# Appendix G2. Liquefaction and Ground Improvement Analysis (Final Draft)

## 1. Introduction and Purpose

This technical memorandum (TM) was initially prepared to document supported details for the Delta Conveyance Project (Project) Engineering Project Reports, (DCA, 2022a, 2022b). At that time of submittal in 2022, the Delta Conveyance Authority (DCA) prepared two Engineering Project Reports, one report for the Central Corridor and Eastern Corridor and another report for the Bethany Reservoir Alternative. In December 2023, the Environmental Impact Report (EIR) (DWR, 2023) was released and stated that the Bethany Reservoir Alternative would be the selected Project and renamed it as the Bethany Reservoir Alignment.

In September 2024, this TM was prepared to describe the selected Delta Conveyance Project, the Bethany Reservoir Alignment. No technical changes and recommendations are presented since the Final Draft Submittal in 2023. It should be noted that the term "Central Corridor" is no longer a part of the Project and the terms "Eastern Corridor" or "East Corridor" should be here on interpreted as part of the Bethany Reservoir Alignment only from Intake C-E-3 down to Lower Roberts Island Tunnel Launch Shaft. It also should be noted that some references to the Central and/or Eastern Corridors remain in the TM to provide a greater extent of background information for portions of the Delta between the intakes and Clifton Court Forebay which also influence design considerations for the Project.

### 1.1 Organization

This TM is organized as follows:

- Introduction
- Purpose
- Overview
- Liquefaction Potential Calculations
- Liquefaction Mitigation Calculations
- Findings
- Conclusions
- References
- Attachment 1 – Map of Analysis Locations
- Attachment 2 – Documentation of Analytical SPT Procedure
- Attachment 3 – Documentation of Analytical CPT Procedure
- Attachment – 4 Shear Wave Velocity Measurements from DCW-CPT-027

## 2. Purpose

This technical memorandum (TM) was prepared to summarize the liquefaction potential and a possible liquefaction mitigation approach at the intakes, pumping plant, and tunnel shaft sites for the Delta Conveyance Project (Project) Bethany Reservoir Alignment. The conceptual level analysis presented in this TM is to support the development of conceptual footprint for key Project elements. A detailed site-specific liquefaction analysis for these and other Project elements, including the tunnels, will be performed upon acquisition of additional geotechnical information during future design phases of the Project.

# 3. Overview

The Project includes the following key facilities:

- Two intake structures on the Sacramento River (C-E-3 and C-E-5)
- Underground Bethany Reservoir Pumping Plant (BRPP) and Surge Basin
- Bethany Reservoir Aqueduct (Aqueduct), leading from BRPP to Bethany Reservoir Discharge Structure
- Bethany Reservoir Discharge Structure
- Bethany Reservoir Alignment tunnel and associated shafts

This TM presents a conceptual evaluation of the liquefaction potential of the foundation soils at the following locations, as shown in Attachment 1:

- Two intake sites
- BRPP and Surge Basin
- Bethany Reservoir Discharge Structure Tunnel shaft sites along the Bethany Reservoir Alignment

A deep mechanical mixing (DMM) approach was considered to reduce the liquefaction susceptibility of the soils, raising the factor of safety (FS) related to liquefaction to greater than 1. By enclosing potentially liquefiable soils in a DMM soil-cement grid, cyclic loading (e.g., earthquake) in the soils would be reduced because most of the earthquake loads would be absorbed by the stiffer soil-cement grid and the generation of excess pore pressure would be slowed. The grid would also form a boundary to restraint soil's lateral deformations.

## 3.1 Geotechnical Information

The DWR collected preliminary geotechnical exploration data in the Delta from 2009 to 2012 and on Bouldin Island in 2018, while preparing the Environmental Impact Report and Environmental Impact Statement for the former WaterFix Project. Approximately 125 soil borings and 85 cone penetrometer tests (CPTs) were completed for the WaterFix Project between 2009 and 2013 (DWR, 2013); an additional 11 soil borings and 13 CPTs were completed on Bouldin Island in 2018 (DWR, 2018); and 11 soil borings and 7 CPTs were completed in 2020 (DWR, 2020). Additional soil boring and CPT sounding logs were also available from DWR's Atlas database and were used to supplement geotechnical information collected for Delta Conveyance while other data was digitized by DCA from nearby projects. References for each source of geotechnical data are given in the sections in which they are used.

Geotechnical data from these preliminary investigations indicate the Sacramento-San Joaquin Delta region is dominated by marsh and tidal estuary deposits, with interbedded alluvium, from the Sacramento and San Joaquin Rivers. The local geological setting is complex, and can be characterized by buried river channels, abundant sand lenses, and upper layers of organic-rich soil. The groundwater level is generally about 5 feet below ground surface (bgs) within much of the Delta, however, historical boring logs at the C.W. Bill Jones Pumping Plant (Central Valley Project) indicate the groundwater level deepens toward the southern end of the Delta (DWR, 2013).

South of the BRPP location, the geology changes beyond the margins of the historical Delta and consists of colluvium from the Coast Range. Farther to the south, the Bethany Reservoir Discharge Structure is underlain by the Panoche Formation, consisting of marine sandstones, clay shales, and minor siltstones. The sandstones are occasionally concretionary, and the clay shales are often thinly bedded, deeply weathered, soft, and friable. These sedimentary formation beds generally dip to the northeast at 20 degrees from horizontal.

## 3.2 Seismic Ground Motions

The current draft Project seismic design criteria specify a combination of probabilistic and deterministic ground motions for conceptual design, depending on the facility type, as discussed in the Concept Engineering Report (CER) Appendix G1 *Concept Seismic Design and Geohazard Criteria*. Preliminary probabilistic and deterministic seismic hazard analyses were performed using the latest generation of earthquake ground motion attenuation relationships and fault source models (as of 2021). Table 1 summarizes the preliminary ground motions by facility that were used in the liquefaction analyses. The Peak Ground Acceleration (PGA) values presented in this table are those at the ground surface and were estimated by multiplying the amplification factors obtained from the site response analysis (CER Appendix G3 *Concept Design Seismic Site Response Analysis*) to the Maximum Design Earthquake (MDE) or Maximum Credible Earthquake (MCE) PGAs at the reference site. The development of reference MDE and MCE ground motions and amplification factors is detailed in the site response analysis TM (CER Appendix G3).

**Table 1. Preliminary Ground Motions at the Selected Project Facility Sites**

| Facility | Maximum Design Earthquake Ground Motions[a] | Controlling Magnitude (Mw)[b] | Peak Ground Acceleration (% of g)[c] | Amplification Factor[d] |
|---|---|---|---|---|
| Canal Ranch Tract Maintenance Shaft | Envelope of 2,475-year probabilistic and 84th-percentile deterministic | 6.60 | 0.33 | 1.02 |
| Intake C-E-3 | Envelope of 975-year probabilistic and 84th-percentile deterministic | 6.60 | 0.30 | 0.67 |
| Intake C-E-5 | Envelope of 975-year probabilistic and 84th-percentile deterministic | 6.60 | 0.33 | 0.88 |
| King Island Maintenance Shaft | Envelope of 2,475-year probabilistic and 84th-percentile deterministic | 6.70 | 0.36 | 0.75 |
| Lower Roberts Island Launch Shaft | Envelope of 2,475-year probabilistic and 84th-percentile deterministic | 6.70 | 0.39 | 0.52 |
| New Hope Maintenance Shaft | Envelope of 2,475-year probabilistic and 84th-percentile deterministic | 6.60 | 0.35 | 0.66 |
| Terminous Tract Reception Shaft | Envelope of 2,475-year probabilistic and 84th-percentile deterministic | 6.70 | 0.45 | 0.60 |
| Twin Cities Launch Shaft | Envelope of 2,475-year probabilistic and 84th-percentile deterministic | 6.50 | 0.31 | 0.92 |
| Upper Jones Tract Maintenance Shaft | Envelope of 2,475-year probabilistic and 84th-percentile deterministic | 6.80 | 0.47 | 0.45 |
| Union Island Tunnel Maintenance Shaft | Envelope of 2,475-year probabilistic and 84th-percentile deterministic ground motions | 6.90 | 0.55 | 0.37 |

| Facility | Maximum Design Earthquake Ground Motions[a] | Controlling Magnitude (Mw)[b] | Peak Ground Acceleration (% of g)[c] | Amplification Factor[d] |
|---|---|---|---|---|
| Bethany Reservoir Pumping Plant | 2019 CBC (MCE) | 6.90 | 0.58 | 0.57 |
| Bethany Reservoir Discharge Structure | 975-year probabilistic ground motions | 6.90 | 0.59 | N/A[e] |

[a] Delta Conveyance Draft Seismic Guidelines (CER Appendix G1)
[b] Controlling earthquake magnitude for deterministic ground motions.
[c] For a reference stiff soil site (Site Class D, with reference seismic shear-wave velocity ($V_{s30}$) = 1,100 feet per second [fps] or 335 meters per second) (CER Appendix G3).
[d] Factors calculated from results of 1-D site response analysis (CER Appendix G3).
Notes:
% = percent
g = acceleration due to gravity
$M_w$ = moment magnitude
N/A = not applicable

# 4. Liquefaction Potential Calculations

## 4.1 Analytical Standard Penetration Test Procedure

Liquefaction potential was evaluated at the selected facility sites, as listed in Table 1 above, using the approach of Youd et al. (2001). At each site, a factor of safety against liquefaction was calculated as the ratio of liquefaction resistance to earthquake loading. This section summarizes the procedures followed to determine the FS of native soils within each borehole and site.

Liquefaction resistance can be quantified using the cyclic resistance ratio (CRR), calculated as a function of standard penetration test (SPT) N-value or CPT cone resistances. The CRR is typically normalized for an earthquake magnitude of 7.5 ($CRR_{7.5}$). The earthquake loading is expressed using the cyclic stress ratio ($CSR_U$), calculated as a function of earthquake loading, stress, and depth. The following FS calculation was used at each location and depth for which an SPT N-value (SPTn) was recorded:

$$FS = \frac{CRR_{7.5}}{CSR_U}(MSF)(K_\alpha)(K_\sigma) \quad [1]$$

Where:

*MSF* is a magnitude scaling factor
$K_\alpha$ is the ground slope/static shear stress correction factor
$K_\sigma$ is the overburden stress correction factor

For a comprehensive discussion of these parameters, refer to Youd et al. (2001). For the conceptual-level analyses summarized herein, the liquefaction of clayey soils was considered possible if the plasticity index (PI) was less than 7 (Idriss and Boulanger, 2008).

The CRR at each facility was scaled by an age factor *K*. Preliminary radiocarbon dating tests collected on Bouldin Island and Lower Roberts Island indicate that the average age of the Modesto formation (Qm) is approximately 10,000 years before present, and the Riverbank Formation's (Qr) age is approximately 40,000 years before present. Following the methodology described in Hayati et al. (2008), the ages of these geologic units result in approximate age factors of *K* = 1.5 and 1.6, respectively. The depths to the Modesto (Qm) and Riverbank Formation (Qr) at each site were taken from Maier et al. (2013) and Gatti et al. (2013), and they are indicated in the SPT analysis tables with the qualifier (m) and (r) for Modesto Formation and Riverbank Formation, respectively.

At each site, an unimproved (native) FS against liquefaction was calculated as the ratio of soil cyclic resistance ratio to cyclic shear stress ratio. An improved FS is also calculated and reflects the improved conditions after implementing a grid of DMM walls.

### 4.2 Analytical Cone Penetration Test Procedure

Liquefaction was also analyzed using representative CPT data at each site with the software CLiq 3.0 (Geologismiki, 2020). The resulting FS versus depth plots were analyzed in conjunction with the liquefaction potential index (LPI) plots at each site to produce an anticipated liquefaction depth. The LPI can be used to evaluate the potential of liquification in a one-dimensional soil column by illustrating the thickness of liquefiable soil layers, which helps to predict the overall performance of the whole site (Jha, 2009). A review of the LPI plot at each site, along with the value of the FS against soil liquefaction, allows for a holistic evaluation of liquefaction susceptibility. Similarly, age factors were also applied to the Qr and Qm soils in the CPT analyses, as described in Section 4.2.

The results of the SPT-based liquefaction analysis are in general consistent with those of the CPT-based analysis, as they suggest similar depths of liquefiable soils (a FS against liquefaction of 1.0 or less). For this conceptual analysis, however, the larger depth of liquefaction calculated using these two approaches was used.

The results of the CPT-based liquefaction analysis were somewhat inconsistent with those of the SPT-based analysis at the BRPP site. The CPT-based analysis results suggest significant liquefaction from depths of about 10 to 75 feet, whereas little to no liquefaction is predicted by the SPT data. These are due to the soil type determination using the CPT data, which resulted in being classified as sandy/silty soils, whereas the observed and logged soil types in the adjacent soil boring were clayey sand and sandy clay. As sandy/silty soils are susceptible to liquefaction, more widespread liquefaction is predicted by the CPT data.

## 5. Liquefaction Mitigation Calculation

This section summarizes the steps taken to determine the improved FS against liquefaction resulting from an implemented soil-cement grid (DMM panels) for soils within each borehole at each site. The improved FS is calculated in a similar manner as described in Section 4 above, but using a reduced cyclic stress ratio ($CSR_I$) following the procedures of Nguyen et al. (2013):

$$CSR_I = CSR_U R_{rd} \quad \textbf{[2]}$$

$R_{rd}$ is a stress reduction coefficient and is a function of the ratio of wall to soil shear moduli ($G_r$), replacement ratio defined as the ratio of DMM panel thickness to cell size ($A_r$), equivalent shear factor ($C_G$), and equivalent shear stiffness of the panels ($\gamma_r$), defined as follows:

$$R_{rd} = min\left\{\frac{1}{G_r\left(A_r C_G \gamma_r + \frac{1}{G_r}(1-A_r)\right)}, 1\right\} \quad \textbf{[3]}$$

Where:

$$C_G = 1 - 0.5\sqrt{1 - A_r}, \quad \gamma_r = \left[1 - (1 - A_r)^{1.3}\left(\frac{G_r - 1}{185}\right)^{0.4}\right] * min\left(\frac{wall\ height}{cell\ size}, 1\right)$$

The soil shear moduli were estimated from the small-strain shear-wave velocities ($V_s$) measured in the seismic CPTs. Where seismic CPT data were not available, the small-strain shear-wave velocities were estimated from the unit weights and SPT N-values available in the soil borings, following the empirical relationship established by Brandenburg et. al. (2010):

$$V_s = 87.8 * {N_{60}}^{0.253}\left(\frac{P}{\sigma'_v}\right)^{0.253n - m} \quad \textbf{[4]}$$

Where:

n and m = 0.5 and 0.25, respectively, for sands
n and m = 0.75 and 0.3725 for silts
n and m = 1.0 and 0.5 for clays

The shear modulus of the soil-cement panels was taken as 285 thousand pounds per square inch [ksi] (1.96 gigapascals [GPa]) (Kongsukprasert and Tatsuoka, 2007). The improved FS for soils was then determined via a cell size sensitivity analysis, where the replacement ratio $A_r$ was adjusted such that all depths were considered unsusceptible to liquefaction. For this exercise, the following equation was used:

$$FS_I = \frac{CRR_{7.5}}{CSR_U * R_{rd}}(MSF)(K_\alpha)(K_\sigma) \quad \textbf{[5]}$$

# 6. Findings

The following subsections present the estimated maximum depths of potentially liquefiable soils and the GMM replacement ratios ($A_r$) and spacings required to mitigate liquefaction (to achieve a factor of safety against liquefaction of 1.0 or greater) at the key facility sites along the Bethany Reservoir Alignment. For each analysis, a DMM panel thickness of 1 meter (36 inches) was assumed. As mentioned above, the maximum depth of liquefaction at each site was taken as the larger of liquefaction depths predicted using the SPT- and CPT-based approaches. All references to elevation are North American Vertical Datum 1988 (NAVD88).

The results of analysis are expressed in terms of the required minimum DMM spacing and replacement ratio and maximum depth of anticipated liquefaction. The minimum spacing is defined as the center-to-center distance between the grid of DMM walls required to maintain a FS greater than or equal to 1.0. The replacement ratio is defined as the percentage of area occupied by the DMM walls, given the corresponding DMM wall spacing and thickness, over a given volume of improved ground.

Attachment 2 summarizes the results of the calculated FS using the SPT N-values, where the liquefaction potential is indicated as “no” for cases where the unimproved or improved FS is at or above 1.0 and “yes” where the unimproved or improved FS is below 1.0, and Attachment 3 presents the calculated FS and LPI plots using the CPT data.

## 6.1 Intake C-E-3

Intake C-E-3 is potentially to be constructed within alternating layers of coarse-grained and fine-grained soils (Figure 1). Figure 2 provides a plan view of the available soil borings and CPTs conducted at this location. Six soil borings at this intake site were drilled within the Sacramento River, with the river bottom typically encountered between El. -20 and El. -25 feet. One additional soil boring (DCC-DH-001) and one CPT (DCC-CPT-002) were also completed on the landside of the levee. The landside explorations were advanced at approximately El. 13 feet and encountered fine-grained soils to approximately El. -20 feet, followed by interbedded fine- and coarse-grained soils. The explorations suggest that the landside soil stratigraphy is consistent with the soils cataloged during the advancement of the in-river explorations.

For the liquefaction analysis, the groundwater depth was set to 6 feet for the landside boring and 0 feet for the overwater explorations. The surcharge due to the water was ignored for the analysis using the in-river borings. This is considered reasonable as a significant portion of the site (that is, the area of the sediment basin) would be excavated to approximately the same elevation as the bottom of the river. Table 2 summarizes the averaged soil parameters for each soil layer at Intake C-E-3 site, and Table 3 summarizes the results of the SPT- and CPT-based analyses.

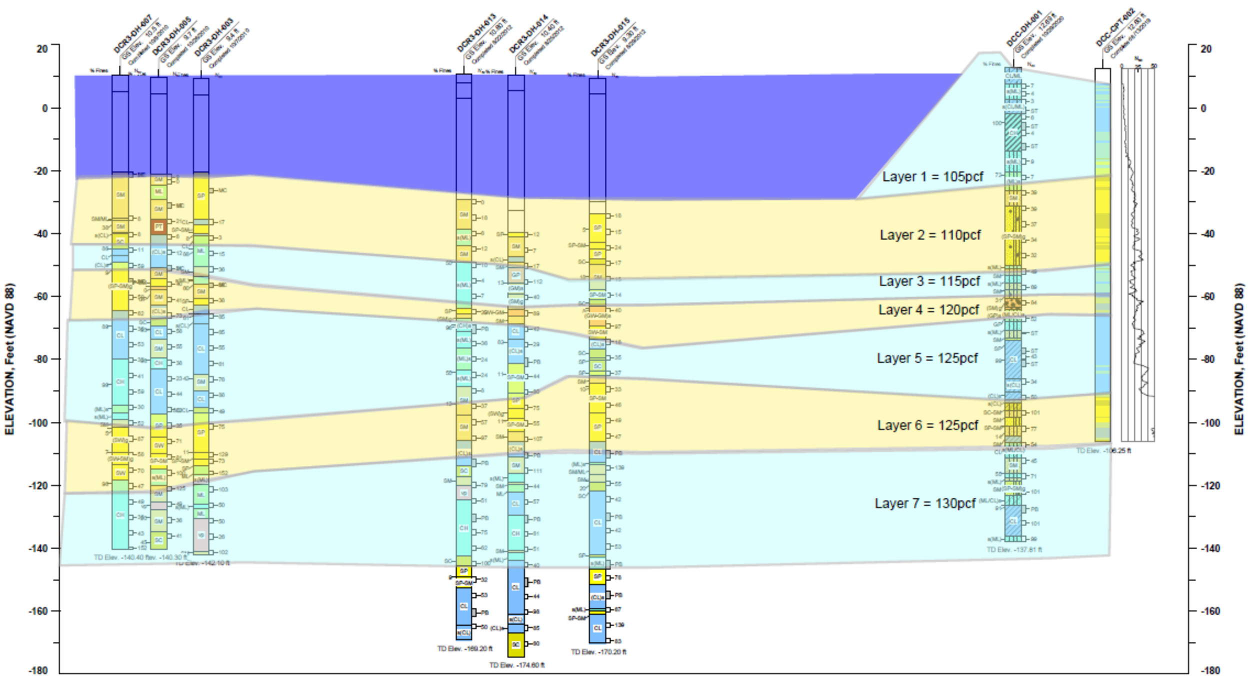


**Figure 1. Conceptual Geological Profile at Intake C-E-3**

*Notes: X-Axis is horizontal distance in feet. Profile is oriented northeast-southwest and faces northwest. Refer to Figure 2 for location of soil borings and CPTs.*


**Figure 2. Plan View of Available Borings and CPTs Used at Intake C-E-3 Site**

*Note: Plan view is oriented north-south.*

**Table 2. Summary of Soil Parameters at Intake C-E-3 Site**

| Explorations Used | Layer (refer to Figure 1) | USCS | Top El. (ft)[a] | Total Unit Weight (pcf) | Average SPT N-value[b] | Average Fines Content (%) | Average Shear Wave Velocity (ft/s)[c] | Shear Modulus G (ksi) |
|---|---|---|---|---|---|---|---|---|
| EXP3 | 1 | CH | 13 | 105 | 4 | 80 | 430 | 4.1 |
| EXP3 | 2 | SM | -30 | 110 | 18 | 17 | 570 | 7.5 |
| EXP3 | 3 | ML (Qr) | -50 | 115 | 11 | 51 | 490 | 6.3 |
| EXP3 | 4 | SP (Qr) | -60 | 120 | 34 | 21 | 690 | 12.8 |
| EXP3 | 5 | CL (Qr) | -75 | 125 | 35 | 44 | 630 | 11.2 |
| EXP3 | 6 | SP (Qr) | -85 | 125 | 49 | 15 | 760 | 16.7 |
| EXP3 | 7 | CL (Qr) | -105 | 130 | 45 | 66 | 710 | 14.2 |

EXP3 = DCC-CPT-002[d], DCC-DH-001[d], DCR3-DH-003[e], DCR3-DH-005[e], DCR3-DH-007[e], DCR3-DH-013[e], DCR3-DH-014[e], DCR3-DH-015[e]

[a] Elevation is given in NAVD88 and represents an average of the idealized soil profile.
[b] Provided for information only. Average value by soil layer not used in evaluation.
[c] Shear wave velocity from DSP-07
[d] DWR (2020)
[e] DWR (2013)

**Table 3. Estimated DMM Cell Size, Minimum Replacement Ratio, and Depth of Liquefiable Soils at Intake C-E-3 Site**

| Location | Intake C-E-3 |
|---|---|
| Average Minimum Calculated Spacing (meters / feet) | 20 / 66 |
| Replacement Ratio (%) | 12 |
| Predicted Depth of Liquefiable Soils (feet)[a] | 60 |

[a] Controlling exploration for depth from CPT analysis (CPT data from DWR, 2020)

## 6.2 Intake C-E-5

Intake C-E-5 has the potential to be constructed within alternating layers of coarse- and fine-grained soils (Figure 3). Figure 4 provides a plan view of the available soil borings and CPTs conducted at this location. Two of the soil borings at this intake site were drilled within the Sacramento River, with the river bottom typically encountered around El. -20 feet. Also, a CPT was also completed near the northern end of the facility site for the WaterFix Project in 2013 and a historical borehole (pc80-pi-2) was advanced on the landside of the levee for the former planned Peripheral Canal alignment. Additionally, a drilled hole (DCC-DH-003) and a CPT (DCC-CPT-003) were recently completed near the landside levee toe. The recent explorations were advanced at approximately El. 13 feet and encountered coarse-grained soils to approximately El. -30 feet, followed by interbedded fine- and coarse-grained soils that agreed with the adjacent overwater soil borings. All explorations at this facility site encountered varying thicknesses of silt and clay, alternating with sand.

Similar to Intake C-E-3 site, the groundwater elevation was set to 10 feet for the landside borings and 0 feet for the overwater explorations for the liquefaction analysis. Table 4 summarizes the averaged soil parameters for each soil layer at Intake C-E-5 site, and Table 5 provides the results of the SPT- and CPT-based.

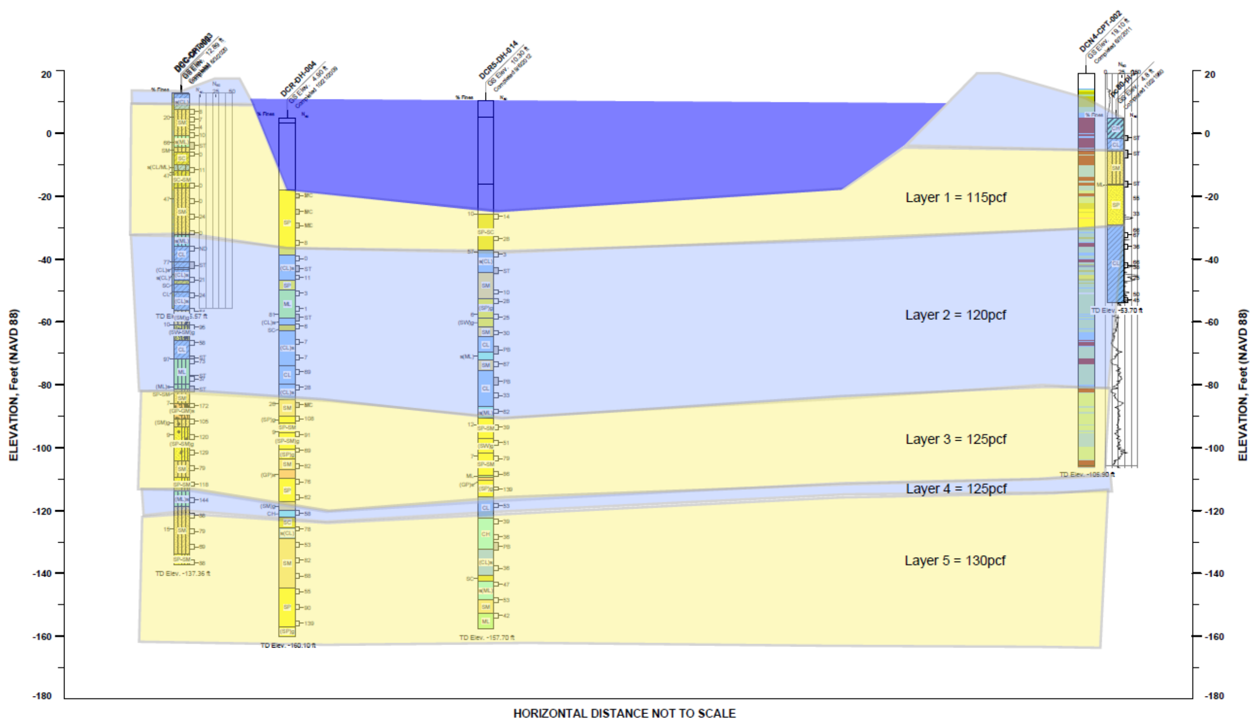


**Figure 3. Conceptual Geological Profile of Intake C-E-5**

*Notes: X-Axis is horizontal distance in feet. Profile is primarily south-north and faces west. The Sacramento River location and depth are schematic only. Refer to Figure 4 for location of borings and CPTs.*

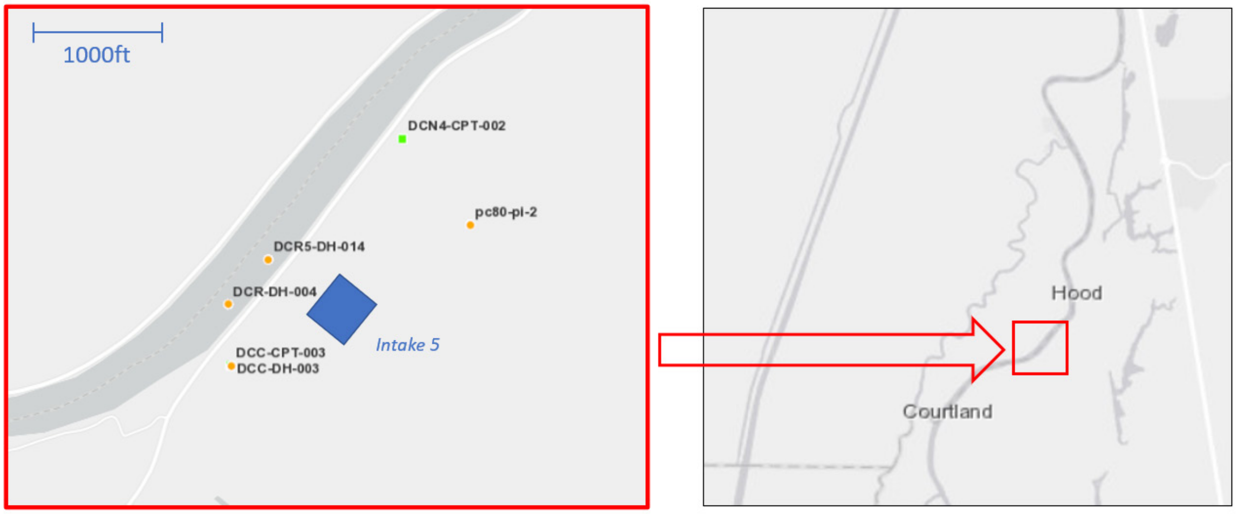


**Figure 4. Plan View of Available Borings and CPT Used at Intake C-E-5 Site**

*Note: Plan view is oriented north-south.*

**Table 4. Summary of Soil Parameters at Intake C-E-5 Site**

| Explorations Used | Layer (refer to Figure 3) | USCS | Top El. (ft)[a] | Total Unit Weight (pcf) | Average SPT N-value[b] | Average Fines Content (%) | Average Shear Wave Velocity (ft/s) | Shear Modulus G (ksi) |
|---|---|---|---|---|---|---|---|---|
| EXP5 | 1 | SP | 10 | 115 | 6 | 26 | 450 | 5.1 |
| EXP5 | 2 | CL (Qr) | -30 | 120 | 25 | 68 | 500 | 6.9 |
| EXP5 | 3 | SP (Qr) | -80 | 125 | 58 | 12 | 800 | 16.9 |
| EXP5 | 4 | CH (Qr) | -110 | 125 | 42 | 77 | 650 | 11.6 |
| EXP5 | 5 | SM (Qr) | -120 | 130 | 54 | 30 | 750 | 16.4 |

EXP5 = DCC-DH-003[c], DCC-CPT-003[c], DCN4-CPT-002[d], DCR5-DH-014[d], DCR-DH-004[d], pc80-pi-2[d]

[a] Elevation is given in NAVD88 and represents an average of the idealized soil profile.
[b] Provided for information only. Average value by soil layer not used in evaluation.
[c] DWR (2020)
[d] DWR (2013)

**Table 5. Estimated DMM Cell Size, Minimum Replacement Ratio, and Depth of Liquefiable Soils at Intake C-E-5 Site**

| Location | Intake C-E-5 |
|---|---|
| Average Minimum Calculated Spacing (meters / feet) | 20 / 63 |
| Replacement Ratio (%) | 13 |
| Predicted Depth of Liquefiable Soils (feet)[a] | 50 |

[a] Controlling exploration for depth from CPT analysis (CPT data from DWR, 2013 and DWR, 2020)

## 6.3 Union Island Tunnel Maintenance Shaft

The Union Island Tunnel Maintenance Shaft could be constructed within alternating layers of coarse-grained and fine-grained soils, underlaying a surface layer of peat (Figure 5). Figure 6 provides the available soil boring and CPT locations. No recent soil data were available for this site, so data from the Peripheral Canal Project (DWR, 1967) were used. The historic boring was drilled at approximately -3 feet elevation and samples were obtained by driving a 2.5-inch ID sampler. The subsurface soils at this site are characterized by a 7-foot-thick layer of fill and peat, followed by a layer of sand and silty sand terminating around a depth of 22 feet, overlying a thin layer of silty clay that terminates around a depth of 25 feet, followed by an additional layer of sand and silty sand terminating around 44 feet in depth and ending in a high-plasticity clay.

For the liquefaction analyses, the groundwater depth was set to 0 feet bgs to reflect the mean water surface of the nearby slough. Table 6 summarizes the average soil parameters for each soil layer at the Union Island Tunnel Maintenance Shaft site, and Table 7 summarizes the results of the SPT- and CPT-based analyses.

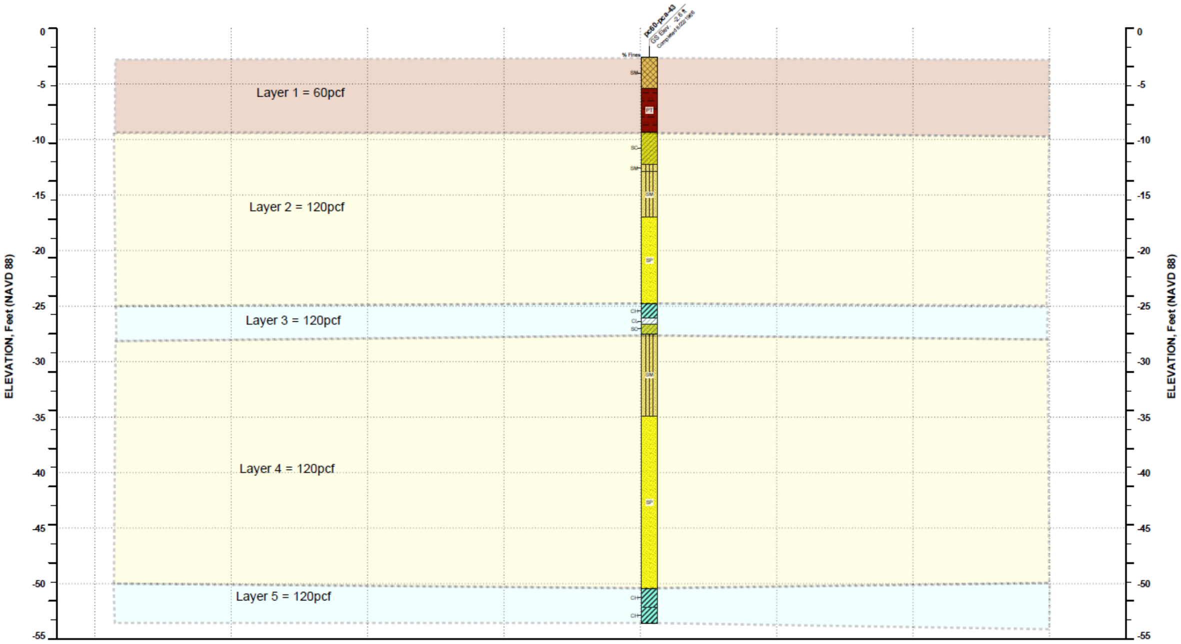


**Figure 5. Conceptual Geologic Profile at Union Island Maintenance Shaft Site**

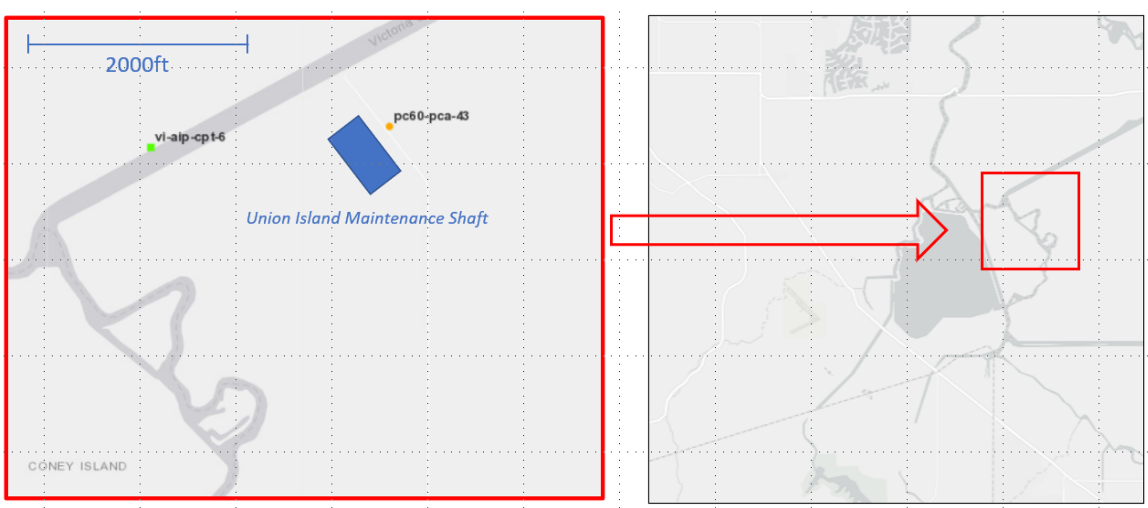


**Figure 6. Plan View of Available Soil Boring and CPT Used at Union Island Maintenance Shaft Site**
*Note: Plan view is oriented north-south*

**Table 6. Summary of Soil Parameters at Union Island Tunnel Maintenance Shaft Site**

| Explorations Used | Layer (refer to Figure 5) | Top Elev. (feet) | USCS[b] | Total Unit Weight (pcf)[c] | Average SPT N-value | Average Fines Content (%) | Average Shear Wave Velocity (fps)[d] | Shear Modulus G (ksi) |
|---|---|---|---|---|---|---|---|---|
| PC60-PCA-43 (BH#2)[a] | 1 | -3 | PT | 60 | 4 | 50 | 400 | 2.0 |
| | 2 | -10 | SM | 120 | 19 | 15 | 450 | 5.5 |
| | 3 | -25 | CH | 120 | 12 | 100 | 550 | 7.1 |
| | 4 | -28 | SM (Qm) | 120 | 41 | 20 | 650 | 11.2 |
| | 5 | -50 | CH (Qm) | 120 | 20 | 100 | 600 | 9.0 |

[a] DWR (1967)
[b] Unified Soil Classification System
[c] Soil parameters taken from DWR (1967), adjusted to be consistent with complementary explorations used in 1-D site response analysis CER Appendix G3.
[d] Shear wave velocity taken from nearby seismic CPT measurements
Notes:
pcf = pound(s) per cubic foot
fps = feet per second
ksi = 1,000 pounds per square inch
Qm = Modesto formation

**Table 7. Estimated DMM Cell Size, Minimum Replacement Ratio, and Depth of Liquefiable Soils at Union Island Tunnel Maintenance Shaft Site**

| Location | Union Island Tunnel Maintenance Shaft |
|---|---|
| Minimum Calculated Spacing (meters / feet) | 14 / 45 |
| Replacement Ratio (%) | 14 |
| Predicted Depth of Liquefiable Soils (feet)[a] | 30 |

[a] CPT used from HTE (2008)

## 6.4 Bethany Reservoir Pumping Plant

The BRPP may be constructed within alternating layers of coarse-grained and fine-grained soils (Figure 7). Figure 8 provides the available soil boring locations. The soil borings drilled near this site (DCW-DH-014 and WAPA-SLTP-B3) were drilled at El. 22 and El. 61 feet, respectively (SLTP, 2018). The SLTP exploration was located at an elevation approximately 20 feet higher than the proposed BRPP, so the top 20 feet of soil was disregarded. This SLTP exploration encountered clayey sand to a depth of 7 feet, followed by a 5-foot-thick silty sand layer before reaching an additional 5-foot layer of lean clay and overlying a 10-foot layer of silty sand, ending in a thin layer of sandy lean clay.

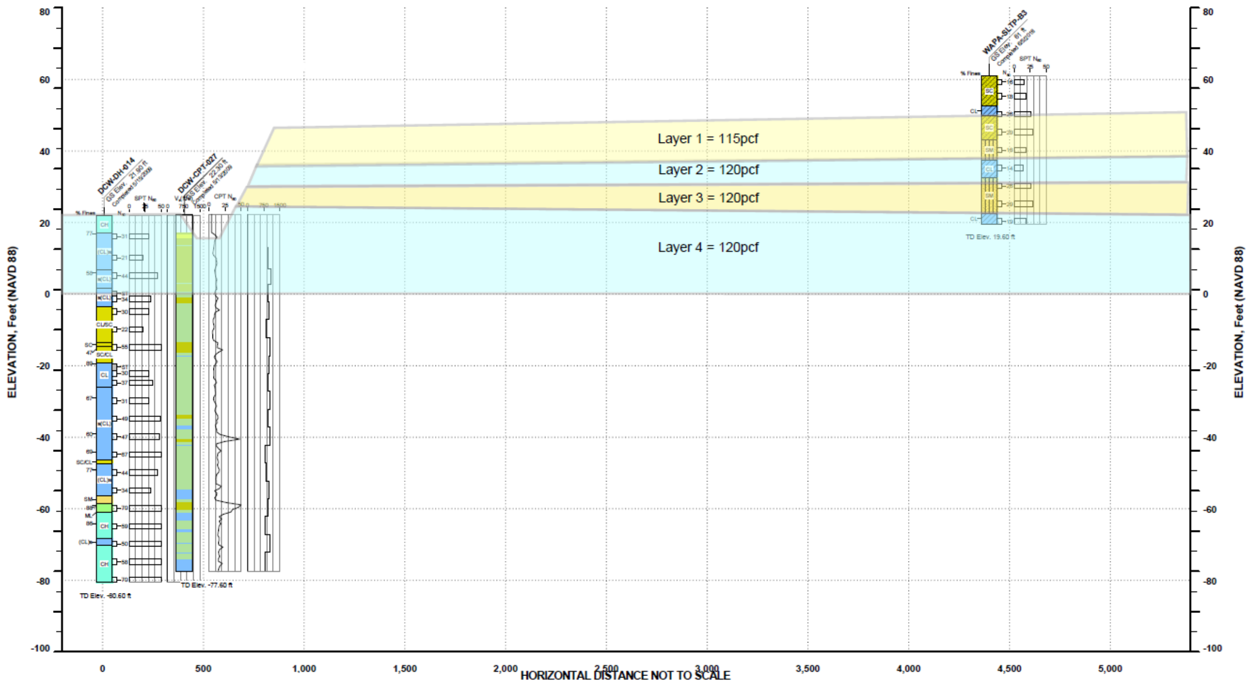


**Figure 7. Conceptual Geological Profile at Bethany Reservoir Pumping Plant Site**

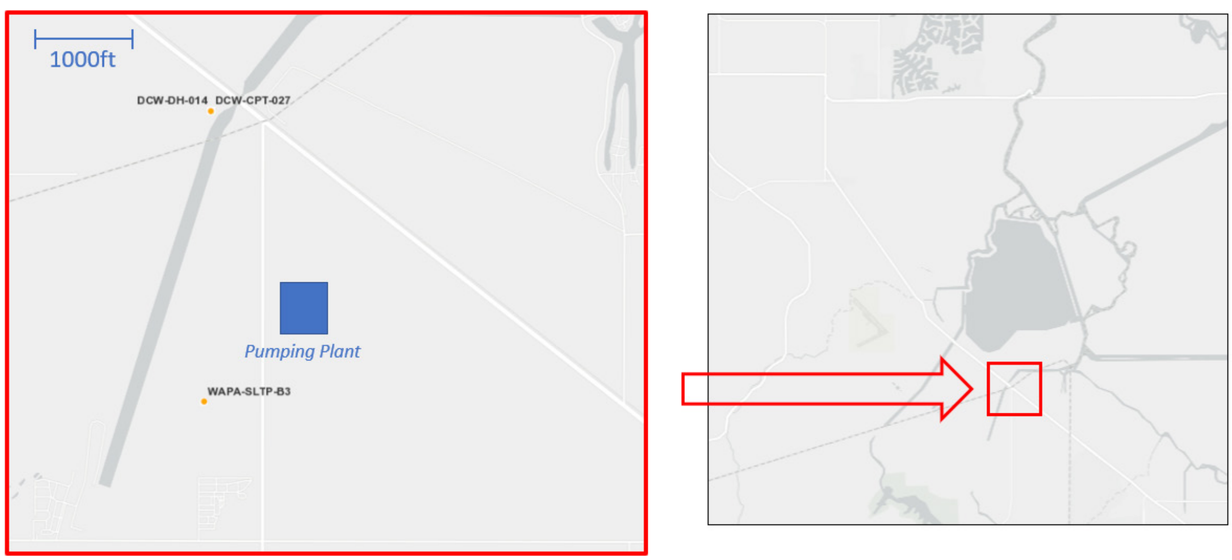


**Figure 8. Plan View of Borings and CPTs Used Near Bethany Reservoir Pumping Plant**

*Note: Plan view is oriented north-south.*

For the liquefaction analyses, the groundwater depth was set to 30 feet bgs to reflect the groundwater measurement taken in the field during drilling of a nearby soil boring (DWR, 2013). Table 8 summarizes the average soil parameters for each soil layer at the BRPP site. Liquefaction was predicted in an isolated zone at a depth of approximately 35 feet in the clayey sand layer using the SPT data. The presence of high clayey fines at this depth (90% Fines Content, see Table 8) would mitigate this isolated risk of liquefaction. For this reason, no ground improvement is anticipated or required at the BRPP site to address liquefaction. More refined analyses will be performed to confirm this during future design phases.

Note, there is a CPT sounding at this site (CPT DCW-CPT-027). However, given the significant underprediction of $N_{60}$ values in the CPT as compared to those measured in an adjacent soil boring, the calculated liquefaction prediction results from the CPT are not considered representative of the conditions at the Bethany Reservoir Pumping Plant site. Furthermore, downhole shear wave velocity measurements, normalized for overburden pressure (Vs1), from CPT DCW-CPT-027 reported no values below 700 fps (see Attachment 4), which indicates the soils are not subject to liquefaction at this site (Andrus & Stokoe, 2000).

**Table 8. Summary of Soil Parameters at Bethany Reservoir Pumping Plant Site**

| Explorations Used | Layer (refer to Figure 7) | Top Elev. (feet) | USCS[c] | Total Unit Weight (pcf)[d] | Average SPT N-value | Average Fines Content (%) | Average Shear Wave Velocity (fps)[e] | Shear Modulus G (ksi) |
|---|---|---|---|---|---|---|---|---|
| DCW-DH-014[a], WAPA-SLTP-B3[b] | 1 | 50 | SC (Qm) | 115 | 18 | 39 | 600 | 10.2 |
| | 2 | 37 | CL (Qm) | 120 | 10 | 90 | 550 | 8.0 |
| | 3 | 33 | SM (Qm) | 120 | 18 | 33 | 650 | 10.7 |
| | 4 | 23 | CL (Qm) | 120 | 22 | 75 | 650 | 11.0 |

[a] DWR (2013)
[b] SLTP (2013)
[c] Unified Soil Classification System
[d] Soil parameters taken from DWR (1967), adjusted to be consistent with complementary explorations used in 1-D site response analysis (CER Appendix G3).
[e] Shear wave velocity taken from nearby seismic CPT measurements
Notes:
% = percent
pcf = pound(s) per cubic foot
fps = feet per second
ksi = 1,000 pounds per square inch
Qm = Modesto Formation

## 6.5 Bethany Reservoir Discharge Structure

The Bethany Reservoir Discharge Structure would be constructed within soft sedimentary rock of the Upper Cretaceous Panoche formation. The formation consists of interbedded shales, sandstones, and occasional siltstones (DWR, 2016). The groundwater level is anticipated to be near the same elevation as the nearby Bethany Reservoir.

The available shear wave velocities measured from Boring DH-1 (DWR, 2016) were normalized for overburden pressure and reported values no lower than 3,800 fps, which indicate no potential for liquefaction at this site (Andrus & Stokoe, 2000). Given the lack of liquefiable soils at this site, no ground improvement should be required for the purposes of liquefaction mitigation at the Bethany Reservoir Discharge Structure site.

### 6.6 Other Facility Sites

For facilities listed in Table 1 that were not analyzed using the SPT N-values, the CPT-based analysis of liquefaction potential was performed using the nearest CPT explorations, as shown in Attachment 1. Table 9 summarizes the findings of analyses performed using the CPT data obtained near the tunnel shaft sites. Note, the nearest CPTs to some of these shaft sites are up to 2 miles away.

**Table 9. Results of CPT-based Liquefaction Analyses at Selected Tunnel Shaft Sites**

| Shaft Site | CPT Used in analysis[a] | Controlling Magnitude ($M_w$)[b] | PGA (% of g)[c] | Amplification Factor[d] | Liquefaction/ Mitigation Depth (feet) |
|---|---|---|---|---|---|
| New Hope | DCEA1-CPT-005, DCE-CPT-013 | 6.60 | 0.35 | 0.66 | 40 |
| Terminous Tract[g] | DCT-CPT-013 | 6.70 | 0.45 | 0.60 | 20[j] |
| Twin Cities | DCE-CPT-008 | 6.50 | 0.31 | 0.92 | 0 |
| King Island | DCEA1-CPT-022 | 6.70 | 0.36 | 0.75 | 15 |
| Lower Roberts Island | DCE-CPT-024, DCEA1-CPT-026, DCE-CPT-023 | 6.70 | 0.39 | 0.52 | 30 |
| Upper Jones Tract[f] | EBMUD-MWH-CPT-05 | 6.80 | 0.47 | 0.45 | 15 |
| Canal Ranch Tract[e] | DCE-CPT-014, DCE-CPT-015, DCE-CPT-016 | 6.60 | 0.33 | 1.02 | 20 |

[a] DWR (2013), DWR (2021), DCA (unpublished), MWH (2014)
[b] Controlling earthquake magnitude for deterministic ground motions.
[c] For a reference stiff soil site (Site Class D, with reference seismic shear-wave velocity ($V_{s30}$) = 1,100 feet per second [fps] or 335 meters per second) (CER Appendix G3).
[d] Factors calculated using 1-D site response analysis (CER Appendix G3).
[e] Facility has been added to current Delta Conveyance alignments.
[f] Peak Ground Acceleration and Amplitude Factor interpolated from adjacent facility sites.
[g] CPT used in analysis is 1.5 miles west of the proposed Terminous Tract site. Liquefaction mitigation depth assumed to be similar to Canal Ranch Tract based on mapped geologic conditions
Notes:
% = percent, PGA = peak ground acceleration, g = acceleration due to gravity, $M_w$ = moment magnitude

## 7. Conclusions

Liquefaction potential was identified at selected key facility sites located along the Bethany Reservoir Alignment. The maximum depth of significant liquefaction and the required minimum ground improvement, if any, were also developed based on the results of these liquefaction analyses. Since the soil underlying the BRPP is dominated by clays, it appears that no ground improvement to address liquefaction is anticipated at this site. Similarly, given the lack of liquefiable soils near Bethany Reservoir, no ground improvement is anticipated for liquefaction mitigation at the Bethany Reservoir Discharge Structure.

For this conceptual design, it is recommended that the design should incorporate a viable ground improvement to reduce the risk of liquefaction and the resulting strength loss, settlements, and lateral spreading. Installation of a grid of DMM panels is considered a viable option for these facilities. Around the sedimentation basin and under levees, the DMM walls could include bentonite mixture, where they will function as hydraulic barriers. The walls could also include steel H-beam reinforcement to serve as excavation support on either side of the planned inlet conduits and as required to facilitate construction phasing.

The recommendations presented herein shall be considered preliminary. Many of the selected facility sites have limited soil data, and for some sites, soil data from distant away were used. The liquefaction potential analyses and the recommended ground improvement, therefore, shall be reevaluated during future design phases, as additional site-specific soil and groundwater data are obtained.

# 8. References

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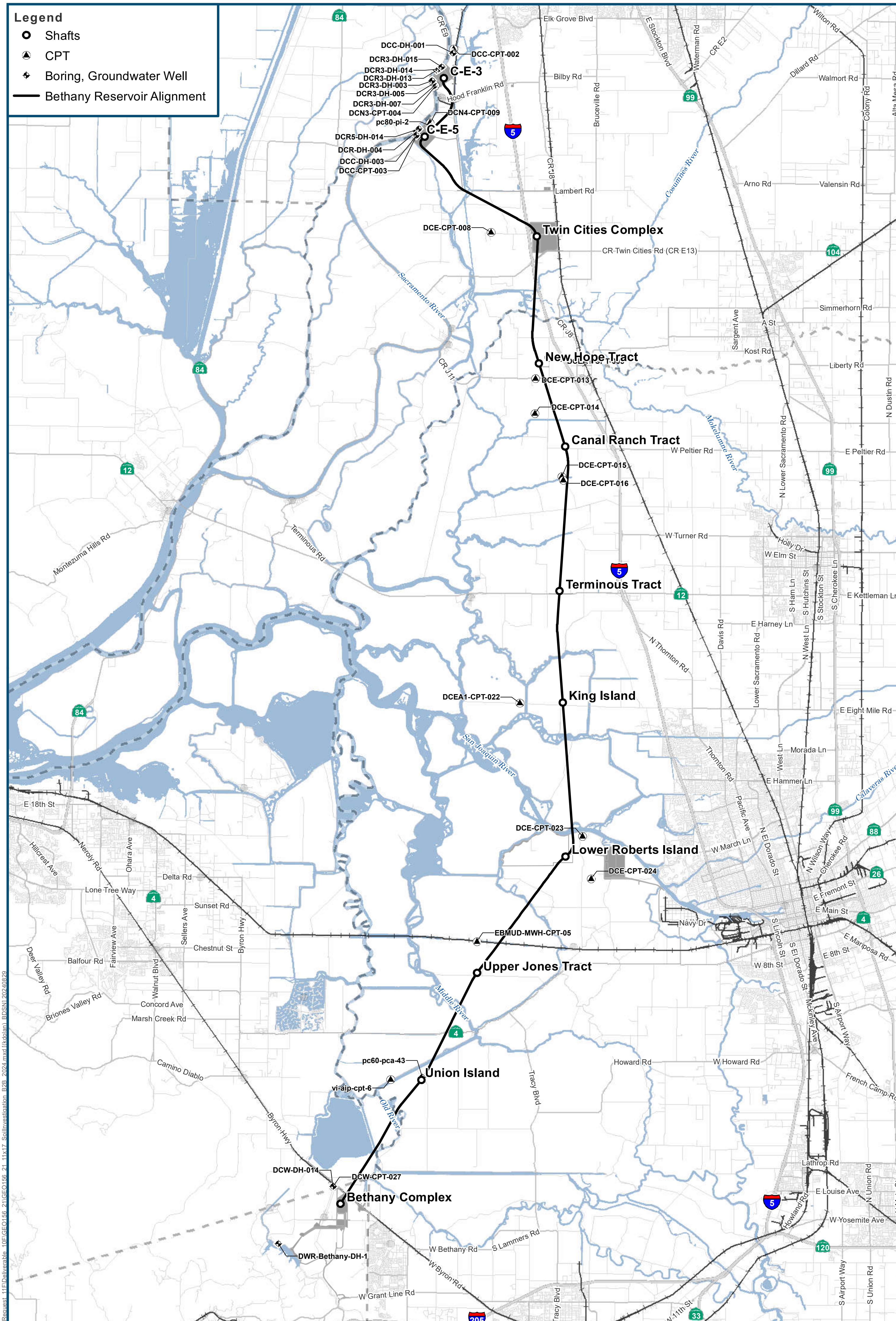
# Attachment 1
# Map of Analysis Locations




For Illustration Purposes Only

N

0 1.5 3 Miles

**Soil Investigations Used in 1-D Site Response Analysis**

Data Source: DCA, DWR

# Attachment 2
# Documentation of Analytical SPT Procedure

## Intake 3 Analytical Results

| DCC-DH-001 | | | | DCR3-DH-003 | | | |
|---|---|---|---|---|---|---|---|
| Min Spacing (ft) | | | 658.3 | Min Spacing (ft) | | | 37.1 |
| Replacement Ratio | | | 1% | Replacement Ratio | | | 17% |
| | | Unimproved | Improved | | | Unimproved | Improved |
| Elev | Soil | Liquefaction | Liquefaction | Elev | Soil | Liquefaction | Liquefaction |
| (ft) | Type | Concern? | Concern? | (ft) | Type | Concern? | Concern? |
| 8 | ML | NO-Above GW | NO-Above GW | -36 | SP | YES | NO |
| 6 | ML | NO-Above GW | NO-Above GW | -41 | CL | NO | NO |
| 3 | CL | NO | NO | -46 | ML | YES | NO |
| -2 | CH | NO | NO | -51 | ML | YES | NO |
| -7 | CH | NO | NO | -61 | SM | NO | NO |
| -16 | ML | NO | NO | -66 | SP | NO | NO |
| -21 | ML | YES | NO | -71 | CL | NO | NO |
| -26 | SM | NO | NO | -76 | CL | NO | NO |
| -31 | SP-SM | NO | NO | -81 | CL | NO | NO |
| -36 | SP-SM | NO | NO | -86 | CL | NO | NO |
| -41 | SP-SM | NO | NO | -91 | SM | NO | NO |
| -46 | SP-SM | NO | NO | -96 | CL | NO | NO |
| -51 | SM | NO | NO | -101 | SC | NO | NO |
| -56 | SM | NO | NO | -110 | SP | NO | NO |
| -61 | GP | NO | NO | -112 | SP-SM | NO | NO |
| -66 | ML | NO | NO | -116 | SP-SM | NO | NO |
| -78 | CL | NO | NO | -121 | ML | NO | NO |
| -86 | CL | NO | NO | -131 | ML | NO | NO |
| -91 | CL | NO | NO | -131 | ML | NO | NO |
| -96 | SM | NO | NO | -136 | ML | NO | NO |
| -101 | SM | NO | NO | -141 | vp | NO | NO |
| -106 | ML | NO | NO | -142 | vp | NO | NO |
| -111 | SM | NO | NO | | | | |
| -116 | ML | NO | NO | | | | |

| DCR3-DH-005 | | | | DCR3-DH-007 | | | |
|---|---|---|---|---|---|---|---|
| Min Spacing (ft) | | | 58.3 | Min Spacing (ft) | | | 64.3 |
| Replacement Ratio | | | 11% | Replacement Ratio | | | 10% |
| | | Unimproved | Improved | | | Unimproved | Improved |
| Elev | Soil | Liquefaction | Liquefaction | Elev | Soil | Liquefaction | Liquefaction |
| (ft) | Type | Concern? | Concern? | (ft) | Type | Concern? | Concern? |
| -23 | SM | YES | NO | -28 | SM | NO | NO |
| -35 | SM | YES | NO | -33 | SM | YES | NO |
| -40 | PT | NO | NO | -38 | CL | NO | NO |
| -45 | PT | YES | NO | -43 | SC | YES | NO |
| -55 | CL | NO | NO | -53 | SP-SM | NO | NO |
| -60 | SP-SM | NO | NO | -58 | SP-SM | NO | NO |
| -65 | SM | NO | NO | -63 | CL | NO | NO |
| -70 | CL | NO | NO | -68 | CL | NO | NO |
| -75 | CL | NO | NO | -73 | CL | NO | NO |
| -80 | SM | NO | NO | -78 | CL | NO | NO |
| -85 | CH | NO | NO | -83 | CH | NO | NO |
| -90 | CL | NO | NO | -88 | CH | NO | NO |
| -95 | CL | NO | NO | -93 | ML | NO | NO |
| -100 | CL | NO | NO | -98 | SM | NO | NO |
| -105 | SP | NO | NO | -103 | SW | NO | NO |
| -110 | SW | NO | NO | -108 | SW-SM | NO | NO |
| -115 | SP-SM | NO | NO | -113 | SW | NO | NO |
| -120 | ML | NO | NO | -118 | CH | NO | NO |
| -125 | SM | NO | NO | -123 | CH | NO | NO |
| -130 | vp | NO | NO | -128 | CH | NO | NO |
| -135 | SM | NO | NO | -133 | CH | NO | NO |
| -140 | SC | NO | NO | -134 | CH | NO | NO |
| | | | | | | | |
| | | | | | | | |

| DCR3-DH-013 | | | | DCR3-DH-014 | | | |
|---|---|---|---|---|---|---|---|
| Min Spacing (ft) | | | 45.4 | Min Spacing (ft) | | | 58.3 |
| Replacement Ratio | | | 14% | Replacement Ratio | | | 11% |
| | | Unimproved | Improved | | | Unimproved | Improved |
| Elev | Soil | Liquefaction | Liquefaction | Elev | Soil | Liquefaction | Liquefaction |
| (ft) | Type | Concern? | Concern? | (ft) | Type | Concern? | Concern? |
| -34 | SM | YES | NO | -38 | SP | YES | NO |
| -39 | SM | NO | NO | -45 | SP | YES | NO |
| -44 | ML | YES | NO | -50 | SM | YES | NO |
| -49 | SM | YES | NO | -55 | SM | NO | NO |
| -54 | ML | YES | NO | -60 | GP | NO | NO |
| -59 | ML | YES | NO | -65 | SM | NO | NO |
| -64 | ML | YES | NO | -70 | GW-GM | NO | NO |
| -69 | SP | NO | NO | -75 | CL | NO | NO |
| -79 | ML | NO | NO | -80 | CL | NO | NO |
| -84 | ML | NO | NO | -90 | SP-SM | NO | NO |
| -89 | ML | NO | NO | -95 | SP-SM | NO | NO |
| -94 | SM | YES | NO | -100 | SP | NO | NO |
| -99 | SM | NO | NO | -105 | SP-SM | NO | NO |
| -104 | SM | NO | NO | -110 | SM | NO | NO |
| -109 | SM | NO | NO | -115 | CL | NO | NO |
| -114 | CL | NO | NO | -120 | SM | NO | NO |
| -124 | SM | NO | NO | -125 | ML | NO | NO |
| -129 | vp | NO | NO | -130 | CL | NO | NO |
| -139 | CH | NO | NO | -140 | CH | NO | NO |
| -144 | CH | NO | NO | -145 | CH | NO | NO |
| -149 | SC | NO | NO | -150 | CL | NO | NO |
| -154 | SP-SM | NO | NO | -160 | CL | NO | NO |
| -159 | CL | NO | NO | -165 | CL | NO | NO |
| -169 | CL | NO | NO | -170 | CL | NO | NO |

*Using updated PGA and M from LCI(2021) and PGA reduction factor from 1-D response analysis*
*Assuming depth to Riverbank Fm. (K=1.6) at 60ft*

## Intake 5 Analytical Results

| DCC-DH-003 | | | |
|---|---|---|---|
| Min Spacing (ft) | | | 72 |
| Replacement Ratio | | | 9% |
| Elev (ft) | Soil Type | Unimproved Liquefaction Concern? | Improved Liquefaction Concern? |
| 8 | SM | NO-Above GW | NO-Above GW |
| 6 | SM | NO-Above GW | NO-Above GW |
| 3 | SM | YES | NO |
| 1 | SM | NO | NO |
| -6 | SC | YES | NO |
| -11 | CL/ML | NO | NO |
| -16 | SC-SM | YES | NO |
| -21 | SM | YES | NO |
| -26 | SM | NO | NO |
| -31 | SM | YES | NO |
| -36 | CL | NO | NO |
| -46 | CL | NO | NO |
| -51 | CL | NO | NO |
| -56 | CL | NO | NO |
| -61 | SW-SM | NO | NO |
| -66 | CL | NO | NO |
| -72 | ML | NO | NO |
| -77 | ML | YES | NO |
| -86 | GP-GM | NO | NO |
| -91 | SM | NO | NO |
| -96 | SP-SM | NO | NO |
| -101 | SP-SM | NO | NO |
| -106 | SM | NO | NO |
| -111 | SP-SM | NO | NO |
| -116 | ML | NO | NO |
| -121 | SM | NO | NO |
| -126 | SM | NO | NO |

| DCR5-DH-014 | | | |
|---|---|---|---|
| Min Spacing (ft) | | | 93 |
| Replacement Ratio | | | 7% |
| Elev (ft) | Soil Type | Unimproved Liquefaction Concern? | Improved Liquefaction Concern? |
| -33 | SP-SC | YES | NO |
| -38 | SP-SC | NO | NO |
| -50 | CL | NO | NO |
| -53 | SM | NO | NO |
| -58 | SP | NO | NO |
| -63 | SP | NO | NO |
| -73 | SM | NO | NO |
| -83 | SM | NO | NO |
| -88 | CL | NO | NO |
| -93 | ML | NO | NO |
| -98 | SP-SM | NO | NO |
| -103 | SW | NO | NO |
| -108 | SP-SM | NO | NO |
| -113 | SP-SM | NO | NO |
| -118 | SP | NO | NO |
| -123 | CL | NO | NO |
| -128 | CH | NO | NO |
| -138 | CH | NO | NO |
| -143 | CL | NO | NO |
| -148 | ML | NO | NO |
| -153 | SM | NO | NO |
| -158 | ML | NO | NO |

| DCR-DH-004 | | | |
|---|---|---|---|
| Min Spacing (ft) | | | 26 |
| Replacement Ratio | | | 24% |
| Elev (ft) | Soil Type | Unimproved Liquefaction Concern? | Improved Liquefaction Concern? |
| -24 | SP | YES | NO |
| -29 | SP | YES | NO |
| -34 | SP | NO | NO |
| -39 | SP | YES | NO |
| -45 | CL | NO | NO |
| -50 | CL | NO | NO |
| -55 | ML | YES | NO |
| -60 | ML | YES | NO |
| -66 | SC | YES | NO |
| -71 | CL | NO | NO |
| -75 | CL | NO | NO |
| -80 | CL | NO | NO |
| -86 | CL | NO | NO |
| -90 | SM | NO | NO |
| -95 | SP | NO | NO |
| -100 | SP-SM | NO | NO |
| -105 | SP | NO | NO |
| -110 | SM | NO | NO |
| -115 | SP | NO | NO |
| -120 | SP | NO | NO |
| -125 | CH | NO | NO |
| -130 | CL | NO | NO |
| -135 | SM | NO | NO |
| -140 | SM | NO | NO |
| -145 | SM | NO | NO |
| -150 | SP | NO | NO |
| -155 | SP | NO | NO |

| pc80-pi-2 | | | |
|---|---|---|---|
| Min Spacing (ft) | | | N/A |
| Replacement Ratio | | | 0% |
| Elev (ft) | Soil Type | Unimproved Liquefaction Concern? | Improved Liquefaction Concern? |
| -18 | SP | NO | NO |
| -23 | SP | NO | NO |
| -28 | CL | NO | NO |
| -38 | CL | NO | NO |
| -48 | ML | NO | NO |

*Using updated PGA and M from LCI(2021) and PGA reduction factor from 1-D response analysis*
*Assuming depth to Modesto Fm. (K=1.5) at 15ft, depth to Riverbank Fm. (K=1.6) at 20ft*

# Bethany Alignment Analytical Results

| WAPA-SLTP-B3 (Pumping Plant) | | | | DCW-DH-014 (Pumping Plant) | | | | PC60-PCA-43 (Union Island Shaft) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Min Spacing (ft) | | | N/A | Min Spacing (ft) | | | N/A | Min Spacing (ft) | | | 45 |
| Replacement Ratio | | | 0% | Replacement Ratio | | | 0% | Replacement Ratio | | | 14% |
| **Elev (ft)** | **Soil Type** | **Unimproved Liquefaction Concern?** | **Improved Liquefaction Concern?** | **Elev (ft)** | **Soil Type** | **Unimproved Liquefaction Concern?** | **Improved Liquefaction Concern?** | **Elev (ft)** | **Soil Type** | **Unimproved Liquefaction Concern?** | **Improved Liquefaction Concern?** |
| 60 | SC | NO-Above GW | NO-Above GW | 17 | CL | NO | NO | -10 | PT | YES | NO |
| 56 | SC | NO-Above GW | NO-Above GW | 11 | CL | NO | NO | -14 | SM | YES | NO |
| 51 | CL | NO | NO | 6 | CL | NO | NO | -17 | SP | YES | NO |
| 46 | SC | NO-Above GW | NO-Above GW | -1 | CL | NO | NO | -26 | CH | NO | NO |
| 41 | SM | NO-Above GW | NO-Above GW | -4 | SC | NO | NO | -28 | SP | YES | NO |
| 36 | CL | NO | NO | -9 | SC | NO | NO | -31 | SM | YES | NO |
| 31 | SM | NO | NO | -14 | SC | NO | NO | -42 | SP | NO | NO |
| 26 | CL | NO | NO | -21 | CL | NO | NO | -51 | CH | NO | NO |
| 21 | CL | NO | NO | -24 | CL | NO | NO | | | | |
| | | | | -29 | CL | NO | NO | | | | |
| | | | | -34 | CL | NO | NO | | | | |
| | | | | -39 | CL | NO | NO | | | | |
| | | | | -44 | CL | NO | NO | | | | |
| | | | | -49 | CL | NO | NO | | | | |
| | | | | -54 | CL | NO | NO | | | | |
| | | | | -59 | ML | NO | NO | | | | |
| | | | | -64 | CH | NO | NO | | | | |
| | | | | -69 | CL | NO | NO | | | | |
| | | | | -74 | CH | NO | NO | | | | |
| | | | | -79 | CL | NO | NO | | | | |

*Using updated PGA and M from LCI(2021) and PGA reduction factor from 1-D response analysis*

*BPP: Assuming depth to Modesto Fm. (K=1.5) at 10ft, depth to Riverbank Fm. (K=1.6) at 60ft (USGS Profile West)*

*Union Island: Assuming depth to Modesto Fm. (K=1.5) at 15ft*

Note:

NO: FS ≥ 1

YES: FS < 1

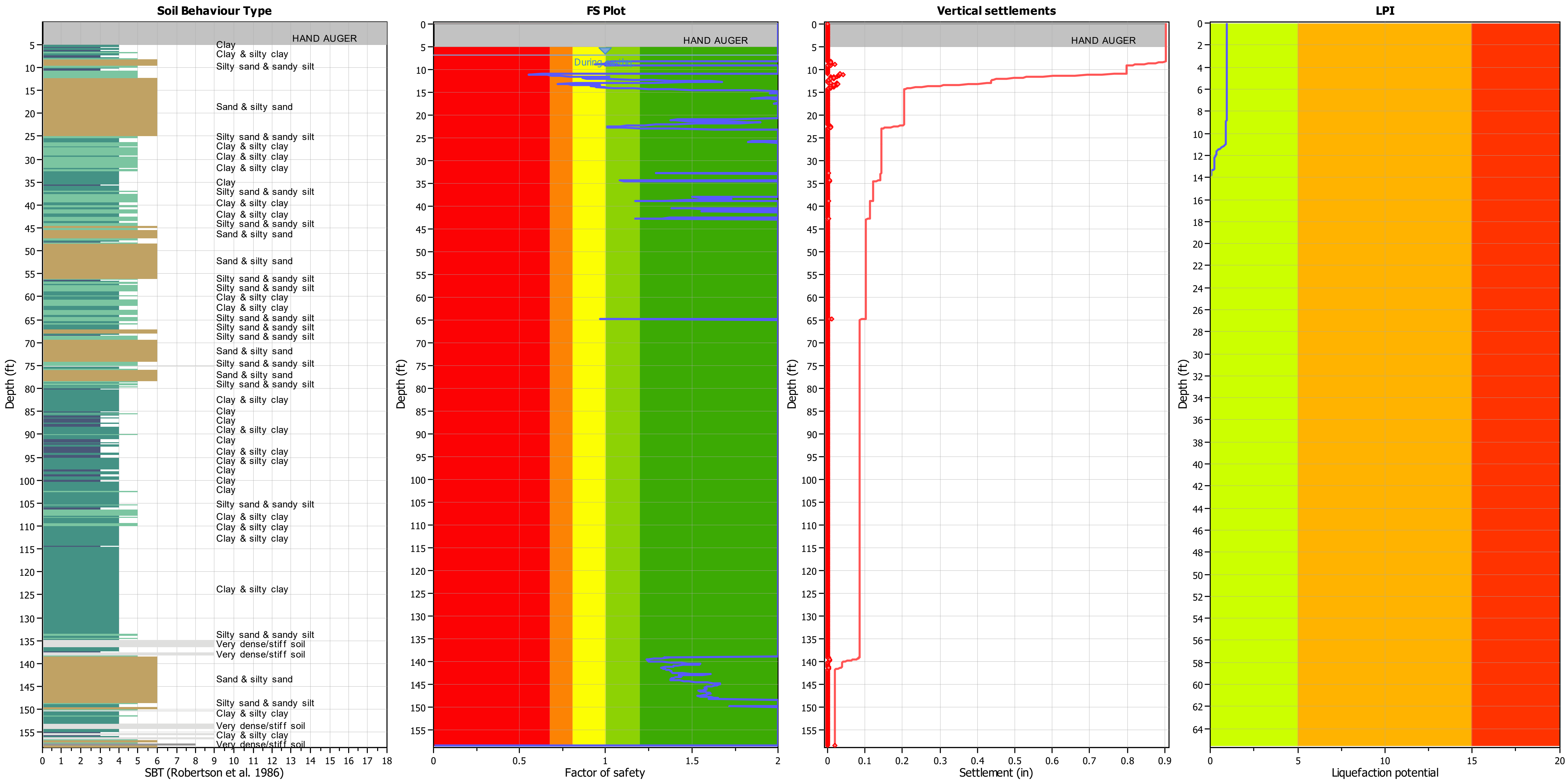
# Attachment 3
# Documentation of Analytical CPT Procedure

**Project:** DCA Liquefaction Evaluation

**Location:**

**CPT: Bacon Is_DCA-CPT-053**

Total depth: 158.30 ft




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Analysis method: | NCEER (1998) | G.W.T. (in-situ): | 0.00 ft | Use fill: | No | Clay like behavior applied: | Sands only |
| Fines correction method: | NCEER (1998) | G.W.T. (earthq.): | 7.00 ft | Fill height: | N/A | Limit depth applied: | No |
| Points to test: | Based on Ic value | Average results interval: | 3 | Fill weight: | N/A | Limit depth: | N/A |
| Earthquake magnitude $M_w$: | 6.60 | Ic cut-off value: | 2.60 | Trans. detect. applied: | Yes | MSF method: | Method based |
| Peak ground acceleration: | 0.29 | Unit weight calculation: | Based on SBT | $K_\sigma$ applied: | Yes | | |

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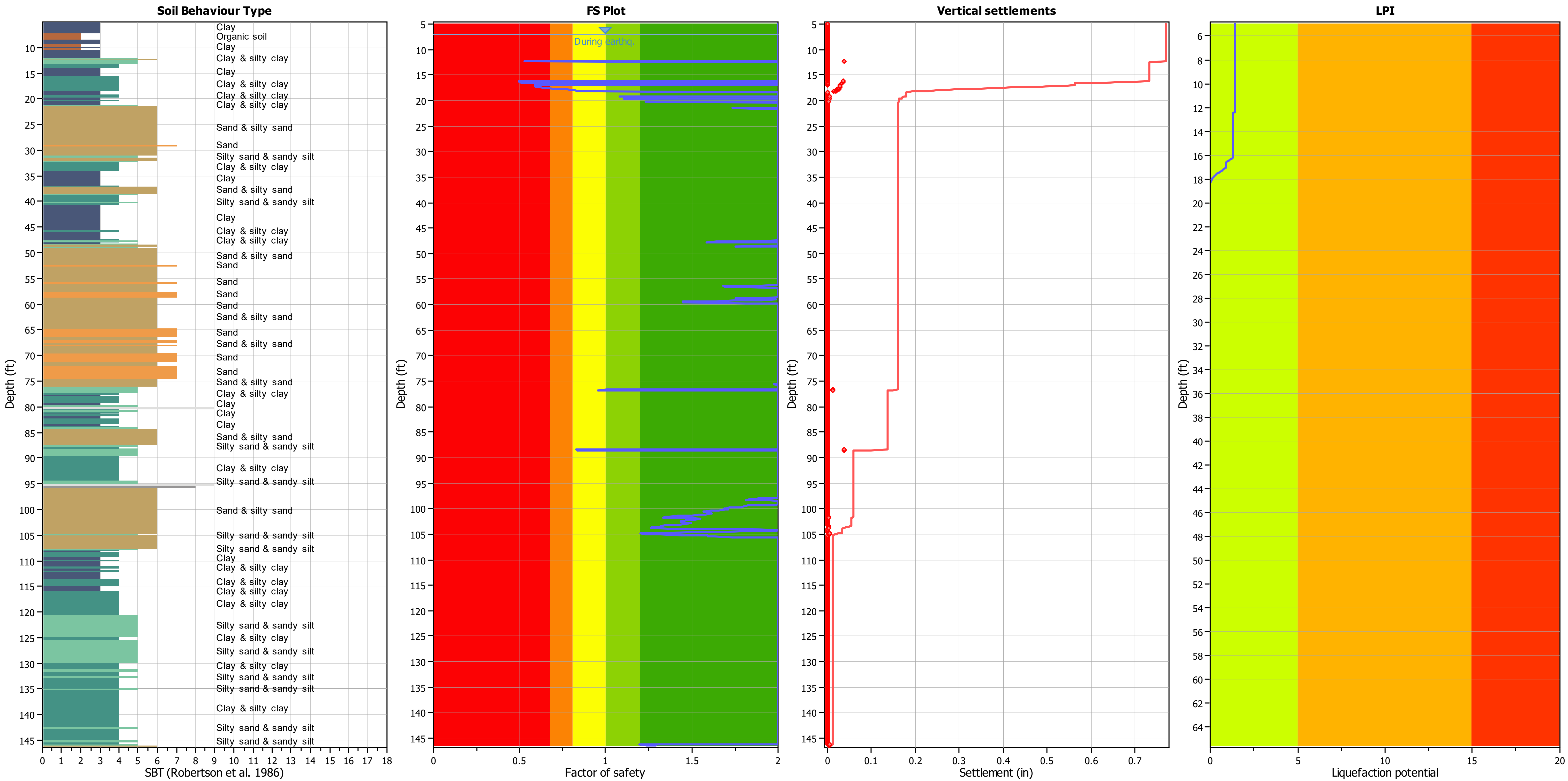
Geotechnical Engineers
Merarhias 56
http://www.geologismiki.gr

**Project:** **DCA Liquefaction Evaluation**
**Location:**

**CPT: Bacon Is_DCA-CPT-054**
Total depth: 146.41 ft




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Analysis method: | NCEER (1998) | G.W.T. (in-situ): | 1.00 ft | Use fill: | No | Clay like behavior applied: | Sands only |
| Fines correction method: | NCEER (1998) | G.W.T. (earthq.): | 7.00 ft | Fill height: | N/A | Limit depth applied: | No |
| Points to test: | Based on Ic value | Average results interval: | 3 | Fill weight: | N/A | Limit depth: | N/A |
| Earthquake magnitude $M_w$: | 6.60 | Ic cut-off value: | 2.60 | Trans. detect. applied: | Yes | MSF method: | Method based |
| Peak ground acceleration: | 0.29 | Unit weight calculation: | Based on SBT | $K_\sigma$ applied: | Yes | | |

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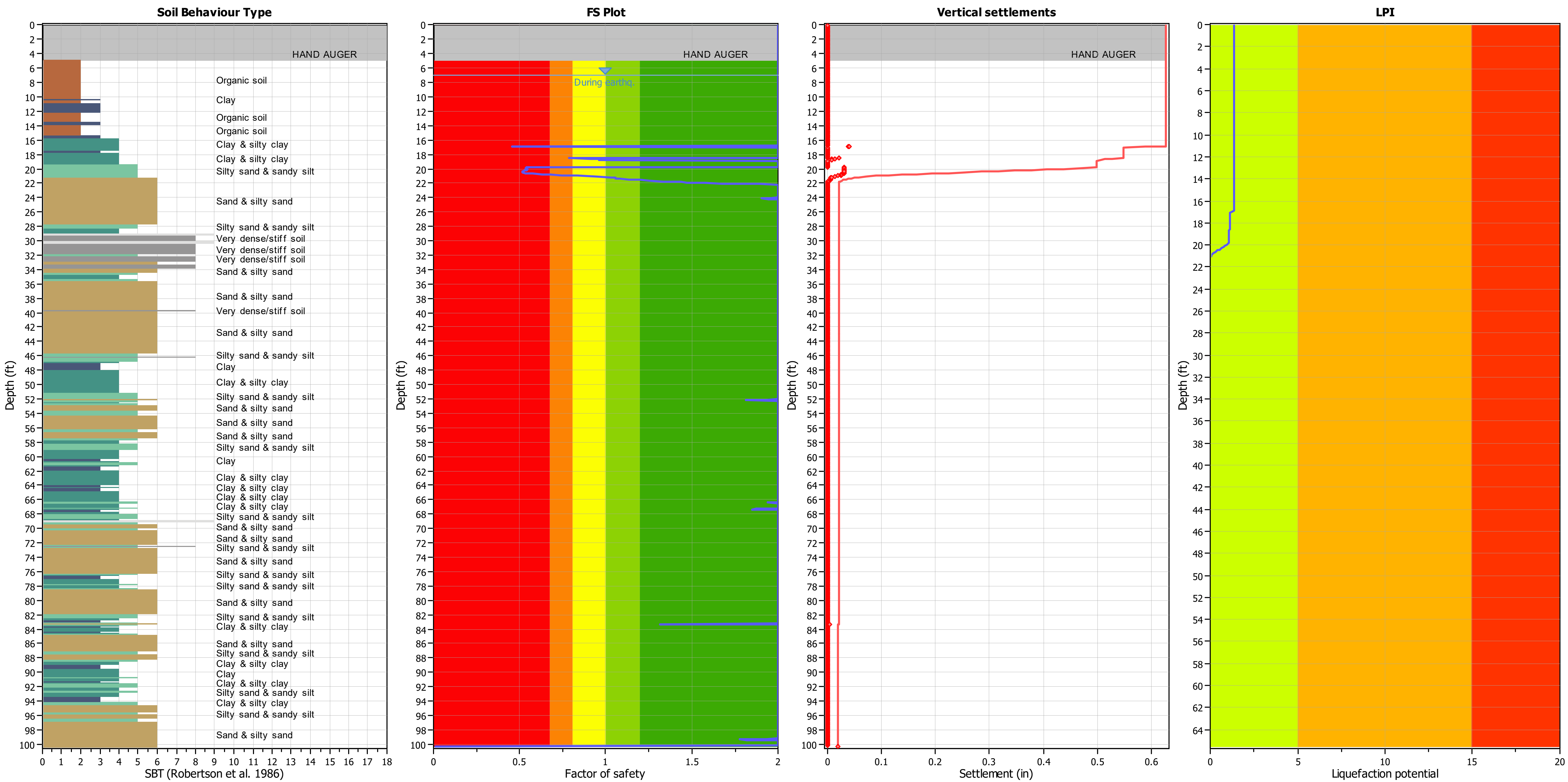
**Project:** DCA Liquefaction Evaluation

**Location:**

**CPT: Bacon Is_DCT-CPT-026**

Total depth: 100.31 ft




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Analysis method: | NCEER (1998) | G.W.T. (in-situ): | 0.00 ft | Use fill: | No | Clay like behavior applied: | Sands only |
| Fines correction method: | NCEER (1998) | G.W.T. (earthq.): | 7.00 ft | Fill height: | N/A | Limit depth applied: | No |
| Points to test: | Based on Ic value | Average results interval: | 3 | Fill weight: | N/A | Limit depth: | N/A |
| Earthquake magnitude $M_w$: | 6.60 | Ic cut-off value: | 2.60 | Trans. detect. applied: | Yes | MSF method: | Method based |
| Peak ground acceleration: | 0.29 | Unit weight calculation: | Based on SBT | $K_\sigma$ applied: | Yes | | |

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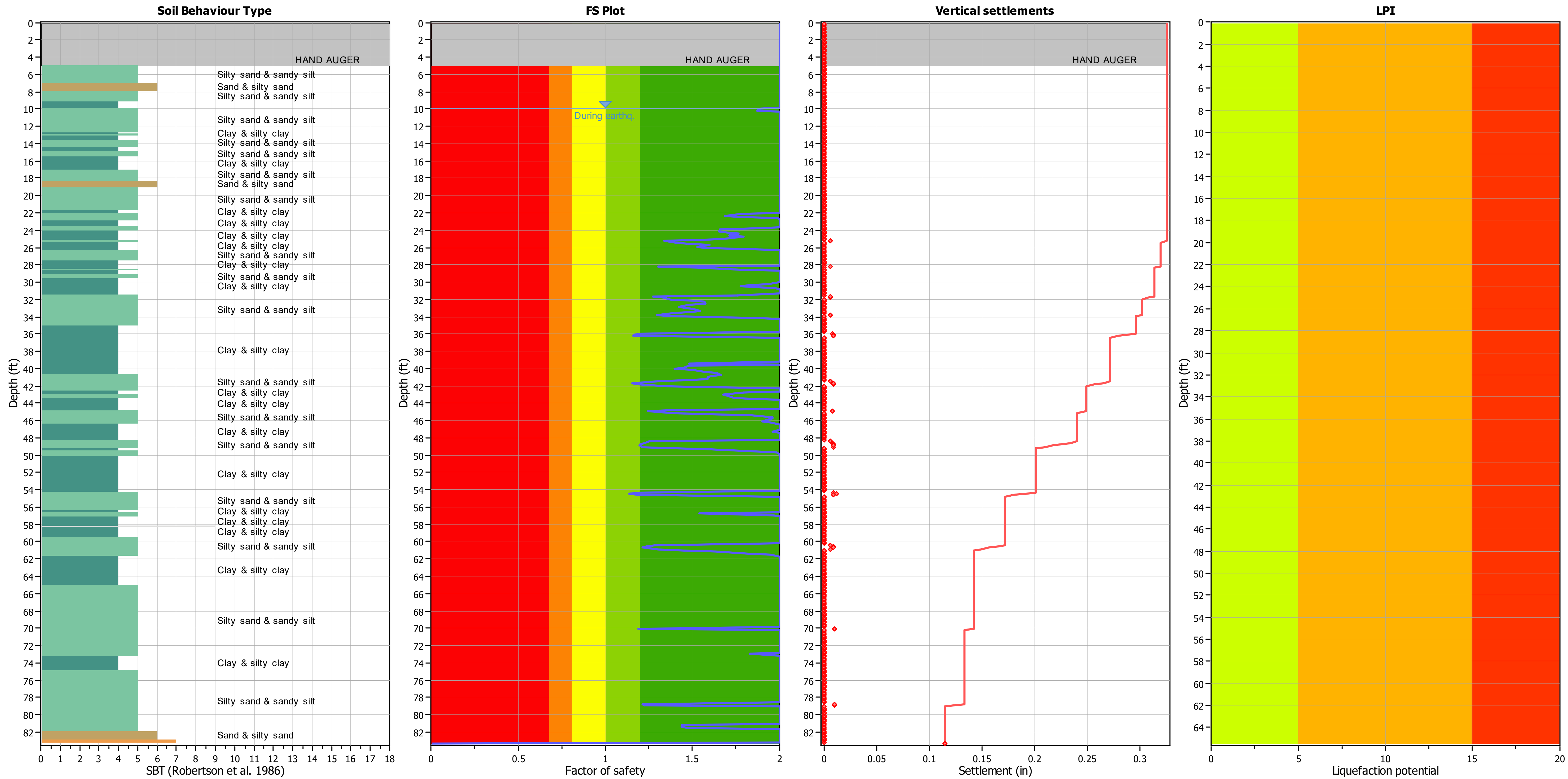
**Project:** DCA Liquefaction Evaluation
**Location:**

**CPT: Banks Connection_DCW-CPT-026**
Total depth: 83.33 ft




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Analysis method: | NCEER (1998) | G.W.T. (in-situ): | 0.00 ft | Use fill: | No | Clay like behavior applied: | Sands only |
| Fines correction method: | NCEER (1998) | G.W.T. (earthq.): | 10.00 ft | Fill height: | N/A | Limit depth applied: | No |
| Points to test: | Based on Ic value | Average results interval: | 3 | Fill weight: | N/A | Limit depth: | N/A |
| Earthquake magnitude $M_w$: | 6.70 | Ic cut-off value: | 2.60 | Trans. detect. applied: | Yes | MSF method: | Method based |
| Peak ground acceleration: | 0.27 | Unit weight calculation: | Based on SBT | $K_\sigma$ applied: | Yes | | |

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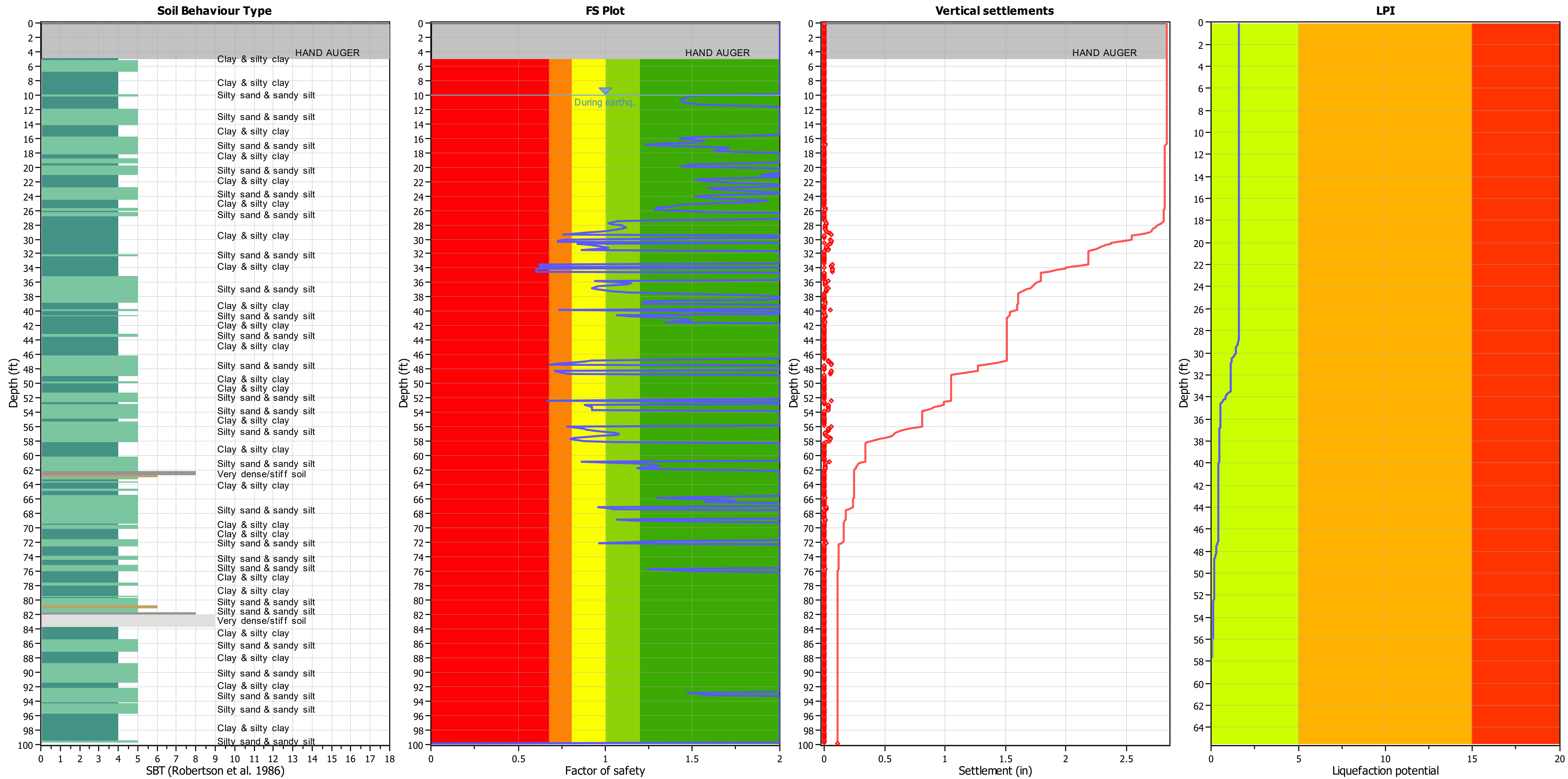
**Project:** **DCA Liquefaction Evaluation**
**Location:**

**CPT: Bethany PP_DCW-CPT-027**
Total depth: 99.90 ft




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Analysis method: | NCEER (1998) | G.W.T. (in-situ): | 1.00 ft | Use fill: | No | Clay like behavior applied: | Sands only |
| Fines correction method: | NCEER (1998) | G.W.T. (earthq.): | 10.00 ft | Fill height: | N/A | Limit depth applied: | No |
| Points to test: | Based on Ic value | Average results interval: | 3 | Fill weight: | N/A | Limit depth: | N/A |
| Earthquake magnitude $M_w$: | 6.90 | Ic cut-off value: | 2.60 | Trans. detect. applied: | Yes | MSF method: | Method based |
| Peak ground acceleration: | 0.33 | Unit weight calculation: | Based on SBT | $K_\sigma$ applied: | Yes | | |

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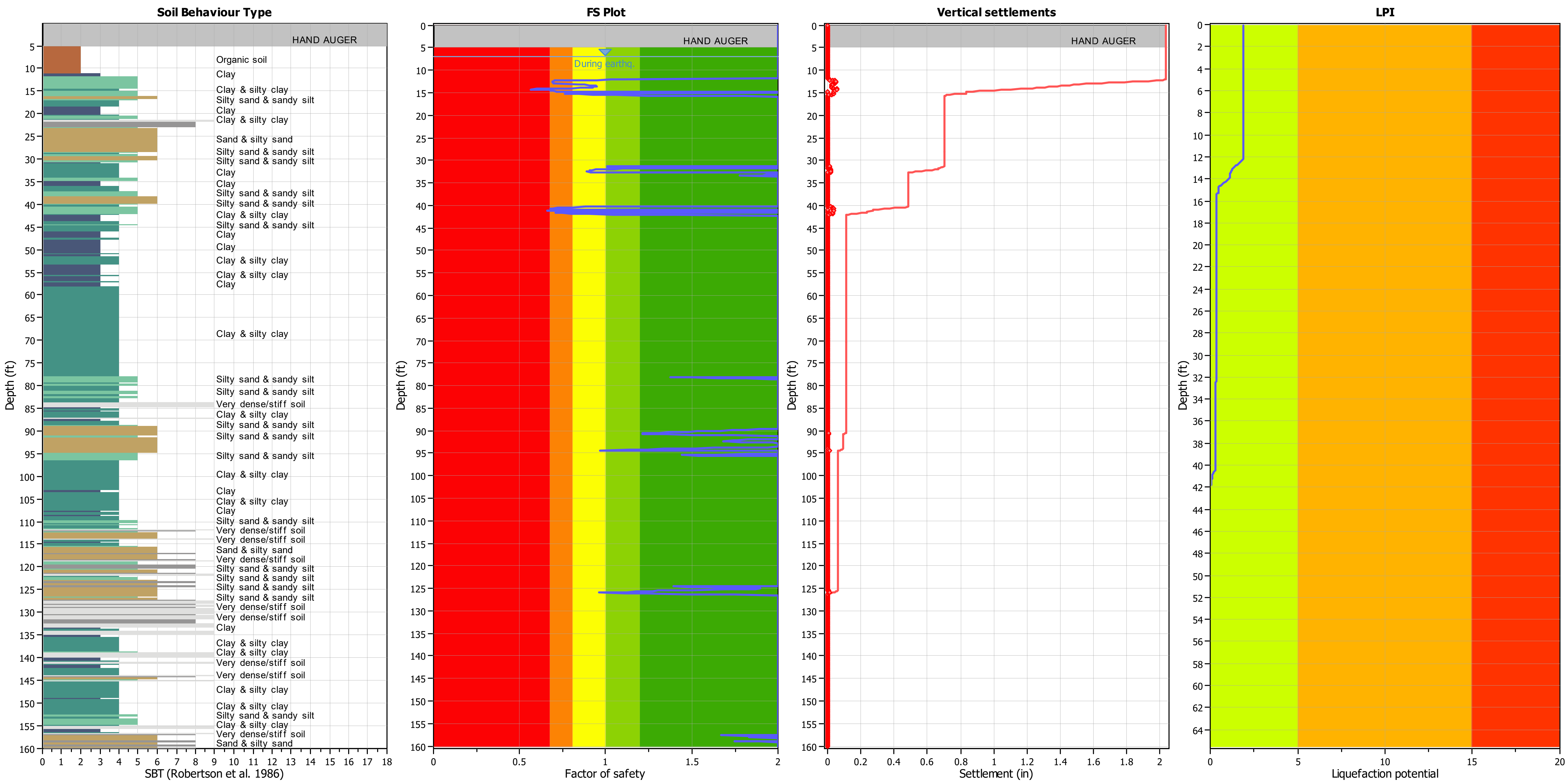
**Project:** **DCA Liquefaction Evaluation** **CPT: Bouldin Is_WFT-CPT-011**

**Location:** Total depth: 160.11 ft




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Analysis method: | NCEER (1998) | G.W.T. (in-situ): | 0.00 ft | Use fill: | No | Clay like behavior applied: | Sands only |
| Fines correction method: | NCEER (1998) | G.W.T. (earthq.): | 7.00 ft | Fill height: | N/A | Limit depth applied: | No |
| Points to test: | Based on Ic value | Average results interval: | 3 | Fill weight: | N/A | Limit depth: | N/A |
| Earthquake magnitude $M_w$: | 6.60 | Ic cut-off value: | 2.60 | Trans. detect. applied: | Yes | MSF method: | Method based |
| Peak ground acceleration: | 0.30 | Unit weight calculation: | Based on SBT | $K_\sigma$ applied: | Yes | | |

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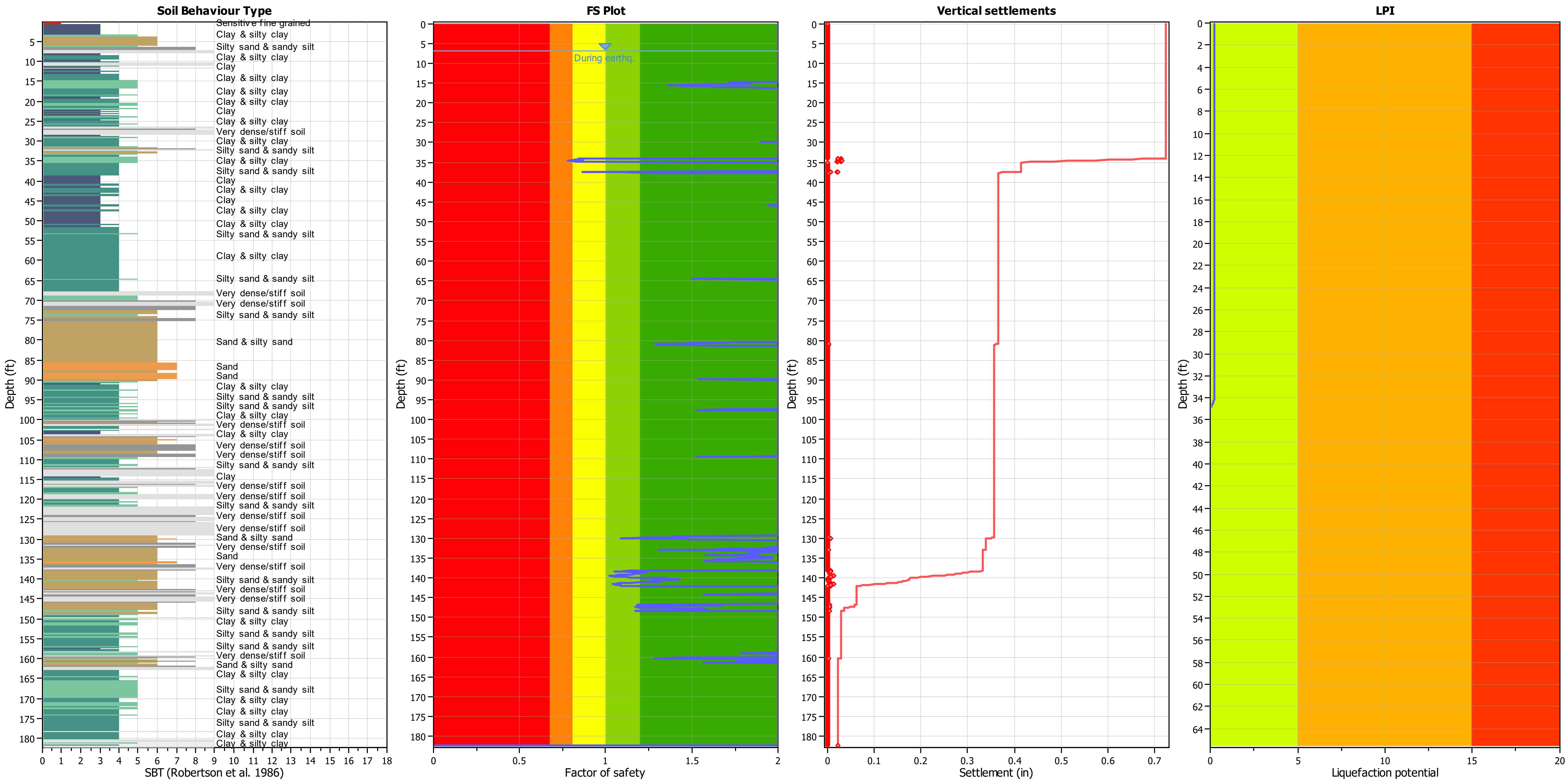
**Project:** DCA Liquefaction Evaluation

**Location:**

**CPT: Bouldin Is_WFT-CPT-018**

Total depth: 182.33 ft




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Analysis method: | NCEER (1998) | G.W.T. (in-situ): | 0.00 ft | Use fill: | No | Clay like behavior applied: | Sands only |
| Fines correction method: | NCEER (1998) | G.W.T. (earthq.): | 7.00 ft | Fill height: | N/A | Limit depth applied: | No |
| Points to test: | Based on Ic value | Average results interval: | 3 | Fill weight: | N/A | Limit depth: | N/A |
| Earthquake magnitude $M_w$: | 6.60 | Ic cut-off value: | 2.60 | Trans. detect. applied: | Yes | MSF method: | Method based |
| Peak ground acceleration: | 0.30 | Unit weight calculation: | Based on SBT | $K_\sigma$ applied: | Yes | | |

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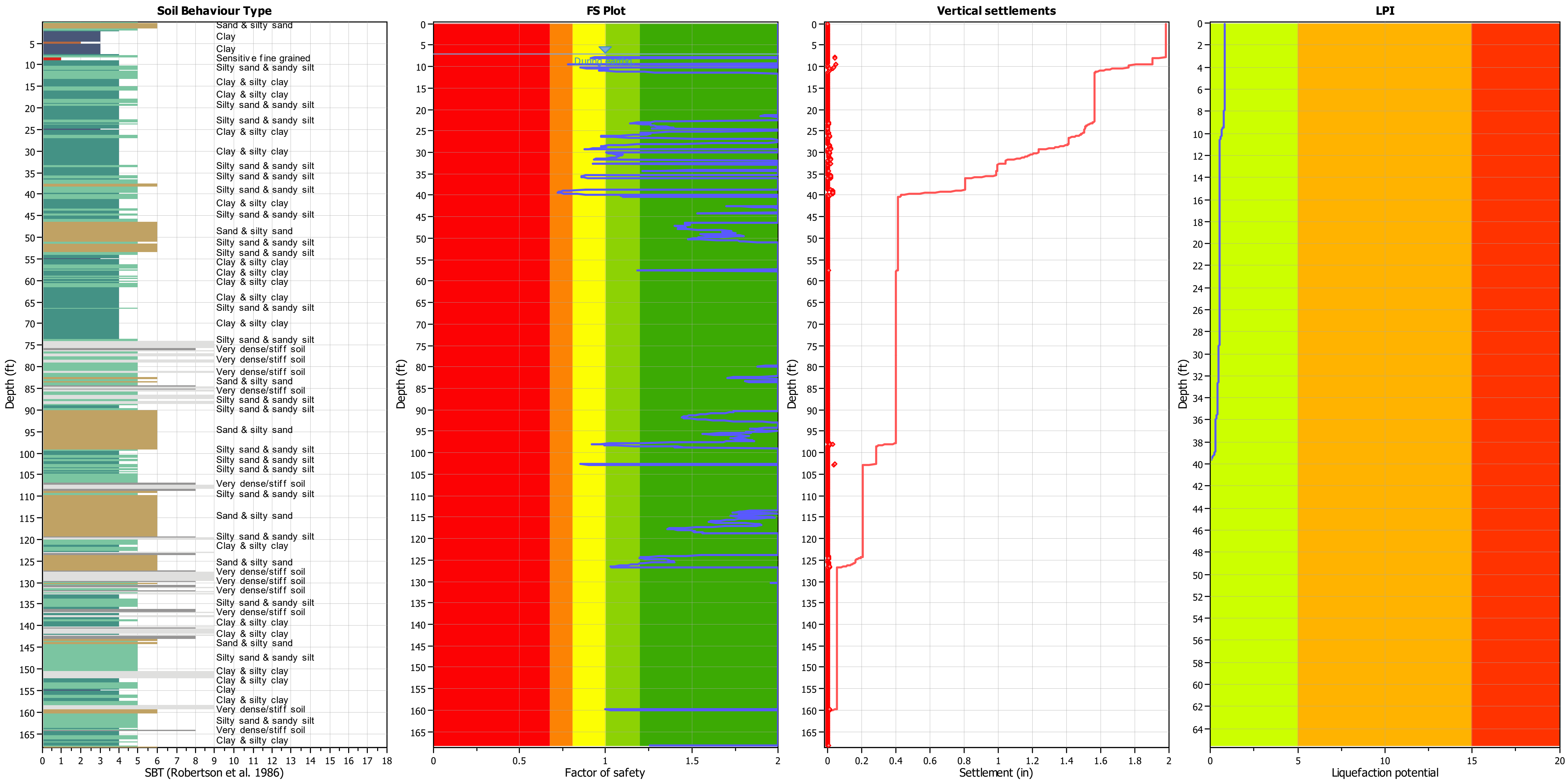
**Project:** **DCA Liquefaction Evaluation**
**Location:**

**CPT: Bouldin Is_WFT-CPT-019**
Total depth: 168.23 ft




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Analysis method: | NCEER (1998) | G.W.T. (in-situ): | 0.00 ft | Use fill: | No | Clay like behavior applied: | Sands only |
| Fines correction method: | NCEER (1998) | G.W.T. (earthq.): | 7.00 ft | Fill height: | N/A | Limit depth applied: | No |
| Points to test: | Based on Ic value | Average results interval: | 3 | Fill weight: | N/A | Limit depth: | N/A |
| Earthquake magnitude $M_w$: | 6.60 | Ic cut-off value: | 2.60 | Trans. detect. applied: | Yes | MSF method: | Method based |
| Peak ground acceleration: | 0.30 | Unit weight calculation: | Based on SBT | $K_\sigma$ applied: | Yes | | |

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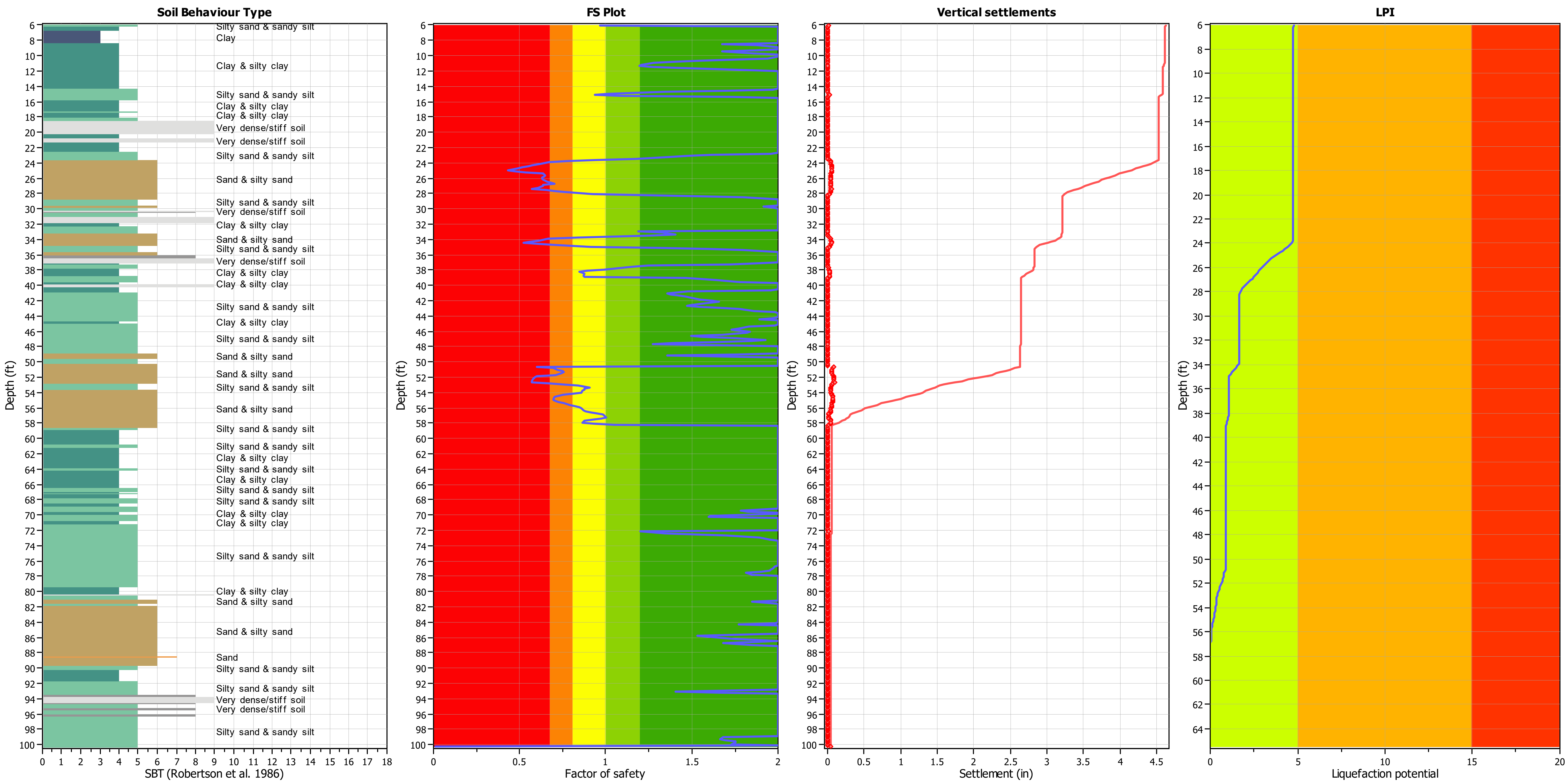
**Project:** **DCA Liquefaction Evaluation**

**Location:**

**CPT: Canal Ranch Tract_DCE-CPT-014**

Total depth: 100.23 ft




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Analysis method: | NCEER (1998) | G.W.T. (in-situ): | 1.00 ft | Use fill: | No | Clay like behavior applied: | Sands only |
| Fines correction method: | NCEER (1998) | G.W.T. (earthq.): | 5.00 ft | Fill height: | N/A | Limit depth applied: | No |
| Points to test: | Based on Ic value | Average results interval: | 3 | Fill weight: | N/A | Limit depth: | N/A |
| Earthquake magnitude $M_w$: | 6.60 | Ic cut-off value: | 2.60 | Trans. detect. applied: | Yes | MSF method: | Method based |
| Peak ground acceleration: | 0.34 | Unit weight calculation: | Based on SBT | $K_\sigma$ applied: | Yes | | |

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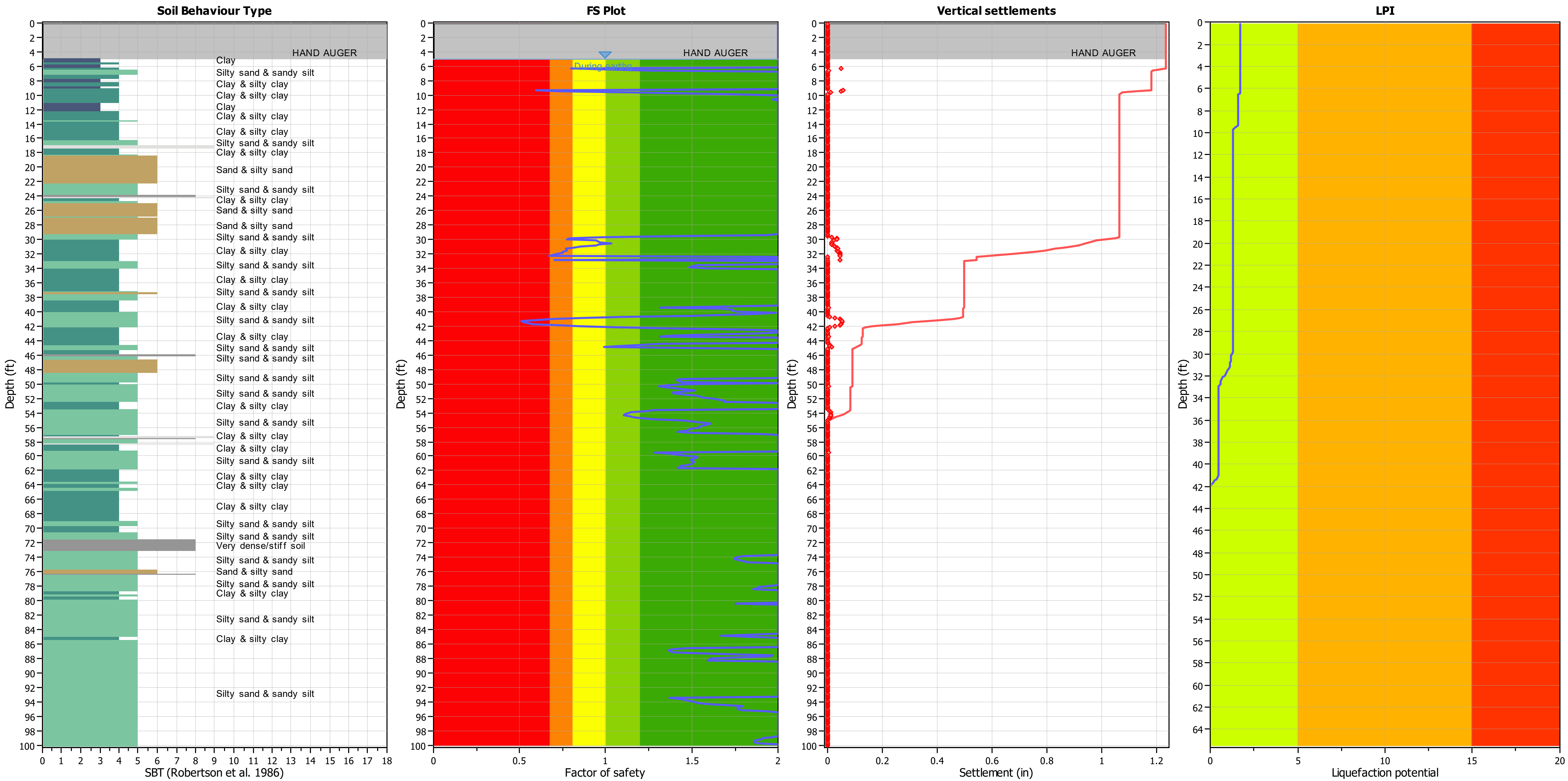
**Project:** **DCA Liquefaction Evaluation**
**Location:**

**CPT: Canal Ranch Tract_DCE-CPT-015**
Total depth: 100.07 ft




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Analysis method: | NCEER (1998) | G.W.T. (in-situ): | 0.00 ft | Use fill: | No | Clay like behavior applied: | Sands only |
| Fines correction method: | NCEER (1998) | G.W.T. (earthq.): | 5.00 ft | Fill height: | N/A | Limit depth applied: | No |
| Points to test: | Based on Ic value | Average results interval: | 3 | Fill weight: | N/A | Limit depth: | N/A |
| Earthquake magnitude $M_w$: | 6.60 | Ic cut-off value: | 2.60 | Trans. detect. applied: | Yes | MSF method: | Method based |
| Peak ground acceleration: | 0.34 | Unit weight calculation: | Based on SBT | $K_\sigma$ applied: | Yes | | |

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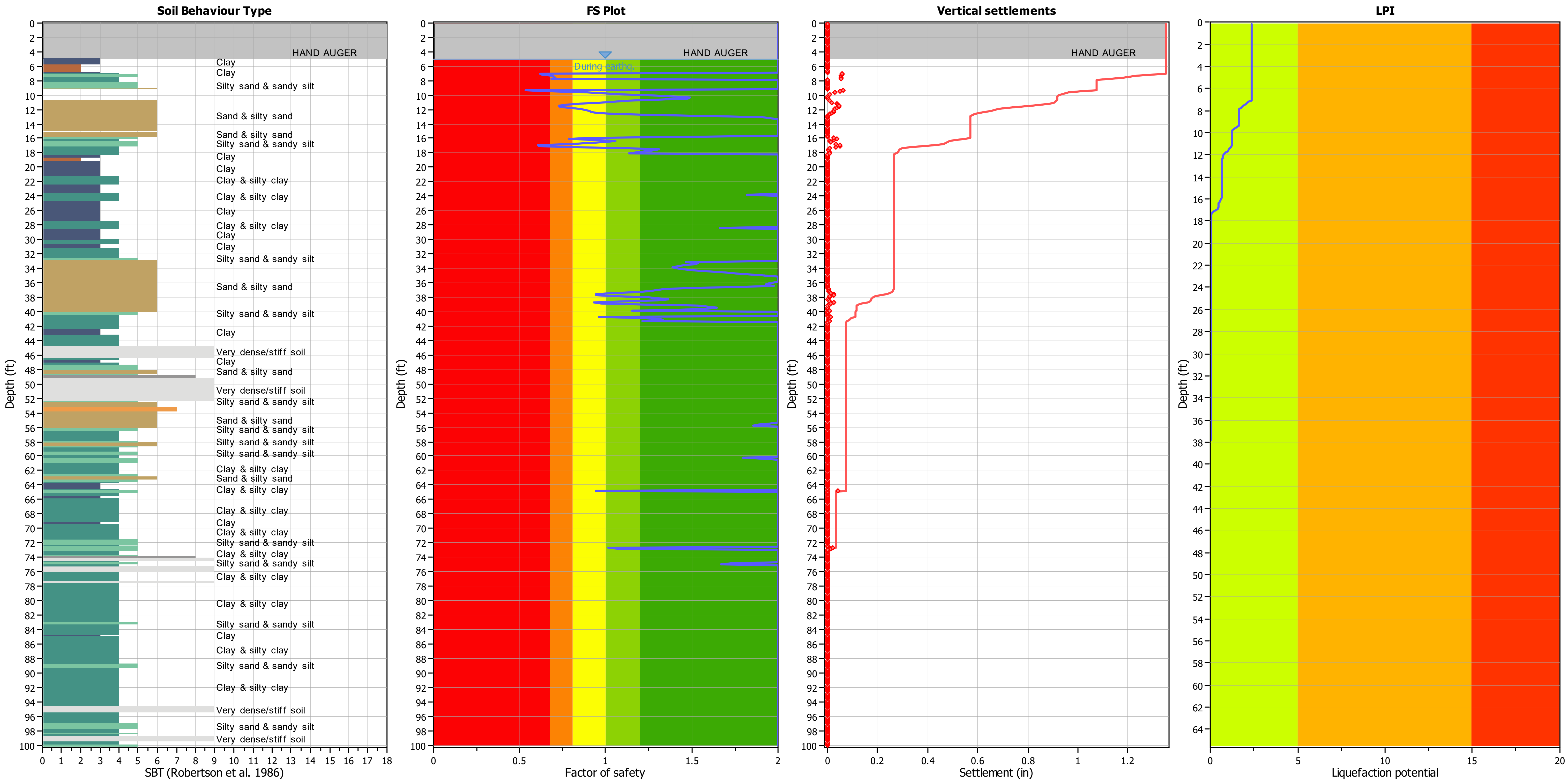
**Project:** **DCA Liquefaction Evaluation**
**Location:**

**CPT: Canal Ranch Tract_DCE-CPT-016**
Total depth: 100.07 ft




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Analysis method: | NCEER (1998) | G.W.T. (in-situ): | 0.00 ft | Use fill: | No | Clay like behavior applied: | Sands only |
| Fines correction method: | NCEER (1998) | G.W.T. (earthq.): | 5.00 ft | Fill height: | N/A | Limit depth applied: | No |
| Points to test: | Based on Ic value | Average results interval: | 3 | Fill weight: | N/A | Limit depth: | N/A |
| Earthquake magnitude $M_w$: | 6.60 | Ic cut-off value: | 2.60 | Trans. detect. applied: | Yes | MSF method: | Method based |
| Peak ground acceleration: | 0.34 | Unit weight calculation: | Based on SBT | $K_\sigma$ applied: | Yes | | |

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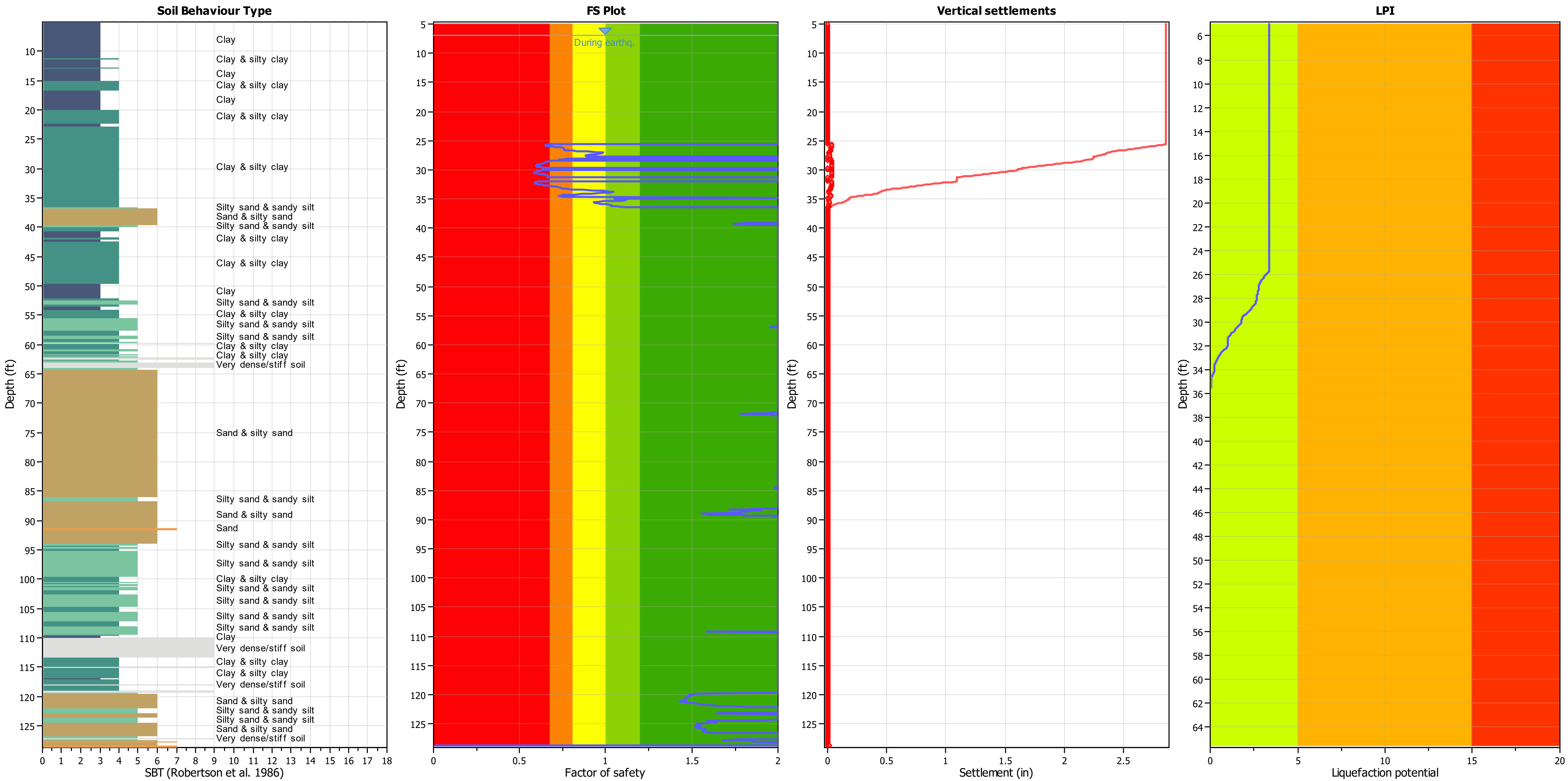
**Project:** **DCA Liquefaction Evaluation**

**Location:**

**CPT: Intake2_DCC-CPT-001**

Total depth: 128.69 ft




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Analysis method: | NCEER (1998) | G.W.T. (in-situ): | 0.00 ft | Use fill: | No | Clay like behavior applied: | Sands only |
| Fines correction method: | NCEER (1998) | G.W.T. (earthq.): | 7.00 ft | Fill height: | N/A | Limit depth applied: | No |
| Points to test: | Based on Ic value | Average results interval: | 3 | Fill weight: | N/A | Limit depth: | N/A |
| Earthquake magnitude $M_w$: | 6.60 | Ic cut-off value: | 2.60 | Trans. detect. applied: | Yes | MSF method: | Method based |
| Peak ground acceleration: | 0.20 | Unit weight calculation: | Based on SBT | $K_\sigma$ applied: | Yes | | |

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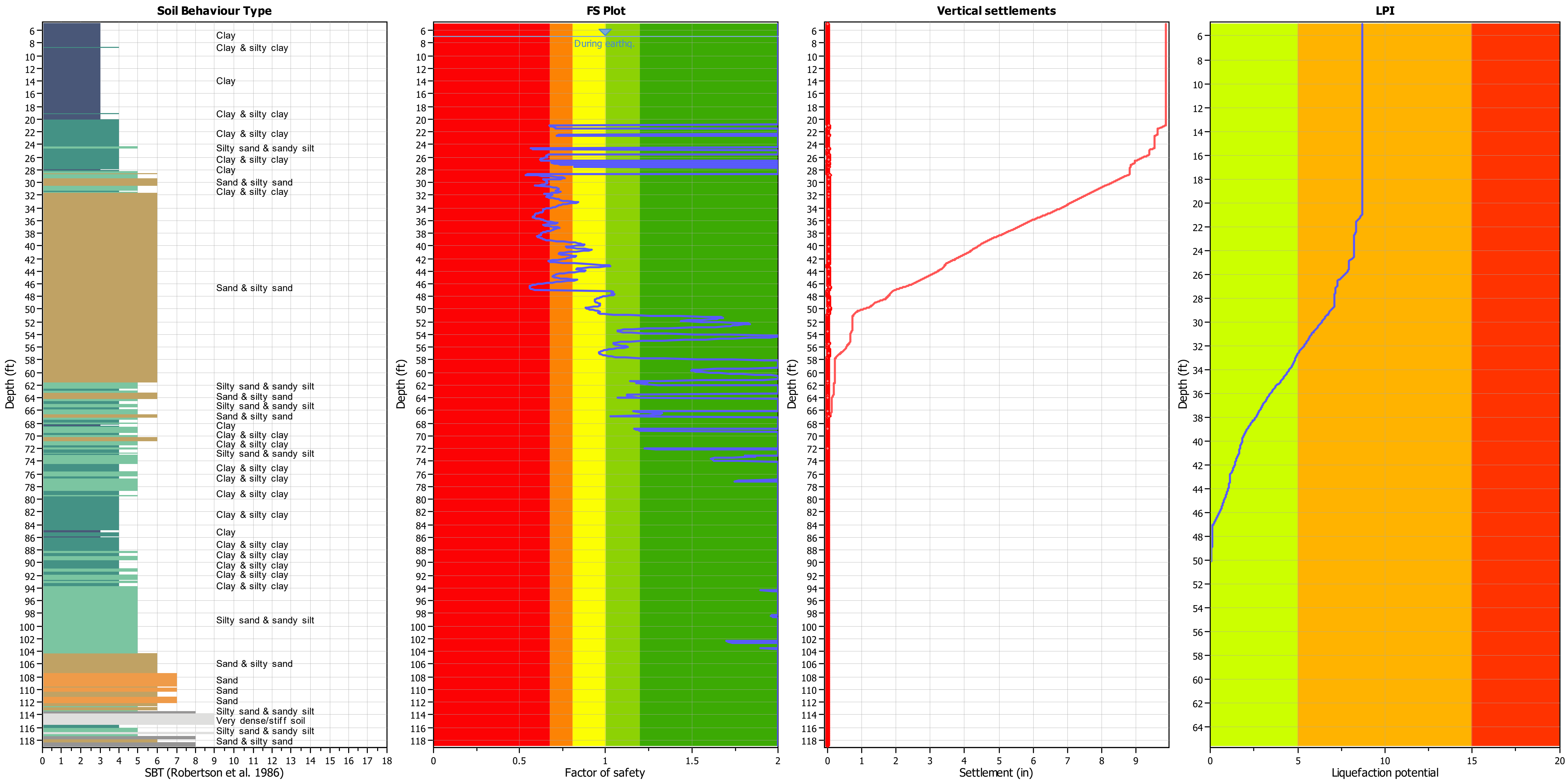
**Project:** DCA Liquefaction Evaluation

**Location:**

**CPT: Intake3_DCC-CPT-002**

Total depth: 118.85 ft




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Analysis method: | NCEER (1998) | G.W.T. (in-situ): | 1.00 ft | Use fill: | No | Clay like behavior applied: | Sands only |
| Fines correction method: | NCEER (1998) | G.W.T. (earthq.): | 7.00 ft | Fill height: | N/A | Limit depth applied: | No |
| Points to test: | Based on Ic value | Average results interval: | 3 | Fill weight: | N/A | Limit depth: | N/A |
| Earthquake magnitude $M_w$: | 6.60 | Ic cut-off value: | 2.60 | Trans. detect. applied: | Yes | MSF method: | Method based |
| Peak ground acceleration: | 0.20 | Unit weight calculation: | Based on SBT | $K_\sigma$ applied: | Yes | | |

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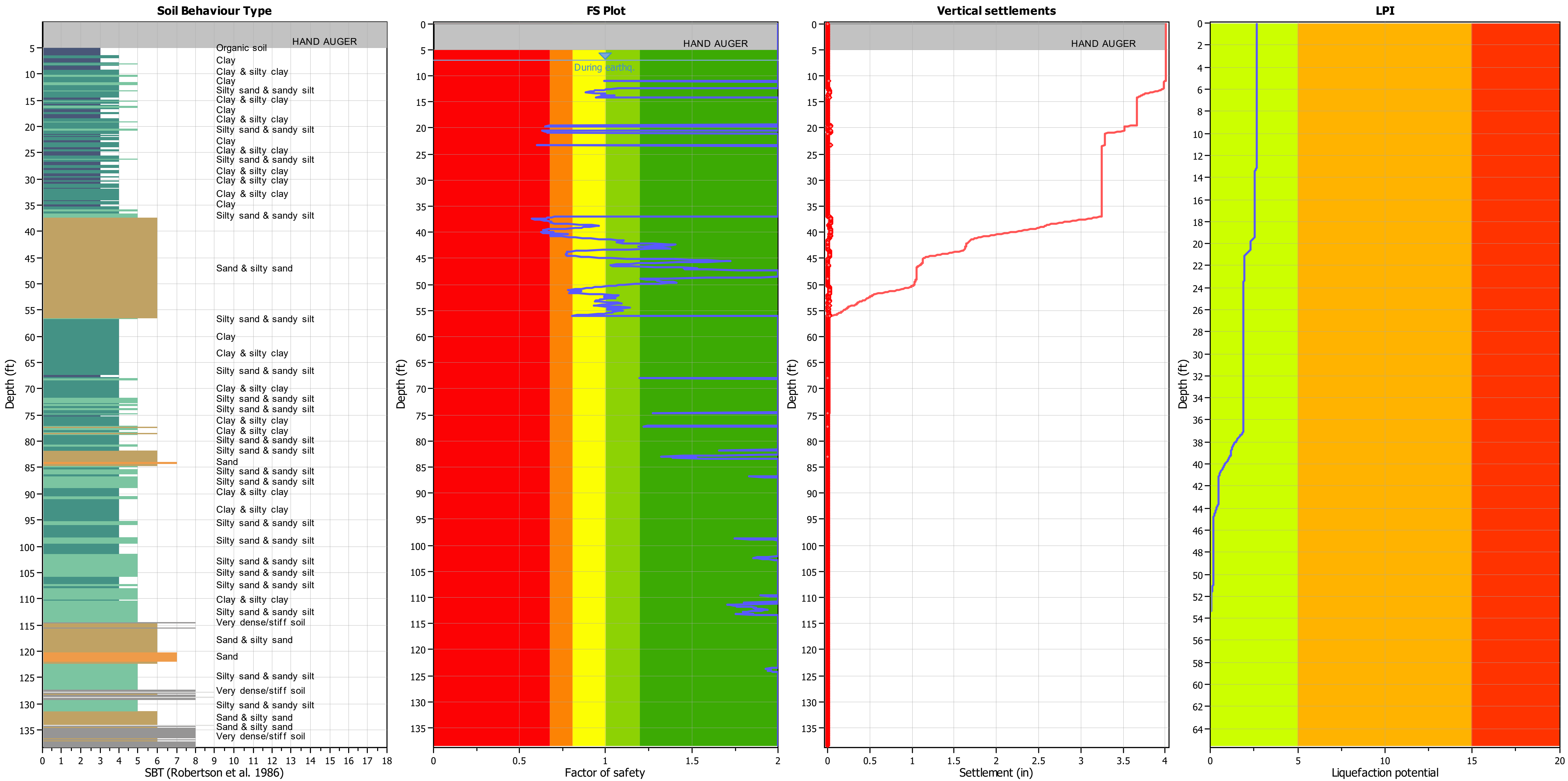
**Project:** DCA Liquefaction Evaluation

**Location:**

**CPT: Intake3_DCN3-CPT-004**

Total depth: 138.37 ft




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Analysis method: | NCEER (1998) | G.W.T. (in-situ): | 0.00 ft | Use fill: | No | Clay like behavior applied: | Sands only |
| Fines correction method: | NCEER (1998) | G.W.T. (earthq.): | 7.00 ft | Fill height: | N/A | Limit depth applied: | No |
| Points to test: | Based on Ic value | Average results interval: | 3 | Fill weight: | N/A | Limit depth: | N/A |
| Earthquake magnitude $M_w$: | 6.60 | Ic cut-off value: | 2.60 | Trans. detect. applied: | Yes | MSF method: | Method based |
| Peak ground acceleration: | 0.20 | Unit weight calculation: | Based on SBT | $K_\sigma$ applied: | Yes | | |

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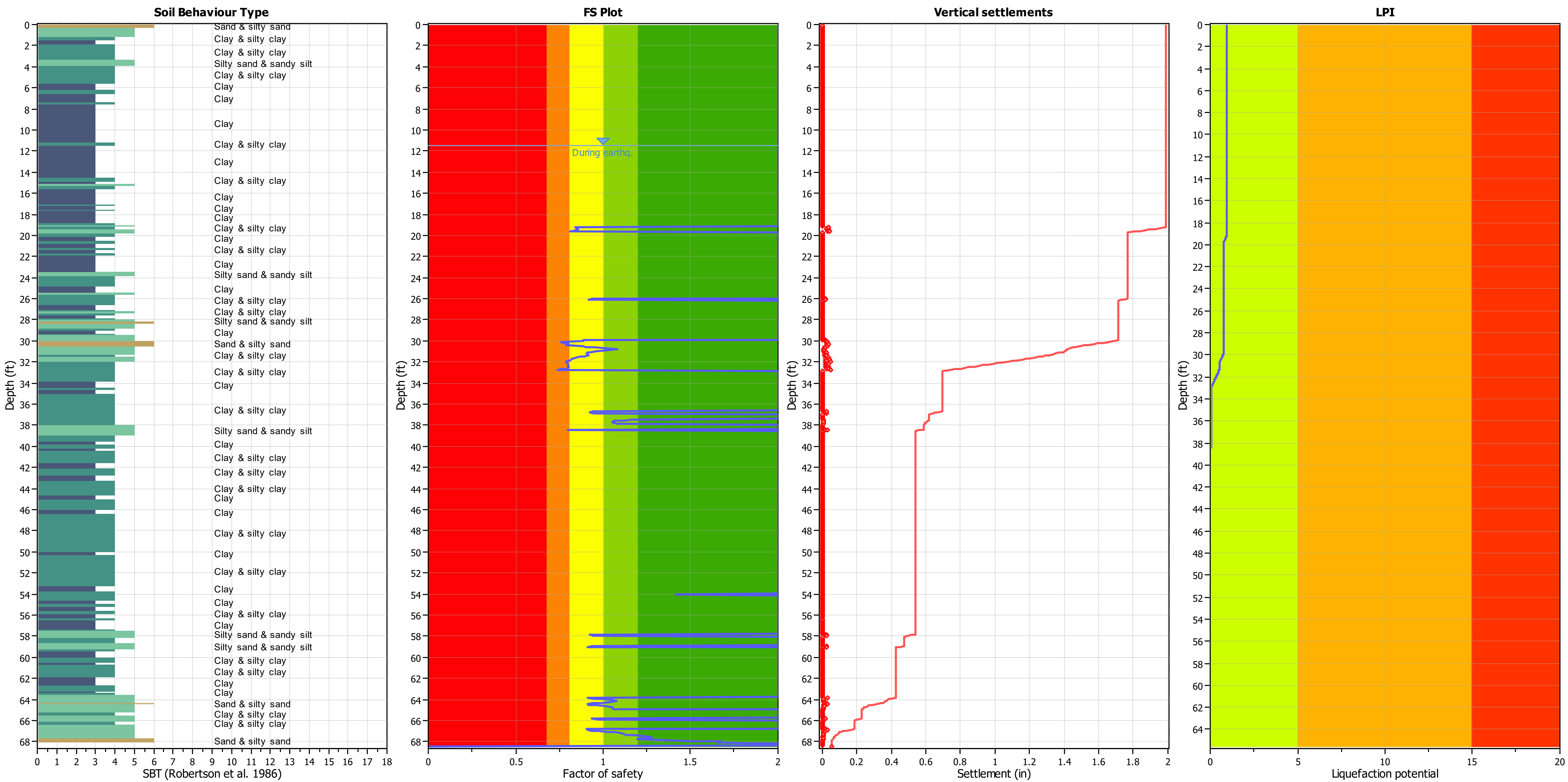
**Project:** DCA Liquefaction Evaluation

**Location:**

**CPT: Intake5_DCC-CPT-003**

Total depth: 68.46 ft




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Analysis method: | NCEER (1998) | G.W.T. (in-situ): | 1.00 ft | Use fill: | No | Clay like behavior applied: | Sands only |
| Fines correction method: | NCEER (1998) | G.W.T. (earthq.): | 11.50 ft | Fill height: | N/A | Limit depth applied: | No |
| Points to test: | Based on Ic value | Average results interval: | 3 | Fill weight: | N/A | Limit depth: | N/A |
| Earthquake magnitude $M_w$: | 6.60 | Ic cut-off value: | 2.60 | Trans. detect. applied: | Yes | MSF method: | Method based |
| Peak ground acceleration: | 0.29 | Unit weight calculation: | Based on SBT | $K_\sigma$ applied: | Yes | | |

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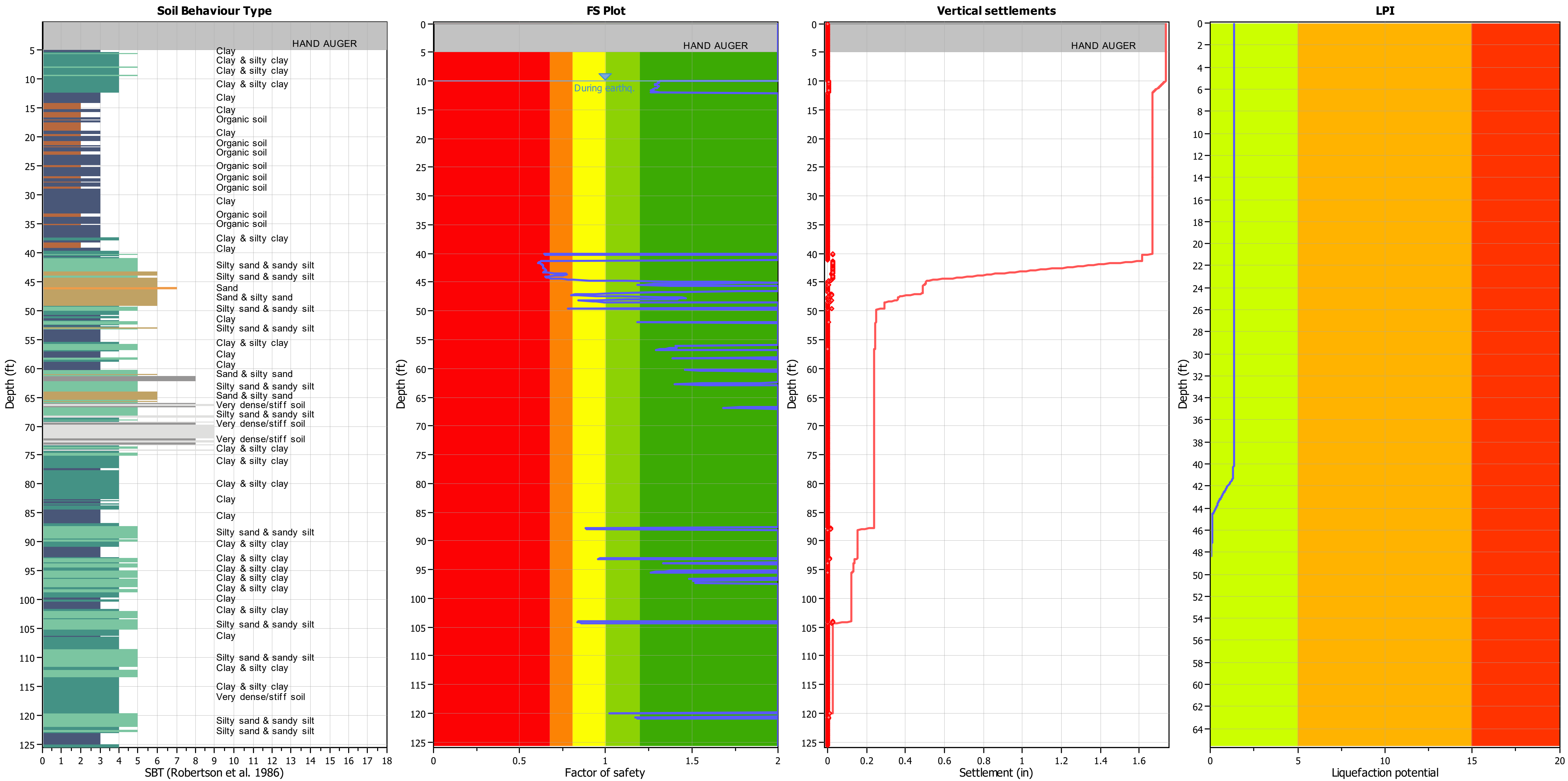
**Project:** DCA Liquefaction Evaluation

**Location:**

**CPT: Intake5_DCN4-CPT-002**

Total depth: 125.57 ft




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Analysis method: | NCEER (1998) | G.W.T. (in-situ): | 1.00 ft | Use fill: | No | Clay like behavior applied: | Sands only |
| Fines correction method: | NCEER (1998) | G.W.T. (earthq.): | 10.00 ft | Fill height: | N/A | Limit depth applied: | No |
| Points to test: | Based on Ic value | Average results interval: | 3 | Fill weight: | N/A | Limit depth: | N/A |
| Earthquake magnitude $M_w$: | 6.60 | Ic cut-off value: | 2.60 | Trans. detect. applied: | Yes | MSF method: | Method based |
| Peak ground acceleration: | 0.29 | Unit weight calculation: | Based on SBT | $K_\sigma$ applied: | Yes | | |

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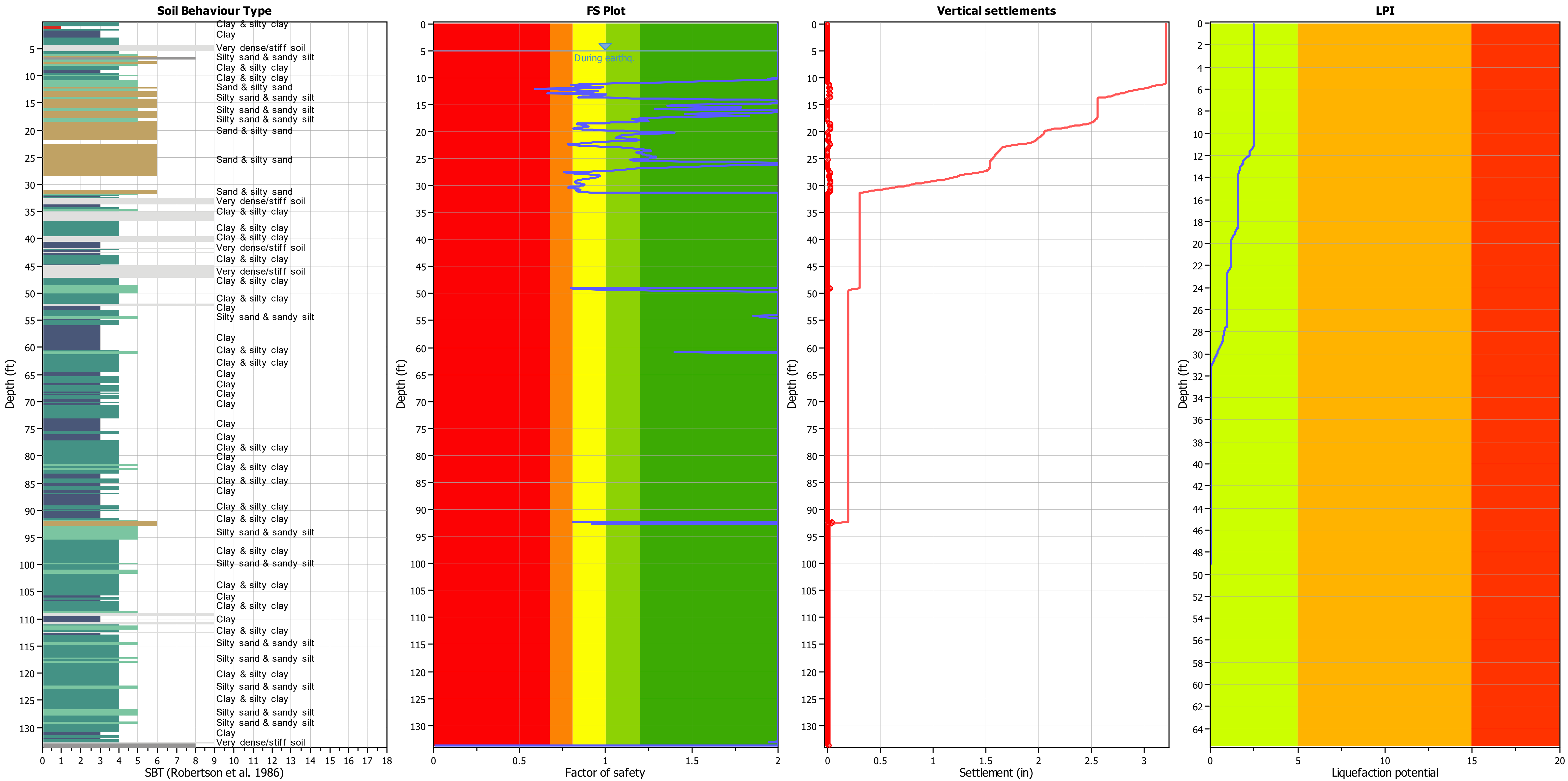
**Project:** **DCA Liquefaction Evaluation**

**Location:**

**CPT: Intake 5_DCN4-CPT-009**

Total depth: 133.69 ft




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Analysis method: | NCEER (1998) | G.W.T. (in-situ): | 1.00 ft | Use fill: | No | Clay like behavior applied: | Sands only |
| Fines correction method: | NCEER (1998) | G.W.T. (earthq.): | 5.00 ft | Fill height: | N/A | Limit depth applied: | No |
| Points to test: | Based on Ic value | Average results interval: | 3 | Fill weight: | N/A | Limit depth: | N/A |
| Earthquake magnitude $M_w$: | 6.60 | Ic cut-off value: | 2.60 | Trans. detect. applied: | Yes | MSF method: | Method based |
| Peak ground acceleration: | 0.29 | Unit weight calculation: | Based on SBT | $K_\sigma$ applied: | Yes | | |

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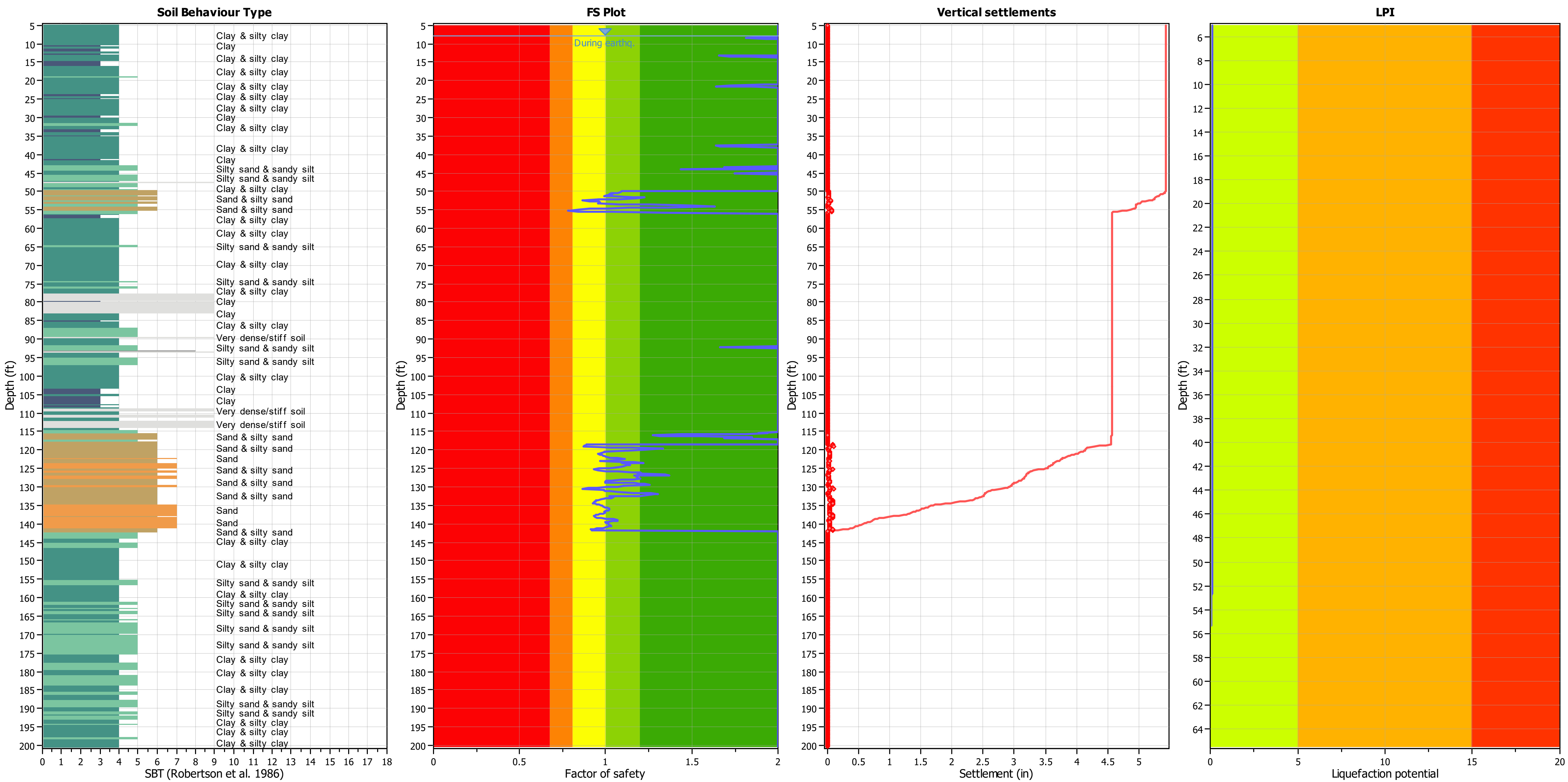
**Project:** DCA Liquefaction Evaluation

**Location:**

**CPT: King Is_DCEA1-CPT-022**

Total depth: 200.30 ft




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Analysis method: | NCEER (1998) | G.W.T. (in-situ): | 1.00 ft | Use fill: | No | Clay like behavior applied: | Sands only |
| Fines correction method: | NCEER (1998) | G.W.T. (earthq.): | 8.00 ft | Fill height: | N/A | Limit depth applied: | No |
| Points to test: | Based on Ic value | Average results interval: | 3 | Fill weight: | N/A | Limit depth: | N/A |
| Earthquake magnitude $M_w$: | 6.70 | Ic cut-off value: | 2.60 | Trans. detect. applied: | Yes | MSF method: | Method based |
| Peak ground acceleration: | 0.27 | Unit weight calculation: | Based on SBT | $K_\sigma$ applied: | Yes | | |

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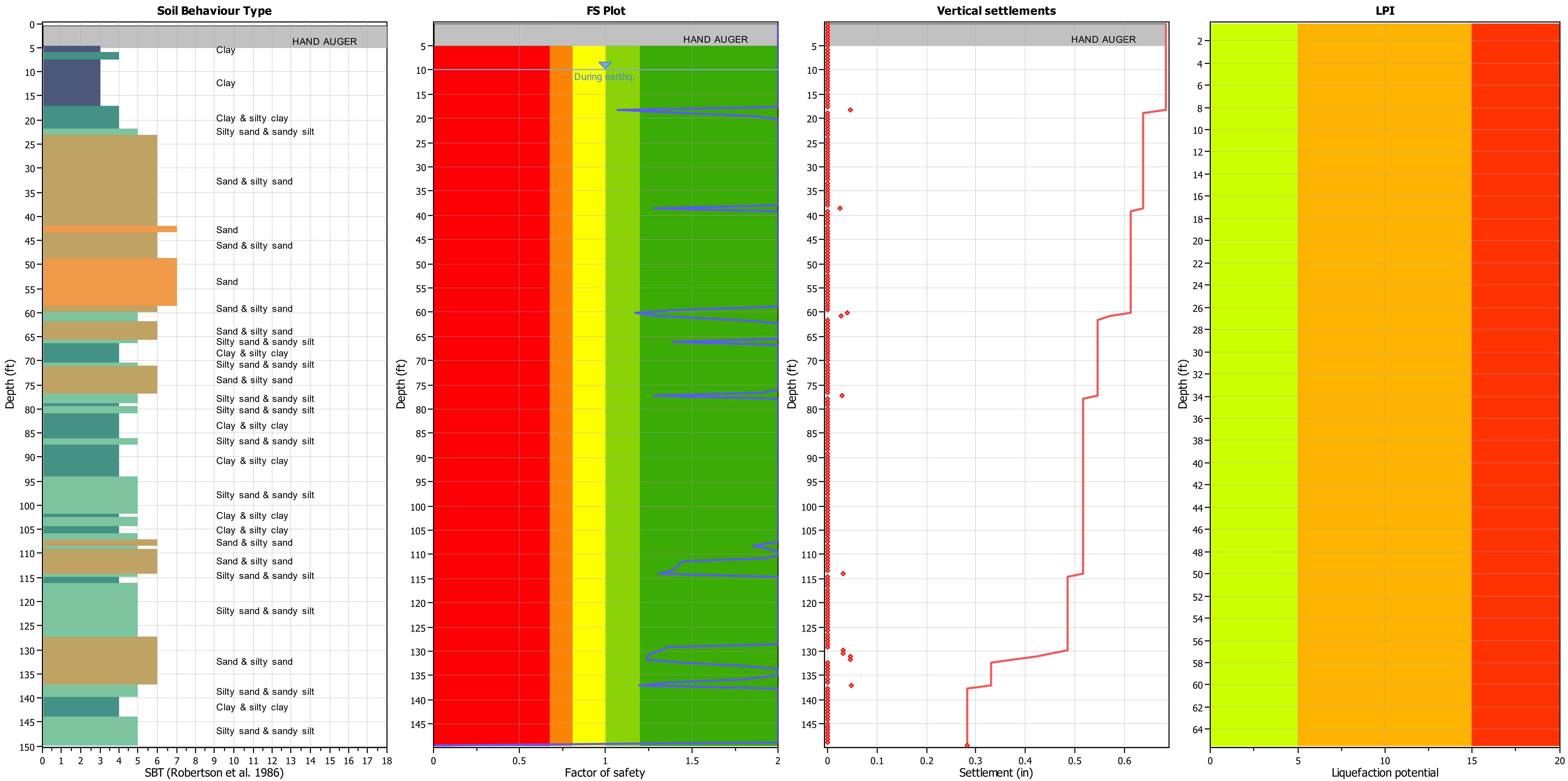
**Project:** DCA Liquefaction Evaluation
**Location:**

**CPT: Lower Jones Tract_EBMUD-MWH-CPT-05**
Total depth: 149.44 ft




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Analysis method: | NCEER (1998) | G.W.T. (in-situ): | 0.00 ft | Use fill: | No | Clay like behavior applied: | Sands only |
| Fines correction method: | NCEER (1998) | G.W.T. (earthq.): | 10.00 ft | Fill height: | N/A | Limit depth applied: | No |
| Points to test: | Based on Ic value | Average results interval: | 3 | Fill weight: | N/A | Limit depth: | N/A |
| Earthquake magnitude $M_w$: | 6.80 | Ic cut-off value: | 2.60 | Trans. detect. applied: | Yes | MSF method: | Method based |
| Peak ground acceleration: | 0.21 | Unit weight calculation: | Based on SBT | $K_\sigma$ applied: | Yes | | |

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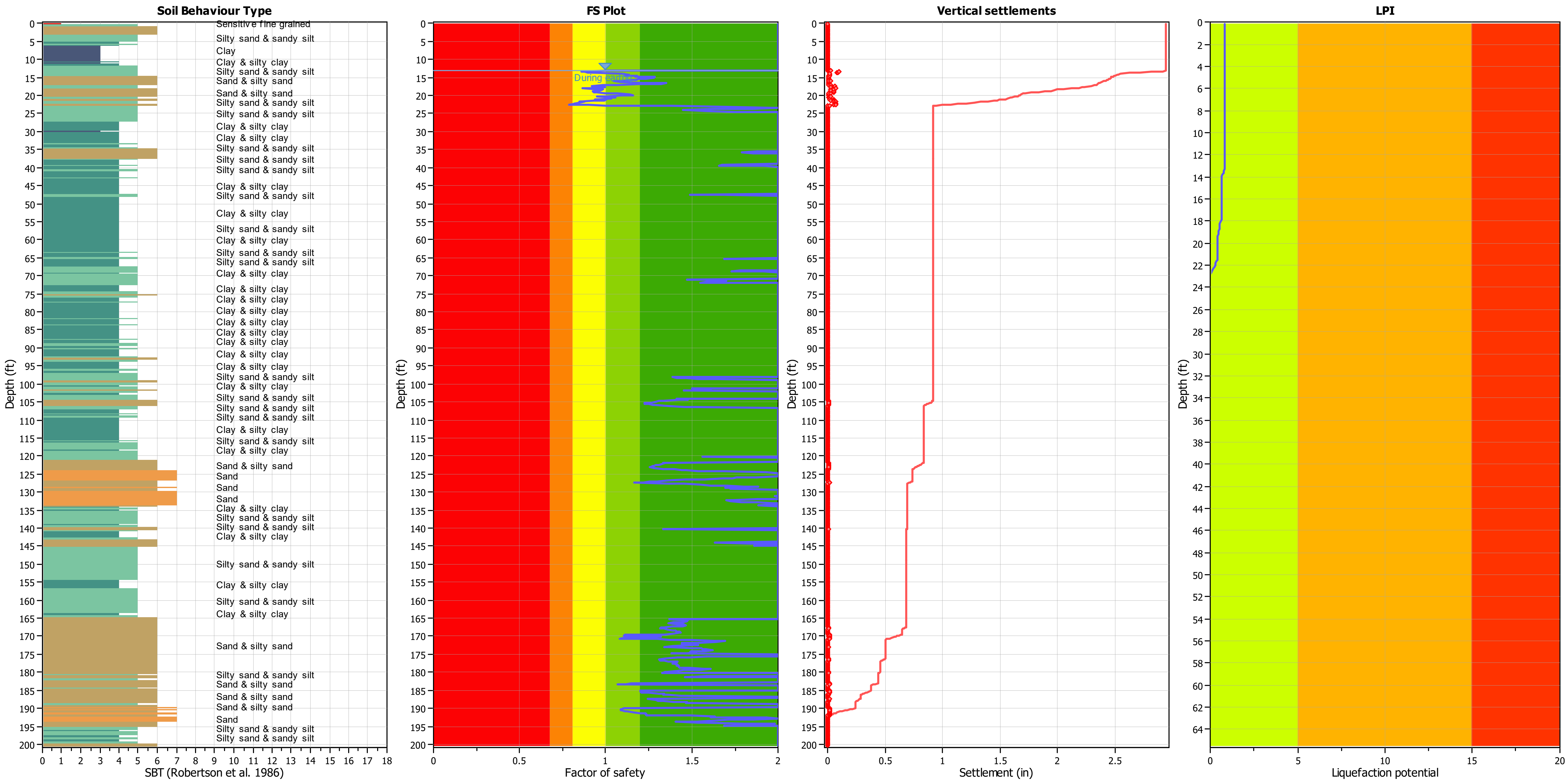
**Project:** DCA Liquefaction Evaluation

**Location:**

**CPT: Lower Roberts Is_DCE-CPT-023**

Total depth: 200.30 ft




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Analysis method: | NCEER (1998) | G.W.T. (in-situ): | 0.00 ft | Use fill: | No | Clay like behavior applied: | Sands only |
| Fines correction method: | NCEER (1998) | G.W.T. (earthq.): | 13.00 ft | Fill height: | N/A | Limit depth applied: | No |
| Points to test: | Based on Ic value | Average results interval: | 3 | Fill weight: | N/A | Limit depth: | N/A |
| Earthquake magnitude $M_w$: | 6.70 | Ic cut-off value: | 2.60 | Trans. detect. applied: | Yes | MSF method: | Method based |
| Peak ground acceleration: | 0.20 | Unit weight calculation: | Based on SBT | $K_\sigma$ applied: | Yes | | |

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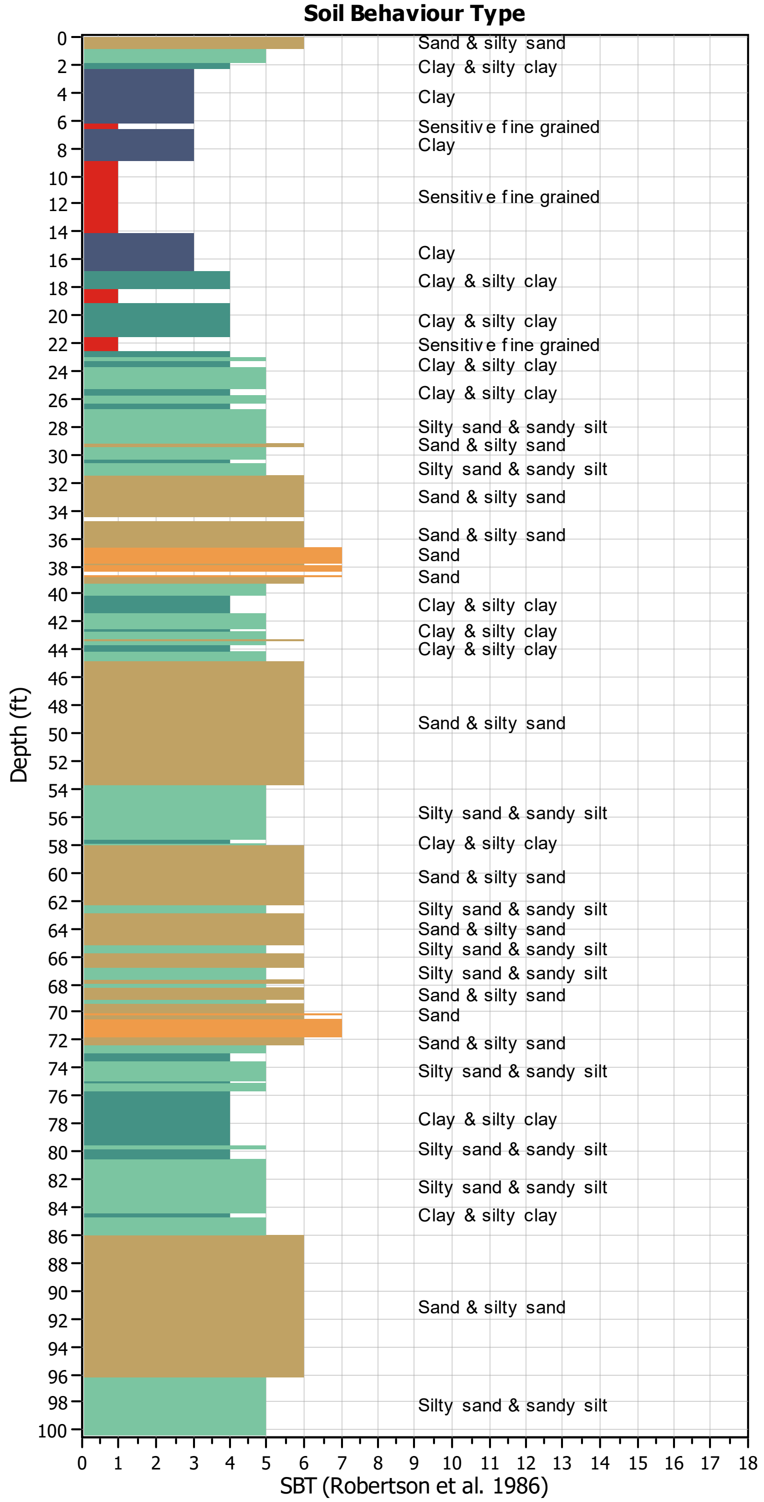
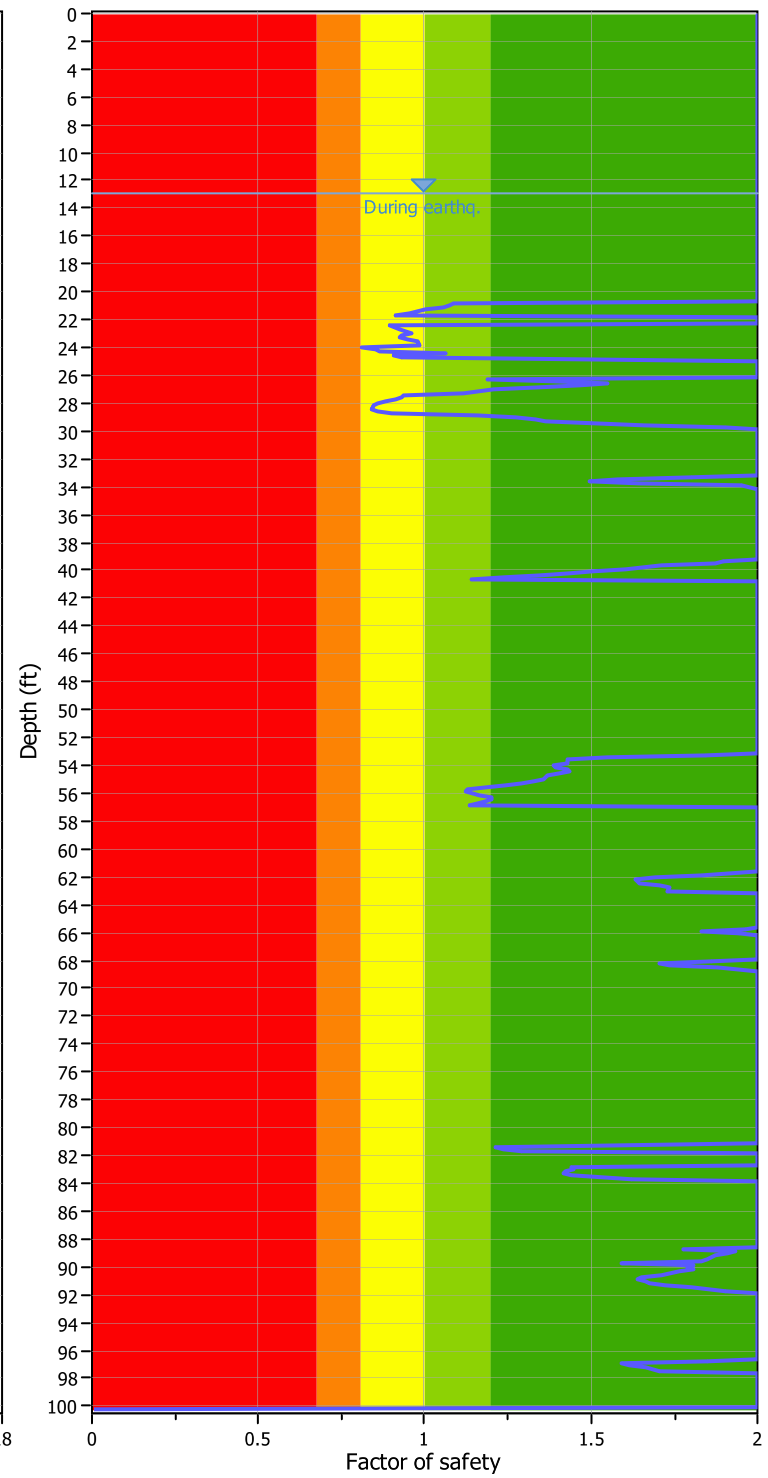
**Project: DCA Liquefaction Evaluation**
**Location:**

**CPT: Lower Roberts Is_DCE-CPT-024**
Total depth: 100.23 ft

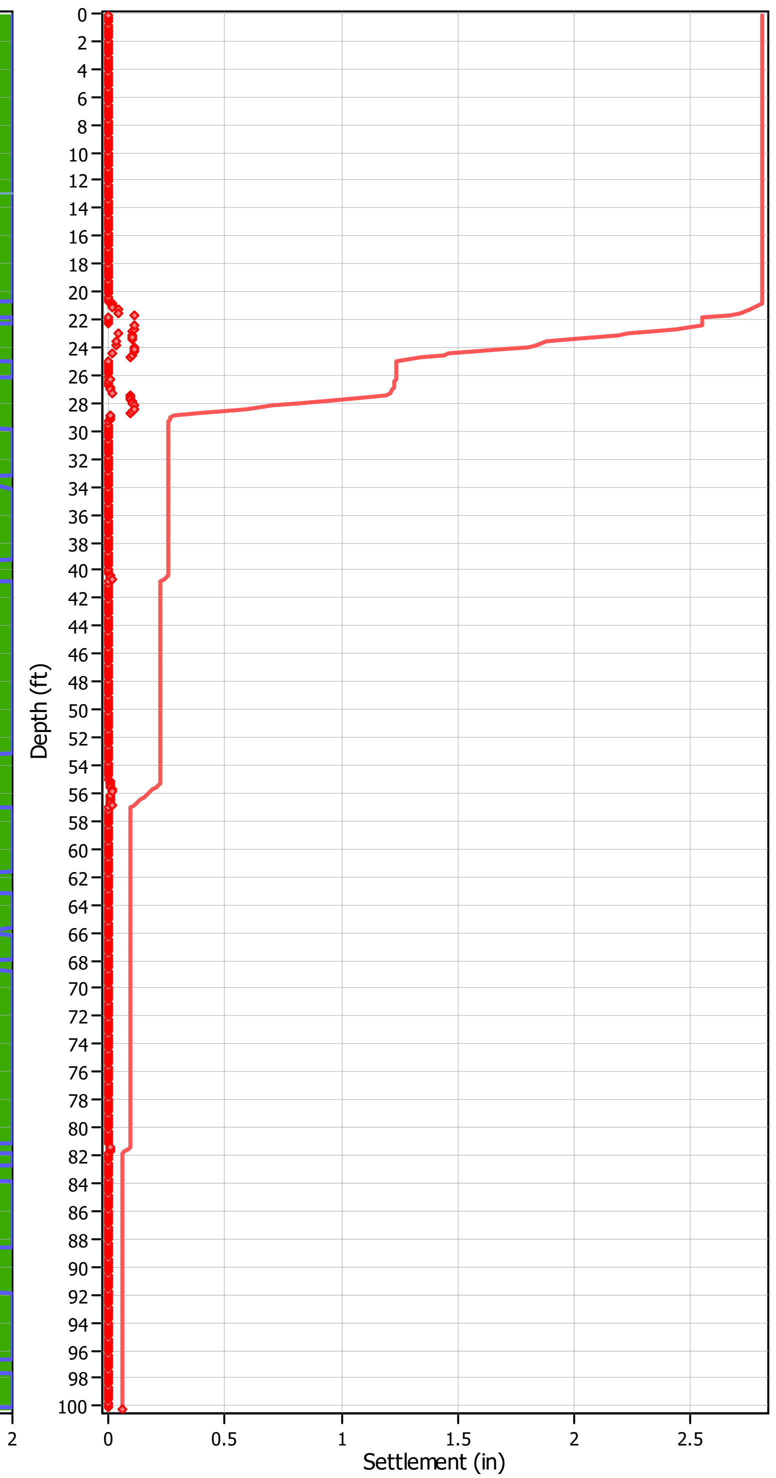
**Soil Behaviour Type**



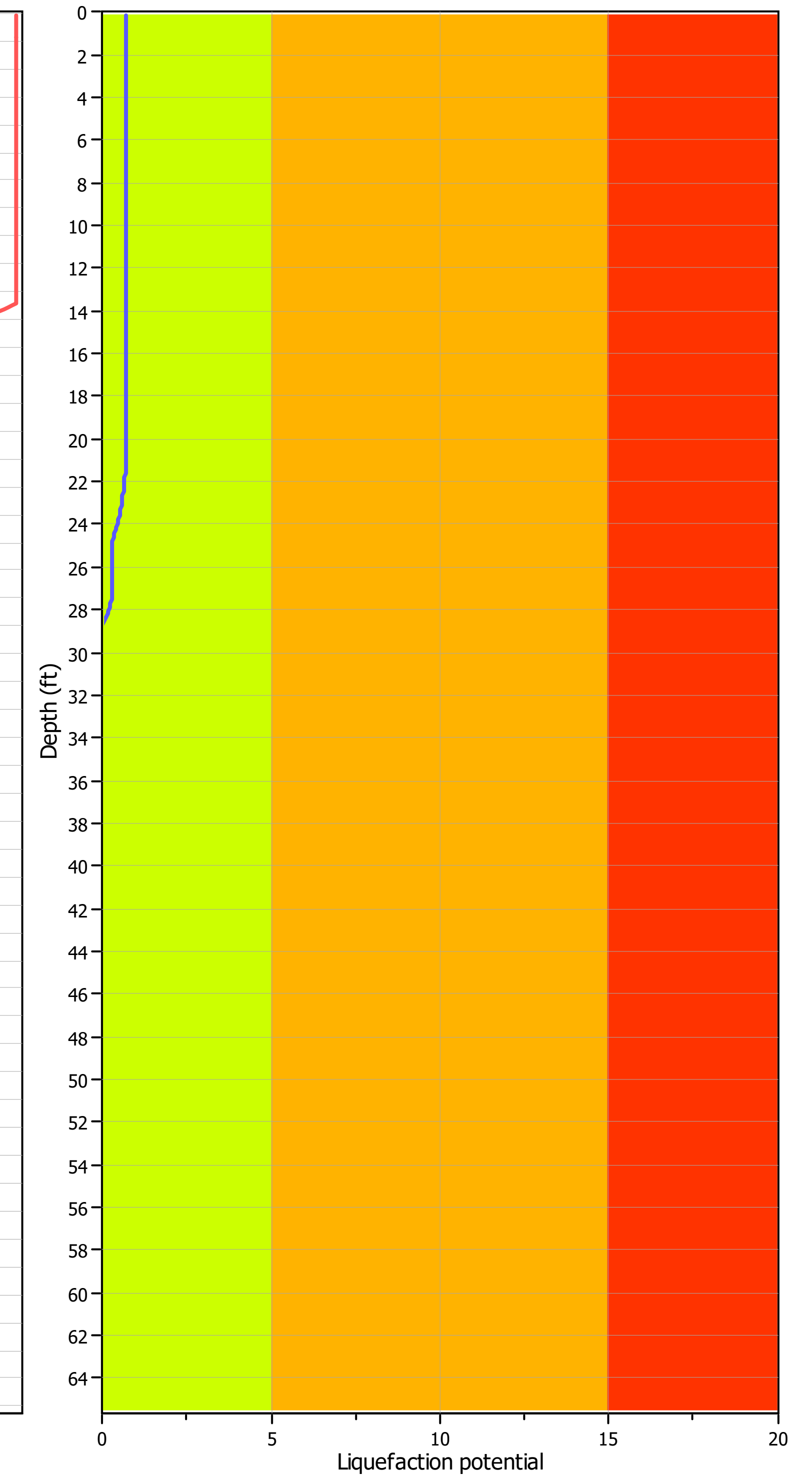

**FS Plot**




**Vertical settlements**




**LPI**




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Analysis method: | NCEER (1998) | G.W.T. (in-situ): | 1.00 ft | Use fill: | No | Clay like behavior applied: | Sands only |
| Fines correction method: | NCEER (1998) | G.W.T. (earthq.): | 13.00 ft | Fill height: | N/A | Limit depth applied: | No |
| Points to test: | Based on Ic value | Average results interval: | 3 | Fill weight: | N/A | Limit depth: | N/A |
| Earthquake magnitude $M_w$: | 6.70 | Ic cut-off value: | 2.60 | Trans. detect. applied: | Yes | MSF method: | Method based |
| Peak ground acceleration: | 0.20 | Unit weight calculation: | Based on SBT | $K_\sigma$ applied: | Yes | | |

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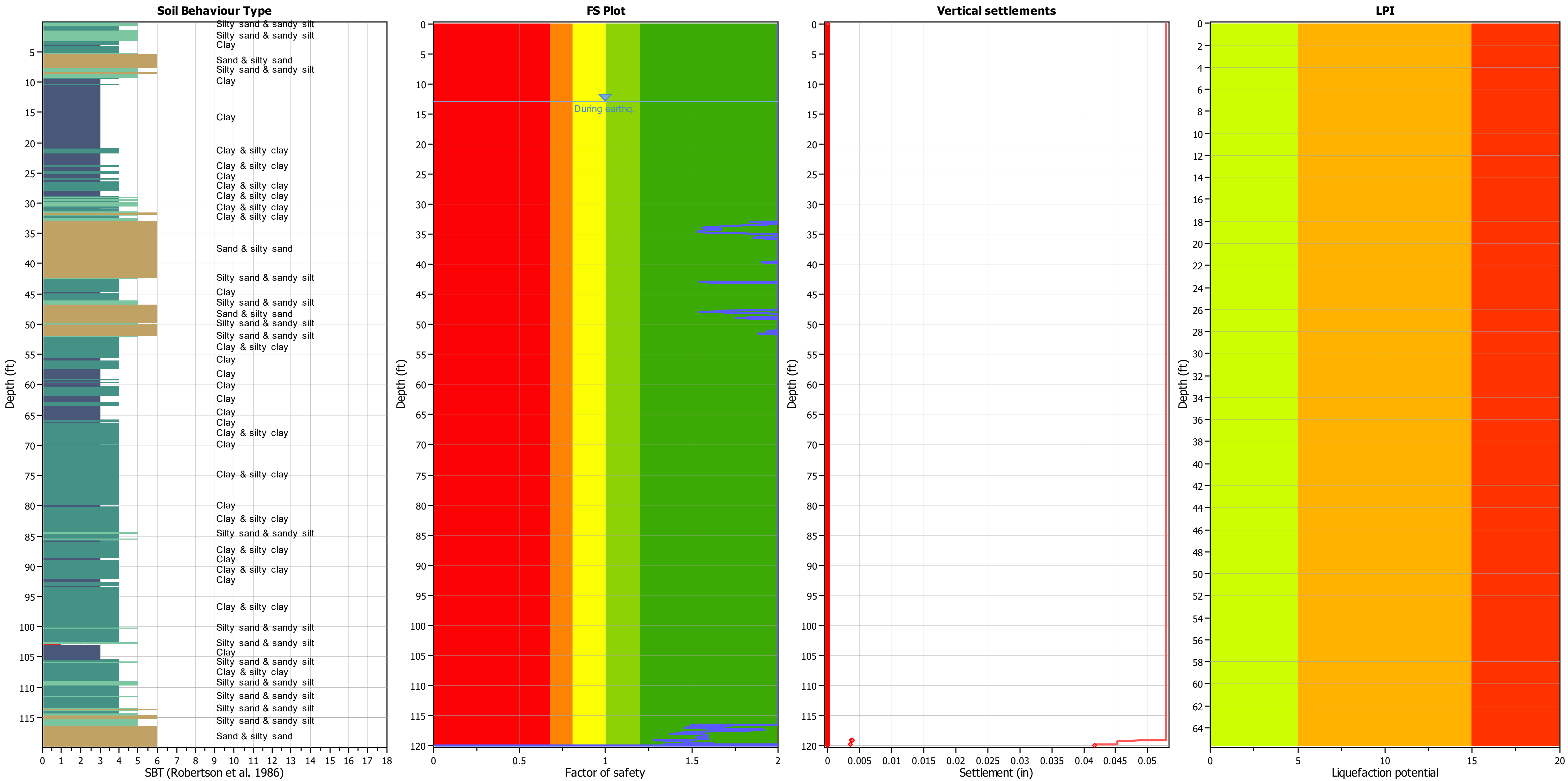
**Project: DCA Liquefaction Evaluation** | **CPT: Lower Roberts Is_DCEA1-CPT-026**
**Location:** | Total depth: 119.98 ft




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Analysis method: | NCEER (1998) | G.W.T. (in-situ): | 1.00 ft | Use fill: | No | Clay like behavior applied: | Sands only |
| Fines correction method: | NCEER (1998) | G.W.T. (earthq.): | 13.00 ft | Fill height: | N/A | Limit depth applied: | No |
| Points to test: | Based on Ic value | Average results interval: | 3 | Fill weight: | N/A | Limit depth: | N/A |
| Earthquake magnitude $M_w$: | 6.70 | Ic cut-off value: | 2.60 | Trans. detect. applied: | Yes | MSF method: | Method based |
| Peak ground acceleration: | 0.20 | Unit weight calculation: | Based on SBT | $K_\sigma$ applied: | Yes | | |

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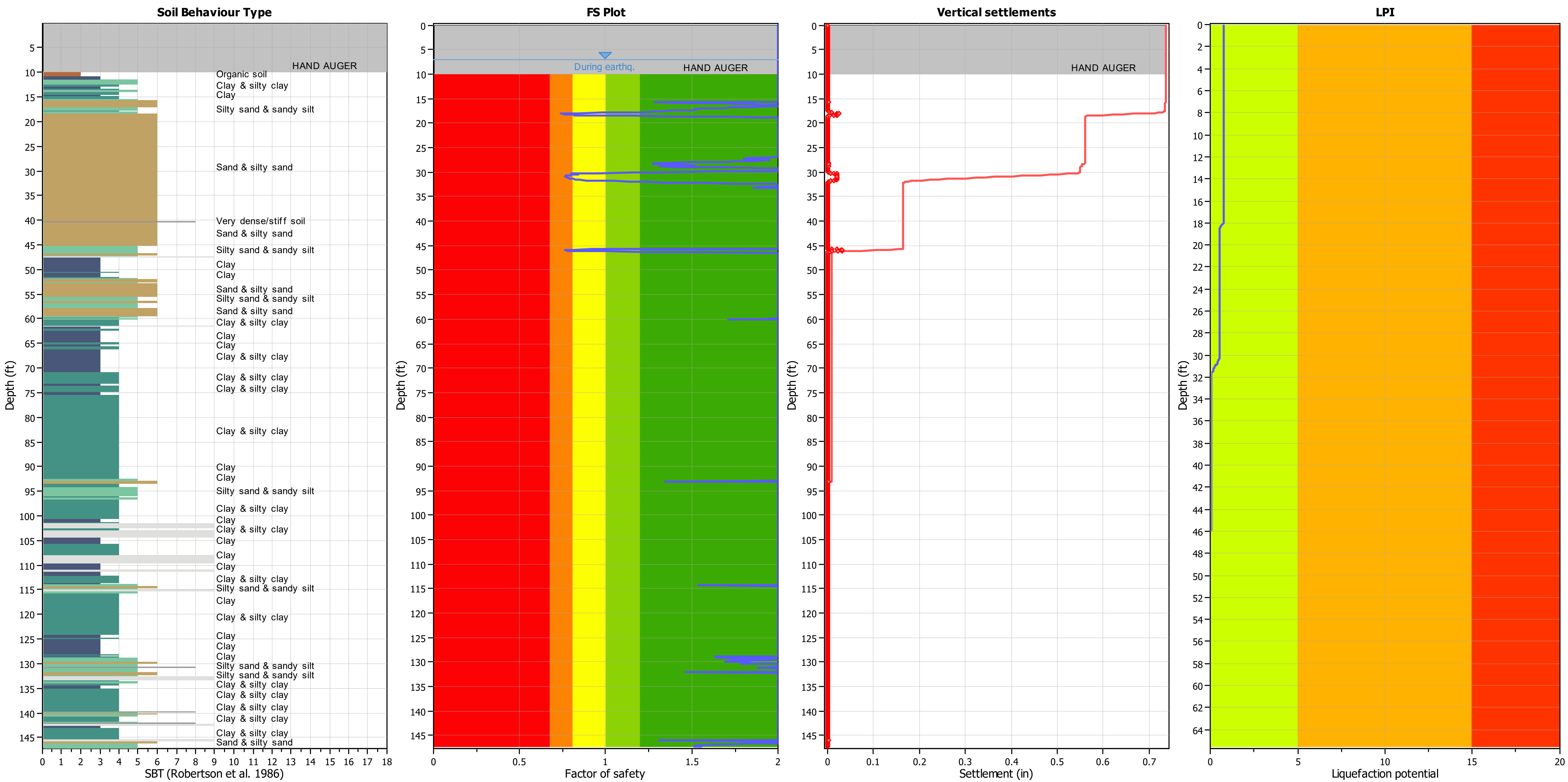
**Project:** DCA Liquefaction Evaluation
**Location:**

**CPT: Mandeville Is_DCA-CPT-007**
Total depth: 147.23 ft




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Analysis method: | NCEER (1998) | G.W.T. (in-situ): | 0.00 ft | Use fill: | No | Clay like behavior applied: | Sands only |
| Fines correction method: | NCEER (1998) | G.W.T. (earthq.): | 7.00 ft | Fill height: | N/A | Limit depth applied: | No |
| Points to test: | Based on Ic value | Average results interval: | 3 | Fill weight: | N/A | Limit depth: | N/A |
| Earthquake magnitude $M_w$: | 6.60 | Ic cut-off value: | 2.60 | Trans. detect. applied: | Yes | MSF method: | Method based |
| Peak ground acceleration: | 0.30 | Unit weight calculation: | Based on SBT | $K_o$ applied: | Yes | | |

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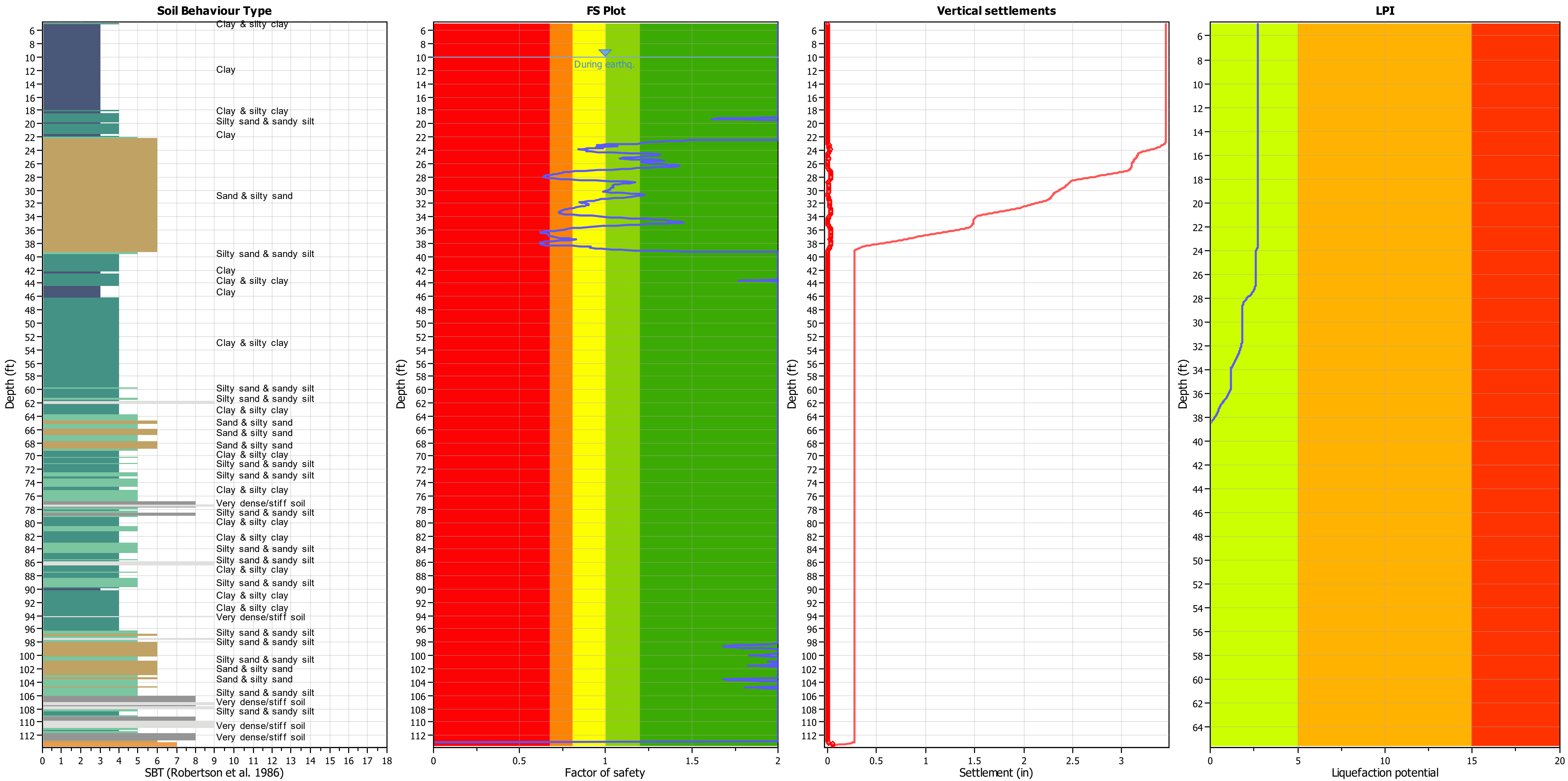
**Project:** **DCA Liquefaction Evaluation**
**Location:**

**CPT: New Hope E_DCEA1-CPT-005**
Total depth: 113.52 ft




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Analysis method: | NCEER (1998) | G.W.T. (in-situ): | 1.00 ft | Use fill: | No | Clay like behavior applied: | Sands only |
| Fines correction method: | NCEER (1998) | G.W.T. (earthq.): | 10.00 ft | Fill height: | N/A | Limit depth applied: | No |
| Points to test: | Based on Ic value | Average results interval: | 3 | Fill weight: | N/A | Limit depth: | N/A |
| Earthquake magnitude $M_w$: | 6.60 | Ic cut-off value: | 2.60 | Trans. detect. applied: | Yes | MSF method: | Method based |
| Peak ground acceleration: | 0.23 | Unit weight calculation: | Based on SBT | $K_\sigma$ applied: | Yes | | |

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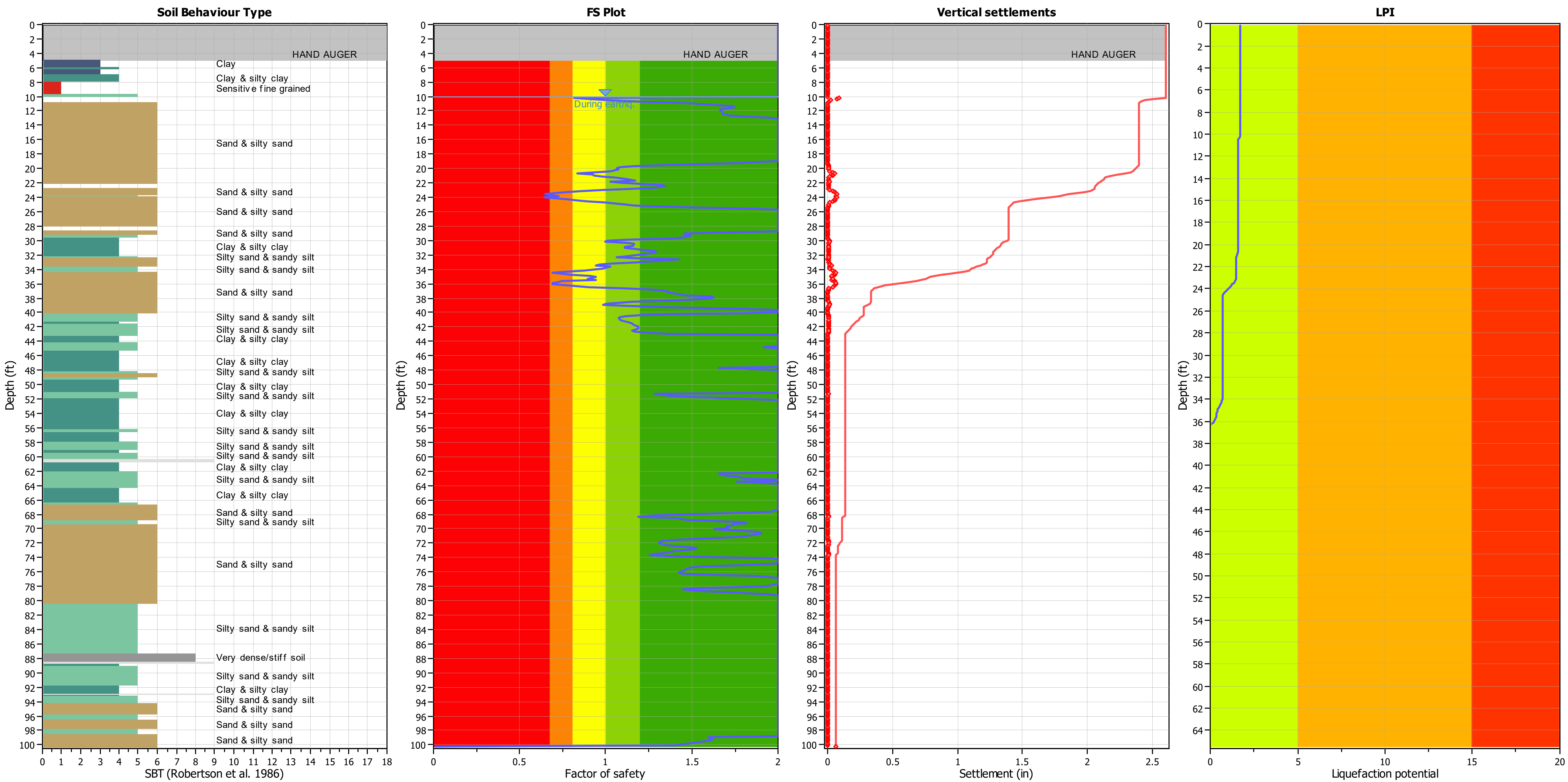
**Project:** DCA Liquefaction Evaluation

**Location:**

**CPT: New Hope E_DCE-CPT-013**

Total depth: 100.23 ft




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Analysis method: | NCEER (1998) | G.W.T. (in-situ): | 0.00 ft | Use fill: | No | Clay like behavior applied: | Sands only |
| Fines correction method: | NCEER (1998) | G.W.T. (earthq.): | 10.00 ft | Fill height: | N/A | Limit depth applied: | No |
| Points to test: | Based on Ic value | Average results interval: | 3 | Fill weight: | N/A | Limit depth: | N/A |
| Earthquake magnitude $M_w$: | 6.60 | Ic cut-off value: | 2.60 | Trans. detect. applied: | Yes | MSF method: | Method based |
| Peak ground acceleration: | 0.23 | Unit weight calculation: | Based on SBT | $K_\sigma$ applied: | Yes | | |

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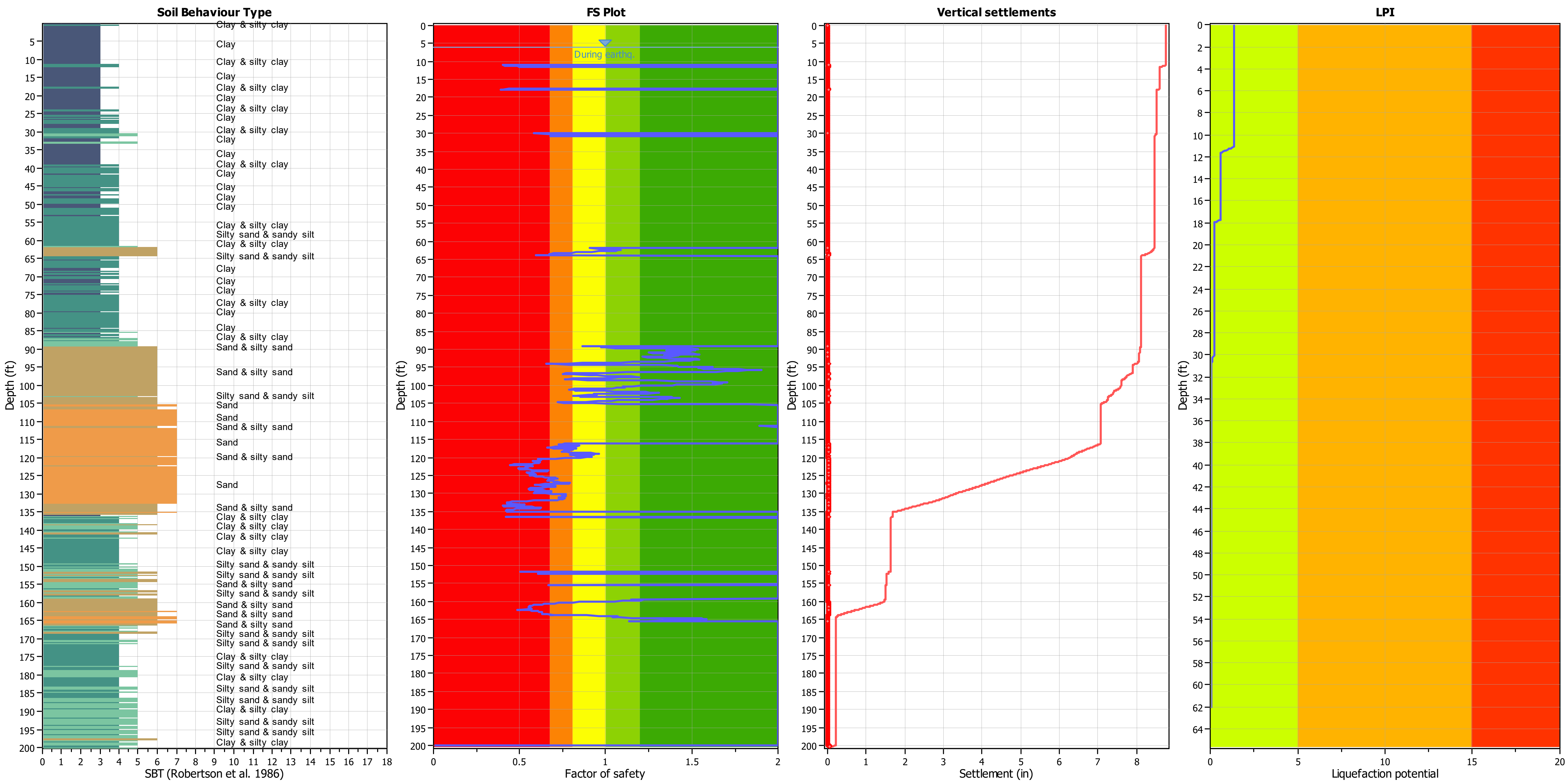
**Project:** DCA Liquefaction Evaluation
**Location:**

**CPT: Byron_DCSOF-CPT-004**
Total depth: 200.28 ft




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Analysis method: | NCEER (1998) | G.W.T. (in-situ): | 1.00 ft | Use fill: | No | Clay like behavior applied: | Sands only |
| Fines correction method: | NCEER (1998) | G.W.T. (earthq.): | 6.00 ft | Fill height: | N/A | Limit depth applied: | No |
| Points to test: | Based on Ic value | Average results interval: | 3 | Fill weight: | N/A | Limit depth: | N/A |
| Earthquake magnitude $M_w$: | 6.90 | Ic cut-off value: | 2.60 | Trans. detect. applied: | Yes | MSF method: | Method based |
| Peak ground acceleration: | 0.58 | Unit weight calculation: | Based on SBT | $K_\sigma$ applied: | Yes | | |

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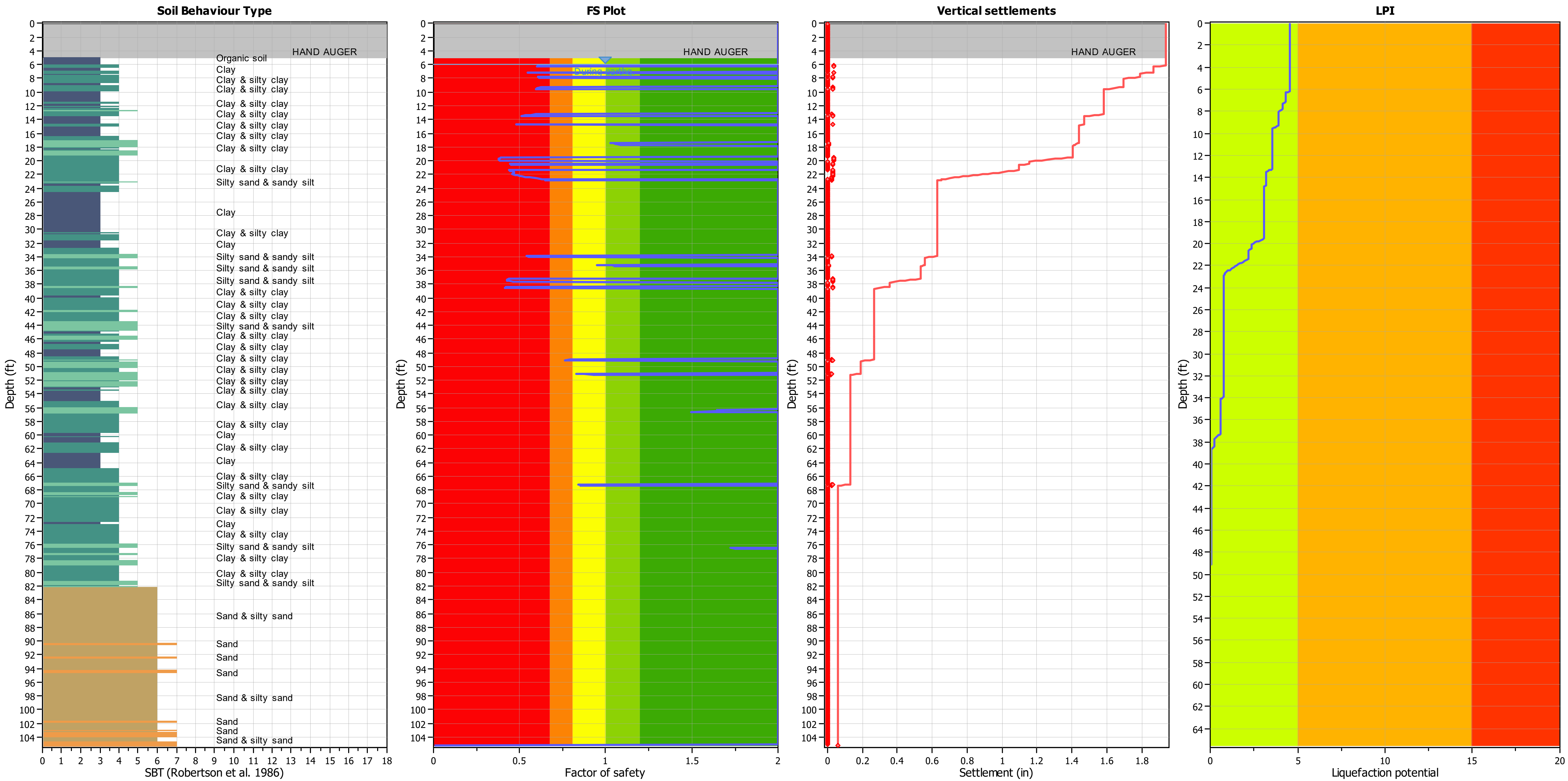
**Project:** DCA Liquefaction Evaluation

**Location:**

**CPT: Southern Forebay N_DCC-CPT-007**

Total depth: 105.23 ft




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Analysis method: | NCEER (1998) | G.W.T. (in-situ): | 0.00 ft | Use fill: | No | Clay like behavior applied: | Sands only |
| Fines correction method: | NCEER (1998) | G.W.T. (earthq.): | 6.00 ft | Fill height: | N/A | Limit depth applied: | No |
| Points to test: | Based on Ic value | Average results interval: | 3 | Fill weight: | N/A | Limit depth: | N/A |
| Earthquake magnitude $M_w$: | 6.70 | Ic cut-off value: | 2.60 | Trans. detect. applied: | Yes | MSF method: | Method based |
| Peak ground acceleration: | 0.33 | Unit weight calculation: | Based on SBT | $K_\sigma$ applied: | Yes | | |

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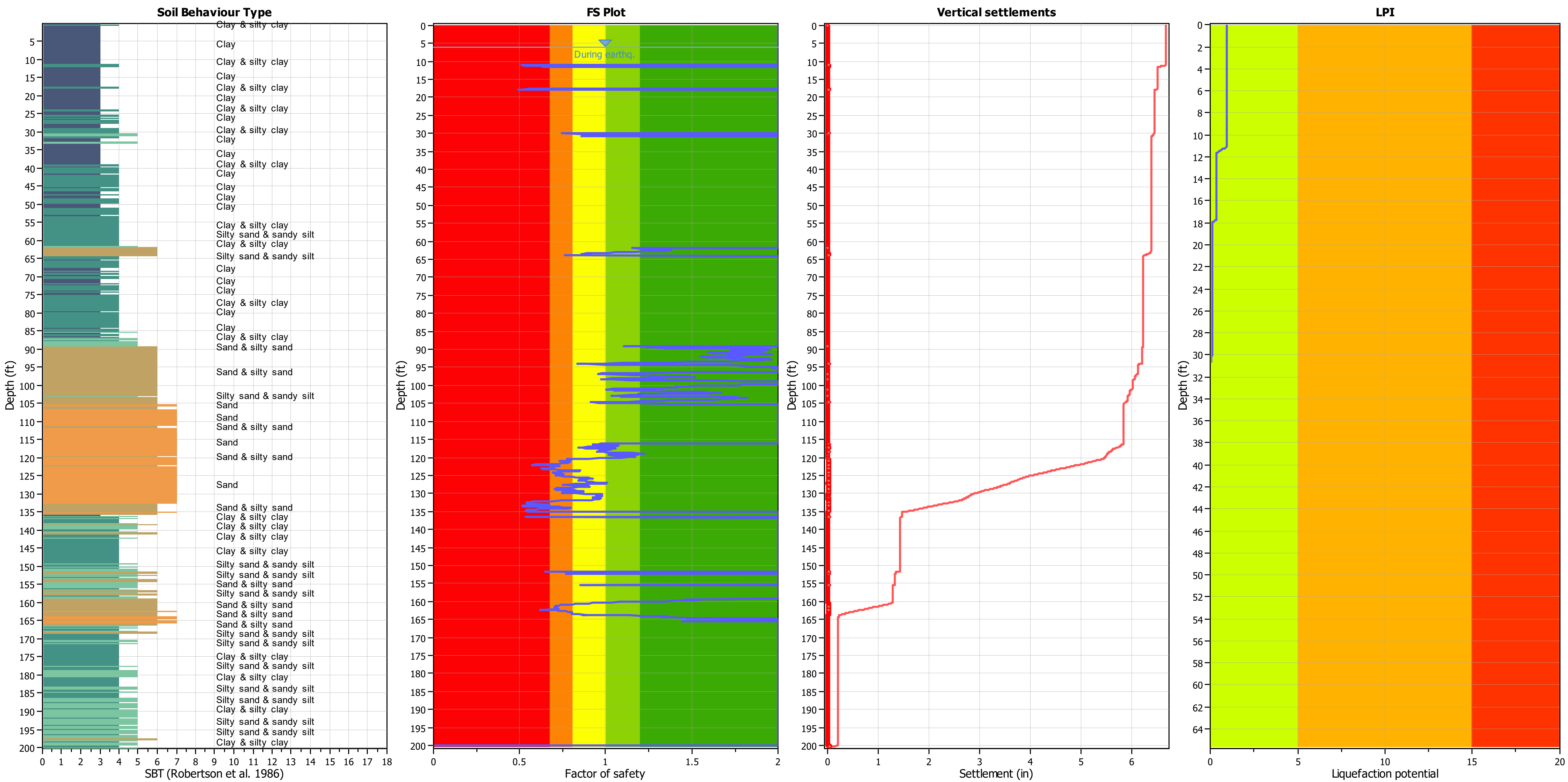
**Project: DCA Liquefaction Evaluation** | **CPT: Southern Forebay N_DCSOF-CPT-004**

**Location:** | Total depth: 200.28 ft




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Analysis method: | NCEER (1998) | G.W.T. (in-situ): | 1.00 ft | Use fill: | No | Clay like behavior applied: | Sands only |
| Fines correction method: | NCEER (1998) | G.W.T. (earthq.): | 6.00 ft | Fill height: | N/A | Limit depth applied: | No |
| Points to test: | Based on Ic value | Average results interval: | 3 | Fill weight: | N/A | Limit depth: | N/A |
| Earthquake magnitude $M_w$: | 6.70 | Ic cut-off value: | 2.60 | Trans. detect. applied: | Yes | MSF method: | Method based |
| Peak ground acceleration: | 0.33 | Unit weight calculation: | Based on SBT | $K_\sigma$ applied: | Yes | | |

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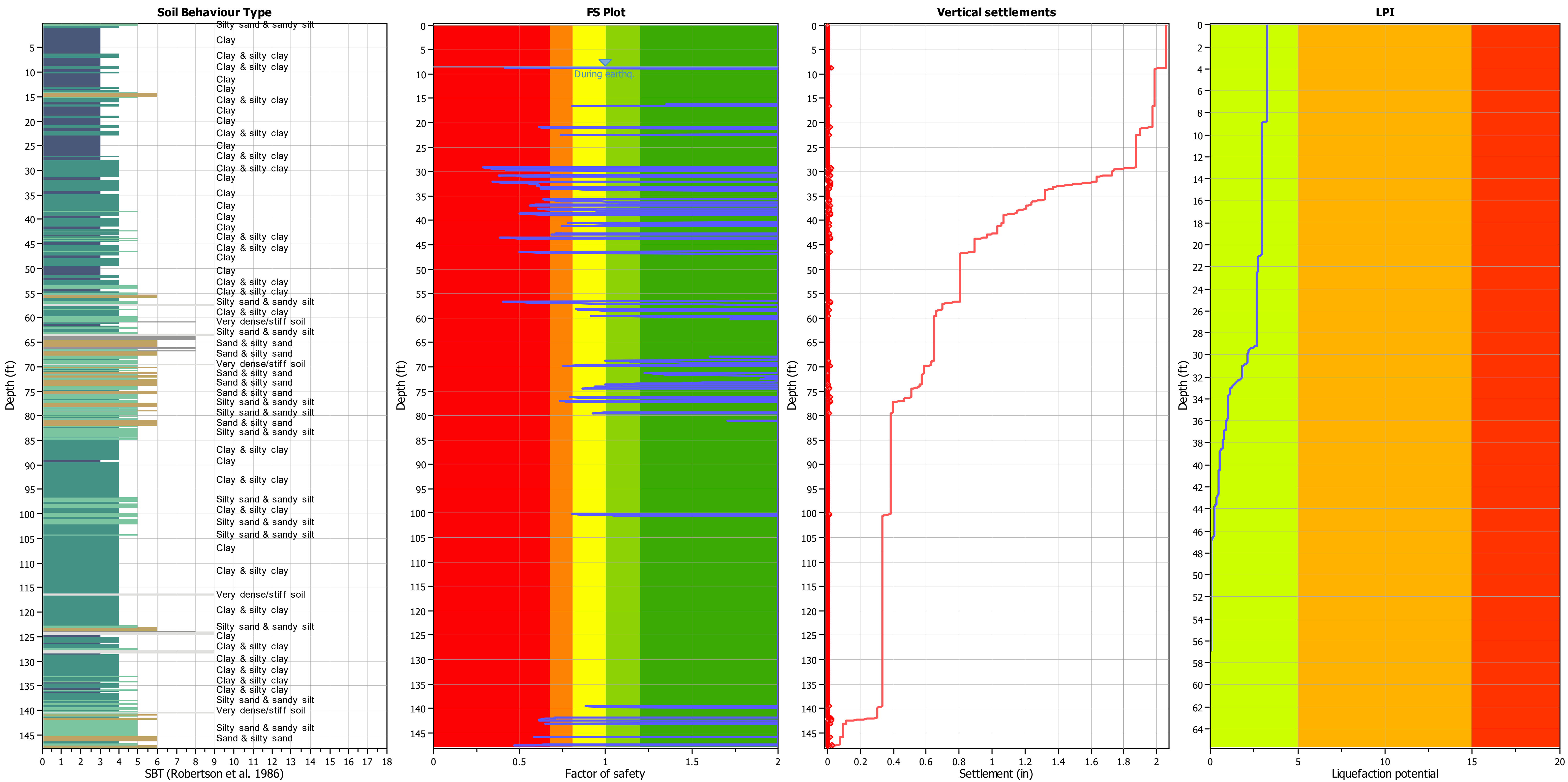
**Project:** DCA Liquefaction Evaluation

**Location:**

**CPT: Southern Forebay S_DCSOF-CPT-048**

Total depth: 147.80 ft




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Analysis method: | NCEER (1998) | G.W.T. (in-situ): | 1.00 ft | Use fill: | No | Clay like behavior applied: | Sands only |
| Fines correction method: | NCEER (1998) | G.W.T. (earthq.): | 8.50 ft | Fill height: | N/A | Limit depth applied: | No |
| Points to test: | Based on Ic value | Average results interval: | 3 | Fill weight: | N/A | Limit depth: | N/A |
| Earthquake magnitude $M_w$: | 6.90 | Ic cut-off value: | 2.60 | Trans. detect. applied: | Yes | MSF method: | Method based |
| Peak ground acceleration: | 0.51 | Unit weight calculation: | Based on SBT | $K_\sigma$ applied: | Yes | | |

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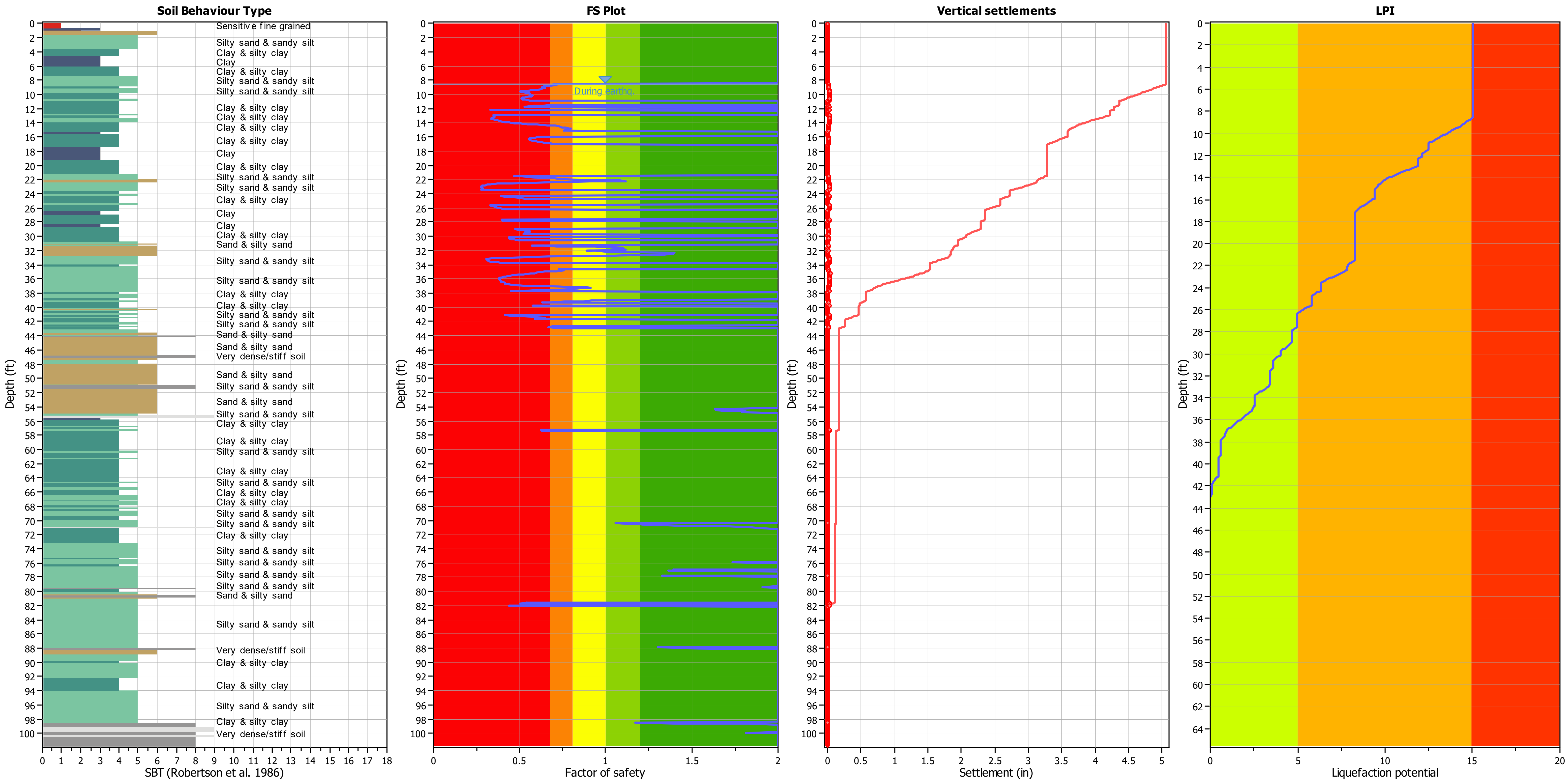
**Project:** DCA Liquefaction Evaluation

**Location:**

**CPT: Southern Forebay S_WTF-SCPT-007**

Total depth: 101.71 ft




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Analysis method: | NCEER (1998) | G.W.T. (in-situ): | 1.00 ft | Use fill: | No | Clay like behavior applied: | Sands only |
| Fines correction method: | NCEER (1998) | G.W.T. (earthq.): | 8.50 ft | Fill height: | N/A | Limit depth applied: | No |
| Points to test: | Based on Ic value | Average results interval: | 3 | Fill weight: | N/A | Limit depth: | N/A |
| Earthquake magnitude $M_w$: | 6.90 | Ic cut-off value: | 2.60 | Trans. detect. applied: | Yes | MSF method: | Method based |
| Peak ground acceleration: | 0.51 | Unit weight calculation: | Based on SBT | $K_\sigma$ applied: | Yes | | |

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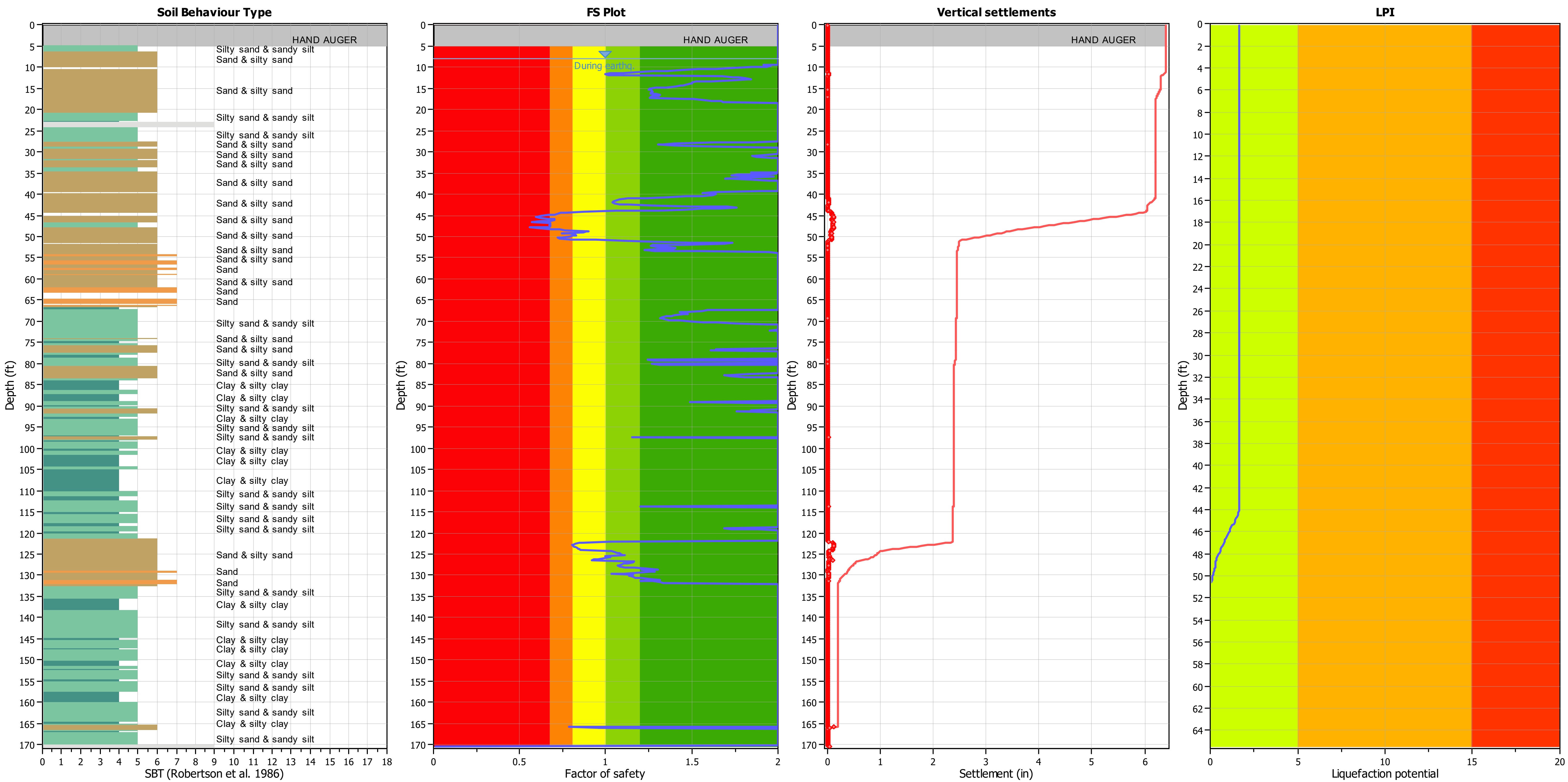
**Project:** DCA Liquefaction Evaluation

**Location:**

**CPT: Staten Is_DCA-CPT-002A**

Total depth: 170.44 ft




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Analysis method: | NCEER (1998) | G.W.T. (in-situ): | 0.00 ft | Use fill: | No | Clay like behavior applied: | Sands only |
| Fines correction method: | NCEER (1998) | G.W.T. (earthq.): | 8.00 ft | Fill height: | N/A | Limit depth applied: | No |
| Points to test: | Based on Ic value | Average results interval: | 3 | Fill weight: | N/A | Limit depth: | N/A |
| Earthquake magnitude $M_w$: | 6.55 | Ic cut-off value: | 2.60 | Trans. detect. applied: | Yes | MSF method: | Method based |
| Peak ground acceleration: | 0.27 | Unit weight calculation: | Based on SBT | $K_\sigma$ applied: | Yes | | |

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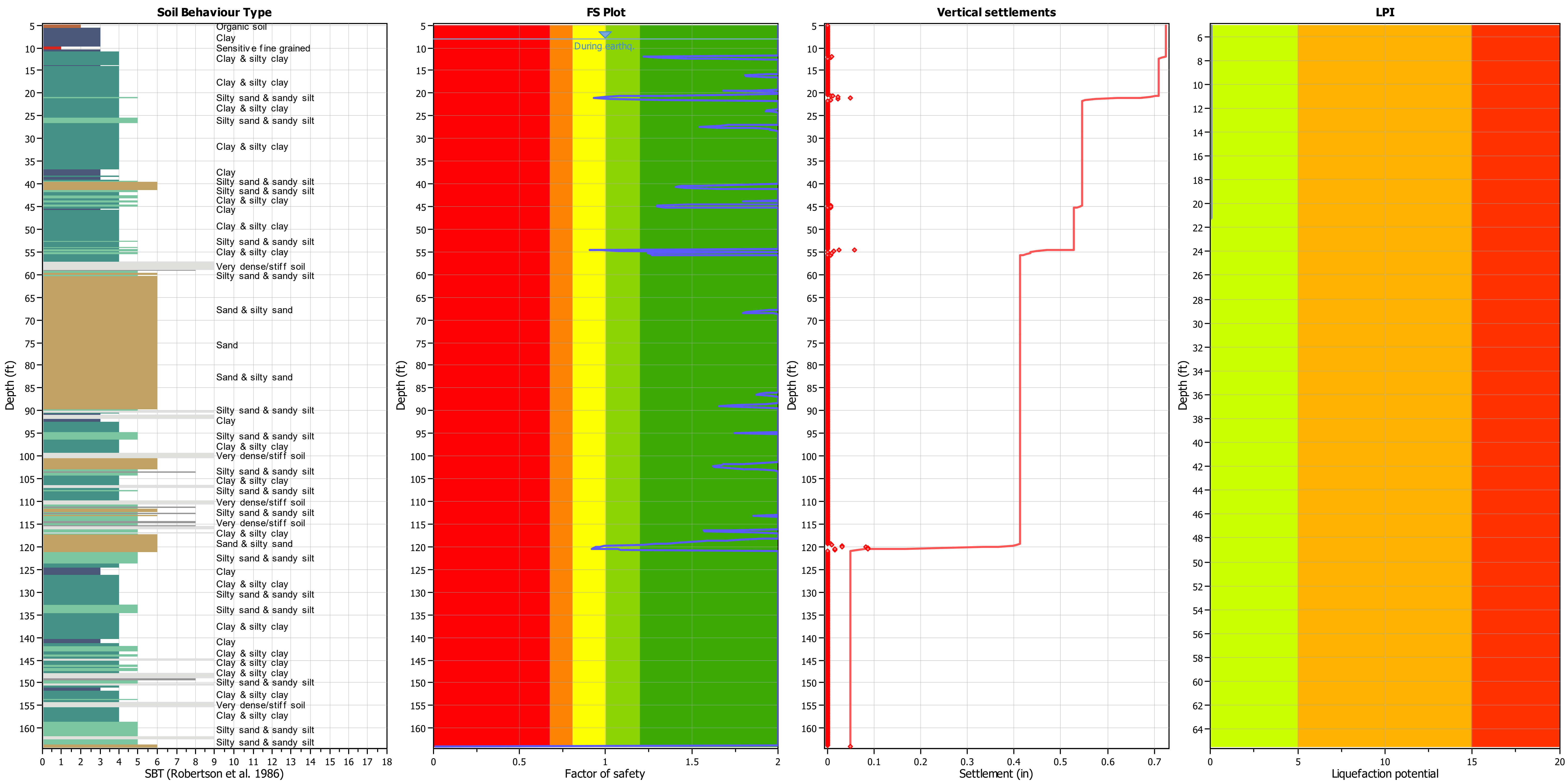
**Project:** DCA Liquefaction Evaluation

**Location:**

**CPT: Staten Is_DCCA1-CPT-033**

Total depth: 164.04 ft




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Analysis method: | NCEER (1998) | G.W.T. (in-situ): | 1.00 ft | Use fill: | No | Clay like behavior applied: | Sands only |
| Fines correction method: | NCEER (1998) | G.W.T. (earthq.): | 8.00 ft | Fill height: | N/A | Limit depth applied: | No |
| Points to test: | Based on Ic value | Average results interval: | 3 | Fill weight: | N/A | Limit depth: | N/A |
| Earthquake magnitude $M_w$: | 6.55 | Ic cut-off value: | 2.60 | Trans. detect. applied: | Yes | MSF method: | Method based |
| Peak ground acceleration: | 0.27 | Unit weight calculation: | Based on SBT | $K_\sigma$ applied: | Yes | | |

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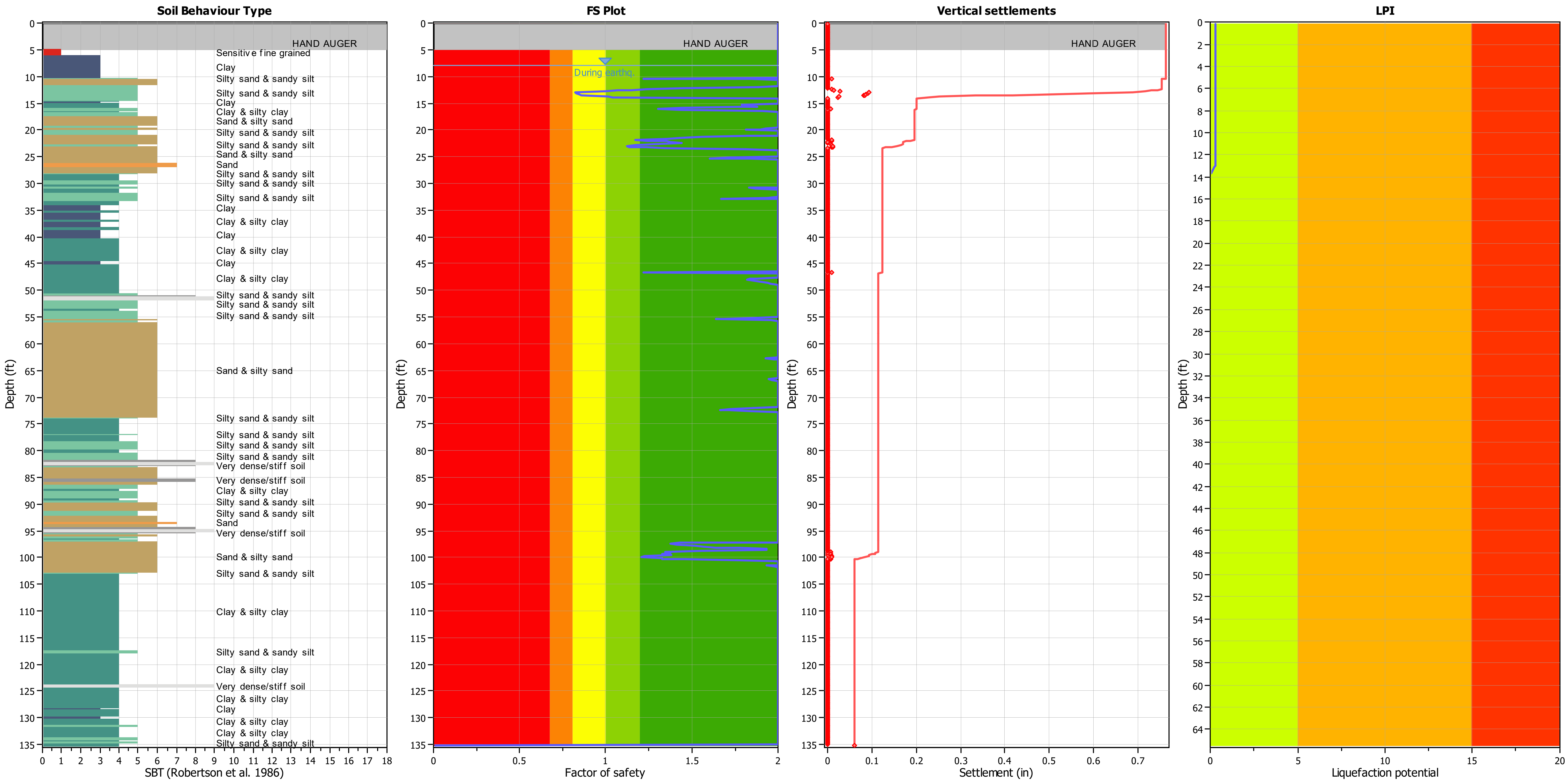
**Project:** DCA Liquefaction Evaluation
**Location:**

**CPT: Staten Is_DCT-CPT-007**
Total depth: 135.17 ft




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Analysis method: | NCEER (1998) | G.W.T. (in-situ): | 0.00 ft | Use fill: | No | Clay like behavior applied: | Sands only |
| Fines correction method: | NCEER (1998) | G.W.T. (earthq.): | 8.00 ft | Fill height: | N/A | Limit depth applied: | No |
| Points to test: | Based on Ic value | Average results interval: | 3 | Fill weight: | N/A | Limit depth: | N/A |
| Earthquake magnitude $M_w$: | 6.55 | Ic cut-off value: | 2.60 | Trans. detect. applied: | Yes | MSF method: | Method based |
| Peak ground acceleration: | 0.27 | Unit weight calculation: | Based on SBT | $K_\sigma$ applied: | Yes | | |

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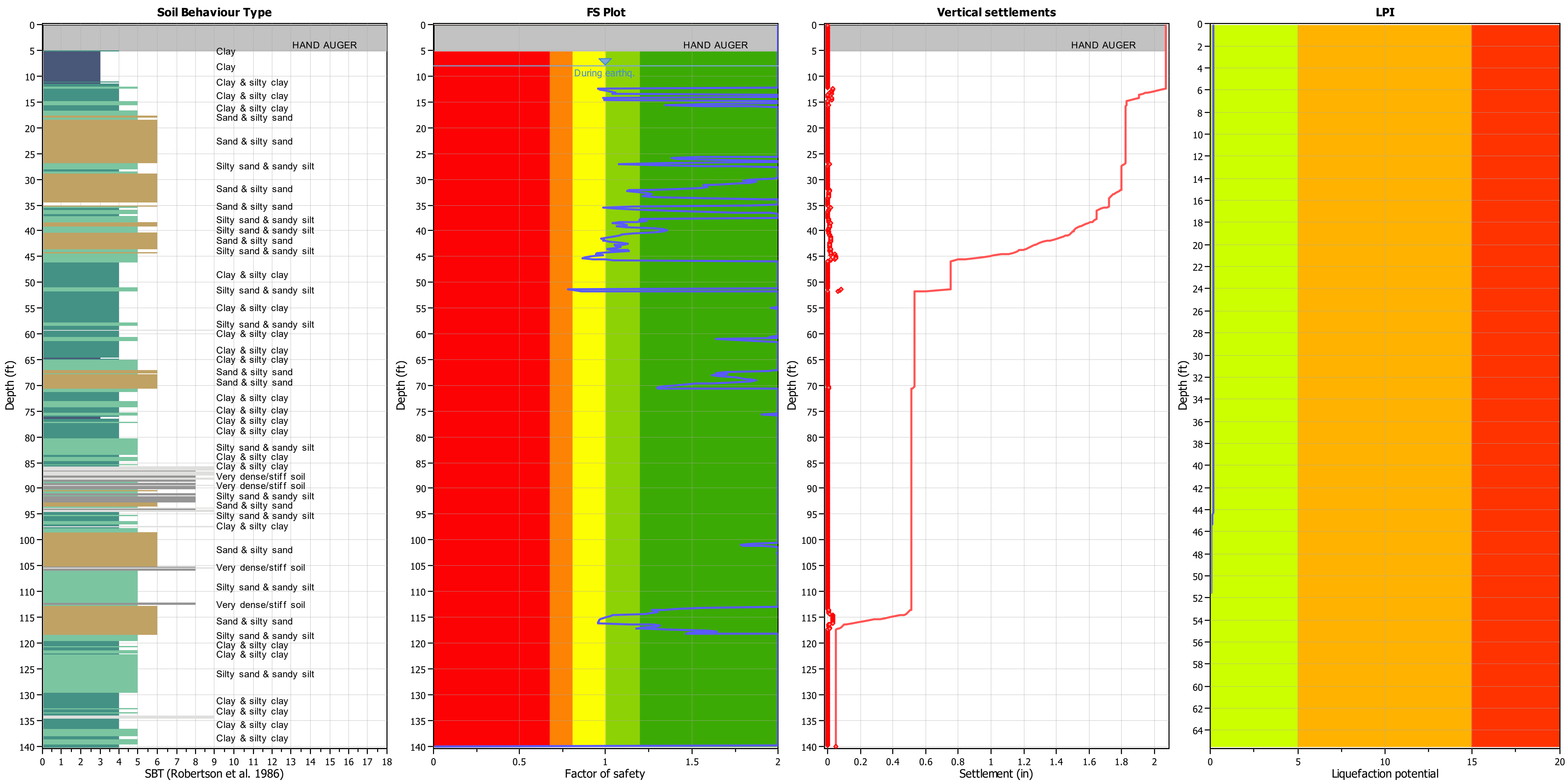
**Project:** DCA Liquefaction Evaluation
**Location:**

**CPT: Staten Is_DCT-CPT-009**
Total depth: 140.09 ft




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Analysis method: | NCEER (1998) | G.W.T. (in-situ): | 0.00 ft | Use fill: | No | Clay like behavior applied: | Sands only |
| Fines correction method: | NCEER (1998) | G.W.T. (earthq.): | 8.00 ft | Fill height: | N/A | Limit depth applied: | No |
| Points to test: | Based on Ic value | Average results interval: | 3 | Fill weight: | N/A | Limit depth: | N/A |
| Earthquake magnitude $M_w$: | 6.55 | Ic cut-off value: | 2.60 | Trans. detect. applied: | Yes | MSF method: | Method based |
| Peak ground acceleration: | 0.27 | Unit weight calculation: | Based on SBT | $K_\sigma$ applied: | Yes | | |

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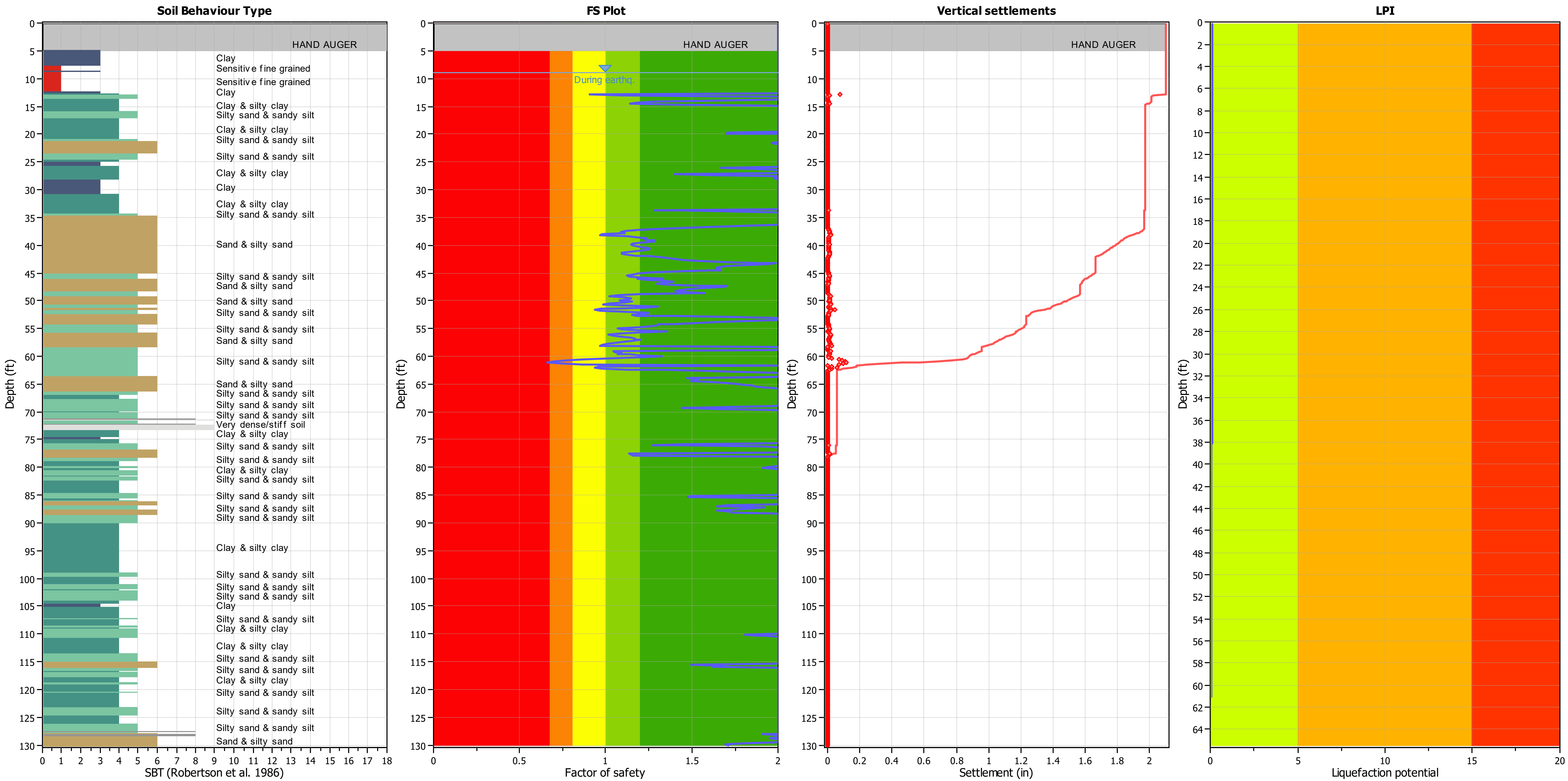
**Project:** **DCA Liquefaction Evaluation**

**Location:**

**CPT: Terminous Tract_DCT-CPT-013**

Total depth: 130.09 ft




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Analysis method: | NCEER (1998) | G.W.T. (in-situ): | 0.00 ft | Use fill: | No | Clay like behavior applied: | Sands only |
| Fines correction method: | NCEER (1998) | G.W.T. (earthq.): | 9.00 ft | Fill height: | N/A | Limit depth applied: | No |
| Points to test: | Based on Ic value | Average results interval: | 3 | Fill weight: | N/A | Limit depth: | N/A |
| Earthquake magnitude $M_w$: | 6.70 | Ic cut-off value: | 2.60 | Trans. detect. applied: | Yes | MSF method: | Method based |
| Peak ground acceleration: | 0.27 | Unit weight calculation: | Based on SBT | $K_\sigma$ applied: | Yes | | |

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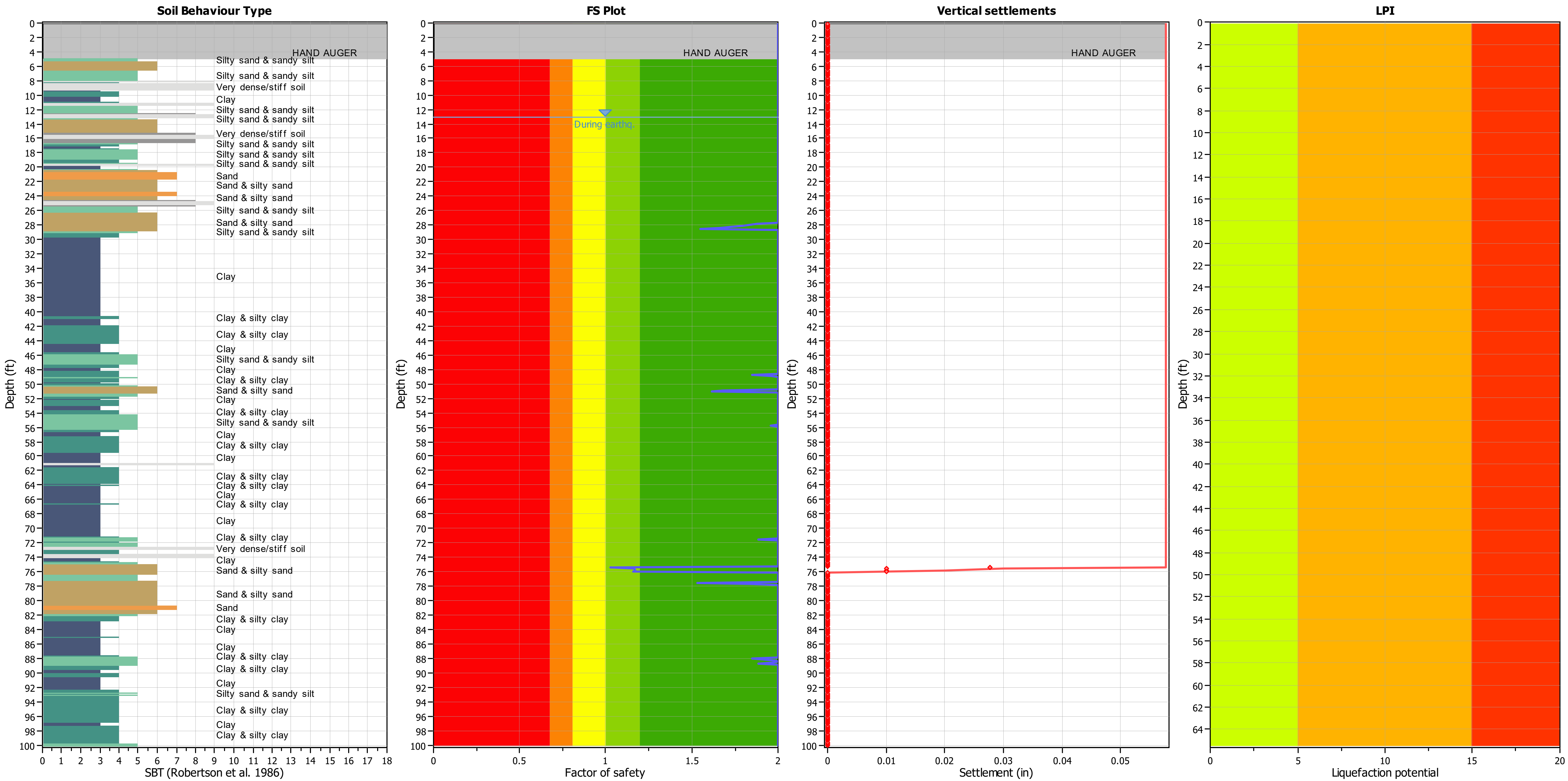
**Project:** **DCA Liquefaction Evaluation** | **CPT: Twin Cities Rd_DCE-CPT-008**

**Location:** | Total depth: 100.07 ft




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Analysis method: | NCEER (1998) | G.W.T. (in-situ): | 0.00 ft | Use fill: | No | Clay like behavior applied: | Sands only |
| Fines correction method: | NCEER (1998) | G.W.T. (earthq.): | 13.00 ft | Fill height: | N/A | Limit depth applied: | No |
| Points to test: | Based on Ic value | Average results interval: | 3 | Fill weight: | N/A | Limit depth: | N/A |
| Earthquake magnitude $M_w$: | 6.50 | Ic cut-off value: | 2.60 | Trans. detect. applied: | Yes | MSF method: | Method based |
| Peak ground acceleration: | 0.29 | Unit weight calculation: | Based on SBT | $K_\sigma$ applied: | Yes | | |

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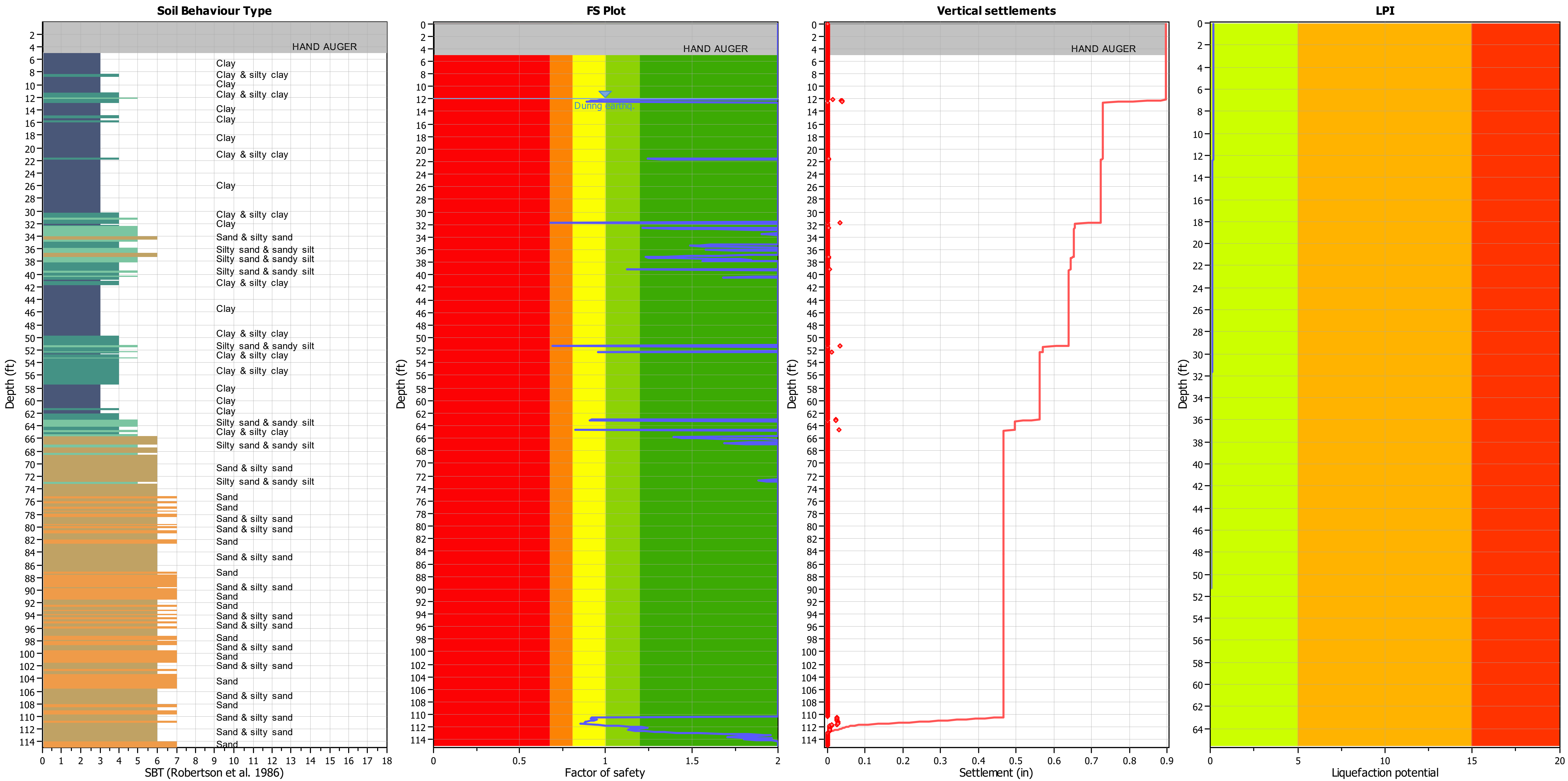
**Project:** **DCA Liquefaction Evaluation**
**Location:**

**CPT: Union Is_DCC-CPT-006**
Total depth: 114.91 ft




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Analysis method: | NCEER (1998) | G.W.T. (in-situ): | 1.00 ft | Use fill: | No | Clay like behavior applied: | Sands only |
| Fines correction method: | NCEER (1998) | G.W.T. (earthq.): | 12.00 ft | Fill height: | N/A | Limit depth applied: | No |
| Points to test: | Based on Ic value | Average results interval: | 3 | Fill weight: | N/A | Limit depth: | N/A |
| Earthquake magnitude $M_w$: | 6.90 | Ic cut-off value: | 2.60 | Trans. detect. applied: | Yes | MSF method: | Method based |
| Peak ground acceleration: | 0.20 | Unit weight calculation: | Based on SBT | $K_\sigma$ applied: | Yes | | |

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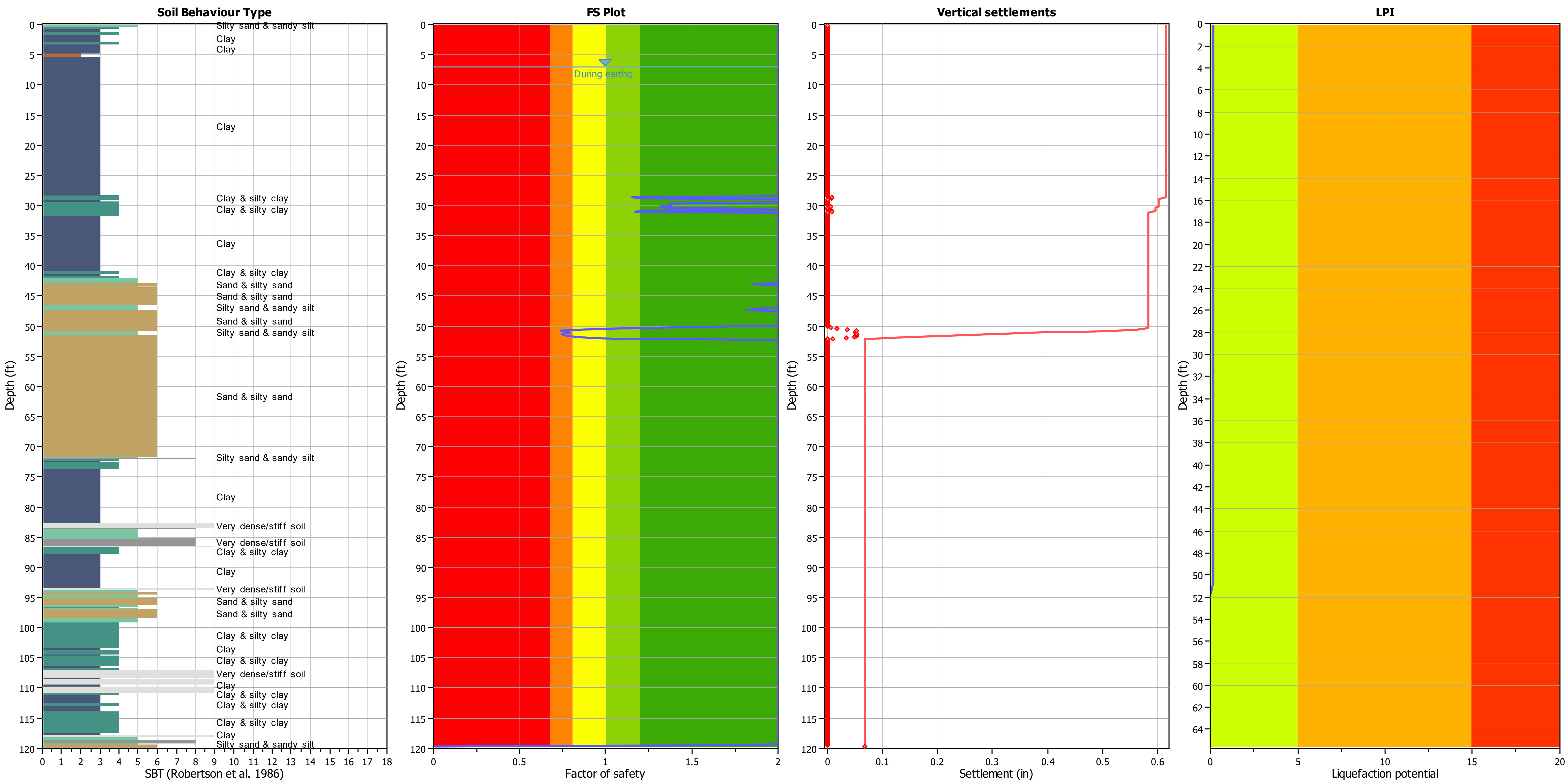
**Project:** DCA Liquefaction Evaluation

**Location:**

**CPT: Union Is_vi-aip-cpt-6**

Total depth: 119.70 ft




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Analysis method: | NCEER (1998) | G.W.T. (in-situ): | 1.00 ft | Use fill: | No | Clay like behavior applied: | Sands only |
| Fines correction method: | NCEER (1998) | G.W.T. (earthq.): | 7.00 ft | Fill height: | N/A | Limit depth applied: | No |
| Points to test: | Based on Ic value | Average results interval: | 3 | Fill weight: | N/A | Limit depth: | N/A |
| Earthquake magnitude $M_w$: | 6.90 | Ic cut-off value: | 2.60 | Trans. detect. applied: | Yes | MSF method: | Method based |
| Peak ground acceleration: | 0.20 | Unit weight calculation: | Based on SBT | $K_\sigma$ applied: | Yes | | |

# Attachment 4
# Shear Wave Velocity Measurements from DCW-CPT-027

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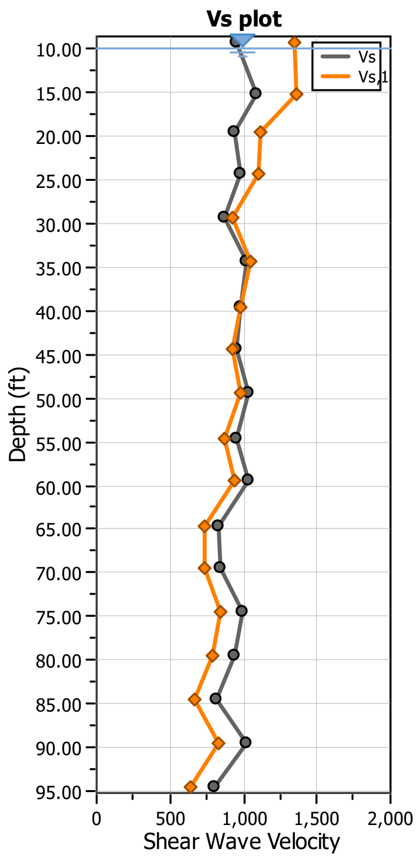
## Vs BASED LIQUEFACTION ANALYSIS REPORT (NCEER 1998)

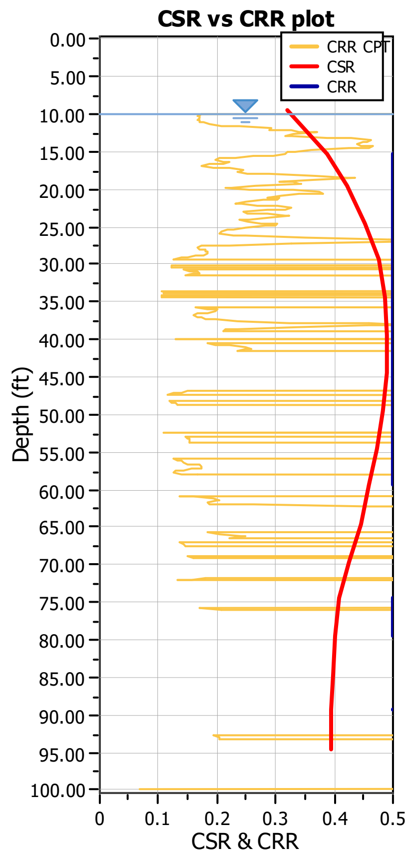
**Project title : DCA Liquefaction Evaluation** **Location :**

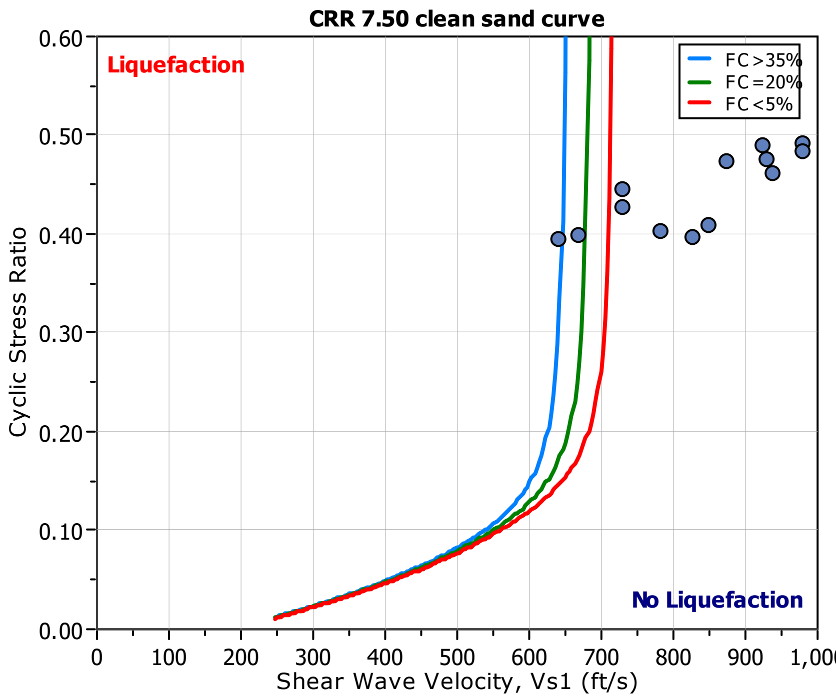
**CPT file : DCW-CPT-027**

**:: Input parameters and analysis properties ::**

| | |
|---|---|
| Calculation m;ethod: | NCEER (1998) |
| G.W.T. (in-situ): | 1.00 ft |
| G.W.T. (earthq.): | 10.00 ft |
| Earthquake magnitude $M_w$: | 6.90 |
| Peak ground acceleration: | 0.62g |



**:: Cyclic Stress Ratio fully adjusted (CSR*) numeric results ::**

| No | Depth (ft) | Weight (pcf) | $u_o$ (tsf) | $\sigma_v$ (tsf) | $\sigma'_v$ (tsf) | $r_d$ | CSR | $K_\sigma$ | MSF | $CSR^*$ | Can Liquefy |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 9.35 | 115.00 | 0.26 | 0.54 | 0.28 | 0.98 | 0.394 | 1.00 | 1.24 | 2.000 | Yes |
| 2 | 15.25 | 115.00 | 0.44 | 0.88 | 0.43 | 0.96 | 0.478 | 1.00 | 1.24 | 0.386 | Yes |
| 3 | 19.52 | 115.00 | 0.58 | 1.12 | 0.54 | 0.95 | 0.523 | 1.00 | 1.24 | 0.423 | Yes |
| 4 | 24.44 | 115.00 | 0.73 | 1.41 | 0.67 | 0.94 | 0.559 | 1.00 | 1.24 | 0.452 | Yes |
| 5 | 29.36 | 115.00 | 0.88 | 1.69 | 0.80 | 0.93 | 0.585 | 1.00 | 1.24 | 0.475 | Yes |
| 6 | 34.44 | 115.00 | 1.04 | 1.98 | 0.94 | 0.89 | 0.586 | 0.97 | 1.24 | 0.487 | Yes |
| 7 | 39.53 | 115.00 | 1.20 | 2.27 | 1.07 | 0.85 | 0.578 | 0.95 | 1.24 | 0.491 | Yes |
| 8 | 44.45 | 115.00 | 1.36 | 2.56 | 1.20 | 0.81 | 0.566 | 0.93 | 1.24 | 0.489 | Yes |
| 9 | 49.37 | 115.00 | 1.51 | 2.84 | 1.33 | 0.77 | 0.549 | 0.92 | 1.24 | 0.483 | Yes |
| 10 | 54.62 | 115.00 | 1.67 | 3.14 | 1.47 | 0.73 | 0.529 | 0.90 | 1.24 | 0.472 | Yes |
| 11 | 59.38 | 115.00 | 1.82 | 3.41 | 1.59 | 0.69 | 0.508 | 0.89 | 1.24 | 0.460 | Yes |
| 12 | 64.63 | 115.00 | 1.99 | 3.72 | 1.73 | 0.65 | 0.483 | 0.88 | 1.24 | 2.000 | Yes |
| 13 | 69.55 | 115.00 | 2.14 | 4.00 | 1.86 | 0.61 | 0.458 | 0.87 | 1.24 | 2.000 | Yes |
| 14 | 74.47 | 115.00 | 2.29 | 4.28 | 1.99 | 0.57 | 0.432 | 0.86 | 1.24 | 0.407 | Yes |
| 15 | 79.39 | 115.00 | 2.45 | 4.56 | 2.12 | 0.55 | 0.422 | 0.85 | 1.24 | 0.402 | Yes |
| 16 | 84.48 | 131.00 | 2.60 | 4.90 | 2.29 | 0.54 | 0.413 | 0.84 | 1.24 | 2.000 | Yes |
| 17 | 89.40 | 115.00 | 2.76 | 5.18 | 2.42 | 0.53 | 0.406 | 0.83 | 1.24 | 0.396 | Yes |
| 18 | 94.48 | 115.00 | 2.92 | 5.47 | 2.56 | 0.51 | 0.399 | 0.82 | 1.24 | 0.393 | Yes |

**Abbreviations**

Depth: Depth from free surface where SPT was performed (ft)
$u_0$: Water pressure at test point (tsf)
$\sigma_v$: Total overburden pressure at test point (tsf)
$\sigma_v'$: Effective overburden pressure based on GWT during earthquake (tsf)
$r_d$: Nonlinear shear mass factor
CSR: Cyclic Stress Ratio ()
MSF: Effective overburden stress factor
$K_\sigma$: Magnitude Scaling Factor
$CSR^*$: CSR fully adjusted

**:: Cyclic Resistance Ratio (CRR) numeric results ::**

| No | Depth (ft) | $V_s$ (ft/s) | Fines % | n | $V_{s1}$ (ft/s) | $V_{s1c}$ (ft/s) | $CRR_{7.5}$ | F.S. | Can Liquefy |
|---|---|---|---|---|---|---|---|---|---|

**:: Cyclic Resistance Ratio (CRR) numeric results ::**

| No | Depth (ft) | $V_s$ (ft/s) | Fines % | n | $V_{s1}$ (ft/s) | $V_{s1c}$ (ft/s) | $CRR_{7.5}$ | F.S. | Can Liquefy |
|---|---|---|---|---|---|---|---|---|---|

**Abbreviations**

| | |
|---|---|
| Depth: | Depth from free surface where Vs was performed (ft) |
| $V_s$: | Estimated Vs (ft/s) |
| n: | Stress exponent normalization factor |
| $V_{s1}$: | Normalized Vs (ft/s) |
| $V_{s1c}$: | Critical value of Vs1, which separates contractive and dilative behavior (tsf) |
| $CRR_{7.5}$: | Cyclic Resistance Ratio for $M_w$ 7.50 |
| F.S.: | Factor of safety against liquefaction |