THURBER ENGINEERING LTD.

September 30, 2020 File: 26259

Westshore Terminals Limited Partnership
1 Roberts Bank
Delta BC V4M 4G5

Attention: Greg Andrew, P.Eng.
Director of Engineering and Environmental Services

BERTH 2 - BERTHING DOLPHIN REPLACEMENT PROJECT
WESTSHORT TERMINALS, ROBERTS BANK, DELTA, B.C.
GEOTECHNICAL ASSESSMENT

Dear Greg:

Thurber Engineering Ltd. (Thurber) is submitting this letter report that summarizes the findings of the offshore geotechnical investigation and provides geotechnical recommendations in support of the Berth 2 berthing dolphins replacement project at the Westshore Terminal in Roberts Bank, Delta, B.C. This report has been revised and supersedes our June 26, 2020 report.

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

1. INTRODUCTION

The Westshore Terminals is a coal export facility located in Roberts Bank in Delta, B.C. Westshore Terminal Limited Partnership (Westshore) is planning to upgrade Berth 2, located on the southeast side of the port, and replace the existing aging infrastructure. The project will be completed in multiple phases and includes the demolition of existing dolphins No. 1 and 5 (including catwalks) and installation of four new dolphins.

Westshore has retained CWA Engineers as the prime consultant and Thurber as the geotechnical consultant to provide detailed engineering design services for the replacement berthing dolphins project. In support of the preliminary design for the dolphin structures, Thurber completed a desktop assessment and provided geotechnical input for the lateral and axial design of the piled foundation. Further details on the desktop assessment and preliminary geotechnical recommendations can be found in our April 24, 2020 letter report.

In support of the detailed design for the dolphin structures, Thurber completed an offshore geotechnical investigation at Berth 2 to confirm the subsurface conditions assumed in the preliminary design stage. This report summarizes the findings of the offshore geotechnical investigation and provides geotechnical input for detailed design.

2. GEOLOGIC CONDITIONS

Westshore Terminals is located in Roberts Bank, within the Strait of Georgia. According to Mosher and Hamilton (1998) and Hart and Barrie (1995), the geology at Roberts Bank comprises Fraser delta sediments of varying thickness which drape underlying sediments. The Fraser River sediments are Holocene deposits and are primarily granular in composition (i.e. sand). The underlying sediments comprise a sequence of glaciomarine sediments (clays with ice-rafted debris) that were deposited during glacial retreat, Pleistocene glacial and interglacial deposits (primarily tills), and Tertiary and older sedimentary rocks.

3. OFFSHORE GEOTECHNICAL INVESTIGATION

The offshore geotechnical investigation was carried out between April 5 and 8, 2020, during a scheduled shutdown at Berth 2. Thurber retained Gregg Drilling and Testing Inc. (Gregg) and Geotech Drilling Canada (Geotech Drilling), subsidiaries of the Geotech Drilling Group of Companies, to complete the offshore geotechnical investigation.

The investigation was executed off a drilling barge and comprised the completion of two cone penetration test (CPT) soundings that were advanced using a 20-ton cone truck. The CPT obtains information on tip resistance, sleeve friction and pore water pressure which is used to evaluate soil behavior type and various soil properties using established correlations.

A sonic track rig was utilized to set the drill casing and drill rod to mud line ahead of the cone push to prevent CPT rod buckling. The sonic rig was also used for drill outs where an early refusal was encountered due to an obstruction, excessive rod flex or friction.

To account for tidal effects, the CPT soundings were surveyed at intermittent periods using a Leica GS15 Real Time Kinematic (RTK) Global Navigation Satellite System (GNSS). Position corrections were received from the Leica Smartnet network RTK base reference system. The survey instrument provided real-time global positioning in both horizontal and vertical directions accurate to +/-5 mm.

The CPT soundings, CPT 20-01 and 20-02, were advanced to El. -97.55 m and El. -93.85 m, respectively, where tip refusal was encountered and is inferred to be the top of the till-like soil deposit. Mudline was encountered at El. -24.45 m and El. -27.31 m at CPT 20-01 and 20-02, respectively. Figure 1 shows the as-built CPT locations and Gregg's CPT data report is included in Appendix A.

Gregg attempted to measure shear and compression wave velocities using a seismic hammer set at mudline level. However, reliable seismic measurements could not be recorded due to apparent ambient noise.

4. SUBSURFACE CONDITIONS

The CPT allows for the classification of the soil stratigraphy using various established methods that utilize the measured cone parameters (tip resistance, sleeve friction and pore pressure response) to identify the soil types and anticipated behaviour. The normalized Soil Behaviour Type (SBTn) method, which uses CPT parameters that are normalized to the effective stress, is considered more reliable for deeper CPT soundings as it accounts for the effect of the overburden pressure (Robertson, 2010).

The interpreted subsurface stratigraphy, using SBTn method, was found to be in general agreement with the findings of our desktop assessment that is summarized in our April 24, 2020 report. In general, the subsurface stratigraphy is inferred to comprise a sequence of Holocene Fraser deltaic materials, glaciomarine silty clays to clayey silts, over glacial till or till-like deposits.

The Holocene Fraser deltaic deposit is inferred to comprise sand with variable silt content ranging from trace silt to silty. The deposit is also inferred to include interbedded silt and clay layers that are typically less than 300 mm thick, except near the bottom of the deposit where silt and clay layers measuring 2.5 m and 4 m thick in CPT 20-01 and 20-02, respectively, were encountered. The deposit is characterized as loose to compact with relative densities of approximately 30% to 50%. The silt and clay lenses are characterized as low plastic (Golder, 2011) with a low sensitivity. The Fraser deltaic sediments extended to depths of 64 m and 58 m (El. -88.45 m and El. 85.3 m) at CPT 20-01 and 20-02, respectively.

The glaciomarine silty clays to clayey silt deposit was 8.5 m and 8 m thick at CPT 20-01 and 20-02, respectively. The deposit is characterized as low to high sensitivity, low to medium plastic and normally to lightly over-consolidated (Golder, 2011).

The CPT soundings encountered tip refusal at the termination depths, and it is inferred that till-like material was encountered at that depth.

5. DESIGN AND CONSTRUCTION CONSIDERATIONS

As the construction of the replacement berthing dolphins will require a complete shutdown of Berth 2, the design of the replacement infrastructure must incorporate a strategy that will minimize the shutdown period. One of the key aspects that will likely govern the shutdown duration is pile installation, particularly where splicing of several pile segments is required. The pile installation duration can be reduced by eliminating or limiting the number of field splices. It is our understanding that CWA has had discussions with several foundation contractors regarding the possibility of handling up to 75 m long pile sections using locally available cranes and barges.

Considering the proposed pile group arrangements of the dolphin structures (see attached preliminary structural drawings in Appendix B), the depth to mudline (~El. -14.3 m at the rear piles and El. -17.8 m at the front piles) and the relative design elevation of the berthing dolphins (top of pile at El. 4.2 m), it is expected that a maximum vertical pile embedment of about 51 m could be achieved with a single 75 m long pipe section.

5.1 Seismic Considerations

Seismic performance is a key design consideration for the proposed replacement structures. It is our understanding that the seismic performance criteria for the project requires the replacement structures be designed to be repairable following a 1:475 year earthquake event and for collapse-prevention in a 1:2,475 year earthquake event.

6. GEOTECHNICAL ASSESSMENT

The subsurface stratigraphy is inferred to comprise a sequence of Holocene Fraser deltaic deposits to about 58 m to 64 m depth below mudline, over glaciomarine silty clays to clayey silts underlain by Pleistocene (glacial till) deposits. As the maximum vertical embedment depths of the piles will likely be limited to about 51 m (El. -67 m for the rear piles and El. -69.3 m for the front piles) as indicated in Section 5, they will be founded entirely in the Holocene Fraser deltaic deposits.

Provided below are the seismic assessment results which include site-specific response and liquefaction analyses, design response spectra for the evaluation of inertial loading, and axial and lateral pile analyses under static and kinematic seismic loading conditions.

7. SEISMIC ASSESSMENT

Seismic assessment includes the completion of a liquefaction triggering analysis to evaluate potential kinematic loading on the foundation and developing a hazard response spectrum to evaluate inertial loading on the foundation. To complete the above analyses, spectral and peak ground accelerations are determined using the 2015 National Building Code of Canada Seismic Hazard Calculator from the Natural Resources Canada website. These accelerations conform to Site Class C conditions and are adjusted using the coefficients provided in Tables 4.1.8.4-B to 4.1.8.4-I of the 2015 National Building Code of Canada (NBCC) for different site classifications.

As the Holocene Fraser deltaic deposits are known to be susceptible to liquefaction under seismic loading, a Site Class F classification is applicable which requires the completion of a site-specific response analysis (SSRA) to establish the peak ground acceleration and cyclic stress ratio profile for liquefaction triggering assessment, and spectral accelerations for evaluation of the inertial loading.

7.1 Site-Specific Response Analysis

SSRAs for the 1:475 year and 1:2,475 year earthquake events were carried out using the software program DEEPSOIL published by the University of Illinois. The analyses were completed using the equivalent-linear model and the Darendeli (2001) reference curves for both the sand and clay layers.

The analyses used the earthquake motion records developed for the George Massey Tunnel replacement (GMTR) project. A total of 33 motion records, 11 records for each of the three earthquake sources (crustal, inslab and interface [i.e. Cascadia subduction event]) were used for the SSRA. The earthquake motion records were linearly scaled using the ratio of the PGA at the Westshore Terminals site to that at the GMTR site. The scaling factors for the 1:475 year and 1:2,475 year earthquake events are summarized in Table 1 below.

Table 1 - Linear Scaling Factor for Earthquake Motion Records

Project	**PGA for 1:2,475-Year Earthquake Event**	**PGA for 1:475-Year Earthquake Event**
	(g)	**(g)**
GMTR project	0.387	0.202
Westshore Terminals	0.422	0.224
Ratio of PGA for Linear Scaling	**1.09**	**1.11**

The maximum stress ratio profiles for the crustal, inslab, and interface earthquake sources are summarized in Appendix C.

Appendix C also includes the recommended 5% damped design response spectra for the 1:475 and 1:2,475 year earthquake events at different embedment depths (see Figures 4 and 5). The figures present the response spectra for selected earthquakes that contribute to the short and long-period hazard at the site (crustal earthquakes, inslab earthquakes and subduction earthquakes). The 2015 NBCC recommended envelope for Site Class E is also plotted for comparison purposes.

7.2 Liquefaction Assessment

Liquefaction triggering assessments are commonly carried out using a stress-based approach, where the earthquake-induced cyclic shear stresses, defined as the Cyclic Stress Ratio (CSR), are compared against the cyclic resistance of the soil, defined as the Cyclic Resistance Ratio (CRR). In general, if the CSR is greater than the CRR, then the soil is considered to be susceptible to liquefaction.

CRR is typically evaluated using semi-empirical relationships that correlate the in-situ CRR of sand and the results of in-situ tests (Idriss and Boulanger, 2008). The earthquake-induced CSR is typically evaluated using the Seed-Idriss simplified procedure. However, this procedure is only recommended for depths not exceeding 34 m. For relatively thick deposits, it is recommended that the CSR be evaluated using a site-specific response analysis (SSRA) (Idriss and Boulanger, 2008). Considering the subsurface stratigraphy at the Site, the CSR profiles for liquefaction triggering assessment were evaluated based on the results of the SSRA.

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The liquefaction assessment was carried out using the software program CLiq (v.2.2.1.4), published by Geologismiki. The assessment followed the methods described by Idriss and Boulanger (2008 and 2014) to evaluate the CRR profiles. The CSR profiles were evaluated using the maximum stress ratio profiles developed from the SSRAs that were multiplied by a 0.65 reference stress level factor (Idriss and Boulanger, 2008). The CRR and CSR profiles were evaluated using a moment magnitude of 7.1 for the crustal and inslab earthquake sources and 9 for the interface earthquake source. Appendix D provides the liquefaction triggering assessment output results for the different earthquake sources and for the 1:475 year and 1:2,475 year earthquake events. The output results include the CSR versus CRR profiles, and the Factor of Safety (FoS) versus depth plots. The FoS is the ratio of CSR to CRR, which indicates liquefaction potential for values less than 1.

The liquefaction assessment indicates depths of liquefaction of 14 m and 47 m under the 1:475 year and 1:2,475 year earthquake events, with the whole soil columns likely experiencing liquefaction and loss of strength. Further, the assessment indicates the potential for limited zones of liquefaction (<150 mm in thickness) to occur below the above reported depths.

Hazards involved with liquefiable soils include loss of side shear and end bearing resistance for pile foundations in the liquefiable zone, vertical deformation and potential for lateral flow slides. The axial and lateral pile analyses provided below include an assessment of the seismic loading conditions.

8. ASSESSMENT OF PILE RESISTANCE

The proposed foundations for the berthing dolphins, as shown on the attached structural drawings in Appendix B, comprise a four-pile dolphin structure with two front piles inclined at 1H:5V and two rear piles at 1H:3V. The proposed piles are 1,524 mm diameter, 25 mm thick steel pipes.

Provided below is a brief summary of the findings of our April 2020 geotechnical desktop assessment, a discussion on the Limit States Design methodology and recommended geotechnical resistance factors, and axial and lateral pile analyses under static and seismic loading conditions.

The desktop assessment included the review of the results of the pile testing program completed at the Westshore Terminal in 1981 and full-scale, compressive static loading tests completed on large diameter, steel pipe piles in Fraser River deposits for the major river crossings (i.e. Alex Fraser Bridge, Pitt River Bridge, George Massey Tunnel, etc.). The recommendations for the evaluation of the axial pile resistance were carried forward from our desktop assessment and adopted in this report as the back-calculated values are considered more reliable than the use of static analytical methods, such as the LCPC method, that are outlined in the Canadian Foundation Engineering Manual (CFEM, 2006).

8.1 Review of the Findings of the Geotechnical Desktop Assessment

Thurber completed a geotechnical desktop assessment that comprised a review of available geotechnical information to provide preliminary design recommendations. The assessment included a review of the results of a pile testing program completed in 1980 in support of the design of Berth 1. The program included the installation of seventeen, closed-ended, steel pipe piles (914 mm x 10.2 mm [0.403" ??]) that were driven to depths ranging from 5 m to 12 m and subjected to tensile loads ranging from 890 kN to 1,200 kN (pile head movement was not recorded during testing). The program also included the installation of three steel pipe piles, two 515 mm in diameter and one 914 mm in diameter, that were driven to embedment depths of 18 m to 22 m and subjected to tensile and compressive loading tests that included measurement of pile head movement.

The results of the Berth 1 pile testing program were analyzed to back-calculate the side shear and end bearing resistance values. Using an effective stress approach, β values ranging from 0.22 to 0.35 were back-calculated for the side shear resistance. The higher β values were back-calculated for the shorter piles which is likely a reflection of the influence of the fill material. End-bearing resistance values of 13 MPa and 9 MPa were back-calculated for the 515 mm and 914 mm test piles, respectively.

Considering the marked difference in the size of the test piles and the proposed production piles for the replacement berthing dolphins (1,524 mm pipe piles), the back-calculated β values from the Berth 1 testing program were reduced by 20% to 0.18 to account for scaling effects. This value correlates reasonably well with back-calculated β values from full-scale pile loading test results on large diameter piles in Fraser River deposits.

Assuming a linear correlation between pile diameter and the back-calculated unit end bearing values from the Berth 1 pile testing program, an inferred unit end bearing resistance of 2.5 MPa was calculated for a 1,524 mm pipe pile corresponding to a toe displacement of 150 mm (i.e. 10% of pile diameter).

Additional details and background information can be found in our April 2020 report.

8.2 Limit States Design and Geotechnical Resistance Factors

Limit States Design is the recommended design methodology in the National Building Code of Canada. According to the CFEM (2006), limit states are defined as conditions under which a structure or its components no longer perform their intended function. The limit state design methodology includes addressing the ultimate limit state (ULS), which is concerned with collapse mechanisms of the structure (i.e. safety), and the serviceability limit state (SLS), which represents conditions of mechanics that restrict or constrain the intended use or function of the structure under anticipated working loads.

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In ULS design, the geotechnical resistance of the deep foundation is multiplied by a geotechnical resistance factor that is less than unity, to account for variabilities in geotechnical parameters and analysis uncertainties when evaluating the geotechnical resistance, and the structural loads are multiplied by load factors that are generally greater than unity to account for uncertainties in loads and their probability of occurrence (CFEM, 2006). For deep foundations, Table 2 summarizes the recommended geotechnical resistance factors.

Table 2 - Geotechnical Resistance Values (Φ) for Deep Foundations

Loading Condition	Design method	Geotechnical Resistance Values Φ
Axial Compression	Static Analysis	0.4
	Dynamic Loading Test	0.5
	Full-Scale Compression Loading Test	0.6
Axial Tension	Static Analysis	0.3
	Full-Scale Tensile Loading Test	0.4
Lateral	Static Analysis	0.5

As shown in Table 2, codes allow for the use of a higher geotechnical resistance factor where field testing has been completed as this is anticipated to reduce the uncertainty that is inherent in a static analysis. Depending on the type of field testing, the geotechnical resistance factors can be increased by up to 0.2 (i.e. 0.6 in lieu of 0.4 if a full-scale static loading testing is completed).

Considering the testing completed at the Westshore facility in support of the Berth 1, resistance factors of 0.4 and 0.6 for analysis of the tensile and compressive geotechnical resistance values can be adopted provided that the results properly account for scaling effects (refer to Section 8.1).

8.3 Axial Pile Resistance

An assessment was completed to evaluate the required pile embedment to resist the design static and seismic (1:475 year and 1:2,475 year earthquake events) loading conditions. The scaled parameters reported in Section 8.1 (β value of 0.18 for side shear and unit end bearing of 2.5 MPa) were used to analyze the axial resistance under static loading conditions. For the assessment of axial shaft resistance under seismic loading conditions, where the thickness of the liquifiable zone was estimated to be approximately 14 m and 47 m thick for the 1:475 year and 1:2,475 year earthquake events as outlined in Section 7.2, a normalized residual shear strength ($s_{u,res}/\sigma'$) of 0.12 was used based on the available CPT data. Plots of the distribution of the unfactored side shear, end bearing and geotechnical resistance values versus depth for the various loading conditions are included in Appendix E.

Using geotechnical resistance factors of 0.4 and 0.6 for tensile and compressive loading, our analyses, summarized in Table 3, indicate that static loading conditions govern axial pile design.

Table 3 - Summary of Geotechnical Assessment for Proposed Four-Pile Dolphin

1H:5V Inclined Piles (1.524 m x 25 mm)			
Design Loading Condition	**Factored Loads (kN)**		**Minimum Required Vertical Pile Embedment (m)**
	Compression	**Tension**	
Static	4,833	1,466	31 m for compression 29 m for tension
Seismic (1:475 year)	750	-	14 m for compression
Seismic (1:2,475 year)	750	-	25 m for compression[1]
Rear 1H:3V Inclined Piles (1.524 m x 25 mm)			
Design Condition	**Factored Loads (kN)**		**Minimum Required Vertical Pile Embedment (m)**
	Compression	**Tension**	
Static	5,151	2,873	33 m for compression 41 m for tension
Seismic (1:475 year)	750	-	14 m for compression
Seismic (1:2,475 year)	750	-	25 m for compression[1]

Note:
1) To limit deformations, the pile length should extend below the liquefiable soils.

8.4 Lateral Pile Resistance

The performance of the proposed four-pile dolphin structure under lateral loading was assessed using Group software by Ensoft Inc. The software analyses the behaviour of single piles and pile groups subjected to axial and lateral loads using two- or three- dimensional models. The soil resistance along the embedded length of a pile is modelled using a series of discrete, non-linear soil springs in the form of t-z and q-w curves for axial loading, t-r curves for torsional loading and p-y curves for lateral loading.

As described in Section 5, the piles, having a maximum vertical embedment of about 51 m, will be founded entirely in the Holocene Fraser deltaic deposits that are characterized as loose to compact. Table 4 summarizes the soil parameters and soil spring models used to evaluate the p-y curves in the Fraser deltaic deposits, and the design loading conditions.

Table 4 – Loading Conditions, Soil Parameters and Spring Models for Lateral Pile Analysis

Design Loading Condition	Design Load	Soil Model	γ_{bulk}[1] (kN/m³)	$\gamma_{submerged}$[2] (kN/m³)	ϕ[3] (°)	$S_{u,res}/\sigma'$[4]
Static	2,000 kN Lateral Load	API Sand	17.5	7.5	32	-
Seismic (1:475 year)	Kinematic[5] (14 m depth of liquefaction)	Soft Clay (Matlock)			-	0.12
Seismic (1:2,475 year)	Kinematic[5] (47 m depth of liquefaction)					

Notes:
1) Bulk unit weight.
2) Submerged unit weight.
3) Internal angle of shearing resistance.
4) Normalized residual shear strength of liquefied soils.
5) No external loading (i.e. ship impact) was assumed under seismic loading conditions.

As recommended in the Ensoft (2019) Group software Technical Manual and CSA S6.1-14 "Commentary on CSA S6-14, Canadian Highway Bridge Design Code" document, the lateral response of the liquefied soils was modelled using the soft clay p-y curve model by Matlock (1970), with the undrained shear strength equal to the residual strength of the liquefied soils ($s_{u,res}/\sigma'$ of 0.12).

Considering the sloping ground conditions at the proposed berthing dolphin locations (22 degrees which is characterized as steep sloping ground), a flow slide failure is likely to occur which will result in very large displacements (> 2 m) within the liquefied zone that will induce kinematic loading on the berthing dolphin piles. In the Group software, the kinematic loading for the 1:475 year and 1:2,475 year earthquake events was modelled by subjecting the piles to external displacements of 2 m within the liquefied zone.

The following assumptions and conditions were adopted in our analysis:

- The pile head was modelled as a fixed connection based on input from CWA.
- For the API sand model in non-liquefied soils, the modulus of subgrade reaction was automatically selected by the software which we consider to be reasonable.
- For the soft clay model, the strain corresponding to one-half the maximum principal stress difference, ε_{50}, was automatically selected by the software which we consider to be reasonable.
- Considering the centre-to-centre spacing of the piles, pile group effects were ignored in the analyses.
- The axial resistance in the software was modelled using a variable resistance model.

The results of the pile group analyses are summarized in Table 5 and include the maximum pile cap and individual pile deformations, and maximum bending moments in the piles. Attached to the report (Appendix F) are profile plots of pile deflections, bending moments and shear for the rear and front piles.

Table 5 – Lateral Pile Assessment Results (1524 mm x 25 mm Pipe Sections)

Design Loading Condition[1]	Pile Cap Results						Pile Results		
	Max. Deformation[2]		Rotation	Moment	Axial Force	Shear Force	Max. Bending Moment	Max. Deformation	Location
	Vert.[3] (mm)	Horiz.[4] (mm)	(°)	(kN•m)	(kN)	(kN)	(kN.m)[5]	(mm)	
Static	<5	45	<0.001	2,700[6] 2,600[6]	-1,250[7] 2,250	300[8] 900[8]	2,700 2,600	40	Front Piles[9] Rear Piles[10]
Seismic (1:475 year)	10	40	0.003	1,100[6] 1,250[6]	1,150 -150[7]	250[8] 50[8]	4,000 3,450	65 65	Front Piles[9] Rear Piles[10]
Seismic (1:2,475 year)	125	850	0.06	9,000[6] 13,500[6]	6,850 -5,850[7]	1,450[8] 1,205[8]	38,000 24,250	2,050 2,000	Front Piles[9] Rear Piles[10]

Notes:

1) Kinematic and external lateral loading are applied in the y-direction.
2) Maximum predicted deformations at the centre of the pile cap (elevation 5.31 m).
3) X-axis is the vertical axis.
4) Horizontal movement is primarily in the direction of the applied load or soil movement (i.e. the y-direction).
5) Resultant maximum bending moment.
6) Resultant bending moment at pile top.
7) Negative value indicates tension.
8) Resultant shear forces at pile top.
9) Front piles have an inclination of 1H:5V.
10) Rear Piles have an inclination of 1H:3V.

Under static loading conditions, the analysis indicates that the berthing dolphin would be expected to undergo lateral and vertical deformations of about 45 mm and less than 5 mm at the pile cap, respectively, as shown in Table 5. Considering the fixed-head connection, the maximum bending moment occurs at the pile head under static loading conditions. The depth-to-fixity, defined as the depth corresponding to the initial zero deformation, occurs at approximately a distance of 30 m from the pile top. If CWA is using a different definition, we encourage you to review the plots to determine a value for your use.

Under the 1:475 year return period earthquake scenario, the analysis indicates that the berthing dolphin will experience minor lateral and vertical deformations. At the pile cap, lateral and vertical deformations of 40 mm and 10 mm, respectively, are predicted. The front and rear piles are anticipated to develop maximum bending moments of about 4,000 kN•m at 37 m from pile top and 3,450 kN•m and 39 m from pile top, respectively.

Under the 1:2475 year return period earthquake scenario, the analysis indicates that the berthing dolphin will experience substantially larger lateral and vertical deformations. At the pile cap, lateral and vertical deformations of about 850 mm and 125 mm, respectively, are predicted. The front and rear piles are anticipated to develop maximum bending moments of about 38,000 kN•m at 70.5 m from pile top and 24,250 kN•m at 55 m from pile top, respectively.

For the assessment of inertial loading, the p-y curves are provided in Appendix G, H and I that represent:

- P-Y curves for cyclic loading, based on 15 cycles.
- P-Y curves for the post-liquefaction 1:475 yr earthquake event, based on a 14 m liquefied soil column. A 2 m external displacement should be applied within the liquefied zone.
- P-Y curves for the post-liquefaction 1:2,475 yr earthquake event, based on a 47 m liquefied soil column. A 2 m external displacement should be applied within the liquefied zone.

9. SUMMARY

The analysis presented in the report indicates that the proposed pile group foundation for the dolphin structures will serve its intended purpose under static and kinematic seismic loading conditions (repairable in 1:475 year earthquake event and collapse-prevention in 1:2,475 year earthquake event).

10. CLOSURE

We trust that this information is sufficient for your current needs. Please contact us if you require additional information.

Yours truly,
Thurber Engineering Ltd.
David Tara, P.Eng.
Review Principal

September 30, 2020

PROFESSIONAL
PROVINCE OF
T. F. D. DAJANI
42524
BRITISH COLUMBIA
ENGINEER

Tareq Dajani, P.Eng.
Geotechnical Engineer

Attachments:
- Statement of Limitations and Conditions (1 page)
- Figure 1 – Site Plan (1 page)
- Appendix A – Gregg's CPT Data Report (49 pages)
- Appendix B - Berthing / Mooring Dolphin Plan and Elevation [Drawing No. 19849-100-SK-100-P1] (1 page)
- Appendix C – Vs Profiles, SSRA Results & Design Response Spectra (6 pages)
- Appendix D – Liquefaction Assessment [CSR vs CRR profiles] (4 pages)
- Appendix E – Axial Pile Resistance (3 pages)
- Appendix F – Lateral Pile Group Analyses (9 pages)
- Appendix G – PY Curves for Cyclic Loading (3 pages)
- Appendix H – PY Curves [475 yr Earthquake Event_Post Liquefaction] (3 pages)
- Appendix I – PY Curves [2475 yr Earthquake Event_Post Liquefaction] (3 pages)

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11. REFERENCES

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STATEMENT OF LIMITATIONS AND CONDITIONS

1. STANDARD OF CARE

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

2. COMPLETE REPORT

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

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

3. BASIS OF REPORT

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

4. USE OF THE REPORT

The information and opinions expressed in the Report, or any document forming part of the Report, are for the sole benefit of the Client. NO OTHER PARTY MAY USE OR RELY UPON THE REPORT OR ANY PORTION THEREOF WITHOUT THURBER'S WRITTEN CONSENT AND SUCH USE SHALL BE ON SUCH TERMS AND CONDITIONS AS THURBER MAY EXPRESSLY APPROVE. Ownership in and copyright for the contents of the Report belong to Thurber. Any use which a third party makes of the Report, is the sole responsibility of such third party. Thurber accepts no responsibility whatsoever for damages suffered by any third party resulting from use of the Report without Thurber's express written permission.

5. INTERPRETATION OF THE REPORT

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

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

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

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

6. RELEASE OF POLLUTANTS OR HAZARDOUS SUBSTANCES

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

7. INDEPENDENT JUDGEMENTS OF CLIENT

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

THURBER

APPENDIX A

Gregg's CPT Data Report (49 pages)

Site Investigation Summary

Cone Penetration Testing Report

GREGG DRILLING AND TESTING CANADA LTD.

2020

Authored by: Shane Kelly, M.Eng., P.Eng. & Sara Szeto, M.Sc.

Prepared for: Thurber Engineering Ltd.

Site: Westshore Terminals, Berth 2, Delta, B.C.

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June 22, 2020

Thurber Engineering Ltd.
Attn: Mr. Tareq Dajani, P.Eng.

Subject: CPT Site Investigation
Westshore Terminals, Berth 2
Delta, British Columbia
Gregg Drilling Project Number: GRG190114
Gregg Drilling Operators: Shane Kelly, Nathan Grewal

Dear Mr. Dajani,

The following report presents the results of Gregg Drilling and Testing Canada Ltd. site investigation for the above referenced site. The following testing services were performed:

1	Cone Penetration Tests	(CPTU)	☒
2	Pore Pressure Dissipation Tests	(PPDT)	☒
3	Seismic Cone Penetration Tests	(SCPTU)	☐
4	UVOST Laser Induced Fluorescence	(UVOST)	☐
5	Groundwater Sampling	(GWS)	☐
6	Soil Sampling	(SS)	☐
7	Vapor Sampling	(VS)	☐
8	Pressuremeter Testing	(PMT)	☐
9	Vane Shear Testing	(VST)	☐
10	Dilatometer Testing	(DMT)	☐

A list of reference papers providing additional background on the specific tests conducted is provided in the bibliography following the text of the report. If you would like a copy of any of these publications or should you have any questions or comments regarding the contents of this report, please do not hesitate to contact our office at 1.844.848.8684.

Sincerely,

Shane Kelly
Vice President, Gregg Drilling and Testing Canada Ltd.

Introduction

The Westshore Terminals is a coal export facility located in Roberts Bank in Delta, B.C. In support of the Berth 2 berthing dolphin replacement project, an offshore cone penetration testing (CPT) program was completed from April 5 to 8, 2020. The program comprised two CPT soundings using a 20-ton cone truck (DP002G) and a sonic track rig, and was executed off a barge.

Cone Penetration Testing Description

Gregg Drilling carries out all Cone Penetration Tests (CPT) using an integrated electronic cone system, *Figure CPT*. The cone takes measurements of tip resistance (q_c), sleeve resistance (f_s), and penetration pore water pressure (u_2). Measurements are taken at either 1.0, 2.0, 2.5 or 5.0 cm intervals during penetration to provide a nearly continuous profile. CPT data reduction and basic interpretation is performed in real time facilitating on-site decision making. The CPT parameters are stored electronically for further analysis and reference. All CPT soundings are performed in accordance with revised ASTM standards (D 5778-12).

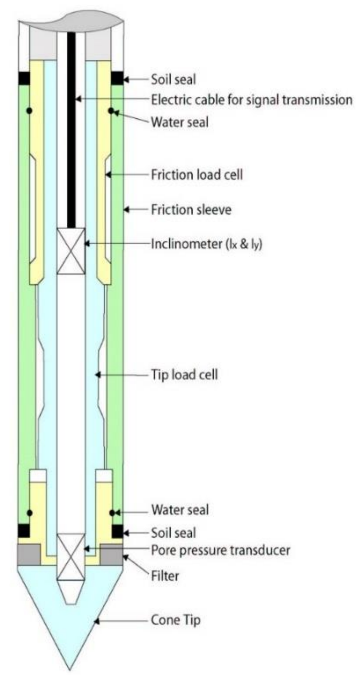


Figure CPT

The Pore pressure transducer is located directly behind the cone tip in the u_2 location. A new saturated filter element is used on each sounding to measure both penetration pore pressures as well as measurements during a dissipation test (*PPDT*). Prior to each test, the filter element is fully saturated with oil under vacuum pressure to improve accuracy.

When the sounding is completed, the test hole is backfilled according to client specifications. If grouting is used, the procedure generally consists of pushing a hollow tremie pipe with a "knock out" plug to the termination depth of the CPT hole. Grout is then pumped under pressure as the tremie pipe is pulled from the hole. Disruption or further contamination to the site is therefore minimized.

A.P. van den Berg (APV) 15cm^2 Standard Cone Specifications:

Dimensions			
Cone base area		**Sleeve surface area**	**Cone net area ratio**
15 cm^2		225 cm^2	0.75
	Cone load cell	**Sleeve load cell**	**Pore pressure transducer**
Max load	150 MPa	1.5 MPa	3.0 MPa

Note: The repeatability during field use will depend somewhat on ground conditions, abrasion, maintenance and zero load stability.

Cone Penetration Data & Interpretation

The Cone Penetration Test (CPT) data collected are presented in graphical and electronic form in the report. The plots include interpreted Soil Behavior Type (SBT) based on the charts described by Robertson (2009 & 2010). Typical plots display SBT based on the non-normalized charts of Robertson (2010). For CPT soundings deeper than 30m, we recommend the use of the normalized charts of Robertson (2009) which can be displayed as SBTn, upon request. The report can also include spreadsheet output of computer calculations of basic interpretation in terms of SBT and SBTn and various geotechnical parameters using current published correlations based on the comprehensive review by Lunne, Robertson and Powell (1997), as well as recent updates by Robertson and Cabal (Guide to Cone Penetration Testing, 2015). The interpretations are presented only as a guide for geotechnical use and should be carefully reviewed. Gregg Drilling does not warranty the correctness or the applicability of any of the geotechnical parameters interpreted by the software and does not assume any liability for use of the results in any design or review. The user should be fully aware of the techniques and limitations of any method used in the software. Some interpretation methods require input of the groundwater level to calculate vertical effective stress. An estimate of the in-situ groundwater level has been made based on field observations and/or CPT results, but should be verified by the user.

A summary of locations and depths is available in Table 1. Note that all penetration depths referenced in the data are with respect to the existing ground surface. Note that it is not always possible to clearly identify a soil type based solely on qt, fs, and u2. In these situations, experience, judgment, and an assessment of the pore pressure dissipation data should be used to infer the correct soil behavior type.

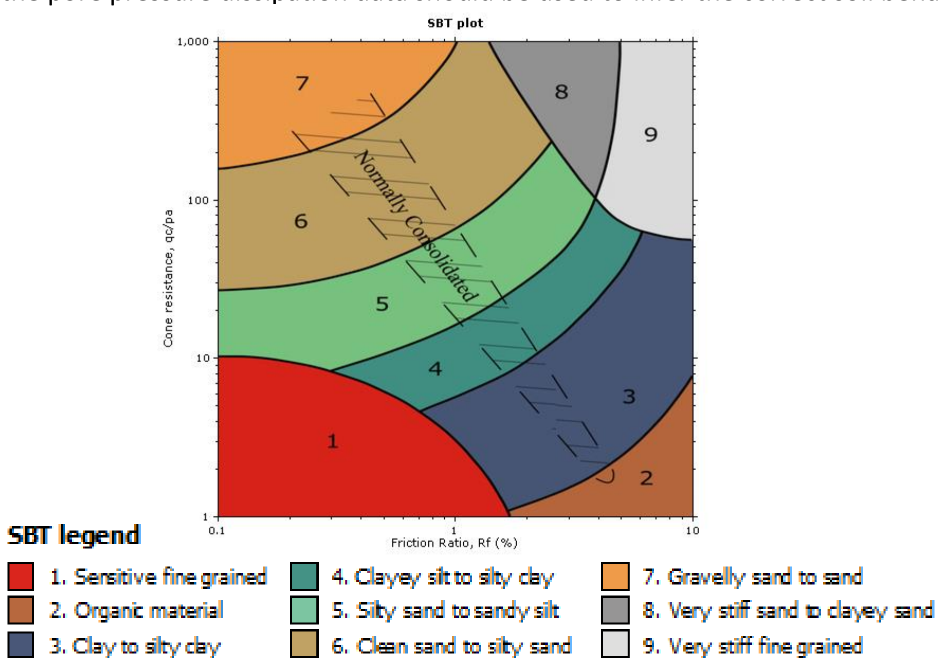


Figure SBT (after Robertson, 2010) – Note: Colors may vary slightly compared to plots.

Cone Penetration Data & Interpretation

Gregg uses a commercial CPT interpretation and plotting software CPeT-IT (https://geologismiki.gr/products/cpet-it/). The software takes the CPT data and performs basic interpretation in terms of soil behavior type (SBT) and various geotechnical parameters using current published empirical correlations based on the comprehensive review by Lunne, Robertson and Powell (1997) and updated by Robertson and Cabal (2015). The interpretation is presented in tabular format. The interpretations are presented only as a guide for geotechnical use and should be carefully reviewed. Gregg does not warranty the correctness or the applicability of any of the geotechnical parameters interpreted by the software and does not assume any liability for any use of the results in any design or review. The user should be fully aware of the techniques and limitations of any method used in the software.

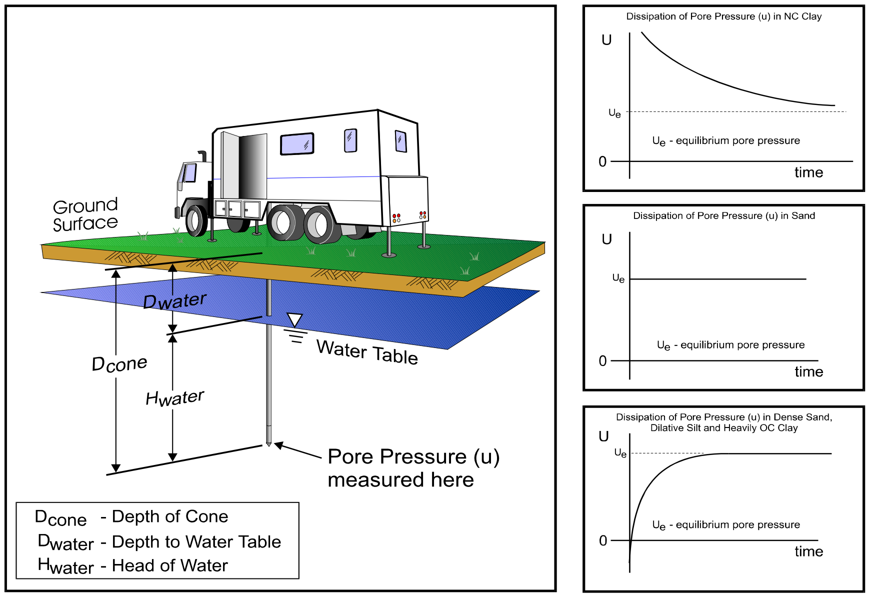
Pore Pressure Dissipation Testing Description

Pore Pressure Dissipation Tests (PPDT's) conducted at various intervals can be used to measure equilibrium water pressure (at the time of the CPT). If conditions are hydrostatic, the equilibrium water pressure can be used to determine the approximate depth of the ground water table. A PPDT is conducted when penetration is halted at specific intervals determined by the field representative. The variation of the penetration pore pressure (*u)* with time is measured behind the tip of the cone and recorded.

Pore pressure dissipation data can be interpreted to provide estimates of:

- Equilibrium piezometric pressure
- Phreatic surface
- In situ horizontal coefficient of consolidation (c_h)
- In situ horizontal coefficient of permeability (k_h)

In order to correctly interpret the equilibrium piezometric pressure and/or the phreatic surface, the pore pressure must be monitored until it reaches equilibrium, *Figure PPDT*. This time is commonly referred to as t_{100}, the point at which 100% of the excess pore pressure has dissipated.



Water Table Calculation

$$D_{water} = D_{cone} - H_{water}$$

where $H_{water} = U_e$ (depth units)

Useful Conversion Factors: 1psi = 0.704m = 2.31 feet (water)
1tsf = 0.958 bar = 13.9 psi
1m = 3.28 feet

Figure PPDT

A complete reference on pore pressure dissipation testing is presented by Robertson et al. 1992 and Lunne et al. 1997.

A summary of the pore pressure dissipation tests can be found in Table 1.

Groundwater Sampling

Gregg Drilling conducts groundwater sampling using a sampler as shown in *Figure GWS*. The groundwater sampler has a retrievable stainless steel or disposable PVC screen with steel drop off tip. This allows for samples to be taken at multiple depth intervals within the same sounding location. In areas of slower water recharge, provisions may be made to set temporary PVC well screens during sampling to allow the pushing equipment to advance to the next sample location while the groundwater is allowed to infiltrate.

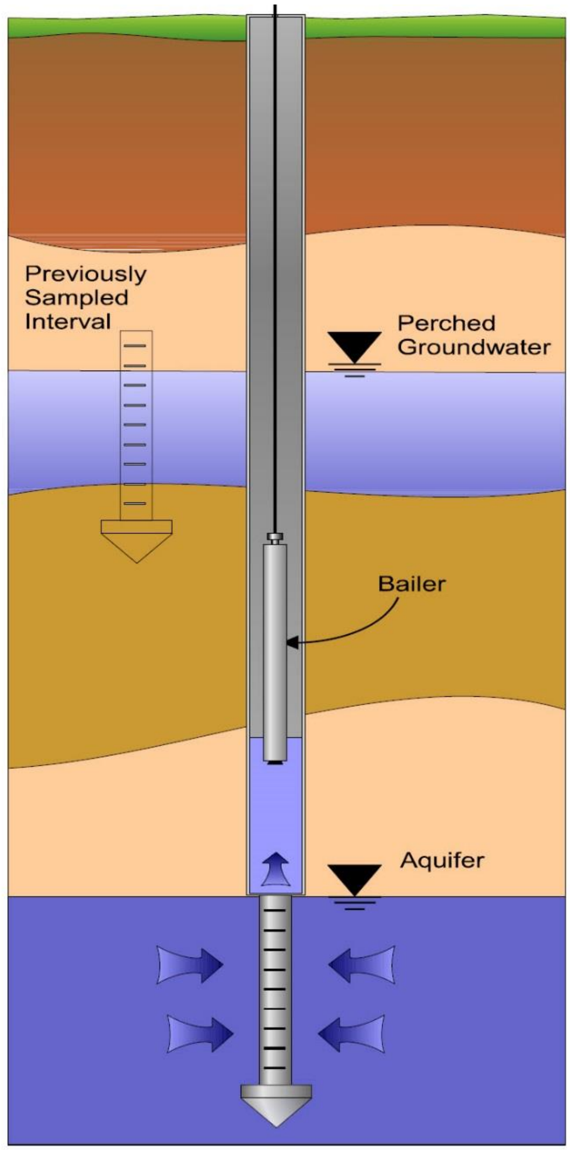


Figure GWS

The groundwater sampler operates by advancing 44.5mm (1¾ inch) hollow push rods with the filter tip in a closed configuration to the base of the desired sampling interval. Once at the desired sample depth, the push rods are retracted; exposing the encased filter screen and allowing groundwater to infiltrate hydrostatically from the formation into the inlet screen. A small diameter bailer (approximately ½ or ¾ inch) is lowered through the push rods into the screen section for sample collection. The number of downhole trips with the bailer and time necessary to complete the sample collection at each depth interval is a function of sampling protocols, volume requirements, and the yield characteristics and storage capacity of the formation. Upon completion of sample collection, the push rods and sampler, with the exception of the PVC screen and steel drop off tip are retrieved to the ground surface, decontaminated and prepared for the next sampling event.

For a detailed reference on direct push groundwater sampling, refer to Zemo et al., 1992.

Soil Sampling

Gregg Drilling uses a piston-type push-in sampler to obtain small soil samples without generating any soil cuttings, *Figure SS*. Two different types of samplers (12 and 18 inch) are used depending on the soil type and density. The soil sampler is initially pushed in a "closed" position to the desired sampling interval using the CPT pushing equipment. Keeping the sampler closed minimizes the potential of cross contamination. The inner tip of the sampler is then retracted leaving a hollow soil sampler with inner 1¼" diameter sample tubes. The hollow sampler is then pushed in a locked "open" position to collect a soil sample. The filled sampler and push rods are then retrieved to the ground surface. Because the soil enters the sampler at a constant rate, the opportunity for 100% recovery is increased. For environmental analysis, the soil sample tube ends are sealed with Teflon and plastic caps. Often, a longer "split tube" can be used for geotechnical sampling.

For a detailed reference on direct push soil sampling, refer to Robertson et al, 1997.

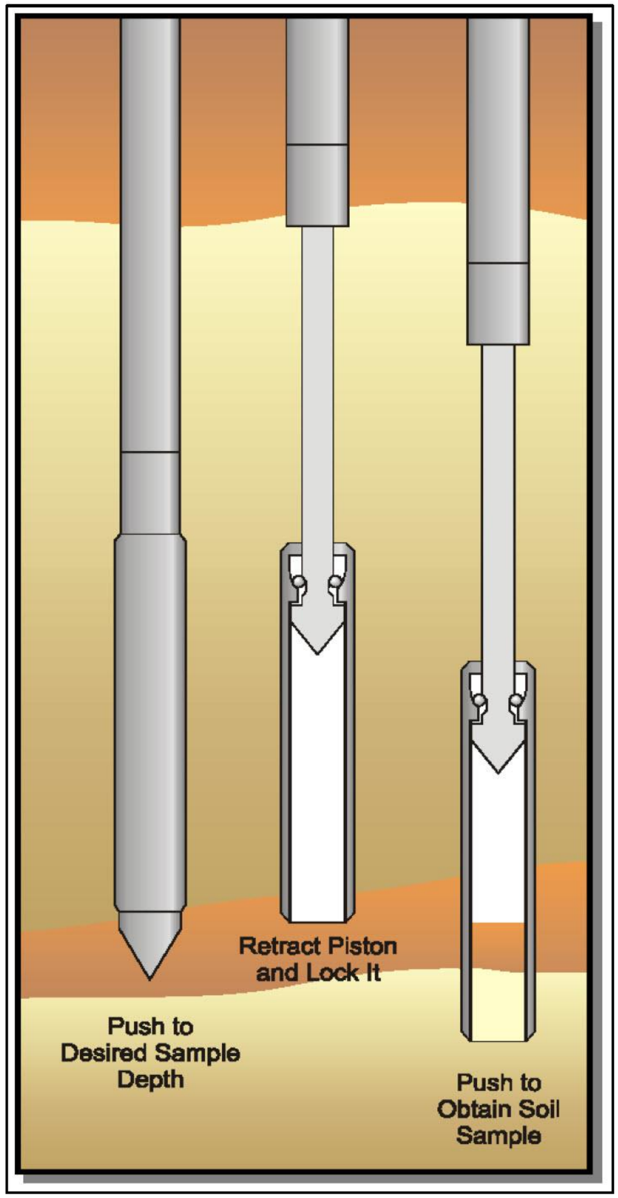


Figure SS

Seismic Cone Penetration Testing

Seismic Cone Penetration Testing (SCPT) can be conducted at various intervals during the Cone Penetration Test. Shear wave velocity (Vs) can then be calculated over a specified interval with depth. A small interval for seismic testing, such as 1-1.5m (3-5ft) allows for a detailed look at the shear wave profile with depth. Conversely, a larger interval such as 3-6m (10-20ft) allows for a more average shear wave velocity to be calculated. Gregg Drilling's cones have a horizontally active geophone located 0.2m (0.66ft) behind the tip.

To conduct the seismic shear wave test, the penetration of the cone is stopped and the rods are decoupled from the rig. An automatic hammer is triggered to send a shear wave into the soil. The distance from the source to the cone is calculated knowing the total depth of the cone and the horizontal offset distance between the source and the cone. To calculate an interval velocity, a minimum of two tests must be performed at two different depths. The arrival times between the two wave traces are compared to obtain the difference in time (Δt). The difference in depth is calculated (Δd) and velocity can be determined using the simple equation: v = Δd/Δt

Multiple wave traces can be recorded at the same depth to improve quality of the data.

A complete reference on seismic cone penetration tests is presented by Robertson et al. 1986 and Lunne et al. 1997.

A summary the shear wave velocities, arrival times and wave traces are provided with the report.

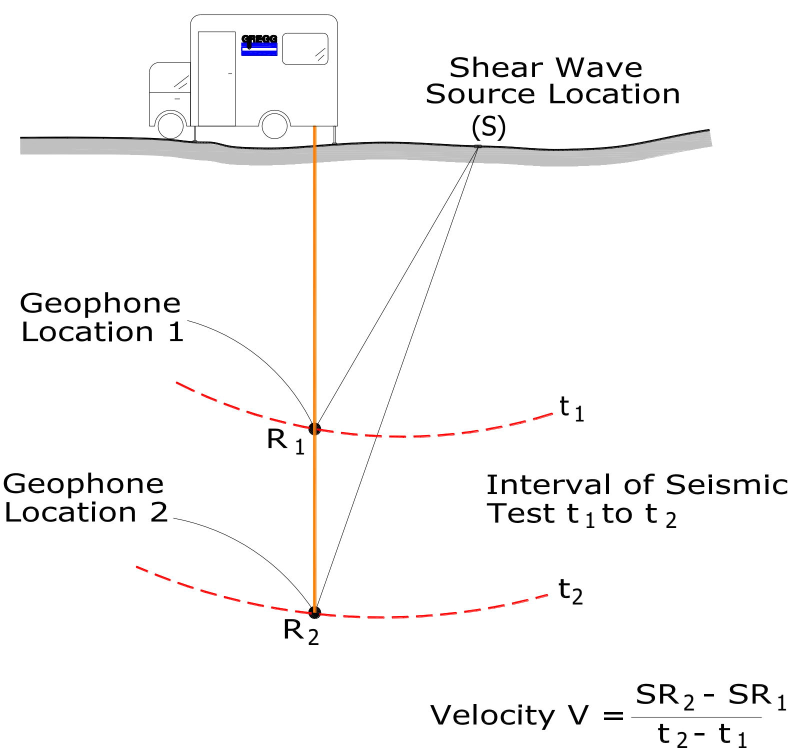


Figure SCPT

iVane Shear Testing

Gregg Drilling operates a digital iVane from A.P. van den Berg, in compliance with ASTM D2573, to measure undrained shear strengths in soft clays. It can be used in soft clays as well as other fine-grained soils such as silts, organic soils, fine-grained tailings and other soft fine-grained materials where a prediction of the peak and remolded undrained shear strength is required.

The iVane is digital and has a torque motor and measuring torque load cell down-hole for improved accuracy and elimination of torque effects associated with the rod string between surface and the test depth. The digital readout displays undrained shear strength and torque versus rotation to provide a detailed record of the test. The iVane can measure a range of undrained shear strength values using different vane sizes. The rate of rotation of the vane can be varied from a slow 0.1 degrees/s up to 6 degrees/s.

The iCone Vane consists of four rectangular blades fixed at 90° angels that are pushed into the ground to the desired depth. Once this depth is reached, the blades are rotated at a constant speed through ranges of the test sequence. The resistance of the soil, and consequently the required torque, will increase until the soil shears. From the point the soil is shearing, the torque value will generally decrease. The highest measured value to shear the soil, is a measure for the undrained shear strength. After the first test to measure the peak undrained shear strength, the soil is remolded by rotating (between 5 and 10 rotations) the vane at a high speed. Then the rate of rotation is slowed to the rate used at peak strength determination to continue the test to measure the remolded shear strength.

The relationship between the undrained shear strength Su, torque T and vane diameter D is given in the following equation:

$S_u = (6T / 7\pi D^3)K$

where:
S_u = peak undrained shear strength in kPa
T = maximum value of measured torque (T_{max}) or residual torque (T_R) corrected for apparatus and rod friction in Nm
D = vane diameter in mm
K = $1x10^6$ (SI units)

Figure Gregg Drilling iVane

References

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

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

Robertson, P.K., 1990. Soil Classification using the Cone Penetration Test. Canadian Geotechnical Journal, Volume 27: 151-158

Robertson, P.K., 2009. Interpretation of Cone Penetration Tests – a unified approach. Canadian Geotechnical Journal, Volume 46: 1337-1355

Robertson, P.K., 2010, "Soil Behavior type from the CPT: an update", 2nd International Symposium on Cone Penetration Testing, Huntington Beach, CA, Vol.2. pp 575-583

Robertson, P.K. and Cabal, K.L., "Guide to Cone Penetration Testing for Geotechnical Engineering", 6th Edition, 2015, 145 p. Free online, http://www.greggdrilling.com/technical-guides.

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

Robertson, P.K., Sully, J., Woeller, D.J., Lunne, T., Powell, J.J.M., and Gillespie, D.J., "Guidelines for Estimating Consolidation Parameters in Soils from Piezocone Tests", Canadian Geotechnical Journal, Vol. 29, No. 4, August 1992, pp. 539-550.

TABLE 1: CPT Summary

CPT Sounding Identification	Date (mm-dd-year)	Start Depth (m)	Termination Depth (m)	Cone ID APV-	Depth of Pore Pressure Dissipation Tests (m)
		Start Elevation (m)	*Termination Elevation (m)*		*Elevation of Pore Pressure Dissipation Tests (m)*
CPT20-01*	04-06-2020	0.0	72.62	191002, 190705, 191213	29.06, 38.34, 72.60
		-24.45	*-97.05*		*-53.51, -62.79, -97.05*
CPT20-02**	04-07-2020	0.0	66.41	190705, 191002, 191213	18.33, 40.37, 43.85, 52.48, 63.69
		-27.31	*-93.72*		*-45.62, -67.68, -71.16, -79.79, -91.00*

Note that the CPTs were advanced from a floating platform that had a deck elevation that ranged from 1.16m to 4.17m elevation during the project. All penetration depths/elevations are with respect to the existing Mudline.
Data has been adjusted to take into consideration tidal changes.
*Seismic testing was completed in CPT20-01 but interpretation was difficult due to ambient noise.
**Data loss at 32.06-33.01m.

TABLE 2: Location Summary

CPT Sounding Identification	Date (mm-dd-year)	Northing (m)	Easting (m)	Elevation (m)
CPT20-01*	04-06-2020	5429039.748	488562.330	3.711
CPT20-02**	04-07-2020	5429141.540	488626.851	3.364

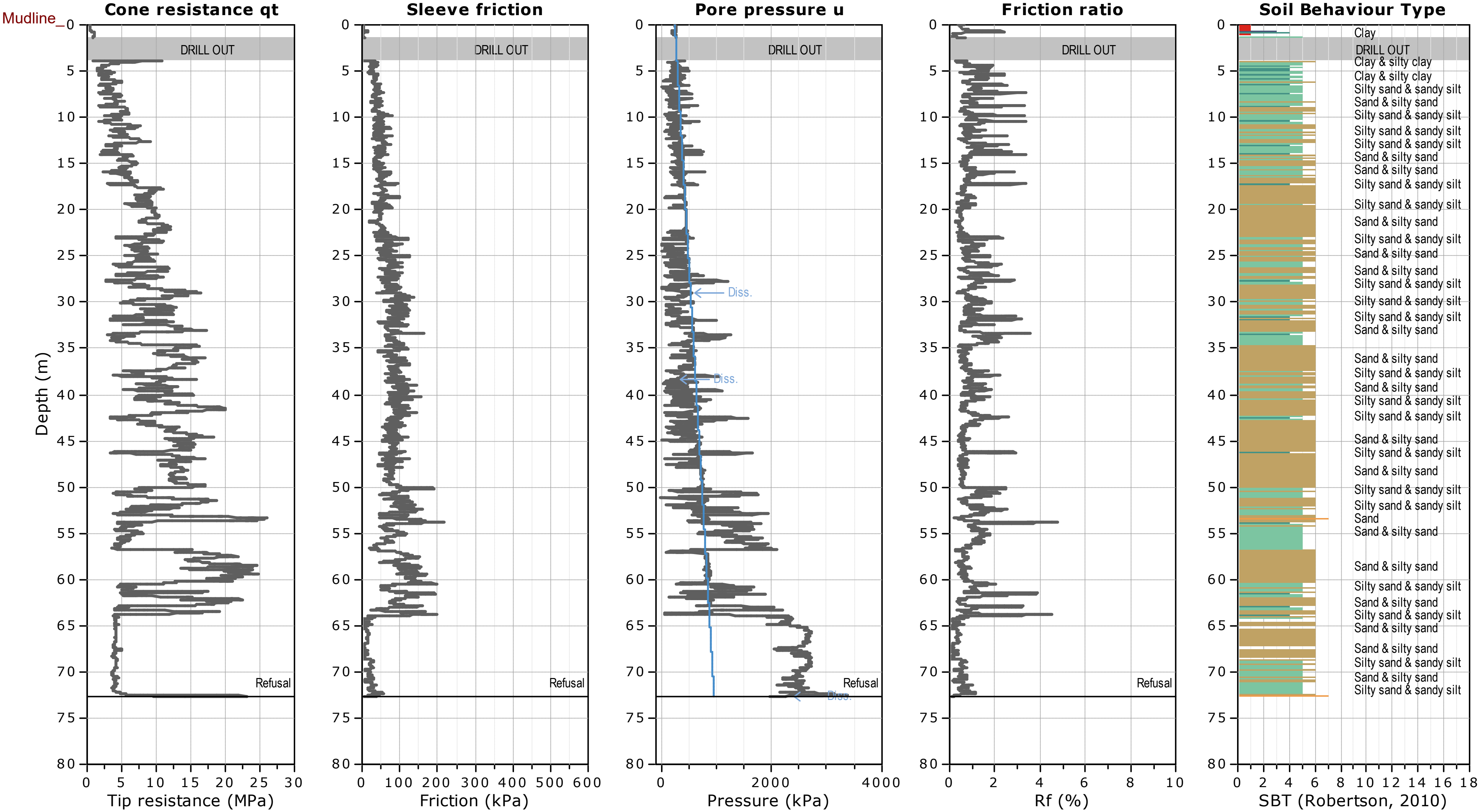
Coordinates provided by McElhanney.
* Coordinates were shot after drilling.
** Coordinates were shot before drilling.

APPENDIX A-I – CPT Plots – Standard

GREGG
GEOTECH DRILLING · GROUP OF COMPANIES

Project: Thurber Engineering Ltd.
Location: Westshore Terminals, Berth 2, Delta, B.C.

CPT20-01
Total depth: 72.62 m, Date: 4/6/2020
Surface Elevation: -24.45 m
Coords: N 5429039.748 m, E 488562.330 m
Cone Operator: Shane Kelly/Nathan Grewal



CPT20-02

Total depth: 66.41 m, Date: 4/7/2020

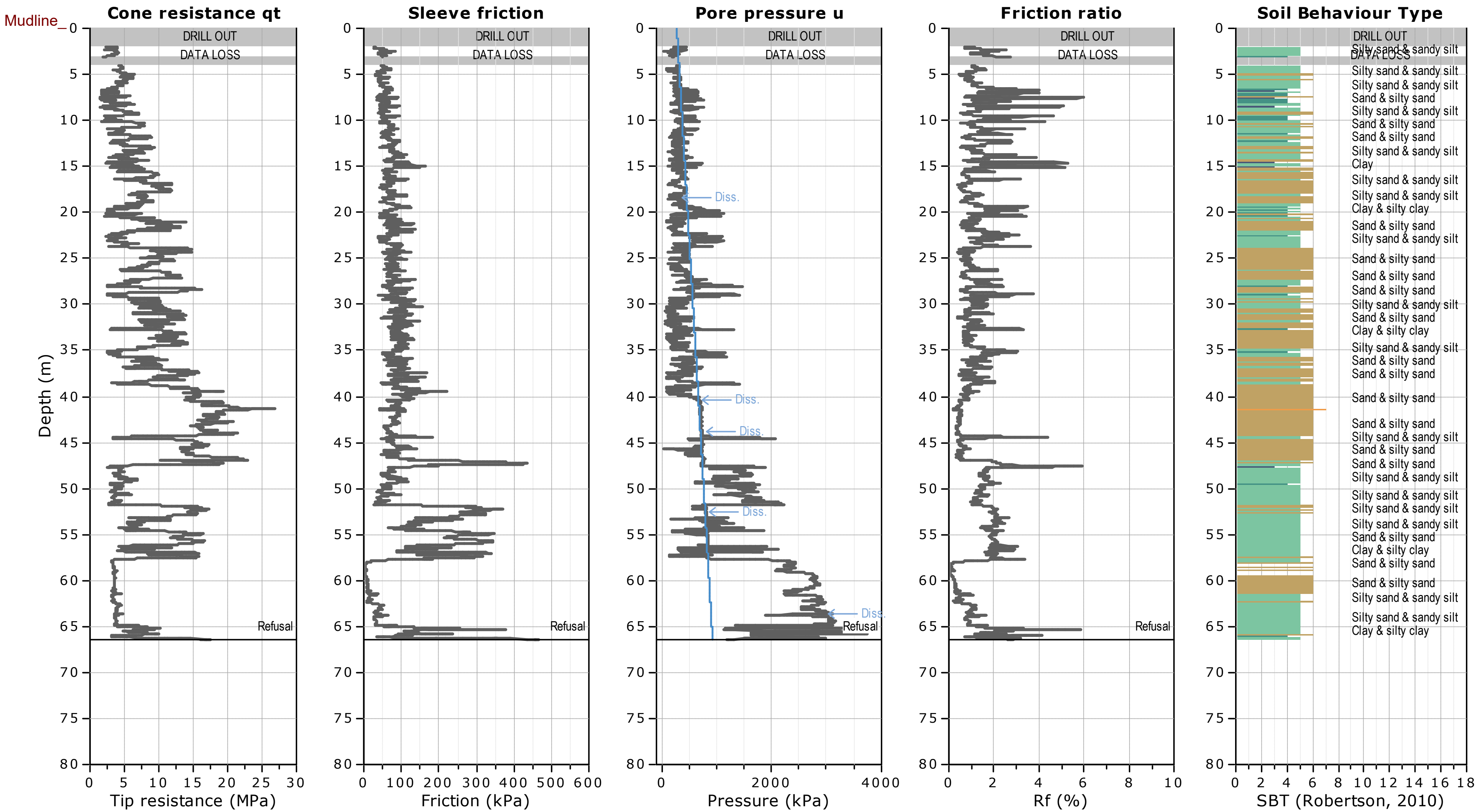
Surface Elevation: -27.31 m

Coords: N 5429141.540 m, E 488626.851 m

Cone Operator: Shane Kelly/Nathan Grewal

Project: Thurber Engineering Ltd.

Location: Westshore Terminals, Berth 2, Delta, B.C.



APPENDIX A-II – CPT Plots – SBTn

CPT20-01

Total depth: 72.62 m, Date: 4/6/2020

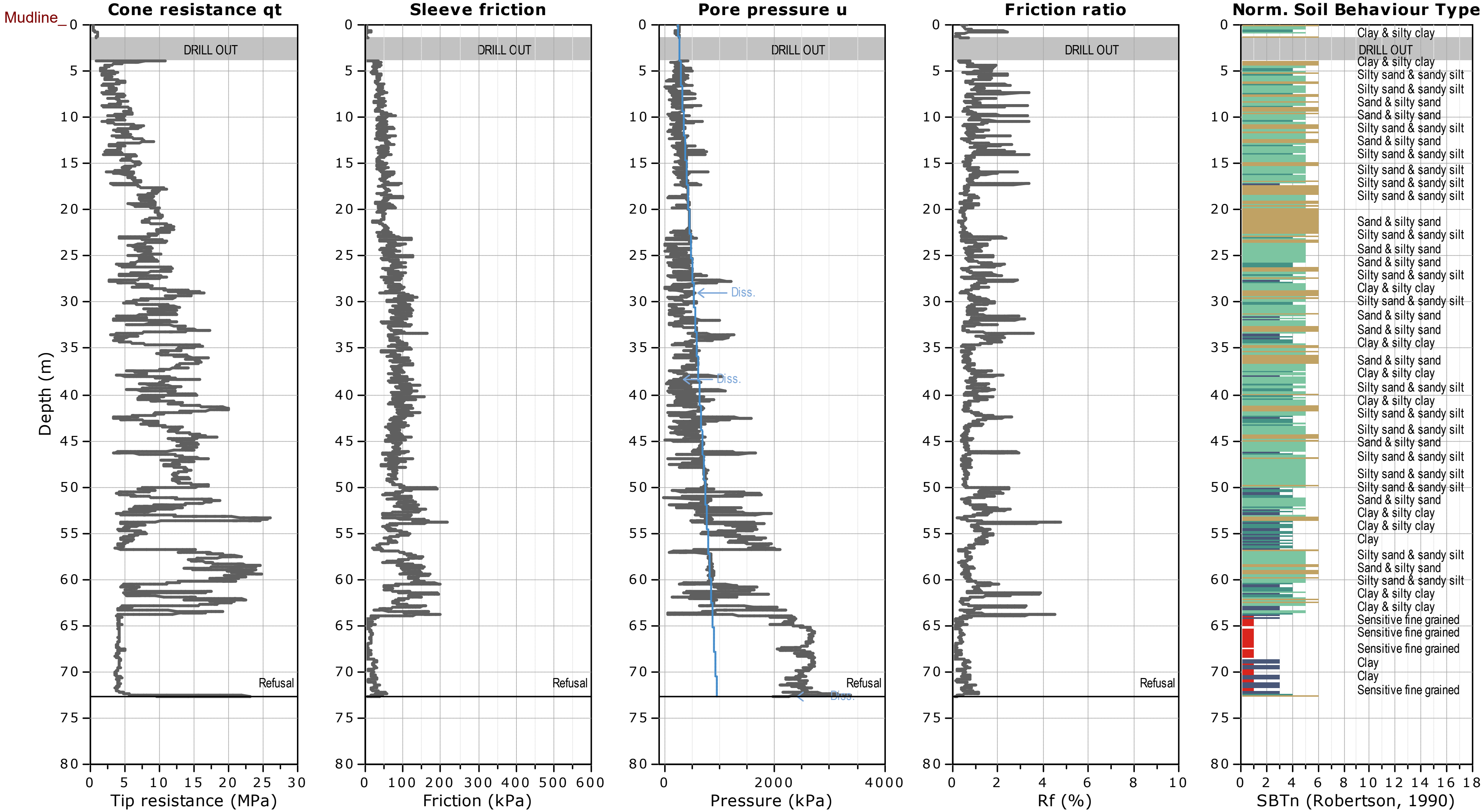
Surface Elevation: -24.45 m

Coords: N 5429039.748 m, E 488562.330 m

Cone Operator: Shane Kelly/Nathan Grewal

Project: Thurber Engineering Ltd.

Location: Westshore Terminals, Berth 2, Delta, B.C.



CPT20-02

Total depth: 66.41 m, Date: 4/7/2020

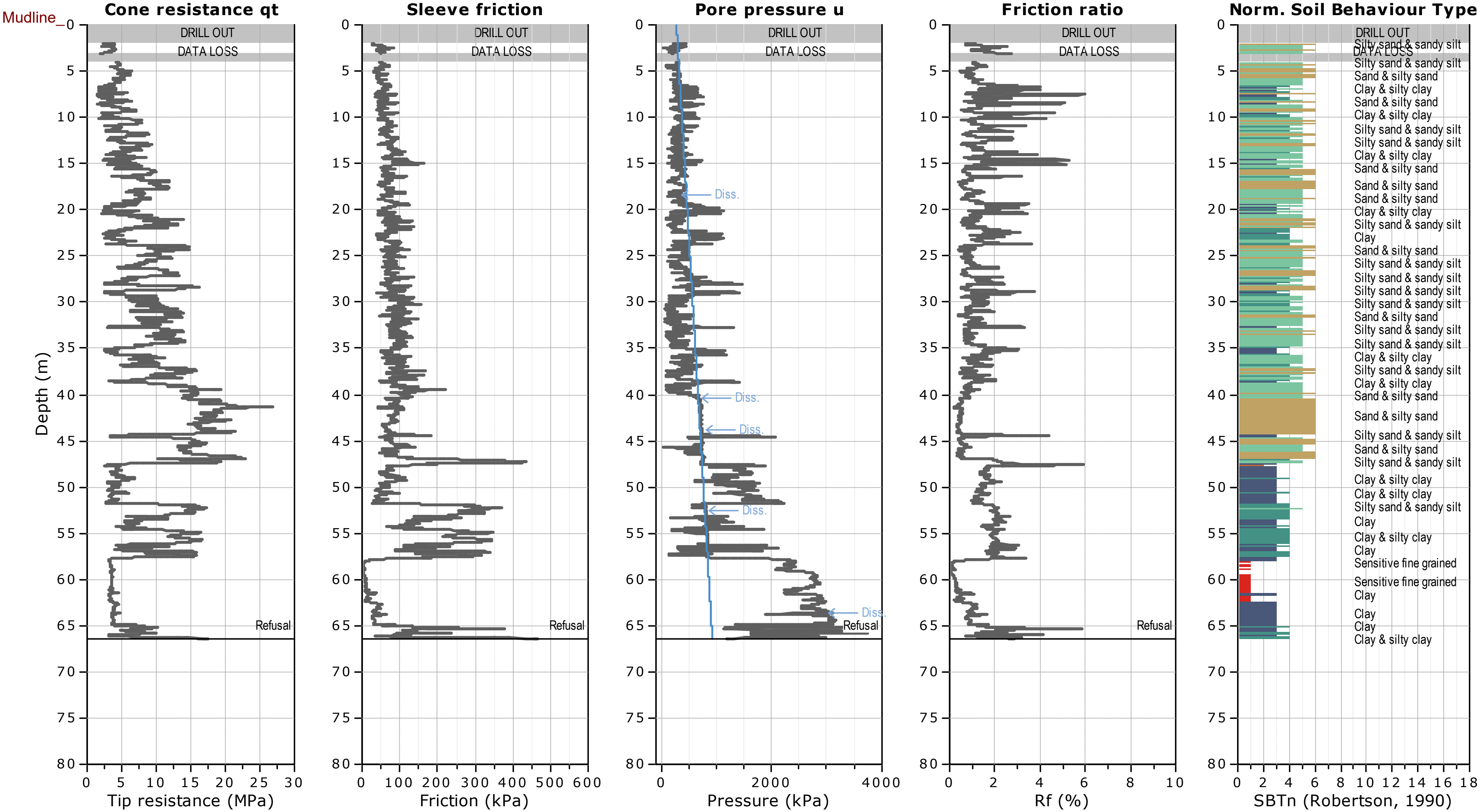
Surface Elevation: -27.31 m

Coords: N 5429141.540 m, E 488626.851 m

Cone Operator: Shane Kelly/Nathan Grewal

Project: Thurber Engineering Ltd.

Location: Westshore Terminals, Berth 2, Delta, B.C.



APPENDIX B – CPT Plots – N_{60}

CPT20-01

Total depth: 72.62 m, Date: 4/6/2020

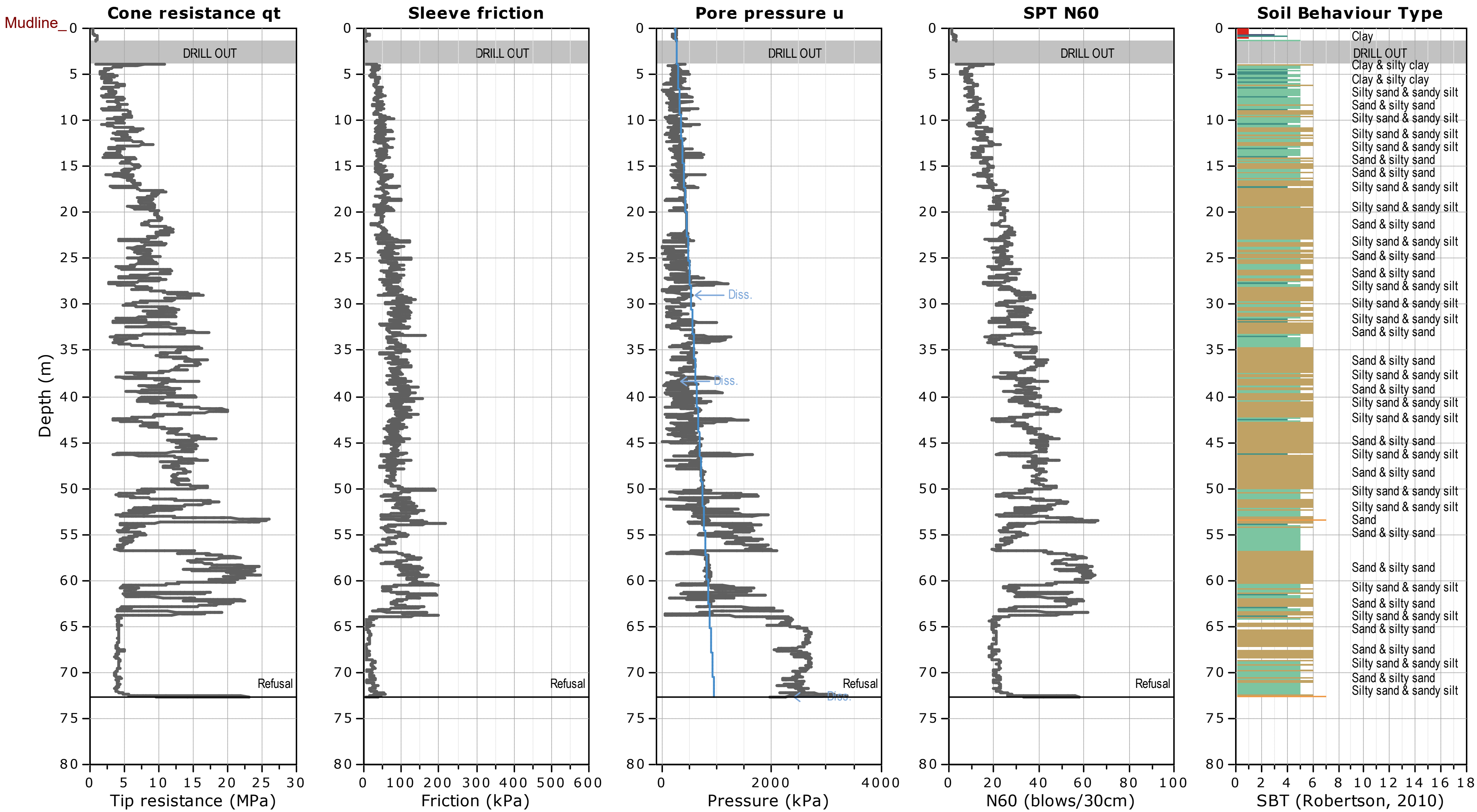
Surface Elevation: -24.45 m

Coords: N 5429039.748 m, E 488562.330 m

Cone Operator: Shane Kelly/Nathan Grewal

Project: Thurber Engineering Ltd.

Location: Westshore Terminals, Berth 2, Delta, B.C.



CPT20-02

Total depth: 66.41 m, Date: 4/7/2020

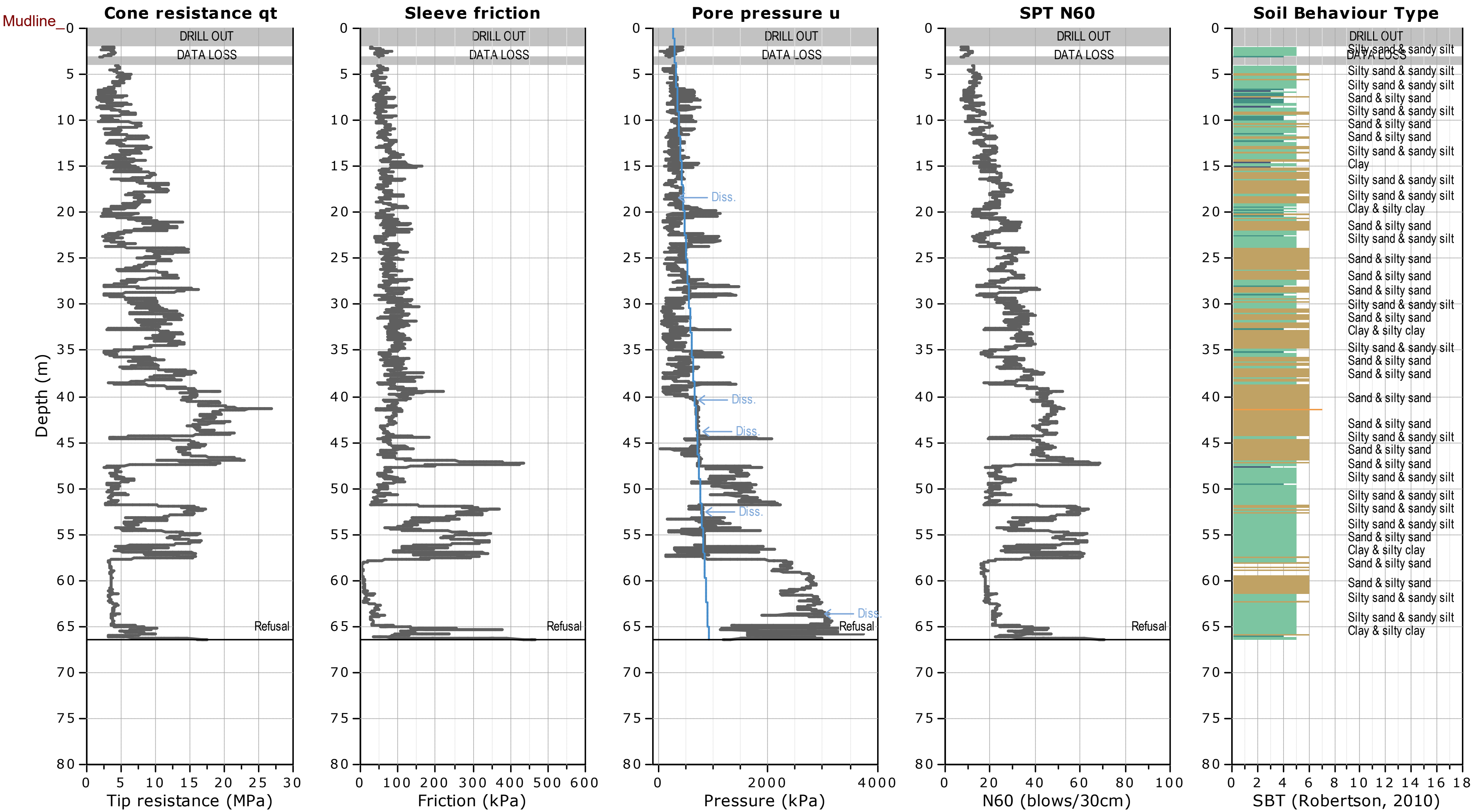
Surface Elevation: -27.31 m

Coords: N 5429141.540 m, E 488626.851 m

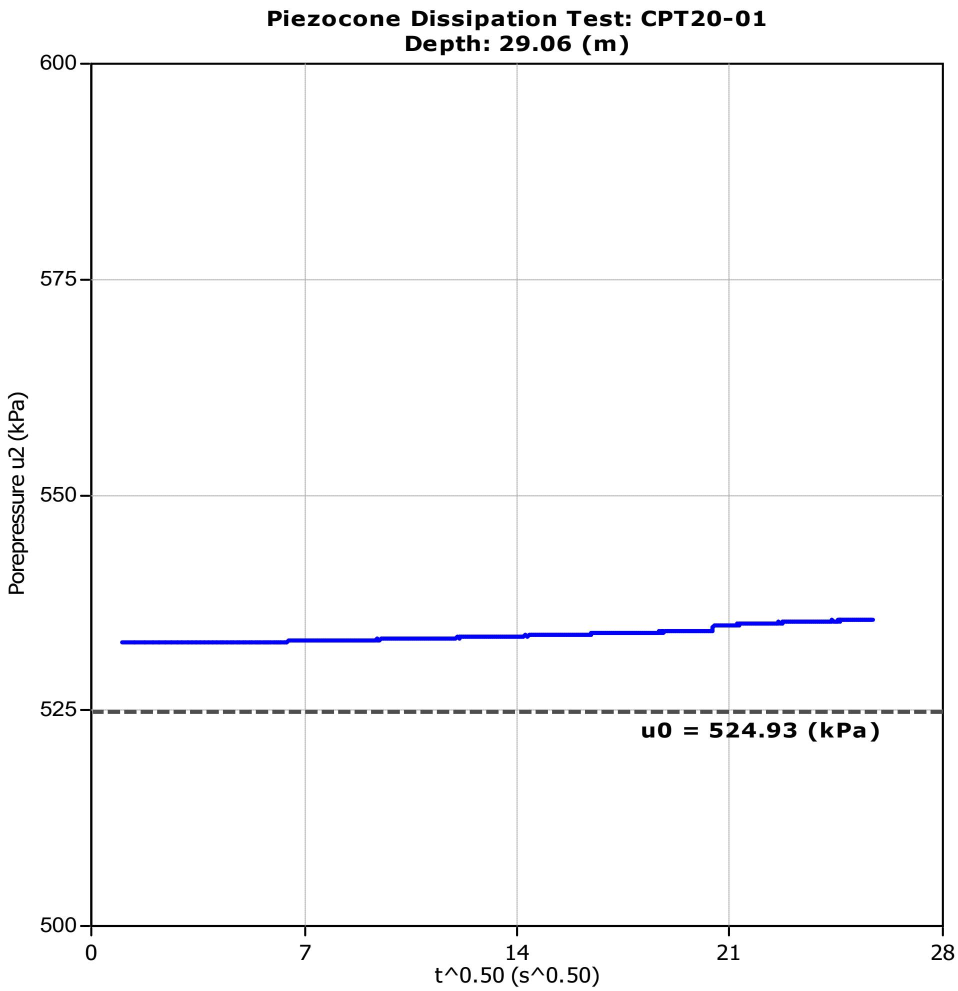
Cone Operator: Shane Kelly/Nathan Grewal

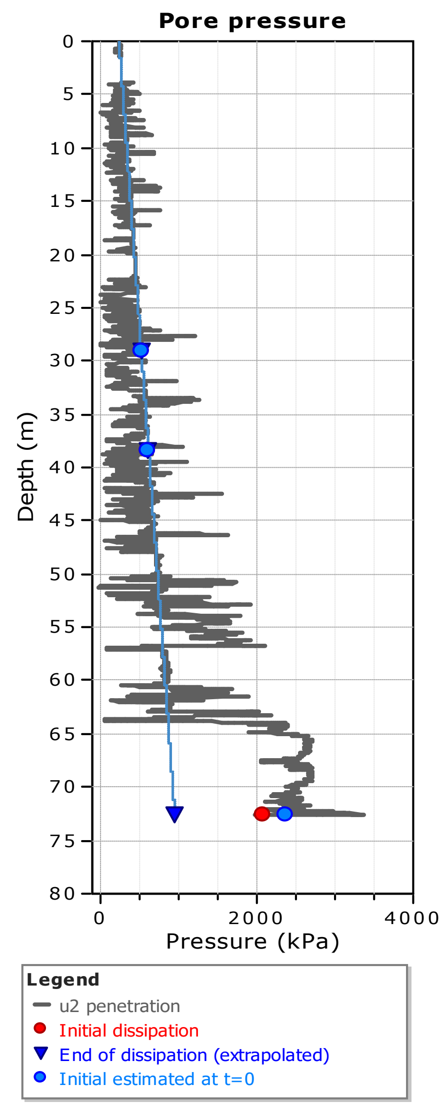
Project: **Thurber Engineering Ltd.**

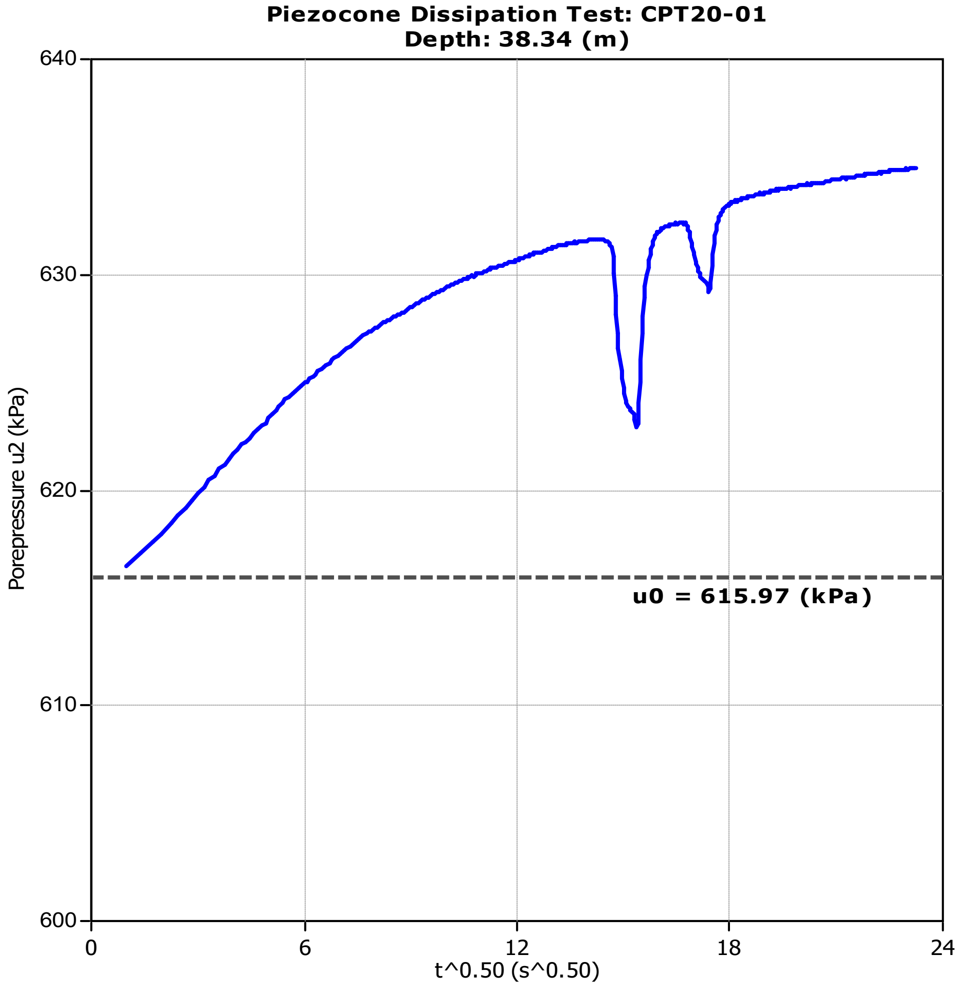
Location: **Westshore Terminals, Berth 2, Delta, B.C.**

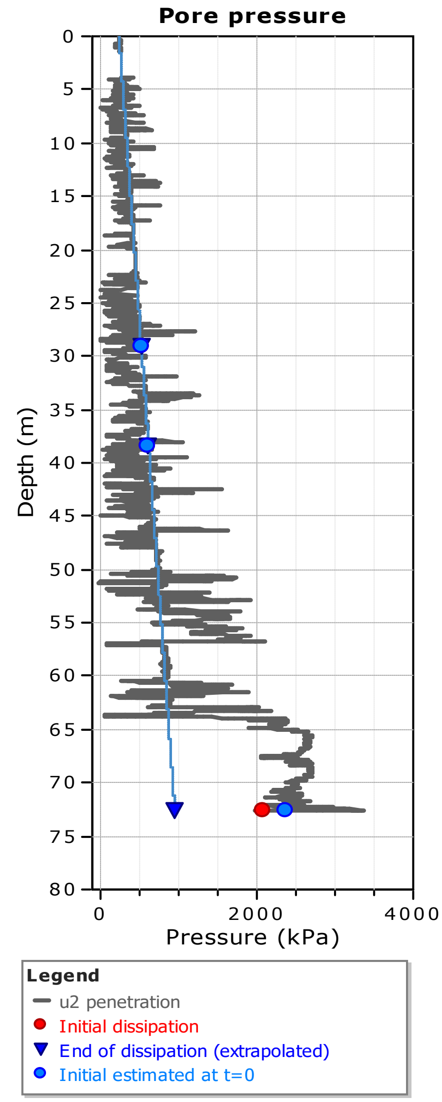


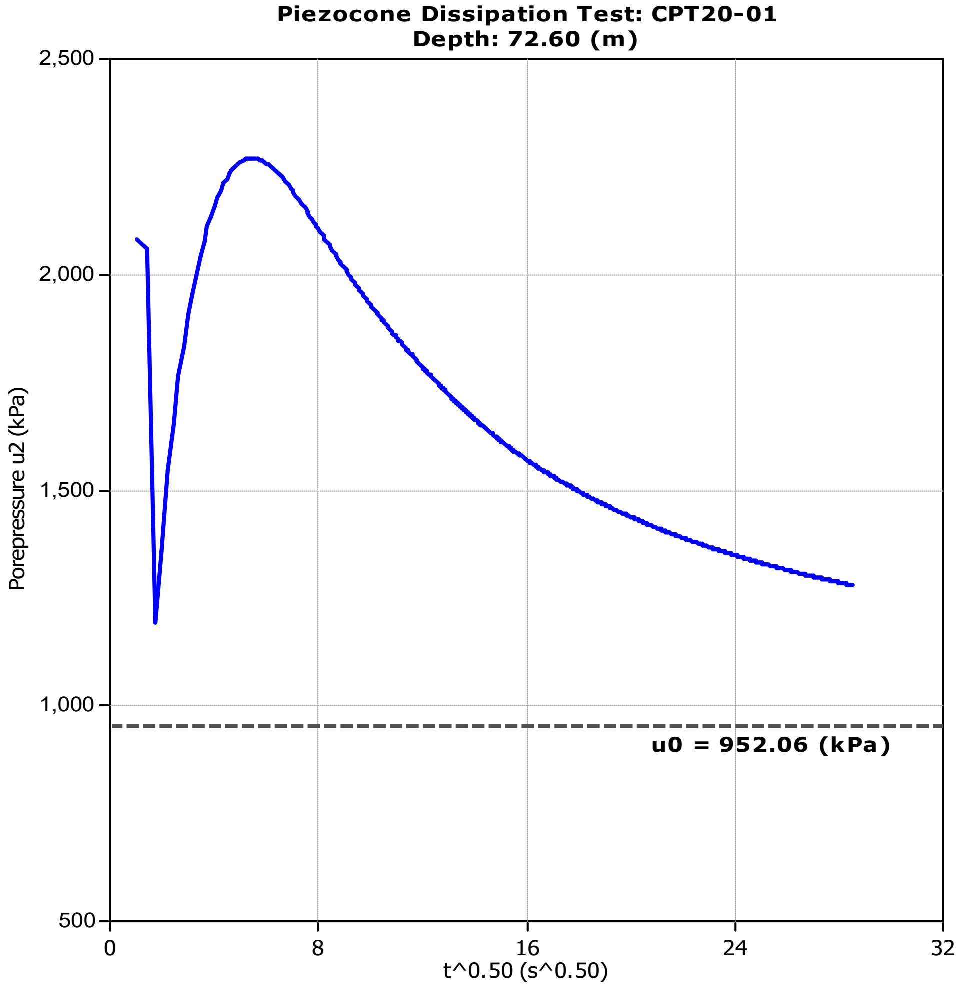
APPENDIX C – Pore Pressure Dissipation Testing Plots

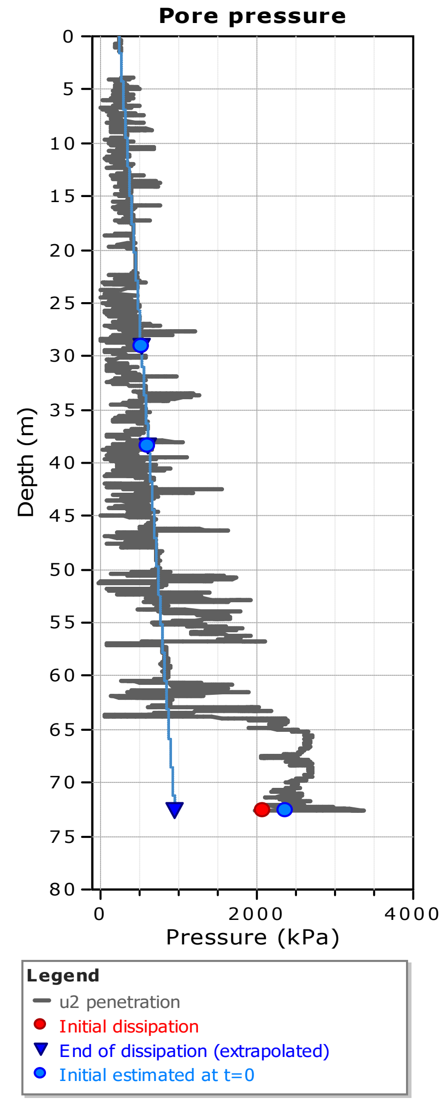

Piezocone Dissipation Test: CPT20-01
Depth: 29.06 (m)
Porepressure u2 (kPa)
t^0.50 (s^0.50)
u0 = 524.93 (kPa)
600
575
550
525
500
0
7
14
21
28

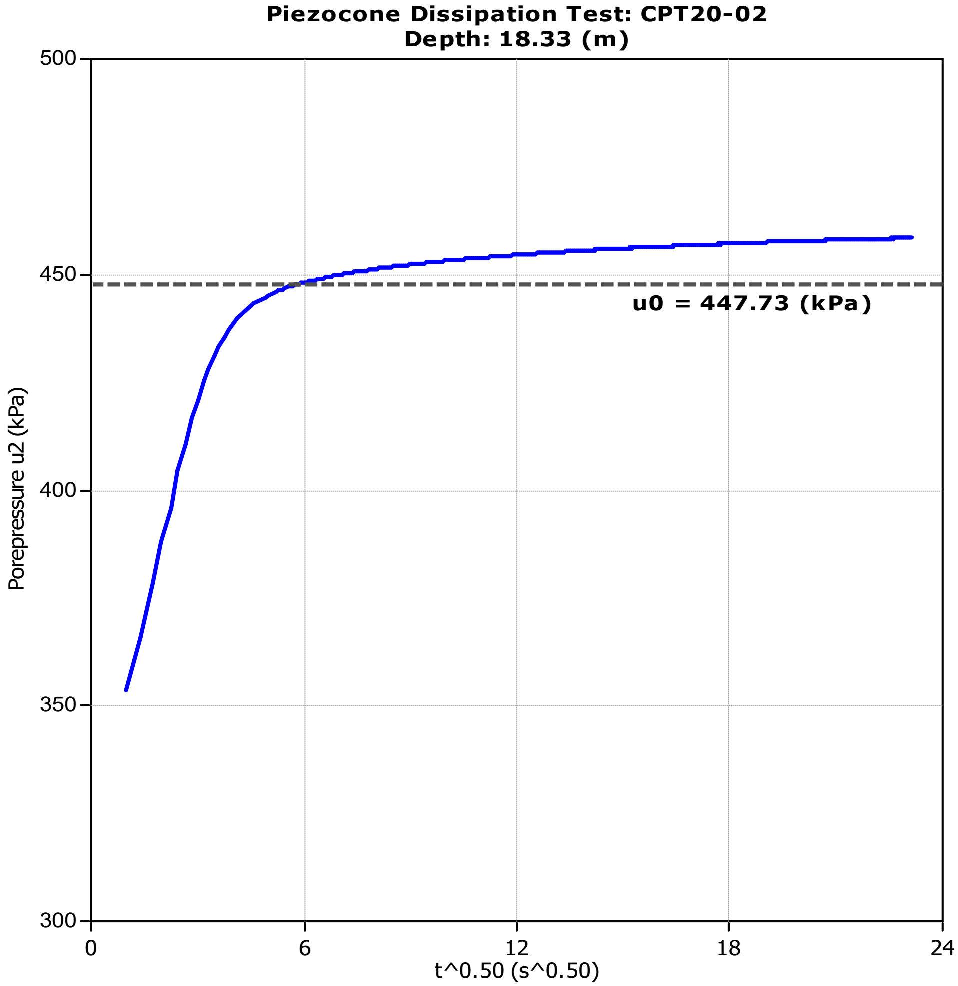

Pore pressure
Depth (m)
Pressure (kPa)
0
2000
4000
Legend
u2 penetration
Initial dissipation
End of dissipation (extrapolated)
Initial estimated at t=0

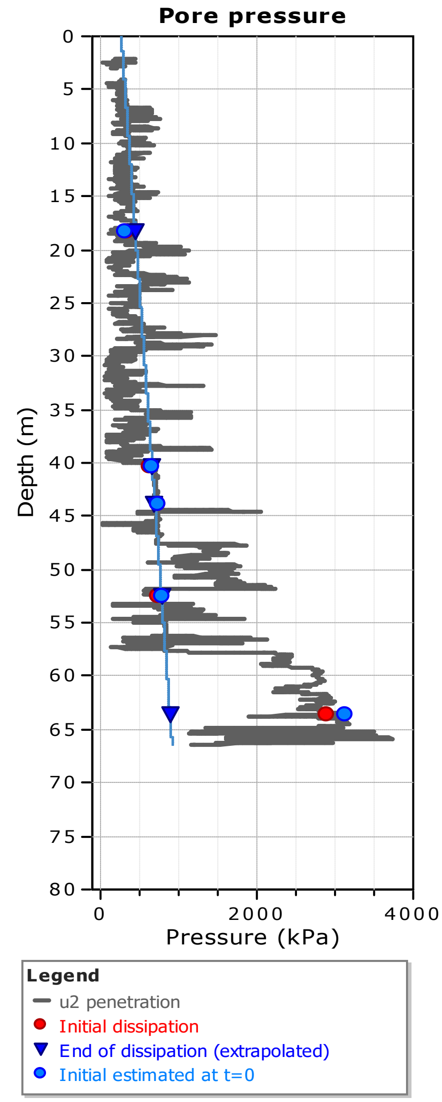

Piezocone Dissipation Test: CPT20-01
Depth: 38.34 (m)
Porepressure u2 (kPa)
t^0.50 (s^0.50)
u0 = 615.97 (kPa)
640
630
620
610
600
0
6
12
18
24

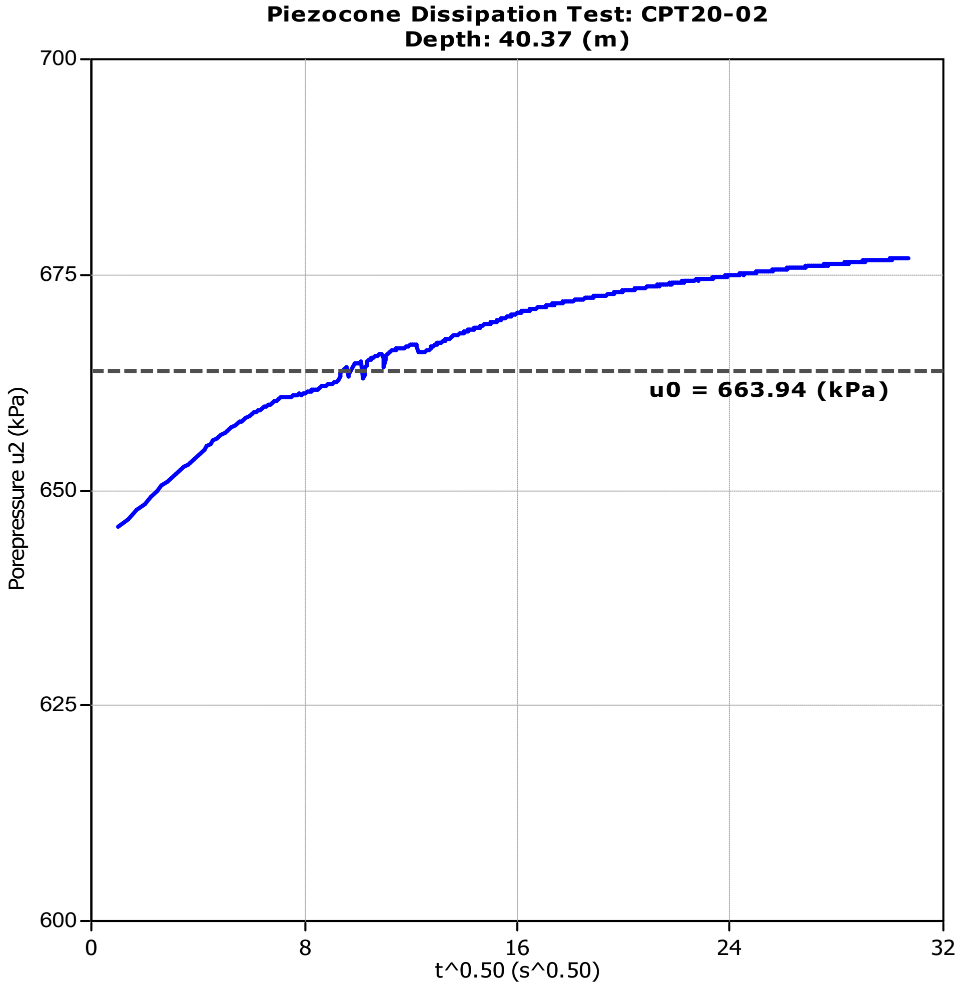

Pore pressure
Depth (m)
Pressure (kPa)
0
2000
4000
Legend
u2 penetration
Initial dissipation
End of dissipation (extrapolated)
Initial estimated at t=0

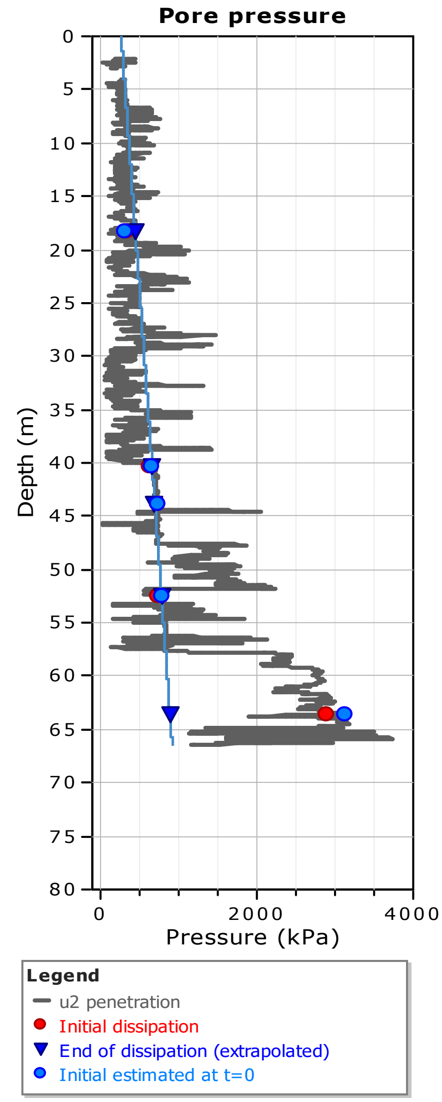

Piezocone Dissipation Test: CPT20-01
Depth: 72.60 (m)
Porepressure u2 (kPa)
2,500
2,000
1,500
1,000
500
0
8
16
24
32
t^0.50 (s^0.50)
u0 = 952.06 (kPa)

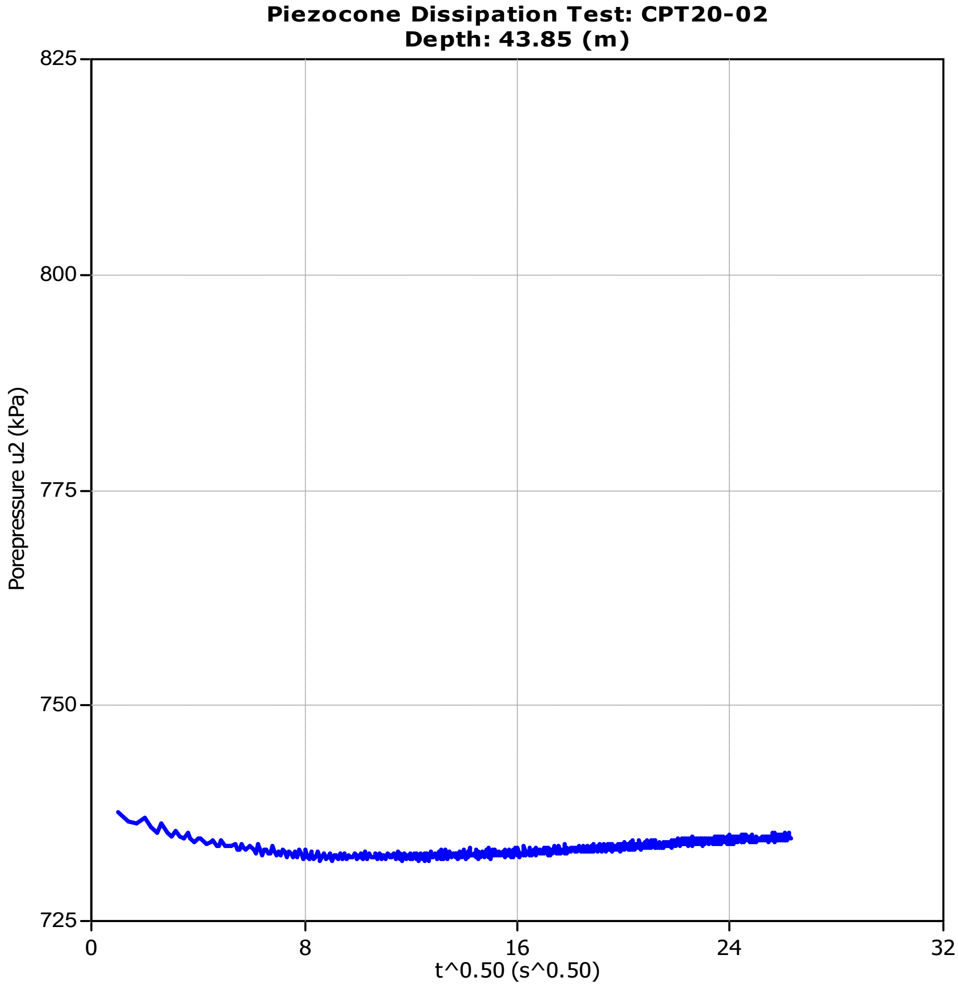

Pore pressure
Depth (m)
Pressure (kPa)
0
2000
4000
Legend
u2 penetration
Initial dissipation
End of dissipation (extrapolated)
Initial estimated at t=0

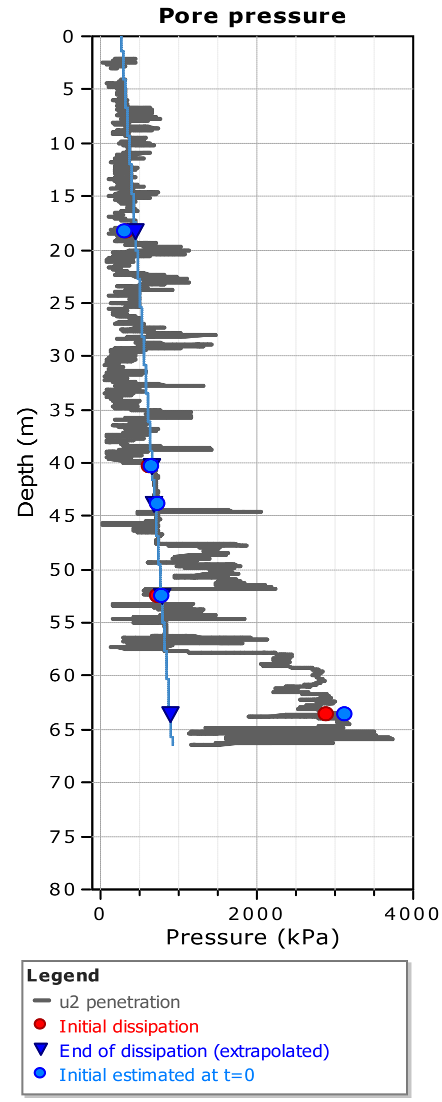

Piezocone Dissipation Test: CPT20-02
Depth: 18.33 (m)
Porepressure u2 (kPa)
t^0.50 (s^0.50)
u0 = 447.73 (kPa)
500
450
400
350
300
0
6
12
18
24

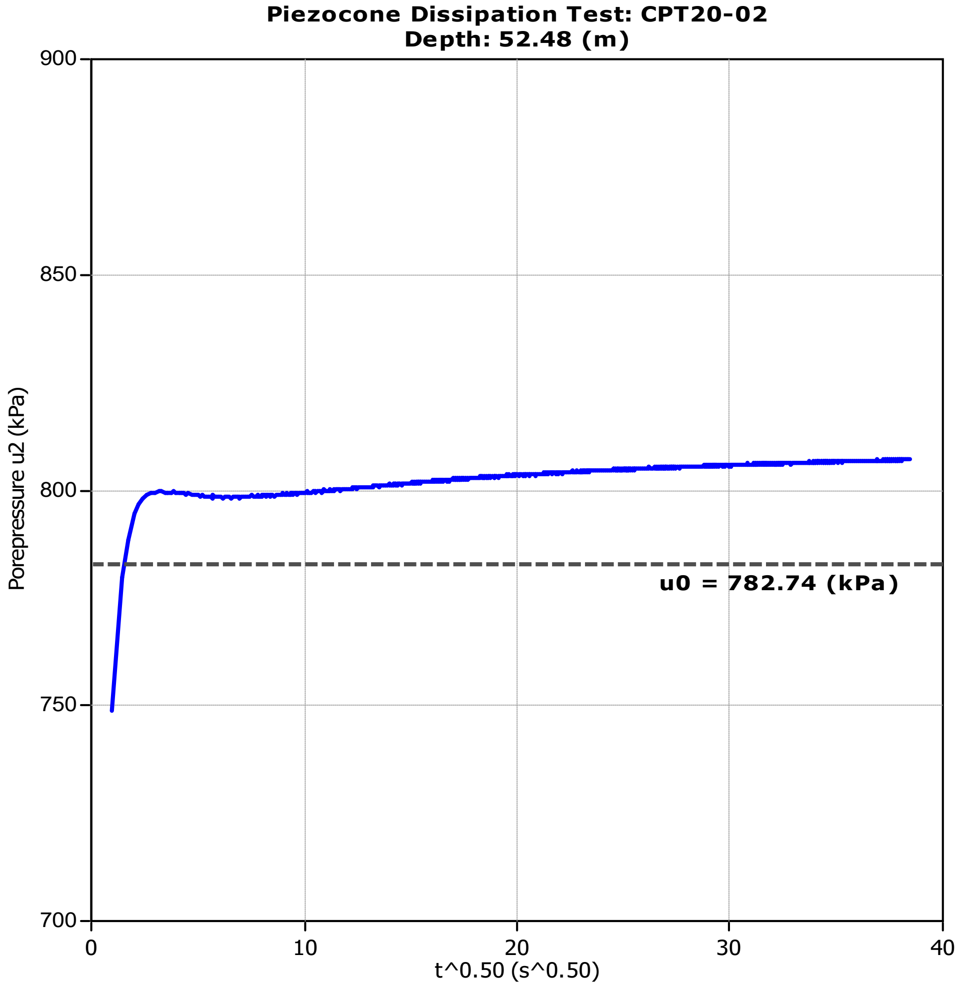

Pore pressure
Depth (m)
Pressure (kPa)
0
2000
4000
Legend
u2 penetration
Initial dissipation
End of dissipation (extrapolated)
Initial estimated at t=0

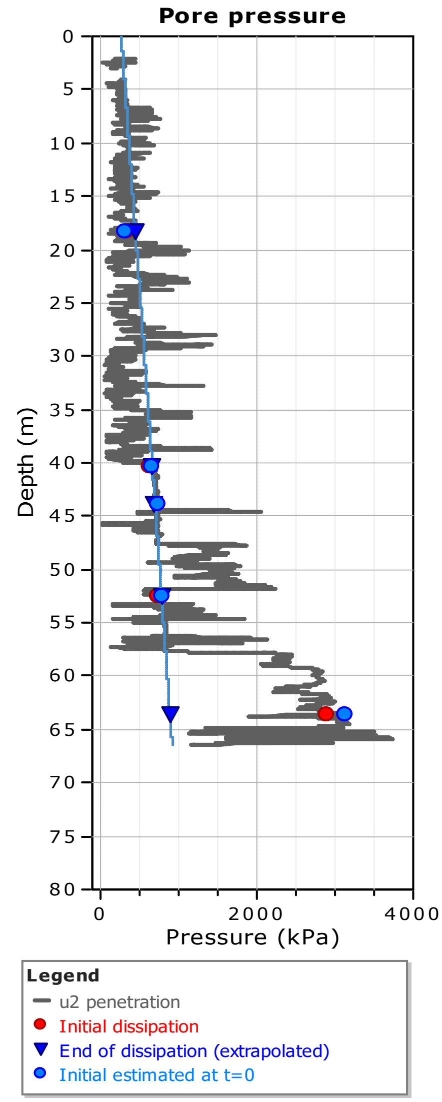

Piezocone Dissipation Test: CPT20-02
Depth: 40.37 (m)
u0 = 663.94 (kPa)
Porepressure u2 (kPa)
t^0.50 (s^0.50)
700
675
650
625
600
0
8
16
24
32

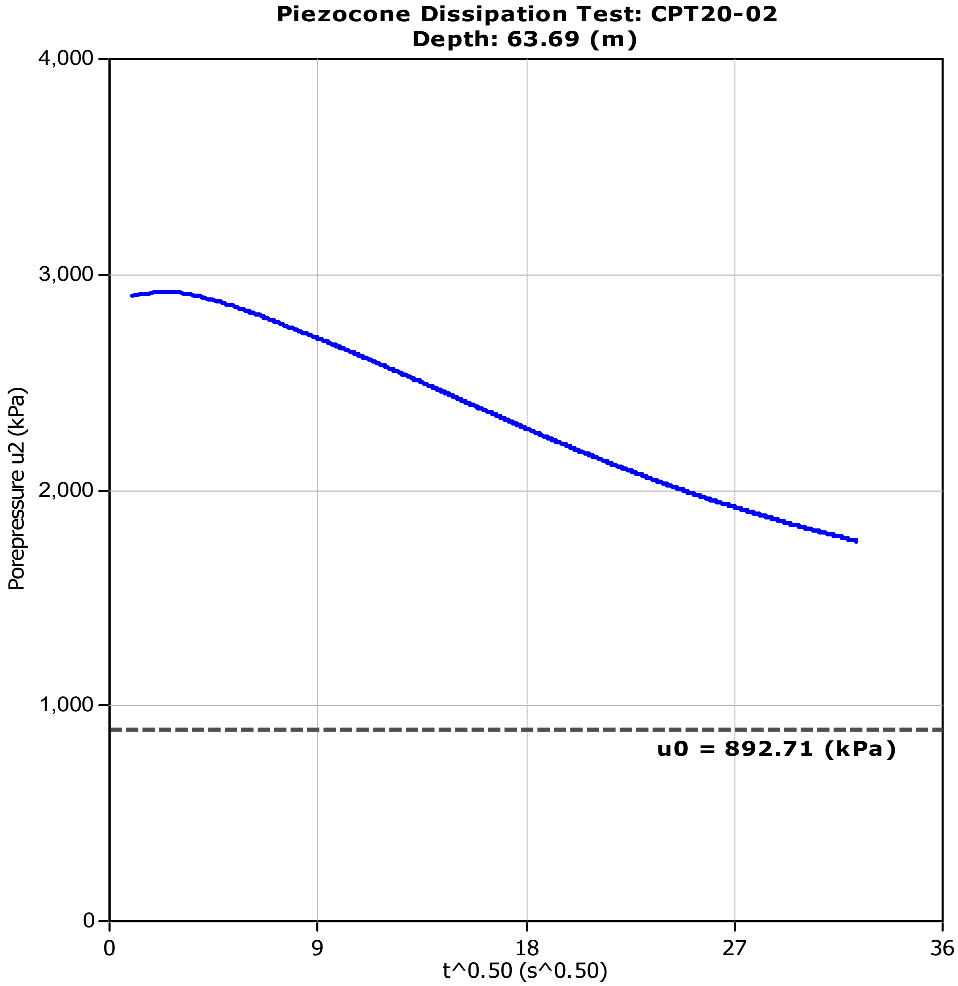

Pore pressure
Depth (m)
Pressure (kPa)
0
2000
4000
Legend
u2 penetration
Initial dissipation
End of dissipation (extrapolated)
Initial estimated at t=0

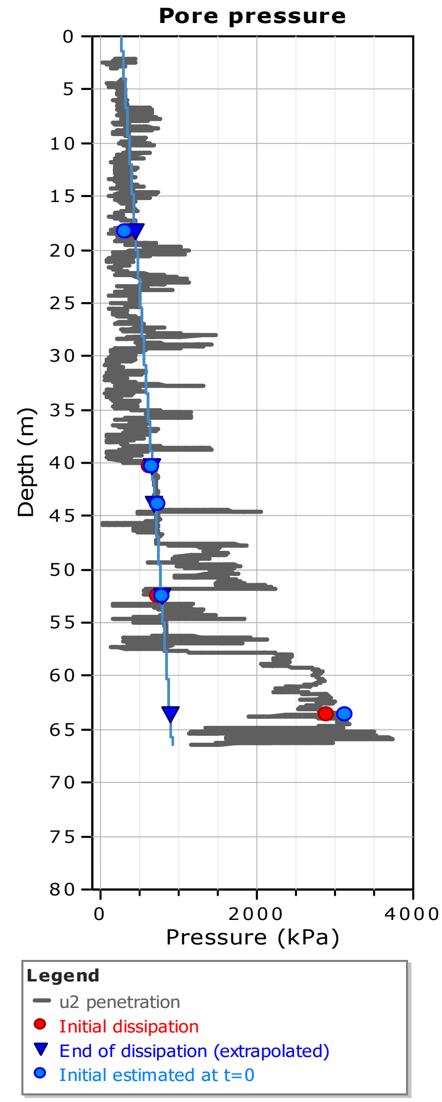

Piezocone Dissipation Test: CPT20-02
Depth: 43.85 (m)
Porepressure u2 (kPa)
825
800
775
750
725
0
8
16
24
32
t^0.50 (s^0.50)


Pore pressure
Depth (m)
Pressure (kPa)
0
2000
4000
Legend
u2 penetration
Initial dissipation
End of dissipation (extrapolated)
Initial estimated at t=0


Piezocone Dissipation Test: CPT20-02
Depth: 52.48 (m)
Porepressure u2 (kPa)
900
850
800
750
700
u0 = 782.74 (kPa)
0
10
20
30
40
t^0.50 (s^0.50)


Pore pressure
Depth (m)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
0
2000
4000
Pressure (kPa)
Legend
u2 penetration
Initial dissipation
End of dissipation (extrapolated)
Initial estimated at t=0


Piezocone Dissipation Test: CPT20-02
Depth: 63.69 (m)
Porepressure u2 (kPa)
4,000
3,000
2,000
1,000
0
0
9
18
27
36
t^0.50 (s^0.50)
u0 = 892.71 (kPa)


Pore pressure
Depth (m)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
0
2000
4000
Pressure (kPa)
Legend
u2 penetration
Initial dissipation
End of dissipation (extrapolated)
Initial estimated at t=0

APPENDIX D-I – CPT Plots – Standard Depth in Elevation

GREGG
GEOTECH DRILLING · GROUP OF COMPANIES

Project: Thurber Engineering Ltd.

Location: Westshore Terminals, Berth 2, Delta, B.C.

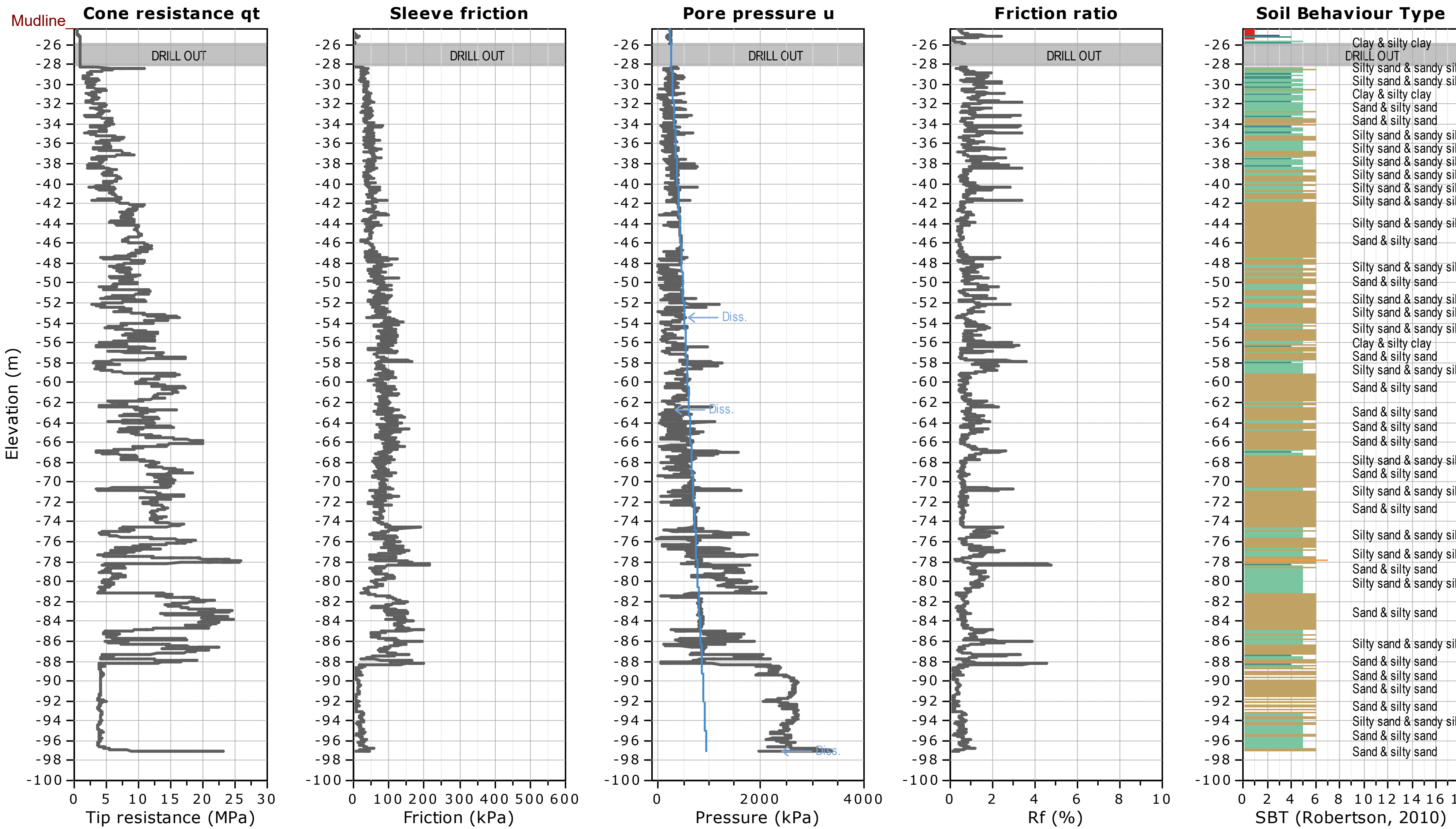
CPT20-01

Total depth: 72.62 m, Date: 4/6/2020

Surface Elevation: -24.45 m

Coords: N 5429039.748 m, E 488562.330 m

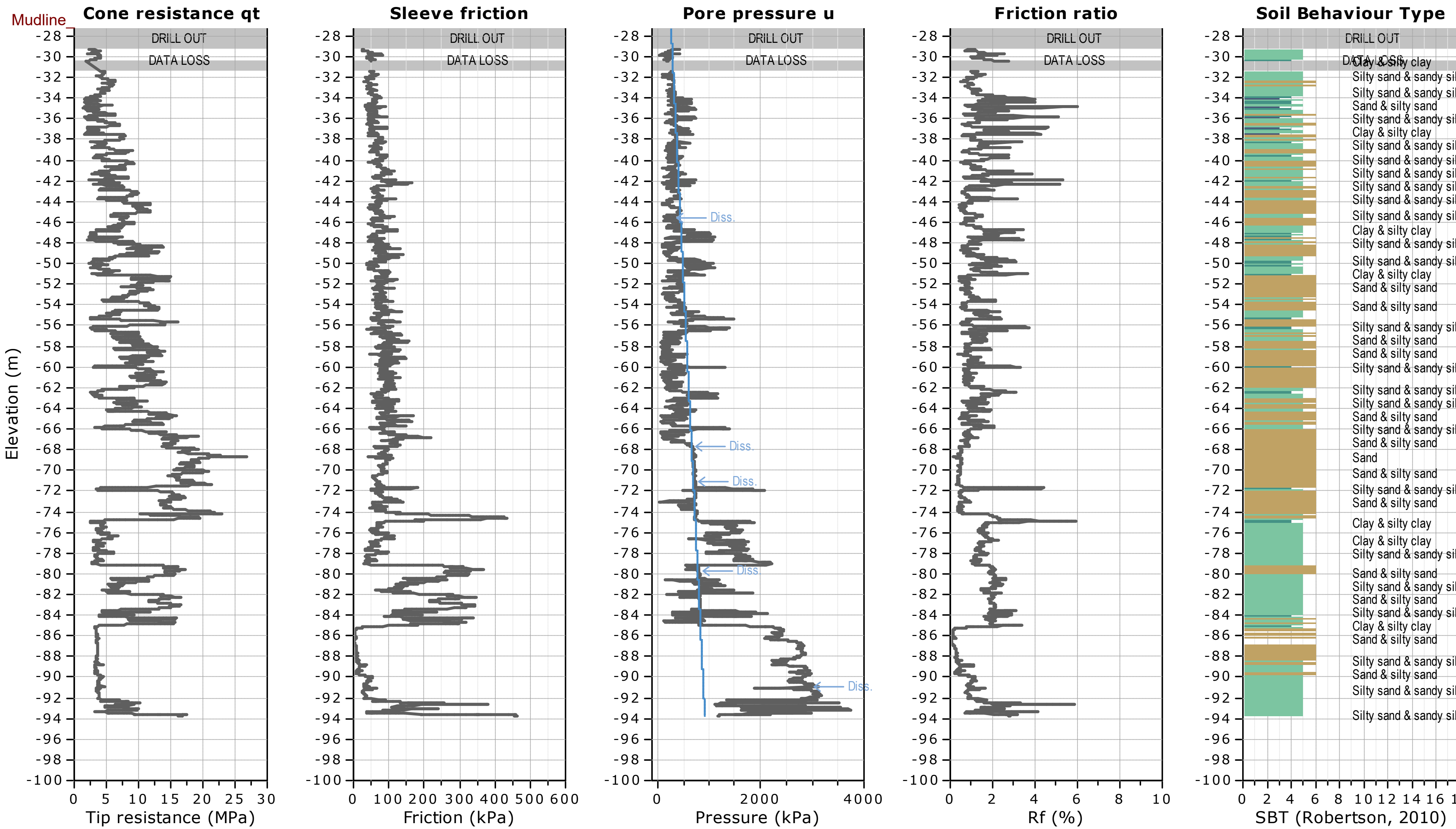
Cone Operator: Shane Kelly/Nathan Grewal



GREGG
GEOTECH DRILLING - GROUP OF COMPANIES

CPT20-02
Total depth: 66.41 m, Date: 4/7/2020
Surface Elevation: -27.31 m
Coords: N 5429141.540 m, E 488626.851 m
Cone Operator: Shane Kelly/Nathan Grewal

Project: Thurber Engineering Ltd.
Location: Westshore Terminals, Berth 2, Delta, B.C.

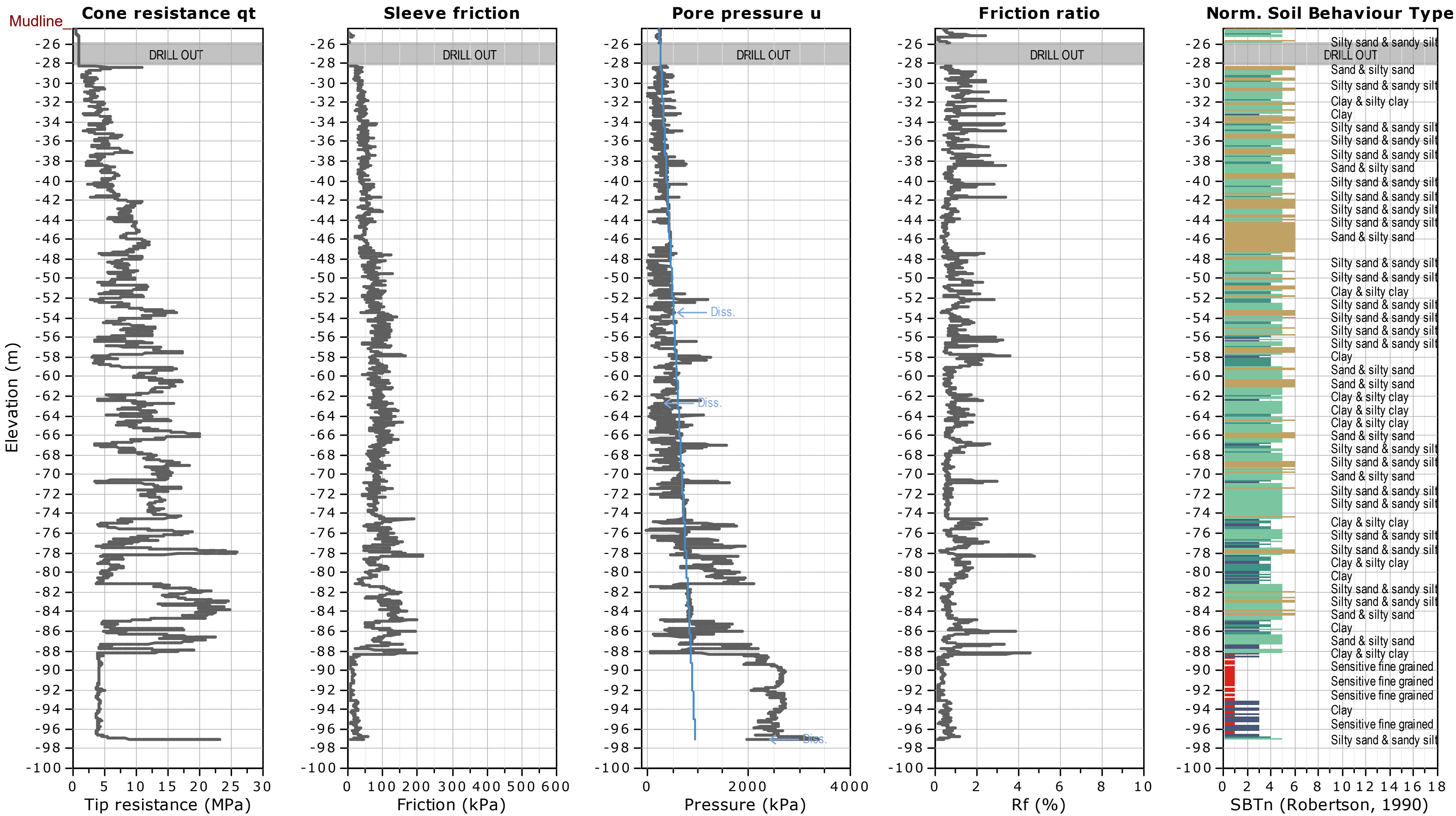


APPENDIX D-II – CPT Plots – SBTn
Depth in Elevation

GREGG
GEOTECH DRILLING · GROUP OF COMPANIES

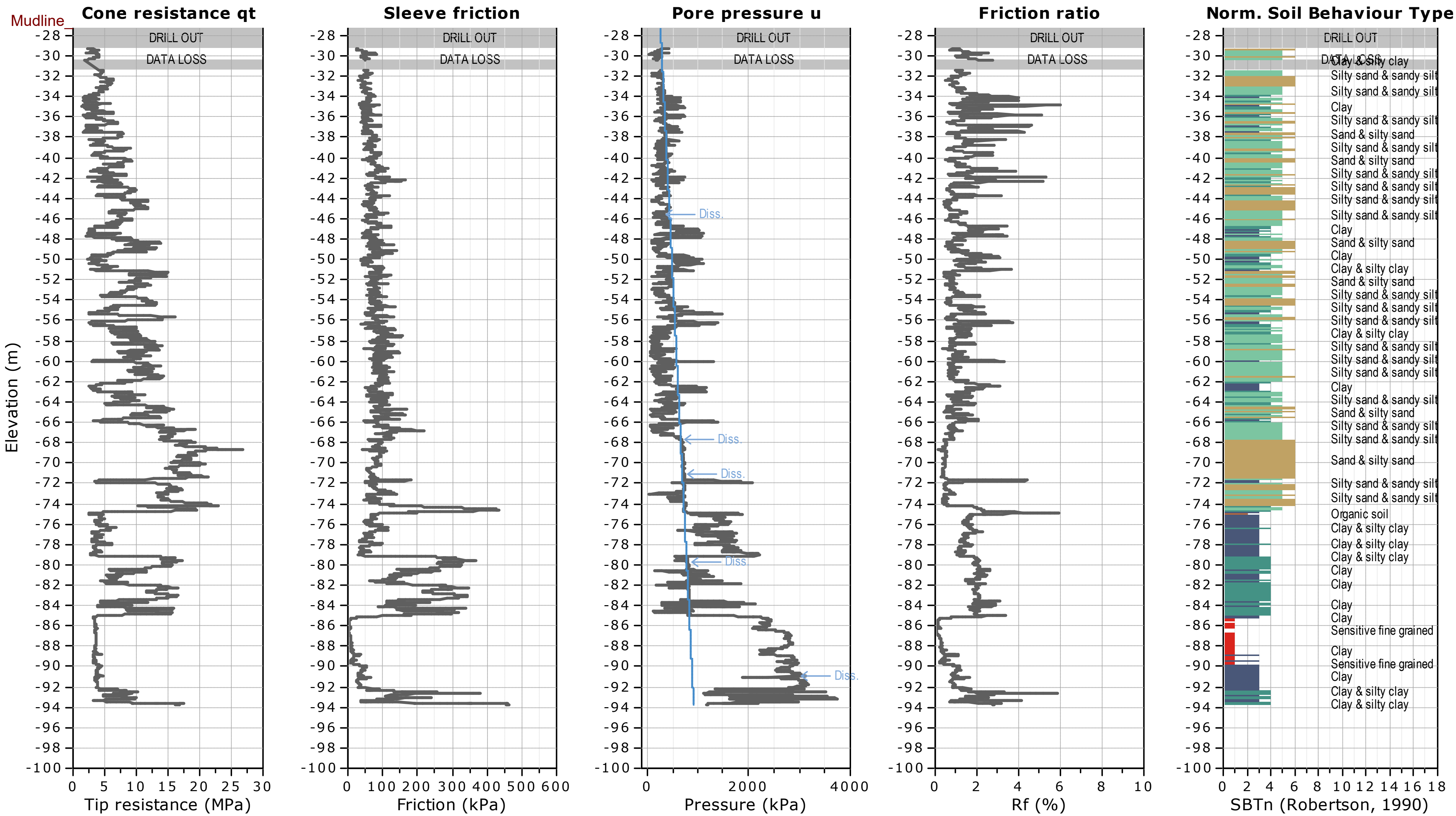
CPT20-01
Total depth: 72.62 m, Date: 4/6/2020
Surface Elevation: -24.45 m
Coords: N 5429039.748 m, E 488562.330 m
Cone Operator: Shane Kelly/Nathan Grewal

Project: **Thurber Engineering Ltd.**
Location: **Westshore Terminals, Berth 2, Delta, B.C.**



CPT20-02
Total depth: 66.41 m, Date: 4/7/2020
Surface Elevation: -27.31 m
Coords: N 5429141.540 m, E 488626.851 m
Cone Operator: Shane Kelly/Nathan Grewal

Project: Thurber Engineering Ltd.
Location: Westshore Terminals, Berth 2, Delta, B.C.

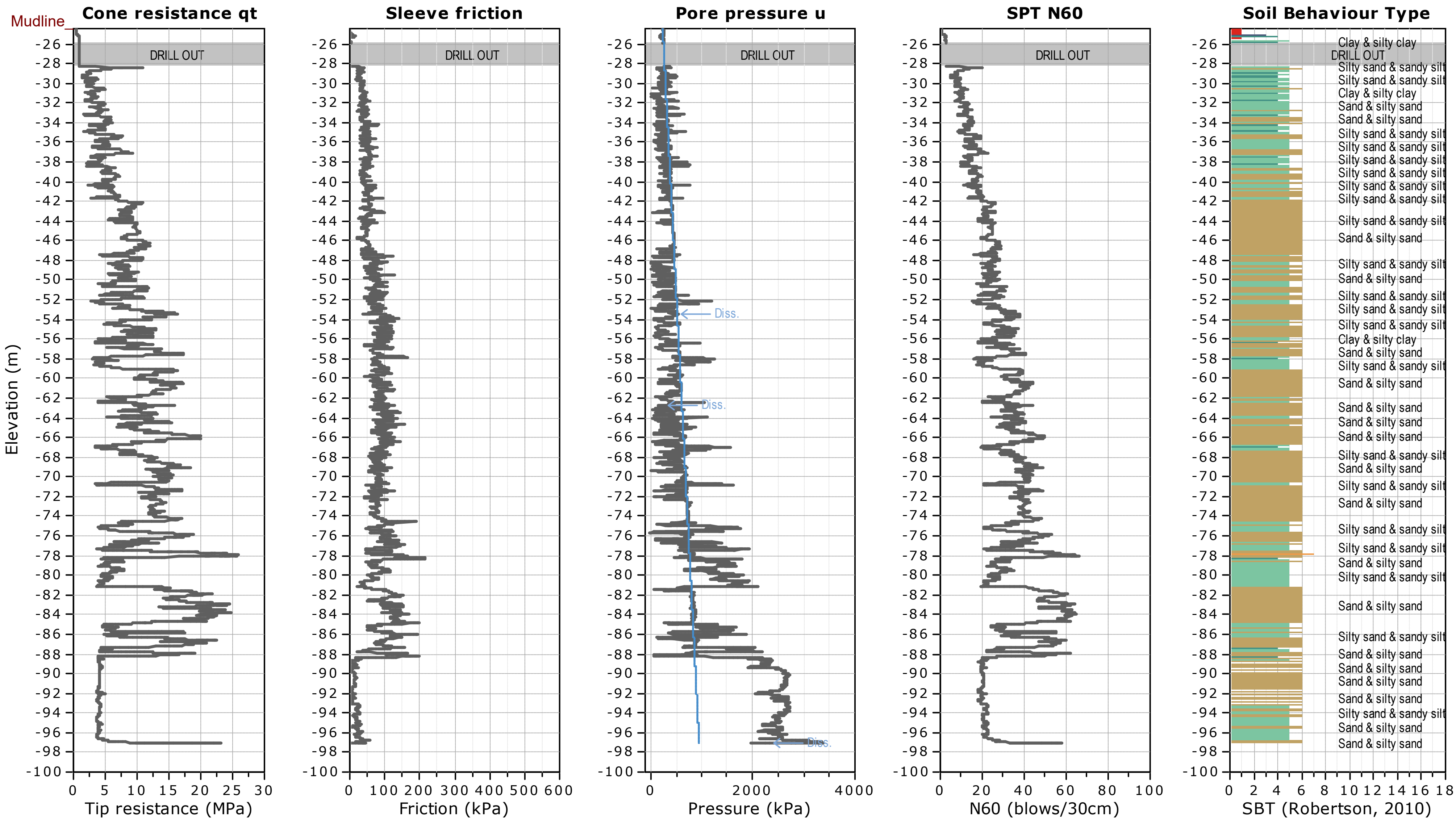


APPENDIX E – CPT Plots – N_{60}
Depth in Elevation

GREGG
GEOTECH DRILLING · GROUP OF COMPANIES

CPT20-01
Total depth: 72.62 m, Date: 4/6/2020
Surface Elevation: -24.45 m
Coords: N 5429039.748 m, E 488562.330 m
Cone Operator: Shane Kelly/Nathan Grewal

Project: Thurber Engineering Ltd.
Location: Westshore Terminals, Berth 2, Delta, B.C.



Project: Thurber Engineering Ltd.

Location: Westshore Terminals, Berth 2, Delta, B.C.

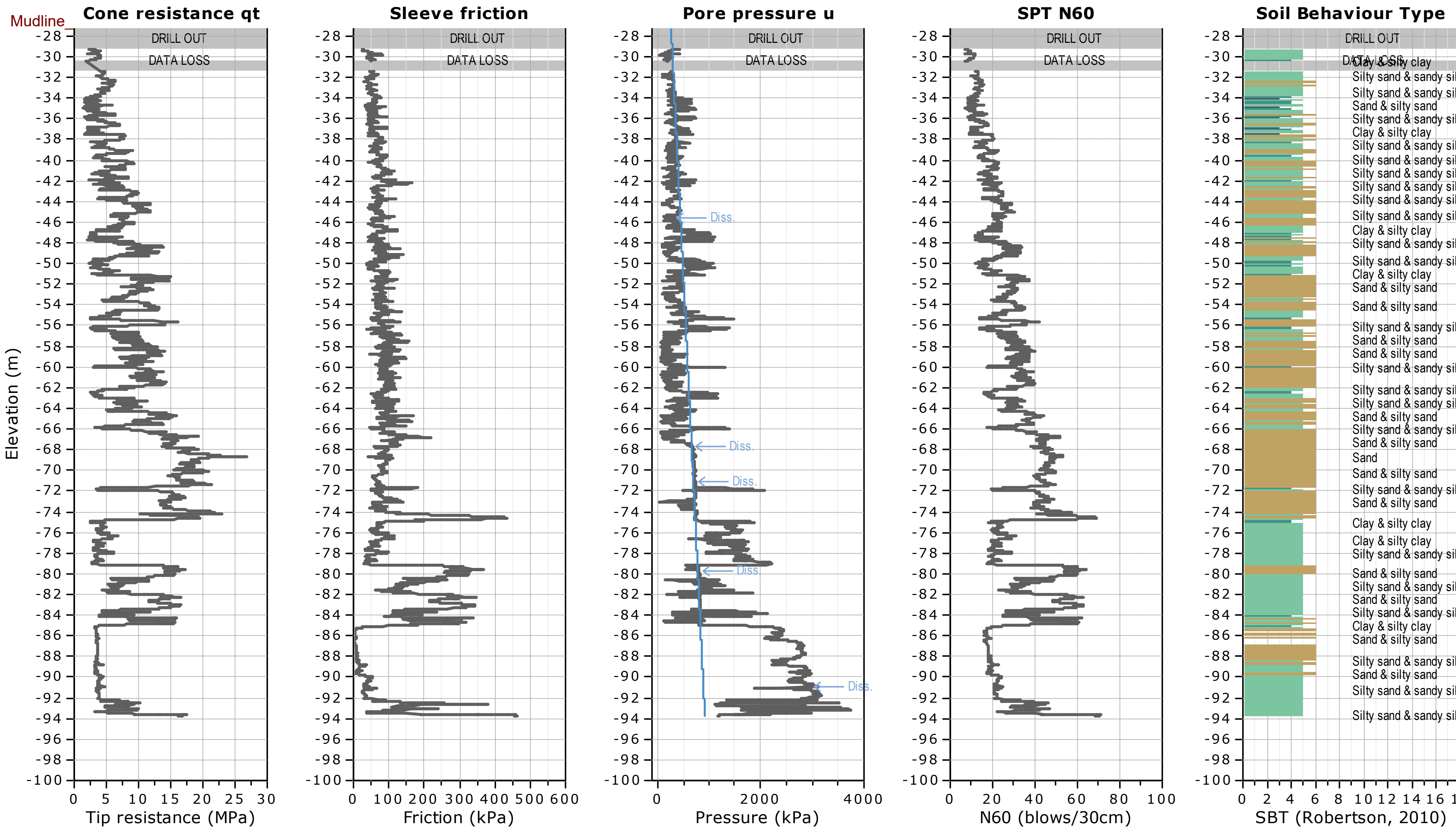
CPT20-02

Total depth: 66.41 m, Date: 4/7/2020

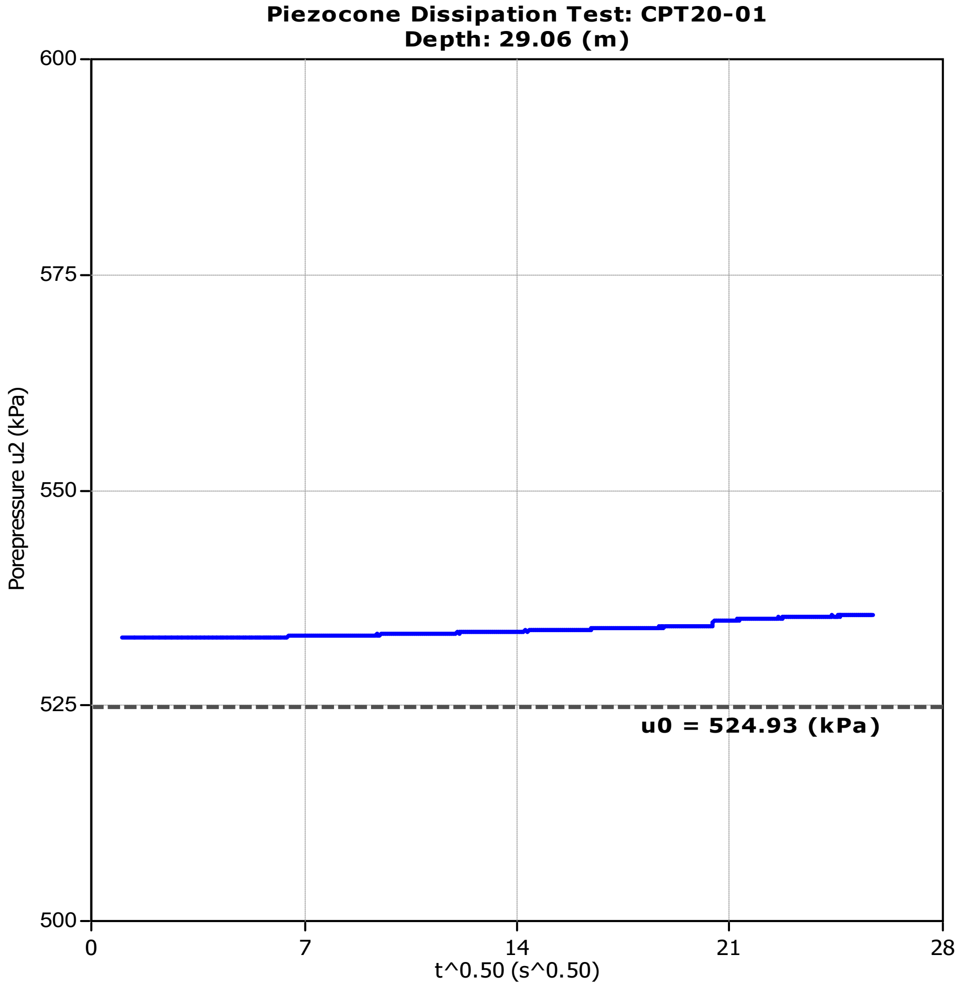
Surface Elevation: -27.31 m

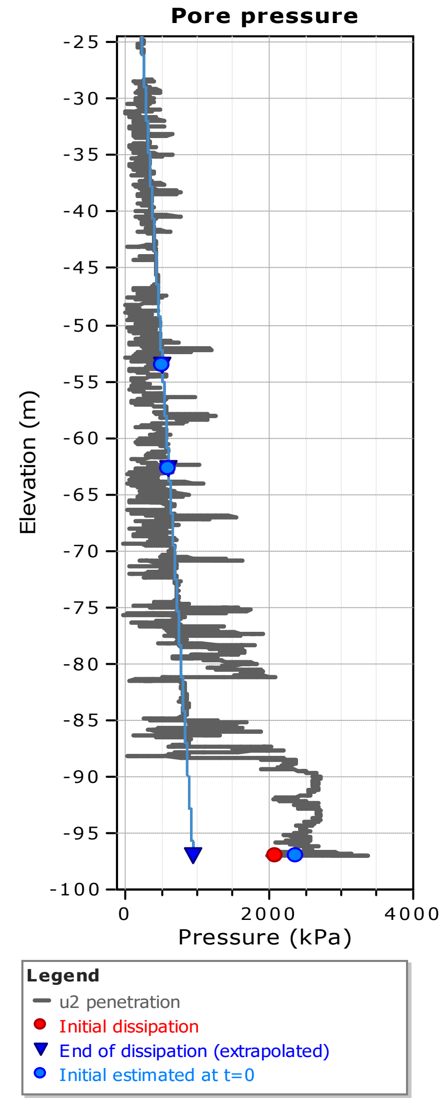
Coords: N 5429141.540 m, E 488626.851 m

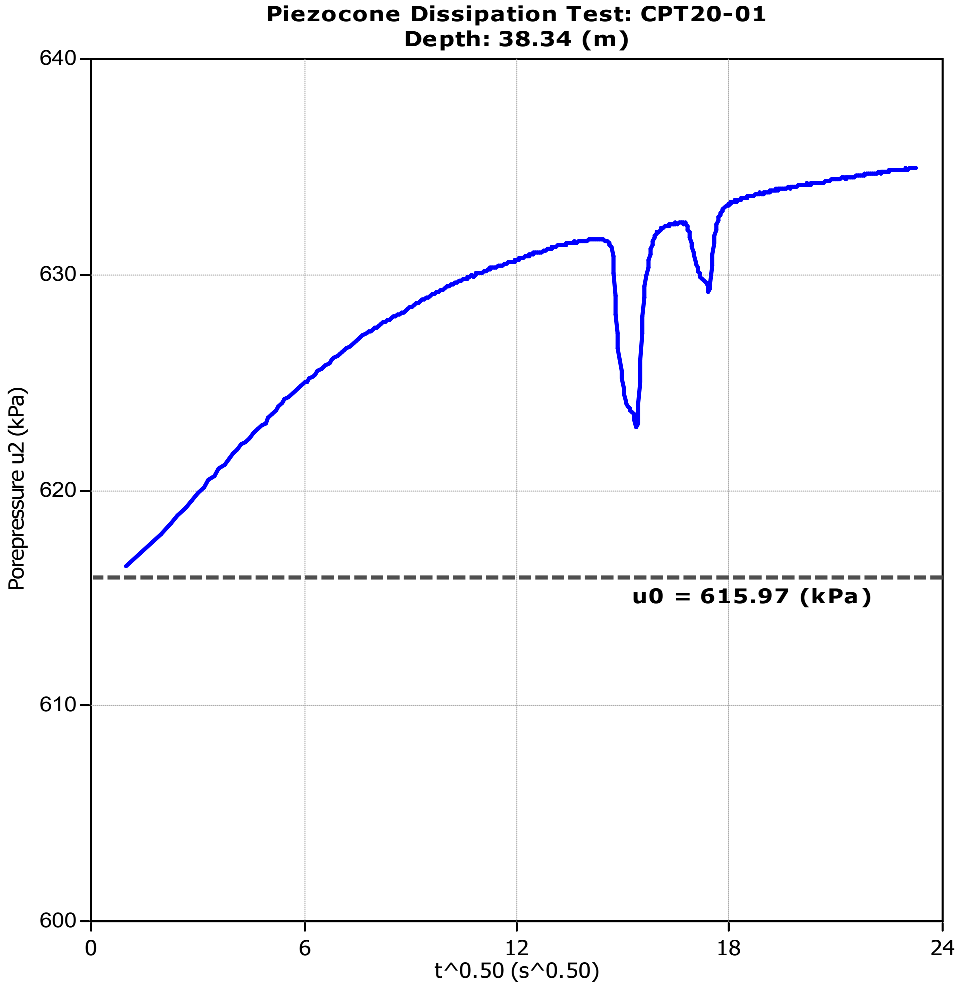
Cone Operator: Shane Kelly/Nathan Grewal

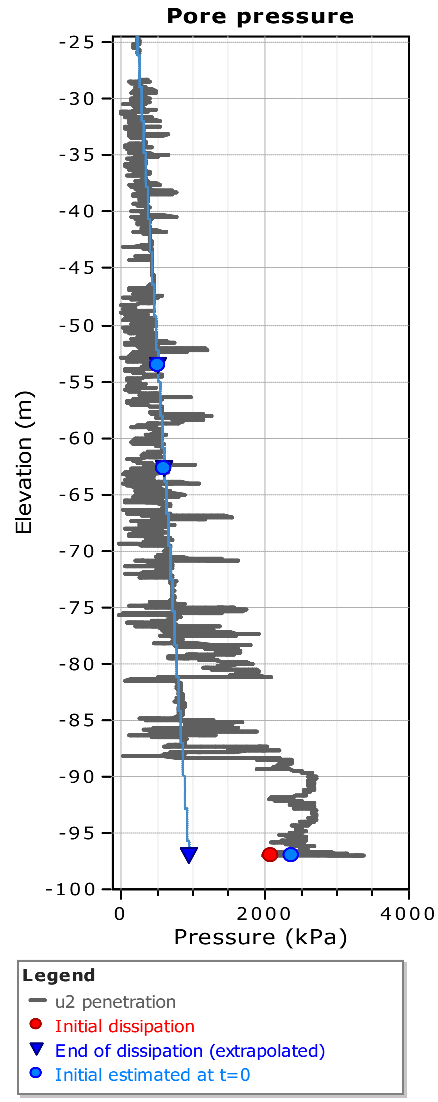


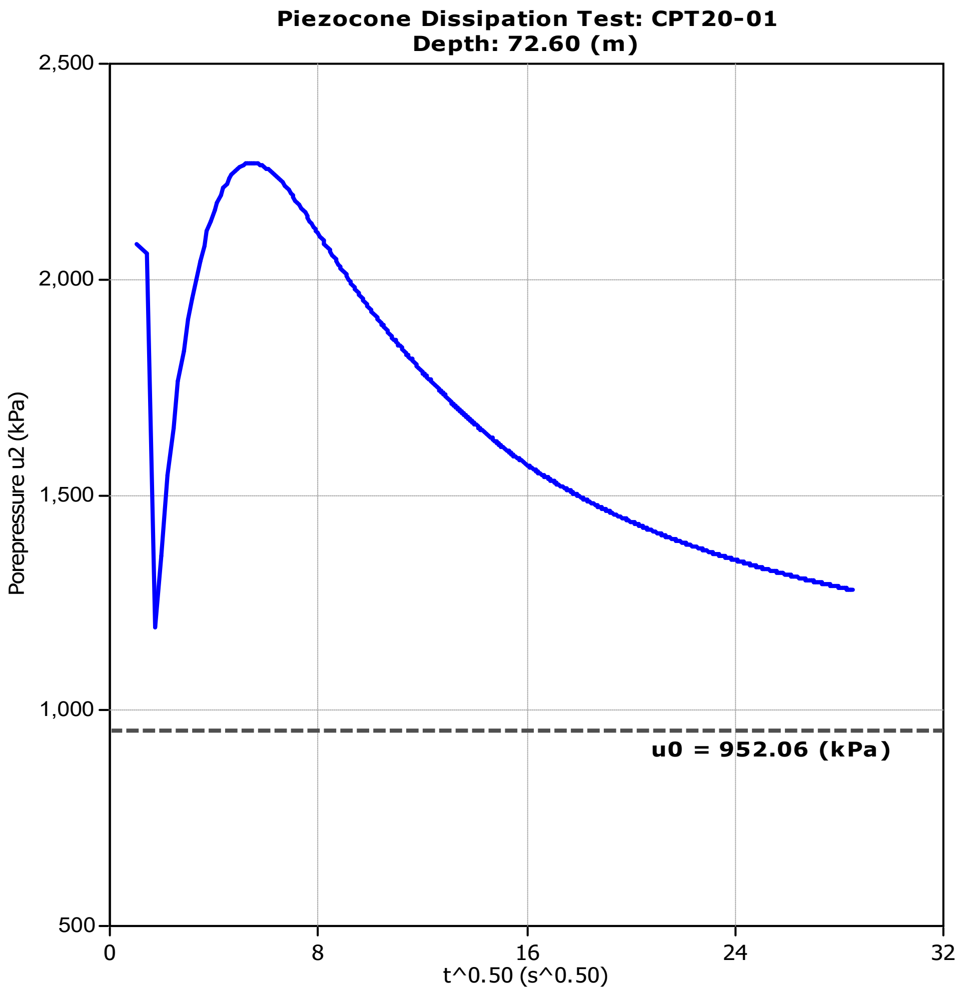
APPENDIX F – Pore Pressure Dissipation Testing Plots
Depth in Elevation

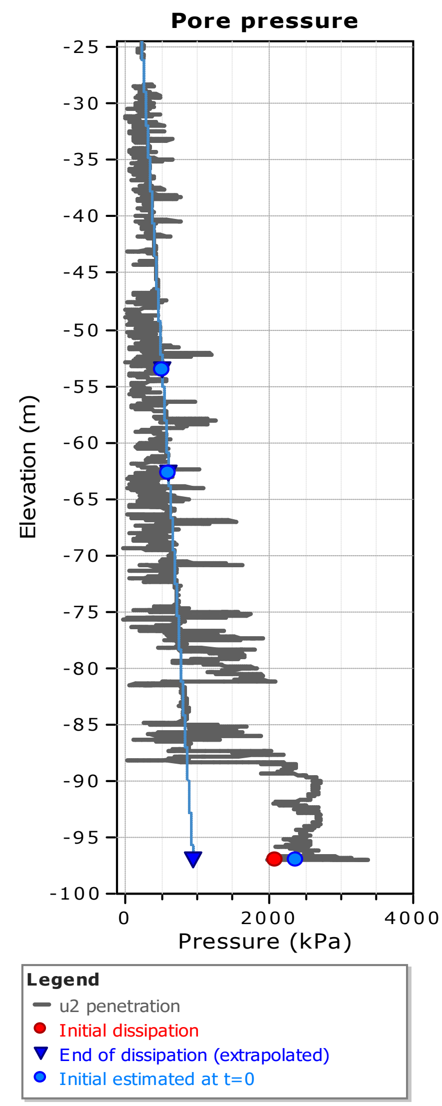

Piezocone Dissipation Test: CPT20-01
Depth: 29.06 (m)
Porepressure u2 (kPa)
600
575
550
525
500
0
7
14
21
28
t^0.50 (s^0.50)
u0 = 524.93 (kPa)

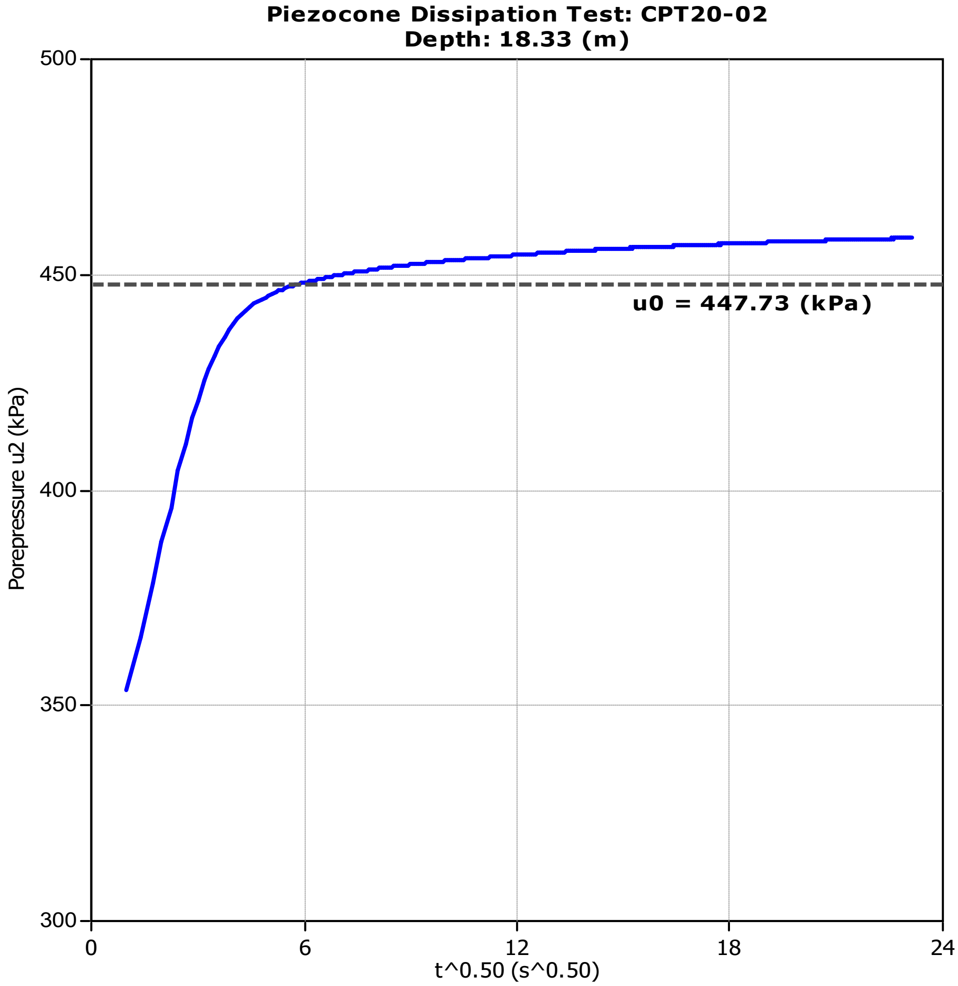

Pore pressure
Elevation (m)
-25
-30
-35
-40
-45
-50
-55
-60
-65
-70
-75
-80
-85
-90
-95
-100
0
2000
4000
Pressure (kPa)
Legend
u2 penetration
Initial dissipation
End of dissipation (extrapolated)
Initial estimated at t=0

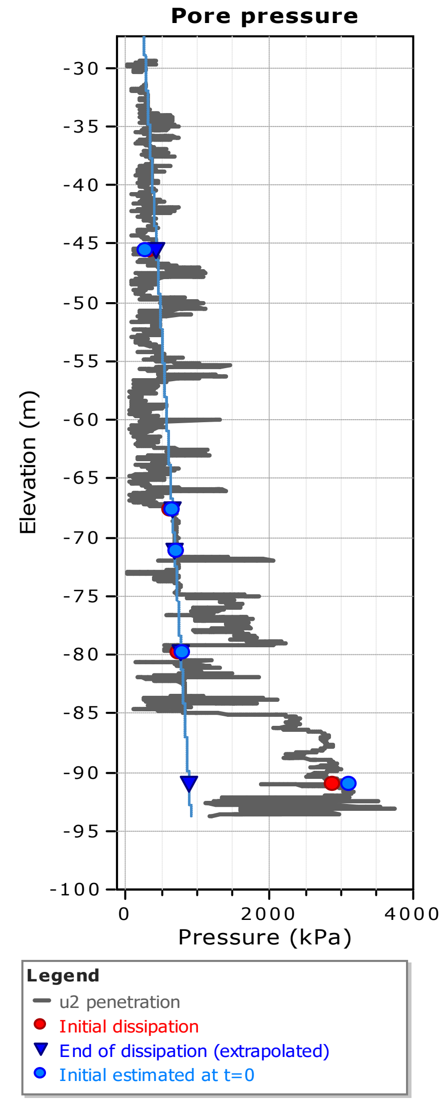

Piezocone Dissipation Test: CPT20-01
Depth: 38.34 (m)
Porepressure u2 (kPa)
t^0.50 (s^0.50)
u0 = 615.97 (kPa)
640
630
620
610
600
0
6
12
18
24

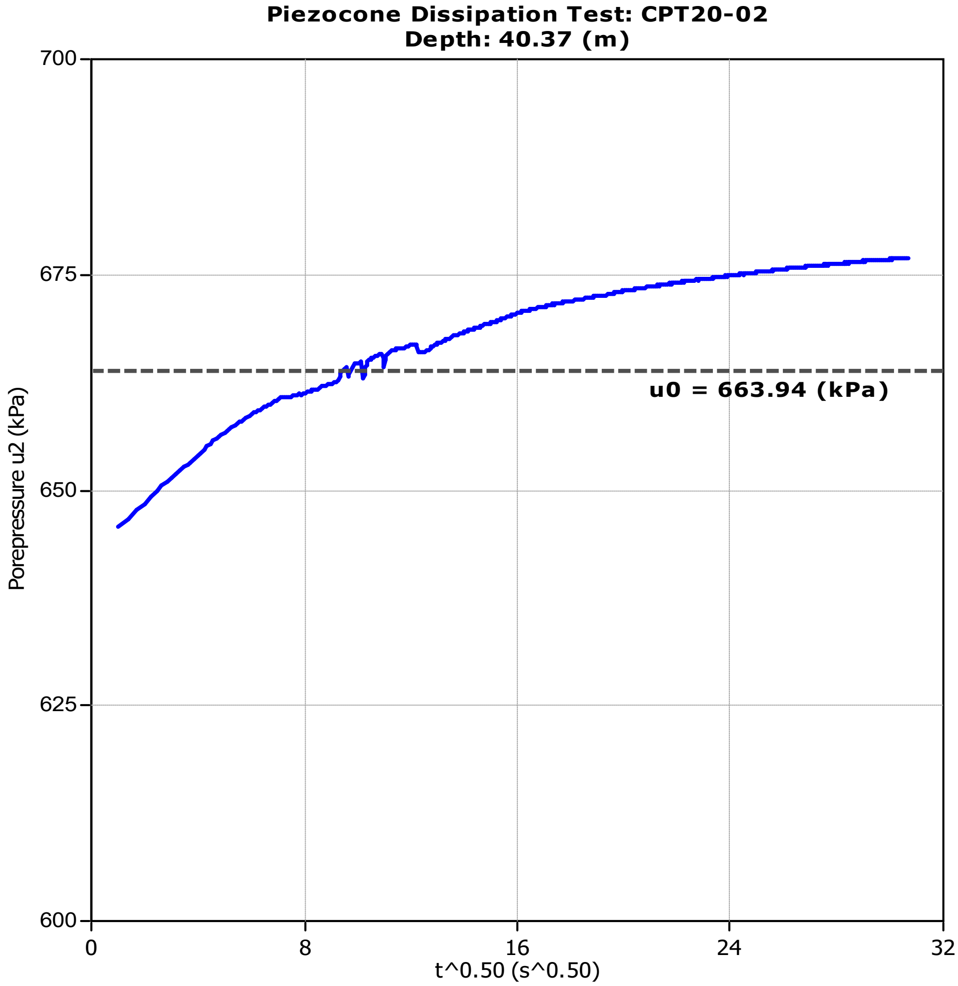

Pore pressure
Elevation (m)
Pressure (kPa)
-25
-30
-35
-40
-45
-50
-55
-60
-65
-70
-75
-80
-85
-90
-95
-100
0
2000
4000
Legend
u2 penetration
Initial dissipation
End of dissipation (extrapolated)
Initial estimated at t=0

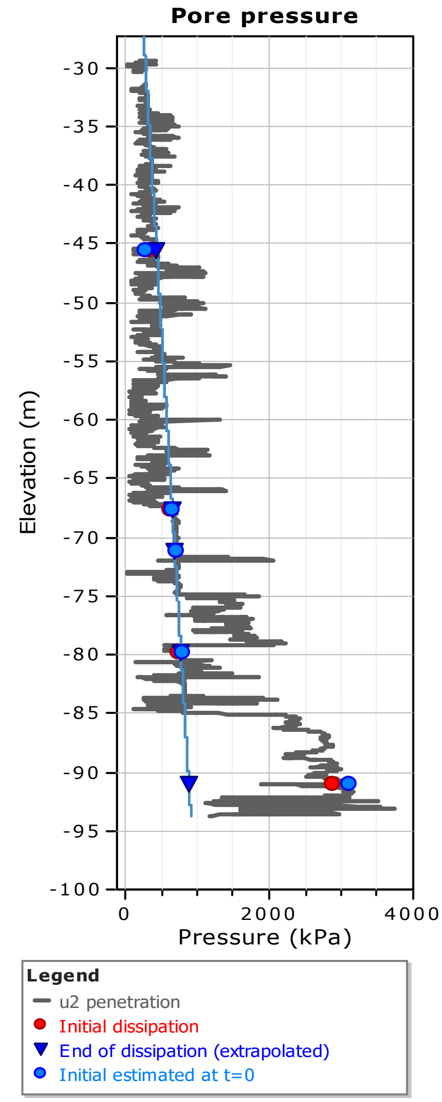

Piezocone Dissipation Test: CPT20-01
Depth: 72.60 (m)
Porepressure u2 (kPa)
2,500
2,000
1,500
1,000
500
0
8
16
24
32
t^0.50 (s^0.50)
u0 = 952.06 (kPa)

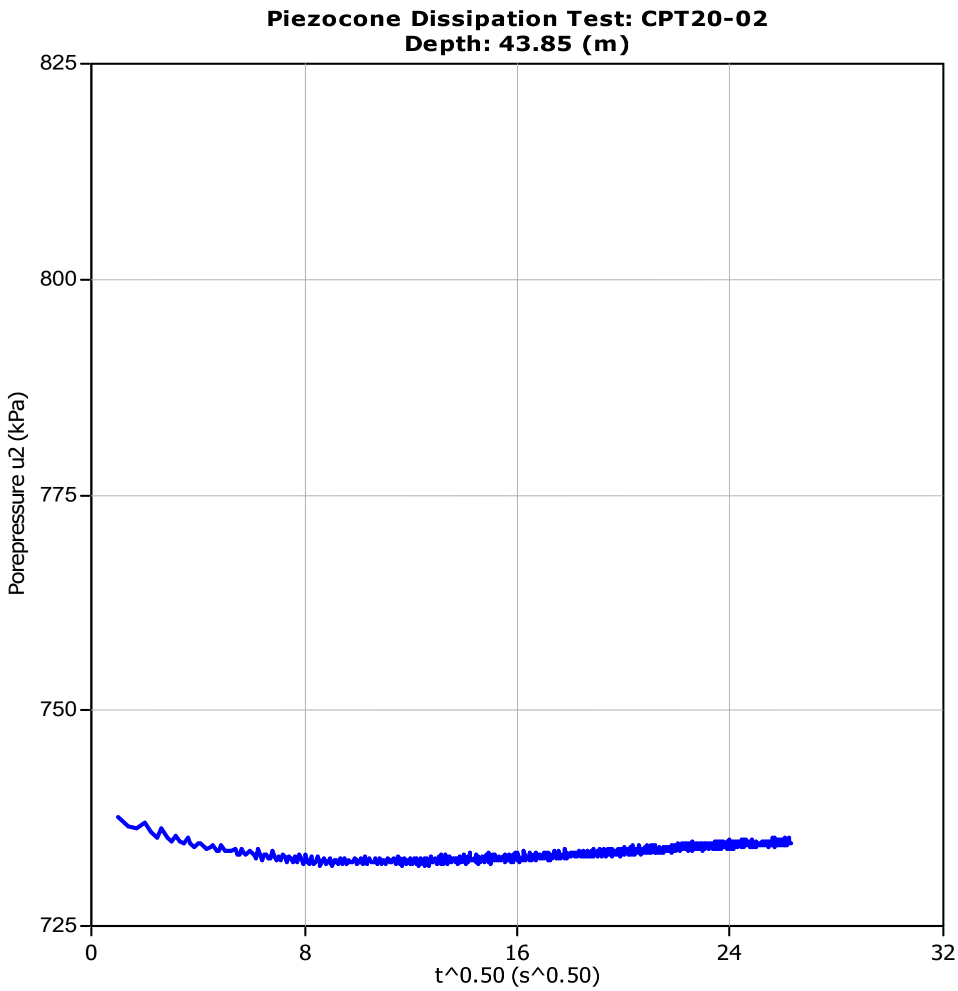

Pore pressure
Elevation (m)
-25
-30
-35
-40
-45
-50
-55
-60
-65
-70
-75
-80
-85
-90
-95
-100
0
2000
4000
Pressure (kPa)
Legend
u2 penetration
Initial dissipation
End of dissipation (extrapolated)
Initial estimated at t=0

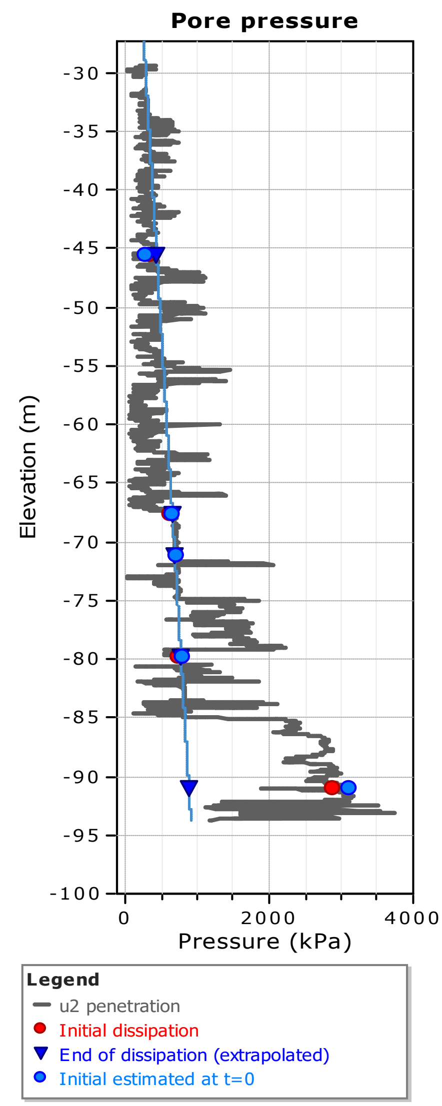

Piezocone Dissipation Test: CPT20-02
Depth: 18.33 (m)
Porepressure u2 (kPa)
t^0.50 (s^0.50)
u0 = 447.73 (kPa)
500
450
400
350
300
0
6
12
18
24

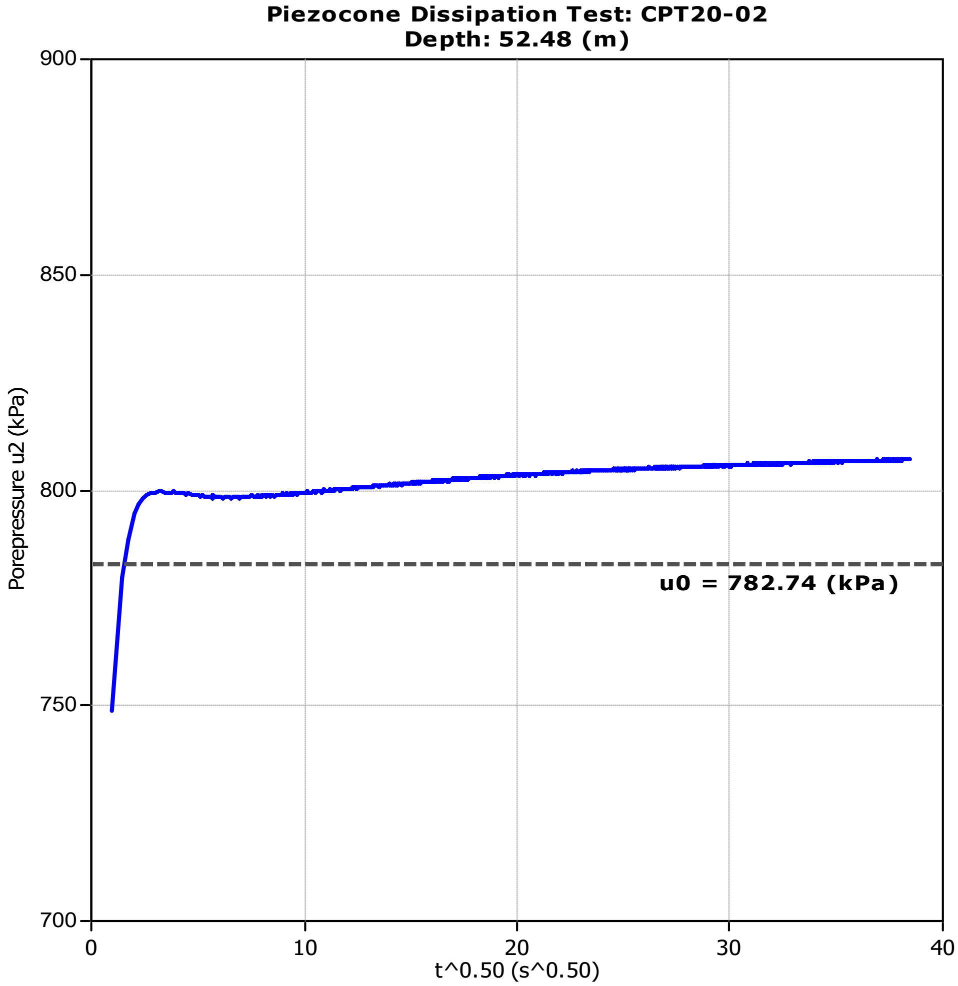

Pore pressure
Elevation (m)
Pressure (kPa)
-30
-35
-40
-45
-50
-55
-60
-65
-70
-75
-80
-85
-90
-95
-100
0
2000
4000
Legend
u2 penetration
Initial dissipation
End of dissipation (extrapolated)
Initial estimated at t=0

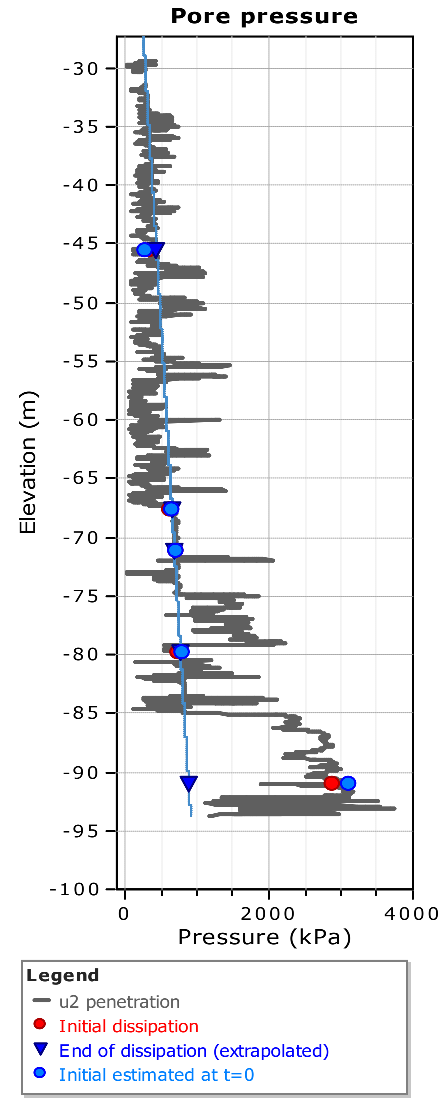

Piezocone Dissipation Test: CPT20-02
Depth: 40.37 (m)
Porepressure u2 (kPa)
700
675
650
625
600
0
8
16
24
32
t^0.50 (s^0.50)
u0 = 663.94 (kPa)

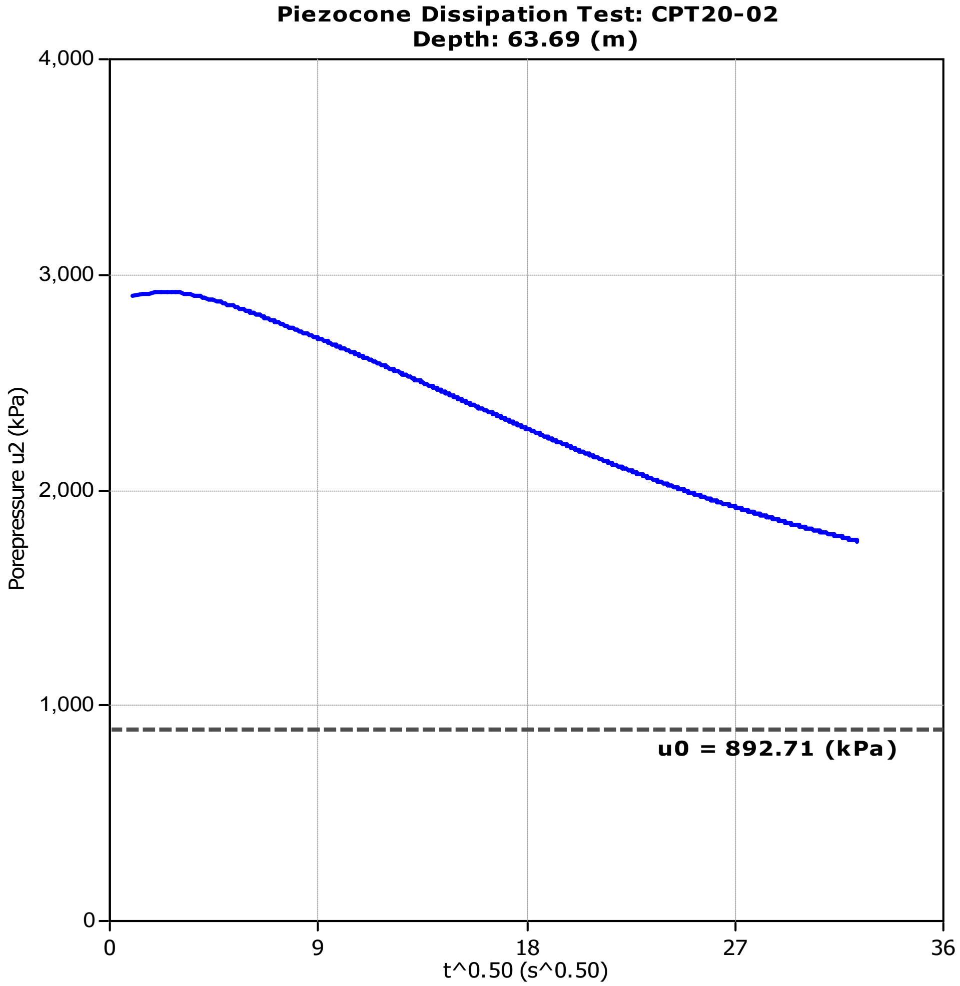

Pore pressure
Elevation (m)
-30
-35
-40
-45
-50
-55
-60
-65
-70
-75
-80
-85
-90
-95
-100
0
2000
4000
Pressure (kPa)
Legend
u2 penetration
Initial dissipation
End of dissipation (extrapolated)
Initial estimated at t=0


Piezocone Dissipation Test: CPT20-02
Depth: 43.85 (m)
Porepressure u2 (kPa)
t^0.50 (s^0.50)
825
800
775
750
725
0
8
16
24
32

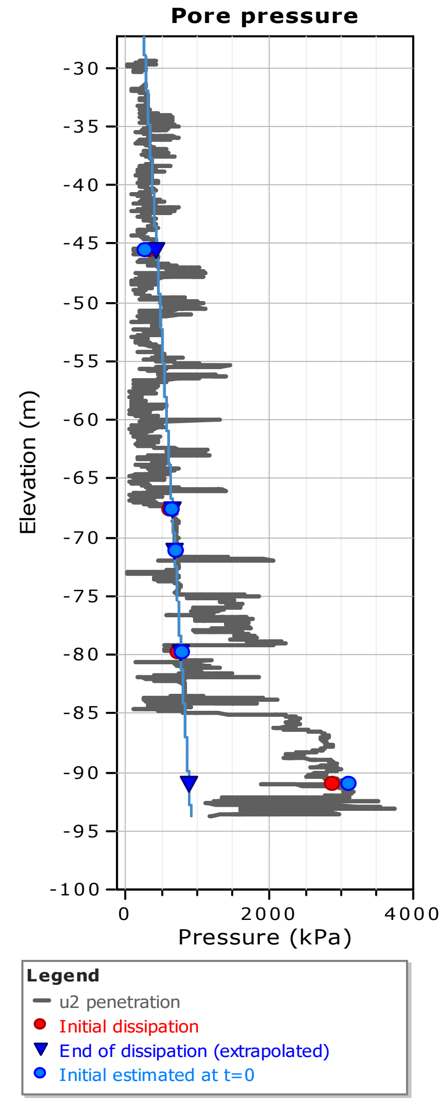

Pore pressure
Elevation (m)
Pressure (kPa)
-30
-35
-40
-45
-50
-55
-60
-65
-70
-75
-80
-85
-90
-95
-100
0
2000
4000
Legend
u2 penetration
Initial dissipation
End of dissipation (extrapolated)
Initial estimated at t=0


Piezocone Dissipation Test: CPT20-02
Depth: 52.48 (m)
Porepressure u2 (kPa)
900
850
800
750
700
0
10
20
30
40
t^0.50 (s^0.50)
u0 = 782.74 (kPa)


Pore pressure
Elevation (m)
-30
-35
-40
-45
-50
-55
-60
-65
-70
-75
-80
-85
-90
-95
-100
0
2000
4000
Pressure (kPa)
Legend
u2 penetration
Initial dissipation
End of dissipation (extrapolated)
Initial estimated at t=0



Piezocone Dissipation Test: CPT20-02
Depth: 63.69 (m)
Porepressure u2 (kPa)
4,000
3,000
2,000
1,000
0
0
9
18
27
36
t^0.50 (s^0.50)
u0 = 892.71 (kPa)



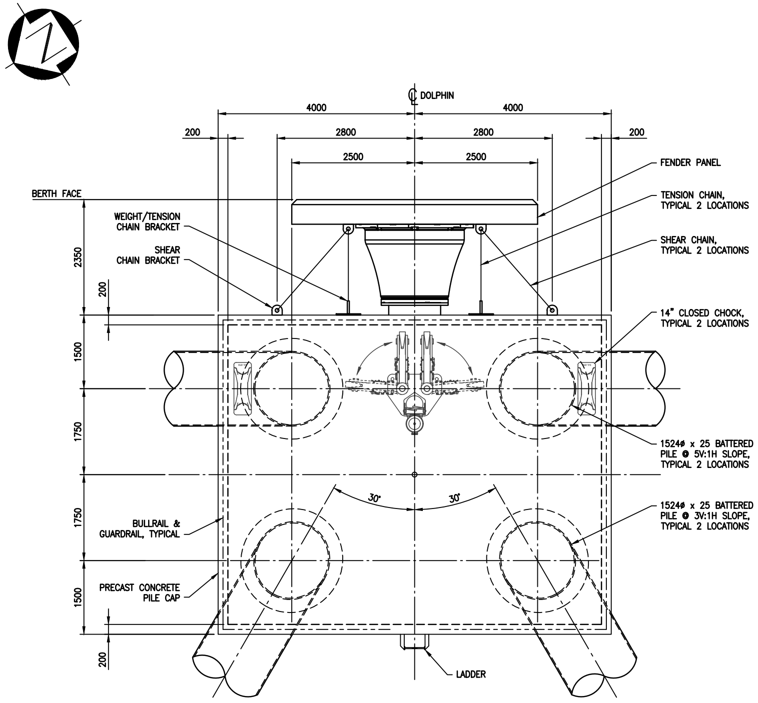
Pore pressure
Elevation (m)
-30
-35
-40
-45
-50
-55
-60
-65
-70
-75
-80
-85
-90
-95
-100
0
2000
4000
Pressure (kPa)
Legend
u2 penetration
Initial dissipation
End of dissipation (extrapolated)
Initial estimated at t=0

THURBER

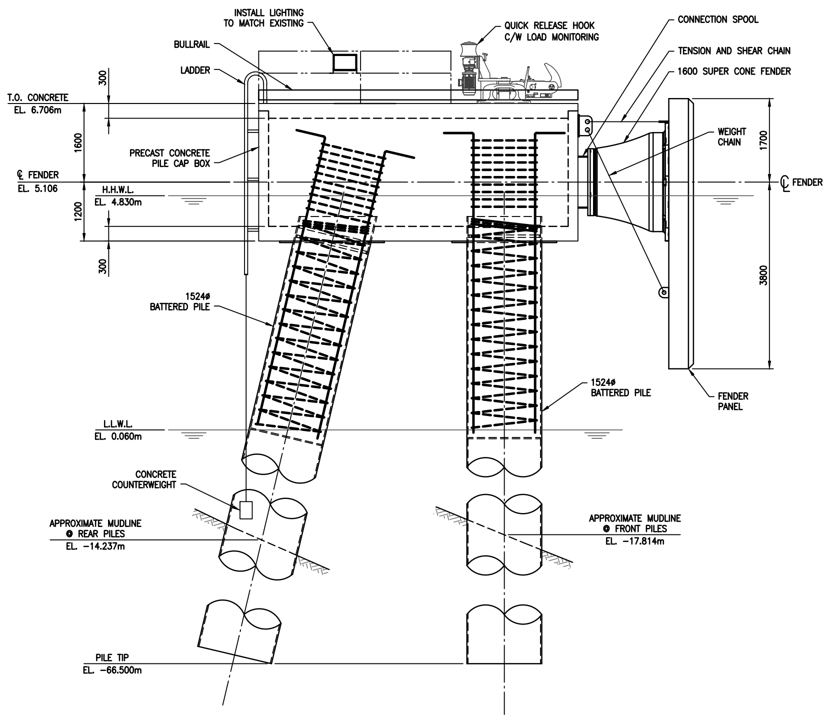
APPENDIX B

Berthing / Mooring Dolphin Plan and Elevation [Drawing No. 19849-100-SK-100-P1]

(1 page)



PLAN – BERTHING/MOORING DOLPHIN
1:50



ELEVATION – BERTHING/MOORING DOLPHIN
1:50

PRELIMINARY
NOT FOR CONSTRUCTION

REF.	DWG. NUMBER	DESCRIPTION

REFERENCE DRAWINGS / DESIGN STANDARDS

CLIENT PROJECT No: | CWA ACAD FILE: 19849-100-SK-100.DWG

No.	YYYY-MM-DD	DESCRIPTION	DRAWN	DWG. CHECK	DESIGN	DESIGN CHECK	APPROVED
P2	2020-01-23	ISSUED FOR INFORMATION	CPL	–	SET	–	CWS
P1	2019-11-13	ISSUED FOR INFORMATION	CPL	–	SET	–	CWS

ISSUES / REVISIONS | * HAND INITIALS ON FILE

CWA
www.cwaengineers.com

DRAWN BY: CPL | SCALE: AS NOTED

Westshore Terminals

BERTH 2 DOLPHIN REPLACEMENT PROJECT

BERTHING/MOORING DOLPHIN
PLAN AND ELEVATION

PROJECT No.	AREA	DEPT.	DWG. No.	REV.
19849	100	SK	110	P2

THURBER

APPENDIX C

Vs Profiles, SSRA Results & Design Response Spectra (6 pages)

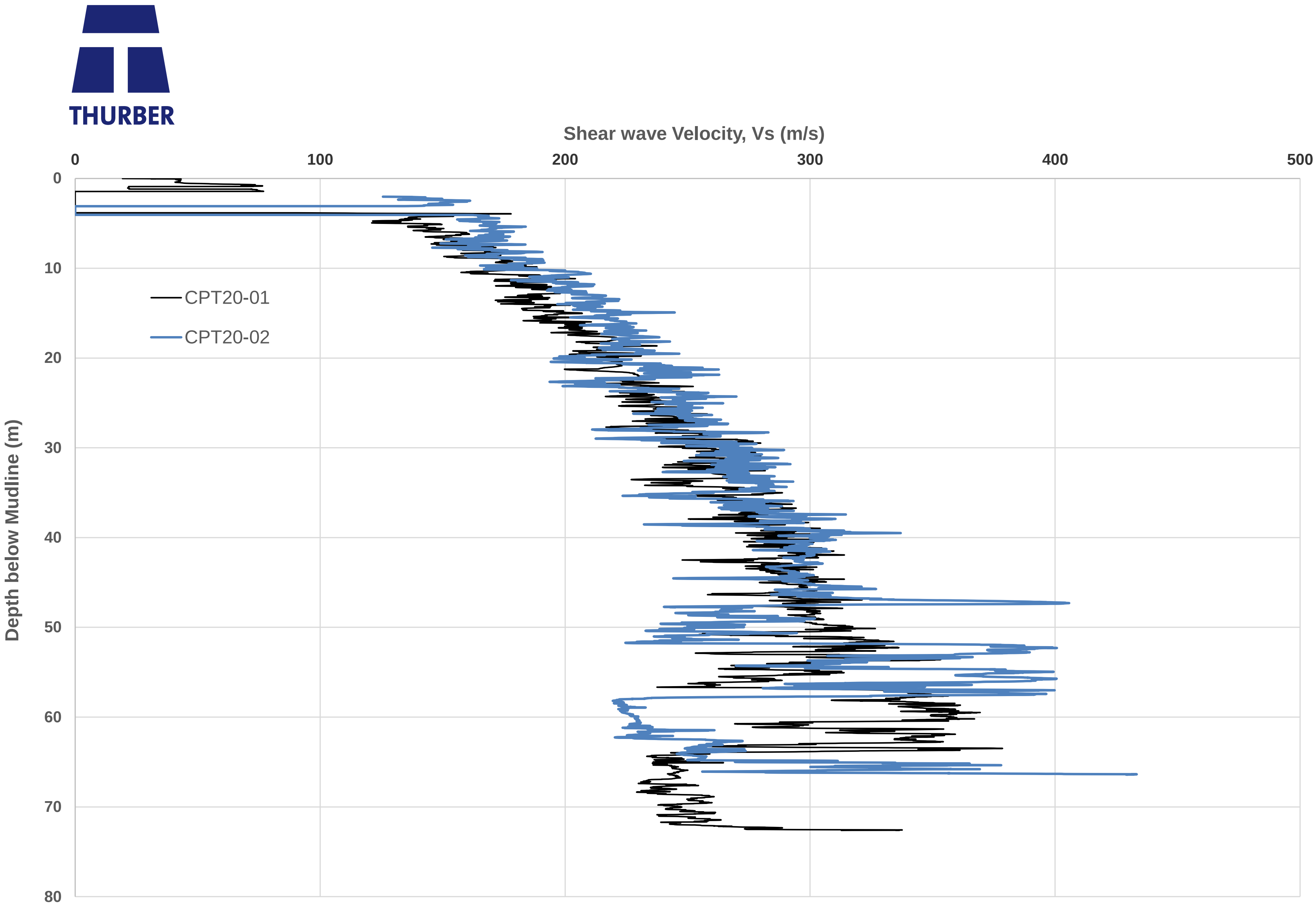
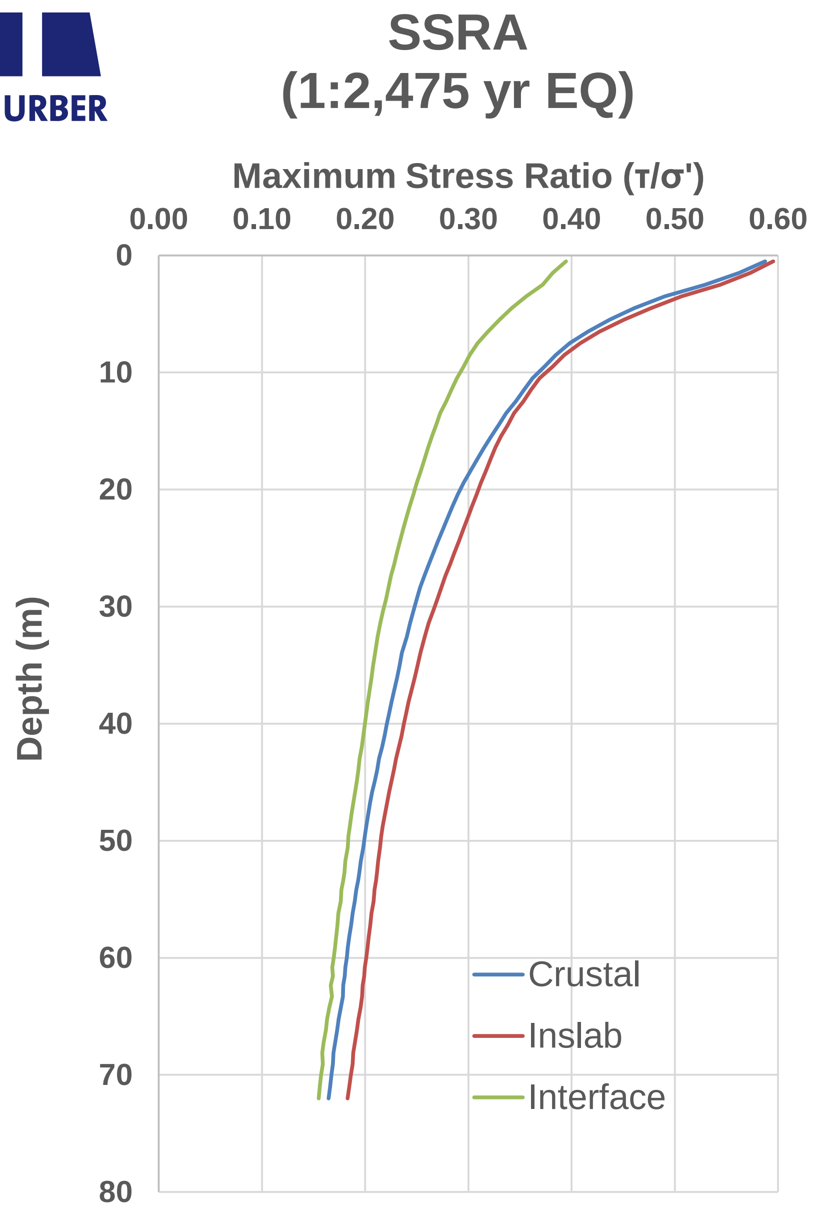
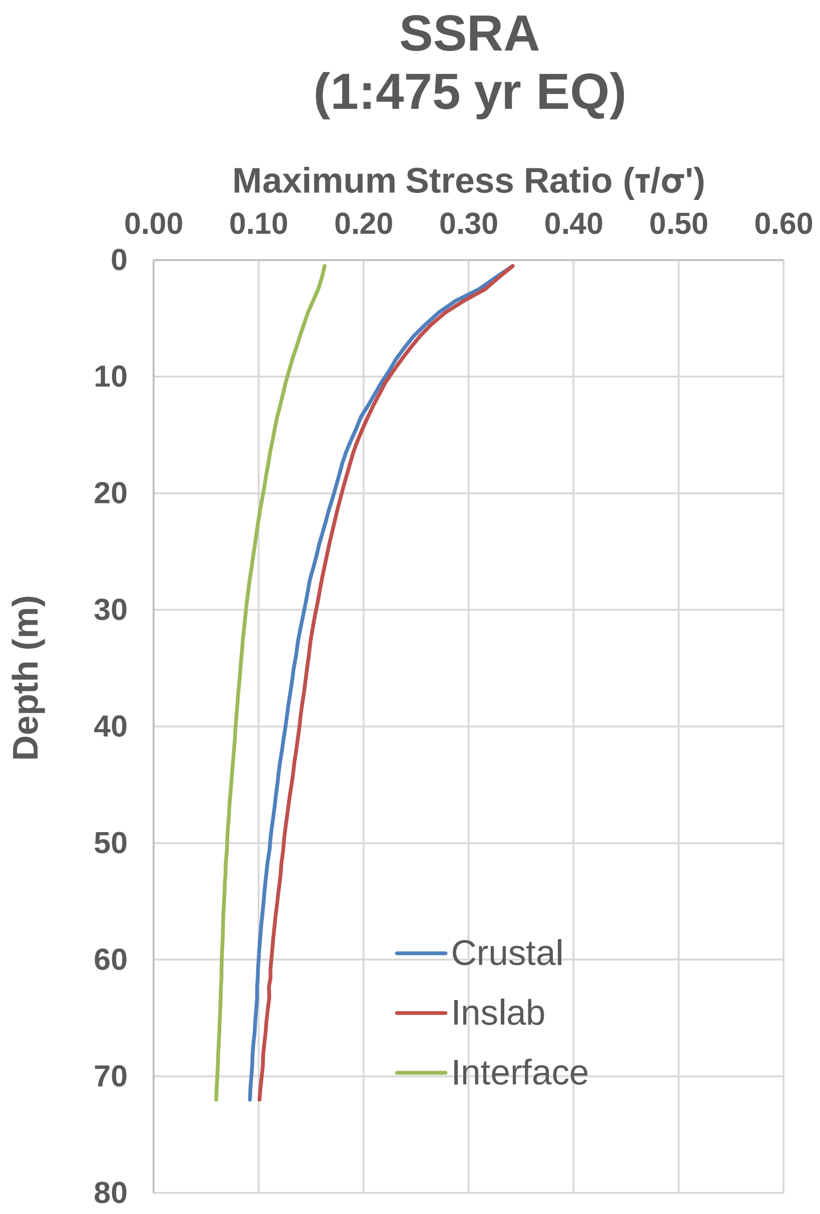


Figure C1 - Interpreted Shear Wave Veloctiy Profiles

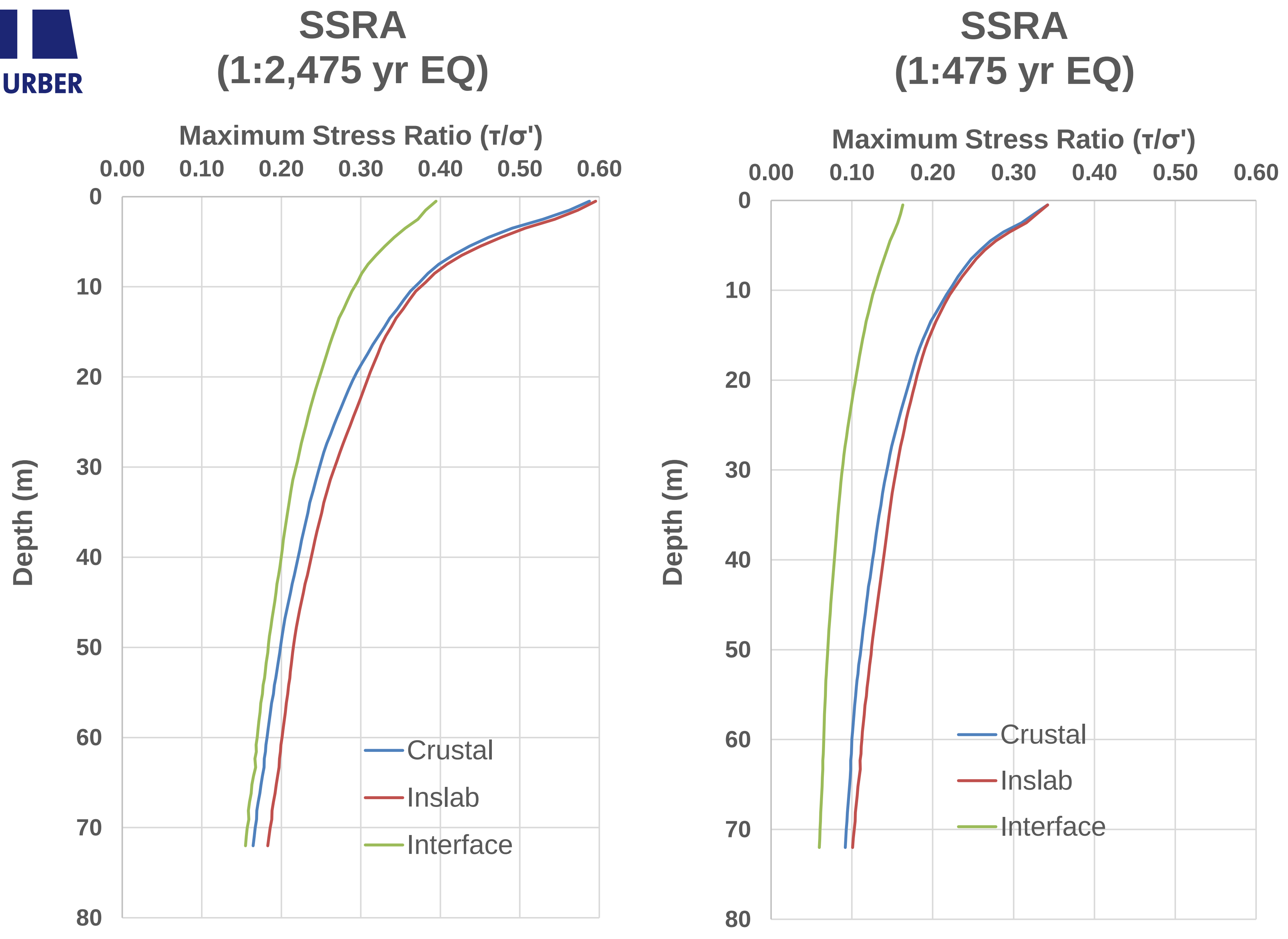
Client: WTLP
File No.: 26259





Client: WTLP
File No.: 26259

Figure C2 - Maximum Stress Ratio (τ/σ') Profiles
CPT20-01



Client: WTLP
File No.: 26259

Figure C3 - Maximum Stress Ratio (τ/σ') Profiles
CPT20-02

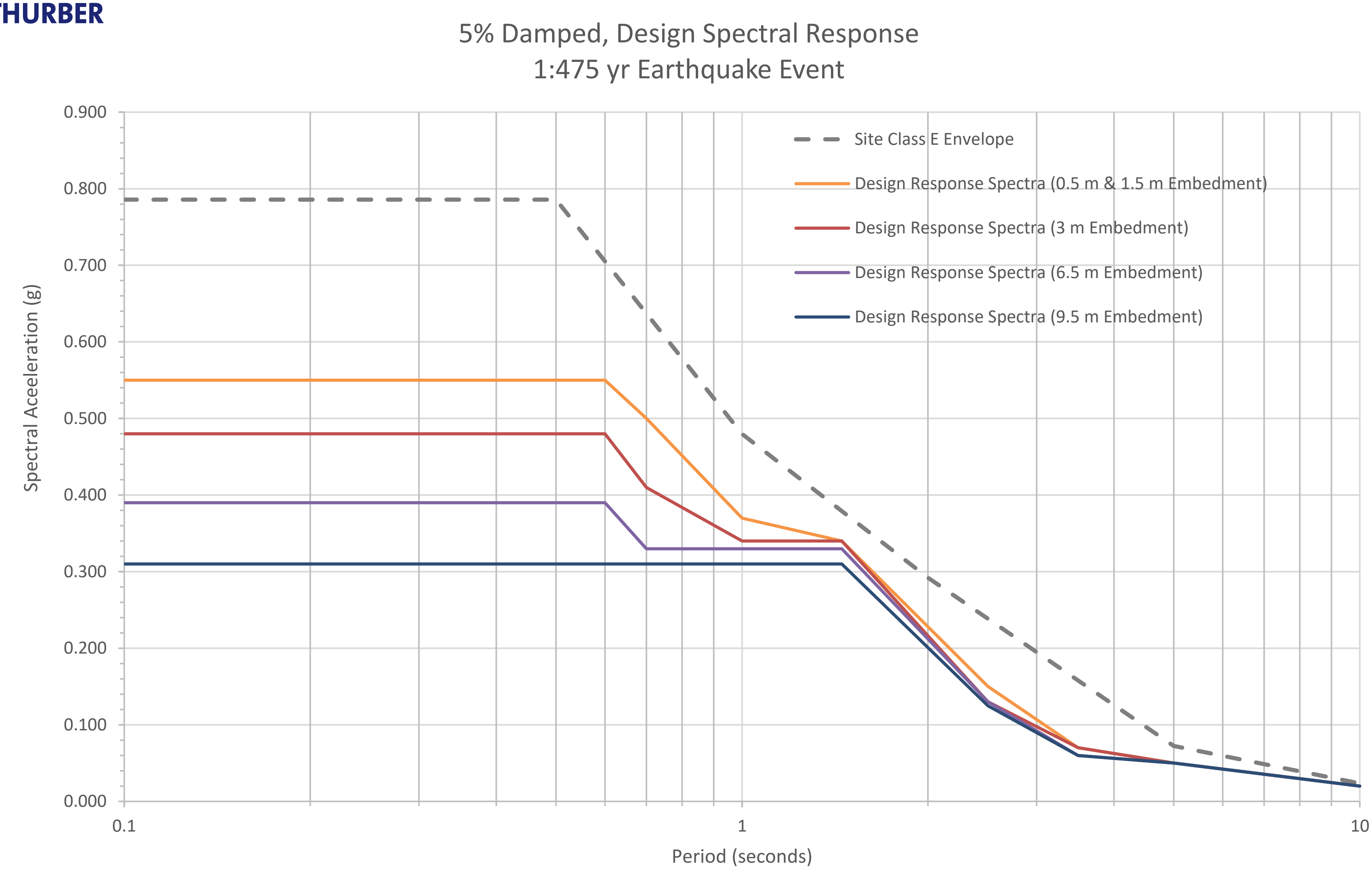


Figure C4 - 5% Damped, Design Response Spectra
1:475 yr Earthquake Event

Client: WTLP
File No.: 26259

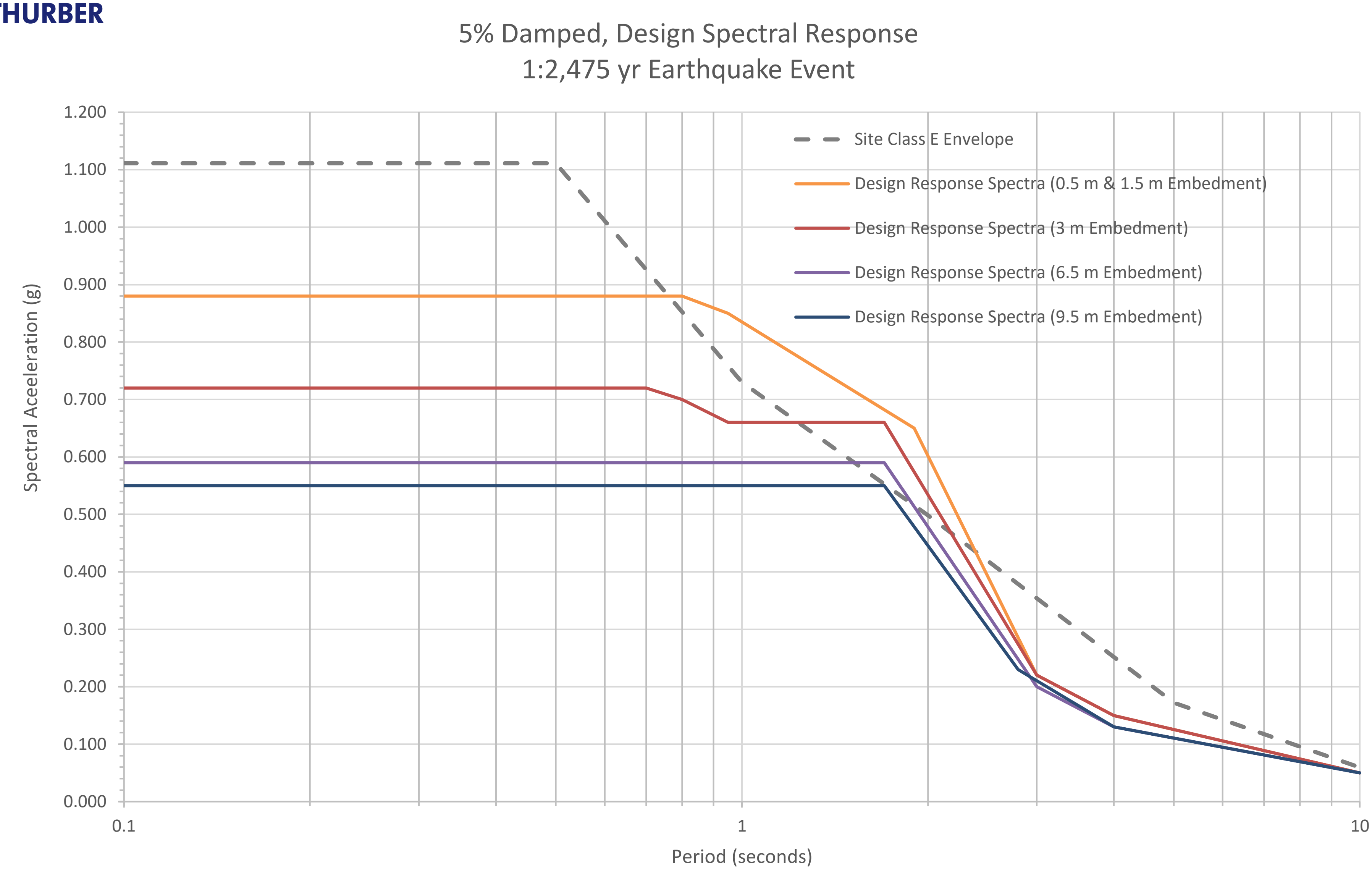


Figure C5 - 5% Damped, Design Response Spectra
1:2,475 yr Earthquake Event

Client: WTLP
File No.: 26259

2,475 yr Earthquake Event

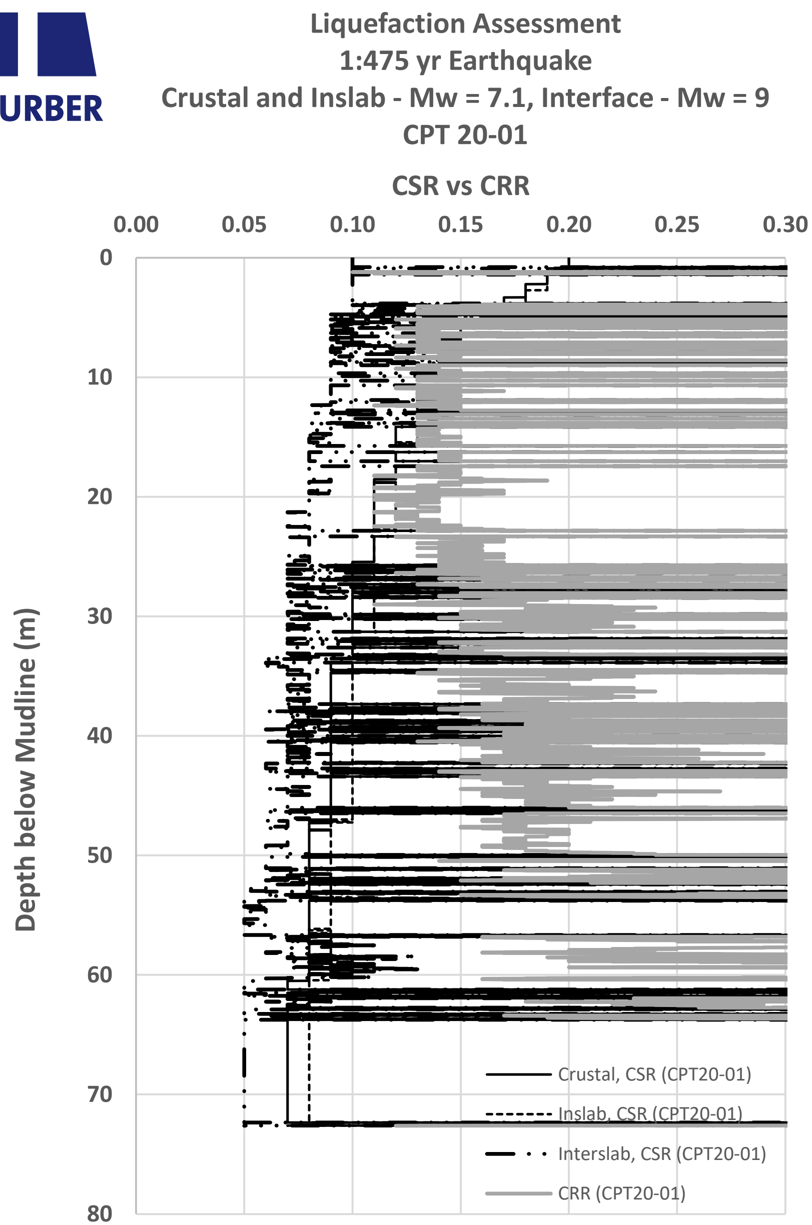
0.5 m Embedment		1.5 m Embedment		3 m Embedment		6.5 m Embedment		9.5 m Embedment	
Design Envelope		Design Envelope		Design Envelope		Design Envelope		Design Envelope	
Period (s)	Sa(g)	Period (s)	Sa(g)	Period (s)	Sa(g)	Period (s)	Sa(g)	Period (s)	Sa(g)
0.1	0.88	0.1	0.88	0.1	0.72	0.1	0.59	0.1	0.55
0.5	0.88	0.5	0.88	0.5	0.72	0.5	0.59	0.5	0.55
0.6	0.88	0.6	0.88	0.6	0.72	0.6	0.59	0.6	0.55
0.7	0.88	0.7	0.88	0.7	0.72	0.7	0.59	0.7	0.55
0.8	0.88	0.8	0.88	0.8	0.7	0.8	0.59	0.8	0.55
0.95	0.85	0.95	0.85	0.95	0.66	0.95	0.59	0.95	0.55
1.9	0.65	1.9	0.65	1.7	0.66	1.7	0.59	1.7	0.55
3	0.22	3	0.22	3	0.22	3	0.2	2.8	0.23
4	0.15	4	0.15	4	0.15	4	0.13	4	0.13
10	0.05	10	0.05	10	0.05	10	0.05	10	0.05

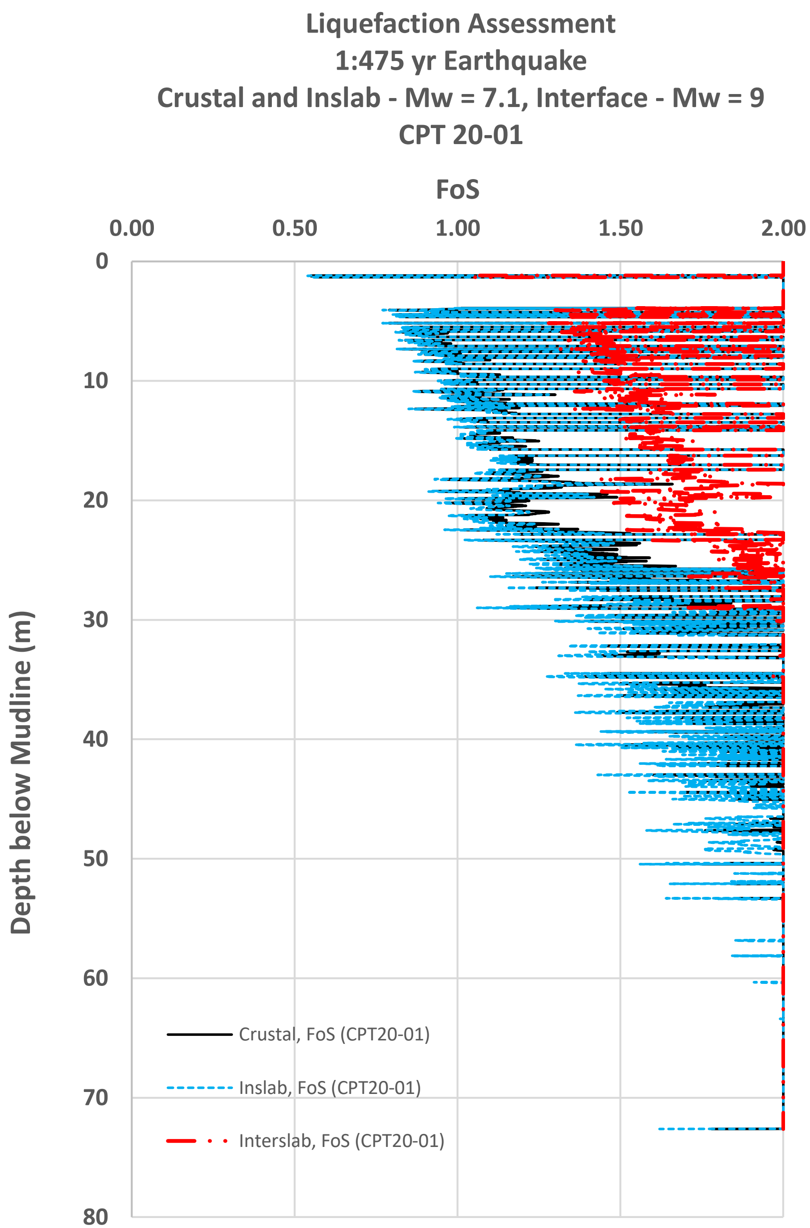
475 yr Earthquake Event

0.5 m Embedment		1.5 m Embedment		3 m Embedment		6.5 m Embedment		9.5 m Embedment	
Design Envelope		Design Envelope		Design Envelope		Design Envelope		Design Envelope	
Period (s)	Sa(g)	Period (s)	Sa(g)	Period (s)	Sa(g)	Period (s)	Sa(g)	Period (s)	Sa(g)
0.1	0.55	0.1	0.55	0.1	0.48	0.1	0.39	0.1	0.31
0.5	0.55	0.5	0.55	0.5	0.48	0.5	0.39	0.5	0.31
0.6	0.55	0.6	0.55	0.6	0.48	0.6	0.39	0.6	0.31
0.7	0.5	0.7	0.5	0.7	0.41	0.7	0.33	0.7	0.31
1	0.37	1	0.37	1	0.34	1	0.33	1	0.31
1.45	0.34	1.45	0.34	1.45	0.34	1.45	0.33	1.45	0.31
2.5	0.15	2.5	0.14	2.5	0.13	2.5	0.13	2.5	0.125
3.5	0.07	3.5	0.07	3.5	0.07	3.5	0.06	3.5	0.06
5	0.05	5	0.05	5	0.05	5	0.05	5	0.05
10	0.02	10	0.02	10	0.02	10	0.02	10	0.02

APPENDIX D

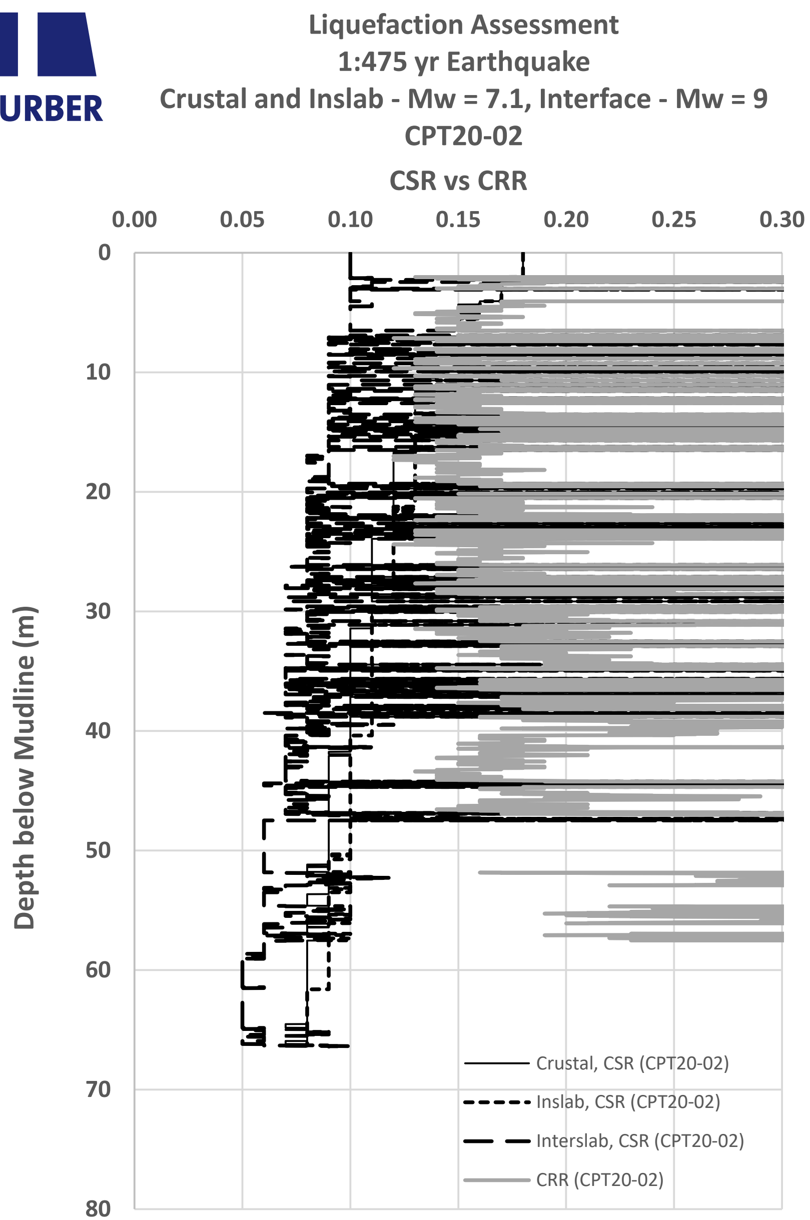
Liquefaction Assessment [CSR vs CRR profiles] (4 pages)

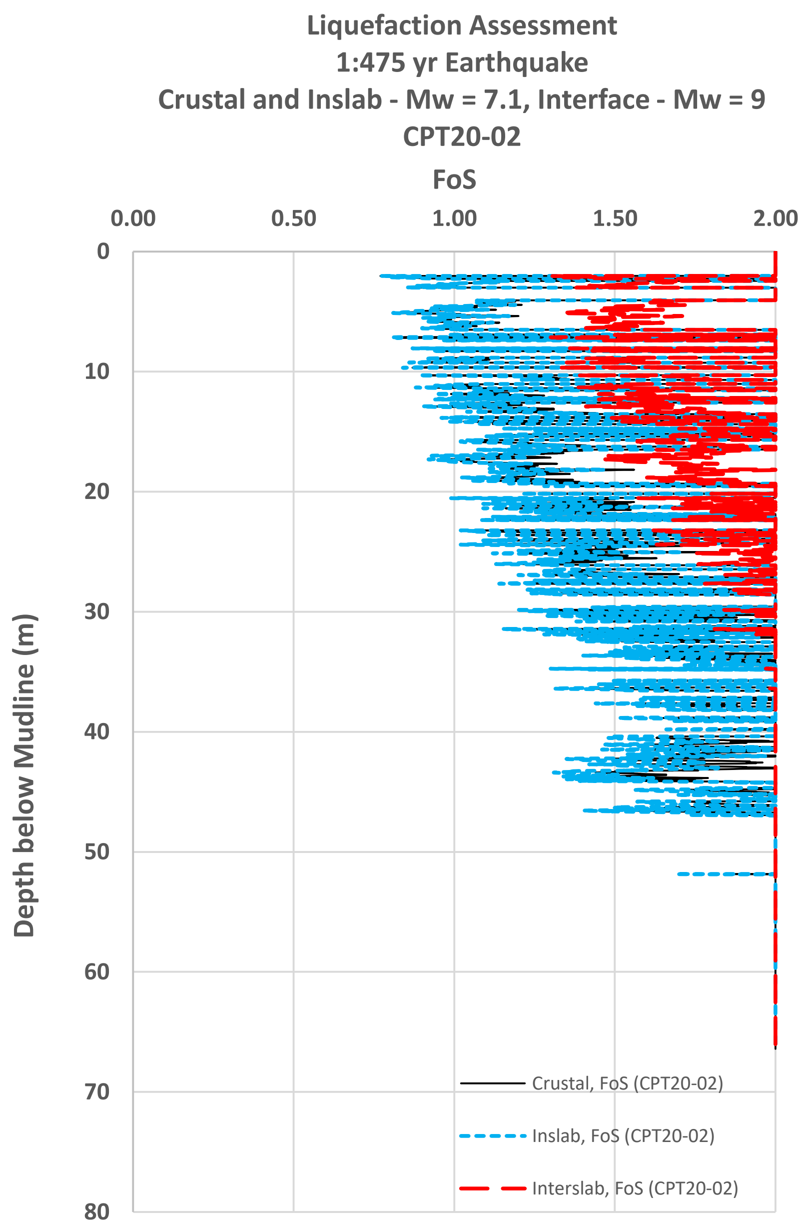




Client: WTLP
File No.: 26259

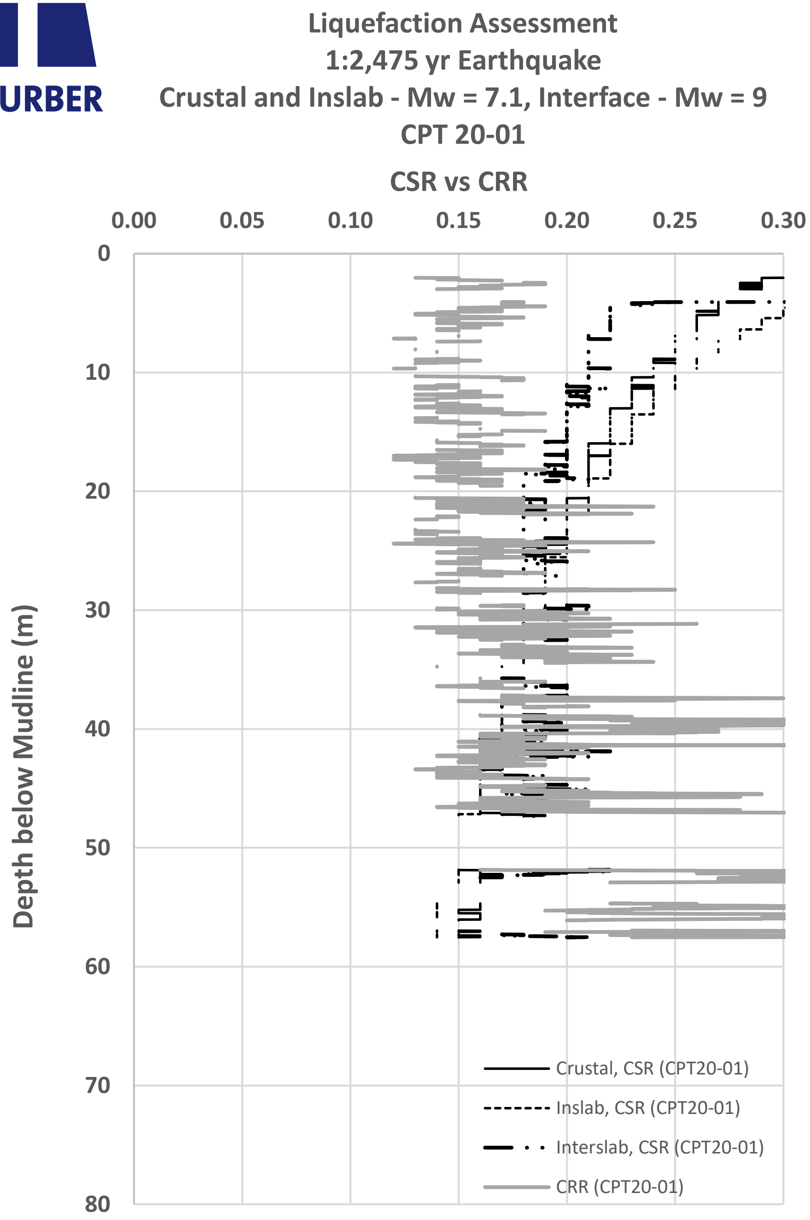
Figure D1 - Liquefaction Assessment (CSR vs CRR)
1:475 year Earthquake Event (CPT20-01)

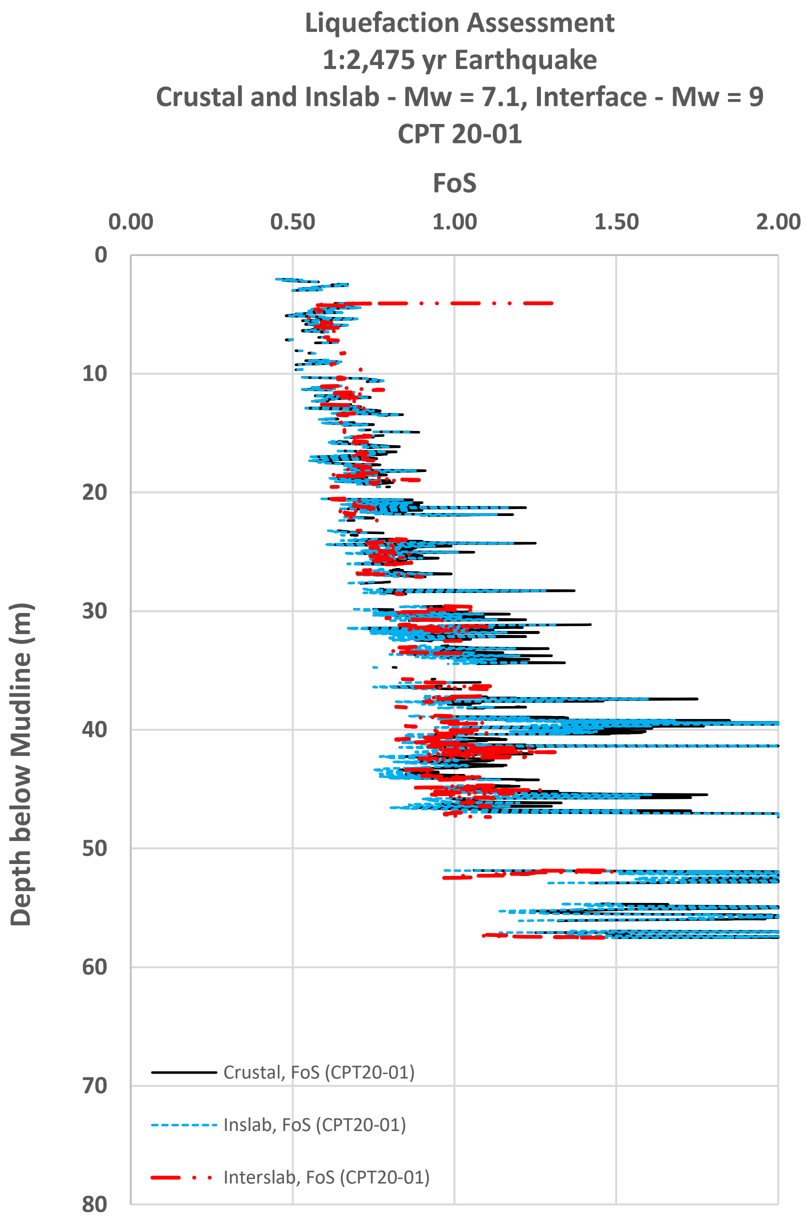




Client: WTLP
File No.: 26259

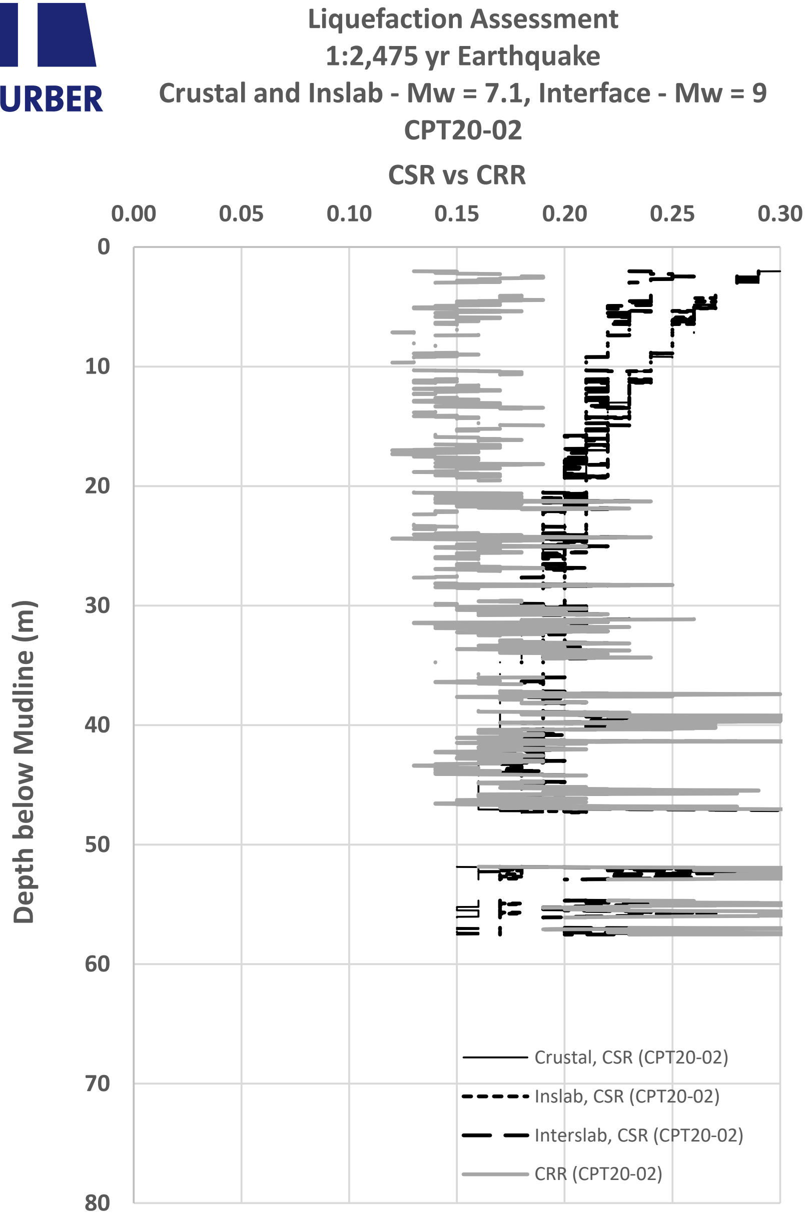
Figure D2 - Liquefaction Assessment (CSR vs CRR)
1:475 year Earthquake Event (CPT20-02)

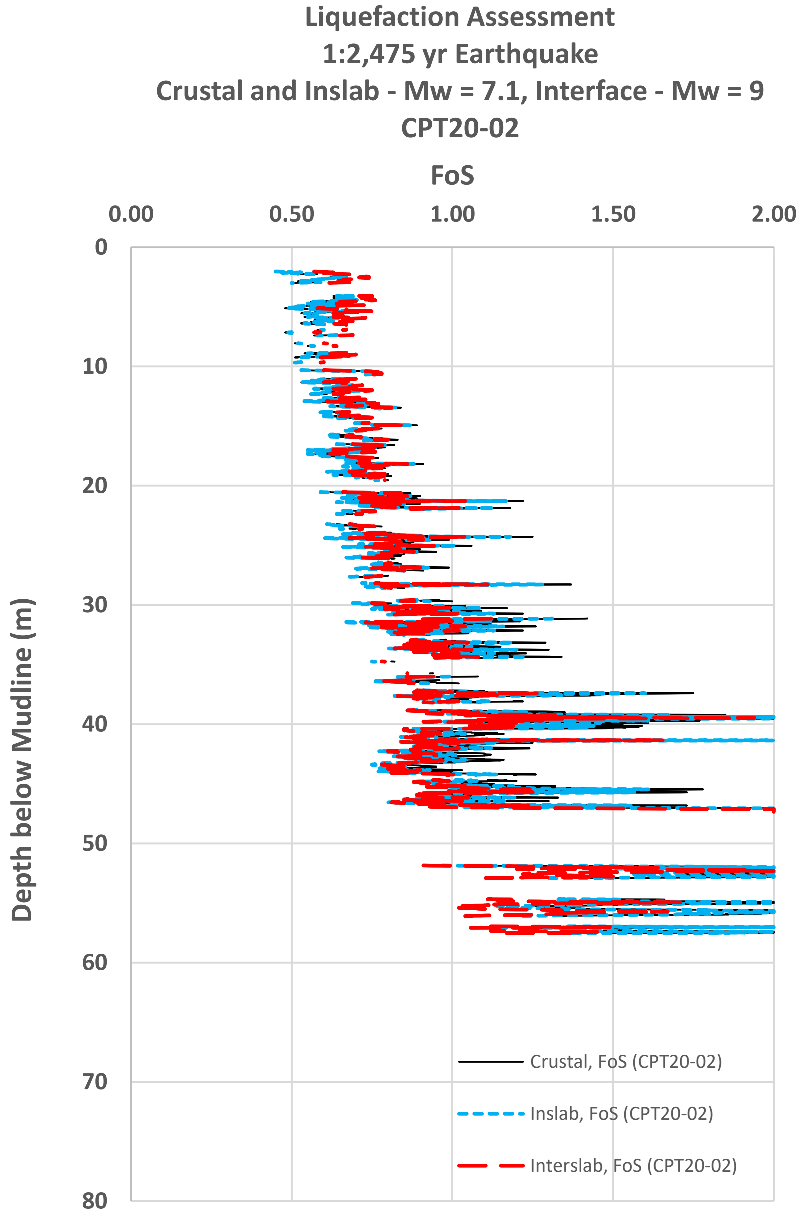




Client: WTLP
File No.: 26259

Figure D3 - Liquefaction Assessment (CSR vs CRR)
1:2,475 year Earthquake Event (CPT20-01)





Client: WTLP
File No.: 26259

Figure D4 - Liquefaction Assessment (CSR vs CRR)
1:2,475 year Earthquake Event (CPT20-02)

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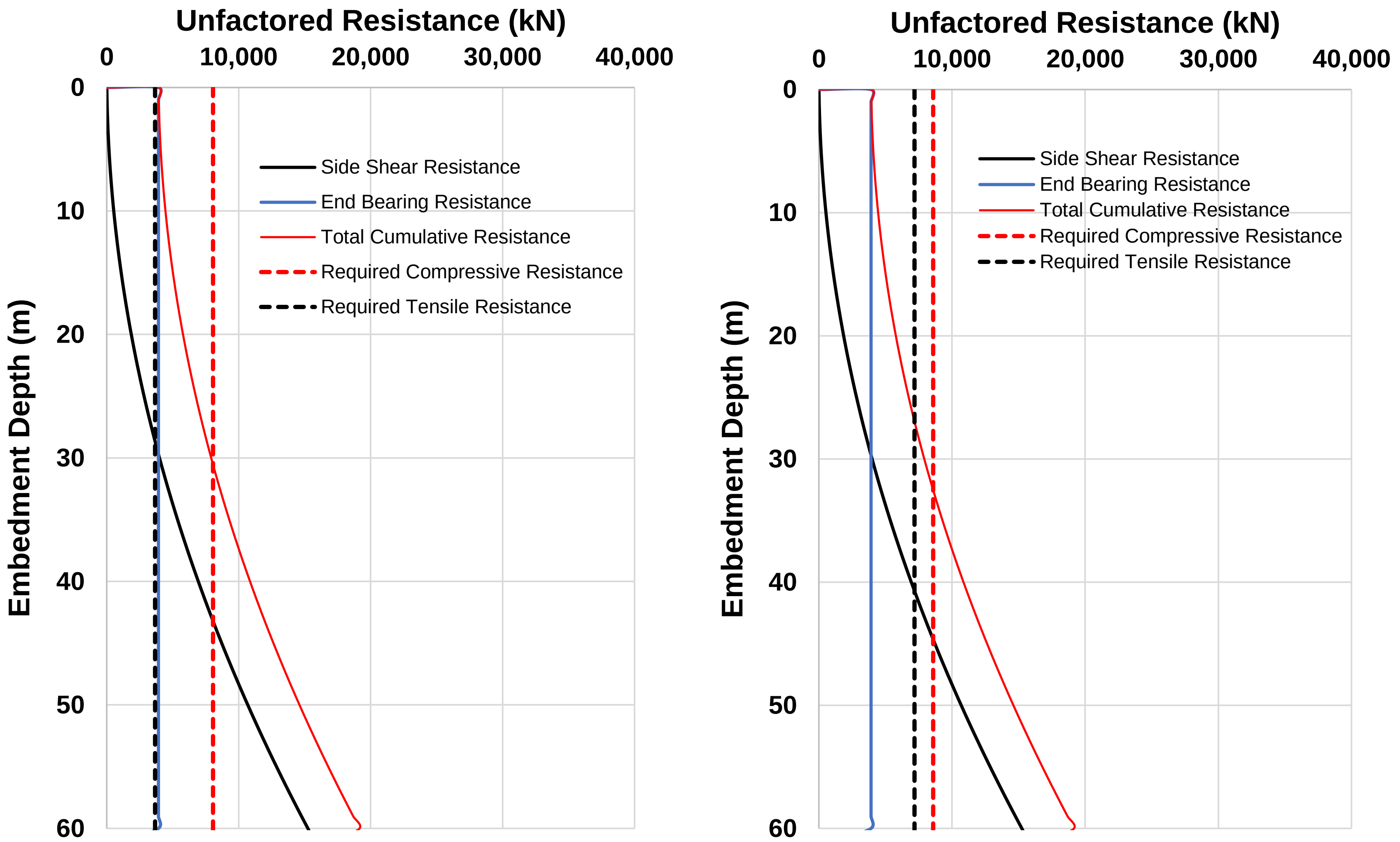
APPENDIX E

Axial Pile Resistance (3 pages)

Spread-out Four Pile Dolphin - 1H:5V Inclined Piles (1.524 m x 32 mm)

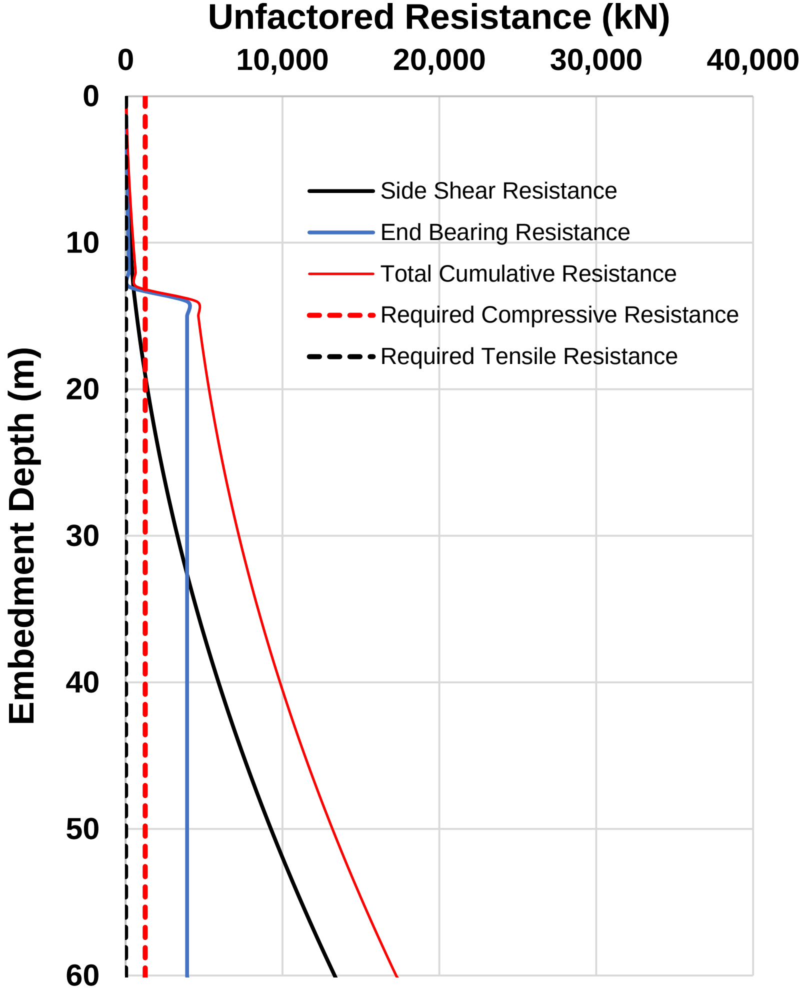
Spread-out Four Pile Dolphin - 1H:3V Inclined Pile (1.524 m x 32 mm)



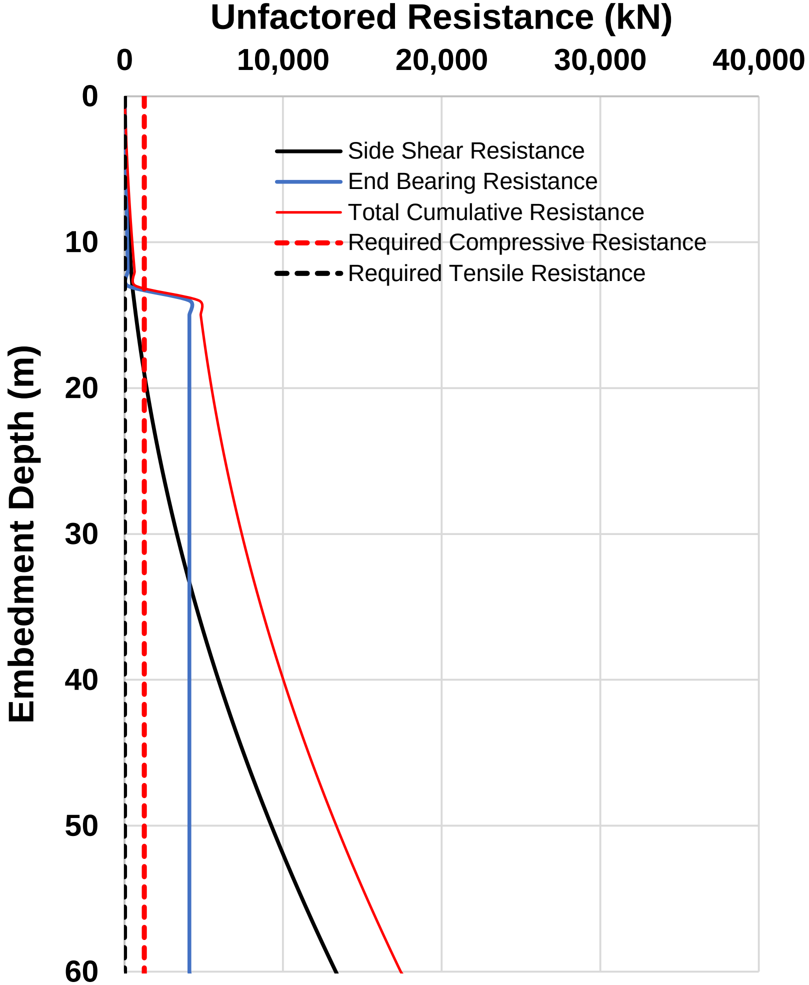
Client: WTLP
File No.: 26259

Figure E1 - Axial Pile Resistance versus Depth
Static Loading Condition

Spread-out Four Pile Dolphin - 1H:5V Inclined Piles (1.524 m x 32 mm)

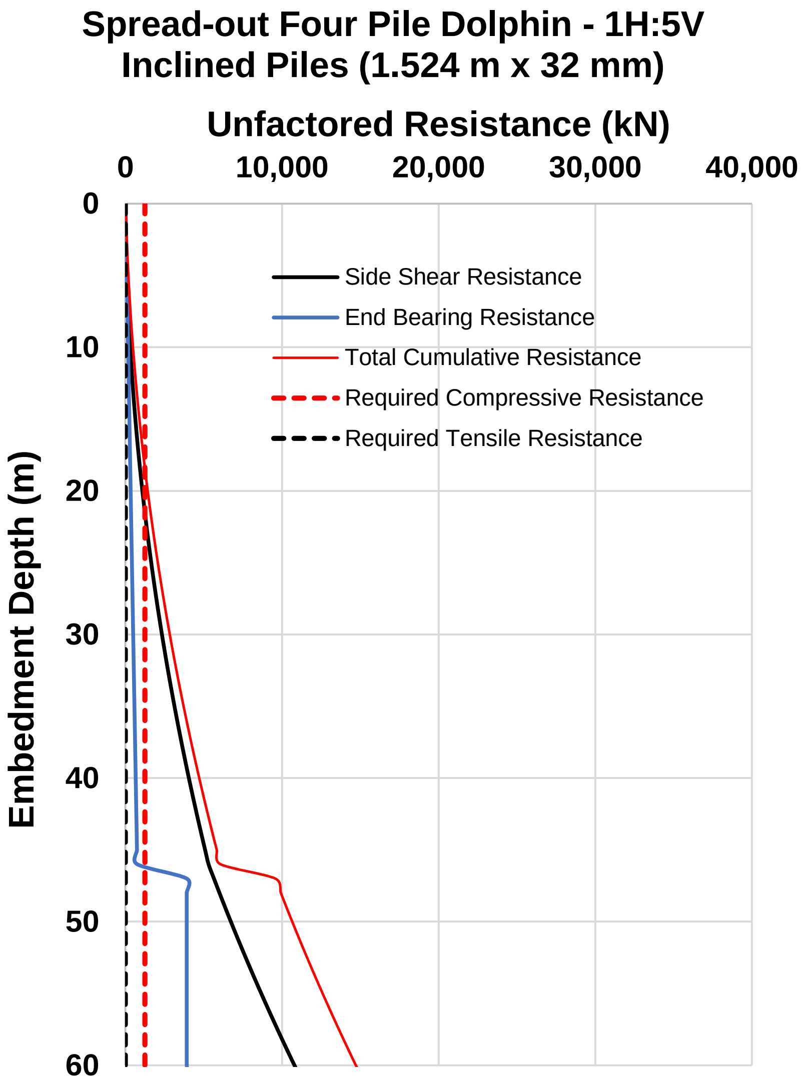


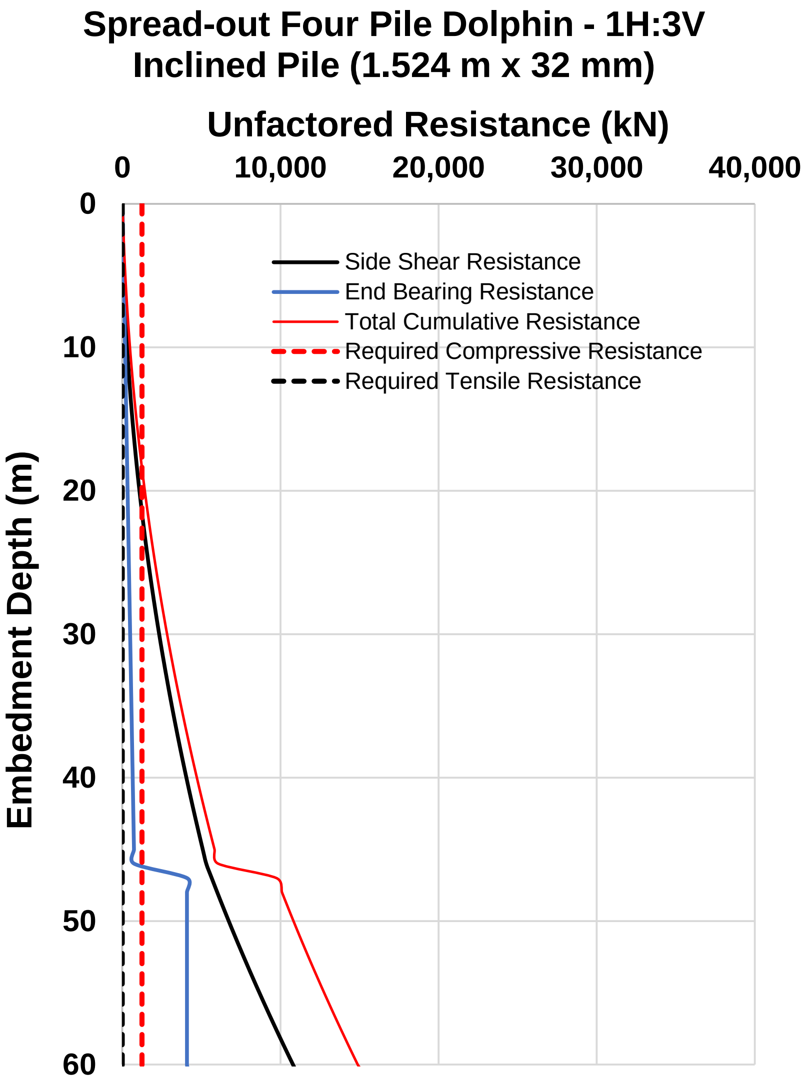
Spread-out Four Pile Dolphin - 1H:3V Inclined Pile (1.524 m x 32 mm)



Client: WTLP
File No.: 26259

Figure E2 - Axial Pile Resistance versus Depth
Seismic (1:475 yr) Loading Condition





Client: WTLP
File No.: 26259

Figure E3 - Axial Pile Resistance versus Depth
Seismic (1:2,475 yr) Loading Condition

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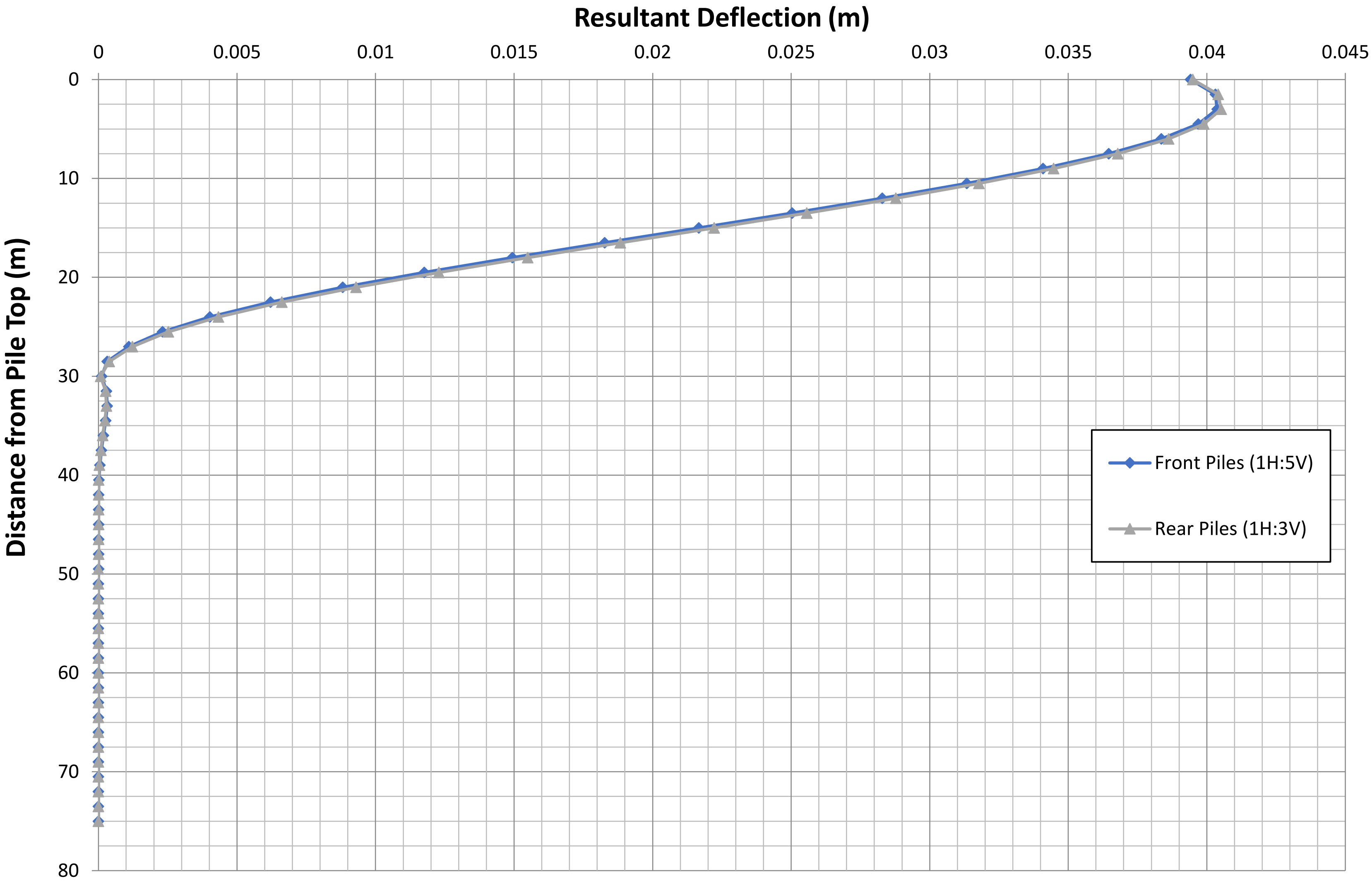
APPENDIX F

Lateral Pile Group Analyses (9 pages)

Lateral Group Pile Analysis
Non-Seismic Loading Condition



Client: WTLP
File No.: 26259

Figure E1 - Total Pile deflection versus Depth
Non-Seismic Loading Condition

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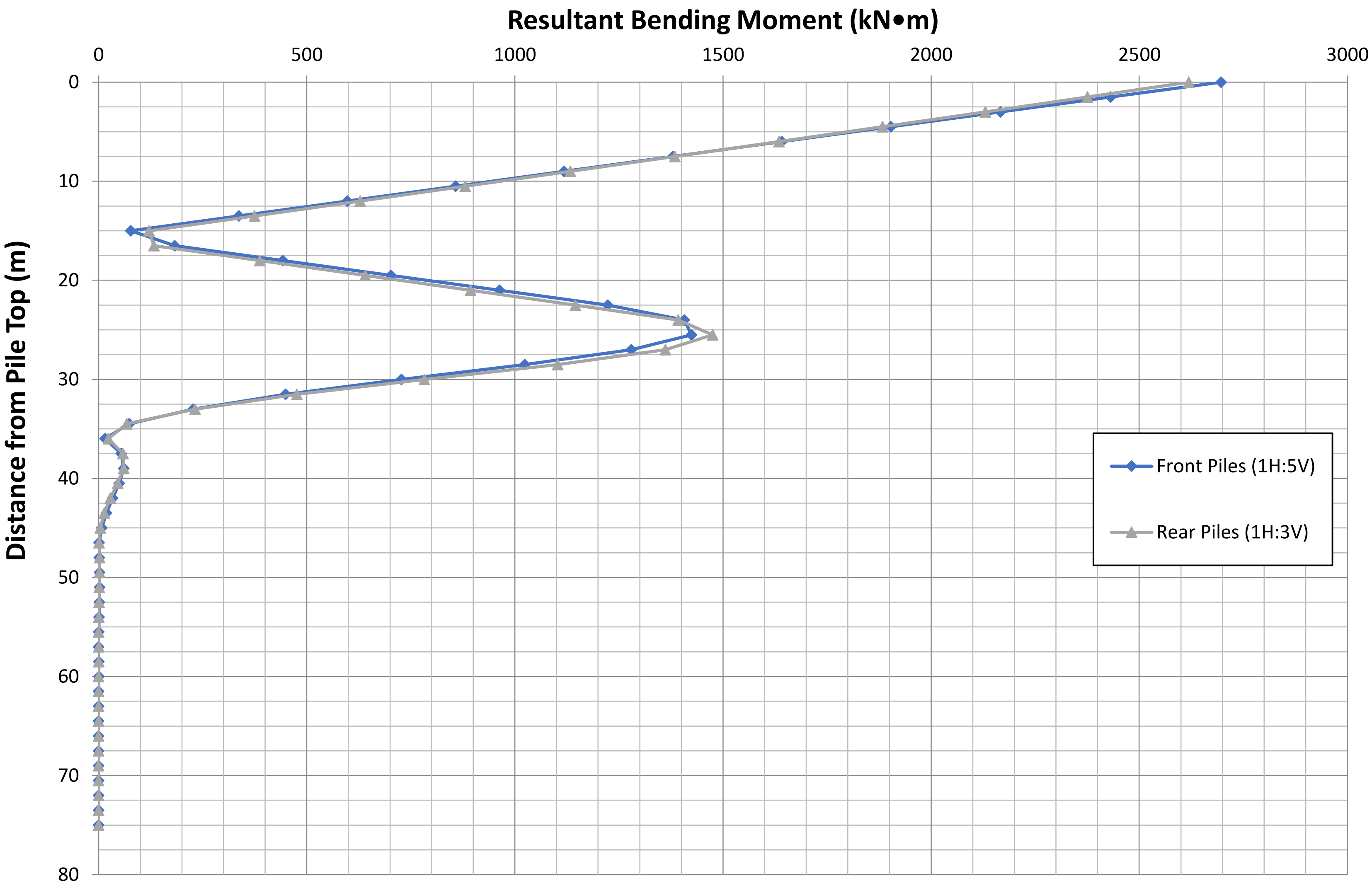
Lateral Group Pile Analysis
Non-Seismic Loading Condition

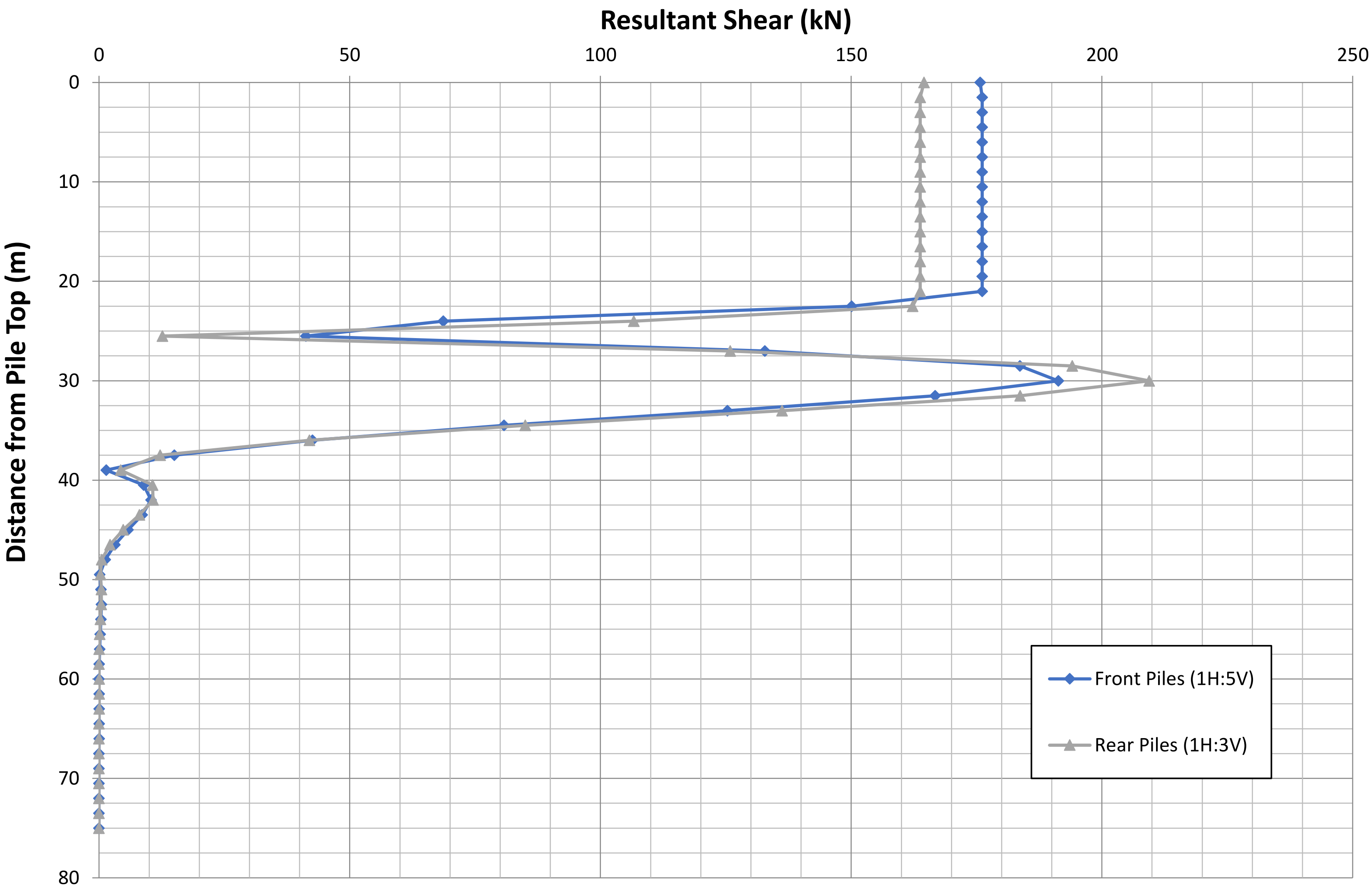


Client: WTLP
File No.: 26259

Figure E2 - Resultant Bending Moment versus Depth
Non-Seismic Loading Condition

THURBER

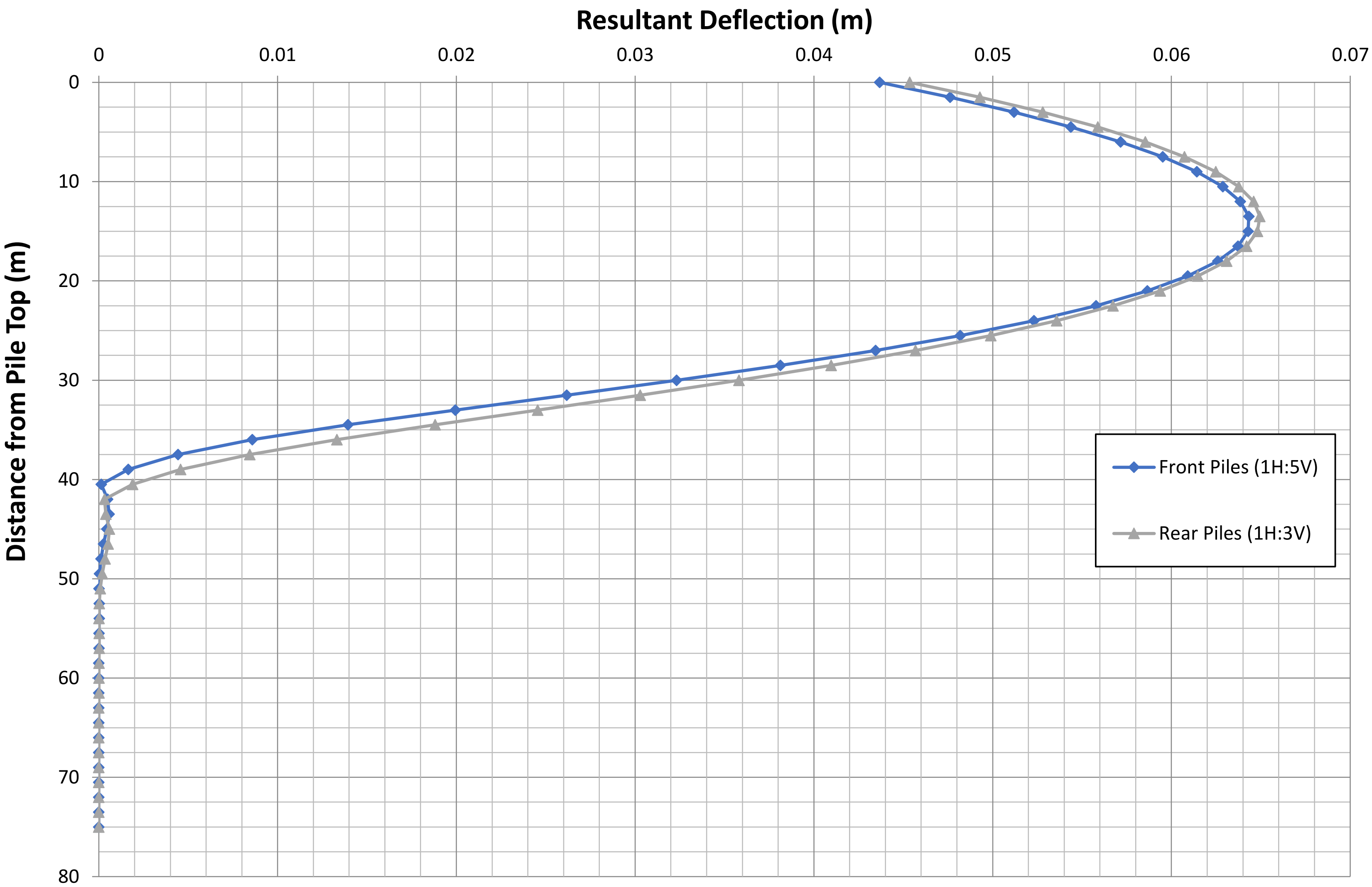
Lateral Group Pile Analysis
Non-Seismic Loading Condition



Client: WTLP
File No.: 26259

Figure E3 - Resultant Shear versus Depth
Non-Seismic Loading Condition

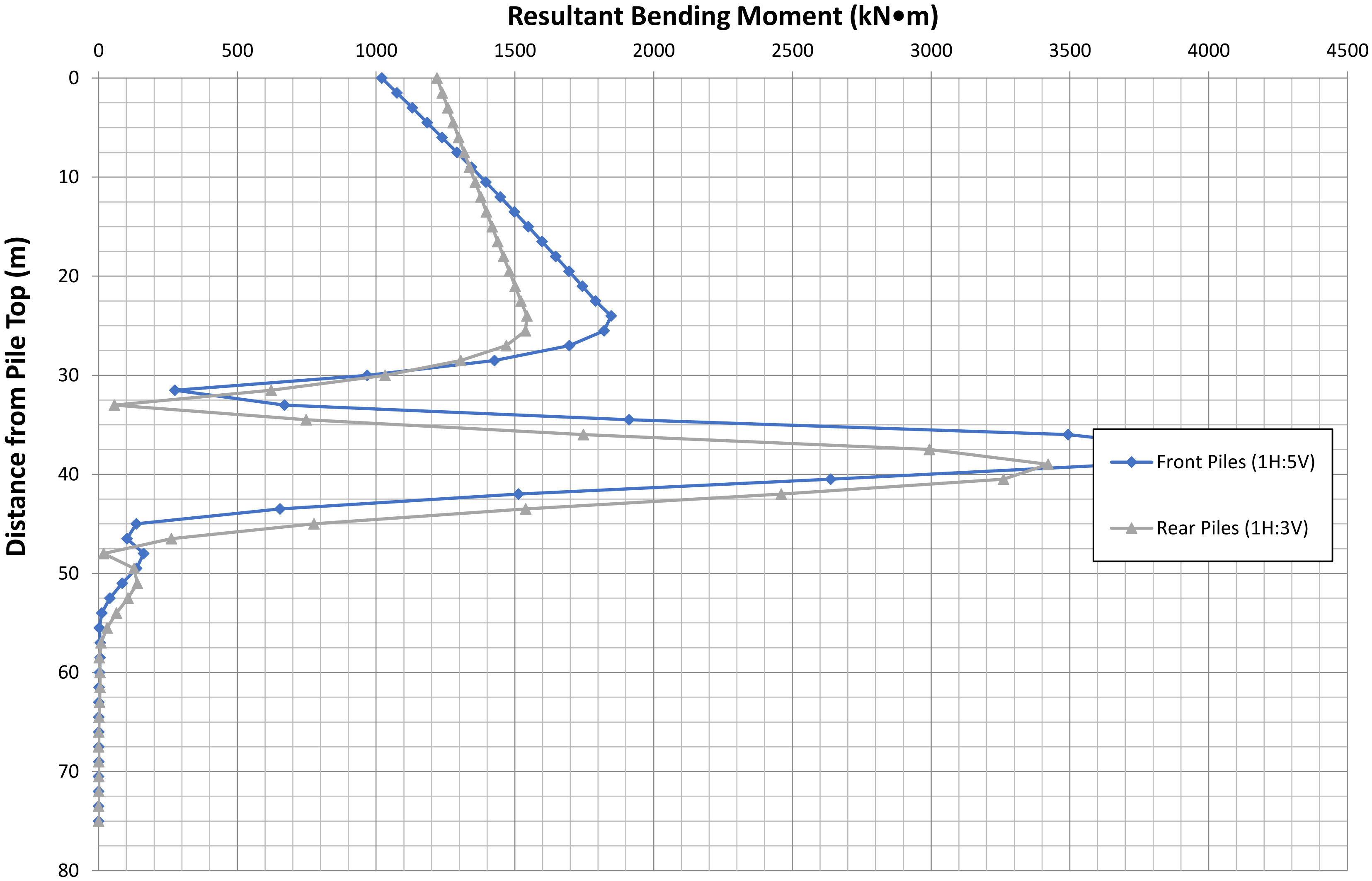
Lateral Group Pile Analysis
Seismic (1:475 yr) Loading Condition



Client: WTLP
File No.: 26259

Figure E4 - Total Pile deflection versus Depth
1:475 year Earthquake Seismic Loading Condition

Lateral Group Pile Analysis
Seismic (1:475 yr) Loading Condition



Client: WTLP
File No.: 26259

Figure E5 - Resultant Bending Moment versus Depth
1:475 year Earthquake Seismic Loading Condition

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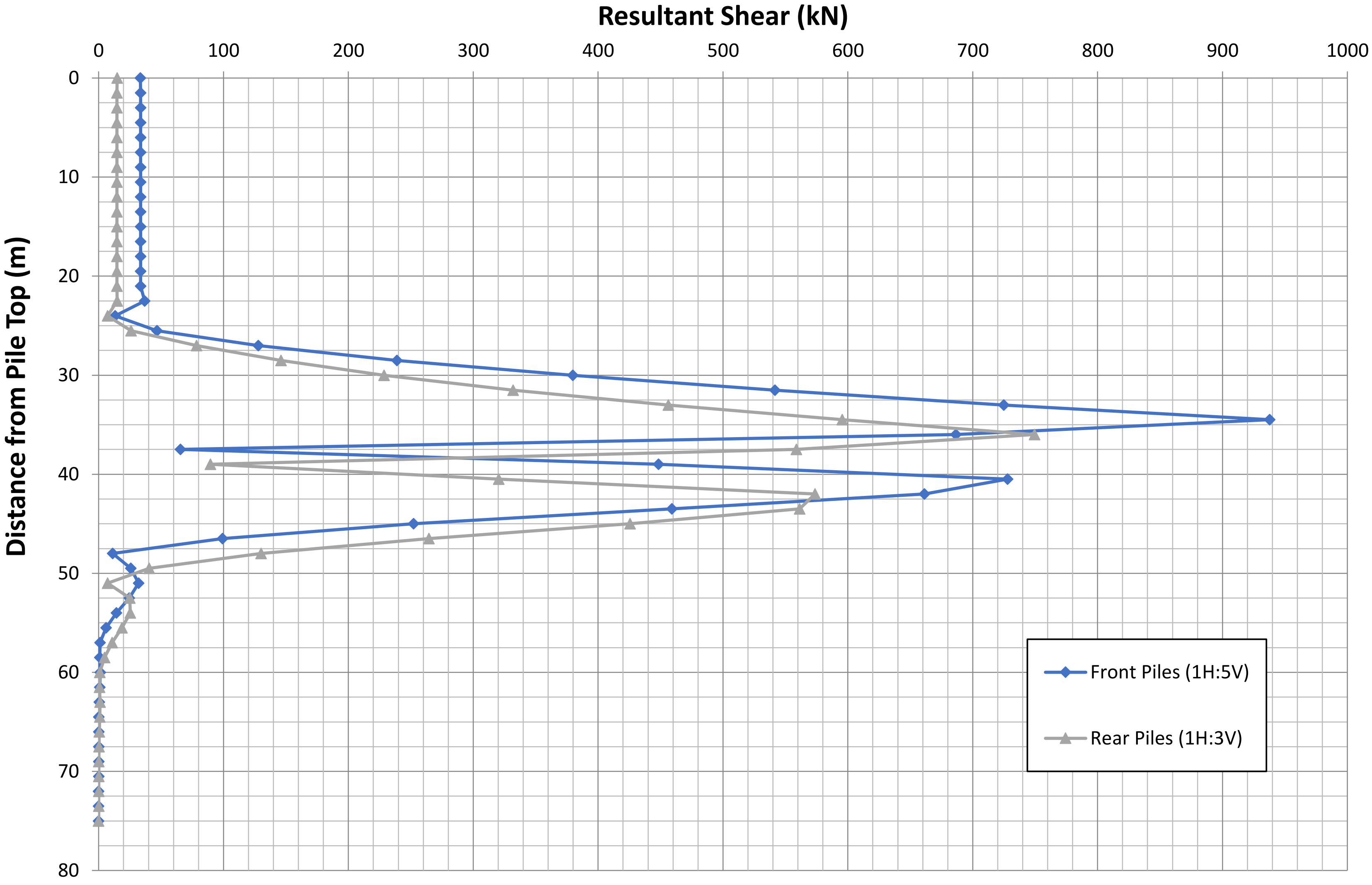
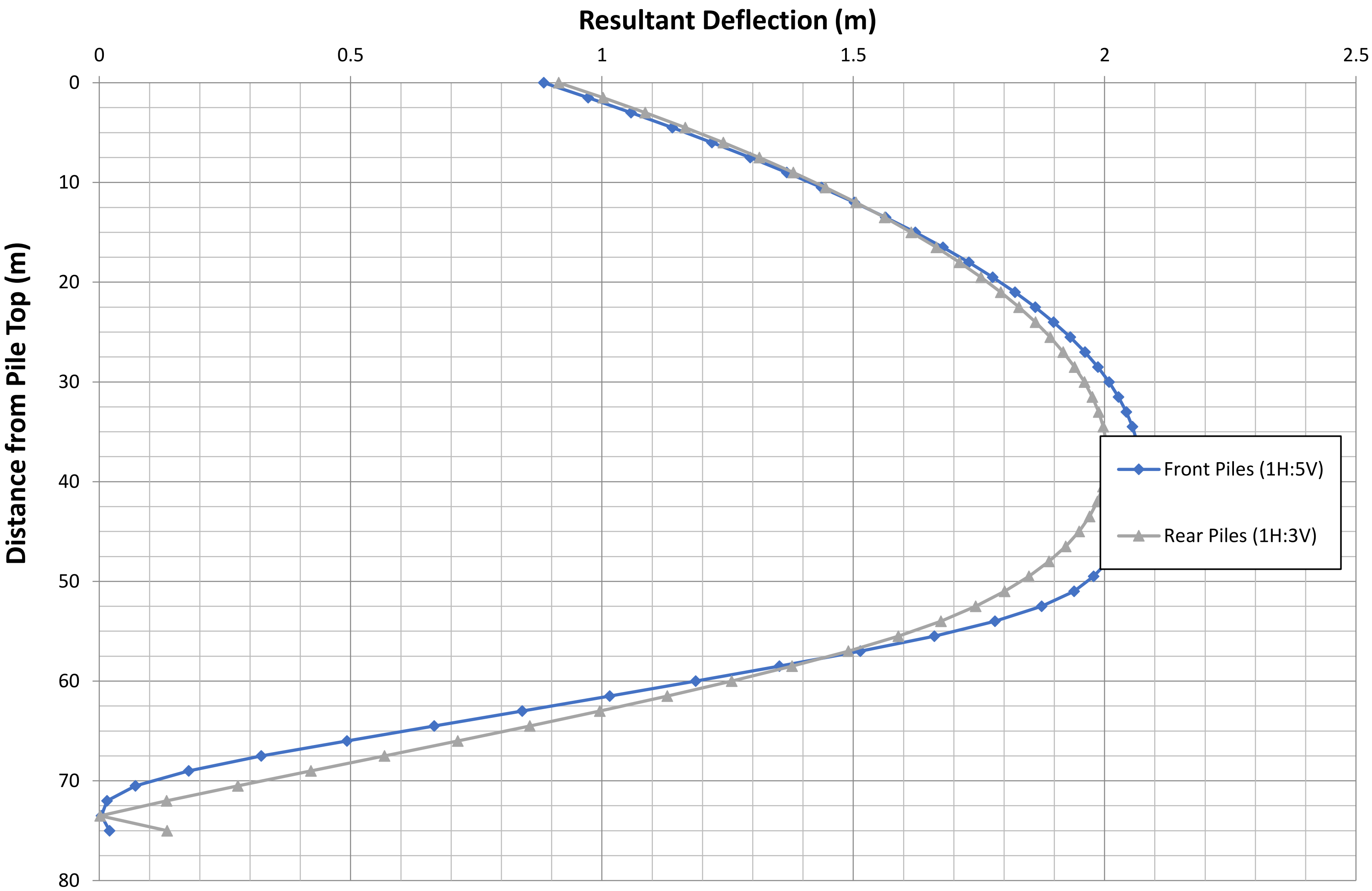
Lateral Group Pile Analysis
Seismic (1:475 yr) Loading Condition



Client: WTLP
File No.: 26259

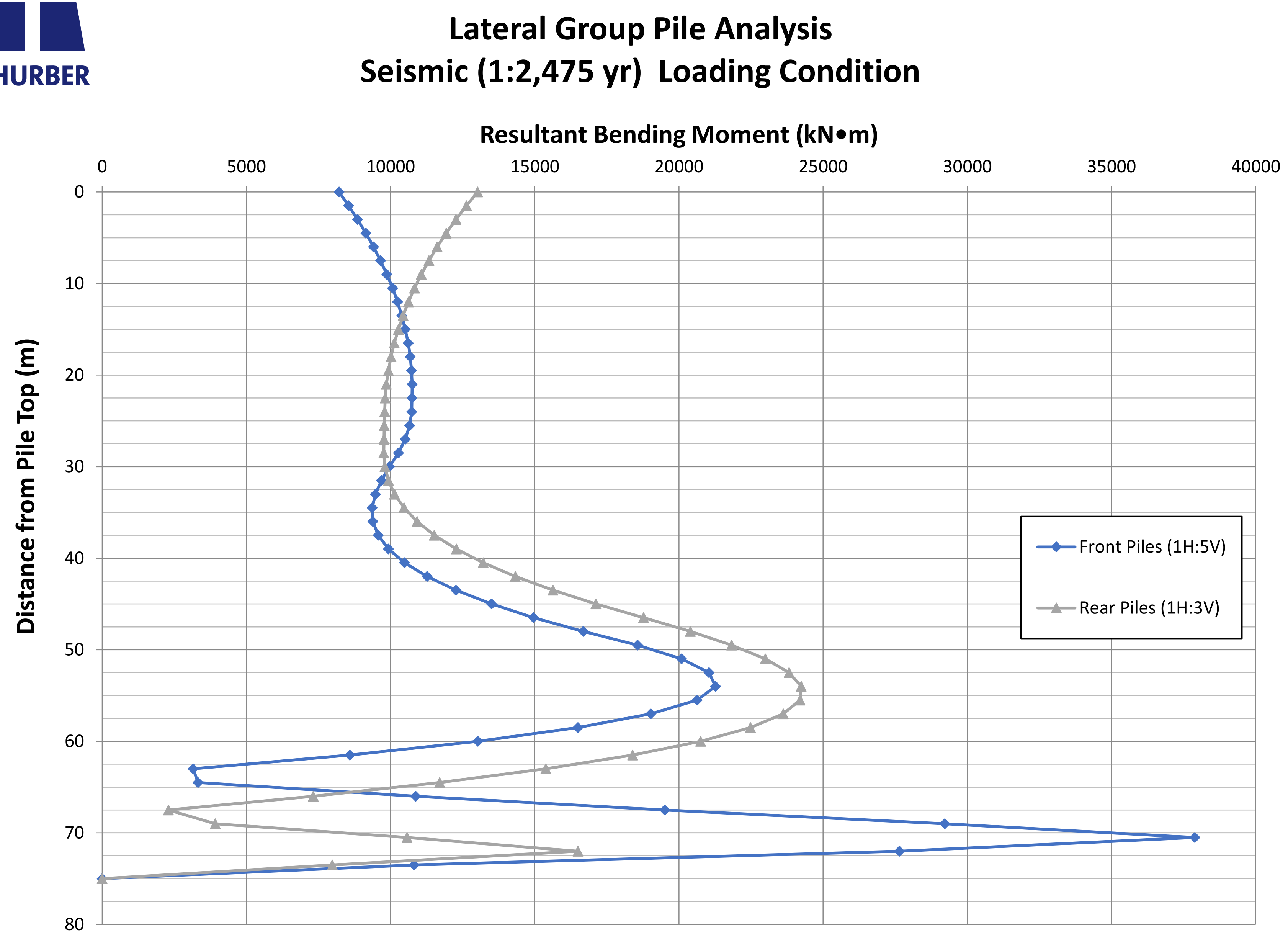
Figure E6 - Resultant Shear versus Depth
1:475 year Earthquake Seismic Loading Condition

Lateral Group Pile Analysis
Seismic (1:2,475 yr) Loading Condition



Client: WTLP
File No.: 26259

Figure E7 - Total Pile deflection versus Depth
1:2,475 year Earthquake Seismic Loading Condition



Client: WTLP
File No.: 26259

Figure E8 - Resultant Bending Moment versus Depth
1:2,475 year Earthquake Seismic Loading Condition

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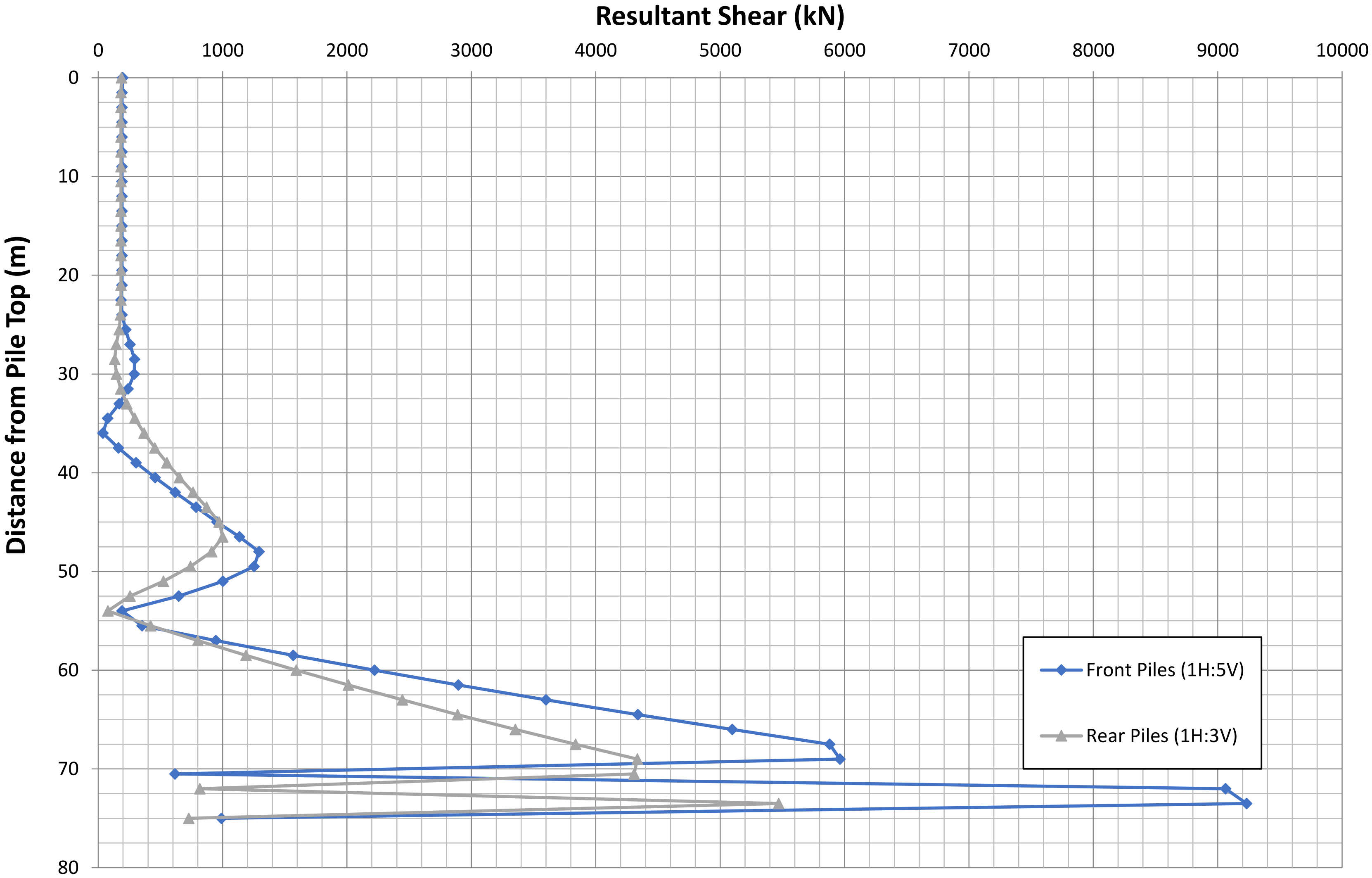
Lateral Group Pile Analysis
Seismic (1:2,475 yr) Loading Condition



Client: WTLP
File No.: 26259

Figure E9 - Resultant Shear versus Depth
1:2,475 year Earthquake Seismic Loading Condition

APPENDIX G

PY Curves for Cyclic Loading (3 pages)

THURBER

PY Curves
Cyclic Loading (15 cycles)

X Deflection (m)
Y Soil Resistance (kN/m)

Embedment = 0.5 m		Embedment = 1.5 m		Embedment = 2.5 m		Embedment = 3.5 m		Embedment = 4.5 m		Embedment = 5.5 m		Embedment = 6.5 m	
X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0014	5.6	0.0016	20.6	0.0016	34.3	0.0014	41.0	0.0012	47.5	0.0014	67.2	0.0016	90.3
0.0028	10.9	0.0032	39.8	0.0032	66.4	0.0027	79.4	0.0024	92.0	0.0028	130.2	0.0032	174.8
0.0042	15.6	0.0049	56.8	0.0048	94.7	0.0041	113.2	0.0037	131.2	0.0042	185.7	0.0048	249.3
0.0057	19.5	0.0065	70.9	0.0064	118.3	0.0054	141.4	0.0049	163.9	0.0057	231.9	0.0064	311.4
0.0071	22.5	0.0081	82.2	0.0080	137.0	0.0068	163.8	0.0061	189.9	0.0071	268.7	0.0080	360.8
0.0085	24.9	0.0097	90.9	0.0096	151.5	0.0082	181.1	0.0073	209.9	0.0085	297.0	0.0096	398.8
0.0099	26.7	0.0113	97.3	0.0112	162.2	0.0095	194.0	0.0086	224.9	0.0099	318.2	0.0112	427.2
0.0113	28.0	0.0129	102.1	0.0128	170.1	0.0109	203.4	0.0098	235.8	0.0113	333.6	0.0128	447.9
0.0127	28.9	0.0146	105.5	0.0144	175.8	0.0122	210.2	0.0110	243.6	0.0127	344.7	0.0144	462.8
0.0142	29.6	0.0162	107.9	0.0160	179.8	0.0136	215.0	0.0122	249.2	0.0141	352.7	0.0160	473.5
0.0173	30.4	0.0198	111.0	0.0196	185.0	0.0166	221.2	0.0149	256.5	0.0173	362.9	0.0196	487.2
0.0204	30.8	0.0234	112.4	0.0231	187.4	0.0196	224.0	0.0177	259.7	0.0204	367.5	0.0232	493.4
0.0264	31.1	0.0302	113.3	0.0298	188.9	0.0253	225.8	0.0228	261.8	0.0263	370.4	0.0299	497.3
0.0323	31.1	0.0370	113.5	0.0365	189.2	0.0310	226.2	0.0279	262.2	0.0323	371.0	0.0366	498.2
0.0383	31.1	0.0438	113.5	0.0432	189.3	0.0367	226.3	0.0330	262.3	0.0382	371.2	0.0433	498.3
0.0459	31.1	0.0525	113.6	0.0519	189.3	0.0441	226.3	0.0397	262.4	0.0458	371.2	0.0520	498.4

Embedment = 7.5 m		Embedment = 8.5 m		Embedment = 9.5 m		Embedment = 10.5 m		Embedment = 11.5 m		Embedment = 12.5 m		Embedment = 13.5 m	
X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0
0.0018	116.6	0.0020	146.3	0.0022	179.3	0.0024	215.6	0.0026	255.3	0.0027	298.2	0.0029	344.5
0.0036	225.9	0.0040	283.3	0.0043	347.2	0.0047	417.6	0.0051	494.3	0.0055	577.5	0.0059	667.1
0.0054	322.1	0.0059	404.0	0.0065	495.1	0.0071	595.4	0.0077	704.8	0.0082	823.4	0.0088	951.1
0.0072	402.3	0.0079	504.6	0.0087	618.4	0.0095	743.6	0.0102	880.3	0.0110	1028.4	0.0117	1188.0
0.0090	466.1	0.0099	584.7	0.0109	716.6	0.0118	861.7	0.0128	1020.1	0.0137	1191.8	0.0147	1376.7
0.0108	515.2	0.0119	646.3	0.0130	792.0	0.0142	952.4	0.0153	1127.5	0.0165	1317.2	0.0176	1521.6
0.0126	551.9	0.0139	692.3	0.0152	848.4	0.0165	1020.2	0.0179	1207.7	0.0192	1410.9	0.0205	1629.8
0.0143	578.7	0.0159	725.9	0.0174	889.6	0.0189	1069.7	0.0204	1266.3	0.0220	1479.4	0.0235	1709.0
0.0161	598.0	0.0178	750.1	0.0196	919.2	0.0213	1105.4	0.0230	1308.6	0.0247	1528.8	0.0264	1766.0
0.0179	611.7	0.0198	767.3	0.0217	940.4	0.0236	1130.8	0.0255	1338.6	0.0274	1563.9	0.0293	1806.5
0.0219	629.4	0.0242	789.6	0.0266	967.6	0.0289	1163.6	0.0312	1377.5	0.0335	1609.2	0.0359	1858.9
0.0259	637.4	0.0287	799.6	0.0314	979.9	0.0342	1178.4	0.0369	1395.0	0.0396	1629.7	0.0424	1882.6
0.0334	642.5	0.0370	806.0	0.0405	987.7	0.0441	1187.7	0.0476	1406.0	0.0512	1642.6	0.0547	1897.5
0.0409	643.6	0.0453	807.3	0.0496	989.4	0.0540	1189.8	0.0583	1408.4	0.0627	1645.4	0.0670	1900.7
0.0485	643.8	0.0536	807.6	0.0588	989.7	0.0639	1190.2	0.0690	1408.9	0.0742	1646.0	0.0793	1901.4
0.0582	643.9	0.0643	807.7	0.0705	989.8	0.0767	1190.3	0.0828	1409.1	0.0890	1646.2	0.0952	1901.6

PY Curves

Cyclic Loading (15 cycles)

Embedment = 14.5 m		Embedment = 15.5 m		Embedment = 16.5 m		Embedment = 17.5 m		Embedment = 18.5 m		Embedment = 19.5 m		Embedment = 20.5 m	
X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0
0.0031	394.1	0.0033	447.0	0.0035	503.2	0.0037	562.8	0.0039	625.6	0.0041	691.8	0.0043	761.3
0.0062	763.1	0.0066	865.6	0.0070	974.5	0.0074	1089.8	0.0078	1211.5	0.0082	1339.7	0.0085	1474.3
0.0094	1088.1	0.0099	1234.1	0.0105	1389.4	0.0111	1553.8	0.0117	1727.4	0.0122	1910.1	0.0128	2102.0
0.0125	1359.0	0.0133	1541.5	0.0140	1735.4	0.0148	1940.7	0.0155	2157.5	0.0163	2385.8	0.0171	2625.4
0.0156	1574.8	0.0166	1786.3	0.0175	2011.0	0.0185	2249.0	0.0194	2500.2	0.0204	2764.7	0.0213	3042.4
0.0187	1740.6	0.0199	1974.3	0.0210	2222.7	0.0222	2485.7	0.0233	2763.4	0.0245	3055.8	0.0256	3362.8
0.0219	1864.5	0.0232	2114.8	0.0245	2380.8	0.0259	2662.5	0.0272	2960.0	0.0285	3273.1	0.0299	3602.0
0.0250	1955.0	0.0265	2217.5	0.0280	2496.4	0.0296	2791.8	0.0311	3103.7	0.0326	3432.1	0.0341	3776.9
0.0281	2020.2	0.0298	2291.4	0.0315	2579.7	0.0333	2884.9	0.0350	3207.2	0.0367	3546.5	0.0384	3902.8
0.0312	2066.6	0.0331	2344.1	0.0351	2638.9	0.0370	2951.2	0.0389	3280.9	0.0408	3628.0	0.0427	3992.4
0.0382	2126.5	0.0405	2412.0	0.0428	2715.5	0.0452	3036.8	0.0475	3376.0	0.0498	3733.2	0.0521	4108.2
0.0451	2153.6	0.0479	2442.8	0.0506	2750.0	0.0534	3075.5	0.0561	3419.0	0.0589	3780.7	0.0616	4160.6
0.0583	2170.7	0.0618	2462.1	0.0653	2771.8	0.0689	3099.8	0.0724	3446.1	0.0760	3810.7	0.0795	4193.5
0.0714	2174.3	0.0757	2466.3	0.0800	2776.5	0.0844	3105.1	0.0887	3451.9	0.0931	3817.1	0.0974	4200.6
0.0845	2175.1	0.0896	2467.2	0.0947	2777.5	0.0999	3106.2	0.1050	3453.2	0.1102	3818.5	0.1153	4202.2
0.1014	2175.3	0.1075	2467.4	0.1137	2777.8	0.1199	3106.5	0.1260	3453.5	0.1322	3818.9	0.1384	4202.5

Embedment = 21.5 m		Embedment = 22.5 m		Embedment = 23.5 m		Embedment = 24.5 m		Embedment = 25.5 m		Embedment = 27.5 m		Embedment = 30 m	
X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0
0.0045	834.1	0.0046	910.3	0.0047	957.3	0.0047	998.1	0.0047	1038.9	0.0047	1120.6	0.0047	1222.6
0.0089	1615.3	0.0093	1762.7	0.0094	1853.8	0.0094	1932.8	0.0094	2011.9	0.0094	2169.9	0.0094	2367.5
0.0134	2303.1	0.0139	2513.3	0.0140	2643.2	0.0140	2755.8	0.0140	2868.5	0.0140	3093.9	0.0140	3375.6
0.0178	2876.6	0.0186	3139.2	0.0187	3301.3	0.0187	3442.1	0.0187	3582.8	0.0187	3864.3	0.0187	4216.2
0.0223	3333.5	0.0232	3637.8	0.0234	3825.7	0.0234	3988.8	0.0234	4151.9	0.0234	4478.1	0.0234	4885.8
0.0267	3684.4	0.0279	4020.7	0.0281	4228.5	0.0281	4408.7	0.0281	4589.0	0.0281	4949.5	0.0281	5400.2
0.0312	3946.5	0.0325	4306.7	0.0327	4529.3	0.0327	4722.3	0.0327	4915.4	0.0327	5301.6	0.0327	5784.3
0.0356	4138.1	0.0372	4515.9	0.0374	4749.2	0.0374	4951.7	0.0374	5154.1	0.0374	5559.0	0.0374	6065.2
0.0401	4276.1	0.0418	4666.4	0.0421	4907.5	0.0421	5116.7	0.0421	5326.0	0.0421	5744.4	0.0421	6267.4
0.0446	4374.3	0.0465	4773.6	0.0468	5020.3	0.0468	5234.3	0.0468	5448.3	0.0468	5876.4	0.0468	6411.4
0.0545	4501.2	0.0568	4912.1	0.0572	5165.9	0.0572	5386.1	0.0572	5606.3	0.0572	6046.8	0.0572	6597.4
0.0644	4558.5	0.0671	4974.6	0.0676	5231.7	0.0676	5454.7	0.0676	5677.7	0.0676	6123.8	0.0676	6681.4
0.0831	4594.6	0.0866	5014.0	0.0872	5273.1	0.0872	5497.9	0.0872	5722.7	0.0872	6172.3	0.0872	6734.3
0.1018	4602.4	0.1061	5022.6	0.1068	5282.0	0.1068	5507.2	0.1068	5732.4	0.1068	6182.8	0.1068	6745.7
0.1205	4604.1	0.1256	5024.4	0.1265	5284.0	0.1265	5509.2	0.1265	5734.5	0.1265	6185.0	0.1265	6748.2
0.1446	4604.5	0.1507	5024.8	0.1518	5284.4	0.1518	5509.7	0.1518	5735.0	0.1518	6185.6	0.1518	6748.8

THURBER

PY Curves
Cyclic Loading (15 cycles)

Embedment = 32.5 m		Embedment = 35 m		Embedment = 37.5 m		Embedment = 40 m		Embedment = 42.5 m		Embedment = 45 m		Embedment = 47.5 m	
X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0
0.0047	1324.6	0.0047	1426.7	0.0047	1528.7	0.0047	1630.7	0.0047	1732.7	0.0047	1834.8	0.0047	1936.8
0.0094	2565.1	0.0094	2762.6	0.0094	2960.2	0.0094	3157.8	0.0094	3355.4	0.0094	3552.9	0.0094	3750.5
0.0140	3657.3	0.0140	3939.0	0.0140	4220.7	0.0140	4502.4	0.0140	4784.1	0.0140	5065.8	0.0140	5347.5
0.0187	4568.0	0.0187	4919.9	0.0187	5271.7	0.0187	5623.6	0.0187	5975.4	0.0187	6327.3	0.0187	6679.1
0.0234	5293.5	0.0234	5701.3	0.0234	6109.0	0.0234	6516.8	0.0234	6924.5	0.0234	7332.2	0.0234	7740.0
0.0281	5850.9	0.0281	6301.5	0.0281	6752.2	0.0281	7202.8	0.0281	7653.5	0.0281	8104.2	0.0281	8554.8
0.0327	6267.0	0.0327	6749.8	0.0327	7232.5	0.0327	7715.2	0.0327	8197.9	0.0327	8680.6	0.0327	9163.4
0.0374	6571.4	0.0374	7077.5	0.0374	7583.7	0.0374	8089.8	0.0374	8596.0	0.0374	9102.2	0.0374	9608.3
0.0421	6790.5	0.0421	7313.5	0.0421	7836.5	0.0421	8359.6	0.0421	8882.6	0.0421	9405.6	0.0421	9928.7
0.0468	6946.5	0.0468	7481.5	0.0468	8016.6	0.0468	8551.6	0.0468	9086.7	0.0468	9621.7	0.0468	10156.8
0.0572	7147.9	0.0572	7698.5	0.0572	8249.1	0.0572	8799.6	0.0572	9350.2	0.0572	9900.8	0.0572	10451.3
0.0676	7238.9	0.0676	7796.5	0.0676	8354.1	0.0676	8911.7	0.0676	9469.3	0.0676	10026.8	0.0676	10584.4
0.0872	7296.3	0.0872	7858.3	0.0872	8420.3	0.0872	8982.3	0.0872	9544.3	0.0872	10106.3	0.0872	10668.2
0.1068	7308.7	0.1068	7871.6	0.1068	8434.6	0.1068	8997.5	0.1068	9560.5	0.1068	10123.4	0.1068	10686.4
0.1265	7311.3	0.1265	7874.5	0.1265	8437.6	0.1265	9000.8	0.1265	9564.0	0.1265	10127.1	0.1265	10690.3
0.1518	7312.0	0.1518	7875.2	0.1518	8438.4	0.1518	9001.6	0.1518	9564.8	0.1518	10128.0	0.1518	10691.2

Embedment = 50 m		Embedment = 52.5 m	
X	Y	X	Y
0.0000	0.0	0.0000	0.0
0.0047	2038.8	0.0047	2140.9
0.0094	3948.1	0.0094	4145.7
0.0140	5629.2	0.0140	5910.9
0.0187	7031.0	0.0187	7382.8
0.0234	8147.7	0.0234	8555.4
0.0281	9005.5	0.0281	9456.1
0.0327	9646.1	0.0327	10128.8
0.0374	10114.5	0.0374	10620.6
0.0421	10451.7	0.0421	10974.7
0.0468	10691.8	0.0468	11226.9
0.0572	11001.9	0.0572	11552.5
0.0676	11142.0	0.0676	11699.6
0.0872	11230.2	0.0872	11792.2
0.1068	11249.3	0.1068	11812.3
0.1265	11253.4	0.1265	11816.6
0.1518	11254.4	0.1518	11817.6

THURBER

APPENDIX H

PY Curves [475 yr Earthquake Event_Post Liquefaction] (3 pages)

THURBER

PY Curves
1:475 yr Earthquake Event (14 m Depth to Liquefaction)

X Deflection (m)
Y Soil Resistance (kN/m)

Embedment = 0.5 m		Embedment = 1.5 m		Embedment = 2.5 m		Embedment = 3.5 m		Embedment = 4.5 m		Embedment = 5.5 m		Embedment = 6.5 m	
X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0002	0.4	0.0002	1.1	0.0002	2.3	0.0002	2.7	0.0002	3.8	0.0002	4.1	0.0002	5.2
0.0015	0.9	0.0015	2.4	0.0015	5.0	0.0015	5.8	0.0015	8.1	0.0015	8.9	0.0015	11.2
0.0046	1.3	0.0046	3.4	0.0046	7.3	0.0046	8.4	0.0046	11.7	0.0046	12.9	0.0046	16.2
0.0122	1.8	0.0122	4.7	0.0122	10.1	0.0122	11.6	0.0122	16.3	0.0122	17.8	0.0122	22.5
0.0244	2.2	0.0244	6.0	0.0244	12.7	0.0244	14.7	0.0244	20.5	0.0244	22.5	0.0244	28.3
0.0366	2.6	0.0366	6.8	0.0366	14.5	0.0366	16.8	0.0366	23.5	0.0366	25.7	0.0366	32.4
0.0610	3.0	0.0610	8.1	0.0610	17.2	0.0610	19.9	0.0610	27.8	0.0610	30.5	0.0610	38.4
0.0914	3.5	0.0914	9.3	0.0914	19.7	0.0914	22.8	0.0914	31.9	0.0914	34.9	0.0914	44.0
0.1372	4.0	0.1372	10.6	0.1372	22.6	0.1372	26.1	0.1372	36.5	0.1372	40.0	0.1372	50.4
0.1829	4.4	0.1829	11.7	0.1829	24.9	0.1829	28.7	0.1829	40.2	0.1829	44.0	0.1829	55.4
0.2438	4.8	0.2438	12.8	0.2438	27.4	0.2438	31.6	0.2438	44.2	0.2438	48.4	0.2438	61.0
0.3048	5.2	0.3048	13.8	0.3048	29.5	0.3048	34.0	0.3048	47.6	0.3048	52.1	0.3048	65.7
0.3962	5.7	0.3962	15.1	0.3962	32.2	0.3962	37.1	0.3962	52.0	0.3962	56.9	0.3962	71.7
0.4877	6.1	0.4877	16.2	0.4877	34.5	0.4877	39.8	0.4877	55.7	0.4877	61.0	0.4877	76.9
0.6096	6.6	0.6096	17.4	0.6096	37.1	0.6096	42.8	0.6096	60.0	0.6096	65.7	0.6096	82.8
0.7315	6.6	0.7315	17.4	0.7315	37.1	0.7315	42.8	0.7315	60.0	0.7315	65.7	0.7315	82.8

Embedment = 7.5 m		Embedment = 8.5 m		Embedment = 9.5 m		Embedment = 10.5 m		Embedment = 11.5 m		Embedment = 12.5 m		Embedment = 13.5 m	
X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0
0.0002	5.6	0.0002	6.7	0.0002	7.0	0.0002	8.1	0.0002	8.5	0.0002	9.5	0.0002	9.9
0.0015	12.0	0.0015	14.3	0.0015	15.1	0.0015	17.4	0.0015	18.2	0.0015	20.5	0.0015	21.3
0.0046	17.3	0.0046	20.7	0.0046	21.8	0.0046	25.2	0.0046	26.3	0.0046	29.6	0.0046	30.7
0.0122	24.0	0.0122	28.7	0.0122	30.2	0.0122	34.9	0.0122	36.4	0.0122	41.1	0.0122	42.6
0.0244	30.3	0.0244	36.1	0.0244	38.1	0.0244	44.0	0.0244	45.9	0.0244	51.8	0.0244	53.7
0.0366	34.7	0.0366	41.4	0.0366	43.6	0.0366	50.3	0.0366	52.6	0.0366	59.3	0.0366	61.5
0.0610	41.1	0.0610	49.0	0.0610	51.7	0.0610	59.7	0.0610	62.3	0.0610	70.3	0.0610	72.9
0.0914	47.0	0.0914	56.1	0.0914	59.2	0.0914	68.3	0.0914	71.3	0.0914	80.4	0.0914	83.5
0.1372	53.8	0.1372	64.3	0.1372	67.7	0.1372	78.2	0.1372	81.6	0.1372	92.1	0.1372	95.5
0.1829	59.3	0.1829	70.7	0.1829	74.6	0.1829	86.0	0.1829	89.9	0.1829	101.3	0.1829	105.2
0.2438	65.2	0.2438	77.9	0.2438	82.1	0.2438	94.7	0.2438	98.9	0.2438	111.5	0.2438	115.7
0.3048	70.3	0.3048	83.9	0.3048	88.4	0.3048	102.0	0.3048	106.5	0.3048	120.1	0.3048	124.7
0.3962	76.7	0.3962	91.5	0.3962	96.5	0.3962	111.3	0.3962	116.3	0.3962	131.1	0.3962	136.1
0.4877	82.2	0.4877	98.1	0.4877	103.4	0.4877	119.3	0.4877	124.6	0.4877	140.5	0.4877	145.8
0.6096	88.5	0.6096	105.7	0.6096	111.4	0.6096	128.5	0.6096	134.2	0.6096	151.4	0.6096	157.1
0.7315	88.5	0.7315	105.7	0.7315	111.4	0.7315	128.5	0.7315	134.2	0.7315	151.4	0.7315	157.1

THURBER

PY Curves
1:475 yr Earthquake Event (14 m Depth to Liquefaction)

Embedment = 14.5 m		Embedment = 15.5 m		Embedment = 16.5 m		Embedment = 17.5 m		Embedment = 18.5 m		Embedment = 19.5 m		Embedment = 20.5 m	
X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0
0.0038	245.1	0.0039	298.0	0.0035	704.6	0.0037	787.9	0.0039	876.0	0.0041	968.6	0.0043	1065.9
0.0075	474.6	0.0077	577.0	0.0070	1364.4	0.0074	1525.8	0.0078	1696.3	0.0082	1875.7	0.0085	2064.1
0.0113	676.7	0.0116	822.7	0.0105	1945.3	0.0111	2175.5	0.0117	2418.5	0.0122	2674.4	0.0128	2943.1
0.0151	845.3	0.0154	1027.6	0.0140	2429.7	0.0148	2717.2	0.0155	3020.8	0.0163	3340.3	0.0171	3675.9
0.0188	979.5	0.0193	1190.8	0.0175	2815.6	0.0185	3148.8	0.0194	3500.6	0.0204	3870.9	0.0213	4259.8
0.0226	1082.6	0.0231	1316.2	0.0210	3112.1	0.0222	3480.3	0.0233	3869.1	0.0245	4278.4	0.0256	4708.2
0.0264	1159.7	0.0270	1409.8	0.0245	3333.4	0.0259	3727.9	0.0272	4144.3	0.0285	4582.7	0.0299	5043.2
0.0301	1216.0	0.0308	1478.2	0.0280	3495.3	0.0296	3908.9	0.0311	4345.6	0.0326	4805.3	0.0341	5288.1
0.0339	1256.5	0.0347	1527.5	0.0315	3611.8	0.0333	4039.2	0.0350	4490.5	0.0367	4965.5	0.0384	5464.4
0.0377	1285.4	0.0386	1562.6	0.0351	3694.8	0.0370	4132.0	0.0389	4593.6	0.0408	5079.6	0.0427	5589.9
0.0460	1322.7	0.0471	1607.9	0.0428	3802.0	0.0452	4251.9	0.0475	4726.8	0.0498	5226.9	0.0521	5752.0
0.0544	1339.5	0.0557	1628.4	0.0506	3850.4	0.0534	4306.0	0.0561	4787.0	0.0589	5293.4	0.0616	5825.3
0.0702	1350.1	0.0719	1641.3	0.0653	3880.9	0.0689	4340.1	0.0724	4824.9	0.0760	5335.4	0.0795	5871.4
0.0860	1352.4	0.0880	1644.1	0.0800	3887.5	0.0844	4347.5	0.0887	4833.1	0.0931	5344.4	0.0974	5881.4
0.1018	1352.9	0.1042	1644.7	0.0947	3888.9	0.0999	4349.1	0.1050	4834.9	0.1102	5346.4	0.1153	5883.5
0.1222	1353.0	0.1251	1644.8	0.1137	3889.2	0.1199	4349.4	0.1260	4835.3	0.1322	5346.8	0.1384	5884.0

Embedment = 21.5 m		Embedment = 22.5 m		Embedment = 23.5 m		Embedment = 24.5 m		Embedment = 25.5 m		Embedment = 27.5 m		Embedment = 30 m	
X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0
0.0045	1167.9	0.0046	1274.5	0.0047	1340.4	0.0047	1397.5	0.0047	1454.6	0.0047	1568.9	0.0047	1711.8
0.0089	2261.6	0.0093	2468.0	0.0094	2595.5	0.0094	2706.2	0.0094	2816.8	0.0094	3038.2	0.0094	3314.8
0.0134	3224.6	0.0139	3518.9	0.0140	3700.7	0.0140	3858.5	0.0140	4016.3	0.0140	4331.8	0.0140	4726.2
0.0178	4027.5	0.0186	4395.2	0.0187	4622.3	0.0187	4819.3	0.0187	5016.4	0.0187	5410.5	0.0187	5903.1
0.0223	4667.2	0.0232	5093.3	0.0234	5356.4	0.0234	5584.8	0.0234	5813.1	0.0234	6269.8	0.0234	6840.7
0.0267	5158.6	0.0279	5629.5	0.0281	5920.4	0.0281	6172.7	0.0281	6425.1	0.0281	6929.9	0.0281	7560.9
0.0312	5525.6	0.0325	6029.9	0.0327	6341.5	0.0327	6611.8	0.0327	6882.2	0.0327	7422.9	0.0327	8098.7
0.0356	5793.9	0.0372	6322.8	0.0374	6649.4	0.0374	6932.9	0.0374	7216.4	0.0374	7783.3	0.0374	8492.0
0.0401	5987.1	0.0418	6533.6	0.0421	6871.1	0.0421	7164.1	0.0421	7457.0	0.0421	8042.8	0.0421	8775.1
0.0446	6124.6	0.0465	6683.7	0.0468	7029.0	0.0468	7328.6	0.0468	7628.3	0.0468	8227.6	0.0468	8976.7
0.0545	6302.2	0.0568	6877.5	0.0572	7232.8	0.0572	7541.2	0.0572	7849.5	0.0572	8466.2	0.0572	9237.1
0.0644	6382.5	0.0671	6965.1	0.0676	7324.9	0.0676	7637.2	0.0676	7949.5	0.0676	8574.0	0.0676	9354.7
0.0831	6433.0	0.0866	7020.2	0.0872	7382.9	0.0872	7697.7	0.0872	8012.4	0.0872	8641.9	0.0872	9428.8
0.1018	6443.9	0.1061	7032.2	0.1068	7395.5	0.1068	7710.8	0.1068	8026.0	0.1068	8656.6	0.1068	9444.8
0.1205	6446.3	0.1256	7034.7	0.1265	7398.2	0.1265	7713.6	0.1265	8029.0	0.1265	8659.8	0.1265	9448.2
0.1446	6446.9	0.1507	7035.3	0.1518	7398.8	0.1518	7714.2	0.1518	8029.7	0.1518	8660.5	0.1518	9449.1

THURBER

PY Curves

1:475 yr Earthquake Event (14 m Depth to Liquefaction)

Embedment = 32.5 m		Embedment = 35 m		Embedment = 37.5 m		Embedment = 40 m		Embedment = 42.5 m		Embedment = 45 m		Embedment = 47.5 m	
X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0
0.0047	1854.6	0.0047	1997.5	0.0047	2140.3	0.0047	2283.2	0.0047	2426.0	0.0047	2568.9	0.0047	2711.8
0.0094	3591.4	0.0094	3868.0	0.0094	4144.7	0.0094	4421.3	0.0094	4697.9	0.0094	4974.5	0.0094	5251.2
0.0140	5120.6	0.0140	5515.0	0.0140	5909.5	0.0140	6303.9	0.0140	6698.3	0.0140	7092.7	0.0140	7487.1
0.0187	6395.7	0.0187	6888.4	0.0187	7381.0	0.0187	7873.6	0.0187	8366.3	0.0187	8858.9	0.0187	9351.5
0.0234	7411.6	0.0234	7982.5	0.0234	8553.3	0.0234	9124.2	0.0234	9695.1	0.0234	10266.0	0.0234	10836.9
0.0281	8191.9	0.0281	8822.9	0.0281	9453.8	0.0281	10084.8	0.0281	10715.8	0.0281	11346.8	0.0281	11977.8
0.0327	8774.6	0.0327	9450.5	0.0327	10126.3	0.0327	10802.2	0.0327	11478.0	0.0327	12153.9	0.0327	12829.8
0.0374	9200.7	0.0374	9909.4	0.0374	10618.0	0.0374	11326.7	0.0374	12035.4	0.0374	12744.1	0.0374	13452.8
0.0421	9507.4	0.0421	10239.8	0.0421	10972.1	0.0421	11704.4	0.0421	12436.7	0.0421	13169.0	0.0421	13901.3
0.0468	9725.9	0.0468	10475.0	0.0468	11224.1	0.0468	11973.3	0.0468	12722.4	0.0468	13471.5	0.0468	14220.7
0.0572	10007.9	0.0572	10778.8	0.0572	11549.7	0.0572	12320.5	0.0572	13091.4	0.0572	13862.2	0.0572	14633.1
0.0676	10135.4	0.0676	10916.1	0.0676	11696.7	0.0676	12477.4	0.0676	13258.1	0.0676	14038.8	0.0676	14819.4
0.0872	10215.6	0.0872	11002.5	0.0872	11789.4	0.0872	12576.2	0.0872	13363.1	0.0872	14149.9	0.0872	14936.8
0.1068	10233.0	0.1068	11021.2	0.1068	11809.4	0.1068	12597.6	0.1068	13385.8	0.1068	14174.0	0.1068	14962.2
0.1265	10236.7	0.1265	11025.2	0.1265	11813.7	0.1265	12602.2	0.1265	13390.7	0.1265	14179.1	0.1265	14967.6
0.1518	10237.6	0.1518	11026.2	0.1518	11814.7	0.1518	12603.3	0.1518	13391.8	0.1518	14180.4	0.1518	14968.9

Embedment = 50 m		Embedment = 52.5 m	
X	Y	X	Y
0.0000	0.0	0.0000	0.0
0.0047	2854.6	0.0047	2997.5
0.0094	5527.8	0.0094	5804.4
0.0140	7881.5	0.0140	8276.0
0.0187	9844.2	0.0187	10336.8
0.0234	11407.7	0.0234	11978.6
0.0281	12608.7	0.0281	13239.7
0.0327	13505.6	0.0327	14181.5
0.0374	14161.5	0.0374	14870.1
0.0421	14633.6	0.0421	15365.9
0.0468	14969.8	0.0468	15718.9
0.0572	15404.0	0.0572	16174.8
0.0676	15600.1	0.0676	16380.8
0.0872	15723.7	0.0872	16510.5
0.1068	15750.4	0.1068	16538.6
0.1265	15756.1	0.1265	16544.6
0.1518	15757.5	0.1518	16546.0

THURBER

APPENDIX I

PY Curves [2475 yr Earthquake Event_Post Liquefaction] (3 pages)

THURBER

PY Curves
1:2,475 yr Earthquake Event (47 m Depth to Liquefaction)

X Deflection (m)
Y Soil Resistance (kN/m)

Embedment = 0.5 m		Embedment = 1.5 m		Embedment = 2.5 m		Embedment = 3.5 m		Embedment = 4.5 m		Embedment = 5.5 m		Embedment = 6.5 m	
X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0002	0.4	0.0002	1.1	0.0002	2.3	0.0002	2.7	0.0002	3.8	0.0002	4.1	0.0002	5.2
0.0015	0.9	0.0015	2.4	0.0015	5.0	0.0015	5.8	0.0015	8.1	0.0015	8.9	0.0015	11.2
0.0046	1.3	0.0046	3.4	0.0046	7.3	0.0046	8.4	0.0046	11.7	0.0046	12.9	0.0046	16.2
0.0122	1.8	0.0122	4.7	0.0122	10.1	0.0122	11.6	0.0122	16.3	0.0122	17.8	0.0122	22.5
0.0244	2.2	0.0244	6.0	0.0244	12.7	0.0244	14.7	0.0244	20.5	0.0244	22.5	0.0244	28.3
0.0366	2.6	0.0366	6.8	0.0366	14.5	0.0366	16.8	0.0366	23.5	0.0366	25.7	0.0366	32.4
0.0610	3.0	0.0610	8.1	0.0610	17.2	0.0610	19.9	0.0610	27.8	0.0610	30.5	0.0610	38.4
0.0914	3.5	0.0914	9.3	0.0914	19.7	0.0914	22.8	0.0914	31.9	0.0914	34.9	0.0914	44.0
0.1372	4.0	0.1372	10.6	0.1372	22.6	0.1372	26.1	0.1372	36.5	0.1372	40.0	0.1372	50.4
0.1829	4.4	0.1829	11.7	0.1829	24.9	0.1829	28.7	0.1829	40.2	0.1829	44.0	0.1829	55.4
0.2438	4.8	0.2438	12.8	0.2438	27.4	0.2438	31.6	0.2438	44.2	0.2438	48.4	0.2438	61.0
0.3048	5.2	0.3048	13.8	0.3048	29.5	0.3048	34.0	0.3048	47.6	0.3048	52.1	0.3048	65.7
0.3962	5.7	0.3962	15.1	0.3962	32.2	0.3962	37.1	0.3962	52.0	0.3962	56.9	0.3962	71.7
0.4877	6.1	0.4877	16.2	0.4877	34.5	0.4877	39.8	0.4877	55.7	0.4877	61.0	0.4877	76.9
0.6096	6.6	0.6096	17.4	0.6096	37.1	0.6096	42.8	0.6096	60.0	0.6096	65.7	0.6096	82.8
0.7315	6.6	0.7315	17.4	0.7315	37.1	0.7315	42.8	0.7315	60.0	0.7315	65.7	0.7315	82.8

Embedment = 7.5 m		Embedment = 8.5 m		Embedment = 9.5 m		Embedment = 10.5 m		Embedment = 11.5 m		Embedment = 12.5 m		Embedment = 13.5 m	
X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0
0.0002	5.6	0.0002	6.7	0.0002	7.0	0.0002	8.1	0.0002	8.5	0.0002	9.5	0.0002	9.9
0.0015	12.0	0.0015	14.3	0.0015	15.1	0.0015	17.4	0.0015	18.2	0.0015	20.5	0.0015	21.3
0.0046	17.3	0.0046	20.7	0.0046	21.8	0.0046	25.2	0.0046	26.3	0.0046	29.6	0.0046	30.7
0.0122	24.0	0.0122	28.7	0.0122	30.2	0.0122	34.9	0.0122	36.4	0.0122	41.1	0.0122	42.6
0.0244	30.3	0.0244	36.1	0.0244	38.1	0.0244	44.0	0.0244	45.9	0.0244	51.8	0.0244	53.7
0.0366	34.7	0.0366	41.4	0.0366	43.6	0.0366	50.3	0.0366	52.6	0.0366	59.3	0.0366	61.5
0.0610	41.1	0.0610	49.0	0.0610	51.7	0.0610	59.7	0.0610	62.3	0.0610	70.3	0.0610	72.9
0.0914	47.0	0.0914	56.1	0.0914	59.2	0.0914	68.3	0.0914	71.3	0.0914	80.4	0.0914	83.5
0.1372	53.8	0.1372	64.3	0.1372	67.7	0.1372	78.2	0.1372	81.6	0.1372	92.1	0.1372	95.5
0.1829	59.3	0.1829	70.7	0.1829	74.6	0.1829	86.0	0.1829	89.9	0.1829	101.3	0.1829	105.2
0.2438	65.2	0.2438	77.9	0.2438	82.1	0.2438	94.7	0.2438	98.9	0.2438	111.5	0.2438	115.7
0.3048	70.3	0.3048	83.9	0.3048	88.4	0.3048	102.0	0.3048	106.5	0.3048	120.1	0.3048	124.7
0.3962	76.7	0.3962	91.5	0.3962	96.5	0.3962	111.3	0.3962	116.3	0.3962	131.1	0.3962	136.1
0.4877	82.2	0.4877	98.1	0.4877	103.4	0.4877	119.3	0.4877	124.6	0.4877	140.5	0.4877	145.8
0.6096	88.5	0.6096	105.7	0.6096	111.4	0.6096	128.5	0.6096	134.2	0.6096	151.4	0.6096	157.1
0.7315	88.5	0.7315	105.7	0.7315	111.4	0.7315	128.5	0.7315	134.2	0.7315	151.4	0.7315	157.1

Client: WTLP
File No.: 26259

P-Y Curves
1:2,475 yr Earthquake Event (47 m Depth to Liquefaction)

THURBER

PY Curves
1:2,475 yr Earthquake Event (47 m Depth to Liquefaction)

Embedment = 14.5 m		Embedment = 15.5 m		Embedment = 16.5 m		Embedment = 17.5 m		Embedment = 18.5 m		Embedment = 19.5 m		Embedment = 20.5 m	
X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0
0.0002	11.0	0.0002	11.3	0.0002	12.4	0.0002	12.8	0.0002	13.9	0.0002	14.2	0.0002	15.3
0.0015	23.6	0.0015	24.4	0.0015	26.7	0.0015	27.5	0.0015	29.8	0.0015	30.6	0.0015	32.9
0.0046	34.1	0.0046	35.2	0.0046	38.6	0.0046	39.7	0.0046	43.0	0.0046	44.2	0.0046	47.5
0.0122	47.3	0.0122	48.8	0.0122	53.5	0.0122	55.0	0.0122	59.7	0.0122	61.2	0.0122	65.9
0.0244	59.6	0.0244	61.5	0.0244	67.4	0.0244	69.3	0.0244	75.2	0.0244	77.2	0.0244	83.0
0.0366	68.2	0.0366	70.4	0.0366	77.1	0.0366	79.4	0.0366	86.1	0.0366	88.3	0.0366	95.0
0.0610	80.9	0.0610	83.5	0.0610	91.5	0.0610	94.1	0.0610	102.1	0.0610	104.7	0.0610	112.7
0.0914	92.6	0.0914	95.6	0.0914	104.7	0.0914	107.7	0.0914	116.8	0.0914	119.9	0.0914	129.0
0.1372	106.0	0.1372	109.4	0.1372	119.9	0.1372	123.3	0.1372	133.8	0.1372	137.2	0.1372	147.7
0.1829	116.6	0.1829	120.5	0.1829	131.9	0.1829	135.7	0.1829	147.2	0.1829	151.0	0.1829	162.5
0.2438	128.4	0.2438	132.6	0.2438	145.2	0.2438	149.4	0.2438	162.0	0.2438	166.2	0.2438	178.9
0.3048	138.3	0.3048	142.8	0.3048	156.4	0.3048	160.9	0.3048	174.5	0.3048	179.1	0.3048	192.7
0.3962	150.9	0.3962	155.9	0.3962	170.7	0.3962	175.7	0.3962	190.5	0.3962	195.4	0.3962	210.3
0.4877	161.7	0.4877	167.0	0.4877	182.9	0.4877	188.2	0.4877	204.2	0.4877	209.5	0.4877	225.4
0.6096	174.2	0.6096	179.9	0.6096	197.1	0.6096	202.8	0.6096	219.9	0.6096	225.6	0.6096	242.8
0.7315	174.2	0.7315	179.9	0.7315	197.1	0.7315	202.8	0.7315	219.9	0.7315	225.6	0.7315	242.8

Embedment = 21.5 m		Embedment = 22.5 m		Embedment = 23.5 m		Embedment = 24.5 m		Embedment = 25.5 m		Embedment = 27.5 m		Embedment = 30 m	
X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0
0.0002	15.7	0.0002	16.7	0.0002	17.1	0.0001	18.2	0.0001	18.5	0.0001	20.0	0.0001	22.3
0.0015	33.7	0.0015	36.0	0.0015	36.8	0.0008	39.1	0.0008	39.9	0.0008	43.0	0.0008	48.1
0.0046	48.6	0.0046	52.0	0.0046	53.1	0.0023	56.5	0.0023	57.6	0.0023	62.1	0.0023	69.3
0.0122	67.4	0.0122	72.1	0.0122	73.6	0.0061	78.3	0.0061	79.9	0.0061	86.1	0.0061	96.1
0.0244	85.0	0.0244	90.8	0.0244	92.8	0.0122	98.7	0.0122	100.6	0.0122	108.4	0.0122	121.1
0.0366	97.3	0.0366	104.0	0.0366	106.2	0.0183	112.9	0.0183	115.2	0.0183	124.1	0.0183	138.6
0.0610	115.3	0.0610	123.3	0.0610	125.9	0.0305	133.9	0.0305	136.5	0.0305	147.1	0.0305	164.4
0.0914	132.0	0.0914	141.1	0.0914	144.2	0.0457	153.3	0.0457	156.3	0.0457	168.4	0.0457	188.2
0.1372	151.1	0.1372	161.5	0.1372	165.0	0.0686	175.4	0.0686	178.9	0.0686	192.8	0.0686	215.4
0.1829	166.3	0.1829	177.8	0.1829	181.6	0.0914	193.1	0.0914	196.9	0.0914	212.2	0.0914	237.1
0.2438	183.1	0.2438	195.7	0.2438	199.9	0.1219	212.5	0.1219	216.7	0.1219	233.6	0.1219	260.9
0.3048	197.2	0.3048	210.8	0.3048	215.3	0.1524	228.9	0.1524	233.5	0.1524	251.6	0.1524	281.1
0.3962	215.2	0.3962	230.1	0.3962	235.0	0.1981	249.9	0.1981	254.8	0.1981	274.6	0.1981	306.8
0.4877	230.7	0.4877	246.6	0.4877	251.9	0.2438	267.8	0.2438	273.1	0.2438	294.3	0.2438	328.8
0.6096	248.5	0.6096	265.6	0.6096	271.3	0.3048	288.5	0.3048	294.2	0.3048	317.0	0.3048	354.1
0.7315	248.5	0.7315	265.6	0.7315	271.3	0.3658	288.5	0.3658	294.2	0.3658	317.0	0.3658	354.1

THURBER

PY Curves
1:2,475 yr Earthquake Event (47 m Depth to Liquefaction)

Embedment = 32.5 m		Embedment = 35 m		Embedment = 37.5 m		Embedment = 40 m		Embedment = 42.5 m		Embedment = 45 m		Embedment = 47.5 m	
X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0	0.0000	0.0
0.0001	23.4	0.0001	25.2	0.0001	26.6	0.0001	28.8	0.0001	30.3	0.0001	31.9	0.0103	1722.8
0.0008	50.4	0.0008	54.3	0.0008	57.4	0.0008	62.0	0.0008	65.3	0.0008	68.7	0.0207	3336.1
0.0023	72.7	0.0023	78.3	0.0023	82.7	0.0023	89.4	0.0023	94.2	0.0023	99.0	0.0310	4756.6
0.0061	100.8	0.0061	108.5	0.0061	114.7	0.0061	124.0	0.0061	130.7	0.0061	137.3	0.0413	5941.0
0.0122	127.0	0.0122	136.7	0.0122	144.6	0.0122	156.3	0.0122	164.7	0.0122	173.0	0.0516	6884.7
0.0183	145.4	0.0183	156.5	0.0183	165.5	0.0183	178.9	0.0183	188.5	0.0183	198.1	0.0620	7609.5
0.0305	172.3	0.0305	185.6	0.0305	196.2	0.0305	212.1	0.0305	223.5	0.0305	234.8	0.0723	8150.8
0.0457	197.3	0.0457	212.4	0.0457	224.6	0.0457	242.8	0.0457	255.8	0.0457	268.8	0.0826	8546.5
0.0686	225.8	0.0686	243.2	0.0686	257.1	0.0686	277.9	0.0686	292.8	0.0686	307.7	0.0930	8831.5
0.0914	248.5	0.0914	267.7	0.0914	283.0	0.0914	305.9	0.0914	322.3	0.0914	338.7	0.1033	9034.4
0.1219	273.6	0.1219	294.6	0.1219	311.4	0.1219	336.7	0.1219	354.7	0.1219	372.8	0.1263	9296.4
0.1524	294.7	0.1524	317.4	0.1524	335.5	0.1524	362.7	0.1524	382.1	0.1524	401.6	0.1492	9414.8
0.1981	321.6	0.1981	346.4	0.1981	366.2	0.1981	395.8	0.1981	417.0	0.1981	438.3	0.1926	9489.4
0.2438	344.7	0.2438	371.2	0.2438	392.4	0.2438	424.2	0.2438	446.9	0.2438	469.7	0.2359	9505.5
0.3048	371.3	0.3048	399.8	0.3048	422.7	0.3048	457.0	0.3048	481.4	0.3048	505.9	0.2792	9508.9
0.3658	371.3	0.3658	399.8	0.3658	422.7	0.3658	457.0	0.3658	481.4	0.3658	505.9	0.3351	9509.8

Embedment = 50 m		Embedment = 52.5 m	
X	Y	X	Y
0.0000	0.0	0.0000	0.0
0.0047	2854.6	0.0047	2997.5
0.0094	5527.8	0.0094	5804.4
0.0140	7881.5	0.0140	8276.0
0.0187	9844.2	0.0187	10336.8
0.0234	11407.7	0.0234	11978.6
0.0281	12608.7	0.0281	13239.7
0.0327	13505.6	0.0327	14181.5
0.0374	14161.5	0.0374	14870.1
0.0421	14633.6	0.0421	15365.9
0.0468	14969.8	0.0468	15718.9
0.0572	15404.0	0.0572	16174.8
0.0676	15600.1	0.0676	16380.8
0.0872	15723.7	0.0872	16510.5
0.1068	15750.4	0.1068	16538.6
0.1265	15756.1	0.1265	16544.6
0.1518	15757.5	0.1518	16546.0