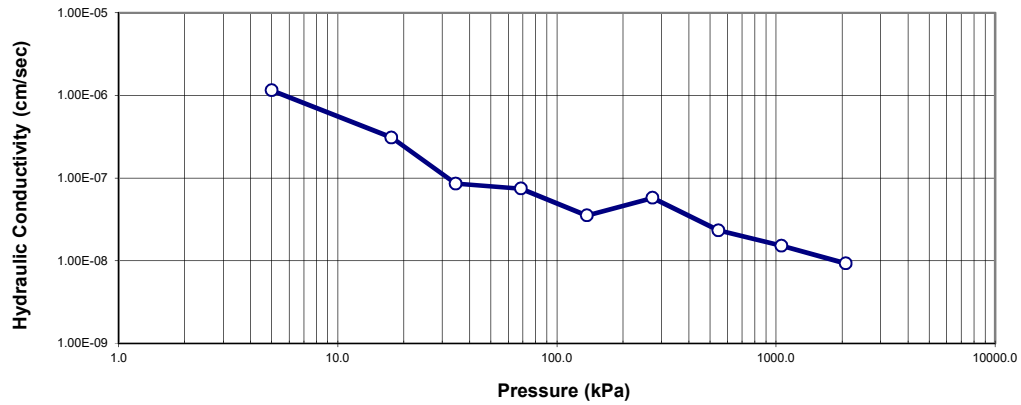
Consolidation Test Report

Highway 406 Culvert
20000

BH 19-03 TW9 25'-27'

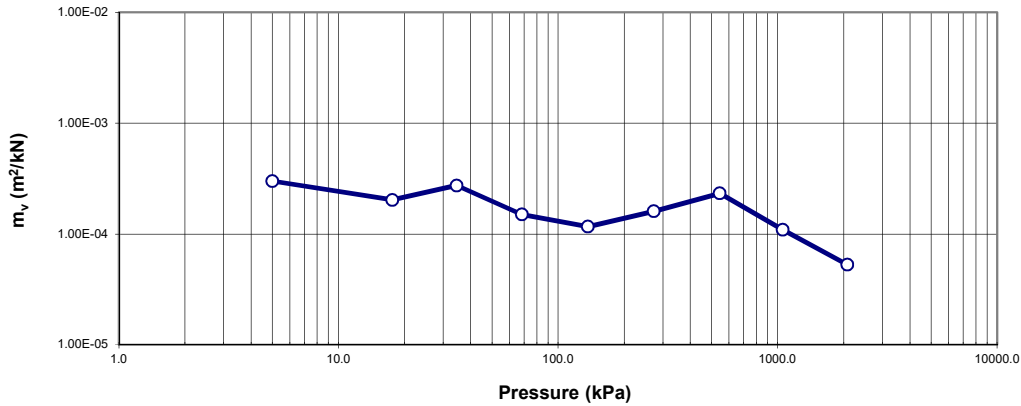
Hydraulic Conductivity vs. Pressure

Project #: 20000
Client: MTO
Project Name: Highway 406 Culvert
Sample: BH 19-03 TW9 25'-27'



m_v vs. Pressure

Project #: 20000
Client: MTO
Project Name: Highway 406 Culvert
Sample: BH 19-03 TW9 25'-27'



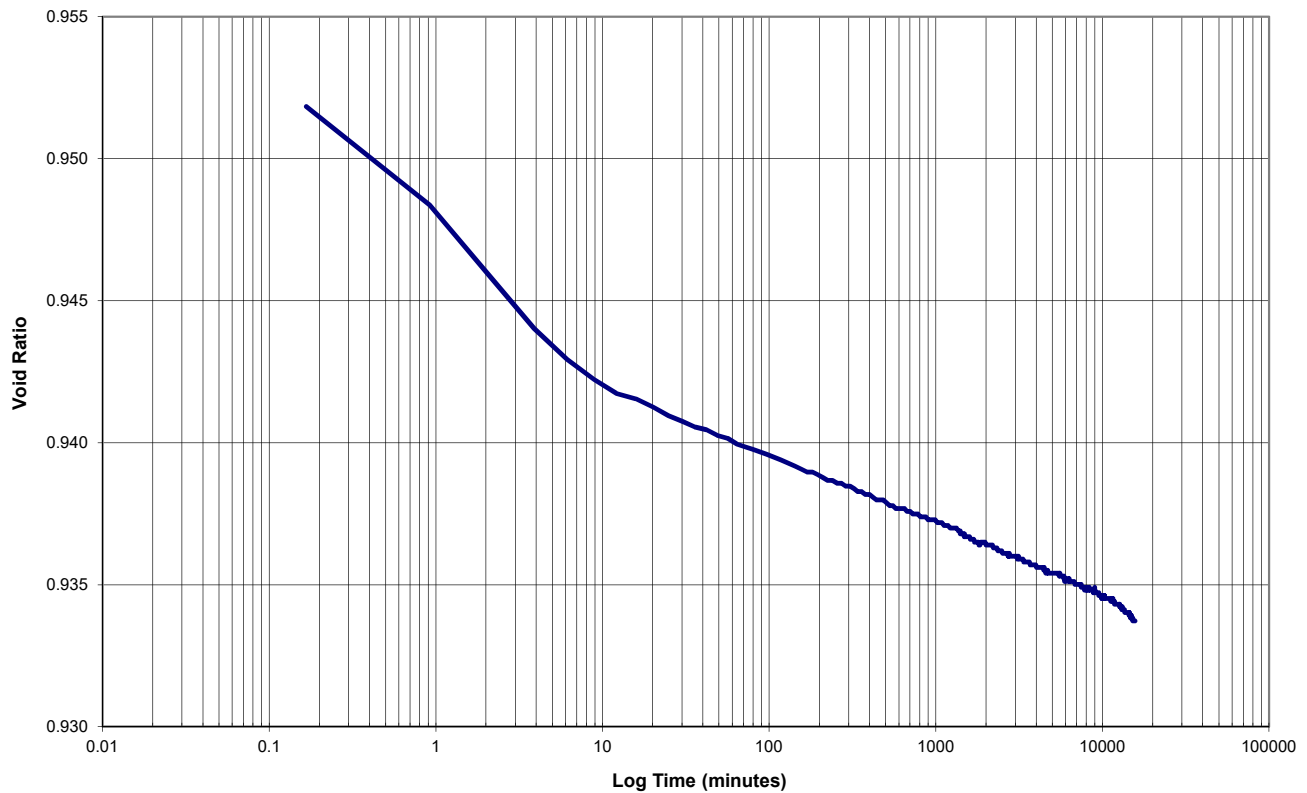
Consolidation Test Report

Highway 406 Culvert
20000

BH 19-03 TW9 25'-27'

Project #: 20000
Client: MTO
Project Name: Highway 406 Culvert
Sample: BH 19-03 TW9 25'-27'

Void Ratio vs. Log Time at 193.6 kPa - Creep Stage Duration of 11 Days





Appendix C

Cone Penetration Test (CPTu) Report

PRESENTATION OF SITE INVESTIGATION RESULTS

Highway 406 Welland Culvert

Prepared for:

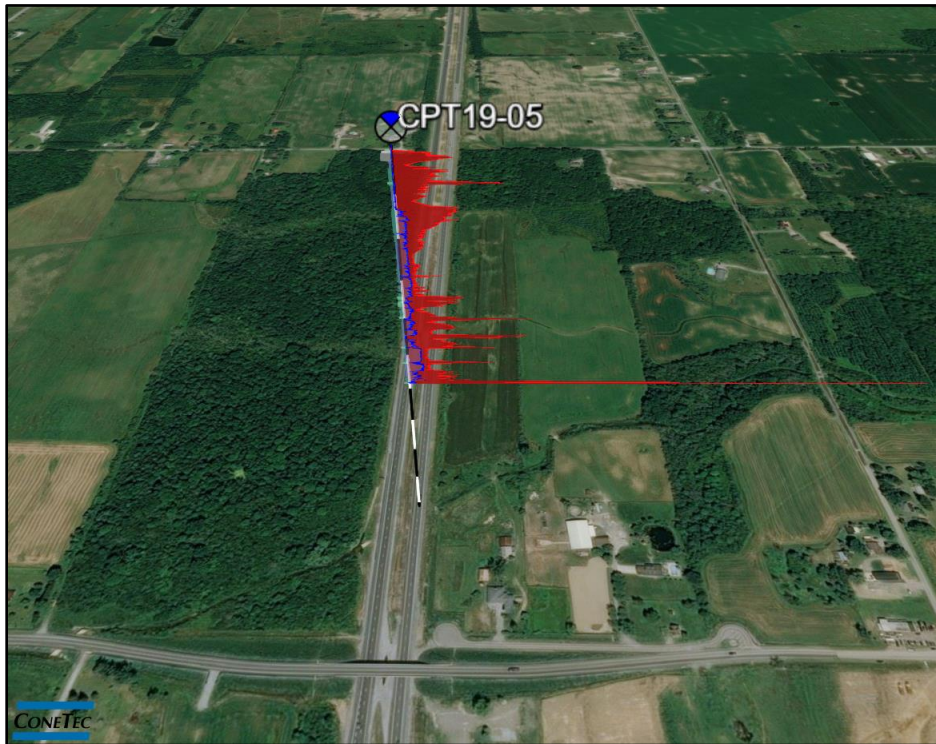
Thurber Engineering

ConeTec Job No: 19-05081

Project Start Date: 22-Nov-2019

Project End Date: 22-Nov-2019

Report Date: 29-Nov-2019



Prepared by:

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ConeTecON@conetec.com
www.conetec.com
www.conetecdataservices.com



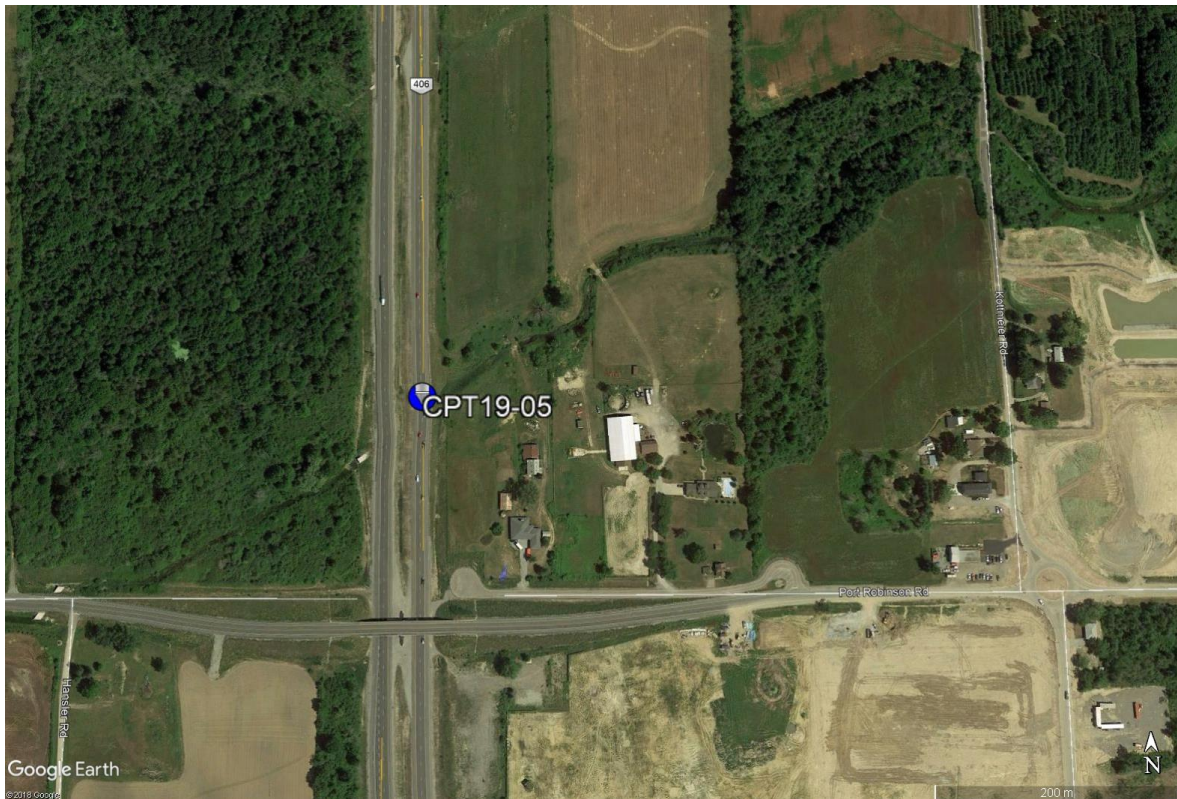
Introduction

The enclosed report presents the results of the site investigation program conducted by ConeTec Investigations Ltd. for Thurber Engineering on Highway 406 Welland Culvert South-West of Niagara Falls, On. The program consisted of one cone penetration test (CPTu),

Project Information

Project	
Client	Thurber Engineering
Project	Highway 406 Welland Culvert
ConeTec project number	19-05081

An aerial overview from Google Earth including the CPTu test locations is presented below.



Rig Description	Deployment System	Test Type
CPT truck rig (C-3)	30 ton rig cylinder	CPTu

Coordinates		
Test Type	Collection Method	EPSG Number
CPTu	Consumer grade GPS	32617

Cone Penetrometers Used for this Project						
Cone Description	Cone Number	Cross Sectional Area (cm ²)	Sleeve Area (cm ²)	Tip Capacity (bar)	Sleeve Capacity (bar)	Pore Pressure Capacity (psi)
408:T1500F15U500	408	15	225	1500	15	500
Cone 408 was used for all CPT soundings.						

Cone Penetration Test (CPTu)	
Depth reference	Depths are referenced to the existing ground surface at the time of each test.
Tip and sleeve data offset	0.1 meter This has been accounted for in the CPT data files.
Additional plots	<ul style="list-style-type: none"> Advanced plots with I_c, S_u, ϕ and $N1(60)$ Soil Behaviour Type (SBT) scatter plots

Calculated Geotechnical Parameter Tables	
Additional information	<p>The Normalized Soil Behaviour Type Chart based on Q_{tn} (SBT Q_{tn}) (Robertson, 2009) was used to classify the soil for this project. A detailed set of calculated CPTu parameters have been generated and are provided in Excel format files in the release folder. The CPTu parameter calculations are based on values of corrected tip resistance (q_t) sleeve friction (f_s) and pore pressure (u_2).</p> <p>Soils were classified as either drained or undrained based on the Q_{tn} Normalized Soil Behaviour Type Chart (Robertson, 2009). Calculations for both drained and undrained parameters were included for materials that classified as silt mixtures (zone 4).</p>

Limitations

This report has been prepared for the exclusive use of Thurber Engineering (Client) for the project titled “Highway 406 Welland Culvert”. The report’s contents may not be relied upon by any other party without the express written permission of ConeTec Investigations Ltd. (ConeTec). ConeTec has provided site investigation services, prepared the factual data reporting and provided geotechnical parameter calculations consistent with current best practices. No other warranty, expressed or implied, is made.

The information presented in the report document and the accompanying data set pertain to the specific project, site conditions and objectives described to ConeTec by the Client. In order to properly understand the factual data, assumptions and calculations, reference must be made to the documents provided and their accompanying data sets, in their entirety.

Cone penetration tests (CPTu) are conducted using an integrated electronic piezocone penetrometer and data acquisition system manufactured by Adara Systems Ltd., a subsidiary of ConeTec.

ConeTec's piezocone penetrometers are compression type designs in which the tip and friction sleeve load cells are independent and have separate load capacities. The piezocones use strain gauged load cells for tip and sleeve friction and a strain gauged diaphragm type transducer for recording pore pressure. The piezocones also have a platinum resistive temperature device (RTD) for monitoring the temperature of the sensors, an accelerometer type dual axis inclinometer and a geophone sensor for recording seismic signals. All signals are amplified down hole within the cone body and the analog signals are sent to the surface through a shielded cable.

ConeTec penetrometers are manufactured with various tip, friction and pore pressure capacities in 5 cm², 10 cm² and 15 cm² tip base area configurations in order to maximize signal resolution for various soil conditions. The specific piezocone used for each test is described in the CPT summary table presented in the first appendix. The 15 cm² penetrometers do not require friction reducers as they have a diameter larger than the deployment rods. The 10 cm² piezocones use a friction reducer consisting of a rod adapter extension behind the main cone body with an enlarged cross-sectional area (typically forty-four millimeter diameter over a length of thirty-two millimeter with tapered leading and trailing edges) located at a distance of 585 millimeters above the cone tip.

The penetrometers are designed with equal end area friction sleeves, a net end area ratio of 0.8 and cone tips with a sixty-degree apex angle.

All ConeTec piezocones can record pore pressure at various locations. Unless otherwise noted, the pore pressure filter is located directly behind the cone tip in the "u₂" position ([ASTM Type 2](#)). The filter is six millimeters thick, made of porous plastic (polyethylene) having an average pore size of 125 microns (90-160 microns). The function of the filter is to allow rapid movements of extremely small volumes of water needed to activate the pressure transducer while preventing soil ingress or blockage.

The piezocone penetrometers are manufactured with dimensions, tolerances and sensor characteristics that are in general accordance with the current [ASTM D5778](#) standard. ConeTec's calibration criteria also meets or exceeds those of the current [ASTM D5778](#) standard. An illustration of the piezocone penetrometer is presented in [Figure CPTu](#).

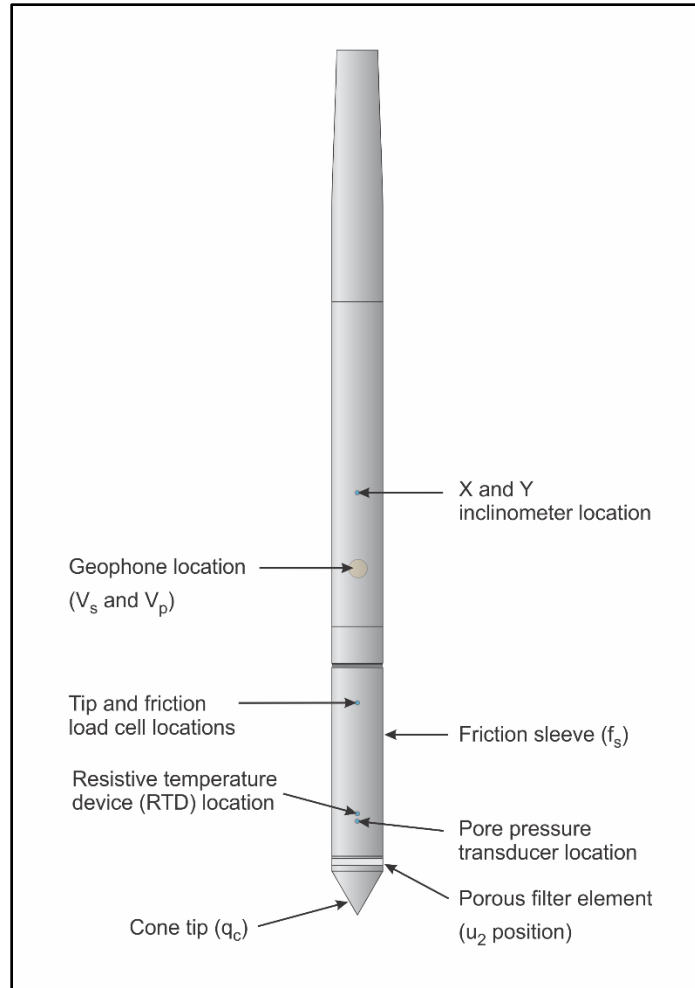


Figure CPTu. Piezocone Penetrometer (15 cm²)

The ConeTec data acquisition systems consist of a Windows based computer and a signal conditioner and power supply interface box with a sixteen bit (or greater) analog to digital (A/D) converter. The data is recorded at fixed depth increments using a depth wheel attached to the push cylinders or by using a spring loaded rubber depth wheel that is held against the cone rods. The typical recording interval is 2.5 centimeters; custom recording intervals are possible. The system displays the CPTu data in real time and records the following parameters to a storage media during penetration:

- Depth
- Uncorrected tip resistance (q_c)
- Sleeve friction (f_s)
- Dynamic pore pressure (u)
- Additional sensors such as resistivity, passive gamma, ultra violet induced fluorescence, if applicable

All testing is performed in accordance to ConeTec's CPT operating procedures which are in general accordance with the current [ASTM D5778](#) standard.

Prior to the start of a CPTu sounding a suitable cone is selected, the cone and data acquisition system are powered on, the pore pressure system is saturated with silicone oil and the baseline readings are recorded with the cone hanging freely in a vertical position.

The CPTu is conducted at a steady rate of two centimeters per second, within acceptable tolerances. Typically, one-meter length rods with an outer diameter of 38.1 millimeters are added to advance the cone to the sounding termination depth. After cone retraction final baselines are recorded.

Additional information pertaining to ConeTec's cone penetration testing procedures:

- Each filter is saturated in silicone oil under vacuum pressure prior to use
- Recorded baselines are checked with an independent multi-meter
- Baseline readings are compared to previous readings
- Soundings are terminated at the client's target depth or at a depth where an obstruction is encountered, excessive rod flex occurs, excessive inclination occurs, equipment damage is likely to take place, or a dangerous working environment arises
- Differences between initial and final baselines are calculated to ensure zero load offsets have not occurred and to ensure compliance with [ASTM](#) standards

The interpretation of piezocone data for this report is based on the corrected tip resistance (q_t), sleeve friction (f_s) and pore water pressure (u). The interpretation of soil type is based on the correlations developed by [Robertson et al. \(1986\)](#) and Robertson (1990, 2009). It should be noted that it is not always possible to accurately identify a soil behaviour type based on these parameters. In these situations, experience, judgment and an assessment of other parameters may be used to infer soil behaviour type.

The recorded tip resistance (q_c) is the total force acting on the piezocone tip divided by its base area. The tip resistance is corrected for pore pressure effects and termed corrected tip resistance (q_t) according to the following expression presented in [Robertson et al. \(1986\)](#):

$$q_t = q_c + (1-a) \cdot u_2$$

where: q_t is the corrected tip resistance

q_c is the recorded tip resistance

u_2 is the recorded dynamic pore pressure behind the tip (u_2 position)

a is the Net Area Ratio for the piezocone (0.8 for ConeTec probes)

The sleeve friction (f_s) is the frictional force on the sleeve divided by its surface area. As all ConeTec piezocones have equal end area friction sleeves, pore pressure corrections to the sleeve data are not required.

The dynamic pore pressure (u) is a measure of the pore pressures generated during cone penetration. To record equilibrium pore pressure, the penetration must be stopped to allow the dynamic pore pressures to stabilize. The rate at which this occurs is predominantly a function of the permeability of the soil and the diameter of the cone.

The friction ratio (R_f) is a calculated parameter. It is defined as the ratio of sleeve friction to the tip resistance expressed as a percentage. Generally, saturated cohesive soils have low tip resistance, high friction ratios and generate large excess pore water pressures. Cohesionless soils have higher tip resistances, lower friction ratios and do not generate significant excess pore water pressure.

A summary of the CPTu soundings along with test details and individual plots are provided in the appendices. A set of files with calculated geotechnical parameters were generated for each sounding based on published correlations and are provided in Excel format in the data release folder. Information regarding the methods used is also included in the data release folder.

For additional information on CPTu interpretations and calculated geotechnical parameters, refer to [Robertson et al. \(1986\)](#), [Lunne et al. \(1997\)](#), [Robertson \(2009\)](#), [Mayne \(2013, 2014\)](#) and [Mayne and Peuchen \(2012\)](#).

References

ASTM D5778-12, 2012, "Standard Test Method for Performing Electronic Friction Cone and Piezocone Penetration Testing of Soils", ASTM International, West Conshohocken, PA. DOI: [10.1520/D5778-12](#).

Lunne, T., Robertson, P.K. and Powell, J. J. M., 1997, "Cone Penetration Testing in Geotechnical Practice", Blackie Academic and Professional.

Mayne, P.W., 2013, "Evaluating yield stress of soils from laboratory consolidation and in-situ cone penetration tests", Sound Geotechnical Research to Practice (Holtz Volume) GSP 230, ASCE, Reston/VA: 406-420. DOI: [10.1061/9780784412770.027](#).

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Mayne, P.W., 2014, "Interpretation of geotechnical parameters from seismic piezocone tests", CPT'14 Keynote Address, Las Vegas, NV, May 2014.

Robertson, P.K., Campanella, R.G., Gillespie, D. and Greig, J., 1986, "Use of Piezometer Cone Data", Proceedings of InSitu 86, ASCE Specialty Conference, Blacksburg, Virginia.

Robertson, P.K., 1990, "Soil Classification Using the Cone Penetration Test", Canadian Geotechnical Journal, Volume 27: 151-158. DOI: [10.1139/T90-014](#).

Robertson, P.K., 2009, "Interpretation of cone penetration tests – a unified approach", Canadian Geotechnical Journal, Volume 46: 1337-1355. DOI: [10.1139/T09-065](#).

The cone penetration test is halted at specific depths to carry out pore pressure dissipation (PPD) tests, shown in [Figure PPD-1](#). For each dissipation test the cone and rods are decoupled from the rig and the data acquisition system measures and records the variation of the pore pressure (u) with time (t).

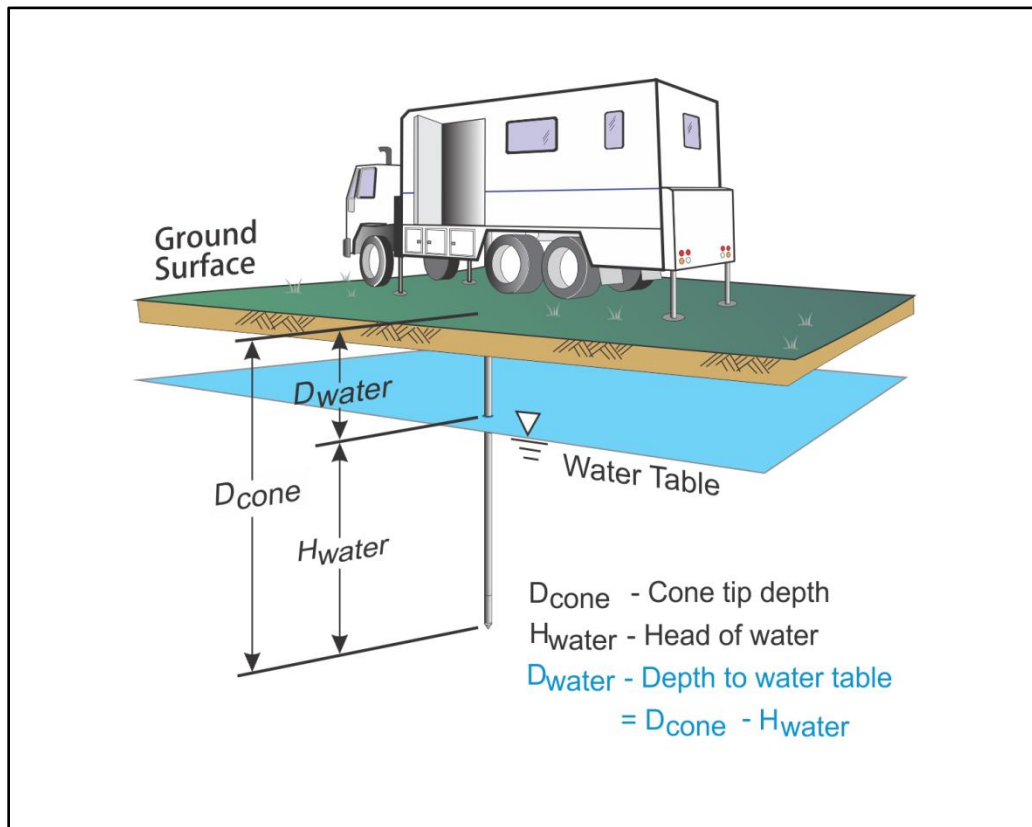


Figure PPD-1. Pore pressure dissipation test setup

Pore pressure dissipation data can be interpreted to provide estimates of ground water conditions, permeability, consolidation characteristics and soil behaviour.

The typical shapes of dissipation curves shown in [Figure PPD-2](#) are very useful in assessing soil type, drainage, in situ pore pressure and soil properties. A flat curve that stabilizes quickly is typical of a freely draining sand. Undrained soils such as clays will typically show positive excess pore pressure and have long dissipation times. Dilative soils will often exhibit dynamic pore pressures below equilibrium that then rise over time. Overconsolidated fine-grained soils will often exhibit an initial dilatory response where there is an initial rise in pore pressure before reaching a peak and dissipating.

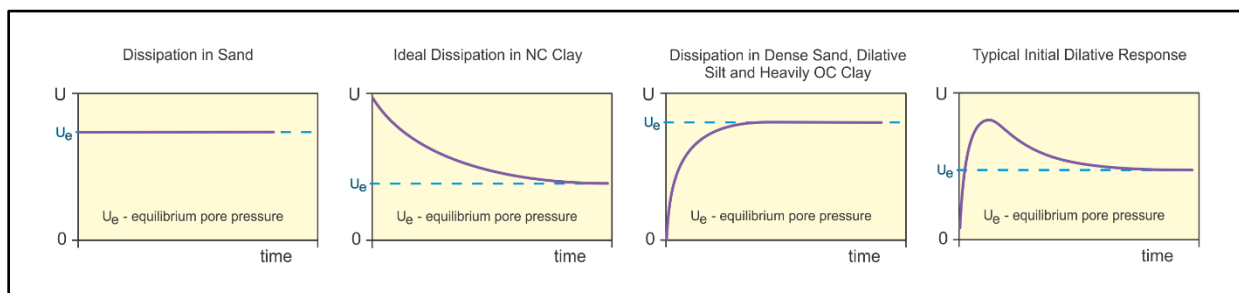


Figure PPD-2. Pore pressure dissipation curve examples

In order to interpret the equilibrium pore pressure (u_{eq}) and the apparent phreatic surface, the pore pressure should be monitored until such time as there is no variation in pore pressure with time as shown for each curve in [Figure PPD-2](#).

In fine grained deposits the point at which 100% of the excess pore pressure has dissipated is known as t_{100} . In some cases this can take an excessive amount of time and it may be impractical to take the dissipation to t_{100} . A theoretical analysis of pore pressure dissipations by [Teh and Houlsby \(1991\)](#) showed that a single curve relating degree of dissipation versus theoretical time factor (T^*) may be used to calculate the coefficient of consolidation (c_h) at various degrees of dissipation resulting in the expression for c_h shown below.

$$c_h = \frac{T^* \cdot a^2 \cdot \sqrt{I_r}}{t}$$

Where:

- T^* is the dimensionless time factor ([Table Time Factor](#))
 a is the radius of the cone
 I_r is the rigidity index
 t is the time at the degree of consolidation

Table Time Factor. T^* versus degree of dissipation ([Teh and Houlsby \(1991\)](#))

Degree of Dissipation (%)	20	30	40	50	60	70	80
$T^* (u_2)$	0.038	0.078	0.142	0.245	0.439	0.804	1.60

The coefficient of consolidation is typically analyzed using the time (t_{50}) corresponding to a degree of dissipation of 50% (u_{50}). In order to determine t_{50} , dissipation tests must be taken to a pressure less than u_{50} . The u_{50} value is half way between the initial maximum pore pressure and the equilibrium pore pressure value, known as u_{100} . To estimate u_{50} , both the initial maximum pore pressure and u_{100} must be known or estimated. Other degrees of dissipations may be considered, particularly for extremely long dissipations.

At any specific degree of dissipation the equilibrium pore pressure (u at t_{100}) must be estimated at the depth of interest. The equilibrium value may be determined from one or more sources such as measuring the value directly (u_{100}), estimating it from other dissipations in the same profile, estimating the phreatic surface and assuming hydrostatic conditions, from nearby soundings, from client provided information, from site observations and/or past experience, or from other site instrumentation.

For calculations of c_h ([Teh and Houlsby \(1991\)](#)), t_{50} values are estimated from the corresponding pore pressure dissipation curve and a rigidity index (I_r) is assumed. For curves having an initial dilatatory response in which an initial rise in pore pressure occurs before reaching a peak, the relative time from the peak value is used in determining t_{50} . In cases where the time to peak is excessive, t_{50} values are not calculated.

Due to possible inherent uncertainties in estimating I_r , the equilibrium pore pressure and the effect of an initial dilatatory response on calculating t_{50} , other methods should be applied to confirm the results for c_h .

Additional published methods for estimating the coefficient of consolidation from a piezocone test are described in Burns and Mayne (1998, 2002), Jones and Van Zyl (1981), Robertson et al. (1992) and Sully et al. (1999).

A summary of the pore pressure dissipation tests and dissipation plots are presented in the relevant appendix.

References

Burns, S.E. and Mayne, P.W., 1998, "Monotonic and dilatory pore pressure decay during piezocone tests", Canadian Geotechnical Journal 26 (4): 1063-1073. DOI: [1063-1073/T98-062](https://doi.org/10.1139/T98-062).

Burns, S.E. and Mayne, P.W., 2002, "Analytical cavity expansion-critical state model cone dissipation in fine-grained soils", Soils & Foundations, Vol. 42(2): 131-137.

Jones, G.A. and Van Zyl, D.J.A., 1981, "The piezometer probe: a useful investigation tool", Proceedings, 10th International Conference on Soil Mechanics and Foundation Engineering, Vol. 3, Stockholm: 489-495.

Robertson, P.K., Sully, J.P., Woeller, D.J., Lunne, T., Powell, J.J.M. and Gillespie, D.G., 1992, "Estimating coefficient of consolidation from piezocone tests", Canadian Geotechnical Journal, 29(4): 539-550. DOI: [10.1139/T92-061](https://doi.org/10.1139/T92-061).

Sully, J.P., Robertson, P.K., Campanella, R.G. and Woeller, D.J., 1999, "An approach to evaluation of field CPTU dissipation data in overconsolidated fine-grained soils", Canadian Geotechnical Journal, 36(2): 369-381. DOI: [10.1139/T98-105](https://doi.org/10.1139/T98-105).

Teh, C.I., and Houlsby, G.T., 1991, "An analytical study of the cone penetration test in clay", Geotechnique, 41(1): 17-34. DOI: [10.1680/geot.1991.41.1.17](https://doi.org/10.1680/geot.1991.41.1.17).

The appendices listed below are included in the report:

- Cone Penetration Test Summary and Standard Cone Penetration Test Plots
- Advanced Cone Penetration Test Plots with I_c , $S_u(N_{kt})$ and $N1(60)I_c$
- Soil Behaviour Type (SBT) Scatter Plots
- Pore Pressure Dissipation Summary and Pore Pressure Dissipation Plots

Cone Penetration Test Summary and Standard Cone Penetration Test Plots

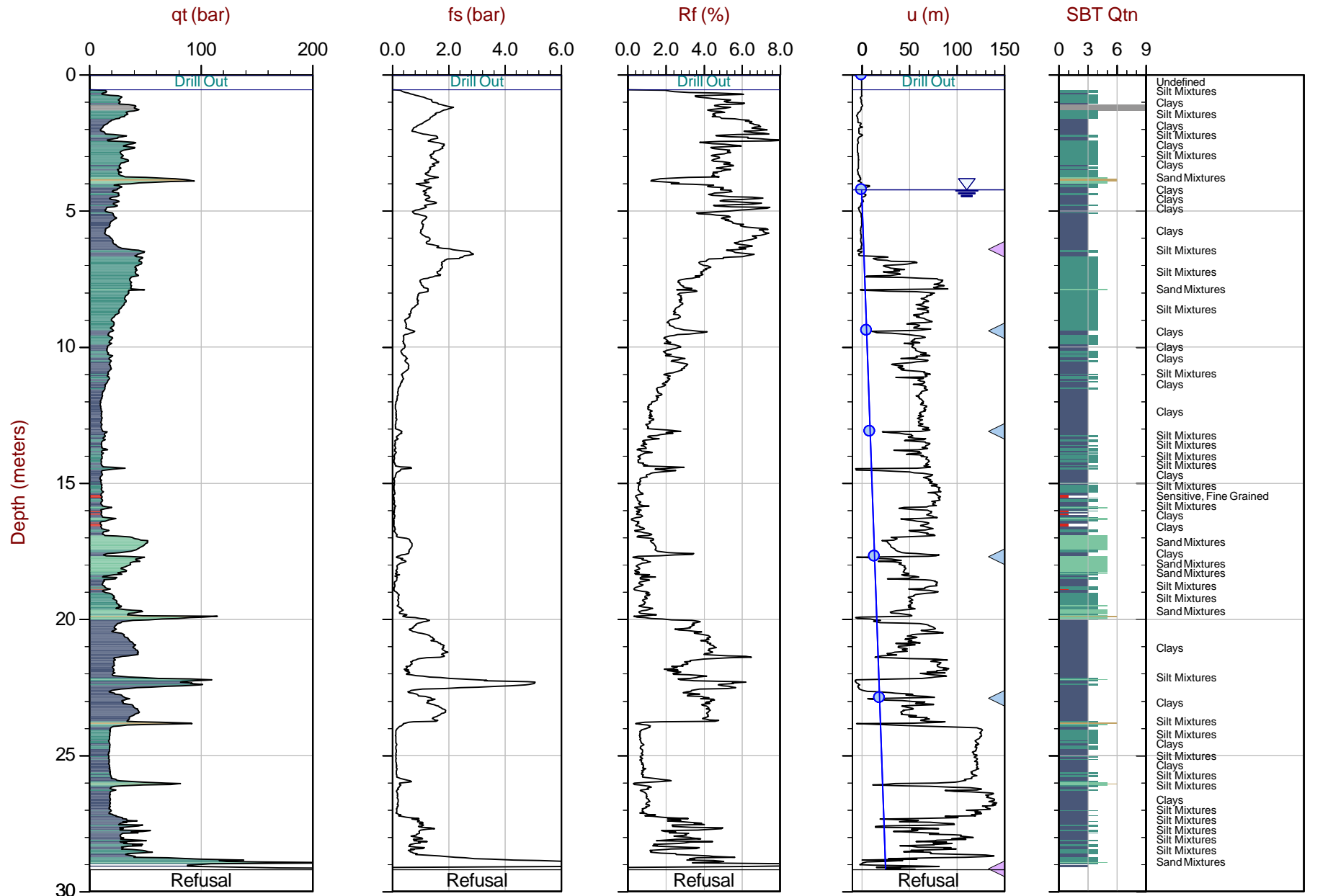


Job No: 19-05081
Client: Thurber Engineering
Project: Highway 406 Welland Culvert
Start Date: 22-Nov-2019
End Date: 22-Nov-2019

CONE PENETRATION TEST SUMMARY

Sounding ID	File Name	Date	Cone	Assumed Phreatic Surface ¹ (m)	Final Depth (m)	Northing ² (m)	Easting ² (m)	Refer to Notation Number
CPT19-05	19-05081_CP05	22-Nov-2019	408:T1500F15U500	4.2	29.200	4766985	643739	

1. The assumed phreatic surface was based on the dynamic pore pressure response. Hydrostatic conditions were assumed for the calculated parameters.
2. Coordinates were acquired using a consumer grade GPS. WGS84 / UTM Zone 17 North



Max Depth: 29.200 m / 95.80 ft

Depth Inc: 0.025 m / 0.082 ft

Avg Int: Every Point

File: 19-05081_CP05.COR

Unit Wt: SBTQtn(PKR2009)

SBT: Robertson, 2009 and 2010

Coords: UTM 11N: 4766985m E: 643739m

Sheet No: 1 of 1

● Equilibrium Pore Pressure (Ueq)
 ● Assumed Ueq
 ▲ Dissipation, Ueq achieved
 ▲ Dissipation, Ueq not achieved
 ▲ Dissipation, Ueq assumed
 — Hydrostatic Line

The reported coordinates were acquired from consumer grade GPS equipment and are only approximate locations. The coordinates should not be used for design purposes.

Advanced Cone Penetration Plots with I_c , $S_u(N_{kt})$ and $N1(60)I_c$



Thurber Engineering

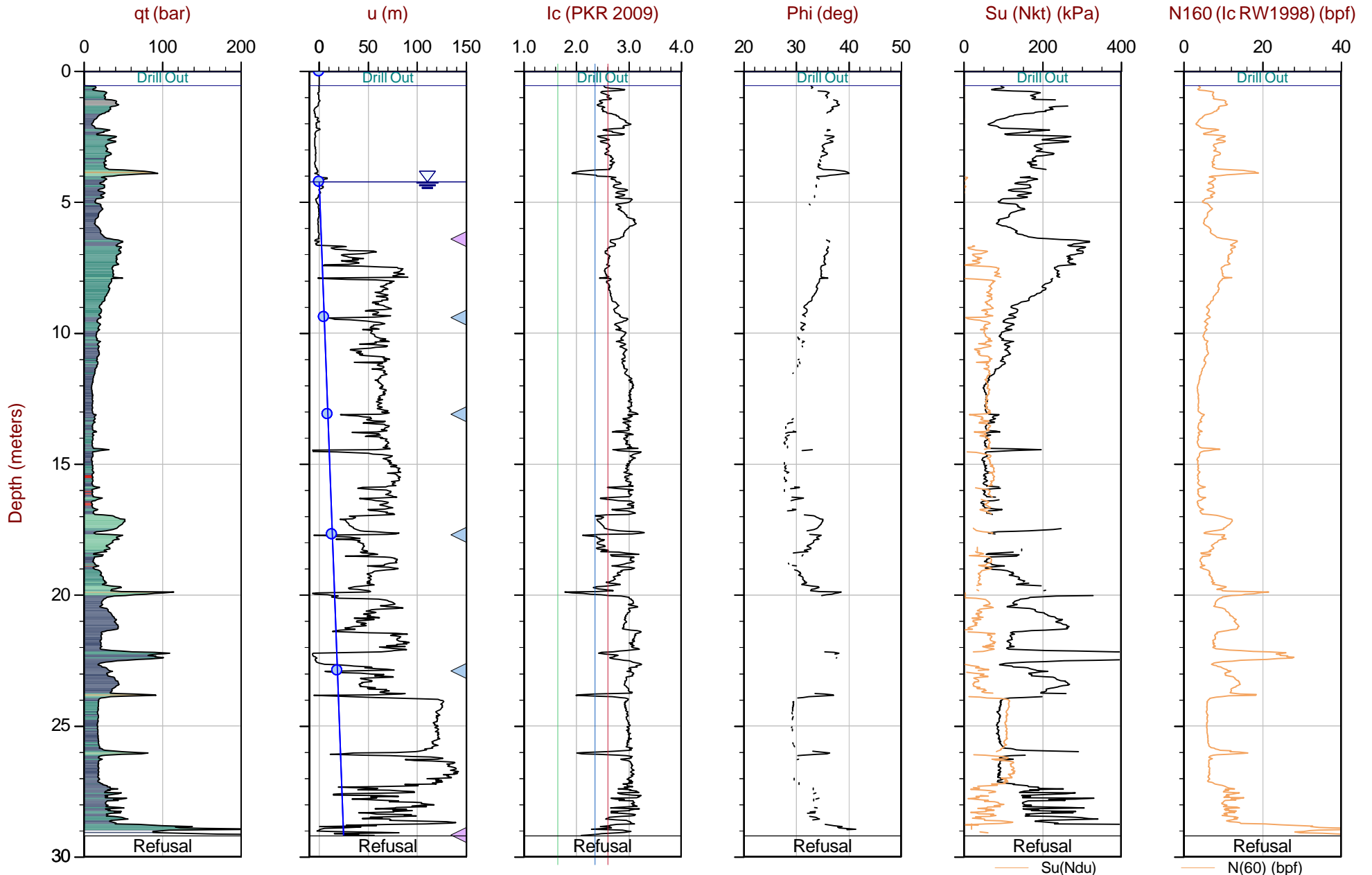
Job No: 19-05081

Date: 2019-11-22 10:36

Site: Highway 406 Welland Culvert

Sounding: CPT19-05

Cone: 408:T1500F15U500



Max Depth: 29.200 m / 95.80 ft

Depth Inc: 0.025 m / 0.082 ft

Avg Int: EveryPoint

File: 19-05081_CP05.COR

Unit Wt: SBTQtn(PKR2009)

Su Nkt/Ndu: 15.0 / 9.0

SBT: Robertson, 2009 and 2010

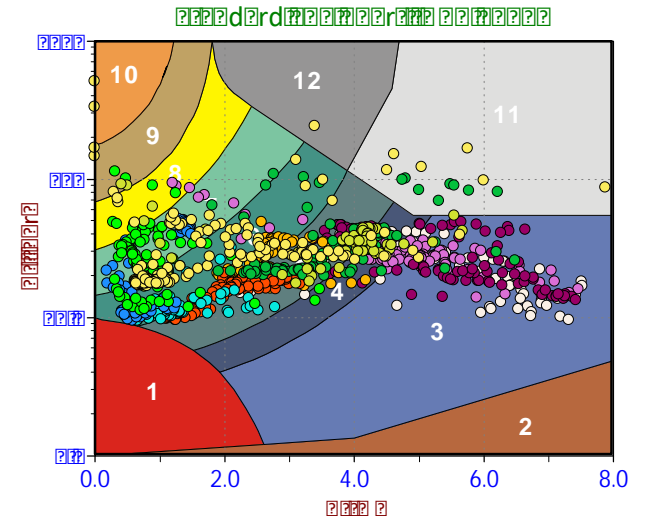
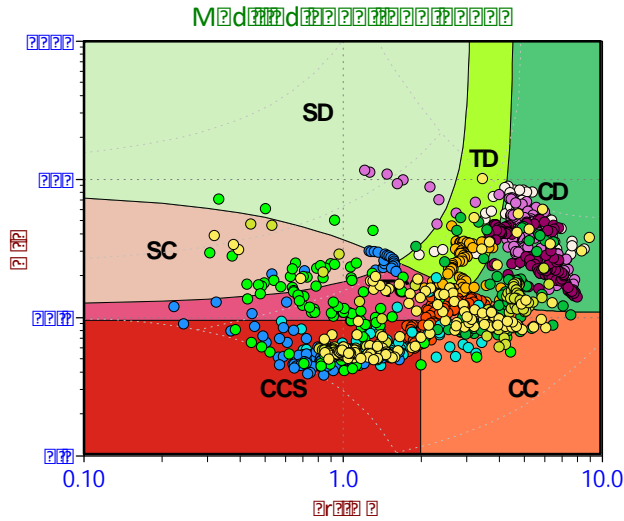
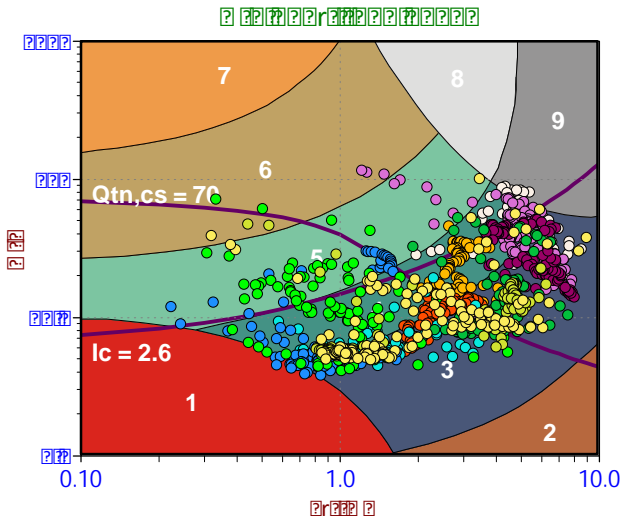
Coords: UTM11N: 4766985m E: 643739m

Sheet No: 1 of 1

● Equilibrium Pore Pressure (Ueq) ● Assumed Ueq ▲ Dissipation, Ueq achieved ▲ Dissipation, Ueq not achieved ▲ Dissipation, Ueq assumed — Hydrostatic Line

The reported coordinates were acquired from consumer grade GPS equipment and are only approximate locations. The coordinates should not be used for design purposes.

Soil Behaviour Type (SBT) Scatter Plots



Depth Ranges

- >0.0 to 2.5 m
- >2.5 to 5.0 m
- >5.0 to 7.5 m
- >7.5 to 10.0 m
- >10.0 to 12.5 m
- >12.5 to 15.0 m
- >15.0 to 17.5 m
- >17.5 to 20.0 m
- >20.0 to 22.5 m
- >22.5 to 25.0 m
- >25.0 m

Legend

- Sensitive, Fine Grained
- Organic Soils
- Clays
- Silt Mixtures
- Sand Mixtures
- Sands
- Gravelly Sand to Sand
- Stiff Sand to Clayey Sand
- Very Stiff Fine Grained

Legend

- CCS (Cont. sensitive clay like)
- CC (Cont. clay like)
- TC (Cont. transitional)
- SC (Cont. sand like)
- CD (Dil. clay like)
- TD (Dil. transitional)
- SD (Dil. sand like)

Legend

- Sensitive Fines
- Organic Soil
- Clay
- Silty Clay
- Clayey Silt
- Silt
- Sandy Silt
- Silty Sand/Sand
- Sand
- Gravelly Sand
- Stiff Fine Grained
- Cemented Sand

Pore Pressure Dissipation Summary and Pore Pressure Dissipation Plots



Job No: 19-05081
Client: Thurber Engineering
Project: Highway 406 Welland Culvert
Start Date: 22-Nov-2019
End Date: 22-Nov-2019

CPT_u PORE PRESSURE DISSIPATION SUMMARY

Sounding ID	File Name	Cone Area (cm ²)	Duration (s)	Test Depth (m)	Estimated Equilibrium Pore Pressure U _{eq} (m)	Calculated Phreatic Surface (m)	Estimated Phreatic Surface (m)	t ₅₀ ^a (s)	Assumed Rigidity Index (I _r)	c _h ^b (cm ² /min)
CPT19-05	19-05081_CP05	15	3405	6.400	Not Achieved					
CPT19-05	19-05081_CP05	15	740	9.400	5.2		4.2	497	100	1.4
CPT19-05	19-05081_CP05	15	1010	13.100	8.9		4.2	598	100	1.2
CPT19-05	19-05081_CP05	15	310	17.700	13.5		4.2	26	100	27.0
CPT19-05	19-05081_CP05	15	3020	22.900	18.7		4.2	1447	100	0.5
CPT19-05	19-05081_CP05	15	405	29.175	Not Achieved					

a. Time is relative to where u_{max} occurred.

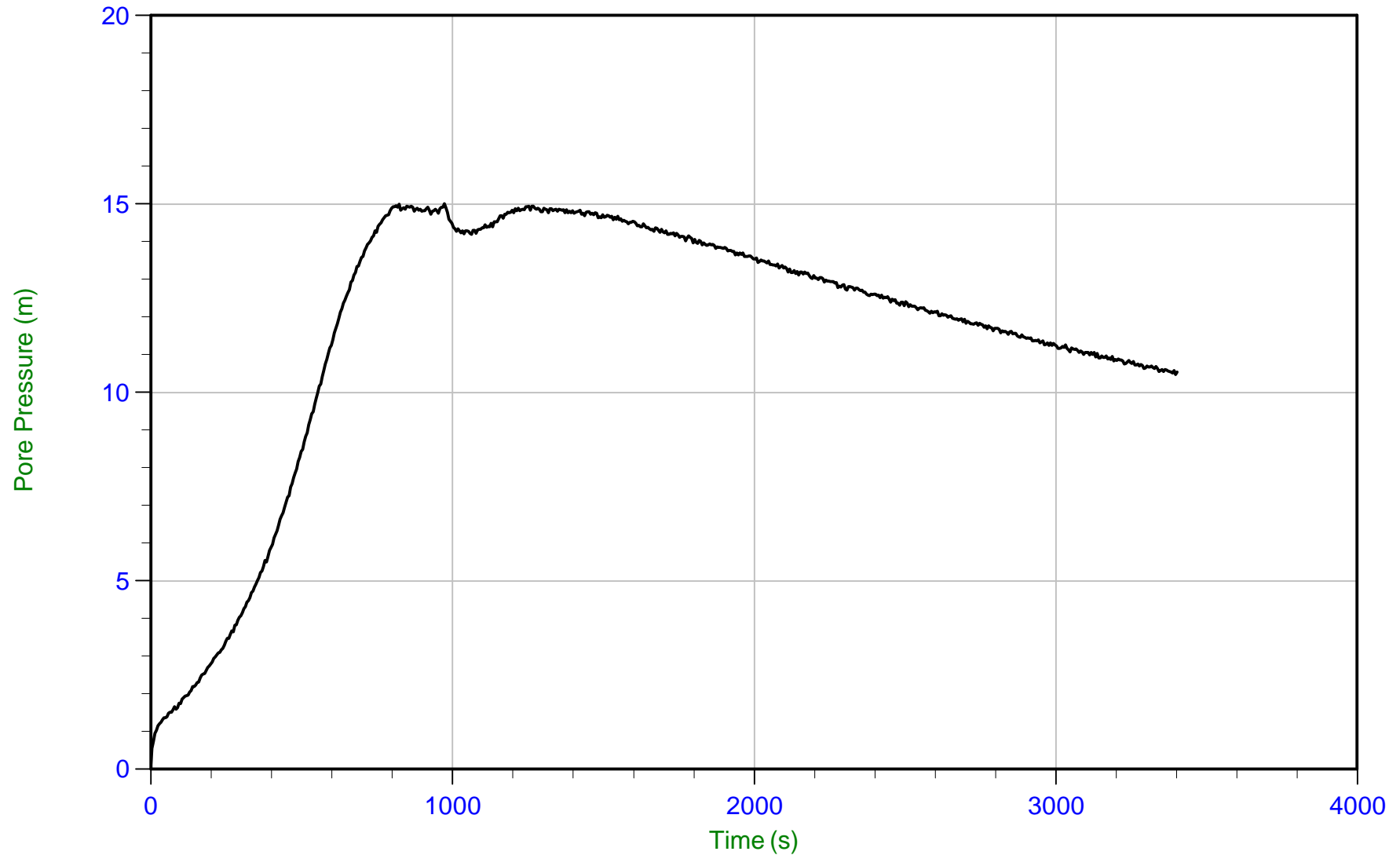
b. Houlsby and Teh, 1991.



Thurber Engineering

Job No: 19-05081
Date: 11/22/2019 10:36
Site: Highway 406 Welland Culvert

Sounding: CPT19-05
Cone: 408:T1500F15U500 Area=15 cm²



Trace Summary:

Filename: 19-05081_CP05.PPF
Depth: 6.400 m / 20.997 ft
Duration: 3405.0 s

u Min: 0.0 m
u Max: 15.0 m
u Final: 10.5 m



Thurber Engineering

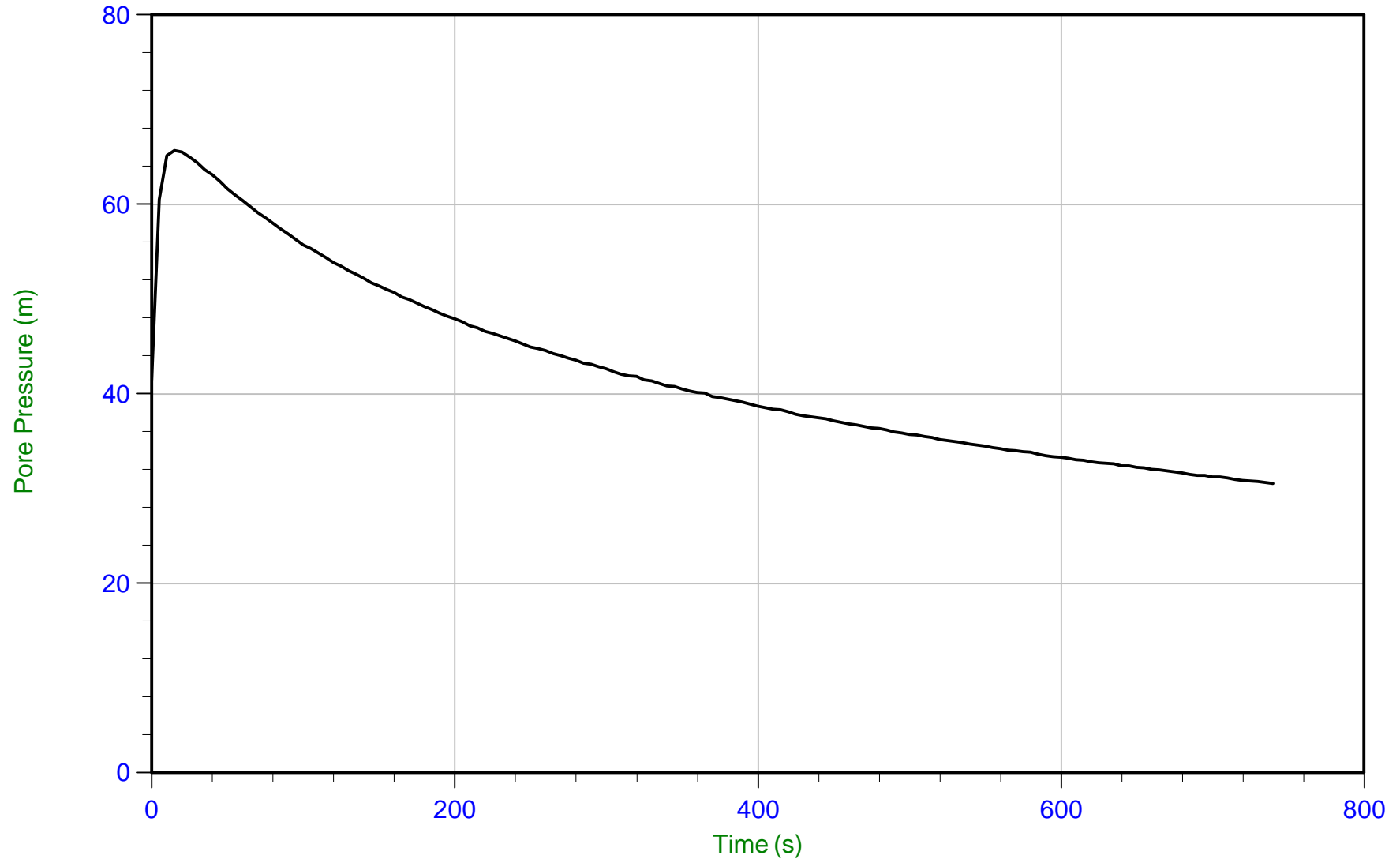
Job No: 19-05081

Date: 11/22/2019 10:36

Site: Highway 406 Welland Culvert

Sounding: CPT19-05

Cone: 408:T1500F15U500 Area=15 cm²



Trace Summary:

Filename: 19-05081_CP05.PPF

Depth: 9.400 m / 30.840 ft

Duration: 740.0 s

u Min: 30.5 m

u Max: 65.7 m

u Final: 30.5 m

WT: 4.226 m / 13.865 ft

Ueq: 5.2 m

U(50): 35.42 m

T(50): 497.4 s

Ir: 100

Ch: 1.4 cm²/min



Thurber Engineering

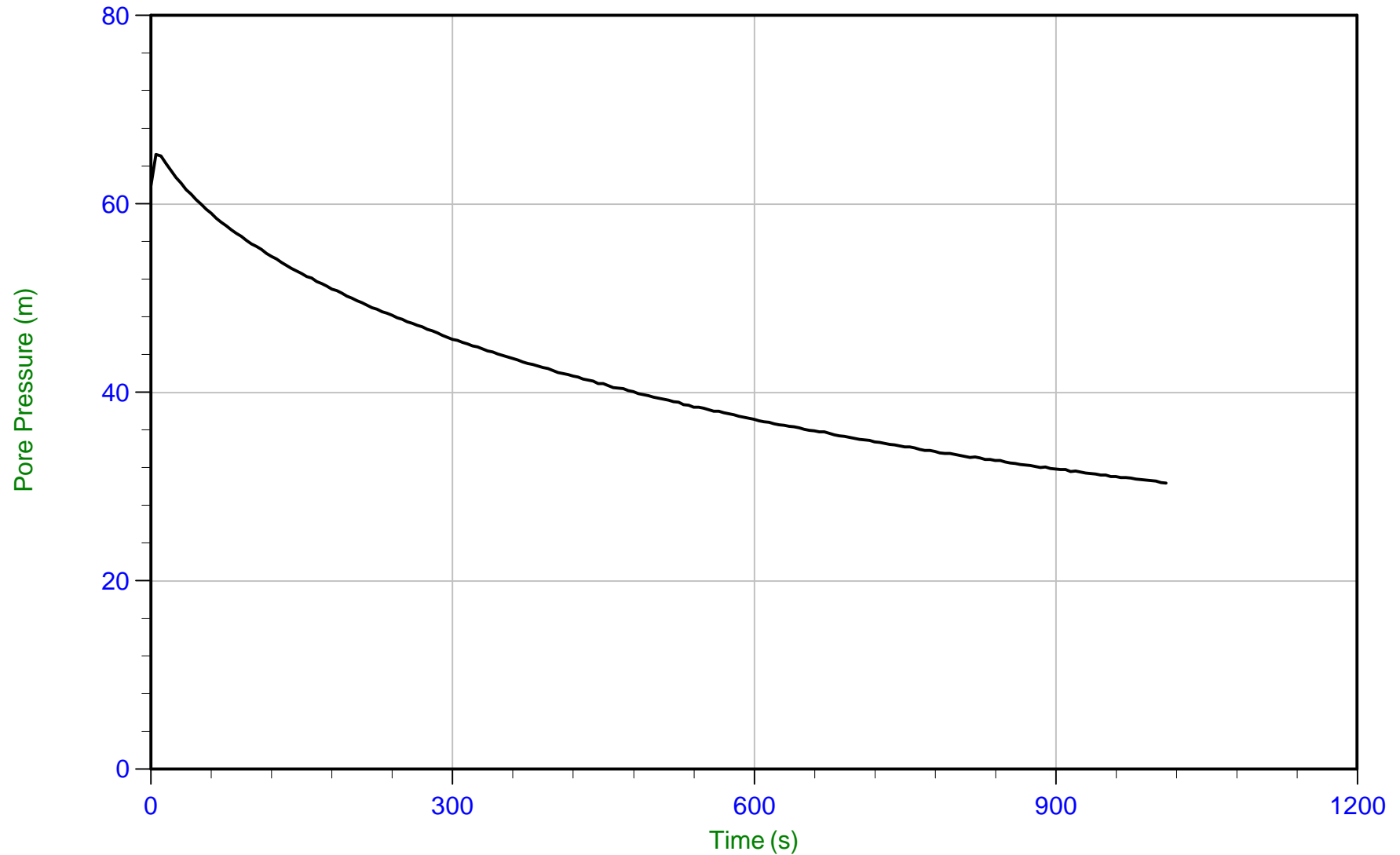
Job No: 19-05081

Date: 11/22/2019 10:36

Site: Highway 406 Welland Culvert

Sounding: CPT19-05

Cone: 408:T1500F15U500 Area=15 cm²



Trace Summary:

Filename: 19-05081_CP05.PPF

Depth: 13.100 m / 42.978 ft

Duration: 1010.0 s

u Min: 30.4 m

u Max: 65.3 m

u Final: 30.4 m

WT: 4.226 m / 13.865 ft

Ueq: 8.9 m

U(50): 37.07 m

T(50): 598.1 s

Ir: 100

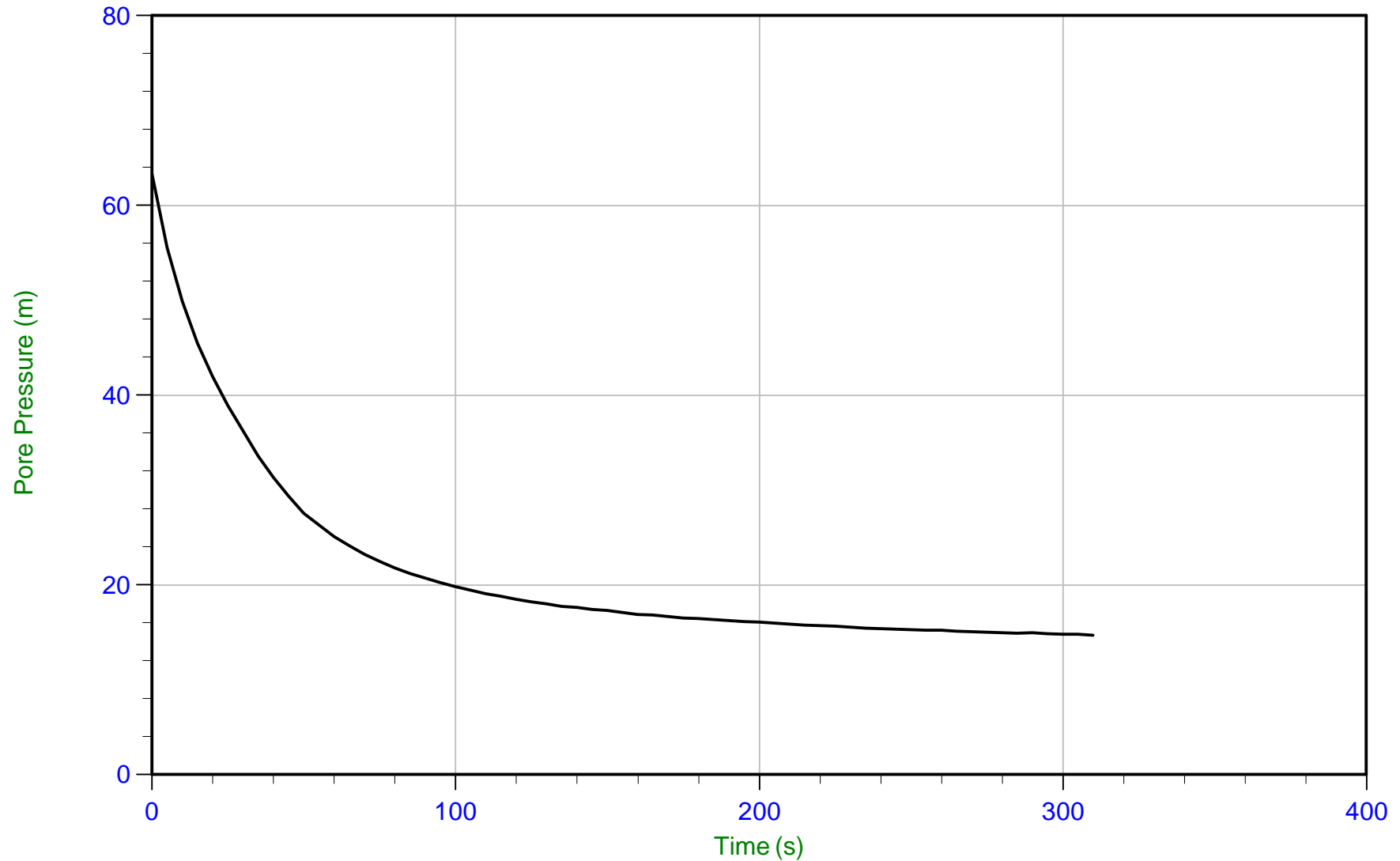
Ch: 1.2 cm²/min



Thurber Engineering

Job No: 19-05081
Date: 11/22/2019 10:36
Site: Highway 406 Welland Culvert

Sounding: CPT19-05
Cone: 408:T1500F15U500 Area=15 cm²



Trace Summary:

Filename: 19-05081_CP05.PPF
Depth: 17.700 m / 58.070 ft
Duration: 310.0 s

u Min: 14.7 m
u Max: 63.3 m
u Final: 14.7 m

WT: 4.226 m / 13.865 ft
Ueq: 13.5 m
U(50): 38.40 m

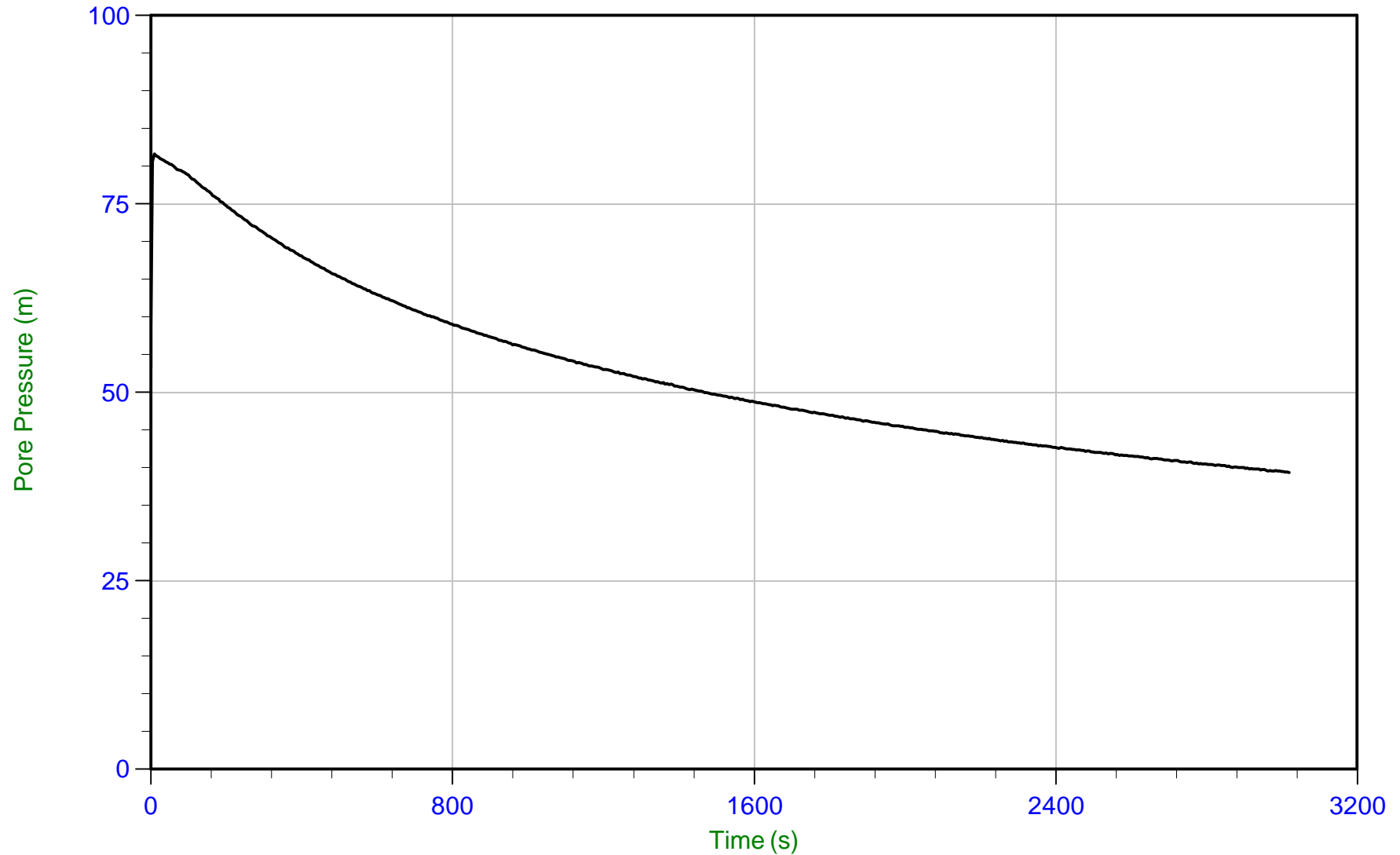
T(50): 26.0 s
Ir: 100
Ch: 27.0 cm²/min



Thurber Engineering

Job No: 19-05081
Date: 11/22/2019 10:36
Site: Highway 406 Welland Culvert

Sounding: CPT19-05
Cone: 408:T1500F15U500 Area=15 cm²



Trace Summary:

Filename: 19-05081_CP05.PPF
Depth: 22.900 m / 75.130 ft
Duration: 3020.0 s

u Min: 39.4 m
u Max: 81.7 m
u Final: 39.4 m

WT: 4.226 m / 13.865 ft
Ueq: 18.7 m
U(50): 50.17 m

T(50): 1447.2 s
Ir: 100
Ch: 0.5 cm²/min



Thurber Engineering

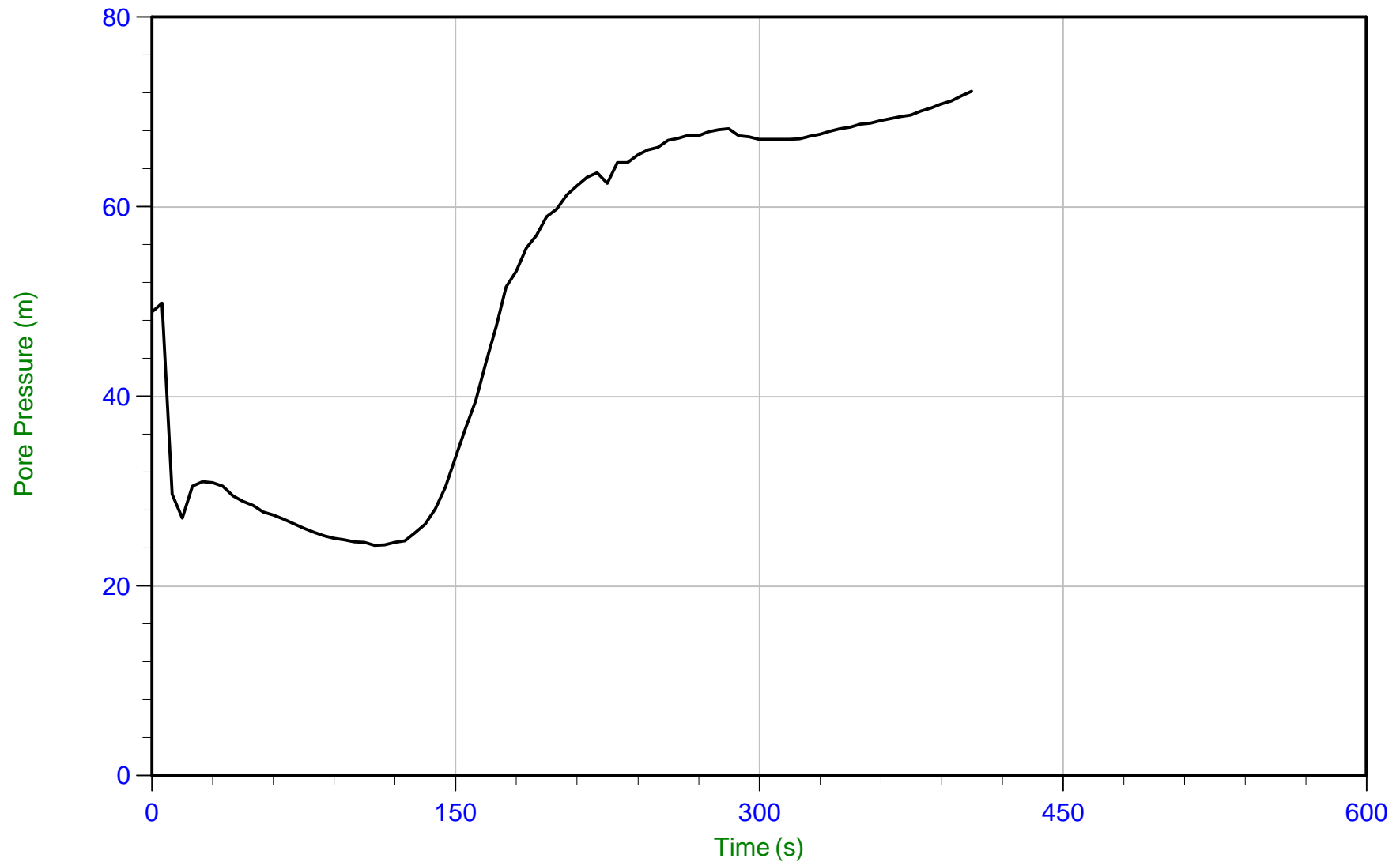
Job No: 19-05081

Date: 11/22/2019 10:36

Site: Highway 406 Welland Culvert

Sounding: CPT19-05

Cone: 408:T1500F15U500 Area=15 cm²



Trace Summary:

Filename: 19-05081_CP05.PPF

Depth: 29.175 m / 95.717 ft

Duration: 405.0 s

u Min: 24.3 m

u Max: 72.2 m

u Final: 72.2 m



Appendix D
Record of Borehole Sheets and Geotechnical Laboratory Test Results
Previous Investigation



Appendix D1
Boreholes C10-1 to C10-3

RECORD OF BOREHOLE No C10-1

1 OF 2

METRIC

W.P. 280-99-00 LOCATION Coords: N:4766880.1 E:326317.5 ORIGINATED BY PK
DIST HWY 406 BOREHOLE TYPE Solid Stem Augers COMPILED BY DB
DATUM Geodetic DATE 07.13.10 CHECKED BY RA

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT			PLASTIC LIMIT w _p	NATURAL MOISTURE CONTENT w	LIQUID LIMIT w _L	UNIT WEIGHT γ kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa							
								○ UNCONFINED	+ FIELD VANE	× LAB VANE					
177.1	Ground Surface					20	40	60	80	100					
176.9	230mm TOPSOIL														
0.2	sandy SILTY CLAY trace sand, firm to very stiff, brown, damp to moist		1	SS	7										
			2	SS	17										
			3	SS	21										
			4	SS	22										
			5	SS	16										
			6	SS	10										
172.7	SILT trace clay, compact, brown, wet		7	SS	11										
171.5	SILTY CLAY trace sand, firm to stiff, brown, moist		8	SS	6										
5.6															
			9	SS	5										
			10	TW	PH										
166.6	SILT trace to some clay, very loose to dense, brown, wet		11	SS	2										
10.5															
164.4	End of Borehole		12	SS	37										
12.7															

Continued Next Page

+³, X³: Numbers refer to Sensitivity ○ 3% STRAIN AT FAILURE

ONTARIO MOT 1-09-4135 CULVERTS2 (KELVIN) GPJ ONTARIO MOT.GDT 09/10/10

RECORD OF BOREHOLE No C10-1

2 OF 2

METRIC

W.P. 280-99-00 LOCATION Coords: N:4766880.1 E:326317.5 ORIGINATED BY PK
 DIST HWY 406 BOREHOLE TYPE Solid Stem Augers COMPILED BY DB
 DATUM Geodetic DATE 07.13.10 CHECKED BY RA

SOIL PROFILE		SAMPLES				GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					PLASTIC NATURAL LIQUID LIMIT MOISTURE LIMIT CONTENT			UNIT WEIGHT γ kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			20	40	60	80	100	W _p	W	W _L		
	Piezometer installation consists of a 19mm diameter, Schedule 40 PVC pipe with a 1.52m slotted screen. Water Level Readings: Date Depth(m) Elevation(m) July.19.10 0.1 177.0 Aug.06.10 0.0 177.1 Aug.13.10 0.0 177.1 Aug.23.10 0.0 177.1																

ONTARIO MOT 1-09-4135 CULVERTS2 (KELVIN).GPJ ONTARIO MOT.GDT 09/10/10

RECORD OF BOREHOLE No C10-2

1 OF 2

METRIC

W.P. 280-99-00 LOCATION Coords: N:4766912.0 E:326352.7 ORIGINATED BY BL
 DIST HWY 406 BOREHOLE TYPE Hollow Stem Augers COMPILED BY DB
 DATUM Geodetic DATE 07.14.10 CHECKED BY RA

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT W _p	NATURAL MOISTURE CONTENT W	LIQUID LIMIT W _L	UNIT WEIGHT γ kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			20 40 60 80 100	20 40 60 80 100					
181.7	Ground Surface													
0.0	FILL - Gravelly Sand, some silt, trace clay, compact, reddish brown, damp to moist		1	SS	17		181							26 56 14 4
181.0			2	SS	5		180							
0.7	FILL - Silty Clay, trace sand, soft to stiff, brown, damp to moist		3	SS	4		179							
			4	SS	12		178							
			5	SS	4		177							0 3 57 40
			6	SS	3		176							
			7	SS	6		175							
176.1			8	SS	19		174							
5.6	SILTY CLAY trace sand, brown, damp to moist		9	SS	16		173							
			10	SS	3		172							0 4 57 39
	very stiff — firm to stiff		11	SS	WOH		171							
			12	SS	WOH		170							
			13	SS	4		169							
	frequent silt layers						168							
							167							

Continued Next Page

+³, X³: Numbers refer to
Sensitivity

○ 3% STRAIN AT FAILURE

ONTARIO MOT 1-09-4135 CULVERTS2 (KELVIN).GPJ, ONTARIO MOT.GDT, 09/13/10

RECORD OF BOREHOLE No C10-3

1 OF 2

METRIC

W.P. 280-99-00 LOCATION Coords: N:4766953.3 E:326381.6 ORIGINATED BY PK
 DIST HWY 406 BOREHOLE TYPE Solid Stem Augers COMPILED BY DB
 DATUM Geodetic DATE 07.14.10 CHECKED BY RA

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT w _p	NATURAL MOISTURE CONTENT w	LIQUID LIMIT w _L	UNIT WEIGHT γ kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa						
178.5	Ground Surface													
178.3	230mm TOPSOIL		1	SS	7									
0.2	FILL - Silty Clay, trace sand to sandy, trace organics, firm to stiff, brown, moist		2	SS	11									
			3	SS	14									
176.4	SILTY CLAY trace sand, very stiff to hard, brown, damp to moist		4	SS	31									
2.1			5	SS	31								0 8 54 38	
			6	SS	31								0 4 59 37	
			7	SS	26									
			8	SS	15								0 3 55 42	
	firm to very stiff		9	TW	PH									
	frequent silt layers		10	SS	7									
			11	SS	16								0 0 82 18	
			12	SS	8									
165.3	SILT trace clay, loose to compact, brown, wet		13	SS	9									
13.2														

ONTARIO MOT 1-09-4135 CULVERTS2 (KELVIN).GPJ ONTARIO MOT.GDT 09/13/10

Continued Next Page

+³, X³: Numbers refer to Sensitivity ○ 3% STRAIN AT FAILURE

RECORD OF BOREHOLE No C10-3

2 OF 2

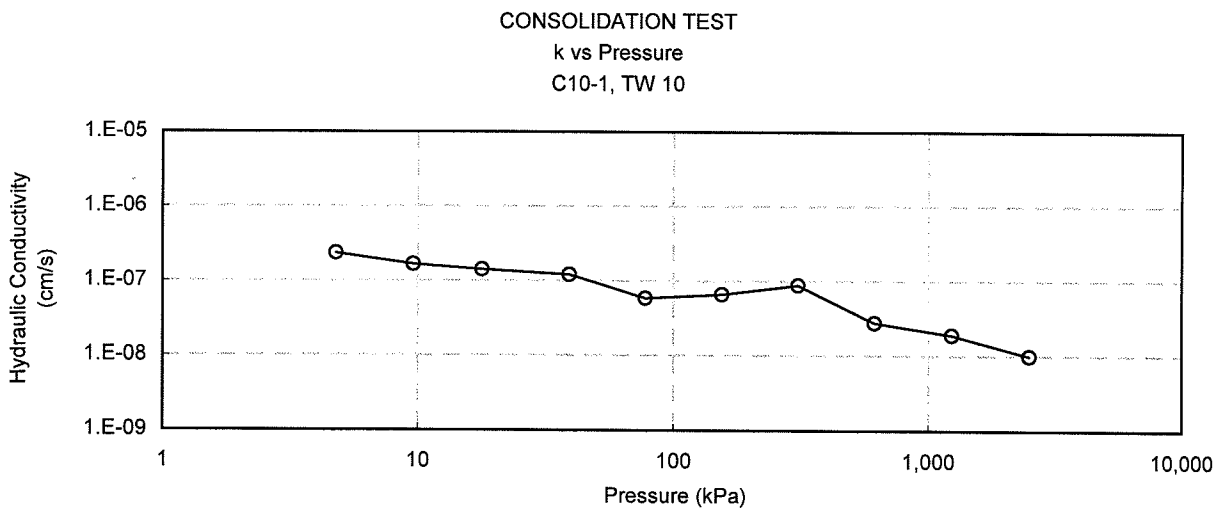
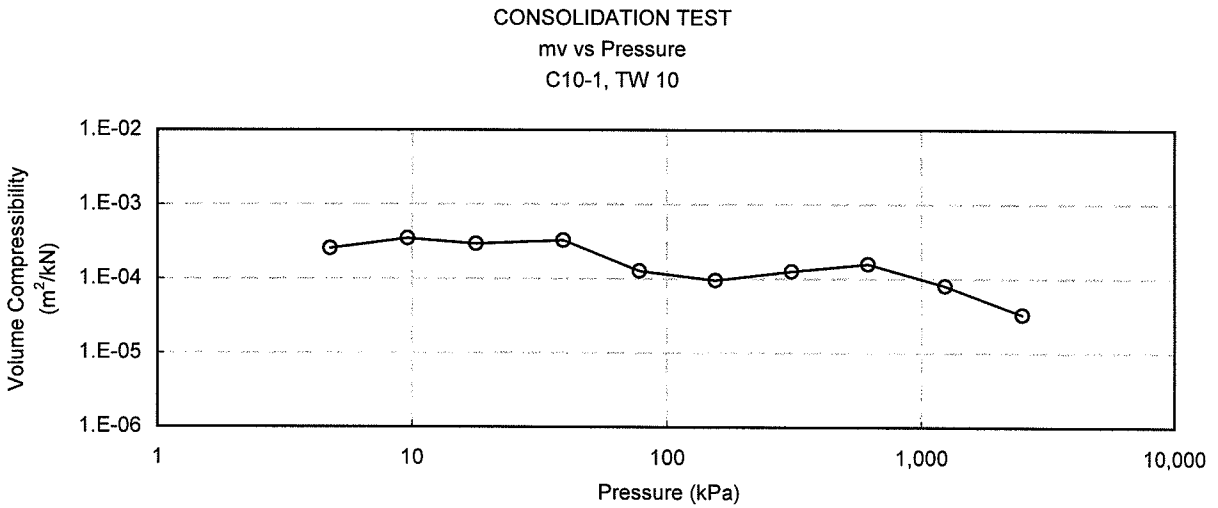
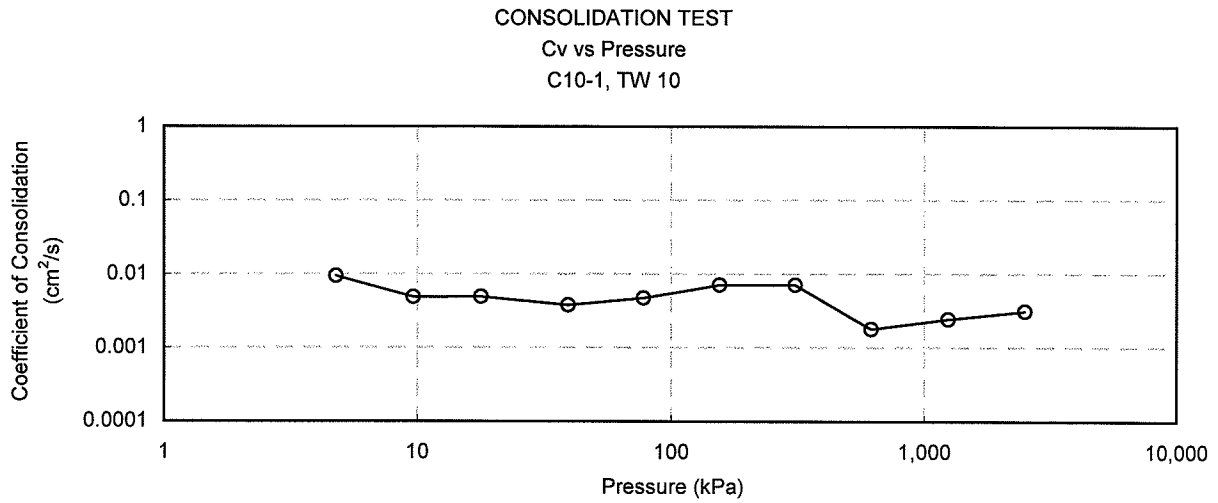
METRIC

W.P. 280-99-00 LOCATION Coords: N:4766953.3 E:326381.6 ORIGINATED BY PK
DIST HWY 406 BOREHOLE TYPE Solid Stem Augers COMPILED BY DB
DATUM Geodetic DATE 07.14.10 CHECKED BY RA

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					PLASTIC NATURAL LIQUID LIMIT MOISTURE CONTENT LIMIT			UNIT WEIGHT γ kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL												
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa					WATER CONTENT (%)																
							20	40	60	80	100	W _p	W	W _L															
162.3			14	SS	21		163																						
16.2	SILTY CLAY trace sand, hard, brown, damp to moist						162																						
161.2			15	SS	33																								
17.3	End of Borehole																												
	<p>Sampler wet at 9.1m.</p> <p>Water level at 8.5m (not stabilized) and hole open to 15.2m on completion.</p> <p>Piezometer installation consists of a 19mm diameter, Schedule 40 PVC pipe with a 1.52m slotted screen.</p> <p>Water Level Readings:</p> <table border="1"> <thead> <tr> <th>Date</th> <th>Depth(m)</th> <th>Elevation(m)</th> </tr> </thead> <tbody> <tr> <td>July.20.10</td> <td>1.5</td> <td>177.0</td> </tr> <tr> <td>July.27.10</td> <td>1.1</td> <td>177.4</td> </tr> <tr> <td>Aug.06.10</td> <td>1.1</td> <td>177.4</td> </tr> </tbody> </table>	Date	Depth(m)	Elevation(m)	July.20.10	1.5	177.0	July.27.10	1.1	177.4	Aug.06.10	1.1	177.4																
Date	Depth(m)	Elevation(m)																											
July.20.10	1.5	177.0																											
July.27.10	1.1	177.4																											
Aug.06.10	1.1	177.4																											

HWY 406 TWINNING - CULVERT#10

FIGURE B7-11



c:\Documents and Settings\Admin\My Documents\Marc P\Projects 2009\Hwy 406 Expansion\1-09-4135 (Hwy 406 Foundations)\Culverts and Retaining Walls\Culverts\Lab Results\1-09-4135 Consolidation Results.xls

Project No. : 1-09-4135
Date : November 2010



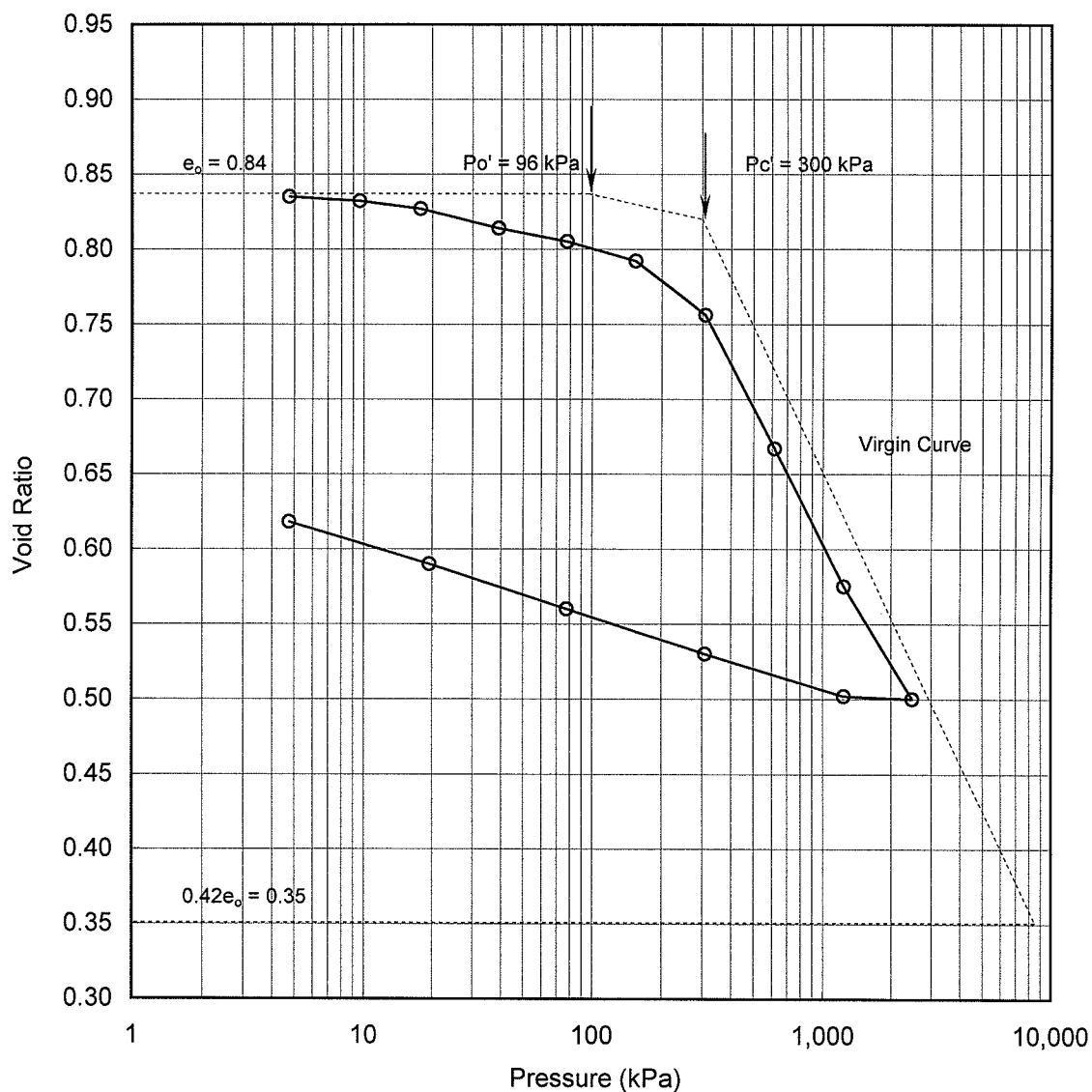
Terraprobe Inc.

Prepared By : HW
Checked By : RA

CONSOLIDATION TEST

e vs Pressure

C10-1, TW 10



Soil Type : Silty Clay

$e_o =$	0.84	$\omega_L =$	35%	$P_o' =$	96 kPa
$\omega =$	22%	$\omega_p =$	19%	$P_c' =$	300 kPa
$\gamma =$	20.7 kN/m ³	PI =	17%	Cc =	0.323
Gs =	2.81			Cr =	0.034

Project No. : 1-09-4135
 Date : November 2010



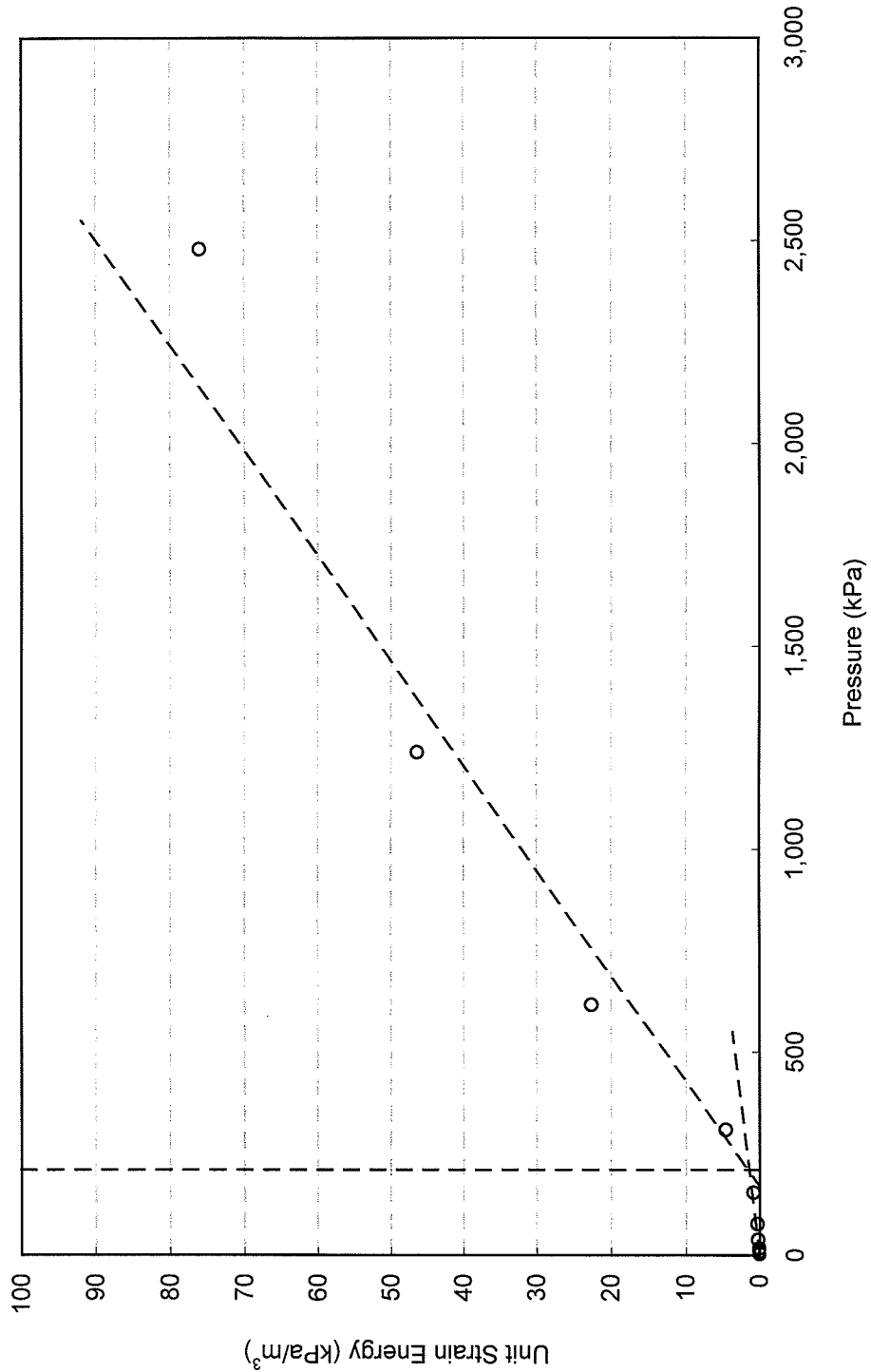
Terraprobe Inc.

Prepared By : HW
 Checked By : RA

HWY 406 TWINNING - CULVERT#10

FIGURE B7-13

CONSOLIDATION TEST Unit Strain Energy vs Pressure C10-1, TW 10



Pc = 210 kPa

Project No. : 1-09-4135
Date : November 2010



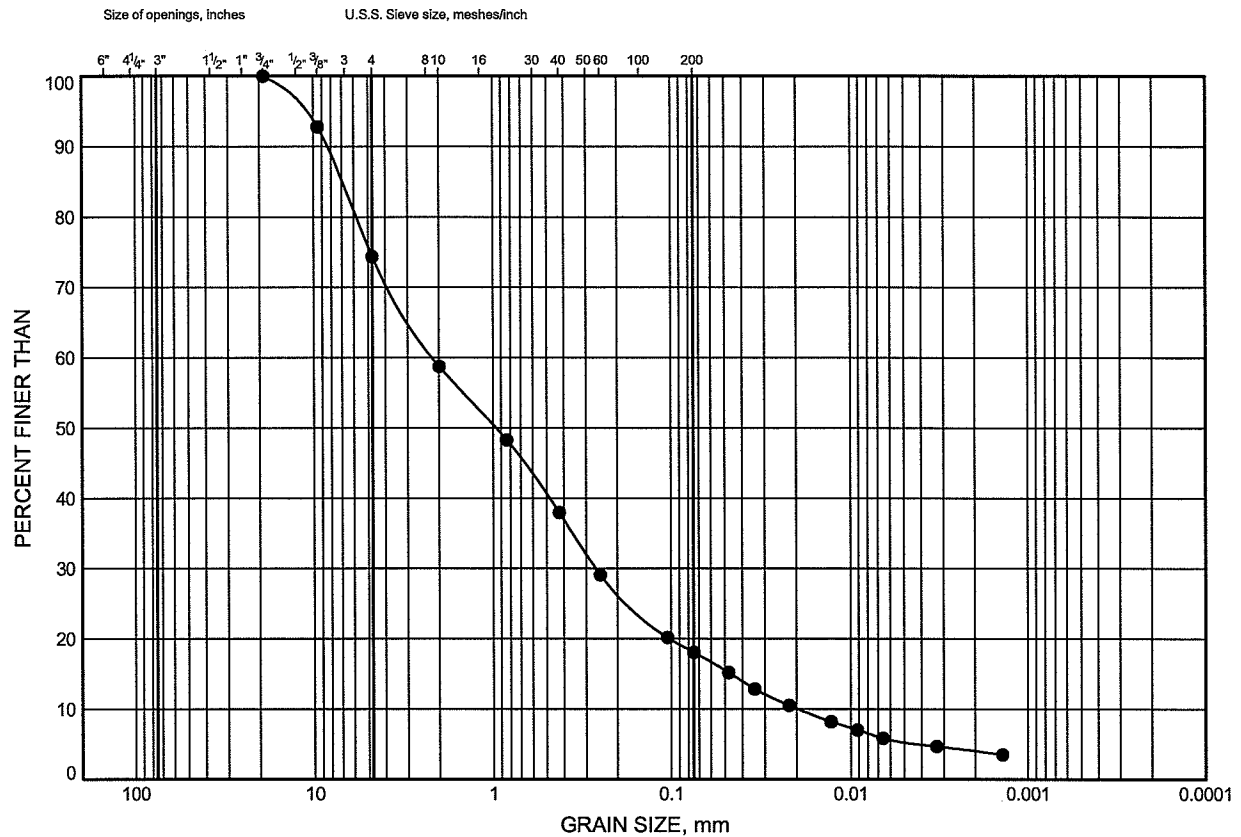
Terraprobe Inc.

Prepared By : HW
Checked By : RA

GRAIN SIZE DISTRIBUTION

FIGURE B7-1

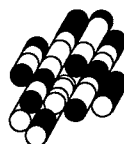
FILL - Gravelly Sand



COBBLE SIZE	COARSE	FINE	COARSE	MEDIUM	FINE	SILT and CLAY
	GRAVEL		SAND			FINE GRAINED

SYMBOL	BOREHOLE	DEPTH (m)	ELEVATION (m)
●	C10-2	0.3	181.4

Date November 2010
Project 1-09-4135

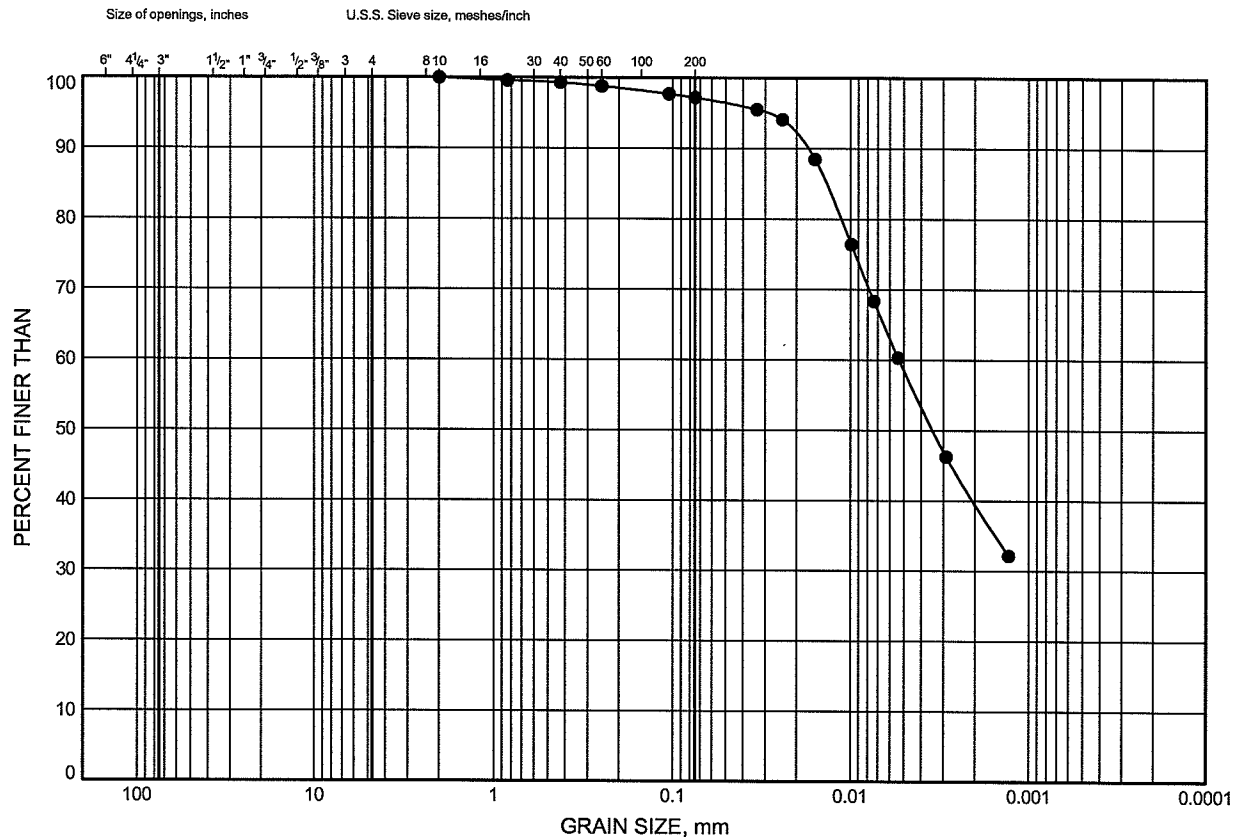


Prep'd K.L.
Chkd. M.P.

GRAIN SIZE DISTRIBUTION

FIGURE B7-2

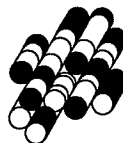
FILL - Silty Clay



COBBLE SIZE	COARSE	FINE	COARSE	MEDIUM	FINE	SILT and CLAY
	GRAVEL		SAND			FINE GRAINED

SYMBOL	BOREHOLE	DEPTH (m)	ELEVATION (m)
●	C10-2	3.2	178.5

Date November 2010
Project 1-09-4135

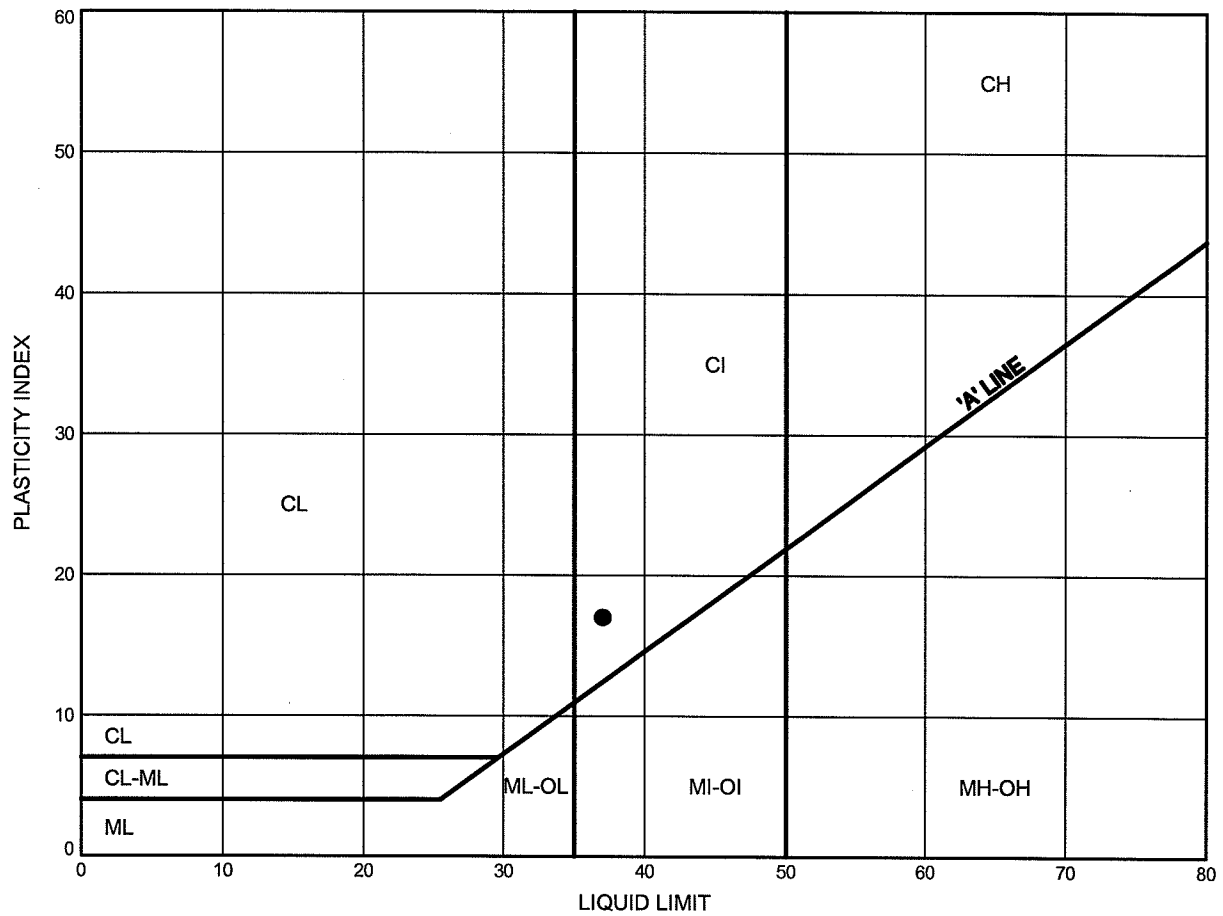


Prep'd K.L.
Chkd. M.P.

ATTERBERG LIMITS TEST RESULTS

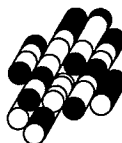
FIGURE B7-3

FILL - Silty Clay



SYMBOL	BOREHOLE	DEPTH (m)	ELEVATION (m)
●	C10-2	3.2	178.5

Date November 2010
 Project 1-09-4135

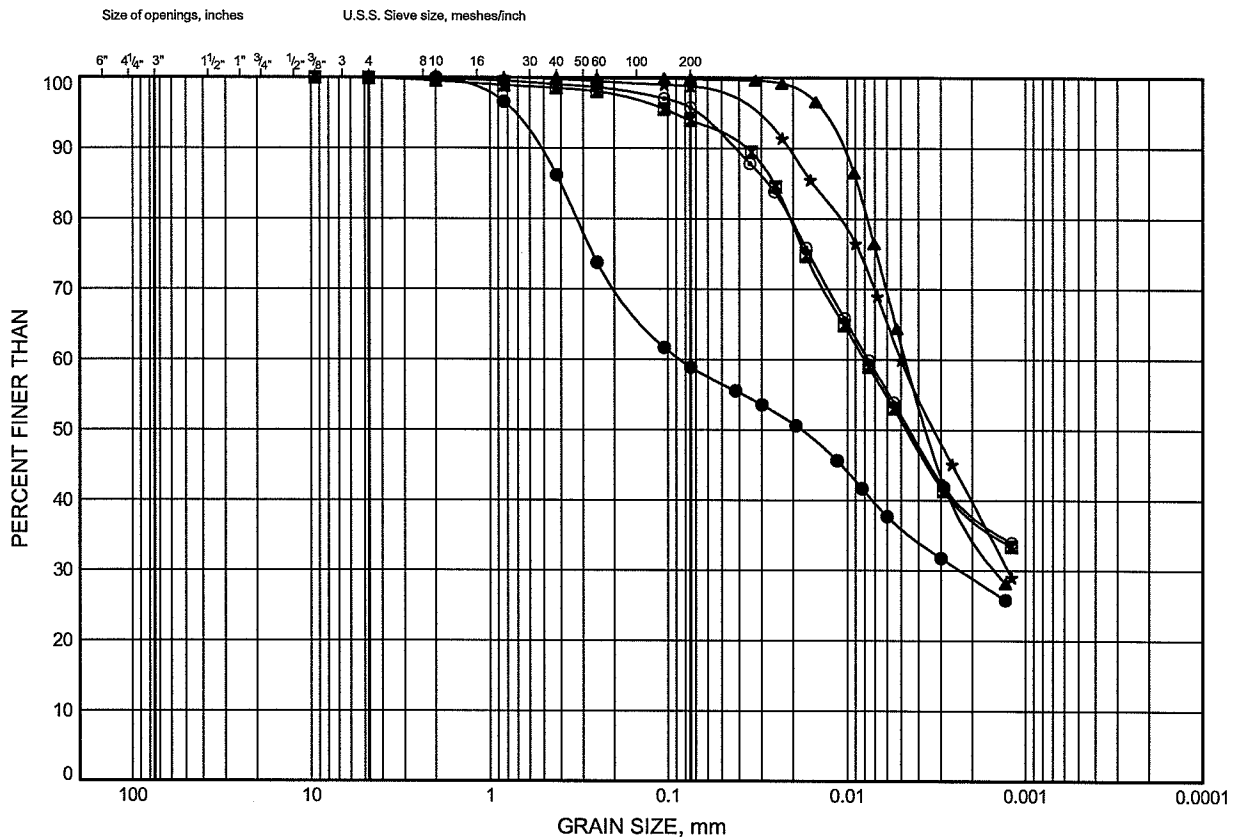


Prep'd K.L.
 Chkd. M.P.

GRAIN SIZE DISTRIBUTION

FIGURE B7-4

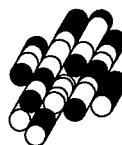
SILTY CLAY



COBBLE SIZE	COARSE	FINE	COARSE	MEDIUM	FINE	SILT and CLAY
	GRAVEL		SAND			FINE GRAINED

SYMBOL	BOREHOLE	DEPTH (m)	ELEVATION (m)
●	C10-1	1.0	176.1
■	C10-1	2.5	174.6
▲	C10-1	7.8	169.3
★	C10-1	9.3	167.8
⊙	C10-2	9.3	172.4

Date November 2010
Project 1-09-4135

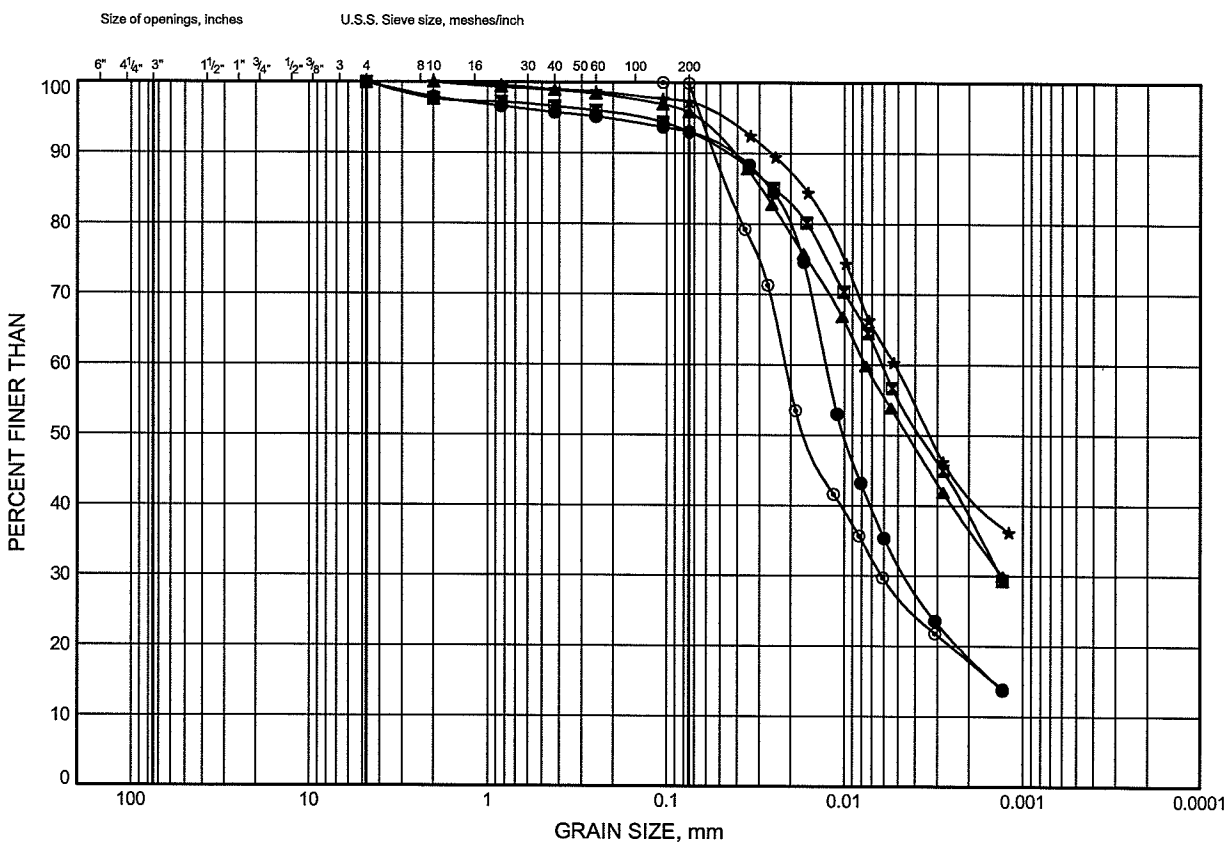


Prep'd K.L.
Chkd. M.P.

GRAIN SIZE DISTRIBUTION

FIGURE B7-5

SILTY CLAY

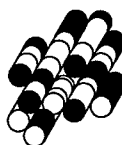


COBBLE SIZE	COARSE	FINE	COARSE	MEDIUM	FINE	SILT and CLAY
	GRAVEL		SAND			FINE GRAINED

SYMBOL	BOREHOLE	DEPTH (m)	ELEVATION (m)
●	C10-2	21.5	160.2
■	C10-3	3.2	175.3
▲	C10-3	4.0	174.5
★	C10-3	6.3	172.2
⊙	C10-3	10.9	167.6

Date November 2010

Project 1-09-4135



Prep'd K.L.

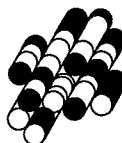
Chkd. M.P.

FIGURE B7-6

SYMBOL	BOREHOLE	DEPTH (m)	ELEVATION (m)
●	C10-1	1.0	176.1
⊠	C10-1	2.5	174.6
▲	C10-1	7.8	169.3
★	C10-1	9.3	167.8
⊙	C10-2	9.3	172.4

Prep'dK.L.....

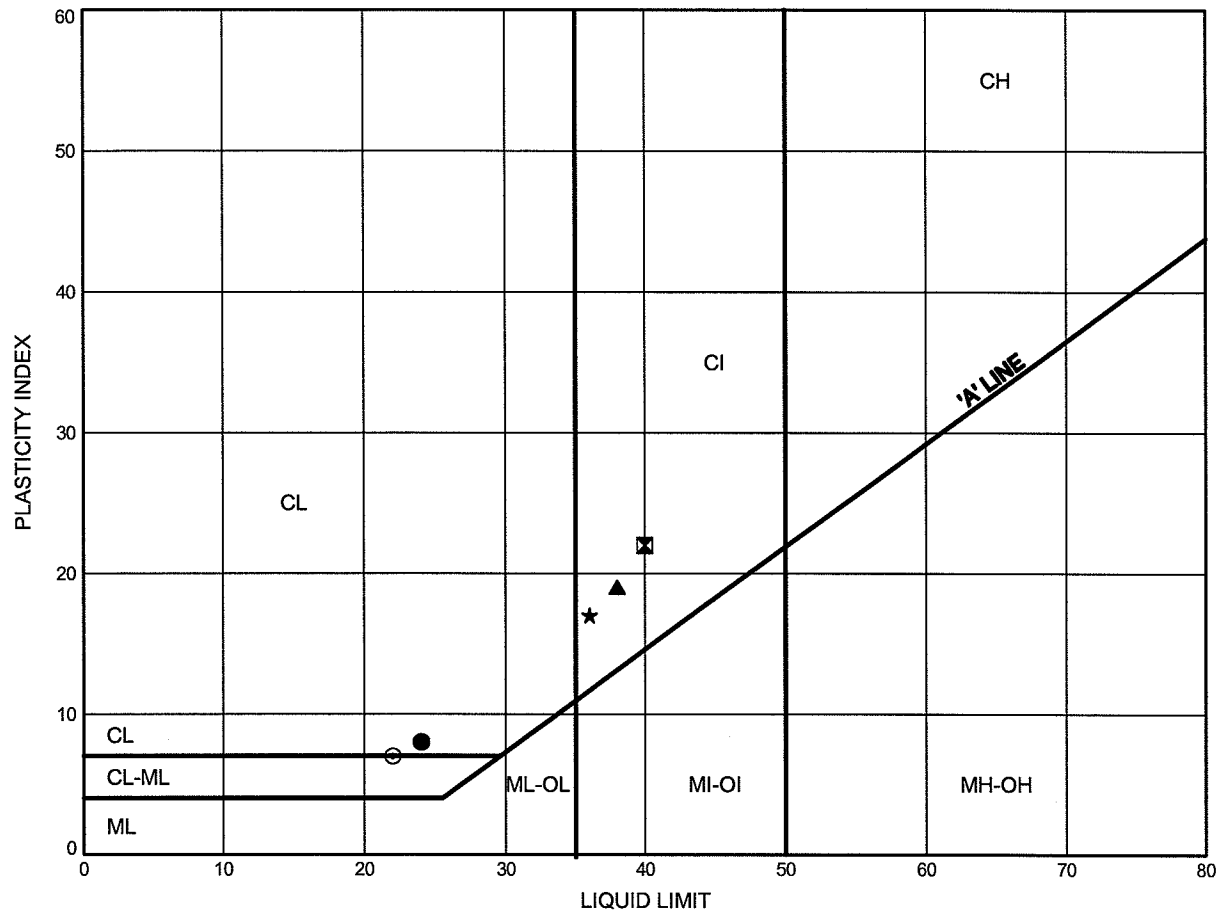
Chkd. M.P.



ATTERBERG LIMITS TEST RESULTS

FIGURE B7-7

SILTY CLAY



SYMBOL	BOREHOLE	DEPTH (m)	ELEVATION (m)
●	C10-2	21.5	160.2
⊠	C10-3	3.2	175.3
▲	C10-3	4.0	174.5
★	C10-3	6.3	172.2
⊙	C10-3	10.9	167.6

Date November 2010
Project 1-09-4135

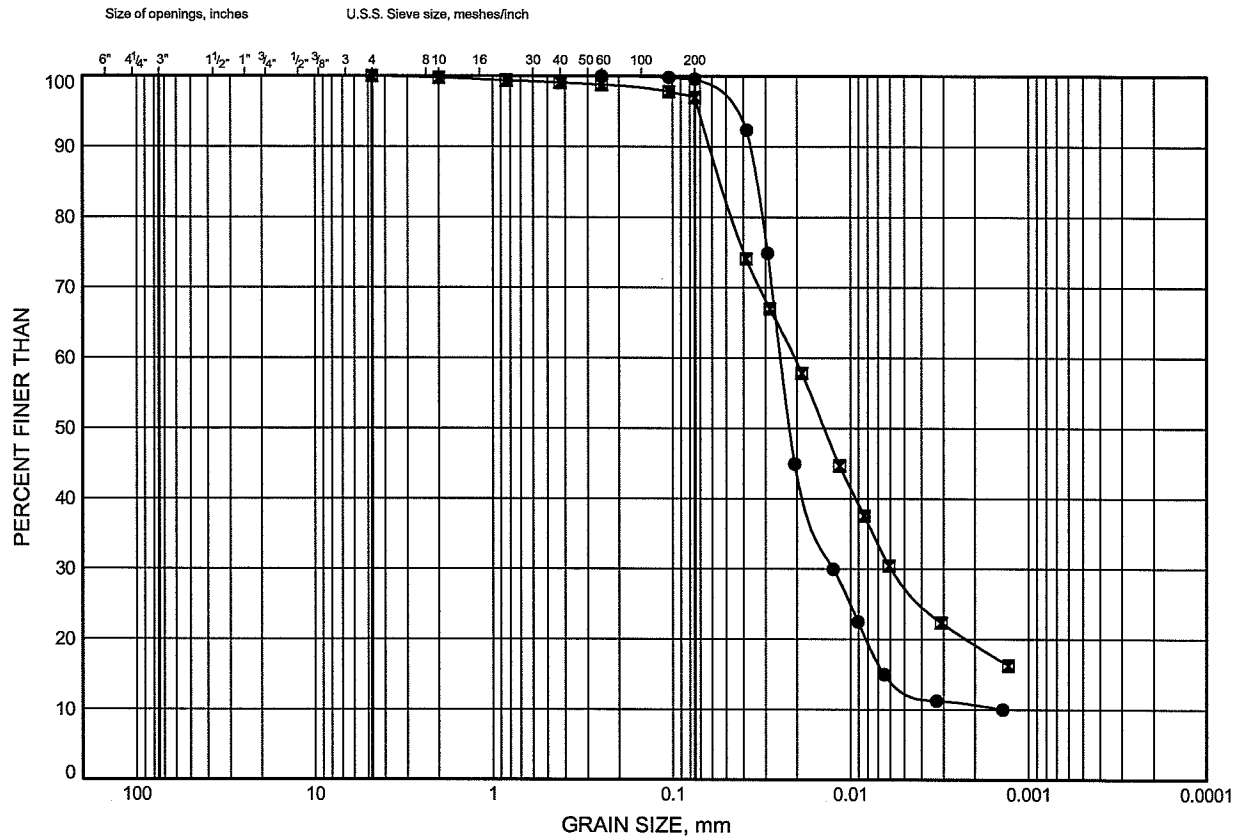


Prep'd K.L.
Chkd. M.P.

GRAIN SIZE DISTRIBUTION

FIGURE B7-8

SILT



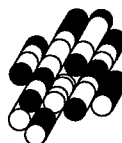
COBBLE SIZE	COARSE	FINE	COARSE	MEDIUM	FINE	SILT and CLAY
	GRAVEL		SAND			FINE GRAINED

SYMBOL BOREHOLE DEPTH (m) ELEVATION (m)

●	C10-1	10.9	166.2
■	C10-2	17.0	164.7

Date November 2010

Project 1-09-4135



Prep'd K.L.

Chkd. M.P.

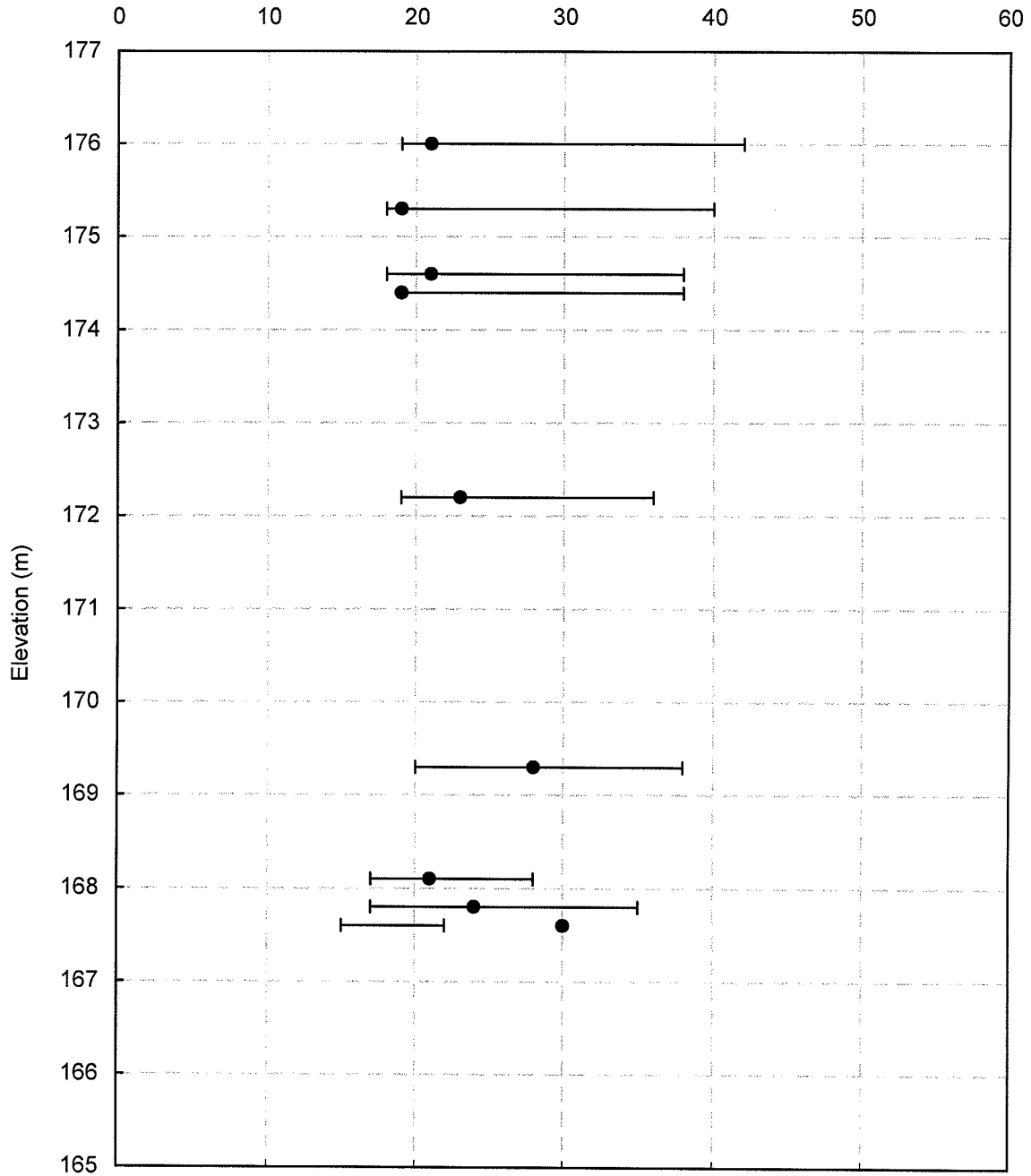
ATTERBERG LIMITS AND WATER CONTENTS

FIGURE B7-9

HWY 406 TWINNING - CULVERT #10

Silty Clay

Atterberg Limits & Water Contents (%)



Project No. : 1-09-4135

Date : November, 2010



Terraprobe Inc.

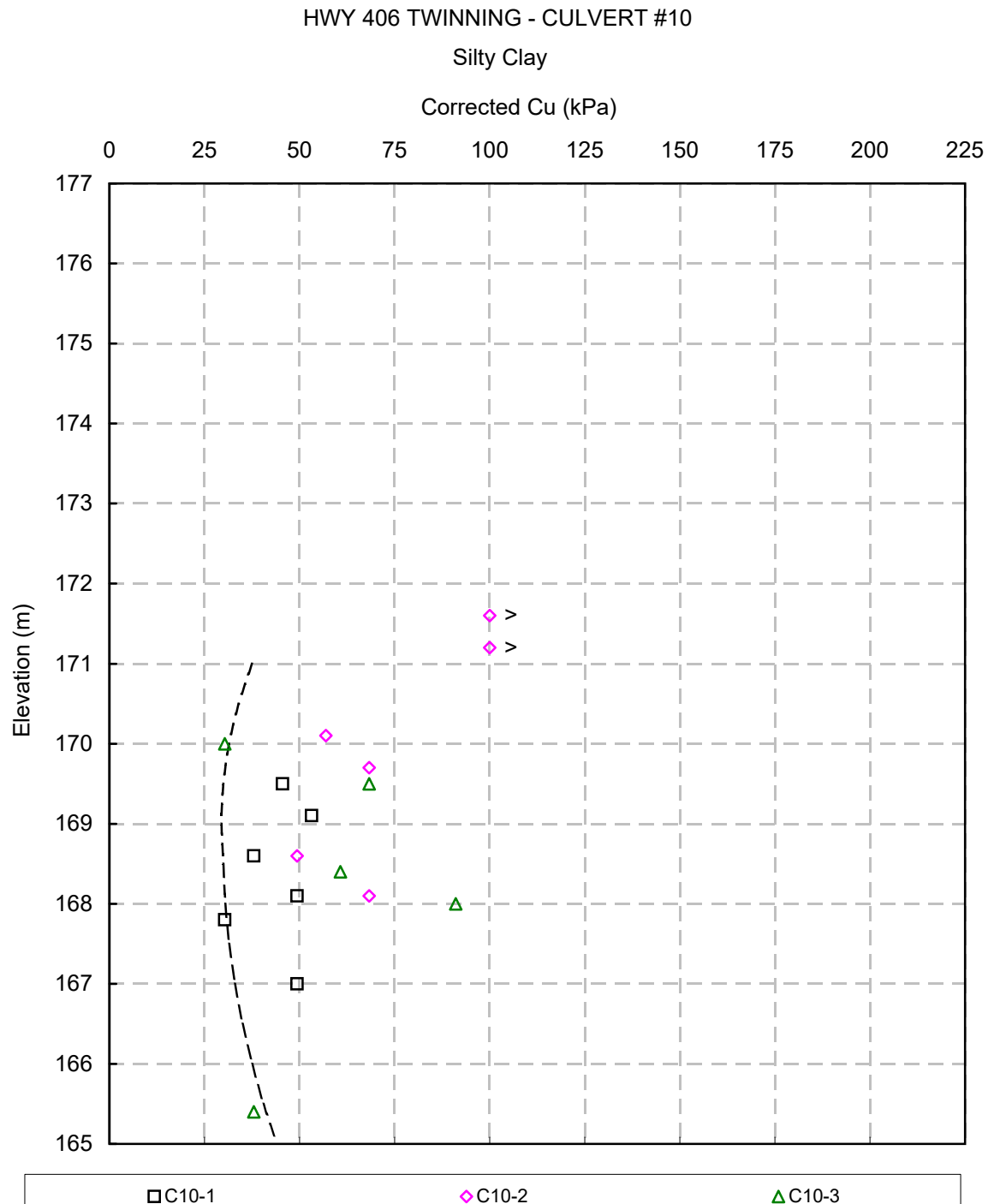
Prepared By : HW

Checked By : RA

CORRECTED UNDRAINED SHEAR STRENGTH

FIGURE B7-10

C:\Documents and Settings\Admin\My Documents\Marc P\Projects 2009\Hwy 406 Expansion\1-09-4135 (Hwy 406 Foundations)\Culverts and Retaining Walls\Culverts\Lab Results\1-09-4135C10 Soil Parameter Estimation.xls



Field Shear Vane Correction

Morris & Williams (1994)
 $(\mu = 1.18 \text{ EXP}(-0.08 I_p) + 0.57)$

Applied Correction Factors

0.78 (Elev. > 174m) 0.95 (Elev. < 174m)

Project No. : 1-09-4135

Date : November, 2010



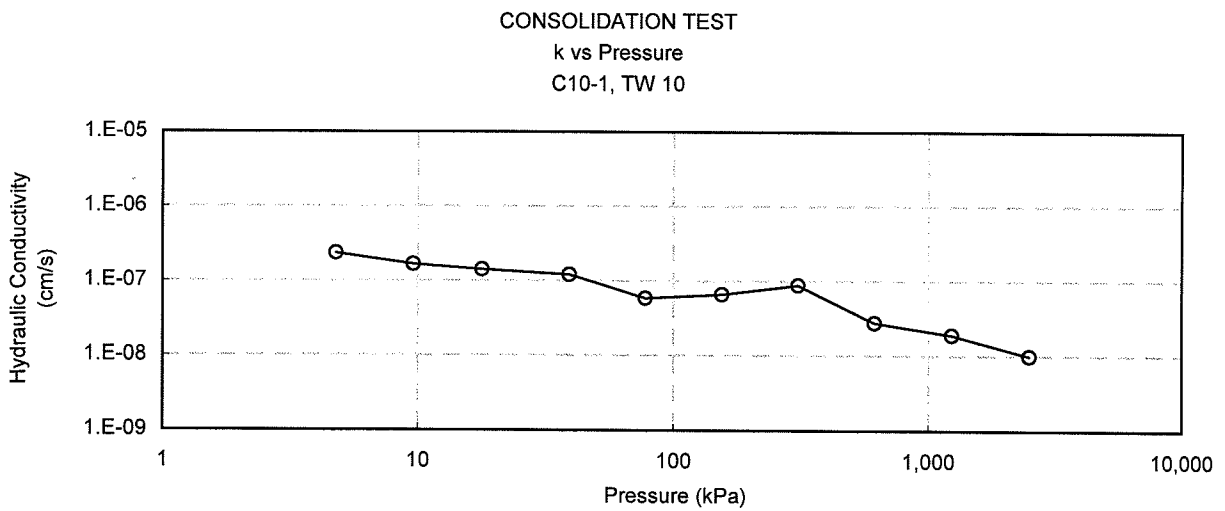
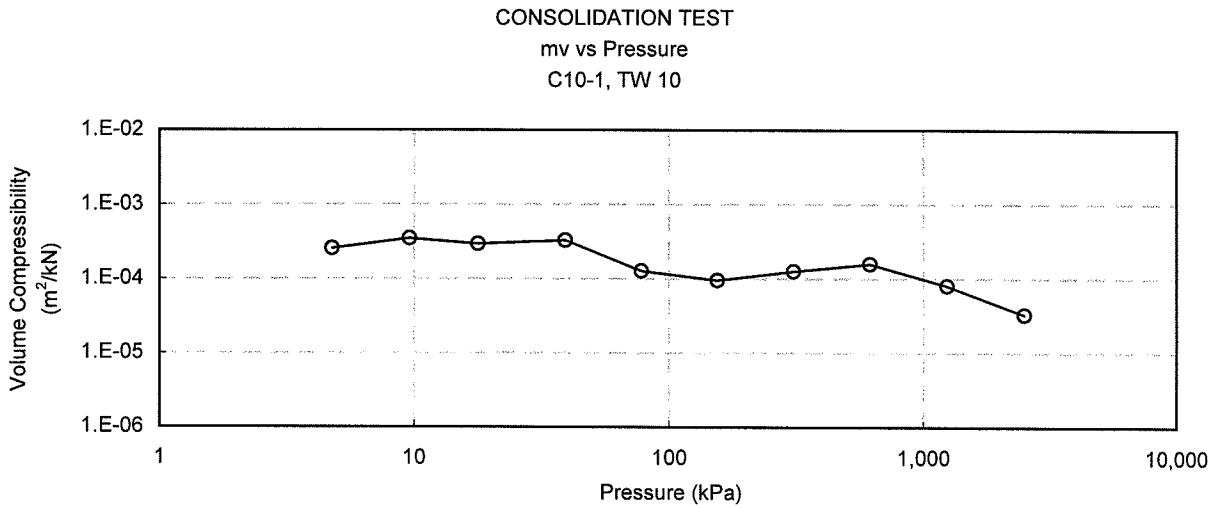
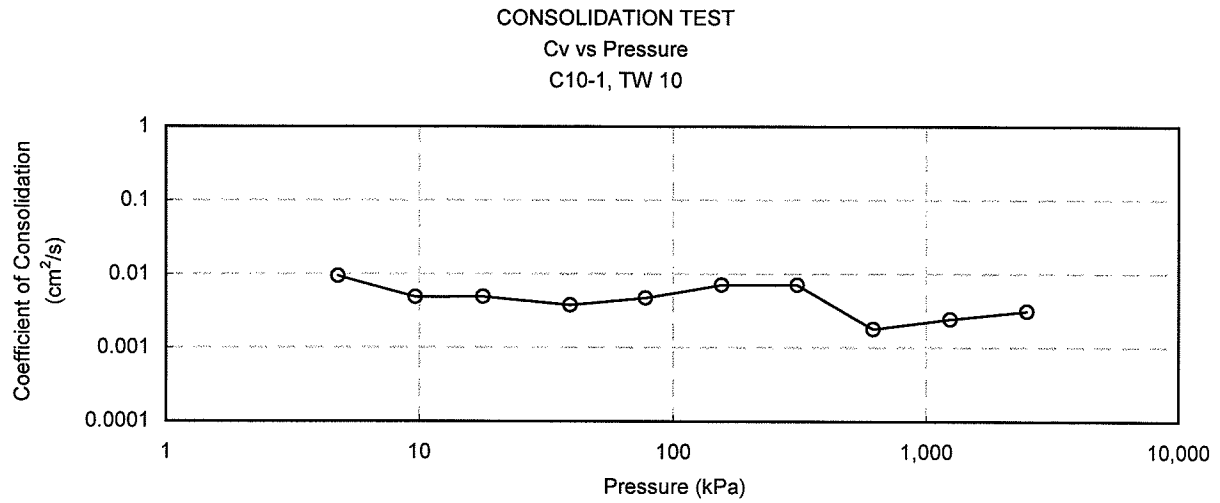
Terraprobe Inc.

Prepared By : HW

Checked By : RA

HWY 406 TWINNING - CULVERT#10

FIGURE B7-11



c:\Documents and Settings\Admin\My Documents\Marc P\Projects 2009\Hwy 406 Expansion\1-09-4135 (Hwy 406 Foundations)\Culverts and Retaining Walls\Culverts\Lab Results\1-09-4135 Consolidation Results.xls

Project No. : 1-09-4135
Date : November 2010



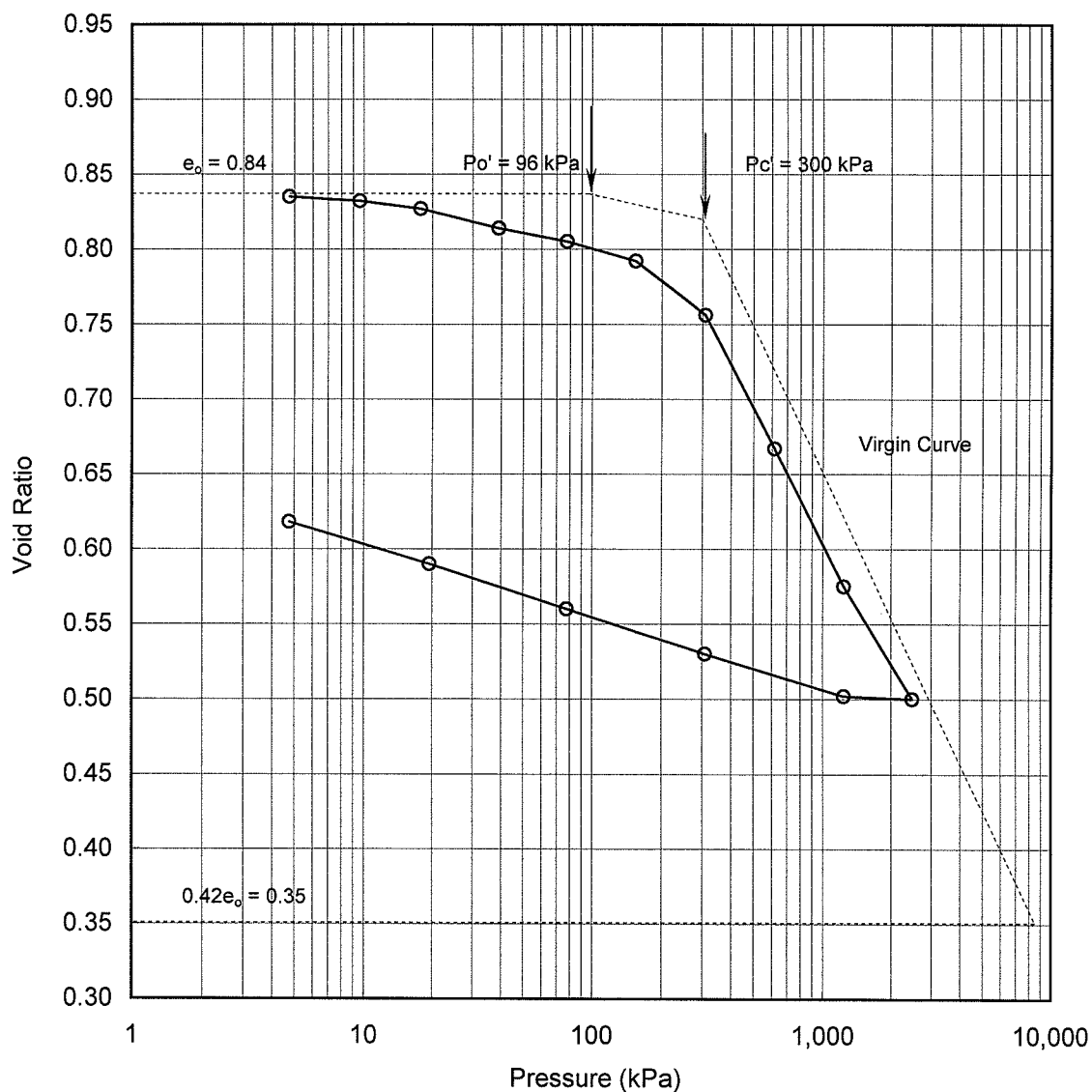
Terraprobe Inc.

Prepared By : HW
Checked By : RA

CONSOLIDATION TEST

e vs Pressure

C10-1, TW 10



Soil Type : Silty Clay

$e_o =$	0.84	$\omega_L =$	35%	$P_o' =$	96 kPa
$\omega =$	22%	$\omega_p =$	19%	$P_c' =$	300 kPa
$\gamma =$	20.7 kN/m ³	PI =	17%	Cc =	0.323
Gs =	2.81			Cr =	0.034

Project No. : 1-09-4135
 Date : November 2010



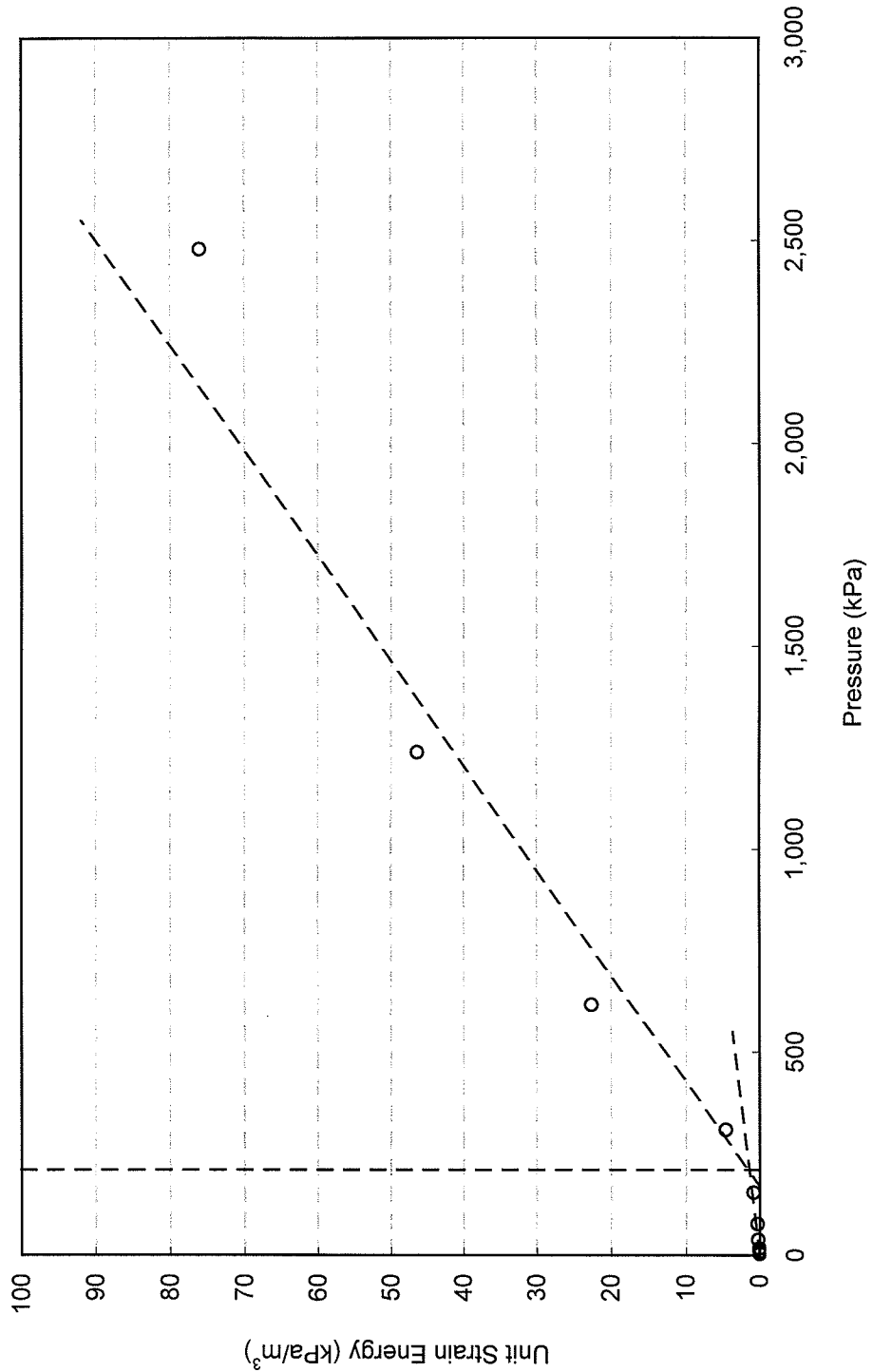
Terraprobe Inc.

Prepared By : HW
 Checked By : RA

HWY 406 TWINNING - CULVERT#10

FIGURE B7-13

CONSOLIDATION TEST Unit Strain Energy vs Pressure C10-1, TW 10



Pc = 210 kPa

Project No. : 1-09-4135
Date : November 2010



Terraprobe Inc.

Prepared By : HW
Checked By : RA



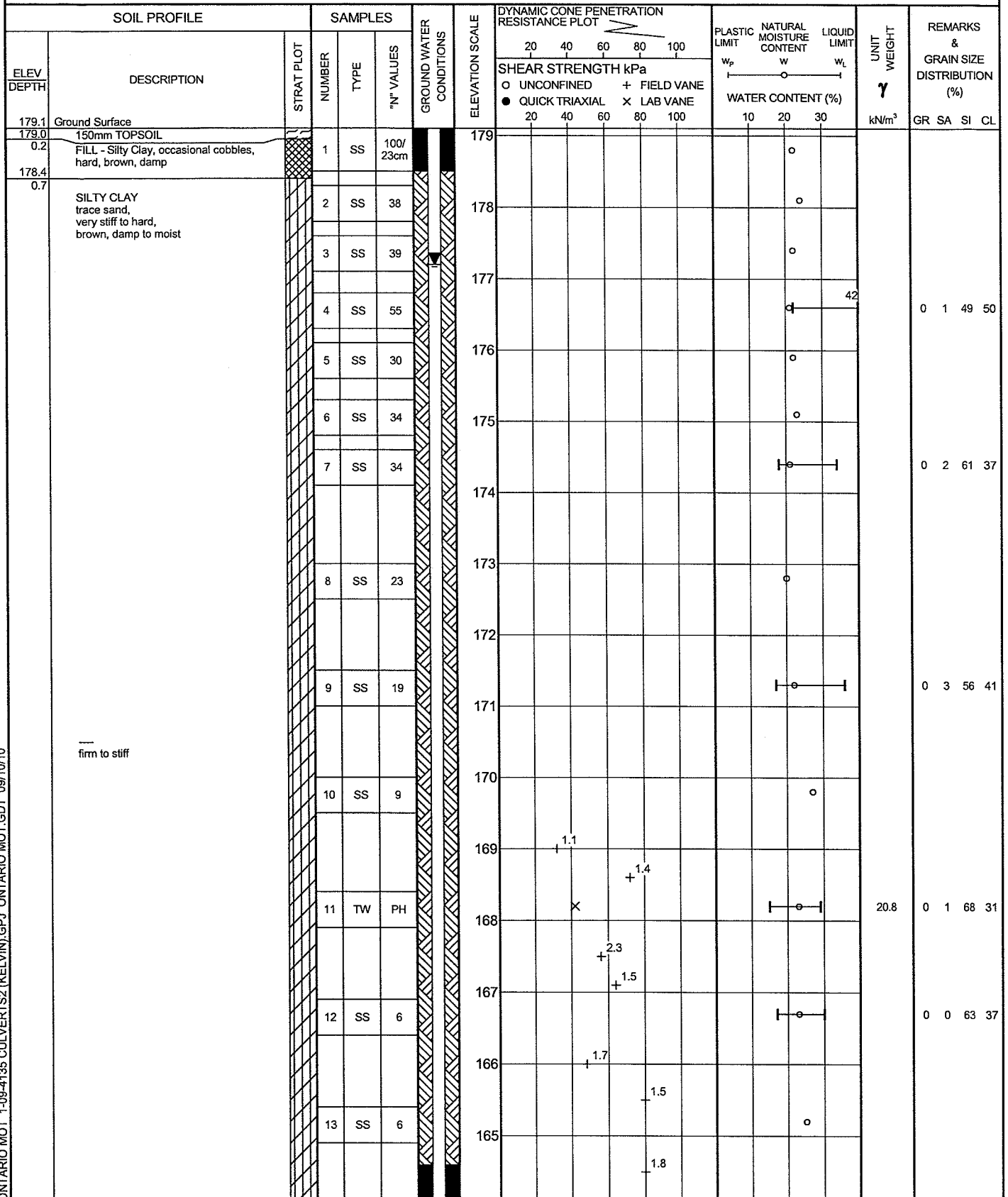
Appendix D2
Borehole C11-3

RECORD OF BOREHOLE No C11-3

1 OF 2

METRIC

W.P. 280-99-00 LOCATION Coords: N:4766795.7 E:326063.9 ORIGINATED BY PK
DIST HWY 406 BOREHOLE TYPE Solid Stem Augers COMPILED BY DB
DATUM Geodetic DATE 07.09.10 - 07.12.10 CHECKED BY RA



Continued Next Page

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

ONTARIO MOT. 1-09-4135 CULVERTS2 (KELVIN).GPJ ONTARIO MOT.GDT 09/10/10

RECORD OF BOREHOLE No C11-3

2 OF 2

METRIC

W.P. 280-99-00 LOCATION Coords: N:4766795.7 E:326063.9 ORIGINATED BY PK
DIST HWY 406 BOREHOLE TYPE Solid Stem Augers COMPILED BY DB
DATUM Geodetic DATE 07.09.10 - 07.12.10 CHECKED BY RA

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT w _p	NATURAL MOISTURE CONTENT w	LIQUID LIMIT w _L	UNIT WEIGHT γ kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			20 40 60 80 100	20 40 60 80 100					
163.6	SILT trace clay, loose, brown, wet		14	SS	5		164						July 09 July 12	
15.5								163						
162.1	CLAYEY SILT trace sand, trace gravel, firm to hard, brown, damp to moist		15	SS	6		162						0 0 86 14	
17.0								161						
								160						
								159						
158.8			16	SS	11									
20.3	End of Borehole		17	SS	59									
	Consolidation test performed on TW 11. Water level at 17.4m (not stabilized) and hole open to 13.7m on completion. SS1 - Sampler bouncing, probably on a cobble. Piezometer installation consists of a 19mm diameter, Schedule 40 PVC pipe with a 1.52m slotted screen. Water Level Readings: Date Depth(m) Elevation(m) July.19.10 5.1 174.0 July.26.10 3.5 175.6 Aug.06.10 2.0 177.1 Aug.13.10 1.9 177.2													

+ 3, X 3:

Numbers refer to
Sensitivity

○ 3% STRAIN AT FAILURE

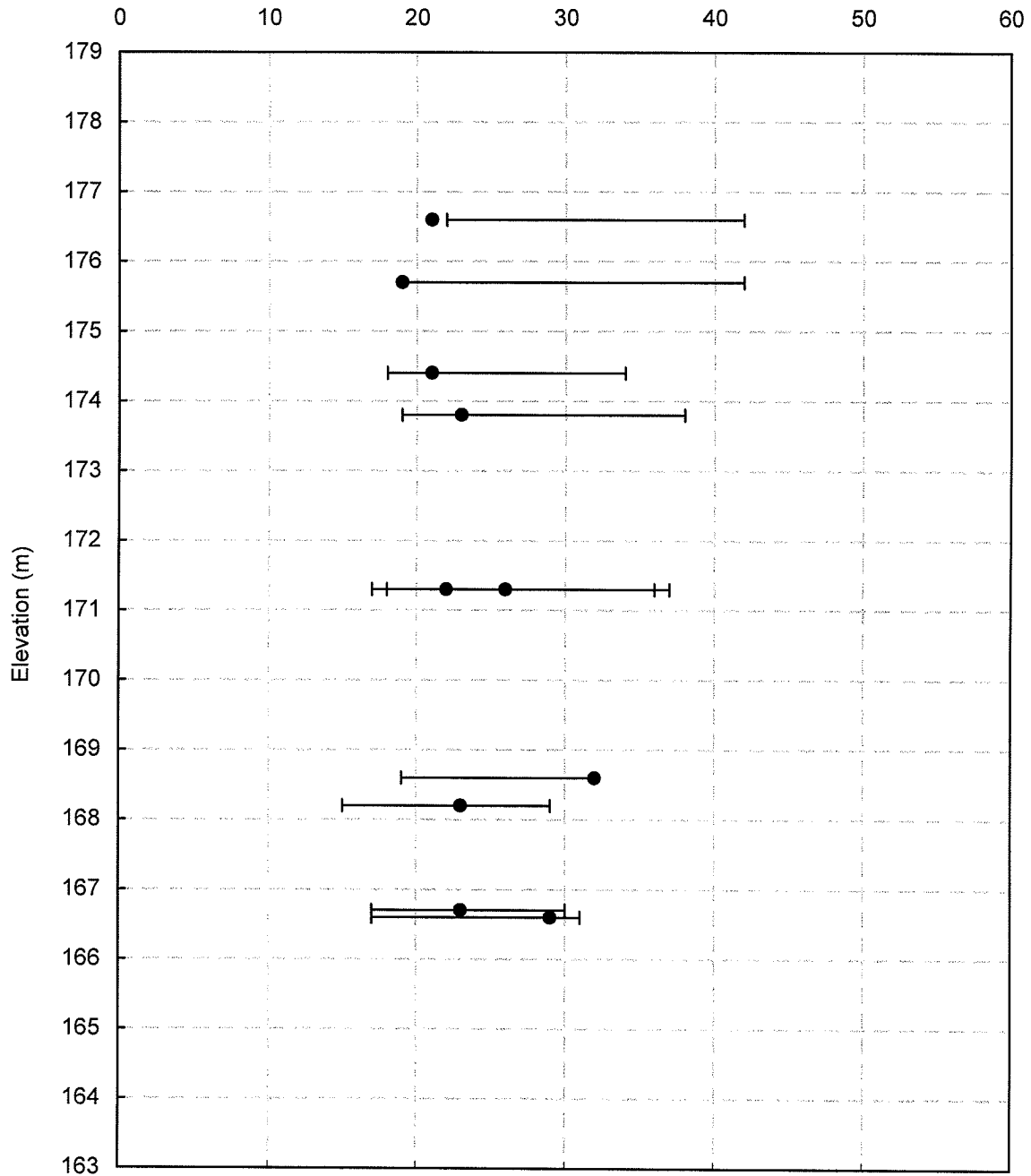
ATTERBERG LIMITS AND WATER CONTENTS

FIGURE B8-11

HWY 406 TWINNING - CULVERT #11

Silty Clay

Atterberg Limits & Water Contents (%)



Project No. : 1-09-4135

Date : November, 2010



Terraprobe Inc.

Prepared By : HW

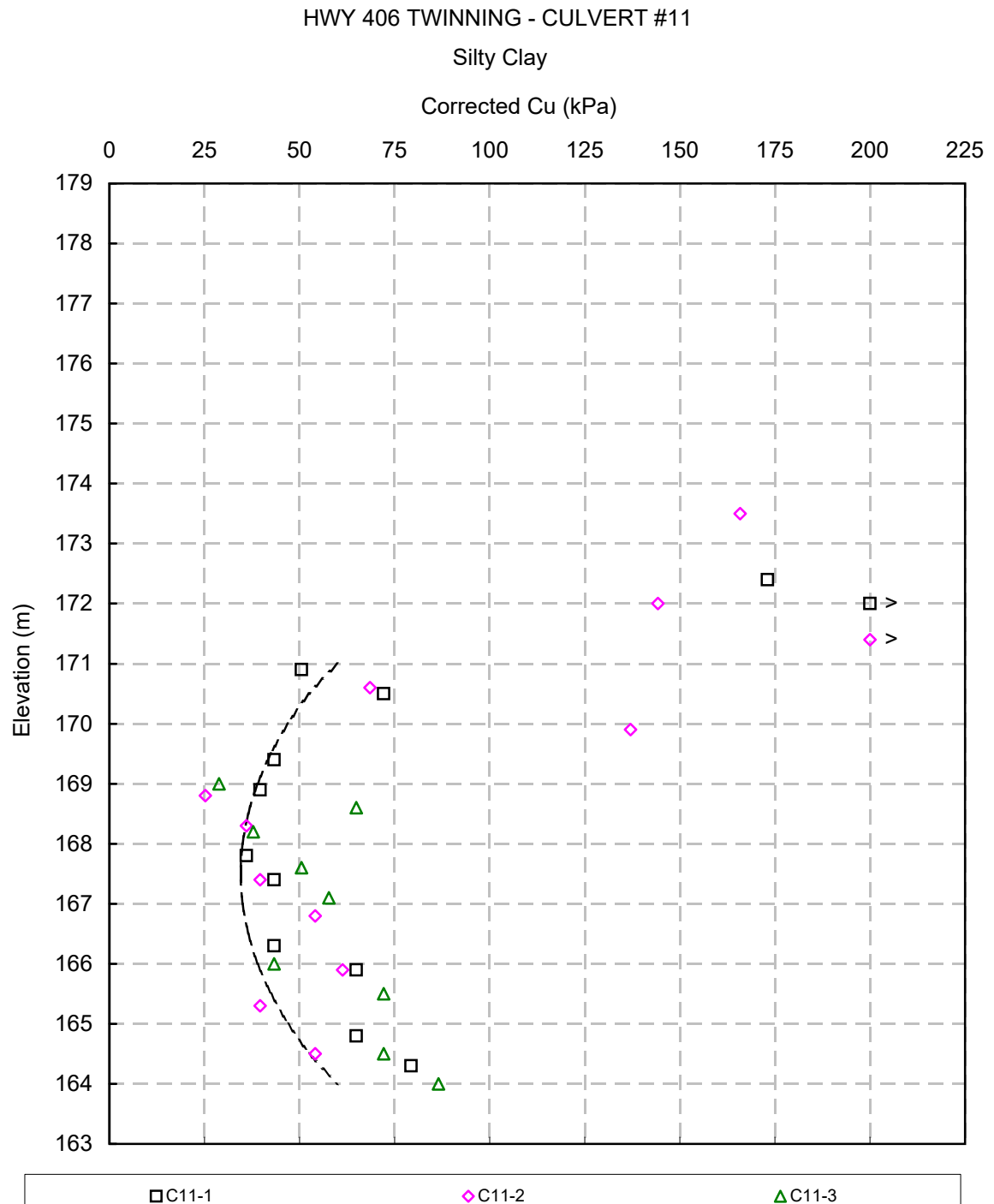
Checked By : RA

C:\Documents and Settings\Admin\My Documents\Marc P\Projects 2009\Hwy 406 Expansion\1-09-4135 (Hwy 406 Foundations)\Culverts and Retaining Walls\Culverts\Lab Results\1-09-4135C11 Soil Parameter Estimation.xls

CORRECTED UNDRAINED SHEAR STRENGTH

FIGURE B8-12

C:\Documents and Settings\Admin\My Documents\Marc P\Projects 2009\Hwy 406 Expansion\1-09-4135 (Hwy 406 Foundations)\Culverts and Retaining Walls\Culverts\Lab Results\1-09-4135C11 Soil Parameter Estimation.xls



Field Shear Vane Correction

Morris & Williams (1994)
 $(\mu = 1.18 \text{ EXP}(-0.08 I_p) + 0.57)$

Applied Correction Factors

0.78 (Elev.>175m) 0.90 (Elev.<175m)

Project No. : 1-09-4135

Date : November, 2010



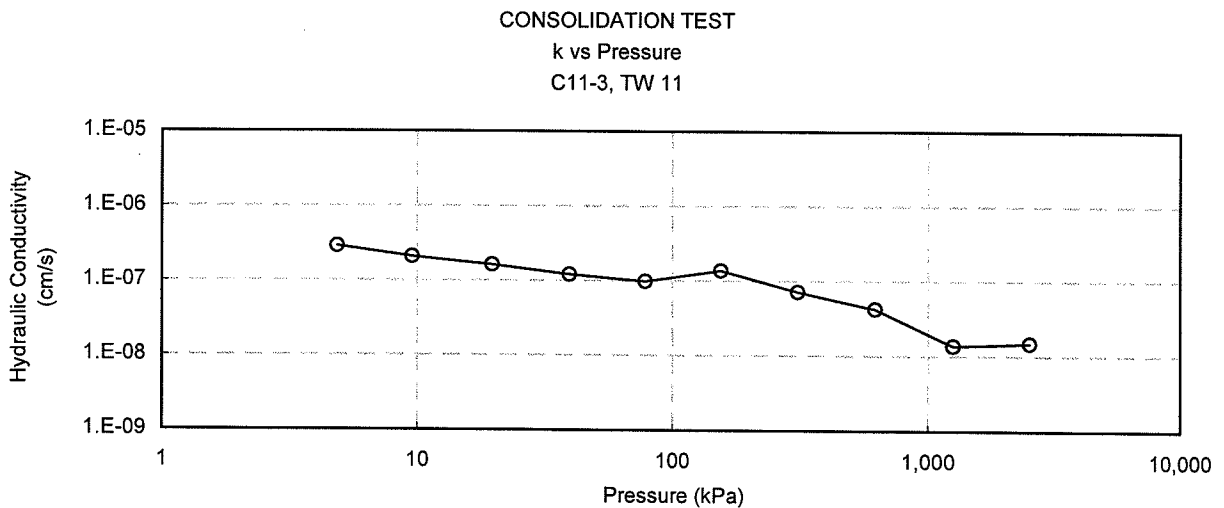
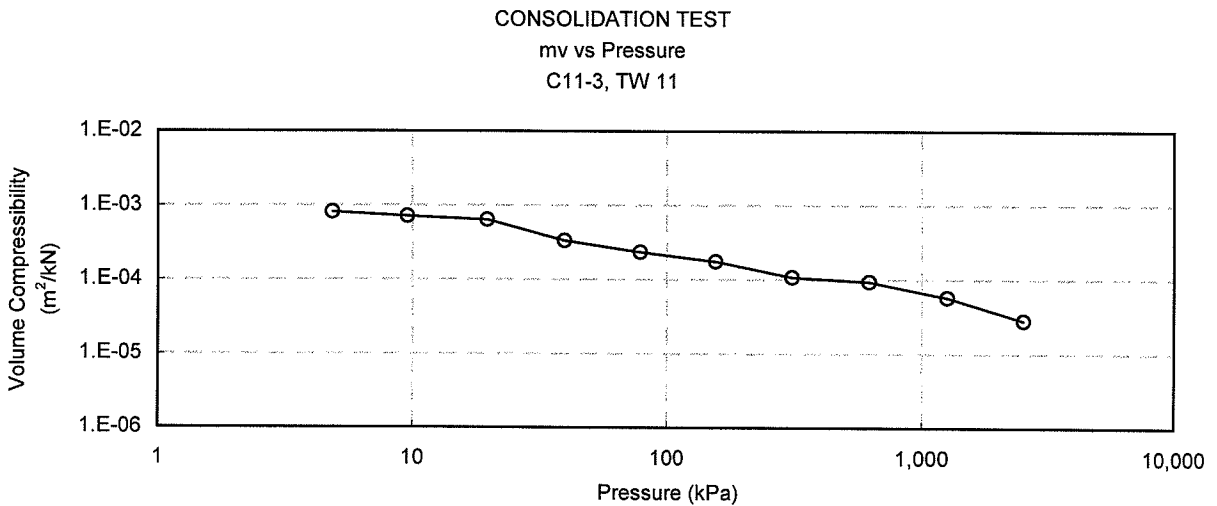
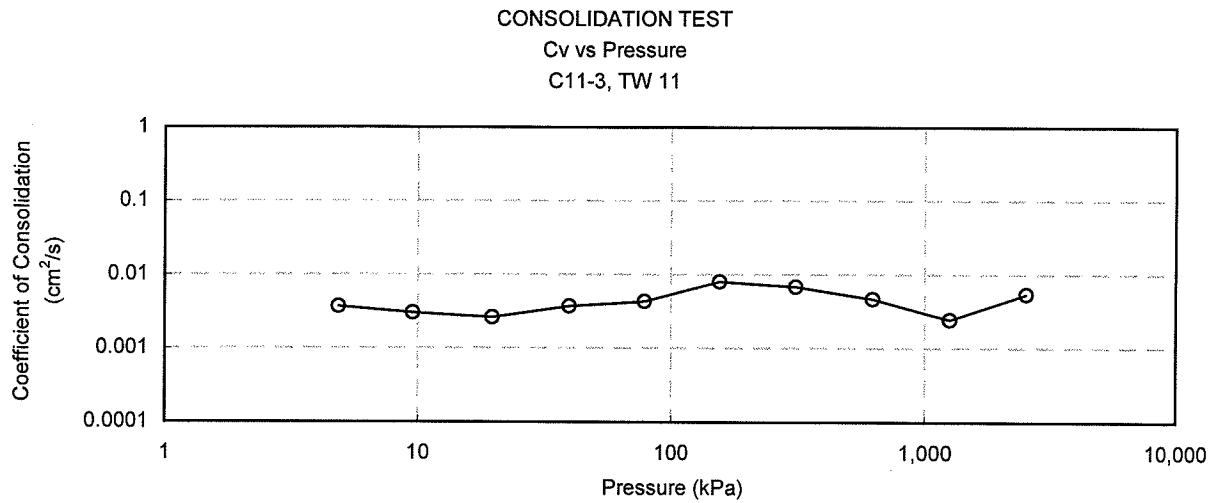
Terraprobe Inc.

Prepared By : HW

Checked By : RA

HWY 406 TWINNING - CULVERT#11

FIGURE B8-13



C:\Documents and Settings\Admin\My Documents\Marc P\Projects 2009\Hwy 406 Expansion\1-09-4135 (Hwy 406 Foundations)\Culverts and Retaining Walls\Culverts\Lab Results\1-09-4135 Consolidation Results.xls

Project No. : 1-09-4135
Date : November 2010



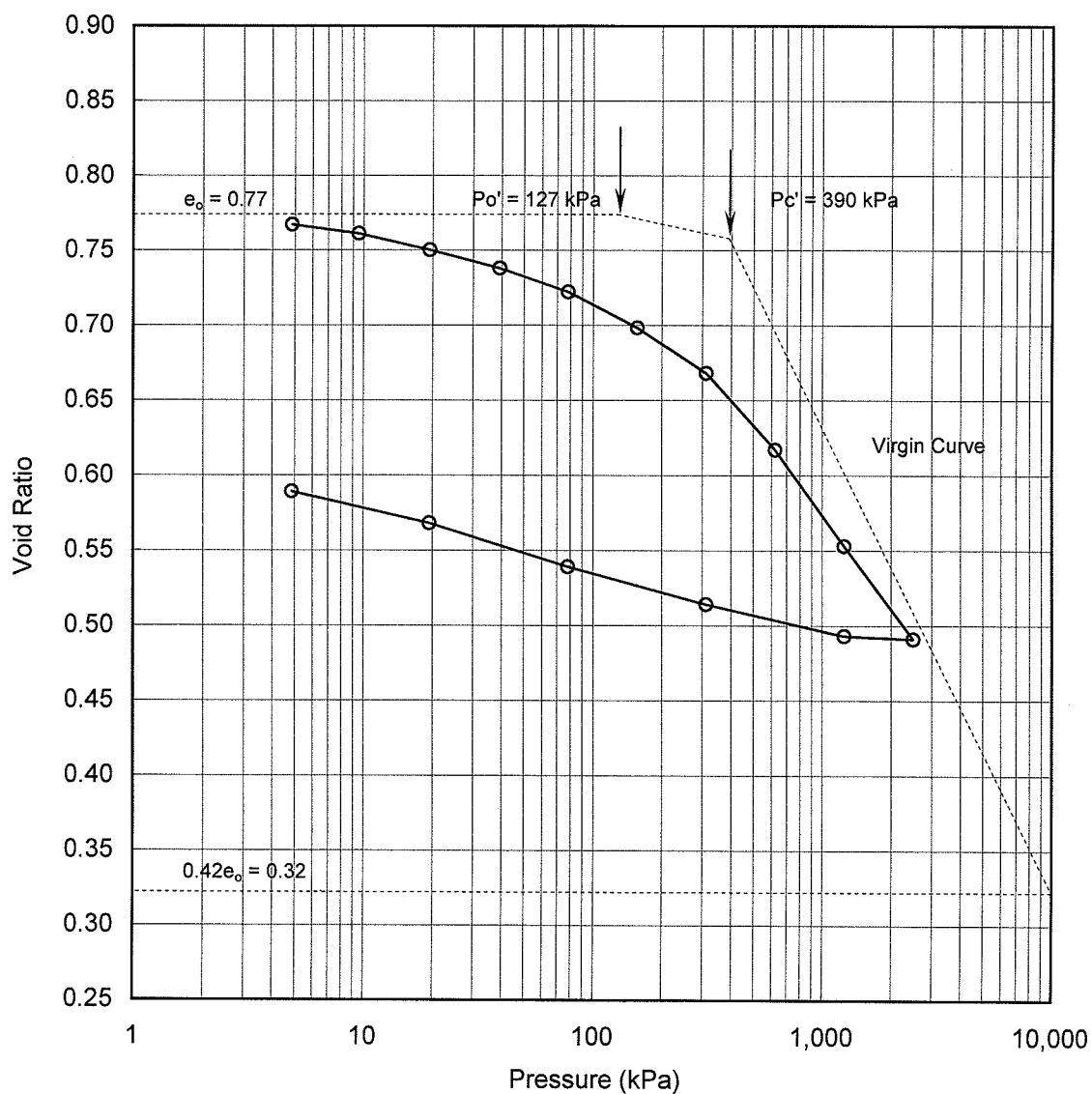
Terraprobe Inc.

Prepared By : HW
Checked By : RA

CONSOLIDATION TEST

e vs Pressure

C11-3, TW 11



Soil Type : Silty Clay

$e_o =$	0.77	$\omega_L =$	29%	$Po' =$	127 kPa
$\omega =$	22%	$\omega_P =$	14%	$Pc' =$	390 kPa
$\gamma =$	20.8 kN/m ³	$PI =$	14%	$Cc =$	0.309
$G_s =$	2.76			$Cr =$	0.033

Project No. : 1-09-4135
 Date : November 2010



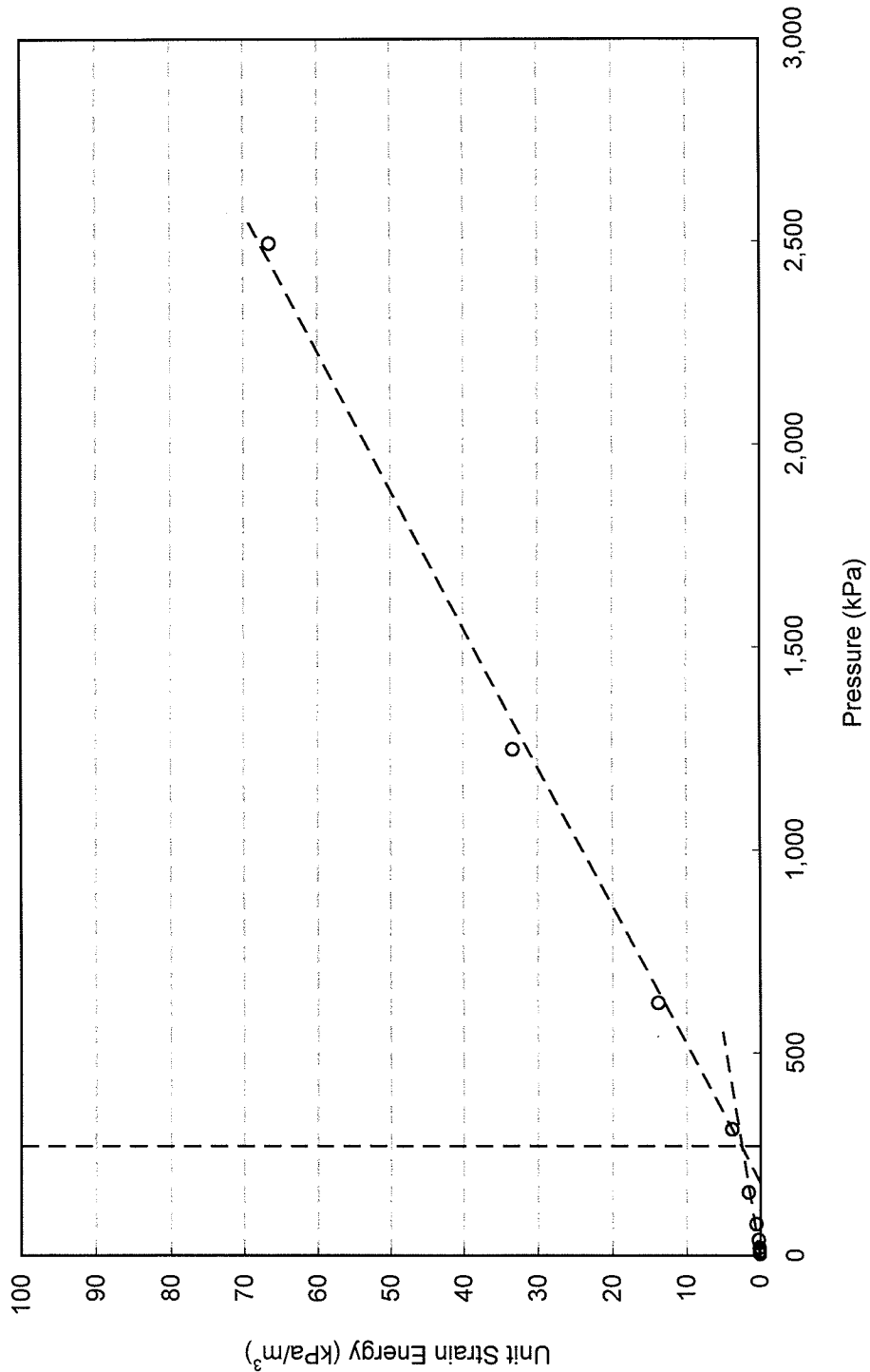
Terraprobe Inc.

Prepared By : HW
 Checked By : RA

HWY 406 TWINNING - CULVERT#11

FIGURE B8-15

CONSOLIDATION TEST Unit Strain Energy vs Pressure C11-3, TW 11



Project No. : 1-09-4135

Date : November 2010



Terraprobe Inc.

Prepared By : HW

Checked By : RA



Appendix D3
Borehole C12-3

1 OF 2

METRIC

W.P.	280-99-00	LOCATION	Coords: N:4767208.6 E:326322.1	ORIGINATED BY	PK
DIST	HWY 406	BOREHOLE TYPE	Solid Stem Augers	COMPILED BY	DB
DATUM	Geodetic	DATE	07.14.10	CHECKED BY	RA

[illegible]

Continued Next Page

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




ONTARIO MOT 1-09-4135 CULVERTS2 (KELVIN).GPJ ONTARIO MOT.GDT 09/10/10

RECORD OF BOREHOLE No C12-3

2 OF 2

METRIC

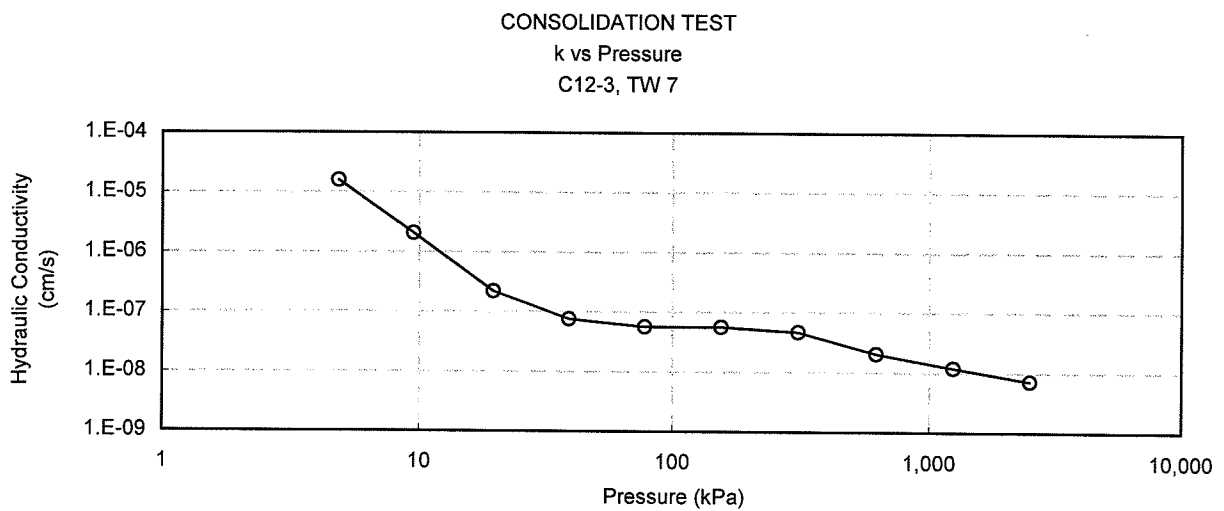
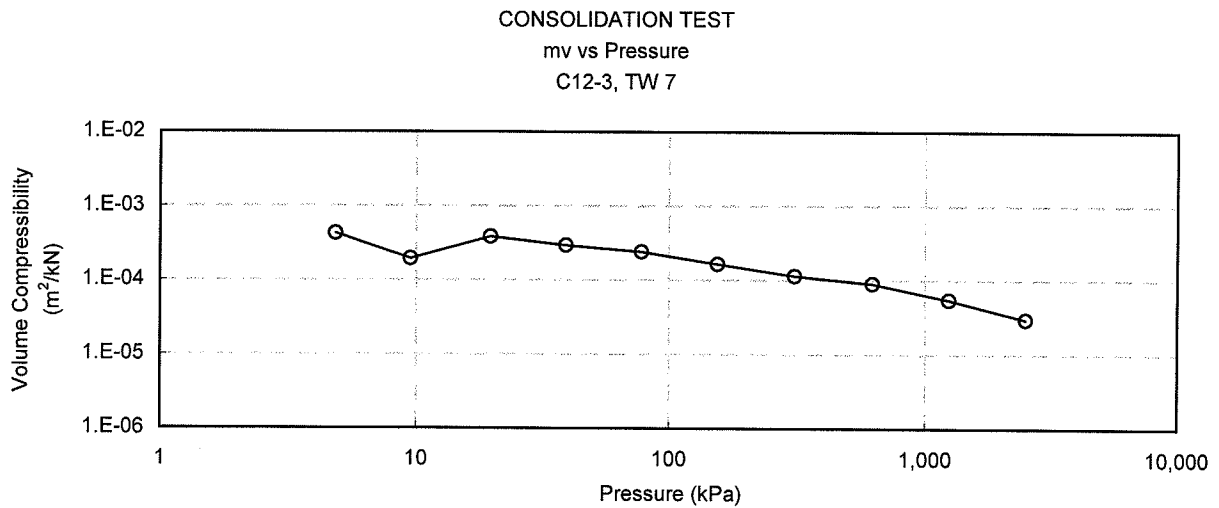
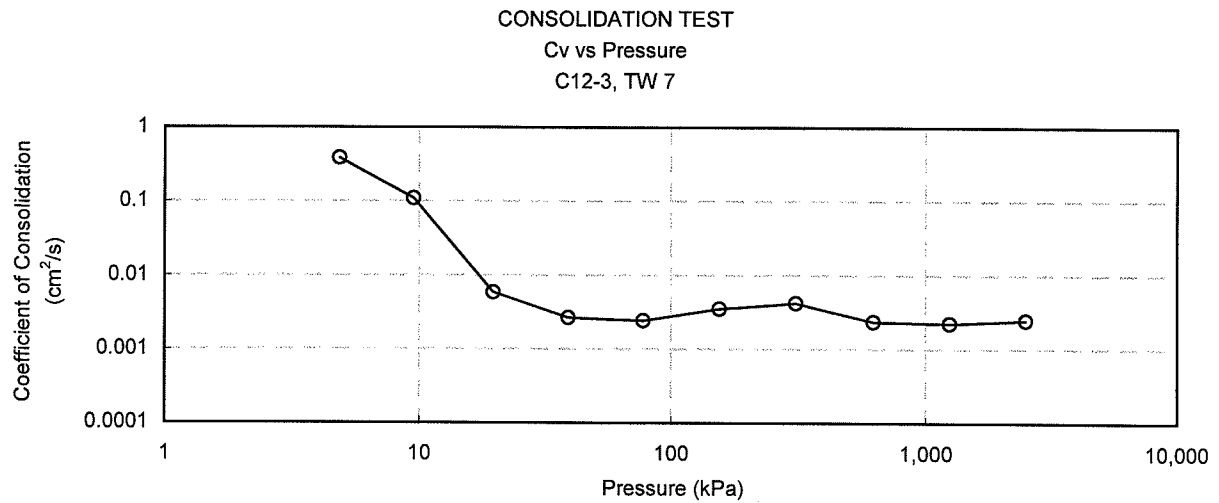
W.P. 280-99-00 LOCATION Coords: N:4767208.6 E:326322.1 ORIGINATED BY PK
DIST HWY 406 BOREHOLE TYPE Solid Stem Augers COMPILED BY DB
DATUM Geodetic DATE 07.14.10 CHECKED BY RA

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT			PLASTIC LIMIT w _p	NATURAL MOISTURE CONTENT w	LIQUID LIMIT w _L	UNIT WEIGHT γ kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL		
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa								WATER CONTENT (%)	
								○ UNCONFINED	+ FIELD VANE	● QUICK TRIAXIAL							× LAB VANE
						20	40	60	80	100	10	20	30				
163.6	SILT occasional silty clay seams and partings, compact, brown, wet		14	SS	7												
162.2																	
162.0	SILTY CLAY trace sand, trace gravel, very stiff to hard, brown, damp to moist		15	SS	12												
17.8																	
159.5			16	SS	24												
20.3																	
	End of Borehole																
	Sampler wet at 9.1m.																
	Consolidation test performed on TW 7.																
	Water level at 12.2m (not stabilized) and hole open to 15.2m on completion.																
	Piezometer installation consists of a 19mm diameter, Schedule 40 PVC pipe with a 1.52m slotted screen.																
	Water Level Readings: Date Depth(m) Elevation(m) July.20.10 2.8 177.0 July.28.10 2.8 177.0																

ONTARIO MOT 1-09-4135 CULVERTS2 (KELVIN).GPJ ONTARIO MOT.GDT 09/10/10

HWY 406 TWINNING - CULVERT#12

FIGURE B9-10



Project No. : 1-09-4135
Date : November 2010



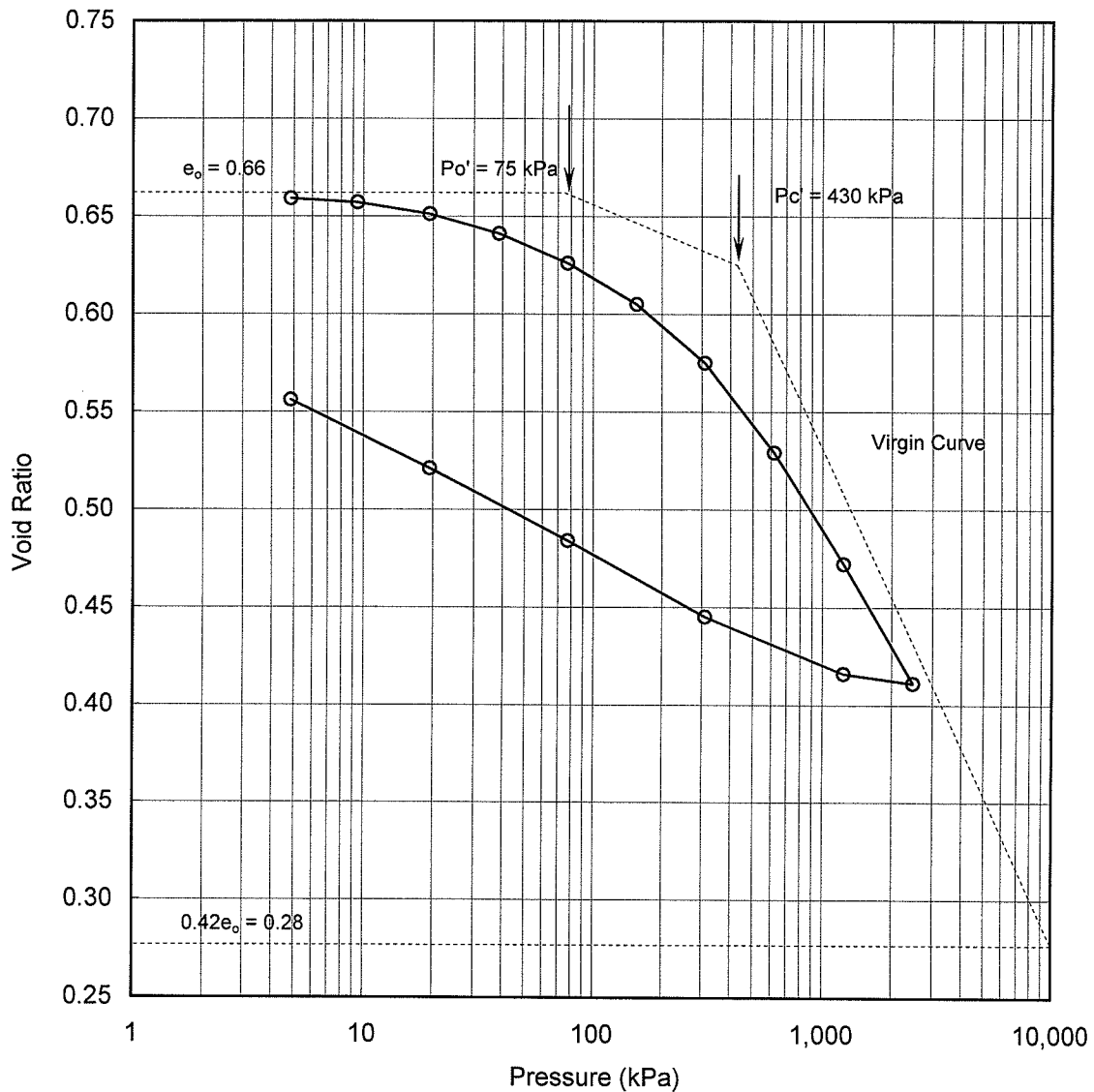
Terraprobe Inc.

Prepared By : HW
Checked By : RA

CONSOLIDATION TEST

e vs Pressure

C12-3, TW 7



Soil Type : Silty Clay

$e_o =$	0.66	$\omega_L =$	31%	$P_{o'} =$	75 kPa
$\omega =$	21%	$\omega_P =$	17%	$P_c =$	430 kPa
$\gamma =$	21.1 kN/m ³	PI =	14%	Cc =	0.255
Gs =	2.78			Cr =	0.049

Project No. : 1-09-4135
 Date : November 2010



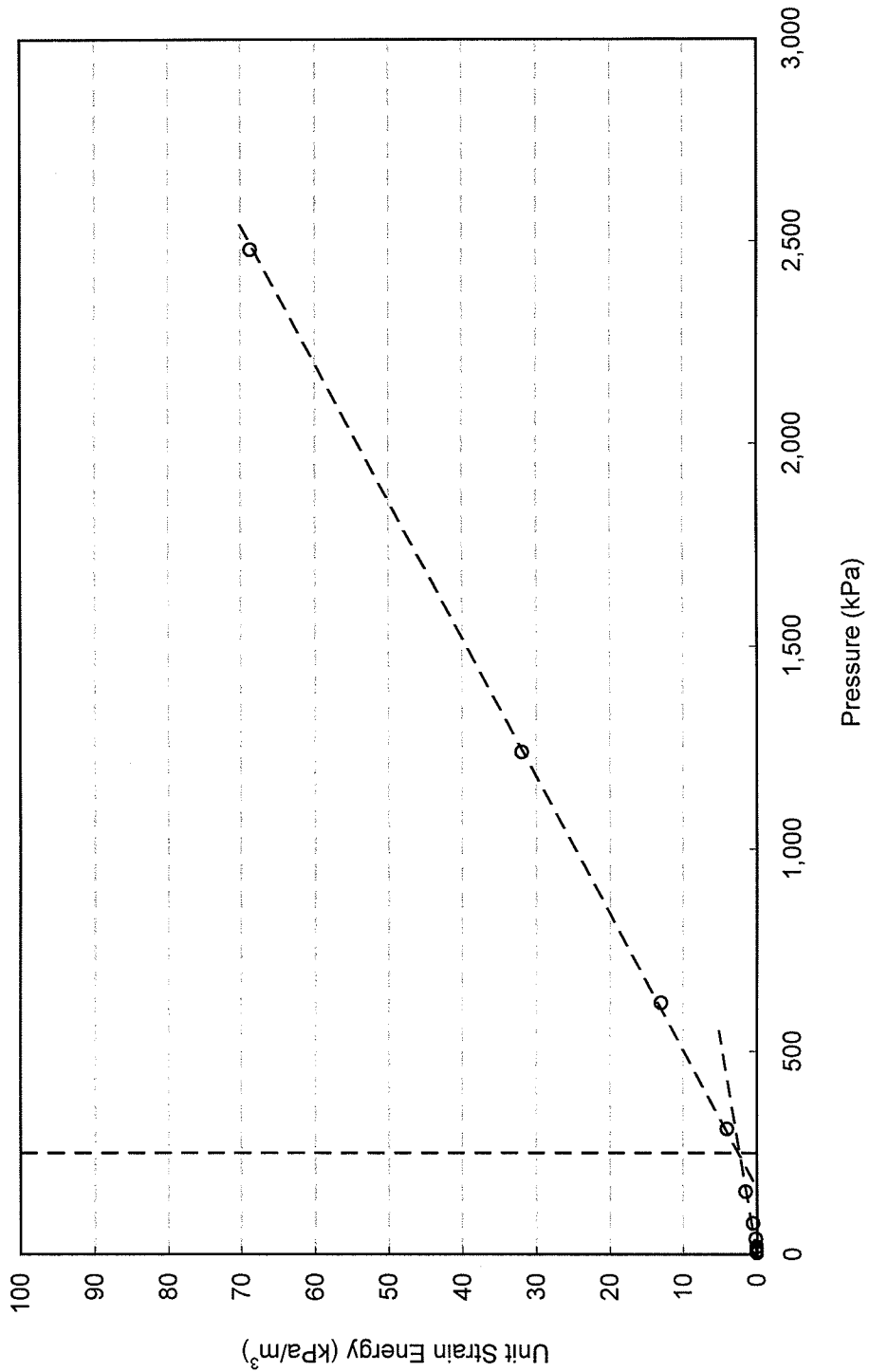
Terraprobe Inc.

Prepared By : HW
 Checked By : RA

HWY 406 TWINNING - CULVERT#12

FIGURE B9-12

CONSOLIDATION TEST Unit Strain Energy vs Pressure C12-3, TW 7



Project No. : 1-09-4135

Date : November 2010



Terraprobe Inc.

Prepared By : HW

Checked By : RA



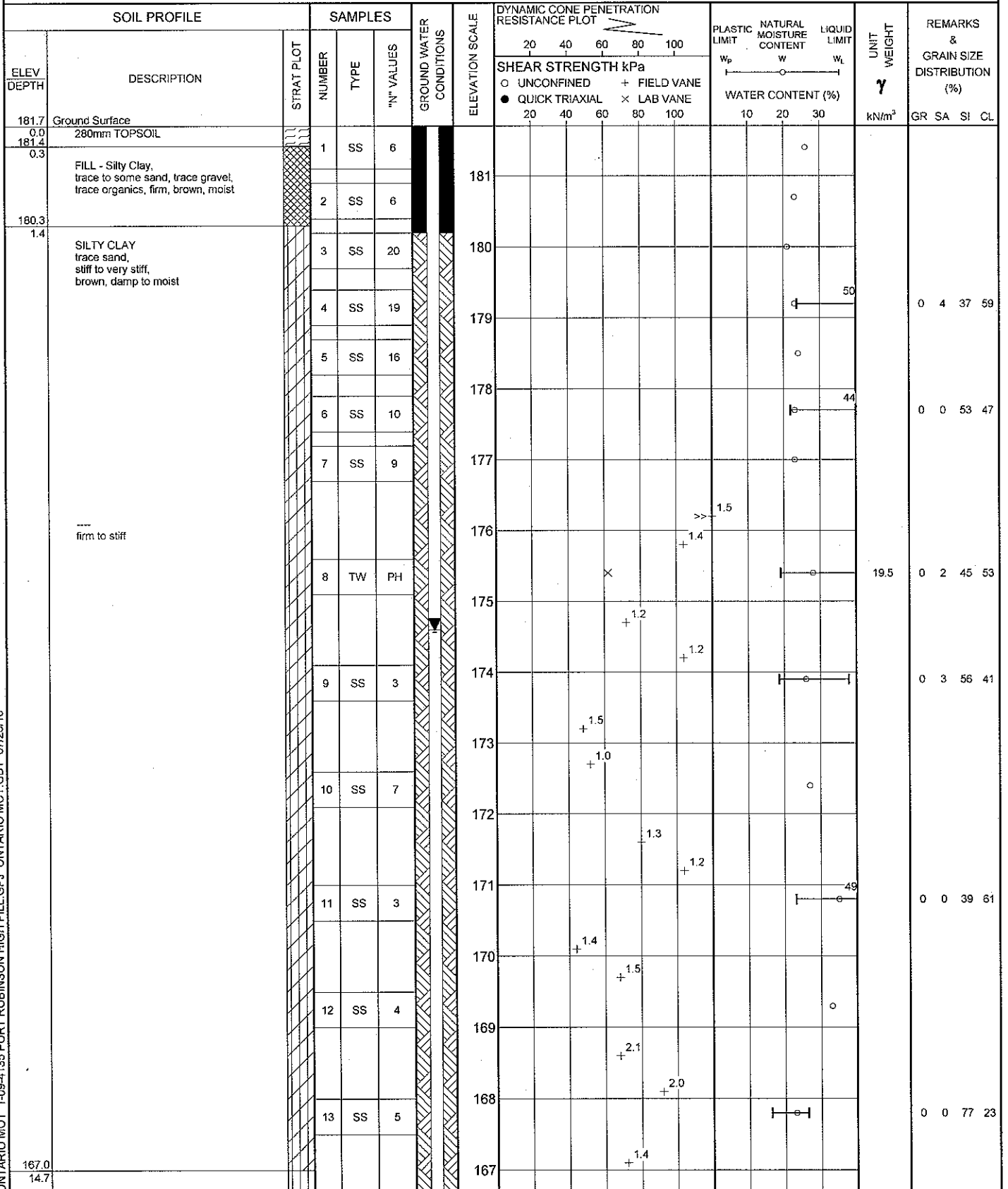
Appendix D4
Boreholes PR-1, PR-5

RECORD OF BOREHOLE No PR1

1 OF 3

METRIC

W.P. 280-99-00 LOCATION Coords: N:4766747.4 E:326297.5 ORIGINATED BY PK
DIST HWY 406 BOREHOLE TYPE Hollow Stem Augers COMPILED BY DB
DATUM Geodetic DATE 01.04.10 - 01.06.10 CHECKED BY RA



Continued Next Page

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

ONTARIO MOT 1-09-4135 PORT ROBINSON HIGH FILL GPJ ONTARIO MOT.GDT 07/25/10

RECORD OF BOREHOLE No PR1

2 OF 3

METRIC

W.P. 280-99-00 LOCATION Coords: N:4766747.4 E:326297.5 ORIGINATED BY PK
DIST HWY 406 BOREHOLE TYPE Hollow Stem Augers COMPILED BY DB
DATUM Geodetic DATE 01.04.10 - 01.06.10 CHECKED BY RA

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT NATURAL LIMIT MOISTURE CONTENT LIQUID LIMIT			UNIT WEIGHT γ kN/m³	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa		WATER CONTENT (%)				
								20 40 60 80 100		W _p	W	W _L		
								○ UNCONFINED + FIELD VANE						
								● QUICK TRIAXIAL × LAB VANE						
								20 40 60 80 100		10 20 30				
														GR SA SI CL
	SILT trace sand, frequent silty clay seams and partings, loose, brown, wet		14	SS	4		166					○		0 0 84 16
			15	SS	6		165					○		0 1 84 15
163.9							164							
17.8	SILTY CLAY TO CLAYEY SILT trace sand, stiff to hard, brown / reddish brown, damp to moist		16	SS	15		163					○		
			17	SS	12		162					○		
			18	SS	29		161					○		
			19	SS	32		160					○		
			20	SS	15		159					○		
			21	SS	10		158					○		
			22	SS	18		157					○		
			23	SS	34		156					○		
154.3	CLAYEY SILT trace to some sand, trace gravel, very stiff to hard, brown, moist (GLACIAL TILL)						155					○		
27.4							154					○		
							153					○		
							152							

Continued Next Page

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

ONTARIO MOT 1-09-4135 PORT ROBINSON HIGH FILL GPJ ONTARIO MOT.GDT 07/26/10

RECORD OF BOREHOLE No PR5

1 OF 3

METRIC

W.P. 280-99-00 LOCATION Coords: N:4766743.3 E:326398.5 ORIGINATED BY PK
DIST HWY 406 BOREHOLE TYPE Hollow Stem Augers COMPILED BY DB
DATUM Geodetic DATE 12.21.09 - 12.22.09 CHECKED BY RA

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT W _p	NATURAL MOISTURE CONTENT W	LIQUID LIMIT W _L	UNIT WEIGHT γ kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			20 40 60 80 100	20 40 60 80 100					
181.2	Ground Surface													
181.0	300mm TOPSOIL													
0.2	FILL - Silty Clay, some sand, trace organics, firm, brown, moist		1	SS	4		181							
180.5														
0.7	SILTY CLAY trace sand, occasional gravel inclusions, stiff to very stiff, brown, moist		2	SS	8		180							
			3	SS	16									
			4	SS	14		179							
			5	SS	11		178							
			6	SS	12		177							
			7	SS	3		176							
			8	SS	2		175							
			9	TW	PH		174							
			10	SS	0		173							
			11	SS	4		172							
			12	SS	3		171							
			13	SS	5		170							
							169							
							168							
							167							

Continued Next Page

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

ONTARIO MOT 1-09-4135 PORT ROBINSON HIGH FILL GPJ ONTARIO MOT.GDT 07/26/10

METRIC

ORIGINATED BY PK

COMPILED BY DB

CHECKED BY RA

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

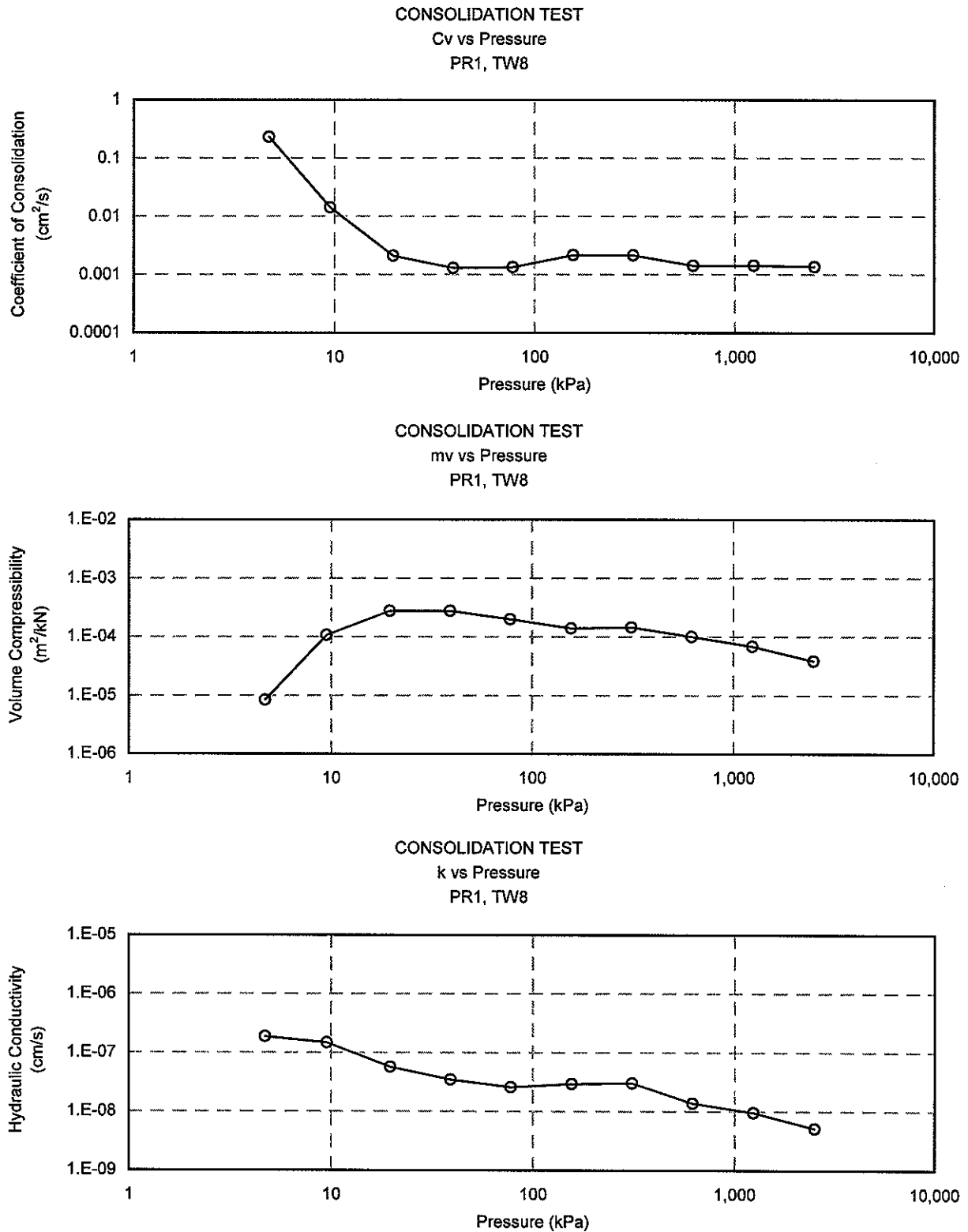
RECORD OF BOREHOLE No PR5

3 OF 3

METRIC

W.P. 280-99-00 LOCATION Coords: N:4766743.3 E:326398.5 ORIGINATED BY PK
DIST HWY 406 BOREHOLE TYPE Hollow Stem Augers COMPILED BY DB
DATUM Geodetic DATE 12.21.09 - 12.22.09 CHECKED BY RA

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					UNIT WEIGHT γ kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			20 40 60 80 100	20 40 60 80 100	PLASTIC LIMIT W _p	NATURAL MOISTURE CONTENT W	LIQUID LIMIT W _L		
150.7 30.5	End of Borehole Unable to push vane beyond 19.2m. Resistance to augering at 28.9m. No sample recovery at SS5 and SS23. Sampler redriven and disturbed sample collected. Consolidation test performed on TW 9. Sampler wet at 6.1m. Borehole was dry (not stabilized) and hole open to full depth on completion. Piezometer installation consists of a 19mm diameter, Schedule 40 PVC pipe with a 1.52m slotted screen. Water Level Readings: Date Depth(m) Elevation(m) Jan.19.10 6.4 174.8 Jan.27.10 6.2 175.0 Feb.08.10 6.3 174.9 Feb.19.10 6.2 175.0		24	SS	92		151							



C:\Documents and Settings\Hongjiu\My Documents\Project 2009\1-09-4135 - HWY 406 Foundations\Port Robinson Rd\1-09-4135 Consolidation Results-PR.xls

Project No. : 1-09-4135
Date : July 2010



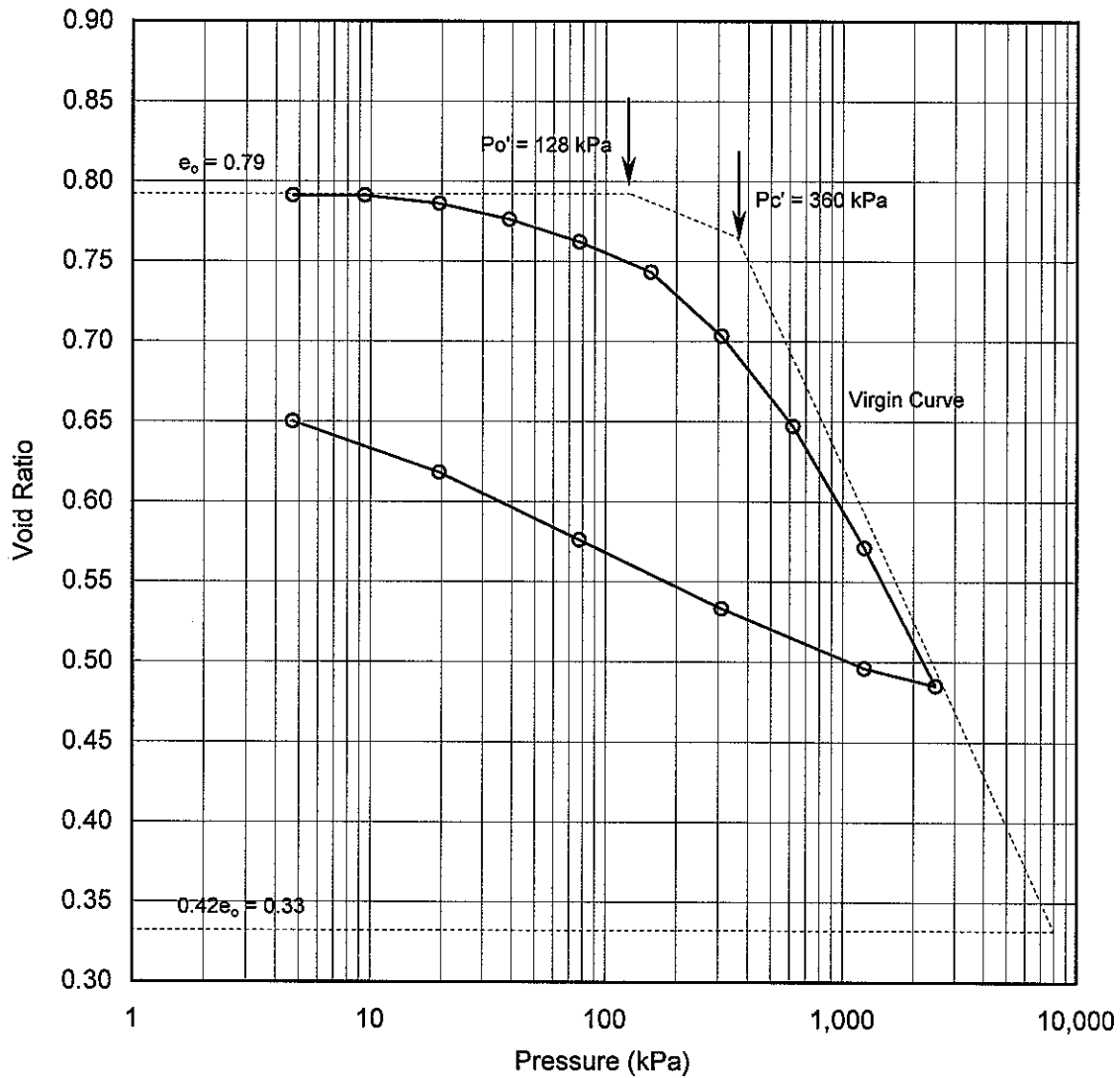
Terraprobe Inc.

Prepared By : HW
Checked By : RA

CONSOLIDATION TEST

e vs Pressure

PR1, TW8



Soil Type : Silty Clay

$e_o =$	0.79	$\omega_L =$	40%	$P_o' =$	128 kPa
$\omega =$	28%	$\omega_p =$	19%	$P_c' =$	360 kPa
$\gamma =$	19.5 kN/m ³	PI =	21%	Cc =	0.321
Gs =	2.78			Cr =	0.060

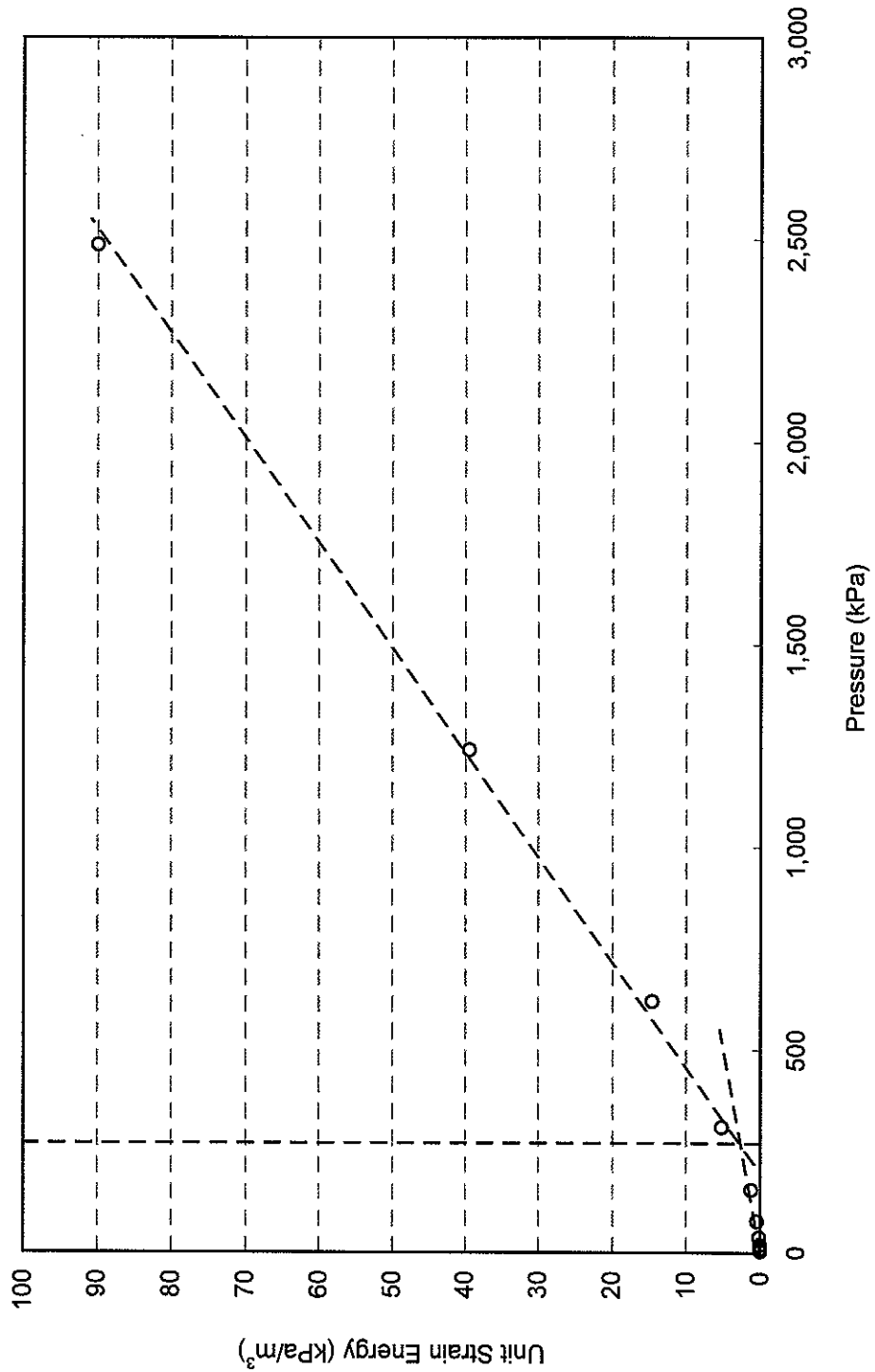
Project No. : 1-09-4135
Date : July 2010



Terraprobe Inc.

Prepared By : HW
Checked By : RA

CONSOLIDATION TEST
Unit Strain Energy vs Pressure
PR1, TW8



Pc = 270 kPa

Project No. : 1-09-4135

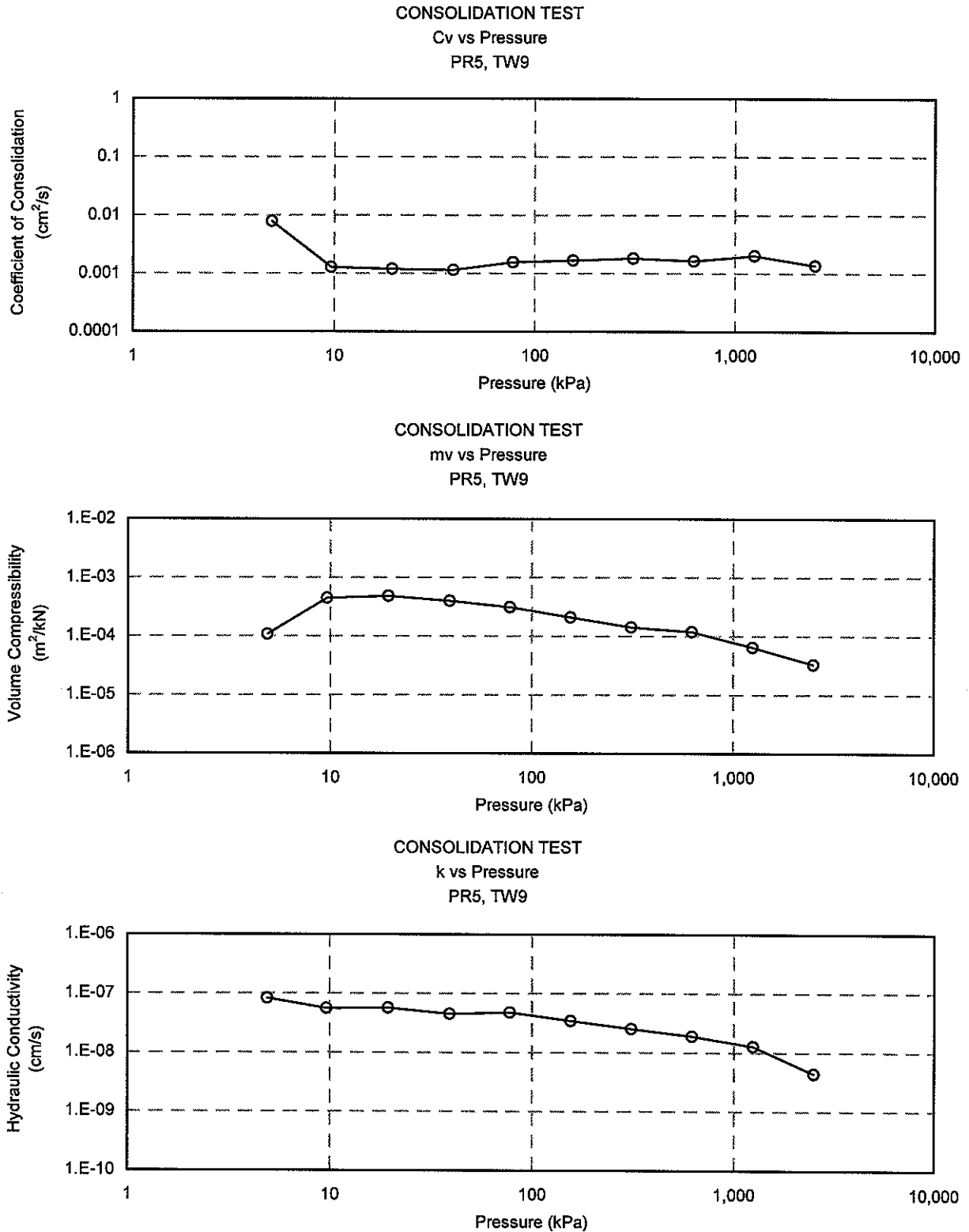
Date : July 2010



Terraprobe Inc.

Prepared By : HW

Checked By : RA



C:\Documents and Settings\Hongliu\My Documents\Project 2009\1-09-4135 - HWY 406 Foundations\Port Robinson Rd\1-09-4135 Consolidation Results-PR.xls

Project No. : 1-09-4135
Date : July 2010



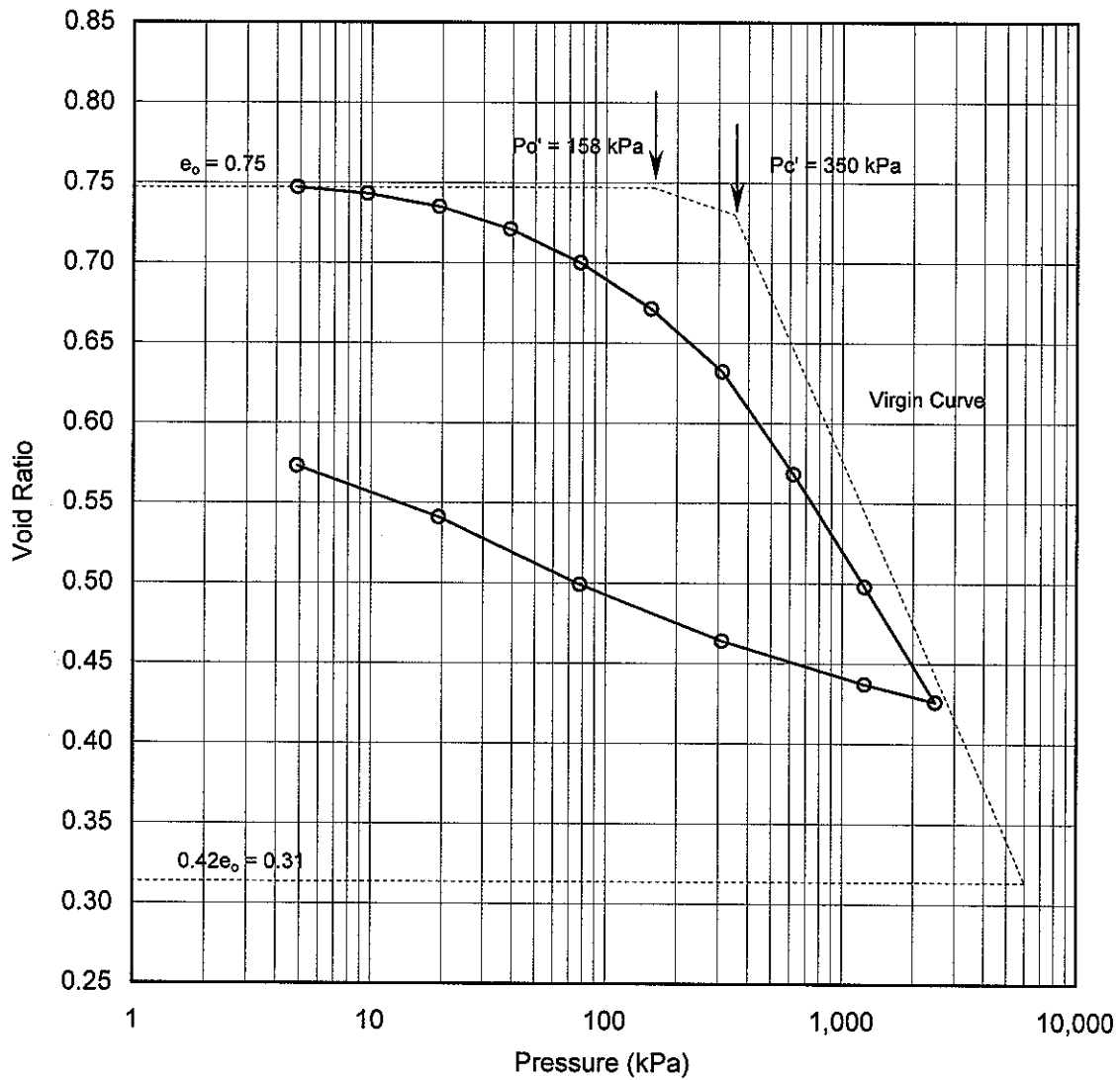
Terraprobe Inc.

Prepared By : HW
Checked By : RA

CONSOLIDATION TEST

e vs Pressure

PR5, TW9



Soil Type : Silty Clay

$e_o =$	0.75	$\omega_L =$	32%	$P_o' =$	158 kPa
$\omega =$	27%	$\omega_P =$	16%	$P_c' =$	350 kPa
$\gamma =$	19.7 kN/m ³	PI =	15%	Cc =	0.337
Gs =	2.76			Cr =	0.049

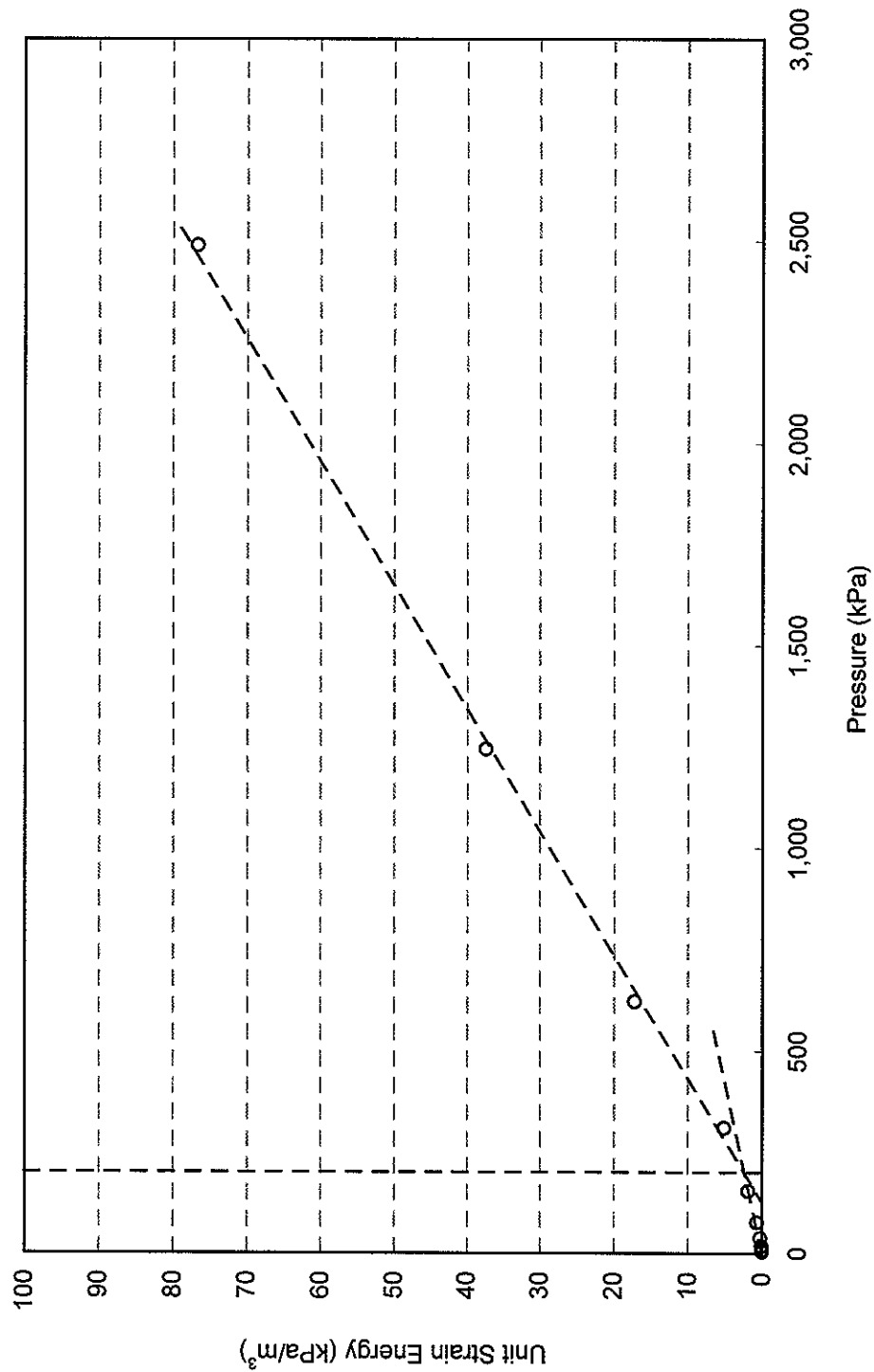
Project No. : 1-09-4135
Date : July 2010



Terraprobe Inc.

Prepared By : HW
Checked By : RA

CONSOLIDATION TEST
Unit Strain Energy vs Pressure
PR5, TW9



$P_c = 200 \text{ kPa}$

Project No. : 1-09-4135

Date : July 2010



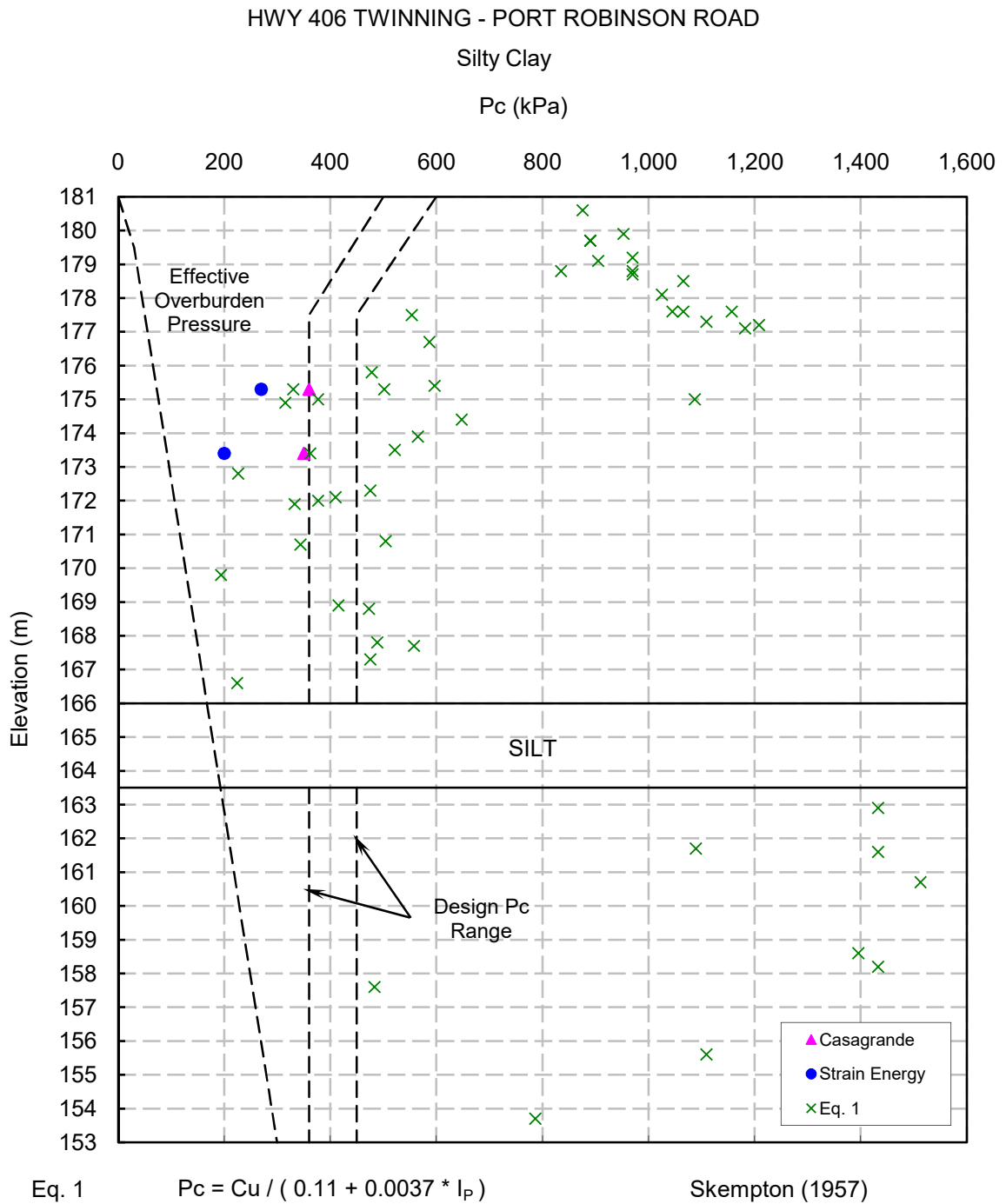
Terraprobe Inc.

Prepared By : HW

Checked By : RA

PREDICTED AND MEASURED PRECONSOLIDATION STRESS

FIGURE F1



Project No. : 1-09-4135

Date : September, 2010



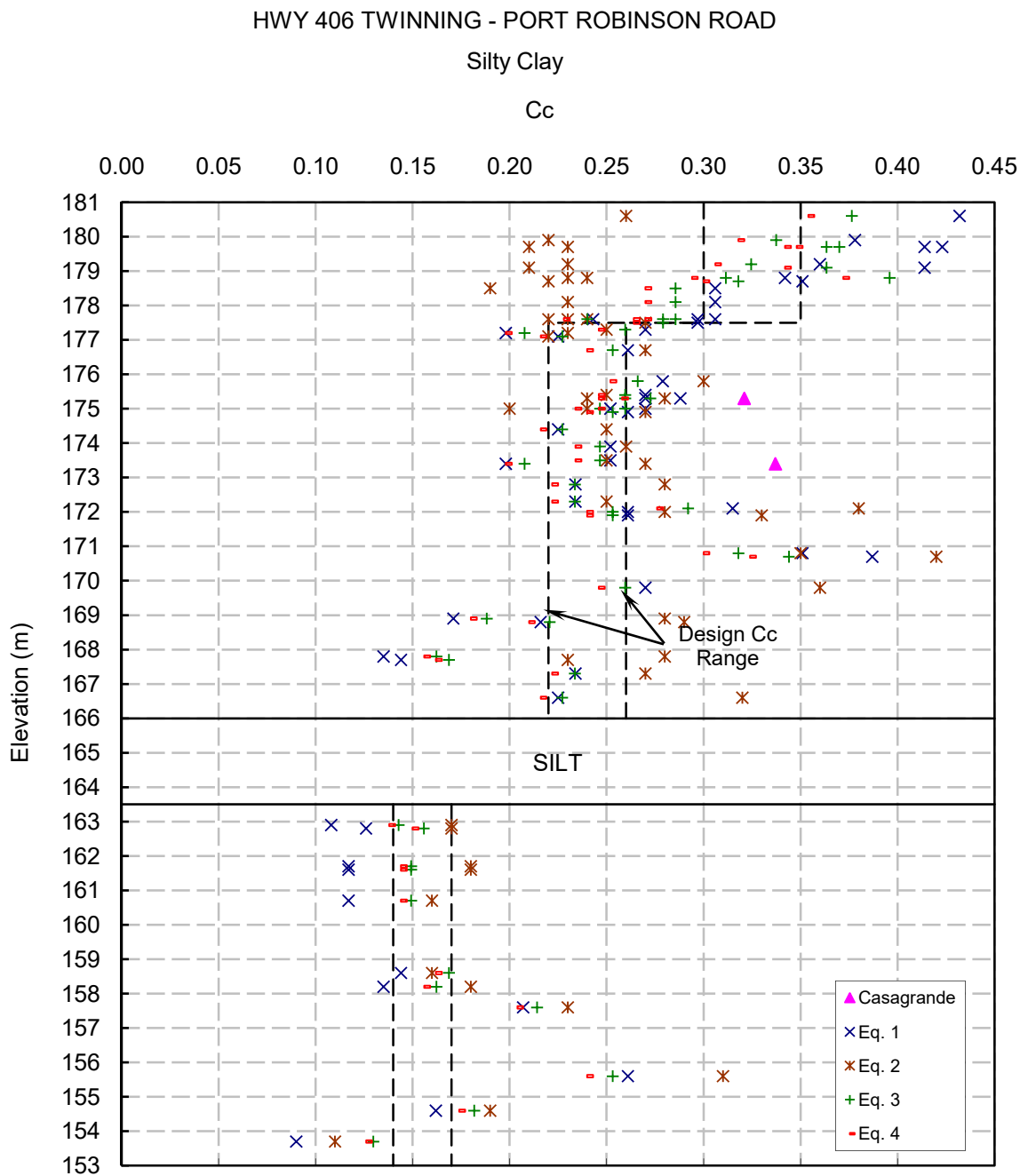
Terraprobe Inc.

Prepared By : HW

Checked By : RA

PREDICTED AND MEASURED COMPRESSION INDEX

FIGURE F2



Eq. 1 $Cc = 0.009 * (LL - 10)$

Terzaghi & Peck (1967)

Eq. 2 $Cc = 0.01 * \omega$

Osterberg (1972)

Eq. 3 $Cc = 0.002343 * LL * Gs$

Nagaraj & Murty (1985)

Eq. 4 $Cc = 0.006 * (LL + 1)$

Lav & Ansal (2001)

Project No. : 1-09-4135

Date : September, 2010



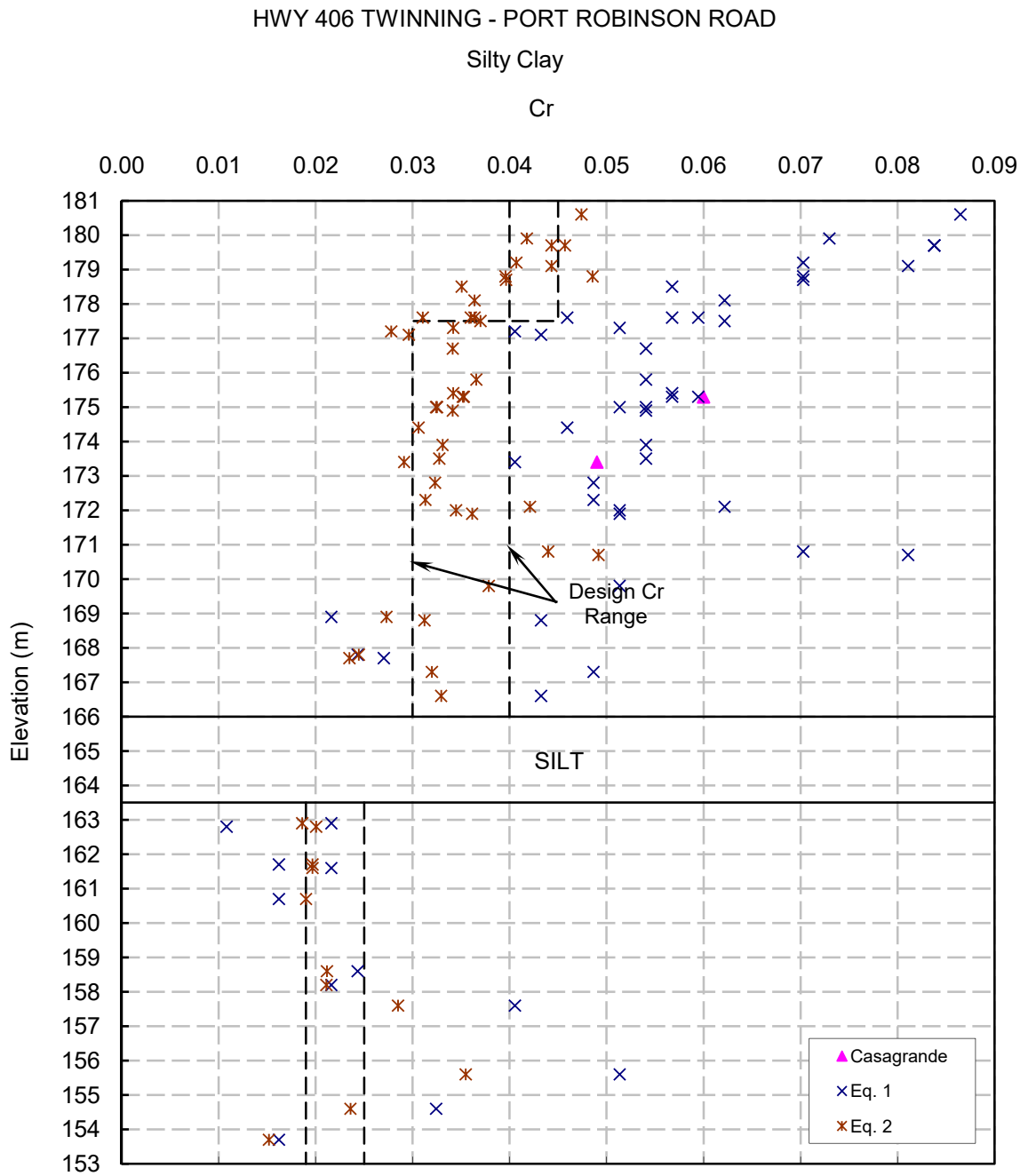
Terraprobe Inc.

Prepared By : HW

Checked By : RA

PREDICTED AND MEASURED RECOMPRESSION INDEX

FIGURE F3



Eq. 1 $Cr = Ip / 370$

Kulhawy & Mayne (1990)

Eq. 2 $Cr = Cc / 5 \sim Cc / 10$

Das (1993)

Project No. : 1-09-4135

Date : September, 2010



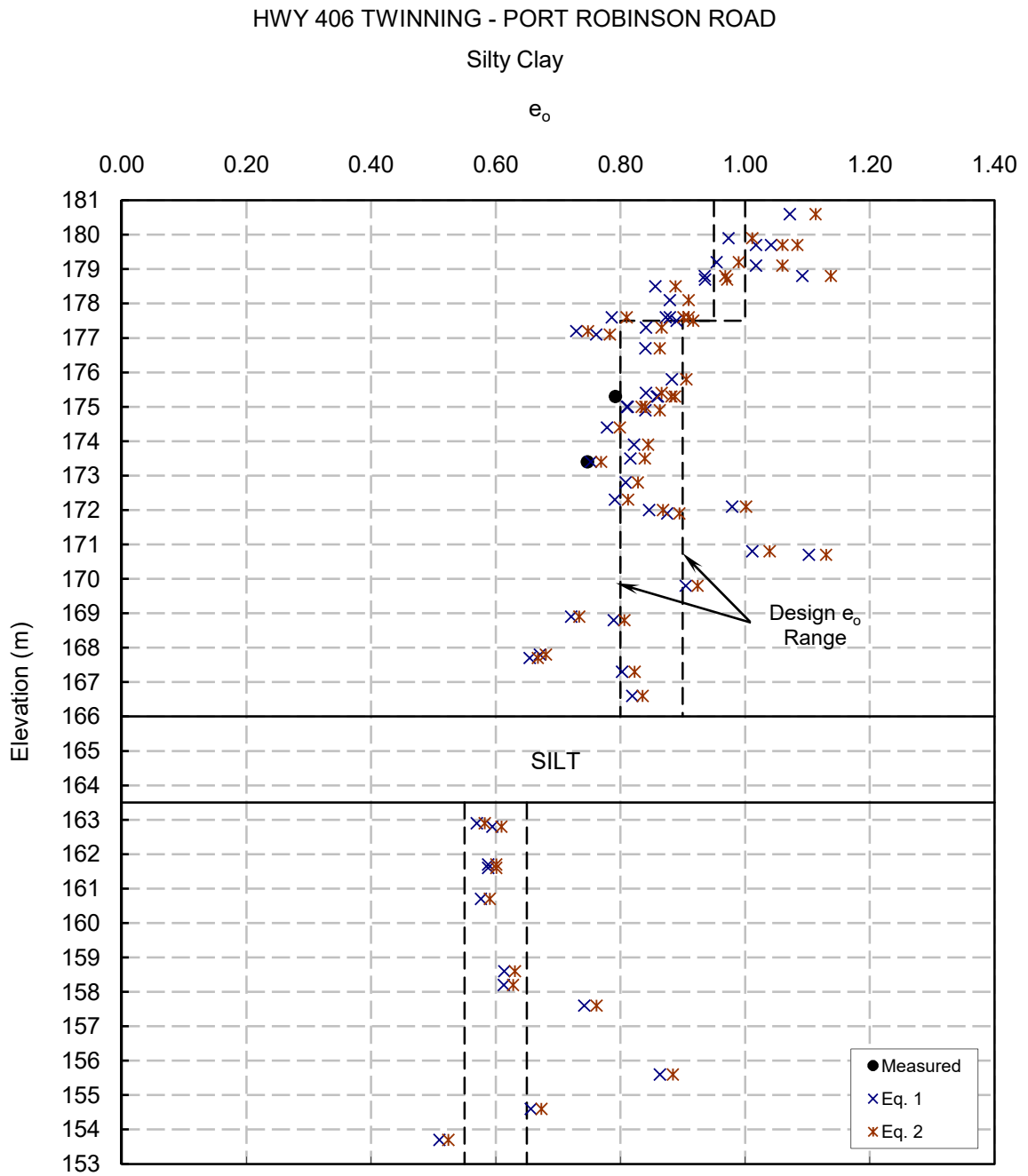
Terraprobe Inc.

Prepared By : HW

Checked By : RA

PREDICTED AND MEASURED VOID RATIO

FIGURE F4



Eq. 1 $e_o = (C_c - 0.256) / 0.43 + 0.84$

derived from Cozzolino (1961)

Eq. 2 $e_o = C_c / 0.40 - 0.001 * \omega + 0.25$

derived from Azzouz et al. (1976)

Project No. : 1-09-4135

Date : September, 2010



Terraprobe Inc.

Prepared By : HW

Checked By : RA



Appendix E

Selected Site Photographs

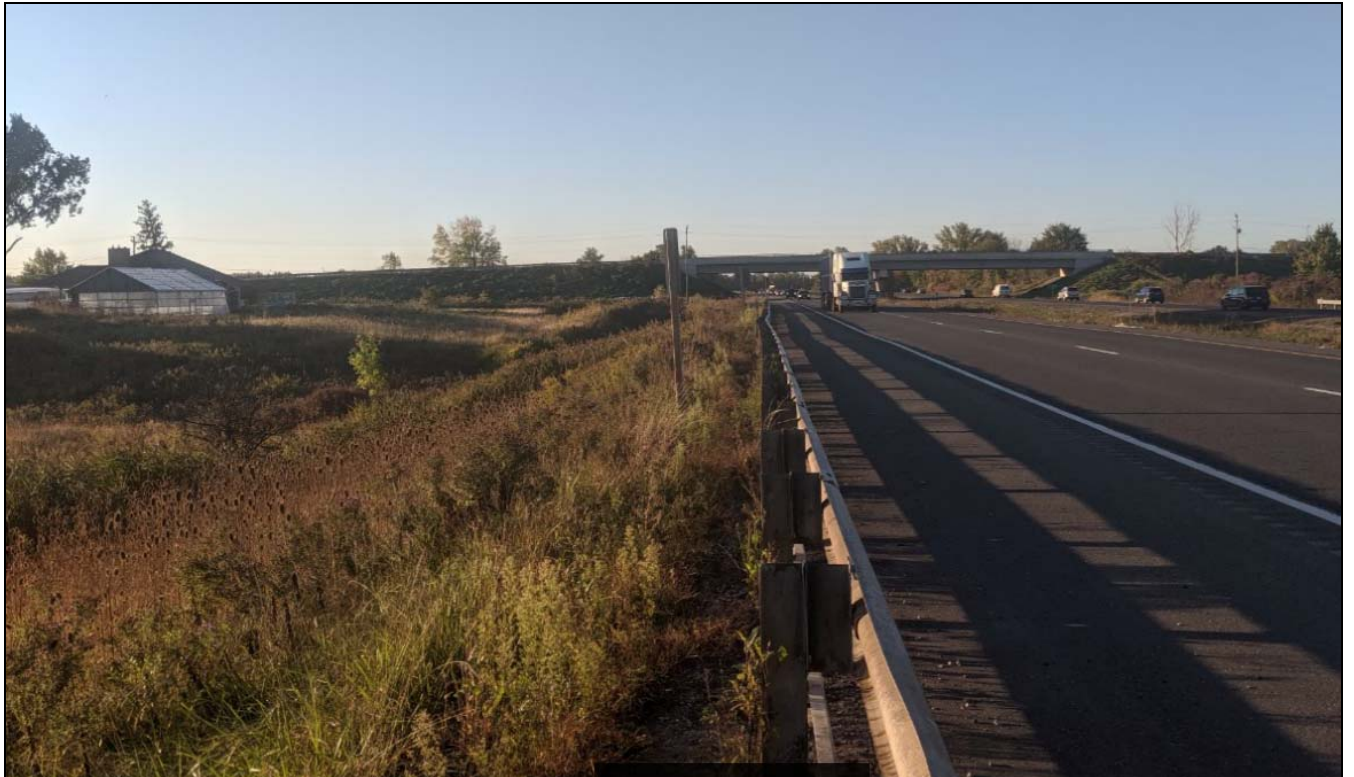


Photo 1 - Highway 406 NBL at the culvert location, looking south towards Port Robinson Road



Photo 2- Looking south at Culvert outlet, east side of Hwy 406



Photo 3- Highway 406 NBL embankment, looking north



Photo 4 - East Embankment Slope at Culvert outlet



Photo 5 - Highway 406 NBL, looking north from north of culvert

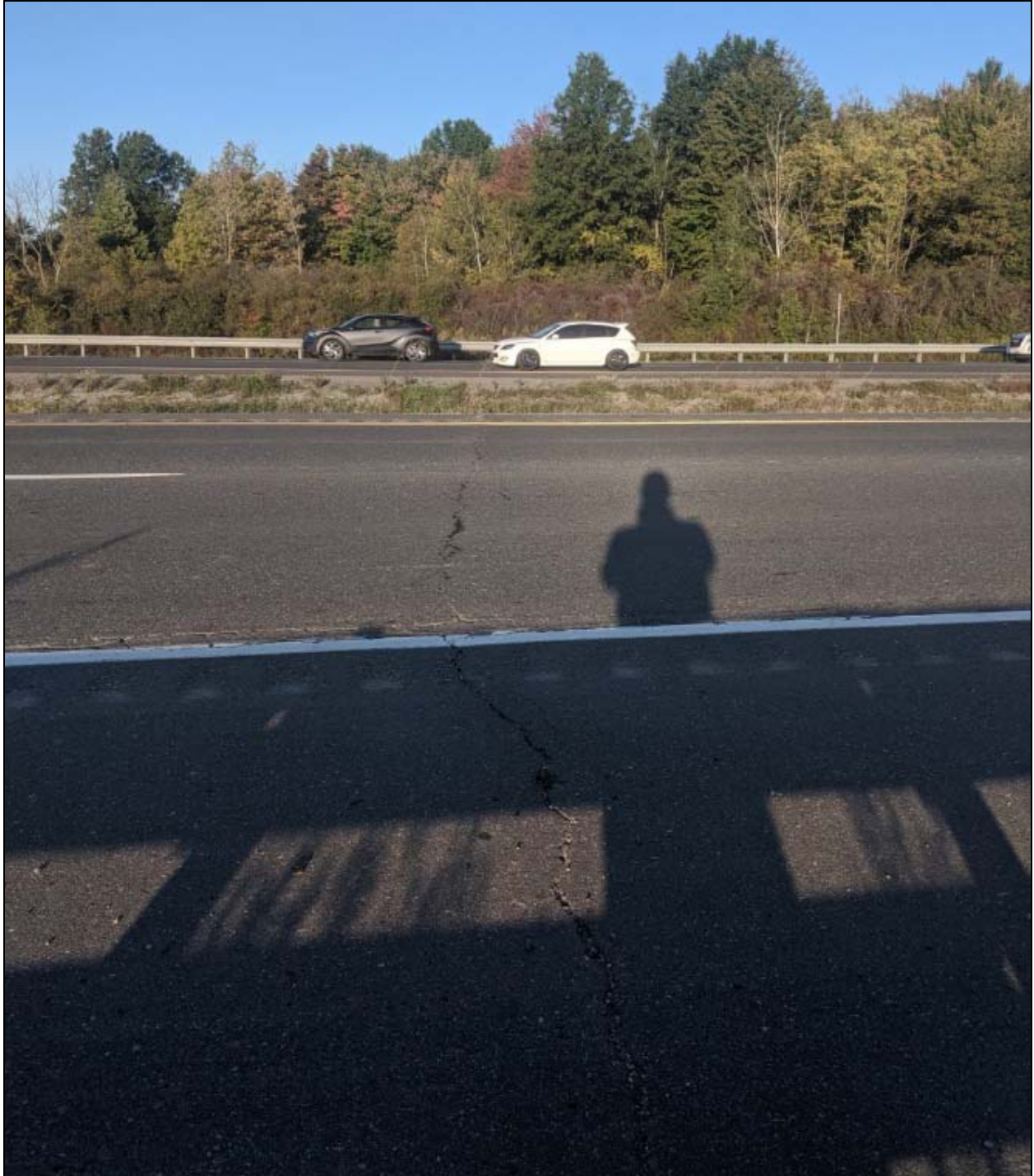
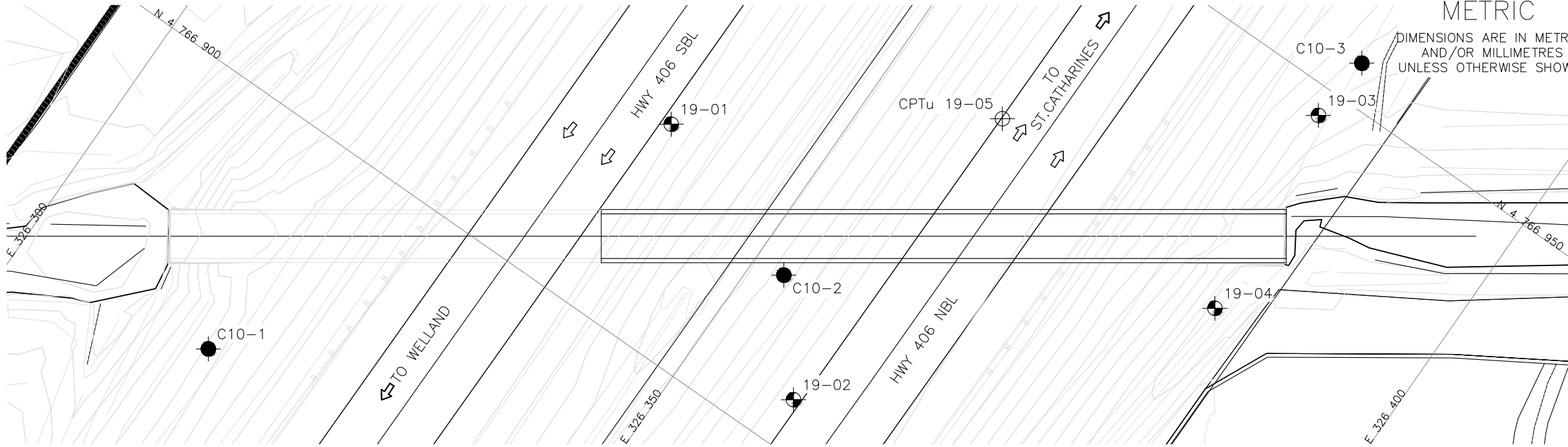


Photo 6- Looking west from Highway 406 NBL shoulder on top of the existing culvert

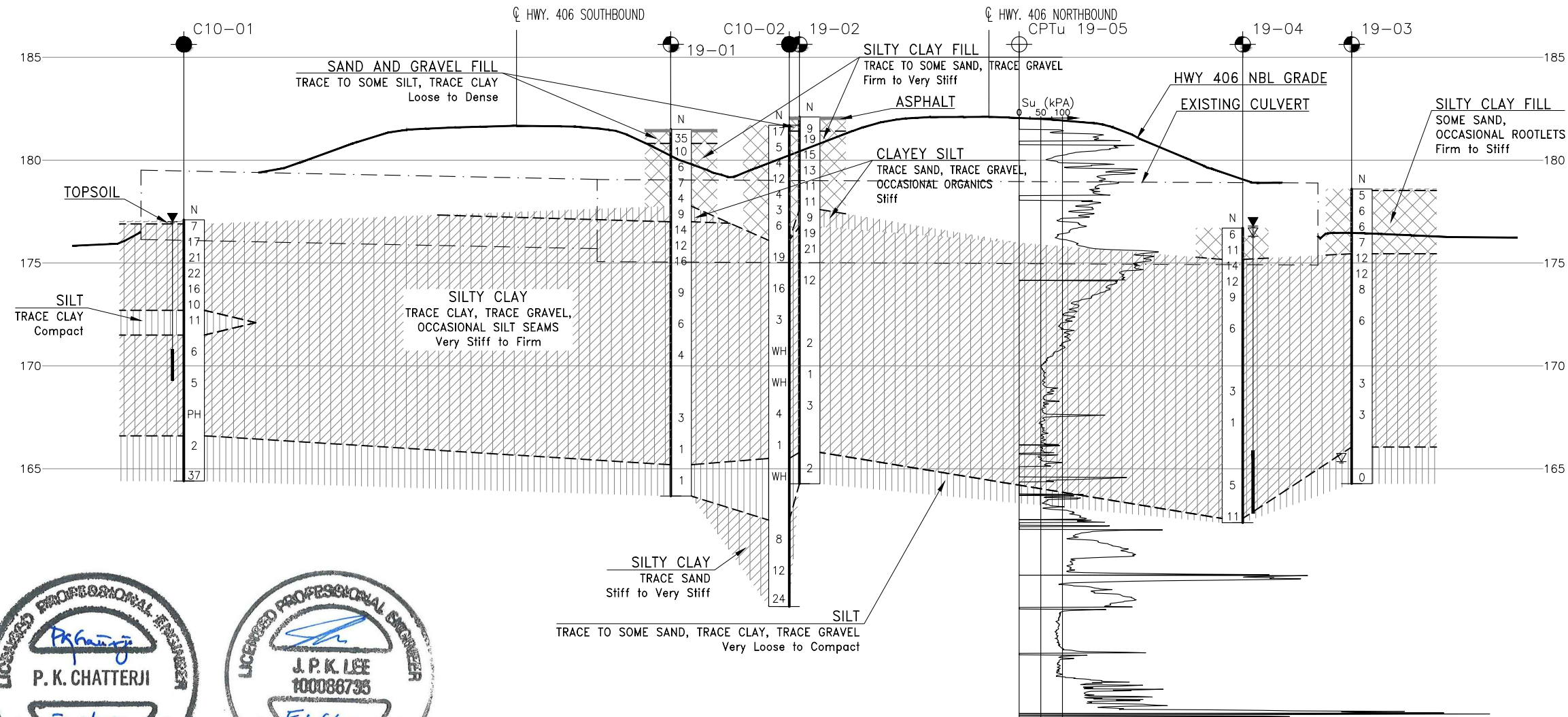


Appendix F

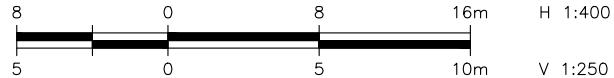
Borehole Locations and Soil Strata Drawing



PLAN
SCALE 1:400



PROFILE ALONG ϕ OF CULVERT



METRIC

DIMENSIONS ARE IN METRES
AND/OR MILLIMETRES
UNLESS OTHERWISE SHOWN

CONT No
WP No 2063-17-00

HIGHWAY 406
CULVERT REPLACEMENT
NORTH OF PORT ROBINSON ROAD
BOREHOLE LOCATIONS AND SOIL STRATA



THURBER ENGINEERING LTD.



43.041765 KEYPLAN -79.235657

LEGEND

- Borehole by Thurber (Current Investigation)
- Borehole by Terraprobe (2010)
- Cone Penetration Test (CPTu)
- N
Blows /0.3m (Std Pen Test, 475J/blow)
- CONE
Blows /0.3m (60° Cone, 475J/blow)
- WH
Weight of Hammer
- Water Level (Open Borehole)
- Piezometer
- 90%
Rock Quality Designation (RQD)
- A/R
Auger Refusal

NO	ELEVATION	NORTHING	EASTING
19-01	181.5	4 766 916.9	326 338.1
19-02	182.1	4 766 904.1	326 359.2
19-03	178.6	4 766 947.8	326 381.1
19-04	176.7	4 766 930.0	326 383.2
C10-01	177.1	4 766 880.1	326 317.5
C10-02	181.7	4 766 912.0	326 352.7
C10-03	178.5	4 766 953.3	326 381.6
CPT 19-05	182.1	4 766 932.7	326 360.1

NOTES

- The boundaries between soil strata have been established only at Borehole locations. Between Boreholes the boundaries are assumed from geological evidence.
- This drawing is for subsurface information only. Surface details and features are for conceptual illustration.
- Coordinate system is MTM NAD 83 Zone 10.

GEOCRES No. 30M3-318



REVISIONS	DATE	BY	DESCRIPTION
DESIGN	RPR	CHK	CODE
DRAWN	BH	CHK	RPR
SITE	34X-0294	STRUCT	DWG 1
LOAD	DATE	DEC	2019



Appendix G

Foundation Comparison





COMPARISON OF ALTERNATIVE CULVERT TYPES

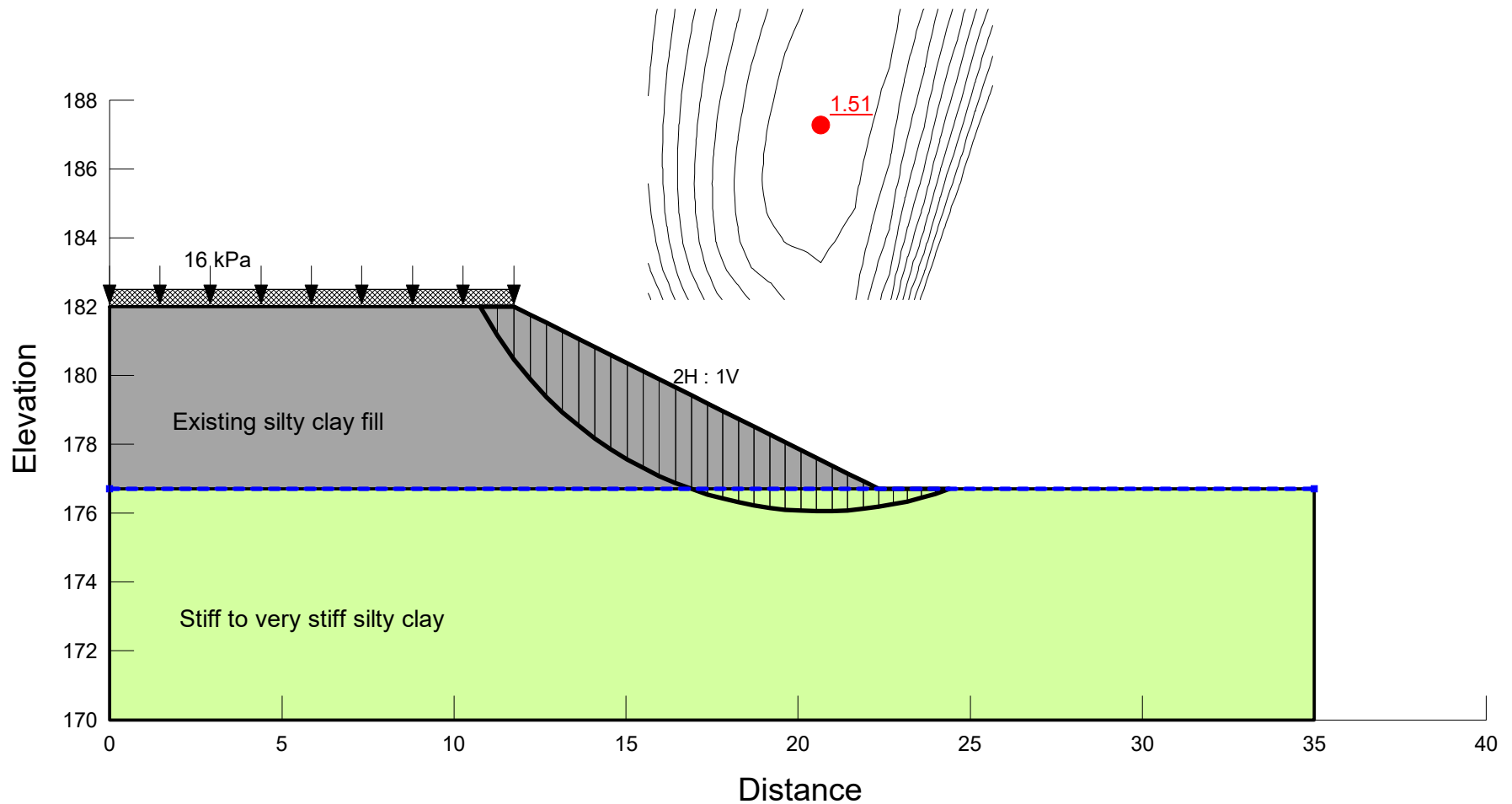
Concrete Box (Closed) Culvert	Concrete Open Footing Culvert	Pipe Culvert
<p>Advantages:</p> <ul style="list-style-type: none"> i. Relatively rapid installation and less disturbance to subgrade soils if pre-cast segments are used. ii. Segmental option can accommodate limited amount of potential differential settlement along culvert axis. iii. Less requirement for soil geotechnical resistances as loading is spread over a larger width. iv. Can accommodate differential settlement. <p>Disadvantages:</p> <ul style="list-style-type: none"> i. More expensive than a CSP culvert. ii. Culvert subgrade preparation and bedding placement must be carried out in the dry. iii. Dewatering is required. iv. Requires subexcavation of soft or organic material from streambed if encountered. v. Requires complete excavation of creek bed. 	<p>Advantages:</p> <ul style="list-style-type: none"> i. Relatively rapid installation if precast units are used. ii. Conventional construction. iii. Generally, less costly than deep foundation elements. iv. Eliminates bedding requirement. v. May have less environmental issues such as those involving spawning fish species. <p>Disadvantages:</p> <ul style="list-style-type: none"> i. Low geotechnical resistances encountered at this site. ii. Requires higher soil geotechnical resistances to support strip footings. iii. Requires excavation below the groundwater level. iv. Potential longer dewatering requirements, due to high water levels. v. Cannot tolerate differential settlement. vi. Shallow foundations close to water would be at risk due to scour, erosion and undermining problems. 	<p>Advantages:</p> <ul style="list-style-type: none"> i. May be installed using trenchless methods. ii. Ease of construction. iii. CSP's can accommodate small differential settlement along culvert axis iv. Steel pipes are likely to be more cost effective than concrete box or open footing culverts. <p>Disadvantages:</p> <ul style="list-style-type: none"> i. Possible hydraulic and/or hydrologic issues. ii. Multiple pipes may be needed to meet hydraulic requirements. iii. CSP cannot be rehabilitated as concrete culverts. iv. Culvert subgrade preparation and bedding placement must be carried out in the dry. v. Dewatering is required. vi. Requires subexcavation of soft or organic material from streambed if encountered.
RECOMMENDED	NOT RECOMMENDED	FEASIBLE



Appendix H

Selected Slope Stability Outputs

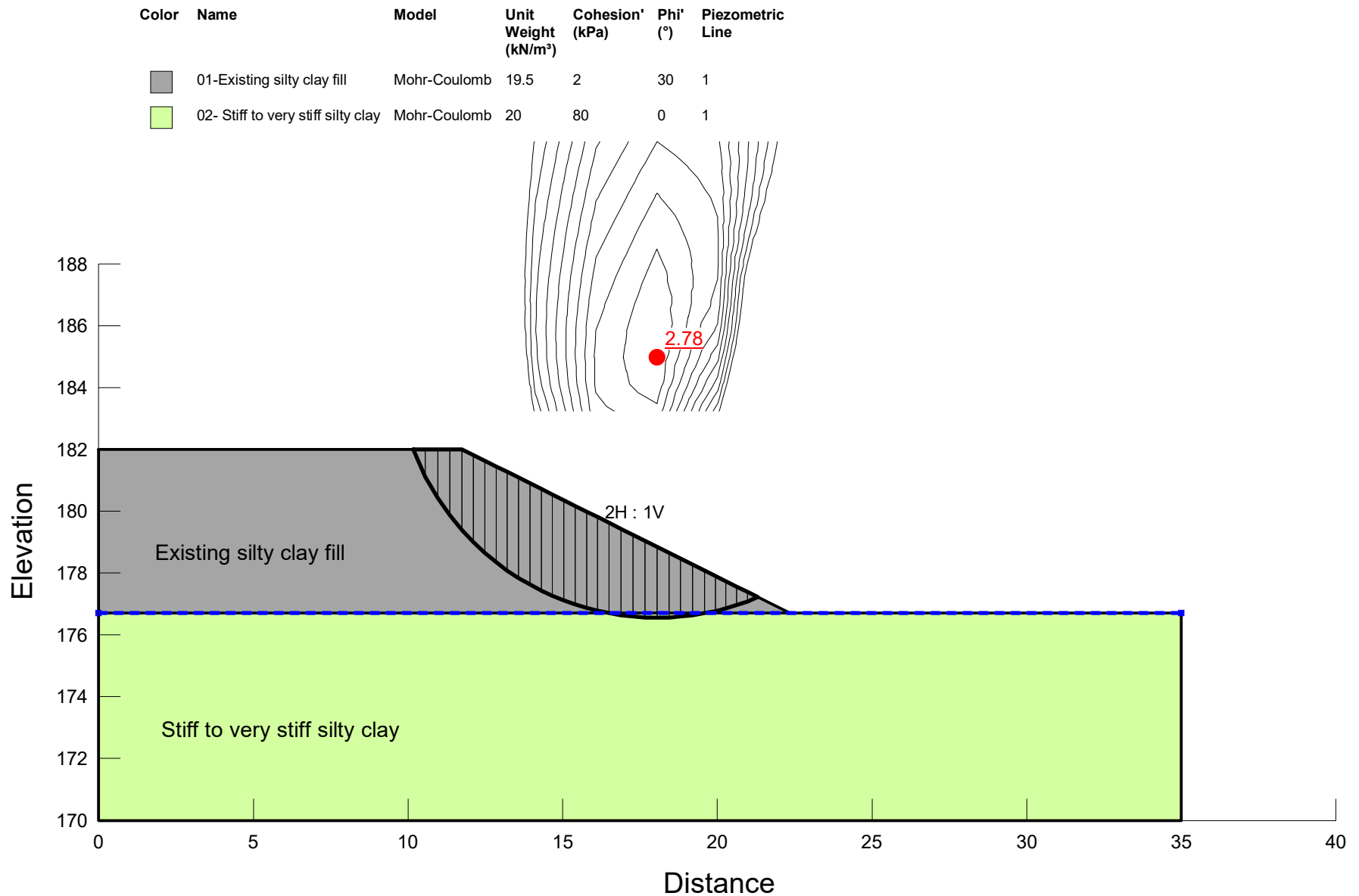
Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Piezometric Line
	01-Existing silty clay fill	Mohr-Coulomb	19.5	2	30	1
	02- Stiff to very stiff silty clay	Mohr-Coulomb	20	2	28	1



Project 20000-Highway 406 Culvert, north of Port Robinson Road		
Analysis Highway 406 Culvert - Drained Analysis		
Seismic Coefficient H: 0g, V: 0g	Last Run 2020-01-21,02:06:35 PM	Scale 1:185

Additional Details
Name: Culvert Rehabilitation, Highway 406
Method: Morgenstern-Price, Half-Sine

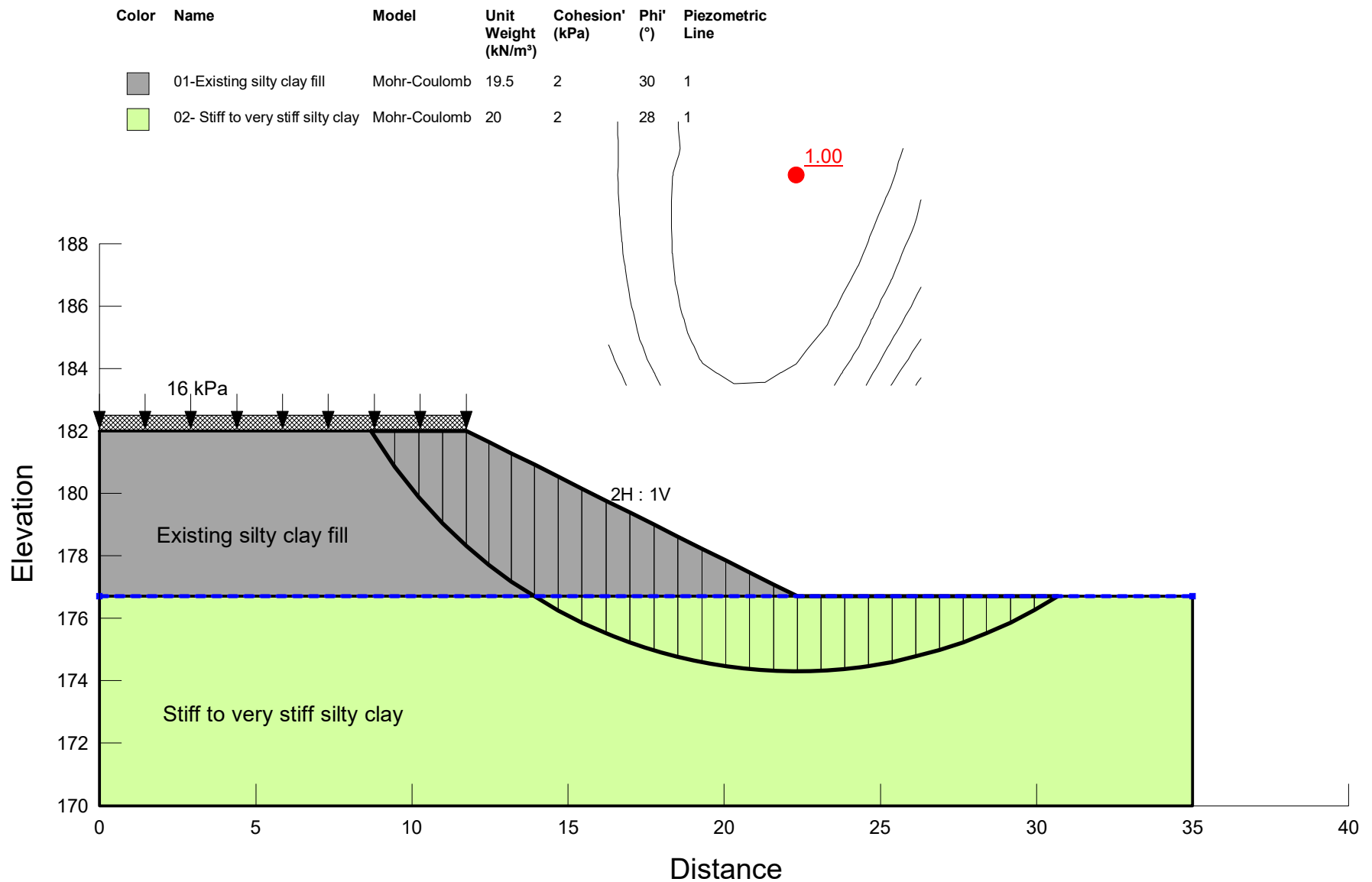
Figure H1



Project		
20000-Highway 406 Culvert, north of Port Robinson Road		
Analysis		
Highway 406 Culvert - Undrained Analysis		
Seismic Coefficient	Last Run	Scale
H: 0g, V: 0g	2020-01-21,02:17:00 PM	1:185

Additional Details
 Name: Culvert Rehabilitation, Highway 406
 Method: Morgenstern-Price, Half-Sine

Figure H2

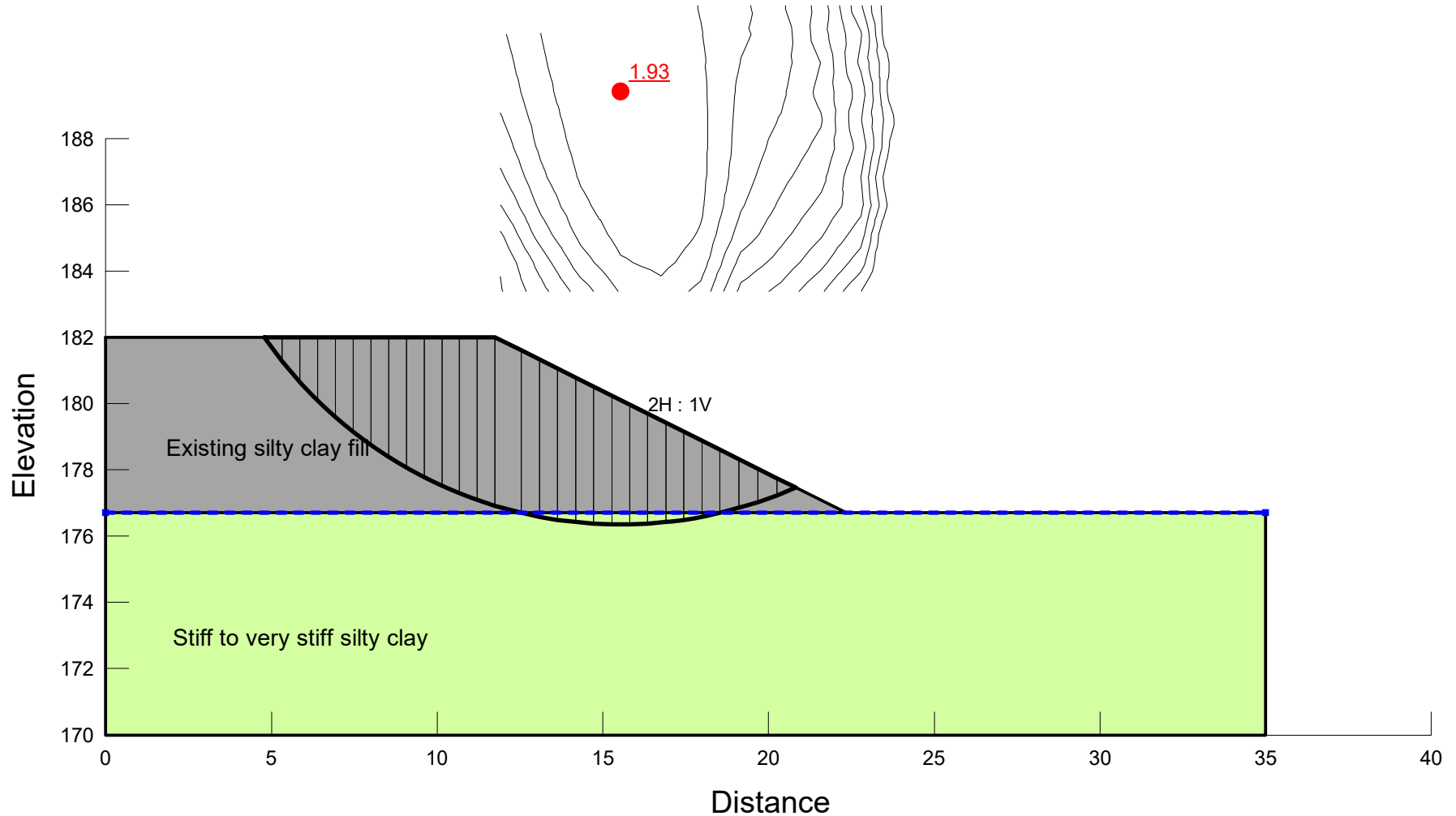


Project		
20000-Highway 406 Culvert, north of Port Robinson Road		
Analysis		
Highway 406 Culvert - Drained Seismic Analysis		
Seismic Coefficient	Last Run	Scale
H: 0.22g, V: 0g	2020-02-07,08:12:40 AM	1:185

Additional Details
 Name: Culvert Rehabilitation, Highway 406
 Method: Morgenstern-Price, Half-Sine

Figure H3

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Piezometric Line
■	01-Existing silty clay fill	Mohr-Coulomb	19.5	2	30	1
■	02- Stiff to very stiff silty clay	Mohr-Coulomb	20	80	0	1



Project 20000-Highway 406 Culvert, north of Port Robinson Road		
Analysis Highway 406 Culvert - Undrained Seismic Analysis		
Seismic Coefficient H: 0.22g, V: 0g	Last Run 2020-02-07,08:05:05 AM	Scale 1:185

Additional Details
Name: Culvert Rehabilitation, Highway 406
Method: Morgenstern-Price, Half-Sine

Figure H4



Appendix I

List of OPSS Documents and Nssp Wording



1. List of OPSS and OPSD Referenced in this Report

- OPSS PROV 206 Construction specification for grading
- OPSS PROV 422 Construction Specification for Precast Reinforced Concrete Box Culverts and Box Sewers in Open Cut
- OPSS PROV 501 Construction specification for compacting
- OPSS.PROV 517 Construction specification for dewatering
- OPSS PROV 539 Construction specification for temporary protection systems
- OPSS PROV 804 Construction specification for seed and cover
- OPSS PROV 902 Construction specification for excavating and backfilling – Structures
- NSSP FOUN0003 Amendment to OPSS.PROV 902
- OPSS PROV 1010 Material specification for aggregates - base, subbase, select subgrade, and backfill material
- OPSD 803.010 Backfill and Cover for Concrete Culverts with Spans less than or equal to 3.0 m.
- OPSD 208.010 Benching of Earth Slope



2. Suggested Text for NSSP on Groundwater Control and Dewatering

Effective dewatering shall be designed and provided by the Contractor during structure excavation, bedding placement and backfilling to allow the work to proceed in the dry. Excavation below the creek and groundwater level will lead to subgrade softening. The dewatering system must be effective to maintain the water level at a minimum depth of 0.5 m below the final subgrade level throughout construction. The dewatering system must remain operational and effective until the culvert is installed and backfilled.

The dewatering system is to be designed in accordance with SP FOUN0003 and OPSS.PROV.517. A preconstruction survey is required, thus Designer Fill-In ** in SP FOUN0003 and SP517F01 should be "Yes". SP FOUN0003 and SP517F01 are attached.

It is recommended that a Professional Engineer with greater than 5 years of experience in designing dewatering systems be retained.

3. Suggested Wording for NSSP on Obstructions

Excavations and installation of cofferdams and roadway protection systems could encounter obstructions embedded in the fill and native soils. Such obstructions may impede excavation progress and/or sheet pile installation. The Contractor shall be prepared to remove, drill through and/or penetrate these obstructions to achieve the design depths.

4. Suggested Wording for NSSP on Operational Constraint - Roadway Protection for Highway 406 SBL Embankment and the Existing West Portion of the Culvert beneath SBL

Temporary protection system shall be installed to protect the roadway traffic of Highway 406 SBL prior to commencing construction work for the new east replacement culvert. The Highway 406 SBL embankment roadway and the existing west portion of the culvert beneath the SBL embankment shall remain operational and must be protected from any damage and/or adverse impact during installation and removal/extraction of the temporary protection system. Care must be exercised during sub-excavation and removal of the existing east culvert footings in order not to induce settlement and undermine the foundation of the existing SBL embankment and west culvert.