Foundation Investigation and Design Report

DB 2018-4013-Two Structural Culvert Replacements on Highway 17
Structural Culvert No.: 29-232/C
Muskrat Creek Crossing of Highway 17
Renfrew County, ON

Project No.: TPB196039
WP 4113-01-01
Ministry of Transportation (MTO), Eastern Region

Geocres No.: 31F-208

Prepared for:
Looby Construction Limited
3035 Ontario Street, Unit 201, Stratford, Ontario N5A 6S5
Attn: Mr. Todd Jeffrey

30-Jul-19

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30-Jul-19

TABLE OF CONTENTS

LIST OF TABLES

LIST OF DRAWINGS

LIST OF APPENDICES

Part A

Foundation Investigation Report
Muskrat Creek Culvert
Highway 17, Renfrew County, ON

1.0 Introduction

Wood Environment & Infrastructure Solutions, a Division of Wood Canada Limited ("Wood") has been retained by Looby Construction Limited to provide foundation design services for two structural culvert replacements on Highway 17 as part of a Design-Build project for the Ministry of Transportation Ontario (MTO), Eastern Region. As part of this project, Wood has completed a final Foundation Investigation and Design Report (FIDR) for the culvert replacement over Muskrat Creek on Highway 17 in Renfrew County, Ontario.

The scope of this report is strictly limited to the geotechnical and foundation aspects of the proposed works. As part of the Design-Build project, there will be ongoing liaison with other members of the Design-Build team during the design and construction phases of this project to confirm that the recommendations in this report have been interpreted and implemented as intended.

The following Foundation Investigation and Design Report made available by MTO to the Design Builder has been referenced in the preparation of the final FIDR:

- Thurber Engineering Ltd., Geocres Number: 31F-201, Report titled "Foundation Investigation and Design Report, Replacement of Structural Culvert No. 29-232/C, Muskrat Creek Crossing of Highway 17, Renfrew County, ON", dated April 2018.

This report is prepared based on the results of the previous investigation as outlined above and the new seismic Cone Penetration Tests (sCPTs) advanced at the site. In total, seven (5) boreholes and four (4) sCPTs were completed by Thurber Engineering Ltd. (Thurber) in 2015 and 2017, respectively, to assess the extent and nature of the subsurface conditions. Additional investigation has been completed by Wood through the advancement of three (3) sCPTs to supplement the previous subsurface information and to provide additional information related to the foundation soils at the new culvert location.

Copies of borehole records from previous foundation investigation are provided in Appendix A. The results of the additional subsurface investigation completed by Wood are presented in Appendix B.

2.0 Site Description and Geological Background

2.1 Site Description

The Muskrat Creek culvert (No.: 29-232/C) is located on Highway 17 in Renfrew County, approximately 5.7 km east of Cobden, Ontario. The location of the culvert is shown on the inset Key Plan on Drawing No. 1. It is noted that for project orientation purposes, Highway 17 within the project limits has one through lane in each direction and will be assumed to run west-east. Based on the General Arrangement (GA) drawing the roadway cross-section consists of two, 3.75 m wide lanes with granular shoulders ranging from 2.5 m to 2.9 m in width. A three-cable guide rail system is present along both sides of the highway in the vicinity of the culvert. The existing culvert is a cast-in-place, concrete, open bottom, rigid frame culvert, with an internal span of 3.1 m, a height of 1.8 m and an approximate length of 25 m. Water flow is from north to south below the highway. The GA drawing provided in Appendix C, indicates that the elevation of the top of the existing stream bed ranges from Elevation 146.8 m at the inlet to 146.7 m at the outlet.

No settlement or stability issues were noted at the culvert at the time of Thurber's field investigation. The slopes of the embankment were observed to be covered with wild grass and brush. The embankment slopes were graded with slopes ranging from approximately 2.0H:1V to 2.5H:1V (Horizontal:Vertical). The elevation at the centreline of the roadway was surveyed at approximately 149.7 m. The elevation of the top of the culvert was approximately 149.1 m and 149.0 m at the inlet and outlet respectively, providing for 600 to 700 mm of cover.

The lands surrounding the project limits include forest, brush, farm fields and swampy areas. The creek channel both upstream and downstream of the culvert is a narrow meandering channel within a swampy area. The water level was fairly low with little visible flow at the time of the field investigation. The storm water drainage in the area is to existing culverts and ditches.

2.2 Geological Background

The site is located within a physiographic region known as the Muskrat Lake Ridges which is characterized as a steep scarp composed of Precambrian rocks overlain by a thin overburden deposit of sand and gravel. (Chapman and Putnam 1984).

3.0 Investigation Program

3.1 Field Work

The subsurface investigation carried out by Thurber, consisted of a total of five (5) boreholes and four (4) sCPTs, and was reported to WSP Canada on behalf of the Ministry of Transportation, Ontario (MTO) for the Muskrat Creek Culvert Replacement project.

The initial field investigation was carried out between June 23 and 24, 2015, and included advancing four boreholes (601 to 604). Due to the shallow termination depth of Borehole 601, an additional Borehole 601A was advanced approximately 1.5 m north and west of Borehole 601. A supplementary field investigation was carried to further assess the very loose to loose silt and sand deposits that had been identified in the boreholes. The supplemental investigation was carried out on May 23, 2017 and included advancing four sCPTs (17-01 to 17-04).

According to the Thurber report, Boreholes 602 and 603 advanced through the roadway embankment were drilled with a CME truck mounted drill rig using hollow stem augers. The inlet and outlet boreholes (Boreholes 601, 601A and 604) were advanced with portable drilling equipment using a full weight hammer, tripod and casing with wash boring. Split spoon samples were collected at regular depth intervals in the boreholes via the completion of Standard Penetration Tests (SPT), following the methods described in ASTM Standard D1586-11. Bedrock was cored in all boreholes, except Borehole 602, with NQ size coring equipment following ASTM Standard D6032-08.

A 25 mm inside diameter PVC piezometer was installed in Borehole 604 to measure the groundwater level at the site. The piezometer construction details were illustrated on the Record of Borehole sheet for Borehole 601. The piezometer was decommissioned on December 16, 2015.

An additional investigation was carried out by Wood on May 22, 2019. To confirm the subsurface conditions, three (3) sCPTs were advanced in the overburden (SCPT19-01, SCPT19-01B and SCPT19-02). The sCPTs were performed in accordance with the current ASTM D5778 and ASTM D7400 standards. Ground surface elevations at test hole locations are referenced to geodetic elevation.

The borehole and sCPTs locations are shown on Drawing No.: 1 and the Record of Borehole sheets are attached in Appendix A.

Tables 3-1 and 3-2 present the locations, ground surface elevations, base elevations and borehole/sCPT depths for boreholes/sCPTs advanced in the additional and previous investigations, respectively.

Table 3-1: New sCPTs Advanced by Wood

Test Hole ID	Northing (m)	Easting (m)	Ground Surface Elevation (m)	Bottom Elevation of Test Hole (m)	Depth (m)
SCPT19-01	5049724.1	278938.5	149.5	147.10	2.40
SCPT19-01B	5049725.1	278938.5	149.5	144.65	4.85
SCPT19-02	5049713.1	278933.9	149.5	141.37	8.13

Table 3-2: Previous Boreholes and sCPTs Advanced by Thurber

Borehole/sCPT ID	Northing (m)	Easting (m)	Ground Surface Elevation (m)	Bottom Elevation of Borehole (m)	Depth (m)
601	5049722.1	278947.1	148.8	145.4	3.4
601A	5049724.2	278947.3	148.2	145.9	2.3
602	5049709.7	278945.5	149.6	140.5	9.1
603	5049714.4	278936.8	149.6	140.4	9.2
604	5049702.6	278935.1	148.6	141.0	7.6
SCPT17-01	5049738.7	278923.5	149.6	144.8	4.8
SCPT17-02	5049717.4	278940.2	149.7	143.0	6.7
SCPT17-03	5049707.0	278942.2	149.7	141.7	8.0
SCPT17-04	5049685.7	278958.8	149.7	142.4	7.3

3.2 Laboratory Testing

As reported by Thurber, geotechnical laboratory testing consisted of natural moisture content determination and visual identification of all soil samples in accordance with the current MTO standards. Grain size distribution analyses and Atterberg Limits testing were also carried out on selected samples to MTO and ASTM standards. All recovered bedrock core was logged and core recoveries and RQD values were measured.

The geotechnical laboratory test results are presented on the Record of Borehole sheets in Appendix A.

Chemical analysis for determination of pH, resistivity, soluble sulphate and chloride concentrations was carried out on two soil samples reported by Thurber.

4.0 Subsurface Conditions

4.1 Subsurface Soil Conditions

The details of the soil stratigraphy encountered in the boreholes are provided in the Record of Borehole sheets attached in Appendix A. Stratigraphic profiles along the culvert alignment and along the highway alignment are presented on Drawing No. 1 for illustrative purposes. An overall description of the stratigraphy is given in the following paragraphs; however, the factual data presented in the Record of Boreholes governs any interpretation of the site conditions at the test locations.

In general, the stratigraphy beneath Highway 17 in the area of the culvert is characterized by an asphalt pavement structure overlying sand with silt and gravel fill, overlying sand with silt and gravel overlying silt with sand, underlain by bedrock.

The bedrock profile varies considerably across the site from the south to north. The depth below existing grade to the bedrock surface ranged from 1.2 m to 2.7 m at the culvert inlet. At the culvert outlet, the depth to the bedrock surface ranged from 6.7 m to 7.8 m below grade.

Asphalt and Topsoil

Two boreholes were advanced through the Highway 17 pavement structure. The thickness of the asphalt ranged from approximately 250 mm to 300 mm.

A topsoil layer with a thickness of 150 mm was encountered at surface in Borehole 604 near the culvert outlet.

Fill

A granular fill layer consisting predominantly of sand and gravel with varying amounts of silt was encountered below the surficial materials in the boreholes. The top of this layer ranged from Elevation 148.2m to 149.4 m. The thickness of the layer ranged from 1.2 m to 2.2 m. The SPT 'N' values generally ranged from 5 blows to 26 blows per 0.3 m of penetration, indicating a loose to compact state. One SPT conducted within the pavement structure base material resulted in 100 blows for 225 mm of penetration. The moisture content of the samples tested ranged from 2% to 24%.

Sand with Silt / Silty Sand

A deposit of sand with silt to silty sand was encountered beneath the fill materials in boreholes 601, 602 and 603. The top of this layer ranged from Elevation 146.8 m to 147.3 m. The thickness of the layer ranged from 0.6 m to 2.9 m. The SPT 'N' values ranged from 2 blows to 21 blows per 0.3 m of penetration, indicating a very loose to compact state, typically a very loose state. The moisture content for the samples tested ranged from 19% to 46%.

Clay

A thin stratum of clay was encountered below the sand with silt deposit in Borehole 602. This layer was encountered at Elevation 144.7 m and had a thickness of 300 mm. The moisture content of the sample tested was 23%.

Silt with Sand

A deposit of silt with sand was encountered beneath the fill materials in Borehole 604, beneath the sand with silt stratum in Borehole 603 and below the clay layer in Borehole 602. The top of this layer ranged from Elevation 144.3 m to 146.2 m. The thickness of the layer ranged from 1.5 m to 4.3 m. The SPT 'N' values ranged from 1 blow to 15 blows per 0.3 m of penetration, indicating a very loose to compact state, typically a very loose to loose state. The moisture content for the samples tested ranged from 13% to 27%.

Silty Sand with Gravel - Till

A glacial till layer consisting predominantly of silty sand with varying amounts of boulder was encountered in Borehole 602. The top of this layer was encountered at Elevation 142.8 m. Borehole 602 was terminated in this layer. An SPT 'N' value of 14 blows was obtained at one test depth. Below this test depth, 100 blows resulted in 0 mm of penetration obtained due to an inferred boulder. The moisture content for the samples tested ranged from 10% to 24%.

Bedrock

The overburden materials were underlain by a grey granite bedrock. All boreholes except Borehole 602 were advanced into bedrock by coring with NQ-size coring equipment. The bedrock profile varies considerably across the site from the north (inlet) to south (outlet). A summary of the bedrock surface elevation is provided in Table 4-1 below.

Table 4-1: Summary of Bedrock

Borehole ID	Ground Surface Elevation (m)	Depth (m)	Bedrock Surface Elevation (m)
601	148.8	2.7	146.1
601A	148.2	1.2	146.9
603	149.6	7.8	141.8
604	148.6	6.7	141.9

The bedrock was noted as being slightly weathered to fresh with a fracture index of 1 fracture per 0.3 m. The total core recovery ranged from 80% to 97%, the solid core recovery ranged from 67% to 86% and the RQD values ranged from 46% to 68%. Based on the RQD values, the rock mass quality ranged from poor to fair.

4.2 Groundwater

The groundwater level in the piezometer installed in borehole 604 was measured on December 16, 2015 during the Thurber investigation. The summarized results are shown in Table 4-2.

Table 4-2: Groundwater Elevation in Borehole

Borehole ID	Existing Ground Surface Elevation (m)	December 16, 2019	
		Water Level Depth (m)	Water Level Elevation (m)
604	148.6	0.93	147.7

The water level in Muskrat Creek was measured at the time of Thurber's field investigation at a depth of 1.5 m below the top of the culvert at the inlet; corresponding Elevation 147.5 m. The groundwater level in the area of the culvert is expected to reflect the creek water level.

It should be noted that groundwater levels in the area are subject to fluctuations both seasonally and with precipitation events.

5.0 Closure

This Foundation Investigation Report was prepared by Mr. Nazmur Rahman, M.A.Sc., PE, P.Eng., Associate Geotechnical Engineer.

Mr. Ty Garde, M.Eng., P.Eng., Principal Geotechnical Engineer and a Designated Foundation Contact for Wood, conducted an independent quality control review of the report.

Sincerely,

Wood Environment & Infrastructure Solutions,
a Division of Wood Canada Limited

Prepared By:	Reviewed By:
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Part B

Foundation Design Report
Muskrat Creek Culvert
Highway 17, Renfrew County, ON

6.0 Discussion and Recommendations

6.1 General

This section of the report provides foundation design recommendations for the Muskrat Creek culvert replacement. The recommendations are based on interpretation of the factual data obtained from the previous and new investigations on site. Geotechnical discussions and recommendations are provided to assist the design team in designing a suitable foundation for the proposed replacement culvert.

A General Arrangement (GA) drawing dated June 2019 was provided by the design team for the preparation of this report. A copy of the GA drawing is provided in Appendix C.

The new Muskrat Creek culvert has been designed in accordance with 2014 Canadian Highway Bridge Design Code (2014 CHBDC). Therefore, the discussion provided herein is based on the 2014 CHBDC.

6.2 Proposed Structure

Based on the June 2019 GA drawing, the existing culvert is to be replaced with a 25 m long, closed bottom concrete culvert with an approximate span of 4 m. The new culvert is to be installed on a new alignment to the west of the existing culvert. The centerline of the new culvert alignment is to be offset from the existing culvert by approximately 5.62 m and 5.31 m at the outlet and inlet, respectively, however, the final location may be changed upon the approval from MTO. It is understood that neither retaining walls or wingwalls are proposed for this project. The top of streambed elevation will be at approximately Elevation 146.8 m at the upstream end and Elevation 146.7 m at the downstream end.

No changes to the profile of Highway 17 above the culvert are proposed, however, temporary embankment widenings may be constructed to allow for staged construction while maintaining two lanes of traffic.

It is understood that creek flow will be maintained through the existing culvert during installation of the new box culvert. The plan includes abandoning the existing culvert by leaving it in place and filling it with grout or concrete after construction of the new culvert is complete.

6.3 Seismic Considerations

6.3.1 Seismic Hazard Values and Site Classification

The seismic hazard data for the CHBDC is based on the fifth-generation seismic model developed by the Geological Survey of Canada (GSC). Seismic hazard data for this site has been obtained from the GSC's seismic hazard calculator. The data includes peak ground acceleration (PGA), peak ground velocity (PGV), and the 5% damped spectral response acceleration values (Sa(T)) for the reference ground condition (Site Class C) for a range of periods (T) and for a range of return periods including the 475-year, 975-year and 2475-year events. The site coefficients used to determine the design spectral acceleration and displacement values are a function of the Site Class and the site-specific peak ground acceleration (PGA).

The 2014 CHBDC contains updated seismic analysis and design methodology. The 2014 CHBDC method uses a site classification system defined by the average soil/bedrock properties (e.g. shear wave velocity, Standard Penetration Test (SPT) resistance, undrained soil shear strength etc.) in the top 30 m below the foundation level. There are 6 site classes from A to F, decreasing in ground stiffness from A, hard rock, to E, soft soil; with site class F used to denote other soils (e.g., sites underlain by thick peat deposits, high plastic clays, liquefiable soils, etc.). The site class is then used to obtain acceleration and velocity-based site coefficients F(PGA) and F(PGV), respectively, for the effects of site-specific soil conditions in design.

Based on the results of the previous and current investigations, for seismic design purposes at this site as determined by Section 4.4.3.2 of 2014 CHBDC, it is recommended that a Site Class of E ("Soft Soil") be used for the design of the new culvert structure.

In accordance with Section 4.4.3.1 of the CHBDC and based on the location of the culvert, the following are the reference Site Class C peak seismic hazard values based on the 5th generation seismic hazard maps published by the GSC.

Table 6-1: Seismic Hazard Values for Ground Condition Site Class C

Seismic Hazard Values	10% Exceedance in 50 years (475 return period)	5% Exceedance in 50 years (975 return period)	2% Exceedance in 50 years (2475 return period)
PGA (g)	0.076	0.126	0.231
PGV (m/sec)	0.055	0.090	0.161
Sa (0.2) (g)	0.123	0.200	0.359
Sa (0.5) (g)	0.072	0.113	0.194
Sa (1.0) (g)	0.038	0.059	0.098
Sa (2.0) (g)	0.018	0.028	0.047

The values given above are for the reference ground condition Site Class C and must be modified to the site specific seismic site classification given above in accordance with Section 4.4.3.3 of the CHBDC.

6.3.2 Seismic Liquefaction Assessment

The results of the 2015 borehole investigation completed by Thurber indicated the presence of very loose to loose silt and sand deposits which were assessed to be liquefiable. The supplemental investigation completed by Thurber in 2017 included sCPT testing to minimize the potential for ground disturbance inherent with SPT testing and to allow for a more rigorous assessment of the potential for liquefaction at the site. To confirm the site condition, additional two (2) sCPTs were carried out by Wood in 2019. The results of SCPTs are included in Appendix A.

The sCPT data obtained during the field investigation was processed using GeoLogismiki's CLiq software. The interpreted results were compared with previous boreholes completed near the culvert. Based on the low SPT 'N' values in the sand and silt, CPT Ic values less than 2.6 and index testing on disturbed soil samples, the loose to very loose sand and non-plastic silt has the potential to experience liquefaction in a seismic event. Based on a design PGA of 0.11g for the 1:475 earthquake, the culvert foundation is not anticipated to liquefy. However, for the design PGA of 0.18g for the 1:975 earthquake, the full depth of loose to very loose sand and silt below the culvert is anticipated to liquefy. A similar extent of liquefaction would be expected for the 1:2475 earthquake. Outputs of the cyclic stress ratio and cyclic resistance ratio for the 1:475 and 1:975 earthquakes for new SCPTs 19-01, 19-01B and 19-02 are shown on plots provided in Appendix D. Thurber analysis results are also provided in Appendix D.

Static and seismic slope stability analyses for the embankment adjacent to the culvert were completed using GeoStudio 2016 Slope/W software. Input parameters for the analysis are based on the in-situ SPT 'N' values and sCPTs results. The following additional parameters were used in the analysis:

- A seismic horizontal loading of 0.133g, equal to ½ of the site adjusted PGA value (0.266g) was used for seismic analysis
- A maximum embankment side slope geometry of 2H:1V.

The results of the global slope stability analysis indicate a factor of safety (FOS) of 1.5 and 1.1 under static and seismic conditions, respectively. The calculated FOS meets the target values of 1.5 and 1.1 under static and seismic conditions, respectively, for a permanent condition. The output models from the global stability analysis for both static and seismic conditions are provided in Appendix D.

6.3.3 Liquefaction Mitigation in Foundation Design Alternatives

The following three alternatives were considered to mitigate the seismic liquefaction issue:

- Excavate to remove liquefiable soils and replace with engineered fill, followed by construction of a conventional culvert structure
- Carry out ground improvement to stabilize the liquefiable soils, followed by construction of a conventional culvert structure
- Leaving the existing liquefiable soils in place and designing the culvert to withstand post-seismic kinematic loads. This alternative could include a rigid cast-in-place box culvert or a culvert supported on deep foundations. Considering the shallow but variable depth to rock, a cast-in-place box culvert is considered to be more practical and cost effective for this site.

6.4 Foundation Design Option

Culvert/foundation alternatives and construction approaches are presented and evaluated in the following paragraphs and a preferred replacement alternative from a foundation engineering perspective is recommended.

Common culvert and foundation types are listed below along with a comparison of these alternatives from a foundation perspective. Their respective advantages and disadvantages are outlined below.

- **Circular Pipes:** From a foundation engineering perspective, circular pipes installed with appropriate granular bedding over the native subgrade are feasible for static design condition. However, it is understood that numerous circular pipes on new alignments would be required to provide the required hydraulic opening. Also, it is unlikely that the circular pipes could be designed to withstand the anticipated kinematic loads, therefore the use of circular pipes would require full removal and replacement of the liquefiable soils or ground improvement.

- **Closed Bottom Box (Concrete):** From a geotechnical perspective, the culvert replacement could also be achieved with a closed bottom concrete culvert. A closed box culvert offers several advantages including spreading the static load over a wider area. In addition, a closed box can more easily be designed to resist kinematic loading associated with liquefaction. Based on a substrate with a top elevation of approximately 146.7 m and a thickness of 350 mm and allowing for a 300 mm thick concrete base, the base of excavation is expected to be at approximate Elevation 145.6 m (based on a 500 mm thick granular pad that is provided below the concrete base) at which elevation the subgrade would be in the native loose sandy silt to silty sand. Bedrock excavation may be required at the culvert inlet (north end of the culvert) to reach the design culvert invert elevation.

- **Open Bottom:** An open bottom culvert was considered for this project; however, the sand and silt subgrade offers relatively low bearing resistance which is insufficient based on the proposed size of the structure at this site. This option would only be feasible if ground improvement or full removal and replacement of the liquefiable soils was carried out.

- **Pre-cast vs Cast-in-Place Concrete Culverts:** A cast-in-place culvert can be constructed as a single, ridged unit to better resist the post-seismic kinematic loads then a series of pre-cast units. Also, a cast-in-place culvert is less prone to disturbance during the removal of temporary protection systems. The use of pre-cast units will generally allow for quicker installation, possibly reducing dewatering requirements and the overall construction schedule. Larger cranes are likely required for installation of large span pre-cast units which may impact the required construction staging zone.

Based on the evaluations presented above, the recommended design approach from a foundation engineering perspective is to leave the existing liquefiable soils in place and to design the replacement culvert to withstand post-seismic kinematic loads which includes settlement and lateral movement of the embankments. The recommended culvert type in order to resist the post-seismic kinematic loads and based on the low static bearing resistance is a cast-in-place concrete box structure.

6.5 Foundation Design Recommendations

6.5.1 Culvert Foundation Bearing Resistances

Based on the GA drawing, the design top of substrate is noted as between Elevations 146.7 m and 147.8 m with a minimum thickness of 350 mm. Assuming a culvert base thickness of 300 mm, the culvert will be founded at approximately Elevation 146 m. The native subgrade within the footprint of most of the culvert is expected to consist of undisturbed native loose sandy silt to silty sand, which will be partially replaced with a 500 mm thick granular pad consisting of OPSS 1010 Granular 'A' or Granular 'B' Type II. Bedrock excavation may be required at the culvert inlet (north end of the culvert) to reach the design culvert invert elevation.

A cast-in-place, 4.6 m wide concrete box culvert founded at Elevation 146.0 m on a granular pad at least 0.5 m thick, can be designed with the following factored geotechnical resistances:

- Factored geotechnical resistance at ULS; 150 kPa
- Factored geotechnical resistance at SLS; 100 kPa

The factored geotechnical resistances include the following factors:

- The factored geotechnical resistance values at SLS provided above correspond to the stress increase relative to current site conditions that will result in 25 mm of total settlement.
- Consequence factor (ψ) of 1.0
- Geotechnical resistance factors (CHBDC Table 6.2):
    - Bearing (ULS), ϕ_{gu} = 0.5 (static analysis; typical degree of understanding)
    - Settlement (SLS), ϕ_{gs} = 0.8 (static analysis; typical degree of understanding)

The structural design of the culvert should consider differential settlement across the culvert. Based on the SLS bearing resistance provided above, a maximum of 25 mm of differential settlement should be anticipated along the culvert alignment.

The geotechnical resistances provided above are for vertical concentric loading and will need to be adjusted for the effects of inclined or eccentric loading, if applicable. The geotechnical resistance should be calculated as illustrated in the CHBDC Clause 6.10.3 and Clause 6.10.4.

Unfactored resistance to lateral forces through sliding resistance between concrete and Granular 'A' or Granular B Type II bedding materials should be evaluated using an unfactored coefficient of friction of 0.55 for a cast-in-place concrete.

Based on the boreholes, sCPTs and serviceability analysis results, a vertical Modulus of Subgrade Reaction (MSR) is estimated to be 5 MPa/m for the proposed culvert base.

6.5.2 Subgrade Preparation, Culvert Bedding and Backfilling

Excavation and backfilling for installation of the new culvert should be carried out in accordance OPSS 902 and MTO Special Provision (SP) No. 109S12, Amendment to OPSS 902, March 2018.

The creek water level was observed at Elevation 147.5 m during the field investigation by Thurber. As such, the base of the excavation would range from 1.5 m to 2.0 m below the measured creek level. Additional comments on groundwater and surface water control are provided in Section 6.6 below. The native subgrade within the footprint of the culvert is expected to consist primarily of native very loose to loose silt with sand to silty sand. However, bedrock excavation is anticipated to be required to achieve the design invert elevation near the inlet.

Subgrade preparation for the culvert structure should include excavation of a transition to reduce the potential for non-uniform and abrupt differential settlement between the possible bedrock and soils. The very loose to loose silt and sand materials will be easily disturbed when saturated, subjected to construction or personal traffic, freeze thaw actions, ingress or ponding water. To protect the exposed subgrade soil, adequate dewatering and placing geotextile over the exposed native subgrade soil and constructing a 0.5 m thick granular pad consisting of Granular 'A' or Granular 'B' Type II compacted to 100% of standard Proctor maximum dry density (SPMDD) over the exposed footprint prior to constructing the culvert are recommended. The geotextile should consist of a non-woven, Class II geotextile in accordance with OPSS 1860. Subgrade protection measures are not required where bedrock is exposed at the culvert founding elevation. The granular pad could be disturbed by construction activities. Should it be necessary to protect the prepared pad surface from disturbance, the new pad surface could be covered with a 50 mm thick concrete working slab. After the concrete for the working slab has set, the culvert base could then be constructed directly on the working slab.

Backfill for the culvert must consist of granular material conforming to OPSS.PROV 1010 Granular A or Granular 'B' Type II material specifications. Heavy compaction equipment, used adjacent to the culvert, must be restricted in accordance with OPSS.PROV 501. Care must be exercised when compacting the fill adjacent to and above the culvert in order not to damage the culvert. It is recommended that the backfill detailing of OPSD 3101.150 be utilized with a frost penetration line below the top of the culvert. The frost treatment depth, k, should be set at 1.9 m. The depth of road bed granular, d, should be set at 0.850 m.

6.5.3 Embankment Reinstatement

Due to the limited cover, embankment reinstatement for the new culvert will consist of structure backfill and the reinstated pavement structure. The existing embankments have slopes ranging from approximately 2.0H:1V to 2.5H:1V and exhibit no signs of instability. The embankments should be reinstated to match the adjacent slopes.

The embankment construction should be carried out in accordance with OPSS.PROV 206. Embankment fill, beyond the limits of structure backfill, should consist of Select Subgrade (SSM) material or better in compliance with OPSS.PROV 1010. The embankment constructed with side slopes at 2H:1V or flatter are considered stable under static and seismic conditions. The fill material should be placed and compacted in accordance with OPSS.PROV 501.

6.5.4 Lateral Earth Pressures

The lateral earth pressures acting on the culvert walls will depend on the type and method of placement of the backfill materials, on the nature of the soils behind the backfill, the magnitude of surcharge including construction loadings, the freedom of lateral movement of the structure, and the drainage conditions behind the walls. Seismic (earthquake) loading must also be taken into account in the design.

Select free-draining granular fill meeting the specifications of Ontario Provincial Standard Specifications (OPSS) Granular ‘A’ or Granular ‘B’ Type II but with less than 5 percent passing the 200 sieve should be used as backfill behind the walls. This fill should be compacted in accordance with OPSS 501. Longitudinal drains and weep holes should be installed to provide positive drainage of the granular backfill. Other aspects of the granular backfill requirements with respect to sub-drains and frost taper should be in accordance with OPSD 3101.150 and 3121.150;

A minimum compaction surcharge of 12 kPa should be included in the lateral earth pressures for the structural design of the walls, in accordance with CHBDC Section 6.9.3 and Figure 6.6. Compaction equipment should be used in accordance with OPSS 501. Other surcharge loadings should be accounted for in the design, as required.

Approach embankments shall be protected adequately to prevent them from being washed off, eroded, undermined, or damaged due to the effects of heavy rainfall, snow melt, or other potential water flows.

Backfill shall be free draining and designed to prevent development of pressures due to the accumulation of free water in either a fluid or frozen state in the vicinity of culvert and the walls shall be well drained so as to prevent the accumulation of water and avoid the associated risk of settlement and erosion of approaches and slopes.

Consideration should be given to placing the granular fill behind the culvert walls first before placing any embankment fill above the granular fill.

The lateral pressures are based on the proposed embankment fill materials and the following parameters (unfactored) may be used for a horizontal back-slope:

Table 6-2: Static Lateral Earth Pressure Coefficients

Parameter	Existing Granular Fill	Granular 'A' or Granular 'B' Type II	Sandy Silt / Silty Sand
Soil Unit Weight (kN/m^3)	20-21	21	18
Horizontal Backfill			
Coefficient of Active Earth Pressure, K_a	0.31	0.27	0.36
Coefficient of at Rest Earth Pressure, K_o	0.47	0.43	0.53
Coefficient of Passive Active Earth Pressure, K_p	3.25	3.69	2.77

Table 6-3: Seismic Active Pressure Coefficients, K_{AE}

Parameter	Existing Granular Fill	Granular 'A' or Granular 'B' Type II
Soil Unit Weight (kN/m^3)	20-21	21
Horizontal Backfill		
Yielding Wall	0.39	0.35
Non-yielding Wall	0.50	0.45

If the wall support and superstructure allow lateral yielding, active earth pressures may be used in the geotechnical design of the structure. If the abutment support does not allow lateral yielding, at-rest earth pressures should be assumed for geotechnical design. The movement to allow active pressures to develop within the backfill, and thereby assume an unrestrained structure, may be taken as follows:

- rotation (i.e., ratio of wall movement to wall height) of approximately 0.002 about the base of a vertical wall;
- horizontal translation of 0.001 times the height of the wall; or
- a combination of both.

Seismic loading will result in increased lateral earth pressures acting on the walls. The walls should be designed to withstand the combined lateral loading for the appropriate static pressure conditions given above, plus the earthquake-induced dynamic earth pressure.

In accordance with Section 4.6.5 and C4.6.5 of the 2014 CHBDC and its Commentary (2014), for walls which do not allow lateral yielding, the horizontal seismic coefficient, k_h, used in the calculation of the seismic lateral earth pressure coefficient, is taken as equal to the seismic horizontal acceleration coefficient at zero wall movement. For structures which allow lateral yielding, k_h is taken as half of the seismic horizontal acceleration coefficient that corresponds to zero wall movement. The seismic vertical acceleration coefficient k_v in both cases should be ignored.

The seismic active pressure coefficients (K_{AE}) for the backfills listed in Table 6-3 may be used in design. The earthquake-induced dynamic pressure distribution, which is to be added to the static earth pressure distribution, is a linear distribution with maximum pressure at the top of the wall and minimum pressure at its toe (i.e., an inverted triangular pressure distribution). The total pressure distribution (static plus seismic) may be determined as follows:

$$\sigma_h(d) = K_a \gamma d + (K_{AE} - K_a) \gamma (H-d)$$

Where: $\sigma_h(d)$ is the lateral earth pressure at depth, d, (kPa);

K_a is the static active earth pressure coefficient;

K_{AE} is the seismic active earth pressure coefficient;

γ is the unit weight of the backfill soil (kN/m^3), as given previously;

d is the depth below the top of the wall (m); and

H is the total height of the wall (m).

6.5.5 Corrosion Potential

A select soil sample obtained from borehole advanced by Thurber was sent to Paracel Laboratories in Ottawa, Ontario for determination of pH, electrical resistivity, chloride content and sulphate content. The method of analytical testing used for the soil specimens is indicated in the analytical laboratory report. The results of the test from sample obtained by Thurber are summarized in Table 6-4.

Table 6-4: Results of Chemical Analysis

Borehole/Sample ID	Sample Depth (m)	pH	Chloride (µg/g)	Sulphate (µg/g)	Electrical Resistivity (Laboratory) (Ω-cm)
601/SS4	2.2	7.7	70	112	3100

The test results indicate that concrete in contact with the tested soil would have a negligible degree of exposure to sulphate attack based on CSA-A23.1. Based on the results obtained, it is anticipated that the general use hydraulic cement (GU) can be used.

Based on the measured resistivity, pH etc., the tested soil samples would be considered noncorrosive to buried metallic elements in accordance with ANSI/AWWA C105/A21.5-05, Appendix A, Table A.1.

6.6 Construction Considerations

6.6.1 Excavations

It is anticipated that temporary excavations in the order of 4 m will be required for the removal of the existing culvert and foundations. All excavations must be conducted in accordance with the requirements of the Occupational Health & Safety Act & Regulations (OHSA) for Construction Projects O. Reg. 213/91 as amended. requirements of the Occupational

Health & Safety Act & Regulations (OHSA) for Construction Projects. The fills at the site should be classified as Type 3 and the very loose to loose native sand and silt materials located below the level of the groundwater and/or the water level in the creek should be considered as Type 4 soils in accordance with OHSA. However, as indicated in the OHSA, if an excavation contains more than one type of soil, the soil type for the excavation shall be classified as the type with the highest number among the soil types present within the excavation. In accordance with OHSA unsupported excavations made in Type 4 soils must have side slopes no steeper than 3H:1V from the base of the excavation.

Subgrade preparation and placement of culvert bedding must be carried out in a dry condition. Where the existing substrate and backfill inside the existing culvert is to remain the unbalanced earth pressures and hydrostatic pressured must be considered when excavating the for the foundations of the new culvert. The temporary protection system or dewatering system should be in accordance with OPSS.PROV 539 and/or OPSS.PROV 517 and SP 517F01. Excavation and removal of the unsuitable material encountered in the area of the structure should be carried out in accordance with OPSS.PROV 902.

6.6.2 Temporary Protection System

It is anticipated that the culvert replacement will be carried out in two stages with both a temporary platform widening and a temporary protection system. Where required, temporary protection systems should be provided in accordance with OPSS.PROV 539 and designed for Performance Level 2. Typical lateral earth pressure coefficients are provided in Table 6-2.

The protection systems should be designed with the penetration depth that is sufficient to provide base fixity and incorporate traffic loading and surcharge loading due to construction equipment and operations, and the slope of temporary embankments above the top of the protection system should and location of existing utilities and trenches also be considered. The variable rock surface may present challenges for protection systems. The bedrock profile varies considerably across the site and that temporary protection system will be installed in ground conditions that include sloping bedrock.

6.6.3 Dewatering

The design builder must be prepared to control the groundwater and surface water flow at the site to permit the proposed culvert replacement to be constructed in a dry and stable excavation. The groundwater level for the site at the time of the proposed replacement should be taken as the water level in the creek. It is recommended that the replacement be conducted during a drier period.

It is understood that the existing culvert will remain operational and will serve as a temporary flow passage for Muskrat Creek during construction of the new box culvert. It is understood that the existing culvert is to be abandoned in place and decommissioned by filling with concrete after construction of the new culvert is complete. Excavations below the groundwater level are anticipated for constructing the box culvert. A cofferdam with pumping from sumps may be required to control inflow of water into the excavation prepare the subgrade and to construct the footings in the dry. Dewatering and surface water diversion must remain operational and effective until the culvert is replaced. The design of the dewatering system should be in accordance with OPSS 517 and SP 517F01.

The groundwater level will fluctuate and the minimum groundwater elevation for the site at the time of the proposed culvert replacement should be taken as the water level in the creek at the time of construction. Excavation below the groundwater level to construct the culvert foundation will be required and excavation below the groundwater level without prior dewatering is not recommended since the inflow of groundwater will cause base heave/boiling and sloughing of the foundation soil below the water level, making it difficult to maintain a dry, sound base on which to work.

Cofferdams may be required to prevent the creek from spilling into the adjacent excavation for the new culvert and during creek realignment. Further assessment of dewatering requirements and the need for a PTTW will be addressed in a separate report.

6.6.4 Erosion Protection

Slope protection and drainage measures will be required to ensure the long-term surficial stability of the embankment slopes. The contractor should provide silt fences and erosion control blankets, as required, throughout the duration of the construction to prevent silt/sediments from running off the site as per OPSS 805. Erosion protection should be provided at the culvert inlet and outlet areas.

Typically, rock protection should be provided over all surfaces with which culvert water is likely to be in contact. Treatment at the outlets should be in accordance with OPSD 810.010. A vegetation cover should be established on all other exposed earth surfaces to protect against surficial erosion in general accordance with OPSS.PROV 804. It is recommended that a clay seal be used to minimize the potential for erosion near the inlet area. The clay seal should extend a minimum of 0.3 m above the high-water level and laterally for the width of the granular material, and have a minimum thickness of 0.5 m. The material requirements should be in accordance with OPSS.PROV 1205. A geosynthetic clay liner may be used as a clay seal.

6.6.5 Geotechnical Instrumentation and Monitoring Plan

A geotechnical instrumentation and monitoring plan (GIMP) will be developed as a separate document. The GIMP will address the monitoring requirements prior to (baseline), during and following the construction activities. It will include a description of the instrumentation type and location, monitoring procedures and frequencies and reporting. It is anticipated the GIMP will include vibration wire pressure cells, vibrating wire strain gauges and multipoint borehole extensometers.

7.0 Closure

This Foundation Investigation Report was prepared by Mr. Nazmur Rahman, M.A.Sc., PE, P.Eng., Associate Geotechnical Engineer.

Mr. Ty Garde, M.Eng., P.Eng., Principal Geotechnical Engineer and a Designated Foundation Contact for Wood, conducted an independent quality control review of the report.

Sincerely,

Wood Environment & Infrastructure Solutions,
a Division of Wood Canada Limited

Prepared By:

Nazmur Rahman, M.A.Sc., P.Eng., P.E
Associate Engineer – Geotechnical

Reviewed By:

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MTO Designated Foundations Contact

Drawings

METRIC

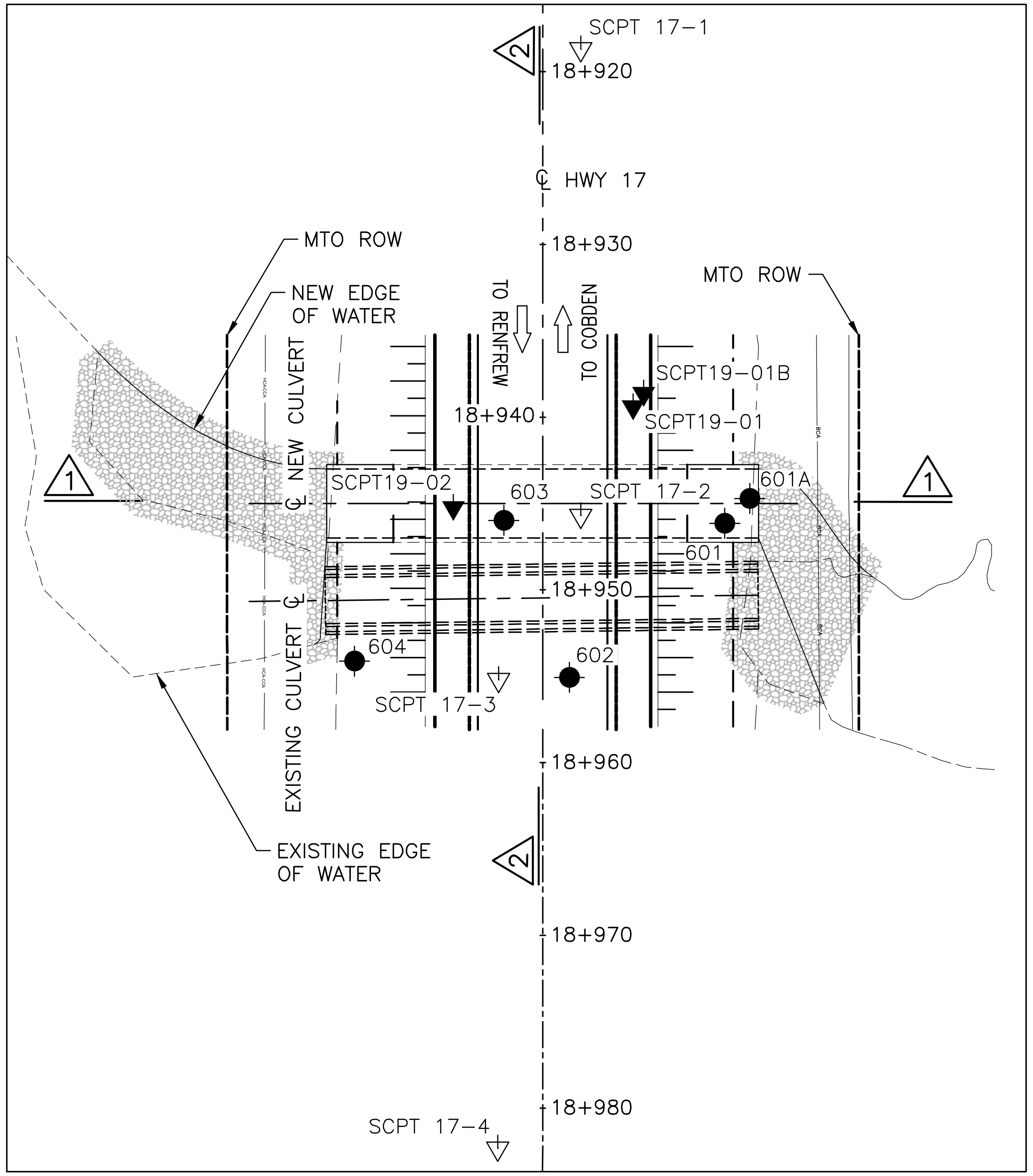
DIMENSIONS ARE IN METRES AND/OR MILLIMETRES UNLESS OTHERWISE SHOWN

Wood Environment & Infrastructure Solutions
A Division of Wood Canada Limited
wood.

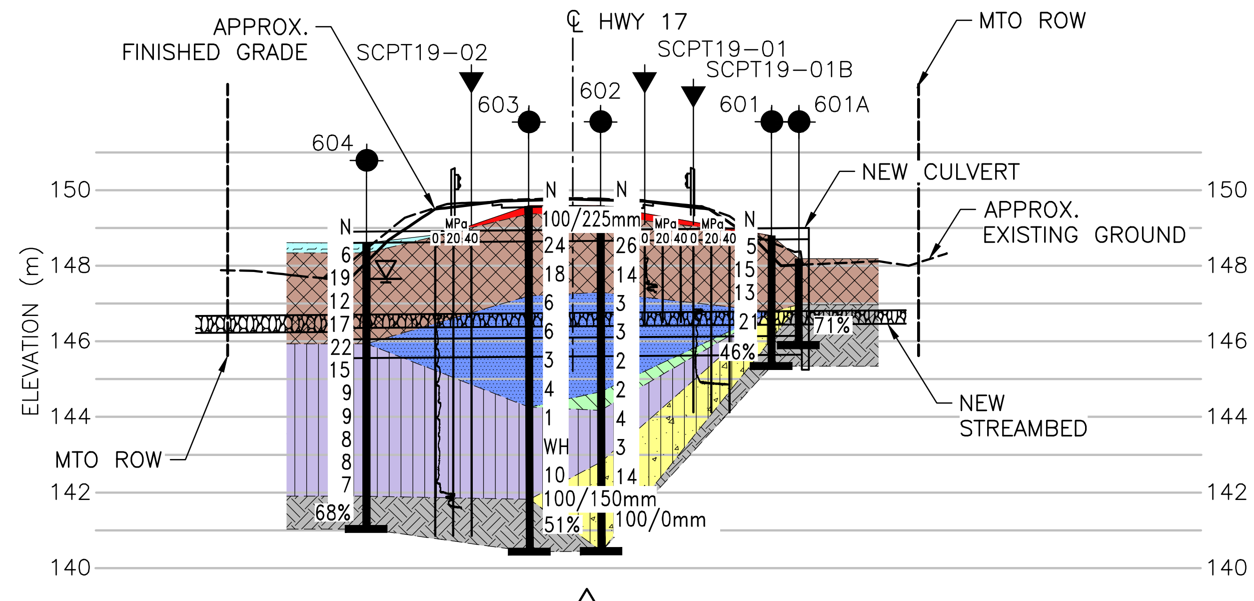
Ministry of Transportation (MTO)
Foundation Investigation and Design
Culvert Replacement
Renfrew County, Ontario

MUSKRAT CREEK CROSSING OF HIGHWAY 17
BOREHOLE LOCATIONS & SOIL STRATA

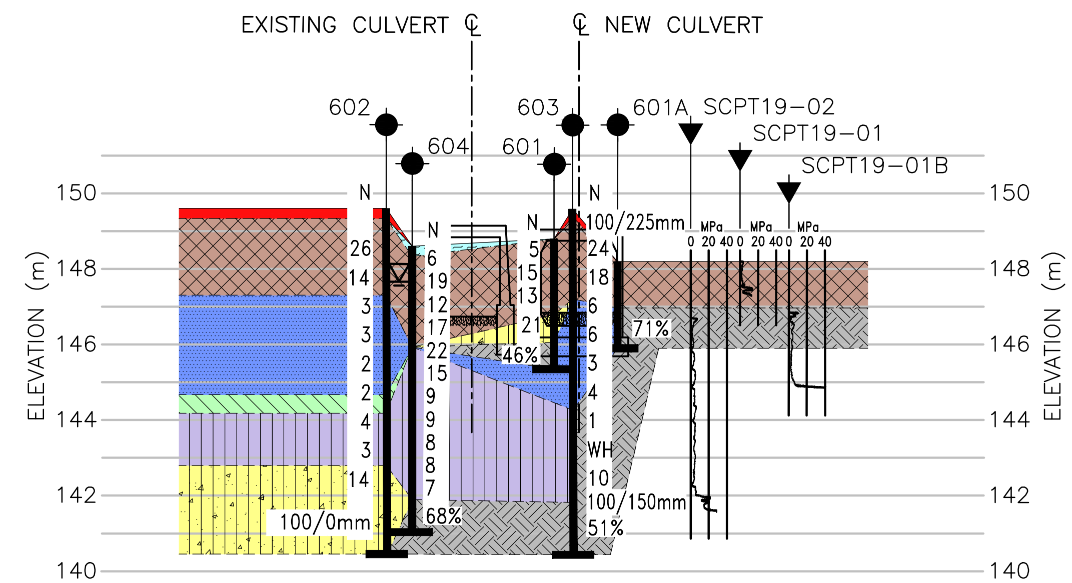
SHEET
—



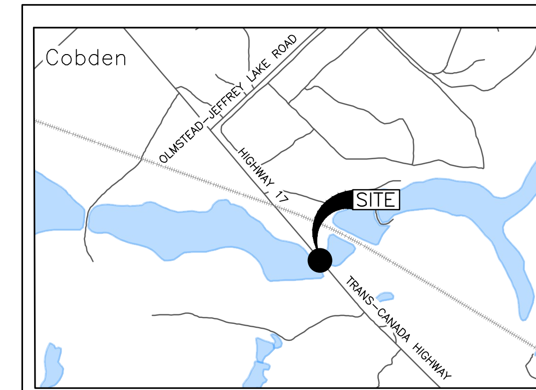
PLAN



1 PROFILE



2 SECTION



KEY PLAN
SCALE
0.25 0 0.5 1Km

LEGEND

Symbol	Description
▼	DYNAMIC CONE PENETRATION TEST LOCATION − CURRENT WOOD INVESTIGATION REPORT No. TPB196039, 2019
▽	DYNAMIC CONE PENETRATION TEST LOCATION − PREVIOUS INVESTIGATION BY OTHERS REPORT No. 19−5161−263, 2018
●	BOREHOLE LOCATION − PREVIOUS INVESTIGATION BY OTHERS REPORT No. 19−5161−263, 2018
N	STANDARD PENETRATION TEST VALUE
15	BLOWS/0.3m UNLESS OTHERWISE STATED (STD. PEN. TEST, 475 J/BLOW)
▽	WATER LEVEL UPON COMPLETION OF DRILLING
46%	ROCK QUALITY DESIGNATION (RQD)
SCPT	MPa 0 20 40

NOTES

1. THIS DRAWING IS TO BE READ IN CONJUNCTION WITH THE ACCOMPANYING FOUNDATION INVESTIGATION AND DESIGN REPORT.
2. THE INTERPRETED STRATIGRAPHY REPRESENTS SIMPLIFIED SUBSURFACE CONDITIONS. THE BOUNDARIES BETWEEN SOIL STRATA HAVE BEEN DEFINED AT BOREHOLE LOCATIONS ONLY. CONDITIONS BETWEEN BOREHOLE LOCATIONS COULD DIFFER FROM ILLUSTRATED CONDITIONS.
3. ELEVATIONS ARE REFERENCED TO GEODETIC DATUM.

REFERENCES

1. THURBER ENGINEERING LTD., "HIGHWAY 17, MUSKRAT CREEK CULVERT REPLACEMENT, BOREHOLE LOCATIONS AND SOIL STRATA", WP No. 4113−01−01, SITE No. 29−232/C, APR 2018.
2. WOOD E&I SOLUTIONS, "MUSKRAT CREEK CULVERT, SITE NO. 29−232/C, GENERAL ARRANGEMENT", WP No. 4113−01−01, SITE No. 29−232/C, SHEET No. S1, JUNE 2019.

0 2 6 10m
VERTICAL SCALE 1:200

0 5 10 15m
HORIZONTAL SCALE 1:400

SIMPLIFIED STRATIGRAPHY

- ASPHALT
- BEDROCK
- SAND
- SAND WITH SILT & GRAVEL FILL
- SILTY SAND TILL
- TOPSOIL
- CLAY
- SILT

No.	ELEVATION	CO−ORDINATES (MTM, NAD 83 ZONE 9) NORTHING	EASTING
WOOD TESTHOLES			
SCPT19−01	149.5	5049724.1	278938.5
SCPT19−01B	149.5	5049725.1	278938.5
SCPT19−02	149.5	5049713.1	278933.9
TESTHOLES BY OTHERS			
601	148.8	5049722.1	278947.1
601A	148.2	5049724.2	278947.3
602	149.6	5049709.7	278945.5
603	149.6	5049714.4	278936.8
604	148.6	5049702.6	278935.1
SCPT 17−1	149.6	5049738.7	278923.5
SCPT 17−2	149.7	5049717.4	278940.2
SCPT 17−3	149.7	5049707.0	278942.2
SCPT 17−4	149.7	5049685.7	278958.8

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PROVINCE OF ONTARIO

REGISTERED PROFESSIONAL ENGINEER
T. J. GARDE
JULY 30, 2019
PROVINCE OF ONTARIO

Geocres No. 31F−208

REVISIONS DATE	REV.	BY	DESCRIPTION
30−JUL−19	1	SJL	FINAL DESIGN SUBMISSION
21−JUN−19	0	SJL	INITIAL DESIGN SUBMISSION

DESIGN NR	CHK TG	DRAWING No. 1	
DRAWN SJL	CHK NR	SITE 29−232/C	DATE 12−JUN−19

DOC: TPB196039−R01002

DATE PLOTTED: 7/30/2019 11:09:36 AM
FILE LOCATION: P:\2019\Geotechnical\Projects\Other Offices\Burlington\TPB196039 − MTO DB Hwy 17 Culvert Replacement\Drafting\AutoCAD files\TPB196039−R01002.dwg

Appendix A

Record of Borehole Sheets

EXPLANATION OF BOREHOLE LOG

Ontario

This form describes some of the information provided on the borehole logs, which is based primarily on examination of the recovered samples, and the results of the field and laboratory tests. Additional description of the soil/rock encountered is given in the accompanying geotechnical report.

GENERAL INFORMATION

Project details, borehole number, location coordinates and type of drilling equipment used are given at the top of the borehole log.

SOIL LITHOLOGY

Elevation and Depth

This column gives the elevation and depth of inferred geologic layers. The elevation is referred to the datum shown in the Description column.

Lithology Plot

This column presents a graphic depiction of the soil and rock stratigraphy encountered within the borehole.

Description

This column gives a description of the soil stratums, based on visual and tactile examination of the samples augmented with field and laboratory test results. Each stratum is described according to the *Modified Unified Soil Classification System(modified slightly so that an inorganic clay of* "*medium* plasticity" is recognized).

The compactness condition of cohesionless soils based on standard penetration testing (SPT) and the consistency of cohesive soils (undrained shear strength) are defined as follows (Ref. Canadian Foundation Engineering Manual, 4th Edition, 2006):

Compactness Cohesionless Soils	SPT N-Value
Very Loose	0 to 4
Loose	4 to 10
Compact	10 to 30
Dense	30 to 50
Very Dense	> 50

Consistency of Cohesive Soils	Undrained Shear Strength	
	kPa	psf
Very Soft	0 to 12	0 to 250
Soft	12 to 25	250 to 500
Firm	25 to 50	500 to 1000
Stiff	50 to 100	1000 to 2000
Very Stiff	100 to 200	2000 to 4000
Hard	Over 200	Over 4000

SOIL SAMPLING

Sample types are abbreviated as follows:

SS	Split Spoon	TW	Thin Walled Open (Pushed)	RC	Rock Core	GS	Grab Sample
AS	Auger Sample	TP	Thin Walled Piston (Pushed)	WS	Washed Sample	AR	Air Return Sample

Additional information provided in this section includes sample numbering, sample recovery and numerical testing results.

Field and Laboratory Testing

Results of field testing (e.g., SPT, pocket penetrometer, and vane testing) and laboratory testing (e.g., natural moisture content, and limits) executed on the recovered samples are plotted in this section.

Definitions of Penetration Resistance

Standard penetration resistance 'N' – The number of blows required to advance a standard split spoon sampler 30 cm into the subsoil, driven by means of a 63.5 kg hammer falling freely a distance of 76 cm.

Dynamic penetration resistance – The number of blows required to advance a 50 mm, 60 degree cone, fitted to the end of drill rods, 30 cm into the subsoil, the driving energy being 474.5 Joules per blow.

INSTRUMENTATION INSTALLATION

Instrumentation installations (monitoring wells, piezometers, inclinometers, etc.) are plotted in this section.

WATER LEVEL

Water levels, if measured during fieldwork, are plotted in the depth/elevation column. These water levels may or may not be representative of the static groundwater level depending on the nature of soil stratum where the piezometer tips are located, the time elapsed from installation to reading and other applicable factors. Other information includes the depth of borehole cave-in, if any. This information is also included in the borehole log footer.

COMMENTS

This column is used to describe non-standard situations or notes of interest.

GENERAL REPORT NOTE

The soil conditions, profiles, comments, conclusions and recommendations found in this report are based upon the samples recovered during the fieldwork. Soils are heterogeneous materials and, consequently, variations (possibly extreme) may be encountered at site locations away from boreholes. During construction, competent, qualified inspection personnel should verify that no significant variations exist from the conditions described in this report.

Rev. date: January 7, 2019

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Geotechnical Discipline - Ontario Region

www.woodplc.com

wood.

MTO SOIL CLASSIFICATION

Based on MTO Soil Classificaiton Manual

Ontario

MAJOR DIVISION				GROUP SYMBOL	TYPICAL DESCRIPTION	INFORMATION REQUIRED FOR DESCRIBING SPOILS	LABORATORY CLASSIFICATION CRITERIA
COARSE GRAINED SOILS (MORE THAN HALF BY WEIGHT LARGER THAN 75µm)	GRAVELS MORE THAN HALF THE COARSE FRACTION LARGER THAN 4.75mm	CLEAN GRAVEL (TRACE OR NO FINES)	WIDE RANGE IN GRAIN SIZE & SUBSTANTIAL AMOUNTS OF ALL INTERMEDIATE PARTICLE SIZES	GW	WELL GRADED GRAVELS, GRAVEL-SAND MIXTURES, LITTLE OR NO FINES	GIVE TYPE, NAME, IF NECESSARY INDICATE APPROX % OF SAND & GRAVEL, MAX SIZE, ANGULARITY, SURFACE CONDITION & HARDNESS OF THE COARSE GRAINS; LOCAL OR GEOLOGICAL NAME, OTHER PERTINENT DESCRPICTIVE INFORMATION & SYMBOL IN PARENTHESIS	$C_U = \frac{D_{60}}{D_{10}}$ GREATER THAN 4; $C_C = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ BETWEEN 1 AND 3
			PREDOMINANTLY ONE SIZE OR RANGE OR SIZES WITH SOME INTERMEDIATE SIZES MISSING	GP	POORLY GRADED GRAVELS, GRAVEL-SAND MIXTURES, LITTLE OR NO FINES		
		GRAVEL WITH FINES (APPLICABLE AMOUNT OF FINES)	NON PLASTIC FINES (FOR IDENTIFICATION SEE ML BELOW)	GM	SILTY GRAVELS, POORLY GRADED GRAVEL-SAND-SILT MIXTURES		
			PLASTIC FINES (FOR IDENTIFICATION SEE CL BELOW)	GC	CLAYEY GRAVELS, POORLY GRADED GRAVEL-SAND-CLAY MIXTURES		
	SANDS MORE THAN HALF THE COARSE FRACTION SMALLER THAN 4.75mm	CLEAN SAND (TRACE OR NO FINES)	WIDE RANGE IN GRAIN SIZE & SUBSTANTIAL AMOUNT OF ALL INTERMEDIATE PARTICLE SIZES	SW	WELL GRADED SANDS, GRAVELLY SANDS, LITTLE OR NO FINES	FOR UNDISTURBED SOILS ADD INFORMATION ON STRATIFICATION, DEGREE OF COMPACTNESS, CEMENTATION, MOISTURE CONDITION & DRAINAGE CHARACTERISTICS	NOT MEETING ALL GRADATION REQUIREMENTS FOR GW
			PREDOMINANTLY ONE SIZE OR RANGE OF SIZES WITH SOME INTERMEDIATE SIZES MISSING	SP	POORLY GRADED SANDS, GRAVELLY SANDS, LITTLE OR NO FINES		
		SAND WITH FINES (APPLICABLE AMOUNT OF FINES)	NON PLASTIC FINES (FOR IDENTIFICATION SEE ML BELOW)	SM	SILTY SANDS, POORLY GRADED SAND-SILT MIXTURES		ATTERBERG LIMITS BELOW A-LINE OR I_P LESS THAN 4
			PLASTIC FINES (FOR IDENTIFICATION SEE CL BELOW)	SC	CLAYEY SANDS, POORLY GRADED SAND-CLAY MIXTURES		ATTERBERG LIMITS ABOVE A-LINE WITH I_P GREATER THAN 7

For SM/SC: ABOVE A-LINE WITH I_P BETWEEN 4 AND 7 ARE BORDERLINE CASES REQUIRING USE OF DUAL SYMBOLS

USE GRAIN SIZE CURVE IN IDENTIFYING THE FACTORS AS GIVEN UNDER FIELD IDENTIFICATION

DETERMINE PERCENTAGE OF GRAVEL & SAND FROM GRAIN SIZE CURVE

DEPENDING ON PERCENTAGE OF FINES (FRACTION SMALLER THAN 75µm) COARSE GRAINED SOILS ARE CLASSIFIED AS FOLLOWS:

LESS THAN 5%:
GW, SP, SW, SP
MORE THAN 12%:
GM, GC, SM, SC
5% TO 12%:
BORDER LINE CASES REQUIRE USE OF DUAL SYMBOL

FINE-GRAINED SOILS (MORE THAN HALF BY WEIGHT SMALLER THAN 75µm)		DRY STRENGTH (CRUSHING CHARACTERISTICS)	DILATANCY (REACTION TO SHAKING)	TOUGHNESS (CONSISTENCY NEAR PLASTIC LIMIT)	GROUP SYMBOL	TYPICAL DESCRIPTION	INFORMATION REQUIRED FOR DESCRIBING SPOILS
IDENTIFICATION PROCEDURE ON FRACTION SMALLER THAN 425 µm							
SILT AND CLAYS	LIQUID LIMIT LESS THAN 35	NONE	QUICK	NONE	ML	INORGANIC SILTS & SANDY SILTS OF SLIGHT PLASTICITY, ROCK FLOUR	GIVE TYPE, NAME, IF NECESSARY INDICATE DEGREE AND CHARACTER OF PLASTICITY, AMOUNT AND MAXIMUM SIZE OF COURSE GRAINS, COLOUR IN WET CONDITION, ODOUR, IF ANY, LOCAL OR GEOLOGIC NAME, OTHER PERTINENT DESCRIPTIVE INFORMATION & SYMBOL IN PARENTHESIS
		MEDIUM TO HIGH	NONE TO VERY SLOW	MEDIUM	CL	SILTY CLAYS (INORGANIC), GRAVELLY CLAYS, SANDY CLAYS, LEAN CLAYS	
		SLIGHT TO MEDIUM	SLOW	SLIGHT	OL	ORGANIC SILT OF LOW PLASTICITY, ORGANIC SANDY SILTS	
	LIQUID LIMIT BETWEEN 35 AND 50	NONE TO SLIGHT	SLOW TO QUICK	SLIGHT	MI	INORGANIC COMPRESSIBLE FINE SANDY SILT WITH CLAY OF MEDIUM PLASTICITY, CLAYEY	
		HIGH	NONE TO VERY SLOW	MEDIUM TO HIGH	CI	SILTY CLAYS (INORGANIC) OF MEDIUM PLASTICITY	FOR UNDISTURBED SOILS ADD INFORMATION ON STRUCTURE, STRATIFICATION, CONSISTANCY IN UNDISTURBED AND REMOLDED STATES, MOISTURE & DRAINAGE CONDITION
		SLIGHT TO MEDIUM	VERY SLOW	SLIGHT	OI	ORGANIC SILTY CLAYS OF MEDIUM PLASTICITY	
	LIQUID LIMIT GREATER THAN 50	SLIGHT TO MEDIUM	SLOW TO NONE	MEDIUM	MH	INORGANIC SILTS, HIGHLY COMPRESSIBLE MICACEOUS OR DIATOMECACOUS FINE SANDY	
		HIGH TO VERY HIGH	NONE	HIGH	CH	CLAYS (INORGANIC) OF HIGH PLASTICITY, FAT CLAYS	
		MEDIUM TO HIGH	NONE TO VERY SLOW	SLIGHT TO MEDIUM	OH	ORGANIC CLAYS OF HIGH PLASTICITY	
HIGH ORGANIC SOILS		READILY IDENTIFIED BY COLOUR, ODOUR, SPONGY FEEL & FREQUENTLY BY FIBROUS TEXTURE			Pt	PEAT AND OTHER HIGHLY ORGANIC SOILS	

Laboratory classification criteria (fine-grained rows):

$C_U = \frac{D_{60}}{D_{10}}$ GREATER THAN 6; $C_C = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ BETWEEN 1 AND 3

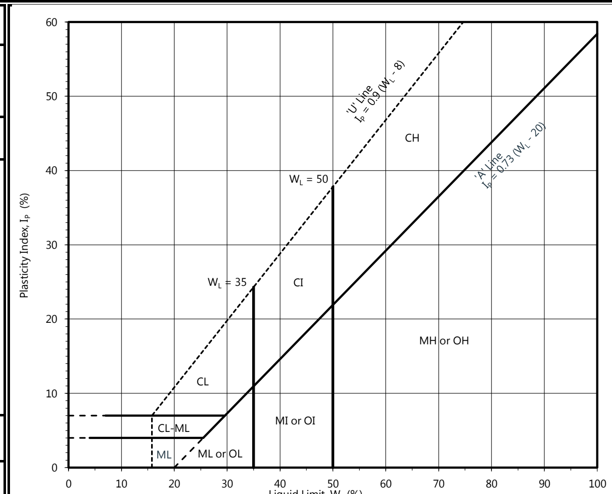
NOT MEETING ALL GRADATION REQUIREMENTS FOR SW

ATTERBERG LIMITS BELOW A-LINE OR I_P LESS THAN 4

ATTERBERG LIMITS ABOVE A-LINE WITH I_P GREATER THAN 7

ABOVE A-LINE WITH I_P BETWEEN 4 AND 7 ARE BORDERLINE CASES REQUIRING USE OF DUAL SYMBOLS

FRACTION		U.S. STANDARD SIEVE SIZE PASSING	RETAINED	DEFINING RANGES OF PERCENTAGE BY WEIGHT OF MINOR COMPONENTS PERCENT	DESCRIPTOR
GRAVEL	COARSE	75 mm	26.5 mm		
	FINE	26.5 mm	4.75 mm	40 - 50	AND
SAND	COARSE	4.75 mm	2.00 mm	30 - 40	Y/EY
	MEDIUM	2.00 mm	425 µm	20 - 30	WITH
	FINE	425 µm	75 µm	10 - 20	SOME
FINES (SILT OF CLAY, BASED ON PLASTICITY)		75 µm		1 - 10	TRACE
OVERSIZED MATERIAL					
ROUNDED OR SUBROUNDED: COBBLES 75 mm TO 200 mm BOULDERS > 200 mm				NOT ROUNDED: ROCK FRAGMENTS > 75 mm ROCKS > 0.76 CUBIC METRE IN VOLUME	



PLASTICITY CHART
FOR LABORATORY CLASSIFICATION OF FINE GRAINED SOILS

BOUNDARY CLASSIFICATION: SOILS POSSESSING CHARACTERISTICS OF TWO GROUPS ARE DESIGNATED BY COMBINATIONS OF GROUP SYMBOLS FOE EXAMPLE GW-GC
WELL GRADED GRAVEL-SAND MIXTURE WITH CLAY BINDER

Wood Environment & Infrastructure Solutions
a Division of Wood Canada Limited
Geotechnical Discipline - Ontario Region

www.woodplc.com

wood.

Rev. date: January 7, 2019

BEDROCK DESCRIPTION

ROCK QUALITY DESIGNATION

The Rock Quality Designation (RQD) is an indirect measure of the number of natural fractures in a rock mass. It is obtained from the rock cores by summing up the length of core pieces of sound rock that are 100 mm or more in length, measured from the midpoint to midpoint of adjacent natural fractures. Note, a natural fracture that is parallel to the core axis should be ignored so that the RQD is not affected. The RQD value is expressed as a percentage of the summed core lengths (100 mm or greater) to the total core length.

RQD originally specified the use of NW core (54 mm diameter). The technique can be used on different core sizes, if the bulk of the fractures caused by drilling stress and handling can be be distinguished from in situ fractures which tend to have some form of joint infill (typically calcite and chlorite being the most common). However, smaller core is more susceptible to breaking; hence, samller core in a rock mass with little joint infill in which natural fractures are hard to distinguish can produce a less accurate measure of RQD. It is generally accepted that the RQD is applicable to NQ core size (45 mm).

SOLID CORE RECOVERY

Solid Core Recovery (SCR) is defined as the percentage of intact cylindrical core pieces to the total length of core.

TOTAL CORE RECOVERY

Total Core Recovery (TCR) is defined as the percentage of intact core pieces to the total length of core.

STRENGTH CLASSIFICATION

Term (Grade)	Field Identification	Approximate Range of Uniaxial Compressive Strength (MPa)
Extremely Weak (R0)	Indented by thumbnail.	0.25 – 1.0
Very Weak (R1)	Crumbles under firm blows with point of geological hammer; can be peeled by a pocket knife.	1.0 – 5.0
Weak (R2)	Can be peeled with a pocket knife with difficulty; shallow indentations made by firm blow with point of geological hammer.	5.0 – 25
Medium Strong (R3)	Cannot be scraped or peeled with a pocket knife; specimen can be fractured with a single firm blow of geological hammer.	25 – 50
Strong (R4)	Specimen requires more than one blow of geological hammer to fracture it.	50 – 100
Very Strong (R5)	Specimen requires many blows of geological hammer to fracture it.	100 – 250
Extremely Strong (R6)	Specimen can only be chipped with geological hammer.	> 250

JOINT SPACING CLASSIFICATION

Term	Average Joint Spacing (m)
Extremely Close	< 0.02
Very Close	0.02 – 0.06
Close	0.06 – 0.20
Moderately Close	0.2 – 0.6
Wise	0.6 – 2.0
Very Wide	2.0 – 6.0
Extremely Wide	> 6.0

ROCK QUALITY CLASSIFICATION

Rock Quality Designation, RQD (%)	Description of Rock Quality
0 – 25	Very Poor
25 – 50	Poor
50 – 75	Fair
75 – 90	Good
90 - 100	Excellent

Reference: Deere et al, 1967

WEATHERING CLASSIFICATION

Term (Grade)	Description
Fresh (W1)	No visible sign of rock material weathering; perhaps slight discoloration on major discontinuity surfaces.
Slightly Weathered (W2)	Discoloration indicates weathering of rock material on discontinuity surfaces. Less than 5% of rock mass altered.
Moderately Weathered (W3)	Less than half of the rock material is decomposed and/or disintegrated into a soil. Fresh or discoloured rock is present either as a continuous framework or as core stones.
Highly Weathered (W4)	More than half of the rock material is decomposed and/or disintegrated into a soil. Fresh or discoloured rock is present either as a discontinuous framework or as core stones.
Completely Weathered (W5)	All rock material is decomposed and/or disintegrated into soil. The original mass structure is still largely intact.
Residual Soil (W6)	All rock material is converted to soil. The mass structure and material fabric are destroyed. There is a large change in volume but the soil has not been significantly transported.

Reference: Brown, 1981, "Suggested Methods for Rock Characterization Testing and Monitoring". International Society for Rock Mechanics.

Ministry of Transportation
Ontario

THURBER

RECORD OF BOREHOLE No 601

METRIC

W.P. 4113-01-01 LOCATION 29-232/C Muskrat Creek Culvert, MTM Zone 9: N 5 049 722.1 E 278 947.1 ORIGINATED BY SMP

HWY 17 BOREHOLE TYPE Portable BQ/NQ Casing COMPILED BY SMP

DATUM Geodetic DATE 2015.10.19 - 2015.10.20 CHECKED BY KP

ELEV / DEPTH	DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	ELEVATION SCALE	WATER CONTENT (%)	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
148.8 / 0.0	Gravel and sand with silt, Loose to compact, Brown, **FILL**	1	SS	5			
		2	SS	15	148		
		3	SS	13	147		46 43 11 (SI+CL)
146.8 / 2.1	**SILTY SAND (SM)** with gravel, Compact, Grey	4	SS	21			19 33 48 (SI+CL)
146.1 / 2.7	**BEDROCK**, Granite, Slightly weathered, Poor quality, Grey	1	RUN		146		RUN #1 TCR=96% SCR=86% RQD=46%
145.4 / 3.4	End of Borehole						

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

GROUND WATER CONDITIONS; STRAT PLOT; UNIT WEIGHT γ kN/m^3

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

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

RECORD OF BOREHOLE No 601A

METRIC

W.P. 4113-01-01 LOCATION 29-232/C Muskrat Creek Culvert, MTM Zone 9: N 5 049 724.2 E 278 947.3 ORIGINATED BY SMP

HWY 17 BOREHOLE TYPE Portable BQ/NQ Casing COMPILED BY SMP

DATUM Geodetic DATE 2015.10.21 - 2015.10.21 CHECKED BY KP

ELEV / DEPTH	DESCRIPTION	STRAT PLOT	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
148.2	Advanced NQ Casing to 600 mm										
0.0	Gravel and sand with silt Loose to compact Brown **FILL** (Inferred)						148				
146.9 1.2	**BEDROCK** Granite Slightly weathered Fair quality Grey		1	RUN			147				RUN #1 TCR=90% SCR=80% RQD=71%
145.9 2.3	End of Borehole						146				

+ ³, × ³: Numbers refer to Sensitivity

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

Ministry of Transportation
Ontario

THURBER

RECORD OF BOREHOLE No 602

METRIC

W.P. 4113-01-01	LOCATION 29-232/C Muskrat Creek Culvert, MTM Zone 9: N 5 049 709.7 E 278 945.5		ORIGINATED BY CAM
HWY 17	BOREHOLE TYPE HSA		COMPILED BY SMP
DATUM Geodetic	DATE 2015.10.16 - 2015.10.16		CHECKED BY KP

SOIL PROFILE

ELEV / DEPTH	DESCRIPTION
149.6	
0.0	**250 mm ASPHALT**
0.2	Sand with silt and gravel Compact Brown **FILL** - Boulder at 1.2 m
147.3 / 2.3	**SAND (SP-SM)** with silt Black to grey Very loose
144.7 / 5.0	**Clay (CL)** with silt and gravel Firm Grey
144.3 / 5.3	**Silt (ML)** with sand Very loose to loose Grey
142.8 / 6.8	**SILTY SAND (SM) TILL** - frequent boulders Compact Grey - Boulder at 7.6 m - Boulder at 8.8 m
140.5 / 9.1	End of Borehole

SAMPLES

NUMBER	TYPE	"N" VALUES	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
1	SS	26	
2	SS	14	39 52 9 (SI+CL)
3	SS	3	
4	SS	3	0 90 10 (SI+CL)
5	SS	2	
6	SS	2	
7	SS	4	
8	SS	3	1 14 79 6
9	SS	14	0 68 32 (SI+CL)
10	SS	100/ 0mm	

GROUND WATER CONDITIONS

ELEVATION SCALE: 149, 148, 147, 146, 145, 144, 143, 142, 141

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

+ 3, × 3: Numbers refer to Sensitivity

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

ONTMT4S 19-5161-263 MUSKRAT CREEK.GPJ 2012TEMPLATE(MTO).GDT 17/1/18

RECORD OF BOREHOLE No 603

METRIC

W.P. 4113-01-01 | LOCATION 29-232/C Muskrat Creek Culvert, MTM Zone 9: N 5 049 714.4 E 278 936.8 | ORIGINATED BY SMP

HWY 17 | BOREHOLE TYPE HSA | COMPILED BY SMP

DATUM Geodetic | DATE 2015.10.22 - 2015.10.22 | CHECKED BY KP

ELEV DEPTH	DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	ELEVATION SCALE	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
149.6						
0.0	**300 mm ASPHALT**					
149.3 / 0.3	Sand with silt and gravel Compact Brown **FILL**	1	SS	100/ 225mm	149	
		2	SS	24		20 69 11 (SI+CL)
		3	SS	18	148	
147.2 / 2.4	**SAND (SP-SM)** with silt Very loose to loose Brown - trace organic matter	4	SS	6	147	
		5	SS	6		2 89 9 (SI+CL)
		6	SS	3	146	
		7	SS	4	145	
144.3 / 5.3	**SILT (ML)** with sand Very loose to compact Grey	8	SS	1	144	0 20 74 6
		9	SS	WH	143	
		10	SS	10		
		11	SS	100/ 150mm	142	
141.8 / 7.8	**BEDROCK** Granite Slightly weathered Fair quality Grey	1	RUN		141	RUN #1 TCR=80% SCR=67% RQD=51%
140.4 / 9.2	End of Borehole					

Column headings: SOIL PROFILE; STRAT PLOT; SAMPLES; 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

+ 3, × 3: Numbers refer to Sensitivity

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

Ministry of Transportation
Ontario

THURBER

RECORD OF BOREHOLE No 604

METRIC

W.P. 4113-01-01
LOCATION 29-232/C Muskrat Creek Culvert, MTM Zone 9: N 5 049 702.6 E 278 935.1
ORIGINATED BY SMP
HWY 17
BOREHOLE TYPE Portable NQ Casing
COMPILED BY SMP
DATUM Geodetic
DATE 2015.10.20 - 2015.10.21
CHECKED BY KP

ELEV / DEPTH	DESCRIPTION	NUMBER	TYPE	"N" VALUES	ELEVATION SCALE	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
148.6						
0.0	**150 mm TOPSOIL**					
0.2	Silty sand with gravel Loose to compact Brown **FILL**	1	SS	6		
		2	SS	19	148	
		3	SS	12	147	36 51 13 (SI+CL)
		4	SS	17		
146.2 / 2.4	**SILT (ML)** with sand Loose to compact Grey	5	SS	22	146	
		6	SS	15		
		7	SS	9	145	4 35 61 (SI+CL)
		8	SS	9	144	
		9	SS	8		
		10	SS	8	143	3 41 39 17
		11	SS	7	142	
141.9 / 6.7	**BEDROCK** Granite Slightly weathered Fair quality Grey	1	RUN			RUN #1 TCR=97% SCR=82% RQD=68%
141.0 / 7.6	End of Borehole Groundwater level was measured in piezometer at 0.93 m BGS (elev. 147.7 m) on 2015/12/16					

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

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

Appendix B

SCPTs Results

PRESENTATION OF SITE INVESTIGATION RESULTS

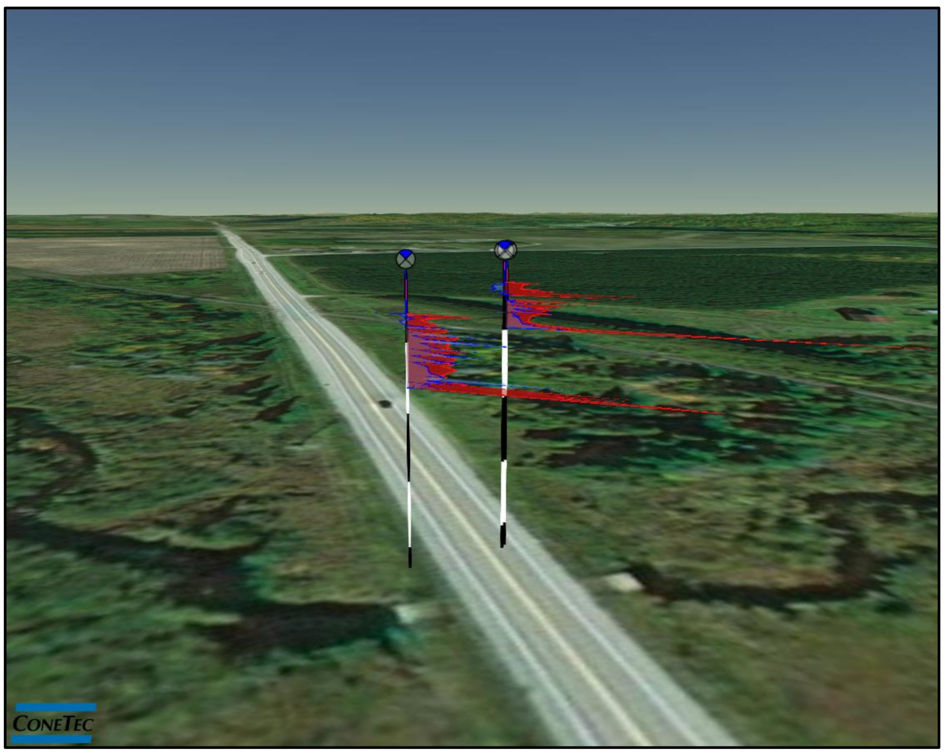
Muskrat Creek HWY 17

Prepared for:

Wood plc

ConeTec Job No: 19-05033

Project Start Date: 22-MAY-2019
Project End Date: 22-MAY-2019
Report Date: 27-MAY-2019



Prepared by:

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www.conetecdataservices.com

Introduction

The enclosed report presents the results of the site investigation program conducted by ConeTec Investigations Ltd. for Wood plc at Muskrat Creek on HWY 17, ON. The program consisted of three seismic cone penetration tests (SCPTu).

Project Information

Project	
Client	Wood plc
Project	Muskrat Creek HWY 17
ConeTec project number	19-05033

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

Rig Description	Deployment System	Test Type
CPT track rig (M5TII)	14 ton rig cylinder	SCPTu

Coordinates		
Test Type	Collection Method	EPSG Number
SCPTu	Consumer grade GPS	32618

Cone Penetrometers Used for this Project						
Cone Description	Cone Number	Cross Sectional Area (cm^2)	Sleeve Area (cm^2)	Tip Capacity (bar)	Sleeve Capacity (bar)	Pore Pressure Capacity (psi)
377:T1000F10U500	377	10	150	1000	10	500
Cone 377 was used for all CPT soundings.						

Cone Penetration Test (CPTu)	
Depth reference	Depths are referenced to the existing ground surface at the time of each test.
Tip and sleeve data offset	0.1 meter This has been accounted for in the CPT data files.
Seismic interpretations	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	Advanced plots with Ic, Su(Nkt), Phi, and N1(60), as well as Soil Behaviour Types (SBT) Scatter Plots are included in the data release package.
Additional comments	No usable seismic data from SCPT19-01 sounding.

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

This report has been prepared for the exclusive use of Wood plc (Client) for the project titled "Muskrat Creek HWY 17". The report's contents may not be relied upon by any other party without the express written permission of ConeTec Investigations Ltd. (ConeTec). ConeTec has provided site investigation services, prepared the factual data reporting and provided geotechnical parameter calculations consistent with current best practices. No other warranty, expressed or implied, is made.

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

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

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

ConeTec penetrometers are manufactured with various tip, friction and pore pressure capacities in 5 cm^2, 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.

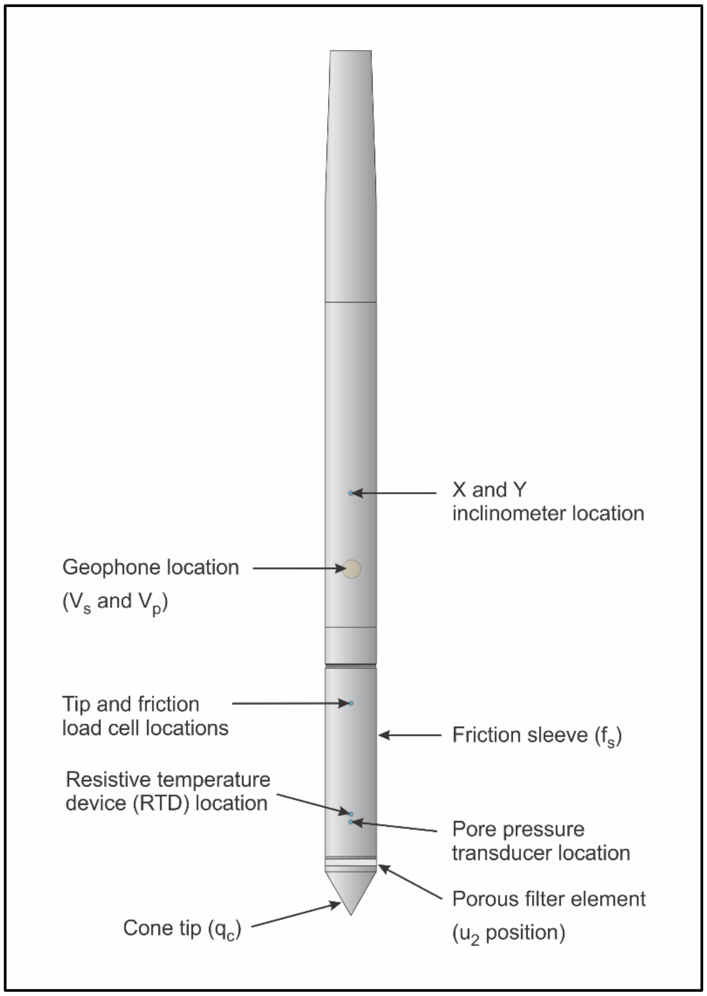

Figure CPTu. Piezocone Penetrometer (15 cm^2)

The ConeTec data acquisition systems consist of a Windows based computer and a signal conditioner and power supply interface box with a 16 bit (or greater) analog to digital (A/D) converter. The data is recorded at fixed depth increments using a depth wheel attached to the push cylinders or by using a spring loaded rubber depth wheel that is held against the cone rods. The typical recording interval is 2.5 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
- Recorded baselines are checked with an independent multi-meter
- Baseline readings are compared to previous readings
- Soundings are terminated at the client's target depth or at a depth where an obstruction is encountered, excessive rod flex occurs, excessive inclination occurs, equipment damage is likely to take place, or a dangerous working environment arises
- Differences between initial and final baselines are calculated to ensure zero load offsets have not occurred and to ensure compliance with ASTM standards

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

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

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

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 piezocone penetrometers are manufactured with a horizontally active geophone (28 hertz) that is rigidly mounted in the body of the cone penetrometer, 0.2 meters behind the cone tip.

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 using an up-hole integrated digital oscilloscope which is part of the SCPTu data acquisition system. An illustration of the shear wave testing configuration is presented in Figure SCPTu-1.

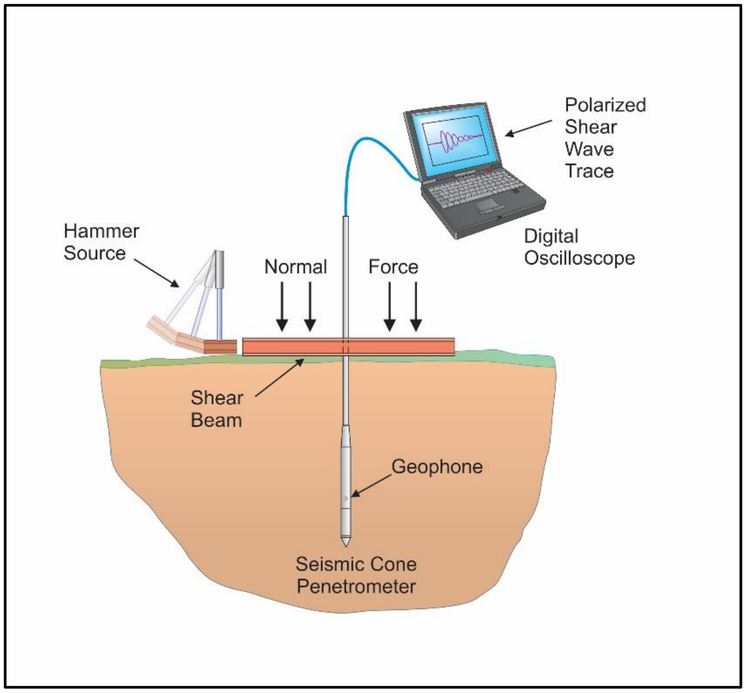

Figure SCPTu-1. Illustration of the SCPTu system

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).

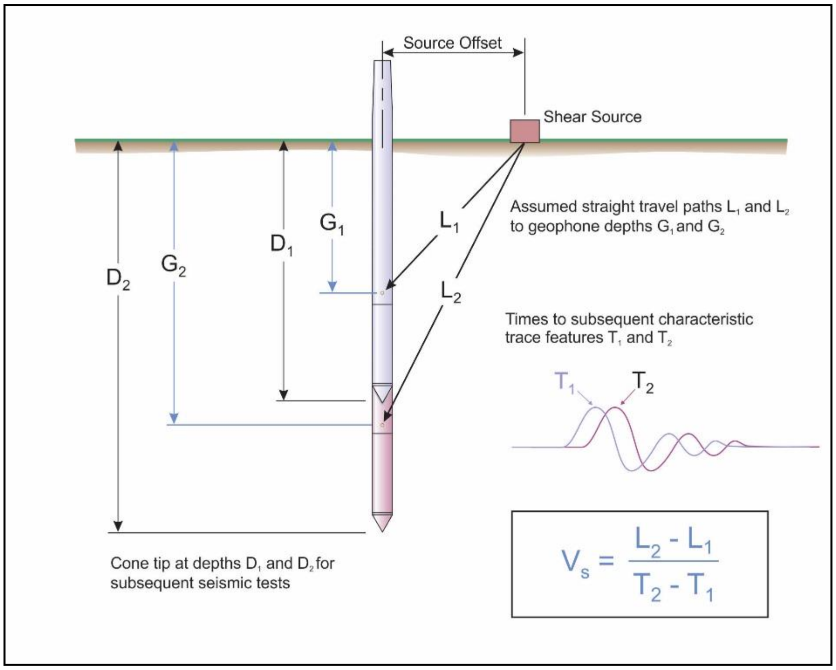

Figure SCPTu-2. Illustration of a seismic cone penetration test

Calculation of the interval velocities are performed by visually picking a common feature (e.g. the first characteristic peak, trough, or crossover) on all of the recorded wave sets and taking the difference in ray path divided by the time difference between subsequent features. 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.

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.

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

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).

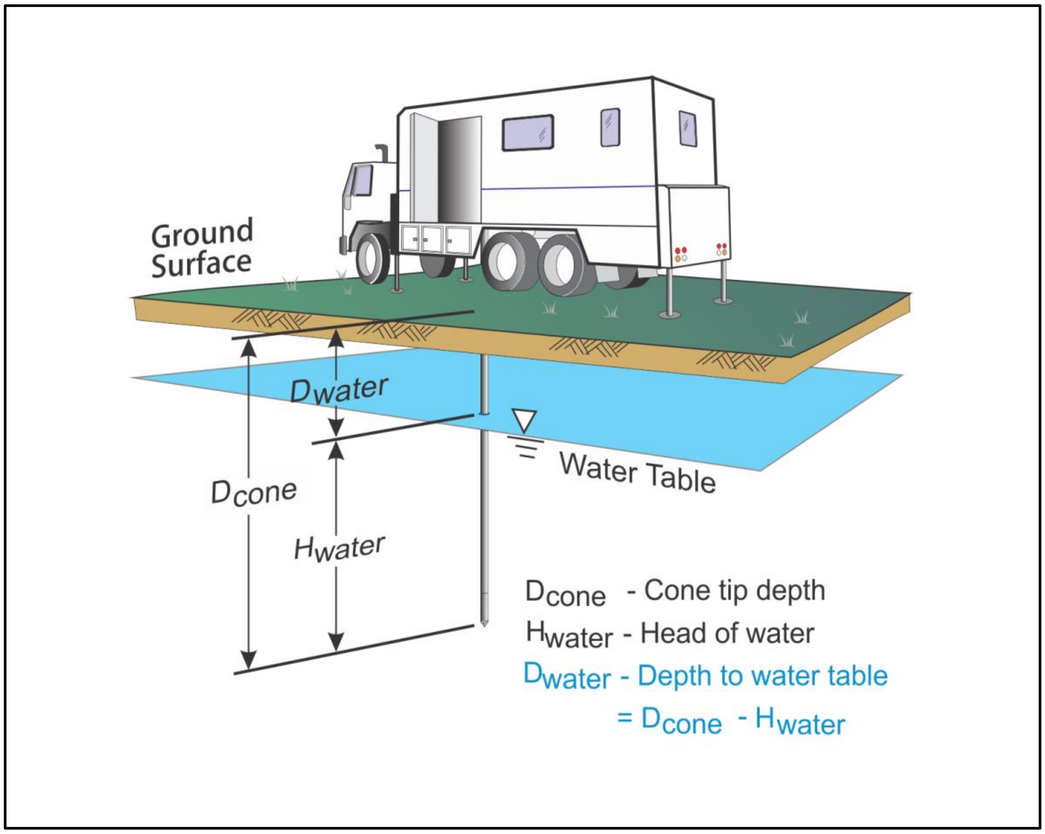

Figure PPD-1. Pore pressure dissipation test setup

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.

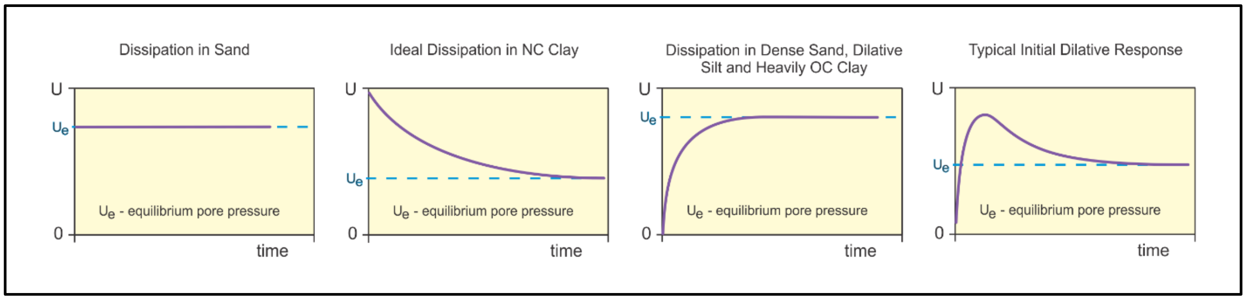

Figure PPD-2. Pore pressure dissipation curve examples

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.

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

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

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

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ASTM D7400-14, 2014, "Standard Test Methods for Downhole Seismic Testing", ASTM, West Conshohocken, US.

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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.

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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.

Robertson, P.K., Sully, J.P., Woeller, D.J., Lunne, T., Powell, J.J.M. and Gillespie, D.G., 1992, “Estimating coefficient of consolidation from piezocone tests”, Canadian Geotechnical Journal, 29(4): 551-557.

Sully, J.P., Robertson, P.K., Campanella, R.G. and Woeller, D.J., 1999, “An approach to evaluation of field CPTU dissipation data in overconsolidated fine-grained soils”, Canadian Geotechnical Journal, 36(2): 369-381.

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
- Advanced Cone Penetration Test Plots with Ic, Su(Nkt), Phi and N1(60)Ic
- Seismic Cone Penetration Test Plots
- Seismic Cone Penetration Test Tabular Results
- Seismic Cone Penetration Test Shear Wave (Vs) Traces
- Seismic Cone Penetration Test Compression Wave (Vp) Traces
- Soil Behaviour Type (SBT) Scatter Plots
- Pore Pressure Dissipation Summary and Pore Pressure Dissipation Plots

Cone Penetration Test Summary and Standard Cone Penetration Test Plots

CONETEC

Job No: 19-05033
Client: Wood plc
Project: Muskrat Creek HWY 17
Start Date: 22-May-2019
End Date: 22-May-2019

CONE PENETRATION TEST SUMMARY

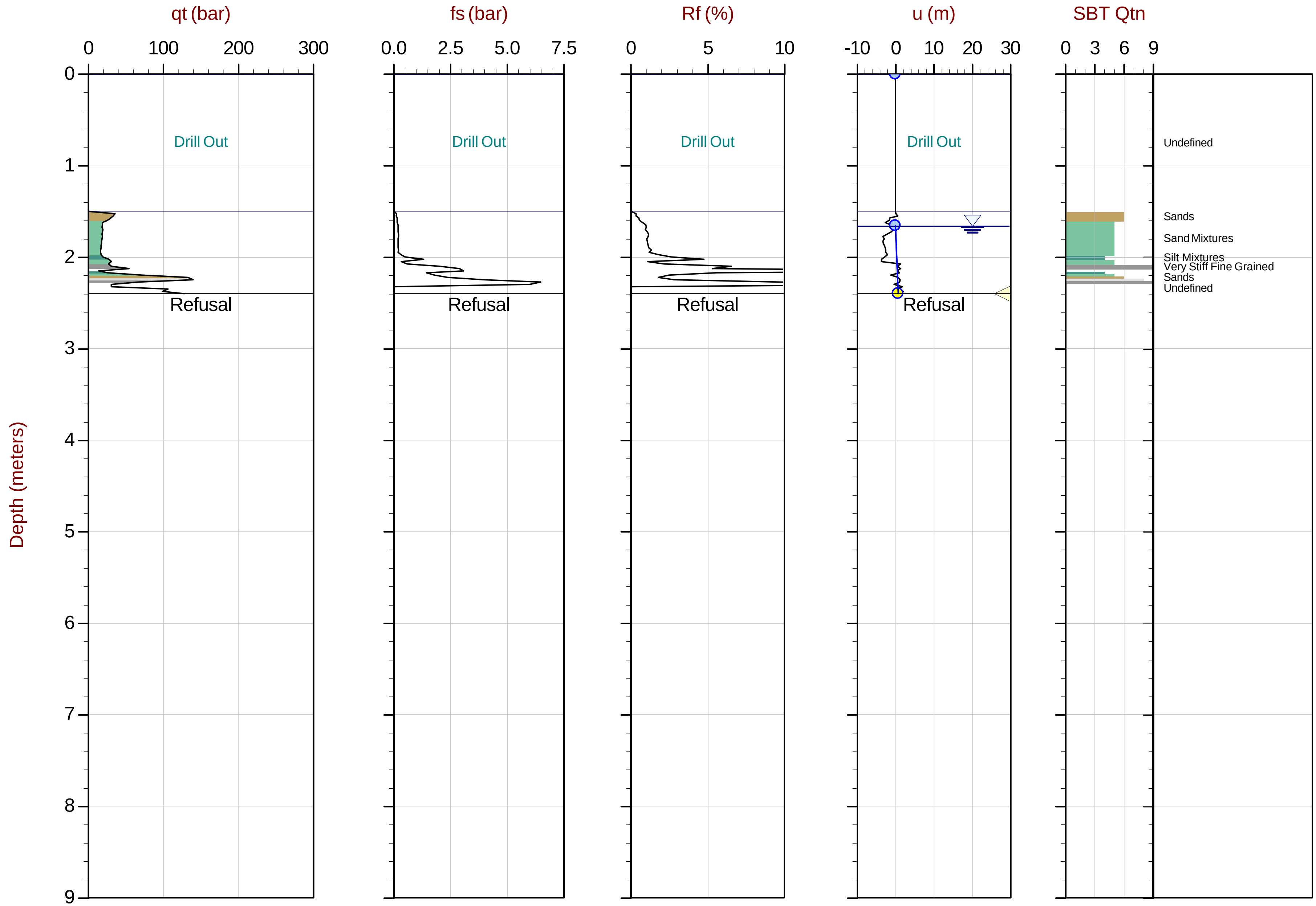
Sounding ID	File Name	Date	Cone	Assumed Phreatic Surface[1] (m)	Final Depth (m)	Northing[2] (m)	Easting[2] (m)	Refer to Notation Number
SCPT19-01	19-05033_SP01	22-May-2019	377:T1000F10U500	1.7	2.400	5049784	357135	3
SCPT19-01B	19-05033_SP01B	22-May-2019	377:T1000F10U500	1.7	4.850	5049785	357135	
SCPT19-02	19-05033_SP02	22-May-2019	377:T1000F10U500	1.8	8.125	5049776	357127	

1. The assumed phreatic surface was based on pore pressure dissipation tests, unless otherwise noted. Hydrostatic conditions were assumed for the calculated
2. Coordinates were acquired using consumer grade GPS equipment in datum: WGS84 / UTM Zone 18 North.
3. No usable seismic data was collected.

Wood plc

Job No: 19-05033
Date: 2019-05-22 10:17
Site: Hwy 17 Cobden

Sounding: SCPT19-01
Cone: 377:T1000F10U500



Max Depth: 2.400 m / 7.87 ft
Depth Inc: 0.025 m / 0.082 ft
Avg Int: Every Point

File: 19-05033_SP01.COR
Unit Wt: SBTQtn (PKR2009)

SBT: Robertson, 2009 and 2010
Coords: UTM 18N N: 5049784m E: 357135m
Page No: 1 of 1

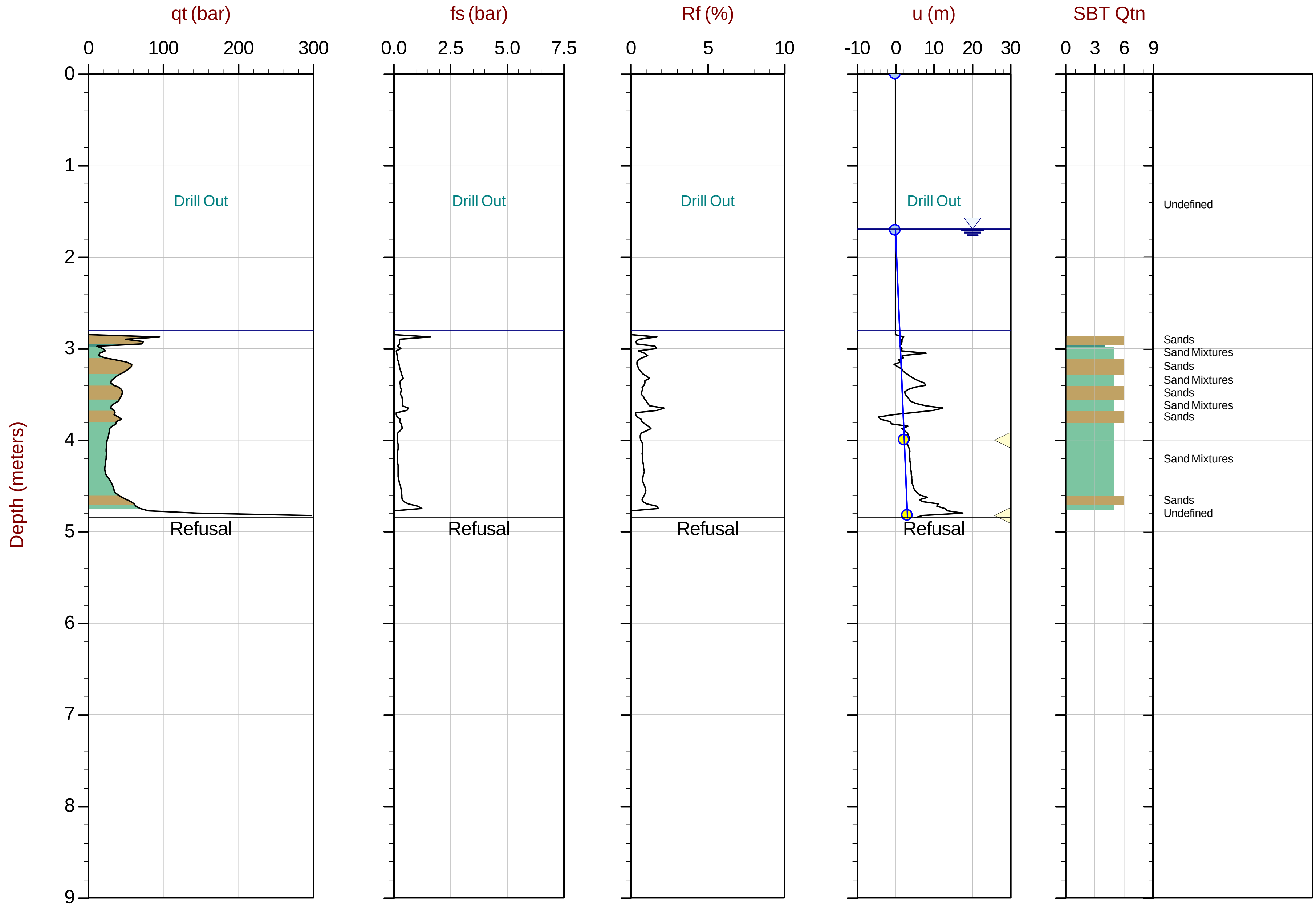
Equilibrium Pore Pressure (Ueq) · Assumed Ueq · Dissipation, Ueq achieved · Dissipation, Ueq not achieved · Dissipation, Ueq assumed · Hydrostatic Line

CONETEC

Wood plc

Job No: 19-05033
Date: 2019-05-22 11:08
Site: Hwy 17 Cobden

Sounding: SCPT19-01B
Cone: 377:T1000F10U500



Max Depth: 4.850 m / 15.91 ft
Depth Inc: 0.025 m / 0.082 ft
Avg Int: Every Point

File: 19-05033_SP01B.COR
Unit Wt: SBTQtn (PKR2009)

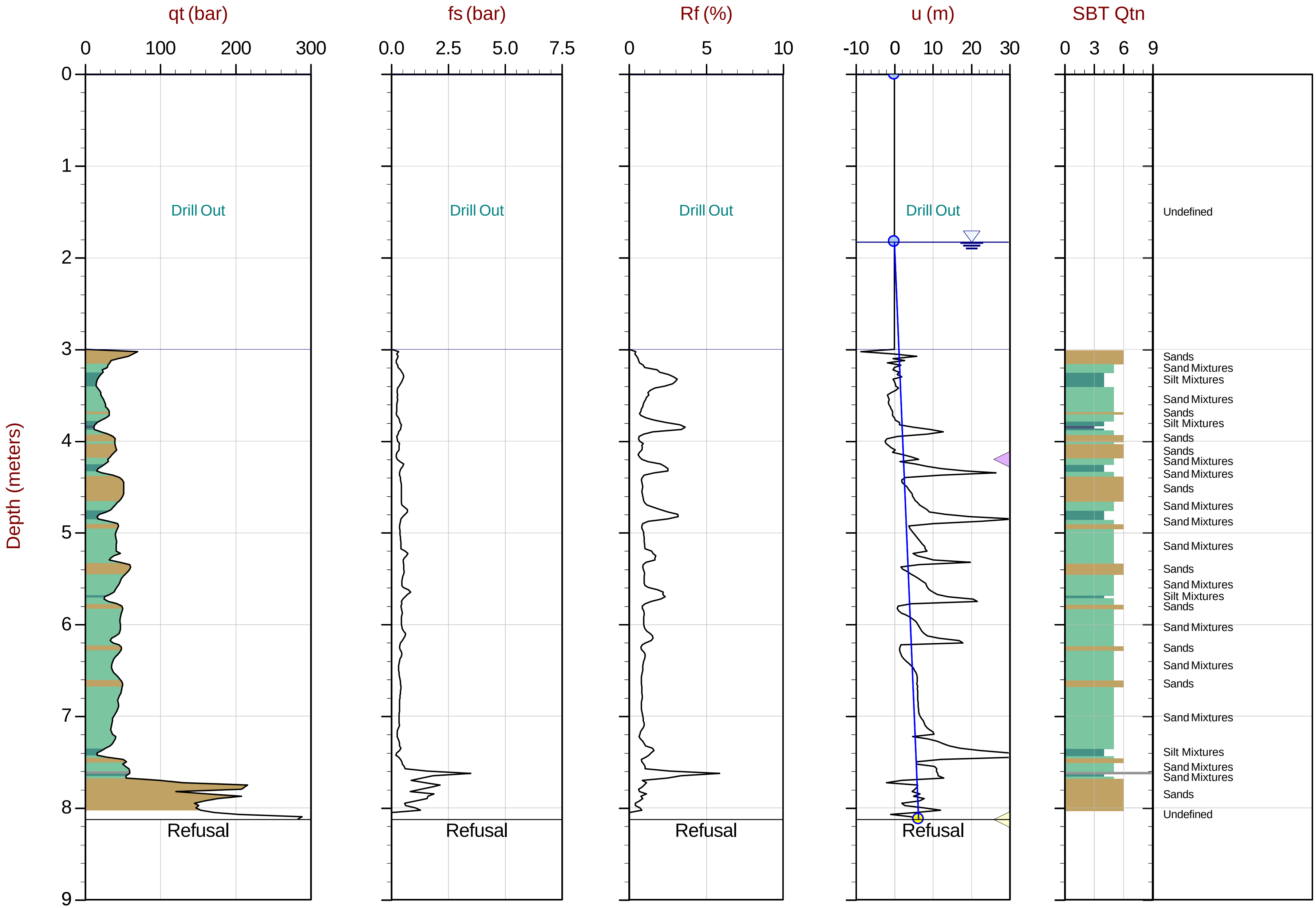
SBT: Robertson, 2009 and 2010
Coords: UTM 18N N: 5049785m E: 357135m
Page No: 1 of 1

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

Wood plc

Job No: 19-05033
Date: 2019-05-22 13:34
Site: Hwy 17 Cobden

Sounding: SCPT19-02
Cone: 377:T1000F10U500



Max Depth: 8.125 m / 26.66 ft
Depth Inc: 0.025 m / 0.082 ft
Avg Int: Every Point

File: 19-05033_SP02.COR
Unit Wt: SBTQtn (PKR2009)

SBT: Robertson, 2009 and 2010
Coords: UTM 18N N: 5049776m E: 357127m
Page No: 1 of 1

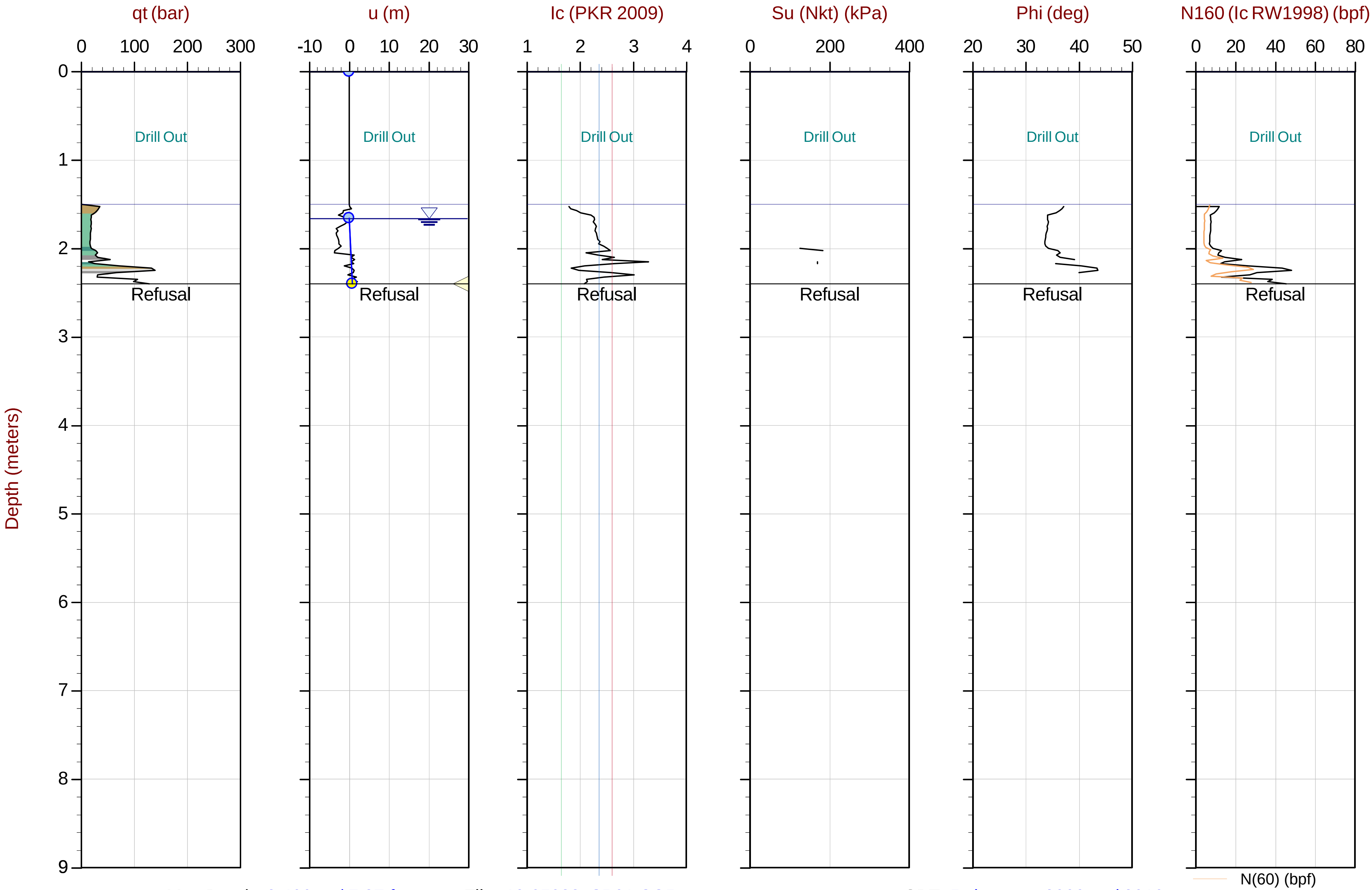
Equilibrium Pore Pressure (Ueq) | Assumed Ueq | Dissipation, Ueq achieved | Dissipation, Ueq not achieved | Dissipation, Ueq assumed | Hydrostatic Line

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

Wood plc

Job No: 19-05033
Date: 2019-05-22 10:17
Site: Hwy 17 Cobden

Sounding: SCPT19-01
Cone: 377:T1000F10U500



Max Depth: 2.400 m / 7.87 ft
Depth Inc: 0.025 m / 0.082 ft
Avg Int: Every Point

File: 19-05033_SP01.COR
Unit Wt: SBTQtn (PKR2009)
Su Nkt: 15.0

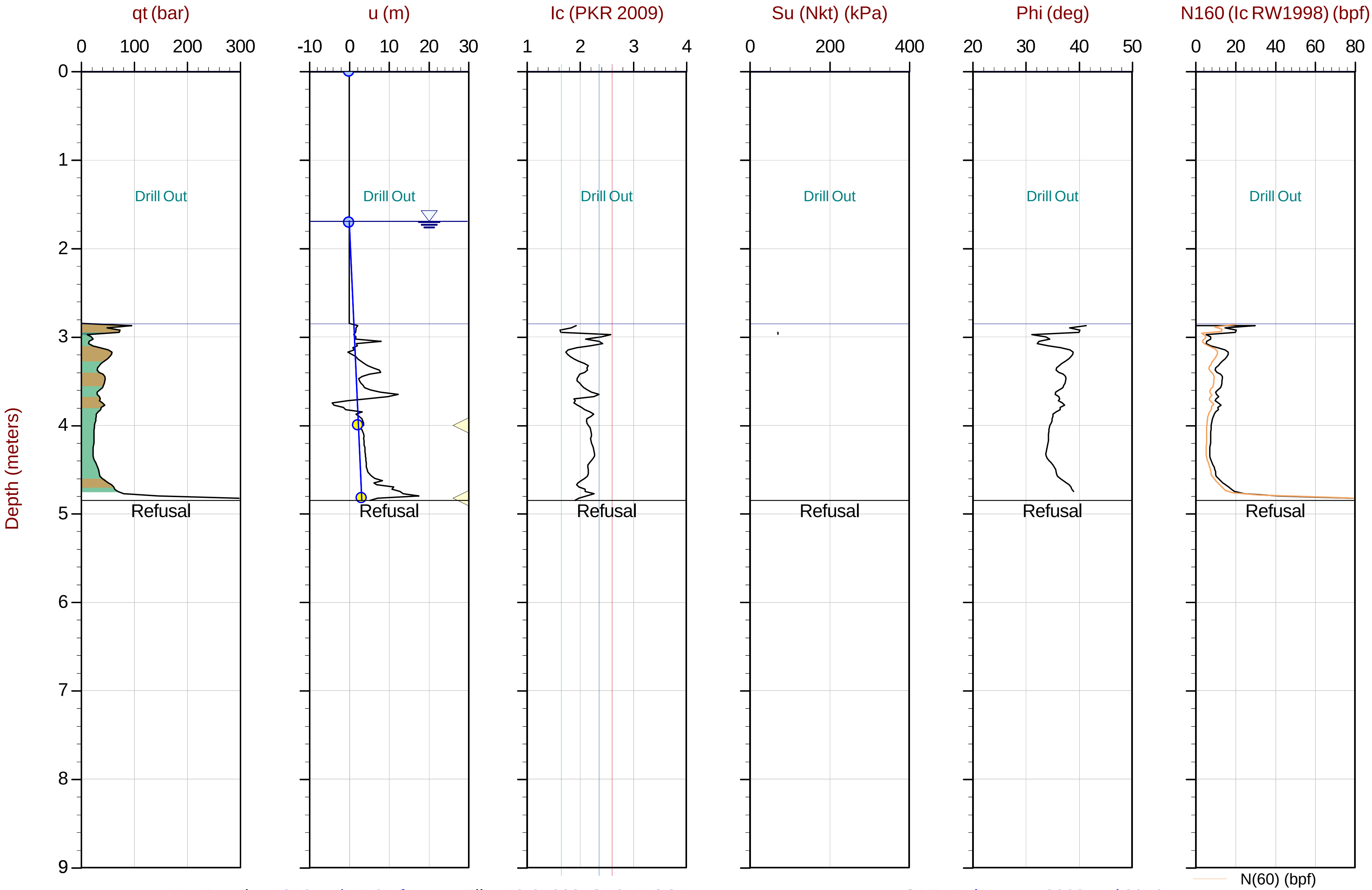
SBT: Robertson, 2009 and 2010
Coords: UTM 18N N: 5049784m E: 357135m
Page No: 1 of 1

Equilibrium Pore Pressure (Ueq) | Assumed Ueq | Dissipation, Ueq achieved | Dissipation, Ueq not achieved | Dissipation, Ueq assumed | Hydrostatic Line

Wood plc

Job No: 19-05033
Date: 2019-05-22 11:08
Site: Hwy 17 Cobden

Sounding: SCPT19-01B
Cone: 377:T1000F10U500



Max Depth: 4.850 m / 15.91 ft
Depth Inc: 0.025 m / 0.082 ft
Avg Int: Every Point

File: 19-05033_SP01B.COR
Unit Wt: SBTQtn (PKR2009)
Su Nkt: 15.0

SBT: Robertson, 2009 and 2010
Coords: UTM 18N N: 5049785m E: 357135m
Page No: 1 of 1

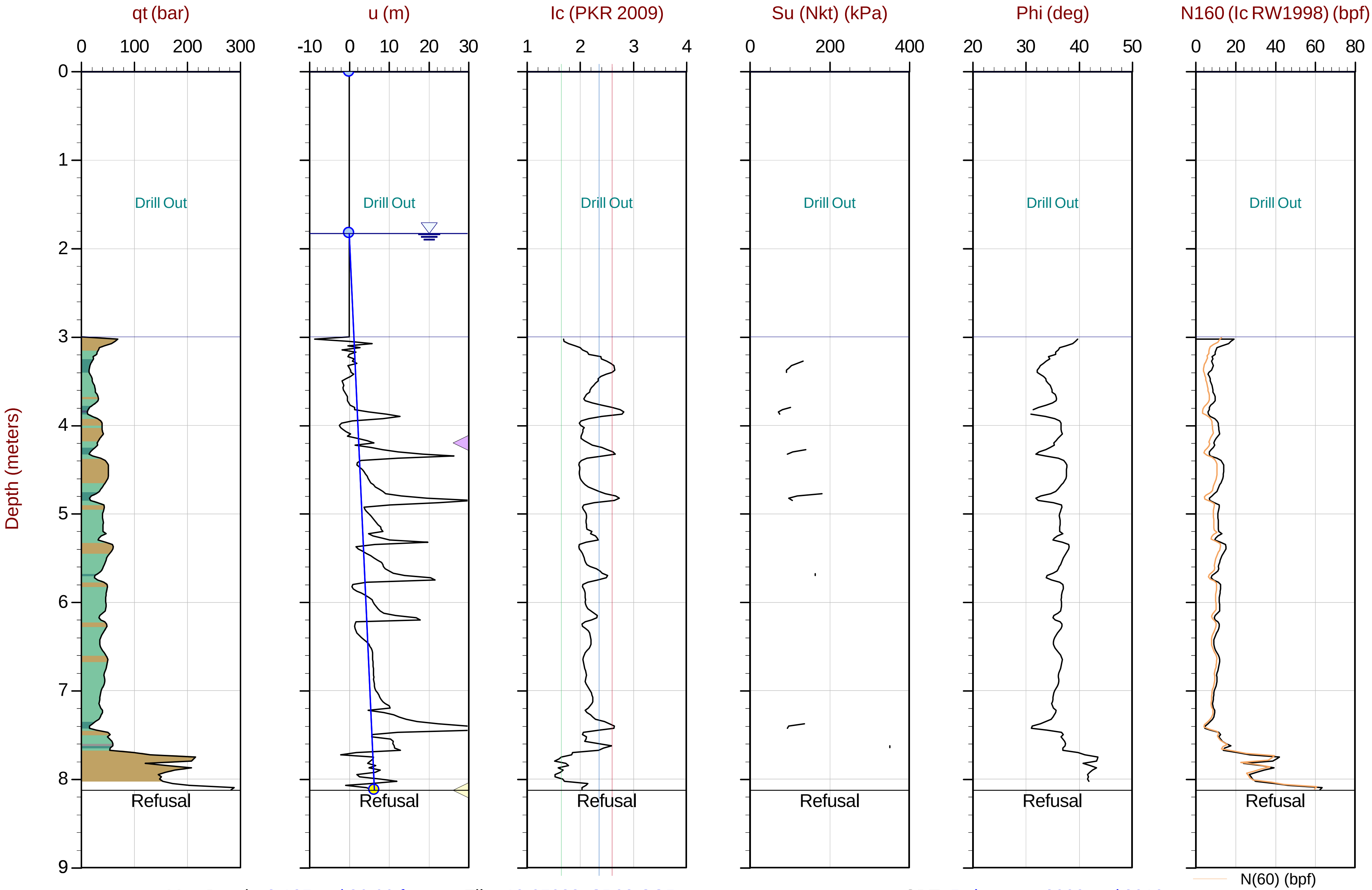
Equilibrium Pore Pressure (Ueq) Assumed Ueq Dissipation, Ueq achieved Dissipation, Ueq not achieved Dissipation, Ueq assumed Hydrostatic Line

CONETEC

Wood plc

Job No: 19-05033
Date: 2019-05-22 13:34
Site: Hwy 17 Cobden

Sounding: SCPT19-02
Cone: 377:T1000F10U500



Max Depth: 8.125 m / 26.66 ft
Depth Inc: 0.025 m / 0.082 ft
Avg Int: Every Point

File: 19-05033_SP02.COR
Unit Wt: SBTQtn (PKR2009)
Su Nkt: 15.0

SBT: Robertson, 2009 and 2010
Coords: UTM 18N N: 5049776m E: 357127m
Page No: 1 of 1

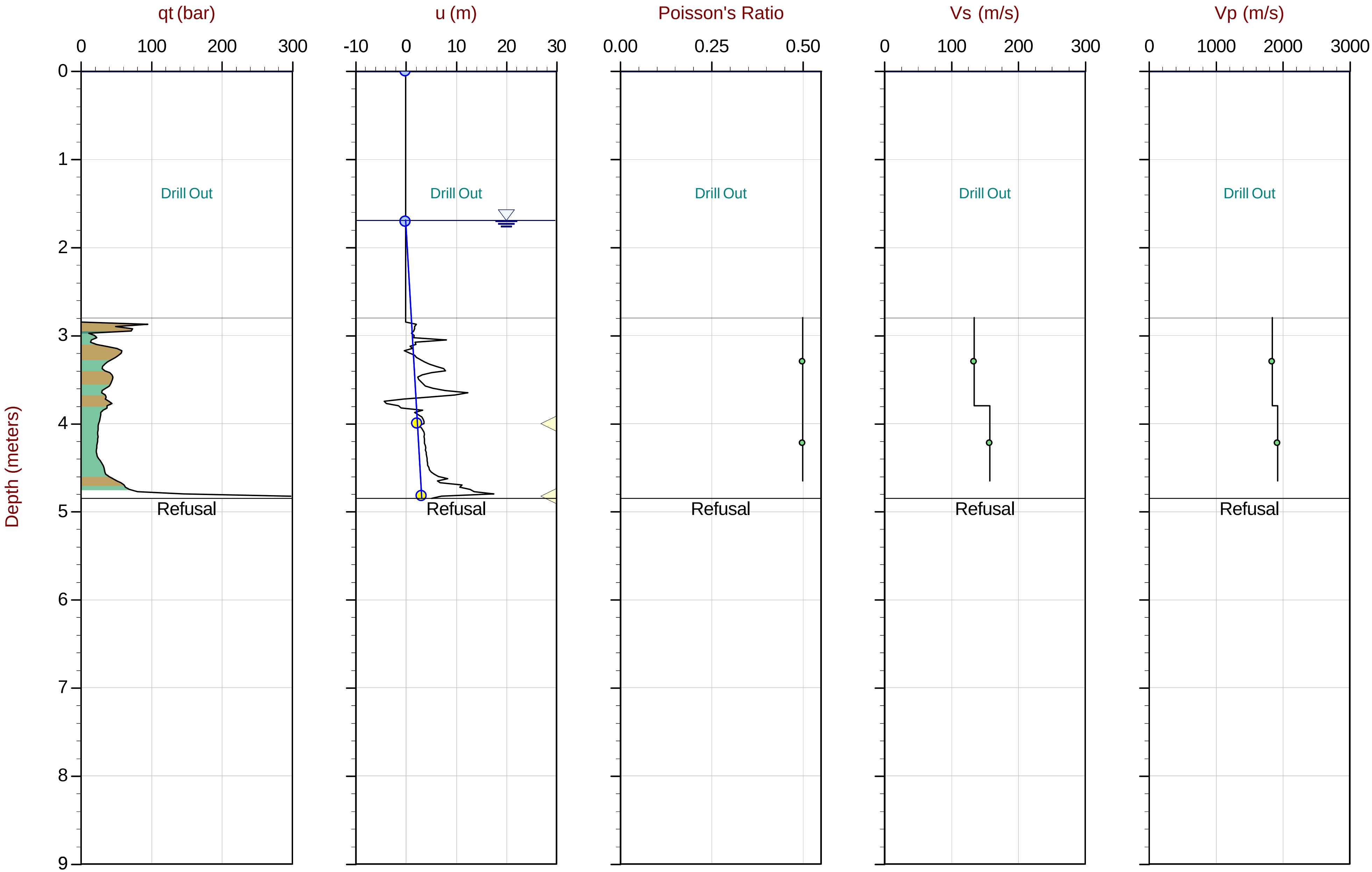
Equilibrium Pore Pressure (Ueq) | Assumed Ueq | Dissipation, Ueq achieved | Dissipation, Ueq not achieved | Dissipation, Ueq assumed | Hydrostatic Line

Seismic Cone Penetration Test Plots

Wood plc

Job No: 19-05033
Date: 2019-05-22 11:08
Site: Hwy 17 Cobden

Sounding: SCPT19-01B
Cone: 377:T1000F10U500



Max Depth: 4.850 m / 15.91 ft
Depth Inc: 0.025 m / 0.082 ft
Avg Int: Every Point

File: 19-05033_SP01B.COR
Unit Wt: SBTQtn (PKR2009)

SBT: Robertson, 2009 and 2010
Coords: UTM 18N N: 5049785m E: 357135m
Page No: 1 of 1

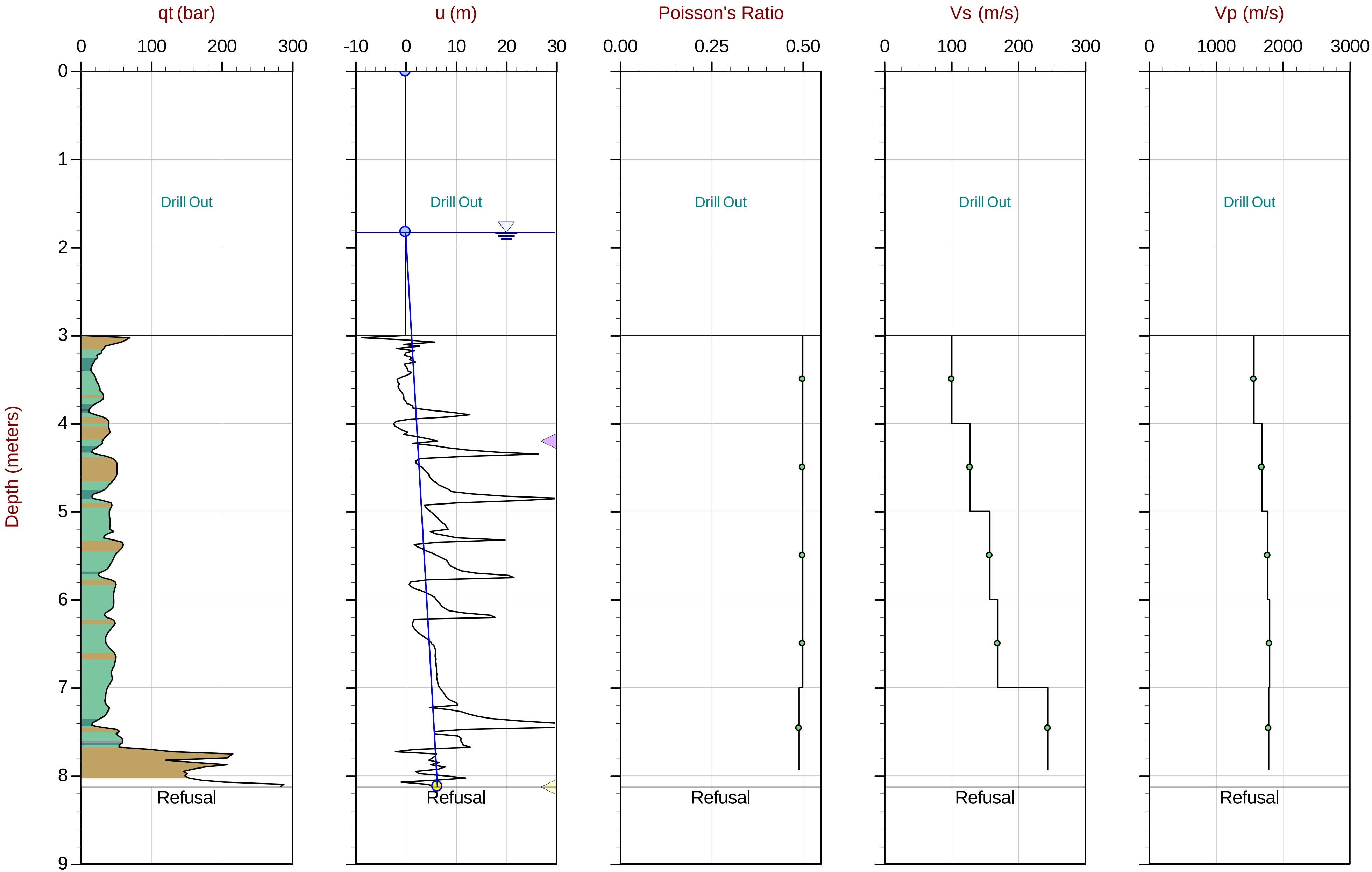
Equilibrium Pore Pressure (Ueq) | Assumed Ueq | Dissipation, Ueq achieved | Dissipation, Ueq not achieved | Dissipation, Ueq assumed | Hydrostatic Line

CONETEC

Wood plc

Job No: 19-05033
Date: 2019-05-22 13:34
Site: Hwy 17 Cobden

Sounding: SCPT19-02
Cone: 377:T1000F10U500



Max Depth: 8.125 m / 26.66 ft
Depth Inc: 0.025 m / 0.082 ft
Avg Int: Every Point

File: 19-05033_SP02.COR
Unit Wt: SBTQtn (PKR2009)

SBT: Robertson, 2009 and 2010
Coords: UTM 18N N: 5049776m E: 357127m
Page No: 1 of 1

Equilibrium Pore Pressure (Ueq) | Assumed Ueq | Dissipation, Ueq achieved | Dissipation, Ueq not achieved | Dissipation, Ueq assumed | Hydrostatic Line

Seismic Cone Penetration Test Tabular Results

Job No:	19-05033
Client:	Wood plc
Project:	Muskrat Creek HWY 17
Sounding ID:	SCPT19-01B
Date:	22-May-2019

Seismic Source:	Beam
Source Offset (m):	0.50
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)
3.00	2.80	2.84			
4.00	3.80	3.83	0.99	7.37	134
4.85	4.65	4.68	0.84	5.34	158

Job No:	19-05033
Client:	Wood plc
Project:	Muskrat Creek HWY 17
Sounding ID:	SCPT19-01B
Date:	22-May-2019

Seismic Source:	Plate
Source Offset (m):	2.00
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)
3.00	2.80	3.44			
4.00	3.80	4.29	0.85	0.46	1848
4.85	4.65	5.06	0.77	0.40	1925

Job No: 19-05033
Client: Wood plc
Project: Muskrat Creek HWY 17
Sounding ID: SCPT19-01B
Date: 22-May-2019

SCPTu SEISMIC WAVE VELOCITY TEST RESULTS

Tip Depth (m)	Geophone Depth (m)	Vs Interval Velocity (m/s)	Vp Interval Velocity (m/s)	Poisson's Ratio
4.00	3.80	134	1848	0.50
4.85	4.65	158	1925	0.50

Job No:	19-05033
Client:	Wood plc
Project:	Muskrat Creek HWY 17
Sounding ID:	SCPT19-02
Date:	22-May-2019

Seismic Source:	Beam
Source Offset (m):	0.50
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)
3.20	3.00	3.04			
4.20	4.00	4.03	0.99	9.76	101
5.20	5.00	5.02	0.99	7.74	128
6.20	6.00	6.02	1.00	6.32	158
7.20	7.00	7.02	1.00	5.87	170
8.13	7.93	7.95	0.93	3.79	245

Job No: 19-05033
Client: Wood plc
Project: Muskrat Creek HWY 17
Sounding ID: SCPT19-02
Date: 22-May-2019

Seismic Source: Plate
Source Offset (m): 1.80
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)
3.20	3.00	3.50			
4.20	4.00	4.39	0.89	0.56	1573
5.20	5.00	5.31	0.93	0.55	1689
6.20	6.00	6.26	0.95	0.53	1777
7.20	7.00	7.23	0.96	0.53	1802
8.13	7.93	8.13	0.90	0.50	1791

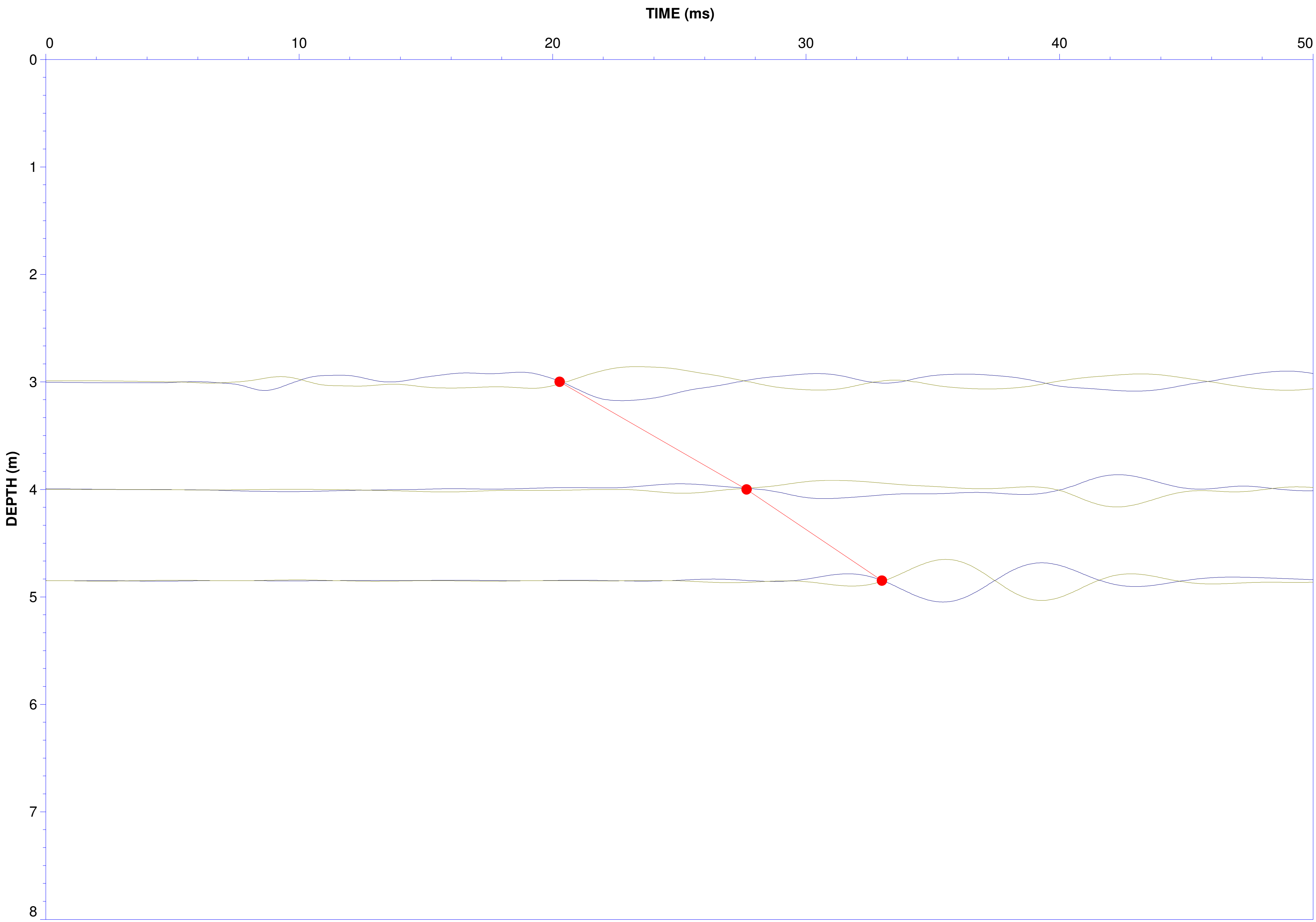
Job No:	19-05033
Client:	Wood plc
Project:	Muskrat Creek HWY 17
Sounding ID:	SCPT19-02
Date:	22-May-2019

SCPTu SEISMIC WAVE VELOCITY TEST RESULTS

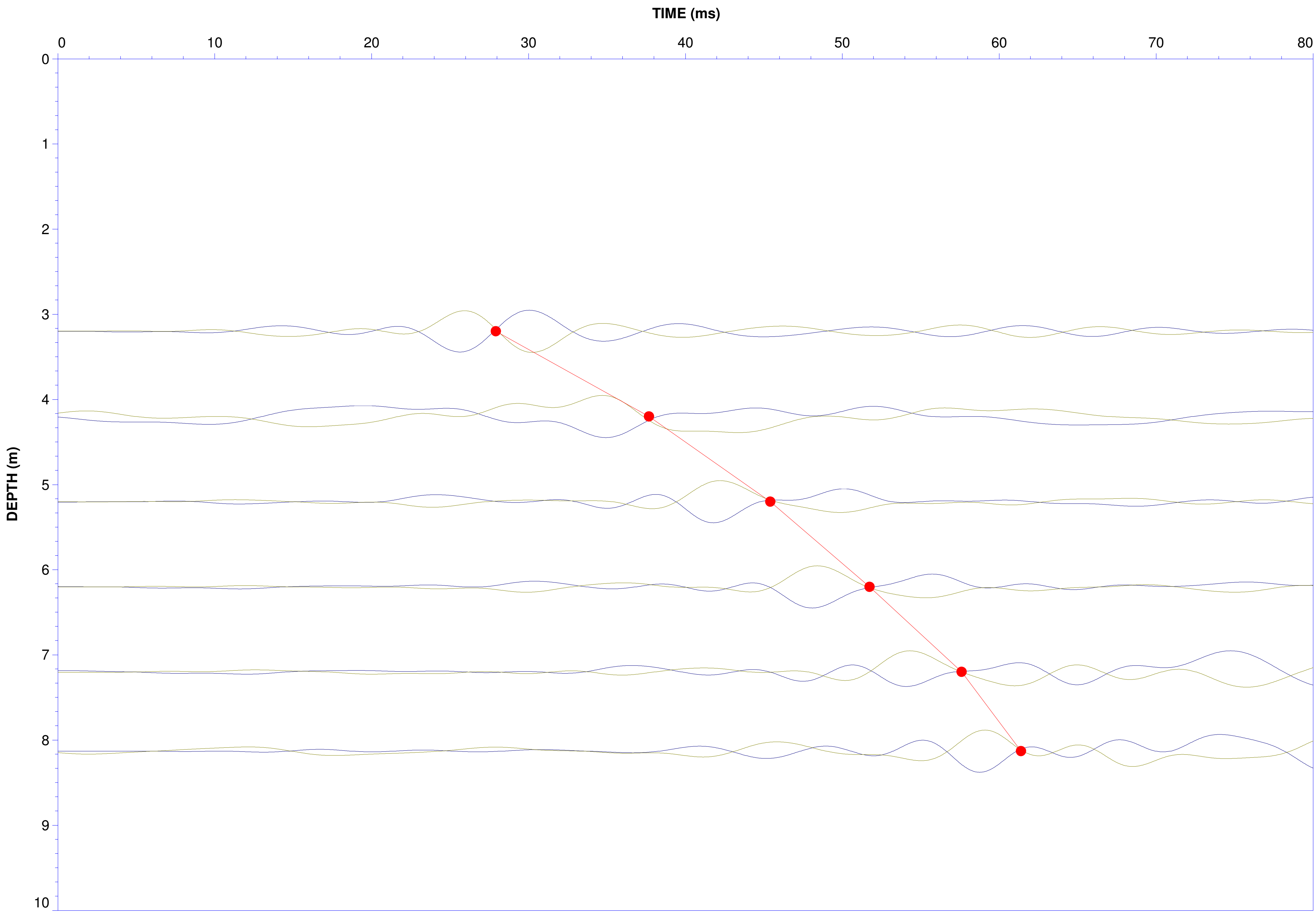
Tip Depth (m)	Geophone Depth (m)	Vs Interval Velocity (m/s)	Vp Interval Velocity (m/s)	Poisson's Ratio
4.20	4.00	101	1573	0.50
5.20	5.00	128	1689	0.50
6.20	6.00	158	1777	0.50
7.20	7.00	170	1802	0.50
8.13	7.93	245	1791	0.49

Seismic Cone Penetration Test Shear Wave (Vs) Traces

Job No: 19-05033	Client: Wood plc	Project Title: Muskrat Creek HWY 17	Filter: 10-200 Hz	Sounding ID: SCPT19-01B	Site: Hwy 17, Cobden
Date: 05-22-19	Cone: 377:T1000F10U500				



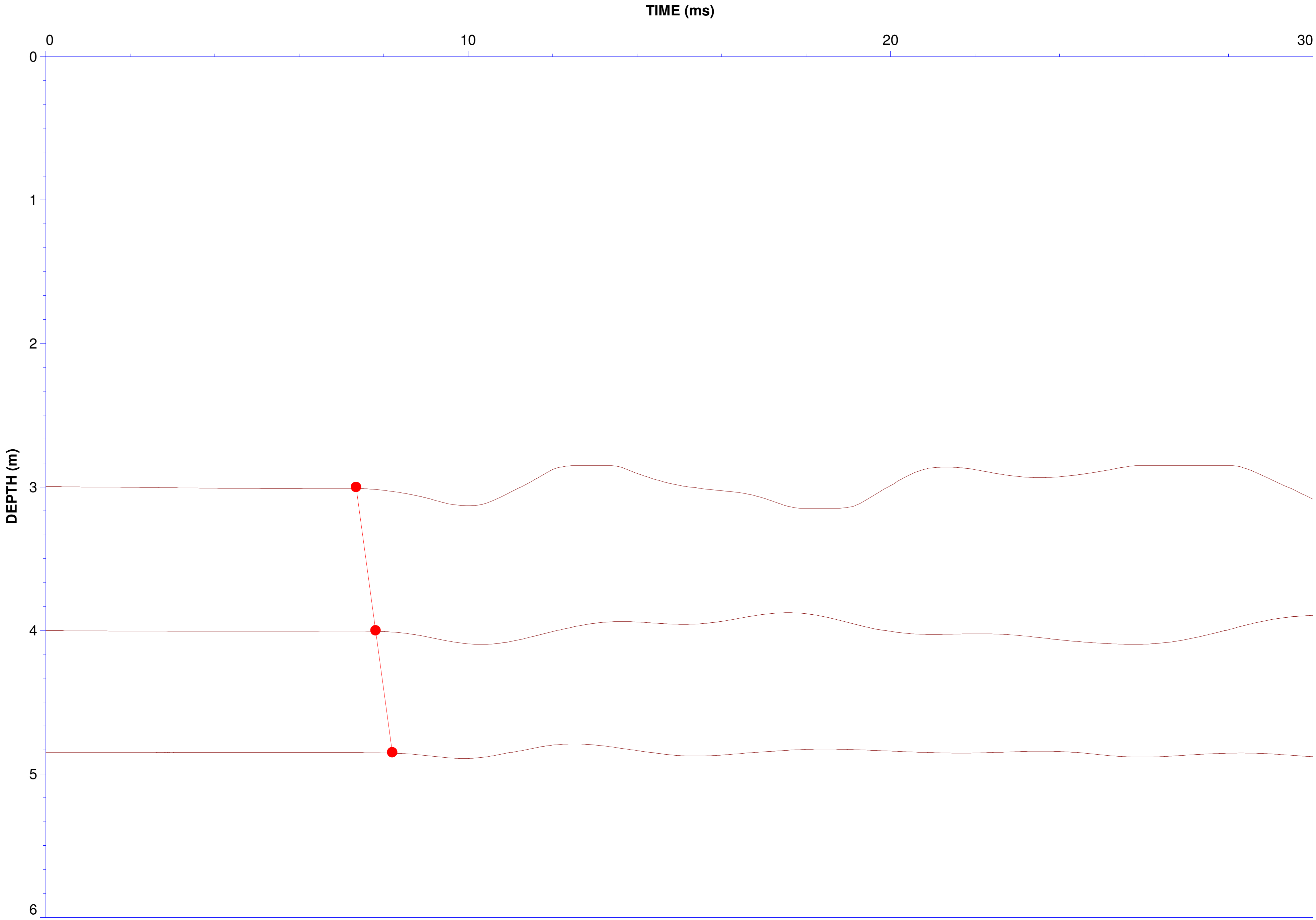
Job No: 19-05033 | Client: Wood plc | Project Title: Muskrat Creek HWY 17 | Filter: 10-200 Hz | Sounding ID: SCPT19-02 | Site: Hwy 17, Cobden
Date: 05-22-19 | Cone: 377:T1000F10U500



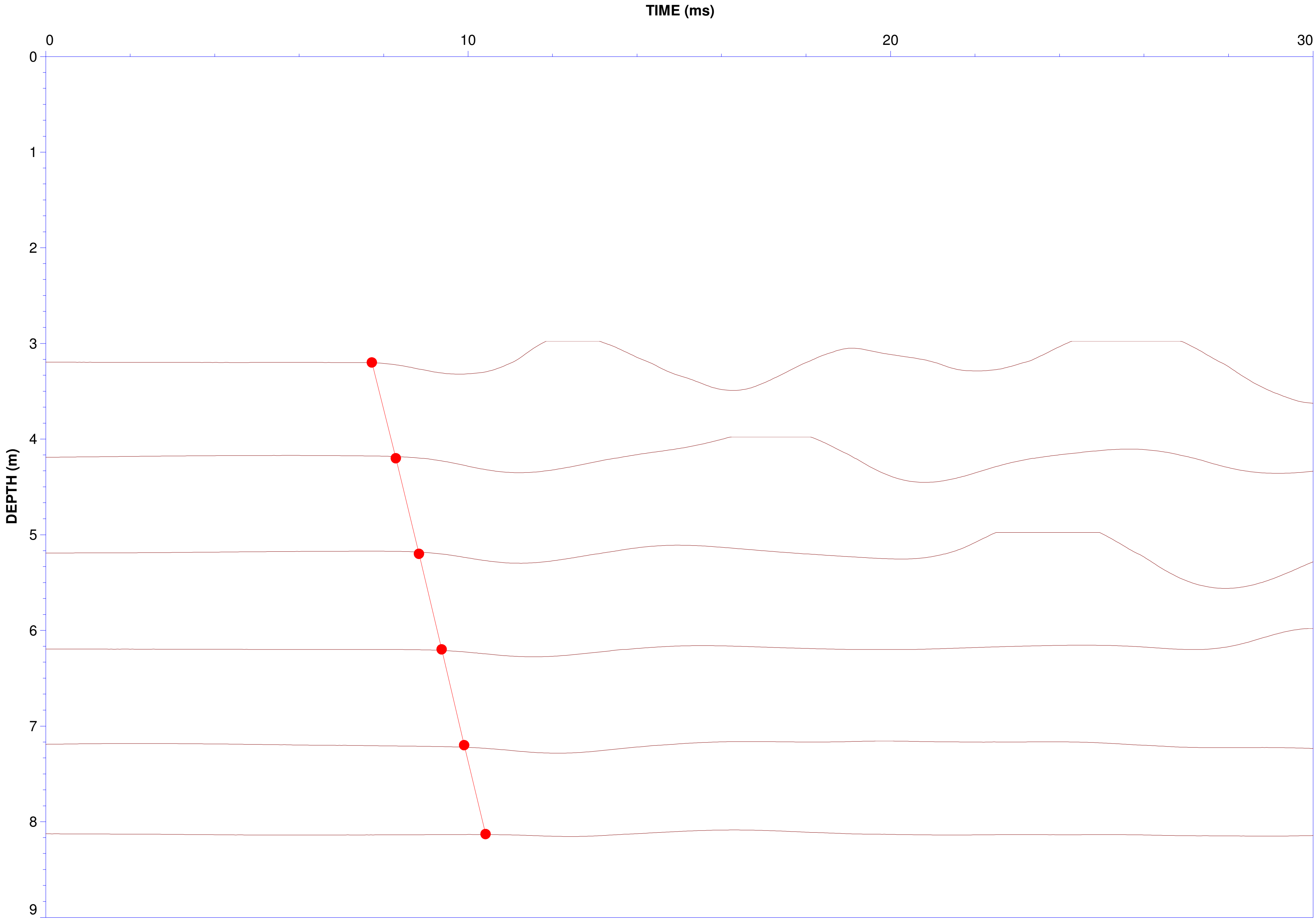
Seismic Cone Penetration Test Compression Wave (Vp) Traces

Job No: 19-05033 | Client: Wood plc | Project Title: Muskrat Creek HWY 17 | Filter: Unfiltered | Sounding ID: SCPT19-01B | Site: Hwy 17, Cobden

Date: 05-22-19 | Cone: 377:T1000F10U500



Job No: 19-05033	Client: Wood plc	Project Title: Muskrat Creek HWY 17	Filter: Unfiltered	Sounding ID: SCPT19-02	Site: Hwy 17, Cobden
Date: 05-22-19	Cone: 377:T1000F10U500				

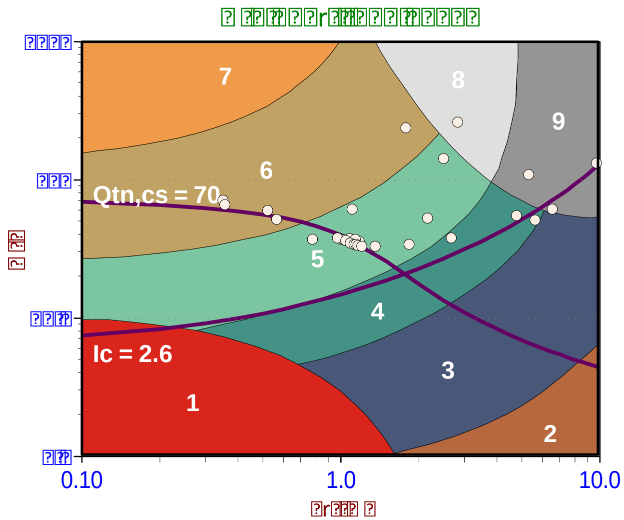


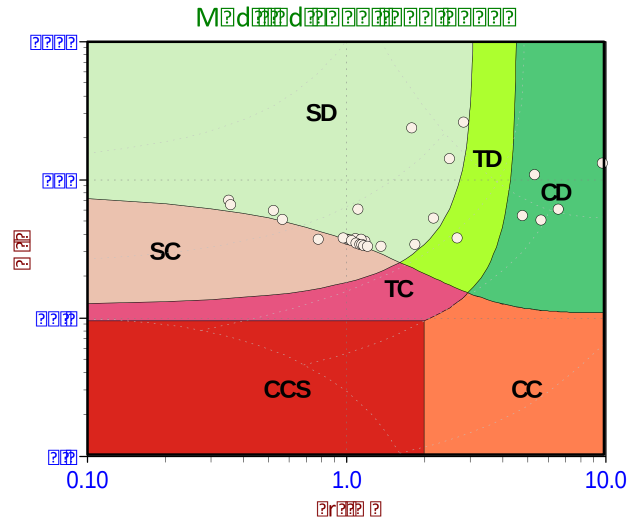
Soil Behaviour Type (SBT) Scatter Plots

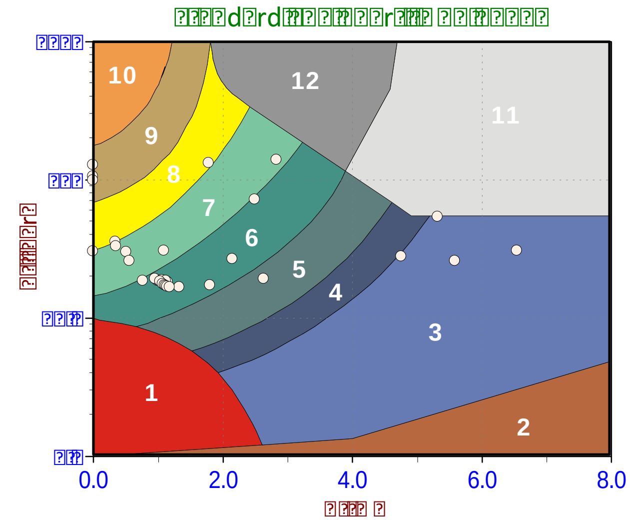
Wood plc

Job No: 19-05033
Date: 2019-05-22 10:17
Site: Hwy 17 Cobden

Sounding: SCPT19-01
Cone: 377:T1000F10U500







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

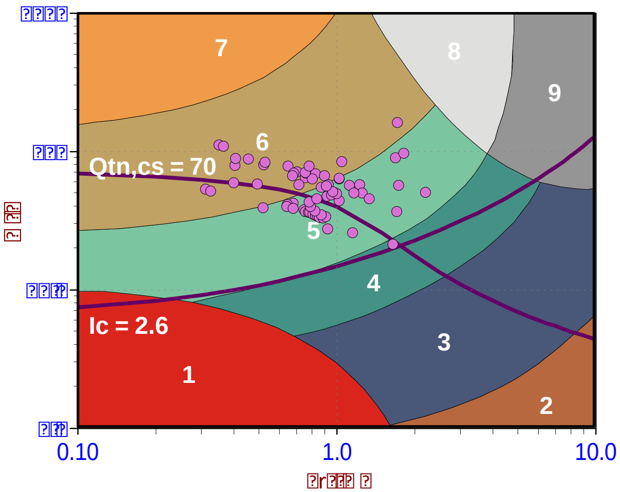
- Sensitive Fines
- Organic Soil
- Clay
- Silty Clay
- Clayey Silt
- Silt
- Sandy Silt
- Silty Sand/Sand
- Sand
- Gravelly Sand
- Stiff Fine Grained
- Cemented Sand

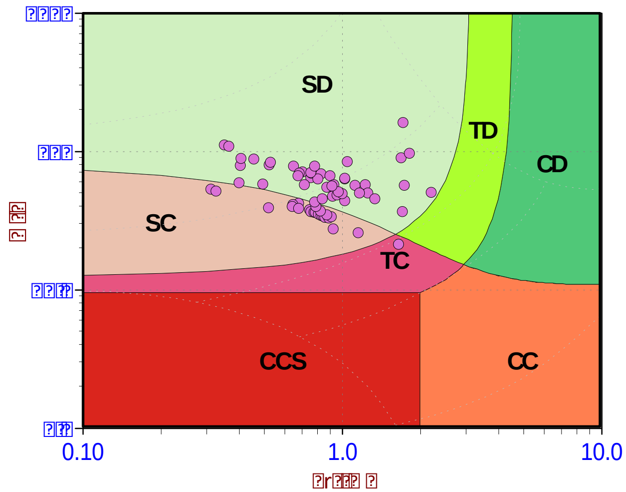
CONETEC

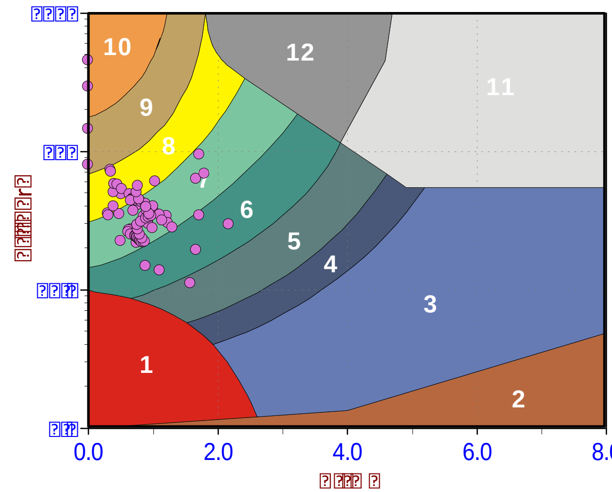
Wood plc

Job No: 19-05033
Date: 2019-05-22 11:08
Site: Hwy 17 Cobden

Sounding: SCPT19-01B
Cone: 377:T1000F10U500







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

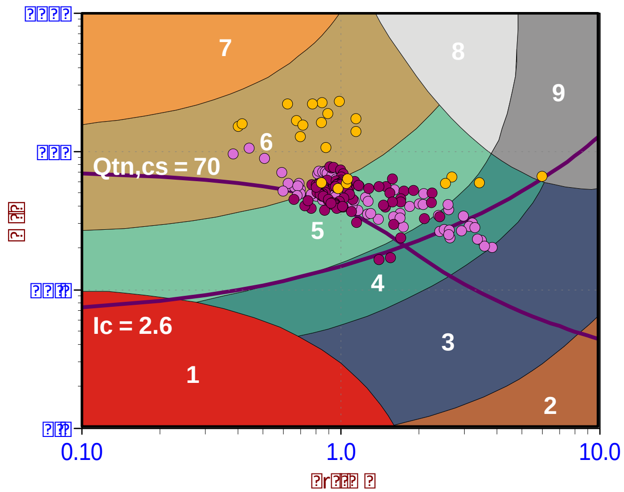
- CCS (Cont. sensitive clay like)
- CC (Cont. clay like)
- TC (Cont. transitional)
- SC (Cont. sand like)
- CD (Dil. clay like)
- TD (Dil. transitional)
- SD (Dil. sand like)

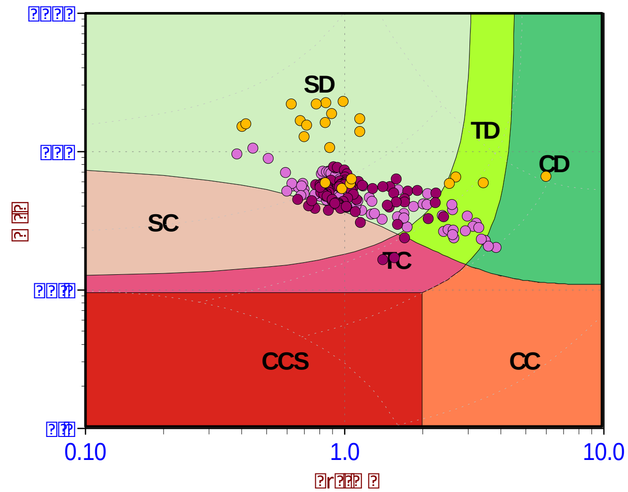
Legend

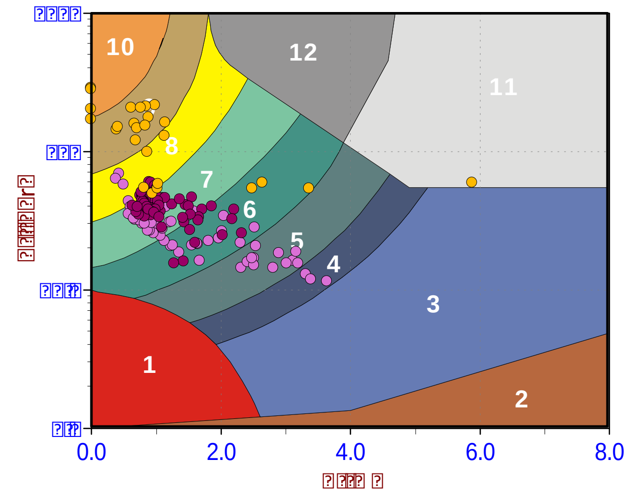
- Sensitive Fines
- Organic Soil
- Clay
- Silty Clay
- Clayey Silt
- Silt
- Sandy Silt
- Silty Sand/Sand
- Sand
- Gravelly Sand
- Stiff Fine Grained
- Cemented Sand

CONETEC

Wood plc	Job No: 19-05033	Sounding: SCPT19-02
	Date: 2019-05-22 13:34	Cone: 377:T1000F10U500
	Site: Hwy 17 Cobden	







Depth Ranges

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

Legend

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

Legend

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

Legend

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

Pore Pressure Dissipation Summary and Pore Pressure Dissipation Plots

Job No:	19-05033
Client:	Wood plc
Project:	Muskrat Creek HWY 17
Start Date:	22-May-2019
End Date:	22-May-2019

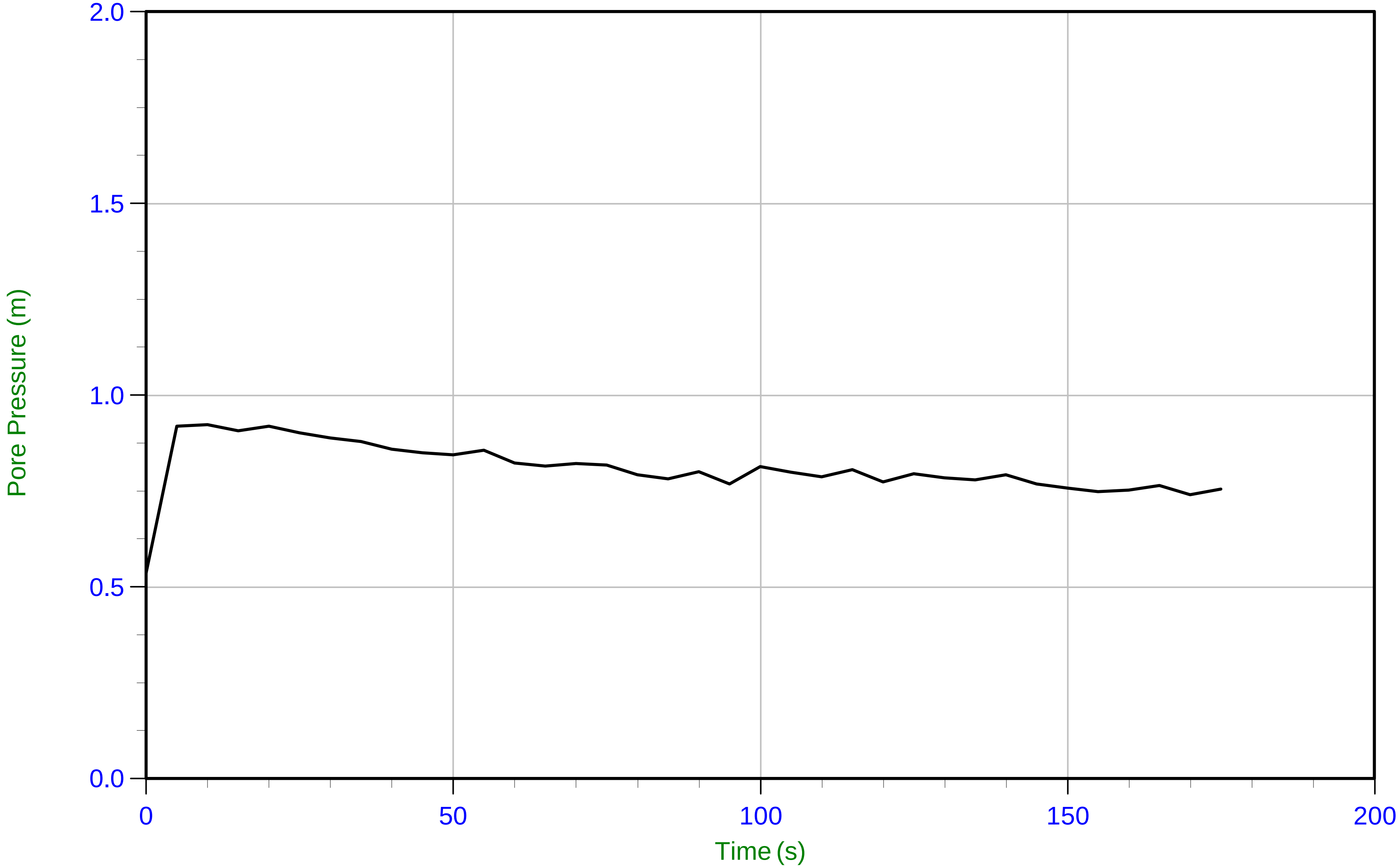
CPTu PORE PRESSURE DISSIPATION SUMMARY

Sounding ID	File Name	Cone Area (cm^2)	Duration (s)	Test Depth (m)	Estimated Equilibrium Pore Pressure U_{eq} (m)	Calculated Phreatic Surface (m)
SCPT19-01	19-05033_SP01	10	175	2.400	0.7	1.7
SCPT19-01B	19-05033_SP01B	10	300	4.000	2.3	1.7
SCPT19-01B	19-05033_SP01B	10	460	4.825	3.1	1.7
SCPT19-02	19-05033_SP02	10	300	4.200	Not Achieved	
SCPT19-02	19-05033_SP02	10	300	8.125	6.3	1.8

Wood plc

Job No: 19-05033
Date: 05/22/2019 10:17
Site: Hwy 17 Cobden

Sounding: SCPT19-01
Cone: 377:T1000F10U500 Area=10 cm²



Trace Summary:

Filename: 19-05033_SP01.PPF
Depth: 2.400 m / 7.874 ft
Duration: 175.0 s

U Min: 0.5 m
U Max: 0.9 m

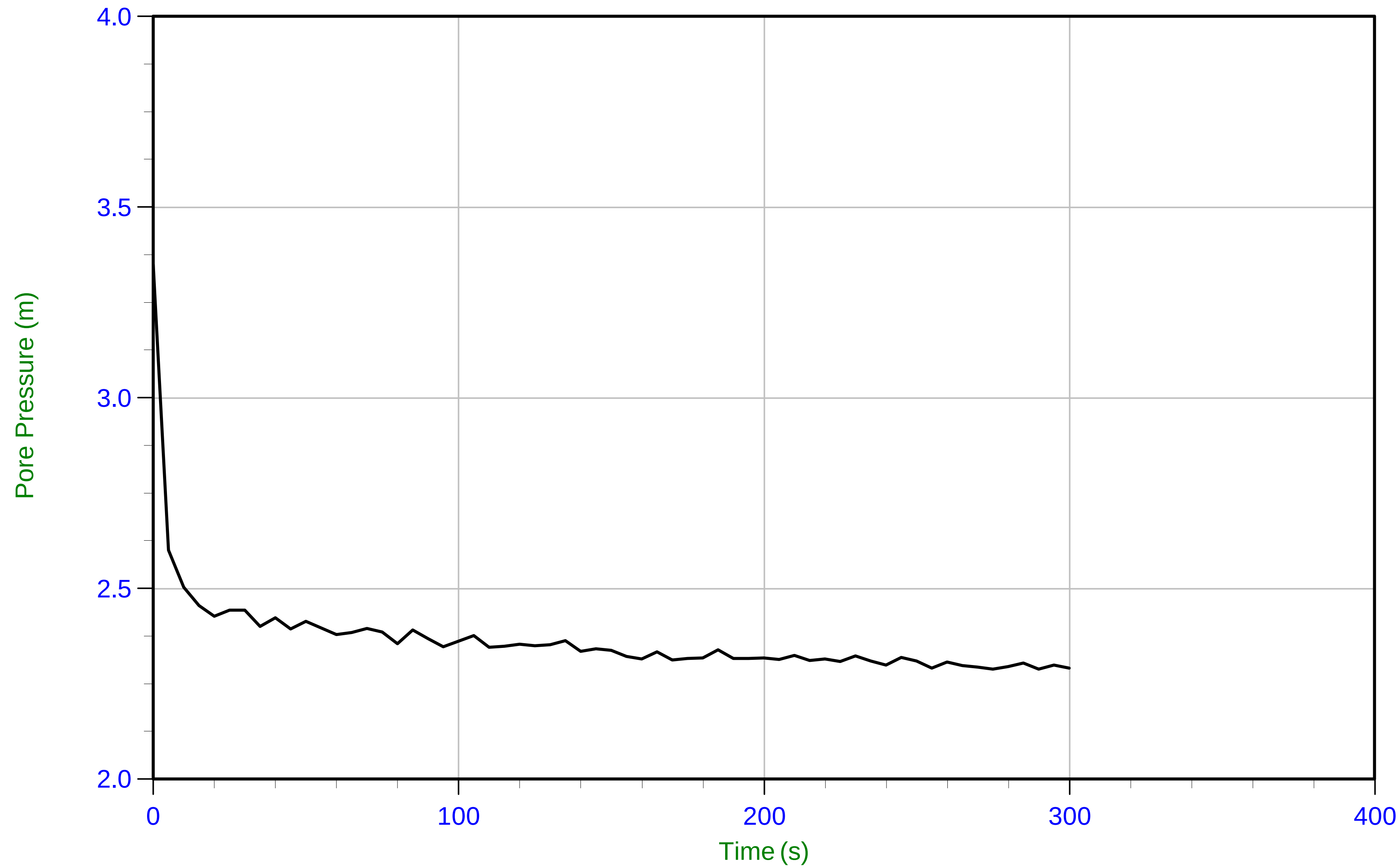
WT: 1.658 m / 5.440 ft
Ueq: 0.7 m

ConeTec

Wood plc

Job No: 19-05033
Date: 05/22/2019 11:08
Site: Hwy 17 Cobden

Sounding: SCPT19-01B
Cone: 377:T1000F10U500 Area=10 cm²



Trace Summary:

Filename: 19-05033_SP01B.PPF
Depth: 4.000 m / 13.123 ft
Duration: 300.0 s

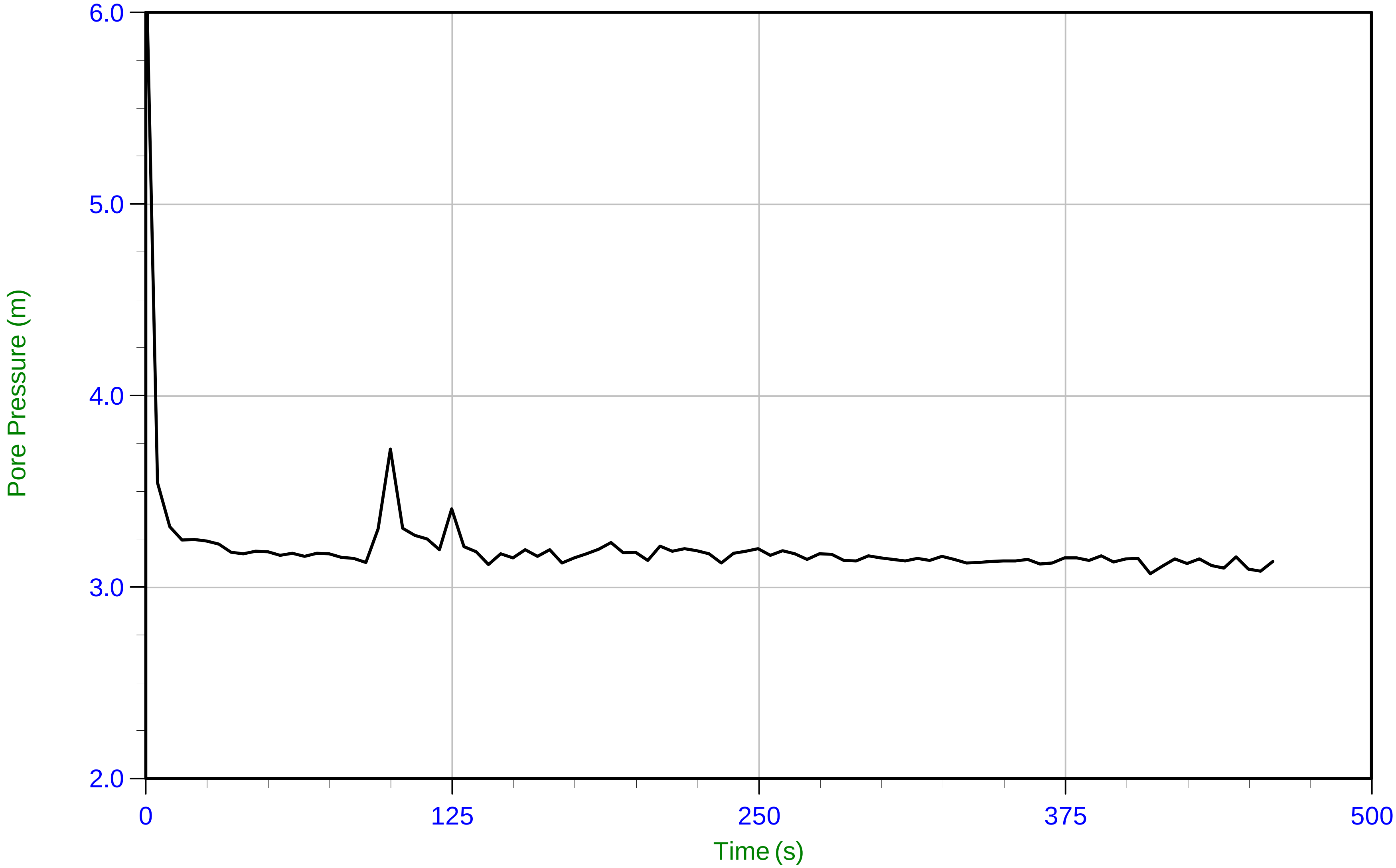
U Min: 2.3 m
U Max: 3.3 m

WT: 1.709 m / 5.607 ft
Ueq: 2.3 m

Wood plc

Job No: 19-05033
Date: 05/22/2019 11:08
Site: Hwy 17 Cobden

Sounding: SCPT19-01B
Cone: 377:T1000F10U500 Area=10 cm²



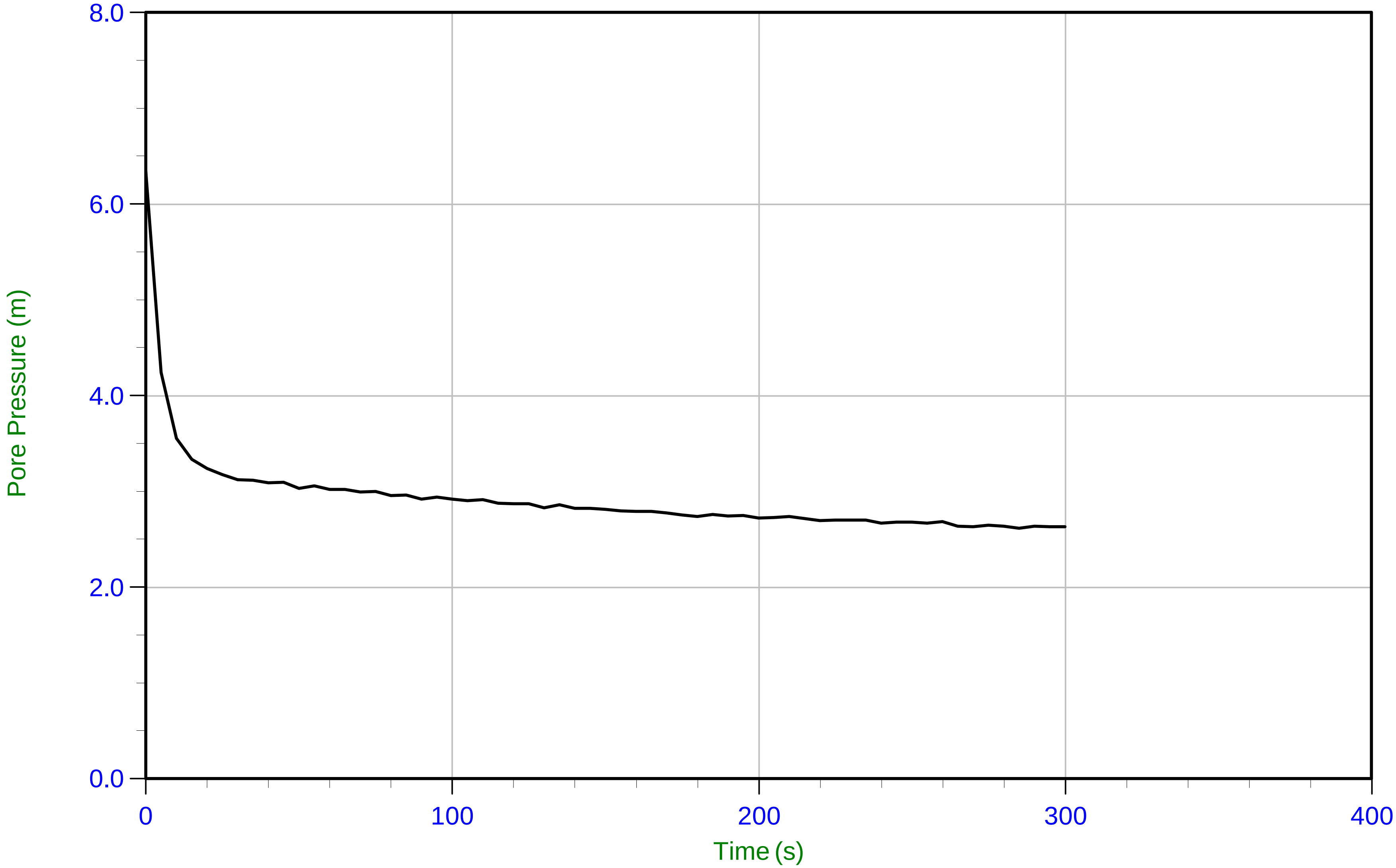
Trace Summary:

Filename: 19-05033_SP01B.PPF
Depth: 4.825 m / 15.830 ft
Duration: 460.0 s

U Min: 3.1 m
U Max: 6.4 m

WT: 1.690 m / 5.545 ft
Ueq: 3.1 m

Wood plc	Job No: 19-05033 Date: 05/22/2019 13:34 Site: Hwy 17 Cobden	Sounding: SCPT19-02 Cone: 377:T1000F10U500 Area=10 cm²



Trace Summary:

Filename: 19-05033_SP02.PPF
Depth: 4.200 m / 13.779 ft
Duration: 300.0 s

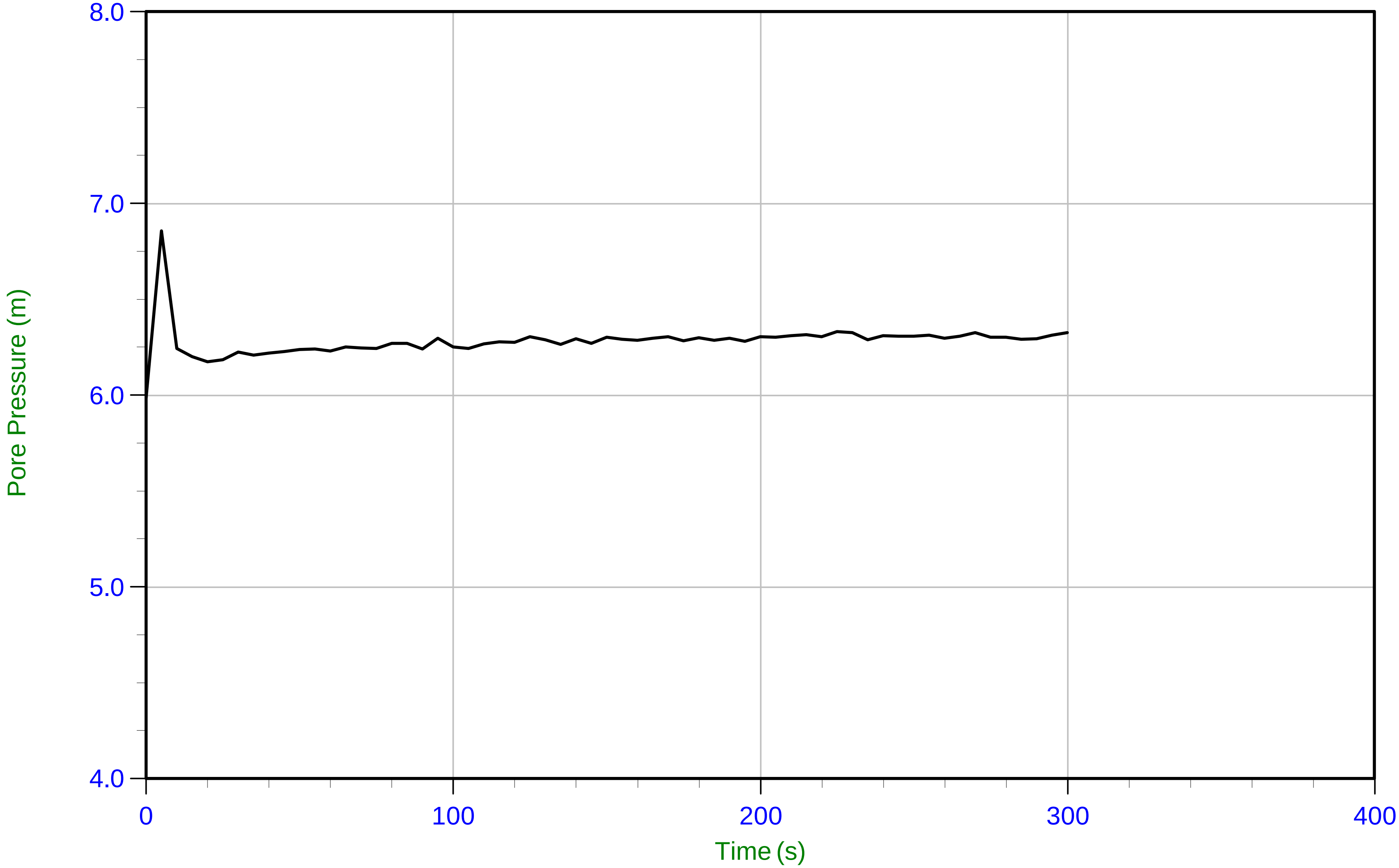
U Min: 2.6 m
U Max: 6.3 m

CONETEC

Wood plc

Job No: 19-05033
Date: 05/22/2019 13:34
Site: Hwy 17 Cobden

Sounding: SCPT19-02
Cone: 377:T1000F10U500 Area=10 cm²



Trace Summary:

Filename: 19-05033_SP02.PPF
Depth: 8.125 m / 26.657 ft
Duration: 300.0 s

U Min: 6.0 m
U Max: 6.9 m

WT: 1.827 m / 5.994 ft
Ueq: 6.3 m

PRESENTATION OF SITE INVESTIGATION RESULTS

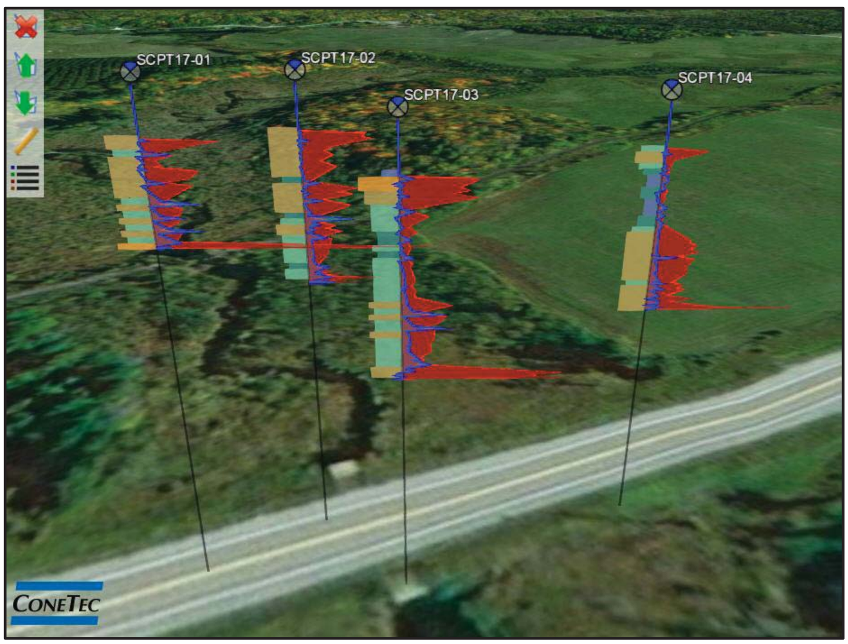
Highway 17 – Muskrat Creek Culvert

Prepared for:

Thurber Engineering Ltd.

ConeTec Job No: 17-05021

Project Start Date: 23-May-2017
Project End Date: 23-May-2017
Report Date: 25-May-2017



Prepared by:

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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. on Highway 17 at the Muskrat Creek Culvert. The program consisted of four seismic cone penetration tests (SCPT) performed on May 23, 2017.

Project Information

Project	
Client	Thurber Engineering Ltd.
Project	Highway 17 - Muskrat Creek Culvert
ConeTec project number	17-05021

A map from Google Earth including the SCPT test locations is presented below.

Rig Description	Deployment System	Test Type
CPT truck rig (C3)	30 ton rig cylinder	SCPT

Coordinates		
Test Type	Collection Method	EPSG Number
SCPT	Consumer grade GPS	32618

Cone Penetration Test (CPT)	
Depth reference	Depths are referenced to the existing ground surface at the time of each test.
Tip and sleeve data offset	0.1 meter This has been accounted for in the CPT data files.
Additional plots	Advanced CPT plots displaying Ic, Su(Nkt), and N1(60) Ic, along with seismic CPT plots are provided.

Cone Penetrometers Used for this Project						
Cone Description	Cone Number	Cross Sectional Area (cm^2)	Sleeve Area (cm^2)	Tip Capacity (bar)	Sleeve Capacity (bar)	Pore Pressure Capacity (psi)
379:T1500F15U500	379	15	225	1500	15	500
Cone 379 was used for both CPT soundings.						

Interpretation Tables	
Additional information	The Normalized Qtn Soil Behaviour Type (SBT-Qtn) classification chart (Robertson, 2009) was used to classify the soil for this project. A detailed set of CPT interpretations were generated and are provided in Excel format files in the release folder. The CPT interpretations are based on values of corrected tip (qt), sleeve friction (fs) and pore pressure (u2). Soils were classified as either drained or undrained based on the Normalized Qtn Soil Behaviour Type (SBT-Qtn) classification chart (Robertson, 2009). Calculations for both drained and undrained parameters were included for materials that classified as silt mixtures – clayey silt to silty clay (zone 4).

Limitations

This report has been prepared for the exclusive use of Thurber Engineering Ltd. (Client) for the project titled “Highway 17 - Muskrat Creek Culvert”. The report’s contents may not be relied upon by any other party without the express written permission of ConeTec Investigations Ltd. (ConeTec). ConeTec has provided site investigation services, prepared the factual data reporting, and provided geotechnical parameter calculations consistent with current best practices. No other warranty, expressed or implied, is made.

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

The cone penetration tests (CPTu) are conducted using an integrated electronic piezocone penetrometer and data acquisition system manufactured by Adara Systems Ltd. of Richmond, British Columbia, Canada.

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

ConeTec penetrometers are manufactured with various tip, friction and pore pressure capacities in 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.

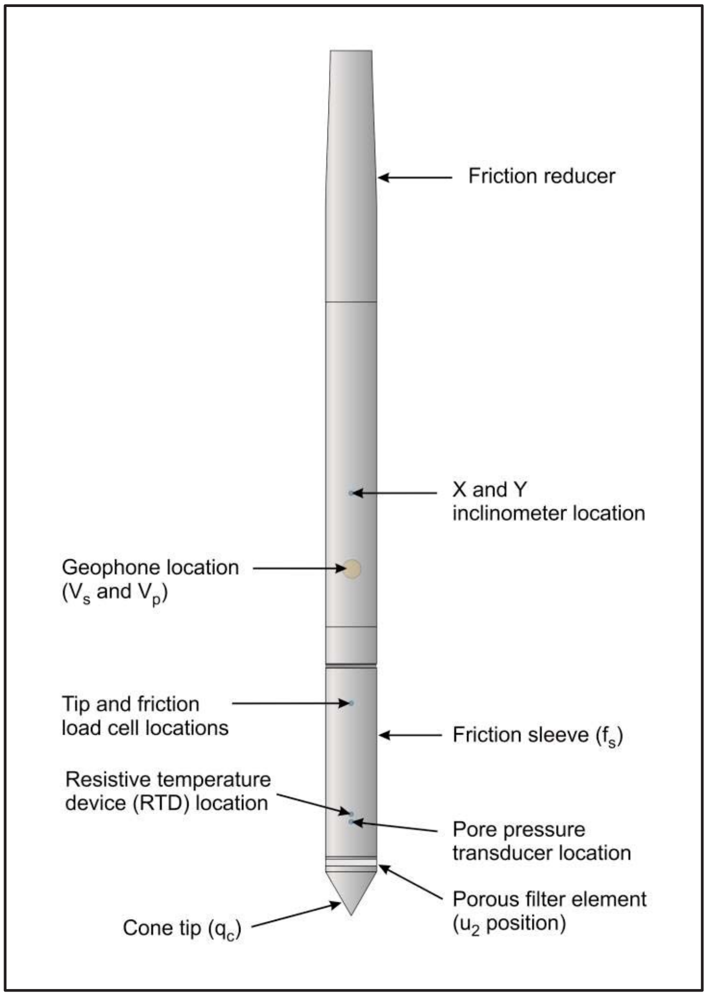

Figure CPTu. Piezocone Penetrometer (15 cm^2)

The ConeTec data acquisition systems consist of a Windows based computer and a signal conditioner and power supply interface box with a 16 bit (or greater) analog to digital (A/D) converter. The data is recorded at fixed depth increments using a depth wheel attached to the push cylinders or by using a spring loaded rubber depth wheel that is held against the cone rods. The typical recording intervals are either 2.5 cm or 5.0 cm depending on project requirements; 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 1.5 inches 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 or glycerine under vacuum pressure prior to use
- Recorded baselines are checked with an independent multi-meter
- Baseline readings are compared to previous readings
- Soundings are terminated at the client's target depth or at a depth where an obstruction is encountered, excessive rod flex occurs, excessive inclination occurs, equipment damage is likely to take place, or a dangerous working environment arises
- Differences between initial and final baselines are calculated to ensure zero load offsets have not occurred and to ensure compliance with ASTM standards

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

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

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

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 interpretation files were generated for each sounding based on published correlations and are provided in Excel format in the data release folder. Information regarding the interpretation methods used is also included in the data release folder.

For additional information on CPTu interpretations, refer to Robertson et al. (1986), Lunne et al. (1997), Robertson (2009), Mayne (2013, 2014) and Mayne and Peuchen (2012).

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

ConeTec's piezocone penetrometers are manufactured with a horizontally active geophone (28 hertz) that is rigidly mounted in the body of the cone penetrometer, 0.2 meters behind the cone tip.

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 triggers the recording of the seismic wave traces. For impulsive devices an accelerometer trigger may be used. The traces are recorded using an up-hole integrated digital oscilloscope which is part of the SCPTu data acquisition system. An illustration of the shear wave testing configuration is presented in Figure SCPTu-1.

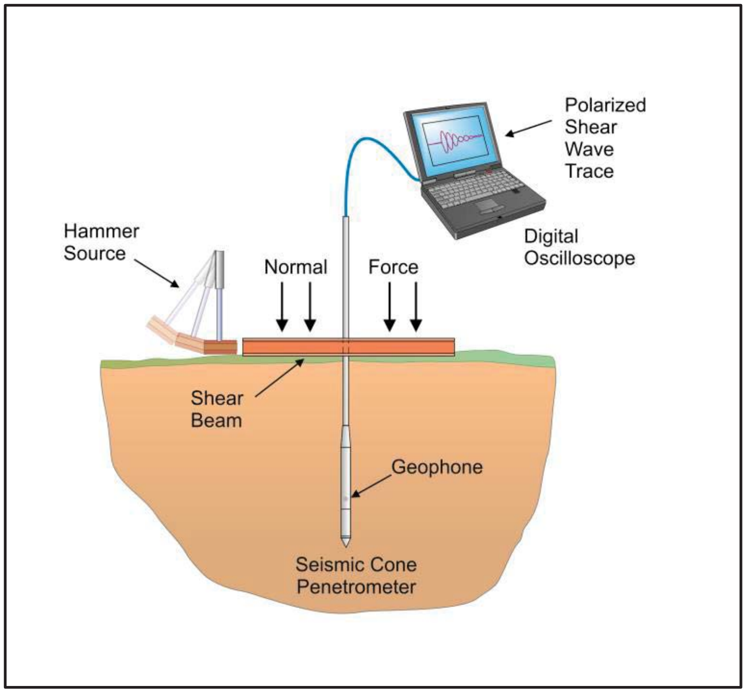

Figure SCPTu-1. Illustration of the SCPTu system

All testing is performed in accordance to ConeTec's SCPTu operating procedures.

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. Multiple wave traces are recorded for quality control 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).

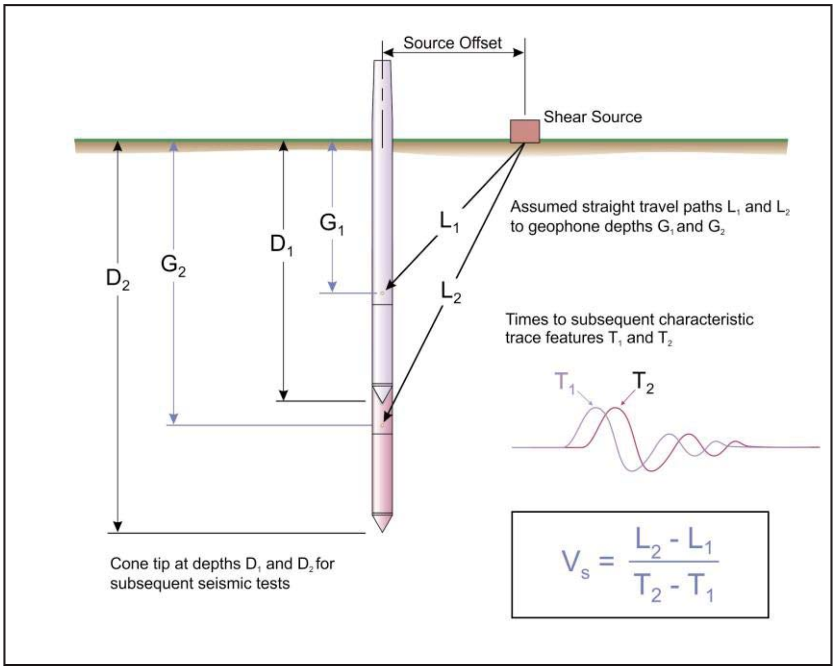

Figure SCPTu-2. Illustration of a seismic cone penetration test

Calculation of the interval velocities are performed by visually picking a common feature (e.g. the first characteristic peak, trough, or crossover) on all of the recorded wave sets and taking the difference in ray path divided by the time difference between subsequent features. 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.

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.

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

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).

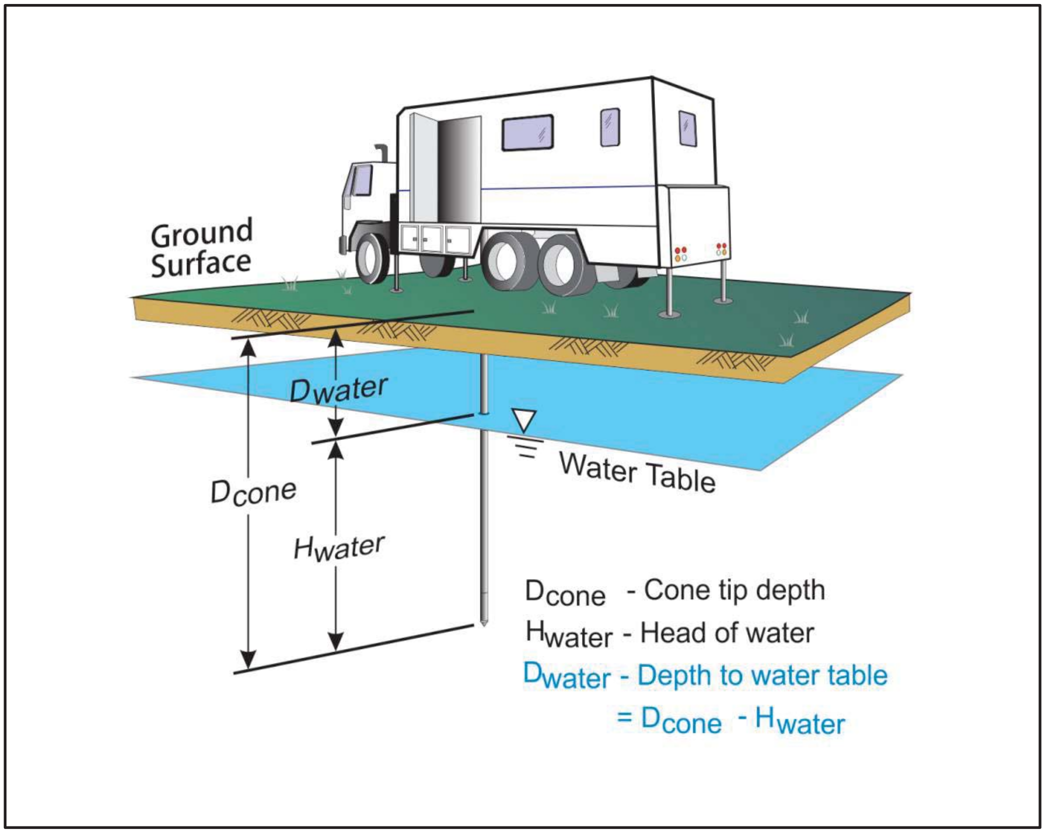

Figure PPD-1. Pore pressure dissipation test setup

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.

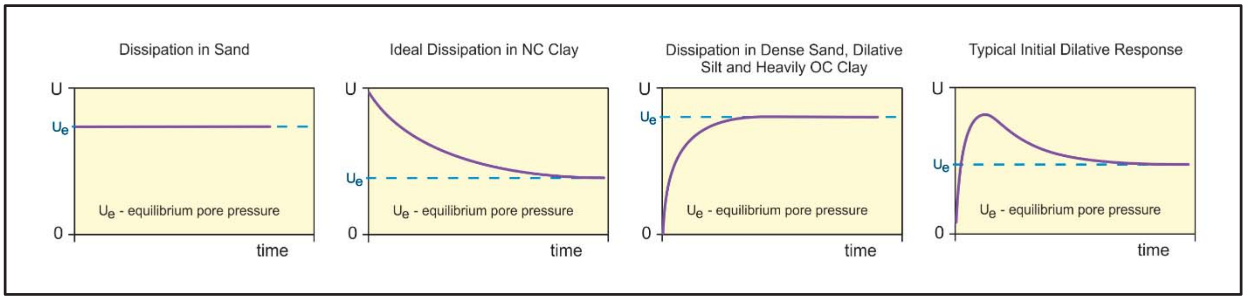

Figure PPD-2. Pore pressure dissipation curve examples

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 of 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.

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

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

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

ASTM D5778-12, 2012, "Standard Test Method for Performing Electronic Friction Cone and Piezocone Penetration Testing of Soils", ASTM, West Conshohocken, US.

Burns, S.E. and Mayne, P.W., 1998, “Monotonic and dilatory pore pressure decay during piezocone tests”, Canadian Geotechnical Journal 26 (4): 1063-1073.

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

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.

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

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

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The appendices listed below are included in the report:

- Cone Penetration Test Summary and Standard Cone Penetration Test Plots
- Advanced Cone Penetration Test Plots displaying Ic, Su(Nkt), and N1(60)Ic
- Seismic Cone Penetration Test Plots
- Seismic Cone Penetration Test Tabular Results
- Pore Pressure Dissipation Summary and Pore Pressure Dissipation Plots

Cone Penetration Test Summary and
Standard Cone Penetration Test Plots

CONETEC

Job No: 17-05021
Client: Thurber Engineering
Project: Hwy 17 - Muskrat Creek Culvert
Start Date: 23-May-2017
End Date: 23-May-2017

CONE PENETRATION TEST SUMMARY

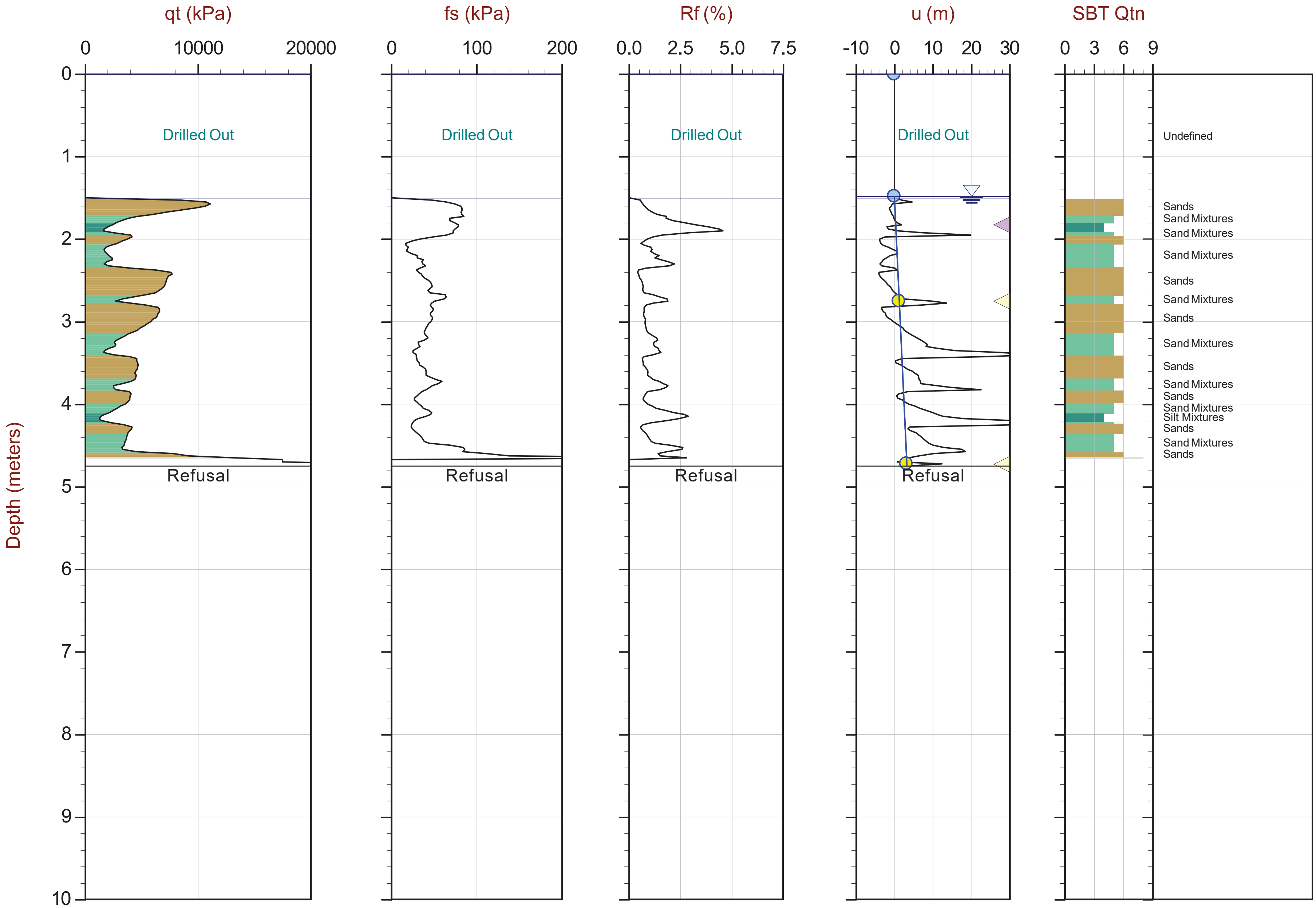
Sounding ID	File Name	Date	Cone	Assumed Phreatic Surface[1] (m)	Final Depth (m)	Northing[2] (m)	Easting (m)	Elevation[3] (m)	Refer to Notation Number
SCPT17-01	17-05021_SP01	23-May-2017	379:T1500F15U500	1.5	4.750	5049789	357129	149.6	
SCPT17-02	17-05021_SP02	23-May-2017	379:T1500F15U500	1.7	6.700	5049779	357140	149.6	
SCPT17-03	17-05021_SP03	23-May-2017	379:T1500F15U500	1.7	8.025	5049767	357132	149.6	
SCPT17-04	17-05021_SP04	23-May-2017	379:T1500F15U500	1.5	7.325	5049744	357150	149.7	

1. The assumed phreatic surface was based on pore pressure dissipation tests. Hydrostatic conditions were assumed for the calculated parameters.
2. Coordinates were collected with a consumer grade GPS device in datum WGS84/UTM Zone 18 North.
3. Elevations were provided by the client.

Thurber Engineering

Job No: 17-05021
Date: 2017-05-23 11:34
Site: Hwy 17 - Muskrat Creek Culvert

Sounding: SCPT17-01
Cone: 379:T1500F15U500



Max Depth: 4.750 m / 15.58 ft
Depth Inc: 0.025 m / 0.082 ft
Avg Int: Every Point

File: 17-05021_SP01.COR
Unit Wt: SBTQtn (PKR2009)

SBT: Robertson, 2009 and 2010
Coords: UTM 18N N: 5049789m E: 357129m Elev: 149.6m
Sheet No: 1 of 1

Equilibrium Pore Pressure (Ueq) Assumed Ueq Dissipation, Ueq achieved Dissipation, Ueq not achieved Hydrostatic Line

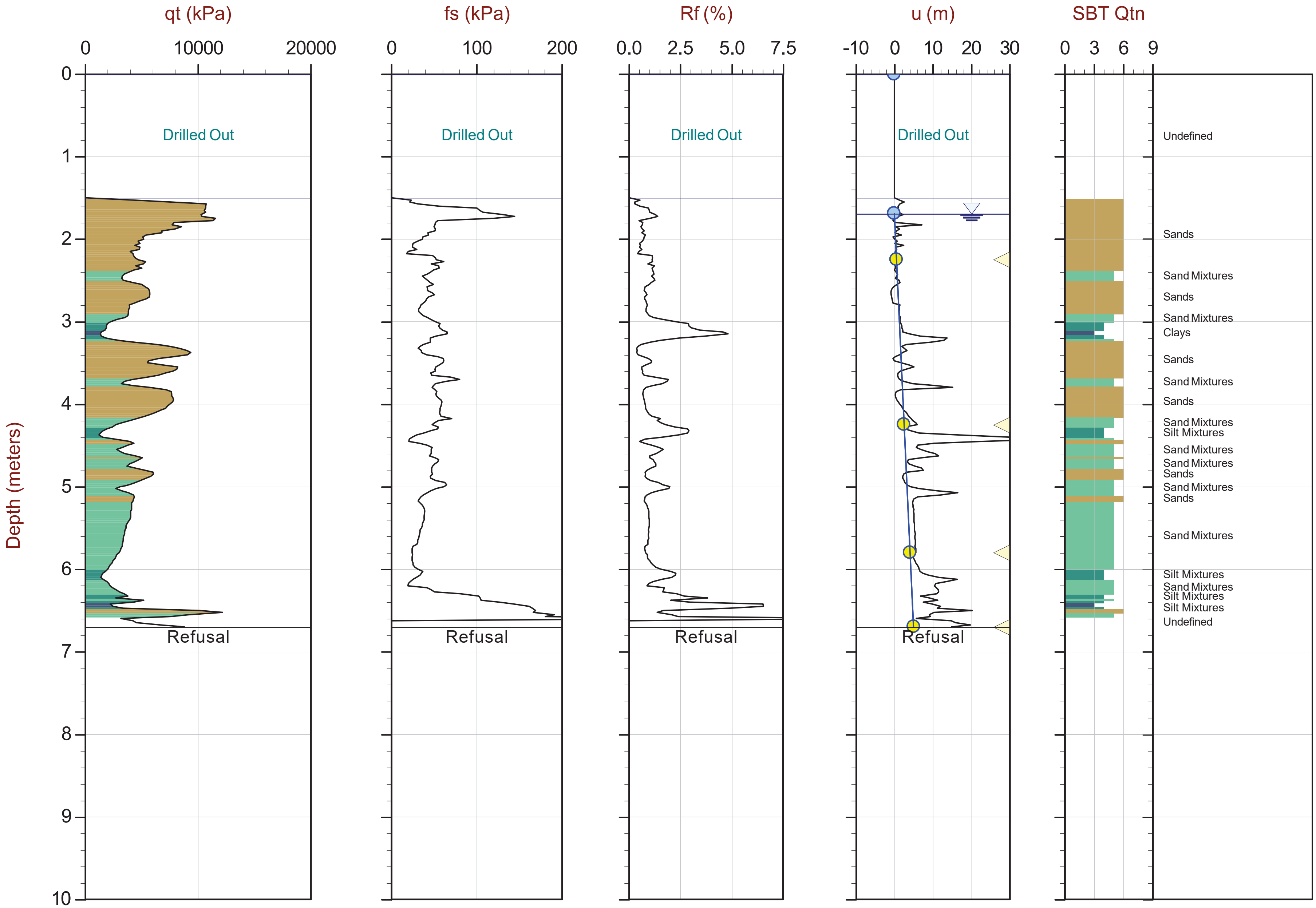
The reported coordinates were acquired from consumer grade GPS equipment and are only approximate locations. The coordinates should not be used for design purposes.

ConeTec

Thurber Engineering

Job No: 17-05021
Date: 2017-05-23 10:19
Site: Hwy 17 - Muskrat Creek Culvert

Sounding: SCPT17-02
Cone: 379:T1500F15U500



Max Depth: 6.700 m / 21.98 ft
Depth Inc: 0.025 m / 0.082 ft
Avg Int: Every Point

File: 17-05021_SP02.COR
Unit Wt: SBTQtn (PKR2009)

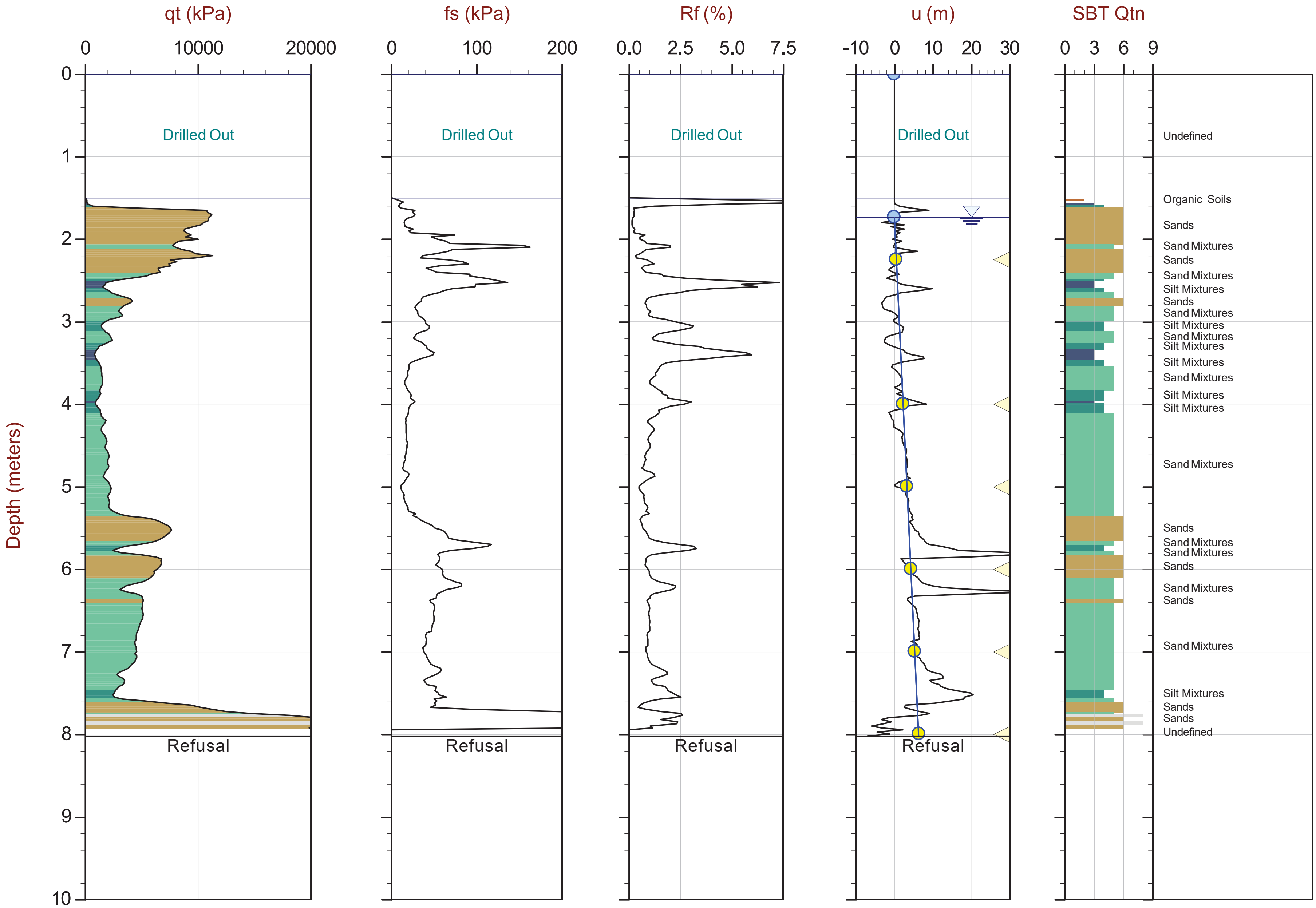
SBT: Robertson, 2009 and 2010
Coords: UTM 18N N: 5049779m E: 357140m Elev: 149.6m
Sheet No: 1 of 1

Equilibrium Pore Pressure (Ueq) | Assumed Ueq | Dissipation, Ueq achieved | Dissipation, Ueq not achieved | Hydrostatic Line

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

Thurber Engineering

Job No: 17-05021
Date: 2017-05-23 12:56
Site: Hwy 17 - Muskrat Creek Culvert
Sounding: SCPT17-03
Cone: 379:T1500F15U500



Max Depth: 8.025 m / 26.33 ft
Depth Inc: 0.025 m / 0.082 ft
Avg Int: Every Point

File: 17-05021_SP03.COR
Unit Wt: SBTQtn (PKR2009)

SBT: Robertson, 2009 and 2010
Coords: UTM 18N N: 5049767m E: 357132m Elev: 149.6m
Sheet No: 1 of 1

Equilibrium Pore Pressure (Ueq) Assumed Ueq Dissipation, Ueq achieved Dissipation, Ueq not achieved Hydrostatic Line

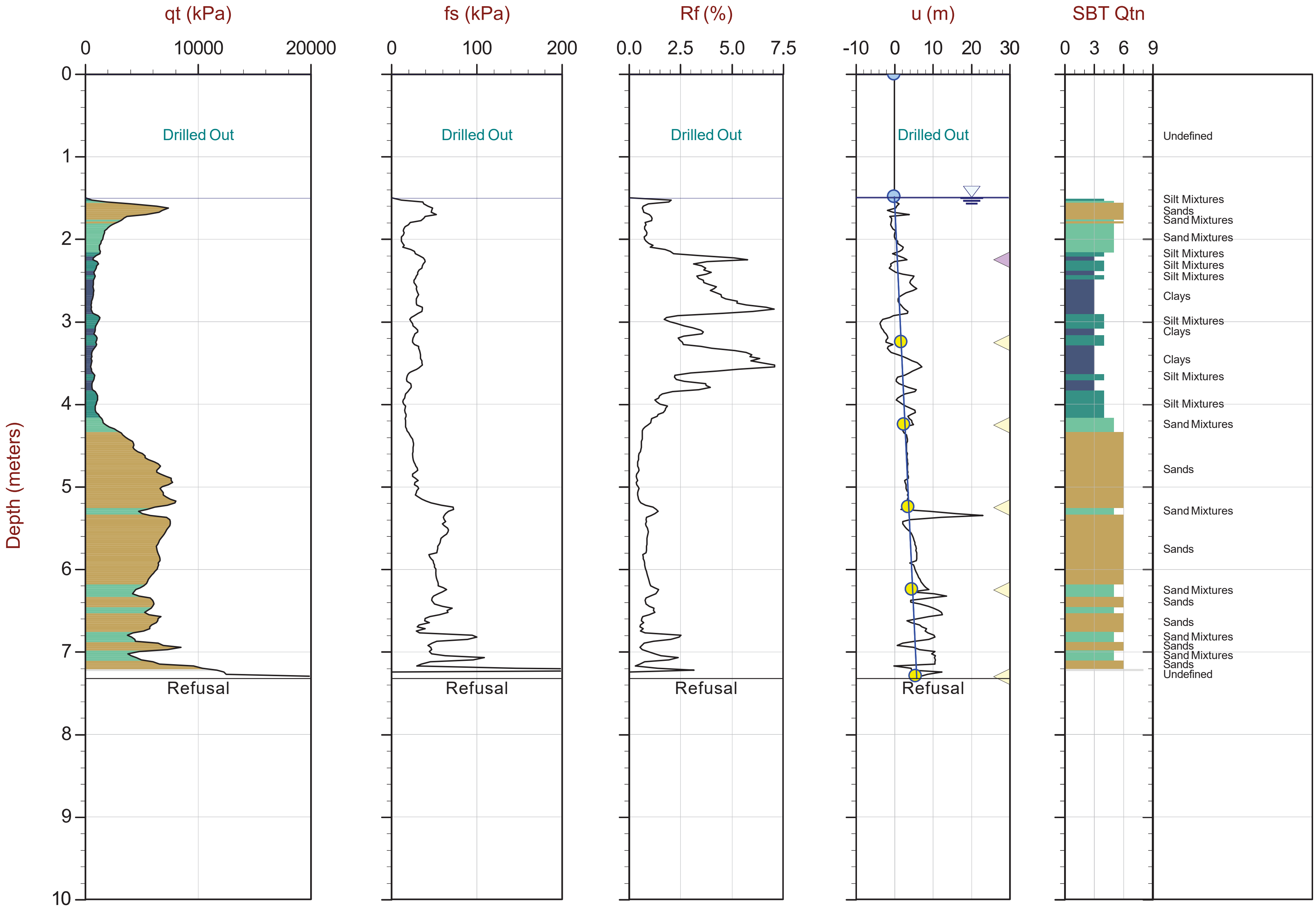
The reported coordinates were acquired from consumer grade GPS equipment and are only approximate locations. The coordinates should not be used for design purposes.

ConeTec

Thurber Engineering

Job No: 17-05021
Date: 2017-05-23 14:17
Site: Hwy 17 - Muskrat Creek Culvert

Sounding: SCPT17-04
Cone: 379:T1500F15U500



Max Depth: 7.325 m / 24.03 ft
Depth Inc: 0.025 m / 0.082 ft
Avg Int: Every Point

File: 17-05021_SP04.COR
Unit Wt: SBTQtn (PKR2009)

SBT: Robertson, 2009 and 2010
Coords: UTM 18N N: 5049744m E: 357150m Elev: 149.7m
Sheet No: 1 of 1

Equilibrium Pore Pressure (Ueq) Assumed Ueq Dissipation, Ueq achieved Dissipation, Ueq not achieved Hydrostatic Line

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

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

ConeTec

Thurber Engineering

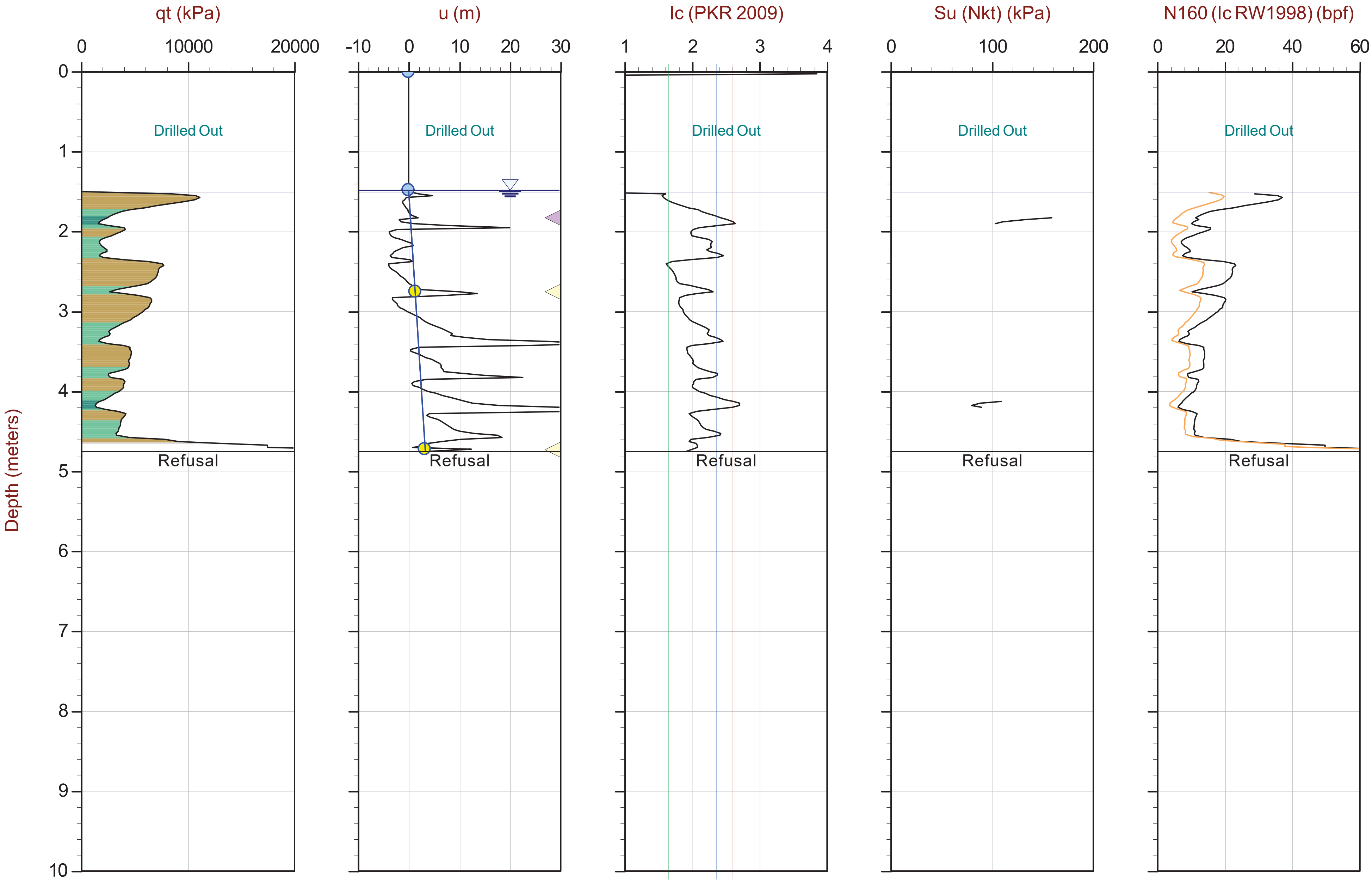
Job No: 17-05021

Date: 2017-05-23 11:34

Site: Hwy 17 - Muskrat Creek Culvert

Sounding: SCPT17-01

Cone: 379:T1500F15U500



Max Depth: 4.750 m / 15.58 ft
Depth Inc: 0.025 m / 0.082 ft
Avg Int: Every Point

File: 17-05021_SP01.COR
Unit Wt: SBTQtn (PKR2009)

SBT: Robertson, 2009 and 2010
Coords: UTM 18N N: 5049789m E: 357129m Elev: 149.6m
Sheet No: 1 of 1

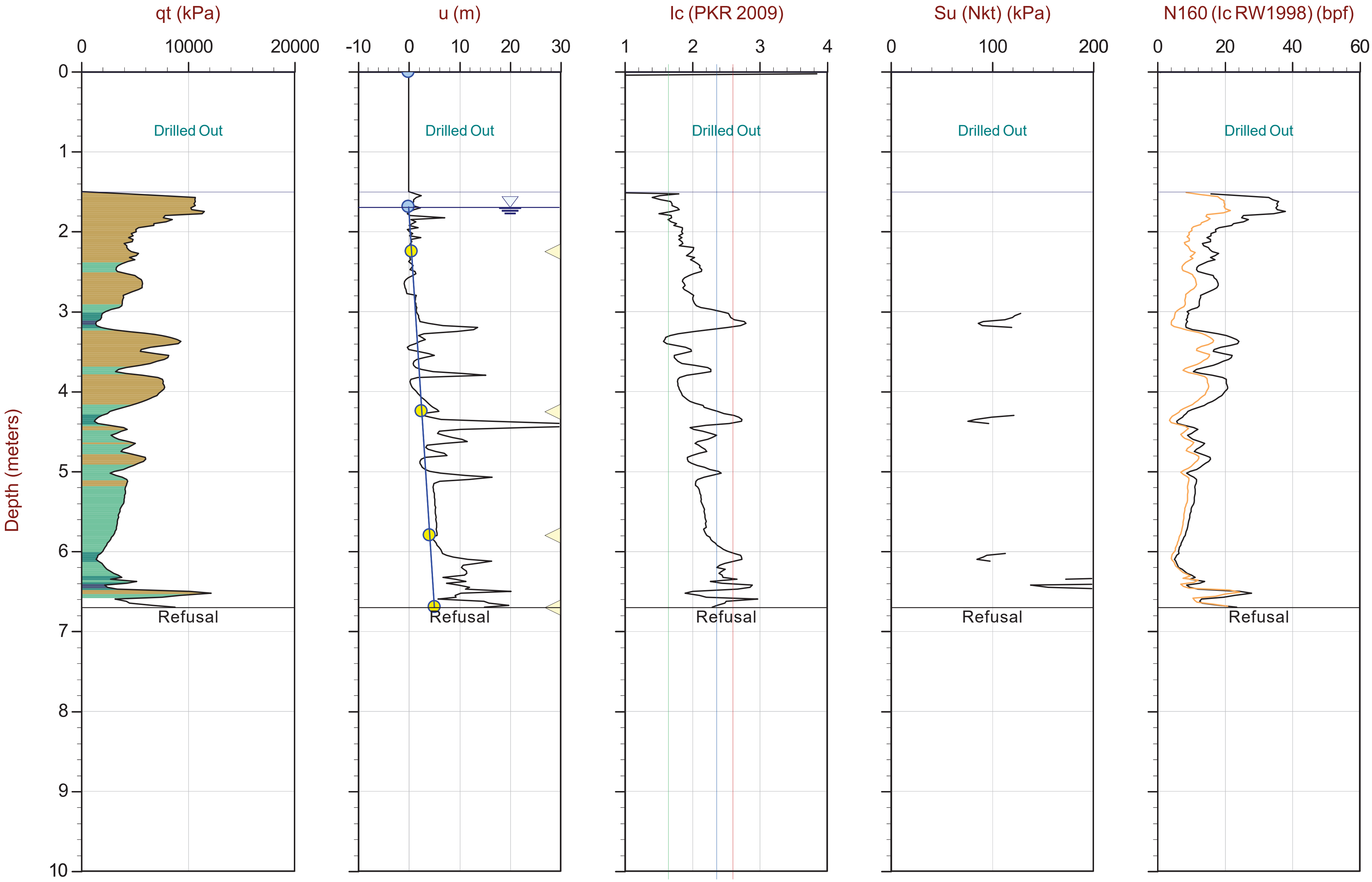
N(60) (bpf) · Equilibrium Pore Pressure (Ueq) · Assumed Ueq · Dissipation, Ueq achieved · Dissipation, Ueq not achieved · Hydrostatic Line

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

CONETEC

Thurber Engineering

Job No: 17-05021
Date: 2017-05-23 10:19
Site: Hwy 17 - Muskrat Creek Culvert
Sounding: SCPT17-02
Cone: 379:T1500F15U500



Max Depth: 6.700 m / 21.98 ft
Depth Inc: 0.025 m / 0.082 ft
Avg Int: Every Point

File: 17-05021_SP02.COR
Unit Wt: SBTQtn (PKR2009)

SBT: Robertson, 2009 and 2010
Coords: UTM 18N N: 5049779m E: 357140m Elev: 149.6m
Sheet No: 1 of 1

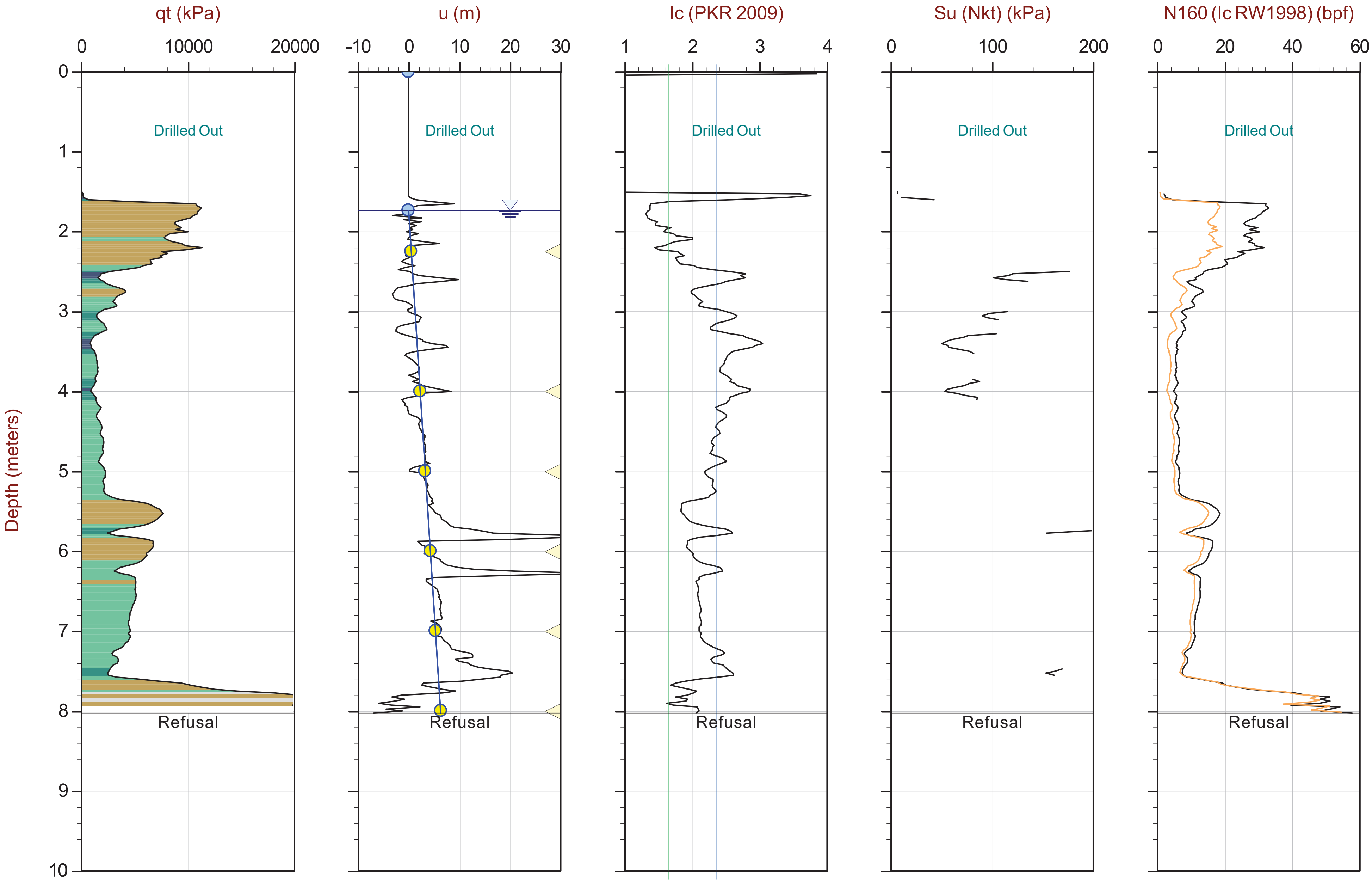
N(60) (bpf) Equilibrium Pore Pressure (Ueq) Assumed Ueq Dissipation, Ueq achieved Dissipation, Ueq not achieved Hydrostatic Line

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

ConeTec

Thurber Engineering

Job No: 17-05021
Date: 2017-05-23 12:56
Site: Hwy 17 - Muskrat Creek Culvert
Sounding: SCPT17-03
Cone: 379:T1500F15U500



Max Depth: 8.025 m / 26.33 ft
Depth Inc: 0.025 m / 0.082 ft
Avg Int: Every Point

File: 17-05021_SP03.COR
Unit Wt: SBTQtn (PKR2009)

SBT: Robertson, 2009 and 2010
Coords: UTM 18N N: 5049767m E: 357132m Elev: 149.6m
Sheet No: 1 of 1

N(60) (bpf) | Equilibrium Pore Pressure (Ueq) | Assumed Ueq | Dissipation, Ueq achieved | Dissipation, Ueq not achieved | Hydrostatic Line

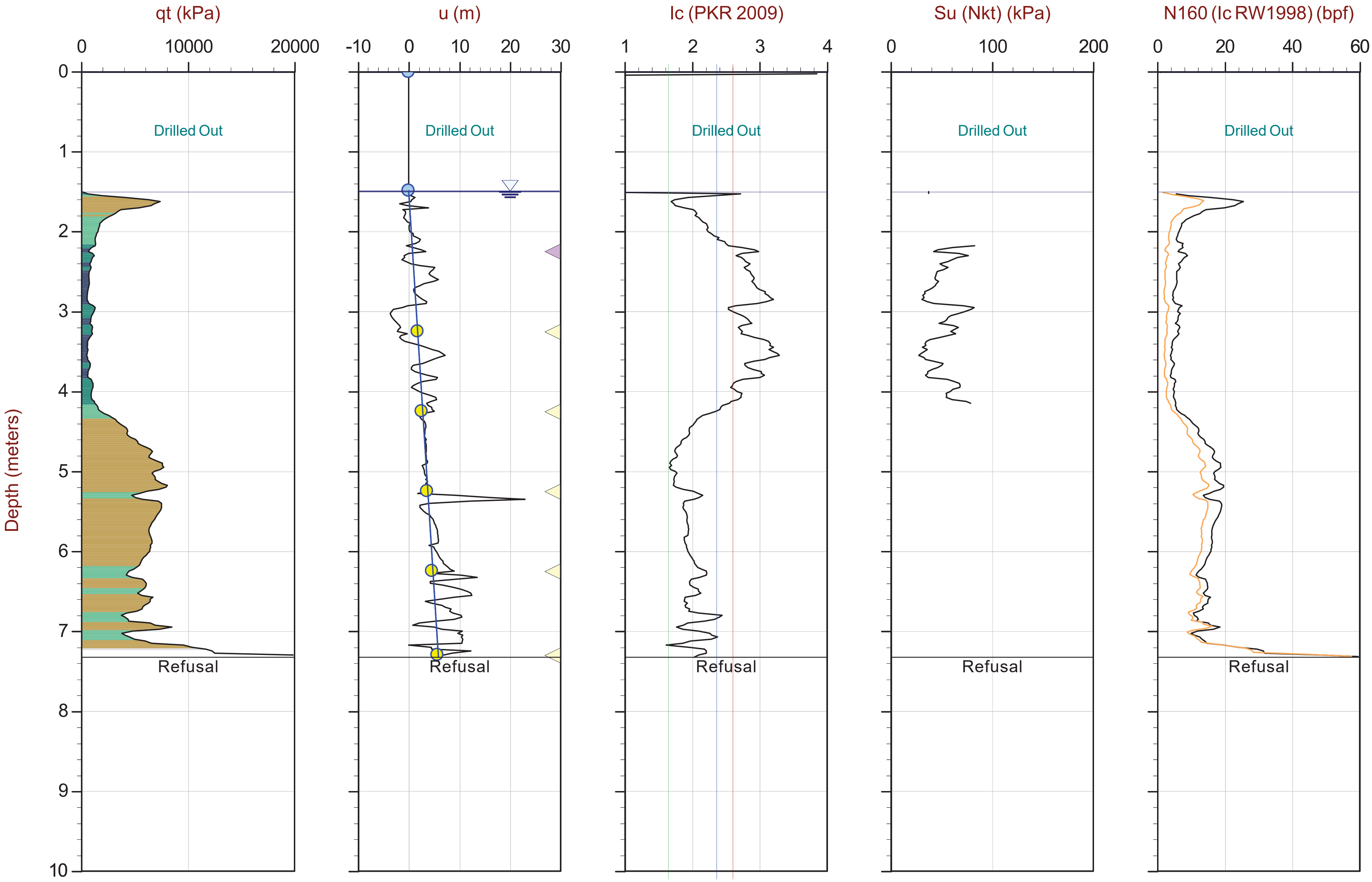
The reported coordinates were acquired from consumer grade GPS equipment and are only approximate locations. The coordinates should not be used for design purposes.

CONETEC

Thurber Engineering

Job No: 17-05021
Date: 2017-05-23 14:17
Site: Hwy 17 - Muskrat Creek Culvert

Sounding: SCPT17-04
Cone: 379:T1500F15U500



Max Depth: 7.325 m / 24.03 ft
Depth Inc: 0.025 m / 0.082 ft
Avg Int: Every Point

File: 17-05021_SP04.COR
Unit Wt: SBTQtn (PKR2009)

SBT: Robertson, 2009 and 2010
Coords: UTM 18N N: 5049744m E: 357150m Elev: 149.7m
Sheet No: 1 of 1

N(60) (bpf) Equilibrium Pore Pressure (Ueq) Assumed Ueq Dissipation, Ueq achieved Dissipation, Ueq not achieved Hydrostatic Line

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

Seismic Cone Penetration Test Plots

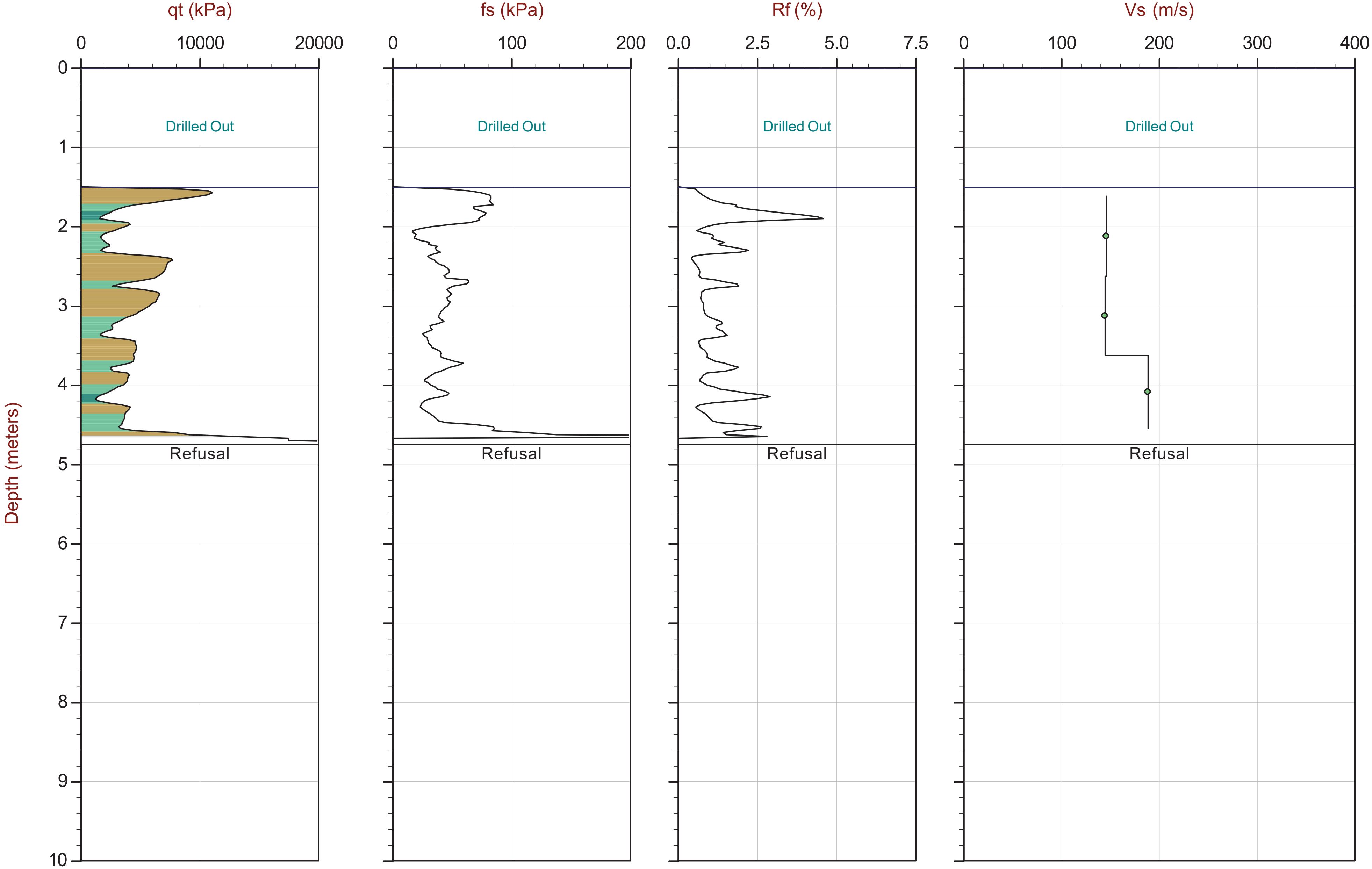
ConeTec

ConeTec

Thurber Engineering

Job No: 17-05021
Date: 2017-05-23 11:34
Site: Hwy 17 - Muskrat Creek Culvert

Sounding: SCPT17-01
Cone: 379:T1500F15U500



Max Depth: 4.750 m / 15.58 ft
Depth Inc: 0.025 m / 0.082 ft
Avg Int: Every Point

File: 17-05021_SP01.COR
Unit Wt: SBTQtn (PKR2009)

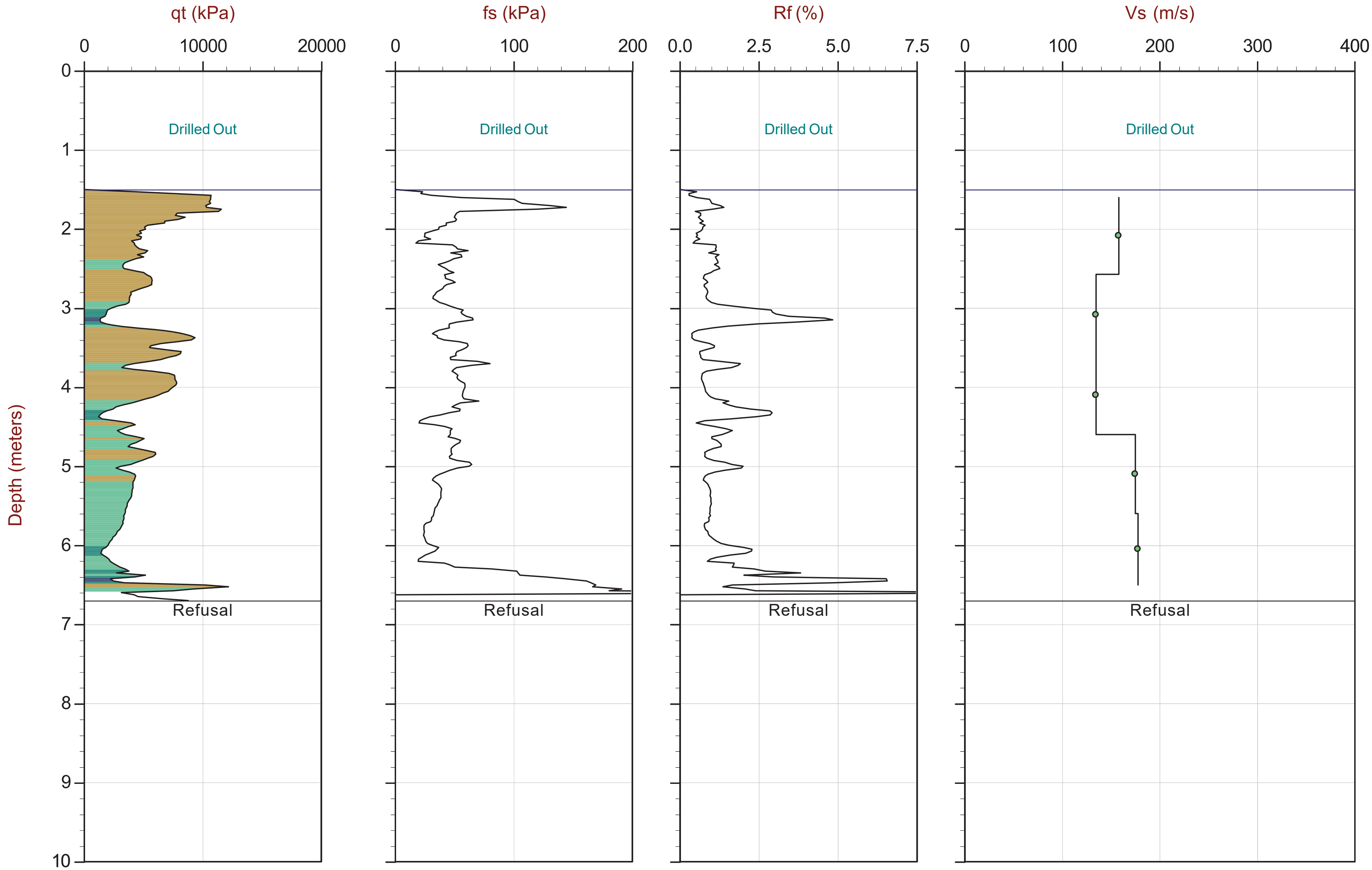
SBT: Robertson, 2009 and 2010
Coords: UTM 18N N: 5049789m E: 357129m Elev: 149.6m
Sheet No: 1 of 1

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

Thurber Engineering

Job No: 17-05021
Date: 2017-05-23 10:19
Site: Hwy 17 - Muskrat Creek Culvert

Sounding: SCPT17-02
Cone: 379:T1500F15U500



Max Depth: 6.700 m / 21.98 ft
Depth Inc: 0.025 m / 0.082 ft
Avg Int: Every Point

File: 17-05021_SP02.COR
Unit Wt: SBTQtn (PKR2009)

SBT: Robertson, 2009 and 2010
Coords: UTM 18N N: 5049779m E: 357140m Elev: 149.6m
Sheet No: 1 of 1

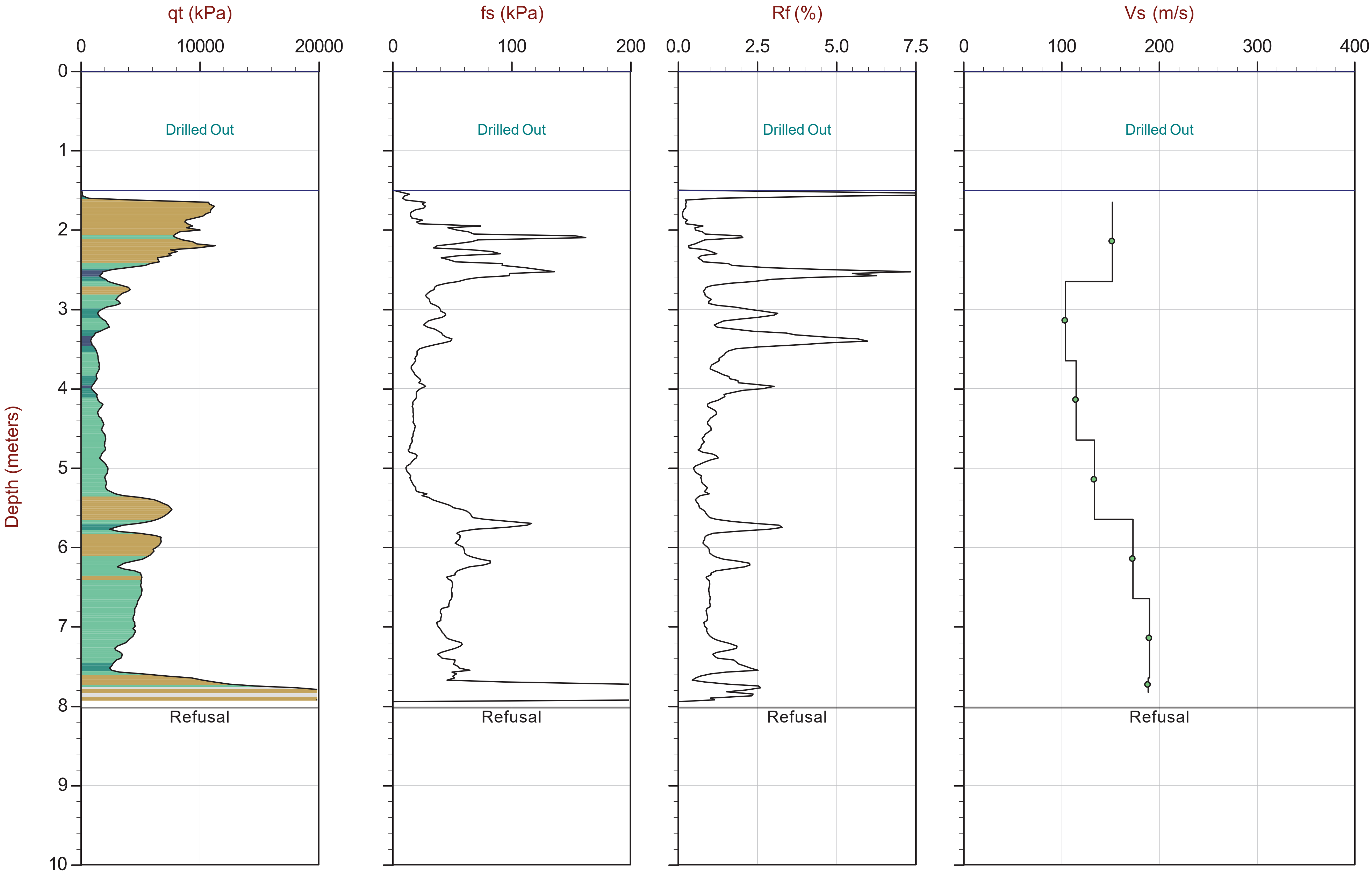
The reported coordinates were acquired from consumer grade GPS equipment and are only approximate locations. The coordinates should not be used for design purposes.

ConeTec

Thurber Engineering

Job No: 17-05021
Date: 2017-05-23 12:56
Site: Hwy 17 - Muskrat Creek Culvert

Sounding: SCPT17-03
Cone: 379:T1500F15U500



Max Depth: 8.025 m / 26.33 ft
Depth Inc: 0.025 m / 0.082 ft
Avg Int: Every Point

File: 17-05021_SP03.COR
Unit Wt: SBTQtn (PKR2009)

SBT: Robertson, 2009 and 2010
Coords: UTM 18N N: 5049767m E: 357132m Elev: 149.6m
Sheet No: 1 of 1

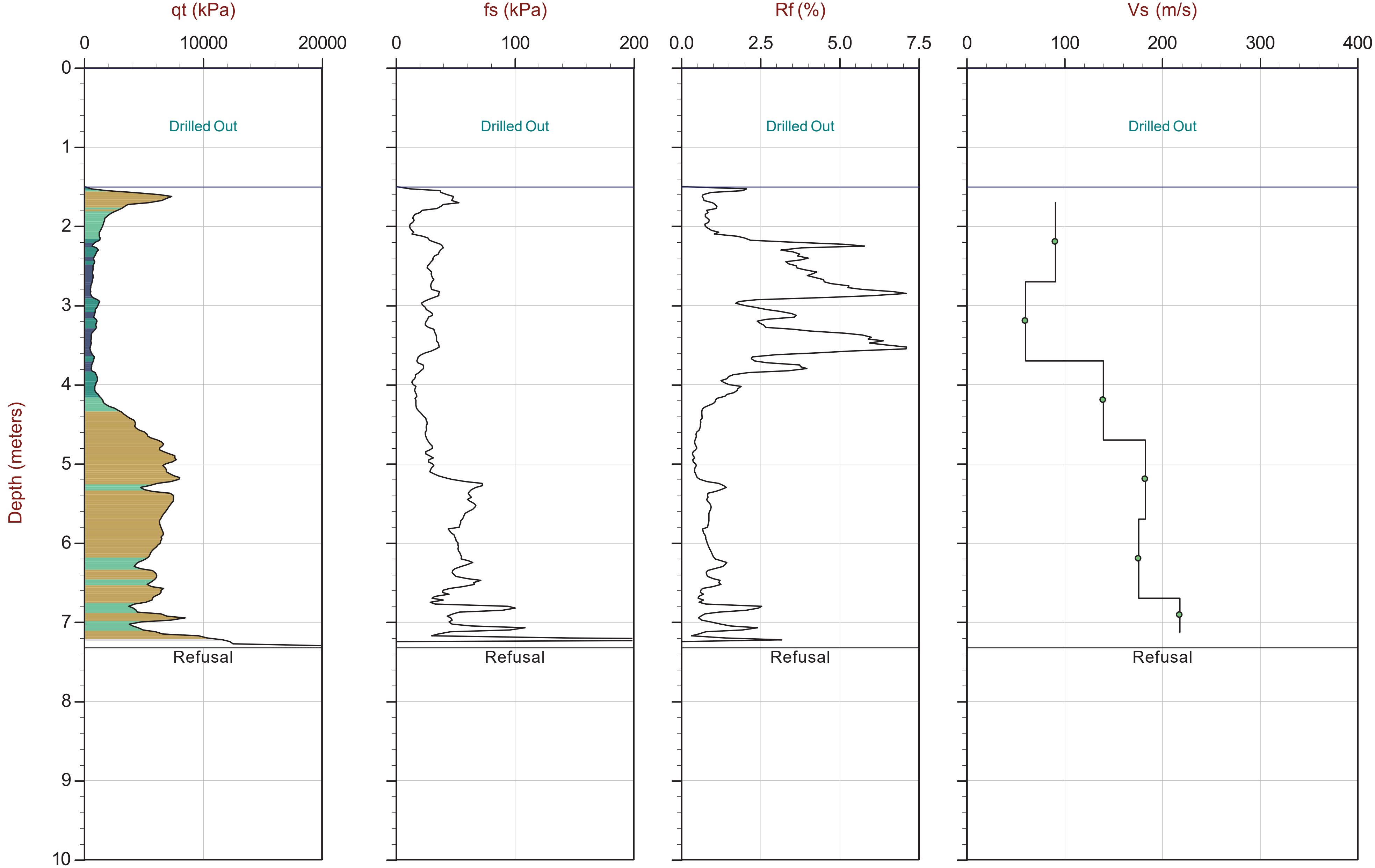
The reported coordinates were acquired from consumer grade GPS equipment and are only approximate locations. The coordinates should not be used for design purposes.

CONETEC

Thurber Engineering

Job No: 17-05021
Date: 2017-05-23 14:17
Site: Hwy 17 - Muskrat Creek Culvert

Sounding: SCPT17-04
Cone: 379:T1500F15U500



Max Depth: 7.325 m / 24.03 ft
Depth Inc: 0.025 m / 0.082 ft
Avg Int: Every Point

File: 17-05021_SP04.COR
Unit Wt: SBTQtn (PKR2009)

SBT: Robertson, 2009 and 2010
Coords: UTM 18N N: 5049744m E: 357150m Elev: 149.7m
Sheet No: 1 of 1

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

Seismic Cone Penetration Test Tabular Results

Job No:	17-05021
Client:	Thurber Engineering
Project:	Hwy 17 - Muskrat Creek Culvert
Sounding ID:	SCPT17-01
Date:	23-May-2017

Seismic Source:	Beam
Source 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)
1.82	1.62	1.71			
2.83	2.63	2.69	0.98	6.69	146
3.83	3.63	3.67	0.98	6.80	145
4.75	4.55	4.58	0.91	4.82	189

Job No:	17-05021	
Client:	Thurber Engineering	
Project:	Hwy 17 - Muskrat Creek Culvert	
Sounding ID:	SCPT17-02	
Date:	23-May-2017	

Seismic Source:	Beam
Source 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)
1.80	1.60	1.69			
2.77	2.57	2.63	0.94	5.92	158
3.80	3.60	3.64	1.01	7.51	135
4.80	4.60	4.63	0.99	7.33	135
5.80	5.60	5.63	0.99	5.69	175
6.70	6.50	6.52	0.90	5.03	178

Job No:	17-05021
Client:	Thurber Engineering
Project:	Hwy 17 - Muskrat Creek Culvert
Sounding ID:	SCPT17-03
Date:	23-May-2017

Seismic Source:	Beam
Source 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)
1.85	1.65	1.74			
2.85	2.65	2.71	0.97	6.35	152
3.85	3.65	3.69	0.98	9.45	104
4.85	4.65	4.68	0.99	8.60	115
5.85	5.65	5.68	0.99	7.43	134
6.85	6.65	6.67	1.00	5.76	173
7.85	7.65	7.67	1.00	5.25	190
8.03	7.83	7.85	0.18	0.95	189

Job No: 17-05021
Client: Thurber Engineering
Project: Hwy 17 - Muskrat Creek Culvert
Sounding ID: SCPT17-04
Date: 23-May-2017

Seismic Source: Beam
Source 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	10.69	91
3.90	3.70	3.74	0.99	16.37	60
4.90	4.70	4.73	0.99	7.11	140
5.90	5.70	5.73	0.99	5.43	183
6.90	6.70	6.72	1.00	5.65	176
7.33	7.13	7.15	0.43	1.97	218

Pore Pressure Dissipation Summary and
Pore Pressure Dissipation Plots

ConeTec

Job No: 17-05021
Client: Thurber Engineering
Project: Hwy 17 - Muskrat Creek Culvert
Start Date: 23-May-2017
End Date: 23-May-2017

CPTu PORE PRESSURE DISSIPATION SUMMARY

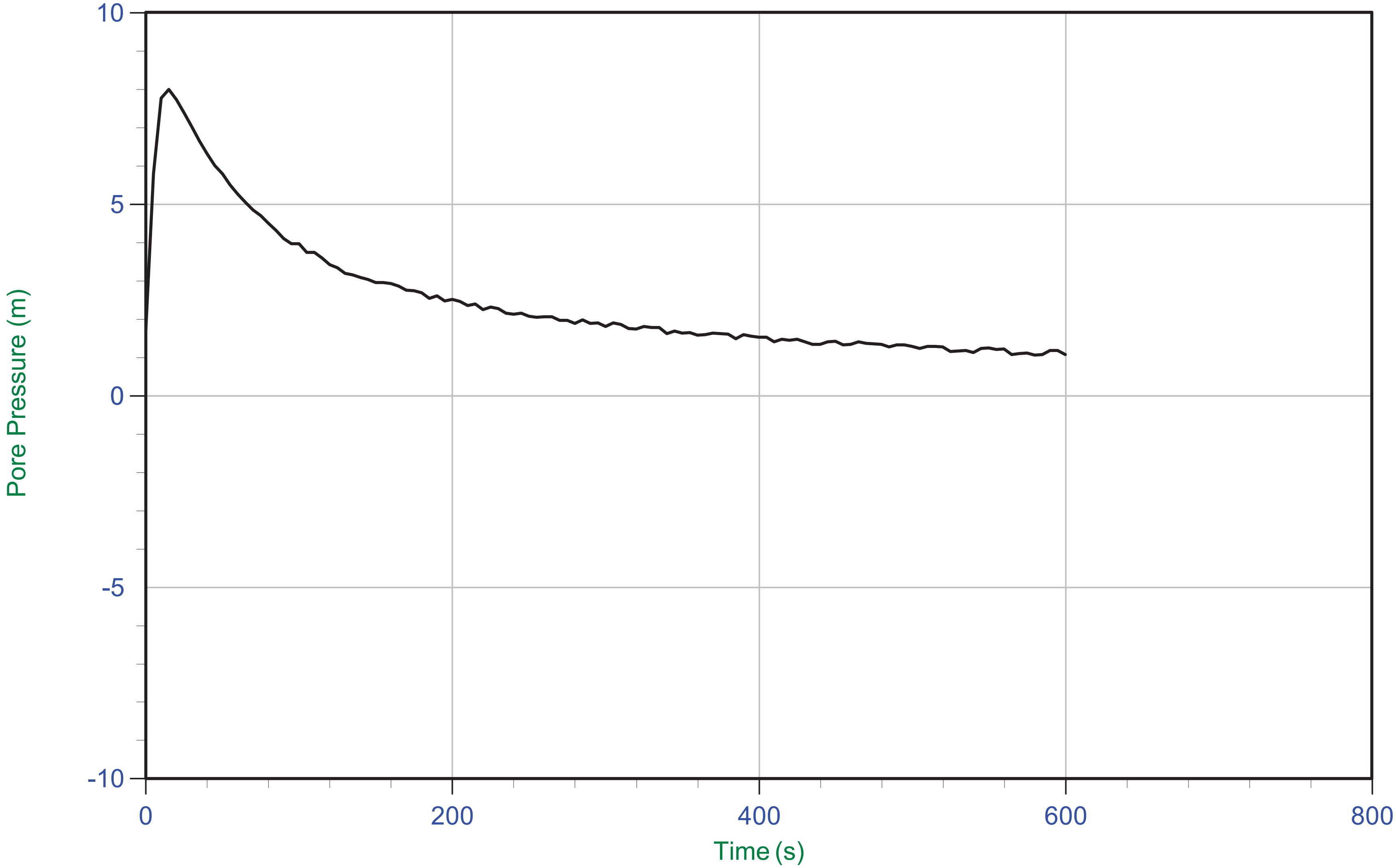
Sounding ID	File Name	Cone Area (cm^2)	Duration (s)	Test Depth (m)	Estimated Equilibrium Pore Pressure U_{eq} (m)	Calculated Phreatic Surface (m)
SCPT17-01	17-05021_SP01	15	600	1.825	Not Achieved	
SCPT17-01	17-05021_SP01	15	500	2.750	1.3	1.5
SCPT17-01	17-05021_SP01	15	350	4.725	3.1	1.6
SCPT17-02	17-05021_SP02	15	200	2.250	0.6	1.7
SCPT17-02	17-05021_SP02	15	250	4.250	2.6	1.7
SCPT17-02	17-05021_SP02	15	350	5.800	4.2	1.7
SCPT17-02	17-05021_SP02	15	300	6.700	5.1	1.6
SCPT17-03	17-05021_SP03	15	300	2.250	0.5	1.7
SCPT17-03	17-05021_SP03	15	350	4.000	2.3	1.7
SCPT17-03	17-05021_SP03	15	300	5.000	3.3	1.7
SCPT17-03	17-05021_SP03	15	250	6.000	4.3	1.7
SCPT17-03	17-05021_SP03	15	250	7.000	5.3	1.7
SCPT17-03	17-05021_SP03	15	250	8.000	6.4	1.6
SCPT17-04	17-05021_SP04	15	310	2.250	Not Achieved	
SCPT17-04	17-05021_SP04	15	450	3.250	1.8	1.5
SCPT17-04	17-05021_SP04	15	250	4.250	2.6	1.7
SCPT17-04	17-05021_SP04	15	300	5.250	3.6	1.6
SCPT17-04	17-05021_SP04	15	200	6.250	4.6	1.7
SCPT17-04	17-05021_SP04	15	300	7.300	5.6	1.7

ConeTec

Thurber Engineering

Job No: 17-05021
Date: 05/23/2017 11:34
Site: Hwy 17 - Muskrat Creek Culvert

Sounding: SCPT17-01
Cone: 379:T1500F15U500 Area=15 cm²

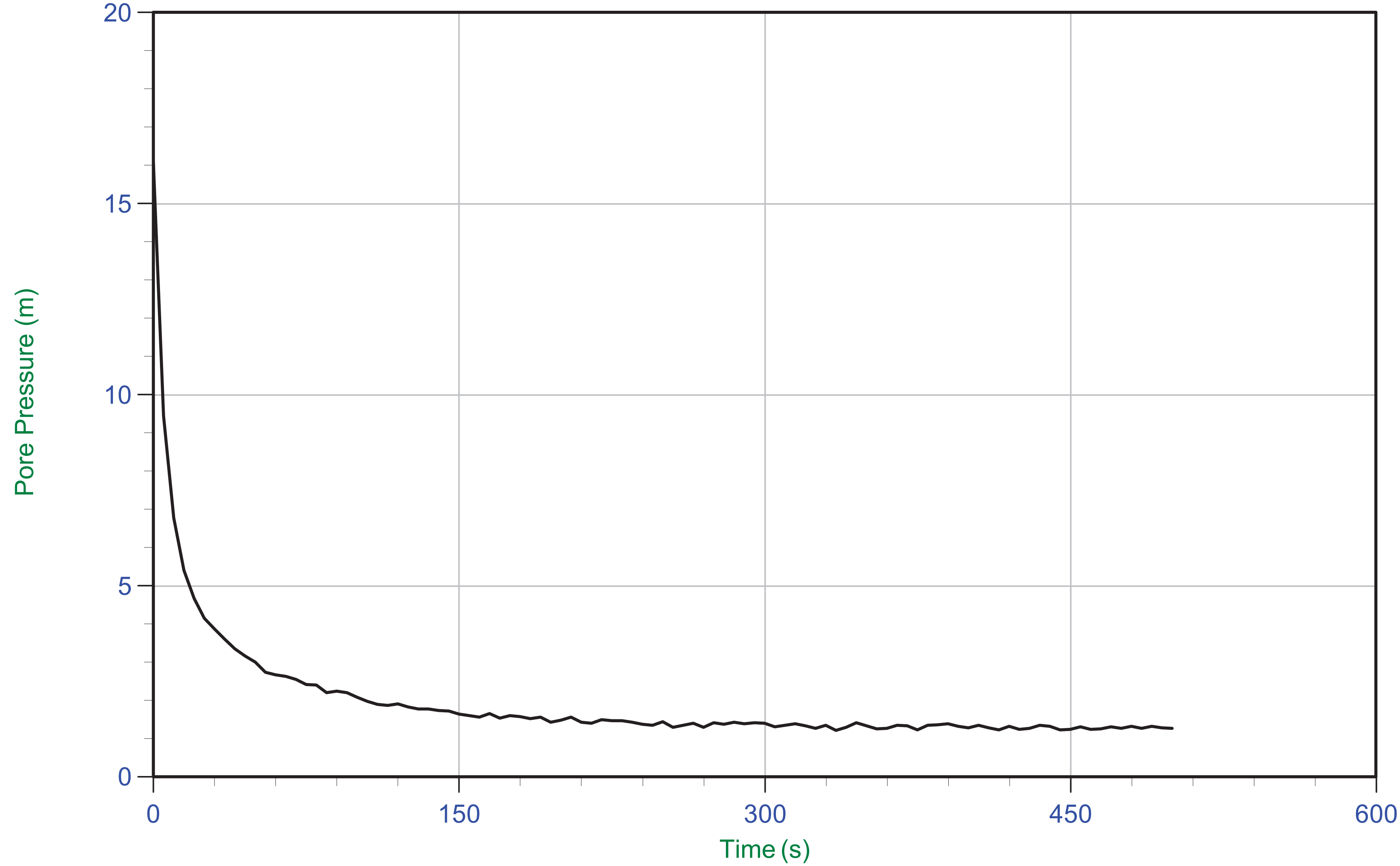


Trace Summary:

Filename: 17-05021_SP01.PPF
Depth: 1.825 m / 5.987 ft
Duration: 600.0 s

U Min: 1.1 m
U Max: 8.0 m

CONETEC	*Thurber Engineering*	Job No: 17-05021 Date: 05/23/2017 11:34 Site: Hwy 17 - Muskrat Creek Culvert	Sounding: SCPT17-01 Cone: 379:T1500F15U500 Area=15 cm²



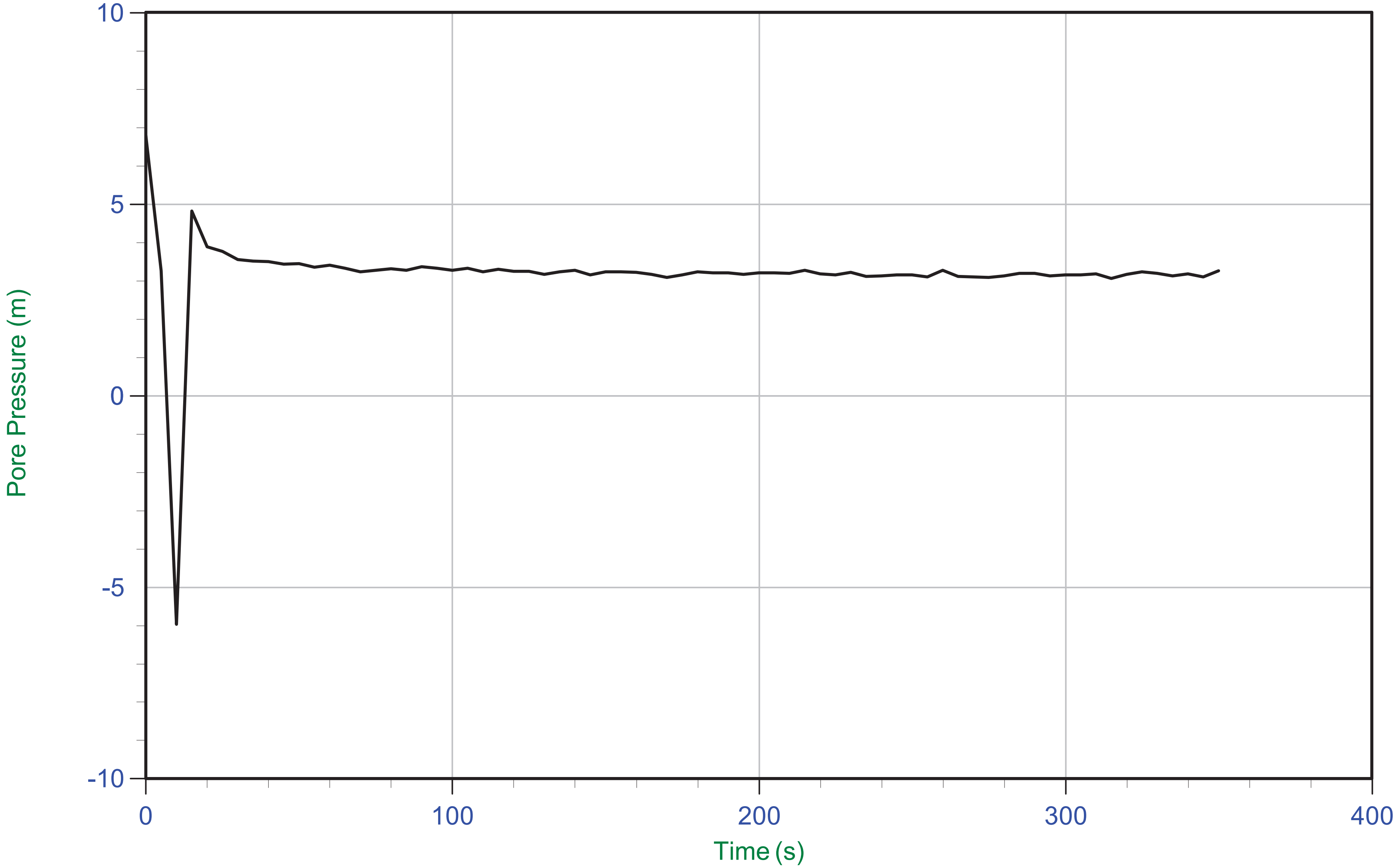
Trace Summary:

Filename: 17-05021_SP01.PPF	U Min: 1.2 m	WT: 1.481 m / 4.859 ft
Depth: 2.750 m / 9.022 ft	U Max: 16.1 m	Ueq: 1.3 m
Duration: 500.0 s		

Thurber Engineering

Job No: 17-05021
Date: 05/23/2017 11:34
Site: Hwy 17 - Muskrat Creek Culvert

Sounding: SCPT17-01
Cone: 379:T1500F15U500 Area=15 cm²

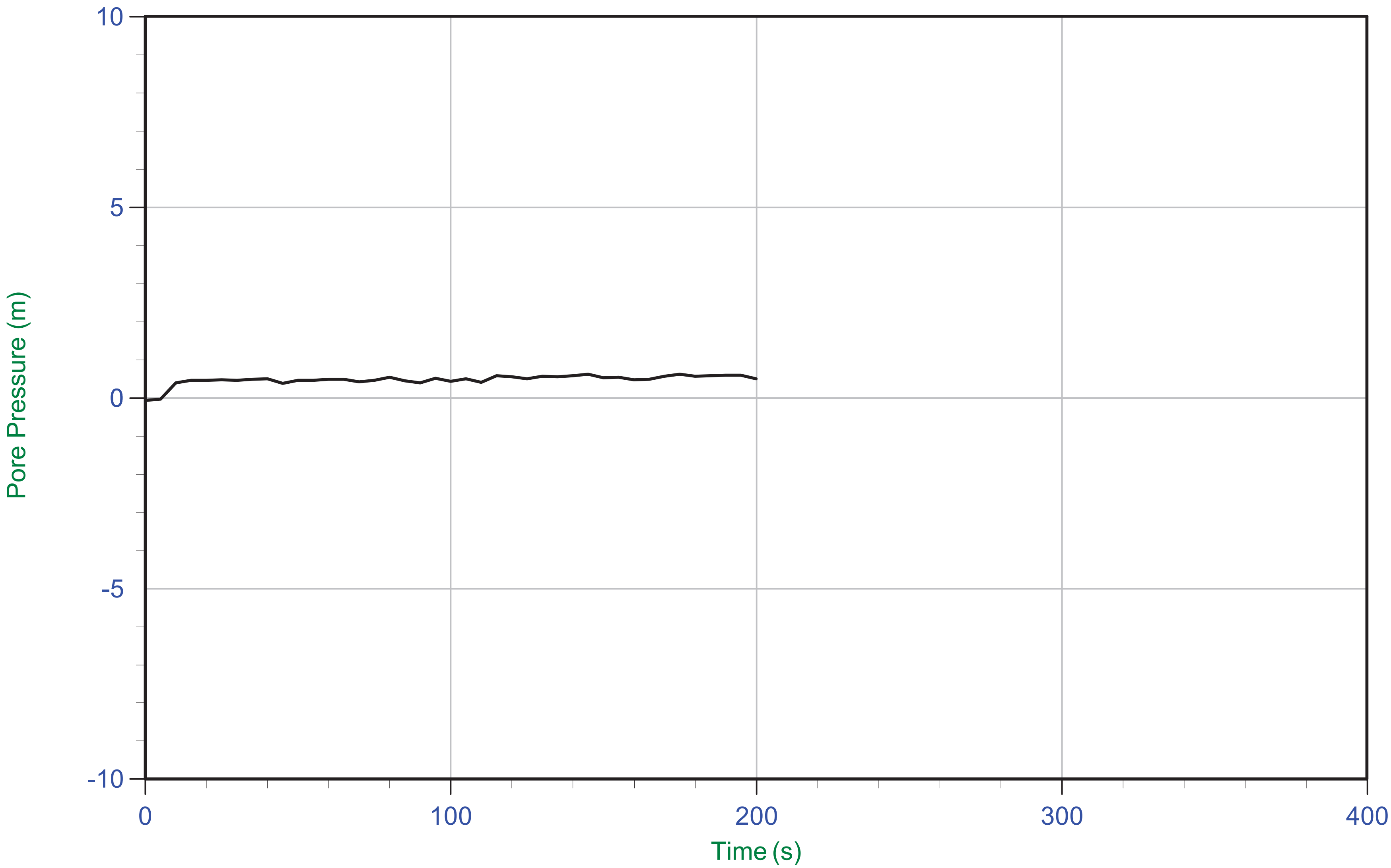


Trace Summary:

Filename: 17-05021_SP01.PPF
Depth: 4.725 m / 15.502 ft
Duration: 350.0 s

U Min: -6.0 m
U Max: 6.8 m

WT: 1.585 m / 5.200 ft
Ueq: 3.1 m



Trace Summary:

Filename: 17-05021_SP02.PPF
Depth: 2.250 m / 7.382 ft
Duration: 200.0 s

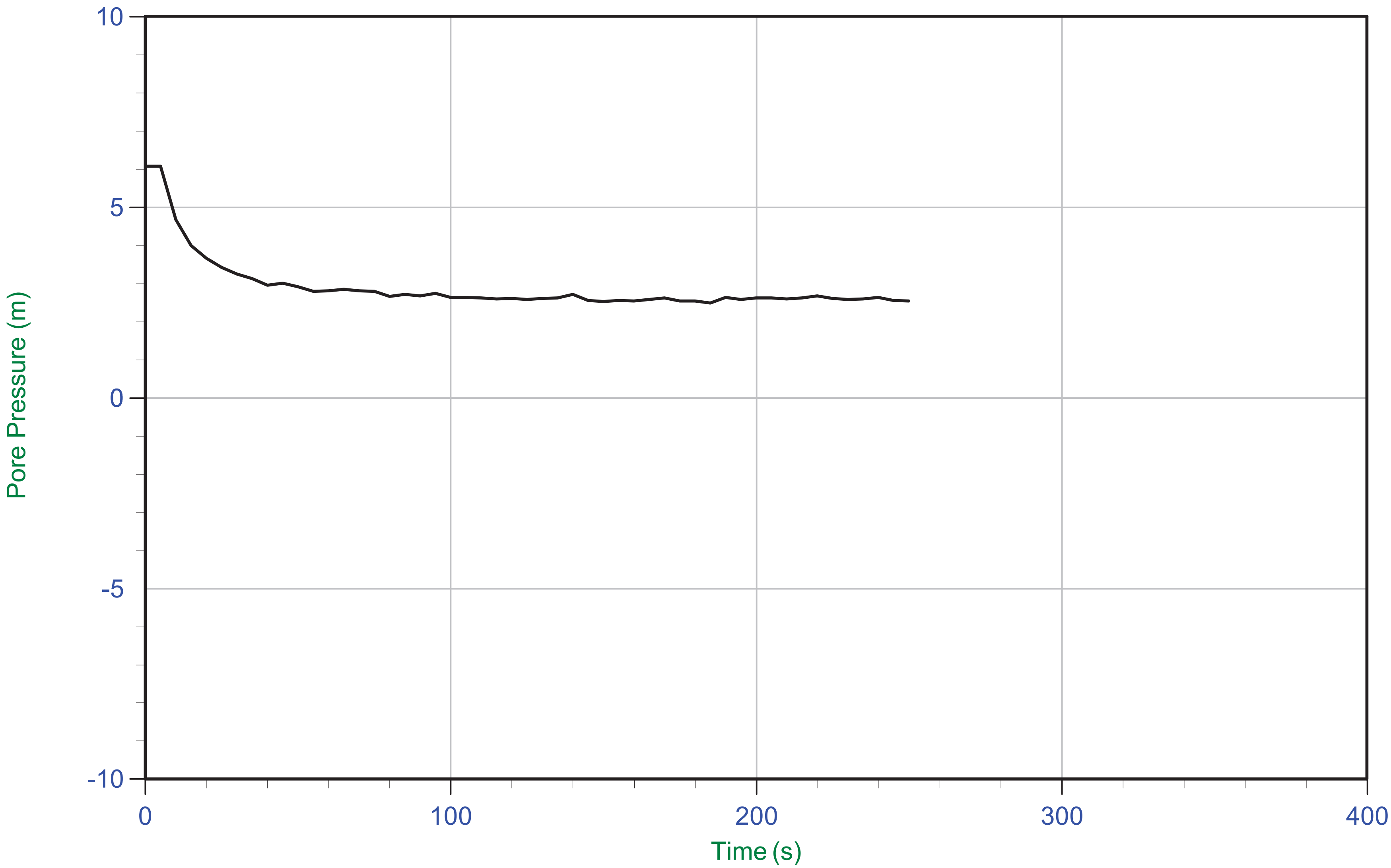
U Min: -0.1 m
U Max: 0.6 m

WT: 1.693 m / 5.554 ft
Ueq: 0.6 m

Thurber Engineering

Job No: 17-05021
Date: 05/23/2017 10:19
Site: Hwy 17 - Muskrat Creek Culvert

Sounding: SCPT17-02
Cone: 379:T1500F15U500 Area=15 cm²



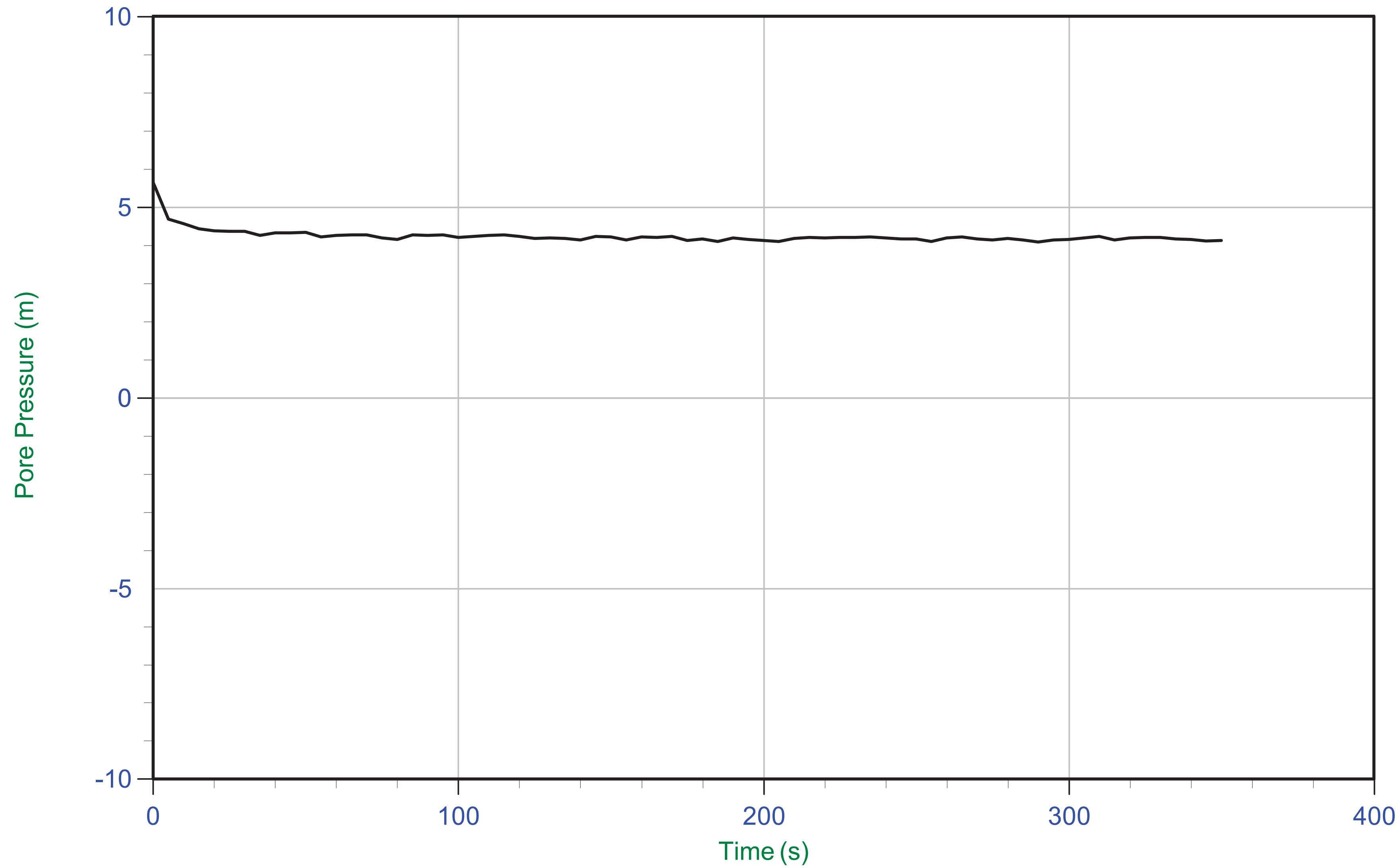
Trace Summary:

Filename: 17-05021_SP02.PPF
Depth: 4.250 m / 13.943 ft
Duration: 250.0 s

U Min: 2.5 m
U Max: 6.1 m

WT: 1.675 m / 5.495 ft
Ueq: 2.6 m

Thurber Engineering	Job No: 17-05021 Date: 05/23/2017 10:19 Site: Hwy 17 - Muskrat Creek Culvert	Sounding: SCPT17-02 Cone: 379:T1500F15U500 Area=15 cm²



Trace Summary:

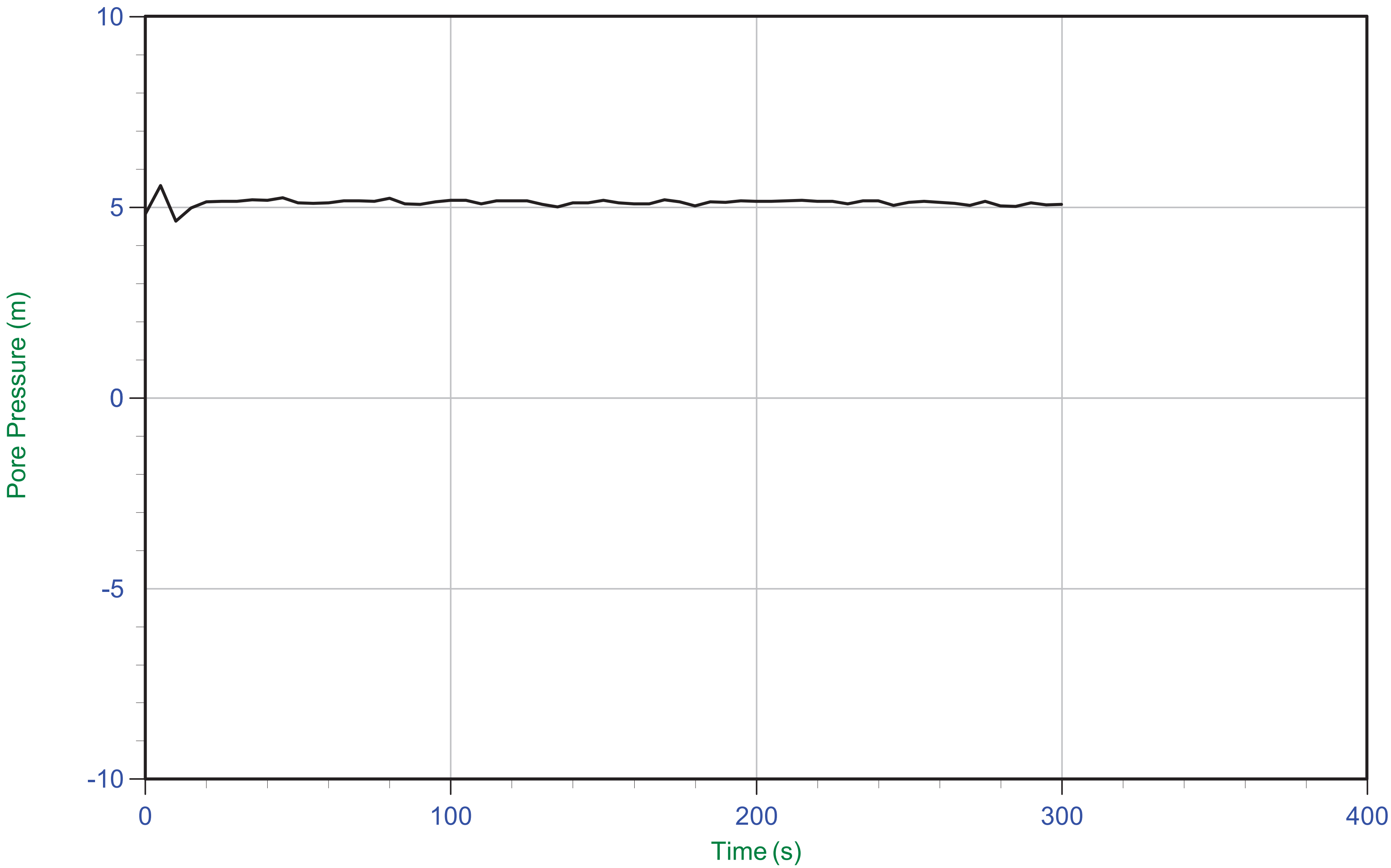
Filename: 17-05021_SP02.PPF	U Min: 4.1 m	WT: 1.648 m / 5.407 ft
Depth: 5.800 m / 19.029 ft	U Max: 5.6 m	Ueq: 4.2 m
Duration: 350.0 s		

CONETEC

Thurber Engineering

Job No: 17-05021
Date: 05/23/2017 10:19
Site: Hwy 17 - Muskrat Creek Culvert

Sounding: SCPT17-02
Cone: 379:T1500F15U500 Area=15 cm²



Trace Summary:

Filename: 17-05021_SP02.PPF
Depth: 6.700 m / 21.981 ft
Duration: 300.0 s

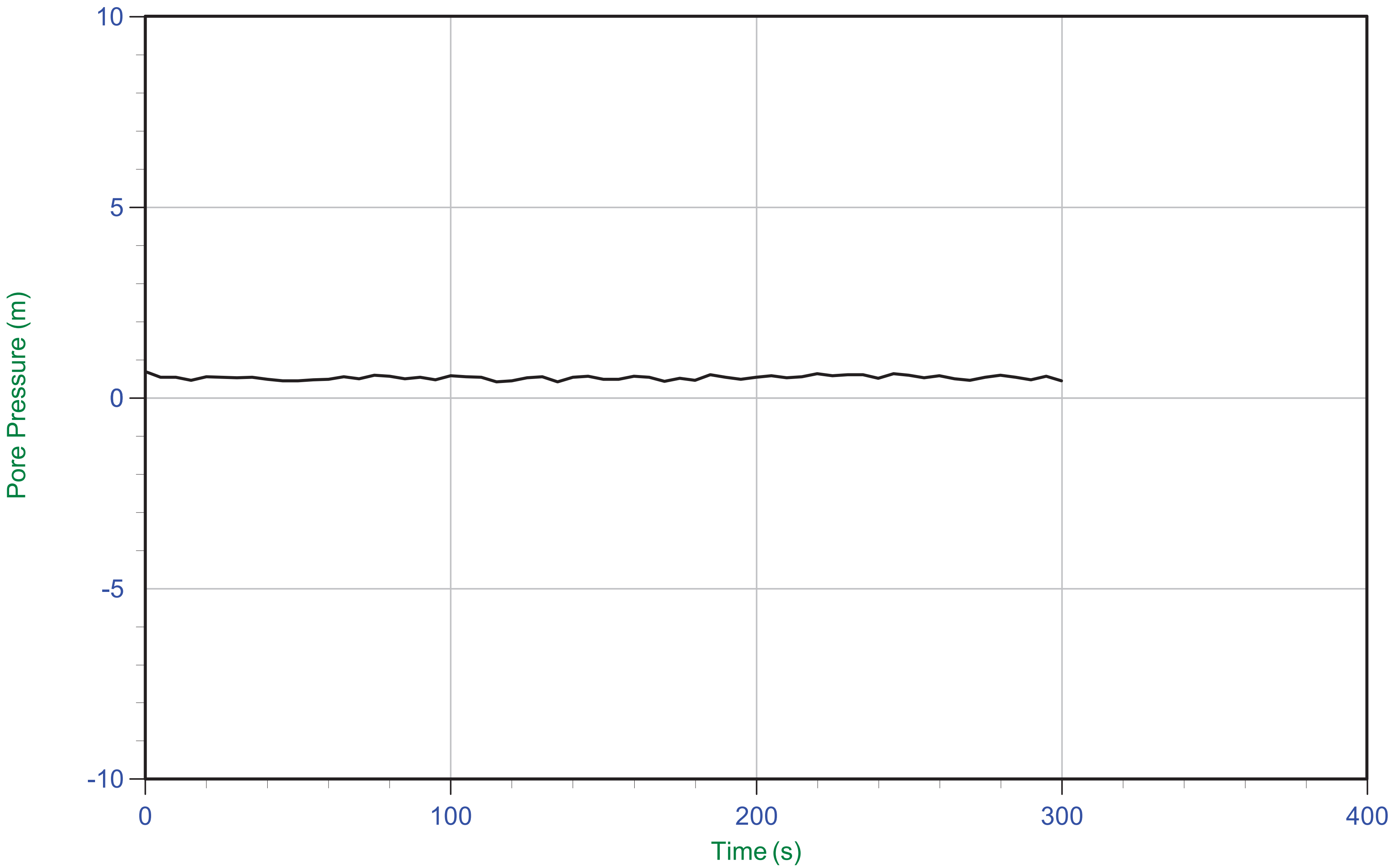
U Min: 4.6 m
U Max: 5.6 m

WT: 1.603 m / 5.259 ft
Ueq: 5.1 m

Thurber Engineering

Job No: 17-05021
Date: 05/23/2017 12:56
Site: Hwy 17 - Muskrat Creek Culvert

Sounding: SCPT17-03
Cone: 379:T1500F15U500 Area=15 cm²



Trace Summary:

Filename: 17-05021_SP03.PPF
Depth: 2.250 m / 7.382 ft
Duration: 300.0 s

U Min: 0.4 m
U Max: 0.7 m

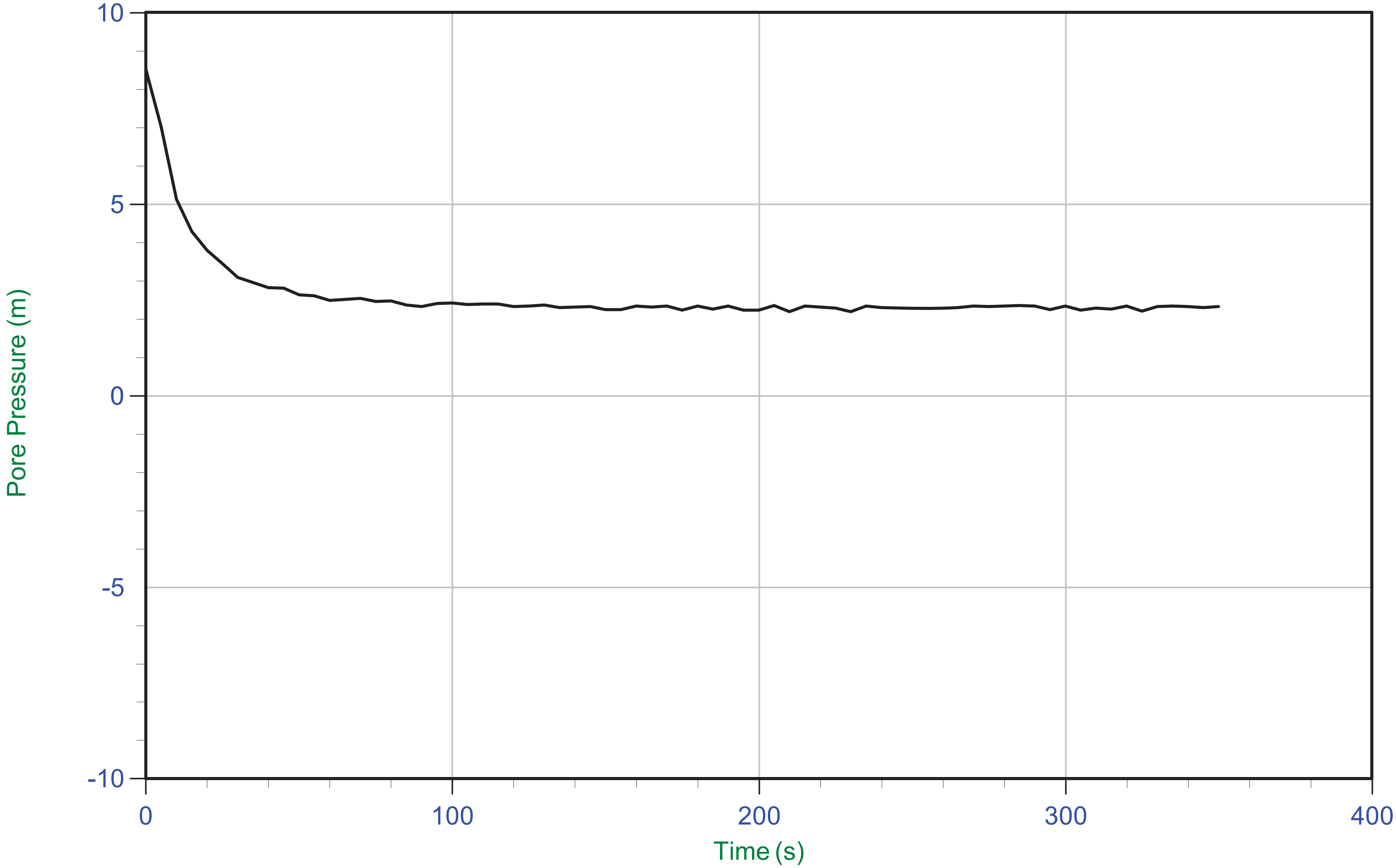
WT: 1.734 m / 5.689 ft
Ueq: 0.5 m

ConeTec

Thurber Engineering

Job No: 17-05021
Date: 05/23/2017 12:56
Site: Hwy 17 - Muskrat Creek Culvert

Sounding: SCPT17-03
Cone: 379:T1500F15U500 Area=15 cm²



Trace Summary:

Filename: 17-05021_SP03.PPF
Depth: 4.000 m / 13.123 ft
Duration: 350.0 s

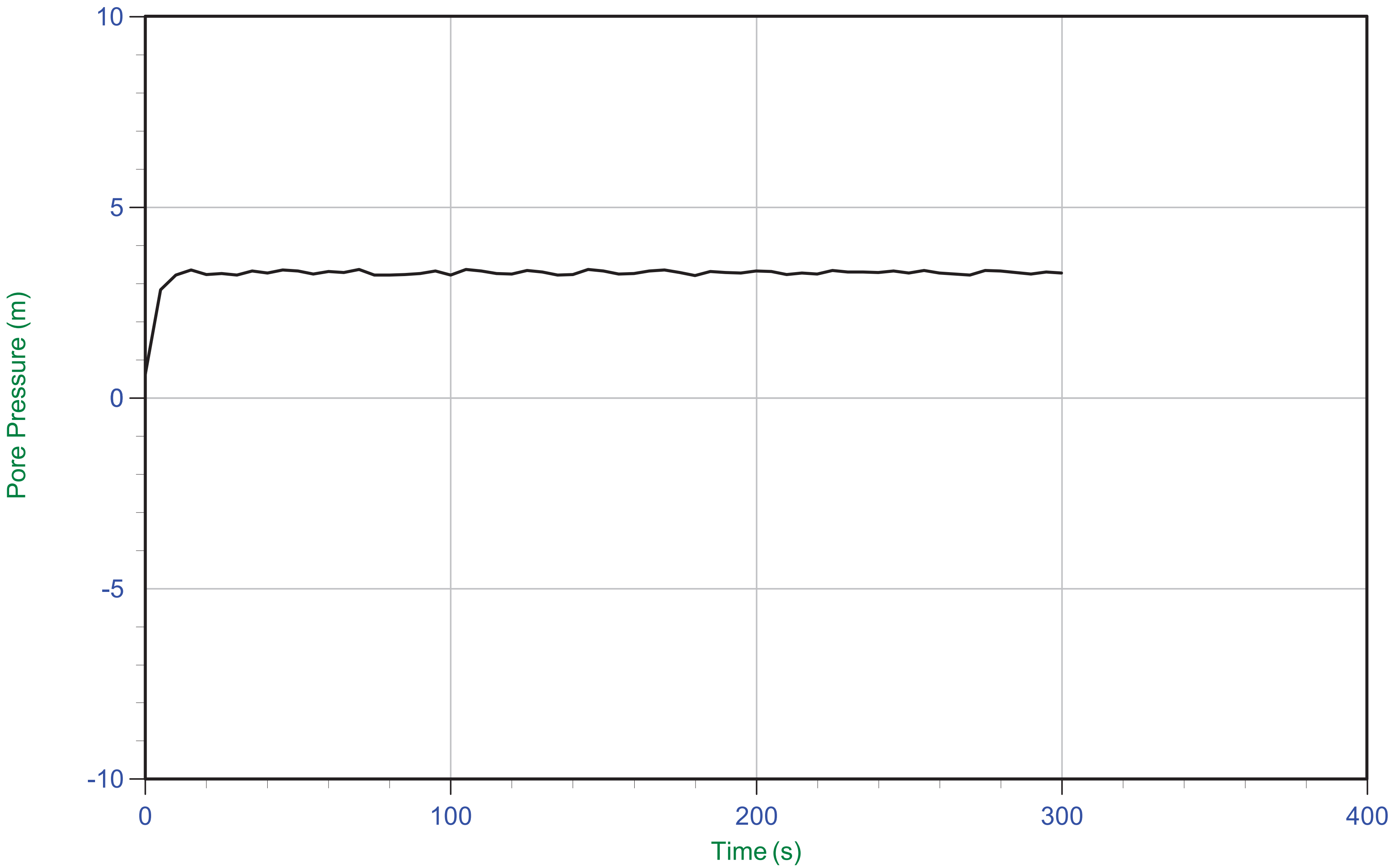
U Min: 2.2 m
U Max: 8.5 m

WT: 1.731 m / 5.679 ft
Ueq: 2.3 m

Thurber Engineering

Job No: 17-05021
Date: 05/23/2017 12:56
Site: Hwy 17 - Muskrat Creek Culvert

Sounding: SCPT17-03
Cone: 379:T1500F15U500 Area=15 cm²



Trace Summary:

Filename: 17-05021_SP03.PPF
Depth: 5.000 m / 16.404 ft
Duration: 300.0 s

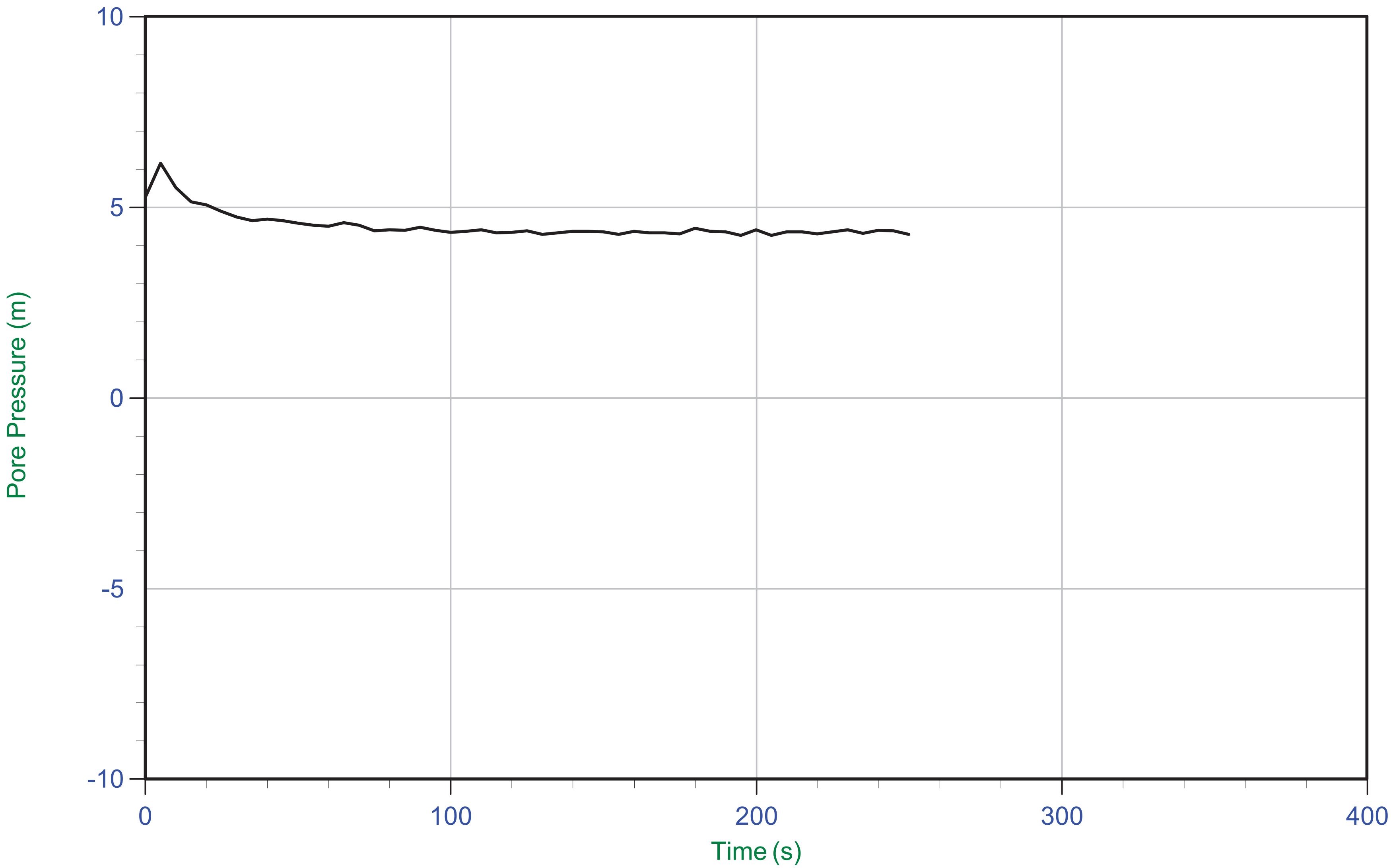
U Min: 0.6 m
U Max: 3.4 m

WT: 1.713 m / 5.620 ft
Ueq: 3.3 m

Thurber Engineering

Job No: 17-05021
Date: 05/23/2017 12:56
Site: Hwy 17 - Muskrat Creek Culvert

Sounding: SCPT17-03
Cone: 379:T1500F15U500 Area=15 cm²



Trace Summary:

Filename: 17-05021_SP03.PPF
Depth: 6.000 m / 19.685 ft
Duration: 250.0 s

U Min: 4.3 m
U Max: 6.2 m

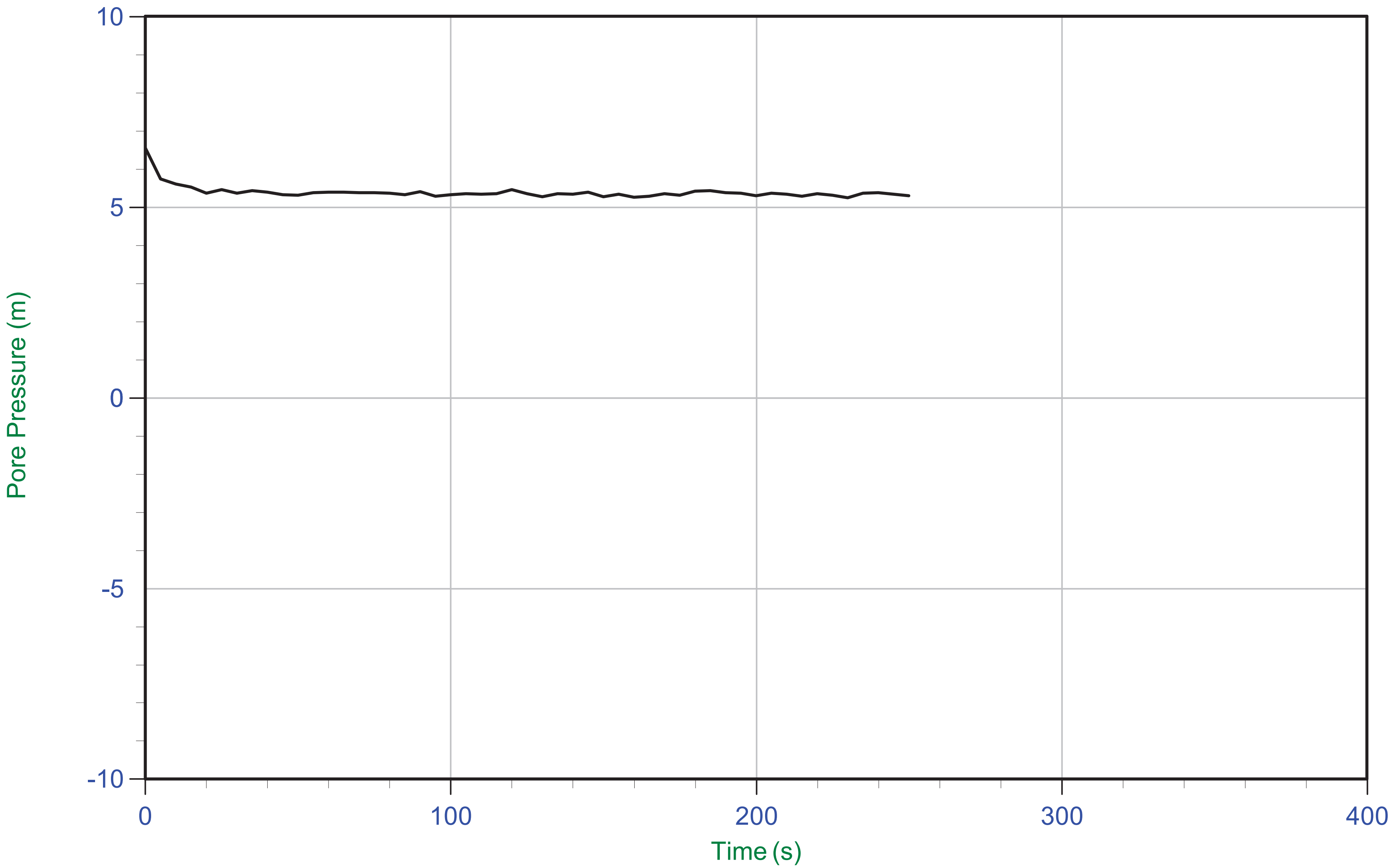
WT: 1.665 m / 5.463 ft
Ueq: 4.3 m

CONETEC

Thurber Engineering

Job No: 17-05021
Date: 05/23/2017 12:56
Site: Hwy 17 - Muskrat Creek Culvert

Sounding: SCPT17-03
Cone: 379:T1500F15U500 Area=15 cm²



Trace Summary:

Filename: 17-05021_SP03.PPF
Depth: 7.000 m / 22.966 ft
Duration: 250.0 s

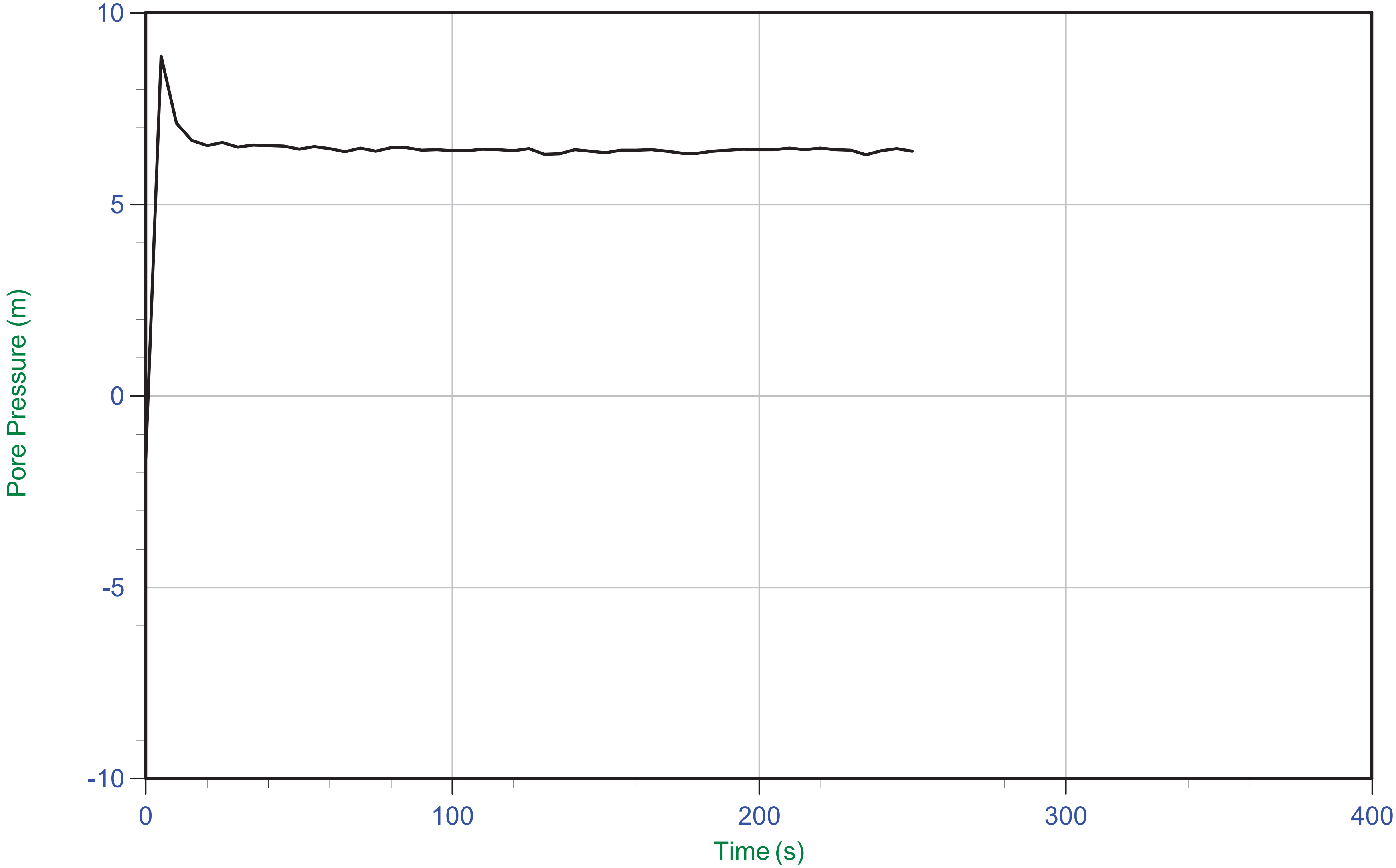
U Min: 5.3 m
U Max: 6.6 m

WT: 1.686 m / 5.531 ft
Ueq: 5.3 m

Thurber Engineering

Job No: 17-05021
Date: 05/23/2017 12:56
Site: Hwy 17 - Muskrat Creek Culvert

Sounding: SCPT17-03
Cone: 379:T1500F15U500 Area=15 cm²



Trace Summary:

Filename: 17-05021_SP03.PPF
Depth: 8.000 m / 26.246 ft
Duration: 250.0 s

U Min: -1.6 m
U Max: 8.9 m

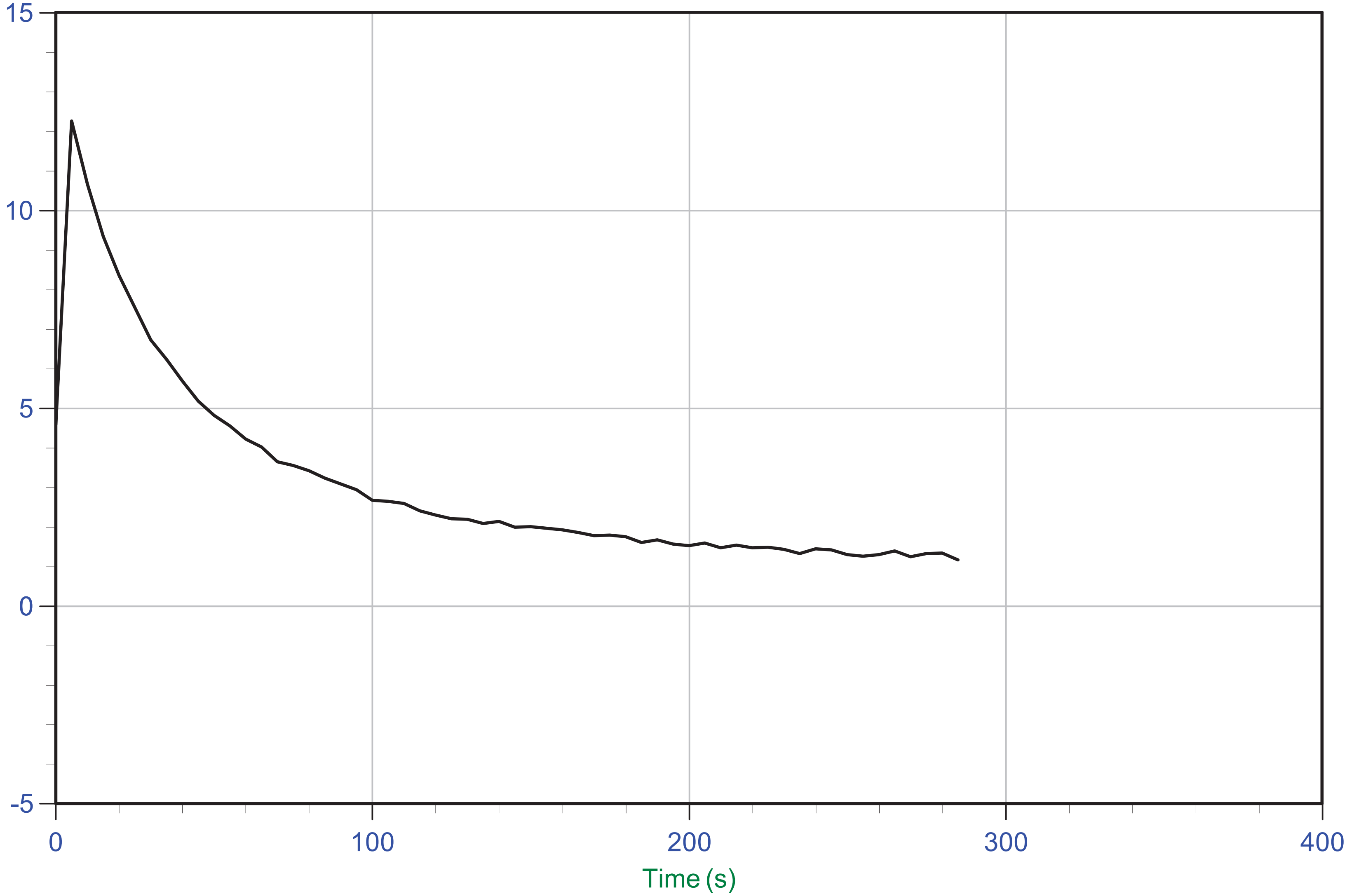
WT: 1.622 m / 5.321 ft
Ueq: 6.4 m

CONETEC

Thurber Engineering

Job No: 17-05021
Date: 05/23/2017 14:17
Site: Hwy 17 - Muskrat Creek Culvert

Sounding: SCPT17-04
Cone: 379:T1500F15U500 Area=15 cm²



Trace Summary:

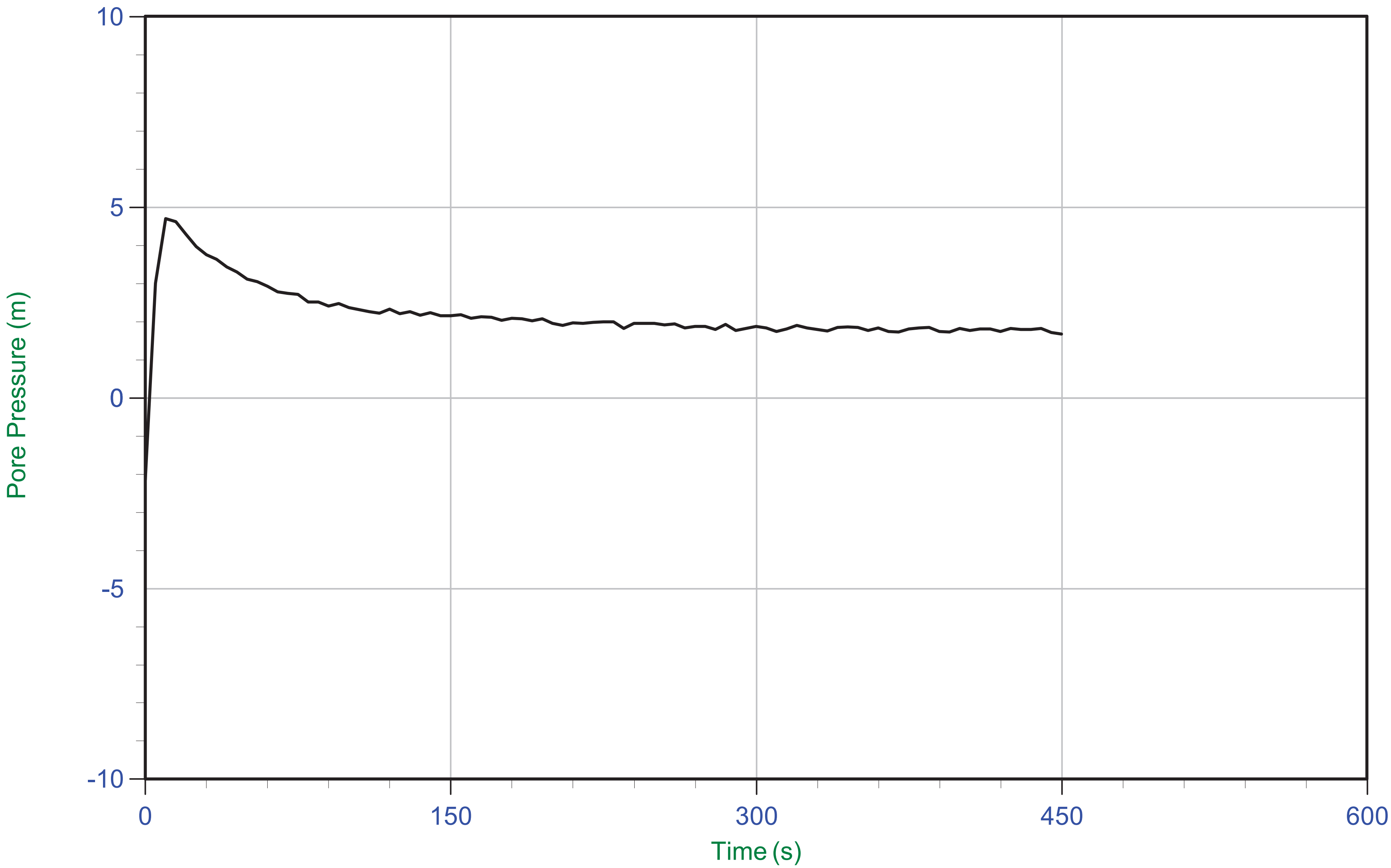
Filename: 17-05021_SP04.PPF
Depth: 2.250 m / 7.382 ft
Duration: 285.0 s

U Min: 1.2 m
U Max: 12.3 m

Thurber Engineering

Job No: 17-05021
Date: 05/23/2017 14:17
Site: Hwy 17 - Muskrat Creek Culvert

Sounding: SCPT17-04
Cone: 379:T1500F15U500 Area=15 cm²



Trace Summary:

Filename: 17-05021_SP04.PPF
Depth: 3.250 m / 10.663 ft
Duration: 450.0 s

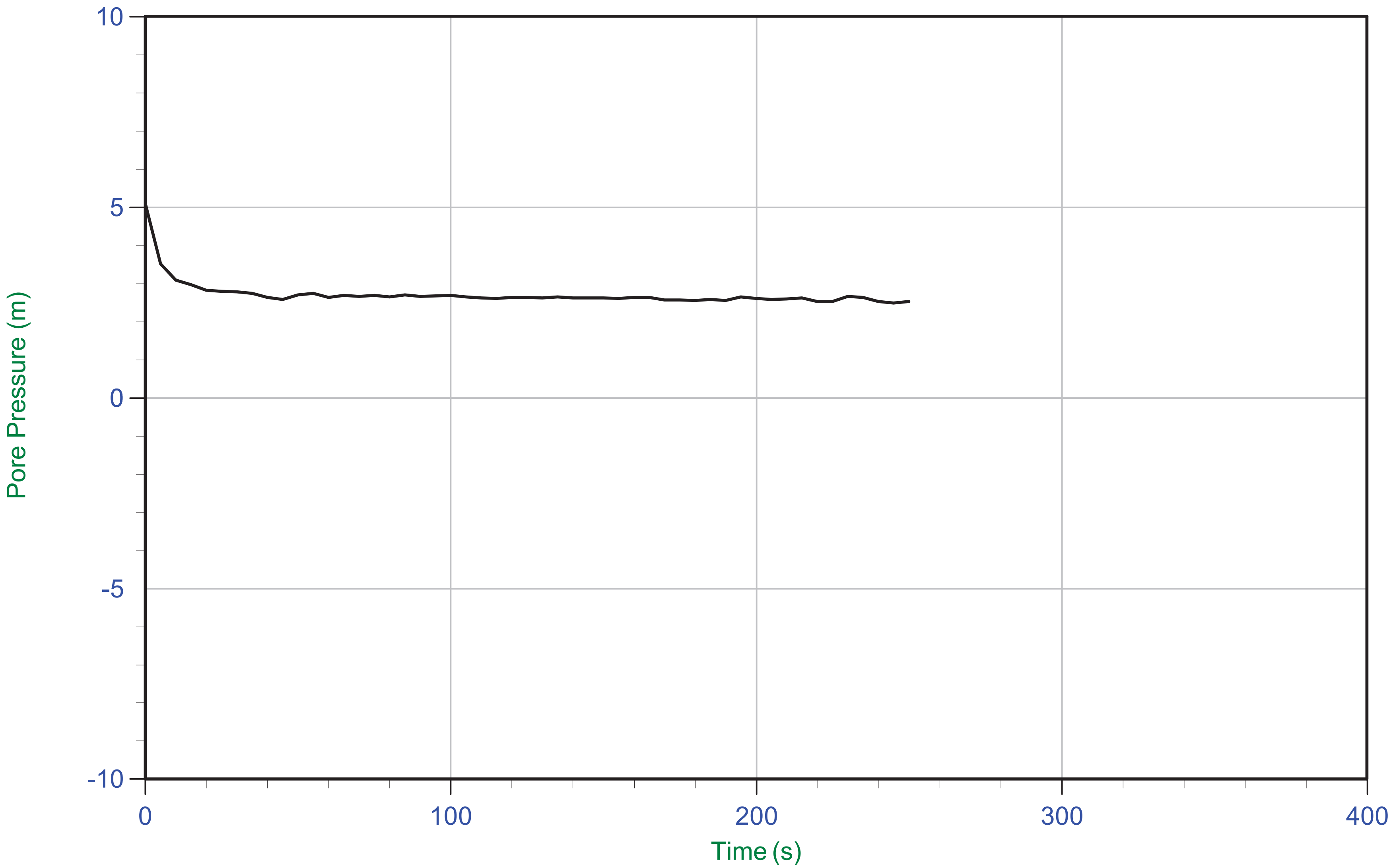
U Min: -2.2 m
U Max: 4.7 m

WT: 1.490 m / 4.888 ft
Ueq: 1.8 m

Thurber Engineering

Job No: 17-05021
Date: 05/23/2017 14:17
Site: Hwy 17 - Muskrat Creek Culvert

Sounding: SCPT17-04
Cone: 379:T1500F15U500 Area=15 cm²



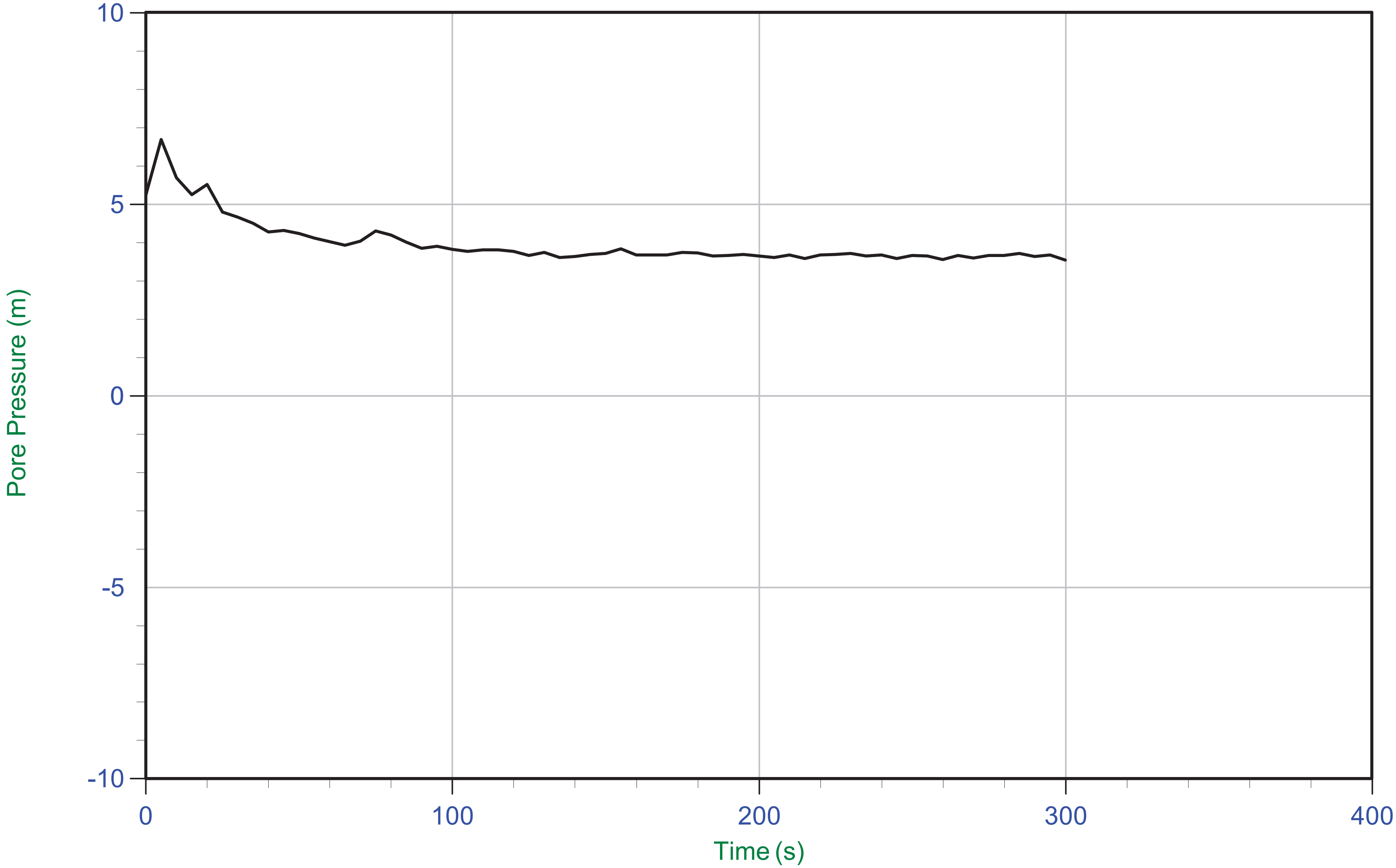
Trace Summary:

Filename: 17-05021_SP04.PPF
Depth: 4.250 m / 13.943 ft
Duration: 250.0 s

U Min: 2.5 m
U Max: 5.1 m

WT: 1.675 m / 5.495 ft
Ueq: 2.6 m

Thurber Engineering	Job No: 17-05021 Date: 05/23/2017 14:17 Site: Hwy 17 - Muskrat Creek Culvert	Sounding: SCPT17-04 Cone: 379:T1500F15U500 Area=15 cm²



Trace Summary:

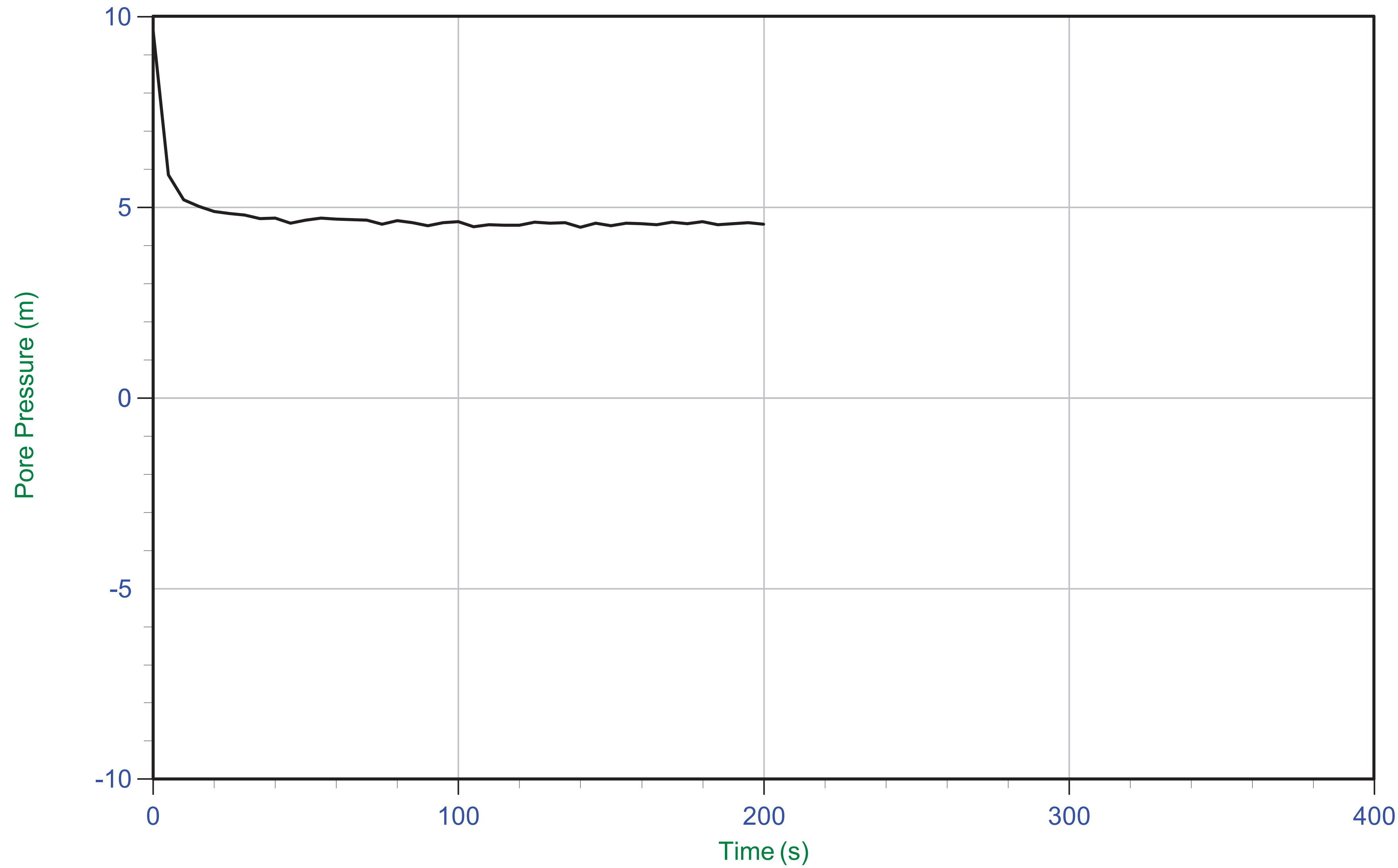
Filename: 17-05021_SP04.PPF	U Min: 3.5 m	WT: 1.635 m / 5.364 ft
Depth: 5.250 m / 17.224 ft	U Max: 6.7 m	Ueq: 3.6 m
Duration: 300.0 s		

ConeTec

Thurber Engineering

Job No: 17-05021
Date: 05/23/2017 14:17
Site: Hwy 17 - Muskrat Creek Culvert

Sounding: SCPT17-04
Cone: 379:T1500F15U500 Area=15 cm²



Trace Summary:

Filename: 17-05021_SP04.PPF
Depth: 6.250 m / 20.505 ft
Duration: 200.0 s

U Min: 4.5 m
U Max: 9.6 m

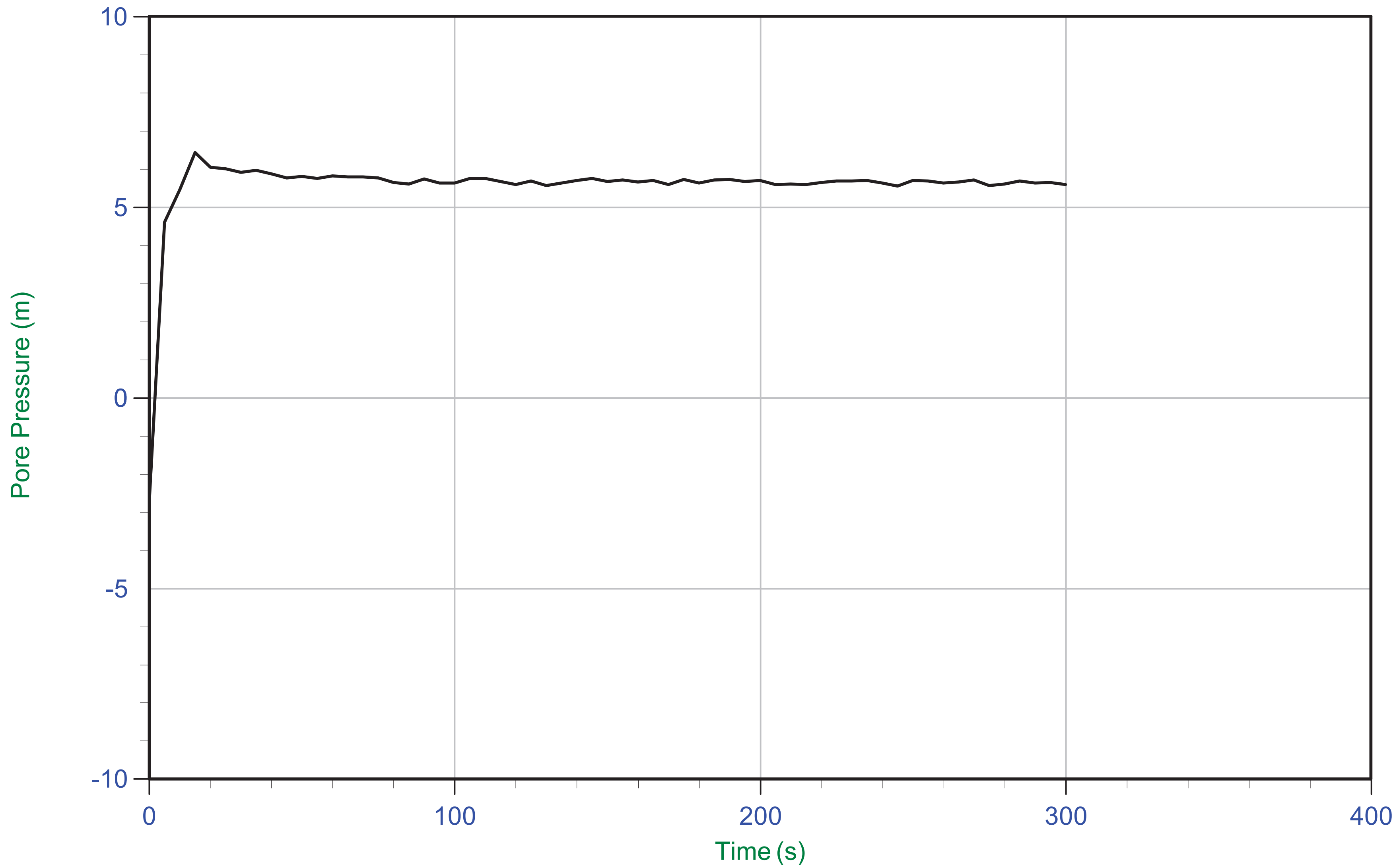
WT: 1.684 m / 5.525 ft
Ueq: 4.6 m

CONETEC

Thurber Engineering

Job No: 17-05021
Date: 05/23/2017 14:17
Site: Hwy 17 - Muskrat Creek Culvert

Sounding: SCPT17-04
Cone: 379:T1500F15U500 Area=15 cm²



Trace Summary:

Filename: 17-05021_SP04.PPF
Depth: 7.300 m / 23.950 ft
Duration: 300.0 s

U Min: -2.7 m
U Max: 6.4 m

WT: 1.667 m / 5.469 ft
Ueq: 5.6 m

Appendix C

General Arrangement Drawing of Muskrat Creek Culvert

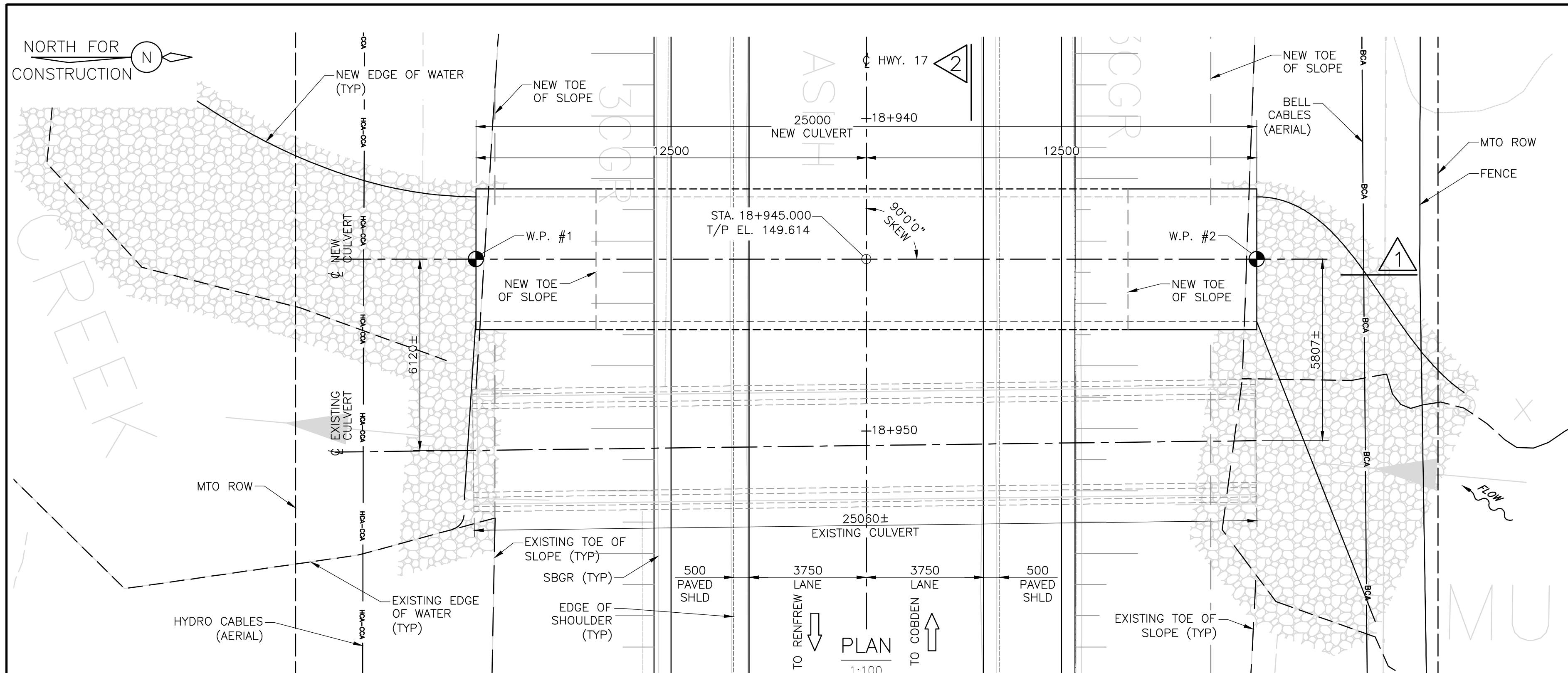
METRIC
DIMENSIONS ARE IN METRES AND/OR MILLIMETRES UNLESS OTHERWISE SHOWN

wood.

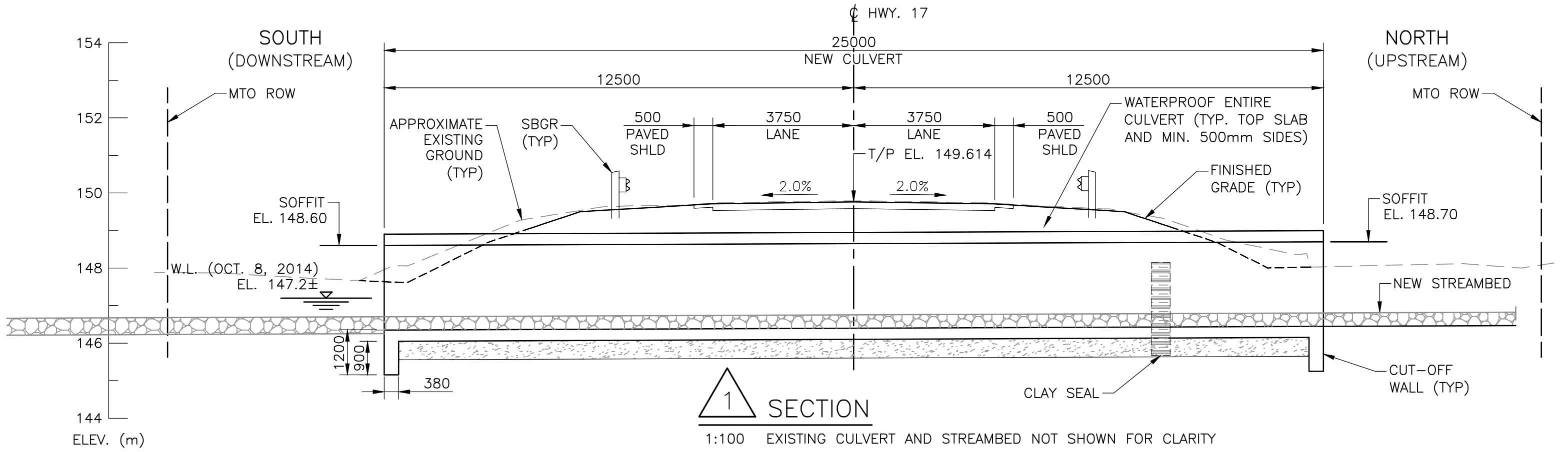
DIST	
CONT No	2018–4013
WP No	4113–01–01

MUSKRAT CREEK CULVERT
SITE NO. 29–232/C
GENERAL ARRANGEMENT

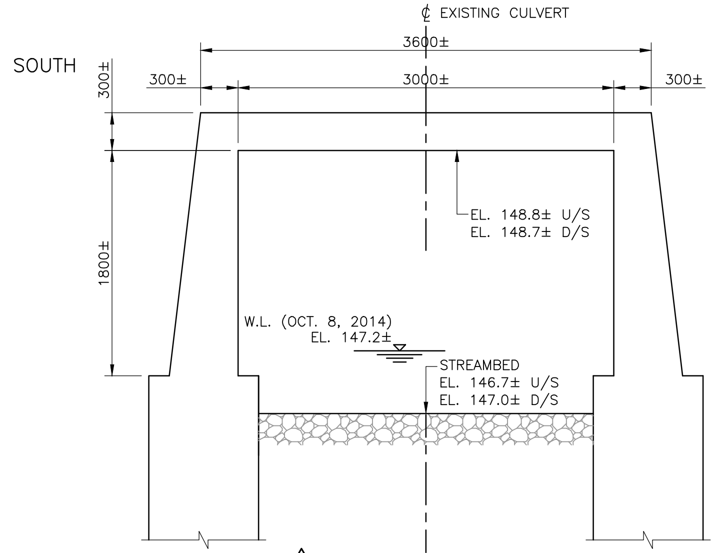
SHEET S1



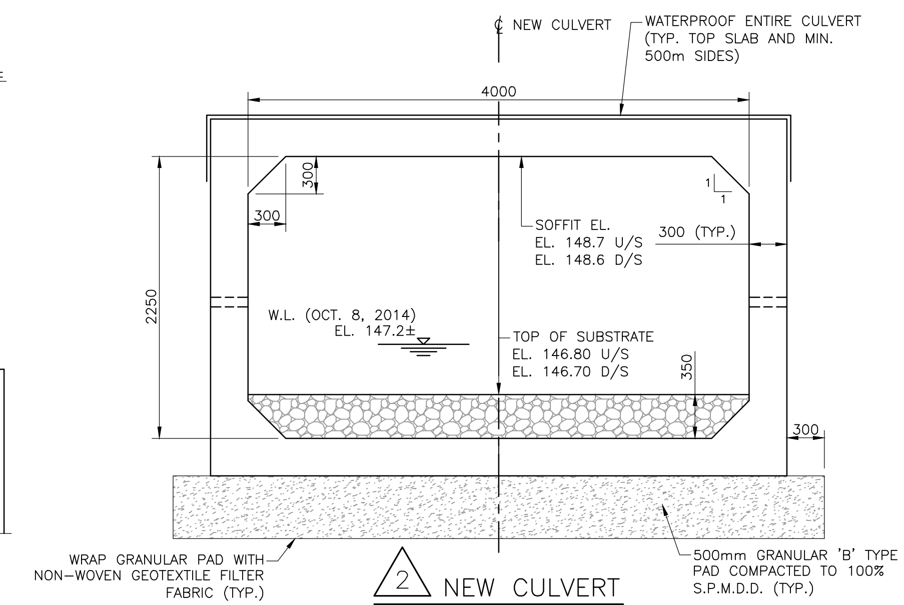
PLAN
1:100



1 SECTION
1:100 EXISTING CULVERT AND STREAMBED NOT SHOWN FOR CLARITY



2 EXISTING CULVERT
1:30

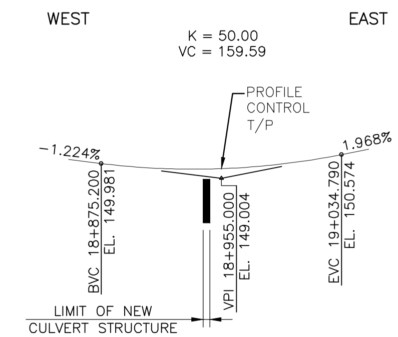


2 NEW CULVERT
1:30

SUBSTRATE RIVERSTONE GRADATION	
% PASSING	STONE DIA. (mm)
100	225
75	200
50	150
30	75
20 (MIN)*	GRANULAR "A"

*FILL ALL VOIDS WITH GRANULAR "A"

W.P. No.	NORTHING	EASTING
1	5049709.163	278927.676
2	5049724.571	278947.364



PROFILE OF HIGHWAY 17
N.T.S.

SCOPE OF WORK:

THE FOLLOWING SCOPE OF WORK IS NOT INTENDED TO BE AN EXHAUSTIVE LIST OF ALL ITEMS REQUIRED TO COMPLETE THE REHABILITATION WORK, NOR IS IT INTENDED TO PROVIDE A SEQUENCE OF CONSTRUCTION ACTIVITIES.

STAGE 1:

1. INSTALL ENVIRONMENTAL PROTECTION, TEMPORARY CONCRETE BARRIERS AND TRAFFIC CONTROL MEASURES. TEMPORARILY WIDEN SHOULDERS AND PAVE ROADWAY.
2. INSTALL TEMPORARY PROTECTION SYSTEM ON THE NORTH PORTION OF THE NEW CULVERT.

STAGE 2:

3. DETOUR TRAFFIC TO NORTH SIDE OF THE STRUCTURE.
4. INSTALL PROTECTION SYSTEMS, COFFERDAMS, AND TEMPORARY FLOW PASSAGE SYSTEMS AND TEMPORARY SUPPORTS AS REQUIRED.
5. REMOVE EXISTING ASPHALT, EXCAVATE FOR NEW CULVERT CONSTRUCTION.
6. INSTALL BEDDING AND CONSTRUCT SOUTH PORTION OF NEW CULVERT.
7. BACKFILL CULVERT, GRADE, TEMPORARILY WIDEN SHOULDERS AND PAVE ROADWAY.

STAGE 3:

8. RELOCATE TEMPORARY CONCRETE BARRIERS AND DETOUR TRAFFIC TO SOUTH SIDE OF STRUCTURE.
9. REPEAT STEPS 4 TO 7 FOR THE NORTH PORTIONS OF THE EXISTING AND NEW CULVERT.
10. BACKFILL CULVERT.

STAGE 4:

11. INSTALL SUBSTRATE RIVERSTONE AND REALIGN CREEK INTO NEW CULVERT.
12. REMOVE TEMPORARY FLOW PASSAGE SYSTEM AND INFILL EXISTING CULVERT.
13. REMOVE PROTECTION SYSTEM AND REMOVE TEMPORARY WIDENINGS. PAVE ROADWAY.
14. REMOVE TRAFFIC CONTROL MEASURES, ASSOCIATED ENVIRONMENTAL PROTECTION MEASURES AND OPEN ROADWAY TO NORMAL TRAFFIC.

GENERAL NOTES:

1. CLASS OF CONCRETE

   CLASS OF CONCRETE SHALL BE 30 MPa.

2. CLEAR COVER TO REINFORCING STEEL

BOTTOM OF TOP SLAB	40 ±10
BOTTOM OF BOTTOM SLAB	100 ±25
REMAINDER	60 ±20 UNLESS OTHERWISE NOTED

3. REINFORCING STEEL

   REINFORCING STEEL SHALL BE GRADE 400W, UNLESS OTHERWISE SPECIFIED.

   UNLESS SHOWN OTHERWISE, TENSION LAP SPLICES SHALL BE CLASS B.

   BAR HOOKS SHALL HAVE STANDARD HOOK DIMENSIONS USING MINIMUM BEND DIAMETERS, WHILE STIRRUPS AND TIES SHALL HAVE MINIMUM HOOK DIMENSIONS. ALL HOOKS SHALL BE IN ACCORDANCE WITH THE STRUCTURAL STANDARD DRAWING SS12–1 UNLESS INDICATED OTHERWISE.

CONSTRUCTION NOTES:

1. THE CONTRACTOR SHALL VERIFY ALL DIMENSIONS AND ELEVATIONS OF THE EXISTING STRUCTURE AND ALL DETAILS ON SITE.
2. THE CONTRACTOR IS RESPONSIBLE FOR THE DESIGN AND INSTALLATION OF ALL TEMPORARY STRUCTURES, CONSTRUCTION PLATFORMS AND DEBRIS CONTAINMENT SYSTEMS ETC.
3. ALL ELEVATIONS ARE TO GEODETIC DATUM.
4. BACKFILL SHALL BE PLACED SIMULTANEOUSLY BEHIND BOTH SIDES OF CULVERT KEEPING THE HEIGHT OF THE BACKFILL APPROXIMATELY THE SAME. AT NO TIME SHALL THE DIFFERENCE IN ELEVATION BE GREATER THAN 500mm.
5. UTILITIES SHOWN ON DRAWING ARE REPRESENTATIVE ONLY. CONTRACTOR TO PERFORM LOCATES.
6. THE CONTRACTOR SHALL DESIGN PROTECTION SYSTEMS AND TEMPORARY FLOW PASSAGE SYSTEMS TO PERMIT EXCAVATION, REMOVAL AND RECONSTRUCTION OF THE CULVERT, BACKFILLING OPERATIONS AND AS REQUIRED TO COMPLETE THE WORK. THE CONTRACTOR SHALL BE RESPONSIBLE FOR ALL REQUIRED LENGTH AND DEPTH OF ALL PROTECTION SYSTEMS.
7. DURING STAGED CONSTRUCTION OF THE NEW CULVERT, CONTRACTOR SHALL EXCAVATE MINIMUM 1.5m OF FILL ALONG THE EAST SIDE OF EXISTING CULVERT TO PREVENT MOVEMENT OF EXISTING CULVERT DUE TO UNBALANCED LOADING.
8. TOP OF CLAY SEAL TO BE 300mm ABOVE 2 YEAR STORM WATER LEVEL.

APPLICABLE STANDARD DRAWINGS:

OPSD 3101.150	WALLS ABUTMENT, BACKFILL MINIMUM GRANULAR REQUIREMENTS
OPSD 3102.100	WALL ABUTMENT BACKFILL DRAIN
OPSD 3941.200	FIGURES IN CONCRETE, SITE NUMBER AND DATE LAYOUT

LIST OF DRAWINGS:

S1 – GENERAL ARRANGEMENT
S2 – BOREHOLE LOCATION AND SOIL STRATA
S3 – CONSTRUCTION STAGING
S4 – CULVERT DETAILS AND REINFORCEMENT
S5 – EROSION AND SEDIMENT CONTROL

LIST OF ABBREVIATIONS

D/S	DENOTES DOWNSTREAM
SHLD	DENOTES SHOULDER
C.J.	DENOTES CONSTRUCTION JOINT
U/S	DENOTES UPSTREAM
W.P.	DENOTES WORK POINT
W.L.	DENOTES WATER LEVEL
T/P	DENOTES TOP OF PAVEMENT

PRELIMINARY
NOT TO BE USED FOR CONSTRUCTION

DRAWING NOT TO BE SCALED
100mm ON ORIGINAL DRAWING

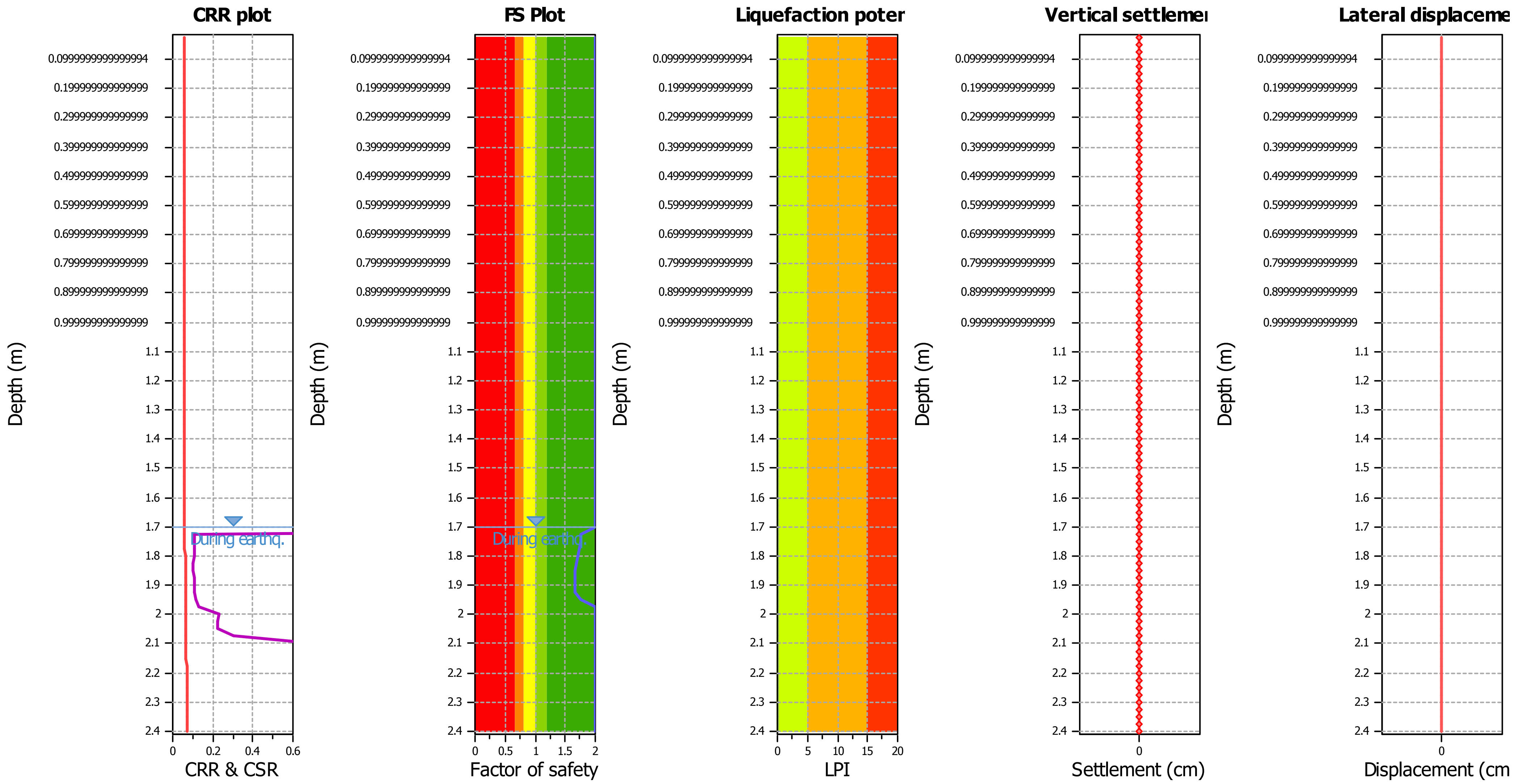
REVISIONS

DESIGN: NK	CHK: NT	CODE CAN/CSA S6–14	LOAD CL–625–ONT	DATE: JULY 2019	
DRAWN: PB	CHK: KA	SITE 29–232/C	STRUCT	SCHEME	DWG: S1

Appendix D

Liquefaction and Slope Stability Analyses Results

Liquefaction analysis overall plots



Input parameters and analysis data

Analysis method:	NCEER (1998)	Depth to water table (erthq.):	1.70 m	Fill weight:	N/A
Fines correction method:	NCEER (1998)	Average results interval:	3	Transition detect. applied:	No
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	7.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sands only
Peak ground acceleration:	0.11	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	1.70 m	Fill height:	N/A	Limit depth:	N/A

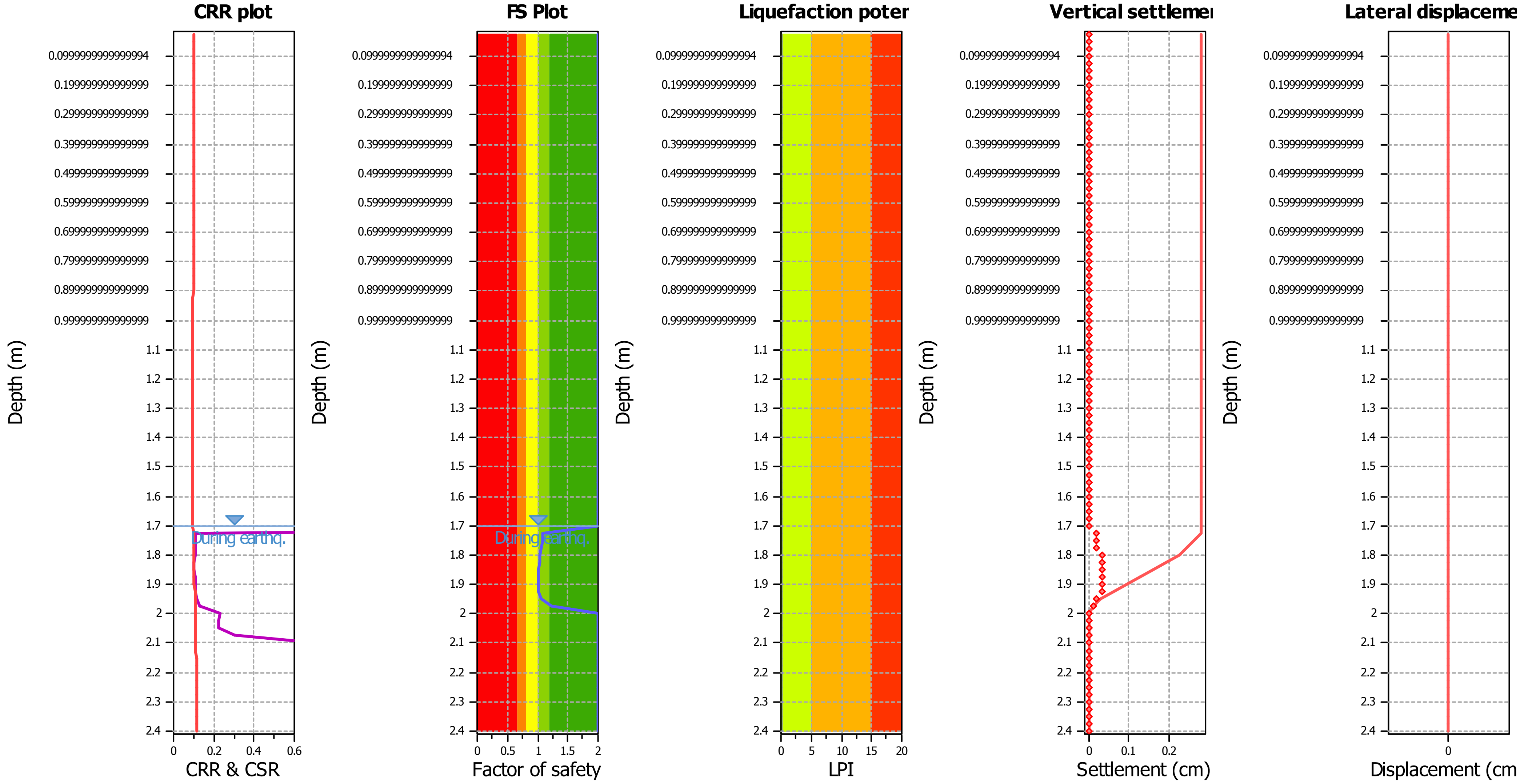
F.S. color scheme

- Almost certain it will liquefy
- Very likely to liquefy
- Liquefaction and no liq. are equally likely
- Unlike to liquefy
- Almost certain it will not liquefy

LPI color scheme

- Very high risk
- High risk
- Low risk

Liquefaction analysis overall plots



Input parameters and analysis data

Analysis method:	NCEER (1998)	Depth to water table (erthq.):	1.70 m	Fill weight:	N/A
Fines correction method:	NCEER (1998)	Average results interval:	3	Transition detect. applied:	No
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	7.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sands only
Peak ground acceleration:	0.18	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	1.70 m	Fill height:	N/A	Limit depth:	N/A

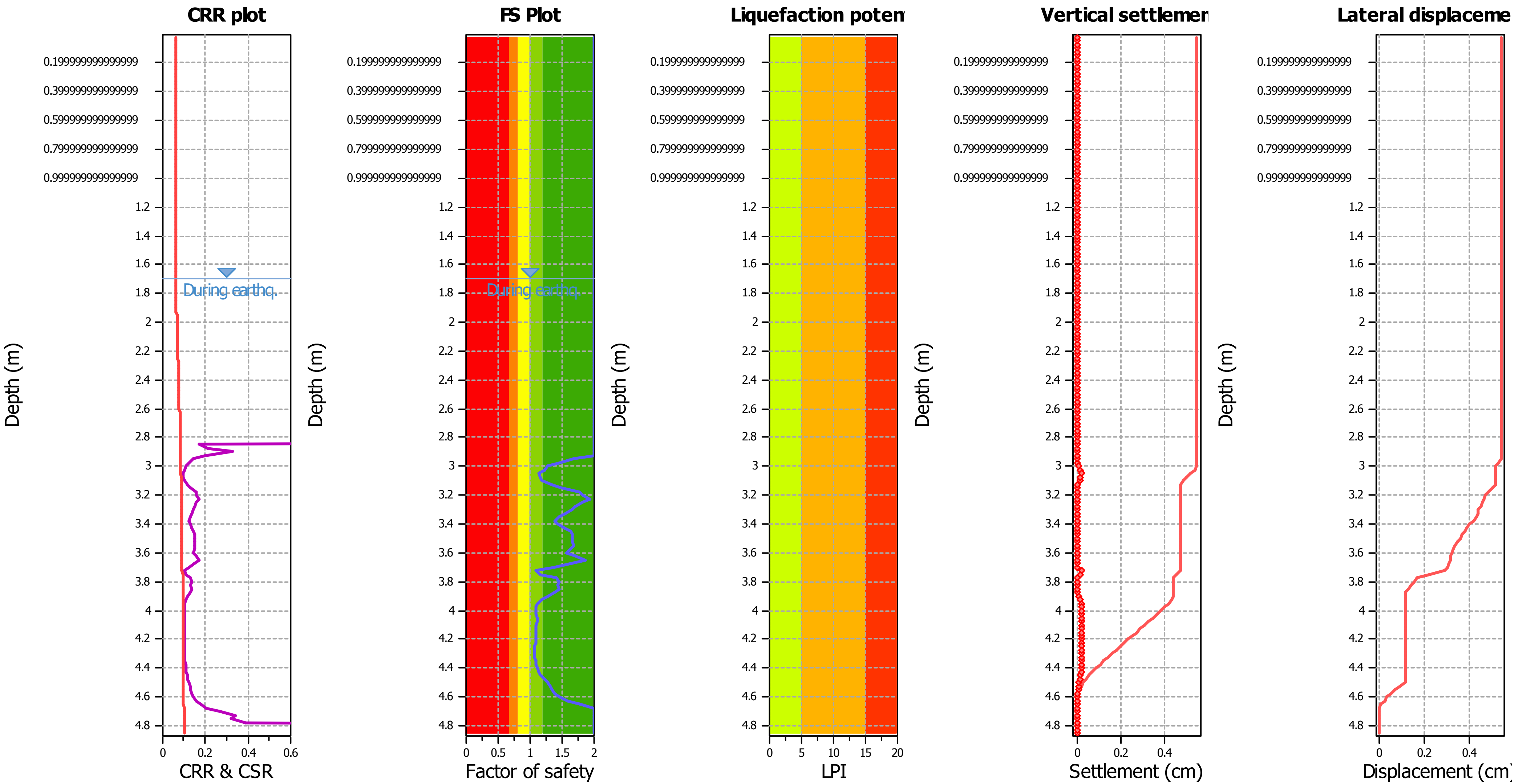
F.S. color scheme

- Almost certain it will liquefy
- Very likely to liquefy
- Liquefaction and no liq. are equally likely
- Unlike to liquefy
- Almost certain it will not liquefy

LPI color scheme

- Very high risk
- High risk
- Low risk

Liquefaction analysis overall plots



Input parameters and analysis data

Analysis method:	NCEER (1998)	Depth to water table (erthq.):	1.70 m	Fill weight:	N/A
Fines correction method:	NCEER (1998)	Average results interval:	3	Transition detect. applied:	No
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	7.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sands only
Peak ground acceleration:	0.11	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	1.70 m	Fill height:	N/A	Limit depth:	N/A

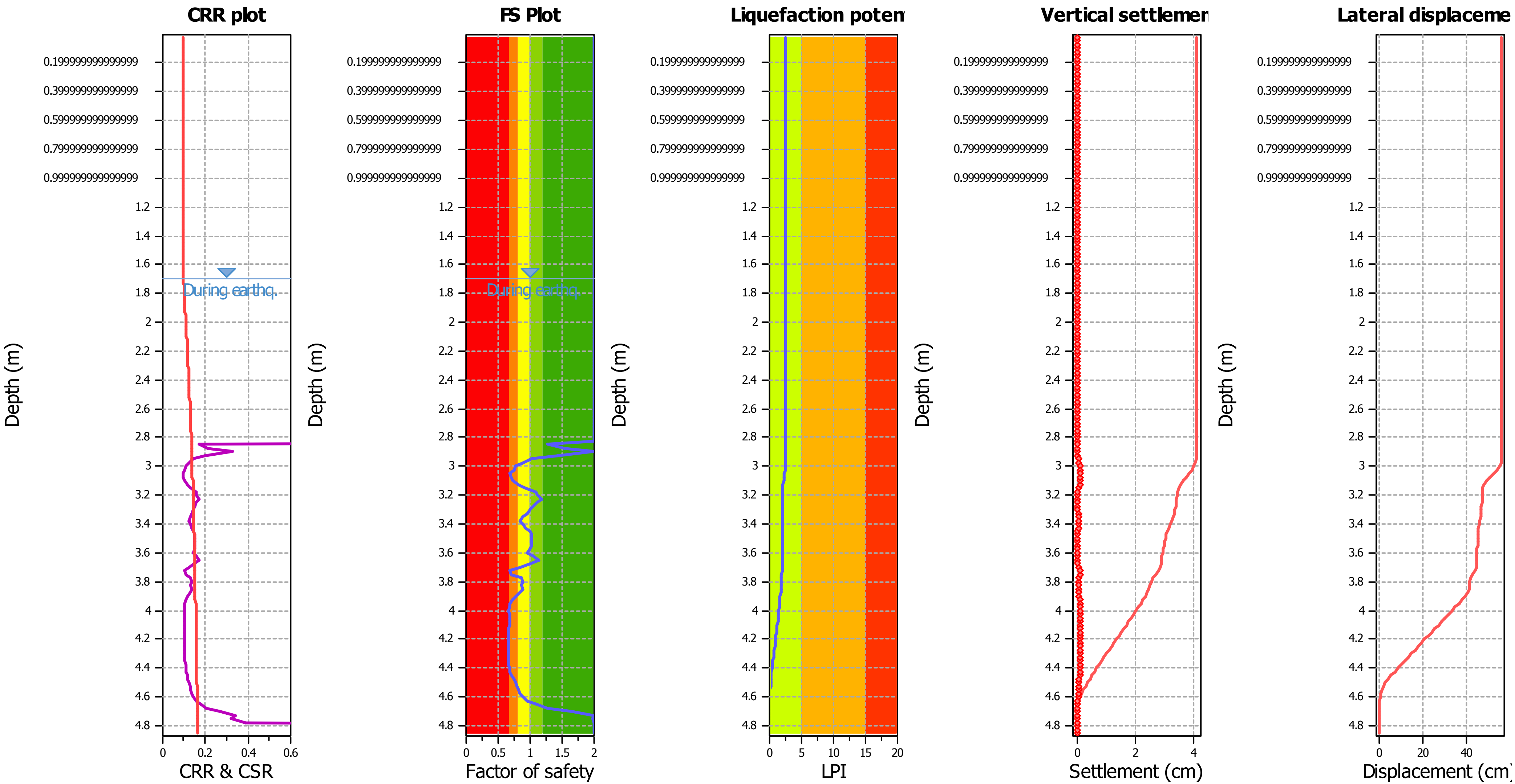
F.S. color scheme

- Almost certain it will liquefy
- Very likely to liquefy
- Liquefaction and no liq. are equally likely
- Unlike to liquefy
- Almost certain it will not liquefy

LPI color scheme

- Very high risk
- High risk
- Low risk

Liquefaction analysis overall plots



Input parameters and analysis data

Analysis method:	NCEER (1998)	Depth to water table (erthq.):	1.70 m	Fill weight:	N/A
Fines correction method:	NCEER (1998)	Average results interval:	3	Transition detect. applied:	No
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	7.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sands only
Peak ground acceleration:	0.18	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	1.70 m	Fill height:	N/A	Limit depth:	N/A

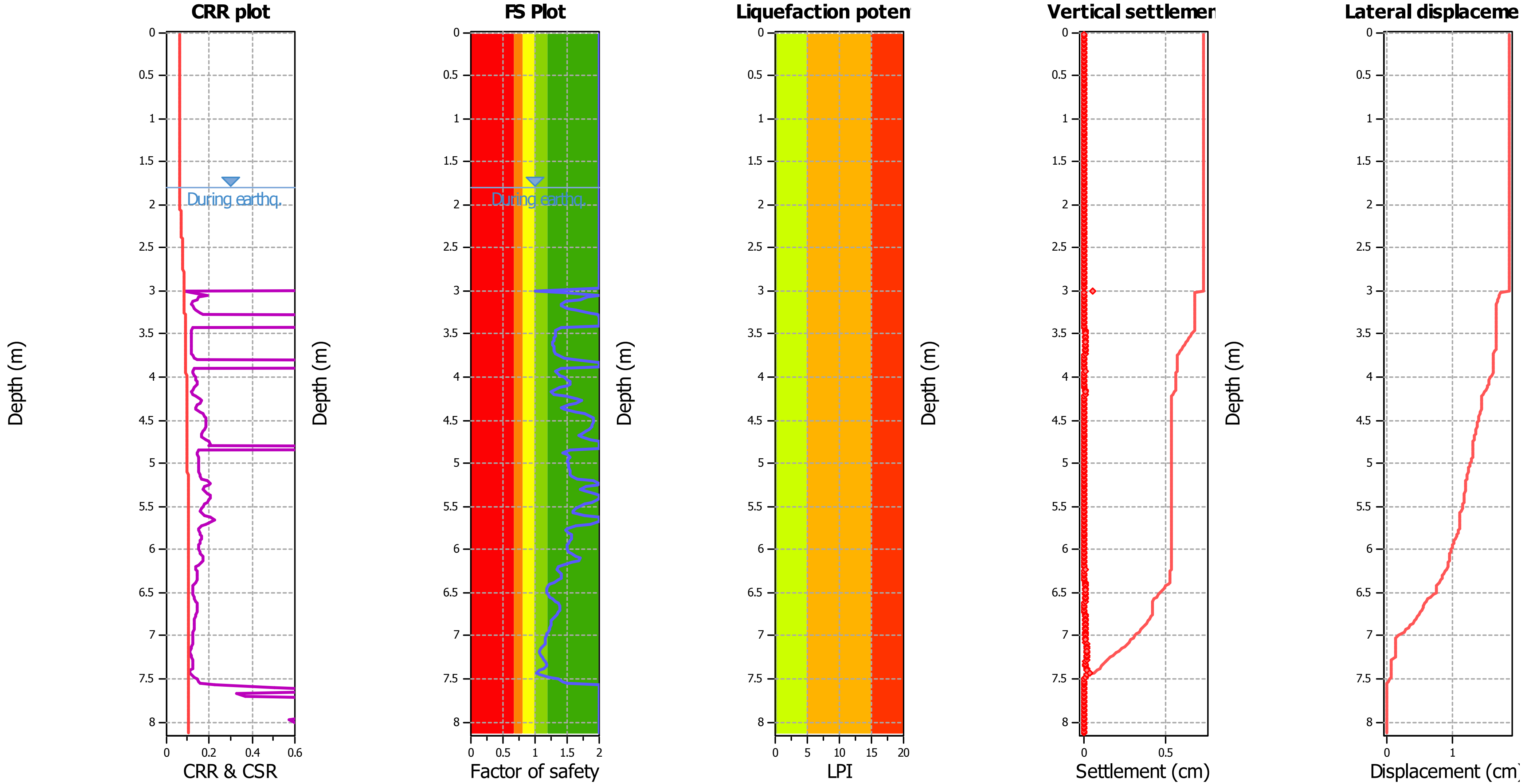
F.S. color scheme

- Almost certain it will liquefy
- Very likely to liquefy
- Liquefaction and no liq. are equally likely
- Unlike to liquefy
- Almost certain it will not liquefy

LPI color scheme

- Very high risk
- High risk
- Low risk

Liquefaction analysis overall plots



Input parameters and analysis data

Analysis method:	NCEER (1998)	Depth to water table (erthq.):	1.80 m	Fill weight:	N/A
Fines correction method:	NCEER (1998)	Average results interval:	3	Transition detect. applied:	No
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	7.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sands only
Peak ground acceleration:	0.11	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	1.80 m	Fill height:	N/A	Limit depth:	N/A

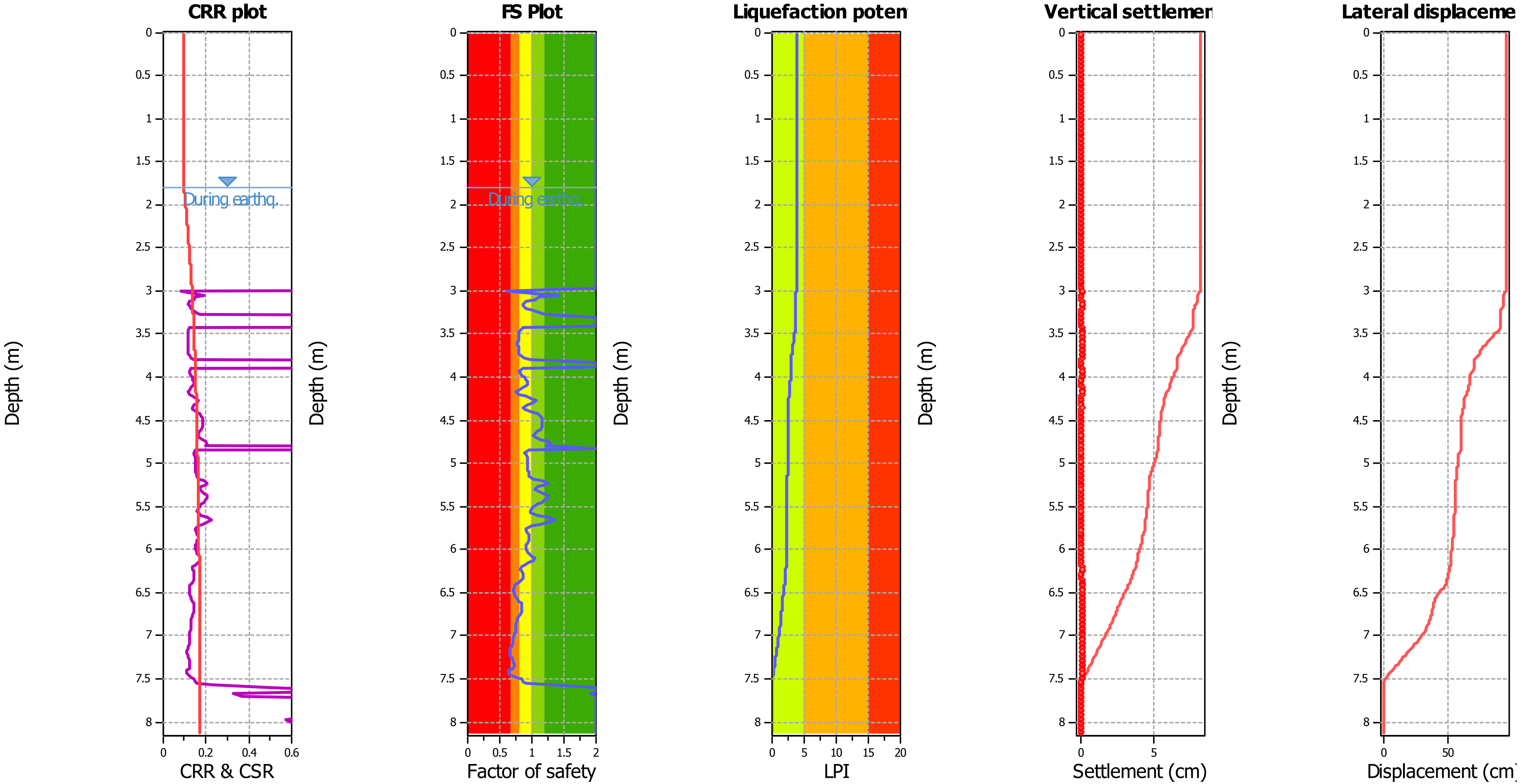
F.S. color scheme

- Almost certain it will liquefy
- Very likely to liquefy
- Liquefaction and no liq. are equally likely
- Unlike to liquefy
- Almost certain it will not liquefy

LPI color scheme

- Very high risk
- High risk
- Low risk

Liquefaction analysis overall plots



Input parameters and analysis data

Analysis method:	NCEER (1998)	Depth to water table (erthq.):	1.80 m	Fill weight:	N/A
Fines correction method:	NCEER (1998)	Average results interval:	3	Transition detect. applied:	No
Points to test:	Based on Ic value	Ic cut-off value:	2.60	K_σ applied:	Yes
Earthquake magnitude M_w:	7.00	Unit weight calculation:	Based on SBT	Clay like behavior applied:	Sands only
Peak ground acceleration:	0.18	Use fill:	No	Limit depth applied:	No
Depth to water table (insitu):	1.80 m	Fill height:	N/A	Limit depth:	N/A

F.S. color scheme

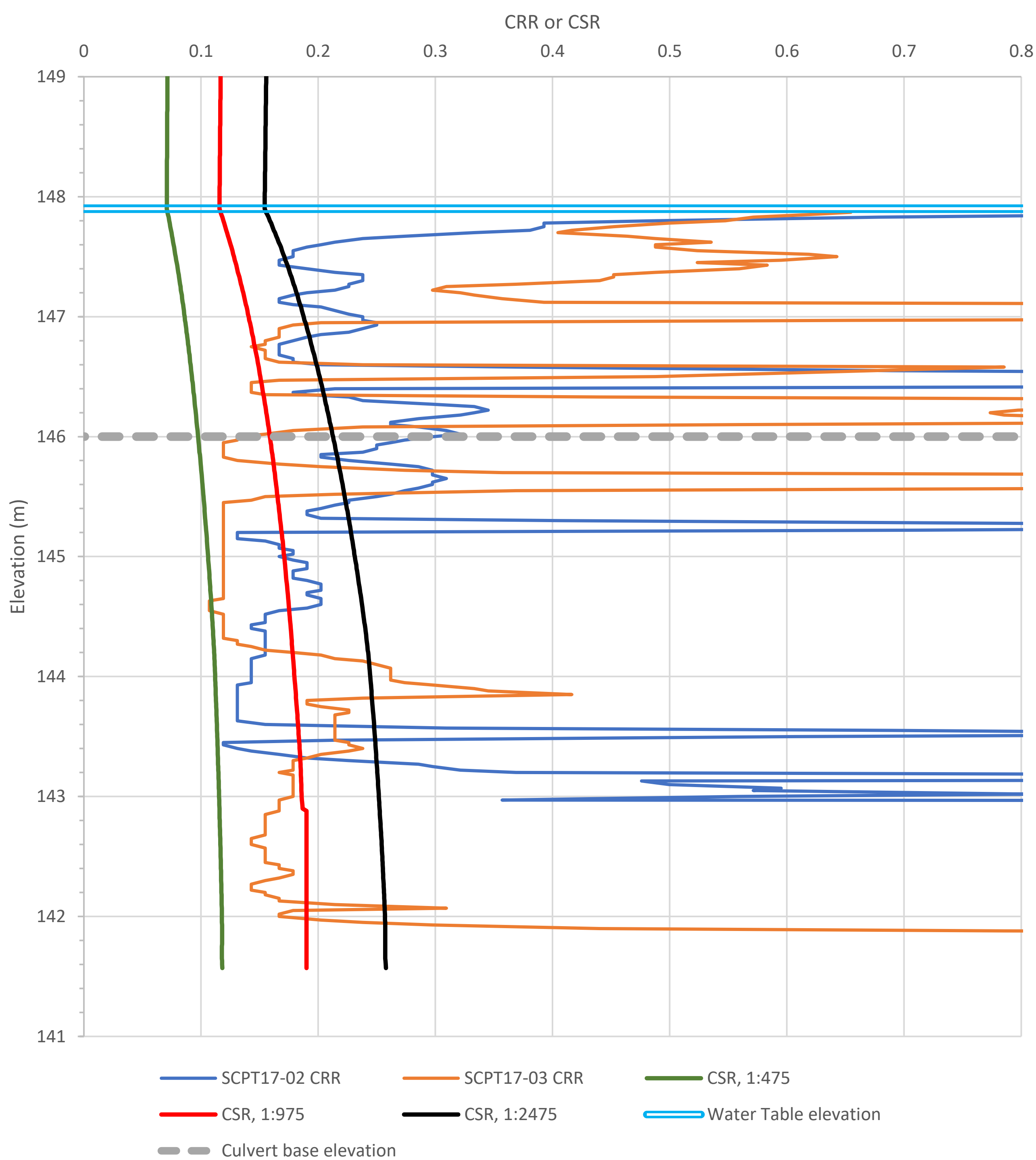
- Almost certain it will liquefy
- Very likely to liquefy
- Liquefaction and no liq. are equally likely
- Unlike to liquefy
- Almost certain it will not liquefy

LPI color scheme

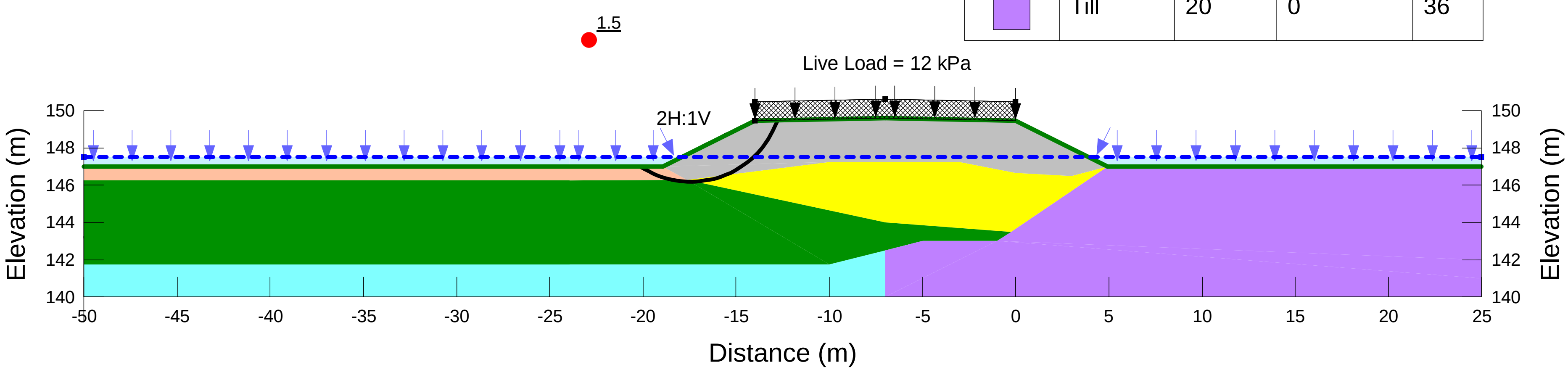
- Very high risk
- High risk
- Low risk

THURBER

Figure 1: Comparison of CRR to CSR for 1:475, 1:975 and 1:2475 return period earthquake



Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Bedrock			
	Fill	20	0	32
	Road Fill	21	0	34
	Sand	18	0	28
	Silt	17	0	28
	Till	20	0	36



Title: Muskrat Culvet_Embankment_Static

Slope Stability Analysis_Static

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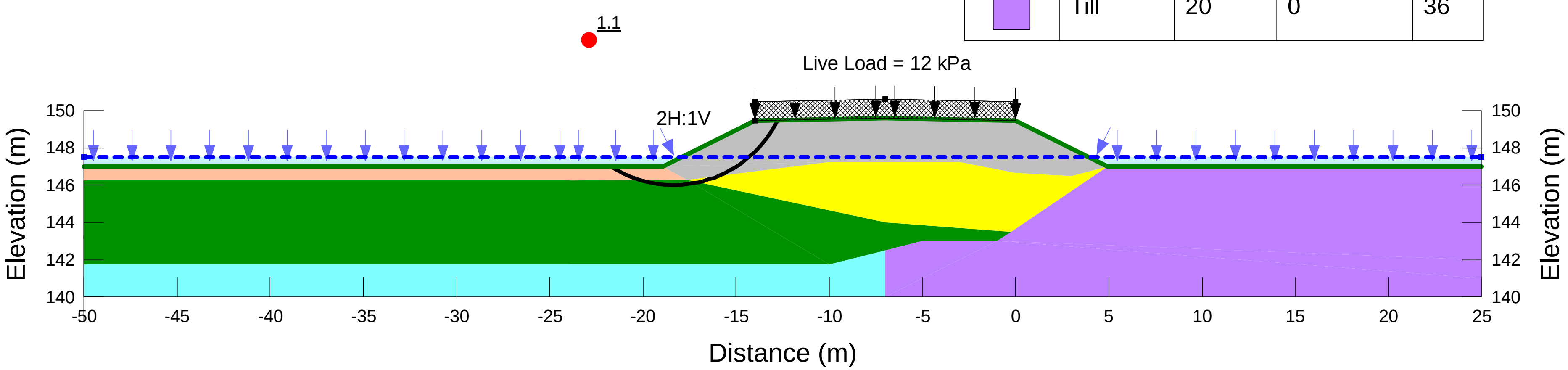
Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Bedrock			
	Fill	20	0	32
	Road Fill	21	0	34
	Sand	18	0	28
	Silt	17	0	28
	Till	20	0	36



Title: Muskrat Culvet_Embankment_Seismic

Slope Stability Analysis_Seismic

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Muskrat Creek Culvert-Rev0.gsz

1:341