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FINAL
FOUNDATION INVESTIGATION REPORT
HIGHWAY 11 CULVERT AT STATION 16+575
HAGGART TOWNSHIP, ONTARIO
ASSIGNMENT NO.: 5021-E-0025
GWP 5278-19-00

GEOCRES NO.: 42H00-094

Location: Lat: 49.289020°, Long: -81.778741°

Client Name: LEA Consulting Ltd.
Date: April 5, 2024
File: 33443

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PART 1. FACTUAL INFORMATION

1. INTRODUCTION

This section of the report presents the factual findings obtained from a foundation investigation conducted by Thurber Engineering Ltd. (Thurber) for the embankment widening and extension of the culvert that crosses Highway 11 near Sta. 16+575 in Haggart Township within the District of Cochrane, Ontario. Thurber carried out the foundation investigation as a subconsultant to LEA Consulting Ltd. (LEA) under Agreement No. 5021-E-0025.

The purpose of this investigation was to explore the subsurface conditions at the site and, based on the data obtained, to provide a borehole location plan, record of boreholes, stratigraphic profile, laboratory test results and a written description of the subsurface conditions. The stratigraphic profile of the subsurface conditions was developed during the current investigation.

It is a condition of this report that Thurber's performance of its professional services is subject to the attached Statement of Limitations and Conditions.

2. SITE DESCRIPTION

2.1 General

The existing culvert crosses Highway 11 approximately 13.0 km west of the junction of Highway 11 and Highway 634. For project purposes, Highway 11 at the culvert site is herein described as oriented east-west, and the culvert is described as oriented north-south.

In the area of the culvert, Highway 11 is a two-lane highway and has a posted speed limit of 90 km/h. The culvert is located within a section of highway with a horizontal curve with the outside of the curve on the north side of the highway alignment. The shoulders of the highway are paved, and guiderails supported on metal posts are present along both shoulders of the highway. The

CNR railway runs approximately 75 m south of the highway alignment; the railway runs approximately parallel to the highway alignment. Traffic volumes for this section of Highway 11 is understood to have been 3,300 AADT in 2016.

The existing roadway embankment side slopes at the site did not show any visible signs of global instability at the time of the investigation. The westbound and eastbound embankment slopes are inclined at approximately 2.3H:1V and 2.8H:1V, respectively.

The existing culvert is reported in drawings provided by LEA to be an 1,800 mm wide, 1,220 mm high, and 42.99 m long reinforced frame box (RFB) culvert. The culvert alignment is approximately perpendicular to the highway alignment. The invert of the culvert is near elevations 226.0 m and 225.4 m at the inlet and outlet, respectively. The road surface is at an approximate elevation of 232.2 m near the highway centreline and the cover above the existing culvert is approximately 5.3 m near the highway centerline. Based on the elevations provided by LEA, the drainage flow is from north to south. The culvert and ditch were dry during the time of the field investigation and slug testing.

The site is in a rural setting and the area adjacent to the highway is undeveloped and vegetated with tall grasses and mixed forests of coniferous and some deciduous trees and shrubs. Overhead utility lines were present along the north side of the highway.

Photographs showing the existing conditions in the project area at the time of the field investigation are included in Appendix D for reference.

2.2 Site Geology

According to Crins et al. 2009[1] the project area is described as Ecoregion 3E (Lake Abitibi Ecoregion) within the Ontario Shield Ecozone. According to Wester et al. 2018[2] the ecoregion is subdivided into Ecodistrict 3E-1 (Clay Belt Ecodistrict). The project area is near center of the ecodistrict, which is characterized by deep, fine texture morainal and glaciolacustrine deposits overlying Precambrian bedrock.

Map M.5036[3] indicates that the project area is composed of till and clay and is within a transition area from morainal to glaciofluvial landform. Map M.2555[4] indicates that the project area is

[1] *https://files.ontario.ca/mnrf-ecosystemspart1-accessible-july2018-en-2020-01-16.pdf*
[2] *https://files.ontario.ca/ecosystems-ontario-part2-03262019.pdf*
[3] *http://www.geologyontario.mndm.gov.on.ca/index.html*
[4] *http://www.geologyontario.mndm.gov.on.ca/index.html*

composed of undifferentiated, fine grained, predominantly silty clay to silt matrix, commonly clast poor, high matrix carbonate content till.

Bedrock Geology Map (MRD126)[5] indicates the site is underlain by metasedimentary rocks: paragneiss and migmatites.

2.3 Existing Subsurface information

Contract drawings 2003-5135 provide details of the realignment of Highway 11 to the north for the section of highway between Sta. 15+100 to 17+300.

The following historical foundation investigation report was available for this site within the Geocres library:

- Geocres Report No. 42H-30 (Golder, 2003)

The historical report presents the results of a foundation investigation carried out for the realignment of Highway 11. This investigation included three test pits and three foundation boreholes identified as 02-1, 02-2, 02-3. The test pits encountered 500 to 900 mm of organics over silty clay. The test pits were indicated to have been terminated at depths ranging from 3.0 to 6.3 m. The foundation boreholes indicated the presence of 0.3 to 0.4 m of topsoil underlain by a deposit of silty clay to clayey silt. A layer of silty sand to sand trace silt was encountered below the silty clay to clayey silt in Borehole 02-2. Silt seams were noted in the bottom 3.0 m of the silty clay to clayey silt layer in Borehole 02-2. Bedrock was not encountered within the depth of field investigation in the historical boreholes. The termination depth of the foundation boreholes ranged from 9.6 to 19.5 m below the ground surface (elev. 217.0 to 207.1 m). The Record of Borehole sheets for the three foundation boreholes are included in Appendix B for reference and the locations are shown on the plan view in Appendix A.

Base plan mapping was provided by LEA for the preparation of this report.

3. SITE INVESTIGATION AND FIELD TESTING

The foundation investigation and field-testing program was carried out between July 5 and July 14, 2023, and consisted of one on-road SCPTu test hole identified as 23-205, two on-road boreholes identified as 23-201 and 23-202, and two off-road boreholes identified as 23-203 and 23-204. The ConeTec report documenting one SCPTu test (SCPT23-205) is provided in Appendix E. Slug testing was carried out in September 2023 in the monitoring well installed in 23-203.

[5] *http://www.geologyontario.mndm.gov.on.ca/mines/data/google/mrd126/doc.kml*

The boreholes were advanced using a track mounted CME 55 LC drill rig equipped with Hollow Stem Augers, NW casing, and NQ coring equipment. The on-road Testhole identified as 23-205 was advanced utilizing SCPTu equipment. Prior to commencement of drilling, utility clearances were obtained in the vicinity of the borehole locations.

A summary of the borehole coordinates, elevations, and termination depths is provided in Table 3-1. The as-drilled borehole elevations were surveyed by Thurber with a Trimble Catalyst DA2 receiver and were checked relative to BM HCP 106 (Elevation 232.597 m). Horizontal locations were measured by Thurber relative to existing site features. The elevations and borehole coordinates were reviewed and referenced to the survey data provided by LEA. The borehole coordinates and elevations are shown on the Borehole Location and Soil Strata drawing included in Appendix A and on the individual Record of Borehole sheets included in Appendix B. The borehole coordinates are referenced to MTM Zone 12.

Table 3-1 Borehole Summary

BOREHOLE NO.	LOCATION	NORTHING (m)	EASTING (m)	GROUND SURFACE ELEVATION (m)	TERMINATION DEPTH (m)
23-201	Westbound lane	5 461 517.8	248 160.9	232.5	18.9 (DCPT 25.8)
23-202	Westbound lane	5 461 506.9	248 188.1	232.8	18.9 (DCPT 26.7)
23-203	North embankment toe	5 461 537.1	248 167.1	226.7	12.5
23-204	North embankment toe	5 461 533.6	248 176.8	227.5	13.6
23-205 (SCPTu)	Westbound lane	5 461 512.6	248 174.8	232.6	21.7

Soil samples were obtained at selected intervals using a split spoon sampler in conjunction with Standard Penetration Testing (SPT) in general accordance with ASTM D 1586. In-situ shear vane testing was carried out within the cohesive layers, where possible, using an MTO ‘N’ sized vane in general accordance with ASTM D 2573. Thin-Walled (Shelby) Tube samples were pushed and retrieved at various elevations in the boreholes to obtain relatively undisturbed cohesive soils samples for further laboratory testing. The boreholes were advanced to sampled depths ranging from 12.5 to 18.9 m below the existing ground surface (elev. 214.2 to 213.6 m). A Dynamic Cone Penetration (DCPT) was completed below the sampled depth in Boreholes 23-201 and 23-202 to a tip elevation at 206.7 and 206.1 m (25.8 and 26.7 m below the ground surface), respectively. Bedrock was not encountered within the depth of investigation. Predrilling was not required to advance the SCPTu equipment.

The drilling and sampling operations were supervised on a full-time basis by a member of Thurber's technical staff. The drilling supervisor logged the boreholes and processed the recovered soil samples for transport to Thurber's Ottawa laboratory for further examination and testing.

A 32 mm diameter monitoring well was installed in Borehole 23-203 to allow for measurements of the groundwater level after drilling. The details for the well are illustrated on the respective Record of Borehole sheet provided in Appendix B.

Following completion of the field investigation, the boreholes were decommissioned in general accordance with O.Reg. 903, as amended. Boreholes 23-201 and 23-202 and Testhole 23-205 were capped with cold patch asphalt to reinstate the pavement surface.

4. LABORATORY TESTING

Laboratory testing was selected in general accordance with the April 2022 version of the MTO Guidelines for Foundation Engineering Services, Section 5. Geotechnical laboratory testing consisted of natural moisture content determination and visual identification of all retained soil samples. Recovered soil samples were selected for grain size distribution and, where appropriate, Atterberg Limit testing in accordance with MTO and ASTM standards. The results of these tests are summarized on the Record of Borehole sheets included in Appendix B.

Two relatively undisturbed soil samples obtained in Thin Walled (Shelby) Tubes were extruded and underwent one-dimensional consolidation testing (ASTM D 2435). Four one-dimensional consolidation tests were also carried out as part of the current assignment for the bridge site (Geocres *TBD*) located approximately 500 m west of the culvert site and the details can be found in that report.

Two soil samples were selected and submitted for analytical testing of corrosivity parameters and sulphate content.

All laboratory test results from the field investigation are provided in Appendix C.

5. DESCRIPTION OF SUBSURFACE CONDITIONS

Details of the encountered soil stratigraphy are presented on the Record of Borehole sheets included in Appendix B and on the Borehole Location and Soil Strata Drawing included in Appendix A. A general description of the stratigraphy, based on the conditions encountered in the boreholes, is given in the following sections. However, the factual data presented on the Record

of Borehole sheets takes precedence over this general description for interpretation of the site conditions. It must be recognized that the soil and groundwater conditions will vary between and beyond borehole locations. Soil classification is in general accordance with ASTM D2487 with the description of secondary components as outlined in the MTO Guideline for Foundation Engineering Services Manual (April 2022).

In general, the encountered stratigraphy consists of sand fill overlaying clayey silt fill over native deposits of silty clay to clayey silt. Organic Silt was encountered near the ground surface in the off-road boreholes.

5.1 Surficial Materials

5.1.1 Asphalt

Asphalt was encountered at the ground surface in on-road Boreholes 23-201 and 23-202. The asphalt was measured to have a thickness of 125 mm to 150 mm.

5.1.2 Topsoil

Topsoil was encountered at the ground surface in off-road Borehole 23-204. The topsoil was measured to have a thickness of 150 mm. A moisture content of 45% was recorded in the topsoil.

5.2 Fill

5.2.1 Sand Fill

A fill layer consisting of sand some gravel was encountered below the asphalt in on-road Boreholes 23-201 and 23-202. The fill layer was 1.1 to 1.3 m thick (base elev. 231.3 m). SPT N-values ranging from 11 to 40 blows were recorded in the fill, indicating a compact to dense relative density.

Moisture contents ranging from 3 to 4% were recorded. The results of gradation analyses completed on two samples of the layer are illustrated in Figure C1 of Appendix C. The results of the tests are summarized in the table below and on the Record of Borehole sheets in Appendix B.

SOIL PARTICLE	PERCENTAGE (%)
Gravel	13 – 15
Sand	75 – 79
Silt	8 – 10
Clay	

5.2.2 Silty Clay to Clayey Silt Fill

A fill layer consisting of silty clay clayey silt was encountered below the sand fill in Boreholes 23-201 and 23-202. Some sand was noted in the layer. The fill layer was 4.6 to 6.4 m thick with an underside depth of 6.1 to 7.6 m (base elev. 226.7 to 224.9 m). SPT N-values in the fill material ranged from 6 to 16 blows. The clayey silt fill is described as very stiff in consistency based on N-values and tactile evaluations of strength.

The recorded moisture contents of the fill ranged from 13 to 22%. The results of gradation analyses completed on two samples of the fill are illustrated on Figure C2 of Appendix C. The results of the tests are summarized in the table below and on the Record of Borehole sheets in Appendix B.

SOIL PARTICLE	PERCENTAGE (%)
Gravel	0
Sand	14 – 15
Silt	46 – 50
Clay	35 – 40

Atterberg Limit testing were completed in two samples of the material. The results are illustrated in Figure C3 Appendix C and summarized below and on the Record of Borehole sheets in Appendix B. The laboratory results indicate that the clayey silt fill exhibits low to intermediate plastic behaviour (CI to CL).

PARAMETER	VALUE
Liquid Limit	31 – 36
Plastic Limit	16 – 19
Plasticity Index	15 – 17

5.3 Organic Silt (OH)

A native layer of organic silt containing wood fragments and peat inclusions was encountered at the ground surface in the off-road Boreholes 23-203 and 23-204. The layer ranged in thickness from 0.6 to 0.9 m (base elev. 226.7 to 225.8 m). SPT N-values of 2 and 4 blows were recorded.

The recorded moisture contents of the layer ranged from 26 to 87%. Low sample recovery prevented sufficient samples to carry out a gradation analysis. Atterberg Limit testing was completed in one sample of the material. The results are illustrated in Figure C4 Appendix C and summarized below and on the Record of Borehole sheets in Appendix B. The laboratory results indicate that the organic silt exhibits high plastic behaviour (OH).

PARAMETER	VALUE
Liquid Limit	62
Plastic Limit	34
Plasticity Index	28

5.4 Silty Clay (Cl) to Clayey Silt (CL)

A layer of silty clay to clayey silt was encountered below the silty clay fill in Boreholes 23-201 and 23-202 and below the organic silt in Boreholes 23-203 and 23-204. Varying amounts of sand were noted in the layer. The layer was not fully penetrated in the boreholes but was proven to be at least 11.3 to 12.8 m thick and extend to depths ranging from 12.5 to 18.9 m (base elev. 214.2 to 213.6 m).

Where SPT were conducted within the layer, the N-values typically ranged from weight-of-hammer (WH) to 8. A value as high as 21 blows was noted in the layer directly below the fill in Borehole 23-202. Field vane tests were performed within this layer where possible. Undrained shear strengths were obtained and ranged from 75 to greater than 100 kPa within the on-road boreholes and 38 to greater than 100 kPa in the off-road boreholes. Remolded vane tests recorded sensitives typically ranging from smaller than 2 to 5, indicating that the clay is medium sensitivity to sensitive (CFEM, 2006). The layer is described as firm to very stiff in consistency based on N-values, undrained shear strength measurements, and tactile evaluations of strength.

The recorded moisture contents of the fill ranged from 16 to 66% but were typically less than 35%. The results of thirteen gradation analyses completed on samples of the layer are illustrated on Figures C5, C6, and C7 of Appendix C. The results of the tests are summarized in the table below and on the Record of Borehole sheets in Appendix B.

SOIL PARTICLE	PERCENTAGE (%)
Gravel	0 – 1
Sand	7 – 18
Silt	40 – 58
Clay	26 – 51

Atterberg Limit testing were completed in thirteen samples of the material. The results are illustrated in Figure C8, C9, and C10 Appendix C and summarized below and on the Record of Borehole sheets in Appendix B. The laboratory results indicate that the silty clay to clayey silt exhibits low to intermediate plastic behaviour (CL to CI).

PARAMETER	VALUE
Liquid Limit	24 – 39
Plastic Limit	15 – 19
Plasticity Index	8 – 20

One-dimensional consolidation testing (ASTM D 2435) on samples from Boreholes 23-201 and 23-203. Load increments were maintained for 24 hours. Photographs of the extruded samples are provided in Appendix C. The testing results are presented in Appendix C and are summarized in Table 5-1. The preconsolidation stresses summarized in the table above were obtained from the end-of-increment void ratio. It should be expected that compressibility characteristics will vary with depth in accordance with the soil index parameters and stress history.

Table 5-1 Advanced Laboratory Test Results

Borehole	23-201	23-203
Sample	ST1	ST1
Sample Depth (m)	8.4 – 9.0	5.3 – 5.9
Sample Elevation (m)	223.8	221.1
Soil Layer	Silty Clay (CI)	Silty Clay (CI)
Moisture Content (%)	24	26
Liquidity Index (-)	0.4	0.5
Initial Void Ratio (-)	0.64	0.67
Moist Unit Weight (kN/m^3)	20.2	20.2
In-situ Vertical Effective Stress (kPa)	168	105
Preconsolidation Stress (kPa)	160	153
Overconsolidation Ratio (-)	~1.0	1.4
Recompression Index (-)	0.03	0.06
Compression Index (-)	0.16	0.16
Coefficient of Reconsolidation (cm^2/sec)	1×10^{-3}	1×10^{-3}
Coefficient of Consolidation (cm^2/sec)	7×10^{-4}	5×10^{-4}
Load Increment Duration (hrs.)	24	24

5.5 Refusal

Bedrock was not encountered within the depth of the borehole investigation. A Dynamic Cone Penetration Test (DCPT) was carried out below the sampled depth in Boreholes 23-201 and 23-202, and a refusal blow count was encountered at depths of 25.8 to 26.7 m (elev. 206.7 to 206.1 m).

The SCPTu test (Borehole 23-205) was advanced by ConeTec to a refusal depth of 21.7 m (elev. 210.9 m).

5.6 Groundwater Level

The measured groundwater levels from the monitoring well and open boreholes are summarized in Table 5-2.

Table 5-2 Measured Water Levels

Borehole	Bottom of Screen Depth /Elevation (m)	Soil in Zone of Screen	Groundwater Level		Date of Measurement	Comments
			Depth (mbgs)	Elevation (m)		
23-202	-	-	dry	-	2023/07/09	Open Borehole
23-203	12.2/ 214.5	Silty Clay	dry dry 5.5	- - 221.2	2023/07/14 2023/07/15 2023/09/10	-
23-204	-	-	dry	-	2023/07/14	Open Borehole

The culvert and ditch were dry during the field investigation and slug testing.

It should be noted that the values shown above are considered short-term readings and may not reflect groundwater levels at the time of construction. 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 and/or prolonged precipitation events.

A Single Well Response Test (SWRT), or “slug test”, was carried out on September 10, 2023, in the monitoring well installed in Borehole 23-203 by lowering the water level within the monitoring well and recording the recovery of the water level over time with a data logger. The slug test was completed and analyzed using the Hvorslev method and the plots of the slug test results are included in Appendix B. The hydraulic conductivity value calculated from the in-situ slug test is summarized in Table 5-3.

Table 5-3 Single Well Response Test Results

Borehole /Monitoring Well	Bottom of Screen Depth /Elevation (m)	Soil in Zone of Screen	Estimated Hydraulic Conductivity (m/s)
23-203	12.2 / 214.5	Silty Clay	2.5×10^{-7}

It should be expected that variations in hydraulic conductivity will exist within the various soils deposits that were encountered.

The well was decommissioned following the completion of the testing on September 10, 2023.

5.7 Analytical Testing

Two soil samples were submitted for analytical testing. The analysis results are included in Appendix C and are summarized in the following table.

Table 5-4 Analytical Test Results

BOREHOLE	23-201	23-203
SAMPLE	SS11	SS3
DEPTH (ft/m)	25'0" – 27'0" 7.6 – 8.2	5'0" – 7'0" 1.5 – 2.1
ELEVATION (m)	224.9	225.2
SOIL TYPE	Clayey Silt (CL)	Clayey Silt (CL)
CONDUCTIVITY (µS/cm)	235	212
pH	7.66	7.79
RESISTIVITY (Ohm-cm)	4,260	4,710
CHLORIDE (µg/g)	32	41
SULPHATE (µg/g)	62	37
SULPHIDE (%)	< 0.04	0.04

6. MISCELLANEOUS

The borehole locations reflect existing site features and access constraints. The as-drilled locations and ground surface elevation were measured by Thurber following completion of the field program. George Downing Estate Drilling Ltd. of Hawkesbury, Ontario, supplied and operated the drill rig used to drill, test, sample, and decommission the boreholes and well. Cone Penetration Testing (CPT) was performed by ConeTec Investigation Ltd. of Burnaby, B.C. Traffic control was performed in accordance with Ontario Book 7 and was provided by Demora Construction Services Inc of North Bay, Ontario. The field investigation was supervised on a full-time basis by Mr. D. Amorim Pereira, Geotechnical Technician. Well slug testing was carried out by Mr. I. Khan, EIT. Overall supervision of the field investigation program was provided by Mr. A. de Oliveira, EIT.

Routine geotechnical laboratory testing and one-dimensional consolidation testing were completed by Thurber's laboratories in Ottawa. Specific gravity testing was carried out by Stantec's geotechnical laboratory in Ottawa. Analytical testing was completed by Paracel Laboratories Ltd. in Ottawa.

Interpretation of the factual data and preparation of this report was completed by Mr. D. Amorim Pereira, Geotechnical Technician, A. de Oliveira, EIT. The report was reviewed by Stephen

Peters, P.Eng. and Dr. P.K. Chatterji, P.Eng., the Designated Principal Contact for MTO Foundation Projects.

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THURBER

STATEMENT OF LIMITATIONS AND CONDITIONS

1. STANDARD OF CARE

This Report has been prepared in accordance with generally accepted engineering or environmental consulting practices in the applicable jurisdiction. No other warranty, expressed or implied, is intended or made.

2. COMPLETE REPORT

All documents, records, data and files, whether electronic or otherwise, generated as part of this assignment are a part of the Report, which is of a summary nature and is not intended to stand alone without reference to the instructions given to Thurber by the Client, communications between Thurber and the Client, and any other reports, proposals or documents prepared by Thurber for the Client relative to the specific site described herein, all of which together constitute the Report.

IN ORDER TO PROPERLY UNDERSTAND THE SUGGESTIONS, RECOMMENDATIONS AND OPINIONS EXPRESSED HEREIN, REFERENCE MUST BE MADE TO THE WHOLE OF THE REPORT. THURBER IS NOT RESPONSIBLE FOR USE BY ANY PARTY OF PORTIONS OF THE REPORT WITHOUT REFERENCE TO THE WHOLE REPORT.

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The Report has been prepared for the specific site, development, design objectives and purposes that were described to Thurber by the Client. The applicability and reliability of any of the findings, recommendations, suggestions, or opinions expressed in the Report, subject to the limitations provided herein, are only valid to the extent that the Report expressly addresses proposed development, design objectives and purposes, and then only to the extent that there has been no material alteration to or variation from any of the said descriptions provided to Thurber, unless Thurber is specifically requested by the Client to review and revise the Report in light of such alteration or variation.

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5. INTERPRETATION OF THE REPORT

a) Nature and Exactness of Soil and Contaminant Description: Classification and identification of soils, rocks, geological units, contaminant materials and quantities have been based on investigations performed in accordance with the standards set out in Paragraph 1. Classification and identification of these factors are judgmental in nature. Comprehensive sampling and testing programs implemented with the appropriate equipment by experienced personnel may fail to locate some conditions. All investigations utilizing the standards of Paragraph 1 will involve an inherent risk that some conditions will not be detected and all documents or records summarizing such investigations will be based on assumptions of what exists between the actual points sampled. Actual conditions may vary significantly between the points investigated and the Client and all other persons making use of such documents or records with our express written consent should be aware of this risk and the Report is delivered subject to the express condition that such risk is accepted by the Client and such other persons. Some conditions are subject to change over time and those making use of the Report should be aware of this possibility and understand that the Report only presents the conditions at the sampled points at the time of sampling. If special concerns exist, or the Client has special considerations or requirements, the Client should disclose them so that additional or special investigations may be undertaken which would not otherwise be within the scope of investigations made for the purposes of the Report.

b) Reliance on Provided Information: The evaluation and conclusions contained in the Report have been prepared on the basis of conditions in evidence at the time of site inspections and on the basis of information provided to Thurber. Thurber has relied in good faith upon representations, information and instructions provided by the Client and others concerning the site. Accordingly, Thurber does not accept responsibility for any deficiency, misstatement or inaccuracy contained in the Report as a result of misstatements, omissions, misrepresentations, or fraudulent acts of the Client or other persons providing information relied on by Thurber. Thurber is entitled to rely on such representations, information and instructions and is not required to carry out investigations to determine the truth or accuracy of such representations, information and instructions.

c) Design Services: The Report may form part of design and construction documents for information purposes even though it may have been issued prior to final design being completed. Thurber should be retained to review final design, project plans and related documents prior to construction to confirm that they are consistent with the intent of the Report. Any differences that may exist between the Report's recommendations and the final design detailed in the contract documents should be reported to Thurber immediately so that Thurber can address potential conflicts.

d) Construction Services: During construction Thurber should be retained to provide field reviews. Field reviews consist of performing sufficient and timely observations of encountered conditions in order to confirm and document that the site conditions do not materially differ from those interpreted conditions considered in the preparation of the report. Adequate field reviews are necessary for Thurber to provide letters of assurance, in accordance with the requirements of many regulatory authorities.

6. RELEASE OF POLLUTANTS OR HAZARDOUS SUBSTANCES

Geotechnical engineering and environmental consulting projects often have the potential to encounter pollutants or hazardous substances and the potential to cause the escape, release or dispersal of those substances. Thurber shall have no liability to the Client under any circumstances, for the escape, release or dispersal of pollutants or hazardous substances, unless such pollutants or hazardous substances have been specifically and accurately identified to Thurber by the Client prior to the commencement of Thurber's professional services.

7. INDEPENDENT JUDGEMENTS OF CLIENT

The information, interpretations and conclusions in the Report are based on Thurber's interpretation of conditions revealed through limited investigation conducted within a defined scope of services. Thurber does not accept responsibility for independent conclusions, interpretations, interpolations and/or decisions of the Client, or others who may come into possession of the Report, or any part thereof, which may be based on information contained in the Report. This restriction of liability includes but is not limited to decisions made to develop, purchase or sell land.

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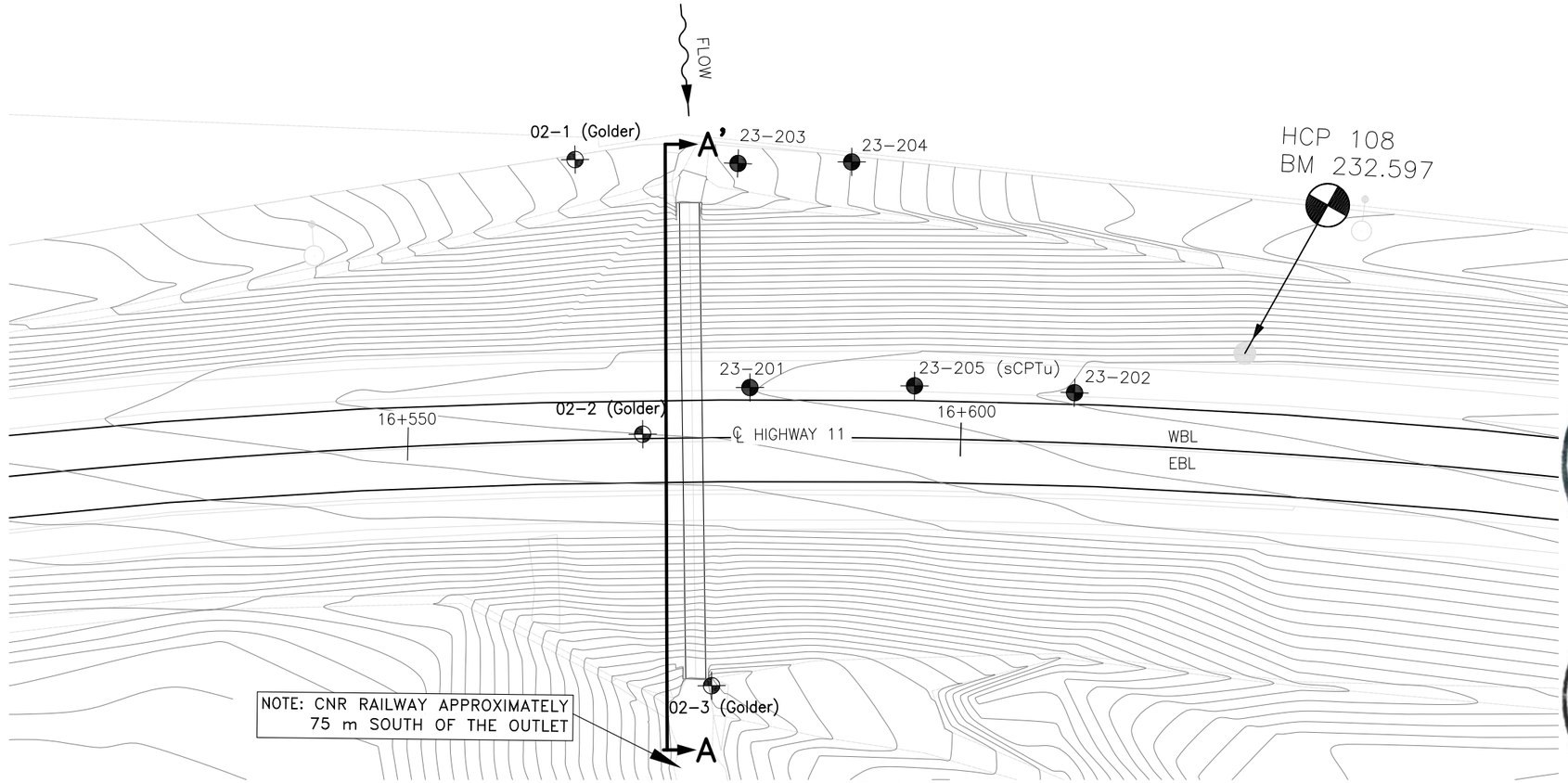
APPENDIX A

Borehole Locations and Strata Drawing

MINISTRY OF TRANSPORTATION, ONTARIO

METRIC

DIMENSIONS ARE IN METRES AND/OR MILLIMETRES UNLESS OTHERWISE SHOWN



PLAN

10 0 10 20m

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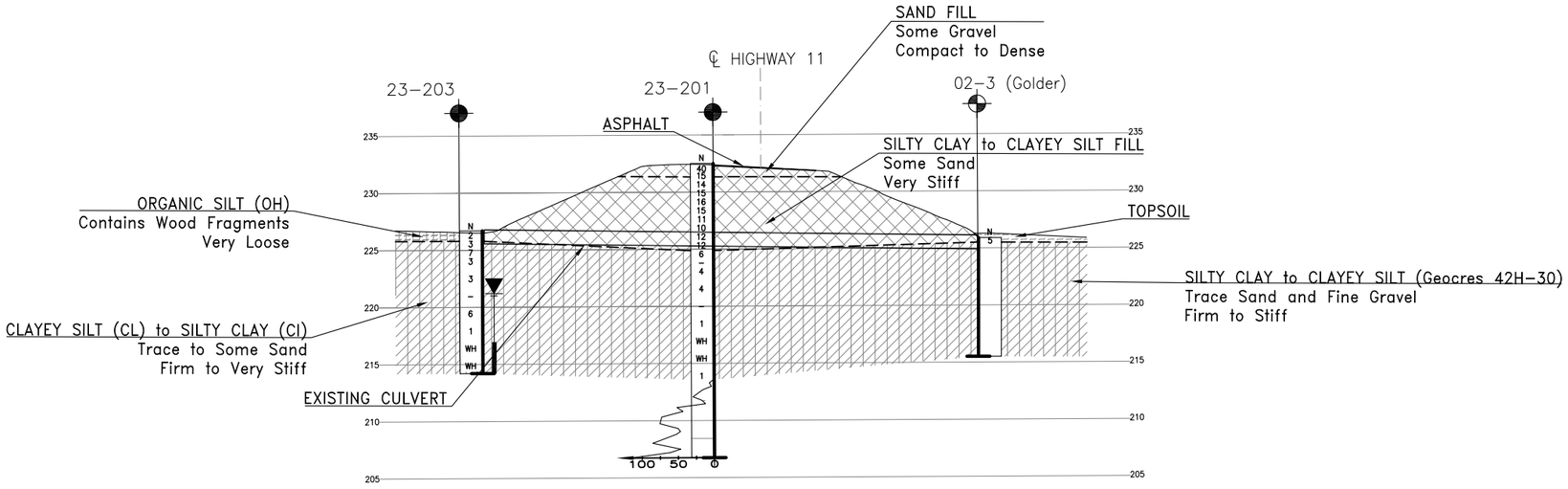


SECTION A–A'

5 0 5 10m H 1:250

5 0 5 10m V 1:250

CONT No
GWP No. 5021–E–0025

SHEET

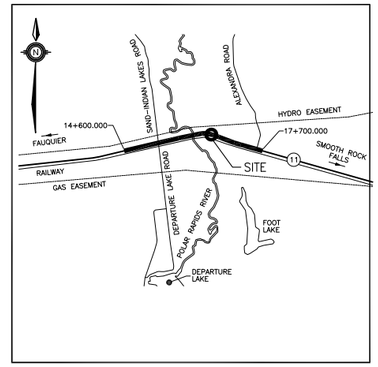
HIGHWAY 11
CULVERT AT Sta 16+575
HAGGART TOWNSHIP
BOREHOLE LOCATIONS AND SOIL STRATA

Ontario

THURBER ENGINEERING LTD.

LICENSED PROFESSIONAL ENGINEER
P. K. CHATTERJI
April 5, 2024
PROVINCE OF ONTARIO

LICENSED PROFESSIONAL ENGINEER
S. PETERS
100194478
April 5, 2024
PROVINCE OF ONTARIO



KEYPLAN

	LEGEND
	Borehole
	Borehole (Previous Investigation)
N	Blows /0.3m (Std Pen Test, 475J/blow)
CONE	Blows /0.3m (60° Cone, 475J/blow)
PH	Pressure, Hydraulic
▽	Water Level Upon Completion of Drilling
	Water Level in Monitoring Well/Piezometer
	Monitoring Well/Piezometer Screen
90%	Rock Quality Designation (RQD)
A/R	Auger Refusal

	NO	ELEVATION	NORTHING	EASTING
	23–201	232.5	5 461 517.8	248 160.9
	23–202	232.8	5 461 506.9	248 188.1
	23–203	226.7	5 461 537.1	248 167.1
	23–204	227.5	5 461 533.6	248 176.8
	23–205	232.6	5 461 512.6	248 174.8
(Golder)	02–1	226.6	5 461 542.7	248 153.5
(Golder)	02–2	226.6	5 461 517.4	248 150.4
(Golder)	02–3	225.9	5 461 493.8	248 148.1

-NOTES-

1) The boundaries between soil strata have been established only at Borehole locations. Between Boreholes the boundaries are assumed from geological evidence.
2) This drawing is for subsurface information only. Surface details and features are for conceptual illustration.
3) Coordinate system is MTM NAD 83 Zone 12.

GEOCRES No. 42H00-094

REVISIONS		
DATE	BY	DESCRIPTION

DESIGN AO	CHK SP	CODE	LOAD	DATE	APR 2024
DRAWN RH	CHK AO	SITE	STRUCT	DWG	1

FILENAME: H:\Drafting\33000\33443\TED-33443-200.dwg
PLOTDATE: 4/4/2024 12:06 PM

THURBER ENGINEERING LTD.

APPENDIX B

Symbols and Terms

Record of Boreholes Sheets

Single Well Response Test

Historical Foundation Boreholes (Geocres 42H-30)

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SYMBOLS, ABBREVIATIONS AND TERMS USED ON TEST HOLE RECORDS

TERMINOLOGY DESCRIBING COMMON SOIL GENESIS

Topsoil	mixture of soil and humus capable of supporting vegetative growth
Peat	mixture of fragments of decayed organic matter
Till	unstratified glacial deposit which may include particles ranging in sizes from clay to boulder
Fill	material below the surface identified as placed by humans (excluding buried services)

TERMINOLOGY DESCRIBING SOIL STRUCTURE:

Desiccated	having visible signs of weathering by oxidization of clay materials, shrinkage cracks, etc.
Fissured	having cracks, and hence a blocky structure
Varved	composed of alternating layers of silt and clay
Stratified	composed of alternating successions of different soil types, e.g. silt and sand
Layer	> 75 mm in thickness
Seam	2 mm to 75 mm in thickness
Parting	< 2 mm in thickness

RECOVERY:

For soil samples, the recovery is recorded as the length of the soil sample recovered.

N-VALUE:

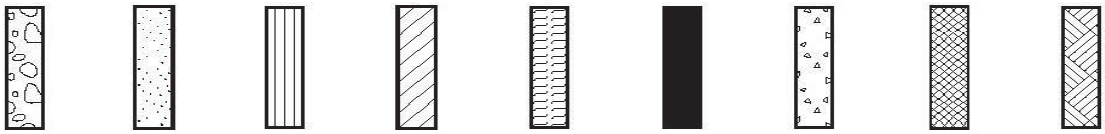
Numbers in this column are the field results of the Standard Penetration Test: the number of blows of a 63.5 kg hammer falling 0.76 m, required to drive a 50 mm O.D. split spoon sampler 0.3 m into undisturbed soil. For samples where insufficient penetration was achieved and N-value cannot be presented, the number of blows are reported over the sampler penetration in millimetres (e.g. 50/75).

DYNAMIC CONE PENETRATION TEST (DCPT):

Dynamic cone penetration tests are performed using a standard 60 degree apex cone connected to an “A” size drill rods with the same standard fall height and weight as the Standard Penetration Test. The DCPT value is the number of blows of the hammer required to drive the cone 0.3 m into the soil. The DCPT is used as a probe to assess soil variability.

THURBER

STRATA PLOT:
Strata plots symbolize the soil and bedrock description. They are combinations of the following basic symbols. The dimensions within the strata symbols are not indicative of the particle size, layer thickness, etc.



Boulders
Cobbles
Gravel

Sand

Silt

Clay

Organics

Asphalt

Concrete

Fill

Bedrock

TEXTURING CLASSIFICATION OF SOILS

Classification	Particle Size
Boulders	Greater than 200 mm
Cobbles	75 – 200 mm
Gravel	4.75 – 75 mm
Sand	0.075 – 4.75 mm
Silt	0.002 – 0.075 mm
Clay	Less than 0.002 mm

TERMS DESCRIBING CONSISTENCY (COHESIVE SOILS ONLY)

Descriptive Term	Undrained Shear Strength (kPa)
Very Soft	12 or less
Soft	12 – 25
Firm	25 – 50
Stiff	50 – 100
Very Stiff	100 – 200
Hard	Greater than 200

NOTE: Clay sensitivity is defined as the ratio of the undisturbed strength over the remolded strength.

SAMPLE TYPES

SS	Split spoon samples
ST	Shelby tube or thin wall tube
DP	Direct push sample
PS	Piston sample
BS	Bulk sample
WS	Wash sample
HQ, NQ, BQ etc.	Rock core sample obtained with the use of standard size diamond coring equipment

TERMS DESCRIBING CONSISTENCY (COHESIONLESS SOILS ONLY)

Descriptive Term	SPT "N" Value
Very Loose	Less than 4
Loose	4 – 10
Compact	10 – 30
Dense	30 – 50
Very Dense	Greater than 50

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MODIFIED UNIFIED SOIL CLASSIFICATION

Major Divisions		Group Symbol	Typical Description
COARSE GRAINED SOIL	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	SILT AND CLAY SOILS $W_L < 35\%$	ML	Inorganic silts, 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.
		OL	Organic silts and organic silty-clays of low plasticity.
	SILT AND CLAY SOILS $35\% < W_L < 50\%$	MI	Inorganic compressible fine sandy silt with clay of medium plasticity, clayey silts.
		CI	Inorganic clays of medium plasticity, silty clays.
		OI	Organic silty clays of medium plasticity.
	SILT AND CLAY SOILS $W_L > 50\%$	MH	Inorganic silts, micaceous or diatomaceous fine sandy of silty soils, elastic silts.
		CH	Inorganic clays of high plasticity, fat clays.
		OH	Organic clays of high plasticity, organic silts.
HIGHLY ORGANIC SOILS		Pt	Peat and other organic soils.

Note - W_L= Liquid Limit

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EXPLANATION OF ROCK LOGGING TERMS

ROCK WEATHERING CLASSIFICATION

Fresh (FR)	No visible signs of weathering.
Fresh Jointed (FJ)	Weathering limited to surface of major discontinuities.
Slightly Weathered (SW)	Penetrative weathering developed on open discontinuity surfaces, but only slight weathering of rock materials.
Moderately Weathered (MW)	Weathering extends throughout the rock mass, but the rock material is not friable.
Highly Weathered (HW)	Weathering extends throughout the rock mass and the rock is partly friable.
Completely Weathered (CW)	Rock is wholly decomposed and in a friable condition, but the rock texture and structures are preserved.

TERMS

Total Core Recovery: (TCR)	Core recovered as a percentage of total core run length.
Solid Core Recovery: (SCR)	Percent ratio of solid core of full cylindrical shape recovered. Expressed with respect to the total length of core run.
Rock Quality Designation: (RQD)	Total length of sound core recovered in pieces 0.1 m in length or larger, as a percentage of total core length
Unconfined Compressive Strength: (UCS)	Axial stress required to break the specimen.
Fracture Index: (FI)	Frequency of natural fractures per 0.3 m of core run.

DISCONTINUITY SPACING

Bedding	Bedding Plane Spacing
Very thickly bedded	Greater than 2 m
Thickly bedded	0.6 to 2 m
Medium bedded	0.2 to 0.6 m
Thinly bedded	60 mm to 0.2 m
Very thinly bedded	20 to 60 mm
Laminated	6 to 20 mm
Thinly laminated	Less than 6 mm

STRENGTH CLASSIFICATION

Rock Strength	Approximate Uniaxial Compressive Strength (MPa)
Extremely Strong	Greater than 250
Very Strong	100 – 250
Strong	50 – 100
Medium Strong	25 – 50
Weak	5 – 25
Very Weak	1 – 5
Extremely Weak	0.25 – 1

Ministry of Transportation
Ontario

THURBER

RECORD OF BOREHOLE No 23-201 1 OF 3 METRIC

GWP# 5278-19-00 LOCATION Lat: 49.289038°, Long: -81.778653° Sta 16+575, Haggart Township, MTM z12: N 5 461 517.8 E 248 160.9 ORIGINATED BY DAP

HWY 11 BOREHOLE TYPE CME 55 LC Track Mounted / HSA COMPILED BY RH

DATUM Geodetic DATE 2023.07.08 - 2023.07.08 CHECKED BY AO

ELEV / DEPTH	DESCRIPTION	STRAT PLOT	SAMPLES NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT 20 40 60 80 100 / SHEAR STRENGTH kPa ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × LAB VANE 20 40 60 80 100	PLASTIC LIMIT w_P / NATURAL MOISTURE CONTENT w / LIQUID LIMIT w_L WATER CONTENT (%) 20 40 60	UNIT WEIGHT γ kN/m^3	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
232.5	**Ground Surface**										
0.0	**ASPHALT (125 mm)**										
0.1	SAND, some gravel compact to dense light brown **FILL**		1	SS	40		232				15 75 10 (SI+CL)
231.3			2	SS	15						
1.2	SILTY CLAY to CLAYEY SILT some sand very stiff greyish brown to brownish grey **FILL**		3	SS	14		231				
			4	SS	15		230				0 15 50 35
			5	SS	16		229				
			6	SS	15						
			7	SS	11		228				
			8	SS	10		227				
			9	SS	12						
			10	SS	12		226				
224.9											
7.6	**CLAYEY SILT (CL)**, some sand very stiff brownish grey with brown mottles **WEATHERED CRUST**		11	SS	6		225				1 18 55 26
224.1											
8.4	**SILTY CLAY (Cl)**, some sand contains sandy silt partings stiff to very stiff grey		1	ST	-		224				0 10 45 45 OED: e_0 = 0.64 C_c = 0.16 C_r = 0.03
			12	SS	4		223				

Continued Next Page

+ ^{3}, × ^{3}: Numbers refer to Sensitivity

20 / 15 ⊕ 5 / 10 (%) STRAIN AT FAILURE

DOUBLE LINE 33443 - 200 BHS- POPLAR RIVER BRIDGE.GPJ 2012TEMPLATE(MTO).GDT 4-4-24

Ministry of Transportation
Ontario

THURBER

RECORD OF BOREHOLE No 23-201 2 OF 3 METRIC

GWP# 5278-19-00 LOCATION Lat: 49.289038°, Long: -81.778653° Sta 16+575, Haggart Township, MTM z12: N 5 461 517.8 E 248 160.9 ORIGINATED BY DAP

HWY 11 BOREHOLE TYPE CME 55 LC Track Mounted / HSA COMPILED BY RH

DATUM Geodetic DATE 2023.07.08 - 2023.07.08 CHECKED BY AO

ELEV / DEPTH	DESCRIPTION	STRAT PLOT	SAMPLES NUMBER	SAMPLES TYPE	SAMPLES "N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT / SHEAR STRENGTH kPa (○ UNCONFINED, ● QUICK TRIAXIAL, + FIELD VANE, × LAB VANE)	PLASTIC LIMIT w_P / NATURAL MOISTURE CONTENT w / LIQUID LIMIT w_L / WATER CONTENT (%)	UNIT WEIGHT γ kN/m^3	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
	Continued From Previous Page										
	SILTY CLAY (CI), some sand contains sandy silt partings stiff to very stiff grey						222	> 118 kPa			
			13	SS	4						0 10 44 46
							221	> 118 kPa > 118 kPa			
			2	ST	-		220				
								> 118 kPa > 118 kPa			
			14	SS	1		219				
							218	5.0 2.0			
			15	SS	WH		217				
								2.0			
							216	3.0			
			16	SS	WH						0 10 42 48
							215	3.0 2.0			
			17	SS	1		214				
213.6											
18.9	End of sampled borehole Borehole advanced with DCPT						213				

Continued Next Page

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

20 / 15 / 10 / 5 (%) STRAIN AT FAILURE

DOUBLE LINE 33443 - 200 BHS- POPLAR RIVER BRIDGE.GPJ 2012TEMPLATE(MTO).GDT 4-4-24

Ministry of Transportation
Ontario

THURBER

RECORD OF BOREHOLE No 23-201 3 OF 3 METRIC

GWP# 5278-19-00 LOCATION Lat: 49.289038°, Long: -81.778653° Sta 16+575, Haggart Township, MTM z12: N 5 461 517.8 E 248 160.9 ORIGINATED BY DAP

HWY 11 BOREHOLE TYPE CME 55 LC Track Mounted / HSA COMPILED BY RH

DATUM Geodetic DATE 2023.07.08 - 2023.07.08 CHECKED BY AO

ELEV / DEPTH	DESCRIPTION	STRAT PLOT	SAMPLES: NUMBER	SAMPLES: TYPE	SAMPLES: "N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT / SHEAR STRENGTH kPa	WATER CONTENT (%)	UNIT WEIGHT γ kN/m³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
	Continued From Previous Page										
	Borehole advanced with DCPT						212				
							211				
							210				
							209				
							208				
206.7							207				
25.8	**End of Borehole on DCPT refusal** A representative open-hole groundwater level measurement was not obtained due to the introduction of water during drilling.										

DYNAMIC CONE PENETRATION RESISTANCE PLOT: 20 40 60 80 100

SHEAR STRENGTH kPa: ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × LAB VANE; 20 40 60 80 100

PLASTIC LIMIT w_P NATURAL MOISTURE CONTENT w LIQUID LIMIT w_L

WATER CONTENT (%): 20 40 60

+ ³, × ³: Numbers refer to Sensitivity

20 / 15 5 / 10 (%) STRAIN AT FAILURE

DOUBLE LINE 33443 - 200 BHS- POPLAR RIVER BRIDGE.GPJ 2012TEMPLATE(MTO).GDT 4-4-24

Ministry of Transportation
Ontario

THURBER

RECORD OF BOREHOLE No 23-202 1 OF 3 METRIC

GWP# 5278-19-00 LOCATION Lat: 49.288942°, Long: -81.778278° Sta 16+575, Haggart Township, MTM z12: N 5 461 506.9 E 248 188.1 ORIGINATED BY DAP

HWY 11 BOREHOLE TYPE CME 55 LC Track Mounted / HSA COMPILED BY RH

DATUM Geodetic DATE 2023.07.09 - 2023.07.09 CHECKED BY AO

ELEV / DEPTH	DESCRIPTION	STRAT PLOT	SAMPLES NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT 20 40 60 80 100 / SHEAR STRENGTH kPa ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × LAB VANE 20 40 60 80 100	PLASTIC LIMIT w_P / NATURAL MOISTURE CONTENT w / LIQUID LIMIT w_L WATER CONTENT (%) 20 40 60	UNIT WEIGHT γ kN/m³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
232.8	**Ground Surface**										
0.0	**ASPHALT (150 mm)**										
0.2	SAND, some gravel compact to dense light brown **FILL**		1	SS	36						13 79 8 (SI+CL)
			2	SS	11		232				
231.3											
1.5	SILTY CLAY to CLAYEY SILT some sand very stiff greyish brown to brownish grey **FILL**		3	SS	11		231				
			4	SS	10		230				
			5	SS	14		229				
			6	SS	6		228				
			7	SS	9		227				0 14 46 40
			8	SS	12						
226.7											
6.1	**SILTY CLAY (CI)**, trace sand very stiff brownish grey with brown mottles **WEATHERED CRUST**		9	SS	21		226				0 9 45 46
225.9											
6.9	**SILTY CLAY (CI)**, trace sand stiff to very stiff grey		10	SS	6		225				
			11	SS	5			> 118 kPa +			
			12	SS	5		224				
							223				

Continued Next Page

+ ³, × ³: Numbers refer to Sensitivity

20 / 15 5 / 10 (%) STRAIN AT FAILURE

DOUBLE LINE 33443 - 200 BHS- POPLAR RIVER BRIDGE.GPJ 2012TEMPLATE(MTO).GDT 4-4-24

Ministry of Transportation
Ontario

THURBER

RECORD OF BOREHOLE No 23-202 2 OF 3 METRIC

GWP# 5278-19-00 LOCATION Lat: 49.288942°, Long: -81.778278° Sta 16+575, Haggart Township, MTM z12: N 5 461 506.9 E 248 188.1 ORIGINATED BY DAP

HWY 11 BOREHOLE TYPE CME 55 LC Track Mounted / HSA COMPILED BY RH

DATUM Geodetic DATE 2023.07.09 - 2023.07.09 CHECKED BY AO

ELEV / DEPTH	DESCRIPTION	STRAT PLOT	SAMPLES NUMBER	SAMPLES TYPE	SAMPLES "N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT / SHEAR STRENGTH kPa (○ UNCONFINED, ● QUICK TRIAXIAL, + FIELD VANE, × LAB VANE)	PLASTIC LIMIT w_P / NATURAL MOISTURE CONTENT w / LIQUID LIMIT w_L / WATER CONTENT (%)	UNIT WEIGHT γ kN/m^3	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
	Continued From Previous Page										
	SILTY CLAY (CI), trace sand stiff to very stiff grey							> 118 kPa > 118 kPa			
			1	ST	-		222				
								2.0			
							221	> 118 kPa			
			13	SS	3						
							220	3.0 2.0			
			14	SS	WH		219				0 7 42 51
								3.0			
							218	2.0			
			2	ST	-						
							217	3.0 2.0			
			15	SS	WH		216				
								2.0			
							215	2.0			
213.9			16	SS	WH						
18.9	End of sampled borehole Borehole advanced with DCPT						214				
							213				

Continued Next Page

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

$\frac{20}{15 \oplus 5}$ (%) STRAIN AT FAILURE

DOUBLE LINE 33443 - 200 BHS- POPLAR RIVER BRIDGE.GPJ 2012TEMPLATE(MTO).GDT 4-4-24

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THURBER

RECORD OF BOREHOLE No 23-202 3 OF 3 METRIC

GWP# 5278-19-00 LOCATION Lat: 49.288942°, Long: -81.778278° Sta 16+575, Haggart Township, MTM z12: N 5 461 506.9 E 248 188.1 ORIGINATED BY DAP

HWY 11 BOREHOLE TYPE CME 55 LC Track Mounted / HSA COMPILED BY RH

DATUM Geodetic DATE 2023.07.09 - 2023.07.09 CHECKED BY AO

ELEV / DEPTH	DESCRIPTION	STRAT PLOT	SAMPLES: NUMBER	SAMPLES: TYPE	SAMPLES: "N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT / SHEAR STRENGTH kPa (○ UNCONFINED, ● QUICK TRIAXIAL, + FIELD VANE, × LAB VANE)	PLASTIC LIMIT w_P / NATURAL MOISTURE CONTENT w / LIQUID LIMIT w_L / WATER CONTENT (%)	UNIT WEIGHT γ kN/m^3	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
	Continued From Previous Page							20 40 60 80 100	20 40 60		
	Borehole advanced with DCPT						212				
							211				
							210				
							209				
							208				
							207				
206.1											
26.7	**End of Borehole on DCPT refusal**										
	Borehole dry upon completion of drilling.										

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

20 / 15 5 / 10 (%) STRAIN AT FAILURE

DOUBLE LINE 33443 - 200 BHS- POPLAR RIVER BRIDGE.GPJ 2012TEMPLATE(MTO).GDT 4-4-24

Ministry of Transportation
Ontario

THURBER

RECORD OF BOREHOLE No 23-203 1 OF 2 METRIC

GWP# 5278-19-00 LOCATION Lat: 49.289212°, Long: -81.778571° Sta 16+575, Haggart Township, MTM z12: N 5 461 537.1 E 248 167.1 ORIGINATED BY DAP

HWY 11 BOREHOLE TYPE CME 55 LC Track Mounted / HSA COMPILED BY RH

DATUM Geodetic DATE 2023.07.14 - 2023.07.14 CHECKED BY AO

ELEV / DEPTH	DESCRIPTION	STRAT PLOT	SAMPLES NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT 20 40 60 80 100 / SHEAR STRENGTH kPa ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × LAB VANE 20 40 60 80 100	PLASTIC LIMIT w_P / NATURAL MOISTURE CONTENT w / LIQUID LIMIT w_L WATER CONTENT (%) 20 40 60	UNIT WEIGHT γ kN/m³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
226.7	**Ground Surface**										
0.0	**ORGANIC SILT (OH)** contains wood fragments very loose grey to dark brown		1	SS	2						
225.8							226				
0.9	**CLAYEY SILT (CL)**, some sand very stiff grey with brown mottles **WEATHERED CRUST**		2	SS	3						0 14 58 28
			3	SS	7		225				
224.4											
2.3	**SILTY CLAY (CI)**, trace sand firm to stiff grey		4	SS	3		224	3.0 2.0			
			5	SS	3		223				
							222	2.0 3.0			
			1	ST	-	▽	221	3.0 2.0			1 8 43 48 OED: e_0 = 0.67 C_c = 0.16 C_r = 0.06
			6	SS	6		220				0 8 44 48
							219	5.0 2.0			
			7	SS	1		218				
								2.0 2.0			
							217				

Continued Next Page

+ ³, × ³: Numbers refer to Sensitivity

20 / 15 5 / 10 (%) STRAIN AT FAILURE

DOUBLE LINE 33443 - 200 BHS- POPLAR RIVER BRIDGE.GPJ 2012TEMPLATE(MTO).GDT 4-4-24

Ministry of Transportation
Ontario

THURBER

RECORD OF BOREHOLE No 23-203 2 OF 2 METRIC

GWP# 5278-19-00 LOCATION Lat: 49.289212°, Long: -81.778571° Sta 16+575, Haggart Township, MTM z12: N 5 461 537.1 E 248 167.1 ORIGINATED BY DAP

HWY 11 BOREHOLE TYPE CME 55 LC Track Mounted / HSA COMPILED BY RH

DATUM Geodetic DATE 2023.07.14 - 2023.07.14 CHECKED BY AO

ELEV / DEPTH	DESCRIPTION	STRAT PLOT	SAMPLES: NUMBER	SAMPLES: TYPE	SAMPLES: "N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT / SHEAR STRENGTH kPa	PLASTIC LIMIT w_P / NATURAL MOISTURE CONTENT w / LIQUID LIMIT w_L / WATER CONTENT (%)	UNIT WEIGHT γ kN/m^3	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
	Continued From Previous Page										
	SILTY CLAY (CI), trace sand firm to stiff grey		8	SS	WH		216	3.0			
								3.0			
			9	SS	WH		215				
214.2								3.0			
12.5	**End of Borehole**							1.0			

Monitoring well installed:
Scredule 40 PVC standpipe with 32-mm diameter and 3.0-m slotted screen.

Water Level Readings:

DATE	DEPTH (m)	ELEV. (m)
2023/07/14	dry	-
2023/07/15	dry	-
2023/09/10	5.5	221.2

DYNAMIC CONE PENETRATION RESISTANCE PLOT: 20 40 60 80 100
SHEAR STRENGTH kPa: ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × LAB VANE: 20 40 60 80 100
WATER CONTENT (%): 20 40 60

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

20 / 15 / 10 / 5 (%) STRAIN AT FAILURE

DOUBLE LINE 33443 - 200 BHS- POPLAR RIVER BRIDGE.GPJ 2012TEMPLATE(MTO).GDT 4-4-24

Ministry of Transportation
Ontario

THURBER

RECORD OF BOREHOLE No 23-204 1 OF 2 METRIC

GWP# 5278-19-00 LOCATION Lat: 49.289181°, Long: -81.778437° Sta 16+575, Haggart Township, MTM z12: N 5 461 533.6 E 248 176.8 ORIGINATED BY DAP

HWY 11 BOREHOLE TYPE CME 55 LC Track Mounted / HSA COMPILED BY RH

DATUM Geodetic DATE 2023.07.14 - 2023.07.14 CHECKED BY AO

ELEV / DEPTH	DESCRIPTION	STRAT PLOT	SAMPLES NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT 20 40 60 80 100 / SHEAR STRENGTH kPa ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × LAB VANE 20 40 60 80 100	PLASTIC LIMIT w_P / NATURAL MOISTURE CONTENT w / LIQUID LIMIT w_L WATER CONTENT (%) 20 40 60	UNIT WEIGHT γ kN/m^3	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
227.5	**Ground Surface**										
0.0	**TOPSOIL (150 mm)**										
0.2	**ORGANIC SILT (OH)** contains peat inclusions loose		1	SS	4						
226.7	light brownish grey						227				
0.8	**CLAYEY SILT (CL)** to **SILTY CLAY (CI)**, some sand trace organics very stiff brownish grey with bornw mottles **WEATHERED CRUST**		2	SS	7						0 15 58 27
			3	SS	8		226				0 10 49 41
225.2											
2.3	**SILTY CLAY (CI)**, trace sand firm to very stiff grey		4	SS	4		225				
			5	SS	3		224				
			6	ST	4						
							223	3.0			
								2.0			
			7	SS	4		222				0 9 43 48
								3.0			
								> 118 kPa			
			8	SS	8		221				
							220	> 118 kPa			
			9	SS	4		219				
								5.0			
							218	3.0			

Continued Next Page

+ ^{3}, × ^{3}: Numbers refer to Sensitivity

20 / 15 5 / 10 (%) STRAIN AT FAILURE

DOUBLE LINE 33443 - 200 BHS- POPLAR RIVER BRIDGE.GPJ 2012TEMPLATE(MTO).GDT 4-4-24

Ministry of Transportation
Ontario

THURBER

RECORD OF BOREHOLE No 23-204 2 OF 2 METRIC

GWP# 5278-19-00 LOCATION Lat: 49.289181°, Long: -81.778437° Sta 16+575, Haggart Township, MTM z12: N 5 461 533.6 E 248 176.8 ORIGINATED BY DAP

HWY 11 BOREHOLE TYPE CME 55 LC Track Mounted / HSA COMPILED BY RH

DATUM Geodetic DATE 2023.07.14 - 2023.07.14 CHECKED BY AO

ELEV / DEPTH	DESCRIPTION	STRAT PLOT	SAMPLES: NUMBER	SAMPLES: TYPE	SAMPLES: "N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT / SHEAR STRENGTH kPa (○ UNCONFINED, ● QUICK TRIAXIAL, + FIELD VANE, × LAB VANE)	PLASTIC LIMIT w_P / NATURAL MOISTURE CONTENT w / LIQUID LIMIT w_L / WATER CONTENT (%)	UNIT WEIGHT γ kN/m^3	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
	Continued From Previous Page										
	SILTY CLAY (CI), trace sand firm to very stiff grey		10	SS	WH		217	4.0 3.0	○		
			11	SS	1		216	> 118 kPa	○		0 9 40 51
213.9			12	SS	1		215 214	3.0	○		
13.6	**End of Borehole** Borehole dry upon completion of drilling.										

+ ^{3}, × ^{3}: Numbers refer to Sensitivity

20 / 15 ⊕ 5 / 10 (%) STRAIN AT FAILURE

DOUBLE LINE 33443 - 200 BHS- POPLAR RIVER BRIDGE.GPJ 2012TEMPLATE(MTO).GDT 4-4-24

THURBER ENGINEERING LTD.

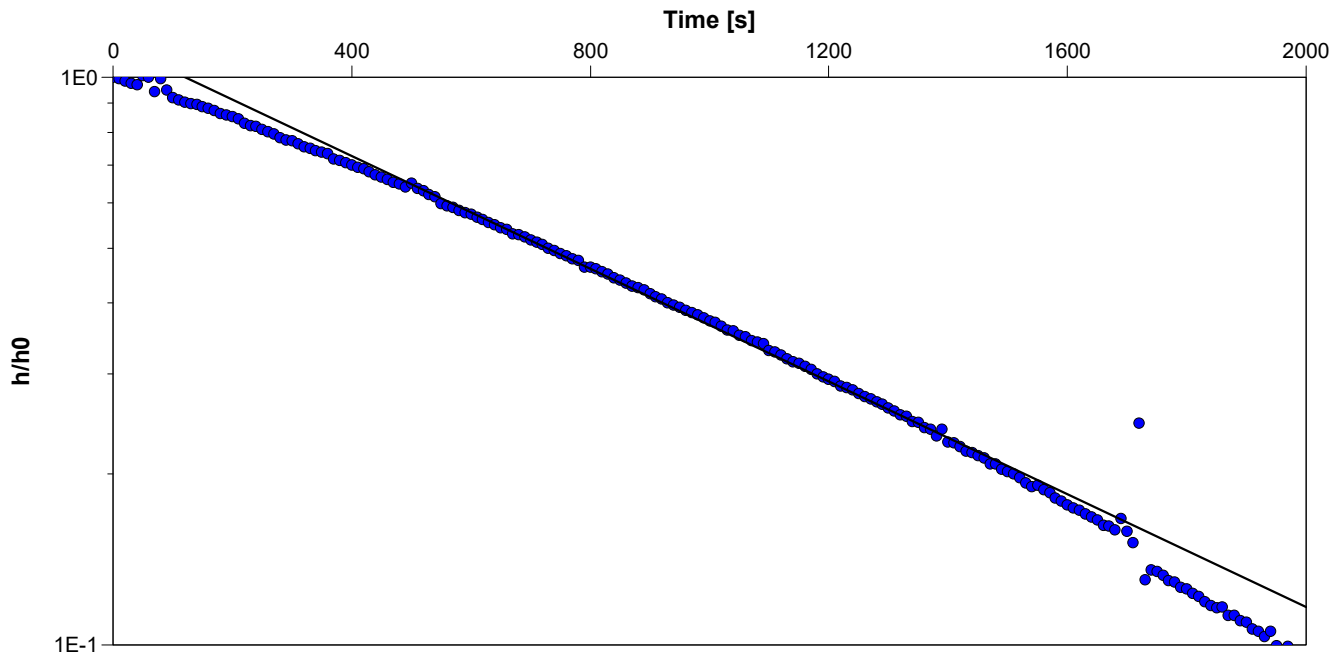
Slug Test Analysis Report

Project: Hwy 11 Poplar Rapids Bridge

Number: 33443

Client: LEA

Location: Haggart Township, Ontario	Slug Test: 23-203	Test Well: 23-203
Test Conducted by: IK		Test Date: 2023-09-08
Analysis Performed by: SM	SWRT Analysis	Analysis Date: 2023-09-27
Aquifer Thickness:		
Reviewed by: AH		



Calculation using Hvorslev

Observation Well	Hydraulic Conductivity [m/s]	
23-203	2.5×10^{-7}	

Golder Associates

RECORD OF BOREHOLE No 02-1

1 OF 1 **METRIC**

PROJECT 021-1153
W.P. 167-98-00
LOCATION 5461542.7 N, 248153.5 E
ORIGINATED BY ES
DIST 53 HWY 11
BOREHOLE TYPE 108mm I.D. Hollow Stem Augers
COMPILED BY DKB
DATUM Geodetic
DATE Oct.2,2002
CHECKED BY ASP

ELEV / DEPTH	DESCRIPTION	STRAT PLOT	SAMPLES: NUMBER	SAMPLES: TYPE	SAMPLES: "N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT / SHEAR STRENGTH kPa (○ UNCONFINED, + FIELD VANE, ● QUICK TRIAXIAL, × REMOULDED)	PLASTIC LIMIT w_P / NATURAL MOISTURE CONTENT w / LIQUID LIMIT w_L / WATER CONTENT (%)	UNIT WEIGHT γ kN/m³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
226.6	GROUND SURFACE										
0.0 / 226.3	Topsoil		1	SS	6		226				
0.3	Silty Clay to Clayey Silt, trace sand and fine gravel Firm to Stiff Grey Moist		2	TO			225				
			3	TO			224				
			4	TO			223				
			5	TO			222				
			6				221				
217.0							220				
							219				
							218				
9.6	END OF BOREHOLE Note: Open borehole dry upon completion of drilling.						217				

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

Golder Associates

RECORD OF BOREHOLE No 02-2

1 OF 2

METRIC

PROJECT 021-1153 | LOCATION 5461517.4 N, 248150.4 E | ORIGINATED BY ES

W.P. 167-98-00 | BOREHOLE TYPE 108mm I.D. Hollow Stem Augers | COMPILED BY DKB

DIST 53 HWY 11 | DATUM Geodetic | DATE Oct.3,2002 | CHECKED BY ASP

ELEV / DEPTH	DESCRIPTION	STRAT PLOT	SAMPLES: NUMBER	SAMPLES: TYPE	SAMPLES: "N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT (20 40 60 80 100) / SHEAR STRENGTH kPa (20 40 60 80 100): ○ UNCONFINED, ● QUICK TRIAXIAL, + FIELD VANE, × REMOULDED	PLASTIC LIMIT w_P / NATURAL MOISTURE CONTENT w / LIQUID LIMIT w_L — WATER CONTENT (%) (10 20 30)	UNIT WEIGHT γ kN/m³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
226.6	GROUND SURFACE										
0.0 / 226.2	Topsoil		1	TO	6		226				
0.4	Silty Clay to Clayey Silt, trace sand and fine gravel Firm to Stiff Grey Moist		2	TO			225				
			3	TO			224			19.5	1 9 41 49
			4	TO			223				
			5	TO			222				
			6	TO			221				
			7	TO			220				
							219				
							218				
							217				
							216				
							215				
214.4 / 12.2	Silty Clay to Clayey Silt, trace sand and fine gravel, occ. silt seams (25mm thick)		8	TO			214			18.9	
							213				
							212				

Continued Next Page

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

RECORD OF BOREHOLE No 02-2

2 OF 2 **METRIC**

PROJECT 021-1153 | LOCATION 5461517.4 N, 248150.4 E | ORIGINATED BY ES

W.P. 167-98-00 | BOREHOLE TYPE 108mm I.D. Hollow Stem Augers | COMPILED BY DKB

DIST 53 HWY 11 | DATUM Geodetic | DATE Oct.3,2002 | CHECKED BY ASP

ELEV / DEPTH	DESCRIPTION	STRAT PLOT	SAMPLES: NUMBER	SAMPLES: TYPE	SAMPLES: "N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT (20 40 60 80 100) / SHEAR STRENGTH kPa (20 40 60 80 100): ○ UNCONFINED, ● QUICK TRIAXIAL, + FIELD VANE, × REMOULDED	PLASTIC LIMIT w_P / NATURAL MOISTURE CONTENT w / LIQUID LIMIT w_L — WATER CONTENT (%) (10 20 30)	UNIT WEIGHT γ kN/m³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
	— CONTINUED FROM PREVIOUS PAGE —										
211.4											
15.2	Silty Sand to Sand, trace silt, trace gravel and clay Loose to very dense Grey Wet Note: blow-back in augers likely disturbed deposit and resulted in a low 'N' value for Sample 9. Cobbles and/or boulders inferred between 17.1m and 18.0m depth.		9	SS	7		211		○		
							210				
							209				
			10	SS	69		208		○		
207.5											
207.1	Silty Sand, trace gravel, occ. cobbles Very dense Grey Wet		11	SS	70				○		
19.5	(Till) END OF BOREHOLE Notes: 1. Sand blow-back in augers to 11.9m depth (El.214.7m) upon penetration of sand deposit at 15.2m depth (El.211.4m). Sand washed out of augers prior to taking Samples 10 and 11. 2. Water level measured in piezometer at 2.5m depth (El. 224.1m) on October 4, 2002. 3. Water level measured in piezometer at 3.3m depth (El. 223.3m) on November 15, 2002.										

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

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

Golder Associates

RECORD OF BOREHOLE No 02-3

1 OF 1 **METRIC**

PROJECT 021-1153
W.P. 167-98-00
DIST 53 HWY 11
DATUM Geodetic
LOCATION 5461493.8 N, 248148.1 E
BOREHOLE TYPE 108mm I.D. Hollow Stem Augers
DATE Oct.2,2002
ORIGINATED BY ES
COMPILED BY DKB
CHECKED BY ASP

ELEV / DEPTH	DESCRIPTION	STRAT PLOT	SAMPLES NUMBER	SAMPLES TYPE	SAMPLES "N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT / SHEAR STRENGTH kPa (○ UNCONFINED, ● QUICK TRIAXIAL, + FIELD VANE, × REMOULDED)	PLASTIC LIMIT w_P / NATURAL MOISTURE CONTENT w / LIQUID LIMIT w_L / WATER CONTENT (%)	UNIT WEIGHT γ kN/m³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
225.9	GROUND SURFACE							20 40 60 80 100	10 20 30		
0.0 / 225.5	Topsoil		1	SS	5		225				
0.4	Silty Clay to Clay Silt, trace sand and fine gravel Firm to Stiff Grey Moist		2	SS			224				
			3	SS			223				
			4	SS			222				
			5	SS			221				
			6	SS			220				
			7	SS			219				
215.5							218				
10.4	END OF BOREHOLE						217				
							216				

Notes:
1. Open borehole dry upon completion of drilling.
2. Piezometer dry on October 3, 2002.
3. Water level measured in piezometer at 6.7m depth (El. 219.2m) on November 15, 2002.

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

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

ON_MOT 021-1153.GPJ ON_MOT.GDT 26/2/03

THURBER ENGINEERING LTD.

APPENDIX C

Particle Size Analysis Figures

Atterberg Limits Figures

Consolidation Testing Results

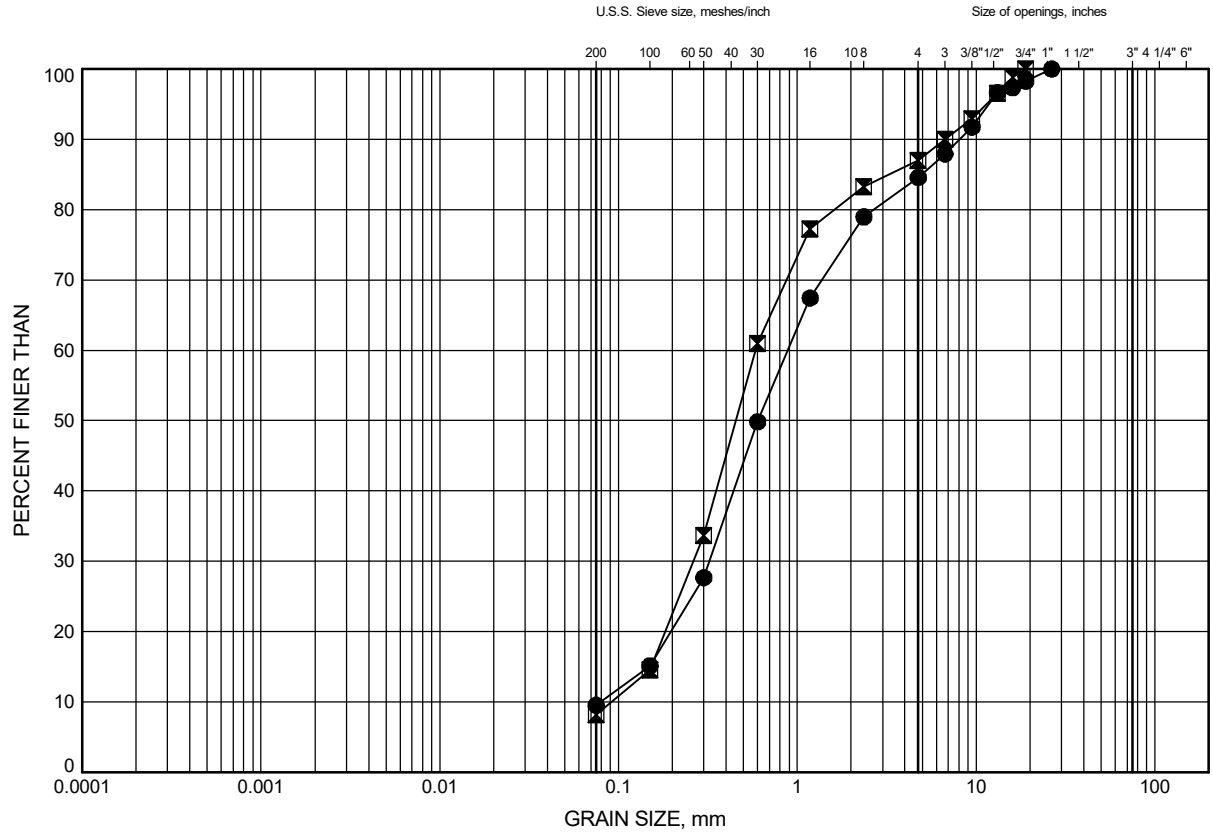
Analytical Testing Results

Highway 11 - Poplar Rapids Bridge

GRAIN SIZE DISTRIBUTION

FIGURE C1

FILL: Sand



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

LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	23-201	0.5	232.0
⊠	23-202	0.5	232.3

Date September 2023

GWP# 5278-19-00

THURBER

Prep'd RH

Chkd. AO

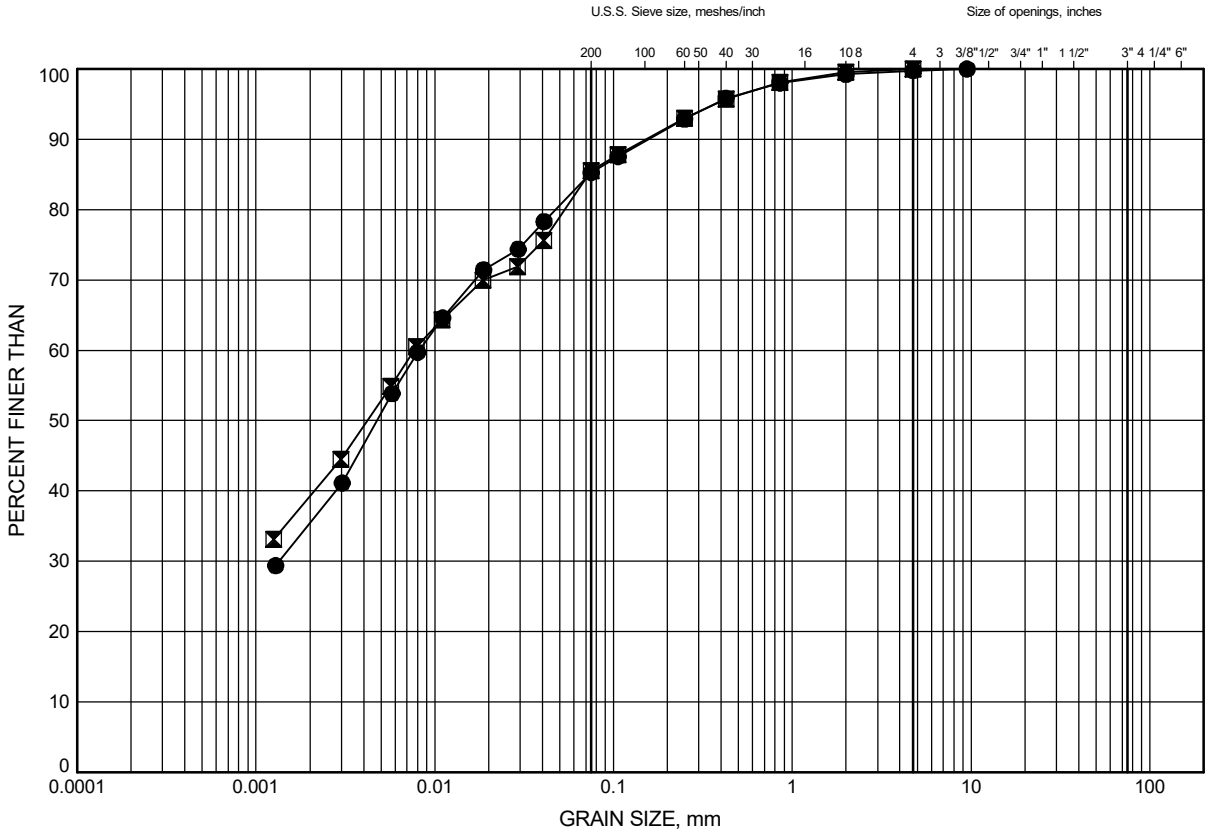
GRAIN SIZE DISTRIBUTION - THURBER 33443 - 200 BHS- POPLAR RIVER BRIDGE.GPJ 9-27-23

Highway 11 - Poplar Rapids Bridge

GRAIN SIZE DISTRIBUTION

FIGURE C2

FILL: Silty Clay to Clayey Silt



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

LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	23-201	2.6	229.9
⊠	23-202	4.9	227.9

Date September 2023

GWP# 5278-19-00

THURBER

Prep'd RH

Chkd. AO

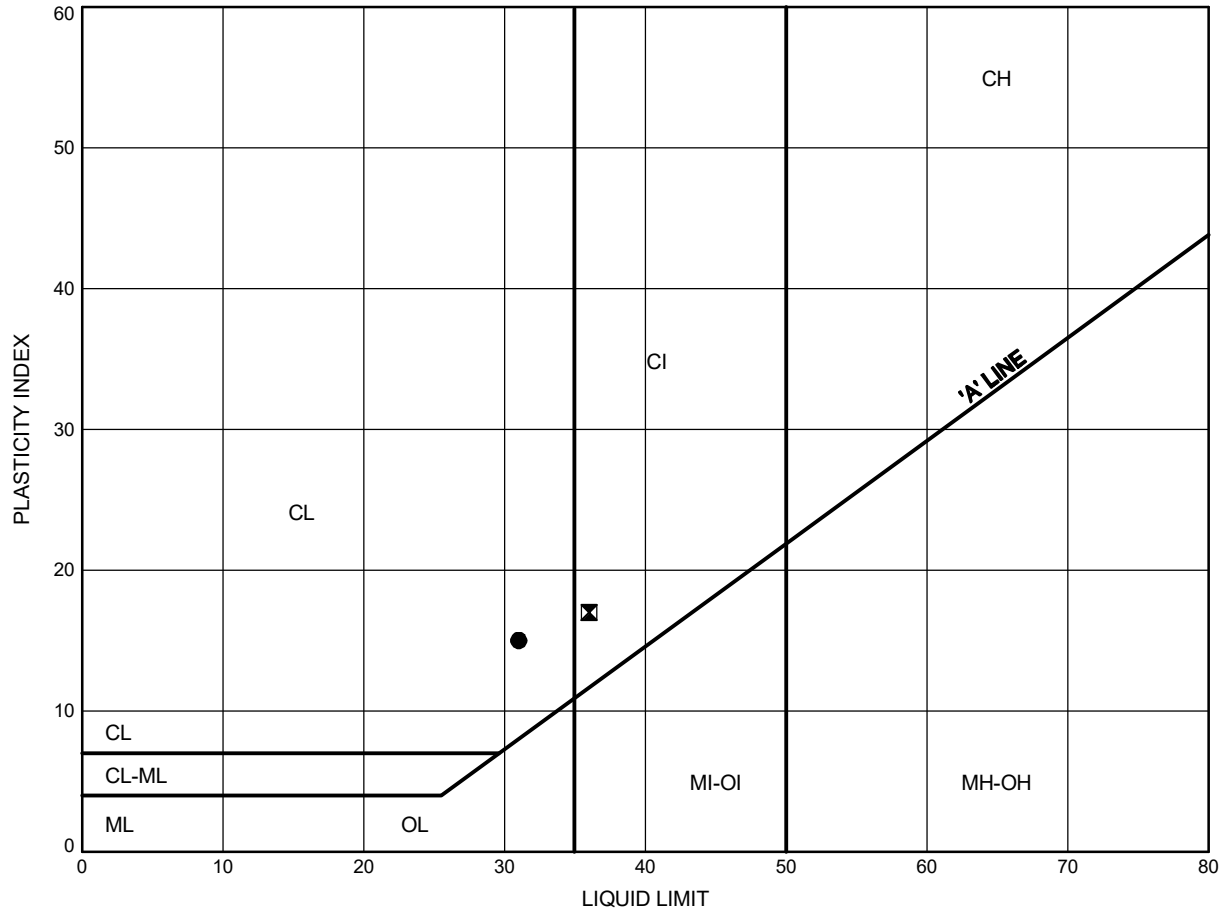
GRAIN SIZE DISTRIBUTION - THURBER 33443 - 200 BHS- POPLAR RIVER BRIDGE.GPJ 9-27-23

Highway 11 - Poplar Rapids Bridge

ATTERBERG LIMITS TEST RESULTS

FIGURE C3

FILL: Silty Clay to Clayey Silt



LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	23-201	2.6	229.9
⊠	23-202	4.9	227.9

Date September 2023

GWP# 5278-19-00

THURBER

Prep'd RH

Chkd. AO

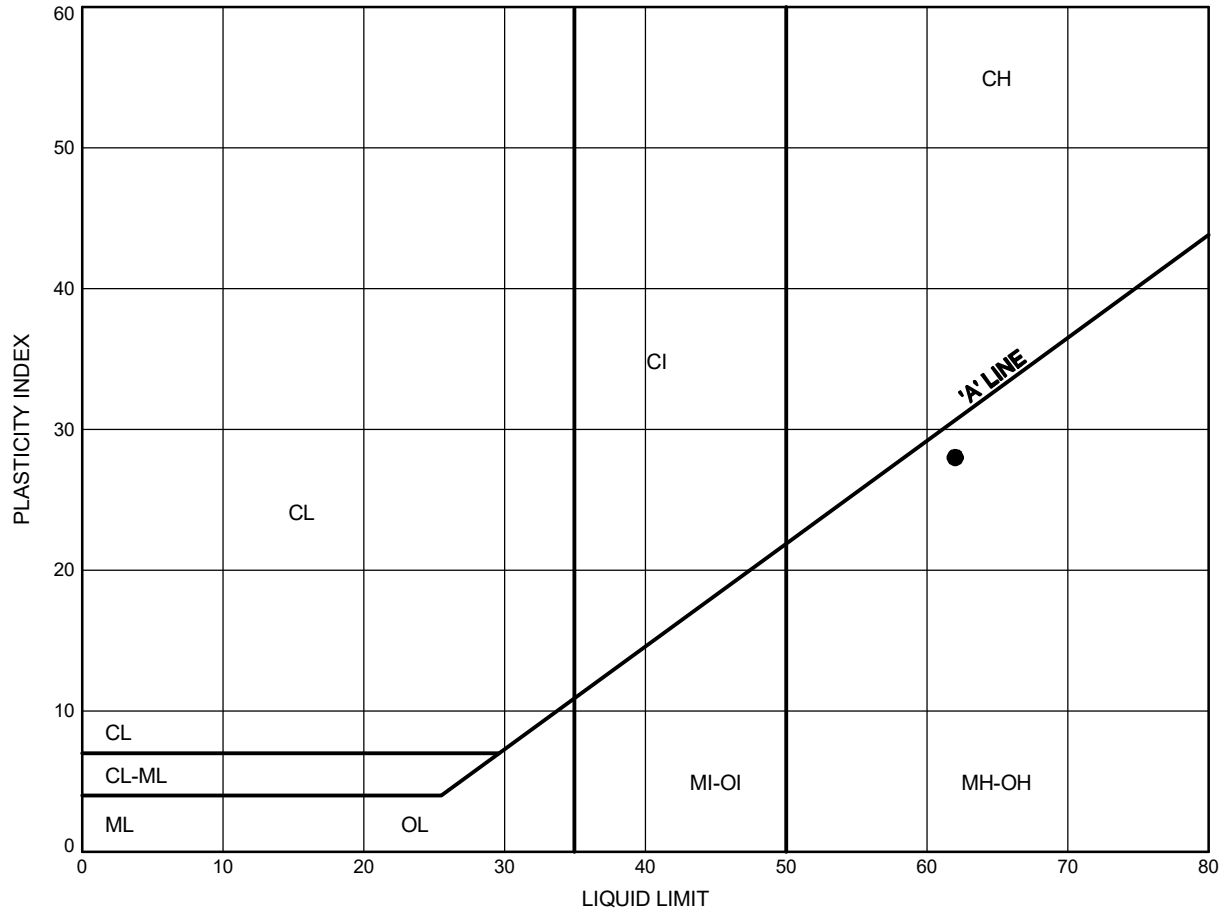
THURBALT 33443 - 200 BHS- POPLAR RIVER BRIDGE.GPJ 9-27-23

Highway 11 - Poplar Rapids Bridge

ATTERBERG LIMITS TEST RESULTS

FIGURE C4

Organic Silt (OH)



LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	23-203	0.3	226.4

Date September 2023

GWP# 5278-19-00

THURBER

Prep'd RH

Chkd. AO

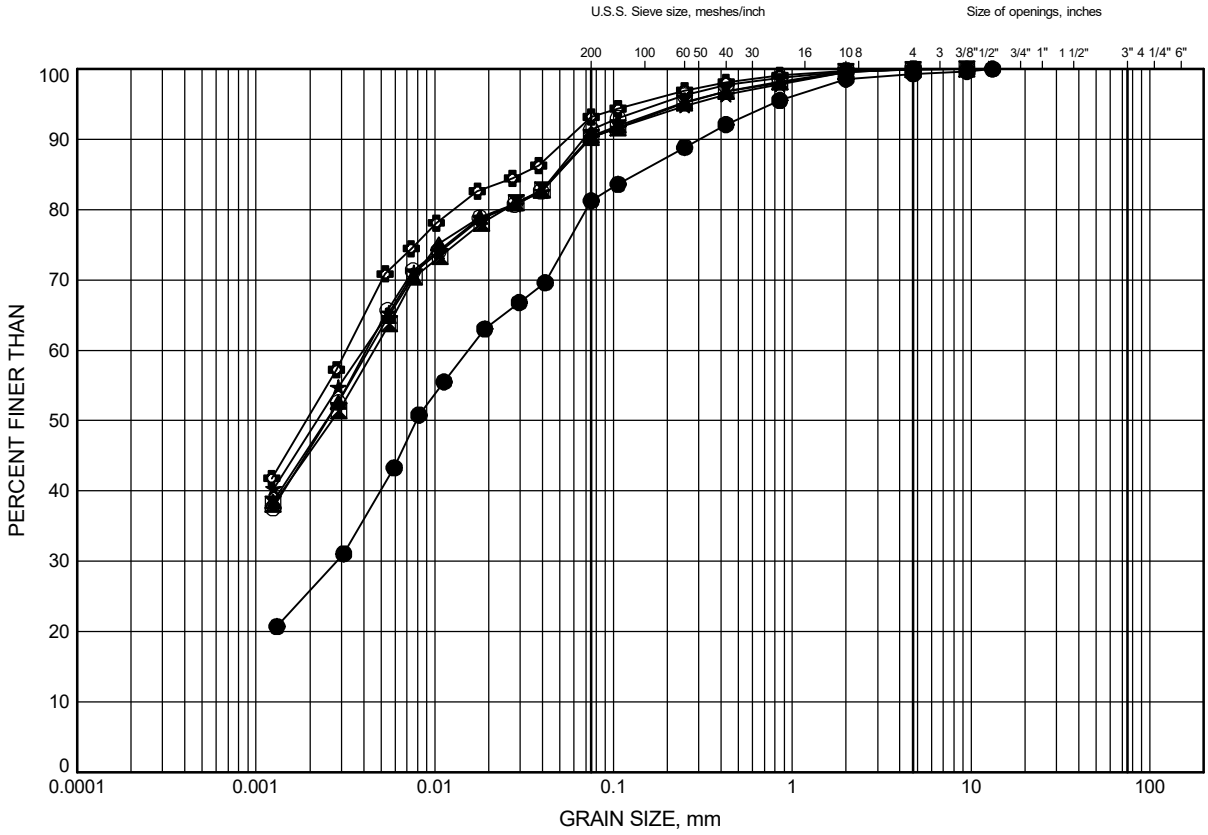
THURBALT 33443 - 200 BHS- POPLAR RIVER BRIDGE.GPJ 9-27-23

Highway 11 - Poplar Rapids Bridge

GRAIN SIZE DISTRIBUTION

FIGURE C5

Silty Clay (CI) to Clayey Silt (CL)



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

LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	23-201	7.9	224.6
⊠	23-201	8.7	223.8
▲	23-201	11.0	221.5
★	23-201	17.1	215.4
⊙	23-202	6.4	226.4
✿	23-202	14.0	218.8

Date September 2023

GWP# 5278-19-00

THURBER

Prep'd RH

Chkd. AO

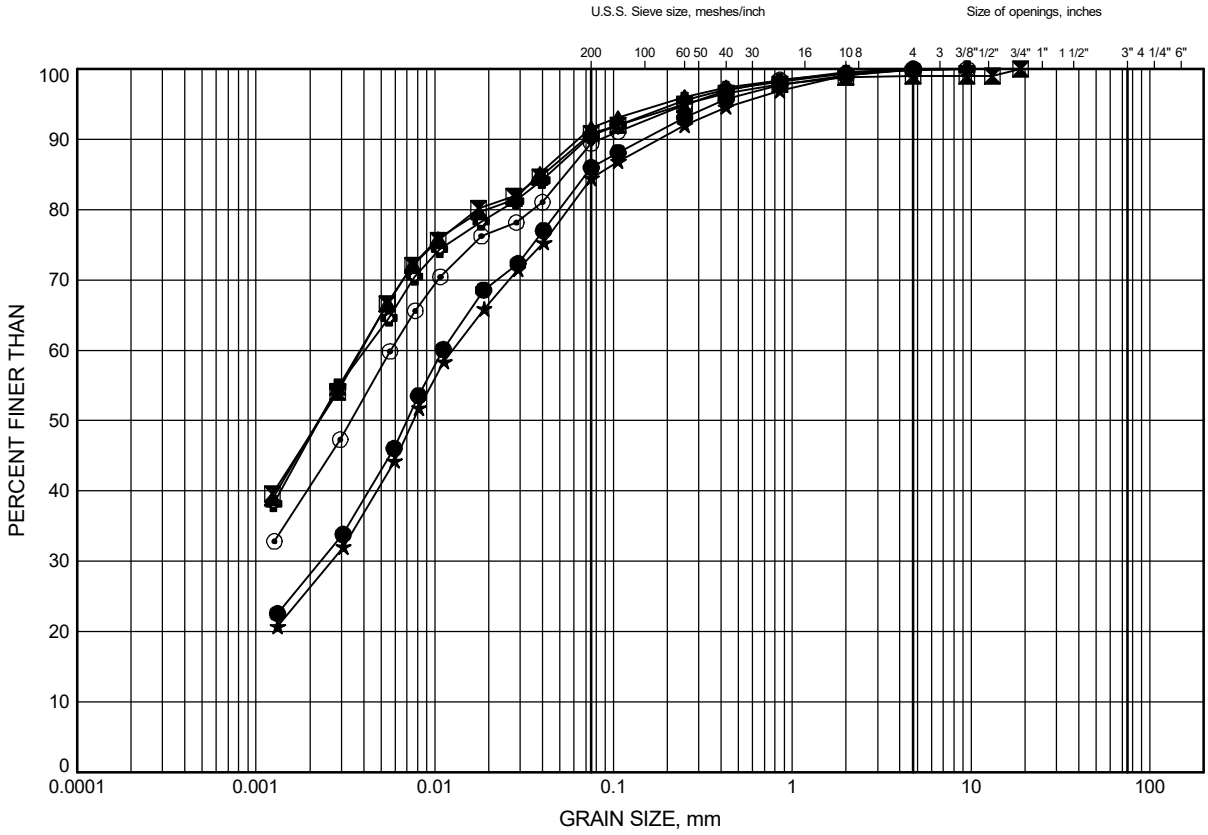
GRAIN SIZE DISTRIBUTION - THURBER 33443 - 200 BHS- POPLAR RIVER BRIDGE.GPJ 9-27-23

Highway 11 - Poplar Rapids Bridge

GRAIN SIZE DISTRIBUTION

FIGURE C6

Silty Clay (CI) to Clayey Silt (CL)



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

LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	23-203	1.1	225.6
⊠	23-203	5.6	221.1
▲	23-203	7.2	219.5
★	23-204	1.1	226.4
⊙	23-204	1.8	225.7
✿	23-204	5.6	221.9

Date September 2023

GWP# 5278-19-00

THURBER

Prep'd RH

Chkd. AO

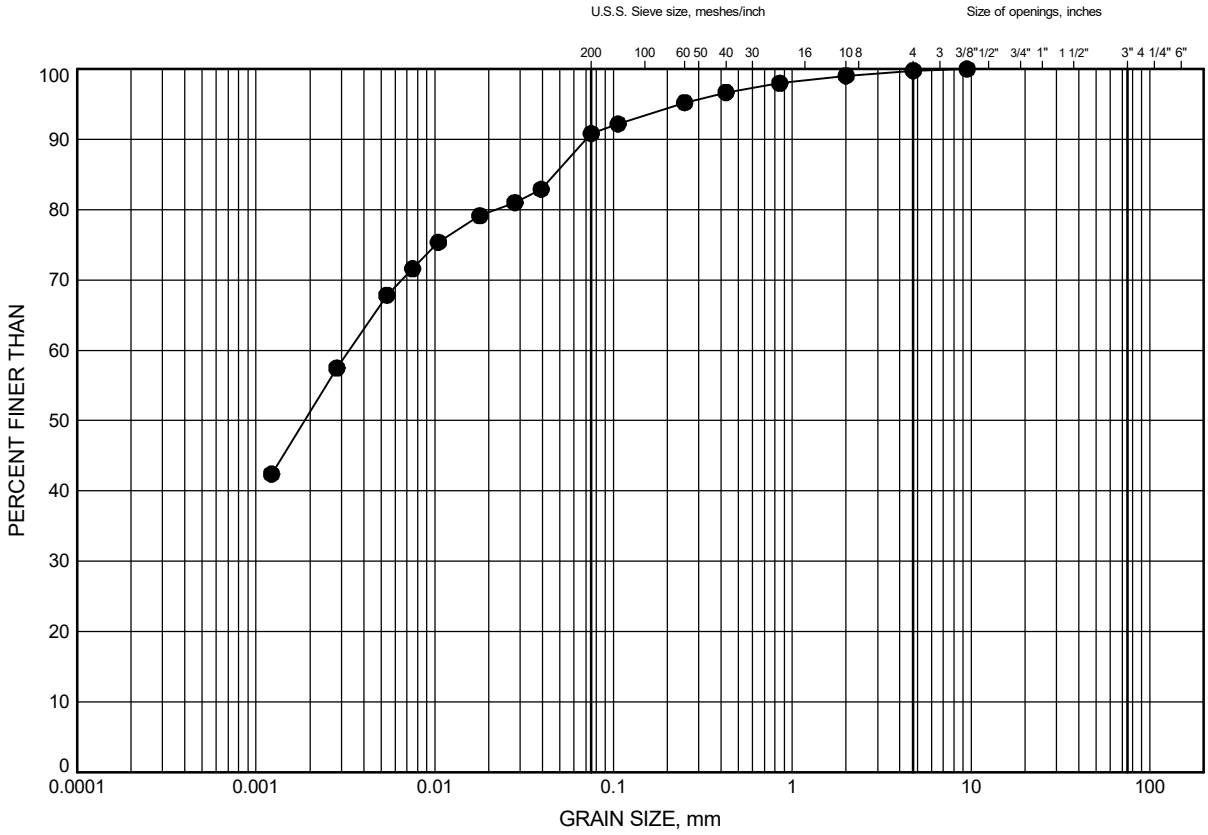
GRAIN SIZE DISTRIBUTION - THURBER 33443 - 200 BHS- POPLAR RIVER BRIDGE.GPJ 9-27-23

Highway 11 - Poplar Rapids Bridge

GRAIN SIZE DISTRIBUTION

FIGURE C7

Silty Clay (CI) to Clayey Silt (CL)



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

LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	23-204	11.7	215.8

Date September 2023

GWP# 5278-19-00

THURBER

Prep'd RH

Chkd. AO

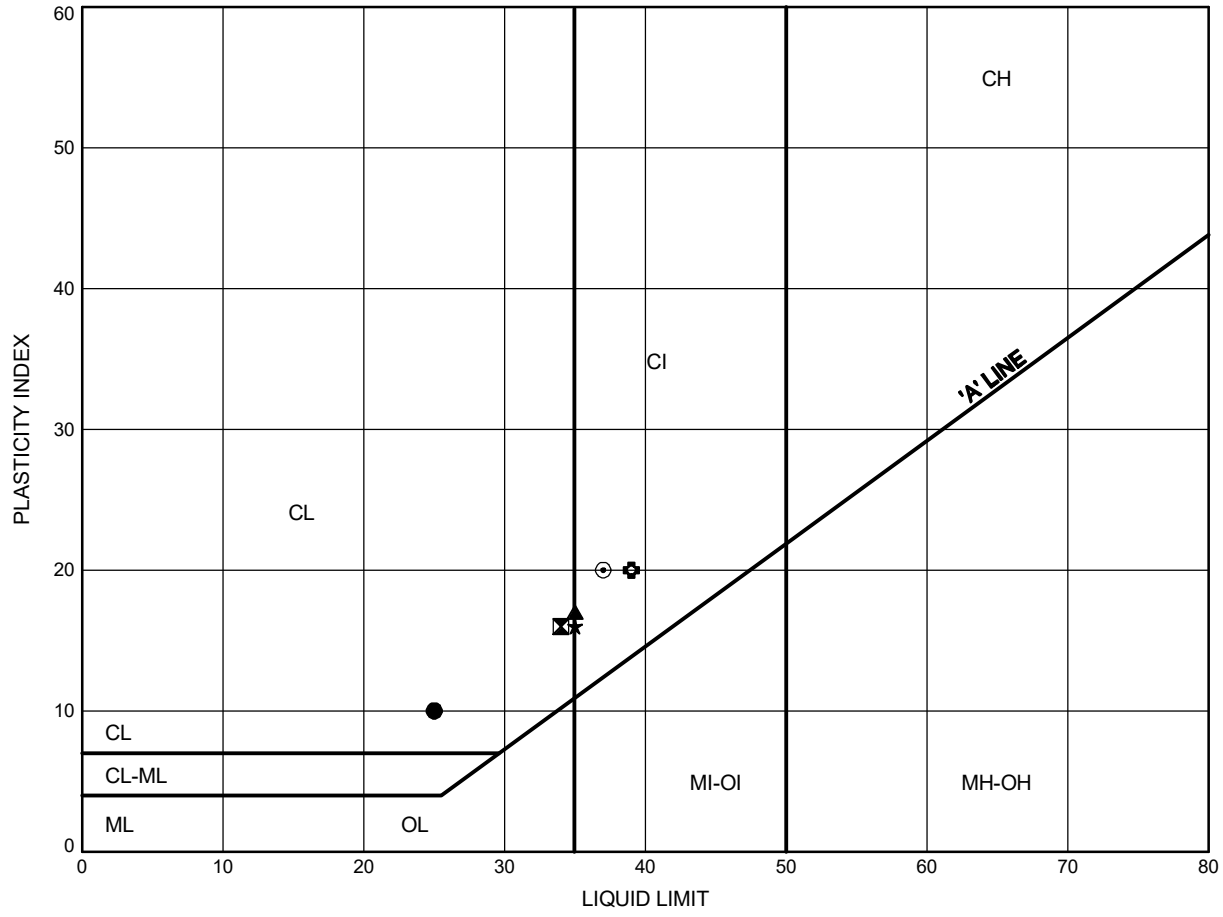
GRAIN SIZE DISTRIBUTION - THURBER 33443 - 200 BHS- POPLAR RIVER BRIDGE.GPJ 9-27-23

Highway 11 - Poplar Rapids Bridge

ATTERBERG LIMITS TEST RESULTS

FIGURE C8

Silty Clay (CI) to Clayey Silt (CL)



LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	23-201	7.9	224.6
⊠	23-201	8.7	223.8
▲	23-201	11.0	221.5
★	23-201	17.1	215.4
⊙	23-202	6.4	226.4
✿	23-202	14.0	218.8

Date September 2023

GWP# 5278-19-00

THURBER

Prep'd RH

Chkd. AO

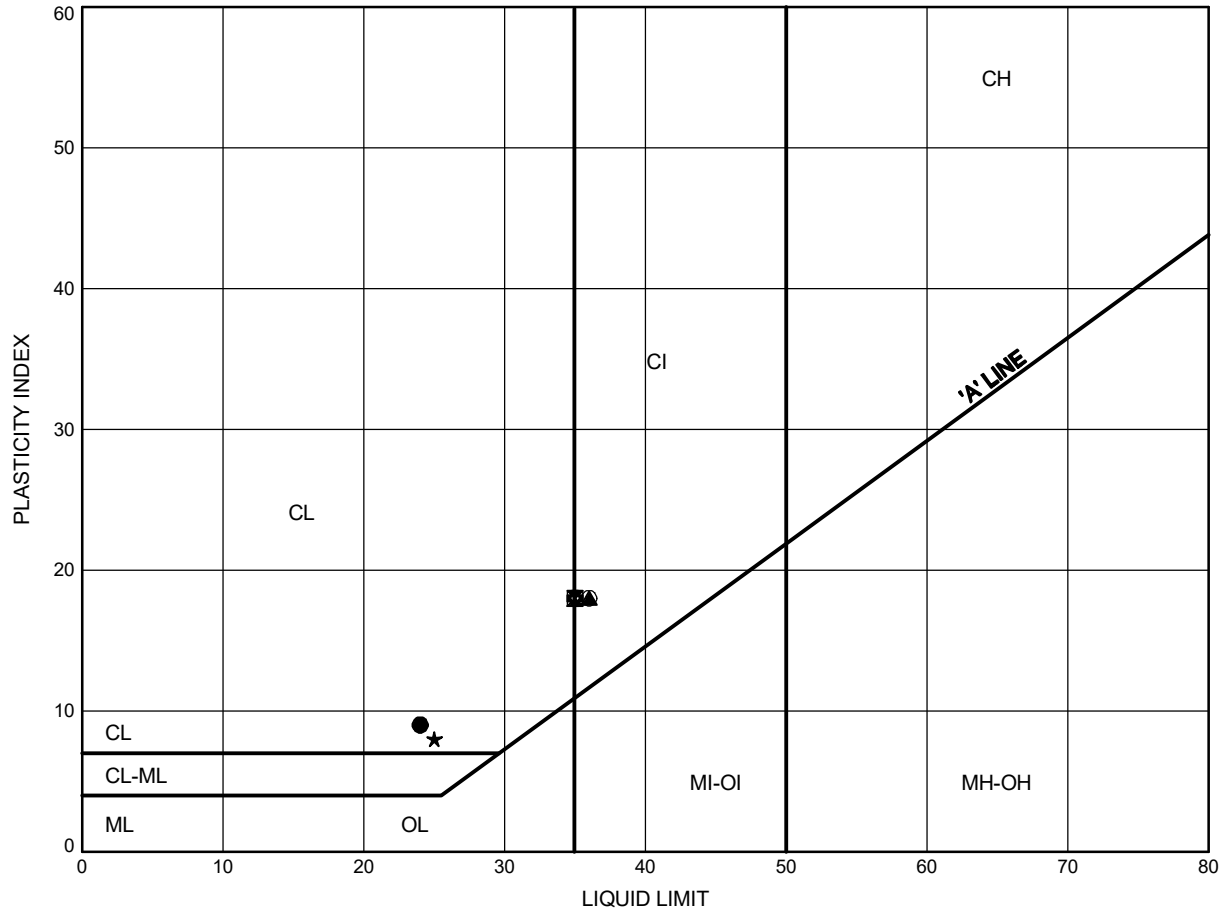
THURBALT 33443 - 200 BHS- POPLAR RIVER BRIDGE.GPJ 9-27-23

Highway 11 - Poplar Rapids Bridge

ATTERBERG LIMITS TEST RESULTS

FIGURE C9

Silty Clay (CI) to Clayey Silt (CL)



LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	23-203	1.1	225.6
⊠	23-203	5.6	221.1
▲	23-203	7.2	219.5
★	23-204	1.1	226.4
⊙	23-204	1.8	225.7
✿	23-204	5.6	221.9

Date September 2023

GWP# 5278-19-00

THURBER

Prep'd RH

Chkd. AO

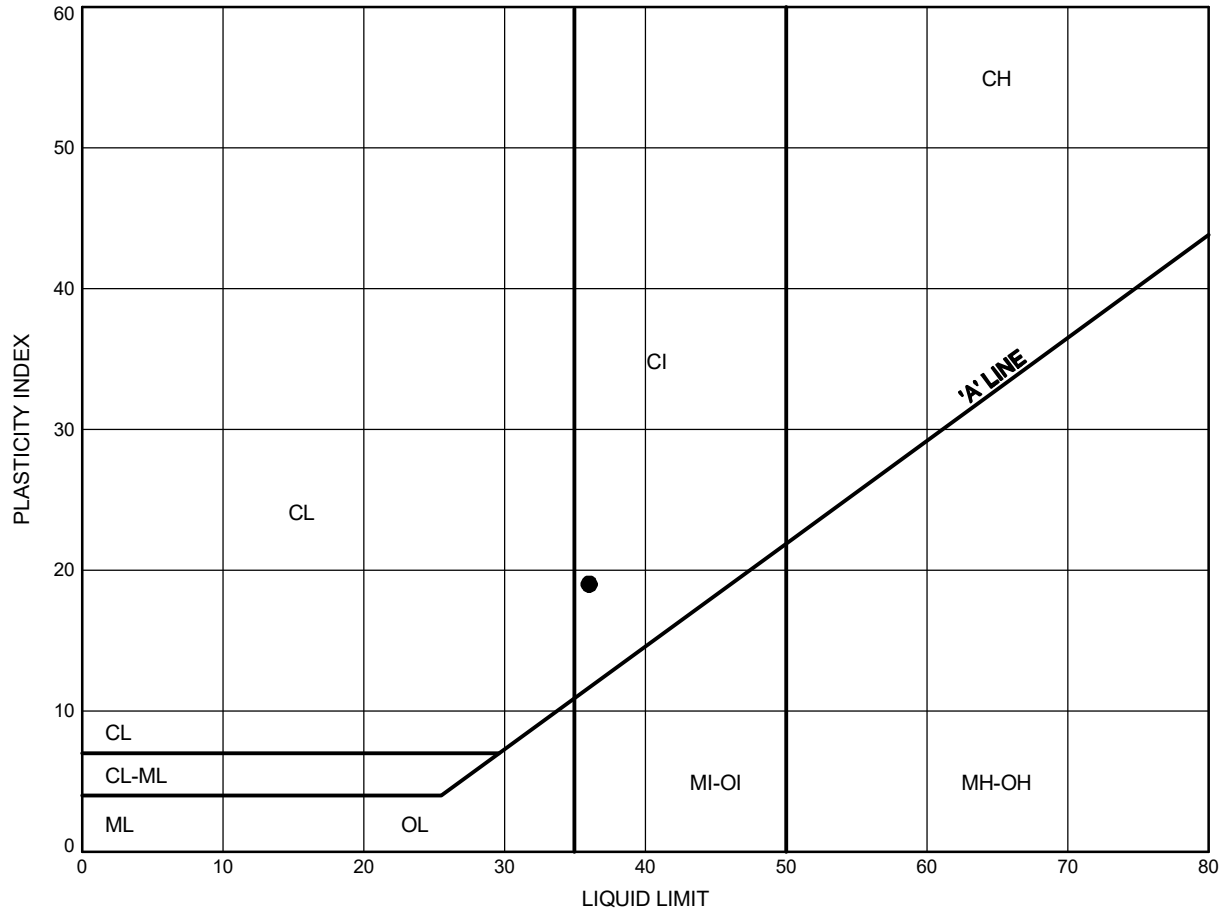
THURBALT 33443 - 200 BHS- POPLAR RIVER BRIDGE.GPJ 9-27-23

Highway 11 - Poplar Rapids Bridge

ATTERBERG LIMITS TEST RESULTS

FIGURE C10

Silty Clay (CI) to Clayey Silt (CL)



LEGEND

SYMBOL	BOREHOLE	DEPTH (m)	ELEV. (m)
●	23-204	11.7	215.8

Date September 2023

GWP# 5278-19-00

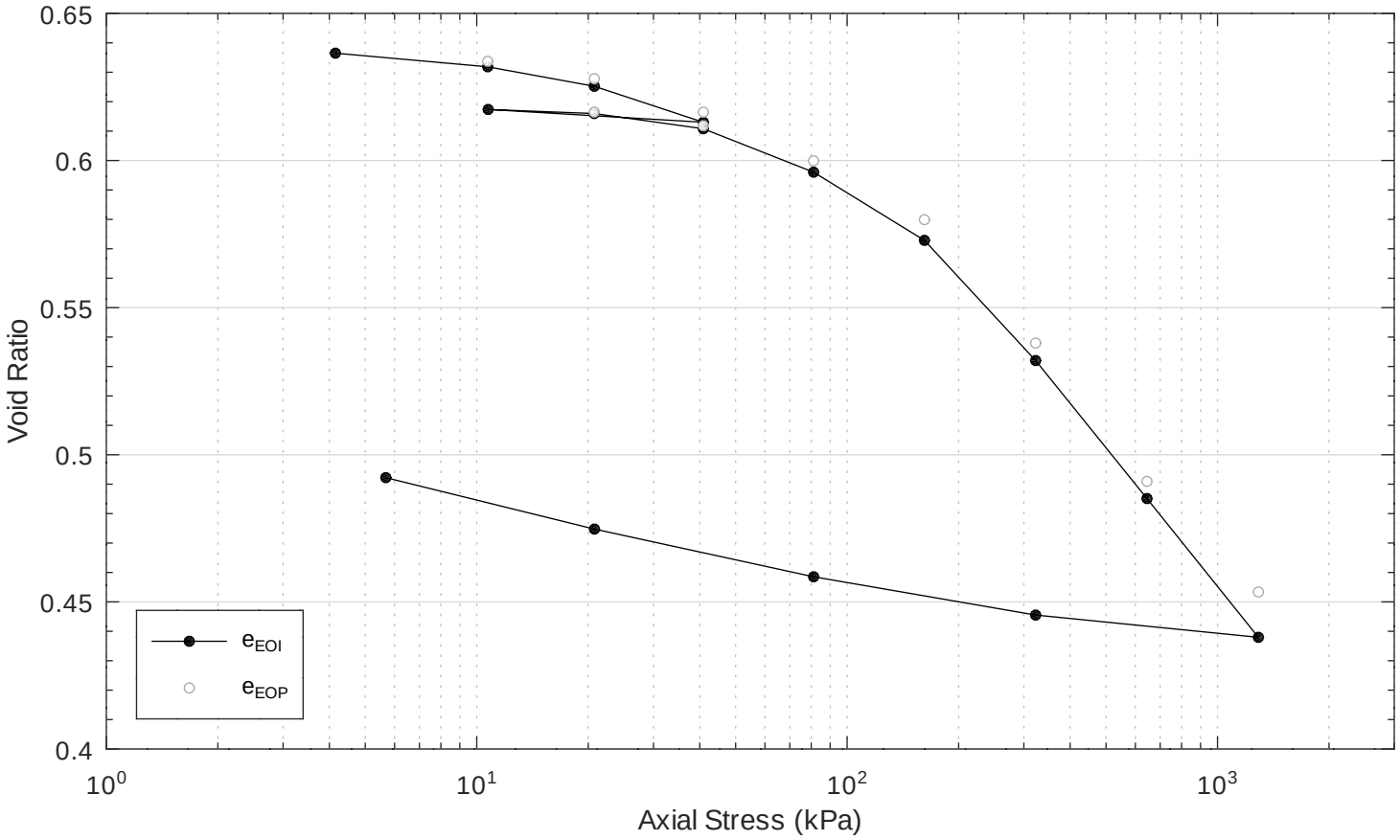
THURBER

Prep'd RH

Chkd. AO

THURBALT 33443 - 200 BHS- POPLAR RIVER BRIDGE.GPJ 9-27-23

Project: 33443
Hwy 11 Poplar Rapids Bridge
Borehole: 23-201
Sample: ST1
Depth: 8.4m
Client: LEA/MTO



Start of Test			2023-08-03
Diameter of Sample	cm	D	6.329
Height of Sample	cm	H_o	2.550
Height of Solids	cm	H_s	1.559
Water Content	%	w_o	24.49
Dry Density	g/cm^3	ρ_d	1.66
Moist Unit Weight	kN/m^3	γ	20.2
Void Ratio	-	e_o	0.636
Degree of Saturation	-	S_{ro}	1.04
Specific Gravity	-	G_s	2.713

End of Test			2023-08-20
Height of Sample	cm	H_f	2.326
Water Content	%	w_f	19.62
Void Ratio	-	e_f	0.492

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

LOADING: the consolidometer was flooded with water with the seating load adjusted to limit swelling

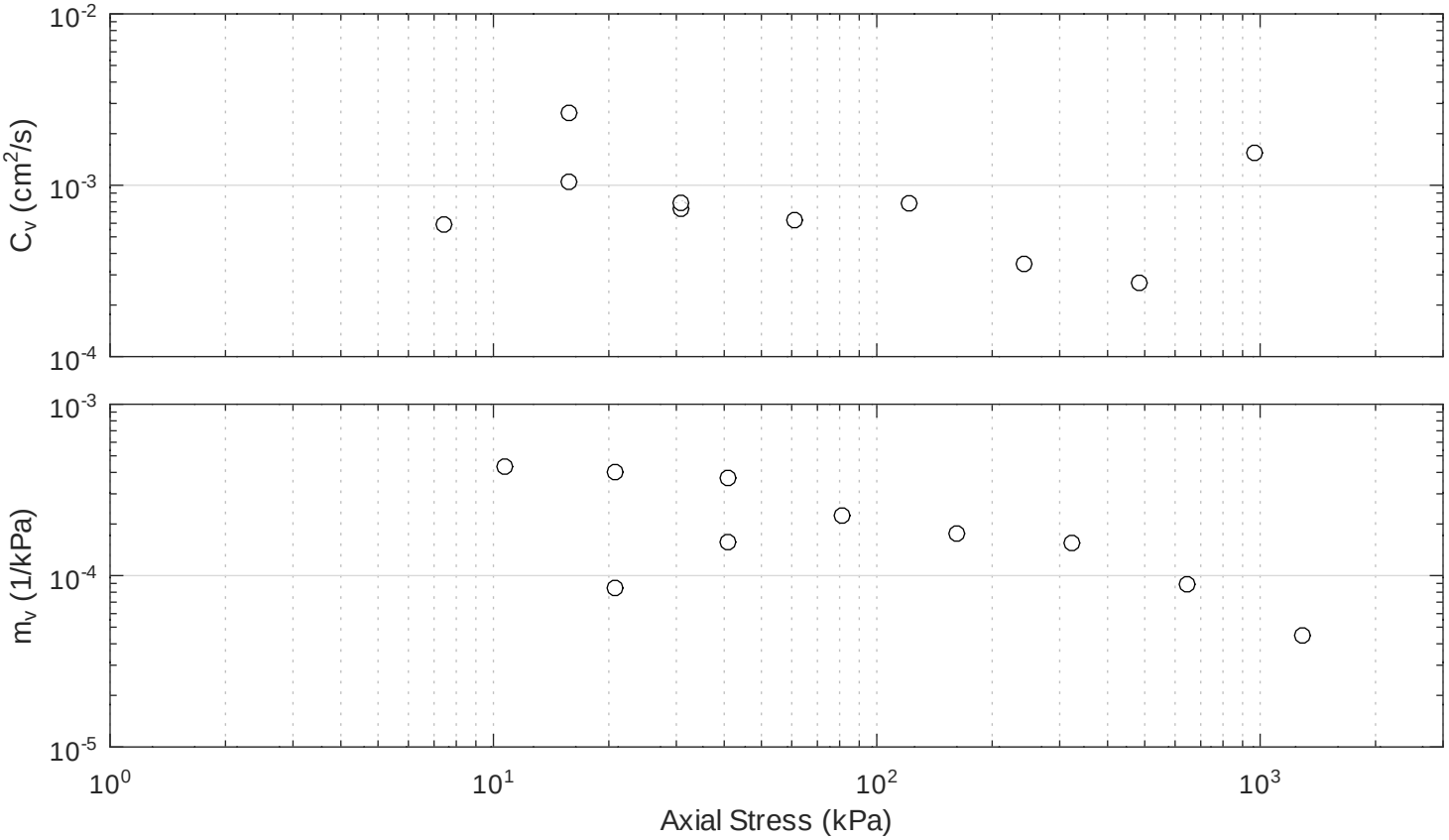
CALCULATIONS: coefficients of consolidation were calculated by the square root time method, secondary consolidation was calculated based on the available duration of the time step

Interpreted Results

Recompression Index (reloading)	-	C_r	0.034
Compression Index	-	C_c	0.157
Recompression Index (unloading)	-	C_r	0.025
Probable Preconsolidation Pressure	kPa	p'_c	160

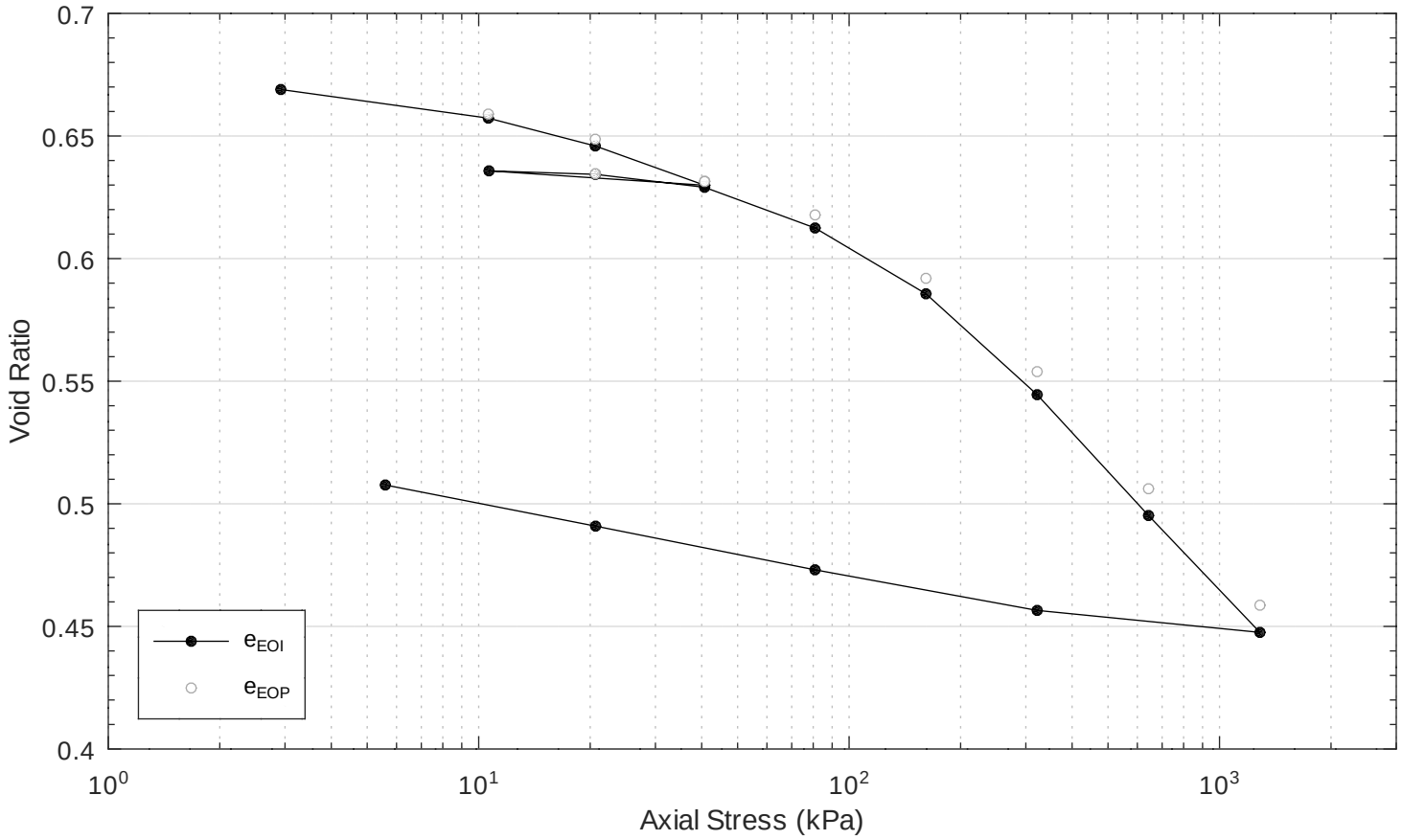
Check: AO Review: _____

Project: 33443
Hwy 11 Poplar Rapids Bridge
Borehole: 23-201
Sample: ST1
Depth: 8.4m
Client: LEA/MTO



Load No.	Axial Stress	Load Duration	System Deflec.	Dial	Sample Height	Axial Strain	Void Ratio	Void Ratio	Time U(0.99)	C_v	k_v	$C_{a\varepsilon}$
	kPa	min	mm	mm	cm	%	(EOI)	(EOP)	min	cm^2/s	cm/s	-
0				10.000	2.550	0.00	0.636					
1	4.2	1440.3	0.006	10.002	2.551	-0.03	0.636					
2	10.7	1440.3	0.053	9.882	2.544	0.25	0.632	0.634	79.1	5.90e-04	2.50e-08	0.0008
3	20.8	1440.2	0.098	9.734	2.533	0.66	0.625	0.628	43.9	1.05e-03	4.13e-08	0.0011
4	40.9	1440.1	0.145	9.495	2.514	1.41	0.613	0.616	61.1	7.29e-04	2.66e-08	0.0017
5	10.7	1440.4	0.117	9.592	2.521	1.14	0.617					
6	20.8	1440.5	0.123	9.564	2.519	1.22	0.616	0.616	17.8	2.64e-03	2.20e-08	0.0001
7	40.9	1440.3	0.150	9.456	2.511	1.54	0.611	0.612	58.4	7.89e-04	1.21e-08	0.0005
8	81.2	1440.1	0.222	9.154	2.488	2.44	0.596	0.600	68.3	6.26e-04	1.38e-08	0.0019
9	161.7	1440.1	0.301	8.713	2.452	3.86	0.573	0.580	52.6	7.84e-04	1.35e-08	0.0028
10	322.8	1440.1	0.403	7.977	2.388	6.36	0.532	0.538	100.9	3.48e-04	5.28e-09	0.0034
11	644.9	1440.3	0.514	7.134	2.315	9.22	0.485	0.491	118.2	2.70e-04	2.35e-09	0.0034
12	1289.2	1440.4	0.673	6.240	2.241	12.11	0.438	0.453	19.9	1.55e-03	6.78e-09	0.0050
13	322.8	1440.1	0.519	6.513	2.253	11.64	0.446					
14	81.2	1440.2	0.421	6.814	2.273	10.85	0.459					
15	20.8	1440.4	0.336	7.152	2.299	9.86	0.475					
16	5.7	2880.0	0.284	7.476	2.326	8.79	0.492					

Project: 33443
Hwy 11 Poplar Rapids Bridge
Borehole: 23-203
Sample: ST1
Depth: 5.3m
Client: LEA/MTO



Start of Test			2023-09-01
Diameter of Sample	cm	D	6.337
Height of Sample	cm	H_o	2.539
Height of Solids	cm	H_s	1.522
Water Content	%	w_o	26.23
Dry Density	g/cm^3	ρ_d	1.63
Moist Unit Weight	kN/m^3	γ	20.2
Void Ratio	-	e_o	0.669
Degree of Saturation	-	S_{ro}	1.07
Specific Gravity	-	G_s	2.722

End of Test			2023-09-18
Height of Sample	cm	H_f	2.294
Water Content	%	w_f	20.62
Void Ratio	-	e_f	0.508

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

LOADING: the consolidometer was flooded with water with the seating load adjusted to limit swelling

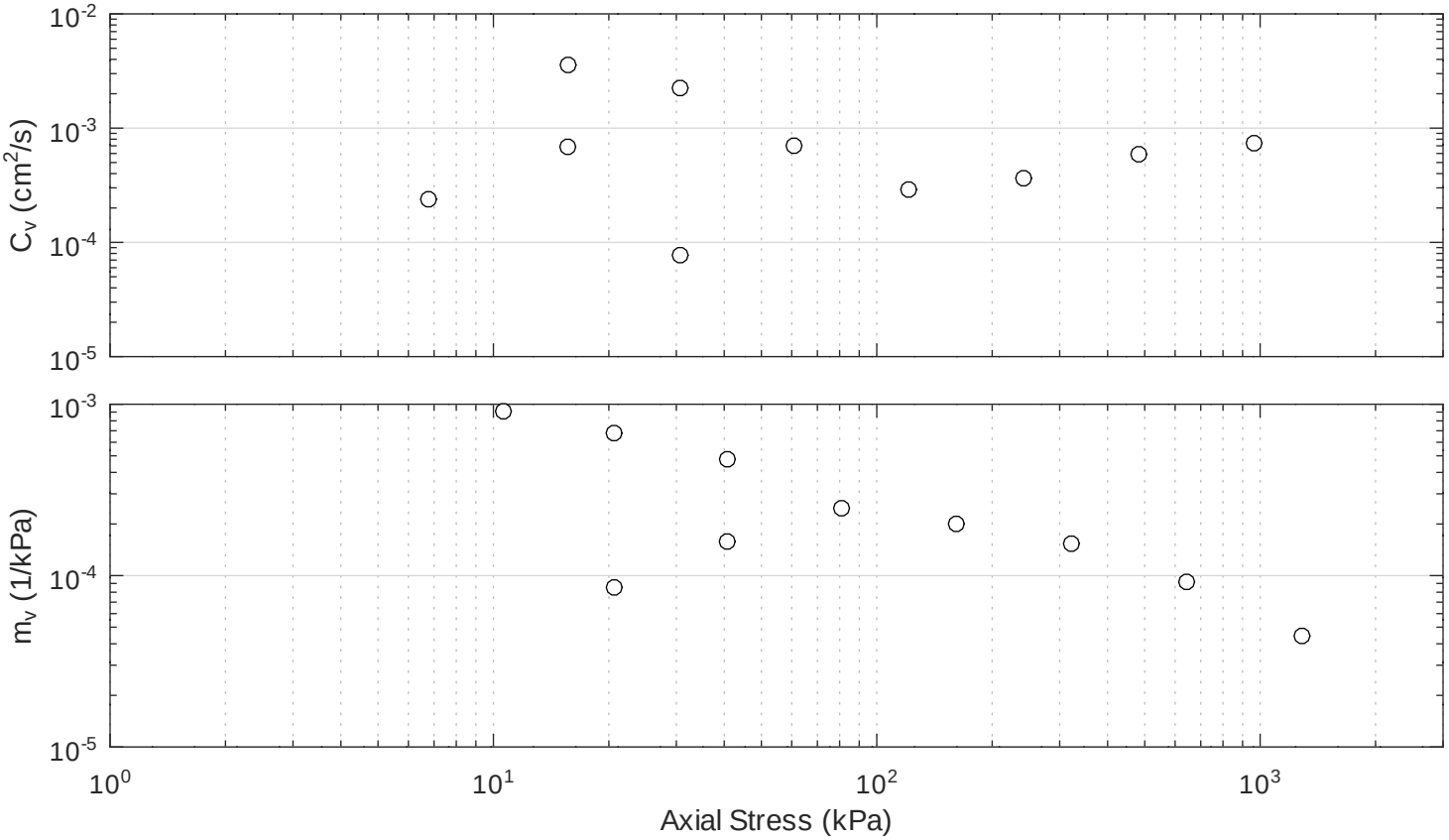
CALCULATIONS: coefficients of consolidation were calculated by the square root time method, secondary consolidation was calculated based on the available duration of the time step

Interpreted Results

Recompression Index (reloading)	-	C_r	0.056
Compression Index	-	C_c	0.158
Recompression Index (unloading)	-	C_r	0.029
Probable Preconsolidation Pressure	kPa	p'_c	153

Check: AO Review: _____

Project: 33443
Hwy 11 Poplar Rapids Bridge
Borehole: 23-203
Sample: ST1
Depth: 5.3m
Client: LEA/MTO

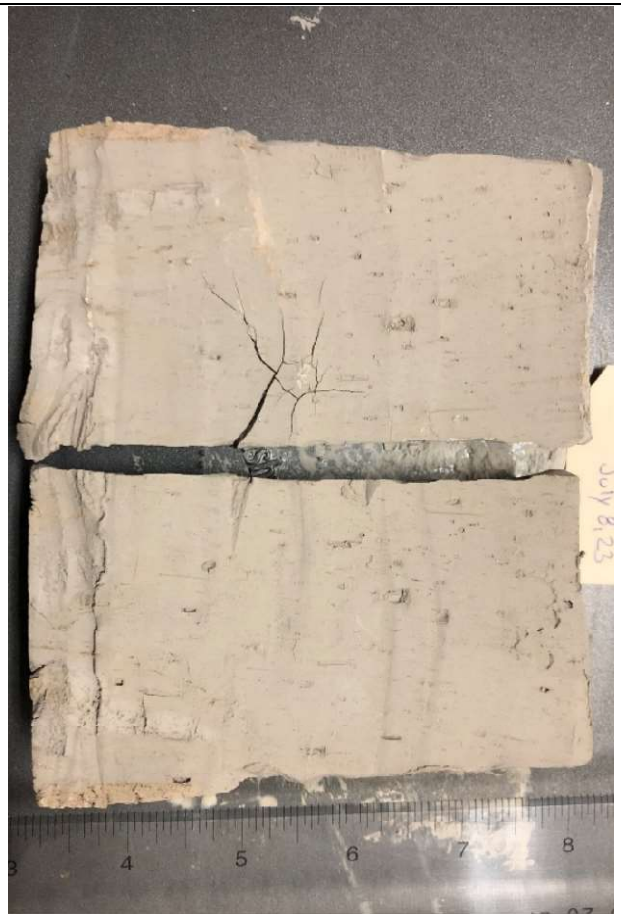


Load No.	Axial Stress	Load Duration	System Deflec.	Dial	Sample Height	Axial Strain	Void Ratio	Void Ratio	Time U(0.99)	C_v	k_v	$C_{a\varepsilon}$
	kPa	min	mm	mm	cm	%	(EOI)	(EOP)	min	cm^2/s	cm/s	-
0				10.000	2.539	0.00	0.669					
1	2.9	1440.1	0.006	9.999	2.540	-0.02	0.669					
2	10.6	1440.3	0.053	9.774	2.522	0.68	0.657	0.659	188.9	2.39e-04	2.13e-08	0.0012
3	20.6	1440.2	0.098	9.556	2.504	1.36	0.646	0.649	64.7	6.86e-04	4.57e-08	0.0012
4	40.8	1440.1	0.145	9.265	2.480	2.32	0.630	0.632	548.5	7.73e-05	3.62e-09	0.0027
5	10.7	1440.5	0.117	9.383	2.489	1.97	0.636					
6	20.7	1440.2	0.123	9.355	2.487	2.05	0.634	0.635	12.7	3.57e-03	2.99e-08	0.0001
7	40.7	1440.2	0.150	9.247	2.479	2.37	0.629	0.631	19.9	2.24e-03	3.48e-08	0.0008
8	80.9	1440.2	0.222	8.923	2.454	3.36	0.612	0.618	60.0	7.01e-04	1.70e-08	0.0021
9	161.2	1440.5	0.301	8.435	2.413	4.97	0.586	0.592	133.1	2.90e-04	5.70e-09	0.0041
10	321.8	1440.4	0.403	7.708	2.350	7.44	0.545	0.554	95.2	3.64e-04	5.48e-09	0.0048
11	643.1	1440.5	0.514	6.847	2.275	10.39	0.495	0.506	51.9	5.91e-04	5.33e-09	0.0044
12	1285.7	1440.1	0.673	5.963	2.203	13.25	0.448	0.459	39.0	7.38e-04	3.22e-09	0.0041
13	321.9	1440.1	0.519	6.254	2.216	12.71	0.457					
14	80.9	1440.1	0.421	6.604	2.241	11.72	0.473					
15	20.7	1440.1	0.336	6.960	2.269	10.65	0.491					
16	5.6	2880.5	0.284	7.268	2.294	9.65	0.508					

THURBER ENGINEERING LTD.

Borehole 23-201, Sample ST1, Depth 8.4 m

(sample width approximately equal to diameter of Thin-Walled sample tube, ~70 mm)

"Wet"	"Dry"
	

Client: LEA Consulting Ltd.

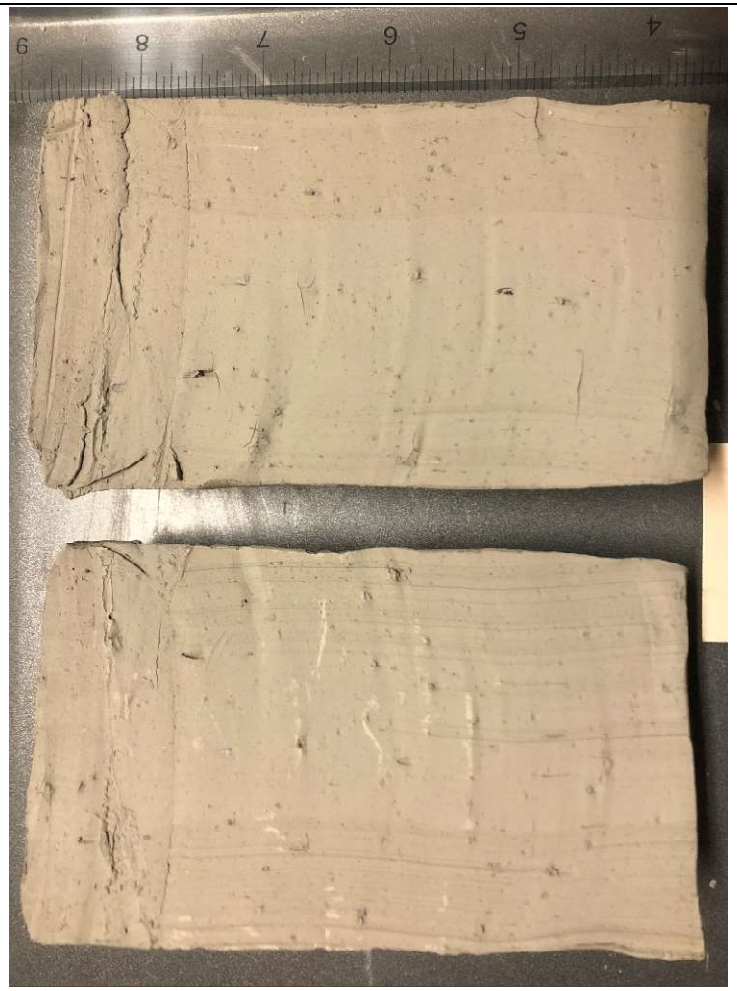
File No.: 33443

April 5, 2024

THURBER ENGINEERING LTD.

Borehole 23-203, Sample ST1, Depth 5.3 m

(sample width approximately equal to diameter of Thin-Walled sample tube, ~70 mm)

"Wet"	"Dry"
	

Client: LEA Consulting Ltd.

File No.: 33443

April 5, 2024

THURBER ENGINEERING LTD.

APPENDIX D

Site Photographs

Photo 1: Culvert inlet/north embankment slope
(taken on July 4, 2023)

Photo 2: Culvert outlet/south embankment slope
(taken on July 04, 2023)

Photo 3: Looing west at culvert outlet and eastbound embankment
(taken on July 04, 2023)

Photo 4: Highway 11 east of the culvert alignment
(taken on July 17, 2023)

Photo 5: Highway 11 west of the culvert alignment
(taken on July 17, 2023)

Photo 6: Looking west at the westbound embankment, side of proposed embankment widening
(taken on July 17, 2023)

Photo 7: Looking east at the westbound embankment, side of embankment widening
(taken on July 17, 2023)

THURBER ENGINEERING LTD.

APPENDIX E

ConeTec Report

PRESENTATION OF SITE INVESTIGATION RESULTS

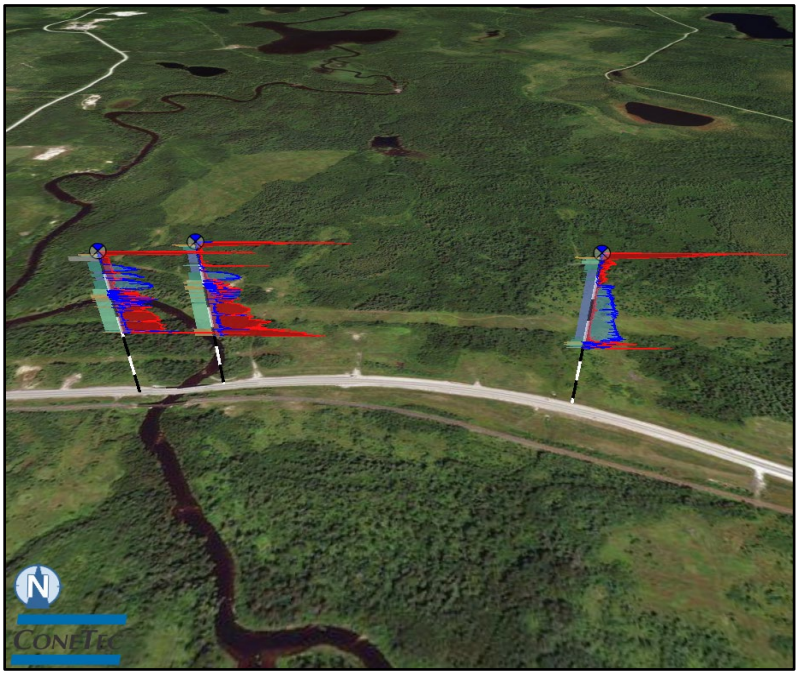
Poplar Rapids Bridge – Highway 11

Prepared for:

Thurber Engineering Ltd.

ConeTec Job No: 23-05-26042

Project Start Date: 2023-07-10
Project End Date: 2023-07-11
Report Date: 2023-07-21



Prepared by:

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Tel: (905) 886-2663
Fax: (905) 886-2664

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 Ltd. at Highway 11 Poplar Rapids River Bridge, ON. The program consisted of 3 seismic cone penetration tests (SCPTu). Please note that this report, which also includes all accompanying data, are subject to the 3rd Party Disclaimer and Client Disclaimer that follow in the 'Limitations' section of this report.

Project Information

Project	
Client	Thurber Engineering Ltd.
Project	Poplar Rapids Bridge - Highway 11
ConeTec project number	23-05-26042

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

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

Coordinates		
Test Type	Collection Method	EPSG Number
SCPTu	Consumer grade GPS	26917

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 (bar)
765:T1500F15U35	765	15	225	1500	15	35
958:T1500F15U35	958	15	225	1500	15	35
The CPTu summary indicates which cone was used for each sounding.						

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.
Seismic calculations	Poisson's ratio (ν) was calculated from the shear wave (V_s) and compression wave (V_p) velocities using the following equation: $$\nu = \frac{(V_p/V_s)^2 - 2}{2\left((V_p/V_s)^2 - 1\right)}$$
Additional plots	• Standard plots with expanded range • Advanced plots with Ic, Su, phi and N1(60) • Seismic plots with Vs, Vp, and Poisson's ratio • Soil Behaviour Type (SBT) scatter plots

Calculated Geotechnical Parameter Tables	
Additional information	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). Effective stresses are calculated based on unit weights that have been assigned to the individual soil behaviour type zones and the assumed equilibrium pore pressure profile. 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).

Limitations

3rd Party Disclaimer

This report titled “Poplar Rapids Bridge - Highway 11”, referred to as the (“Report”), was prepared by ConeTec for Thurber Engineering Ltd.. The Report is confidential and may not be distributed to or relied upon by any third parties without the express written consent of ConeTec. Any third parties gaining access to the Report do not acquire any rights as a result of such access. Any use which a third party makes of the Report, or any reliance on or decisions made based on it, are the responsibility of such third parties. ConeTec accepts no responsibility for loss, damage and/or expense, if any, suffered by any third parties as a result of decisions made, or actions taken or not taken, which are in any way based on, or related to, the Report or any portion(s) thereof.

Client Disclaimer

ConeTec was retained by Thurber Engineering Ltd. to collect and provide the raw data (“Data”) which is included in this report titled “Poplar Rapids Bridge - Highway 11”, which is referred to as the (“Report”). ConeTec has collected and reported the Data in accordance with current industry standards. No other warranty, express or implied, with respect to the Data is made by ConeTec. In order to properly understand the Data included in the Report, reference must be made to the documents accompanying and other sources referenced in the Report in their entirety. Any analysis, interpretation, judgment, calculations and/or geotechnical parameters (collectively “Interpretations”) included in the Report, including those based on the Data, are outside the scope of ConeTec’s retainer and are included in the Report as a courtesy only. Other than the Data, the contents of the Report (including any Interpretations) should not be relied upon in any fashion without independent verification and ConeTec is in no way responsible for any loss, damage or expense resulting from the use of, and/or reliance on, such material by any party.

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 two geophone sensors for recording seismic signals. All signals are amplified and measured with minimum 16 bit resolution down hole within the cone body, and the signals are sent to the surface using a high bandwidth, error corrected digital interface through a shielded cable.

ConeTec penetrometers are manufactured with various tip, friction and pore pressure capacities in both 10 cm^2 and 15 cm^2 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 cm^2 penetrometers do not require friction reducers as they have a diameter larger than the deployment rods. The 10 cm^2 piezocones use a friction reducer consisting of a rod adapter extension behind the main cone body with an enlarged cross sectional area (typically 44 mm diameter over a length of 32 mm with tapered leading and trailing edges) located at a distance of 585 mm 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 60 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 "u_2" position (ASTM Type 2). The filter is 6 mm 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.

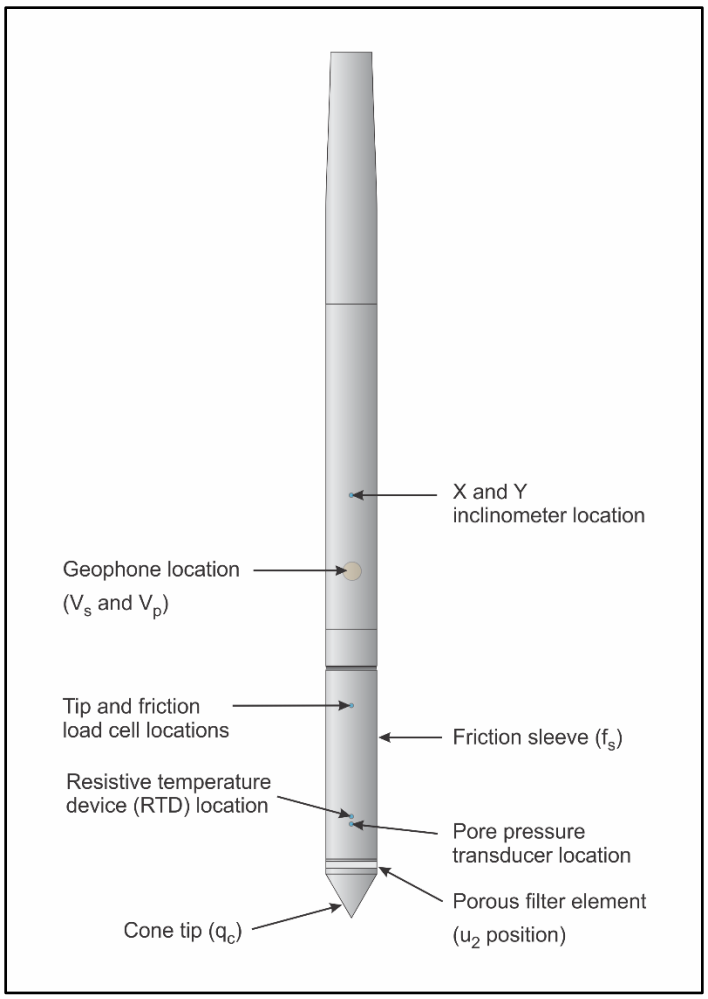


Figure CPTu. Piezocone Penetrometer (15 cm^2)

The ConeTec data acquisition systems consist of a Windows based computer and a signal interface box and power supply. The signal interface combines depth increment signals, seismic trigger signals and the downhole digital data. This combined data is then sent to the Windows based computer for collection and presentation. 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 cm; 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 either glycerine or 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 2 cm/s, within acceptable tolerances. Typically one meter length rods with an outer diameter of 38.1 mm 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
- 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):

$$q_t = q_c + (1\text{-}a) \bullet u_2$$

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 (Rf) 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).

Shear wave velocity (Vs) testing is performed in conjunction with the piezocone penetration test (SCPTu) in order to collect interval velocities. For some projects seismic compression wave velocity (Vp) testing is also performed.

ConeTec's 15 cm^2 piezocone penetrometers are manufactured with one horizontally active geophone (28 hertz) and one vertically active geophone (28 hertz). Both geophones are rigidly mounted in the body of the cone penetrometer, 0.2 meters behind the cone tip. The vertically mounted geophone is more sensitive to compression waves; however, it is often affected by the compression wave travelling through the cone rods.

Shear waves are typically generated by using an impact hammer horizontally striking a beam that is held in place by a normal load. In some instances an auger source or an imbedded impulsive source maybe used for both shear waves and compression waves. The hammer and beam act as a contact trigger that initiates the recording of the seismic wave traces. For impulsive devices an accelerometer trigger may be used. The traces are recorded in the memory of the cone using a fast analog to digital converter. The seismic trace is then transmitted digitally uphole to a Windows based computer through a signal interface box for recording and analysis. An illustration of the shear wave testing configuration is presented in Figure SCPTu-1.

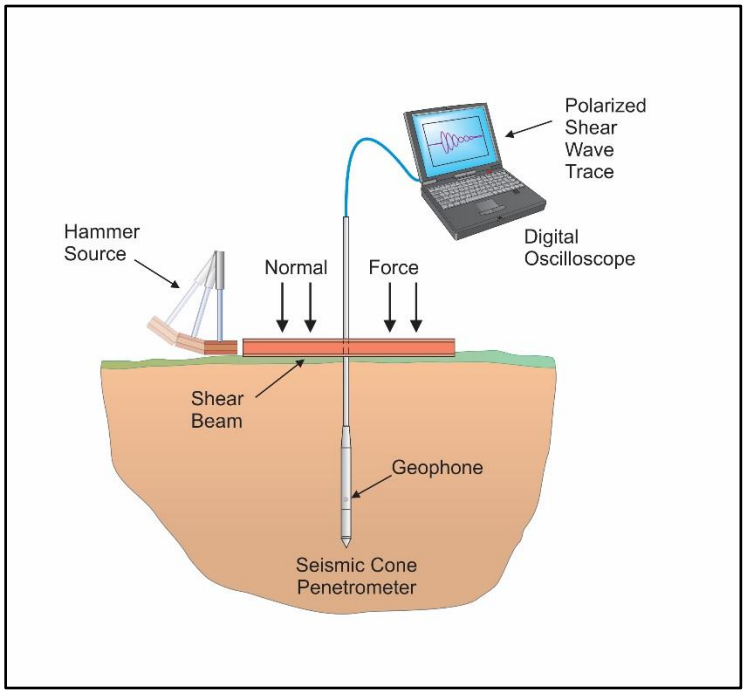


Figure SCPTu-1. Illustration of the SCPTu system

All testing is performed in accordance to ConeTec's SCPTu operating procedures which are in general accordance with the current ASTM D5778 and ASTM D7400 standards.

Prior to the start of a SCPTu sounding, the procedures described in the Cone Penetration Test section are followed. In addition, the active axis of the geophone is aligned parallel to the beam (or source) and the horizontal offset between the cone and the source is measured and recorded.

Prior to recording seismic waves at each test depth, cone penetration is stopped and the rods are decoupled from the rig to avoid transmission of rig energy down the rods. Typically, five wave traces for each orientation are recorded for quality control and uncertainty analysis purposes. After reviewing wave traces for consistency the cone is pushed to the next test depth (typically one meter intervals or as requested by the client). Figure SCPTu-2 presents an illustration of a SCPTu test.

For additional information on seismic cone penetration testing refer to Robertson et. al. (1986).

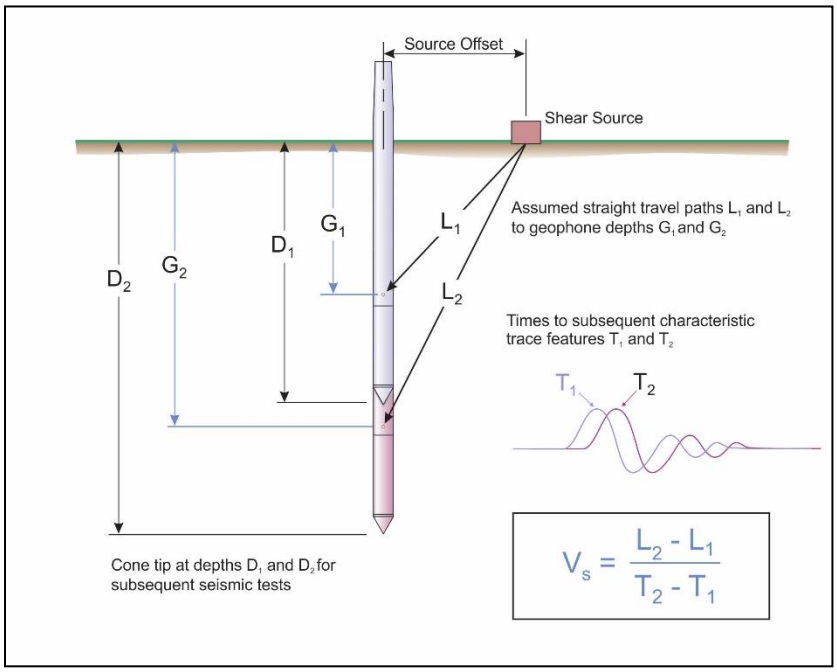


Figure SCPTu-2. Illustration of a seismic cone penetration test

For the determination of interval travel times the wave traces from all depths are displayed in analysis software. The results of the interval picks are supplied in the relevant appendix of this report. Standard practice for ConeTec is to record five wave traces for each source direction at each test depth. Outlier impacts are identified in the field and the impacts are repeated. For the final wave trace profile, the traces are stacked in the time domain to display a single average trace.

Determination of the shear wave interval velocities are performed by visually picking a common feature (e.g. the first characteristic peak, trough, or crossover) on all of the trace depths and taking the difference in ray path divided by the time difference between features at subsequent depths. The same process is used for compression waves, however the first break is most commonly used for selecting an arrival time. For velocity calculation, the ray path is defined as the straight-line distance from the seismic source to the geophone, accounting for beam offset, source depth and geophone offset from the cone tip.

In some cases, usually for shear wave velocity testing, more than one characteristic marker may be used. If there is an overlap between different sets of characteristic markers, then the average time value for those sets of interval times is applied to the determination of velocity.

Ideally, all depths are used for the determination of the velocity profile. However, an interval may be skipped if there is some ambiguity or quality concern with a particular depth, resulting in a larger interval.

Tabular results and SCPTu plots are presented in the relevant appendix.

The average shear wave velocity to a depth of 30 meters (V_{s30}) has been calculated and provided for all applicable soundings using an equation presented in Crow et al. (2012).

$$V_{s30} = \frac{total\ thickness\ of\ all\ layers\ (30m)}{\sum(layer\ traveltimes)}$$

The layer travel times refers to the travel times propagating in the vertical direction, not the measured travel times from an offset source.

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).

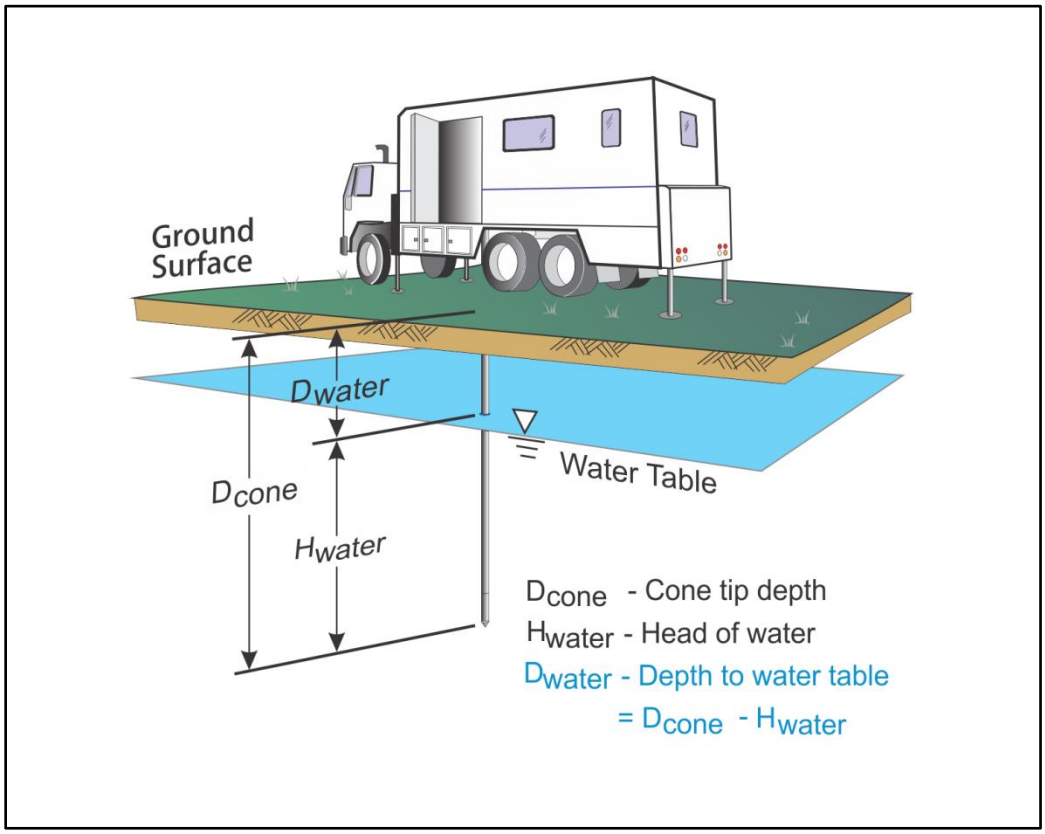


Figure PPD-1. Pore pressure dissipation test setup

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.

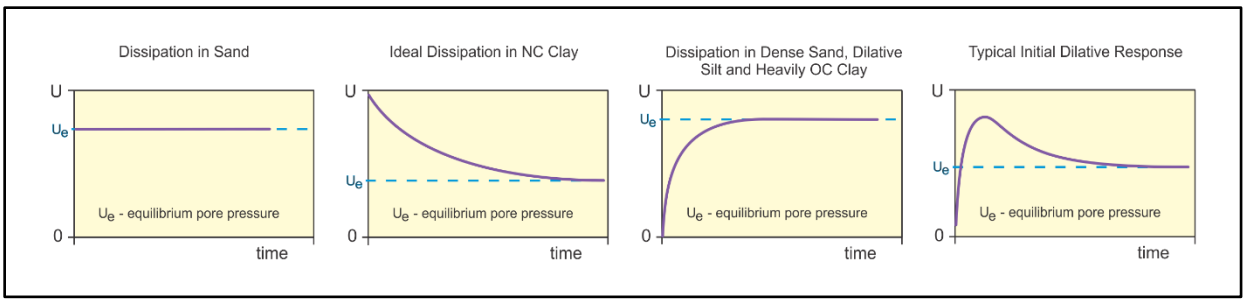


Figure PPD-2. Pore pressure dissipation curve examples

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 dilatory 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.

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

ASTM D5778-20, 2020, "Standard Test Method for Performing Electronic Friction Cone and Piezocone Penetration Testing of Soils", ASTM, West Conshohocken, US.

ASTM D7400/D7400M-19, 2019, "Standard Test Methods for Downhole Seismic Testing", ASTM, West Conshohocken, US.

Crow, H.L., Hunter, J.A., Bobrowsky, P.T., 2012, "National shear wave measurement guidelines for Canadian seismic site assessment", GeoManitoba 2012, Sept 30 to Oct 2, Winnipeg, Manitoba.

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.

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

Mayne, P.W. and Peuchen, J., 2012, "Unit weight trends with cone resistance in soft to firm clays", Geotechnical and Geophysical Site Characterization *4,* Vol. 1 (Proc. ISC-4, Pernambuco), CRC Press, London: 903-910.

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.

Robertson, P.K., 2009, "Interpretation of cone penetration tests – a unified approach", Canadian Geotechnical Journal, Volume 46: 1337-1355.

Robertson, P.K., Campanella, R.G., Gillespie D and Rice, A., 1986, "Seismic CPT to Measure In-Situ Shear Wave Velocity", Journal of Geotechnical Engineering ASCE, Vol. 112, No. 8: 791-803.

Teh, C.I., and Houlsby, G.T., 1991, "An analytical study of the cone penetration test in clay", Geotechnique, 41(1): 17-34.

The appendices listed below are included in the report:

- Cone Penetration Test Summary and Standard Cone Penetration Test Plots
- Standard Cone Penetration Test Plots with Expanded Range
- Advanced Cone Penetration Test Plots with Ic, Su(Nkt), Phi and N1(60)Ic
- Seismic Cone Penetration Test Plots
- Seismic Cone Penetration Test Shear Wave (Vs) Tabular Results
- Seismic Cone Penetration Test Shear Wave (Vs) Traces
- Seismic Cone Penetration Test Compression Wave (Vp) Tabular Results
- Seismic Cone Penetration Test Compression Wave (Vp) Traces
- Seismic Cone Penetration Test Poisson's Ratio Tabular Results
- Soil Behaviour Type (SBT) Scatter Plots
- Pore Pressure Dissipation Summary and Pore Pressure Dissipation Plots
- Description of Methods for Calculated CPT Geotechnical Parameters

Cone Penetration Test Summary and Standard Cone Penetration Test Plots

CONETEC

Job No:	23-05-26042
Client:	Thurber Engineering Ltd.
Project:	Poplar Rapids Bridge - Highway 11
Start Date:	2023-07-10
End Date:	2023-07-11

CONE PENETRATION TEST SUMMARY

Sounding ID	File Name	Date	Cone	Cone Area (cm^2)	Assumed Phreatic Surface[1] (m)	Final Depth (m)	Northing[2] (m)	Easting[2] (m)	Refer to Notation Number
SCPT23-107	23-05-26042_SP23-107	2023-07-10	958:T1500F15U35	15	6.3	22.175	5459917	442998	
SCPT23-108	23-05-26042_SP23-108	2023-07-10	958:T1500F15U35	15	7.1	18.925	5459902	442905	
SCPT23-205	23-05-26042_SP23-205	2023-07-11	765:T1500F15U35	15	7.8	21.725	5459882	443394	

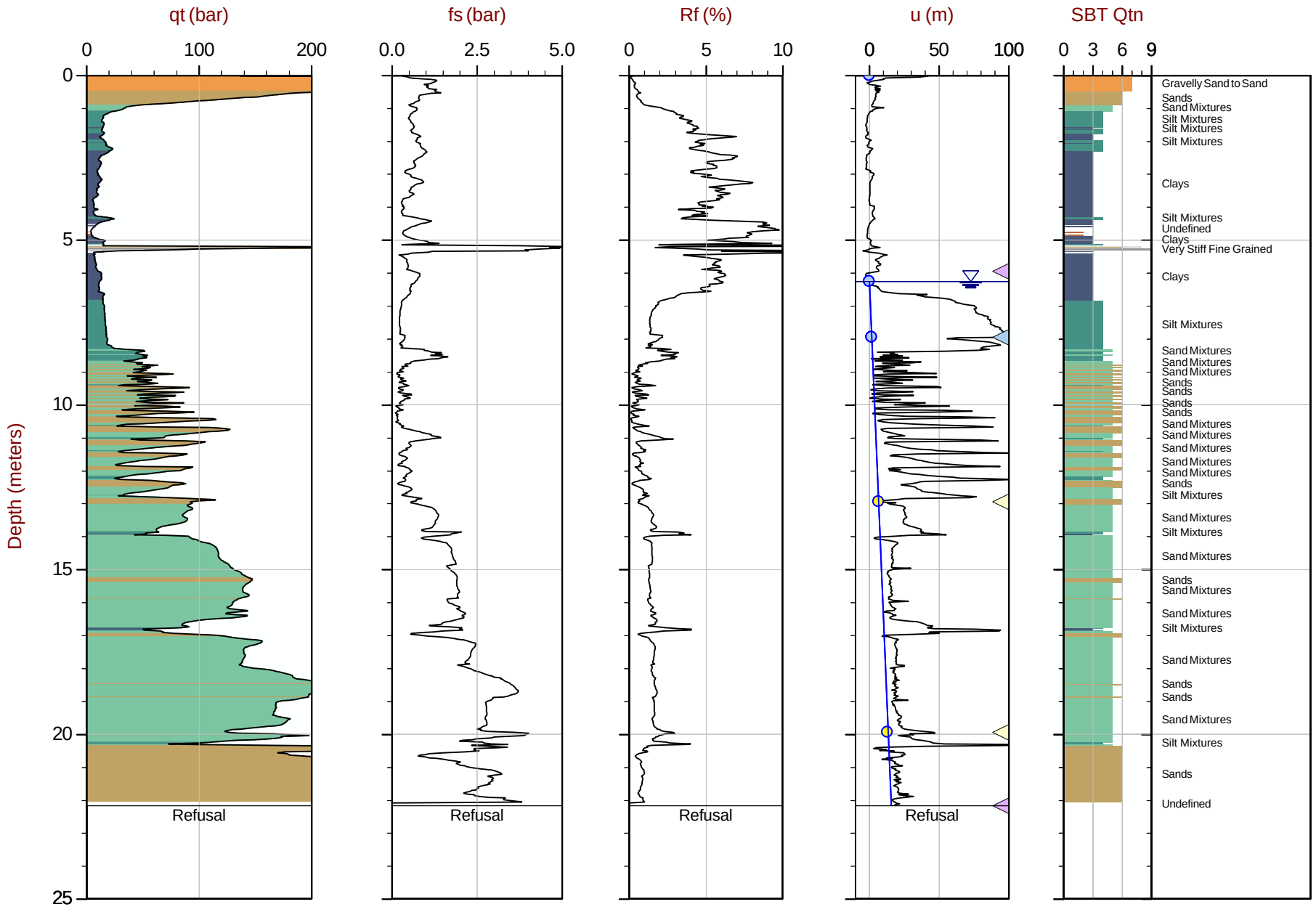
1. The assumed phreatic surface was based on pore pressure dissipation tests. Hydrostatic conditions were assumed for the calculated parameters.
2. Coordinates were acquired using consumer grade GPS equipment, Datum: NAD 83 / UTM Zone 17N.

CONETEC

Thurber

Job No: 23-05-26042
Date: 2023-07-10 14:57
Site: Poplar Rapids Bridge, ON

Sounding: SCPT23-107
Cone: 958:T1500F15U35 Area= 15cm2



Max Depth: 22.175 m / 72.75 ft
Depth Inc: 0.025 m / 0.082 ft
Avg Int: Every Point

File: 23-05-26042_SP23-107.COR
Unit Wt: SBTQtn (PKR2009)

SBT: Robertson, 2009 and 2010
Coords: UTM 17N N: 5459917m E: 442998m
Sheet No: 1 of 1

Overplot Item: Ueq, Assumed Ueq, Dissipation, Ueq achieved, Dissipation, Ueq not achieved, Dissipation, Ueq assumed, Hydrostatic Line

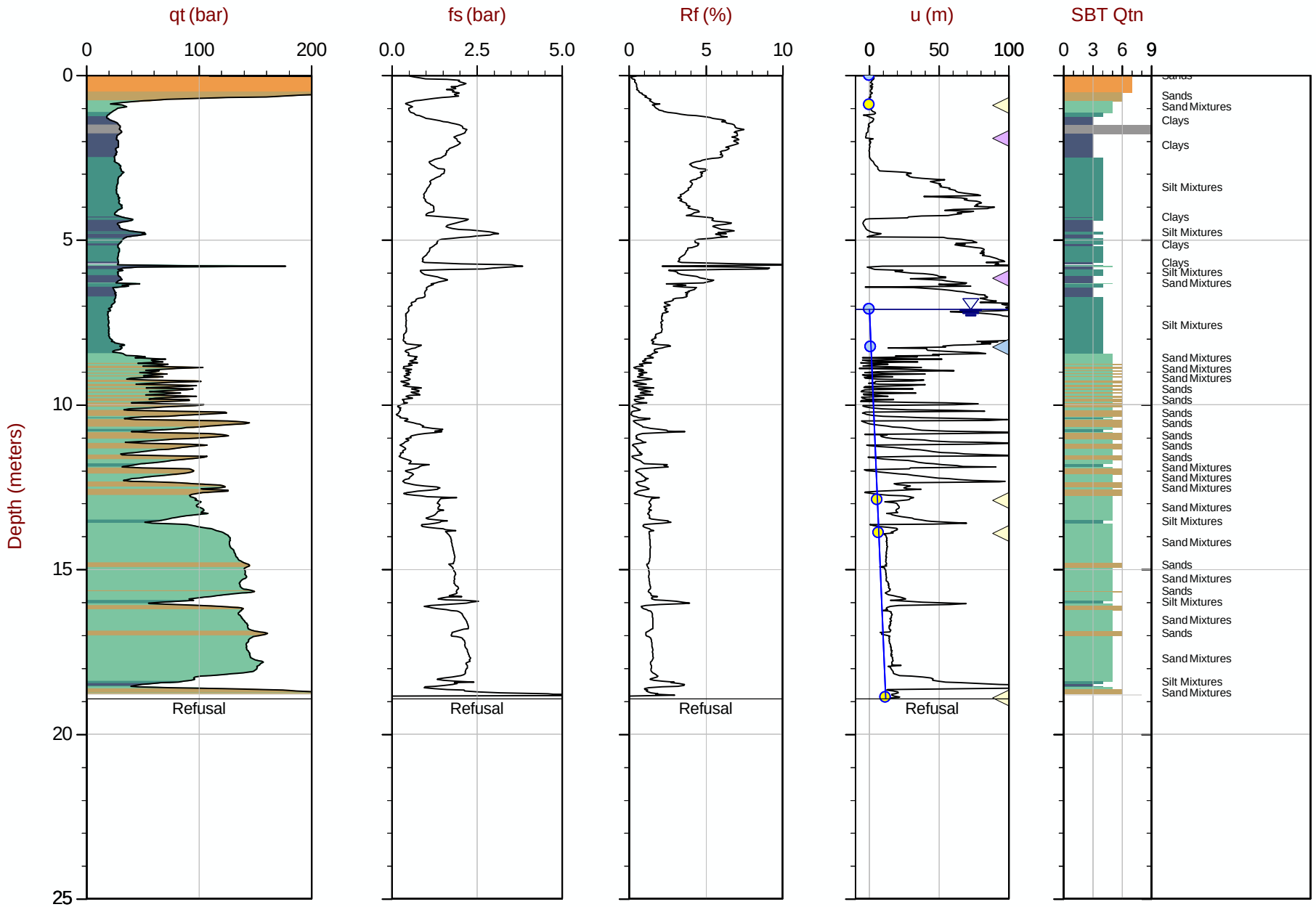
The reported coordinates were acquired from Hand Held GPS equipment and are only approximate locations. The coordinates should not be used for design purposes.

CONETEC

Thurber

Job No: 23-05-26042
Date: 2023-07-10 08:39
Site: Poplar Rapids Bridge, ON

Sounding: SCPT23-108
Cone: 958:T1500F15U35 Area= 15cm2



Max Depth: 18.925 m / 62.09 ft
Depth Inc: 0.025 m / 0.082 ft
Avg Int: Every Point

File: 23-05-26042_SP23-108.COR
Unit Wt: SBTQtn (PKR2009)

SBT: Robertson, 2009 and 2010
Coords: UTM 17N N: 5459902m E: 442905m
Sheet No: 1 of 1

Overplot Item: Ueq, Assumed Ueq, Dissipation, Ueq achieved, Dissipation, Ueq not achieved, Dissipation, Ueq assumed, Hydrostatic Line

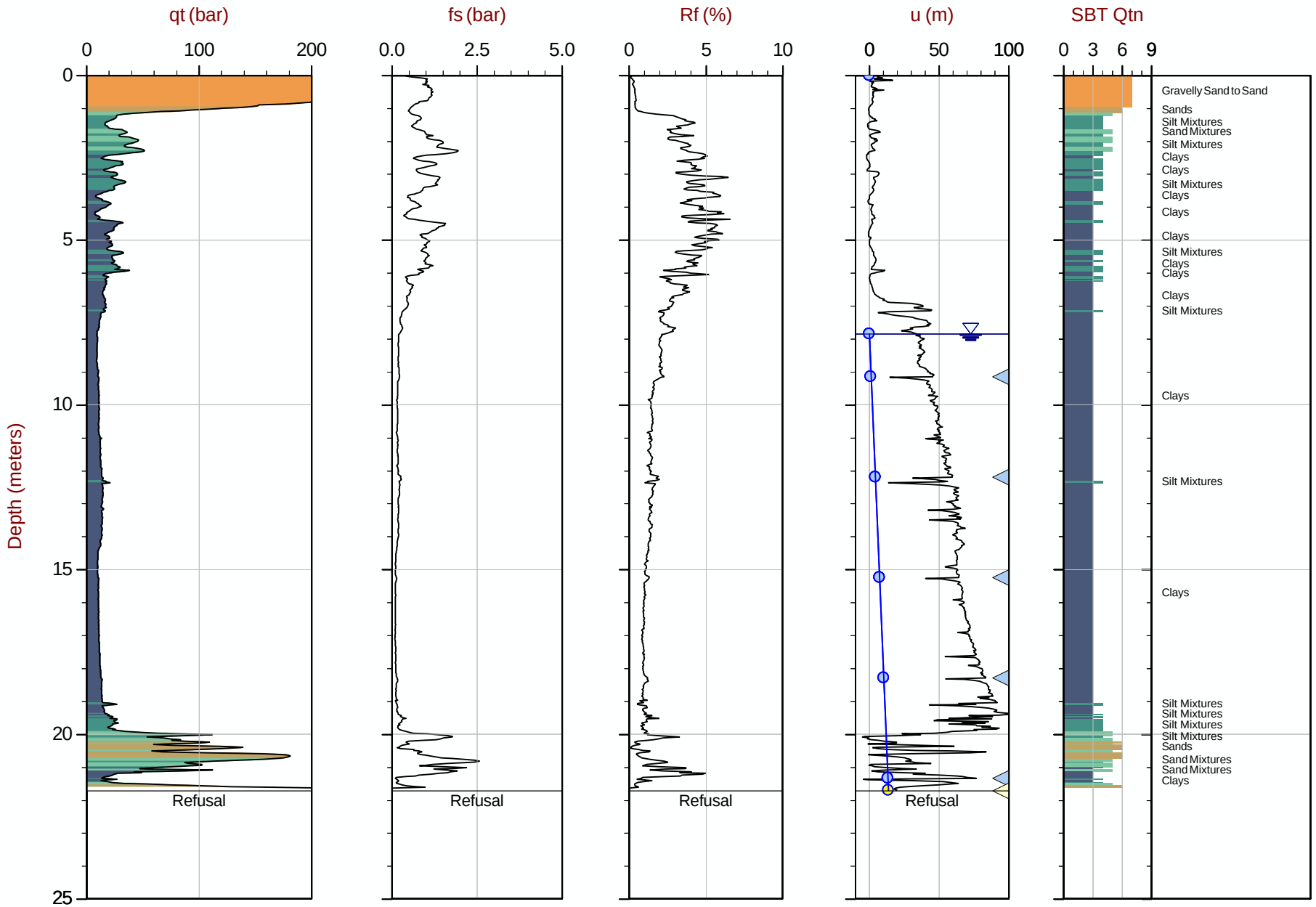
The reported coordinates were acquired from Hand Held GPS equipment and are only approximate locations. The coordinates should not be used for design purposes.

CONETEC

Thurber

Job No: 23-05-26042
Date: 2023-07-11 07:32
Site: Poplar Rapids Bridge, ON

Sounding: SCPT23-205
Cone: 765:T1500F15U35 Area= 15cm2



Max Depth: 21.725 m / 71.28 ft
Depth Inc: 0.025 m / 0.082 ft
Avg Int: Every Point

File: 23-05-26042_SP23-205.COR
Unit Wt: SBTQtn (PKR2009)

SBT: Robertson, 2009 and 2010
Coords: UTM 17N N: 5459882m E: 443394m
Sheet No: 1 of 1

Overplot Item: Ueq, Assumed Ueq, Dissipation, Ueq achieved, Dissipation, Ueq not achieved, Dissipation, Ueq assumed, Hydrostatic Line

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

Standard Cone Penetration Test Plots with Expanded Range

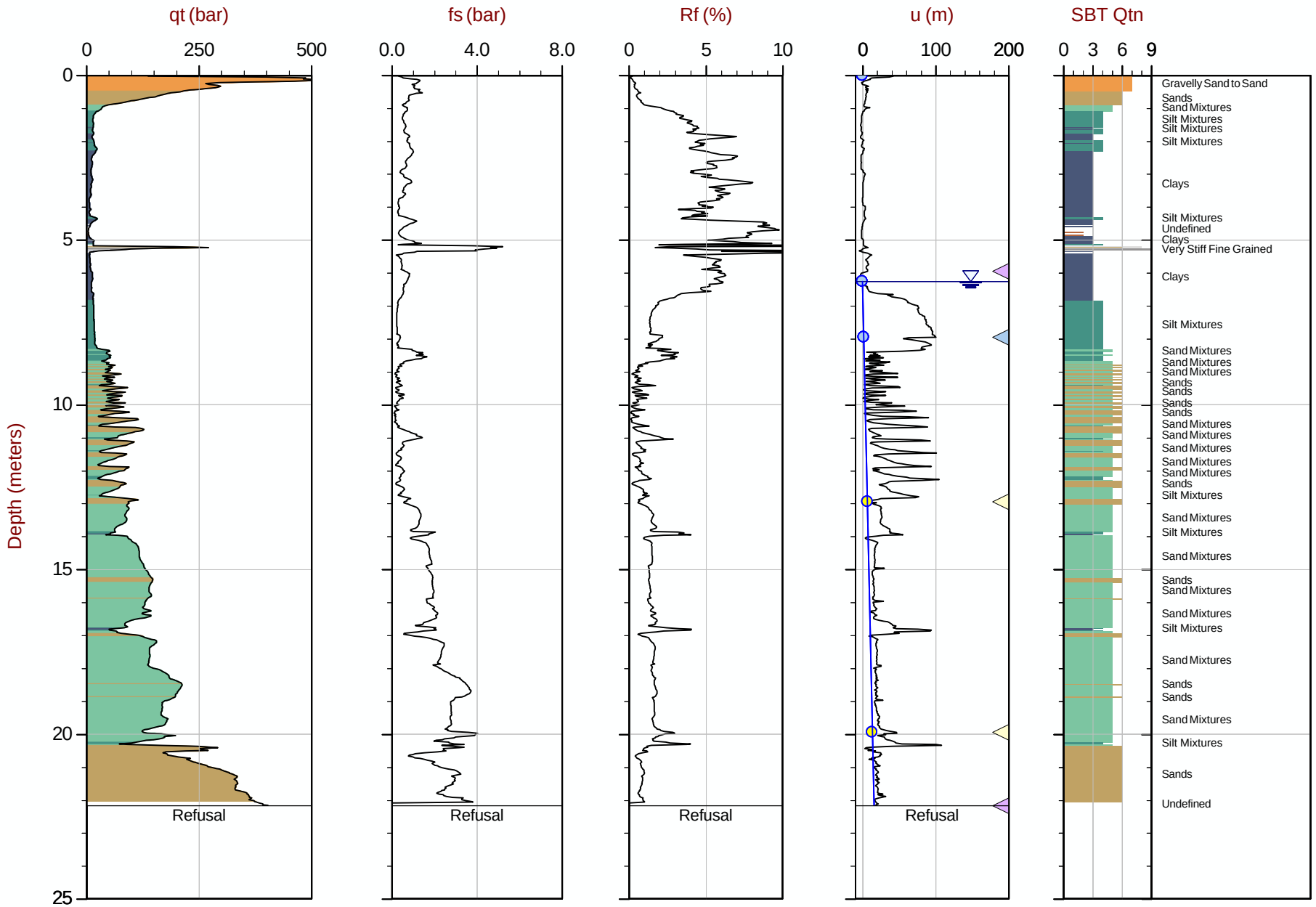
CONETEC

CONETEC

Thurber

Job No: 23-05-26042
Date: 2023-07-10 14:57
Site: Poplar Rapids Bridge, ON

Sounding: SCPT23-107
Cone: 958:T1500F15U35 Area= 15cm2



Max Depth: 22.175 m / 72.75 ft
Depth Inc: 0.025 m / 0.082 ft
Avg Int: Every Point

File: 23-05-26042_SP23-107.COR
Unit Wt: SBTQtn (PKR2009)

SBT: Robertson, 2009 and 2010
Coords: UTM 17N N: 5459917m E: 442998m
Sheet No: 1 of 1

Overplot Item: Ueq, Assumed Ueq, Dissipation, Ueq achieved, Dissipation, Ueq not achieved, Dissipation, Ueq assumed, Hydrostatic Line

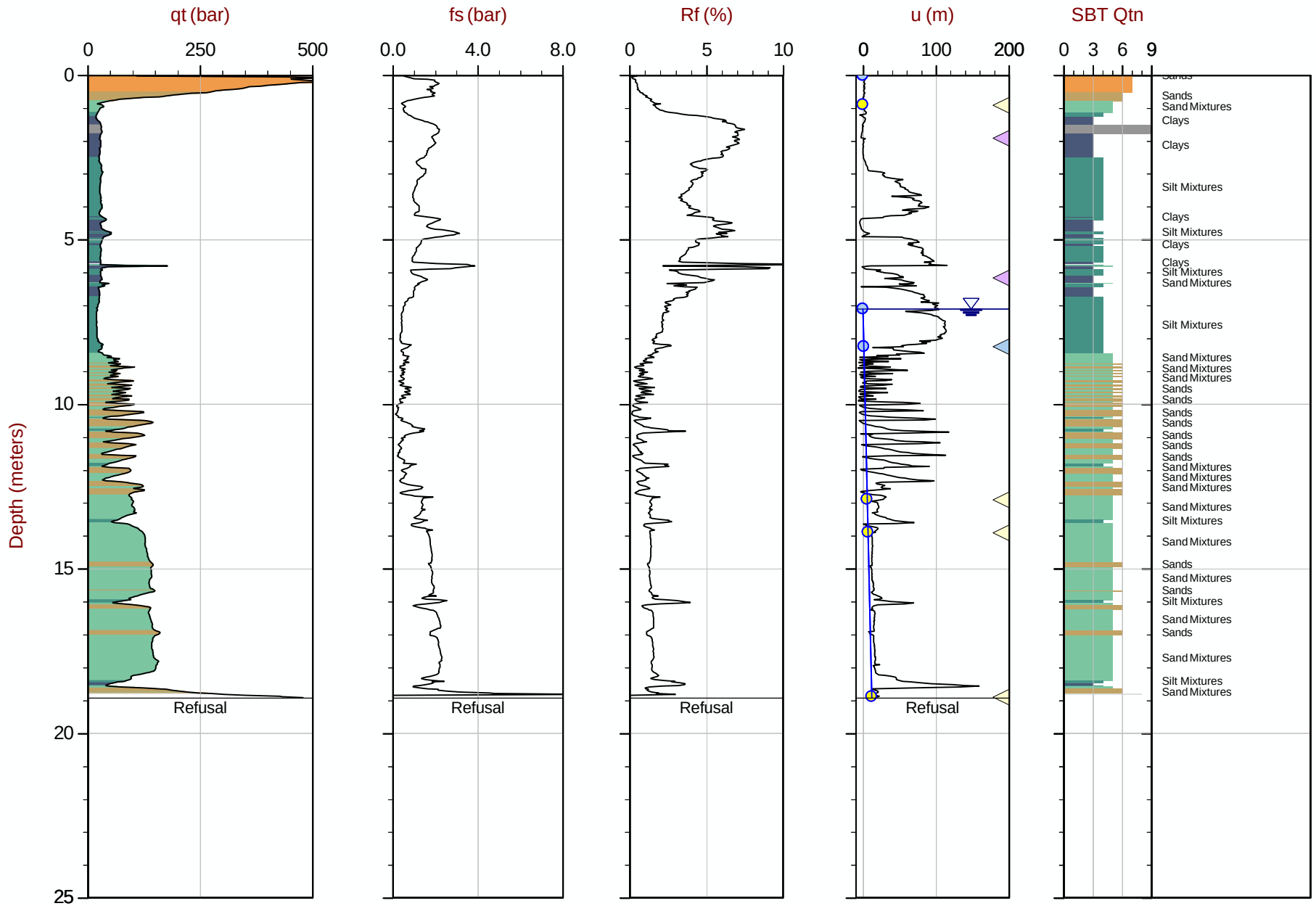
The reported coordinates were acquired from Hand Held GPS equipment and are only approximate locations. The coordinates should not be used for design purposes.

CONETEC

Thurber

Job No: 23-05-26042
Date: 2023-07-10 08:39
Site: Poplar Rapids Bridge, ON

Sounding: SCPT23-108
Cone: 958:T1500F15U35 Area= 15cm2



Max Depth: 18.925 m / 62.09 ft
Depth Inc: 0.025 m / 0.082 ft
Avg Int: Every Point

File: 23-05-26042_SP23-108.COR
Unit Wt: SBTQtn (PKR2009)

SBT: Robertson, 2009 and 2010
Coords: UTM 17N N: 5459902m E: 442905m
Sheet No: 1 of 1

Overplot Item: Ueq, Assumed Ueq, Dissipation, Ueq achieved, Dissipation, Ueq not achieved, Dissipation, Ueq assumed, Hydrostatic Line

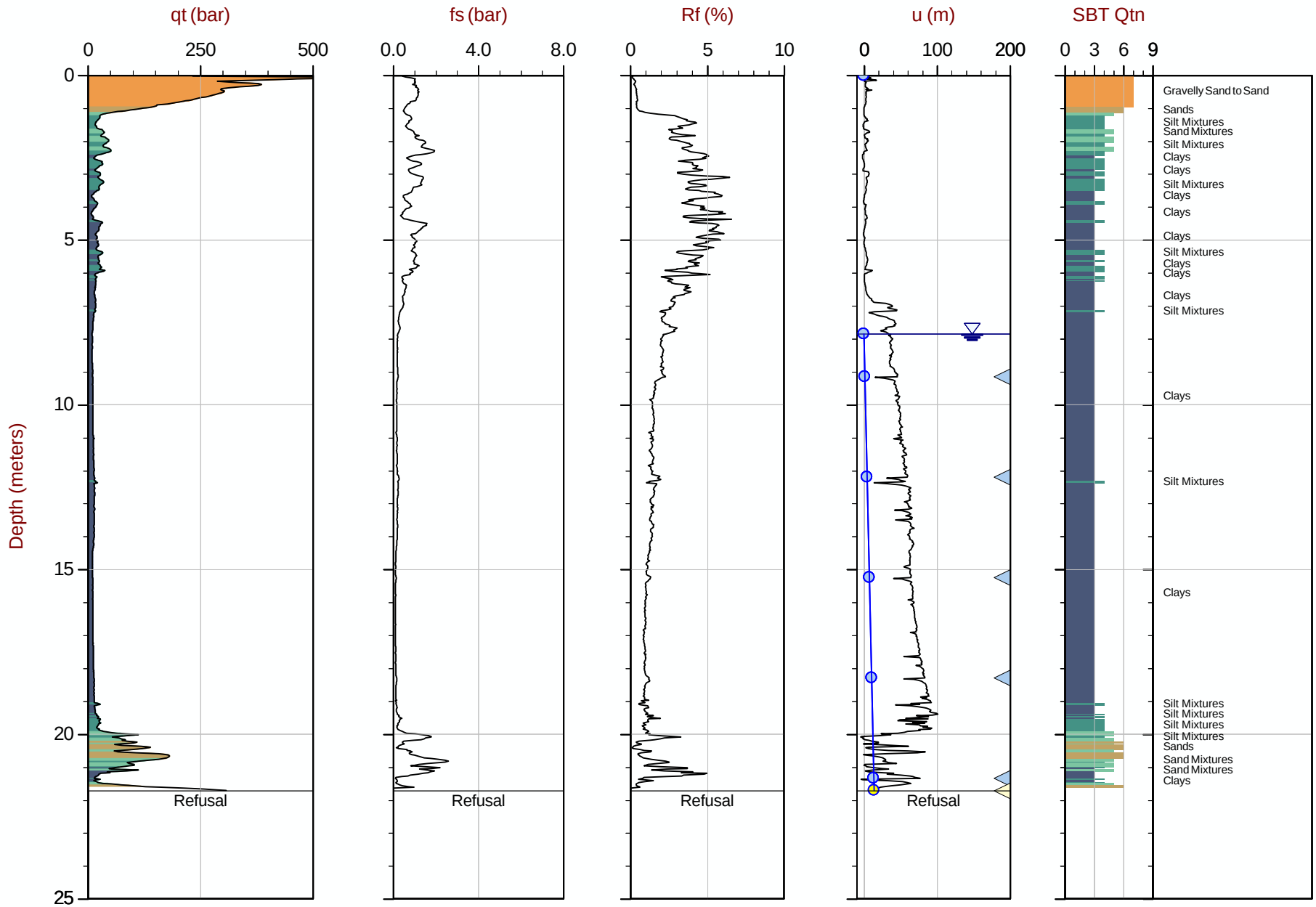
The reported coordinates were acquired from Hand Held GPS equipment and are only approximate locations. The coordinates should not be used for design purposes.

CONETEC

Thurber

Job No: 23-05-26042
Date: 2023-07-11 07:32
Site: Poplar Rapids Bridge, ON

Sounding: SCPT23-205
Cone: 765:T1500F15U35 Area= 15cm2



Max Depth: 21.725 m / 71.28 ft
Depth Inc: 0.025 m / 0.082 ft
Avg Int: Every Point

File: 23-05-26042_SP23-205.COR
Unit Wt: SBTQtn (PKR2009)

SBT: Robertson, 2009 and 2010
Coords: UTM 17N N: 5459882m E: 443394m
Sheet No: 1 of 1

Overplot Item: Ueq, Assumed Ueq, Dissipation, Ueq achieved, Dissipation, Ueq not achieved, Dissipation, Ueq assumed, Hydrostatic Line

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

Advanced Cone Penetration Plots with Ic, Su(Nkt), Phi and N1(60)Ic

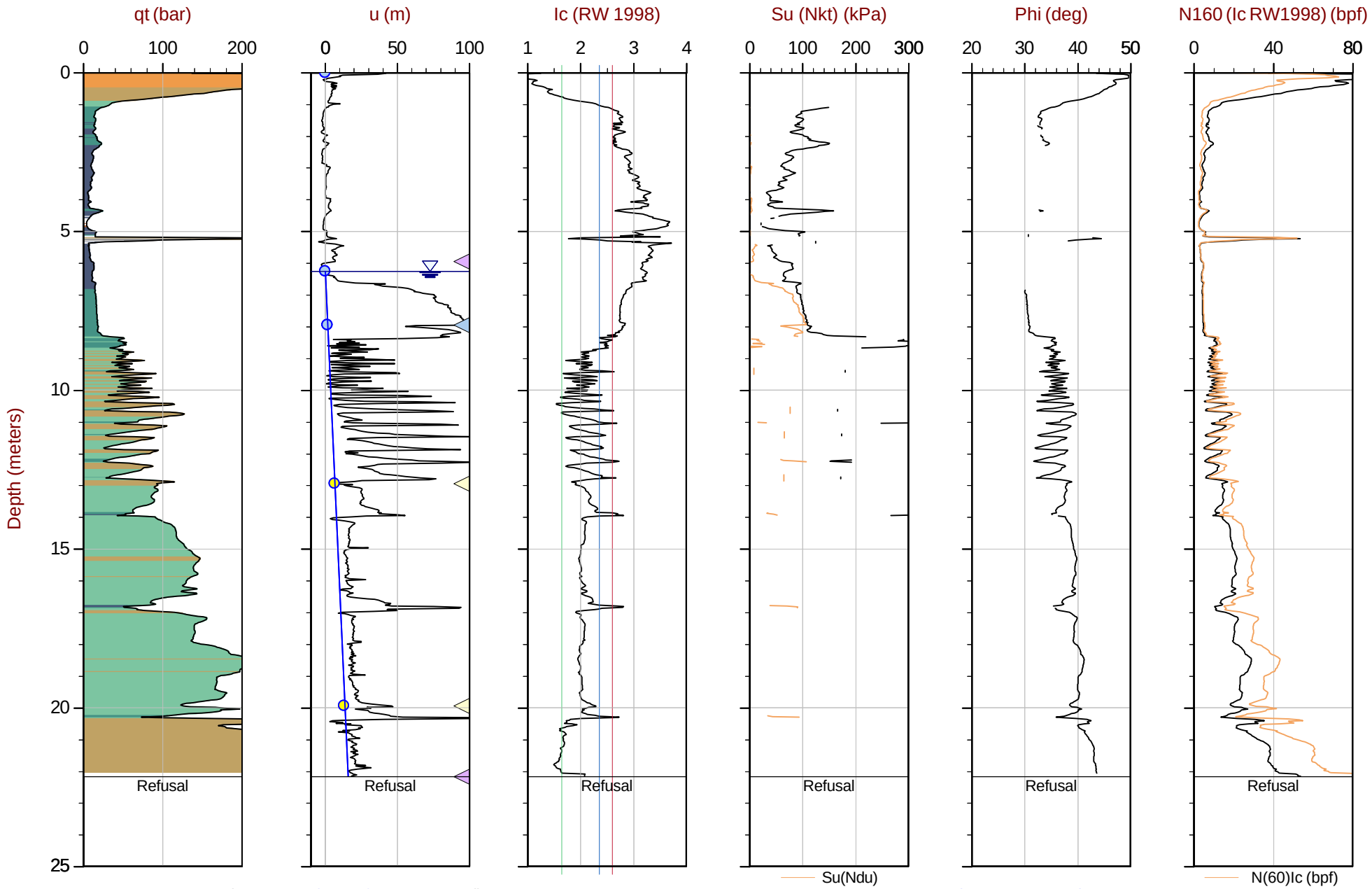
CONETEC

CONETEC

Thurber

Job No: 23-05-26042
Date: 2023-07-10 14:57
Site: Poplar Rapids Bridge, ON

Sounding: SCPT23-107
Cone: 958:T1500F15U35 Area= 15cm2



Max Depth: 22.175 m / 72.75 ft
Depth Inc: 0.025 m / 0.082 ft
Avg Int: Every Point

File: 23-05-26042_SP23-107.COR
Unit Wt: SBTQtn (PKR2009)
Su Nkt/Ndu: 15.0 / 9.0

SBT: Robertson, 2009 and 2010
Coords: UTM 17N N: 5459917m E: 442998m
Sheet No: 1 of 1

Overplot Item: Ueq | Assumed Ueq | Dissipation, Ueq achieved | Dissipation, Ueq not achieved | Dissipation, Ueq assumed | Hydrostatic Line

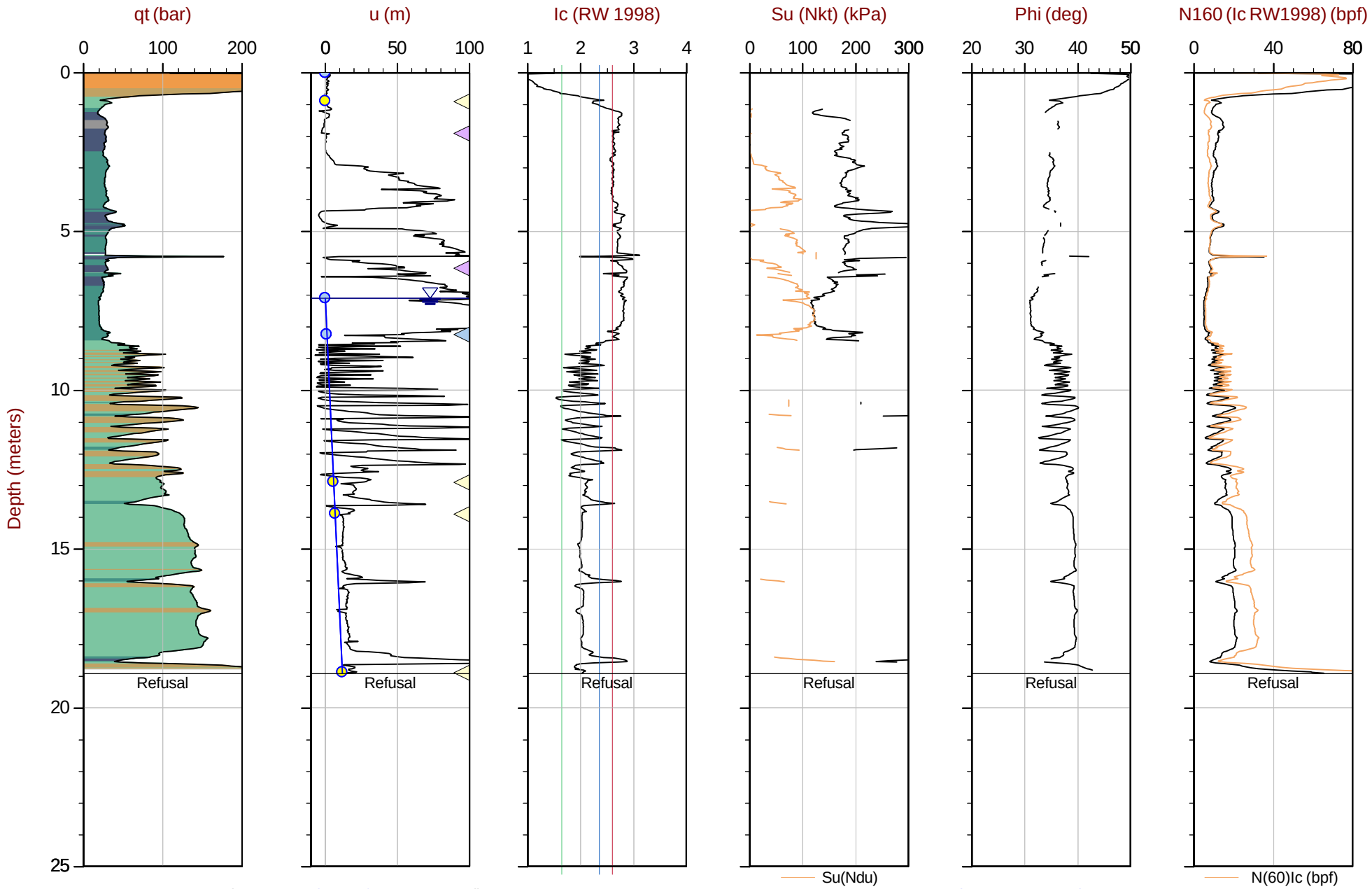
The reported coordinates were acquired from Hand Held GPS equipment and are only approximate locations. The coordinates should not be used for design purposes.

CONETEC

Thurber

Job No: 23-05-26042
Date: 2023-07-10 08:39
Site: Poplar Rapids Bridge, ON

Sounding: SCPT23-108
Cone: 958:T1500F15U35 Area= 15cm2



Max Depth: 18.925 m / 62.09 ft
Depth Inc: 0.025 m / 0.082 ft
Avg Int: Every Point

File: 23-05-26042_SP23-108.COR
Unit Wt: SBTQtn (PKR2009)
Su Nkt/Ndu: 15.0 / 9.0

SBT: Robertson, 2009 and 2010
Coords: UTM 17N N: 5459902m E: 442905m
Sheet No: 1 of 1

Overplot Item: Ueq, Assumed Ueq, Dissipation, Ueq achieved, Dissipation, Ueq not achieved, Dissipation, Ueq assumed, Hydrostatic Line

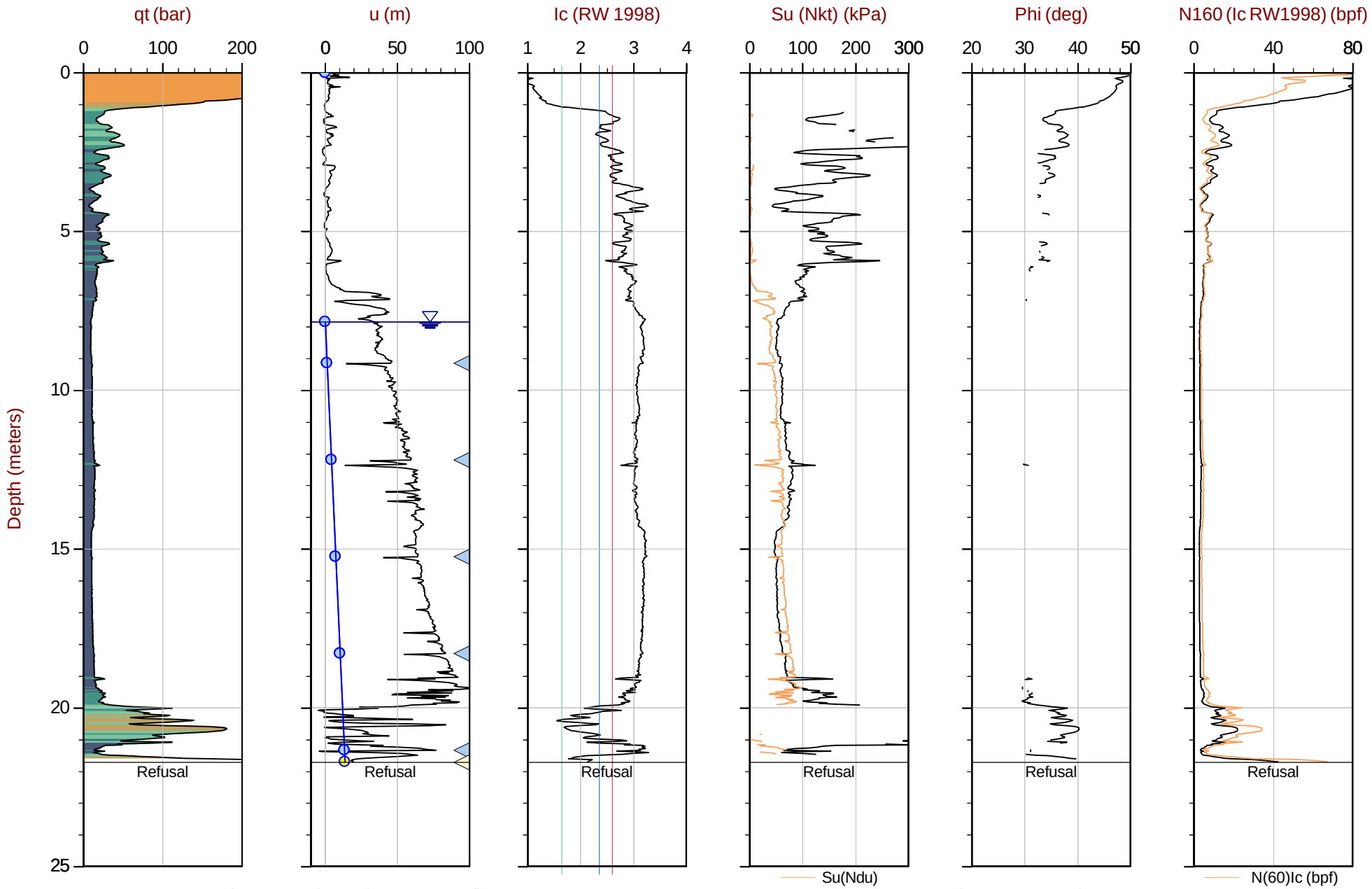
The reported coordinates were acquired from Hand Held GPS equipment and are only approximate locations. The coordinates should not be used for design purposes.

CONETEC

Thurber

Job No: 23-05-26042
Date: 2023-07-11 07:32
Site: Poplar Rapids Bridge, ON

Sounding: SCPT23-205
Cone: 765:T1500F15U35 Area= 15cm2



Max Depth: 21.725 m / 71.28 ft
Depth Inc: 0.025 m / 0.082 ft
Avg Int: Every Point

File: 23-05-26042_SP23-205.COR
Unit Wt: SBTQtn (PKR2009)
Su Nkt/Ndu: 15.0 / 9.0

SBT: Robertson, 2009 and 2010
Coords: UTM 17N N: 5459882m E: 443394m
Sheet No: 1 of 1

Overplot Item: Ueq, Assumed Ueq, Dissipation, Ueq achieved, Dissipation, Ueq not achieved, Dissipation, Ueq assumed, Hydrostatic Line

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

Seismic Cone Penetration Test Plots

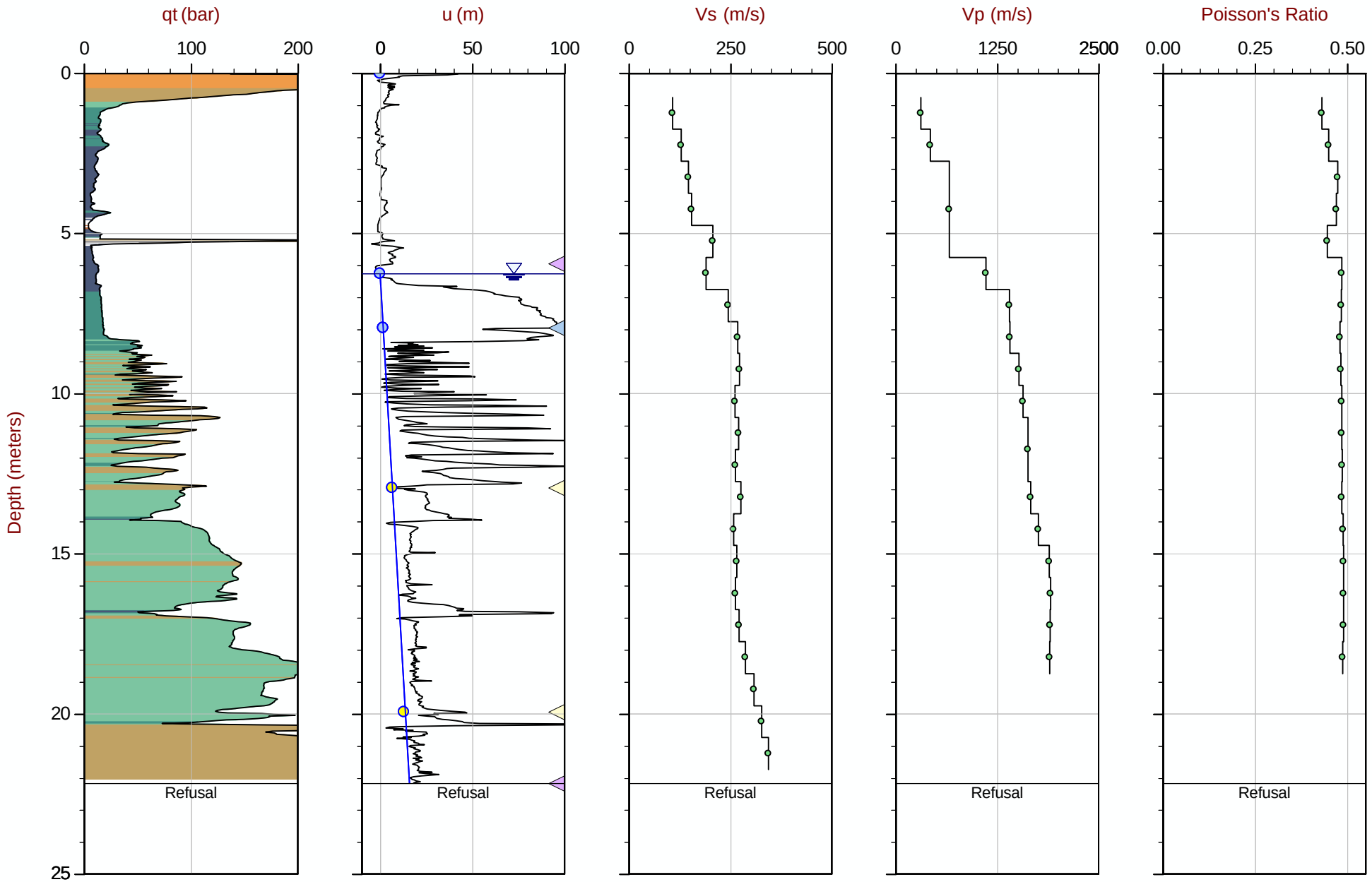
CONETEC

CONETEC

Thurber

Job No: 23-05-26042
Date: 2023-07-10 14:57
Site: Poplar Rapids Bridge, ON

Sounding: SCPT23-107
Cone: 958:T1500F15U35 Area= 15cm2



Max Depth: 22.175 m / 72.75 ft
Depth Inc: 0.025 m / 0.082 ft
Avg Int: Every Point

File: 23-05-26042_SP23-107.COR
Unit Wt: SBTQtn (PKR2009)

SBT: Robertson, 2009 and 2010
Coords: UTM 17N N: 5459917m E: 442998m
Sheet No: 1 of 1

Overplot Item: Ueq, Assumed Ueq, Dissipation, Ueq achieved, Dissipation, Ueq not achieved, Dissipation, Ueq assumed, Hydrostatic Line

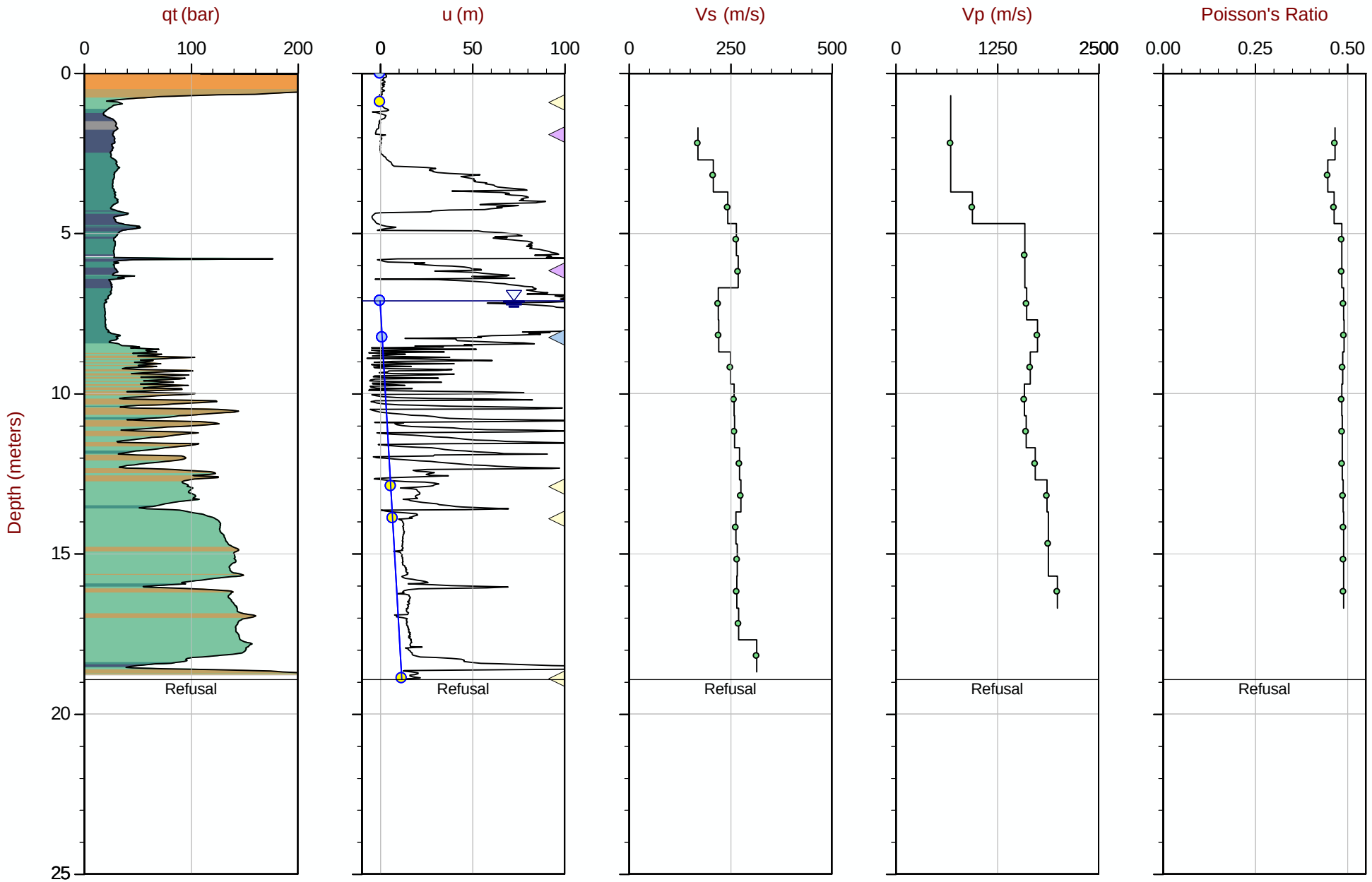
The reported coordinates were acquired from Hand Held GPS equipment and are only approximate locations. The coordinates should not be used for design purposes.

CONETEC

Thurber

Job No: 23-05-26042
Date: 2023-07-10 08:39
Site: Poplar Rapids Bridge, ON

Sounding: SCPT23-108
Cone: 958:T1500F15U35 Area= 15cm2



Max Depth: 18.925 m / 62.09 ft
Depth Inc: 0.025 m / 0.082 ft
Avg Int: Every Point

File: 23-05-26042_SP23-108.COR
Unit Wt: SBTQtn (PKR2009)

SBT: Robertson, 2009 and 2010
Coords: UTM 17N N: 5459902m E: 442905m
Sheet No: 1 of 1

Overplot Item: Ueq, Assumed Ueq, Dissipation, Ueq achieved, Dissipation, Ueq not achieved, Dissipation, Ueq assumed, Hydrostatic Line

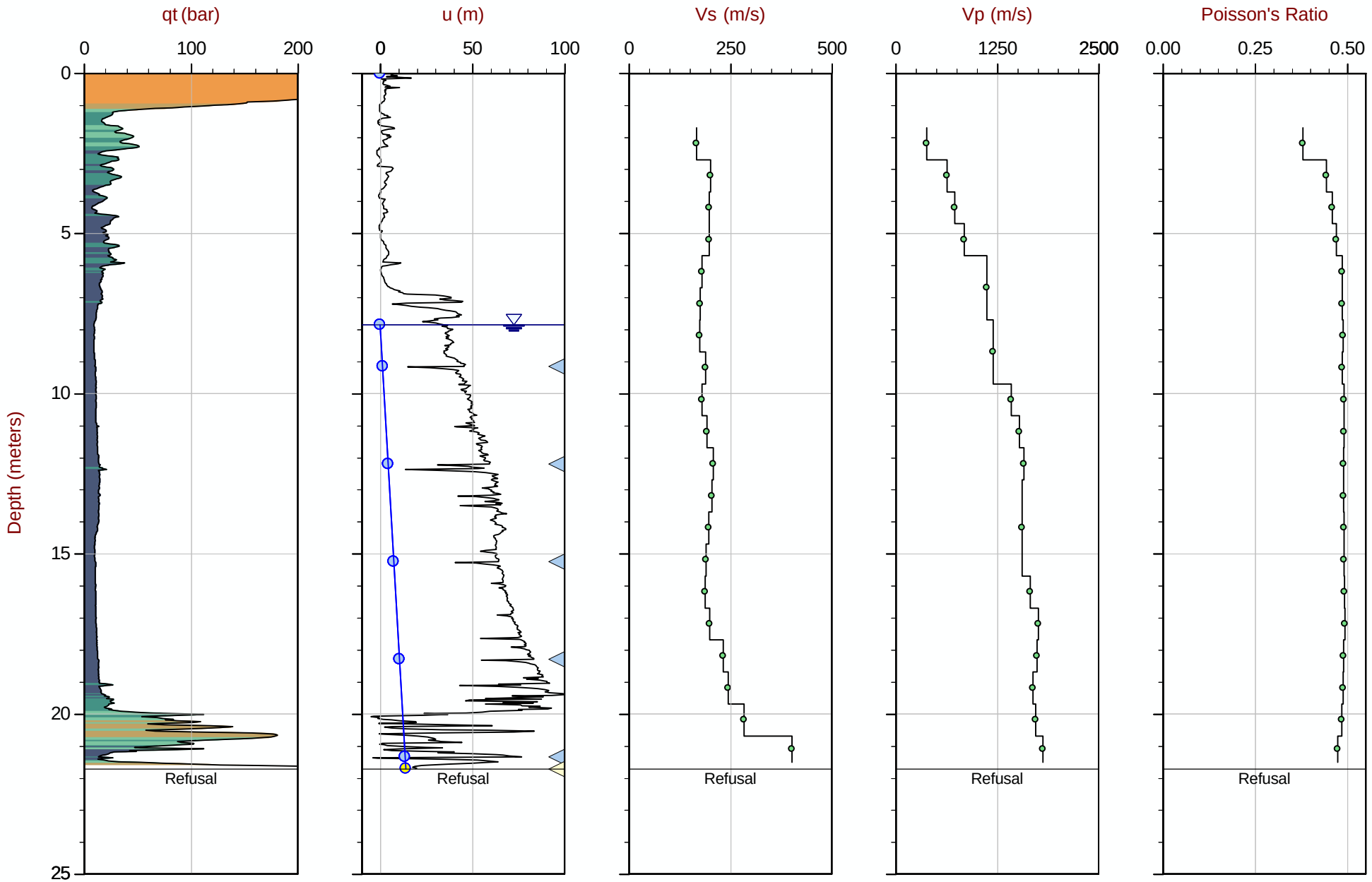
The reported coordinates were acquired from Hand Held GPS equipment and are only approximate locations. The coordinates should not be used for design purposes.

CONETEC

Thurber

Job No: 23-05-26042
Date: 2023-07-11 07:32
Site: Poplar Rapids Bridge, ON

Sounding: SCPT23-205
Cone: 765:T1500F15U35 Area= 15cm2



Max Depth: 21.725 m / 71.28 ft
Depth Inc: 0.025 m / 0.082 ft
Avg Int: Every Point

File: 23-05-26042_SP23-205.COR
Unit Wt: SBTQtn (PKR2009)

SBT: Robertson, 2009 and 2010
Coords: UTM 17N N: 5459882m E: 443394m
Sheet No: 1 of 1

Overplot Item: Ueq, Assumed Ueq, Dissipation, Ueq achieved, Dissipation, Ueq not achieved, Dissipation, Ueq assumed, Hydrostatic Line

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

Seismic Cone Penetration Test Shear Wave (Vs) Tabular Results

CONETEC

Job No:	23-05-26042
Client:	Thurber Engineering Ltd.
Project:	Poplar Rapids Bridge - Highway 11
Sounding ID:	SCPT23-107
Date:	10-Jul-2023
Seismic Source:	Beam
Seismic Offset (m):	0.55
Source Depth (m):	0.00
Geophone Offset (m):	0.20

SCPTu SHEAR WAVE VELOCITY TEST RESULTS - Vs

Tip Depth (m)	Geophone Depth (m)	Ray Path (m)	Ray Path Difference (m)	Travel Time Interval (ms)	Interval Velocity (m/s)
0.95	0.75	0.93			
1.95	1.75	1.83	0.90	8.39	108
2.95	2.75	2.80	0.97	7.53	129
3.95	3.75	3.79	0.99	6.73	147
4.95	4.75	4.78	0.99	6.43	154
5.95	5.75	5.78	0.99	4.79	207
6.95	6.75	6.77	1.00	5.24	190
7.95	7.75	7.77	1.00	4.07	245
8.95	8.75	8.77	1.00	3.71	269
9.95	9.75	9.77	1.00	3.67	272
10.95	10.75	10.76	1.00	3.81	262
11.95	11.75	11.76	1.00	3.69	271
12.95	12.75	12.76	1.00	3.80	263
13.95	13.75	13.76	1.00	3.62	276
14.95	14.75	14.76	1.00	3.87	258
15.95	15.75	15.76	1.00	3.75	267
16.95	16.75	16.76	1.00	3.80	263
17.95	17.75	17.76	1.00	3.68	272
18.95	18.75	18.76	1.00	3.48	287
19.95	19.75	19.76	1.00	3.24	309
20.95	20.75	20.76	1.00	3.05	327
21.95	21.75	21.76	1.00	2.90	344

Job No:	23-05-26042
Client:	Thurber Engineering Ltd.
Project:	Poplar Rapids Bridge - Highway 11
Sounding ID:	SCPT23-108
Date:	10-Jul-2023
Seismic Source:	Beam
Seismic Offset (m):	0.55
Source Depth (m):	0.00
Geophone Offset (m):	0.20

SCPTu SHEAR WAVE VELOCITY TEST RESULTS - Vs

Tip Depth (m)	Geophone Depth (m)	Ray Path (m)	Ray Path Difference (m)	Travel Time Interval (ms)	Interval Velocity (m/s)
1.90	1.70	1.79			
2.90	2.70	2.76	0.97	5.69	170
3.90	3.70	3.74	0.99	4.73	208
4.90	4.70	4.73	0.99	4.07	243
5.90	5.70	5.73	0.99	3.76	265
6.90	6.70	6.72	1.00	3.70	269
7.90	7.70	7.72	1.00	4.53	220
8.90	8.70	8.72	1.00	4.49	222
9.90	9.70	9.72	1.00	3.98	251
10.90	10.70	10.71	1.00	3.84	260
11.90	11.70	11.71	1.00	3.84	260
12.90	12.70	12.71	1.00	3.66	273
13.90	13.70	13.71	1.00	3.62	276
14.90	14.70	14.71	1.00	3.78	264
15.90	15.70	15.71	1.00	3.74	267
16.90	16.70	16.71	1.00	3.75	266
17.90	17.70	17.71	1.00	3.70	271
18.90	18.70	18.71	1.00	3.17	315

Job No:	23-05-26042
Client:	Thurber Engineering Ltd.
Project:	Poplar Rapids Bridge - Highway 11
Sounding ID:	SCPT23-205
Date:	11-Jul-2023
Seismic Source:	Beam
Seismic Offset (m):	0.55
Source Depth (m):	0.00
Geophone Offset (m):	0.20

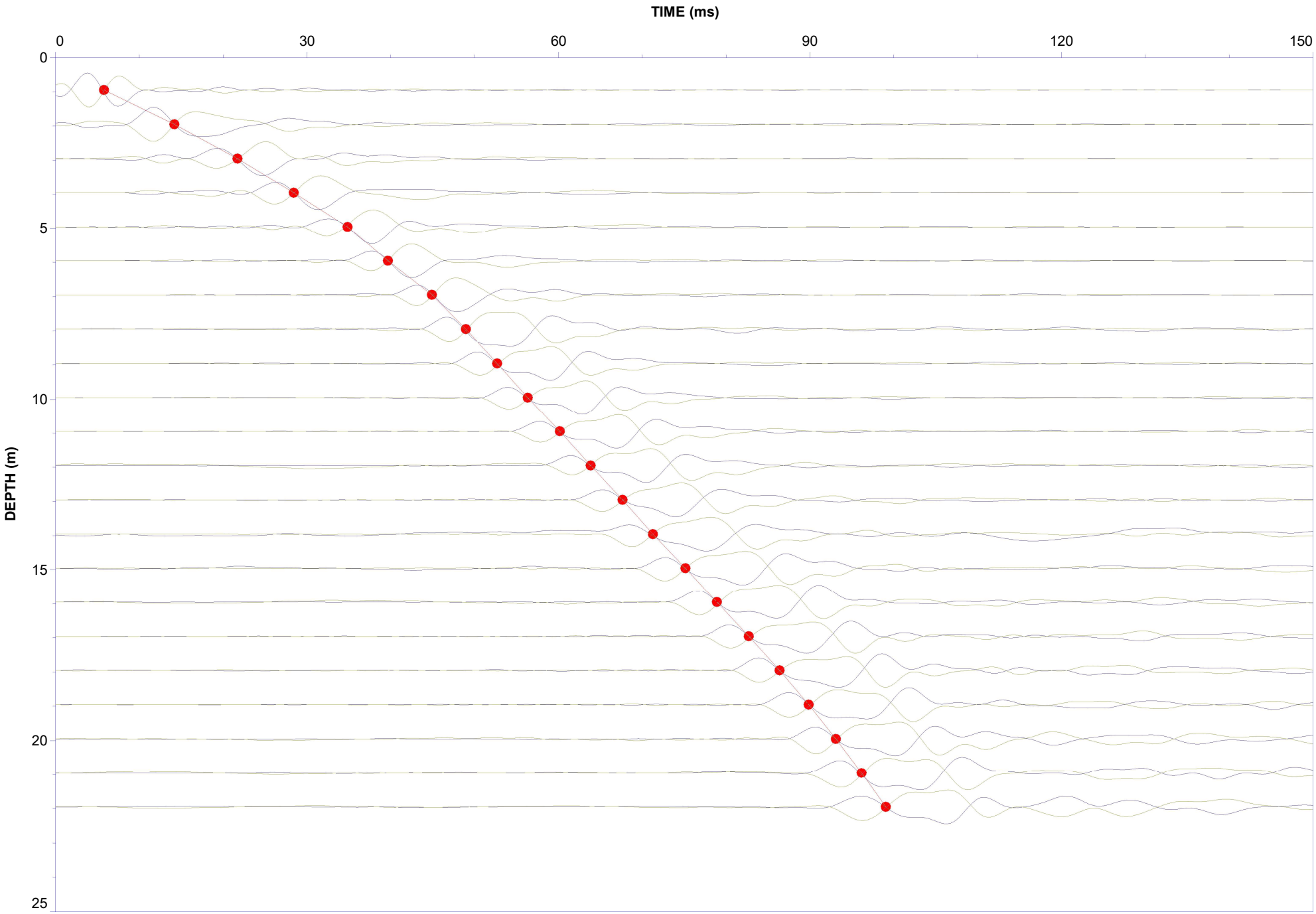
SCPTu SHEAR WAVE VELOCITY TEST RESULTS - Vs

Tip Depth (m)	Geophone Depth (m)	Ray Path (m)	Ray Path Difference (m)	Travel Time Interval (ms)	Interval Velocity (m/s)
1.90	1.70	1.79			
2.90	2.70	2.76	0.97	5.79	167
3.90	3.70	3.74	0.99	4.90	201
4.90	4.70	4.73	0.99	5.01	198
5.90	5.70	5.73	0.99	5.01	198
6.90	6.70	6.72	1.00	5.51	181
7.90	7.70	7.72	1.00	5.66	176
8.90	8.70	8.72	1.00	5.70	175
9.90	9.70	9.72	1.00	5.28	189
10.90	10.70	10.71	1.00	5.53	181
11.90	11.70	11.71	1.00	5.18	193
12.90	12.70	12.71	1.00	4.81	208
13.90	13.70	13.71	1.00	4.87	205
14.90	14.70	14.71	1.00	5.07	197
15.90	15.70	15.71	1.00	5.25	190
16.90	16.70	16.71	1.00	5.30	189
17.90	17.70	17.71	1.00	5.02	199
18.90	18.70	18.71	1.00	4.29	233
19.90	19.70	19.71	1.00	4.08	245
20.90	20.70	20.71	1.00	3.51	284
21.72	21.52	21.53	0.82	2.04	402

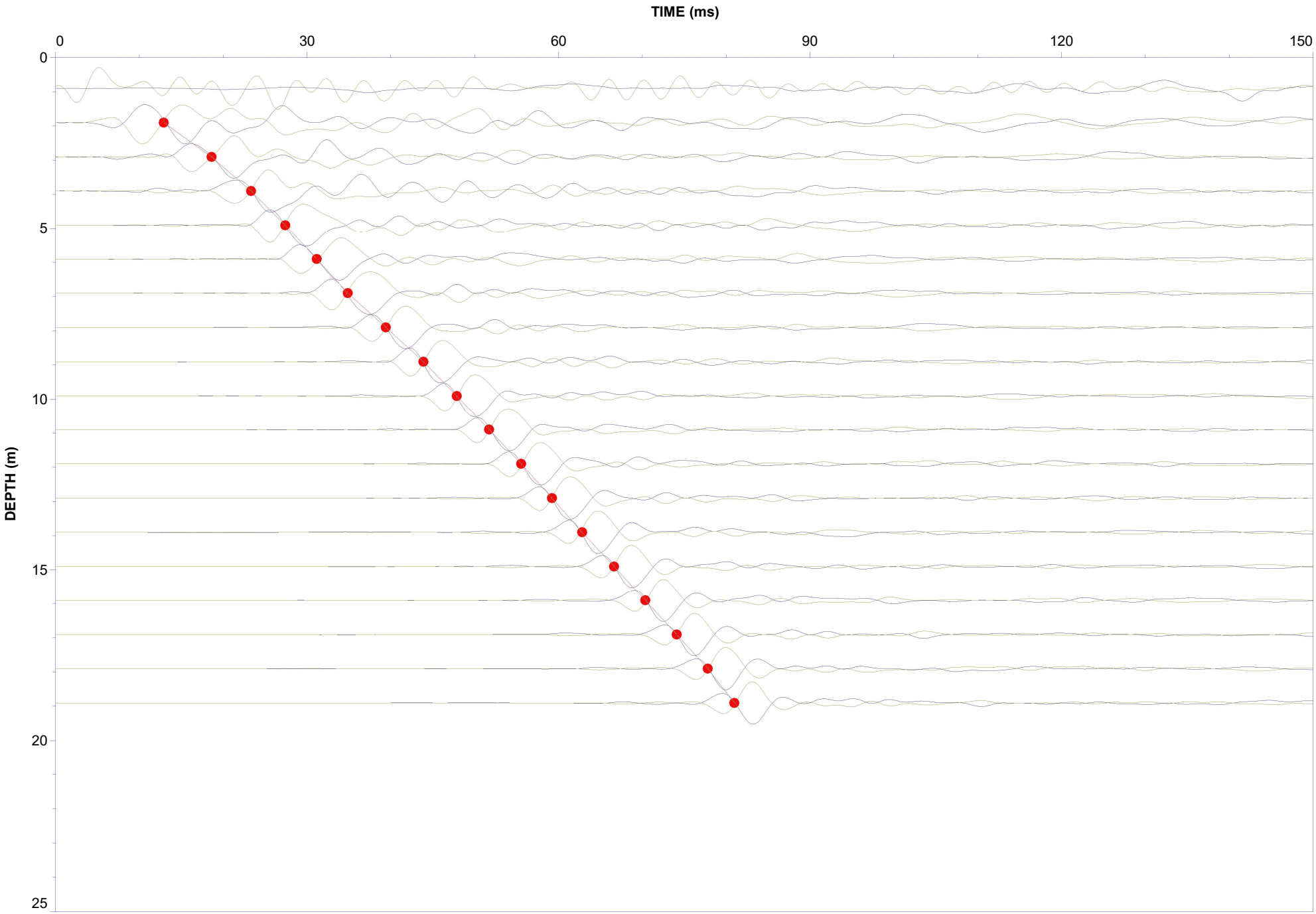
Seismic Cone Penetration Test Shear Wave (Vs) Traces

CONETEC

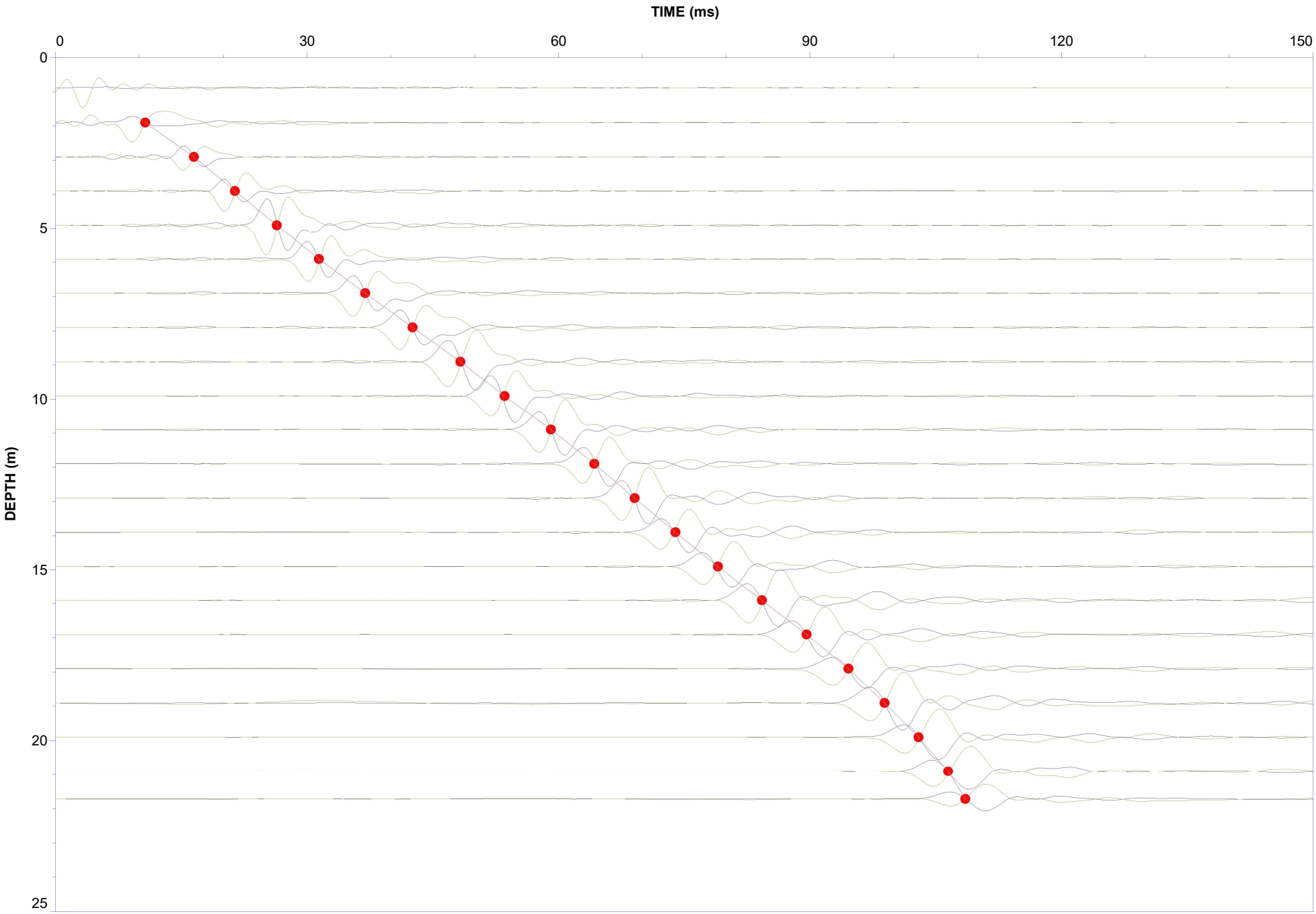
Job No: 23-05-26042 Client: Thurber Project: Poplar Rapids Bridge - Highway 11 Filter: 0-200Hz Sounding: SCPT23-107
Analysis: S-Wave_Geo-X Date: 10-Jul-2023



Job No: 23-05-26042 Client: Thurber Project: Poplar Rapids Bridge - Highway 11 Filter: 0-300Hz Sounding: SCPT23-108
Analysis: S-Wave_Geo-X Date: 10-Jul-2023



Job No: 23-05-26042 Client: Thurber Project: Poplar Rapids Bridge - Highway 11 Filter: 0-350Hz Sounding: SCPT23-205
Analysis: S-Wave_Geo-X Date: 11-Jul-2023



Seismic Cone Penetration Test Compression Wave (Vp) Tabular Results

CONETEC

Job No:	23-05-26042
Client:	Thurber
Project:	Poplar Rapids Bridge - Highway 11
Sounding ID:	SCPT23-107
Date:	10-Jul-2023
Seismic Source:	Plate
Seismic Offset (m):	1.40
Source Depth (m):	0.00
Geophone Offset (m):	0.20

SCPTu COMPRESSION WAVE VELOCITY TEST RESULTS - Vp

Tip Depth (m)	Geophone Depth (m)	Ray Path (m)	Ray Path Difference (m)	Travel Time Interval (ms)	Interval Velocity (m/s)
0.95	0.75	1.59			
1.95	1.75	2.24	0.65	2.10	311
2.95	2.75	3.09	0.85	1.98	428
5.95	5.75	5.92	2.83	4.28	663
6.95	6.75	6.89	0.98	0.88	1115
7.95	7.75	7.88	0.98	0.70	1403
8.95	8.75	8.86	0.99	0.70	1409
9.95	9.75	9.85	0.99	0.65	1521
10.95	10.75	10.84	0.99	0.63	1574
12.95	12.75	12.83	1.99	1.22	1631
13.95	13.75	13.82	0.99	0.60	1664
14.95	14.75	14.82	1.00	0.57	1759
15.95	15.75	15.81	1.00	0.53	1895
16.95	16.75	16.81	1.00	0.52	1914
17.95	17.75	17.81	1.00	0.52	1906
18.95	18.75	18.80	1.00	0.53	1897

Job No:	23-05-26042
Client:	Thurber
Project:	Poplar Rapids Bridge - Highway 11
Sounding ID:	SCPT23-108
Date:	10-Jul-2023
Seismic Source:	Plate
Seismic Offset (m):	1.40
Source Depth (m):	0.00
Geophone Offset (m):	0.20

SCPTu COMPRESSION WAVE VELOCITY TEST RESULTS - Vp

Tip Depth (m)	Geophone Depth (m)	Ray Path (m)	Ray Path Difference (m)	Travel Time Interval (ms)	Interval Velocity (m/s)
0.90	0.70	1.57			
3.90	3.70	3.96	2.39	3.52	679
4.90	4.70	4.90	0.95	1.00	948
6.90	6.70	6.85	1.94	1.22	1594
7.90	7.70	7.83	0.98	0.61	1615
8.90	8.70	8.81	0.99	0.56	1747
9.90	9.70	9.80	0.99	0.60	1658
10.90	10.70	10.79	0.99	0.62	1587
11.90	11.70	11.78	0.99	0.62	1609
12.90	12.70	12.78	0.99	0.58	1724
13.90	13.70	13.77	0.99	0.53	1869
15.90	15.70	15.76	1.99	1.06	1886
16.90	16.70	16.76	1.00	0.50	1993

Job No:	23-05-26042
Client:	Thurber
Project:	Poplar Rapids Bridge - Highway 11
Sounding ID:	SCPT23-205
Date:	11-Jul-2023
Seismic Source:	Plate
Seismic Offset (m):	1.40
Source Depth (m):	0.00
Geophone Offset (m):	0.20

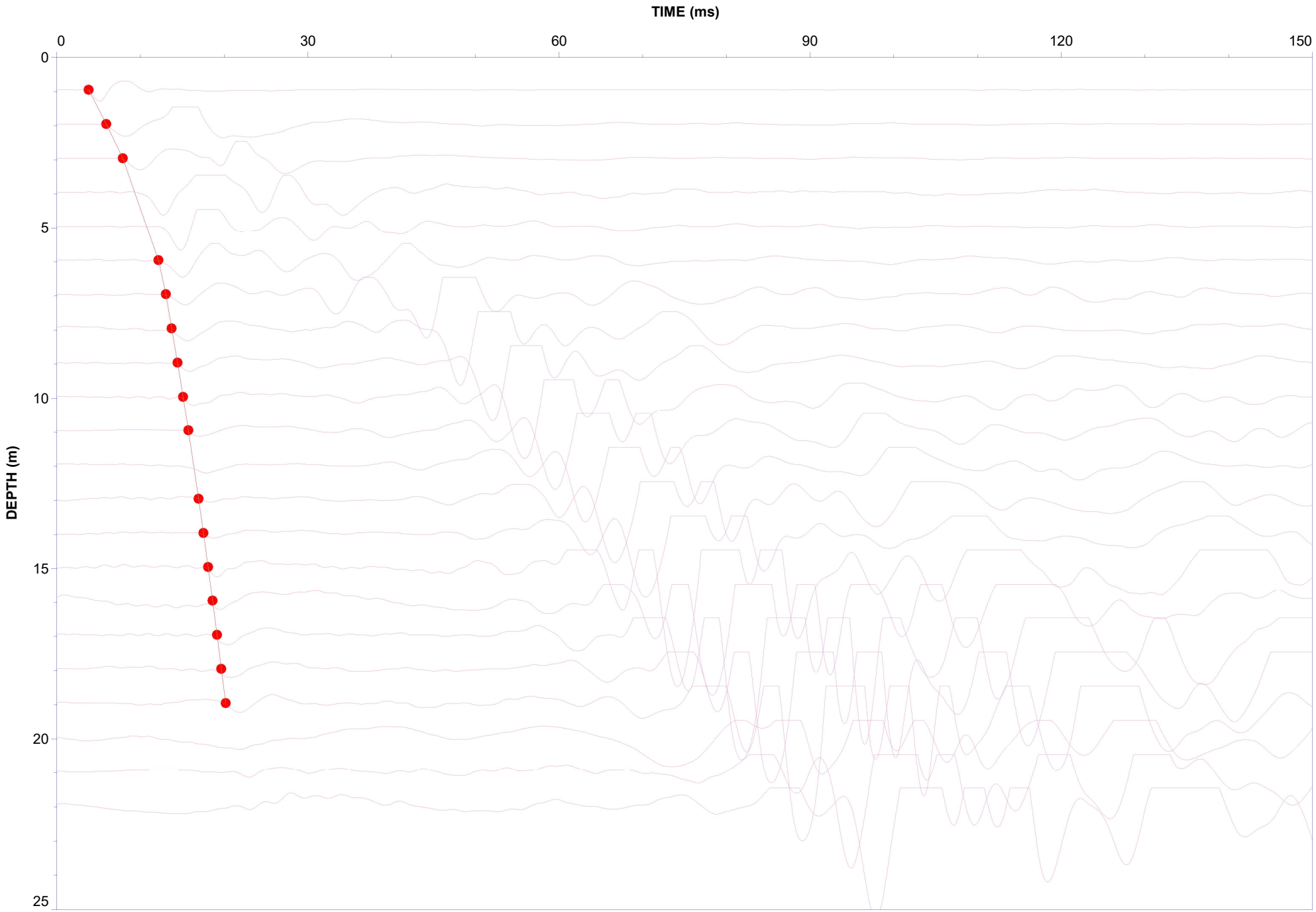
SCPTu COMPRESSION WAVE VELOCITY TEST RESULTS - Vp

Tip Depth (m)	Geophone Depth (m)	Ray Path (m)	Ray Path Difference (m)	Travel Time Interval (ms)	Interval Velocity (m/s)
1.90	1.70	2.20			
2.90	2.70	3.04	0.84	2.21	380
3.90	3.70	3.96	0.92	1.44	634
4.90	4.70	4.90	0.95	1.30	730
5.90	5.70	5.87	0.97	1.14	844
7.90	7.70	7.83	1.96	1.74	1122
9.90	9.70	9.80	1.98	1.64	1205
10.90	10.70	10.79	0.99	0.69	1428
11.90	11.70	11.78	0.99	0.65	1527
12.90	12.70	12.78	0.99	0.63	1583
15.90	15.70	15.76	2.99	1.92	1559
16.90	16.70	16.76	1.00	0.60	1661
17.90	17.70	17.76	1.00	0.57	1760
18.90	18.70	18.75	1.00	0.57	1744
19.90	19.70	19.75	1.00	0.59	1694
20.90	20.70	20.75	1.00	0.58	1728
21.72	21.52	21.57	0.82	0.45	1818

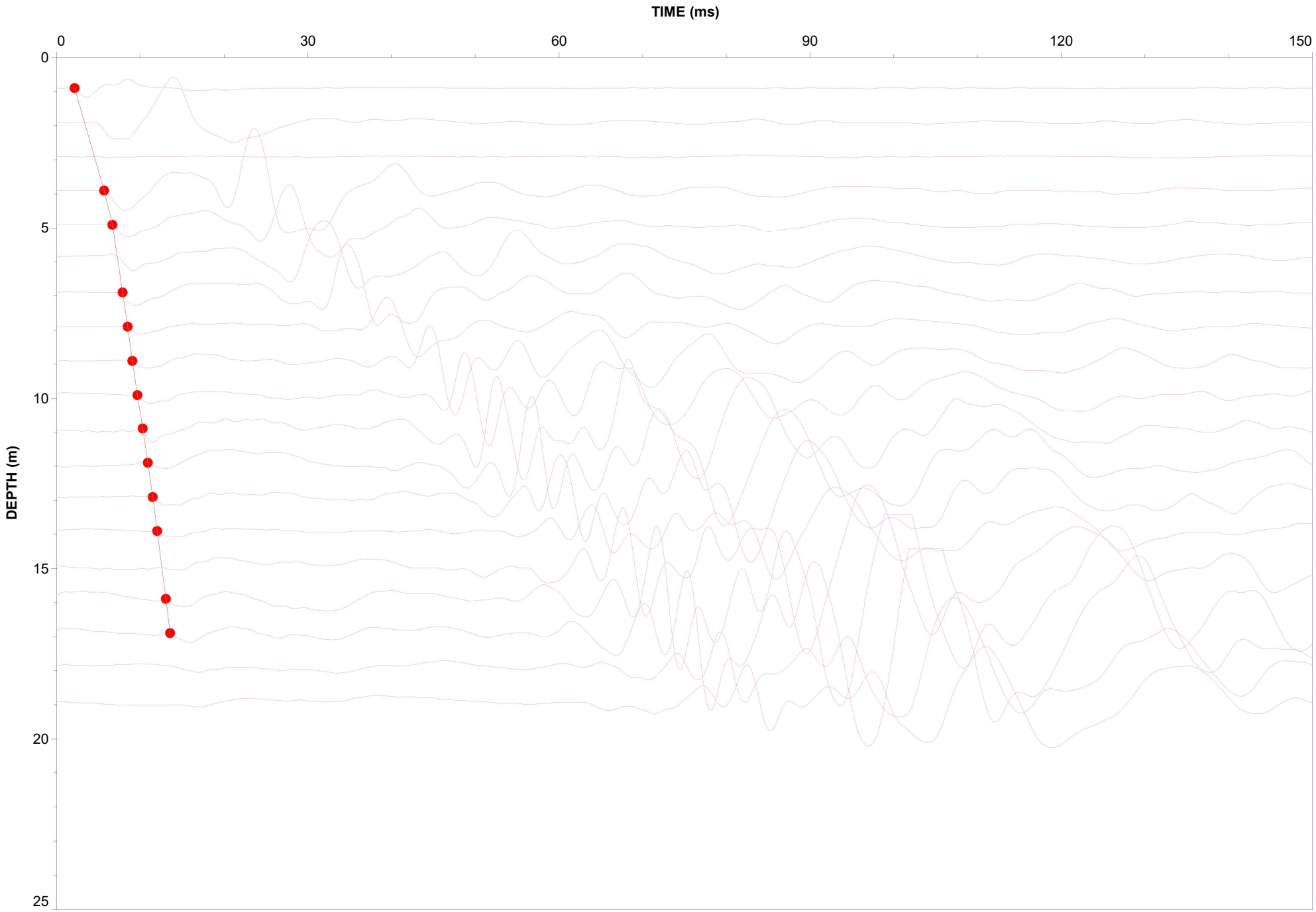
Seismic Cone Penetration Test Compression Wave (Vp) Traces

CONETEC

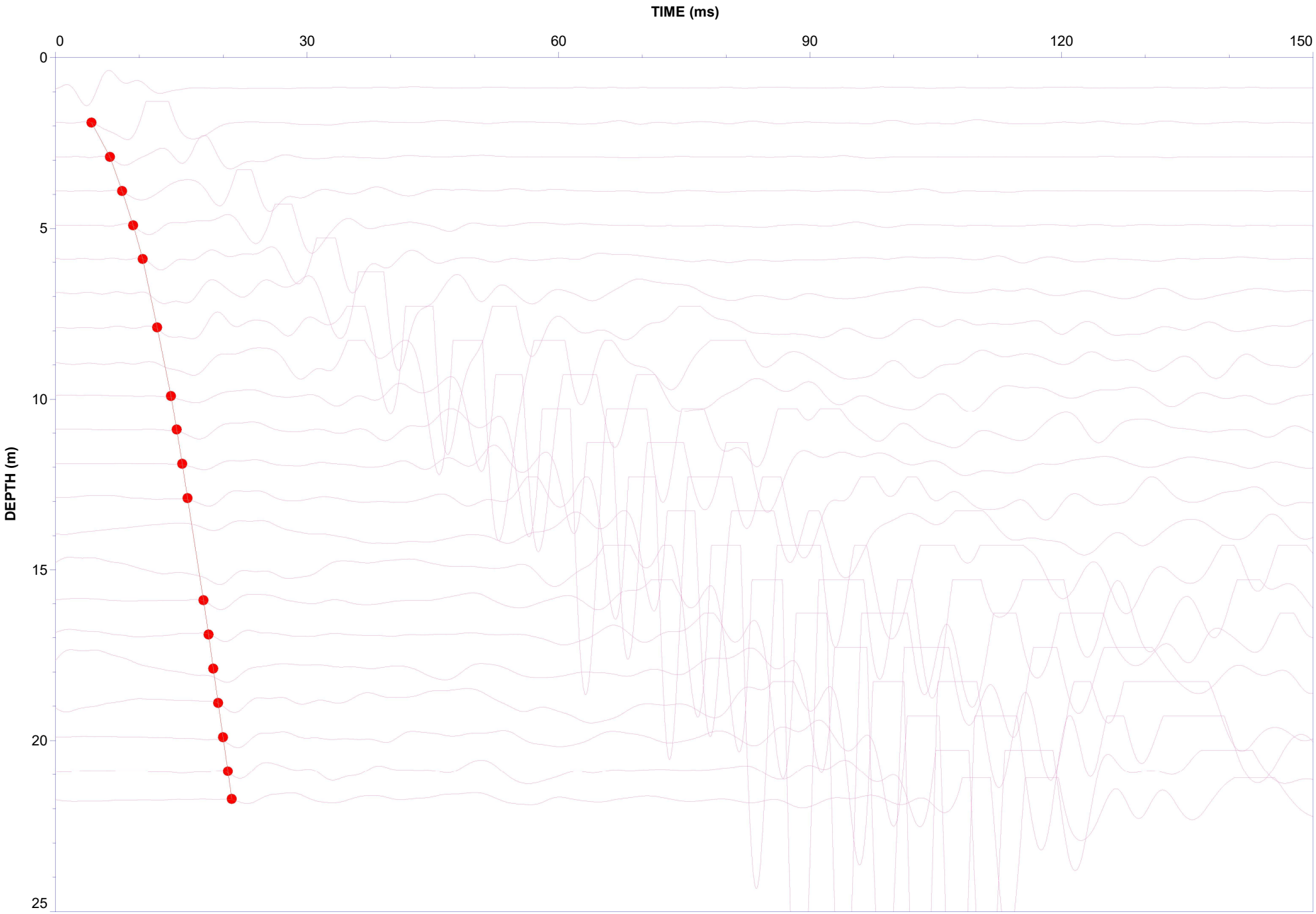
Job No: 23-05-26042 Client: Thurber Project: Poplar Rapids Bridge - Highway 11 Filter: 0-500Hz Sounding: SCPT23-107
Analysis: P-Wave_Geo-X Date: 10-Jul-2023



Job No: 23-05-26042 Client: Thurber Project: Poplar Rapids Bridge - Highway 11 Filter: 0-500Hz Sounding: SCPT23-108
Analysis: P-Wave_Geo-X Date: 10-Jul-2023



Job No: 23-05-26042 Client: Thurber Project: Poplar Rapids Bridge - Highway 11 Filter: 0-300Hz Sounding: SCPT23-205
Analysis: P-Wave_Geo-X Date: 11-Jul-2023



Seismic Cone Penetration Test Poisson's Ratio Tabular Results

CONETEC

Job No:	23-05-26042
Client:	Thurber
Project:	Poplar Rapids Bridge - Highway 11
Sounding ID:	SCPT23-107
Date:	10-Jul-2023

SCPTu POISSON'S RATIO RESULTS

Depth From (m)	Depth To (m)	Vs Interval Velocity (m/s)	Vp Interval Velocity (m/s)	Poisson's Ratio
0.75	1.75	108	311	0.43
1.75	2.75	129	428	0.45
2.75	3.75	147	663	0.47
3.75	4.75	154	663	0.47
4.75	5.75	207	663	0.45
5.75	6.75	190	1115	0.49
6.75	7.75	245	1403	0.48
7.75	8.75	269	1409	0.48
8.75	9.75	272	1521	0.48
9.75	10.75	262	1574	0.49
10.75	11.75	271	1631	0.49
11.75	12.75	263	1631	0.49
12.75	13.75	276	1664	0.49
13.75	14.75	258	1759	0.49
14.75	15.75	267	1895	0.49
15.75	16.75	263	1914	0.49
16.75	17.75	272	1906	0.49
17.75	18.75	287	1897	0.49

Job No:	23-05-26042
Client:	Thurber
Project:	Poplar Rapids Bridge - Highway 11
Sounding ID:	SCPT23-108
Date:	10-Jul-2023

SCPTu POISSON'S RATIO RESULTS

Depth From (m)	Depth To (m)	Vs Interval Velocity (m/s)	Vp Interval Velocity (m/s)	Poisson's Ratio
1.70	2.70	170	679	0.47
2.70	3.70	208	679	0.45
3.70	4.70	243	948	0.47
4.70	5.70	265	1594	0.49
5.70	6.70	269	1594	0.49
6.70	7.70	220	1615	0.49
7.70	8.70	222	1747	0.49
8.70	9.70	251	1658	0.49
9.70	10.70	260	1587	0.49
10.70	11.70	260	1609	0.49
11.70	12.70	273	1724	0.49
12.70	13.70	276	1869	0.49
13.70	14.70	264	1886	0.49
14.70	15.70	267	1886	0.49
15.70	16.70	266	1993	0.49

Job No:	23-05-26042
Client:	Thurber
Project:	Poplar Rapids Bridge - Highway 11
Sounding ID:	SCPT23-205
Date:	11-Jul-2023

SCPTu POISSON'S RATIO RESULTS

Depth From (m)	Depth To (m)	Vs Interval Velocity (m/s)	Vp Interval Velocity (m/s)	Poisson's Ratio
1.70	2.70	167	380	0.38
2.70	3.70	201	634	0.44
3.70	4.70	198	730	0.46
4.70	5.70	198	844	0.47
5.70	6.70	181	1122	0.49
6.70	7.70	176	1122	0.49
7.70	8.70	175	1205	0.49
8.70	9.70	189	1205	0.49
9.70	10.70	181	1428	0.49
10.70	11.70	193	1527	0.49
11.70	12.70	208	1583	0.49
12.70	13.70	205	1559	0.49
13.70	14.70	197	1559	0.49
14.70	15.70	190	1559	0.49
15.70	16.70	189	1661	0.49
16.70	17.70	199	1760	0.49
17.70	18.70	233	1744	0.49
18.70	19.70	245	1694	0.49
19.70	20.70	284	1728	0.49
20.70	21.52	402	1818	0.47

Soil Behaviour Type (SBT) Scatter Plots

CONETEC

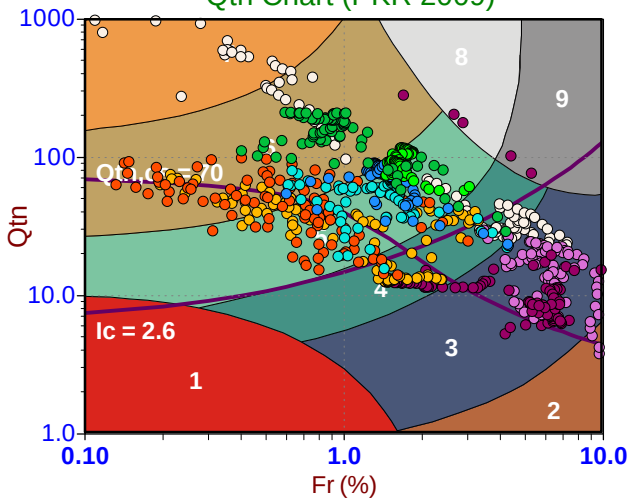
CONETEC

Thurber

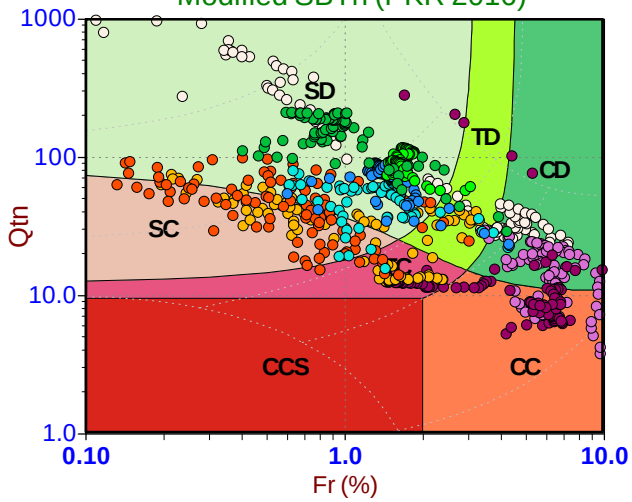
Job No: 23-05-26042
Date: 2023-07-10 14:57
Site: Poplar Rapids Bridge, ON

Sounding: SCPT23-107
Cone: 958:T1500F15U35

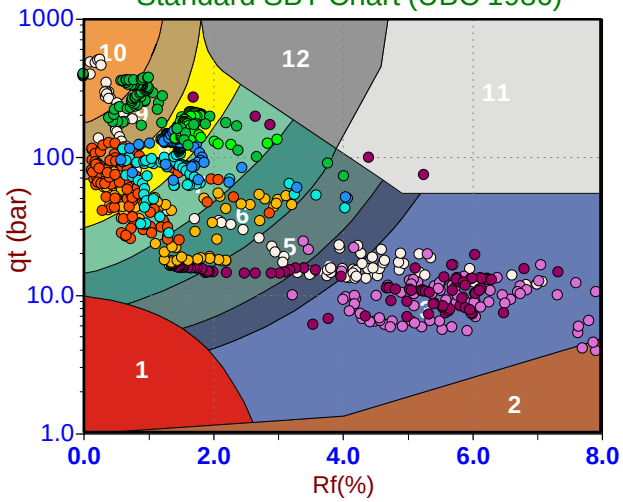
Qtn Chart (PKR 2009)



Modified SBTn (PKR 2016)



Standard SBT Chart (UBC 1986)



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

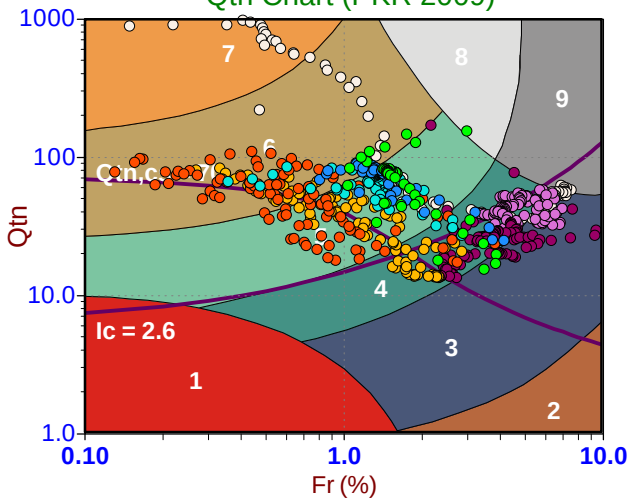
CONETEC

Thurber

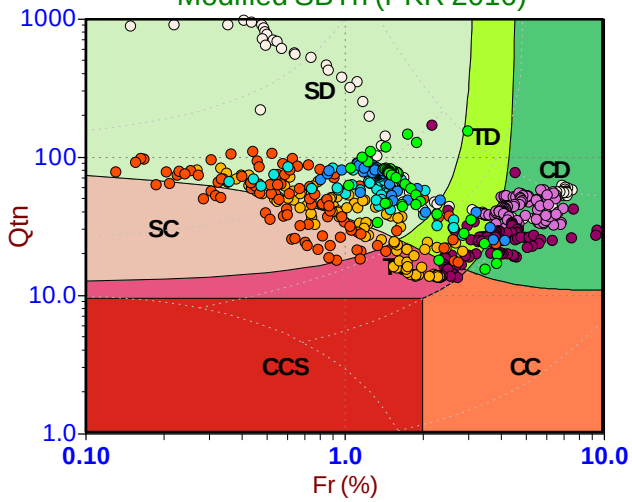
Job No: 23-05-26042
Date: 2023-07-10 08:39
Site: Poplar Rapids Bridge, ON

Sounding: SCPT23-108
Cone: 958:T1500F15U35

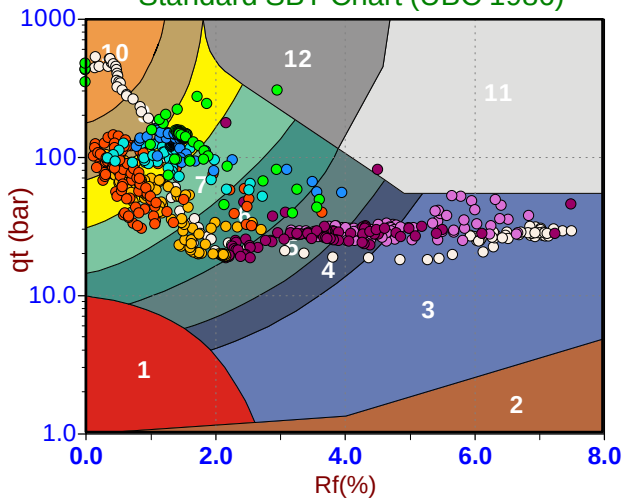
Qtn Chart (PKR 2009)



Modified SBTn (PKR 2016)



Standard SBT Chart (UBC 1986)



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

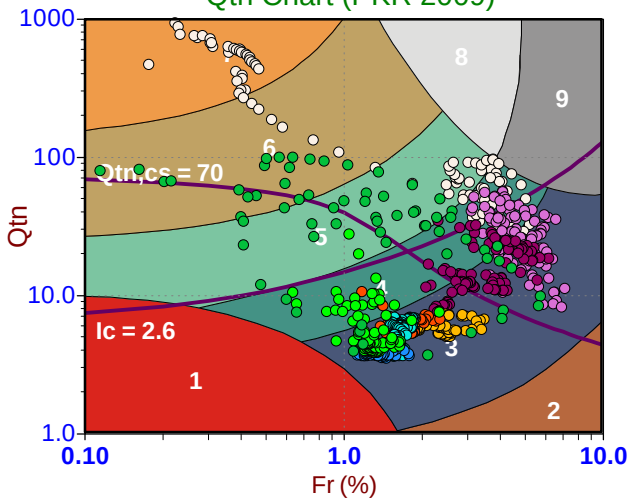
CONETEC

Thurber

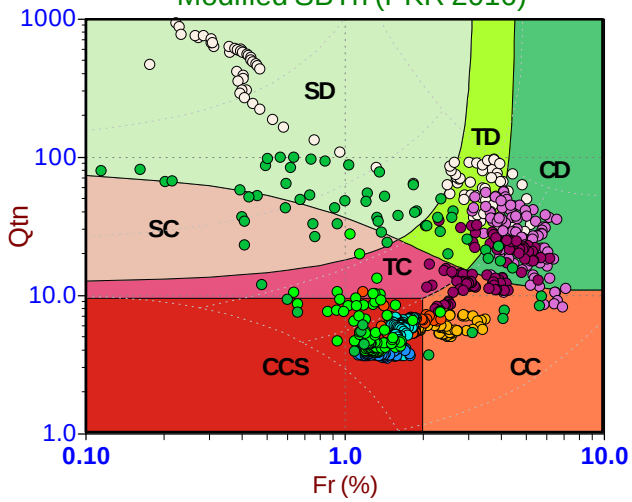
Job No: 23-05-26042
Date: 2023-07-11 07:32
Site: Poplar Rapids Bridge, ON

Sounding: SCPT23-205
Cone: 765:T1500F15U35

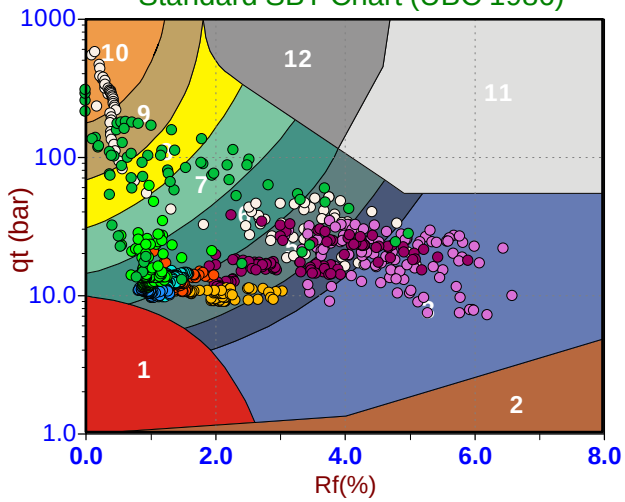
Qtn Chart (PKR 2009)



Modified SBTn (PKR 2016)



Standard SBT Chart (UBC 1986)



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:	23-05-26042
Client:	Thurber Engineering Ltd.
Project:	Poplar Rapids Bridge - Highway 11
Start Date:	2023-07-10
End Date:	2023-07-11

CPTu PORE PRESSURE DISSIPATION SUMMARY

Sounding ID	File Name	Cone Area (cm^2)	Duration (s)	Test Depth (m)	$U_{initial}$ (m)	U_{max} (m)	U_{min} (m)	U_{final} (m)	Equilibrium Pore Pressure U_{eq} (m)	Estimated Equilibrium Pore Pressure U_{eq} (m)	Estimated Phreatic Surface (m)	Percent Dissipation (%)	t_{50} $(s)_1$	Assumed Rigidity Index (I_r)	c_h $(cm^2/min)_2$	Refer to Notation Number
SCPT23-107	23-05-26042_SP23-107	15	3390	5.950	6.1	11.4	5.5	5.5								
SCPT23-107	23-05-26042_SP23-107	15	1860	7.950	96.6	96.6	47.4	47.4		1.7	6.3	51.9	1705	100	0.4	3
SCPT23-107	23-05-26042_SP23-107	15	300	12.950	6.5	23.3	4.7	6.7	6.7		6.3	100.0				
SCPT23-107	23-05-26042_SP23-107	15	175	19.950	49.7	52.4	12.7	13.0	13.0		6.9	100.0				
SCPT23-107	23-05-26042_SP23-107	15	305	22.175	18.2	19.6	-1.0	15.6								
SCPT23-108	23-05-26042_SP23-108	15	640	0.900	1.3	1.3	-0.5	0.0	0.0							
SCPT23-108	23-05-26042_SP23-108	15	265	1.900	-0.1	2.1	-0.1	1.5								
SCPT23-108	23-05-26042_SP23-108	15	16320	6.150	32.5	85.7	32.5	42.6								
SCPT23-108	23-05-26042_SP23-108	15	610	8.250	46.4	75.9	31.5	31.5		1.1	7.1	33.0	363	100	1.9	3
SCPT23-108	23-05-26042_SP23-108	15	305	12.900	26.4	27.4	5.9	5.9	5.8		7.1	100.0				
SCPT23-108	23-05-26042_SP23-108	15	125	13.900	13.8	13.8	5.3	6.8	6.8		7.1	100.0				
SCPT23-108	23-05-26042_SP23-108	15	100	18.900	21.1	21.1	-8.9	11.7	11.8		7.1	100.0				
SCPT23-205	23-05-26042_SP23-205	15	5040	9.150	45.5	46.7	23.0	23.0		1.3	7.9	50.8	4499	100	0.2	3
SCPT23-205	23-05-26042_SP23-205	15	3720	12.200	59.4	62.1	40.7	40.7		4.3	7.9	34.0				3
SCPT23-205	23-05-26042_SP23-205	15	3600	15.250	63.9	63.9	41.6	41.6		7.4	7.9	39.5				3
SCPT23-205	23-05-26042_SP23-205	15	3780	18.300	83.5	83.5	51.9	51.9		10.4	7.9	43.3				3
SCPT23-205	23-05-26042_SP23-205	15	600	21.350	78.5	78.5	13.9	13.9		13.5	7.9	99.4	36	100	19.3	3
SCPT23-205	23-05-26042_SP23-205	15	310	21.725	19.0	20.3	6.0	13.9	13.9		7.9	100.0	8	100	93.5	

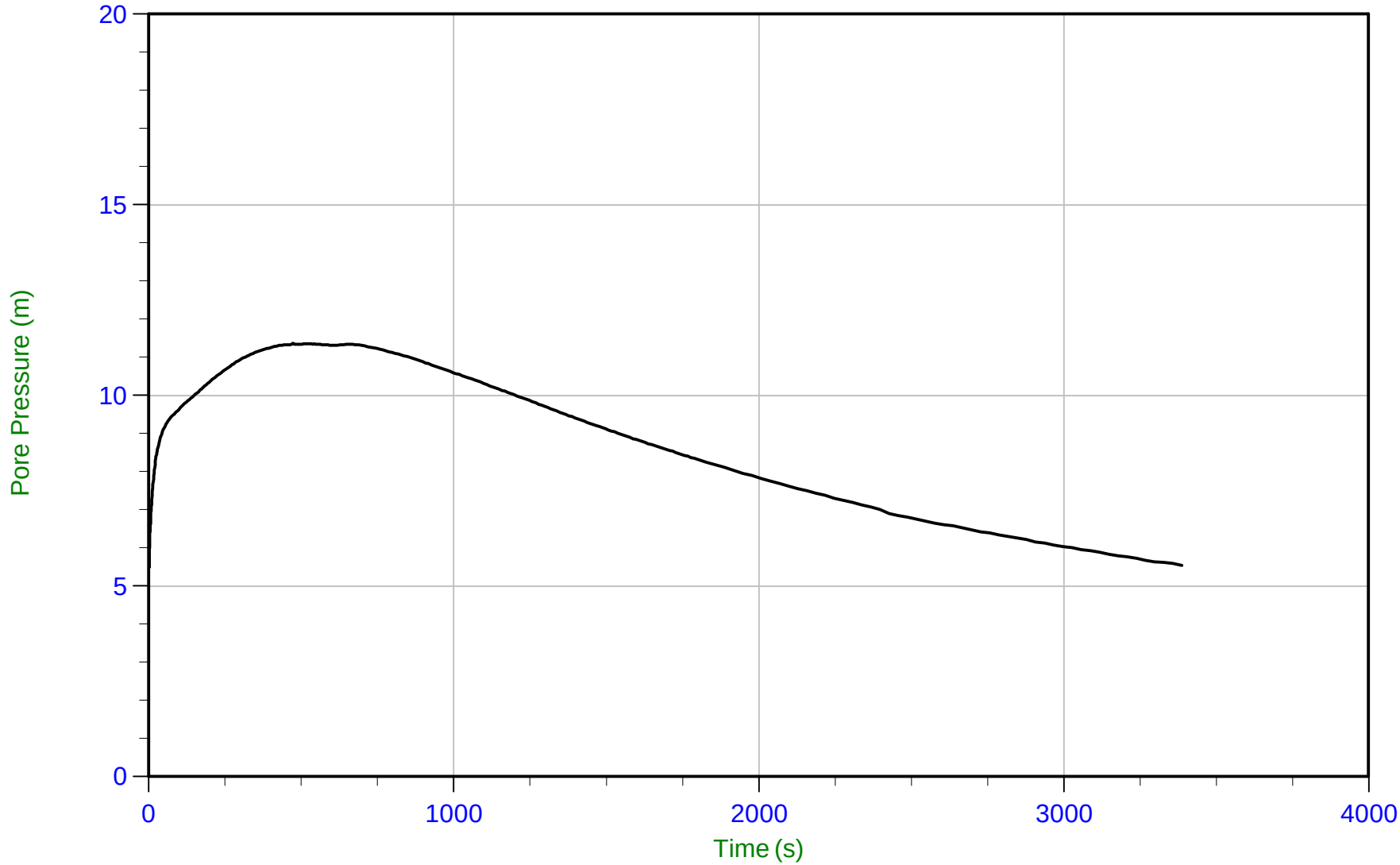
1. Time for 50 percent dissipation based in U_{max}, U_{min}, and the applied U_{eq}. Note the time is relative to where U_{max} occurred.
2. Houlsby and Teh, 1991.
3. The estimated equilibrium pore pressure was based on a hydrostatic assumption from the assumed phreatic surface.

CONETEC

Thurber

Job No: 23-05-26042
Date: 07/10/2023 14:57
Site: Poplar Rapids Bridge, ON

Sounding: SCPT23-107
Cone: 958:T1500F15U35 Area=15 cm²



Trace Summary:

Filename: 23-05-26042_SP23-107.PPF2
Depth: 5.950 m / 19.521 ft
Duration: 3390.0 s

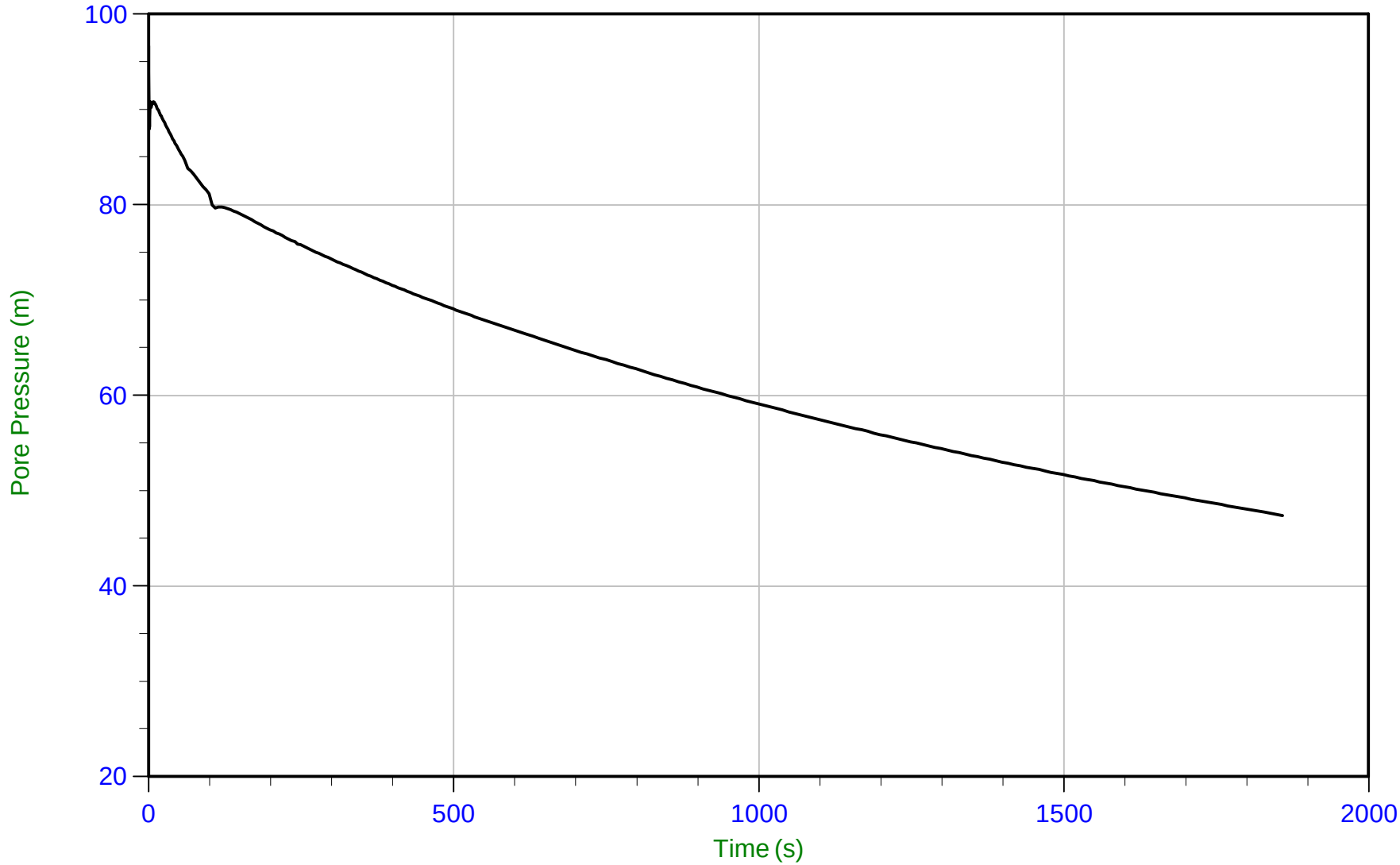
u Min: 5.5 m
u Max: 11.4 m
u Final: 5.5 m

CONETEC

Thurber

Job No: 23-05-26042
Date: 07/10/2023 14:57
Site: Poplar Rapids Bridge, ON

Sounding: SCPT23-107
Cone: 958:T1500F15U35 Area=15 cm²



Trace Summary:

Filename: 23-05-26042_SP23-107.PPF2
Depth: 7.950 m / 26.082 ft
Duration: 1860.0 s

u Min: 47.4 m
u Max: 96.6 m
u Final: 47.4 m

WT: 6.255 m / 20.521 ft
Ueq: 1.7 m
U(50): 49.17 m

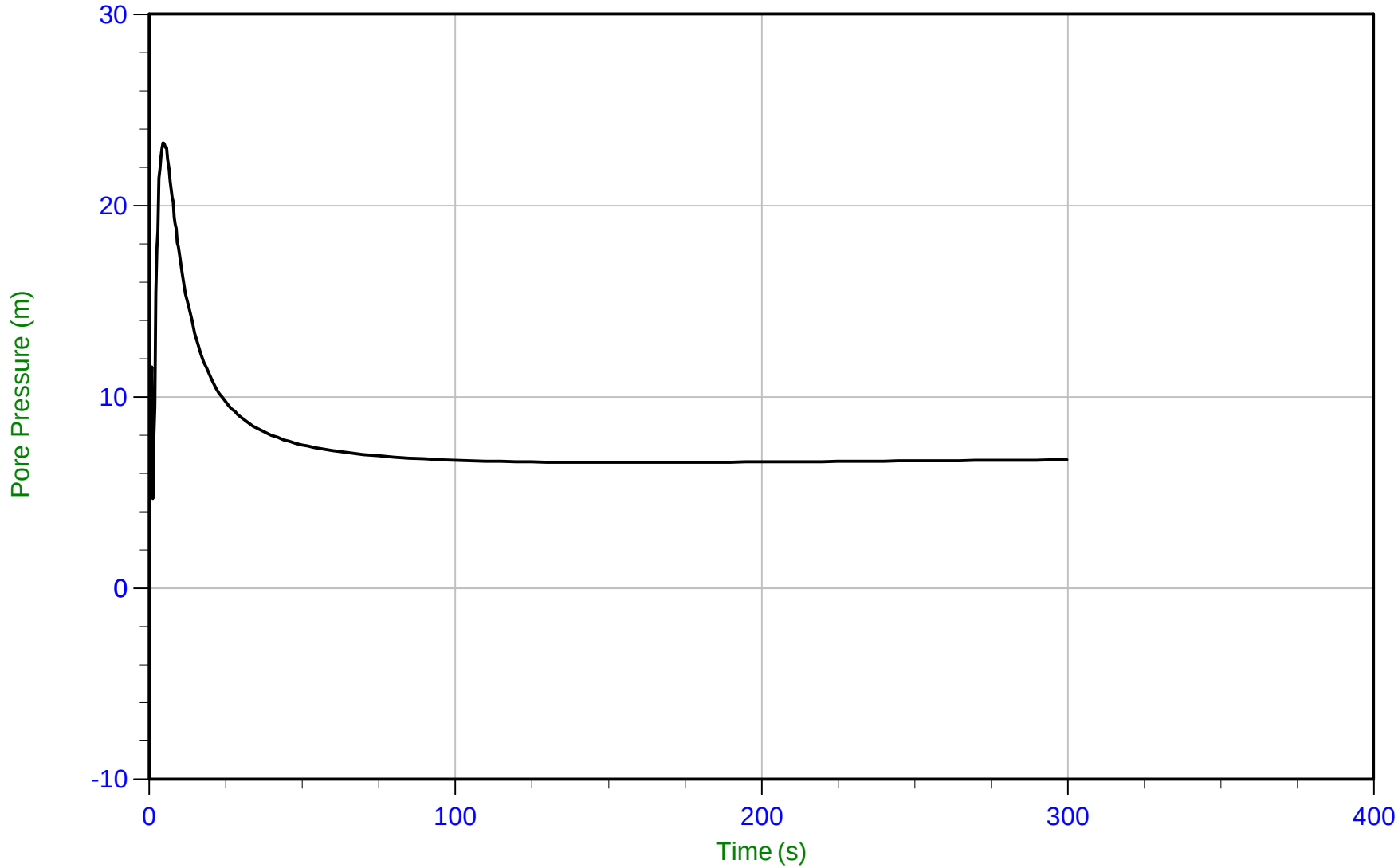
T(50): 1705.0 s
Ir: 100
Ch: 0.4 cm²/min

CONETEC

Thurber

Job No: 23-05-26042
Date: 07/10/2023 14:57
Site: Poplar Rapids Bridge, ON

Sounding: SCPT23-107
Cone: 958:T1500F15U35 Area=15 cm²



Trace Summary:

Filename: 23-05-26042_SP23-107.PPF2
Depth: 12.950 m / 42.486 ft
Duration: 300.0 s

u Min: 4.7 m
u Max: 23.3 m
u Final: 6.7 m

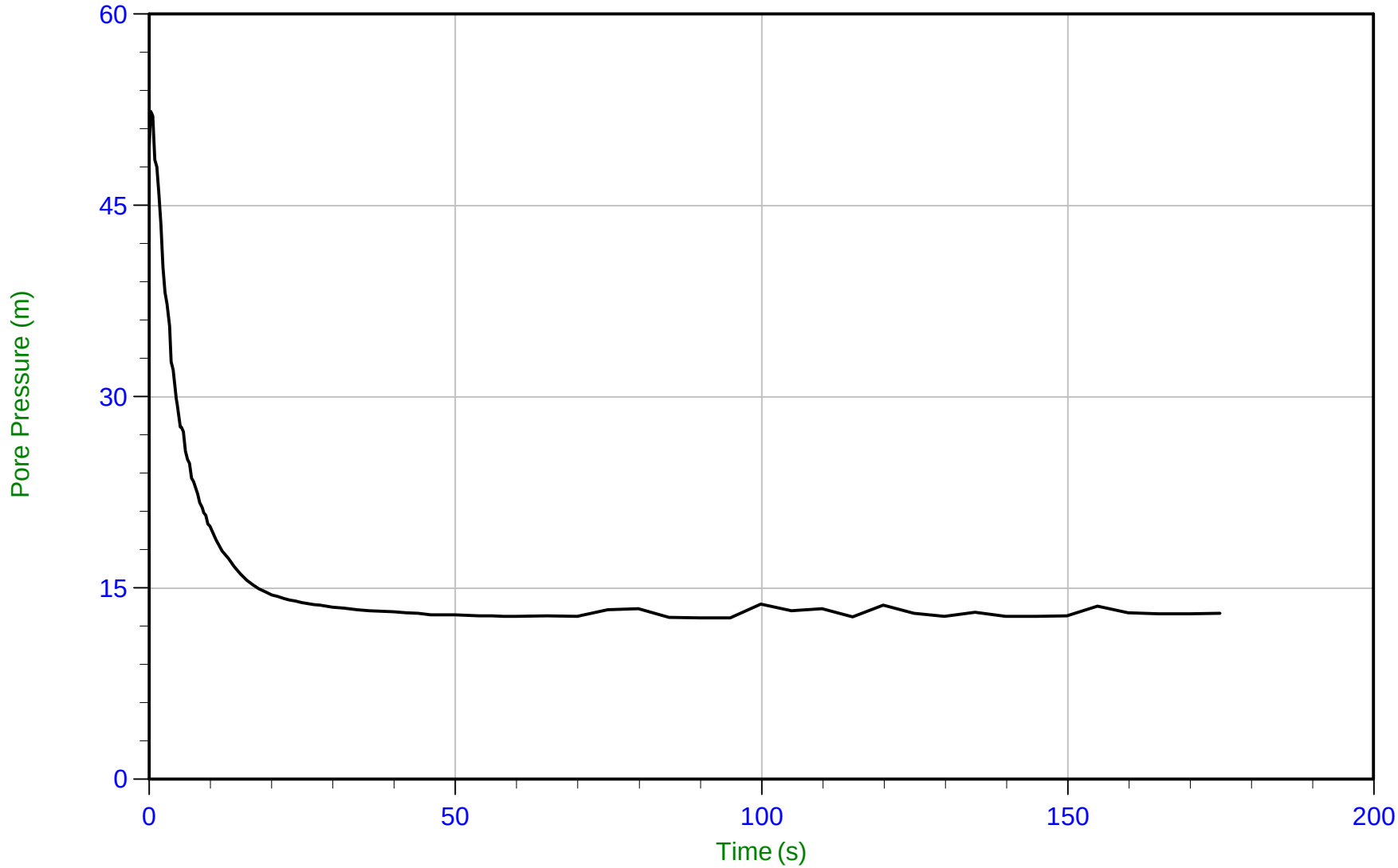
WT: 6.255 m / 20.521 ft
Ueq: 6.7 m

CONETEC

Thurber

Job No: 23-05-26042
Date: 07/10/2023 14:57
Site: Poplar Rapids Bridge, ON

Sounding: SCPT23-107
Cone: 958:T1500F15U35 Area=15 cm²



Trace Summary:

Filename: 23-05-26042_SP23-107.PPF2
Depth: 19.950 m / 65.452 ft
Duration: 175.0 s

u Min: 12.7 m
u Max: 52.4 m
u Final: 13.0 m

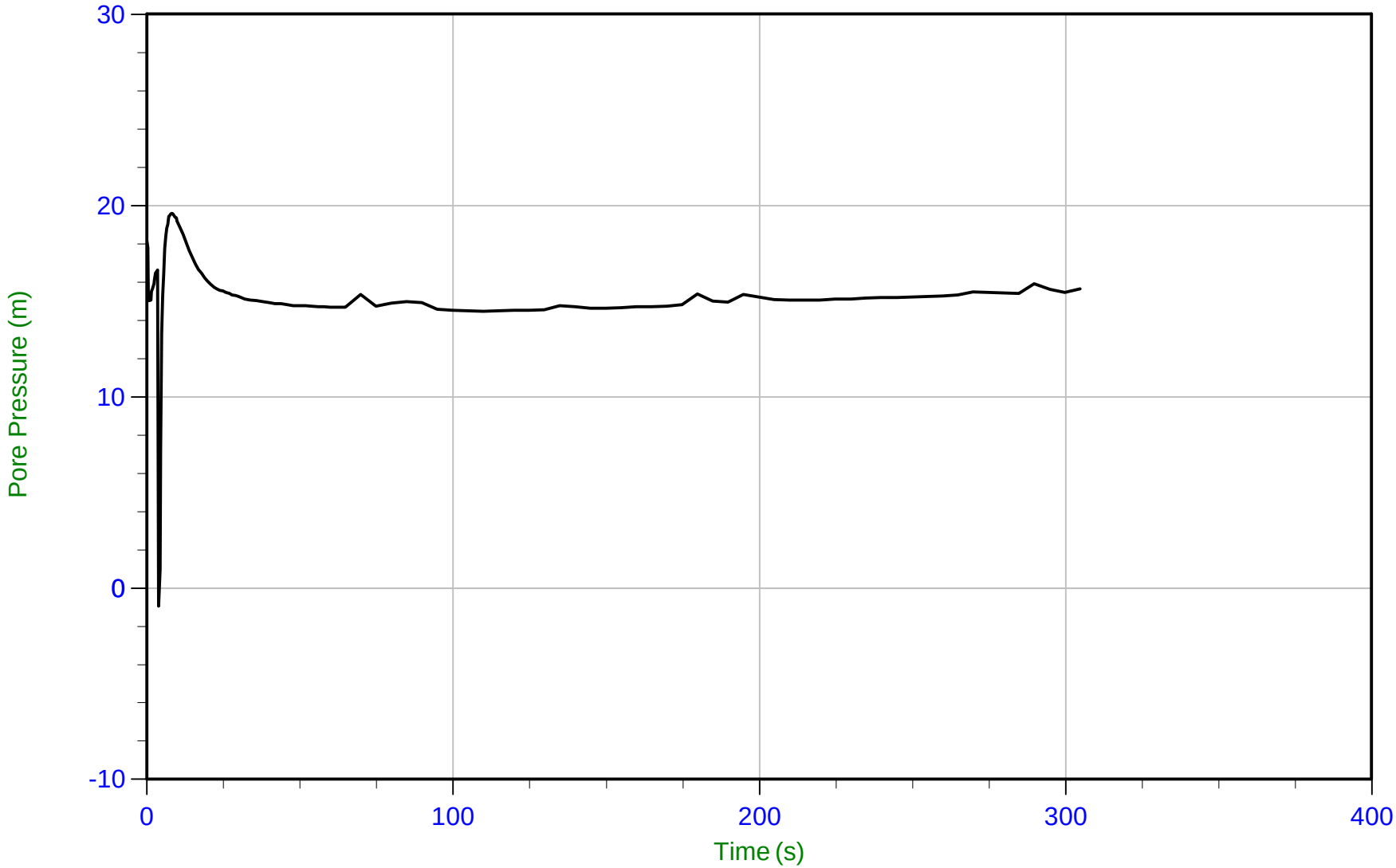
WT: 6.946 m / 22.788 ft
Ueq: 13.0 m

CONETEC

Thurber

Job No: 23-05-26042
Date: 07/10/2023 14:57
Site: Poplar Rapids Bridge, ON

Sounding: SCPT23-107
Cone: 958:T1500F15U35 Area=15 cm²



Trace Summary:

Filename: 23-05-26042_SP23-107.PPF2
Depth: 22.175 m / 72.752 ft
Duration: 305.0 s

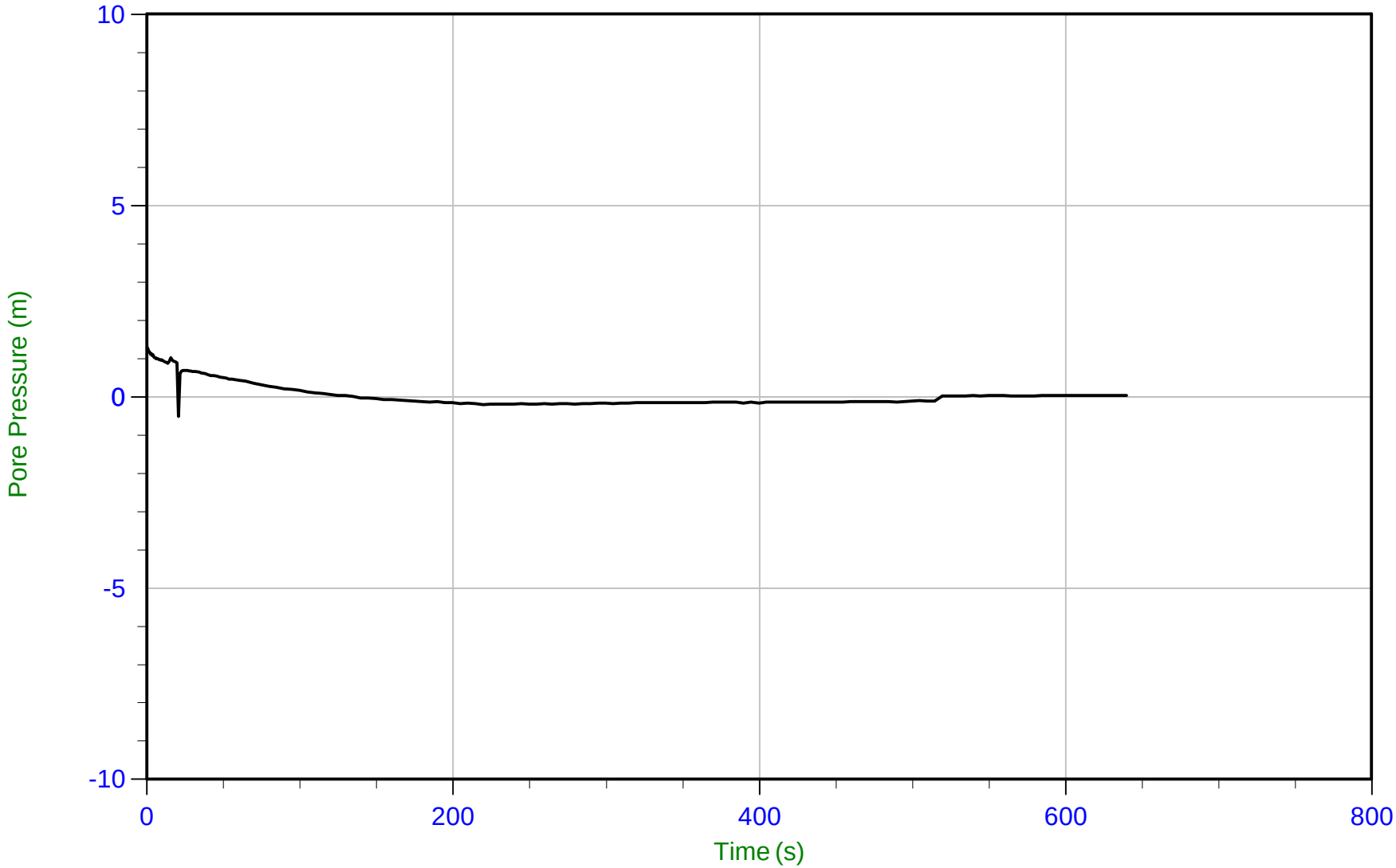
u Min: -1.0 m
u Max: 19.6 m
u Final: 15.6 m

CONETEC

Thurber

Job No: 23-05-26042
Date: 07/10/2023 08:39
Site: Poplar Rapids Bridge, ON

Sounding: SCPT23-108
Cone: 958:T1500F15U35 Area=15 cm²



Trace Summary:

Filename: 23-05-26042_SP23-108.PPF2
Depth: 0.900 m / 2.953 ft
Duration: 640.1 s

u Min: -0.5 m
u Max: 1.3 m
u Final: 0.0 m

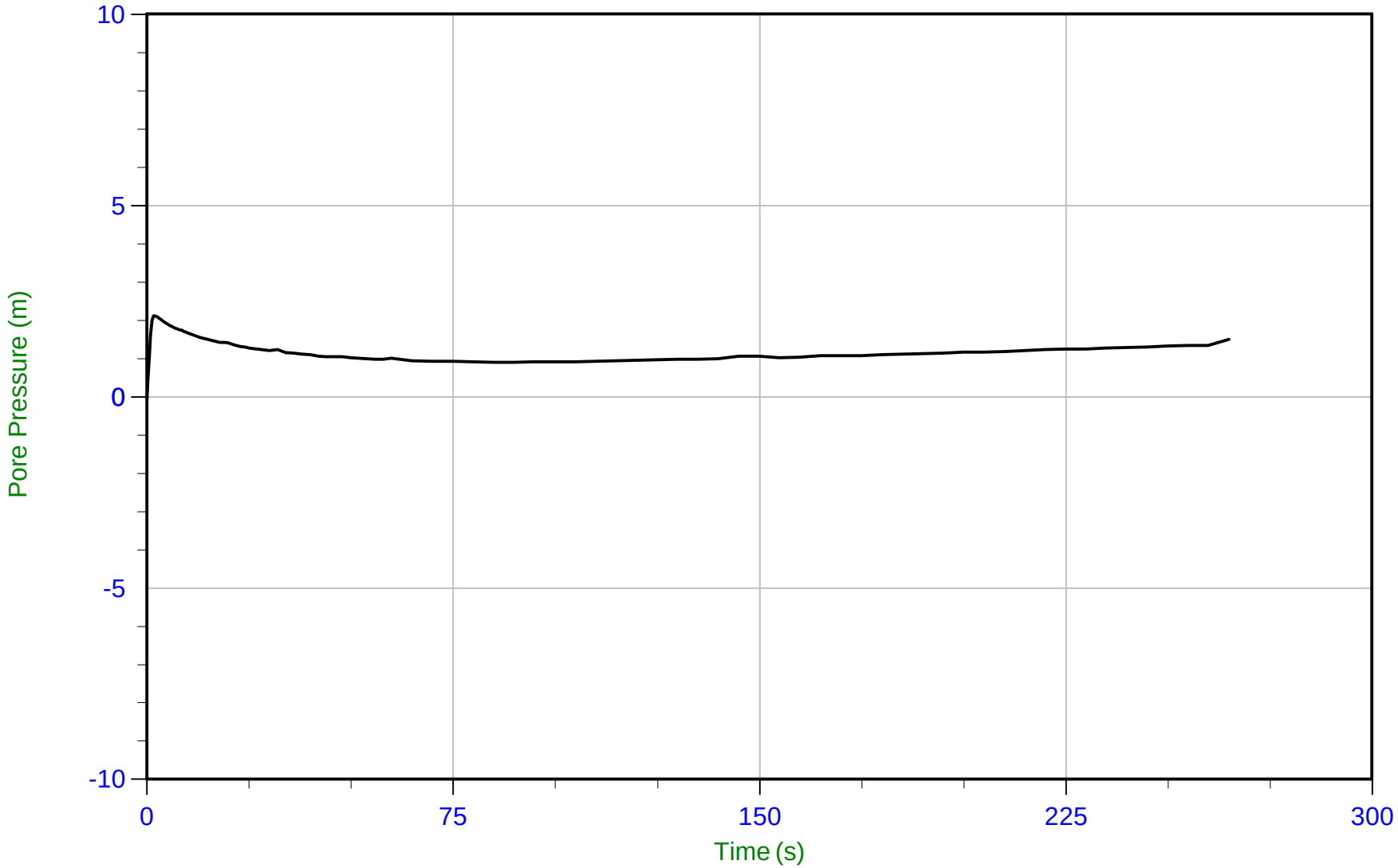
WT: 0.900 m / 2.953 ft
Ueq: 0.0 m

CONETEC

Thurber

Job No: 23-05-26042
Date: 07/10/2023 08:39
Site: Poplar Rapids Bridge, ON

Sounding: SCPT23-108
Cone: 958:T1500F15U35 Area=15 cm²



Trace Summary:

Filename: 23-05-26042_SP23-108.PPF2
Depth: 1.900 m / 6.234 ft
Duration: 265.0 s

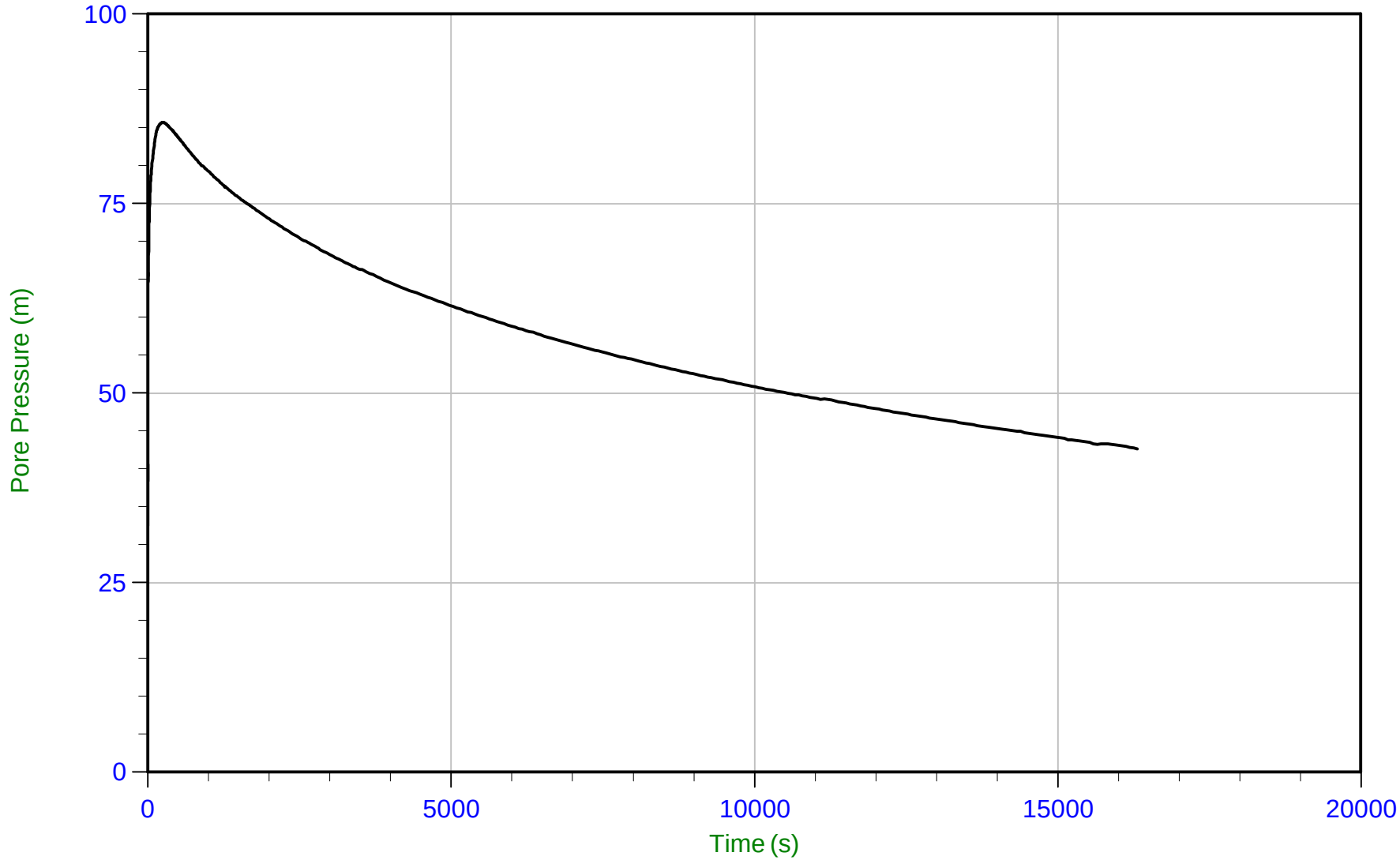
u Min: -0.1 m
u Max: 2.1 m
u Final: 1.5 m

CONETEC

Thurber

Job No: 23-05-26042
Date: 07/10/2023 08:39
Site: Poplar Rapids Bridge, ON

Sounding: SCPT23-108
Cone: 958:T1500F15U35 Area=15 cm²



Trace Summary:

Filename: 23-05-26042_SP23-108.PPF2
Depth: 6.150 m / 20.177 ft
Duration: 16320.0 s

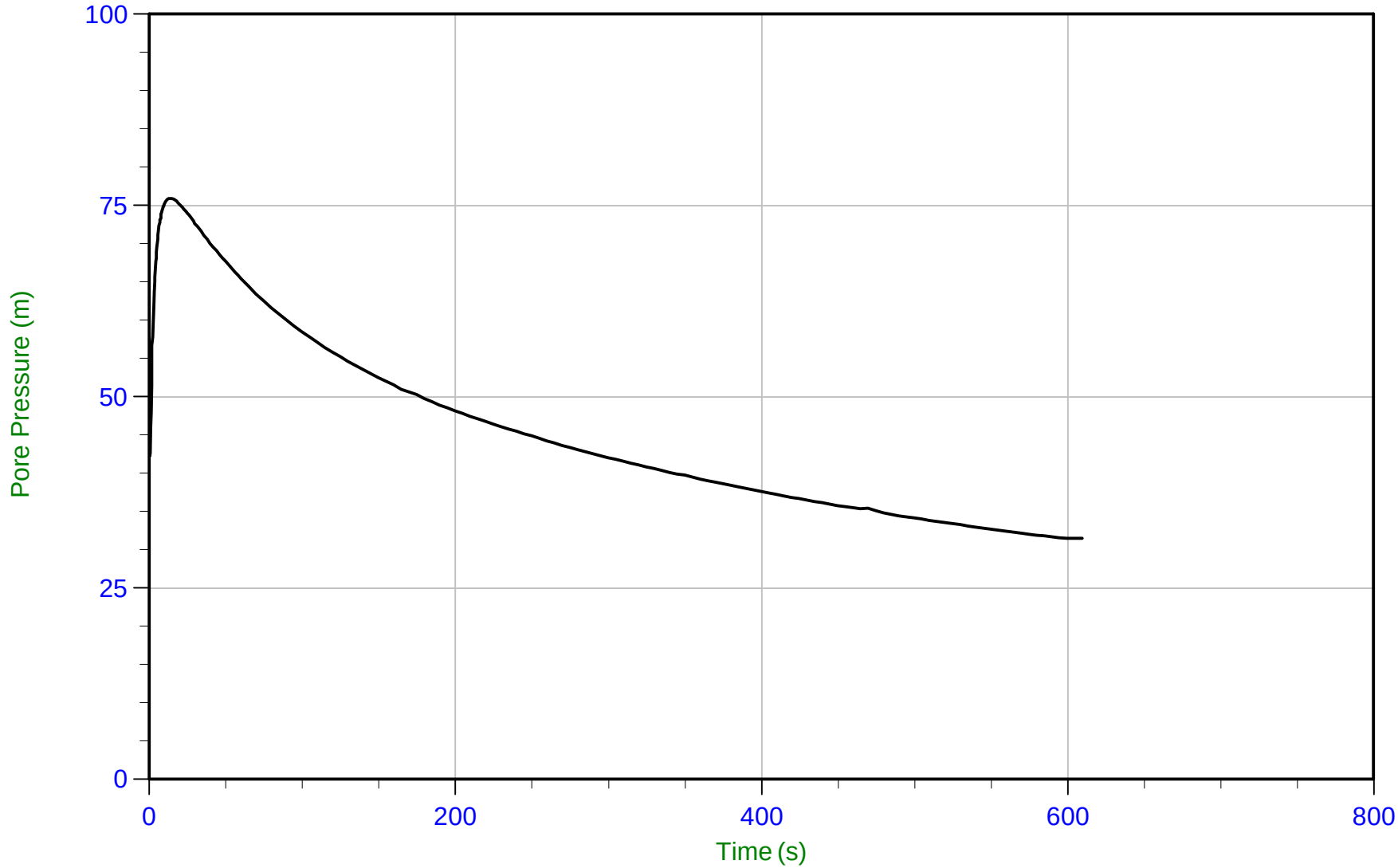
u Min: 32.5 m
u Max: 85.7 m
u Final: 42.6 m

CONETEC

Thurber

Job No: 23-05-26042
Date: 07/10/2023 08:39
Site: Poplar Rapids Bridge, ON

Sounding: SCPT23-108
Cone: 958:T1500F15U35 Area=15 cm²



Trace Summary:

Filename: 23-05-26042_SP23-108.PPF2
Depth: 8.250 m / 27.067 ft
Duration: 610.0 s

u Min: 31.5 m
u Max: 75.9 m
u Final: 31.5 m

WT: 7.106 m / 23.313 ft
Ueq: 1.1 m
U(50): 38.53 m

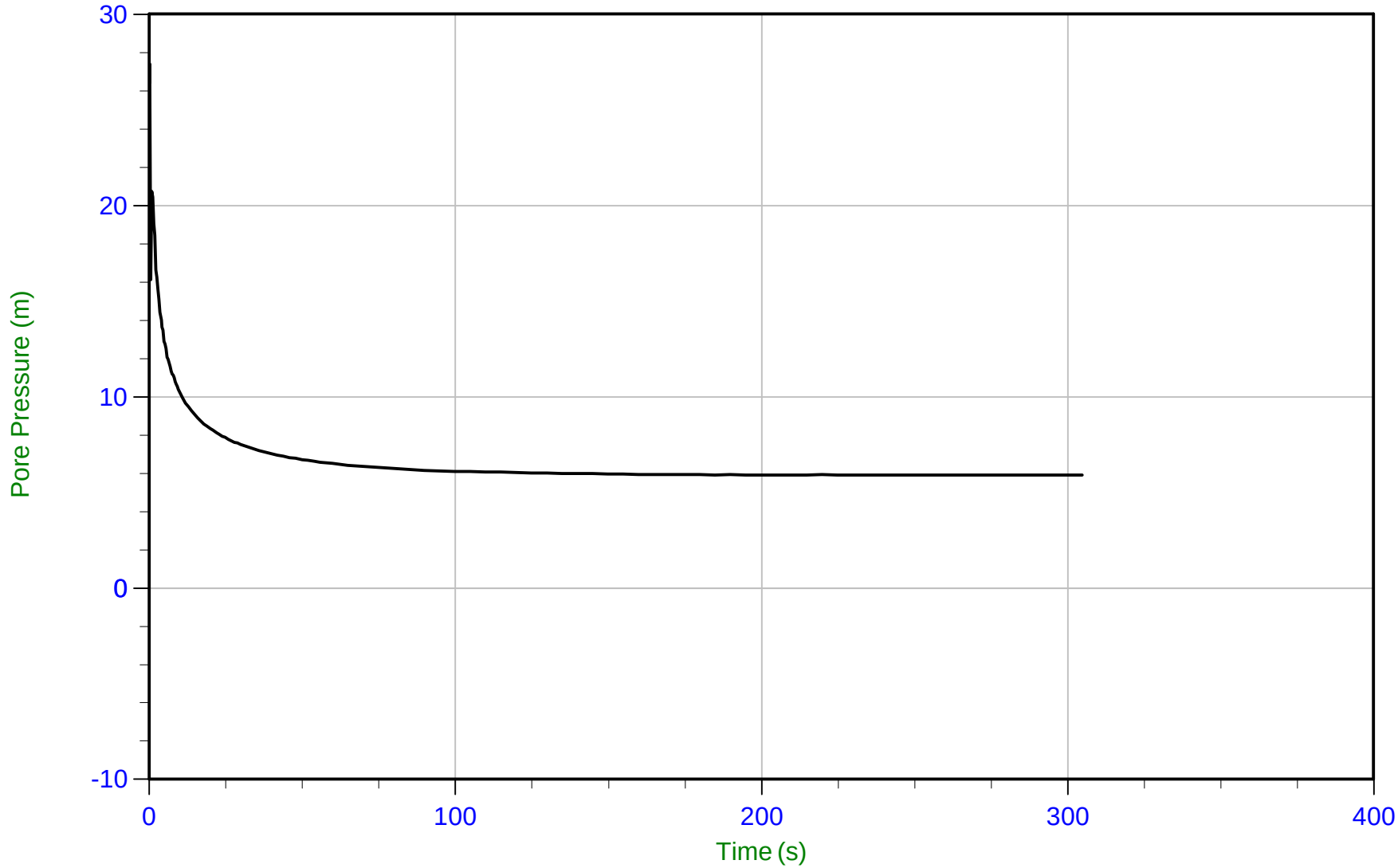
T(50): 363.1 s
Ir: 100
Ch: 1.9 cm²/min

CONETEC

Thurber

Job No: 23-05-26042
Date: 07/10/2023 08:39
Site: Poplar Rapids Bridge, ON

Sounding: SCPT23-108
Cone: 958:T1500F15U35 Area=15 cm²



Trace Summary:

Filename: 23-05-26042_SP23-108.PPF2
Depth: 12.900 m / 42.322 ft
Duration: 305.0 s

u Min: 5.9 m
u Max: 27.4 m
u Final: 5.9 m

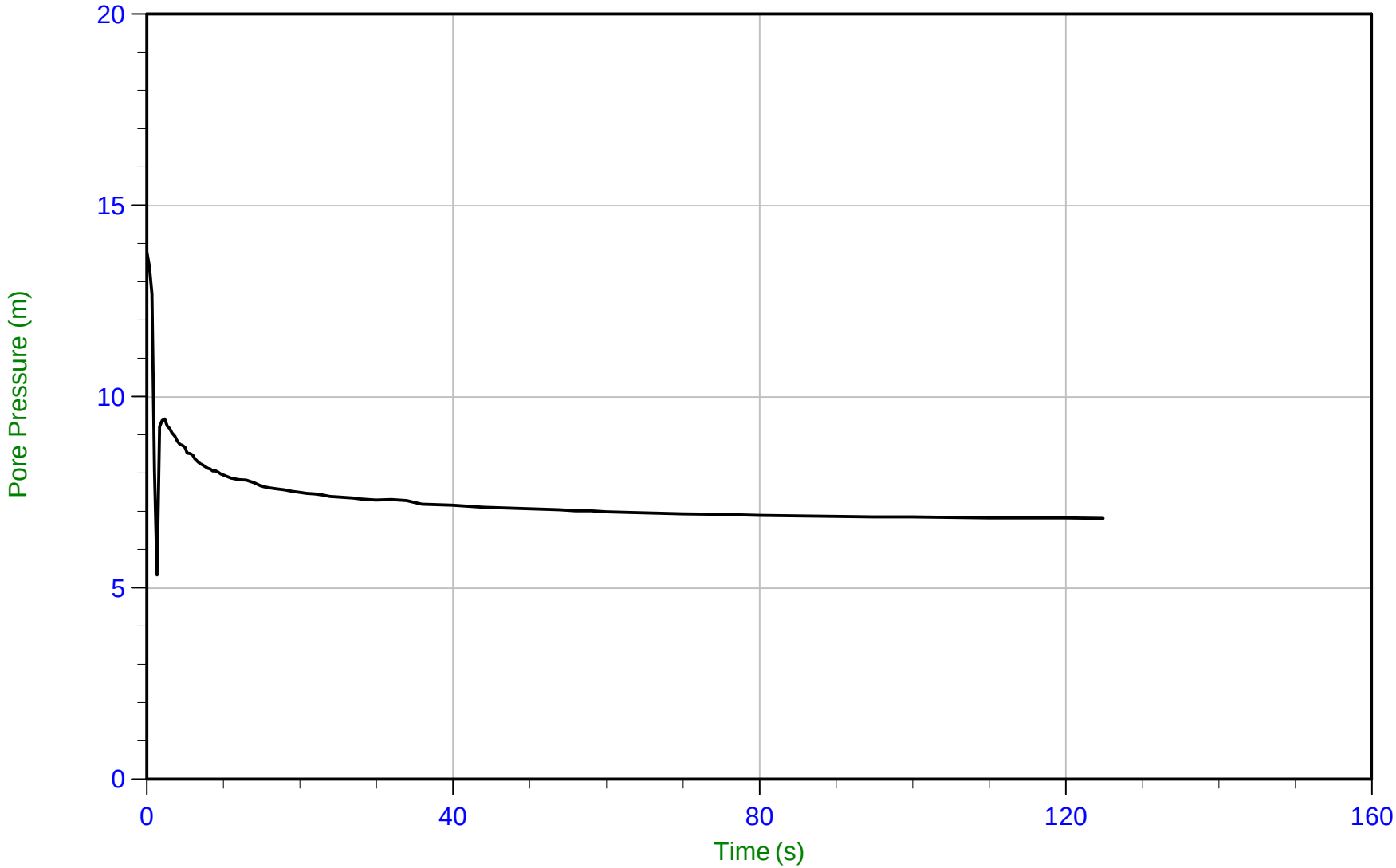
WT: 7.106 m / 23.313 ft
Ueq: 5.8 m

CONETEC

Thurber

Job No: 23-05-26042
Date: 07/10/2023 08:39
Site: Poplar Rapids Bridge, ON

Sounding: SCPT23-108
Cone: 958:T1500F15U35 Area=15 cm²



Trace Summary:

Filename: 23-05-26042_SP23-108.PPF2
Depth: 13.900 m / 45.603 ft
Duration: 125.0 s

u Min: 5.3 m
u Max: 13.8 m
u Final: 6.8 m

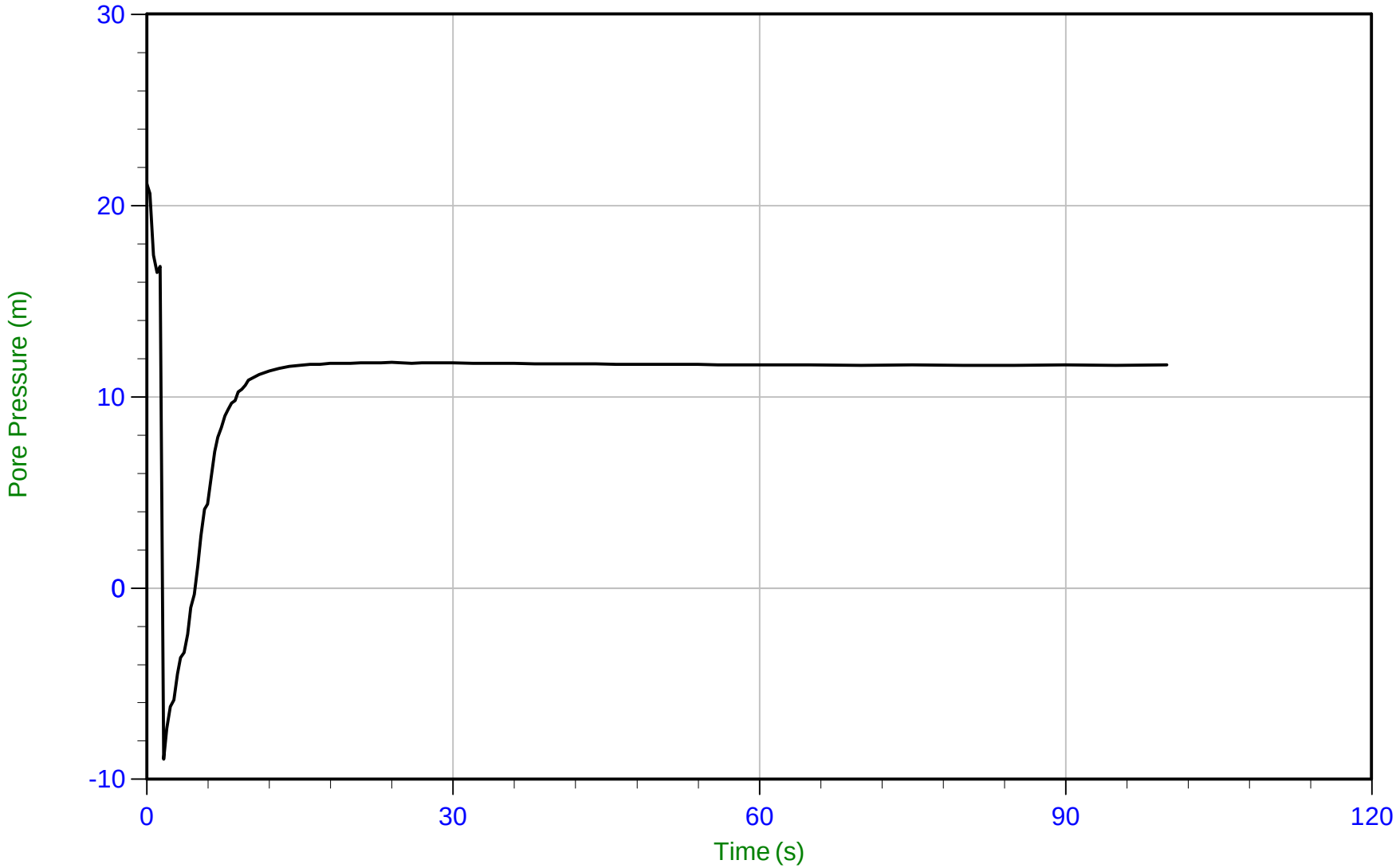
WT: 7.076 m / 23.215 ft
Ueq: 6.8 m

CONETEC

Thurber

Job No: 23-05-26042
Date: 07/10/2023 08:39
Site: Poplar Rapids Bridge, ON

Sounding: SCPT23-108
Cone: 958:T1500F15U35 Area=15 cm²



Trace Summary:

Filename: 23-05-26042_SP23-108.PPF2
Depth: 18.900 m / 62.007 ft
Duration: 100.0 s

u Min: -8.9 m
u Max: 21.1 m
u Final: 11.7 m

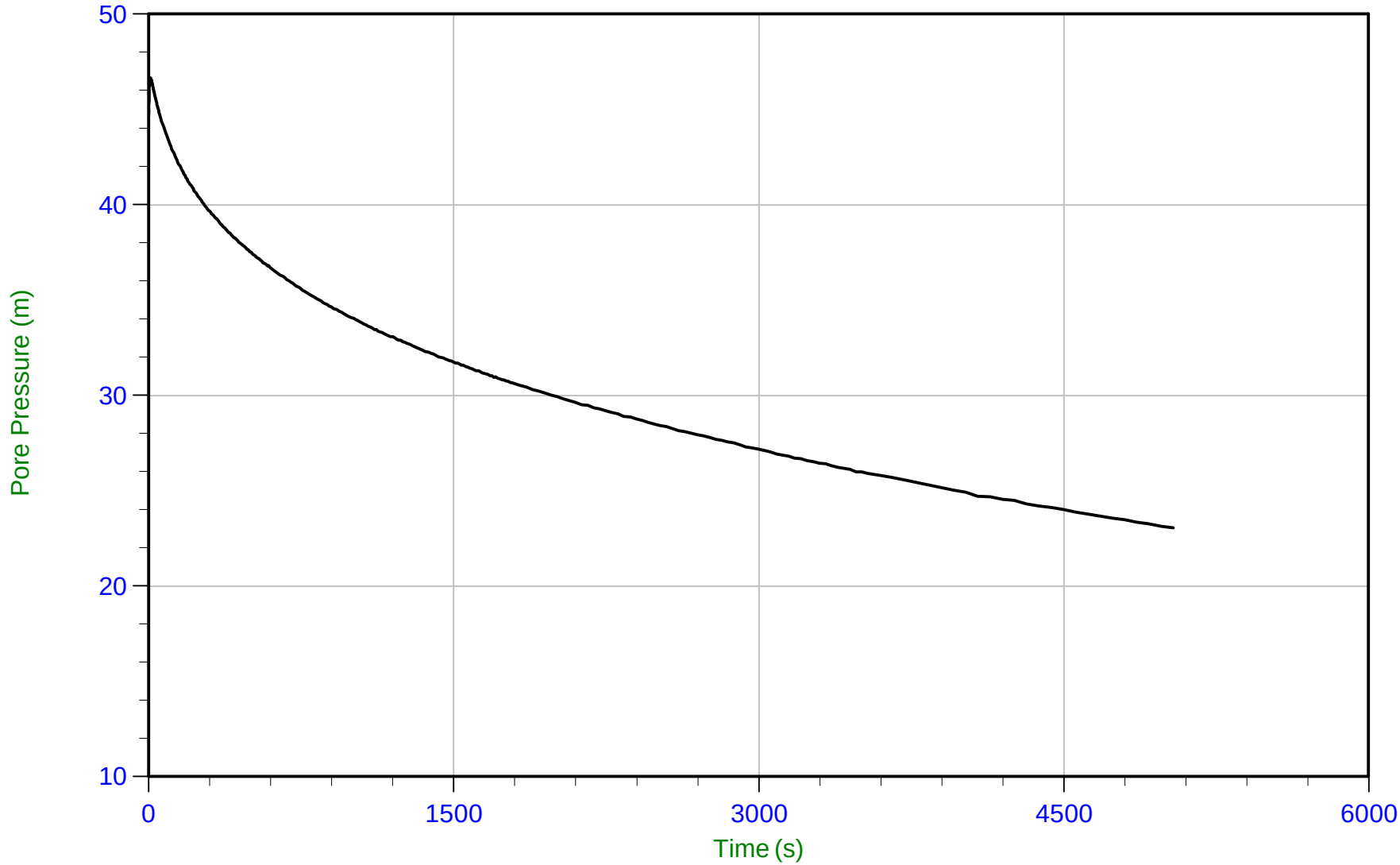
WT: 7.097 m / 23.284 ft
Ueq: 11.8 m

CONETEC

Thurber

Job No: 23-05-26042
Date: 07/11/2023 07:32
Site: Poplar Rapids Bridge, ON

Sounding: SCPT23-205
Cone: 765:T1500F15U35 Area=15 cm²



Trace Summary:

Filename: 23-05-26042_SP23-205.PPF2
Depth: 9.150 m / 30.019 ft
Duration: 5040.0 s

u Min: 23.0 m
u Max: 46.7 m
u Final: 23.0 m

WT: 7.850 m / 25.754 ft
Ueq: 1.3 m
U(50): 23.98 m

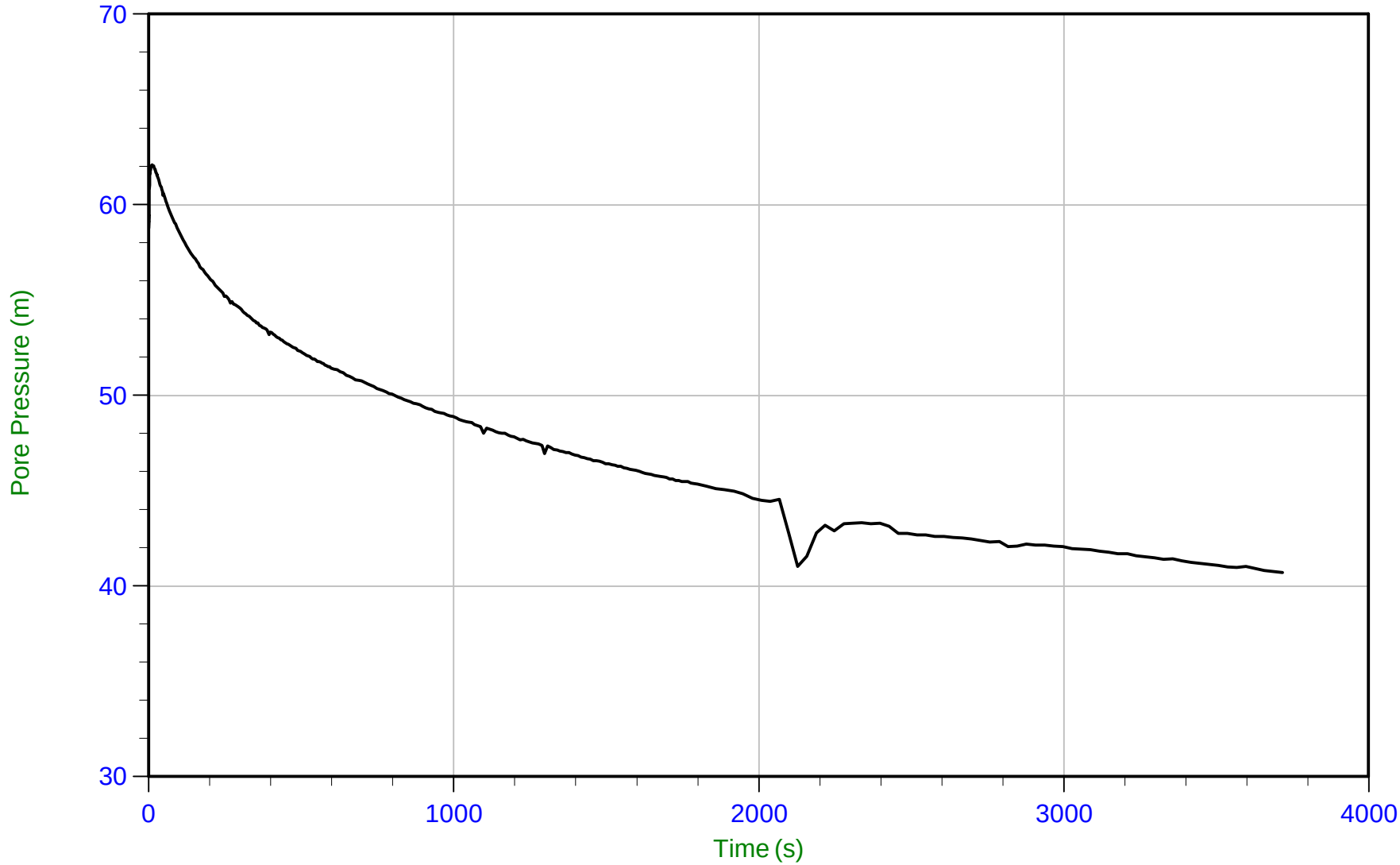
T(50): 4499.3 s
Ir: 100
Ch: 0.2 cm²/min

CONETEC

Thurber

Job No: 23-05-26042
Date: 07/11/2023 07:32
Site: Poplar Rapids Bridge, ON

Sounding: SCPT23-205
Cone: 765:T1500F15U35 Area=15 cm²



Trace Summary:

Filename: 23-05-26042_SP23-205.PPF2
Depth: 12.200 m / 40.026 ft
Duration: 3720.0 s

u Min: 40.7 m
u Max: 62.1 m
u Final: 40.7 m

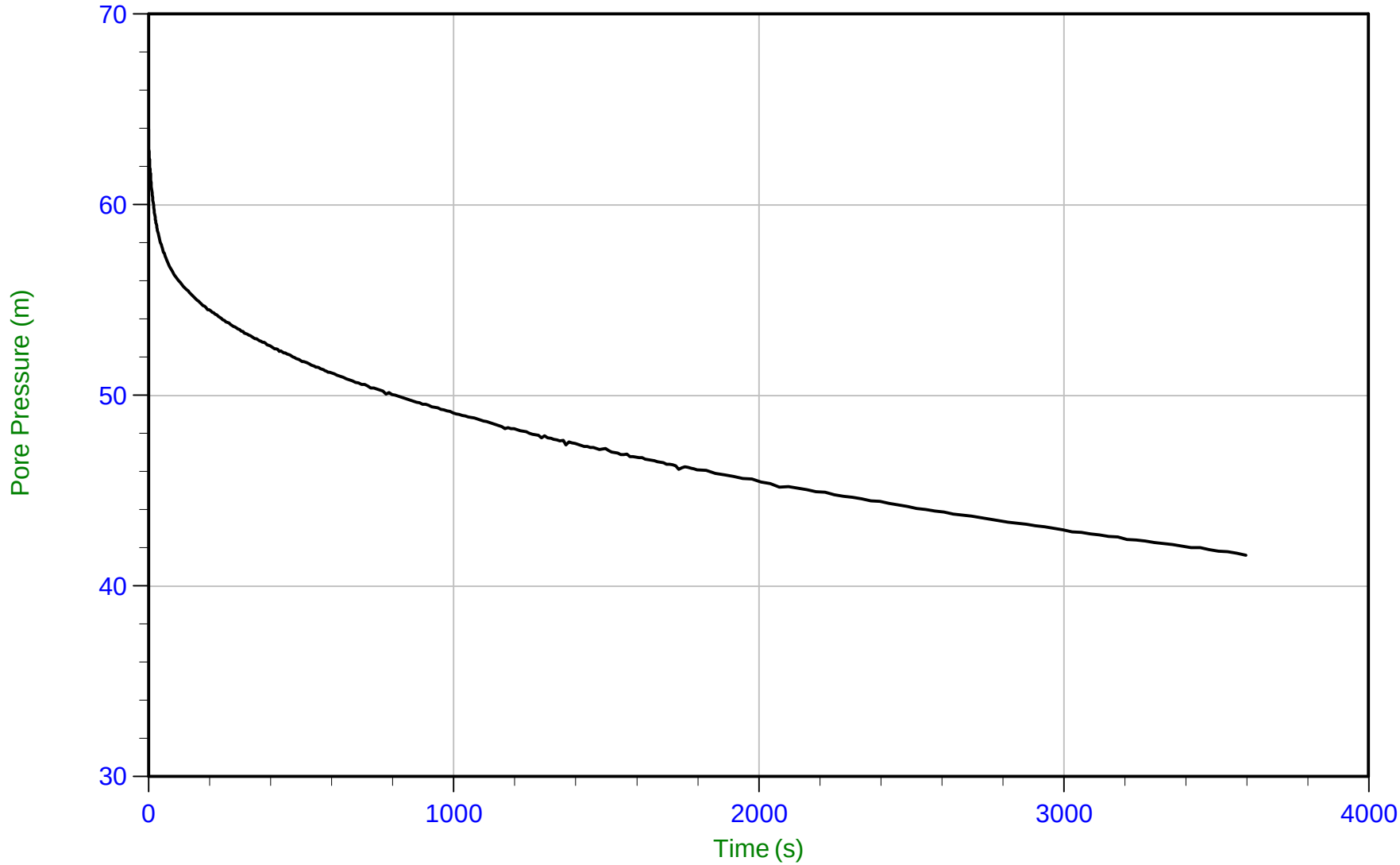
WT: 7.862 m / 25.794 ft
Ueq: 4.3 m

CONETEC

Thurber

Job No: 23-05-26042
Date: 07/11/2023 07:32
Site: Poplar Rapids Bridge, ON

Sounding: SCPT23-205
Cone: 765:T1500F15U35 Area=15 cm²



Trace Summary:

Filename: 23-05-26042_SP23-205.PPF2
Depth: 15.250 m / 50.032 ft
Duration: 3600.0 s

u Min: 41.6 m
u Max: 63.9 m
u Final: 41.6 m

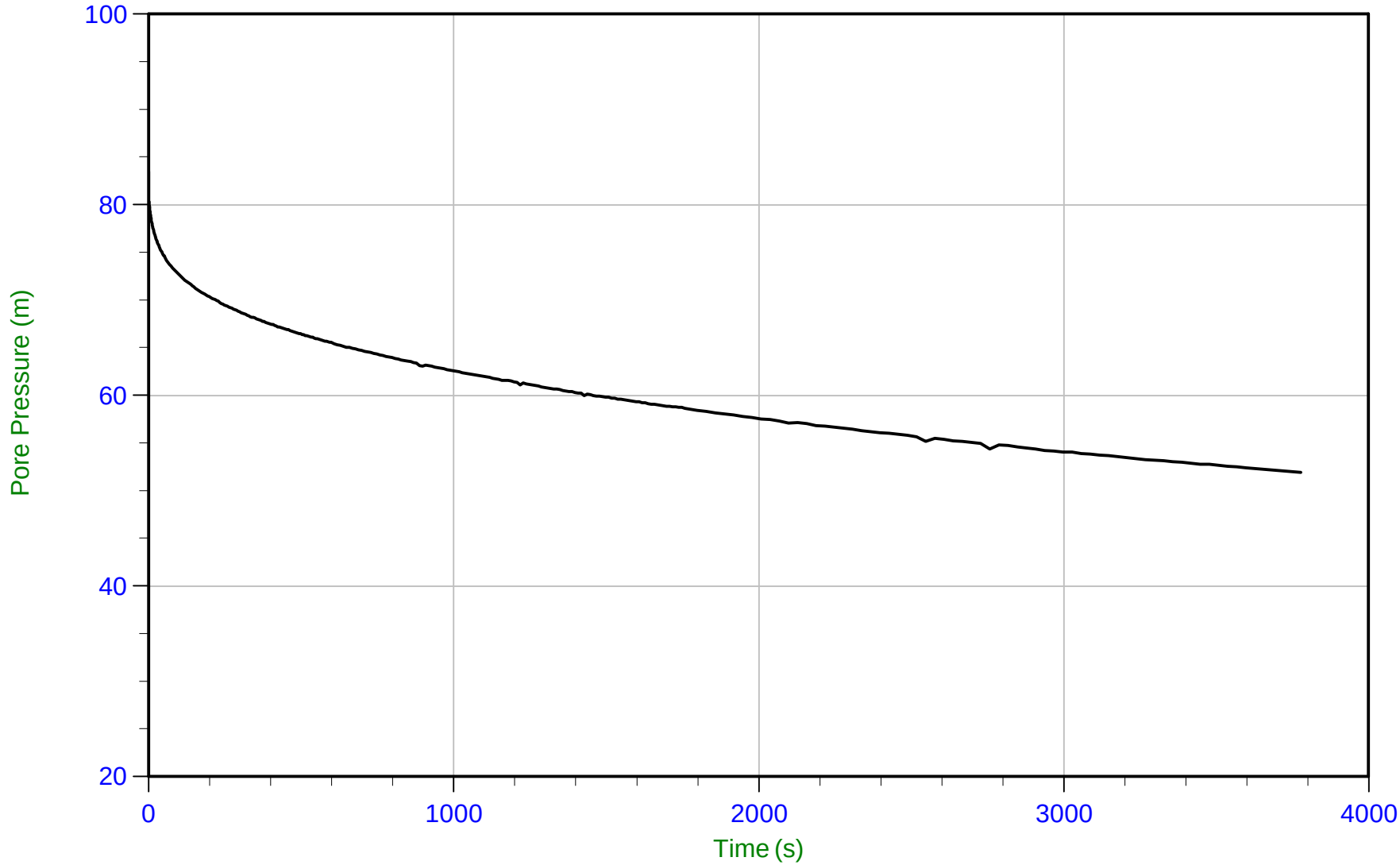
WT: 7.862 m / 25.794 ft
Ueq: 7.4 m

CONETEC

Thurber

Job No: 23-05-26042
Date: 07/11/2023 07:32
Site: Poplar Rapids Bridge, ON

Sounding: SCPT23-205
Cone: 765:T1500F15U35 Area=15 cm²



Trace Summary:

Filename: 23-05-26042_SP23-205.PPF2
Depth: 18.300 m / 60.039 ft
Duration: 3780.0 s

u Min: 51.9 m
u Max: 83.5 m
u Final: 51.9 m

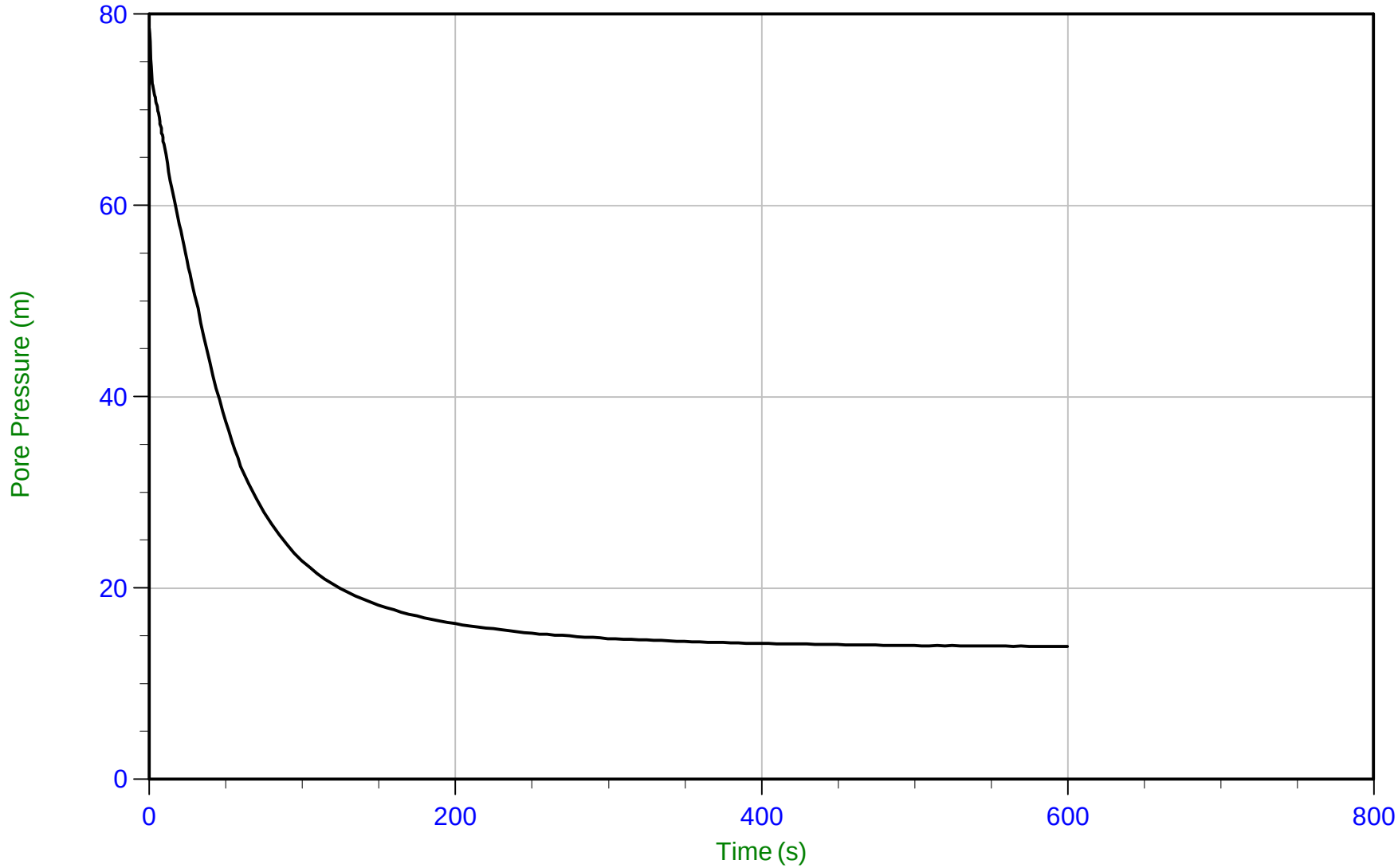
WT: 7.862 m / 25.794 ft
Ueq: 10.4 m

CONETEC

Thurber

Job No: 23-05-26042
Date: 07/11/2023 07:32
Site: Poplar Rapids Bridge, ON

Sounding: SCPT23-205
Cone: 765:T1500F15U35 Area=15 cm²



Trace Summary:

Filename: 23-05-26042_SP23-205.PPF2
Depth: 21.350 m / 70.045 ft
Duration: 600.0 s

u Min: 13.9 m
u Max: 78.5 m
u Final: 13.9 m

WT: 7.862 m / 25.794 ft
Ueq: 13.5 m
U(50): 46.01 m

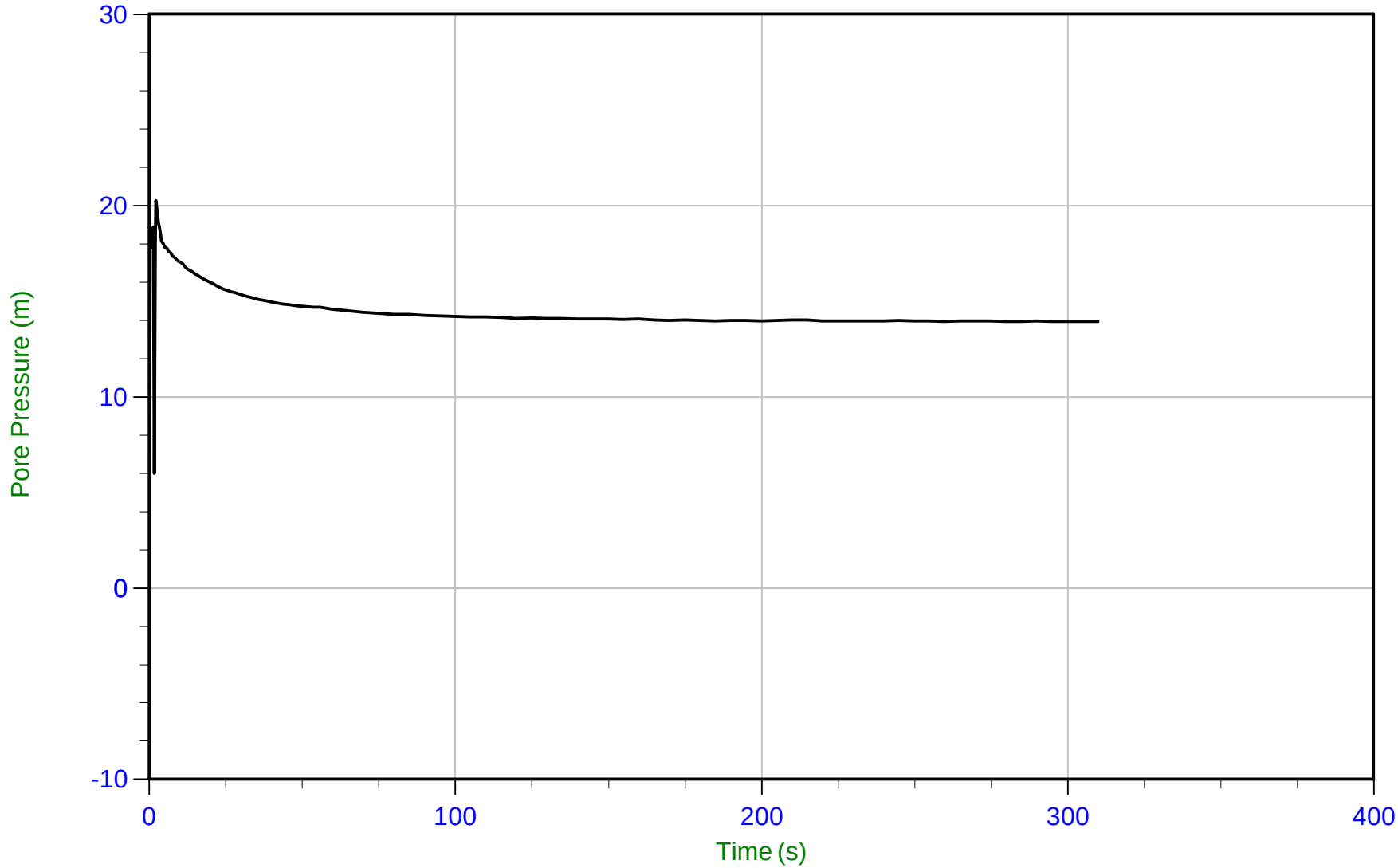
T(50): 36.3 s
Ir: 100
Ch: 19.3 cm²/min

CONETEC

Thurber

Job No: 23-05-26042
Date: 07/11/2023 07:32
Site: Poplar Rapids Bridge, ON

Sounding: SCPT23-205
Cone: 765:T1500F15U35 Area=15 cm²



Trace Summary:

Filename: 23-05-26042_SP23-205.PPF2
Depth: 21.725 m / 71.275 ft
Duration: 310.0 s

u Min: 6.0 m
u Max: 20.3 m
u Final: 13.9 m

WT: 7.862 m / 25.794 ft
Ueq: 13.9 m
U(50): 17.06 m

T(50): 7.5 s
Ir: 100
Ch: 93.5 cm²/min

Description of Methods for Calculated CPT Geotechnical Parameters

CONETEC

CALCULATED CPT GEOTECHNICAL PARAMETERS

A Detailed Description of the Methods Used in ConeTec's CPT Geotechnical Parameter Calculation and Plotting Software

Revision SZW-Rev 18

Revised February 10, 2023
Prepared by Jim Greig, M.A.Sc, P.Eng (BC, AB, ON)

Limitations

The geotechnical parameter output was prepared specifically for the site and project named in the accompanying report subject to objectives, site conditions and criteria provided to ConeTec by the client. The output may not be relied upon by any other party or for any other site without the express written permission of ConeTec Group (ConeTec) or any of its affiliates. For this project, ConeTec has provided site investigation services, prepared factual data reporting and produced geotechnical parameter calculations consistent with current best practices. No other warranty, expressed or implied, is made.

To understand the calculations that have been performed and to be able to reproduce the calculated parameters the user is directed to the basic descriptions for the methods in this document and the detailed descriptions and their associated limitations and appropriateness in the technical references cited for each parameter.

ConeTec's Calculated CPT Geotechnical Parameters as of February 10, 2023.

ConeTec's CPT parameter calculation and plotting routine provides a tabular output of geotechnical parameters based on current published CPT correlations and is subject to change to reflect the current state of practice. Due to drainage conditions and the basic assumptions and limitations of the correlations, not all geotechnical parameters provided are considered applicable for all soil types. The results are presented only as a guide for geotechnical use and should be carefully examined for consideration in any geotechnical design. Reference to current literature is strongly recommended. ConeTec does not warranty the correctness or the applicability of any of the geotechnical parameters calculated by the program and does not assume liability for any use of the results in any design or review. For verification purposes we recommend that representative hand calculations be done for any parameter that is critical for design purposes. The end user of the parameter output should also be fully aware of the techniques and the limitations of any method used by the program. The purpose of this document is to inform the user as to which methods were used and to direct the end user to the appropriate technical papers and/or publications for further reference.

The geotechnical parameter output was prepared specifically for the site and project named in the accompanying report subject to objectives, site conditions and criteria provided to ConeTec by the client. The output may not be relied upon by any other party or for any other site without the express written permission of ConeTec Group (ConeTec) or any of its affiliates.

The CPT calculations are based on values of tip resistance, sleeve friction and pore pressures considered at each data point or averaged over a user specified layer thickness (e.g., 0.20 m). Note that q_t is the tip resistance corrected for pore pressure effects and q_c is the recorded tip resistance. The corrected tip resistance (corrected using u_2 pore pressure values) is used for all calculations. Since all ConeTec cones have equal end area friction sleeves pore pressure corrections to sleeve friction, f_s, are not performed.

Corrected tip resistance: $q_t = q_c + (1-a) \cdot u_2$ (consistent units are required)

where: q_t is the corrected tip resistance
q_c is the recorded tip resistance
u_2 is the recorded dynamic pore pressure from behind the tip (u_2 position)
a is the Net Area Ratio for the cone (typically 0.80 for ConeTec cones)

The total stress calculations are based on soil unit weight values that have been assigned to the Soil Behavior Type (SBT) zones, from a user defined unit weight profile, by using a single uniform value throughout the profile, through unit weight estimation techniques described in various technical papers or from a combination of these methods. The parameter output files indicate the method(s) used.

Effective vertical overburden stresses are calculated using the total stress and equilibrium pore pressure (u_{eq} or u_o) values derived from an assumed hydrostatic distribution of pore pressures below the water table or from a user defined equilibrium pore pressure profile (typically obtained from CPT dissipation tests) or a combination of the two. For over water projects the stress effects of the column of water above the mudline are taken into account as is the appropriate unit weight of water. How this is done depends on where the instruments are zeroed (i.e. on deck or at the mudline). The parameter output files indicate the method(s) used.

A majority of parameter calculations are derived from or driven by results based on material types as determined by the various soil behavior type charts depicted in Figures 1 through 6. The parameter output files indicate the method(s) used.

The Soil Behavior Type classification chart shown in Figure 1 is the classic non-normalized SBT Chart developed at the University of British Columbia and reported in Robertson, Campanella, Gillespie and Greig (1986). Figure 2 shows the original normalized (linear method) SBTn chart developed by Robertson (1990). The Bq classification charts

shown in Figures 3a and 3b incorporate pore pressures into the SBT classification and are based on the methods described in Robertson (1990). Many of these charts have been summarized in Lunne, Robertson and Powell (1997). The Jefferies and Davies SBT chart shown in Figure 3c is based on the techniques discussed in Jefferies and Davies (1993) which introduced the concept of the Soil Behavior Type Index parameter, I_c. Take note that the I_c parameter developed by Robertson and Fear (1995) and Robertson and Wride (1998) is similar in concept but uses a slightly different calculation method than that defined by Jefferies and Davies (1993) as the latter incorporates pore pressure in their technique through the use of the Bq parameter. The normalized Qtn SBT chart shown in Figure 4 is based on the work by Robertson (2009) utilizing a variable stress ratio exponent, n, for normalization based on a slightly modified redefinition and iterative approach for I_c. The boundary curves drawn on the chart are based on the work described in Robertson (2010).

Figure 5 shows a revised 1986 SBT Chart presented to CPT'10 by Robertson (2010b). It is known as the Updated non-normalized Soil Behavior Chart (also referred to as the Rev SBT Chart (PKR2010) in our output files). This chart was produced to be more in line with all post-1986 Robertson charts having the same 9 soil type zones, a $\log_{10}$ axis for friction ratio, R_f in this case, and a unitless tip resistance axis.

Figure 6 shows a revised behavior based chart by Robertson (2016) depicting contractive-dilative zones. As the zones represent material behavior rather than soil gradation ConeTec has chosen a set of zone colors that are less likely to be confused with material type colors from previous SBT charts. These colors differ from those used by Dr. Robertson. A green palette was selected for the dilative (desirable) side of the chart and a red palette for the contractive side of the chart.

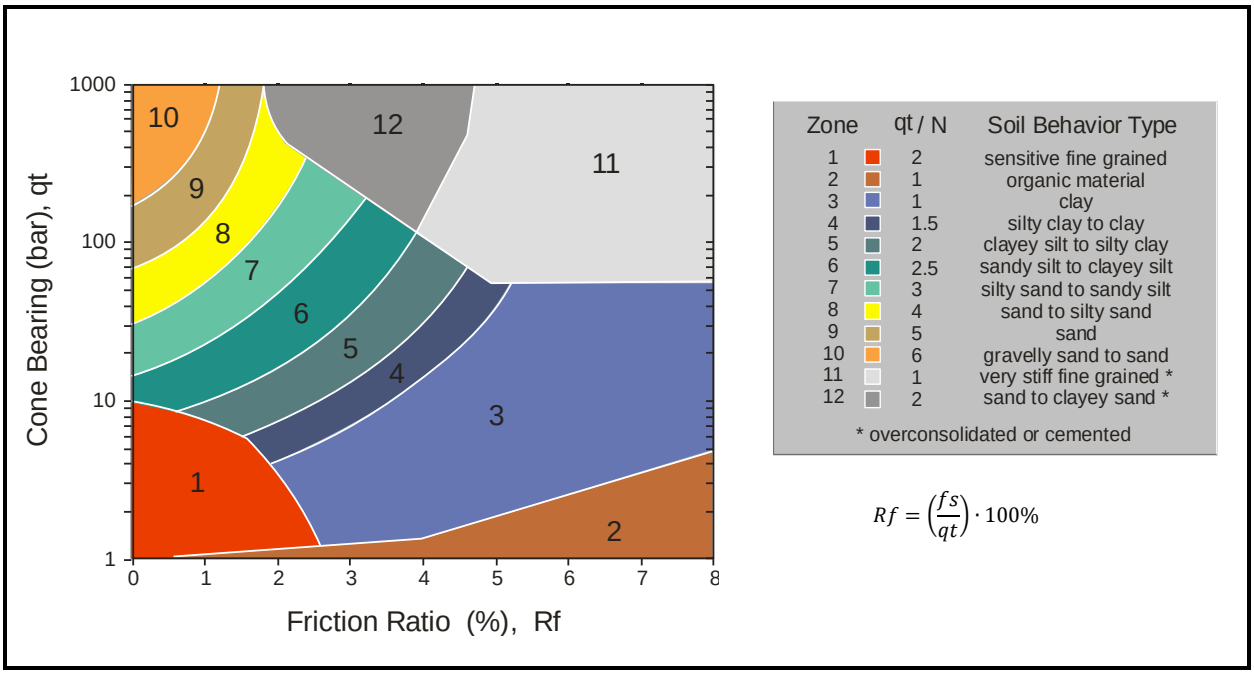


Figure 1. Non-normalized Soil Behavior Type Classification Chart (SBT)

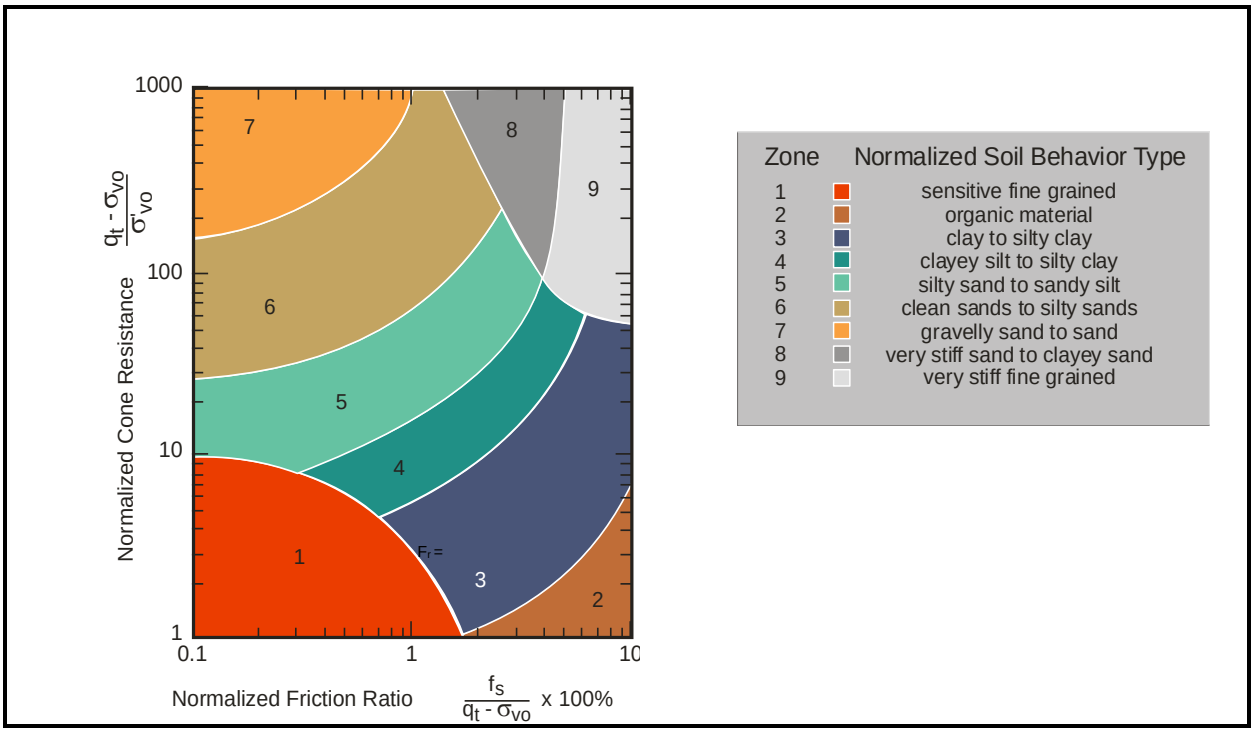


Figure 2. Normalized Soil Behavior Type Classification Chart (SBTn)

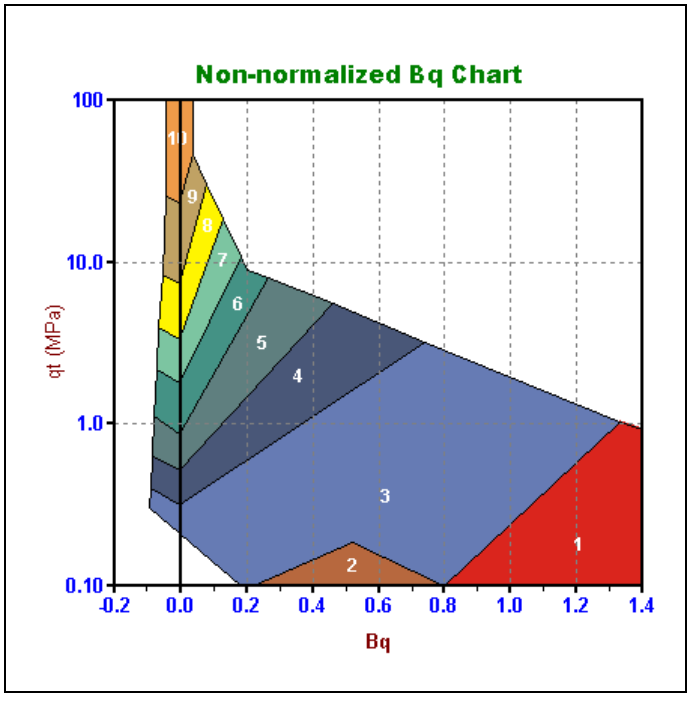


Figure 3a. Alternate Soil Behavior Type Chart (SBT Bq): q_t - B_q

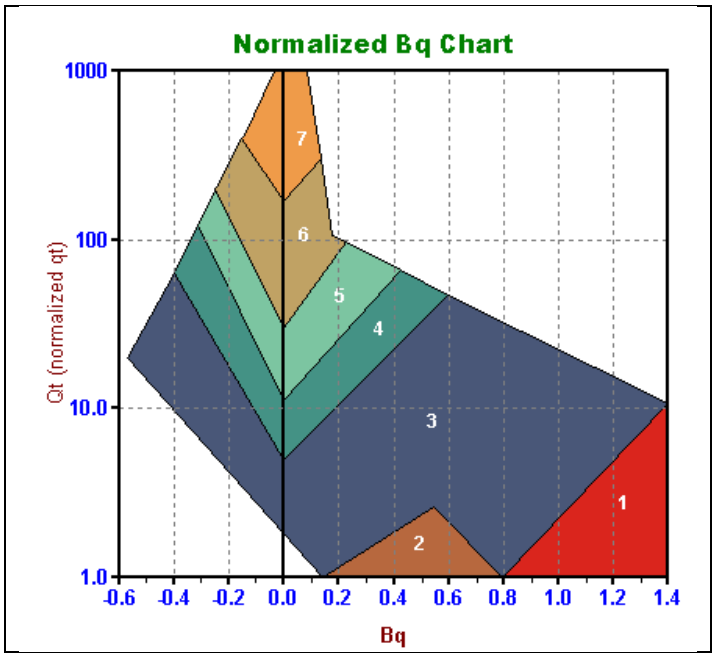


Figure 3b. Alternate Soil Behavior Type Charts (SBT Bqn): Q_t-B_q

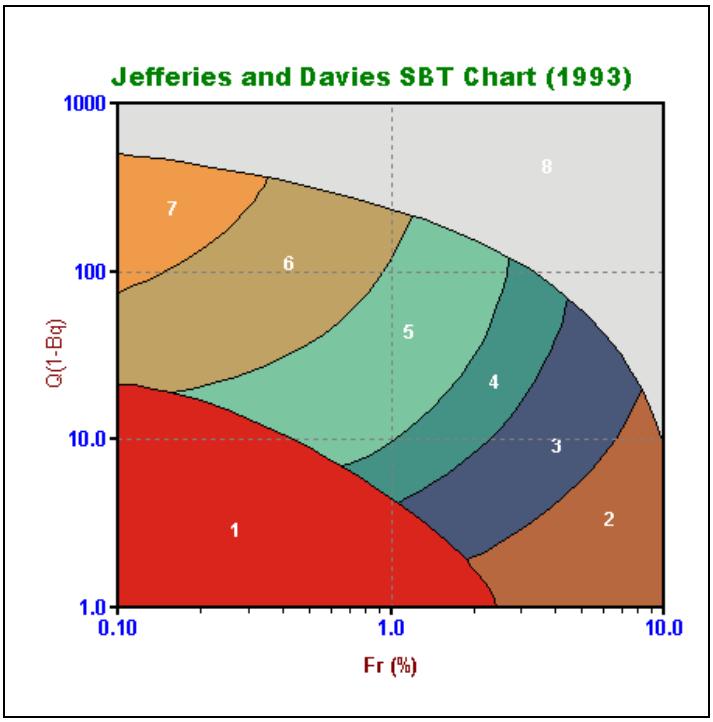


Figure 3c. Alternate Soil Behavior Type Charts: $Q(1-B_q)$ - F_r

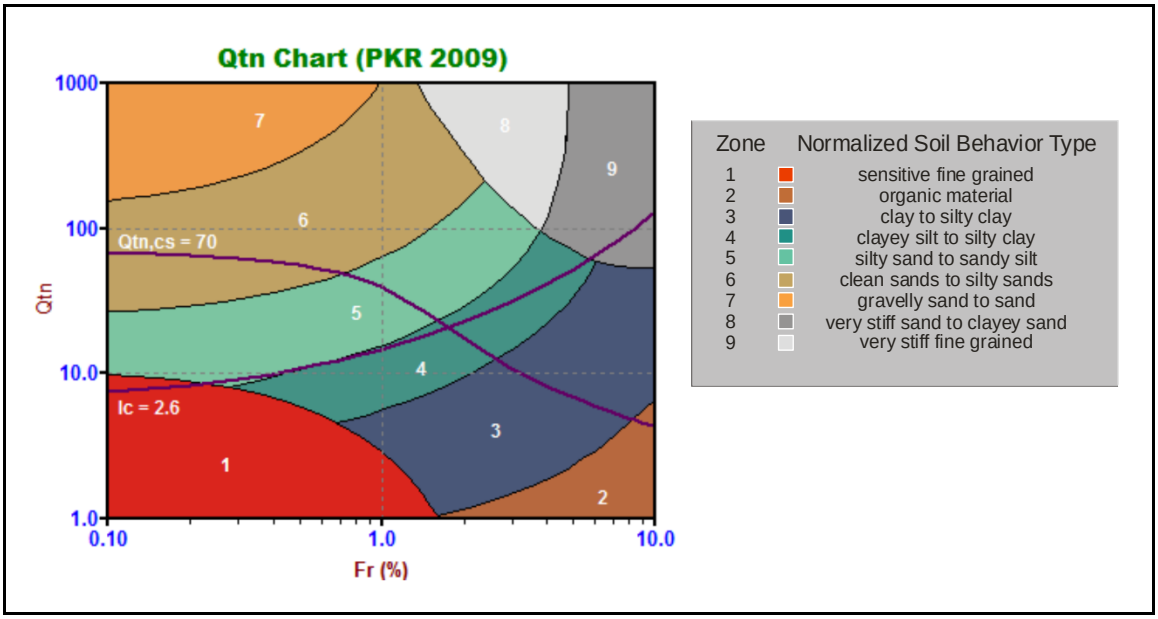


Figure 4. Normalized Soil Behavior Type Chart using Q_{tn} (SBT Qtn)

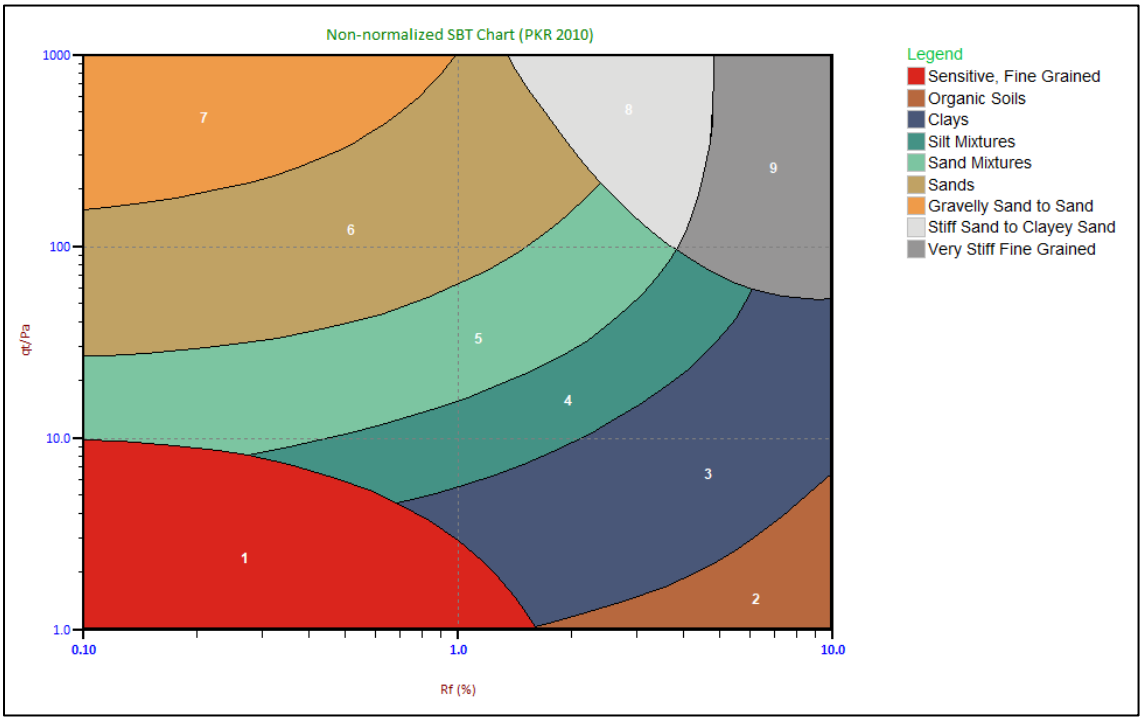


Figure 5. Non-normalized Soil Behavior Type Chart (2010)

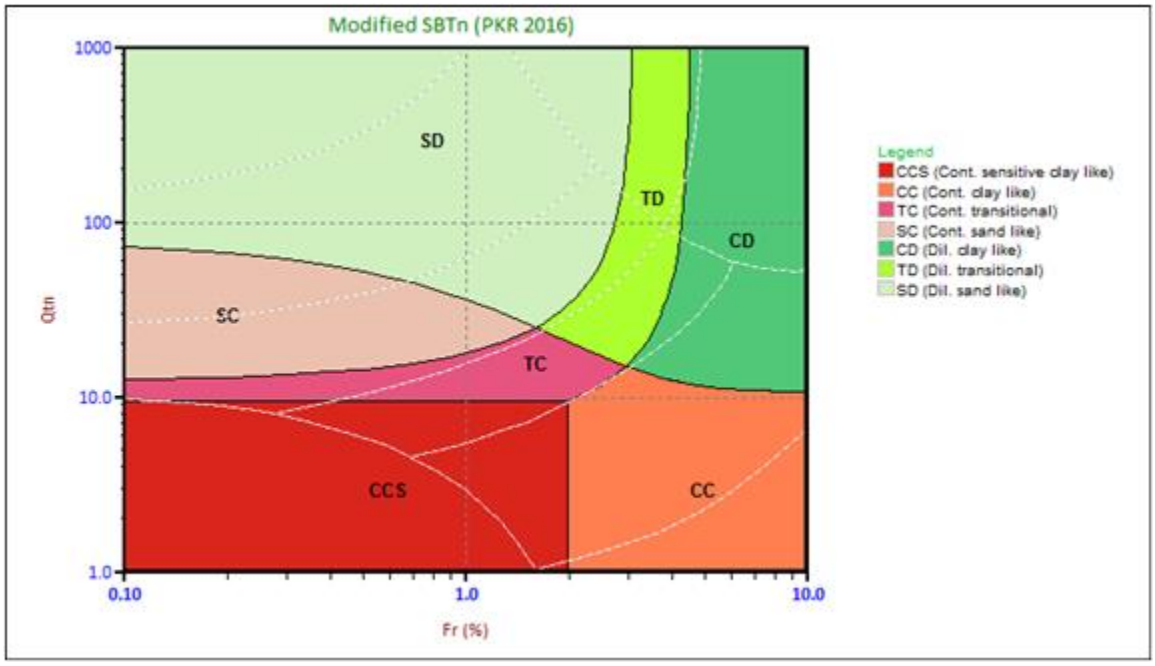


Figure 6. Modified SBTn Behavior Based Chart

Details regarding the geotechnical parameter calculations are provided in Tables 1a and 1b. The appropriate references cited are listed in Table 2. Non-liquefaction specific parameters are detailed in Table 1a and liquefaction specific parameters are detailed in Table 1b.

Where methods are based on charts or techniques that are too complex to describe in this summary, we recommend that the user refer to the cited material. Specific limitations for each method are described in the cited material.

Where the results of a calculation/correlation are deemed *'invalid'* the value will be represented by the text strings "-9999", "-9999.0", the value 0.0 (Zero) or an empty cell. Invalid results will occur because of (and not limited to) one or a combination of:

1. Invalid or undefined CPT data (e.g., drilled out section or data gap).

2. Where the calculation method is inappropriate, for example, drained parameters in a material behaving in an undrained manner (and vice versa).

3. Where input values are beyond the range of the referenced charts or specified limitations of the correlation method.

4. Where pre-requisite or intermediate parameter calculations are invalid.

The parameters selected for output from the program are often specific to a particular project. As such, not all of the calculated parameters listed in Tables 1and 1a may be included in the output files delivered with this report.

The output files are typically provided in Microsoft Excel XLS, XLSX or CSV format. The ConeTec software has several options for output depending on the number or types of calculated parameters desired or those specifically contracted for by the client. Each output file is named using the original file base name (from the .COR file) followed

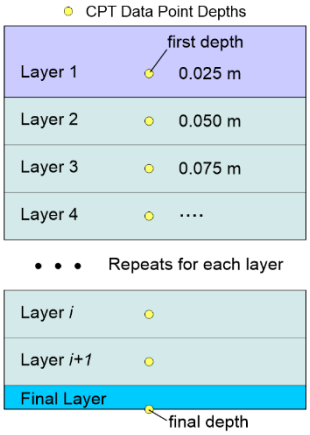
by a three or four character indicator of the output set selected (e.g. BSC, TBL, NLI, NL2, IFI, IFI2, IFI3) and possibly followed by an operator selected suffix identifying the characteristics of the particular calculation run.

Table 1a. CPT Parameter Calculation Methods – Non liquefaction Parameters

Reference Notes: CK* - Common Knowledge, U* - Unpublished

Calculated Parameter	Description	Equation	Ref
Depth	Mid Layer Depth *(where calculations are done at each point then Mid Layer Depth = Recorded Depth)*	*[Depth (Layer Top) + Depth (Layer Bottom)]/ 2.0*	CK*
Elevation	Elevation of Mid Layer is based on the sounding collar elevation supplied by the client or through a site survey In Sweden a variation of elevation is used where the elevation increases with depth. We refer to this as inverse elevation.	Elevation = Collar Elevation – Depth InverseElevation = Collar Elevation + Depth	CK* N/A
Avg qc	Averaged recorded tip value (q_c)	$Avgqc = \frac{1}{n}\sum_{i=1}^{n} q_c$ *n=1 when calculations are done at each point*	CK*
Avg qt	Averaged corrected tip (q_t) where: $q_t = q_c + (1-a)\cdot u_2$ Averaged q_t is not calculated using the average q_c and averaged u values. Averaged q_t is based on the average of the q_t values calculated at each data point.	$Avgqt = \frac{1}{n}\sum_{i=1}^{n} q_t$ *n=1 when calculations are done at each point*	1
Avg fs	Averaged sleeve friction (f_s) No pore pressure corrections are applied to f_s.	$Avgfs = \frac{1}{n}\sum_{i=1}^{n} fs$ *n=1 when calculations are done at each point*	CK*
Avg Rf	Averaged friction ratio (R_f) where friction ratio is defined as: $R_f = 100\% \cdot \frac{fs}{q_t}$	$AvgRf = 100\% \cdot \frac{Avgfs}{Avgqt}$ *not an average of individual R_f values*	CK*
Avg u	Averaged dynamic pore pressure *(u)*	$Avgu = \frac{1}{n}\sum_{i=1}^{n} u_i$ *n=1 when calculations are done at each point*	CK*
Avg Res	Averaged Resistivity (this data is not always available since it is a specialized test requiring an additional module)	$AvgRes = \frac{1}{n}\sum_{i=1}^{n} Resistivity_i$ *n=1 when calculations are done at each point*	CK*
Avg UVIF	Averaged UVIF ultra-violet induced fluorescence (this data is not always available since it is a specialized test requiring an additional module)	$AvgUVIF = \frac{1}{n}\sum_{i=1}^{n} UVIF_i$ *n=1 when calculations are done at each point*	CK*
Avg Temp	Averaged Temperature (this data is not always available)	$AvgTemp = \frac{1}{n}\sum_{i=1}^{n} Temperature_i$ *n=1 when calculations are done at each point*	CK*
Avg Gamma	Averaged Gamma Counts (this data is not always available since it is a specialized test requiring an additional module)	$AvgGamma = \frac{1}{n}\sum_{i=1}^{n} Gamma_i$ *n=1 when calculations are done at each point*	CK*
SBT	Soil Behavior Type as defined by Robertson et al 1986 (often referred to as Robertson and Campanella, 1986)	See Figure 1	1, 5
SBTn	Normalized Soil Behavior Type as defined by Robertson 1990 (linear normalization using Q_t, now referred to as Q_{t1})	See Figure 2	2, 5

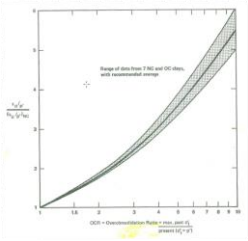
Calculated Parameter	Description	Equation	Ref
SBT-Bq	Non-normalized Soil Behavior type based on non-normalized tip resistance and the B_q parameter	See Figure 3a	1, 2, 5
SBT-Bqn	Normalized Soil Behavior type based on normalized tip resistance (Q_t, now called Q_{t1}) and the B_q parameter	See Figure 3b	2, 5
SBT-JandD	Soil Behavior Type as defined by Jeffries and Davies	See Figure 3c	7
SBT Qtn	Soil Behavior Type as defined by Robertson (2009) using a variable stress ratio exponent for normalization based on $I_{c\ (PKR\ 2009)}$	See Figure 4	15
Modified Non-normalized SBT Chart SBT (PKR2010)	This is a revised version of the simple 1986 non-normalized SBT chart (presented at CPT '10). The revised version has been reduced from 12 zones to 9 zones to be similar to the normalized Robertson charts. Other updates include a dimensionless tip resistance normalized to atmospheric pressure, q_t/P_a, on the vertical axis and a log scale for non-normalized friction ratio, R_f, along the horizontal axis.	See Figure 5	33
Modified SBTn (contractive /dilative)	Modified SBTn chart as defined by Robertson (2016) indicating zones of contractive/dilative behavior. Note that ConeTec displays the chart with colors different from Robertson. ConeTec's colors were chosen to avoid confusion with soil type descriptions.	See Figure 6	30
Unit Wt.	Unit Weight of soil determined from one of the following user selectable options: 1) uniform value 2) value assigned to each SBT zone 3) value assigned to each SBTn zone 4) value assigned to SBTn zone as determined from Robertson and Wride (1998) based on q_{c1n} 5) values assigned to SBT Qtn zones 6) values based on Robertson updated non-normalized Soil Behavior Type Chart (2010b) 6) Mayne f_s (sleeve friction) method 7) Robertson and Cabal 2010 method 8) user supplied unit weight profile The last option may co-exist with any of the other options.	See references	3, 5, 15, 21, 24, 29, 33

Calculated Parameter	Description	Equation	Ref
TStress σ_v	Total vertical overburden stress at Mid Layer Depth *A layer is defined as the averaging interval specified by the user where depths are reported at their respective mid-layer depth.* For data calculated at each point layers are defined using the recorded depth as the mid-point of the layer. Thus, a layer starts half-way between the previous depth and the current depth unless this is the first point in which case the layer start is at zero depth. The layer bottom is half-way from the current depth to the next depth unless it is the last data point. Defining layers affects how stresses are calculated since the unit weight attributed to a data point is used throughout the entire layer. This means that to calculate the stresses the total stress at the top and bottom of a layer are required. The stress at mid layer is determined by adding the incremental stress from the layer top to the mid-layer depth. The stress at the layer bottom becomes the stress at the top of the subsequent layer. Stresses are NOT calculated from mid-point to mid-point. For over-water work the total stress due to the column of water above the mid line is taken into account where appropriate.	$TStress = \sum_{i=1}^{n} \gamma_i h_i$ *where* γ_i is layer unit weight h_i is layer thickness 	CK*
EStress σ_v'	Effective vertical overburden stress at mid-layer depth.	$\sigma_v' = \sigma_v - u_{eq}$	CK*
Equil u u_{eq} or u_0	Equilibrium pore pressures are determined from one of the following user selectable options: 1) hydrostatic below the water table 2) user supplied profile 3) combination of those above When a user supplied profile is used/provided a linear interpolation is performed between equilibrium pore pressures defined at specific depths. If the profile values start below the water table then a linear transition from zero pressure at the water table to the first defined pointed is used. Equilibrium pore pressures may come from dissipation tests, adjacent piezometers or other sources. Occasionally, an extra equilibrium point ("assumed value") will be provided in the profile that does not come from a recorded value to smooth out any abrupt changes or to deal with material interfaces. These "assumed" values will be indicated on our plots and in tabular summaries.	For the hydrostatic option: $u_{eq} = \gamma_w \cdot (D - D_{wt})$ where u_{eq} is equilibrium pore pressure γ_w is the unit weight of water D is the current depth D_{wt} is the depth to the water table	CK*
K_0	Coefficient of earth pressure at rest, K_0.	$K_O = (1 - \sin\Phi') OCR^{\sin\Phi'}$	17
C_n	Overburden stress correction factor used for $(N_1)_{60}$ and older CPT parameters.	$C_n = (P_a/\sigma_v')^{0.5}$ where $0.0 < C_n < 2.0$ *(user adjustable, typically ranging from 1.7 to 2.0)* P_a *is atmospheric pressure (100 kPa)*	4, 12

Calculated Parameter	Description	Equation	Ref
C_q	Overburden stress normalizing factor.	$C_q = 1.8 / [0.8 + (\sigma_v'/P_a)]$ where *$0.0 < C_q < 2.0$ (user adjustable)* *P_a is atmospheric pressure (100 kPa)* *Robertson and Wride define C_q to be the same as C_n. The Olson definition above is used in the program.*	3, 12
N_{60}	SPT N value at 60% energy calculated from q_t/N ratios assigned to each SBT zone. This method has abrupt N value changes at zone boundaries.	*See Figure 1*	5
$(N_1)_{60}$	SPT N_{60} value corrected for overburden pressure.	$(N_1)_{60} = C_n \bullet N_{60}$	4
$N_{60}I_c$	SPT N_{60} values based on the I_c parameter, as defined by Robertson and Wride 1998 (3), or by Robertson 2009 (15).	$(q_t/P_a)/ N_{60} = 8.5 (1 – I_c/4.6)$ $(q_t/P_a)/ N_{60} = 10^{(1.1268 – 0.2817Ic)}$ P_a being atmospheric pressure	3, 5 15, 31
$(N_1)_{60}I_c$	SPT N_{60} value corrected for overburden pressure (using N_{60} I_c). User has 3 options.	*1) $(N_1)_{60}Ic = C_n \bullet (N_{60} I_c)$* 2) $q_{c1n}/ (N_1)_{60}I_c = 8.5 (1 – I_c/4.6)$ 3) $(Q_{tn})/ (N_1)_{60}I_c = 10^{(1.1268 – 0.2817Ic)}$	4 5 15, 31
S_u or S_u (N_{kt})	Undrained shear strength based on q_t S_u factor N_{kt} is user selectable.	$Su = \frac{qt - \sigma_v}{N_{kt}}$	1, 5
S_u or S_u (N_{du}) or S_u ($N_{\Delta u}$)	Undrained shear strength based on pore pressure S_u factor $N_{\Delta u}$ is user selectable.	$Su = \frac{u_2 - u_{eq}}{N_{\Delta u}}$	1, 5
D_r	Relative Density determined from one of the following user selectable options: 1) Ticino Sand 2) Hokksund Sand 3) Schmertmann (1978) 4) Jamiolkowski (1985) - All Sands 5) Jamiolkowski et al (2003) (various compressibilities, K_o)	See reference (methods 1 through 4) Jamiolkowski et al (2003) reference	5 14
PHI ϕ	Friction Angle determined from one of the following user selectable options (methods 1 through 4 are for sands and method 5 is for silts and clays): 1) Campanella and Robertson 2) Durgunoglu and Mitchel 3) Janbu 4) Kulhawy and Mayne 5) NTH method (clays and silts)	See appropriate reference	5 5 5 11 23
Delta U/q_t $\Delta u/q_t$ du/q_t	Differential pore pressure ratio (older parameter used before B_q was established)	$= \frac{\Delta u}{qt}$ *where:* $\Delta u = u - u_{eq}$ *and u = dynamic pore pressure* *u_{eq} = equilibrium pore pressure*	39

Calculated Parameter	Description	Equation	Ref
B_q	Pore pressure parameter	$Bq = \frac{\Delta u}{qt - \sigma_v}$ where: $\Delta u = u - u_{eq}$ *and* u *= dynamic pore pressure* u_{eq} *= equilibrium pore pressure*	1, 2, 5
Net q_t or qtNet	Net tip resistance (used in many subsequent correlations)	$qt - \sigma_v$	36
q_e or qE or q_E	Effective tip resistance (using the dynamic pore pressure u_2 and not equilibrium pore pressure)	$q_t - u_2$	36
qeNorm	Normalized effective tip resistance	$\frac{qt - u_2}{\sigma_v'}$	36
Q_t or Norm: Qt or Q_{t1}	Normalized q_t for Soil Behavior Type classification as defined by Robertson (1990) using a linear stress normalization. Note this is different from Q_{tn}. This parameter was renamed to Q_{t1} in Robertson, 2009. Without normalization limits this parameter calculates to very high unrealistic values at low stresses.	$Qt = \frac{qt - \sigma_v}{\sigma_v'}$	2, 5, 15
F_r or Norm: Fr	Normalized Friction Ratio for Soil Behavior Type classification as defined by Robertson (1990)	$Fr = 100\% \cdot \frac{fs}{qt - \sigma_v}$	2, 5
Q(1-B_q) Q(1-B_q) + 1	Q(1-B_q) grouping as suggested by Jefferies and Davies for their classification chart and the establishment of their I_c parameter. Later papers added the +1 term to the equation.	$Q \cdot (1 - Bq)$ $Q \cdot (1 - Bq) + 1$ *where Bq is defined as above and Q is the same as the normalized tip resistance,* Q_{t1}*, defined above*	6, 7, 34
q_{c1}	Normalized tip resistance, q_{c1}, using a fixed stress ratio exponent, n (this method has stress units)	$q_{c1} = q_t \cdot (Pa/\sigma_v')^{0.5}$ where: P_a = atmospheric pressure	21
q_{c1} (0.5)	Normalized tip resistance, q_{c1}, using a fixed stress ratio exponent, n (this method is unit-less)	$q_{c1}(0.5) = (q_t/P_a) \cdot (Pa/\sigma_v')^{0.5}$ where: P_a = atmospheric pressure	5
q_{c1} (C_n)	Normalized tip resistance, q_{c1}, based on C_n (this method has stress units)	$q_{c1}(Cn) = C_n * q_t$	5, 12
q_{c1} (C_q)	Normalized tip resistance, q_{c1}, based on C_q (this method has stress units)	$q_{c1}(Cq) = C_q * q_t$ (some papers use q_c)	5, 12
q_{c1n}	normalized tip resistance, q_{c1n}, using a variable stress ratio exponent, n (where n=0.0, 0.70, or 1.0) (this method is unit-less)	$q_{c1n} = (q_t / P_a)(P_a/\sigma_v')^n$ where: P_a = atm. Pressure and n varies as described below	3

Calculated Parameter	Description	Equation	Ref
I_c or Ic (RW1998)	Soil Behavior Type Index as defined by Robertson and Wride (1997, 1998) for estimating grain size characteristics and providing smooth gradational changes across the SBTn chart. Ic(RW1998) is different from that of Jefferies and Davies (7) and is different from Ic(PKR2009).	$I_c = [(3.47 - \log_{10}Q)^2 + (\log_{10} Fr + 1.22)^2]^{0.5}$ *Where:* $Q = \left(\frac{qt - \sigma_v}{P_a}\right)\left(\frac{P_a}{\sigma_v'}\right)^n$ *Or* $Q = q_{c1n} = \left(\frac{qt}{P_a}\right)\left(\frac{P_a}{\sigma_v'}\right)^n$ *depending on the iteration in determining I_c* *And Fr is in percent* *P_a = atmospheric pressure* *n has the following distinct values:* *0.5, 0.75 and 1.0* *and is determined in an iterative manner based on the resulting I_c in each iteration* *Note that NCEER replaced 0.75 with 0.70*	3, 4, 5 10
I_c (PKR 2009)	Soil Behavior Type Index, I_c (PKR 2009) is based on a variable stress ratio exponent n, which itself is based on I_c (PKR 2009). An iterative calculation is required to determine I_c (PKR 2009) and its corresponding n (PKR 2009).	*I_c (PKR 2009) =* *$[(3.47 - \log_{10}Q_{tn})^2 + (1.22 + \log_{10}F_r)^2]^{0.5}$*	15
n (PKR 2009)	Stress ratio exponent n, based on I_c (PKR 2009). An iterative calculation is required to determine n (PKR 2009) and its corresponding I_c (PKR 2009).	*n (PKR 2009) = 0.381 (I_c) + 0.05 (σ_v'/P_a) – 0.15*	15
Q_{tn} (PKR 2009)	Normalized tip resistance using a variable stress ratio exponent based on I_c (PKR 2009) and n (PKR 2009). An iterative calculation is required to determine Q_{tn} (PKR 2009).	*$Q_{tn} = [(qt - \sigma_v)/P_a](P_a/\sigma_v')^n$* *where P_a = atmospheric pressure (100 kPa)* *n = stress ratio exponent described above*	15
FC	Apparent fines content (%)	*FC=1.75($Ic^{3.25}$) - 3.7* *FC=100 for $I_c > 3.5$* *FC=0 for $I_c < 1.26$* *FC = 5% if $1.64 < I_c < 2.6$ AND $F_r<0.5$*	3
I_c Zone	This parameter is the Soil Behavior Type zone based on the I_c parameter (valid for zones 2 through 7 on SBTn or SBT Qtn charts)	$I_c < 1.31$ Zone = 7 $1.31 < I_c < 2.05$ Zone = 6 $2.05 < I_c < 2.60$ Zone = 5 $2.60 < I_c < 2.95$ Zone = 4 $2.95 < I_c < 3.60$ Zone = 3 $I_c > 3.60$ Zone = 2	3
CD	The contractive / dilative boundary on Robertson's Modified SBTn (contractive/dilative) Chart shown in Figure 6 above. The boundary is marked as CD = 70 on the chart in the relevant paper. Similar to the $Q_{tn,cs}$ = 70 line in Figure 4.	$CD = 70 = (Q_{tn} - 11)(1 + 0.06F_r)^{17}$ lower bound of CD = 60: $CD = 60 = (Q_{tn} - 9.5)(1 + 0.06F_r)^{17}$	30

Calculated Parameter	Description	Equation	Ref
I_B	Hyberbolic fit defining the boundary between SBT soil types proposed by Schneider as a better fit than the I_c circles. I_B = 32 represents the boundary for most sand like soils. I_B = 22 represents the upper boundary for most clay like soils. The region between I_B=22 and I_B=32 is the "transitional soil" zone.	$I_B = 100\ (Q_{tn} + 10) / (70 + Q_{tn}\ F_r)$	30
State Param or State Parameter or ψ	The state parameter index, ψ, is defined as the difference between the current void ratio, e, and the critical void ratio, e_c. Positive ψ - contractive soil Negative ψ - dilative soil This is based on the work by Been and Jefferies (1985) and Plewes, Davies and Jefferies (1992) This method uses mean normal stresses based on a uniform value of K_0 or a calculated K_0 using methods described elsewhere in this document	See reference	6, 8
Yield Stress σ_p'	Yield stress is calculated using the following methods 1) General method 2) 1st order approximation using q_tNet (clays) 3) 1st order approximation using Δu_2 (clays) 4) 1st order approximation using q_e (clays) 5) Based on Vs	All stresses in kPa 1) $\sigma_p' = 0.33 \cdot (q_t - \sigma_v)^{m'} (\sigma_{atm}/100)^{1-m'}$ where $m' = 1 - \frac{0.28}{1 + (I_c / 2.65)^{25}}$ 2) $\sigma_p' = 0.33 \cdot (q_t - \sigma_v)$ 3) $\sigma_p' = 0.54 \cdot (\Delta u_2)$ $\Delta u_2 = u_2 - u_0$ 4) $\sigma_p' = 0.60 \cdot (q_t - u_2)$ 5) $\sigma_p' = (Vs/4.59)^{1.47}$	19 20 20 20 18
OCR OCR(JS1978) YSR(Mayne2014) YSR (qtNet) YSR (deltaU) YSR (qe) YSR (Vs) OCR (PKR2015)	Over Consolidation Ratio based on 1) Schmertmann (1978) method involving a plot plot of S_u/σ_v' /($S_u/\sigma_v')_{NC}$ and OCR  2) based on Yield stresses described above 3) approximate version based on qtNet 4) approximate version based on Δu 5) approximate version based on effective tip, q_e 6) approximate version based on shear wave velocity, V_s and σ_v' 7) based on Qt	1) requires a user defined value for NC Su/P_c' ratio 2 through 5) *based on yield stresses* 6) YSR (Vs) = $\sigma_p'(Vs) / \sigma_v'$ 7) OCR = $0.25 \cdot (Qt)^{1.25}$	9 19 20 20 20 18 32
Es/qt	Intermediate parameter for calculating Young's Modulus, E, in sands. It is the Y axis of the reference chart. Note that Figured 5.59 from reference 5, Lunne, Robertson and Powell, (LRP) has an error. The X axis values are too high by a factor of 10. The plot is based on Baldi's (not Bellotti as cited in	Based on Figure 5.59 in the reference	5, 37

Calculated Parameter	Description	Equation	Ref
	LRP) original Figure 3 where the X axis is: $\frac{q_c}{\sqrt{\sigma'_v}}$ (both in kPa) with a range of 200 to 3000. Figure 5.59 from LRP shows a dimensionless form of the equation, q_{c1}, displaying the same range of values. Figure 5.59's X axis uses $q_{c1} = \left(\frac{q_c}{P_a}\right)\left(\frac{P_a}{\sigma'_v}\right)^{0.5}$ The two expressions are not the same: they differ by a factor of $\frac{\sqrt{P_a}}{P_a}$. With P_a taken to be 100 kPa the factor is 1/10. Substituting typical values of 200 bar (20000 kPa) for q_c and 225 kPa for σ_v' one gets: 20000 / 15 = 1333.33 for Bellotti's axis and $(200/1)(100/225)^{0.5}$ = 200 * (10/15) = 133.3 for LRP's axis (noting that P_a = 1 bar) showing a factor of 10 difference.		
Es or E_s Young's Modulus E	Young's Modulus based on the work done in Italy. There are three types of sands considered in this technique. The user selects the appropriate type for the site from: a) OC Sands b) Aged NC Sands c) Recent NC Sands Each sand type has a family of curves that depend on mean normal stress. The program calculates mean normal stress and linearly interpolates between the two extremes provided in the E_s/q_t chart. E_s is evaluated for an axial strain of 0.1%.	Mean normal stress is evaluated from: $\sigma'_m = \frac{1}{3}(\sigma'_v + \sigma'_h + \sigma'_h)$ where σ_v'= vertical effective stress σ_h'= horizontal effective stress *and* $\sigma_h = K_o \cdot \sigma_v'$ with K_o assumed to be 0.5	5
Delta U/TStress $\Delta u / \sigma_v$	Differential pore pressure ratio with respect to total stress	$= \frac{\Delta u}{\sigma_v}$ *where:* $\Delta u = u - u_{eq}$	39
Delta U/EStress, P Value, Excess Pore Pressure Ratio $\Delta u/\sigma_v'$	Differential pore pressure ratio with respect to effective stress. Key parameter (P, Normalized Pore Pressure Parameter, Excess Pore Pressure Ratio) in the Winckler et. al. static liquefaction method.	$= \frac{\Delta u}{\sigma'_v}$ *where:* $\Delta u = u - u_{eq}$	25, 25a
Su/EStress S_u/σ_v'	Undrained shear strength ratio with respect to vertical effective overburden stress using the S_u (N_{kt}) method	= *Su* (N_{kt}) / σ_v'	9, 23
Vs or V_s	Recorded shear wave velocities (not estimated). The shear wave velocities are typically collected over 1 m depth intervals. Each data point over the relevant depth range is assigned the same V_s value.	recorded data	27
Vp or V_p	Recorded compression wave (or P wave) velocities (not estimated). The P wave velocities are typically collected over 1 m depth intervals. Each data point over the relevant depth range is assigned the same V_p value.	recorded data	27

Calculated Parameter	Description	Equation	Ref
V_{s30} V_{s100}	The average shear wave velocity of the near surface materials to a depth of 30 m (100 ft). It is based on the sum of all travel times through all layers in the top 30m (100 ft). V_{s100} is the same calculation as V_{s30} except down to a depth of 100 feet.	$V_{s30} = \frac{total\ thickness\ of\ all\ layers\ to\ 30\ m}{\Sigma\left(\frac{layer\ thickness}{layer\ shear\ wave\ velocity}\right)}$ $V_{s30} = \frac{total\ thickness\ of\ all\ layers\ to\ 30\ m}{\Sigma\ (layer\ travel\ times)}$	38
G_{max}	G_{max} determined from SCPT shear wave velocities (not estimated values). Note that seismic data (V_s) is collected over set depth intervals (typically 1 meter). Each data point over the test segment is assigned the same V_s value. Since soil density changes with depth, slightly different G_{max} values may be calculated over the test depth interval.	$G_{max} = \rho V_s^2$ where ρ is the mass density of the soil determined from the estimated unit weights at each test depth	27
qtNet/G_{max}	Net tip resistance ratio with respect to the small strain modulus G_{max} determined from SCPT shear wave velocities (not estimated values)	$= (qt - \sigma_v) / G_{max}$ where $G_{max} = \rho V_s^2$ and ρ is the mass density of the soil determined from the estimated unit weights at each test depth	15, 28, 30
qUlt	A site specific and client specific parameter for estimating the limiting stress for "crane walk" accessibility	$q_{ult} = CraneWalkFactor \cdot S_u$ Where: *CraneWalkFactor* is client provided	U*
Estimated G_o	Estimated value for small strain shear modulus	$G_o = 0.0188[10^{(0.55Ic + 1,68)}](q_t - \sigma_v)$	15
Estimated E_{25}	Estimated value for Young's Modulus, E, at a 25% working load	$E_{25} = \alpha_E$ (qtNet) where $\alpha_E = 0.015[10^{(0.55Ic + 1,68)}]$	15
k_{SBT}	Estimated soil permeability derived from Soil Behavior Type (SBT) Chart I_c values.	For $1.0 < I_c \leq 3.27$: $k = 10^{(0.952 - 3.04Ic)}$ in m/s For $3.27 < Ic < 4.0$: $k = 10^{(-4.52 - 1.37Ic)}$ in m/s	35
M or D' Constrained Modulus	Constrained Modulus based on 1) Robertson, M 2) Mayne, D'	1) Robertson $M = \alpha_M (q_t - \sigma_v)$ $I_c > 2.2$ (fine grained) $\alpha_M = Qt$ when $Qt < 14$ $\alpha_M = 14$ when $Qt > 14$ $Ic < 2.2$ (coarse grained) $\alpha_M = 0.0188\ [10^{(0.55Ic + 1.68)}]$ $D' = \alpha_D (qt - \sigma_v)$ where $\alpha_D = 5$	32 23

Table 1b. CPT Parameter Calculation Methods – Liquefaction Parameters

Calculated Parameter	Description	Equation	Ref
K_{SPT} or K_s	Equivalent clean sand factor for $(N_1)60$	$K_{SPT} = 1 + ((0.75/30) \bullet (FC - 5))$	10
K_{CPT} or K_c (RW1998)	Equivalent clean sand correction for q_{c1N}	$K_{cpt} = 1.0$ for $I_c \leq 1.64$ $K_{cpt} = f(I_c)$ for $I_c > 1.64$ (see reference) $K_c = -0.403\ I_c^4 + 5.581\ I_c^3 - 21.63 I_c^2 + 33.75\ I_c - 17.88$	3, 10
K_c (PKR 2010)	Clean sand equivalent factor to be applied to Q_{tn}	$K_c = 1.0$ for $I_c \leq 1.64$ $K_c = -0.403\ I_c^4 + 5.581\ I_c^3 - 21.63 I_c^2 + 33.75\ I_c - 17.88$ for $I_c > 1.64$	16
$(N_1)_{60cs}I_C$	Clean sand equivalent SPT $(N_1)_{60}I_c$. User has 3 options.	1) $(N_1)_{60cs}Ic = \alpha + \beta((N_1)_{60}I_c)$ 2) $(N_1)_{60cs}Ic = K_{SPT} * ((N_1)_{60}I_c)$ 3) $(q_{c1ncs})/(N_1)_{60cs}I_c = 8.5\ (1 - I_c/4.6)$ FC ≤ 5%: $\alpha = 0,\ \beta = 1.0$ FC ≥ 35% $\alpha = 5.0,\ \beta = 1.2$ 5% < FC < 35% $\alpha = exp[1.76 - (190/FC^2)]$ $\beta = [0.99 + (FC^{1.5}/1000)]$	10 10 5
q_{c1ncs}	Clean sand equivalent q_{c1n}	$q_{c1ncs} = q_{c1n} \bullet K_{cpt}$	3
$Q_{tn,cs}$ (PKR 2010)	Clean sand equivalent for Q_{tn} described above - Q_{tn} being the normalized tip resistance based on a variable stress exponent as defined by Robertson (2009)	$Q_{tn,cs} = Q_{tn} \cdot K_c$ (PKR 2016)	16
Su(Liq)/ESv or $S_u(Liq)/\sigma_v'$	Liquefied shear strength ratio as defined by Olson and Stark	$\frac{S_u(Liq)}{\sigma_v'} = 0.03 + 0.0143(q_{c1})$ Note: σ_v' and s_v' are synonymous	13
Su(Liq)/ESv or $S_u(Liq)/\sigma_v'$ (PKR 2010)	Liquefied shear strength ratio as defined by Robertson (2010)	$\frac{S_u(Liq)}{\sigma_v'}$ Based on a function involving $Q_{tn,cs}$	16
S_u (Liq) (PKR 2010)	Liquefied shear strength derived from the liquefied shear strength ratio and effective overburden stress	$S_u(Liq) = \sigma_v' \cdot \left(\frac{S_u(Liq)}{\sigma_v'}\right)$	16
Cont/Dilat Tip	Contractive / Dilative q_{c1} Boundary based on $(N_1)_{60}$	$(\sigma_v')_{boundary} = 9.58 \times 10^{-4}\ [(N_1)_{60}]^{4.79}$ q_{c1} is calculated from specified q_t(MPa)/N ratio	13
CRR	Cyclic Resistance Ratio (for Magnitude 7.5)	$q_{c1ncs} < 50$: $CRR_{7.5} = 0.833\ [q_{c1ncs}/1000] + 0.05$ $50 \leq q_{c1ncs} < 160$: $CRR_{7.5} = 93\ [q_{c1ncs}/1000]^3 + 0.08$	10
Kg or K_g	Small strain Stiffness Ratio Factor, K_g	$[G_{max}/q_t]/[q_{c1n}{}^{-m}]$ m = empirical exponent, typically 0.75	26

Calculated Parameter	Description	Equation	Ref
K_g*	Revised K_g factor extended to fine grained soils (Robertson).	$K_g^* = (G_o / q_n)(Q_{tn})^{0.75}$ where q_n is the net tip resistance = $q_t - \sigma_v$	30
SP Distance	State Parameter Distance, Winckler static liquefaction method	Perpendicular distance on Q_{tn} chart from plotted point to state parameter Ψ = -0.05 curve	25
URS NP Fr	Normalized friction ratio point on Ψ = -0.05 curve used in SP distance calculation		25
URS NP Q_{tn}	Normalized tip resistance (Q_{tn}) point on Ψ = -0.05 curve used in SP Distance calculation		25

Table 2. References

No.	Reference
1	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.
2	Robertson, P.K., 1990, "Soil Classification Using the Cone Penetration Test", Canadian Geotechnical Journal, Volume 27. This includes the discussions and replies.
3	Robertson, P.K. and Wride (Fear), C.E., 1998, "Evaluating cyclic liquefaction potential using the cone penetration test", Canadian Geotechnical Journal, 35: 442-459.
4	Robertson, P.K. and Wride, C.E., 1997, "Cyclic Liquefaction and its Evaluation Based on SPT and CPT", NCEER Workshop Paper, January 22, 1997.
5	Lunne, T., Robertson, P.K. and Powell, J. J. M., 1997, " Cone Penetration Testing in Geotechnical Practice," Blackie Academic and Professional.
6	Plewes, H.D., Davies, M.P. and Jefferies, M.G., 1992, "CPT Based Screening Procedure for Evaluating Liquefaction Susceptibility", 45th Canadian Geotechnical Conference, Toronto, Ontario, October 1992.
7	Jefferies, M.G. and Davies, M.P., 1993, "Use of CPTu to Estimate equivalent N_{60}", Geotechnical Testing Journal, 16(4): 458-467.
8	Been, K. and Jefferies, M.P., 1985, "A state parameter for sands", Geotechnique, 35(2), 99-112.
9	Schmertmann, 1978, "Guidelines for Cone Penetration Test Performance and Design", Federal Highway Administration Report FHWA-TS-78-209, U.S. Department of Transportation.
10	Proceedings of the NCEER Workshop on Evaluation of Liquefaction Resistance of Soils, Salt Lake City, 1996, chaired by Leslie Youd.
11	Kulhawy, F.H. and Mayne, P.W., 1990, "Manual on Estimating Soil Properties for Foundation Design, Report No. EL-6800", Electric Power Research Institute, Palo Alto, CA, August 1990, 306 p.
12	Olson, S.M. and Stark, T.D., 2002, "Liquefied strength ratio from liquefied flow failure case histories", Canadian Geotechnical Journal, 39: 951-966.
13	Olson, Scott M. and Stark, Timothy D., 2003, "Yield Strength Ratio and Liquefaction Analysis of Slopes and Embankments", Journal of Geotechnical and Geoenvironmental Engineering, ASCE, August 2003.
14	Jamiolkowski, M.B., Lo Presti, D.C.F. and Manassero, M., 2003, "Evaluation of Relative Density and Shear Strength of Sands from CPT and DMT", Soil Behaviour and Soft Ground Construction, ASCE, GSP N0. 119, 201-238.
15	Robertson, P.K., 2009, "Interpretation of cone penetration tests – a unified approach", Canadian Geotechnical Journal, 46: 1337-1355.
16	Robertson, P.K., 2010a, "Evaluation of Flow Liquefaction and Liquefied Strength Using the Cone Penetration Test", Journal of Geotechnical and Geoenvironmental Engineering, ASCE, June 2010.
17	Mayne, P.W. and Kulhawy, F.H., 1982, "Ko-OCR Relationships in Soil", Journal of the Geotechnical Engineering Division, ASCE, Vol. 108, GT6, pp. 851-872.
18	Mayne, P.W., Robertson P.K. and Lunne T., 1998, "Clay stress history evaluated from seismic piezocone tests", Proceedings of the First International Conference on Site Characterization – ISC '98, Atlanta Georgia, Volume 2, 1113-1118.

No.	Reference
19	Mayne, P.W., 2014, "Generalized CPT Method for Evaluating Yield Stress in Soils", Geocharacterization for Modeling and Sustainability (GSP 235: Proc. GeoCongress 2014, Atlanta, GA), ASCE, Reston, Virginia: 1336-1346.
20	Mayne, P.W., 2015, "Geocharacterization by In-Situ Testing", Continuing Education Course, Vancouver, BC, January 6-8, 2015.
21	Robertson, P.K. and Fear, C.E., 1995, "Liquefaction of sands and its evaluation", Proceedings of the First International Conference on Earthquake Engineering, Keynote Lecture IS Tokyo '95, Tokyo Japan, 1995.
22	Mayne, P.W., Peuchen, J. and Boumeester, D., 2010, "Soil unit weight estimation from CPTs", Proceeding of the 2nd International Symposium on Cone Penetration Testing (CPT '10), Vol 2, Huntington Beach, California; Omnipress: 169-176.
23	Mayne, P.W., 2007, "NCHRP Synthesis 368 on Cone Penetration Test", Transportation Research Board, National Academies Press, Washington, D.C., 118 pages.
24	Mayne, P.W., 2014, "Interpretation of geotechnical parameters from seismic piezocone tests.", Key note address #2, proceedings, 3rd International Symposium on Cone Penetration Testing (CPT'14, Las Vegas), ISSMGE Technical Committee TC102.
25	Winckler, Christina, Davidson, Richard, Yenne, Lisa, Pilz, Jorgen, 2014, "CPTu-Based State Characterization of Tailings Liquefaction Susceptibility", Tailings and Mine Waste, 2014.
25a	Winckler, Christina, Davidson, Richard, Yenne, Lisa, Pilz, Jorgen, 2014, "CPTu-Based State Characterization of Tailings Liquefaction Susceptibility", Powerpoint presentation, Tailings and Mine Waste, 2014.
26	Schneider, J.A. and Moss, R.E.S., 2011, "Linking cyclic stress and cyclic strain based methods for assessment of cyclic liquefaction triggering in sands", Geotechnique Letters 1, 31-36.
27	Rice, A., 1984, "The Seismic Cone Penetrometer", M.A.Sc. thesis submitted to the University of British Columbia, Dept. of Civil Engineering, Vancouver, BC, Canada.
28	Gillespie, D.G., 1990, "Evaluating Shear Wave Velocity and Pore Pressure Data from the Seismic Cone Penetration Test", Ph.D. thesis submitted to the University of British Columbia, Dept. of Civil Engineering, Vancouver, BC, Canada.
29	Robertson, P.K and Cabal, K.L., 2010, "Estimating soil unit weight from CPT", Proceedings of the 2nd International Symposium on Cone Penetration Testing (CPT '10), Huntington Beach, California.
30	Robertson, P.K., 2016, "Cone penetration test (CPT)-based soil behaviour type (SBT) classification system – an update", Canadian Geotechnical Journal, July 2016.
31	Robertson, P.K., 2012, "Interpretation of in-situ tests – some insights", Mitchell Lecture, ISC'4, Recife, Brazil.
32	Robertson, P.K., Cabal, K.L. 2015, "Guide to Cone Penetration Testing for Geotechnical Engineering", 6th Edition.
33	Robertson, P.K., 2010b, "Soil behaviour type from CPT: an update", Proceedings of the 2nd International Symposium on Cone Penetration Testing (CPT '10), Huntington Beach, California.
34	Been, K., Romero, S., Obermeyer, J. and Hebeler, G., 2012, "Determining in situ state of sand and silt tailings from the CPT", Tailings and Mine Waster 2012, 325-333.
35	Robertson, P.K., 2010, "Estimating in-situ soil permeability from CPT & CPTu", Proceedings of the 2nd International Symposium on Cone Penetration Testing (CPT '10), Huntington Beach, California.
36	Mayne, P.W., Cargill, E. and Greig, J., 2023, "The Cone Penetration Test: A CPT Design Parameter Manual", ConeTec Group
37	Baldi, G., Bellotti, R., Ghionna,V., Jamiolkowski, M. and Lo Presti, D. 1989. Modulus of sands from CPTs and DMTs. *Proc. Intl. Conf. on Soil Mechanics & Foundation Engineering*, Vol. 1 (ICSMFE, Rio de Janeiro), Balkema, Rotterdam: 165–170. www.issmge.org
38	Crow, H.L, Hunter, J.A. and Bobrowsky, P.T., 2012, "National shear wave measurement guidelines for Canadian seismic site assessment", Proceedings of GeoManitoba 2012, the 65th Canadian Geotechnical Conference.
39	Campanella, R.G., Robertson, P.K., Gillespie, D., 1982, "Cone penetration testing in deltaic soils", Canadian Geotechnical Journal, 20: 23-35.