Presentation of Site Investigation Results

B27D-B1 B27A-B327F-B1

APPLIED RESEARCH & INNOVATION BRANCH

Prepared by: ConeTec Inc.

COLORADO
Department of Transportation

PRESENTATION OF SITE INVESTIGATION RESULTS

CDOT Research Project

Prepared for:

Colorado Department of Transportation

ConeTec Job No: 21-52-23158

Project Start Date: 2021-Oct-18
Project End Date: 2021-Oct-20
Report Date: 2021-Oct-28

Prepared by:

ConeTec Inc.

3750 West 500 South, Salt Lake City, UT 84104

Tel: (801) 973-3801

Fax: (801) 973-3802

ConeTecSLC@conetec.com

www.conetec.com
www.conetecdataservices.com

ABOUT THIS REPORT

The enclosed report presents the results of the site investigation program conducted by ConeTec, Inc. The program consisted of Piezocone Penetration Testing and Pore Pressure Dissipation Testing. Please note that this report, which also includes all accompanying data, are subject to the 3rd Party Disclaimer and Client Disclaimer that follow in the 'Limitations' section of this report.

Project Information

Client	Colorado Department of Transportation
Project	CDOT Research Project
ConeTec Project Number	21-52-23158
Rig Description	25-ton CPT Truck Rig (C-7A)

Coordinates

Collection Method	USB/Serial GPS
EPSG Number	4326 (WGS 84 / LatLong)

Cone Penetration Test (CPTu)

Depth Reference	Existing ground surface at the time of the investigation
Sleeve data offset	0.1 Meters

Calculated Geotechnical Parameters 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).

Please refer to the list of attached documents following the text of this report. A test summary, location map, and plots are included. Thank you for the opportunity to work on this project.

CONETEC

LIMITATIONS

3ʳᵈ Party Disclaimer

- The "Report" refers to this report titled CDOT Research Project
- The Report was prepared by ConeTec for Colorado Department of Transportation

The Report is confidential and may not be distributed to or relied upon by any third parties without the express written consent of ConeTec. Any third parties gaining access to the Report do not acquire any rights as a result of such access. Any use which a third party makes of the Report, or any reliance on or decisions made based on it, are the responsibility of such third parties. ConeTec accepts no responsibility for loss, damage and/or expense, if any, suffered by any third parties as a result of decisions made, or actions taken or not taken, which are in any way based on, or related to, the Report or any portion(s) thereof.

Client Disclaimer

- ConeTec was retained by Colorado Department of Transportation
- The "Report" refers to this report titled CDOT Research Project
- ConeTec was retained to collect and provide the raw data ("Data") which is included in the Report.

ConeTec has collected and reported the Data in accordance with current industry standards. No other warranty, express or implied, with respect to the Data is made by ConeTec. In order to properly understand the Data included in the Report, reference must be made to the documents accompanying and other sources referenced in the Report in their entirety. Other than the Data, the contents of the Report (including any Interpretations) should not be relied upon in any fashion without independent verification and ConeTec is in no way responsible for any loss, damage or expense resulting from the use of, and/or reliance on, such material by any party.

CONTENTS

The following listed below are included in the report:

- **Site Map**
- **Piezocone Penetration Test (CPTu) Sounding Summary**
- **CPTu Plots**
- **Pore Pressure Dissipation (PPD) Test Summary**
- **PPD Test Plots**
- **Methodology Statements**
- **Data File Formats**
- **Description of Methods for Calculated CPT Geotechnical Parameters**

SITE MAP
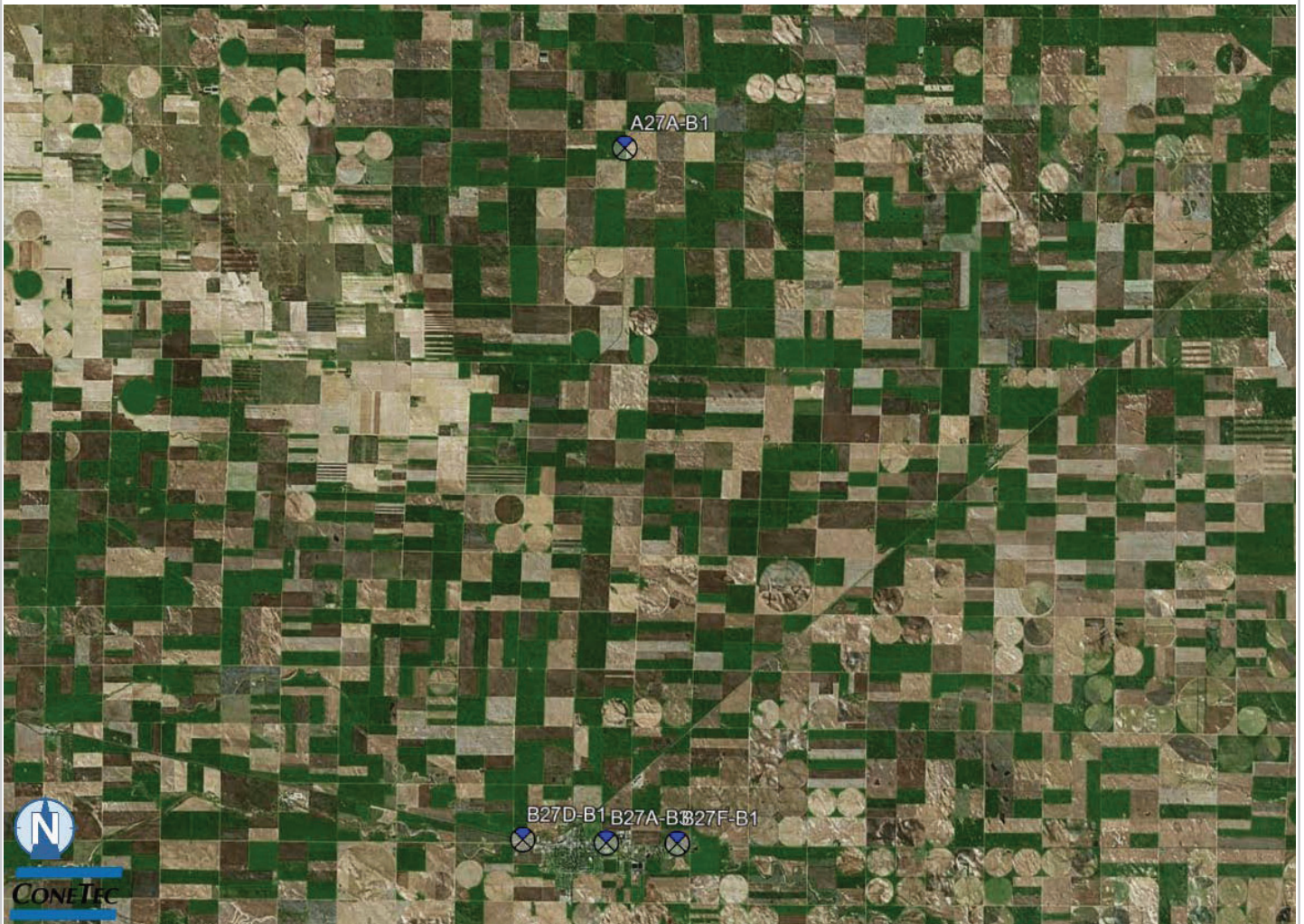
⊗ **Sounding Location**

All sounding locations are approximate

Cone Penetration Test Summary and Standard Cone Penetration Test Plots

CONE PENETRATION TEST SUMMARY

Sounding ID	File Name	Date	Cone	Cone Area (cm²)	Assumed Phreatic Surface[1] (ft)	Final Depth (ft)	Latitude[2]	Longitude[2]	Elevation[3] (ft)	Refer to Notation Number
A27A-B1	21-52-23158_CP-A27A-B1	20-Oct-2021	778:T1500F15U35	15	>60.3	60.28	40.758818	-102.286747	3761	
A27A-B2	21-52-23158_CP-A27A-B2	20-Oct-2021	778:T1500F15U35	15	>68.4	68.40	40.758718	-102.286863	3767	
A27A-B3	21-52-23158_CP-A27A-B3	20-Oct-2021	778:T1500F15U35	15	>79.2	79.15	40.758946	-102.286916	3768	
B27A-B3	21-52-23156_CP-B27A-B3	19-Oct-2021	778:T1500F15U35	15	>101.8	101.79	40.585643	-102.290600	3728	
B27D-B1	21-52-23158_CP-B27D-B1	20-Oct-2021	778:T1500F15U35	15	>101.1	101.05	40.586271	-102.317931	3740	
B27D-B2	21-52-23156_CP-B27D-B2	19-Oct-2021	778:T1500F15U35	15	>60.2	60.20	40.586454	-102.318416	3748	
B27D-B3	21-52-23156_CP-B27D-B3	19-Oct-2021	778:T1500F15U35	15	>101.6	101.54	40.586377	-102.317587	3747	
B27F-B1	21-52-23156_CP-B27F-B1	19-Oct-2021	778:T1500F15U35	15	>68.1	68.08	40.585636	-102.267408	3707	
B27F-B2	21-52-23158_CP-B27F-B2	20-Oct-2021	778:T1500F15U35	15	>76.7	76.61	40.585691	-102.267592	3711	

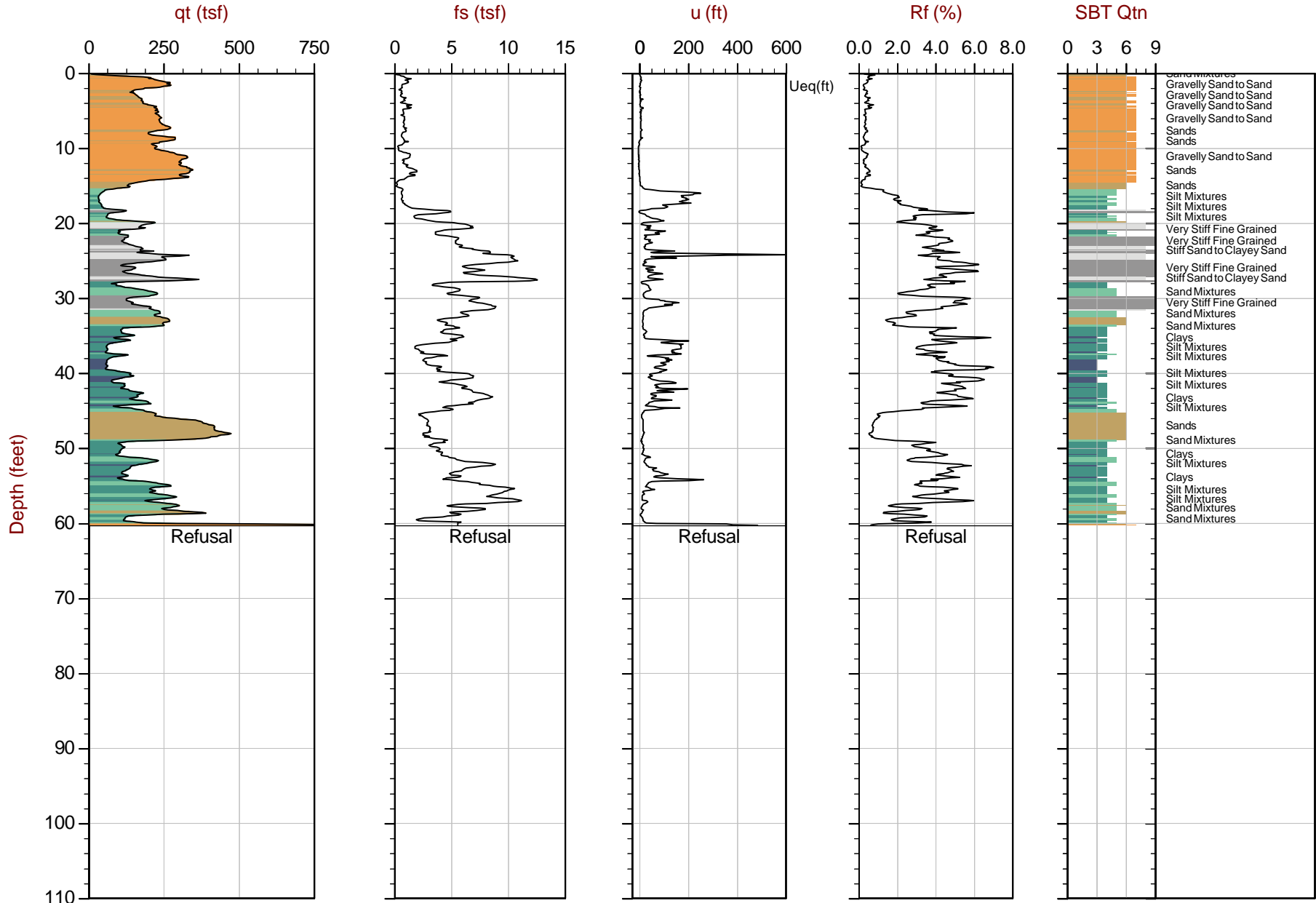1. The phreatic surface used for the calculated parameters is assumed to be below the depth of all soundings based on the pore pressure dissipation test at B27D-B3.

2. The coordinates were collected using consumer grade GPS equipment. EPSG number: 32610 (WGS84 / UTM Zone 10S).

3. Elevations are referenced to the ground surface and were acquired from the Google Earth Elevation for the recorded coordinates.

CDOT

Job No: 21-52-23158
Date: 2021-10-20 13:32
Site: CDOT Research Project

Sounding: A27A-B1
Cone: 778:T1500F15U35

Depth (feet)

qt (tsf)	fs (tsf)	u (ft)	Rf (%)	SBT Qtn

SBT labels (right axis, top to bottom):
Sand Mixtures
Gravelly Sand to Sand
Gravelly Sand to Sand
Gravelly Sand to Sand
Gravelly Sand to Sand
Sands
Sands
Gravelly Sand to Sand
Sands
Sands
Silt Mixtures
Silt Mixtures
Silt Mixtures
Very Stiff Fine Grained
Very Stiff Fine Grained
Stiff Sand to Clayey Sand
Very Stiff Fine Grained
Stiff Sand to Clayey Sand
Sand Mixtures
Very Stiff Fine Grained
Sand Mixtures
Sand Mixtures
Clays
Silt Mixtures
Silt Mixtures
Silt Mixtures
Silt Mixtures
Clays
Silt Mixtures
Sands
Sand Mixtures
Clays
Silt Mixtures
Clays
Silt Mixtures
Silt Mixtures
Sand Mixtures
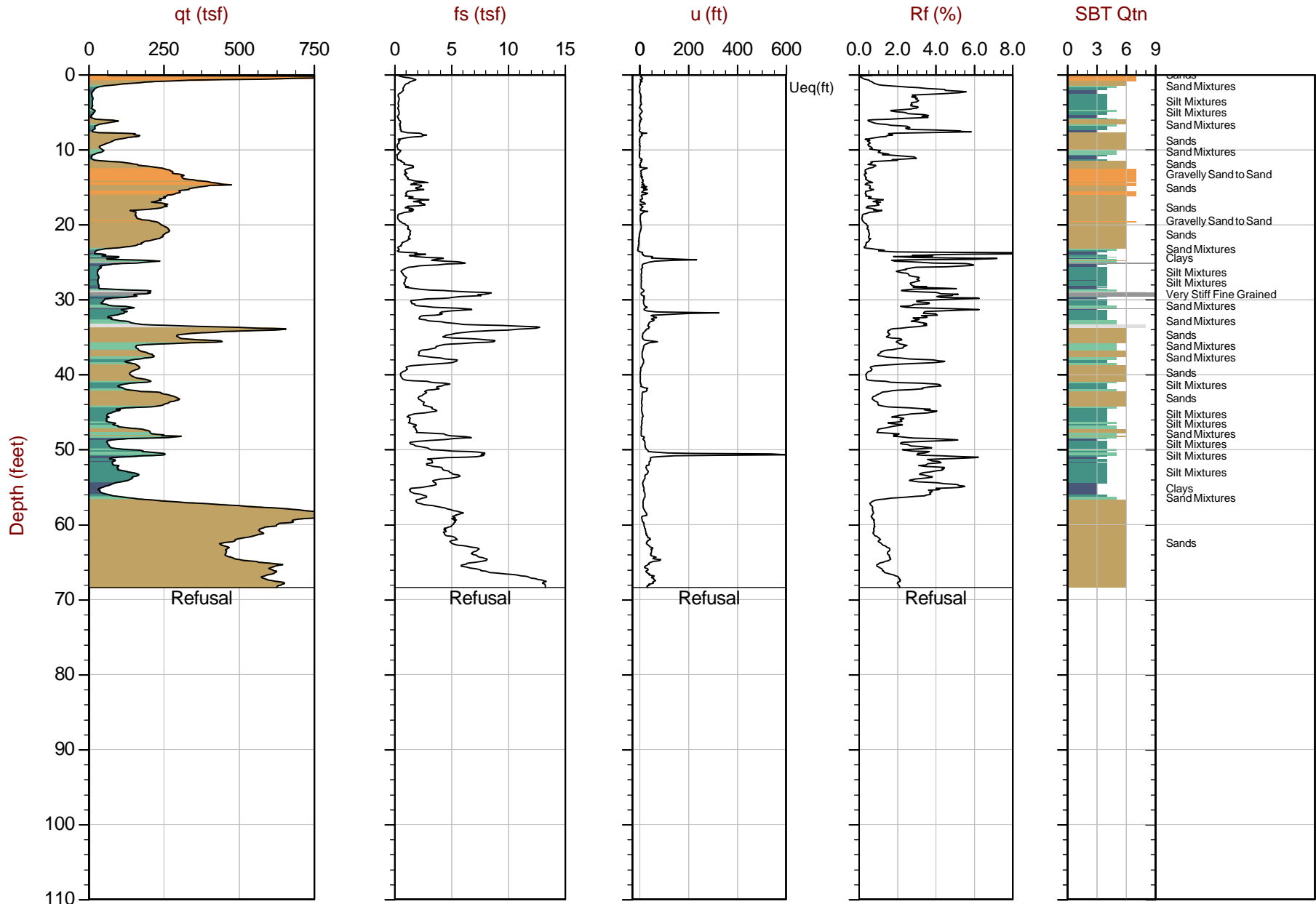Sand Mixtures

Refusal

Ueq(ft)

Max Depth: 18.375 m / 60.28 ft
Depth Inc: 0.025 m / 0.082 ft
Avg Int: Every Point

File: 21-52-23158_CP-A27A-B1.COR
Unit Wt: SBTQtn (PKR2009)

SBT: Robertson, 2009 and 2010
Coords: Lat: 40.758818 Long: -102.286747
Sheet No: 1 of 1

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

CDOT

Job No: 21-52-23158
Date: 2021-10-20 12:33
Site: CDOT Research Project

Sounding: A27A-B2
Cone: 778:T1500F15U35

qt (tsf) — 0, 250, 500, 750

fs (tsf) — 0, 5, 10, 15

u (ft) — 0, 200, 400, 600 — Ueq(ft)

Rf (%) — 0.0, 2.0, 4.0, 6.0, 8.0

SBT Qtn — 0, 3, 6, 9

Depth (feet)

SBT labels (top to bottom):
Sands
Sand Mixtures
Silt Mixtures
Silt Mixtures
Sand Mixtures
Sands
Sand Mixtures
Sands
Gravelly Sand to Sand
Sands
Sands
Gravelly Sand to Sand
Sands
Sand Mixtures
Clays
Silt Mixtures
Silt Mixtures
Very Stiff Fine Grained
Sand Mixtures
Sand Mixtures
Sands
Sand Mixtures
Sand Mixtures
Sands
Silt Mixtures
Sands
Silt Mixtures
Silt Mixtures
Sand Mixtures
Silt Mixtures
Silt Mixtures
Silt Mixtures
Clays
Sand Mixtures
Sands

Refusal (at ~69 ft across all columns)

Max Depth: 20.850 m / 68.40 ft
Depth Inc: 0.025 m / 0.082 ft
Avg Int: Every Point

File: 21-52-23158_CP-A27A-B2.COR
Unit Wt: SBTQtn (PKR2009)

SBT: Robertson, 2009 and 2010
Coords: Lat: 40.758718 Long: -102.286863
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.
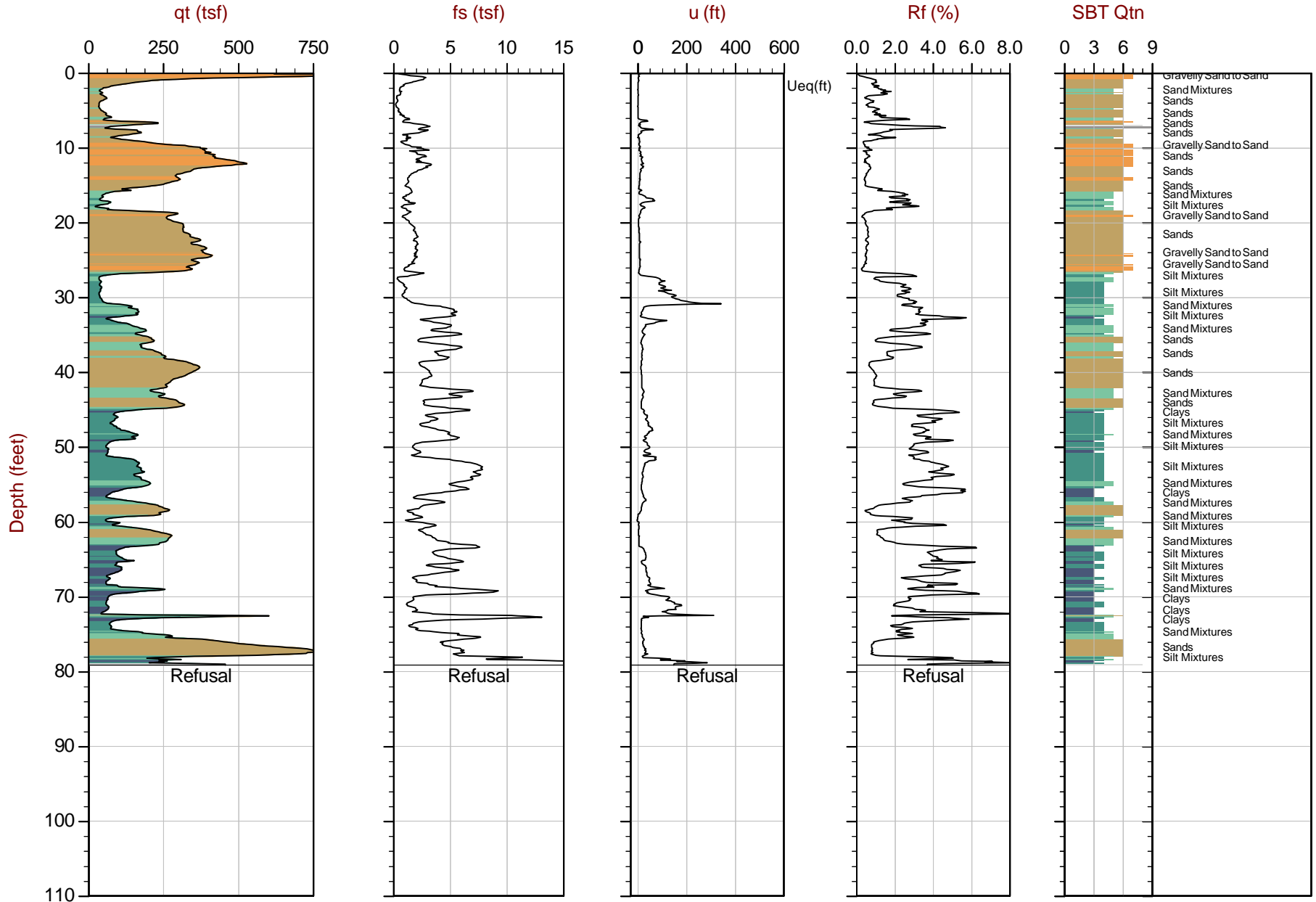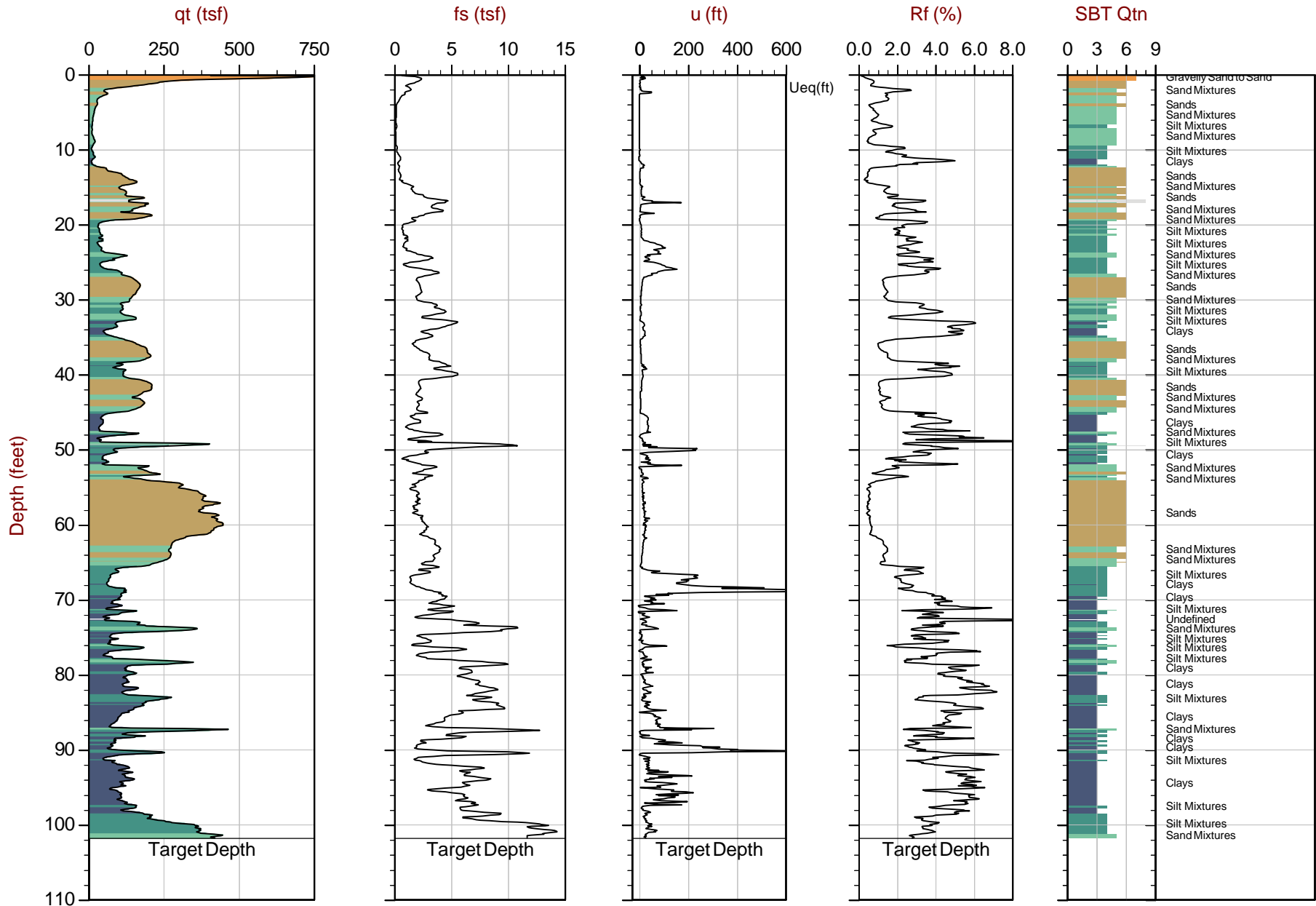
CONETEC

CDOT

Job No: 21-52-23158
Date: 2021-10-20 11:07
Site: CDOT Research Project

Sounding: A27A-B3
Cone: 778:T1500F15U35

Max Depth: 24.125 m / 79.15 ft
Depth Inc: 0.025 m / 0.082 ft
Avg Int: Every Point

File: 21-52-23158_CP-A27A-B3.COR
Unit Wt: SBTQtn (PKR2009)

SBT: Robertson, 2009 and 2010
Coords: Lat: 40.758946 Long: -102.286916
Sheet No: 1 of 1

● Equilibrium Pore Pressure (Ueq)   ● Assumed Ueq   ◁ Dissipation, Ueq achieved   ◁ Dissipation, Ueq not achieved   —— Hydrostatic Line
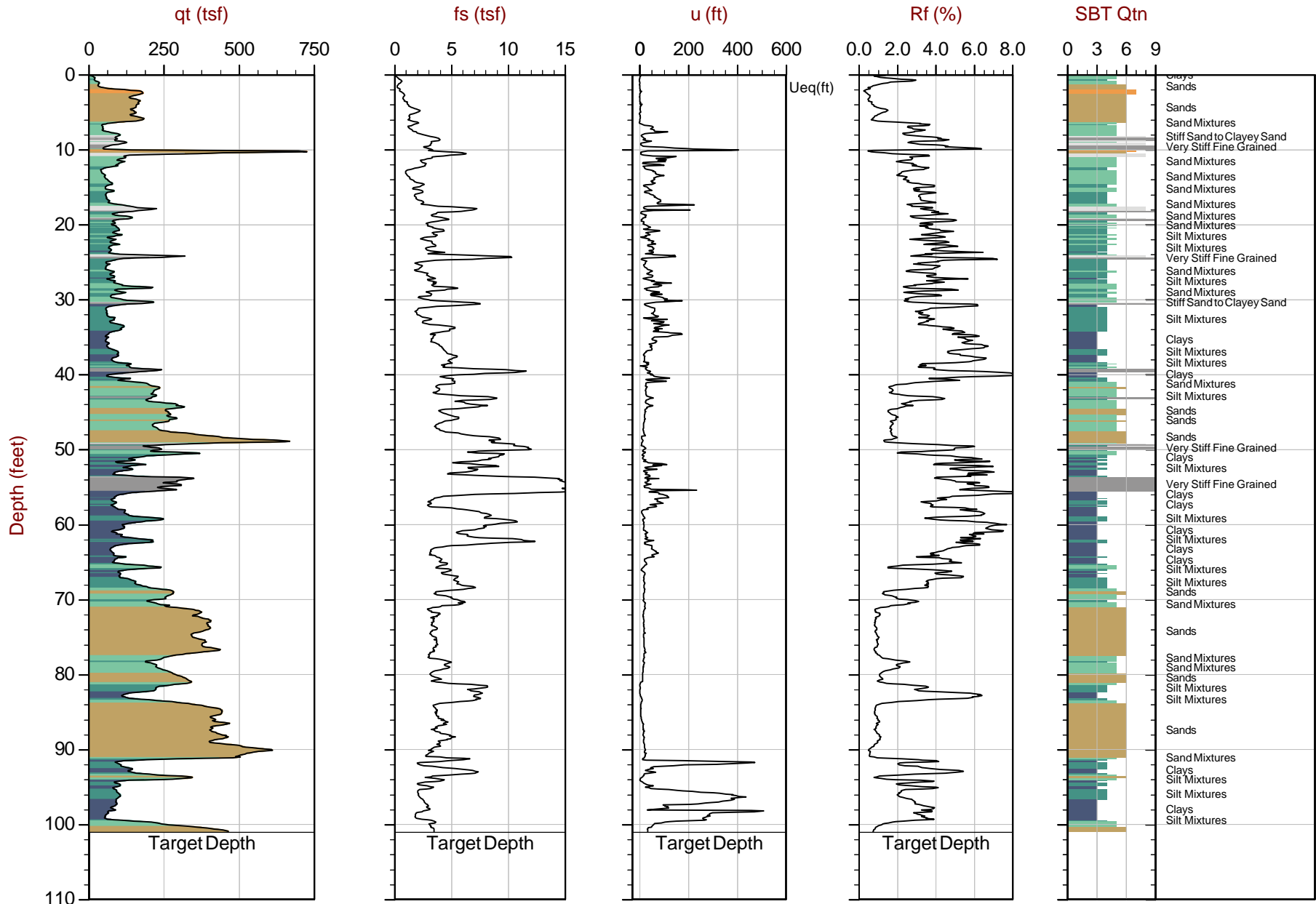The reported coordinates were acquired from consumer grade GPS equipment and are only approximate locations. The coordinates should not be used for design purposes.

CONETEC

CDOT

Job No: 21-52-23158
Date: 2021-10-19 13:34
Site: CDOT Research Project

Sounding: B27A-B3
Cone: 778:T1500F15U35

qt (tsf) — 0, 250, 500, 750

fs (tsf) — 0, 5, 10, 15

u (ft) — 0, 200, 400, 600

Rf (%) — 0.0, 2.0, 4.0, 6.0, 8.0

SBT Qtn — 0, 3, 6, 9

Depth (feet)

Ueq(ft)

SBT Qtn classifications (top to bottom):
Gravelly Sand to Sand
Sand Mixtures
Sands
Sand Mixtures
Silt Mixtures
Sand Mixtures
Silt Mixtures
Clays
Sands
Sand Mixtures
Sands
Sand Mixtures
Sand Mixtures
Silt Mixtures
Silt Mixtures
Sand Mixtures
Silt Mixtures
Sand Mixtures
Sands
Sand Mixtures
Silt Mixtures
Silt Mixtures
Clays
Sands
Sand Mixtures
Silt Mixtures
Sands
Sand Mixtures
Sand Mixtures
Clays
Sand Mixtures
Silt Mixtures
Clays
Sand Mixtures
Sand Mixtures
Sands
Sand Mixtures
Sand Mixtures
Silt Mixtures
Clays
Clays
Silt Mixtures
Undefined
Sand Mixtures
Silt Mixtures
Silt Mixtures
Clays
Clays
Silt Mixtures
Clays
Sand Mixtures
Clays
Clays
Silt Mixtures
Clays
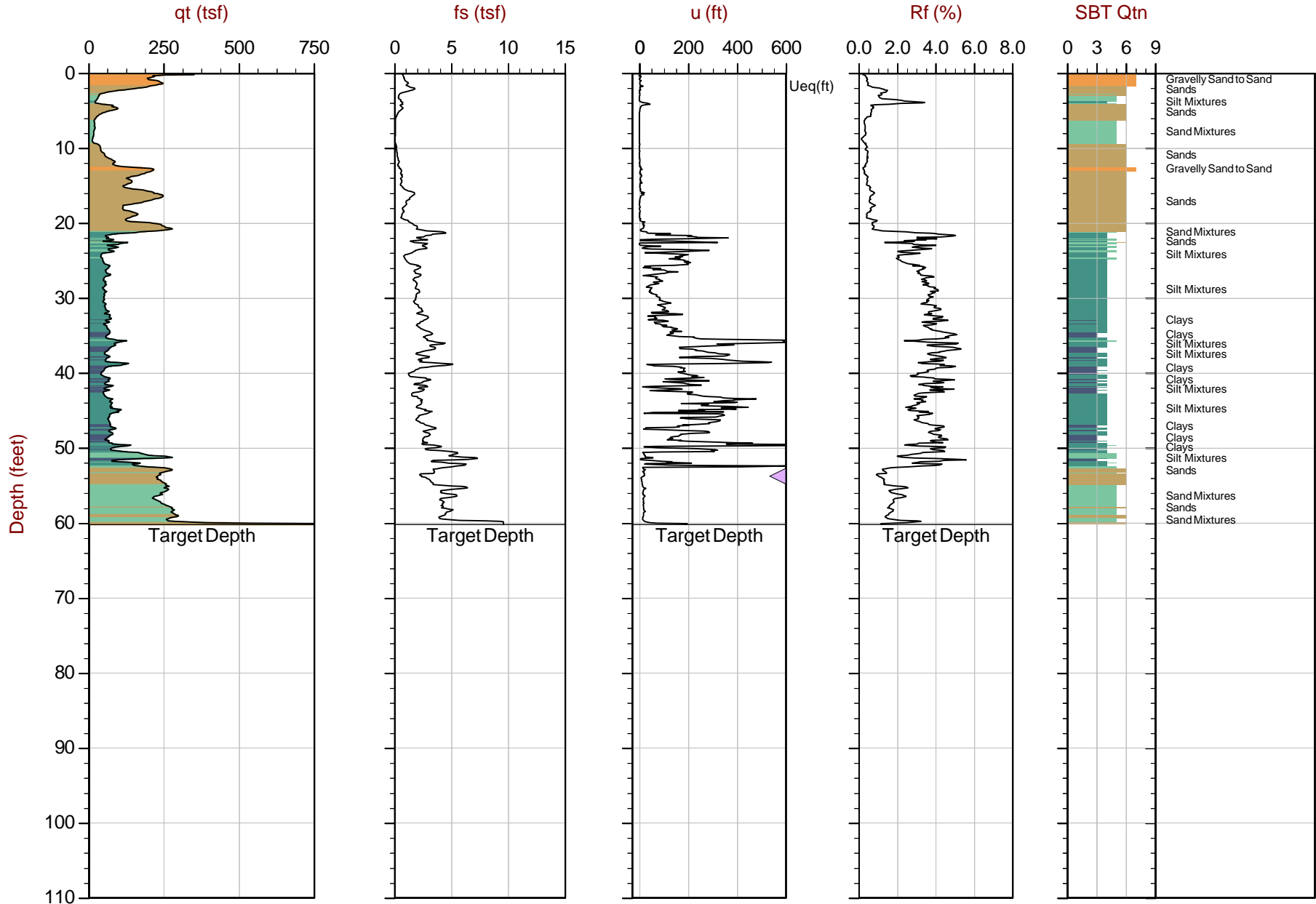Silt Mixtures
Silt Mixtures
Sand Mixtures

Target Depth (×5)

Max Depth: 31.025 m / 101.79 ft
Depth Inc: 0.025 m / 0.082 ft
Avg Int: Every Point

File: 21-52-23158_CP-B27A-B3.COR
Unit Wt: SBTQtn (PKR2009)

SBT: Robertson, 2009 and 2010
Coords: Lat: 40.585643 Long: -102.290600
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.
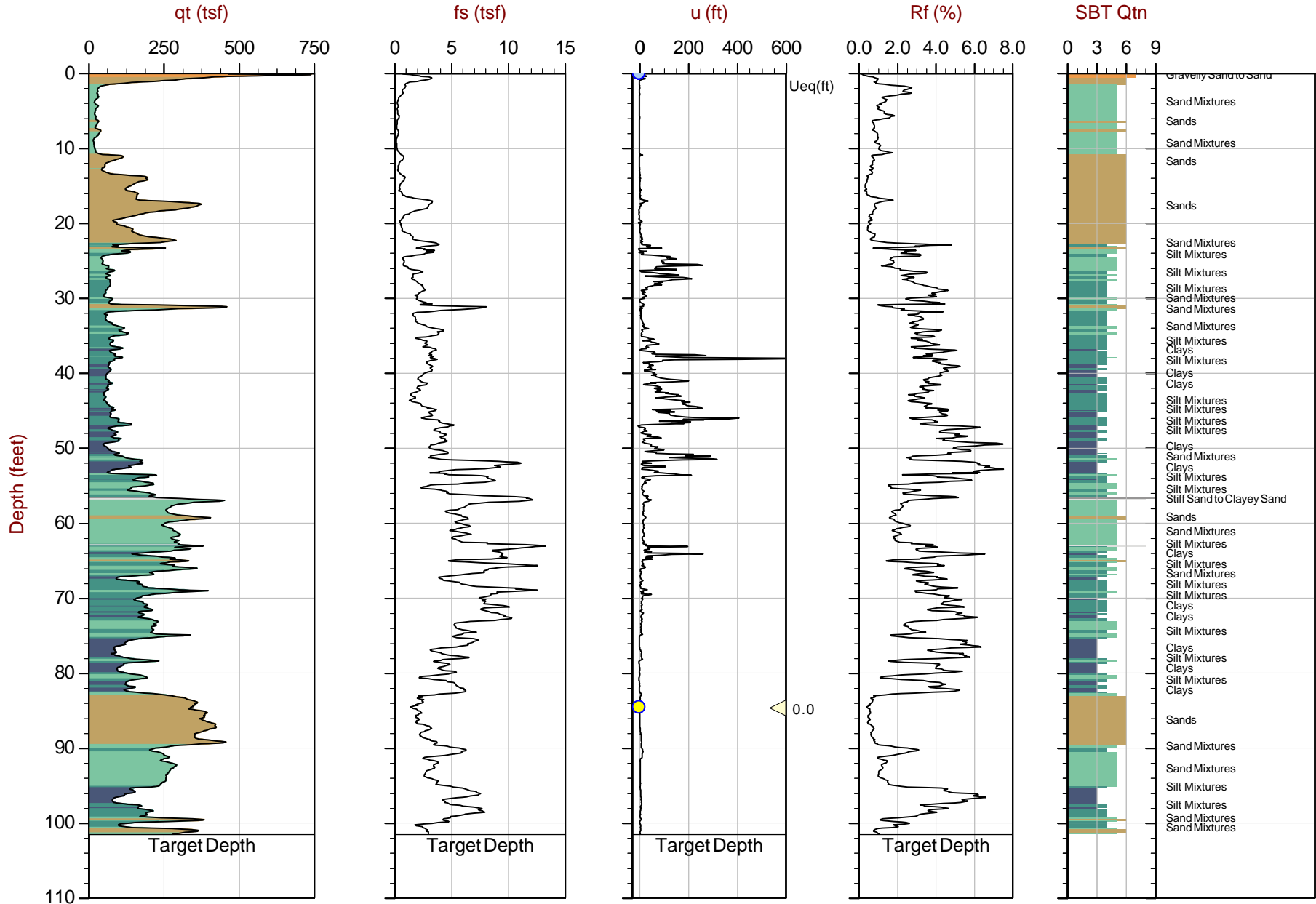
CONETEC

CDOT

Job No: 21-52-23158
Date: 2021-10-20 14:58
Site: CDOT Research Project

Sounding: B27D-B1
Cone: 778:T1500F15U35

qt (tsf) — 0, 250, 500, 750
fs (tsf) — 0, 5, 10, 15
u (ft) — 0, 200, 400, 600
Rf (%) — 0.0, 2.0, 4.0, 6.0, 8.0
SBT Qtn — 0, 3, 6, 9

Depth (feet)

Ueq(ft)

Target Depth

SBT column labels:
Clays
Sands
Sands
Sand Mixtures
Stiff Sand to Clayey Sand
Very Stiff Fine Grained
Sand Mixtures
Sand Mixtures
Sand Mixtures
Sand Mixtures
Sand Mixtures
Sand Mixtures
Silt Mixtures
Silt Mixtures
Very Stiff Fine Grained
Sand Mixtures
Silt Mixtures
Sand Mixtures
Stiff Sand to Clayey Sand
Silt Mixtures
Clays
Silt Mixtures
Silt Mixtures
Clays
Sand Mixtures
Silt Mixtures
Sands
Sands
Sands
Very Stiff Fine Grained
Clays
Silt Mixtures
Very Stiff Fine Grained
Clays
Clays
Silt Mixtures
Clays
Silt Mixtures
Clays
Clays
Silt Mixtures
Silt Mixtures
Sands
Sand Mixtures
Sands
Sand Mixtures
Sand Mixtures
Sands
Silt Mixtures
Silt Mixtures
Sands
Sand Mixtures
Clays
Silt Mixtures
Silt Mixtures
Clays
Silt Mixtures

Max Depth: 30.800 m / 101.05 ft
Depth Inc: 0.025 m / 0.082 ft
Avg Int: Every Point

File: 21-52-23158_CP-B27D-B1.COR
Unit Wt: SBTQtn (PKR2009)

SBT: Robertson, 2009 and 2010
Coords: Lat: 40.586271 Long: -102.317931
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.
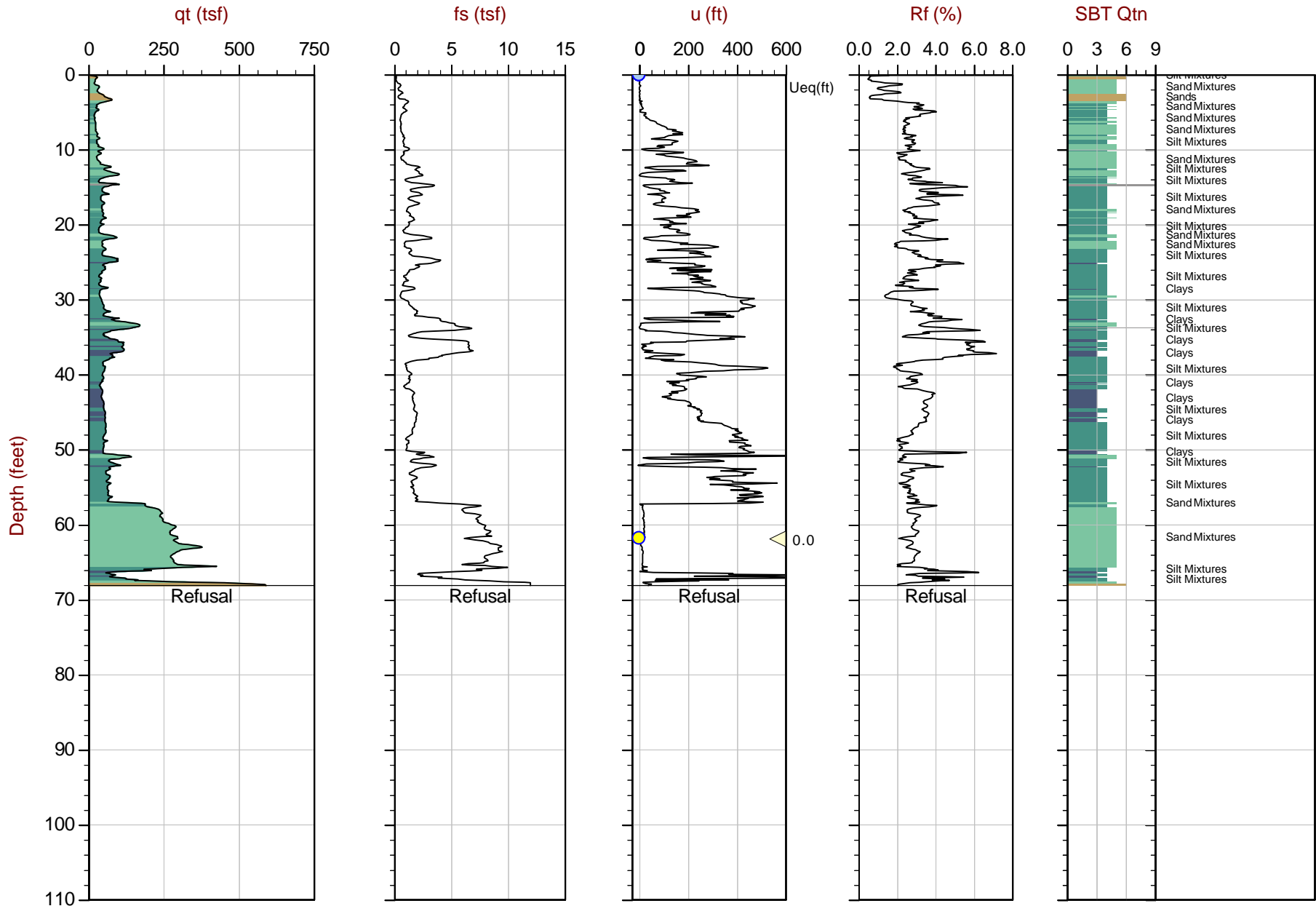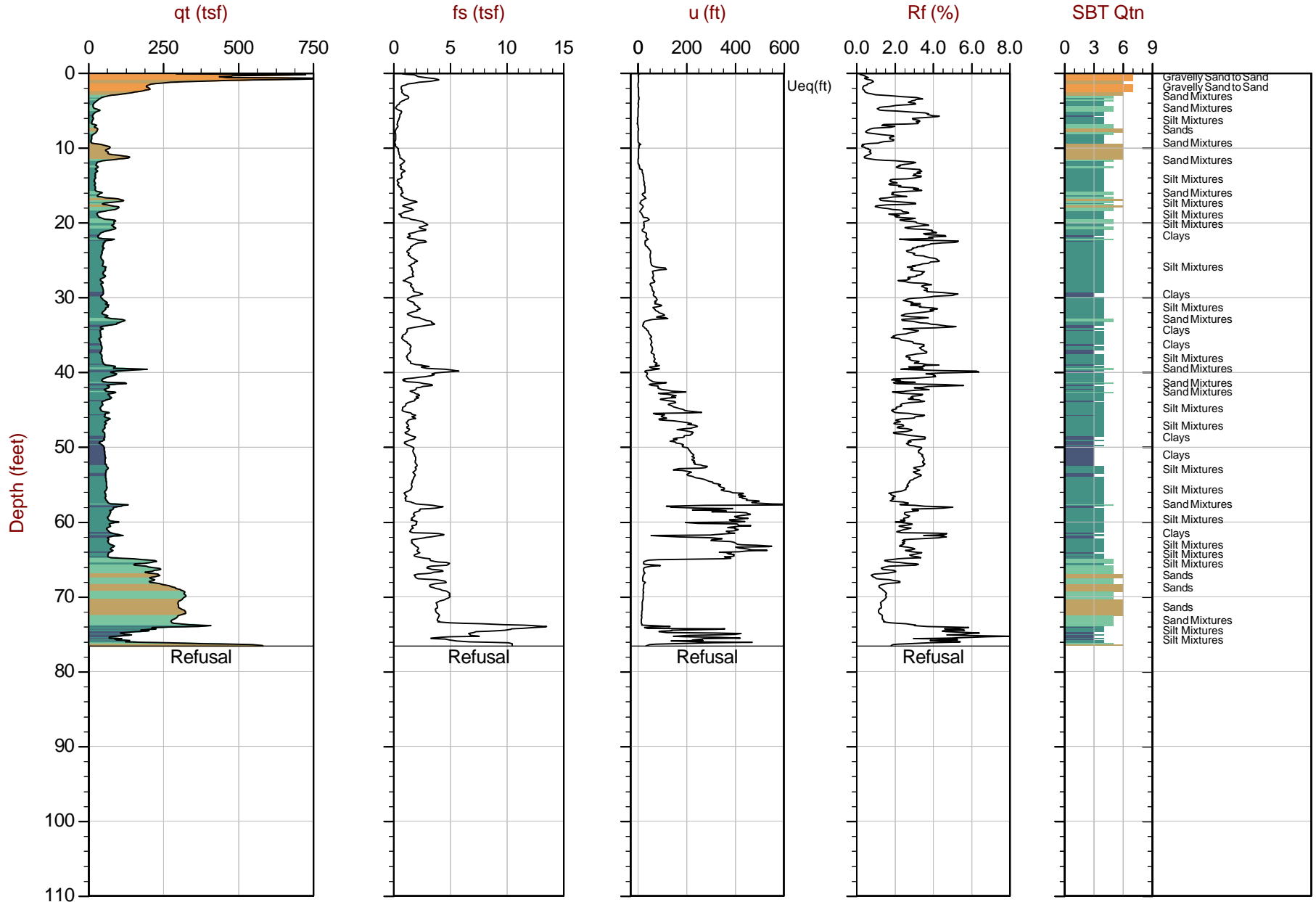
CONETEC

CDOT

Job No: 21-52-23158
Date: 2021-10-19 10:47
Site: CDOT Research Project

Sounding: B27D-B2
Cone: 778:T1500F15U35

qt (tsf)	fs (tsf)	u (ft)	Rf (%)	SBT Qtn

Depth (feet)

SBT column labels (top to bottom):
Gravelly Sand to Sand
Sands
Silt Mixtures
Sands
Sand Mixtures
Sands
Gravelly Sand to Sand
Sands
Sand Mixtures
Sands
Silt Mixtures
Silt Mixtures
Clays
Clays
Silt Mixtures
Silt Mixtures
Clays
Clays
Silt Mixtures
Silt Mixtures
Clays
Clays
Clays
Silt Mixtures
Sands
Sand Mixtures
Sands
Sand Mixtures

Ueq(ft)

Target Depth (×4)

Max Depth: 18.350 m / 60.20 ft
Depth Inc: 0.025 m / 0.082 ft
Avg Int: Every Point

File: 21-52-23158_CP-B27D-B2.COR
Unit Wt: SBTQtn (PKR2009)

SBT: Robertson, 2009 and 2010
Coords: Lat: 40.586454 Long: -102.318416
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

CDOT

Job No: 21-52-23158
Date: 2021-10-19 11:54
Site: CDOT Research Project

Sounding: B27D-B3
Cone: 778:T1500F15U35

qt (tsf)	fs (tsf)	u (ft)	Rf (%)	SBT Qtn

SBT column labels (top to bottom):
Gravelly Sand to Sand
Sand Mixtures
Sands
Sand Mixtures
Sands

Sands

Sand Mixtures
Silt Mixtures
Silt Mixtures
Silt Mixtures
Sand Mixtures
Sand Mixtures
Sand Mixtures
Silt Mixtures
Clays
Silt Mixtures
Clays
Clays
Silt Mixtures
Silt Mixtures
Silt Mixtures
Silt Mixtures
Clays
Sand Mixtures
Clays
Silt Mixtures
Silt Mixtures
Stiff Sand to Clayey Sand
Sands
Sand Mixtures
Silt Mixtures
Clays
Silt Mixtures
Sand Mixtures
Silt Mixtures
Silt Mixtures
Clays
Clays
Silt Mixtures
Clays
Silt Mixtures
Clays
Silt Mixtures
Clays
Sands
Sand Mixtures
Sand Mixtures
Silt Mixtures
Silt Mixtures
Sand Mixtures
Sand Mixtures

Ueq(ft)
Target Depth

Max Depth: 30.950 m / 101.54 ft
Depth Inc: 0.025 m / 0.082 ft
Avg Int: Every Point

File: 21-52-23158_CP-B27D-B3.COR
Unit Wt: SBTQtn (PKR2009)

SBT: Robertson, 2009 and 2010
Coords: Lat: 40.586377 Long: -102.317587
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

CDOT

Job No: 21-52-23158
Date: 2021-10-19 15:29
Site: CDOT Research Project

Sounding: B27F-B1
Cone: 778:T1500F15U35

qt (tsf)	fs (tsf)	u (ft)	Rf (%)	SBT Qtn

Depth (feet)

qt (tsf): 0 250 500 750
fs (tsf): 0 5 10 15
u (ft): 0 200 400 600 — Ueq(ft)
Rf (%): 0.0 2.0 4.0 6.0 8.0
SBT Qtn: 0 3 6 9

SBT classifications (from top to bottom):
Silt Mixtures
Sand Mixtures
Sands
Sand Mixtures
Sand Mixtures
Sand Mixtures
Silt Mixtures
Sand Mixtures
Silt Mixtures
Silt Mixtures
Silt Mixtures
Sand Mixtures
Silt Mixtures
Sand Mixtures
Sand Mixtures
Silt Mixtures
Silt Mixtures
Clays
Silt Mixtures
Clays
Silt Mixtures
Clays
Clays
Silt Mixtures
Clays
Clays
Silt Mixtures
Clays
Silt Mixtures
Clays
Silt Mixtures
Silt Mixtures
Sand Mixtures
Sand Mixtures
Silt Mixtures
Silt Mixtures

Refusal (at ~68 ft across qt, fs, u, Rf tracks)

0.0 (Dissipation, Ueq achieved marker)

Max Depth: 20.750 m / 68.08 ft
Depth Inc: 0.025 m / 0.082 ft
Avg Int: Every Point

File: 21-52-23158_CP-B27F-B1.COR
Unit Wt: SBTQtn (PKR2009)

SBT: Robertson, 2009 and 2010
Coords: Lat: 40.585636 Long: -102.267408
Sheet No: 1 of 1

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

CONETEC

CDOT

Job No: 21-52-23158
Date: 2021-10-20 08:59
Site: CDOT Research Project

Sounding: B27F-B2
Cone: 778:T1500F15U35

qt (tsf)

0   250   500   750

fs (tsf)

0   5   10   15

u (ft)

0   200   400   600

Ueq(ft)

Rf (%)

0.0   2.0   4.0   6.0   8.0

SBT Qtn

0   3   6   9

Depth (feet)

Refusal — Refusal — Refusal — Refusal

SBT labels (top to bottom):
Gravelly Sand to Sand
Gravelly Sand to Sand
Sand Mixtures
Sand Mixtures
Silt Mixtures
Sands
Sand Mixtures
Sand Mixtures
Silt Mixtures
Sand Mixtures
Silt Mixtures
Silt Mixtures
Silt Mixtures
Clays
Silt Mixtures
Clays
Silt Mixtures
Sand Mixtures
Clays
Clays
Silt Mixtures
Sand Mixtures
Sand Mixtures
Sand Mixtures
Silt Mixtures
Silt Mixtures
Clays
Clays
Silt Mixtures
Silt Mixtures
Sand Mixtures
Silt Mixtures
Clays
Silt Mixtures
Silt Mixtures
Silt Mixtures
Sands
Sands
Sands
Sand Mixtures
Silt Mixtures
Silt Mixtures

Max Depth: 23.350 m / 76.61 ft
Depth Inc: 0.025 m / 0.082 ft
Avg Int: Every Point

File: 21-52-23158_CP-B27F-B2.COR
Unit Wt: SBTQtn (PKR2009)

SBT: Robertson, 2009 and 2010
Coords: Lat: 40.585691 Long: -102.267592
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.

Pore Pressure Dissipation Summary and Pore Pressure Dissipation Plots

CPTu PORE PRESSURE DISSIPATION SUMMARY

Sounding ID	File Name	Cone Area (cm^2)	Duration (s)	Test Depth (ft)	Estimated Equilibrium Pore Pressure U_{eq} (ft.)	Calculated Phreatic Surface (ft.)	Refer to Notation Number
B27D-B2	21-52-23158_CP-B27D-B2	15	790	53.72	Not Achieved		1
B27D-B3	21-52-23158_CP-B27D-B3	15	395	84.64	0.0	84.6	
B27F-B1	21-52-23158_CP-B27F-B1	15	650	61.84	0.0	61.8	

1. Pore pressure dissipation test stopped by client.

CONETEC

CDOT

Job No: 21-52-23158
Date: 10/19/2021 10:47
Site: CDOT Research Project

Sounding: B27D-B2
Cone: 778:T1500F15U35 Area=15 cm²
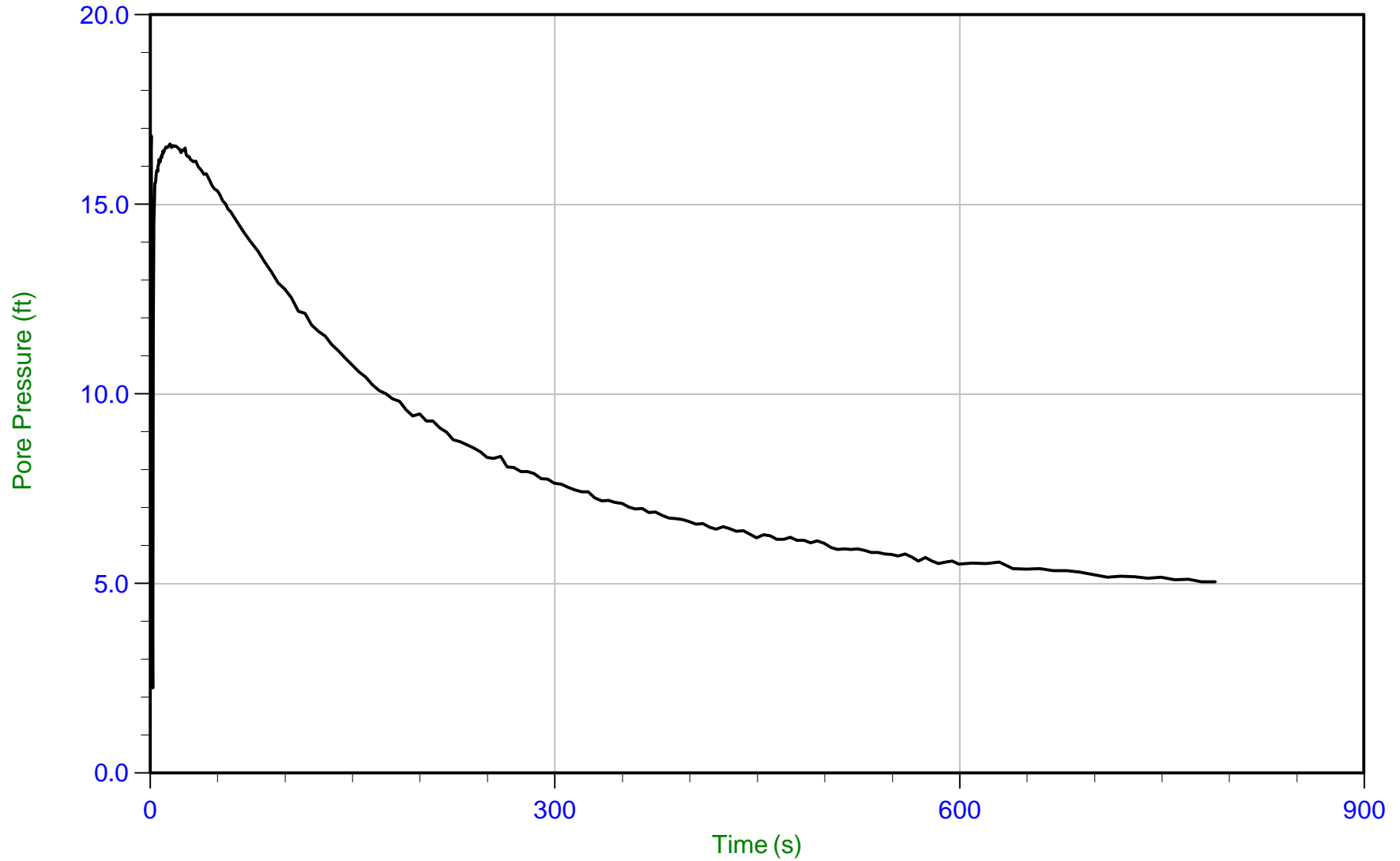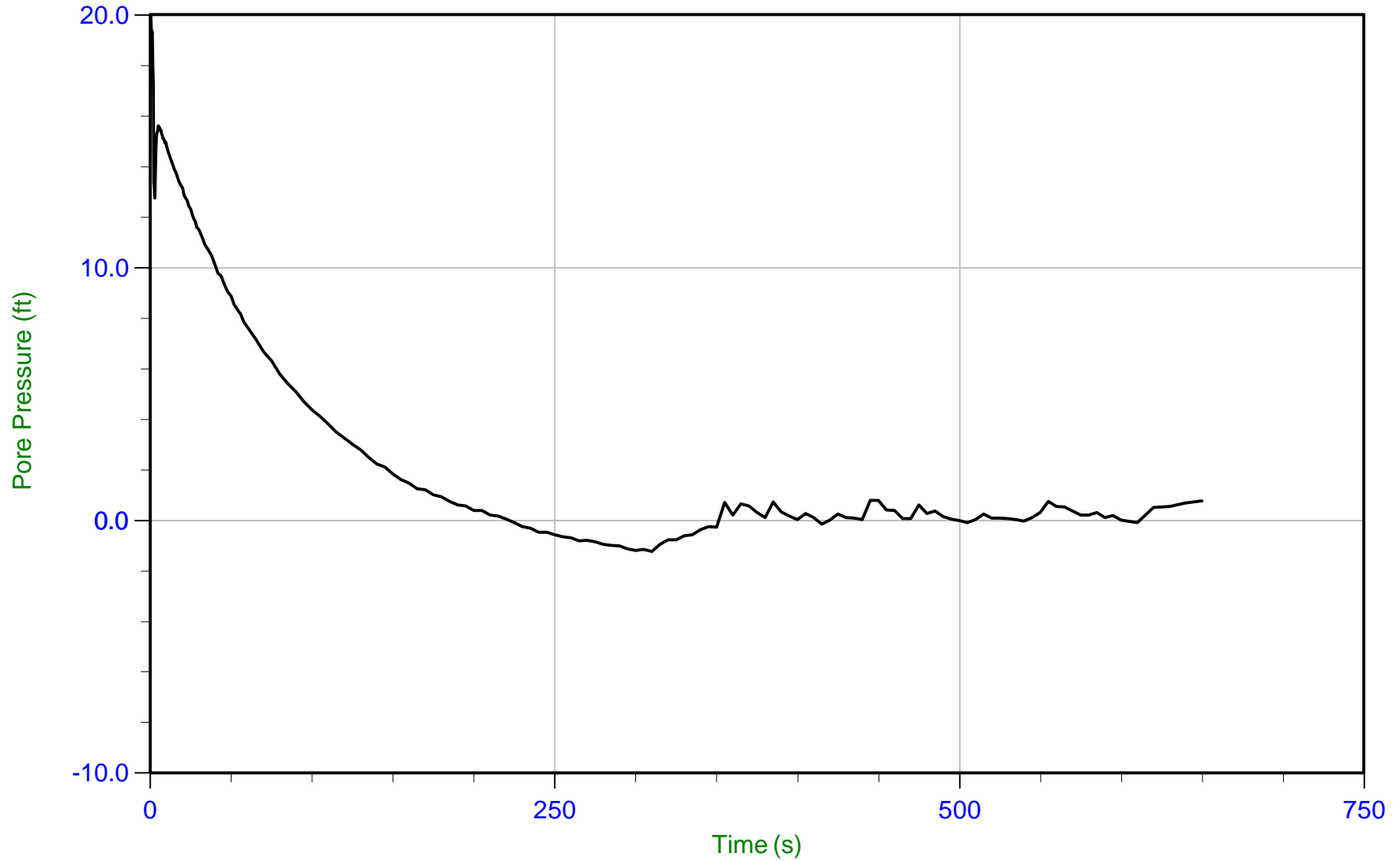
Trace Summary:

Filename: 21-52-23158_CP-B27D-B2.ppd2
Depth: 16.375 m / 53.723 ft
Duration: 790.0 s

u Min: 2.2 ft
u Max: 20.3 ft
u Final: 5.1 ft

CDOT

Trace Summary:

Filename: 21-52-23158_CP-B27D-B3.ppd2
Depth: 25.800 m / 84.645 ft
Duration: 395.0 s

u Min: -2.4 ft
u Max: 1.8 ft
u Final: -1.9 ft

WT: 25.800 m / 84.645 ft
Ueq: 0.0 ft

Methodology Statements

METHODOLOGY STATEMENTS

CONE PENETRATION TEST (CPTu) - eSeries

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

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

ConeTec penetrometers are manufactured with various tip, friction and pore pressure capacities in both 10 cm^2 and 15 cm^2 tip base area configurations in order to maximize signal resolution for various soil conditions. The specific piezocone used for each test is described in the CPT summary table. 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 millimeters diameter over a length of 32 millimeters with tapered leading and trailing edges) located at a distance of 585 millimeters above the cone tip.

The penetrometers are designed with equal end area friction sleeves, a net end area ratio of 0.8 and cone tips with a 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 six millimeters thick, made of porous plastic (polyethylene) having an average pore size of 125 microns (90-160 microns). The function of the filter is to allow rapid movements of extremely small volumes of water needed to activate the pressure transducer while preventing soil ingress or blockage.

The piezocone penetrometers are manufactured with dimensions, tolerances and sensor characteristics that are in general accordance with the current ASTM D5778 standard. ConeTec's calibration criteria also meets or exceeds those of the current ASTM D5778 standard. An illustration of the piezocone penetrometer is presented in Figure CPTu.
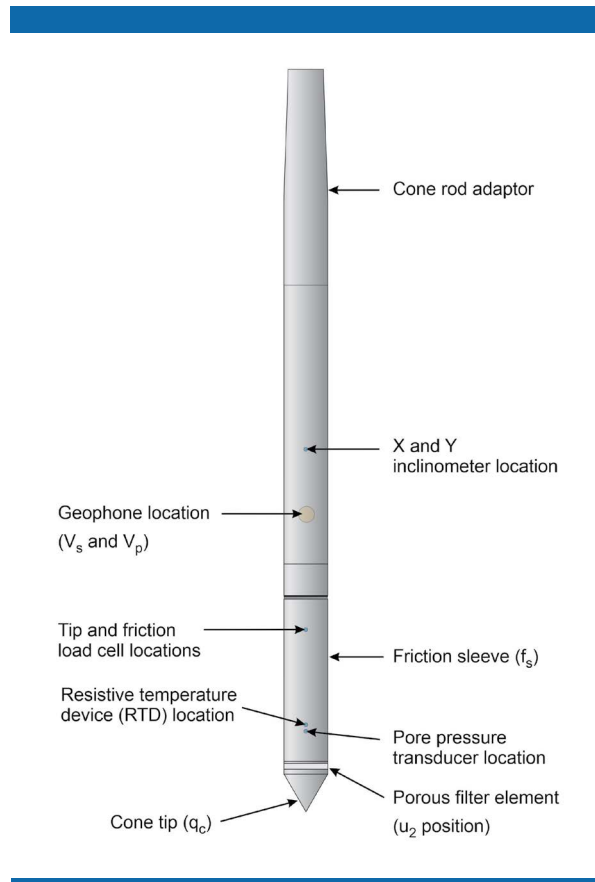
Figure CPTu. Piezocone Penetrometer (15 cm²)

The ConeTec data acquisition system consists of a Windows based computer, signal interface box, and power supply. The signal interface combines depth increment signals, seismic trigger signals and the downhole digital data. This combined data is then sent to the Windows based computer for collection and presentation. The data is recorded at fixed depth increments using a depth encoder that is either portable or integrated into the rig. The typical recording interval is 2.5 centimeters; custom recording intervals are possible.

The system displays the CPTu data in real time and records the following parameters to a storage media during penetration:
- Depth
- Uncorrected tip resistance (q_c)
- Sleeve friction (f_s)
- Dynamic pore pressure (u)
- Additional sensors such as resistivity, passive gamma, ultra violet induced fluorescence, if applicable

All testing is performed in accordance to ConeTec's CPTu operating procedures which are in general accordance with the current ASTM D5778 standard.

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

The CPTu is conducted at a steady rate of two centimeters per second, within acceptable tolerances. Typically one meter length rods with an outer diameter of 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 under vacuum pressure prior to use
- Baseline readings are compared to previous readings
- Soundings are terminated at the client's target depth or at a depth where an obstruction is encountered, excessive rod flex occurs, excessive inclination occurs, equipment damage is likely to take place, or a dangerous working environment arises
- Differences between initial and final baselines are calculated to ensure zero load offsets have not occurred and to ensure compliance with ASTM standards

The interpretation of piezocone data for this report is based on the corrected tip resistance (q_t), sleeve friction (f_s) and pore water pressure (u). The interpretation of soil type is based on the correlations developed by Robertson, P.K., 2010. The Soil Behavior Type (SBT) classification chart developed by Robertson, P.K., 2010 is presented in Figure SBT. It should be noted that it is not always possible to accurately identify a soil behavior type based on these parameters. In these situations, experience, judgment and an assessment of other parameters may be used to infer soil behavior type.
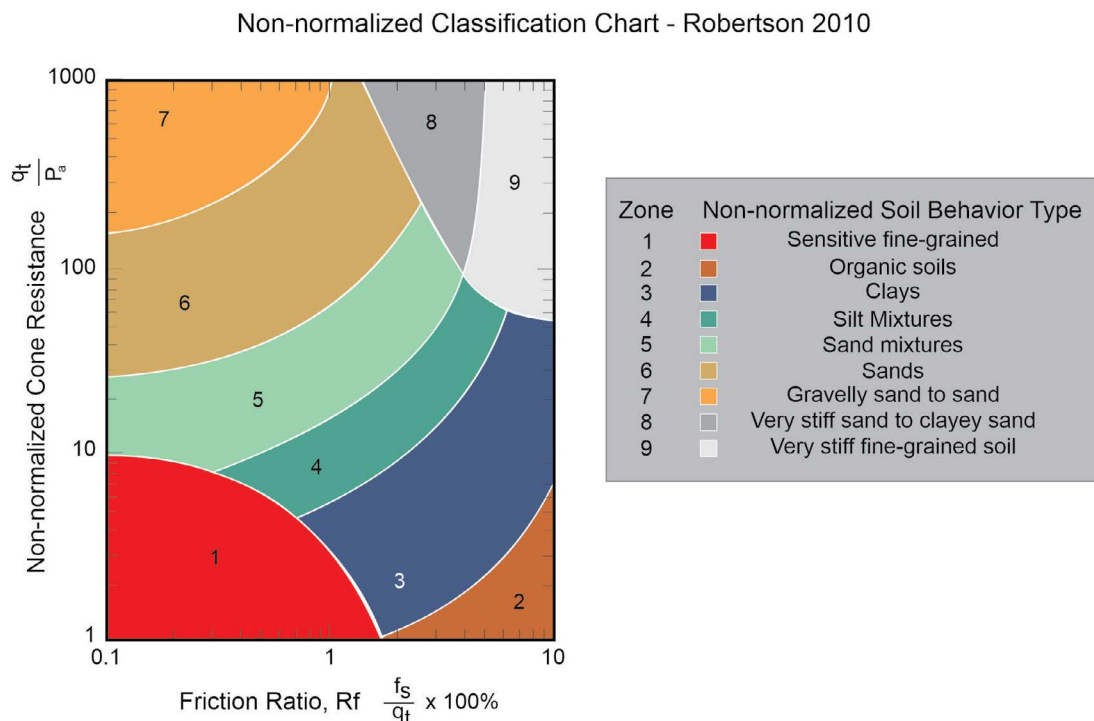
Figure SBT. Non-Normalized Soil Behavior Type Classification Chart (SBT)

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

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

where: q_t is the corrected tip resistance

q_c is the recorded tip resistance

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

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

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

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

The friction ratio (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.

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

REFERENCES

ASTM D5778-20, 2020, "Standard Test Method for Performing Electronic Friction Cone and Piezocone Penetration Testing of Soils", ASTM International, West Conshohocken, PA. DOI: 10.1520/D5778-20.

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

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

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

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

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

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

Robertson, P.K., 2010. Soil behavior type from the CPT: an update. 2nd International Symposium on Cone Penetration Testing, CPT'10, Huntington Beach, CA, USA

CONETEC

PORE PRESSURE DISSIPATION TEST

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).
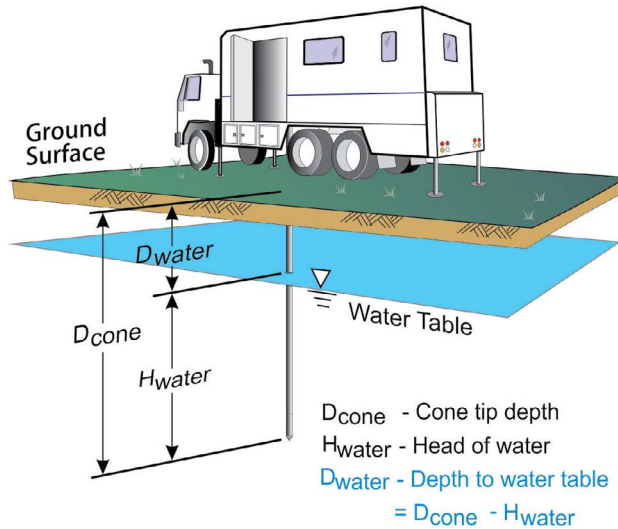

Figure PPD-1. Pore pressure dissipation test setup

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

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.
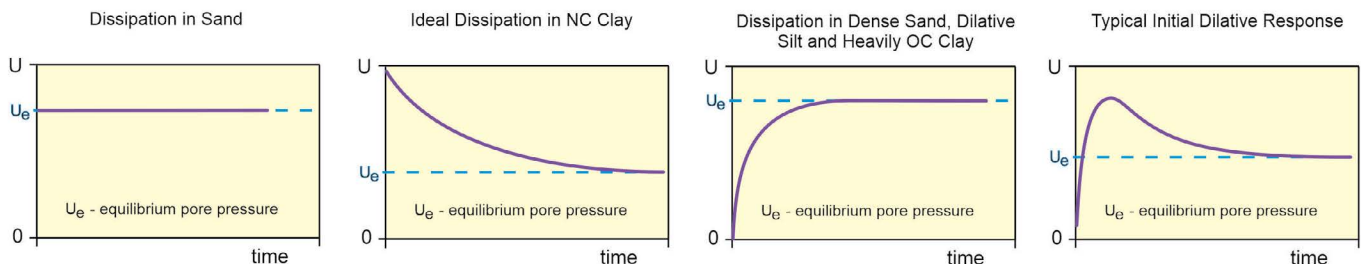
Figure PPD-2. Pore pressure dissipation curve examples

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.

CONE PENETRATION DIGITAL
FILE FORMATS - eSeries

CPT Data Files (COR Extension)

ConeTec CPT data files are stored in ASCII text files that are readable by almost any text editor. ConeTec file names start with the job number (which includes the two digit year number) an underscore as a separating character, followed by two letters based on the type of test and the sounding ID. The last character position is reserved for an identifier letter (such as b, c, d etc) used to uniquely distinguish multiple soundings at the same location. The CPT sounding file has the extension COR. As an example, for job number 21-02-00001 the first CPT sounding will have file name 21-02-00001_CP01.COR

The sounding (COR) file consists of the following components:
1. Two lines of header information
2. Data records
3. End of data marker
4. Units information

Header Lines

Line 1: Columns 1-6 may be blank or may indicate the version number of the recording software

Columns 7-21 contain the sounding Date and Time (Date is MM:DD:YY)

Columns 23-38 contain the sounding Operator

Columns 51-100 contain extended Job Location information

Line 2: Columns 1-16 contain the Job Location

Columns 17-32 contain the Cone ID

Columns 33-47 contain the sounding number

Columns 51-100 may contain extended sounding ID information

Data Records

The data records contain 4 or more columns of data in floating point format. A comma and spaces separate each data item:

Column 1: Sounding Depth (meters)

Column 2: Tip (q_c), recorded in units selected by the operator

Column 3: Sleeve (f_s), recorded in units selected by the operator

Column 4: Dynamic pore pressure (u), recorded in units selected by the operator

Column 5: Empty or may contain other requested data such as Gamma, Resistivity or UVIF data

End of Data Marker

After the last line of data there is a line containing an ASCII 26 (CTL-Z) character (small rectangular shaped character) followed by a newline (carriage return / line feed). This is used to mark the end of data.

CONETEC

Units Information

The last section of the file contains information about the units that were selected for the sounding. A separator bar makes up the first line. The second line contains the type of units used for depth, q_c, f_s and u. The third line contains the conversion values required for ConeTec's software to convert the recorded data to an internal set of base units (bar for q_c, bar for f_s and meters for u). Additional lines intended for internal ConeTec use may appear following the conversion values.

CPT Data Files (XLS Extension)

Excel format files of ConeTec CPT data are also generated from corresponding COR files. The XLS files have the same base file name as the COR file with a -BSC suffix. The information in the file is presented in table format and contains additional information about the sounding such as coordinate information, and tip net area ratio.

The BSCI suffix is given to XLS files which are enhanced versions of the BSC files and include the same data records in addition to inclination data collected for each sounding.

CPT Dissipation Files (XLS Extension)

Pore pressure dissipation files are provided in Excel format and contain each dissipation trace that exceeds a minimum duration (selected during post-processing) formatted column wise within the spreadsheet. The first column (Column A) contains the time in seconds and the second column (Column B) contains the time in minutes. Subsequent columns contain the dissipation trace data. The columns extend to the longest trace of the data set.

Detailed header information is provided at the top of the worksheet. The test depth in meters and feet, the number of points in the trace and the particular units are all presented at the top of each trace column.

CPT Dissipation files have the same naming convention as the CPT sounding files with a "–PPD" suffix.

Data Records

Each file will contain dissipation traces that exceed a minimum duration (selected during post-processing) in a particular column. The dissipation pore pressure values are typically recorded at varying time intervals throughout the trace; rapidly to start and increasing as the duration of the test lengthens. The test depth in meters and feet, the number of points in the trace and the trace number are identified at the top of each trace column.

Cone Type Designations

Cone ID	Cone Description	Tip Cross Sect. Area (cm²)	Tip Capacity (bar)	Sleeve Area (cm²)**	Sleeve Capacity (bar)	Pore Pressure Capacity (bar)
EC###	A15T1500F15U35	15	1500	225	15	35
EC###	A15T375F10U35	15	375	225	10	35
EC###	A10T1000F10U35	10	1000	150	10	35

refers to the Cone ID number
**Outer Cylindrical Area

CONETEC

Description of Methods for Calculated CPT Geotechnical Parameters

CONETEC

CALCULATED CPT GEOTECHNICAL PARAMETERS

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

Revision SZW-Rev 14

Revised November 26, 2019
Prepared by Jim Greig, M.A.Sc, P.Eng (BC)

Limitations

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

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

BETTER INFORMATION, **BETTER DECISIONS**

ConeTec's Calculated CPT Geotechnical Parameters as of November 26, 2019

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

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

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

The tip correction is: $\qquad q_t = q_c + (1-a) \bullet u_2 \qquad$ (consistent units are implied)

$\qquad\qquad$ where: $\quad q_t$ is the corrected tip resistance

$\qquad\qquad\qquad\qquad q_c$ is the recorded tip resistance

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

$\qquad\qquad\qquad\qquad a$ is the Net Area Ratio for the cone (typically 0.80 for ConeTec cones)

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

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

A majority of parameter calculations are derived or driven by results based on material types as determined by the various soil behavior type charts depicted in Figures 1 through 5. The parameter output files indicate the method(s) used.

The Soil Behavior Type classification chart shown in Figure 1 is the classic non-normalized SBT Chart developed at the University of British Columbia and reported in Robertson, Campanella, Gillespie and Greig (1986). Figure 2 shows the original normalized (linear method) SBT chart developed by Robertson (1990). The Bq classification charts shown in Figures 3a and 3b incorporate pore pressures into the SBT classification and are based on the methods described in Robertson (1990). Many of these charts have been summarized in Lunne, Robertson and Powell (1997). The

Jefferies and Davies SBT chart shown in Figure 3c is based on the techniques discussed in Jefferies and Davies (1993) which introduced the concept of the Soil Behavior Type Index parameter, I_c. Please note that the I_c parameter developed by Robertson and Fear (1995) and Robertson and Wride (1998) is similar in concept but uses a slightly different calculation method than that used by Jefferies and Davies (1993) as the latter incorporates pore pressure in their technique through the use of the Bq parameter. The normalized Qtn SBT chart shown in Figure 4 is based on the work by Robertson (2009) utilizing a variable stress ratio exponent, n, for normalization based on a slightly modified redefinition and iterative approach for I_c. The boundary curves drawn on the chart are based on the work described in Robertson (2010).

Figure 5 shows a revised behavior based chart by Robertson (2016) depicting contractive-dilative zones. As the zones represent material behavior rather than soil gradation ConeTec has chosen a set of zone colors that are less likely to be confused with material type colors from previous SBT charts. These colors differ from those used by Dr. Robertson.
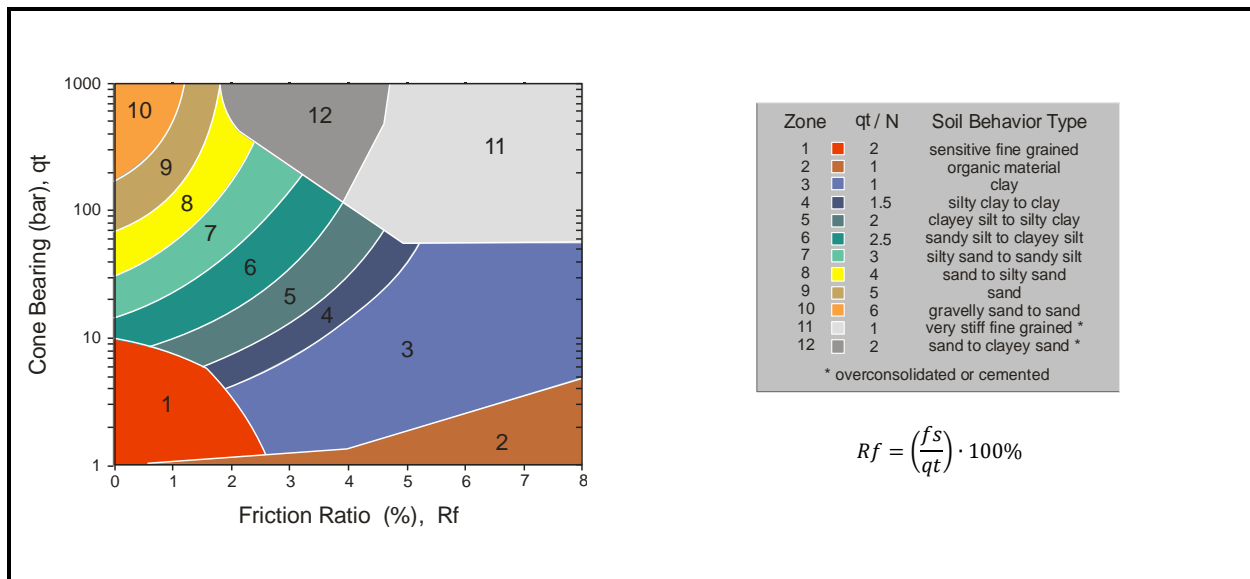

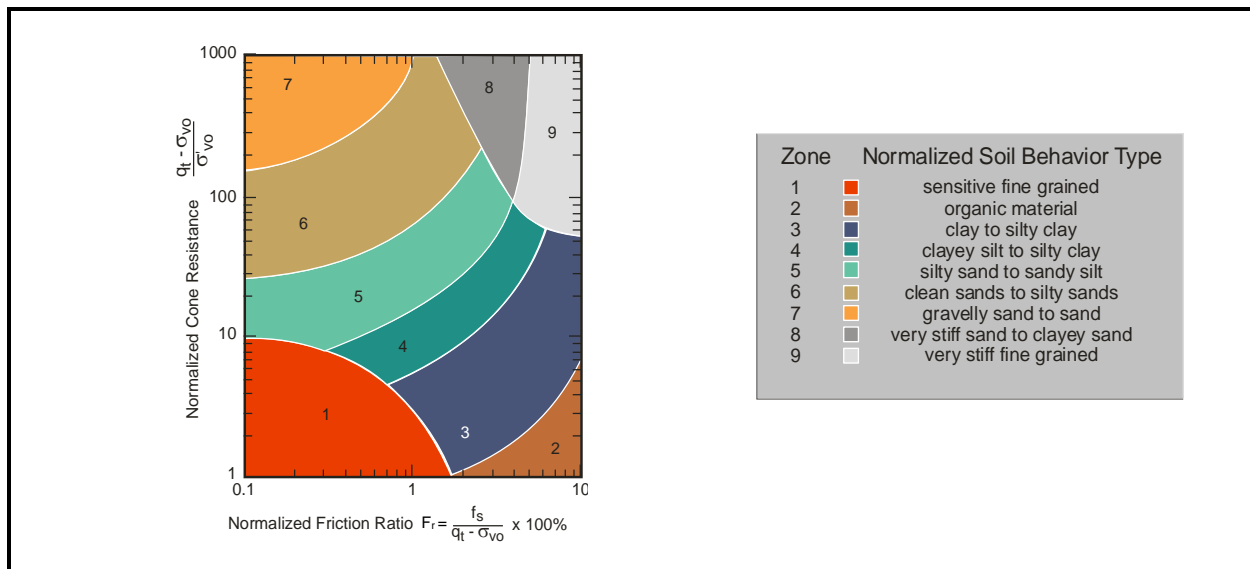Figure 1. Non-Normalized Soil Behavior Type Classification Chart (SBT)

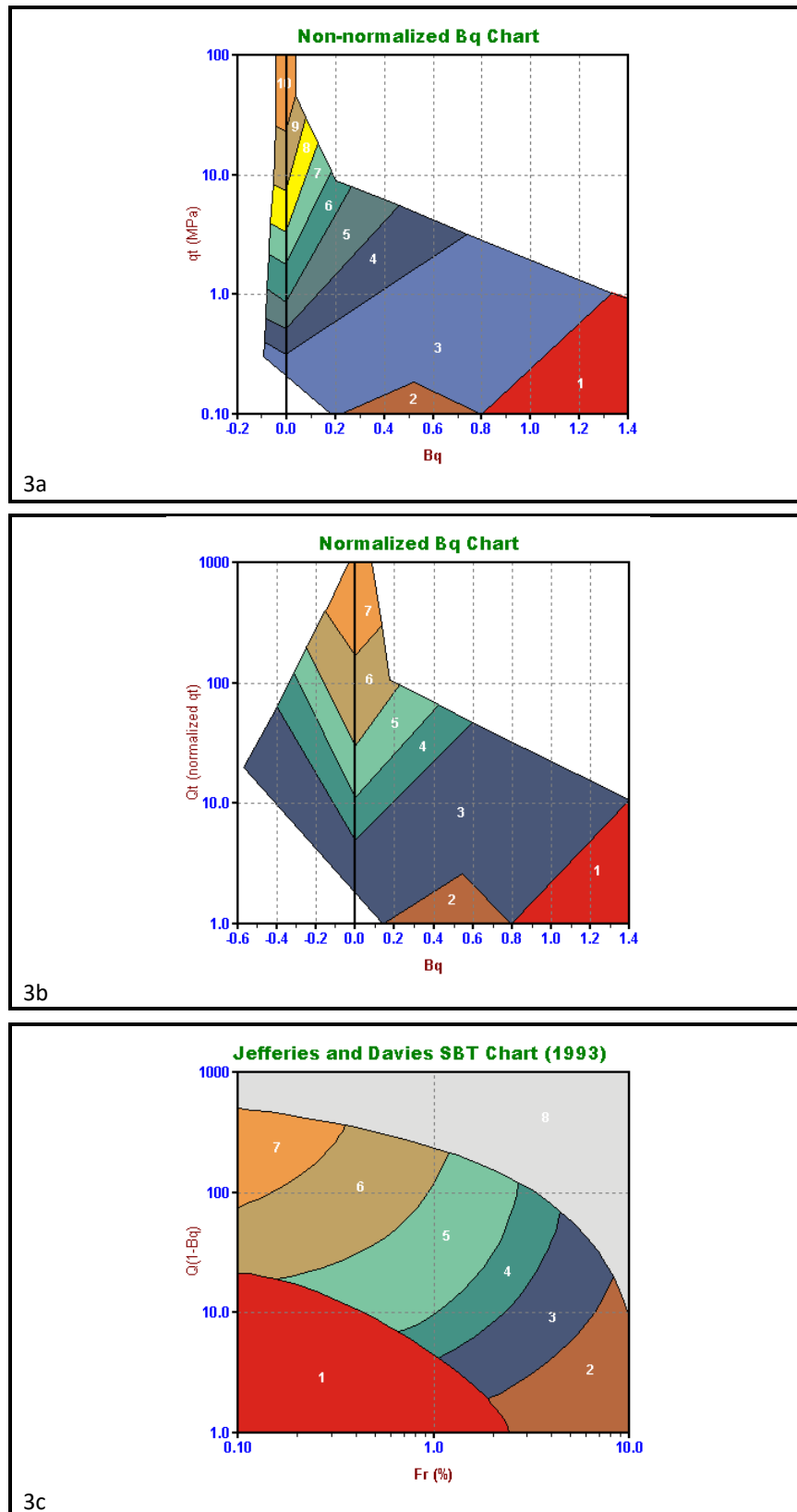Figure 2. Normalized Soil Behavior Type Classification Chart (SBTn)

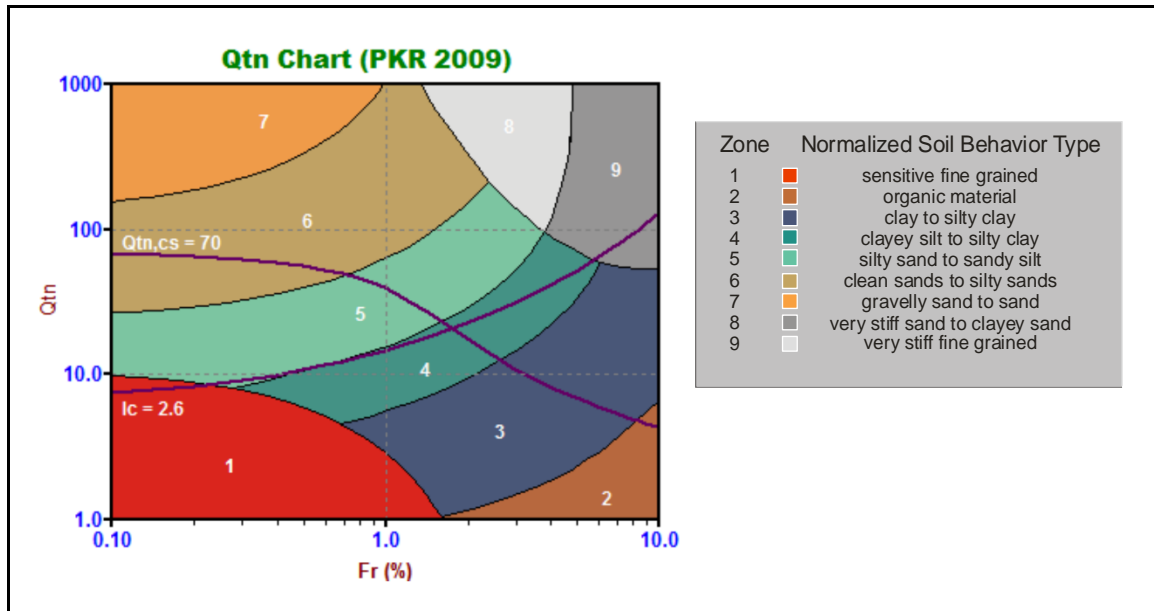Figure 3. Alternate Soil Behavior Type Charts

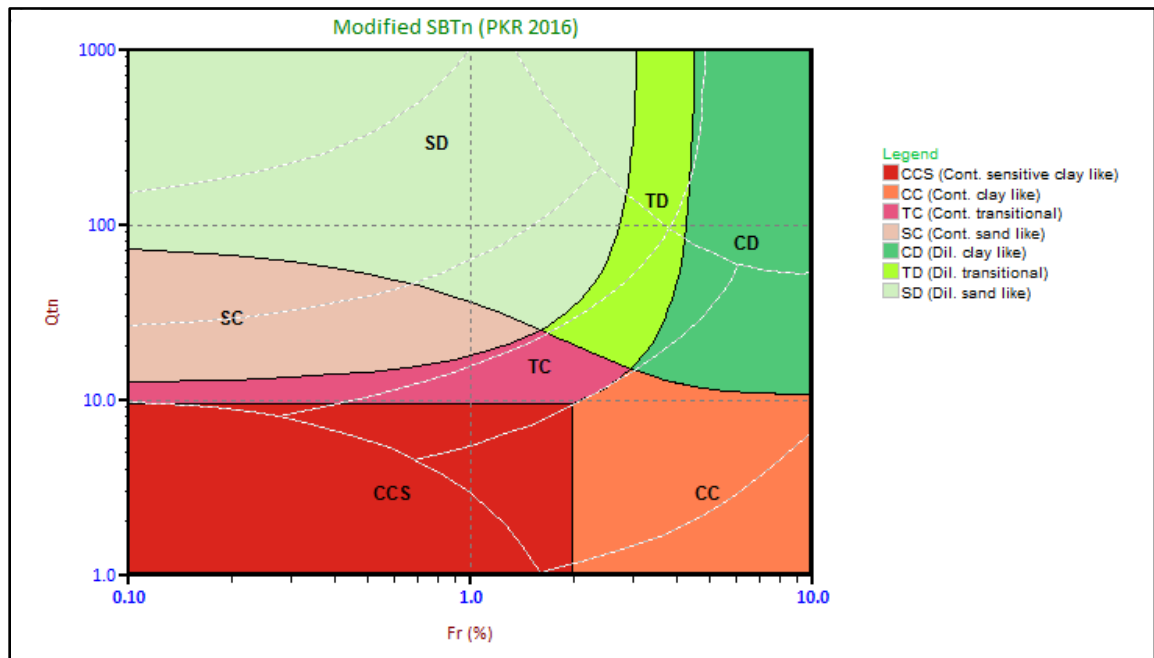Figure 4.   Normalized Soil Behavior Type Chart using Q$_{tn}$ (SBT Qtn)

Figure 5.   Modified SBTn Behavior Based Chart

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

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

CONETEC

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

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

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

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

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

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

The output files are typically provided in Microsoft Excel XLS or XLSX format. The ConeTec software has several options for output depending on the number or types of calculated parameters desired or requested by the client. Each output file is named using the original COR file base name followed by a three or four letter indicator of the output set selected (e.g. BSC, TBL, NLI, NL2, IFI, IFI2) and possibly followed by an operator selected suffix identifying the characteristics of the particular calculation run.

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

Calculated Parameter	Description	Equation	Ref
Depth	Mid Layer Depth *(where calculations are done at each point then Mid Layer Depth = Recorded Depth)*	*[Depth (Layer Top) + Depth (Layer Bottom)]/ 2.0*	CK*
Elevation	Elevation of Mid Layer based on sounding collar elevation supplied by client or through site survey	Elevation = Collar Elevation - Depth	CK*
Avg qc	Averaged recorded tip value (q_c)	$Avgqc = \dfrac{1}{n}\sum\limits_{i=1}^{n} q_c$ *n=1 when calculations are done at each point*	CK*
Avg qt	Averaged corrected tip (q_t) where: $q_t = q_c + (1-a) \bullet u_2$	$Avgqt = \dfrac{1}{n}\sum\limits_{i=1}^{n} q_t$ *n=1 when calculations are done at each point*	1
Avg fs	Averaged sleeve friction (f_s)	$Avgfs = \dfrac{1}{n}\sum\limits_{i=1}^{n} fs$ *n=1 when calculations are done at each point*	CK*
Avg Rf	Averaged friction ratio (R_f) where friction ratio is defined as: $Rf = 100\% \bullet \dfrac{fs}{q_t}$	$AvgRf = 100\% \cdot \dfrac{Avgfs}{Avgqt}$ *n=1 when calculations are done at each point*	CK*
Avg u	Averaged dynamic pore pressure *(u)*	$Avgu = \dfrac{1}{n}\sum\limits_{i=1}^{n} u_i$ *n=1 when calculations are done at each point*	CK*

Calculated Parameter	Description	Equation	Ref
Avg Res	Averaged Resistivity (this data is not always available since it is a specialized test requiring an additional module)	$AvgRes = \frac{1}{n}\sum_{i=1}^{n} Resistivity_i$ *n=1 when calculations are done at each point*	CK*
Avg UVIF	Averaged UVIF ultra-violet induced fluorescence (this data is not always available since it is a specialized test requiring an additional module)	$AvgUVIF = \frac{1}{n}\sum_{i=1}^{n} UVIF_i$ *n=1 when calculations are done at each point*	CK*
Avg Temp	Averaged Temperature (this data is not always available since it requires specialized calibrations)	$AvgTemp = \frac{1}{n}\sum_{i=1}^{n} Temperature_i$ *n=1 when calculations are done at each point*	CK*
Avg Gamma	Averaged Gamma Counts (this data is not always available since it is a specialized test requiring an additional module)	$AvgGamma = \frac{1}{n}\sum_{i=1}^{n} Gamma_i$ *n=1 when calculations are done at each point*	CK*
SBT	Soil Behavior Type as defined by Robertson et al 1986 (often referred to as Robertson and Campanella, 1986)	See Figure 1	1, 5
SBTn	Normalized Soil Behavior Type as defined by Robertson 1990 (linear normalization)	See Figure 2	2, 5
SBT-Bq	Non-normalized Soil Behavior type based on the Bq parameter	See Figure 3	1, 2, 5
SBT-Bqn	Normalized Soil Behavior based on the Bq parameter	See Figure 3	2, 5
SBT-JandD	Soil Behavior Type as defined by Jeffries and Davies	See Figure 3	7
SBT Qtn	Soil Behavior Type as defined by Robertson (2009) using a variable stress ratio exponent for normalization based on I_c	See Figure 4	15
Modified SBTn (contractive /dilative)	Modified SBTn chart as defined by Robertson (2016) indicating zones of contractive/dilative behavior.	See Figure 5	30
Unit Wt.	Unit Weight of soil determined from one of the following user selectable options: 1) uniform value 2) value assigned to each SBT zone 3) value assigned to each SBTn zone 4) value assigned to SBTn zone as determined from Robertson and Wride (1998) based on q_{c1n} 5) values assigned to SBT Qtn zones 6) Mayne fs (sleeve friction) method 7) Robertson 2010 method 8) user supplied unit weight profile The last option may co-exist with any of the other options	See references	3, 5, 15, 21, 24, 29

CONETEC

Calculated Parameter	Description	Equation	Ref
TStress σ_v	Total vertical overburden stress at Mid Layer Depth *A layer is defined as the averaging interval specified by the user where depths are reported at their respective mid-layer depth.* *For data calculated at each point layers are defined using the recorded depth as the mid-point of the layer. Thus, a layer starts half-way between the previous depth and the current depth unless this is the first point in which case the layer start is at zero depth. The layer bottom is half-way from the current depth to the next depth unless it is the last data point.* *Defining layers affects how stresses are calculated since the unit weight attributed to a data point is used throughout the entire layer. This means that to calculate the stresses the total stress at the top and bottom of a layer are required. The stress at mid layer is determined by adding the incremental stress from the layer top to the mid-layer depth. The stress at the layer bottom becomes the stress at the top of the subsequent layer. Stresses are NOT calculated from mid-point to mid-point.* *For over-water work the total stress due to the column of water above the mud line is taken into account where appropriate.*	$$TStress = \sum_{i=1}^{n} \gamma_i h_i$$ *where* γ is layer unit weight h_i is layer thickness	CK*
EStress $\sigma_v{}'$	Effective vertical overburden stress at mid-layer depth	$\sigma_v{}' = \sigma_v - u_{eq}$	CK*

Equil u
u_{eq} or u_0
	Equilibrium pore pressure determined from one of the following user selectable options:
	
	    1) hydrostatic below water table
	    2) user supplied profile
	    3) combination of those above
	
	When a user supplied profile is used/provided a linear interpolation is performed between equilibrium pore pressures defined at specific depths. If the profile values start below the water table then a linear transition from zero pressure at the water table to the first defined pointed is used.
	
	Equilibrium pore pressures may come from dissipation tests, adjacent piezometers or other sources. Occasionally, an extra equilibrium point ("assumed value") will be provided in the profile that does not come from a recorded value to smooth out any abrupt changes or to deal with material interfaces. These "assumed" values will be indicated on our plots and in tabular summaries.
		For hydrostatic option:
		
		$u_{eq} = \gamma_w \cdot (D - D_{wt})$
		where u_{eq} is equilibrium pore pressure
		        γ_w is unit weight of water
		        D is the current depth
		        D_{wt} is the depth to the water table
			CK*

K_0	Coefficient of earth pressure at rest, K_0	$K_0 = (1 - sin\Phi')\,OCR^{\,sin\Phi'}$	17
C_n	Overburden stress correction factor used for $(N_1)_{60}$ and older CPT parameters	$C_n = (P_a/\sigma_v{}')^{0.5}$ *where $0.0 < C_n < 2.0$ (user adjustable, typically 1.7)* *P_a is atmospheric pressure (100 kPa)*	12
C_q	Overburden stress normalizing factor	$C_q = 1.8 / (0.8 + (\sigma_v{}'/P_a))$ *where $0.0 < C_q < 2.0$ (user adjustable)* *P_a is atmospheric pressure (100 kPa)*	3, 12

CONETEC

Calculated Parameter	Description	Equation	Ref
N_{60}	SPT N value at 60% energy calculated from q_t/N ratios assigned to each SBT zone. This method has abrupt N value changes at zone boundaries.	*See Figure 1*	5
$(N1)60$	SPT N_{60} value corrected for overburden pressure	$(N_1)_{60} = C_n \cdot N_{60}$	4
$N60Ic$	SPT N_{60} values based on the I_c parameter [as defined by Roberston and Wride 1998 (5), or by Robertson 2009 (15)].	$(q_t/P_a)/ N_{60} = 8.5 (1 - I_c/4.6)$ $(q_t/P_a)/ N_{60} = 10^{(1.1268 - 0.2817Ic)}$ Pa being atmospheric pressure	5 15, 31
$(N1)60Ic$	SPT N_{60} value corrected for overburden pressure (using N_{60} I_c). User has 3 options.	1) $(N_1)_{60}Ic = C_n \cdot (N_{60} Ic)$ 2) $q_{c1n}/ (N_1)_{60}Ic = 8.5 (1 - I_c/4.6)$ 3) $(Q_{tn})/ (N_1)_{60}Ic = 10^{(1.1268 - 0.2817Ic)}$	4 5 15, 31
Su or Su (Nkt)	Undrained shear strength based on q_t S_u factor N_{kt} is user selectable	$Su = \dfrac{qt - \sigma_v}{N_{kt}}$	1, 5
Su or Su (Ndu)	Undrained shear strength based on pore pressure S_u factor $N_{\Delta u}$ is user selectable	$Su = \dfrac{u_2 - u_{eq}}{N_{\Delta u}}$	1, 5
Dr	Relative Density determined from one of the following user selectable options: a) Ticino Sand b) Hokksund Sand c) Schmertmann (1978) d) Jamiolkowski (1985) - All Sands e) Jamiolkowski et al (2003) (various compressibilities, K_o)	See reference (methods a through d) Jamiolkowski et al (2003) reference	5 14
PHI ϕ	Friction Angle determined from one of the following user selectable options (methods a through d are for sands and method e is for silts and clays): a) Campanella and Robertson b) Durgunoglu and Mitchel c) Janbu d) Kulhawy and Mayne e) NTH method (clays and silts)	See appropriate reference	5 5 5 11 23
Delta U/qt	Differential pore pressure ratio (older parameter used before B_q was established)	$= \dfrac{\Delta u}{qt}$ where: $\Delta u = u - u_{eq}$ and u = dynamic pore pressure u_{eq} = equilibrium pore pressure	CK*
Bq	Pore pressure parameter	$Bq = \dfrac{\Delta u}{qt - \sigma_v}$ where : $\Delta u = u - u_{eq}$ and u = dynamic pore pressure u_{eq} = equilibrium pore pressure	1, 2, 5
Net qt or qtNet	Net tip resistance (used in many subsequent correlations)	$qt - \sigma_v$	CK*
qe	Effective tip resistance (using the dynamic pore pressure u_2 and not equilibrium pore pressure)	$qt - u_2$	CK*

CONETEC

Calculated Parameter	Description	Equation	Ref
qeNorm	Normalized effective tip resistance	$\dfrac{qt - u_2}{\sigma_v'}$	CK*
Q_t or Norm: Qt	Normalized q_t for Soil Behavior Type classification as defined by Robertson (1990) using a linear stress normalization. Note this is different from Q_{tn}.	$Qt = \dfrac{qt - \sigma_v}{\sigma_v'}$	2, 5
F_r or Norm: Fr	Normalized Friction Ratio for Soil Behavior Type classification as defined by Robertson (1990)	$Fr = 100\% \cdot \dfrac{fs}{qt - \sigma_v}$	2, 5
Q(1-Bq)	Q(1-Bq) grouping as suggested by Jefferies and Davies for their classification chart and the establishment of their I_c parameter	$Q \cdot (1 - Bq)$ *where Bq is defined as above and Q is the same as the normalized tip resistance, Q_t, defined above*	6, 7
qc1	Normalized tip resistance, q_{c1}, using a fixed stress ratio exponent, n (this method has stress units)	$q_{c1} = q_t \cdot (Pa/\sigma_v')^{0.5}$ where: Pa = atmospheric pressure	21
qc1 (0.5)	Normalized tip resistance, q_{c1}, using a fixed stress ratio exponent, n (this method is unit-less)	$q_{c1}(0.5) = (q_t/P_a) \cdot (Pa/\sigma_v')^{0.5}$ where: Pa = atmospheric pressure	5
qc1 (Cn)	Normalized tip resistance, q_{c1}, based on C_n (this method has stress units)	$q_{c1}(Cn) = C_n * q_t$	5, 12
qc1 (Cq)	Normalized tip resistance, q_{c1}, based on C_q (this method has stress units)	$q_{c1}(Cq) = C_q * q_t$ (some papers use q_c)	5, 12
qc1n	normalized tip resistance, q_{c1n}, using a variable stress ratio exponent, n (where n=0.0, 0.70, 1.0) (this method is unit-less)	$q_{c1n} = (q_t / P_a)(P_a/\sigma_v')^n$ where: P_a = atm. Pressure and n varies as described below	3, 5
I_c or Ic (RW1998)	Soil Behavior Type Index as defined by Robertson and Fear (1995) and Robertson and Wride (1998) for estimating grain size characteristics and providing smooth gradational changes across the SBTn chart	$I_c = [(3.47 - \log_{10}Q)^2 + (\log_{10} Fr + 1.22)^2]^{0.5}$ *Where:* $\quad Q = \left(\dfrac{qt - \sigma_v}{P_a}\right)\left(\dfrac{P_a}{\sigma_v'}\right)^n$ *Or* $\quad Q = q_{c1n} = \left(\dfrac{qt}{P_a}\right)\left(\dfrac{P_a}{\sigma_v'}\right)^n$ *depending on the iteration in determining I_c* *And* Fr is in percent $\quad\quad$ P_a = atmospheric pressure *n varies between 0.5, 0.70 and 1.0 and is selected in an iterative manner based on the resulting I_c*	3, 5, 21
Ic (PKR 2009)	Soil Behavior Type Index, I_c (PKR 2009) based on a variable stress ratio exponent n, which itself is based on I_c (PKR 2009). An iterative calculation is required to determine Ic (PKR 2009) and its corresponding n (PKR 2009).	I_c (PKR 2009) = $[(3.47 - \log_{10}Q_{tn})^2 + (1.22 + \log_{10}F_r)^2]^{0.5}$	15

CONETEC

Calculated Parameter	Description	Equation	Ref
n (PKR 2009)	Stress ratio exponent n, based on I_c (PKR 2009). An iterative calculation is required to determine n (PKR 2009) and its corresponding Ic (PKR 2009).	$n\ (PKR\ 2009) = 0.381\ (I_c) + 0.05\ (\sigma_v'/P_a) – 0.15$	15
Qtn (PKR 2009)	Normalized tip resistance using a variable stress ratio exponent based on I_c (PKR 2009) and n (PKR 2009). An iterative calculation is required to determine Qtn (PKR 2009).	$Q_{tn} = [(qt - \sigma_v)/P_a](P_a/\sigma_v')^n$ where P_a = atmospheric pressure (100 kPa) n = stress ratio exponent described above	15
FC	Apparent fines content (%)	$FC=1.75(Ic^{3.25}) - 3.7$ $FC=100$ for $I_c > 3.5$ $FC=0$ for $I_c < 1.26$ $FC = 5\%$ if $1.64 < I_c < 2.6$ AND $F_r<0.5$	3
I_c Zone	This parameter is the Soil Behavior Type zone based on the I_c parameter (valid for zones 2 through 7 on SBTn or SBT Qtn charts)	$I_c < 1.31$ Zone = 7 $1.31 < I_c < 2.05$ Zone = 6 $2.05 < I_c < 2.60$ Zone = 5 $2.60 < I_c < 2.95$ Zone = 4 $2.95 < I_c < 3.60$ Zone = 3 $I_c > 3.60$ Zone = 2	3
State Param or State Parameter or ψ	The state parameter index, ψ, is defined as the difference between the current void ratio, e, and the critical void ratio, e_c. Positive ψ - contractive soil Negative ψ - dilative soil This is based on the work by Been and Jefferies (1985) and Plewes, Davies and Jefferies (1992) - vertical effective stress is used rather than a mean normal stress	See reference	6, 8
Yield Stress σ_p'	Yield stress is calculated using the following methods a) General method b) 1st order approximation using q_tNet (clays) c) 1st order approximation using Δu_2 (clays) d) 1st order approximation using q_e (clays)	All stresses in kPa a) $\sigma_p'= 0.33\cdot(q_t – \sigma_v)^{m'}\ (\sigma_{atm}/100)^{1-m'}$ where $\quad m'=1-\dfrac{0.28}{1+(I_c/2.65)^{25}}$ b) $\sigma_p' = 0.33\cdot(q_t – \sigma_v)$ c) $\sigma_p' = 0.54\cdot (\Delta u_2)$ $\Delta u_2 = u_2 – u_0$ d) $\sigma_p' = 0.60 \cdot (q_t – u_2)$	19 20 20 20
OCR OCR(JS1978) OCR(Mayne2014) OCR (qtNet) OCR (deltaU) OCR (qe) OCR (Vs) OCR (PKR2015)	Over Consolidation Ratio based on a) Schmertmann (1978) method involving a plot plot of S_u/σ_v' /(S_u/σ_v')$_{NC}$ and OCR b) based on Yield stresses described above c) approximate version based on qtNet d) approximate version based on Δu e) approximate version based on effective tip, q_e f) approximate version based on shear wave velocity, V_s g) based on Qt	 a) requires a user defined value for NC S_u/P_c' ratio b through f) *based on yield stresses* g) OCR = $0.25\cdot(Qt)^{1.25}$	 9 19 20 20 20 18 32

Calculated Parameter	Description	Equation	Ref
Es/qt	Intermediate parameter for calculating Young's Modulus, E, in sands. It is the Y axis of the reference chart.	Based on Figure 5.59 in the reference	5
Es Young's Modulus E	Young's Modulus based on the work done in Italy. There are three types of sands considered in this technique. The user selects the appropriate type for the site from: a) OC Sands b) Aged NC Sands c) Recent NC Sands Each sand type has a family of curves that depend on mean normal stress. The program calculates mean normal stress and linearly interpolates between the two extremes provided in the E_s/q_t chart. Es is evaluated for an axial strain of 0.1%.	Mean normal stress is evaluated from: $$\sigma_m^{'} = \frac{1}{3}\left(\sigma_v^{'} + \sigma_h^{'} + \sigma_h^{'}\right)^3$$ where σ_v' = vertical effective stress σ_h' = horizontal effective stress and $\sigma_h = K_o \cdot \sigma_v'$ with K_o assumed to be 0.5	5
Delta U/TStress	Differential pore pressure ratio with respect to total stress	$= \dfrac{\Delta u}{\sigma_v}$ where: $\Delta u = u - u_{eq}$	CK*
Delta U/Estress, P Value, Excess Pore Pressure Ratio	Differential pore pressure ratio with respect to effective stress. Key parameter (P, Normalized Pore Pressure Parameter, Excess Pore Pressure Ratio) in the Winckler et. al. static liquefaction method.	$= \dfrac{\Delta u}{\sigma_v^{'}}$ where: $\Delta u = u - u_{eq}$	25, 25a, CK*
Su/EStress	Undrained shear strength ratio with respect to vertical effective overburden stress using the S_u (N_{kt}) method	$= Su \, (N_{kt}) \, / \, \sigma_v'$	CK*
Gmax	G_{max} determined from SCPT shear wave velocities (not estimated values)	$G_{max} = \rho V_s^2$ where ρ is the mass density of the soil determined from the estimated unit weights at each test depth	27
qtNet/Gmax	Net tip resistance ratio with respect to the small strain modulus G_{max} determined from SCPT shear wave velocities (not estimated values)	$= (qt - \sigma_v) / G_{max}$ where $G_{max} = \rho V_s^2$ and ρ is the mass density of the soil determined from the estimated unit weights at each test depth	15, 28, 30

*CK – common knowledge

Table 1b. CPT Parameter Calculation Methods – Liquefaction Parameters

Calculated Parameter	Description	Equation	Ref
K_{SPT}	Equivalent clean sand factor for $(N_1)60$	$K_{SPT} = 1 + ((0.75/30) \cdot (FC - 5))$	10
K_{CPT} or K_C (RW1998)	Equivalent clean sand correction for q_{c1N}	$K_{cpt} = 1.0$ for $I_c \leq 1.64$ $K_{cpt} = f(I_c)$ for $I_c > 1.64$ (see reference) $K_c = -0.403\, I_c^4 + 5.581\, I_c^3 - 21.63 I_c^2 + 33.75\, I_c - 17.88$	3, 10
Kc (PKR 2010)	Clean sand equivalent factor to be applied to Q_{tn}	$K_c = 1.0$ for $I_c \leq 1.64$ $K_c = -0.403\, I_c^4 + 5.581\, I_c^3 - 21.63 I_c^2 + 33.75\, I_c - 17.88$ for $I_c > 1.64$	16
$(N_1)_{60cs}Ic$	Clean sand equivalent SPT $(N_1)_{60}I_c$. User has 3 options.	1) $(N_1)_{60cs}Ic = \alpha + \beta((N_1)_{60}I_c)$ 2) $(N_1)_{60cs}Ic = K_{SPT} * ((N_1)_{60}I_c)$ 3) $(q_{c1ncs})/(N_1)_{60cs}Ic = 8.5\,(1 - I_c/4.6)$ $FC \leq 5\%$: $\alpha = 0$, $\beta = 1.0$ $FC \geq 35\%$ $\alpha = 5.0$, $\beta = 1.2$ $5\% < FC < 35\%$ $\alpha = exp[1.76 - (190/FC^2)]$ $\beta = [0.99 + (FC^{1.5}/1000)]$	10 10 5
q_{c1ncs}	Clean sand equivalent q_{c1n}	$q_{c1ncs} = q_{c1n} \cdot K_{cpt}$	3
Qtn,cs (PKR 2010)	Clean sand equivalent for Q_{tn} described above - Q_{tn} being the normalized tip resistance based on a variable stress exponent as defined by Robertson (2009)	$Q_{tn,cs} = Q_{tn} \cdot K_c$ (PKR 2016)	16
Su(Liq)/ESv	Liquefied shear strength ratio as defined by Olson and Stark	$\dfrac{Su(Liq)}{\sigma_v'} = 0.03 + 0.0143(q_{c1})$ Note: σ_v' and s_v' are synonymous	13
Su(Liq)/ESv (PKR 2010)	Liquefied shear strength ratio as defined by Robertson (2010)	$\dfrac{Su(Liq)}{\sigma_v'}$ Based on a function involving $Q_{tn,cs}$	16
Su (Liq) (PKR 2010)	Liquefied shear strength derived from the liquefied shear strength ratio and effective overburden stress		16
Cont/Dilat Tip	Contractive / Dilative qc1 Boundary based on $(N_1)_{60}$	$(\sigma_v')_{boundary} = 9.58 \times 10^{-4}\, [(N_1)_{60}]^{4.79}$ $qc1$ is calculated from specified $qt(MPa)/N$ ratio	13
CRR	Cyclic Resistance Ratio (for Magnitude 7.5)	$q_{c1ncs} < 50$: $CRR_{7.5} = 0.833\,[q_{c1ncs}/1000] + 0.05$ $50 \leq q_{c1ncs} < 160$: $CRR_{7.5} = 93\,[q_{c1ncs}/1000]^3 + 0.08$	10
Kg	Small strain Stiffness Ratio Factor, Kg	$[Gmax/qt]/[qc1n^{-m}]$ m = empirical exponent, typically 0.75	26

CONETEC

Calculated Parameter	Description	Equation	Ref
SP Distance	State Parameter Distance, Winckler static liquefaction method	Perpendicular distance on Qtn chart from plotted point to state parameter Ψ = -0.05 curve	25
URS NP Fr	Normalized friction ratio point on Ψ = -0.05 curve used in SP Distance calculation		25
URS NP Qtn	Normalized tip resistance (Qtn) point on Ψ = -0.05 curve used in SP Distance calculation		25

CONETEC

Table 2. References

No.	Reference
1	Robertson, P.K., Campanella, R.G., Gillespie, D. and Greig, J., 1986, "Use of Piezometer Cone Data", Proceedings of InSitu 86, ASCE Specialty Conference, Blacksburg, Virginia.
2	Robertson, P.K., 1990, "Soil Classification Using the Cone Penetration Test", Canadian Geotechnical Journal, Volume 27. This includes the discussions and replies.
3	Robertson, P.K. and Wride (Fear), C.E., 1998, "Evaluating cyclic liquefaction potential using the cone penetration test", Canadian Geotechnical Journal, 35: 442-459.
4	Robertson, P.K. and Wride, C.E., 1997, "Cyclic Liquefaction and its Evaluation Based on SPT and CPT", NCEER Workshop Paper, January 22, 1997.
5	Lunne, T., Robertson, P.K. and Powell, J. J. M., 1997, " Cone Penetration Testing in Geotechnical Practice," Blackie Academic and Professional.
6	Plewes, H.D., Davies, M.P. and Jefferies, M.G., 1992, "CPT Based Screening Procedure for Evaluating Liquefaction Susceptibility", 45th Canadian Geotechnical Conference, Toronto, Ontario, October 1992.
7	Jefferies, M.G. and Davies, M.P., 1993, "Use of CPTu to Estimate equivalent N_{60}", Geotechnical Testing Journal, 16(4): 458-467.
8	Been, K. and Jefferies, M.P., 1985, "A state parameter for sands", Geotechnique, 35(2), 99-112.
9	Schmertmann, 1978, "Guidelines for Cone Penetration Test Performance and Design", Federal Highway Administration Report FHWA-TS-78-209, U.S. Department of Transportation.
10	Proceedings of the NCEER Workshop on Evaluation of Liquefaction Resistance of Soils, Salt Lake City, 1996, chaired by Leslie Youd.
11	Kulhawy, F.H. and Mayne, P.W., 1990, "Manual on Estimating Soil Properties for Foundation Design, Report No. EL-6800", Electric Power Research Institute, Palo Alto, CA, August 1990, 306 p.
12	Olson, S.M. and Stark, T.D., 2002, "Liquefied strength ratio from liquefied flow failure case histories", Canadian Geotechnical Journal, 39: 951-966.
13	Olson, Scott M. and Stark, Timothy D., 2003, "Yield Strength Ratio and Liquefaction Analysis of Slopes and Embankments", Journal of Geotechnical and Geoenvironmental Engineering, ASCE, August 2003.
14	Jamiolkowski, M.B., Lo Presti, D.C.F. and Manassero, M., 2003, "Evaluation of Relative Density and Shear Strength of Sands from CPT and DMT", Soil Behaviour and Soft Ground Construction, ASCE, GSP N0. 119, 201-238.
15	Robertson, P.K., 2009, "Interpretation of cone penetration tests – a unified approach", Canadian Geotechnical Journal, 46: 1337-1355.
16	Robertson, P.K., 2010, "Evaluation of Flow Liquefaction and Liquefied Strength Using the Cone Penetration Test", Journal of Geotechnical and Geoenvironmental Engineering, ASCE, June 2010.
17	Mayne, P.W. and Kulhawy, F.H., 1982, "Ko-OCR Relationships in Soil", Journal of the Geotechnical Engineering Division, ASCE, Vol. 108, GT6, pp. 851-872.
18	Mayne, P.W., Robertson P.K. and Lunne T., 1998, "Clay stress history evaluated from seismic piezocone tests", Proceedings of the First International Conference on Site Characterization – ISC '98, Atlanta Georgia, Volume 2, 1113-1118.

ConeTec

No.	Reference
19	Mayne, P.W., 2014, "Generalized CPT Method for Evaluating Yield Stress in Soils", Geocharacterization for Modeling and Sustainability (GSP 235: Proc. GeoCongress 2014, Atlanta, GA), ASCE, Reston, Virginia: 1336-1346.
20	Mayne, P.W., 2015, "Geocharacterization by In-Situ Testing", Continuing Education Course, Vancouver, BC, January 6-8, 2015.
21	Robertson, P.K. and Fear, C.E., 1995, "Liquefaction of sands and its evaluation", Proceedings of the First International Conference on Earthquake Engineering, Keynote Lecture IS Tokyo '95, Tokyo Japan, 1995.
22	Mayne, P.W., Peuchen, J. and Boumeester, D., 2010, "Soil unit weight estimation from CPTs", Proceeding of the 2nd International Symposium on Cone Penetration Testing (CPT '10), Vol 2, Huntington Beach, California; Omnipress: 169-176.
23	Mayne, P.W., 2007, "NCHRP Synthesis 368 on Cone Penetration Test", Transportation Research Board, National Academies Press, Washington, D.C., 118 pages.
24	Mayne, P.W., 2014, "Interpretation of geotechnical parameters from seismic piezocone tests.", Key note address #2, proceedings, 3rd International Symposium on Cone Penetration Testing (CPT'14, Las Vegas), ISSMGE Technical Committee TC102.
25	Winckler, Christina, Davidson, Richard, Yenne, Lisa, Pilz, Jorgen, 2014, "CPTu-Based State Characterization of Tailings Liquefaction Susceptibility", Tailings and Mine Waste, 2014.
25a	Winckler, Christina, Davidson, Richard, Yenne, Lisa, Pilz, Jorgen, 2014, "CPTu-Based State Characterization of Tailings Liquefaction Susceptibility", Powerpoint presentation, Tailings and Mine Waste, 2014.
26	Schneider, J.A. and Moss, R.E.S., 2011, "Linking cyclic stress and cyclic strain based methods for assessment of cyclic liquefaction triggering in sands", Geotechnique Letters 1, 31-36.
27	Rice, A., 1984, "The Seismic Cone Penetrometer", M.A.Sc. thesis submitted to the University of British Columbia, Dept. of Civil Engineering, Vancouver, BC, Canada.
28	Gillespie, D.G., 1990, "Evaluating Shear Wave Velocity and Pore Pressure Data from the Seismic Cone Penetration Test", Ph.D. thesis submitted to the University of British Columbia, Dept. of Civil Engineering, Vancouver, BC, Canada.
29	Robertson, P.K and Cabal, K.L., 2010, "Estimating soil unit weight from CPT", Proceedings of the 2nd International Symposium on Cone Penetration Testing (CPT '10), Huntington Beach, California.
30	Robertson, P.K., 2016, "Cone penetration test (CPT)-based soil behaviour type (SBT) classification system – an update", Canadian Geotechnical Journal, July 2016.
31	Robertson, P.K., 2012, "Interpretation of in-situ tests – some insights", Mitchell Lecture, ISC'4, Recife, Brazil.
32	Robertson, P.K., Cabal, K.L. 2015, "Guide to Cone Penetration Testing for Geotechnical Engineering", 6th Edition.