Geotechnical Engineering Report Bayou De Cade Marsh Creation and Ridge Restoration (TE-0138) Terrebonne Parish, Louisiana

Fugro Project No. 04.55174066
October 2018

FUGRO USA LAND, INC.

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Report No. 04.55174066
October 3, 2018

COASTAL PROTECTION AND RESTORATION AUTHORITY
150 Terrace Avenue
Baton Rouge, Louisiana 70802

Attention: Ms. April Newman
CPRA Project Manager

Geotechnical Engineering Report
Bayou De Cade Marsh Creation and Ridge Restoration (TE-0138)
Terrebonne Parish, Louisiana

Fugro USA Land, Inc. (Fugro) is pleased to submit this geotechnical engineering report for the referenced project. Fugro's services were authorized by the State of Louisiana Coastal Protection and Restoration Authority (CPRA) on March 5, 2018 under Contract No. 440010495. This study was performed in general accordance with Fugro's Proposal No. 04.55174066_rev2, dated December 19, 2017. This engineering report follows Fugro's geotechnical data report, dated June 8, 2018.

We appreciate the opportunity to be of service to CPRA and look forward to working together on the next phase of the project. Please call if you have any questions about this report.

Sincerely,
FUGRO USA LAND, INC.

Samuel M. Bryant, P.E.
Vice President

Eric Marx, P.E.
Vice President

Copies Submitted: pdf to addressee

STATE OF LOUISIANA
SAMUEL M BRYANT
License No. 40695
10-3-18
PROFESSIONAL ENGINEER

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ILLUSTRATIONS

APPENDICES

1. INTRODUCTION

1.1 Project Description

The Louisiana Coastal Protection and Restoration Authority (CPRA) is planning to restore 11,726 linear feet of ridge habitat along the northern bank of Bayou De Cade and create/nourish approximately 504 acres of marsh by pumping hydraulically dredged material from Lake De Cade to the designated fill sites.

The site is located as shown on Plate 1. A site layout is presented as Plate 2. The project site is located in Terrebonne Parish, Louisiana, about 12 miles west of Dulac and immediately west of Lake De Cade.

Approximate project area center coordinates are N29°22’37.23” and W90°55’00.39”.

Survey data obtained by Fugro for explorations are based on the North American Datum 1983 (NAD83), Louisiana State Plane South.

Elevations noted herein are based on the North American Vertical Datum 1988 (NAVD88), Geoid 12B, which is the same as 12A but includes Puerto Rico.

The land owner for the marsh creation area is Apache Louisiana Minerals LLC.

Fugro (2018) is a geotechnical data report for field exploration and laboratory testing performed for the reference project and includes the data used to support the engineering analyses included herein.

1.2 Purposes and Scope

The purpose of the geotechnical engineering study was to: 1) develop geotechnical engineering parameters needed for evaluations, 2) perform settlement studies for dredge fill placement, and perform slope stability evaluations for proposed containment berms and borrow trenches.

1.3 Authorization and Personnel

Ms. April Newman is the CPRA Project Manager and Mr. Travis Byland, P.E., is the CPRA Technical Lead. Mr. Eric Marx, P.E., is the Fugro Project Manager, and Mr. Sam Bryant, P.E., is the Fugro technical lead.

1.4 Report Applicability

Findings, and conclusions presented in this report are based on the project description, as described herein, and the authorized scope of work, and information from Fugro (2018).

If there are differences or changes in project location or design features from those described herein, Fugro should be authorized to review changes and propose additional exploration and laboratory testing, if deemed appropriate. Observations, conclusions, and recommendations may not apply to locations beyond explorations performed for this study and beyond project boundaries.

Fugro prepared this report exclusively for CPRA to guide geotechnical aspects of design and construction of proposed features. The study was conducted using the standard level of care and diligence normally practiced by recognized engineering firms now performing similar services under similar circumstances in the area. This report, including all illustrations and appendices, should be used in its entirety. This report should be made available for information only and not as a warranty of subsurface conditions.

2. SUBSURFACE CONDITIONS

2.1 Site Description

Topographic and existing feature information is presented on Plate 2. Saucier (1994, Plate 14) indicate the site is underlain by Holocene Interdistributary deposits. Surficial conditions range from over water to within the marsh area and out in Lake De Cade, to just above water land surfaces around the marsh perimeter.

2.2 Geologic Conditions

Saucier (1994, Plate 14) indicates the site is underlain by Holocene deltaic interdistributary deposits in brackish to saline marsh environments. Saucier (1994, Plate 27) suggests the Pleistocene surface is at about El-350 ft.

2.3 Geographic Information System Database

Information developed or obtained for the project was included in a geographic information system (GIS) database using ESRI (2018) ArcGIS, version 10.4. Data from explorations, i.e., field and laboratory data, was included in a GIS database using Bentley Systems (2018) gINT, version 10. The gINT database file is linked to ArcGIS for processing. CPT electronic data files are included in the ArcGIS database.

2.4 Subsurface Conditions

2.4.1 Cross-Sections

Example subsurface profiles, presented as Plates 3a to 3d, generally show the distribution of subsurface conditions across the section lines. Profile locations are shown on Plate 2.

2.4.2 Earth Materials

Earth materials encountered in explorations consist mostly of soft clay with interbedded sand and silt layers. Organic and peat layers are also present. Compared to Profile A-A’, Profile B-B seems to indicate a more continuous sandy zone following along the profile line between about El-13 and -5 ft.

2.4.3 Water Conditions

A nearby CRMS (2018) gauge CRMS0398-H01, located about 3/4-mile north of the marsh site center, indicates a mean water elevation of about El+0.65 ft, a range from about El-0.5 ft to as high as El+2.0 ft, and with a more typical range from about El+0.2 to El+1 ft for daily measurements between October 2016 to September/October 2017.

3. PARAMETER SYNTHESIS

3.1 Introduction

Appendix A presents a synthesis of material characteristics and engineering properties using field exploration and laboratory data, included in the Fugro (2018) data report. Parameter assessments are developed for explorations around and within the marsh restoration area, and dredge fill materials that will be generated from lake borings, B-9 to B-15, see Plate 2.

3.2 Foundation Soils

3.2.1 State Conditions

Atterberg limit data are presented on Plate A-2. Materials generally classify as lean to fat clays, although organic materials are noted on the boring and CPT logs. Atterberg limit, moisture content, and liquidity index data versus elevation are presented on Plate A-3. Moisture content and total unit weight versus elevation profiles are presented Plates A-4. Dry Density and void ratio versus elevation are presented on Plates A-5.

3.2.2 Undrained Shear Strength and Preconsolidation Pressure

Undrained shear strength data, including unconsolidated-undrained triaxial and mini-vane data, as well as a comparison with CPT-interpreted shear strength data, are presented on Plate A-6. Plate A-7 presents estimated preconsolidation pressure, overconsolidation ratios (OCR), and undrained shear strength versus elevation. Plate A-8 compares preconsolidation pressure with CPT-interpreted preconsolidation pressure. Explanatory notes regarding how undrained shear strength, OCR and preconsolidation pressure were estimated are presented on Plate A-9.

3.2.3 Compressibility and Permeability

Plate A-10 summarizes foundation soil consolidation test results in terms of vertical strain versus log stress. The graphs are separated into CH, OH and CL materials. Compression ratios are noted in the lower left-hand corner of Plate A-10.

Consolidation test data in terms of void ratio versus log stress and log permeability is presented on Plate A-11. Tabulated results for the red trend lines shown on Plate A-11 are shown on Plate A-12

CPT-interpreted constrained modulus versus elevation is shown on Plate A-13. The red trend line on Plate A-13 was computed using a recompression ratio of 0.02, which compares to the value of 0.025 shown on Plate A-10 for CL materials.

3.2.4 Consolidation State

Foundation soils appear to be at least moderately overconsolidated above El -30 ft based on the following:

- As shown on Plate A-3, moisture contents are generally less than the liquid limit and liquidity indices are less than 1, although there is wide scatter.
- Comparison of preconsolidation pressures interpreted from laboratory consolidation tests are greater than estimated vertical effective stresses as shown on Plate A-7.
- CPT-interpreted preconsolidation pressures, shown on Plate A-8, are also greater that estimated effective vertical pressures, although they appear lower that the interpreted preconsolidation trend line shown on Plate A-8 above about El-15 ft.
- Between about El-30 ft and El-60 ft, i.e., the extent of field exploration, conditions approach a virtually normally consolidated condition.

3.2.5 Drained Shear Strength Parameters

Plate A-14 presents Brandon (2014) correlations between drained friction angle and material type. Friction angles range from 24 to 32 for material types ranging from organic fat clay (CHO) to peat (PT). A drained friction angle of 27 degrees was selected for evaluations, as applicable.

3.2.6 Bulking Factors

Bulking factor, as defined herein, is the ratio between saturated soil volume placed in dike containment areas to the insitu saturated soil volume characterized from borings near trench borrow areas. Plate A-16 presents void ratio and moisture content for marsh area borings down to El-15 ft. Plate A-17 presents estimates for bulking factors, which range from about 1.3 to 1.7.

Bulking factors are not provided for dredge fill materials, as they will be deposited as slurry type materials and “bulking” depends on what partially-consolidated fill placement void ratio is selected to estimate the bulking from an insitu conditions, i.e., those encountered in the Lake De Cade borings, B-10 to B-15. There are also other material losses from dredge fill slurry placement, e.g., suspended solids that weir off the site.

3.3 Dredge Fill Soils

Consolidation information used to develop void ratio versus log stress and permeability versus void ratio for samples composited from lake boring samples is presented on Plates A-19 and A-20. Tabulated results are shown on Plate A-21. An initial void ratio for dredge fill materials was set at 7.0 based on information from the column settling tests (Fugro, 2018) and from the Stark (2005) correlation with plasticity index.

4. SETTLEMENT EVALUATIONS

4.1 Introduction

Appendix B presents settlement evaluations for self-weight settlement estimates for dredge fill material and foundation soil compression from dredge fill placement, and for containment dike settlement. PSDDF software (Stark, 2014) was used for settlement analyses, with input developed from consolidation test data included in Fugro (2018) and information described in Stark, Choi, H. and O'Meara (2005). Settle3D, Version 4.017 (Rocscience, 2018) was used to estimate perimeter ridge/dike settlement.

4.2 Dredge Fill Settlement

4.2.1 Input Parameters

CPRA-provided water elevations, subsidence rate, and marsh fill surface target elevations as presented on Plate B-2.

Foundation soil profile compressibility parameters are presented on Plate B-3 for seven layers included as PSDDF input. Computed void ratio versus vertical effective stress and void ratio versus permeability tabulated input included in PSDDF are presented on Plates B-4 through B-6, with plots presented on Plate B-7.

Based on discussions with Mr. Byland, a dredge fill lift placement schedule, presented on Plate B-8, was developed out to 150 days from commencement of fill placement.

Based on synthesis of column settling tests, self-weight/low stress consolidation tests on slurry samples, comparison with data in Stark, Choi, and O'Meara (2005), the red trend line shown on Plate B-9 was set for void ratio versus stress for dredge fill. The red trend line shown on Plate B-10 was set for permeability versus void ratio for dredge fill. Tabulated values are presented on Plate B-11.

Per month rainfall and evaporation input is shown on Plate B-12, with sources also referenced on Plate B-11. The Houma station, used for rainfall data, is located as shown on Plate B-13.

Estimated saturation and desiccation limits for dredge fill are presented on Plate B-14.

4.2.2 Methodology

PSDDF uses one-dimensional, finite-strain consolidation theory to compute primary time-rate compression and settlement for foundation soils and self-weight compression for dredge fill materials placed with no initial effective stress profile. The program also models secondary compression and desiccation. Scheduled fill lift thicknesses can be placed to simulate extended placement over days or months. Dredge fill materials are modeled with an assumption that initial vertical stresses are zero for an initial void ratio.

Drainage boundary conditions can be added for foundation soils. Drainage at a fill/foundation interface is controlled by contrasting permeabilities between fill and foundation soils.

4.2.3 Results

Plate B-15 presents estimated dredge fill surface versus year for the case with 9 fill lifts placed over 150 days, with a 2-ft-thick first lift followed by eight, 1-ft-thick lifts. Mudline at beginning of fill placement is El -2 ft. Fill is placed over 150 days and does not rise above El +2.2 ft. Top of fill and original mudline elevations are shown with and without CPRA-provided estimated subsidence. CPRA-provided estimated rises in sea level are also shown for comparison with fill surface. A target elevation of between El+0.9 and +1.3 ft was set by CPRA at 2040.

The greatest uncertainty with the settlement estimate lies with dredge fill compressibility and permeability characterization, as material characteristics can vary widely based on methods of construction and borrow source variability.

Settlement versus time curves are presented on Plate B-16 for one 5-ft-thick lift placed instantaneously at time zero. Estimated marsh surface elevations do not fall within target elevations by 2040 for that case.

There are marsh areas with proposed borrow trenches inside the containment dike, which were not modeled.

4.3 Earthen Ridge/Containment Dike Settlement

4.3.1 Description

Settle3D (Rocscience, 2018) was used to estimate perimeter earthen ridge settlement. The analyses are also appropriate to represent containment dikes with similar fill heights planned on the project. Evaluations are presented in Appendix B, Plates 18 to 21, following marsh area settlement evaluations. Data from all the exploration locations in the marsh area was considered for the analyses. Plate B-18 presents shows how earthen ridge embankment and dredge fill loads were modeled. The configuration for the southeast end of Section T-21 with target crest height of El+5 ft, a 10-ft-wide crest, and 5H:1V side slopes. An initial ground surface/mudline was set at El 0 ft. was selected for evaluation. Ridge embankment fill was placed as one, 5-ft-thick lift placed at time zero.

Plate B-19 presents the subsurface soil thicknesses and consolidation parameters, which are the same as those used for dredge fill settlement using PSDDF.

4.3.2 Results

Plate B-20 presents estimated settlement versus year for the mudline surface, including primary recompression, primary consolidation, and secondary consolidation. Subsidence was added in using the CPRA-provided subsidence rate of 7 mm/year. Plate B-21 presents an approximate ridge crest elevation versus time, estimated by adding 5 ft to mudline elevations.

Containment dike embankment compression is not included in the settlement estimates. Embankment compression is uncertain, as compressibility characterization of soft soil materials excavated via excavators or clam shell and placed as dumped materials is very uncertain. Dike crests should be maintained during marsh material placement at a level that provides required freeboard.

5. SLOPE STABILITY EVALUATIONS

5.1 Introduction

Appendix C presents slope stability evaluations for selected dike and borrow trench configurations. Factors of safety are presented on Plate C-1. Slope stability sections were developed from CPRA (2018) drawings. Sections were developed for the following areas:

- T-21, southeast end.
- T-25, northwest end.
- T-33, northwest end.

Selected slope sections are located as shown on Plate C-2. Typical dike and borrow trench geometries are shown on Plates C-3 and C-4.

5.2 Methodology and Input

SLOPE/W (GEO-SLOPE, 2015) was used for limit equilibrium slope stability analyses, in conjunction with the Morgenstern and Price method, entry and exit search modes, and optimized non-circular potential failure surfaces, as programmed into SLOPE/W. Unit weight and shear profiles were developed from information presented in Appendix A. Unit weight and undrained shear strength profiles for foundation soils below about El 0 ft are presented on Plate C-6. A unit weight of 115 pcf and an undrained shear strength of 200 psf was assumed for foundation soils above El 0 ft. A unit weight of 100 pcf and an undrained shear strength of 100 psf was assumed for dike materials and for dredge fill materials. The water level was set at El+0.6 ft.

Use of undrained shear strengths for foundation soils prior to dike placement will normally be more critical than post-consolidation and settlement processes, as post-construction undrained shear strength should increase as a result of strength gain during the consolidation process.

However, drained shear strength may control excavated trench slopes in the long term. Hence, the trench slope for section T-21, southeast end, was checked using drained strength parameters. No laboratory tests were performed to develop drained strength parameters; hence, an effective stress or drained strength friction angle of 27 degrees with no cohesion was assumed based on drained strength correlations in Brandon (2011).

Construction equipment loading was included for all slope stability evaluations, except for the long-term, trench slope case with drained strength parameters.

5.3 Results

5.3.1 Summary

Factors of safety for the selected sections and different slopes, i.e., inside and outside dike slopes, trench slopes, and without and with equipment loads, are summarized on Plate C-1. Graphical slope stability results follow Plate C-5. Factors of safety using undrained strengths for end of construction conditions exceed 1.5.

5.3.2 Trench Slope with Equipment Loads

Plates C-10 for Section T-21 and Plate C-21 for Section T-33 indicate factors of safety for equipment loads near trench slopes in excess of 1.5 undrained strength. Equipment loads were placed about 5 ft from the trench crest. However, because excavator equipment will likely disturb insitu soils as in moves around, equipment loads should be placed as far as possible from the trench crest, with a suggested minimum distance of 10 ft, i.e., equal to the maximum trench height.

5.3.3 Trench Slopes with Drained Strength

For 2H:1V excavated trench slopes, using assumed drained strength parameters with only a friction angle and no cohesion because excavated a below the water level and will remain saturated, factors of safety are near unity (1) for long-term conditions. Without cohesion, slope stability solutions approach an infinite slope solution with a factor of safety equal to $\tan(\phi)/\tan(\beta)$ with ϕ equal to the friction angle and β equal to the slope angle.

2H:1V trench slopes can likely be excavated in the short term, but may begin to slough sometime after excavation, depending on the actual drained friction angle. Because potential failure surfaces for long term conditions should be shallow, containment dike toes that are at least 25 away from trench crest areas should not be impacted.

Dike slopes are flatter than 2H:1V; typical section indicate dike slopes no steeper than 3H:1V, or 18.4 degrees. Assuming a drained friction angle of 27 degrees, a factor of safety of 1.5 is calculated.

6. REFERENCES

Brandon, T., Martin, L., Martin, S., and Xu, G. (2011) "Strength and Compressibility Correlations for New Orleans Area Soils," submitted to the New Orleans District, U.S. Army Corps of Engineers, January 6.

Brandon, T. (2011) "S-Case Analysis Parameters for Outfall Canals," submitted to the New Orleans District, U.S. Army Corps of Engineers, GCAT March 15.

Coastal Protection and Restoration Authority (CPRA) (2018) "Bayou De Cade Marsh Creation and Ridge Restoration Project, TE-0138, Terrebonne Parish, 30% Construction Plans, July, *includes typical dike and borrow trench geometry*.

Coastwide Reference Monitoring System (CRMS) (2018) https://www.lacoast.gov/crms_viewer2/default.aspx

Fugro USA Land, Inc. (2018) "DRAFT, Geotechnical Data Report, Bayou De Cade Marsh Creation and Ridge Restoration (TE-0138), Terrebonne Parish, Louisiana," Fugro Project No. 04.55174066, June 8.

ESRI (2018) "ArcGIS, version 10.4," https://www.esri.com/en-us/home.

GEO-SLOPE International Ltd. (2015) "Stability Modeling with SLOPE/W," June 2015 Edition.

Robertson, P.K. and Cabal, K.L. (2015) "Guide to Cone Penetration Testing for Geotechnical Engineering, 6th Edition," prepared for Gregg Drilling & Testing, Inc.

Rocscience, Inc. (2018) "Settle3D, Version 4.017," www.rocscience.com, September 27.

Saucier, R.T. (1994) "Geomorphology and Quaternary Geologic History of the Lower Mississippi River Valley, Volumes I and II," prepared for The President Mississippi River Commission Vicksburg, Mississippi and US Army of Corps of Engineers, December.

SCTCS (2018) "Final Report: Settling Properties of Fine-Grained Sediments: Bayou De Cade Marsh Creation and Ridge Restoration (TE-0138) (Fugro Project no. 04.55174066)," Submitted to Fugro USA Land, Inc., June 6.

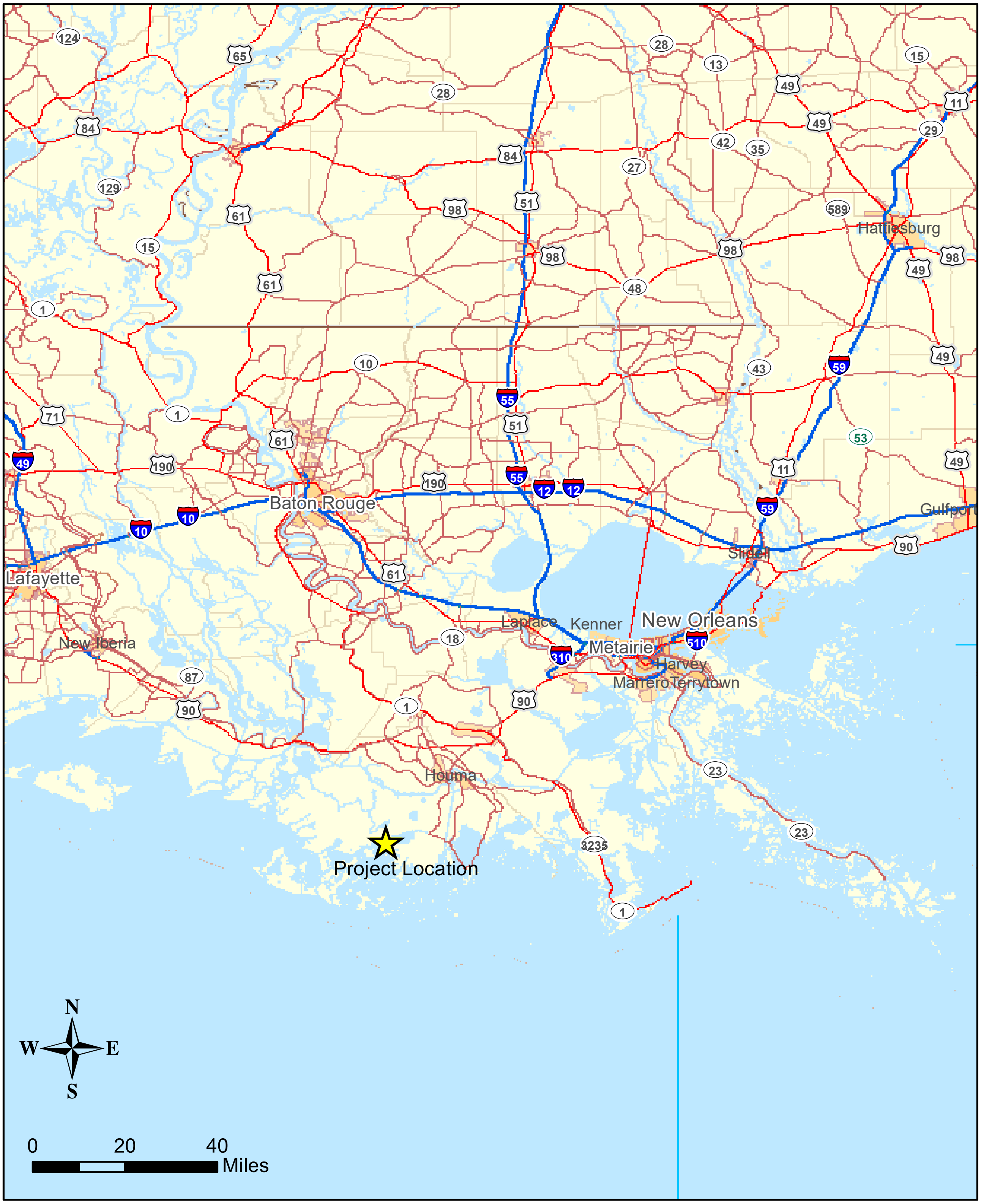
Stark, T.D., Choi, H. and O'Meara, T.J. (2005) "Dredged Material Properties and Other Input Values for Use with the PDSSF Primary Consolidation, Secondary Compression, and Desiccation of Dredged Fill (PSDDF) Computer Model," Instruction Report EL-05XX, prepared for US Army Corps of Engineers, October.

Stark, T.D. (2014) “DRAFT, Program Documentation and User’s Guide: PSDDF Primary Consolidation, Secondary Compression, and Desiccation of Dredged Fill,” Instruction Report EL-14-XX, prepared for US Army Corps of Engineers, October.

U.S. Army Corps of Engineers (USACE) (1987) “Confined Disposal of Dredged Material,” EM 1110-2-5027, September 30, *column settling testing described in Section 3-3 and Appendix B, Plans and Specifications*.

U.S. Army Corps of Engineers (USACE) (2015) “Dredging and Dredged Material Management,” EM 1110-2-5025, July 31, *supersedes EM 1110-2-5027, column settling testing described in Appendix G, Plans and Specifications and Appendix H, Column Settling Test Procedures*.

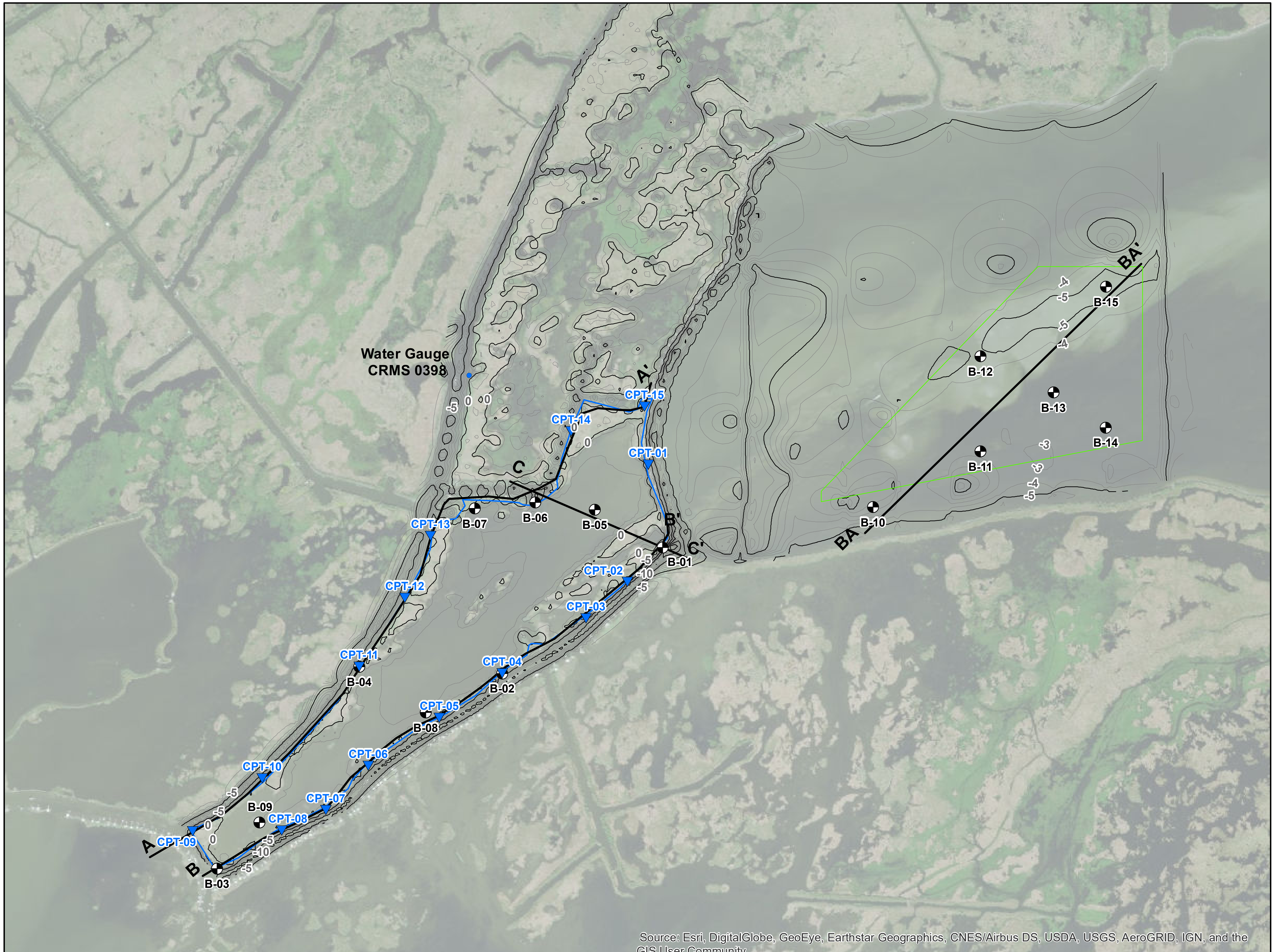
PLATES



VICINITY MAP

Bayou De Cade Marsh Creation and Ridge
Restoration Terrebonne Parish, Louisiana

Plate 1



Legend

- Fugro CPT
- Fugro Boring
- Subsurface Profile Line Location
- Project Area
- Borrow Area

Topographic Survey Contours (Feet, NAVD88)
(survey data provided by client)

- -5 Contour interval is 5 feet
- Contour interval is 1 foot

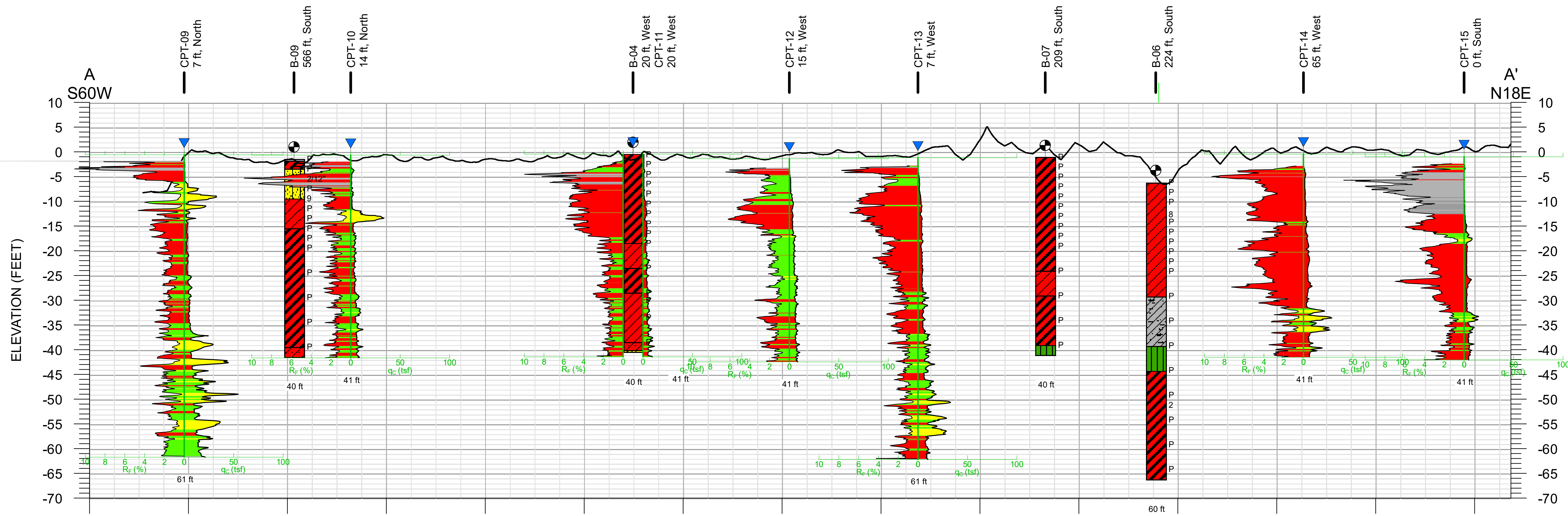
N
W E
S

0 2,000 4,000
Feet

SITE LAYOUT AND EXPLORATION PLAN
Bayou De Cade Marsh Creation
and Ridge Restoration
Terrebonne Parish, Louisiana

Plate 2

N:\Projects\02_2017\04_5517_4066_Bayou_De_Cade\Outputs\05_22_18_Eng_Rpt\mxd\Plate_2_Site_Map.mxd, 6/7/2018, w.cupples



20 ft

1000 ft

Vertical Exaggeration = 50.0X

Legend

Fugro Boring Location

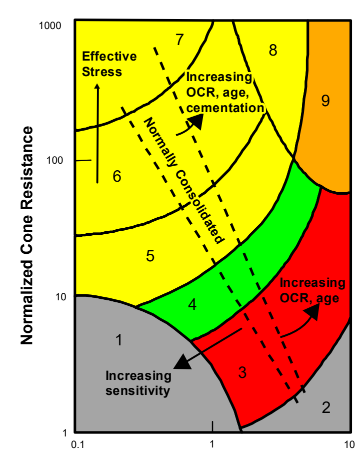
Fugro CPT

13 Field SPT N-Value

P Push

Soil Descriptions

- High-Plasticity Organic (OH)
- Peat
- Lean CLAY (CL)
- Sandy Lean Clay (CL)
- Fat CLAY (CH)
- Silt (ML)
- Silty SAND (SM)



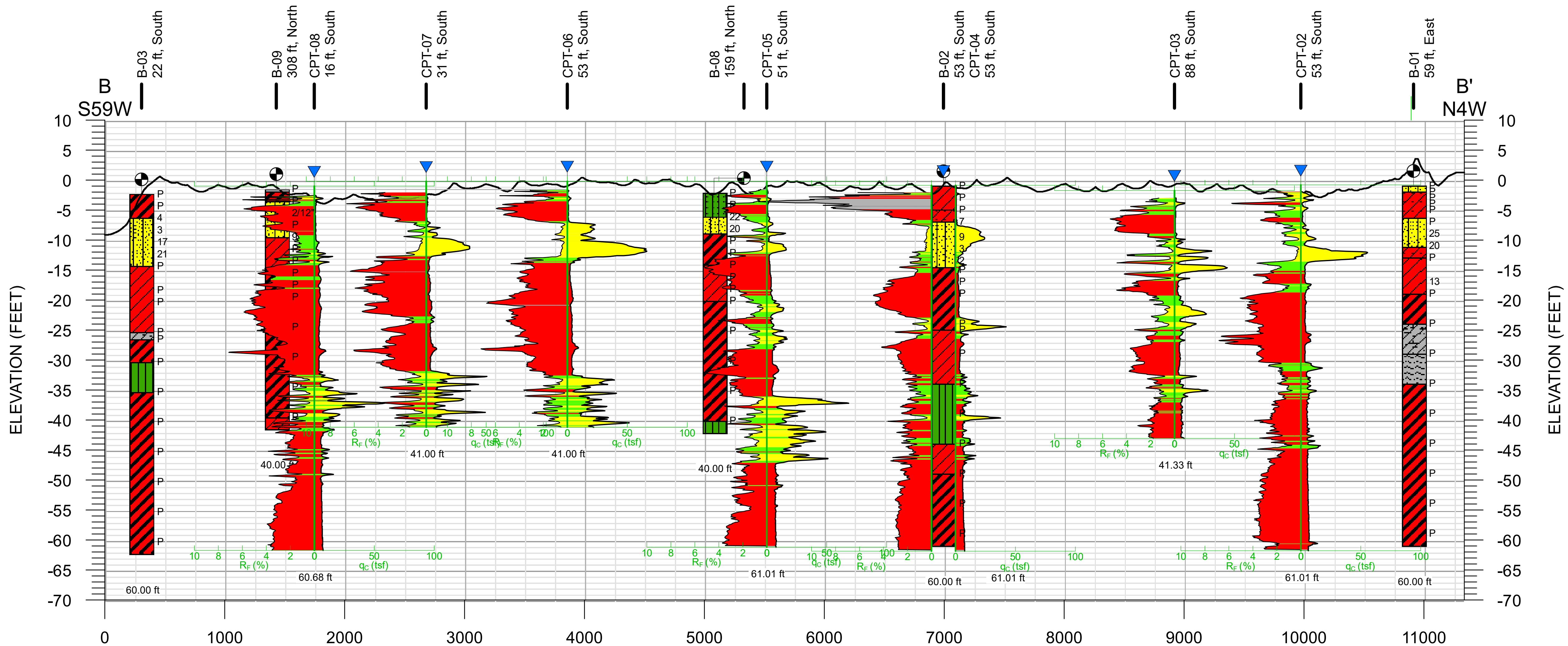
Zone	Soil Behavior Type	U.S.C.S.
1	Sensitive Fine-grained	OL-CH
2	Organic Material	OL-OH
3	Clay to Silty Clay	CL-CH
4	Clayey Silt to Silty Clay	MH-CL
5	Silty Sand to Sandy Silt	SM-ML
6	Sand to Silty Sand	SP-SM
7	Gravelly Sand to Sand	GP-SP
8	Sand to Clayey Sand	SP-SC
9	Very Stiff Fine-grained*	CH-CL

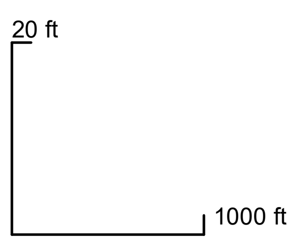
*overconsolidated or cemented

SBT CORRELATION CHART
ROBERTSON, 1990

SUBSURFACE PROFILE A-A'

Bayou De Cade Marsh
Creation and Ridge Restoration
Terrebonne Parish, Louisiana





Vertical Exaggeration = 50.0X

Legend

- Fugro Boring Location
- Fugro CPT
- 13 Field SPT N-Value
- P Push

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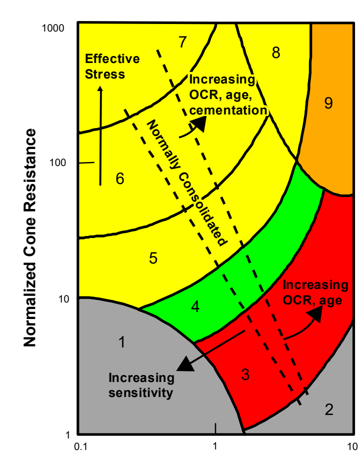

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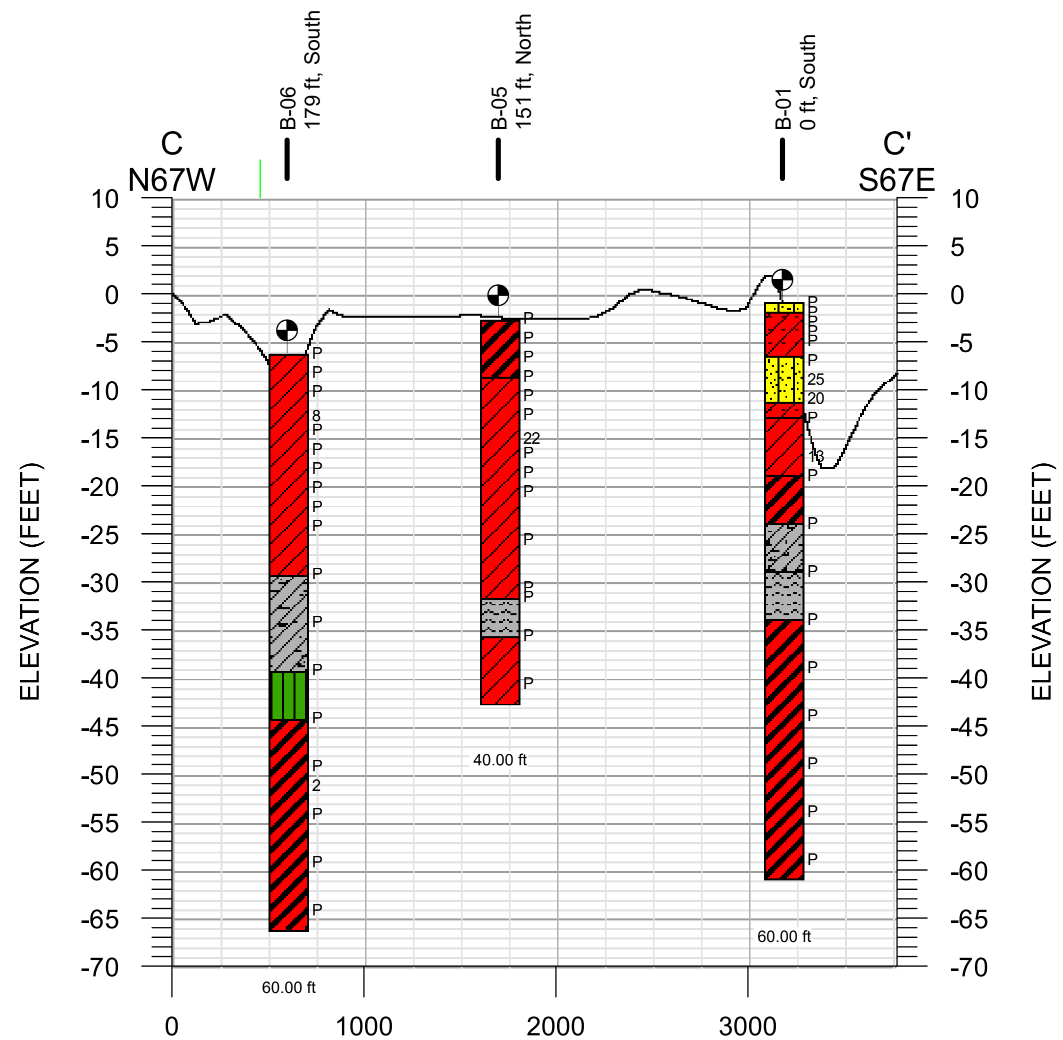
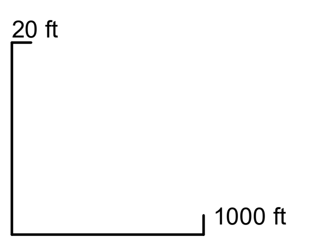
SBT CORRELATION CHART
ROBERTSON, 1990

SUBSURFACE PROFILE B-B'
Bayou De Cade Marsh
Creation and Ridge Restoration
Terrebonne Parish, Louisiana





Vertical Exaggeration = 50.0X

Legend

- Fugro Boring Location
- Fugro CPT
- 13 Field SPT N-Value
- P Push

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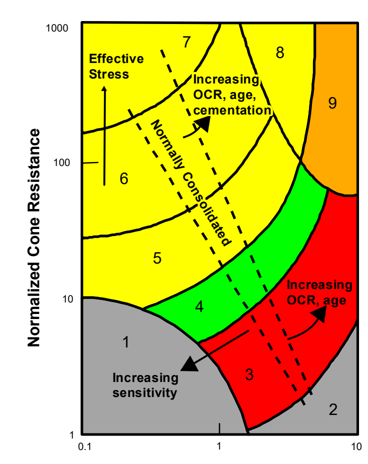

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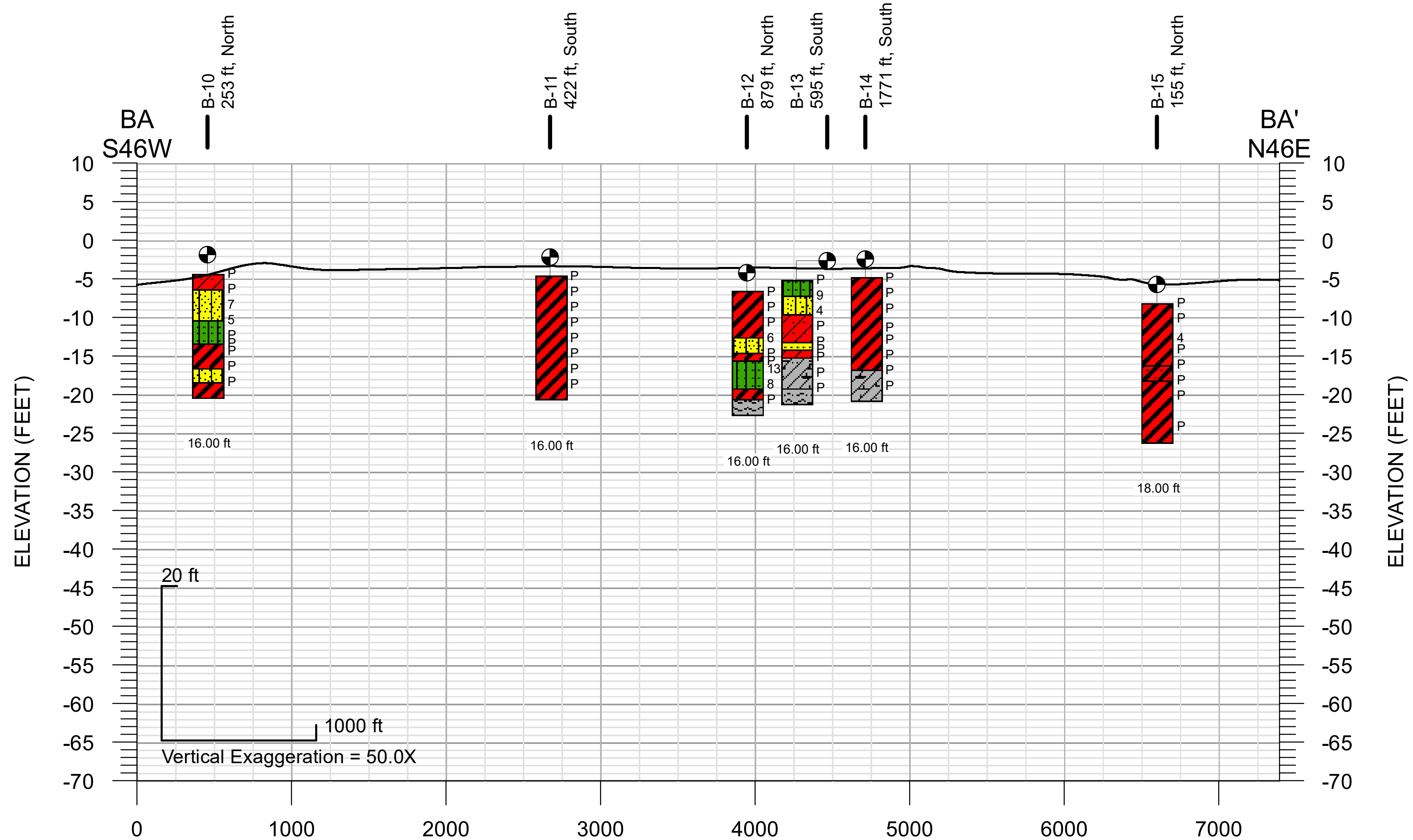
**SBT CORRELATION CHART
ROBERTSON, 1990**

SUBSURFACE PROFILE C-C'
Bayou De Cade Marsh
Creation and Ridge Restoration
Terrebonne Parish, Louisiana



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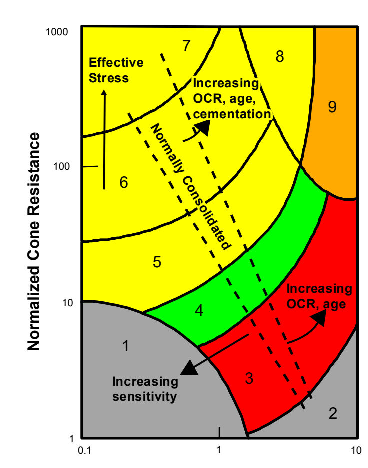
- Silt (ML)
- Silty SAND (SM)



Zone	Soil Behavior Type	U.S.C.S.
1	Sensitive Fine-grained	OL-CH
2	Organic Material	OL-OH
3	Clay to Silty Clay	CL-CH
4	Clayey Silt to Silty Clay	MH-CL
5	Silty Sand to Sandy Silt	SM-ML
6	Sand to Silty Sand	SP-SM
7	Gravelly Sand to Sand	GP-SP
8	Sand to Clayey Sand	SP-SC
9	Very Stiff Fine-grained*	CH-CL

*overconsolidated or cemented

SBT CORRELATION CHART
ROBERTSON, 1990

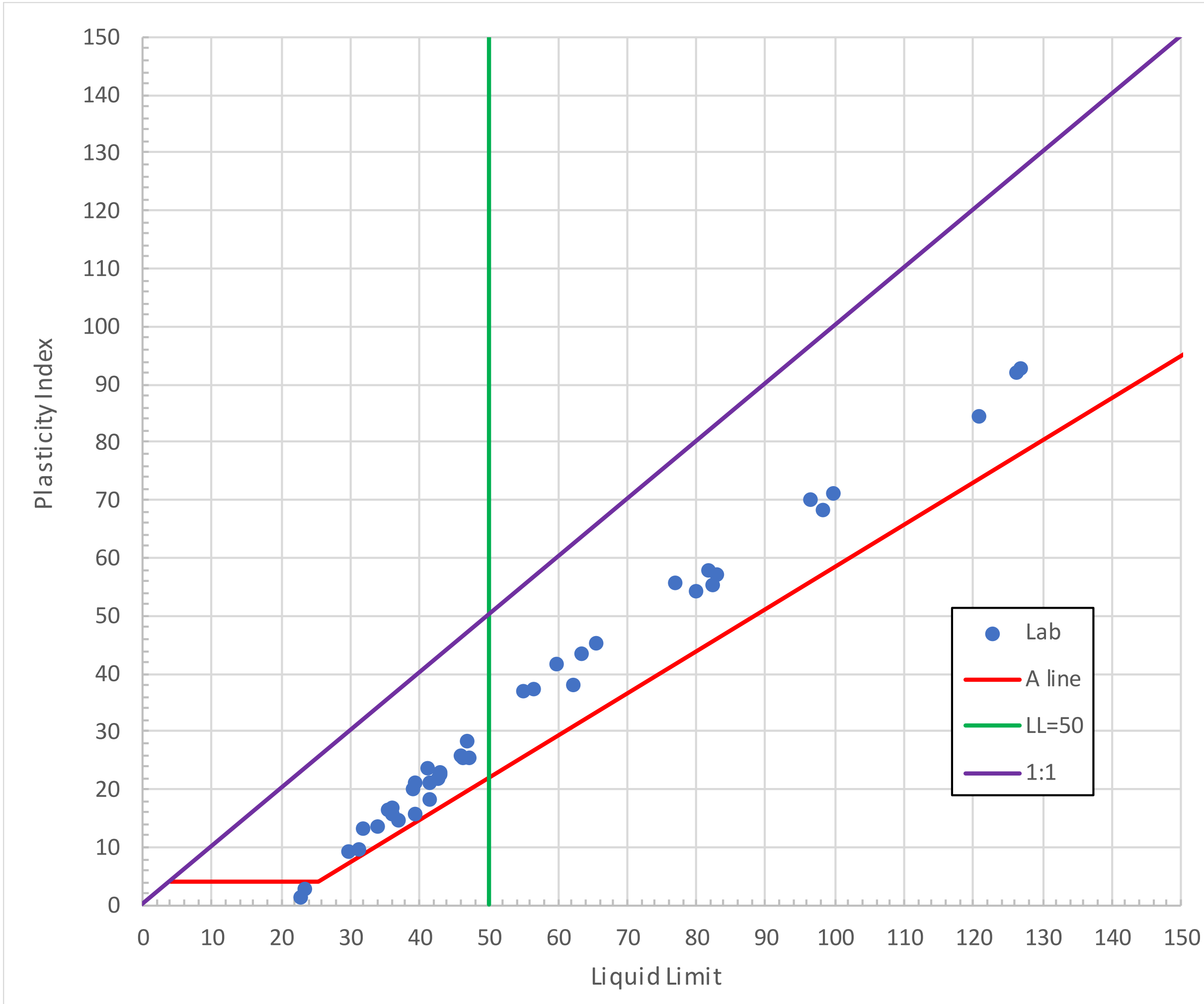
SUBSURFACE PROFILE Borrow Area A
Bayou De Cade Marsh Creation
and Ridge Restoration
Terrebonne Parish, Louisiana

N:\Projects\02_2017\04_5517_4066_Bayou_De_Cade\Outputs\05_22_18_Eng_Rpt\mxd\Plate_3d_Profile_Borrow_Area_A.mxd, 6/7/2018, w.cupples

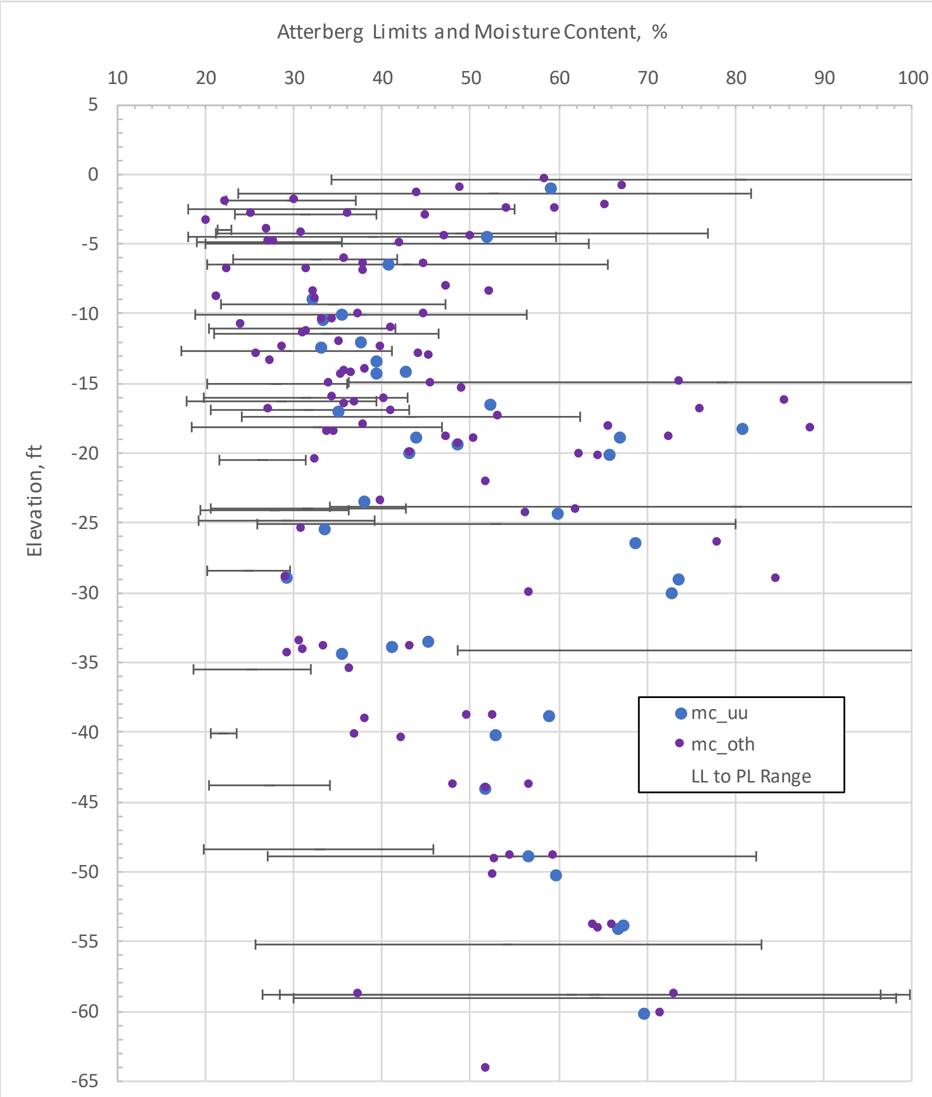
APPENDIX A

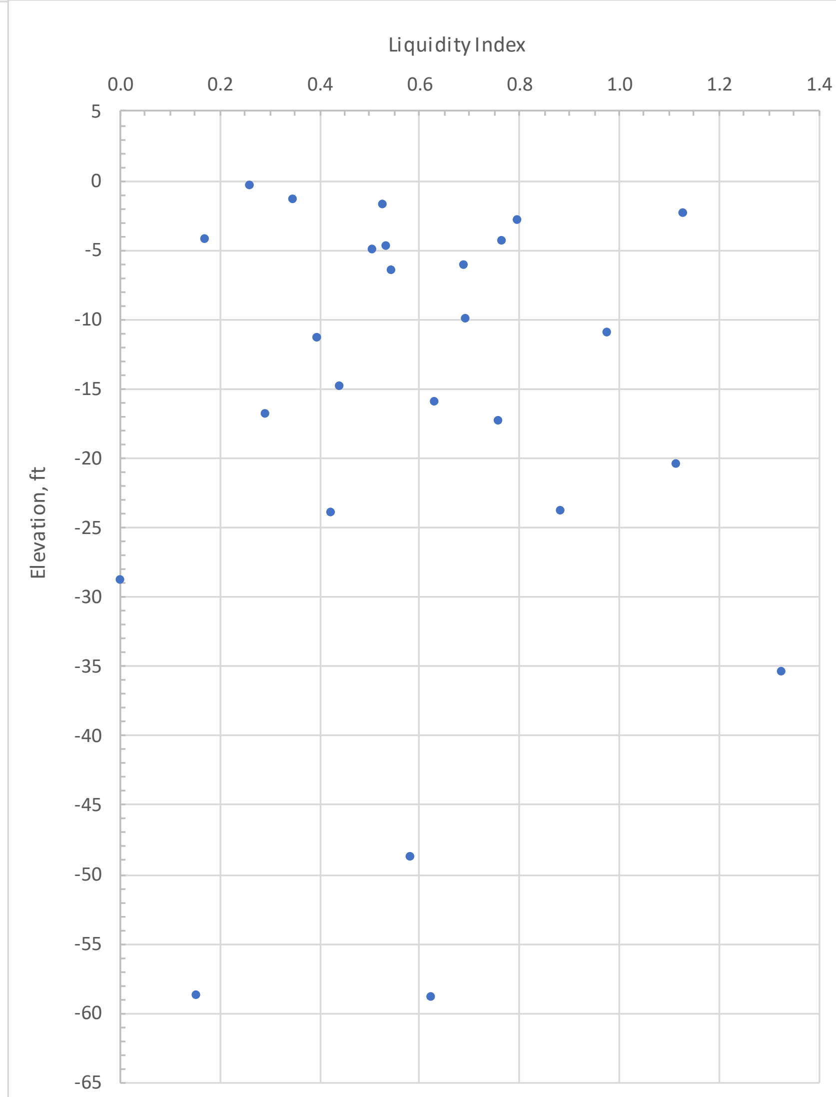
PARAMETERS SYNTHESIS

Foundation Soils



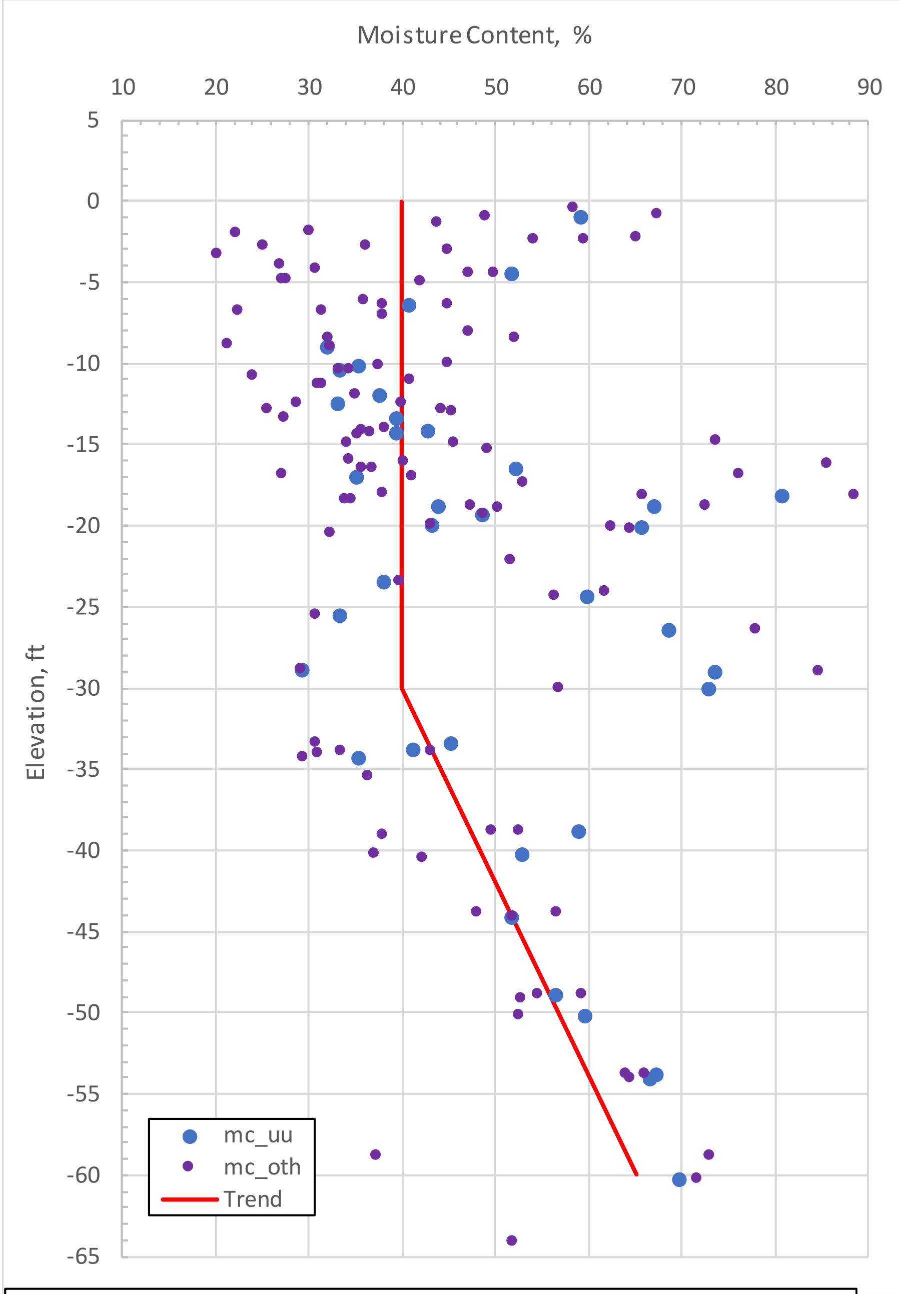
Atterberg Limits

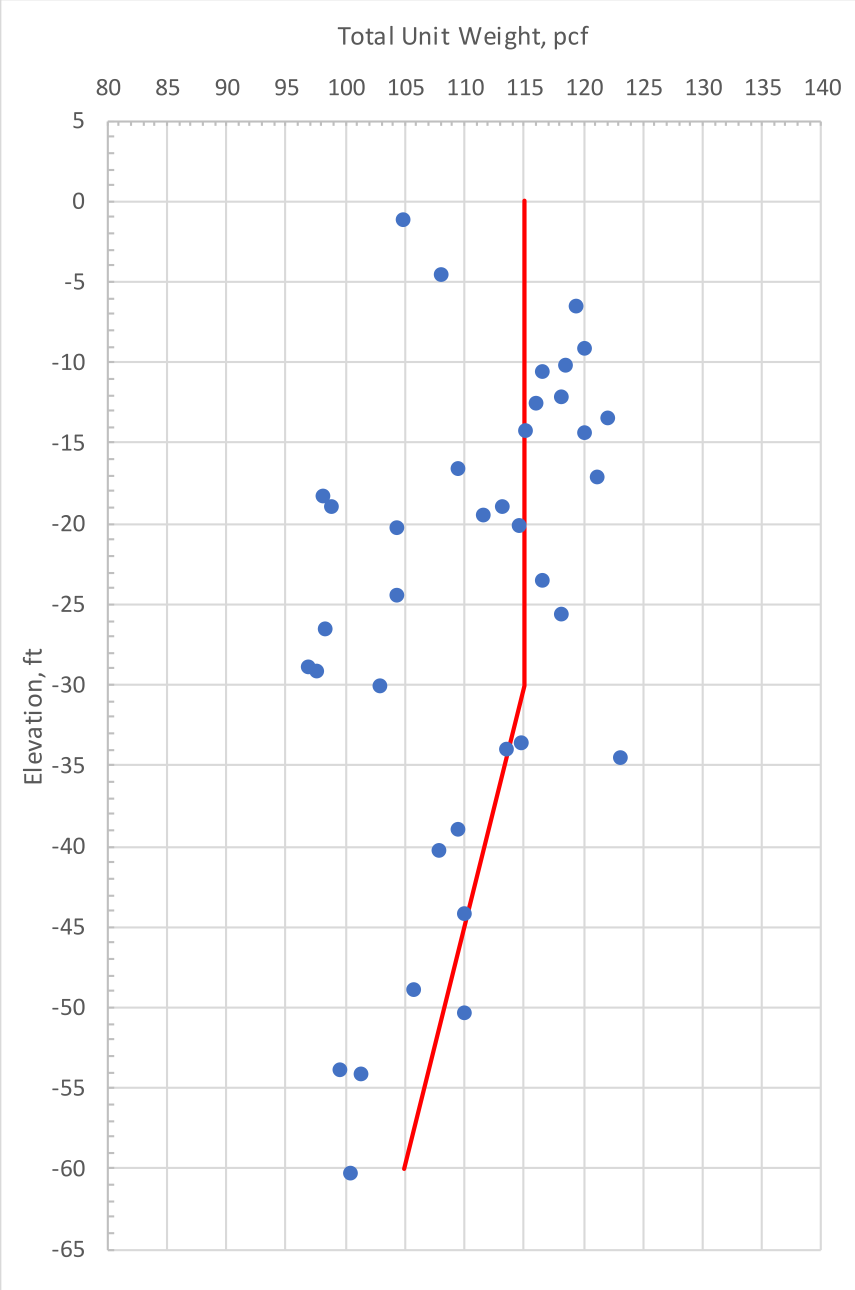




Notes:
1) In general, moisture contents are greater than Plastic Limits (PL) and less than Liquid Limits, and Liquidity Indices are less than 1, suggesting an overconsolidated state.
2) At some elevations, e.g., El-28 ft, El-38 to El-45 ft, moisture contents appear to be greater than the LL, suggesting a state closer to normally consolidated.

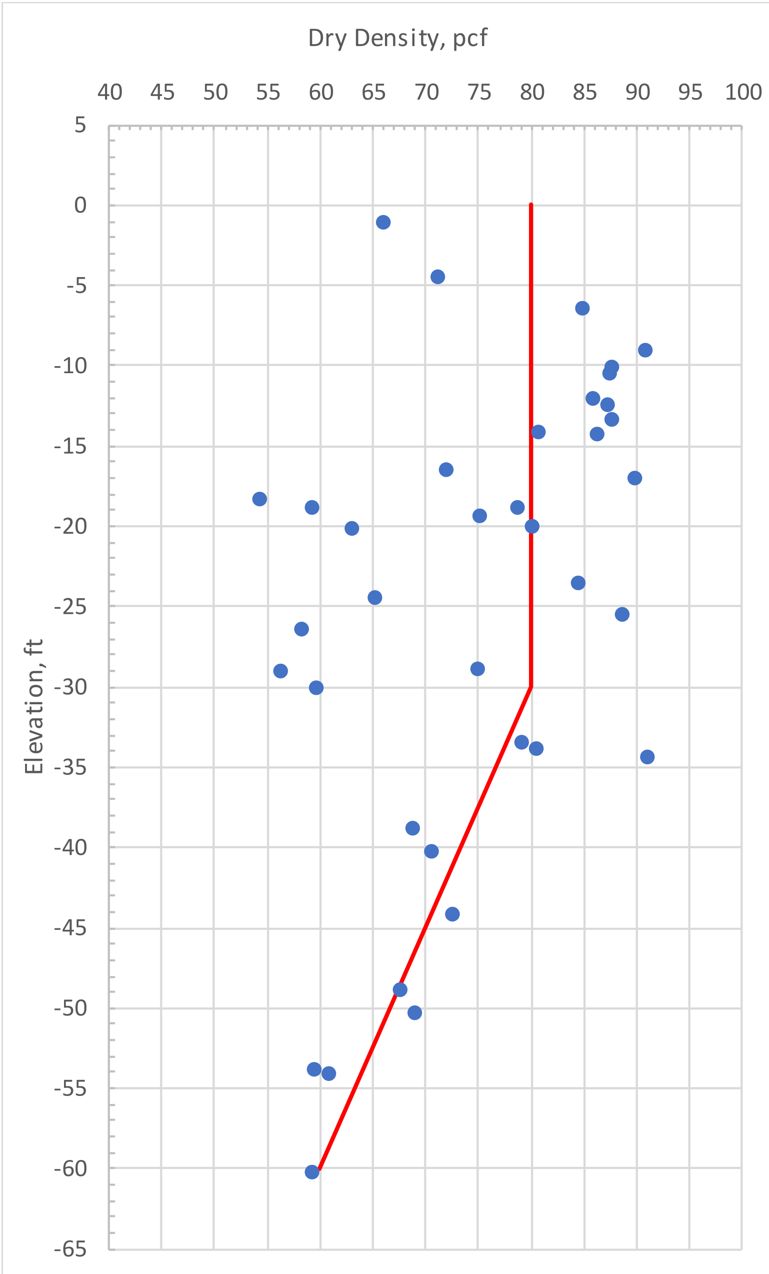
Atterberg Limits, Moisture Content and Liquidity Index versus Elevation

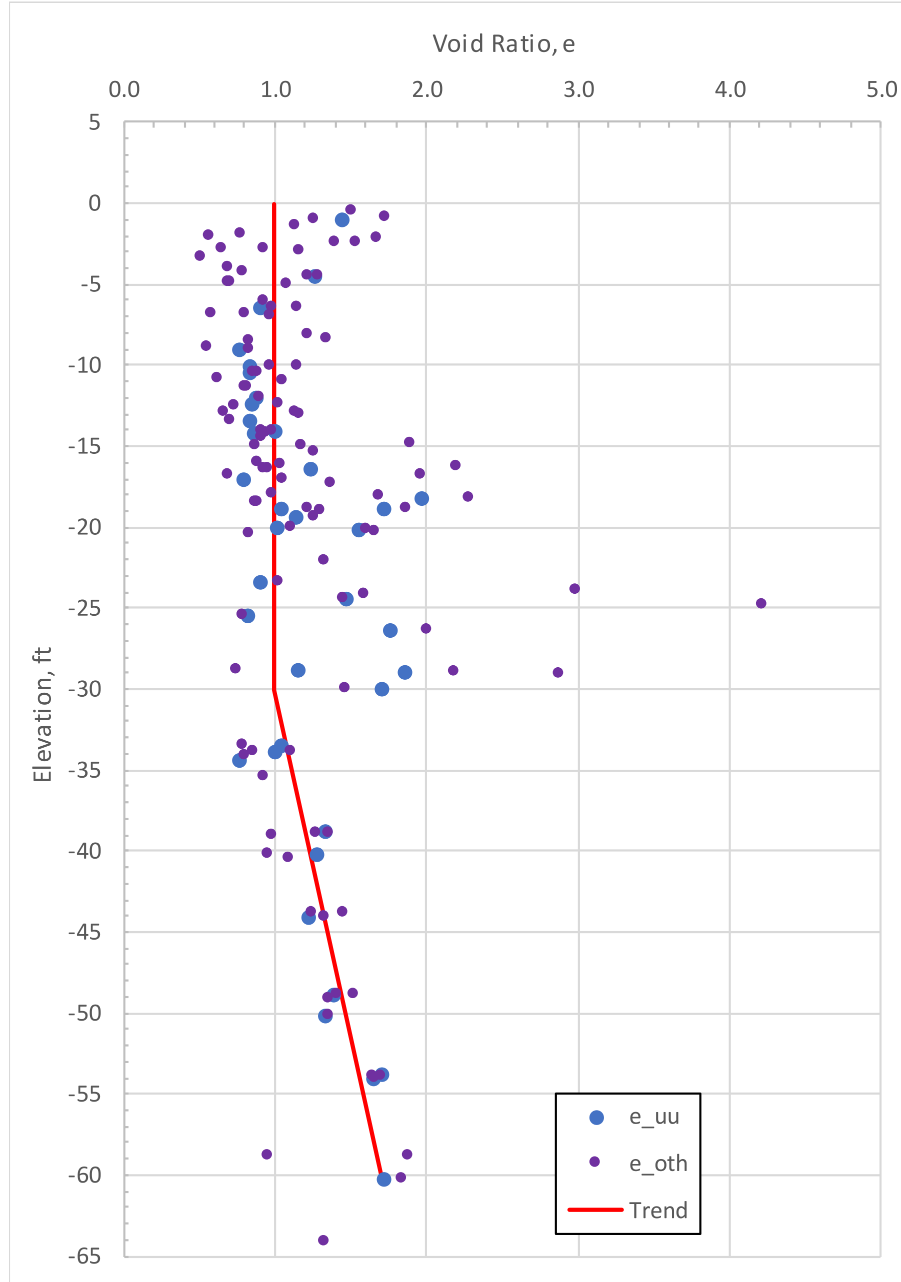




Dry Density and Total Unit Weight versus Elevation

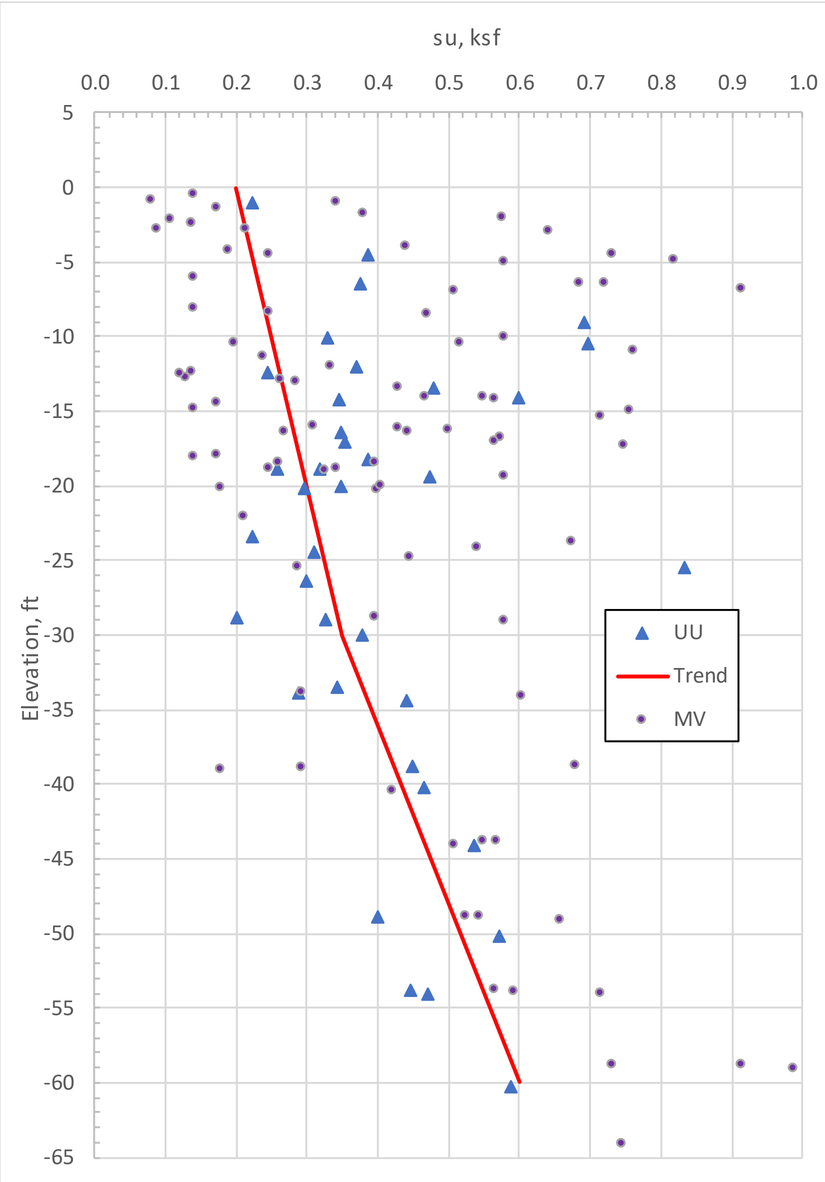
Plate A-4

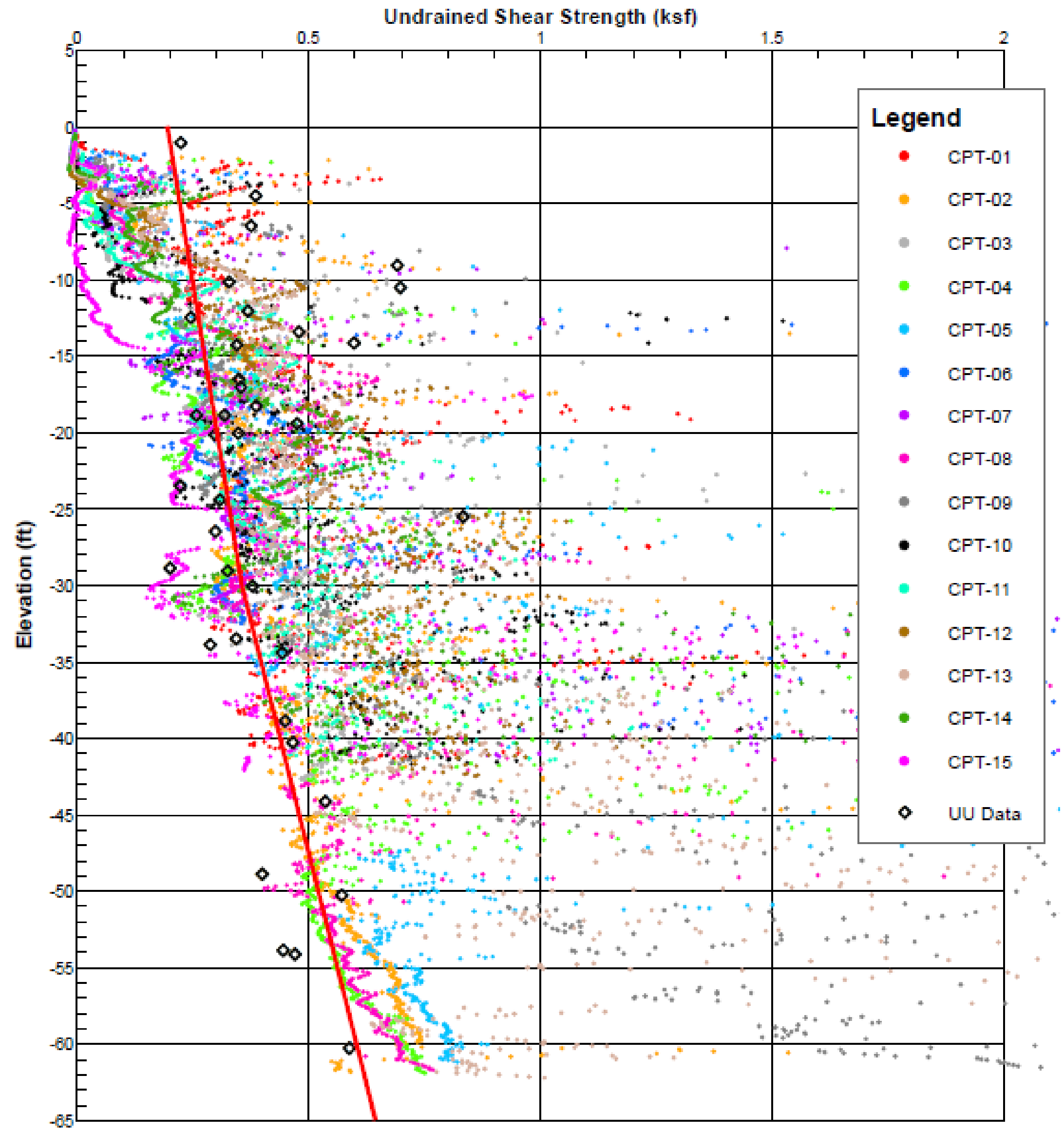




Dry Density and Void Ratio versus Elevation

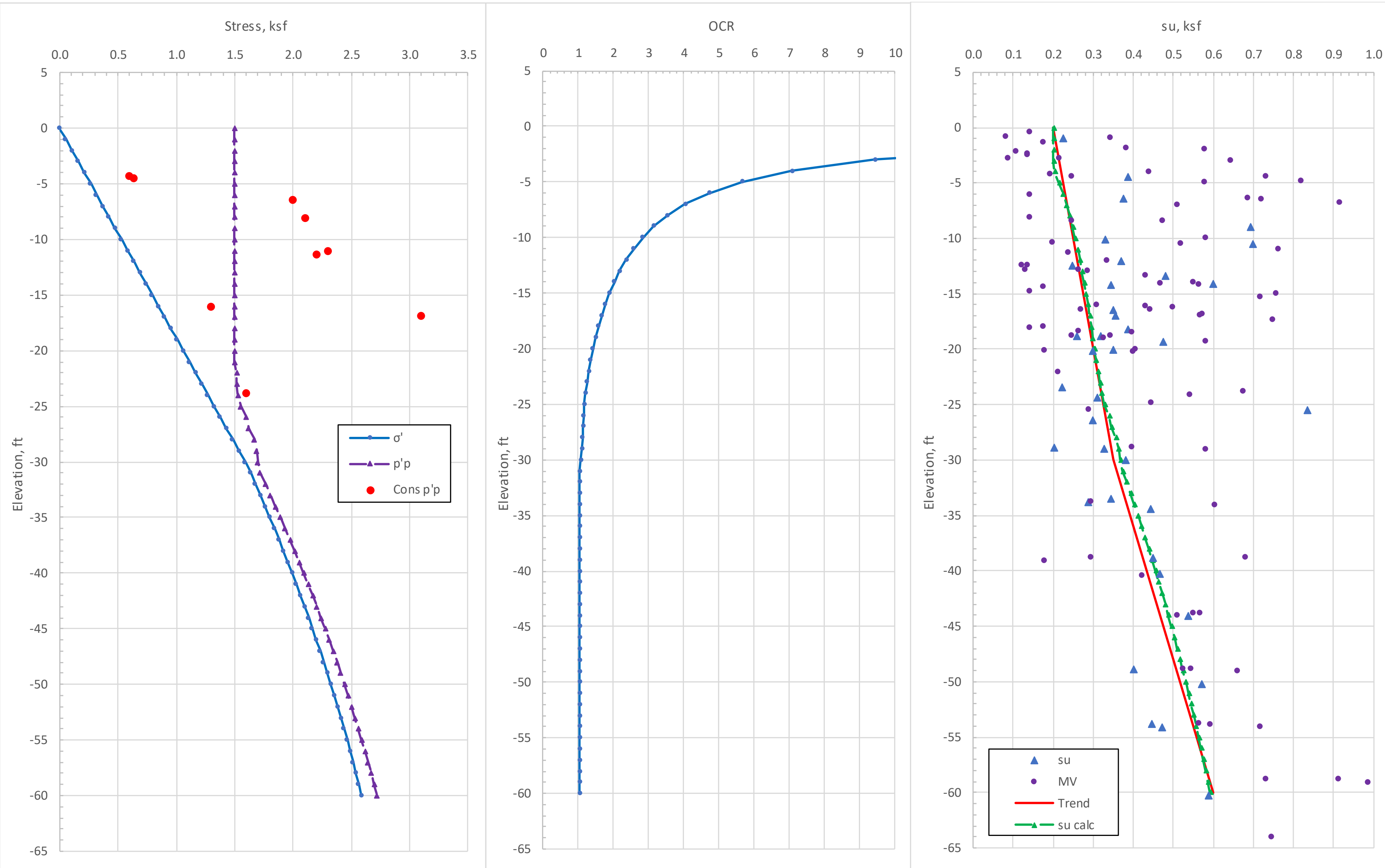
Plate A-5



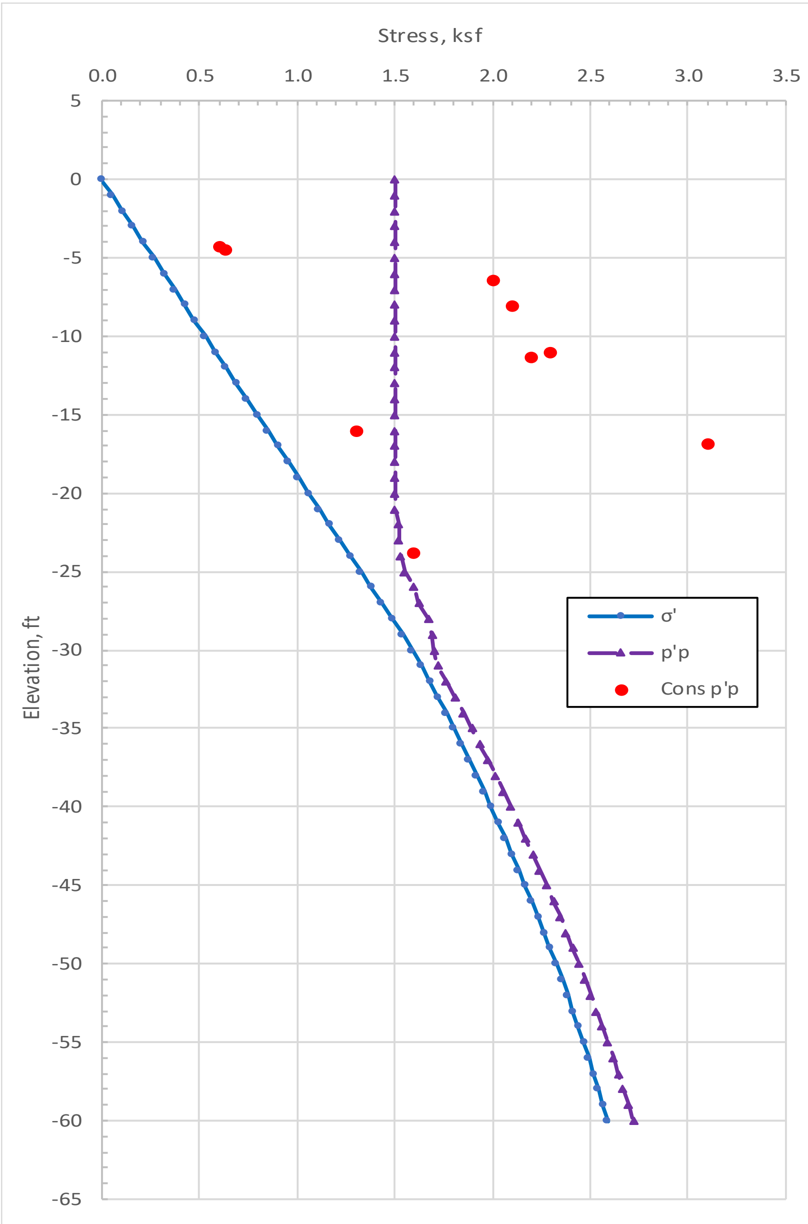


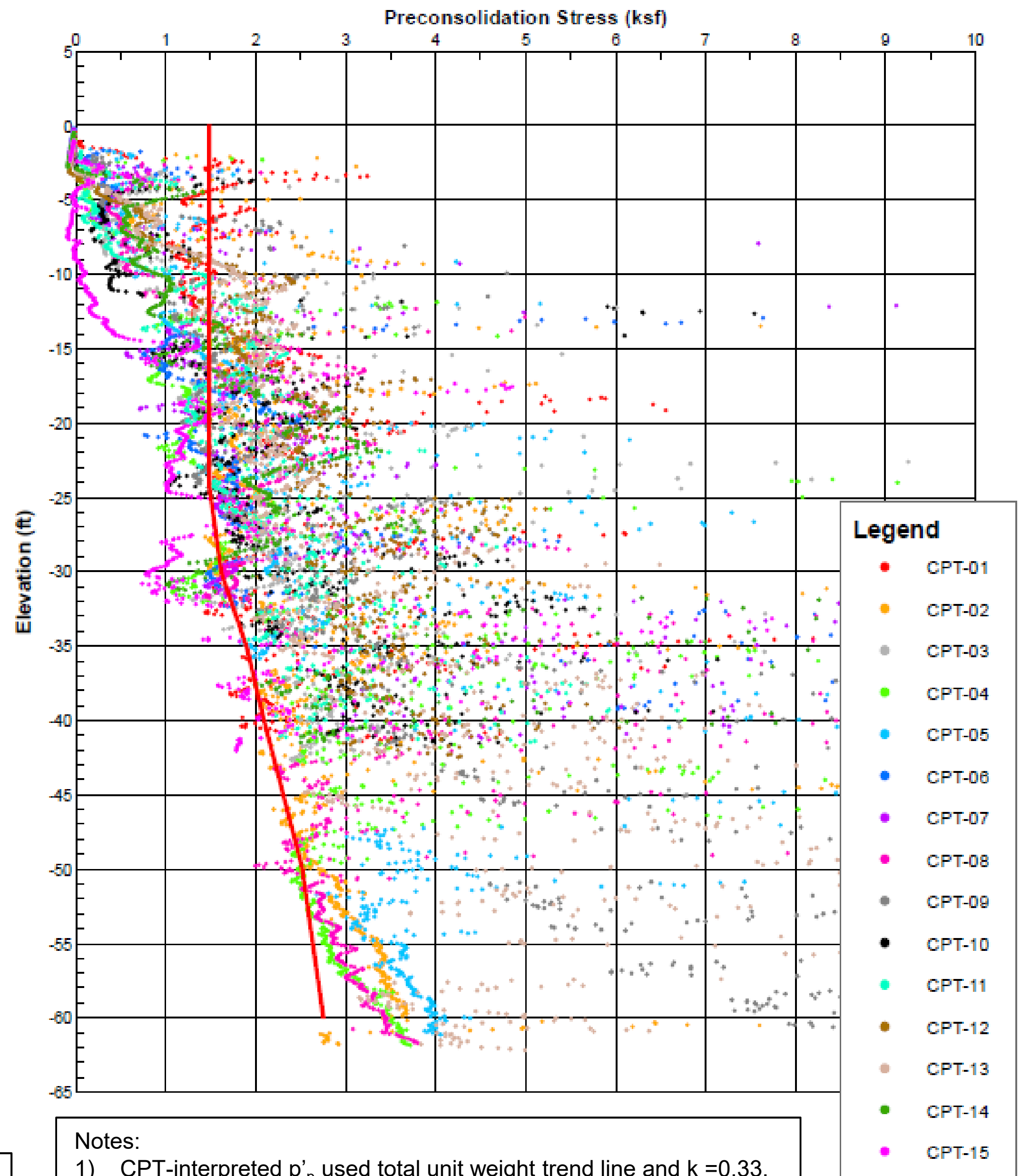
Note: CPT interpreted s_u used total unit weight trend line and N_k=15.

Undrained Shear Strength versus Elevation and Comparison with CPT Interpreted Undrained Shear Strength



Estimated Vertical Effective Stress, Past Maximum Pressure, Overconsolidation Ratio, and Undrained Shear Strength versus Elevation





Comparison of Past Maximum Pressure versus Elevation with CPT-Interpreted Past Maximum Pressure

Notes:
1) CPT-interpreted p'_p used total unit weight trend line and k =0.33.
2) Better fit above El-15 ft could be achieved by increasing k value.

Plate A-8

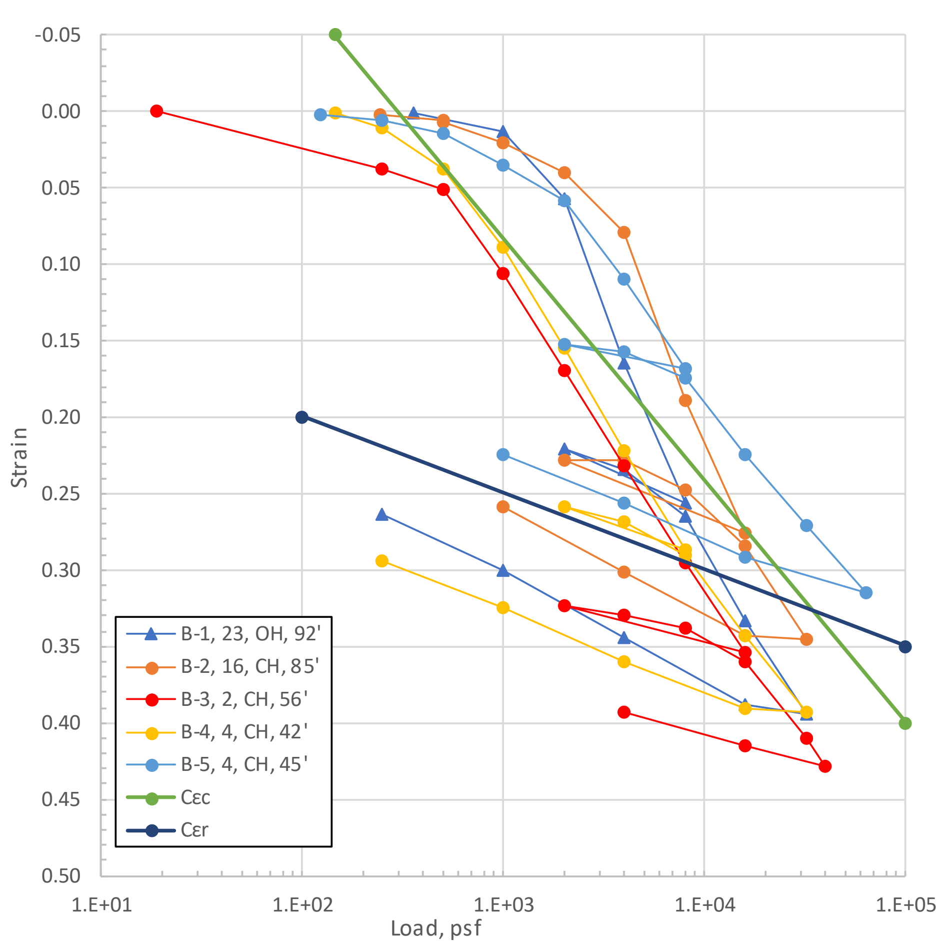
Notes:
1) Vertical effective stress, σ' based on total unit weight vs elevation trend from ground surface at El 0 ft to El-60 ft.
2) Calc $s_u = (s_u/p')_{NC} * OCR^n = 0.22 * OCR^{0.75}$.
3) Overconsolidation ratio, OCR, was iterated over elevation range to fit a calculated s_u close to trendline. Then, OCR was used to compute a past maximum pressure to compare with past maximum pressure values from consolidation tests.
4) CPT interpreted past maximum pressure computed using Robertson and Cabal (2015), see excerpt below, with k = 0.33. Appears a higher k should be used to match CPT estimate to trendline above El-10 ft, or trendline should be lowered by decreasing OCR.

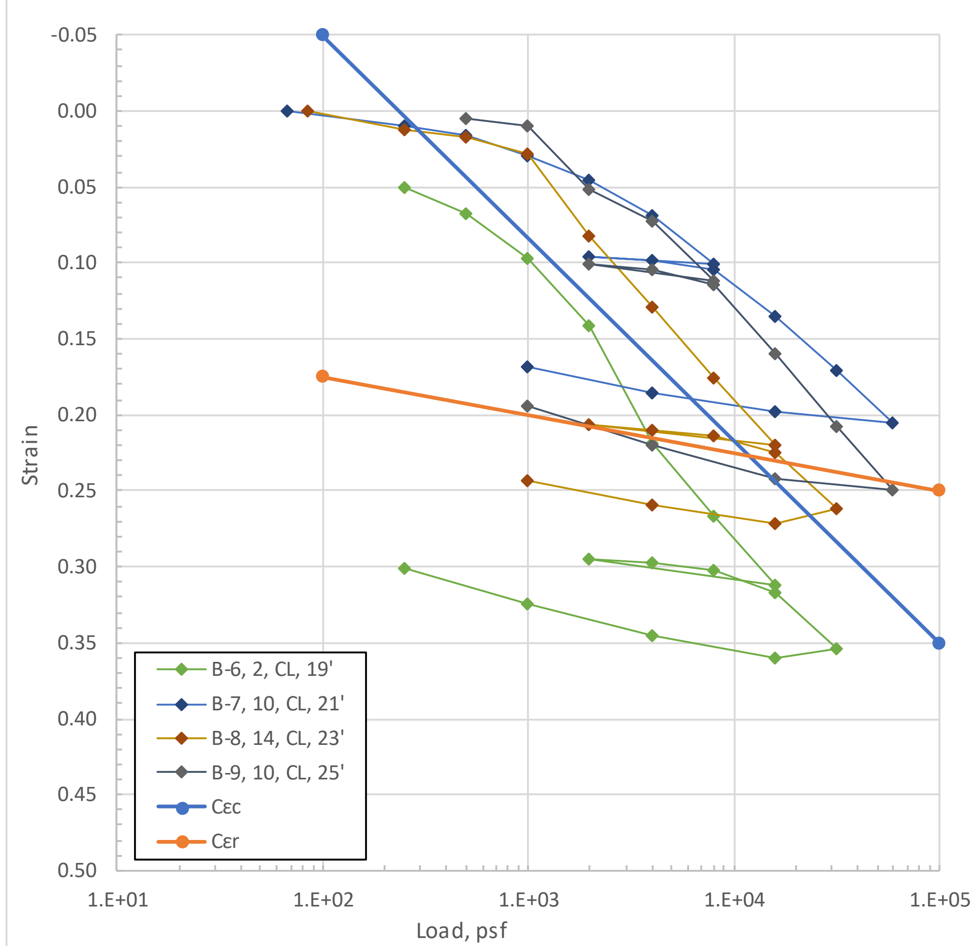
Stress History - Overconsolidation Ratio (OCR)

Kulhawy and Mayne (1990) suggested a simpler method: $\sigma'_p = k\,(q_t - \sigma_{vo})$

An average value of k = 0.33 can be assumed, with an expected range of 0.2 to 0.5. Higher values of k are recommended in aged, heavily overconsolidated clays. If previous experience is available in the same deposit, the values of k should be adjusted to reflect this experience and to provide a more reliable profile of OCR. The simpler Kulhawy and Mayne approach is valid for $Q_t < 20$. For larger, moderate to high-risk projects, where additional high quality field and laboratory data may be available, site-specific correlations should be developed based on consistent and relevant values of OCR.

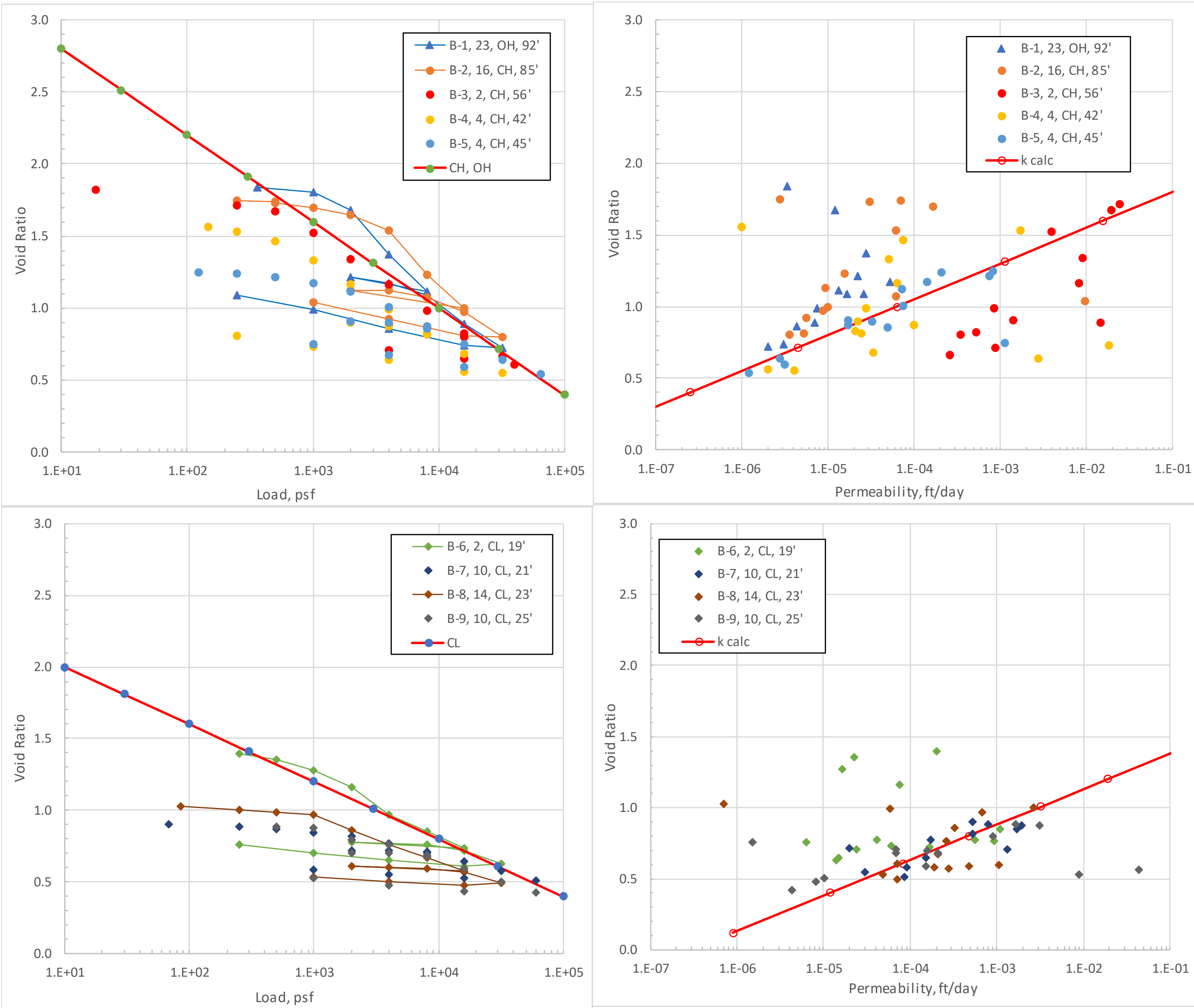
Notes Regarding Estimated Past Maximum Pressure, Overconsolidation Ratio, and Undrained Shear Strength





Number	Matl	$C_{\varepsilon c}$	$C_{\varepsilon r}$	$C_{\varepsilon r}/C_{\varepsilon c}$	avg mc	avg e_o
					%	
1	CH, OH	0.159	0.050	0.315	65.2	1.64
2	CL	0.133	0.025	0.188	44.1	1.09

Void Ratio versus Log Stress from Foundation Soil Consolidation Tests



Void Ratio versus Log Stress and Void Ratio versus Log Permeability from Foundation Soil Consolidation Tests

Plate A-11

Matl	1			Matl	2	
Classif	CH, OH			Classif	CL	
e_o	2.8			e_o	2.0	
C_c	0.600	C_k/C_c		C_c	0.400	C_k/C_c
C_k	0.250	0.417		C_k	0.250	0.625
σ	e calc	k calc		σ	e calc	k calc
psf		ft/day		psf		ft/day
1.0E+00	3.400	2.51E+05		1.0E+00	2.400	1.19E+03
3.0E+00	3.114	1.80E+04		3.0E+00	2.209	2.06E+02
1.0E+01	2.800	1.00E+03		1.0E+01	2.000	3.00E+01
3.0E+01	2.514	7.16E+01		3.0E+01	1.809	5.17E+00
1.0E+02	2.200	3.98E+00		1.0E+02	1.600	7.54E-01
3.0E+02	1.914	2.85E-01		3.0E+02	1.409	1.30E-01
1.0E+03	1.600	1.58E-02		1.0E+03	1.200	1.89E-02
3.0E+03	1.314	1.13E-03		3.0E+03	1.009	3.26E-03
1.0E+04	1.000	6.31E-05		1.0E+04	0.800	4.75E-04
3.0E+04	0.714	4.52E-06		3.0E+04	0.609	8.20E-05
1.0E+05	0.400	2.51E-07		1.0E+05	0.400	1.19E-05
5.0E+05	-0.019	5.28E-09		5.0E+05	0.120	9.09E-07

Notes:
1) Red trend lines shown in previous figure computed using values shown in red.
2) Material 2 was used for developing foundation soil consolidation parameters for PSDDF, see computed curves in Appendix B.

Tabulated Void Ratio versus Log Stress and Void Ratio versus Log Permeability from Foundation Soil Consolidation Tests

Notes:

1) CPT-interpreted constrained modulus based on Robertson and Cabel (2015), see except below.
2) Red trendline computed using formula for M with $C_c/(1+e) = C_\varepsilon = 0.02$, and σ_{vo} = vertical effective stress.
3) $C_\varepsilon = 0.02$ suggests an overconsolidated profile.

Constrained Modulus

Consolidation settlements can be estimated using the 1-D Constrained Modulus, M, where;

$$M = 1/\ m_v = \delta\sigma_v\ /\ \delta\varepsilon = 2.3\ (1+e_0)\ \sigma'_{vo}\ /\ C_c$$

Where m_v = equivalent oedometer coefficient of compressibility.

Constrained modulus can be estimated from CPT results using the following empirical relationship;

$$M = \alpha_M\ (q_t - \sigma_{vo})$$

Sangrelat (1970) suggested that α_M varies with soil plasticity and natural water content for a wide range of fine-grained soils and organic soils, although the data were based on q_c. Meigh (1987) suggested that α_M lies in the range 2 – 8, whereas Mayne (2001) suggested a general value of 5. Robertson (2009) suggested that α_M varies with Q_t, such that;

When $I_c > 2.2$ (fine-grained soils) use:

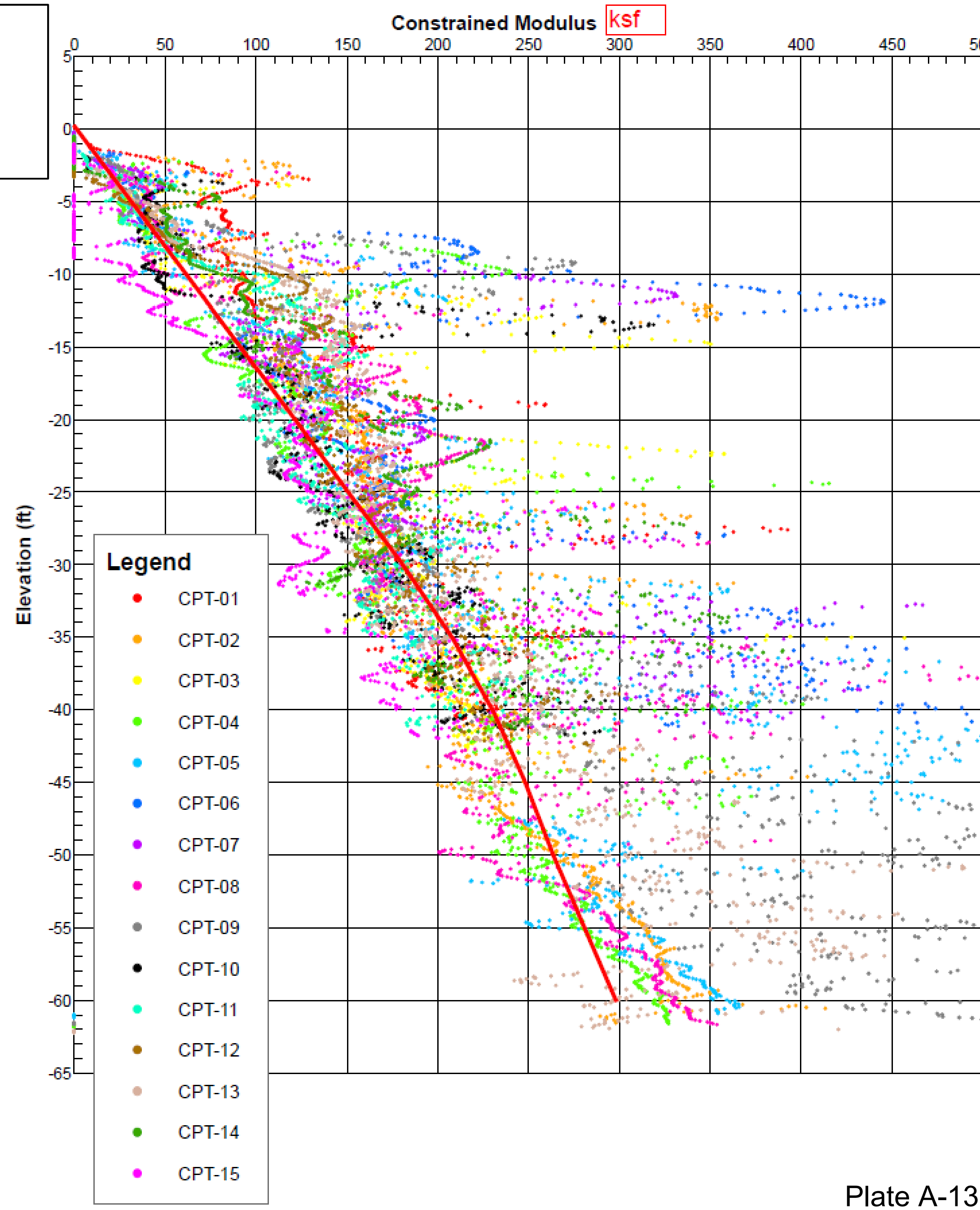
$\alpha_M = Q_t$ when $Q_t < 14$

$\alpha_M = 14$ when $Q_t > 14$

When $I_c < 2.2$ (coarse-grained soils) use:

$$\alpha_M = 0.0188\ [10^{\ (0.55Ic + 1.68)}]$$

Estimates of drained 1-D constrained modulus from undrained cone penetration will be approximate. Estimates can be improved with additional information about the soil, such as plasticity index and natural water content, where α_M can be lower in organic soils and soils with high water content.



Constrained Modulus versus Elevation

Note:
A drained friction angle of 27 degrees was selected for slope stability analyses.

S-Case Analysis Parameters for Outfall Canals

GCAT March 15, 2011

Summary

A literature review and analysis was performed to offer some guidance on the selection of drained strength parameters for use in S-case analyses performed on levees, particularly the levee fill materials in the outfall canals.

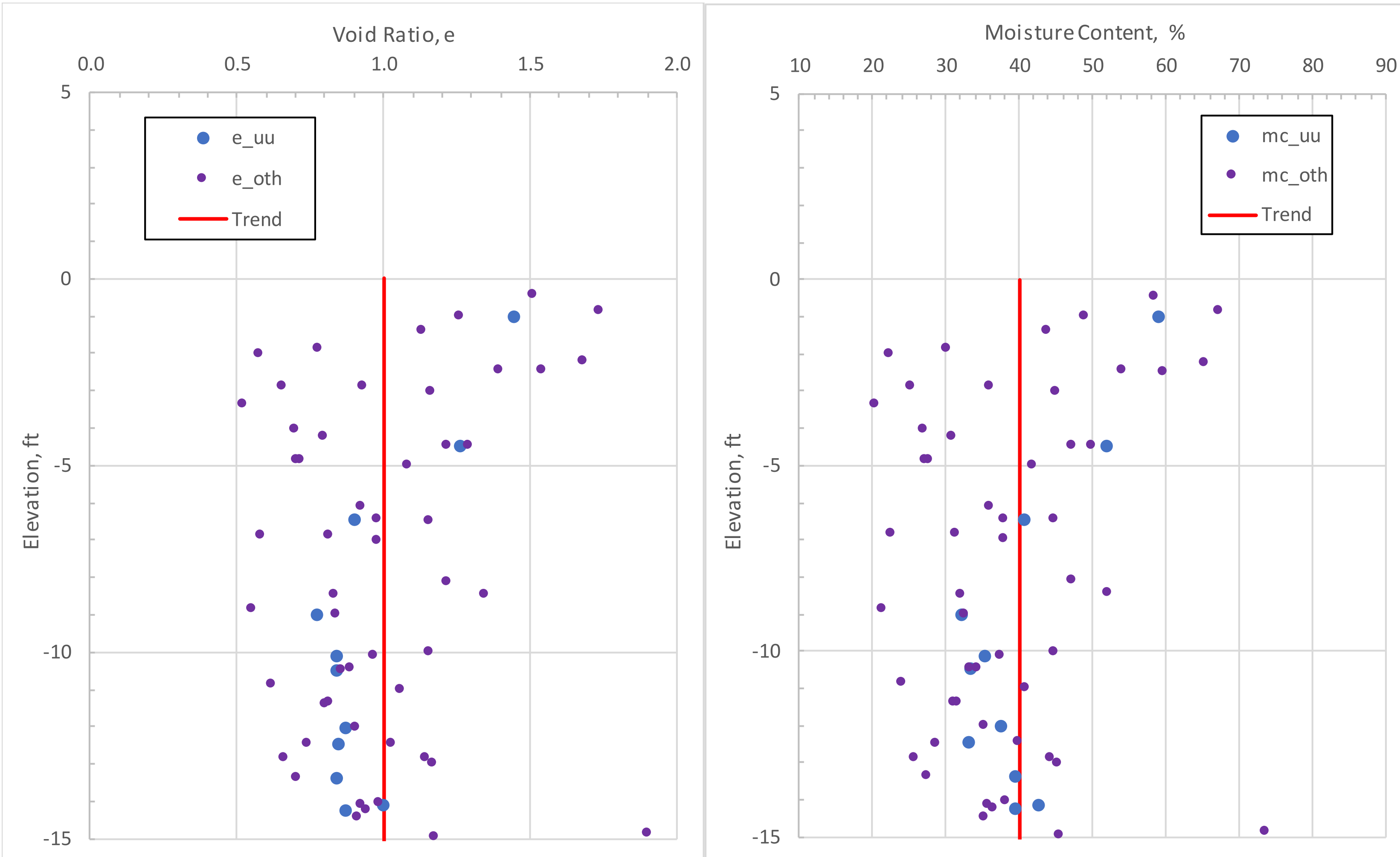
Based on the review of geotechnical laboratory test results performed by Brandon et al. (2011), drained friction angles are provided as a function of the MVN soil classification type as shown below:

Soil Type	Design cohesion c'	Design friction angle ϕ'
CH	0	26
CHO	0	24
CL	0	32
ML	0	34
PT	0	30
SC	0	33
SM	0	33
SP	0	34

These values represent the mean value from CU (R-bar) triaxial test results minus one standard deviation, or the mean value determined from direct shear tests for cases where no triaxial test results were available. The value of $c' = 0$ shown in the table above reflects the assumption that the soils are assumed to be normally consolidated.

Drained Shear Strength Parameters, excerpted from Brandon (2011).

Bulking Factors for Borrow Area Trenches



Marsh Area Borings, Void Ratio and Moisture Content versus Elevation above El-15 ft

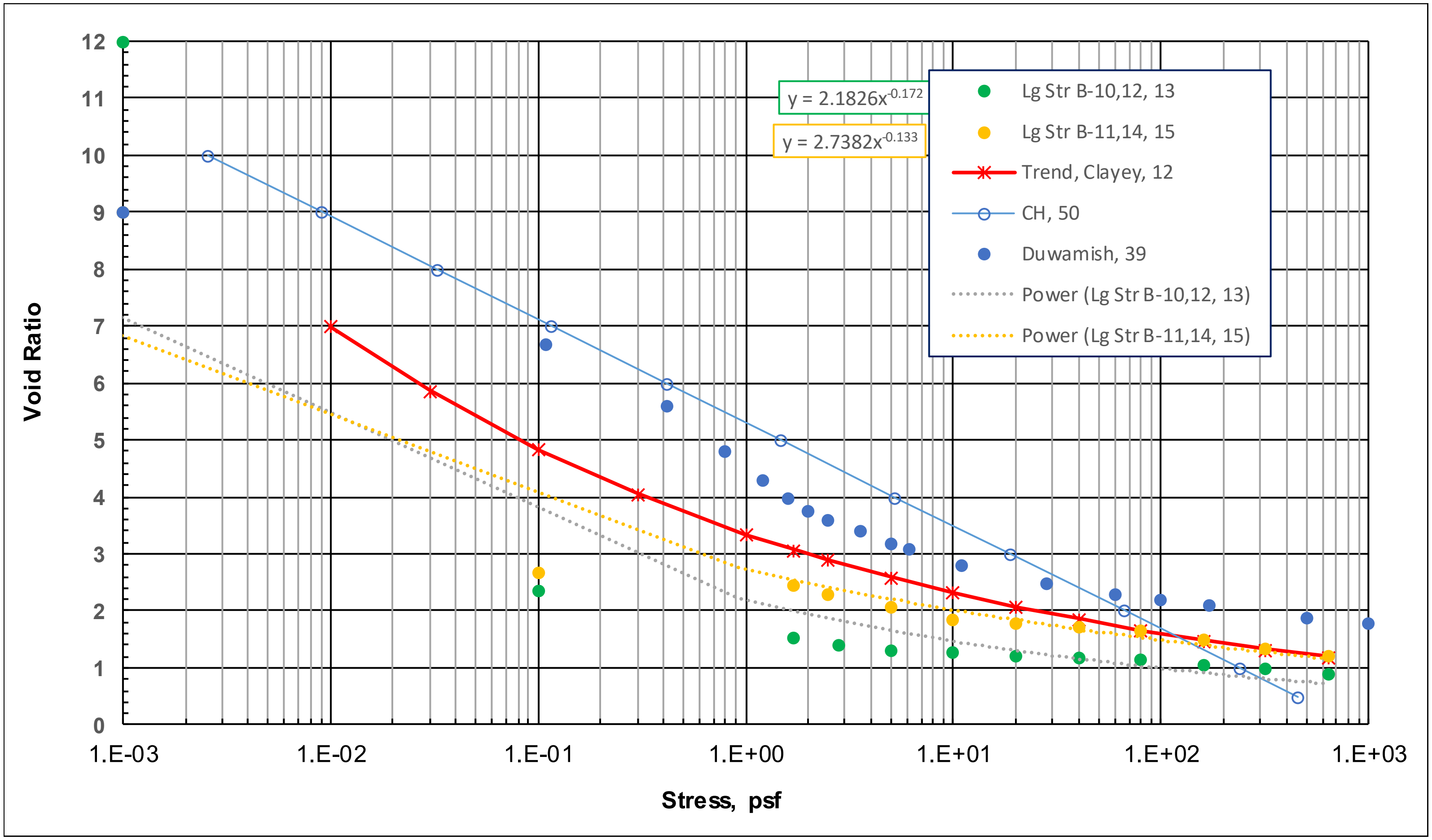
Notes for Bulking Factors for Excavated Materials from Borrow Trenches, above about El-10 ft (not dredged materials from lake borings):

1) Initial void ratios range from about 0.6 to 1.4, with a trend line average of about 1, for materials above about El-10 ft for borings B-1 to B-9, located around the marsh area perimeter.
2) Borrow area trenches will be ocated around march restoration area, no closer than about 25 ft inside or outside containment dikes.
3) Trenches will be excavated using extended excavator or clam shell methods.
4) Bulking factors are defined as the ratio between excavated and placed material soil volumes in containment dikes to the insitu soil volume.
5) Void ratios for excavated and placed materials will likely be somewhat greater than for insitu materials, but much less than void ratios for dredged materials placed at high void ratios.
6) Increased soil volume for materials be excavator in dike containment areas will depend on soil chunks and clod sizes will coalesce after placement and consolidate in the long term. Some materials may fluidize, e.g., sand, as water is added during the excavation and placement process and run off dike construction slopes as they are constructed.
7) A bulking factor greater than 2 seems high, as that would mean a doubling of the soil volume between insitu and placement after excavation.
8) A bulking factor between say 1.3 (a 30% increase in volume) to 1.7 (a 70% increase in volume) seems more reasonable.

Parameter	Unit	InSitu	As Placed	Bulking Factor
mc	%	40	65	
e		1.0	1.7	1.32
γ_d	pcf	79.2	60.1	
γ	pcf	110.9	99.2	
mc	%	35	70	
e		0.9	1.8	1.47
γ_d	pcf	84.6	57.4	
γ	pcf	114.2	97.5	
mc	%	35	80	
e		0.9	2.1	1.61
γ_d	pcf	84.6	52.5	
γ	pcf	114.2	94.6	
mc	%	35	85	
e		0.9	2.2	1.68
γ_d	pcf	84.6	50.4	
γ	pcf	114.2	93.3	

Estimated Bulking Factors for Borrow Trench Area Materials

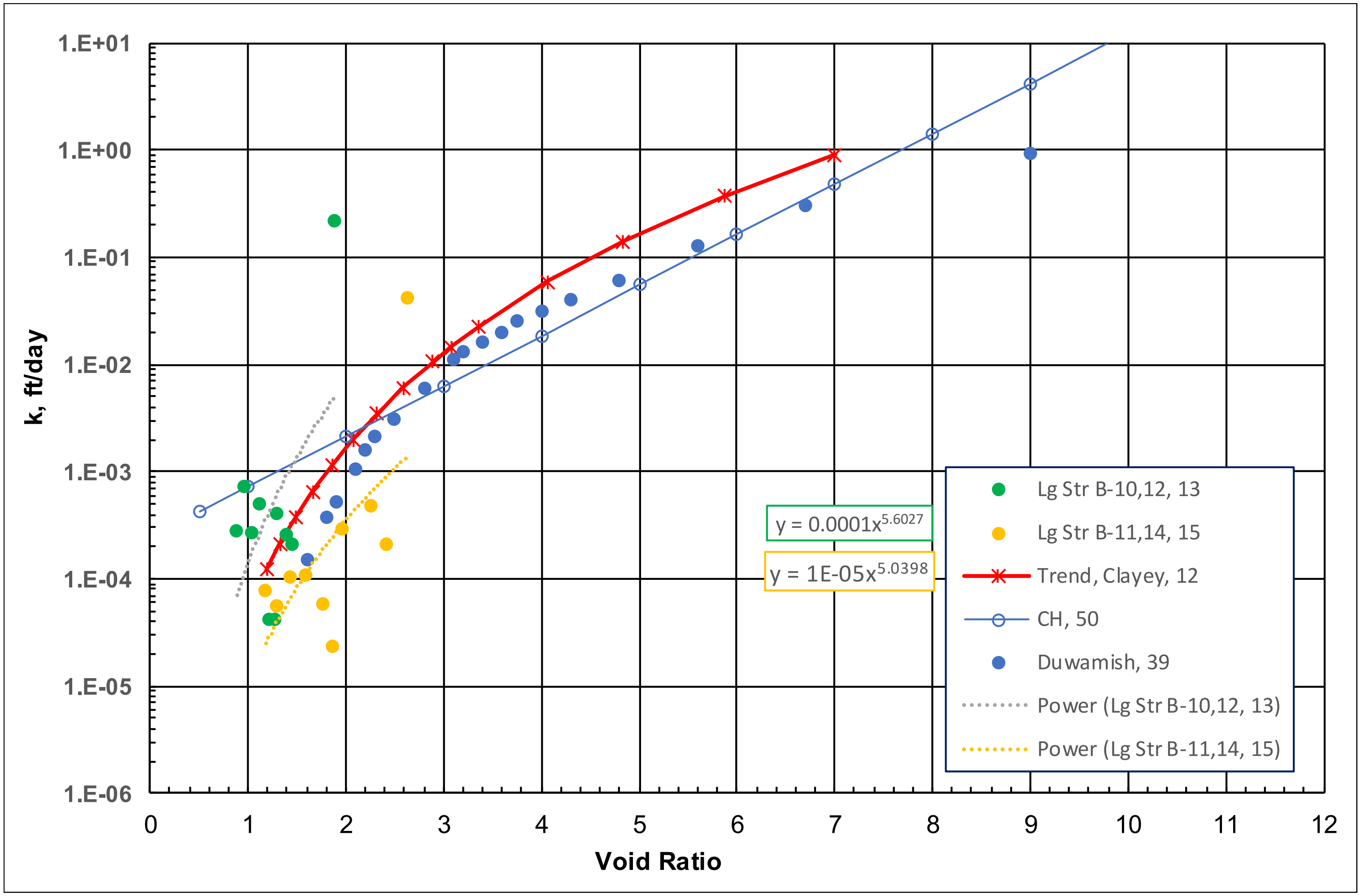
Dredge Fill



Sample	LL	PL	PI
B-10,12,13	73	28	45
B-11,14,15	93	29	64

Notes:
1) Red trendline used for PSDDF input.
2) Duwamish, PI=39; and CH, PI=50 data from Stark (2005) database.

Borrow Area/Dredge Fill Material Void Ratio Versus Stress



Notes:
1) Red trendline used for PSDDF input.
2) Duwamish, 39 and CH, 50 data from Stark (2005) database.

Borrow Area/Dredge Fill Material Permeability Versus Void Ratio

Point	e	σ'	k	
		psf	ft/day	cm/sec
1	7.00	0.01	9.08E-01	3.20E-04
2	5.87	0.03	3.74E-01	1.32E-04
3	4.84	0.1	1.42E-01	5.00E-05
4	4.06	0.3	5.85E-02	2.06E-05
5	3.35	1.0	2.21E-02	7.81E-06
6	3.08	1.7	1.44E-02	5.09E-06
7	2.89	2.5	1.06E-02	3.73E-06
8	2.59	5	6.05E-03	2.13E-06
9	2.32	10	3.46E-03	1.22E-06
10	2.07	20	1.98E-03	6.98E-07
11	1.86	40	1.13E-03	3.99E-07
12	1.66	80	6.46E-04	2.28E-07
13	1.49	160	3.70E-04	1.30E-07
14	1.33	320	2.11E-04	7.46E-08
15	1.19	640	1.21E-04	4.26E-08

Tabulated Borrow Area/Dredge Fill Material Compressibility and Permeability Input

APPENDIX B

SETTLEMENT EVALUATIONS

Marsh Area Settlement

Year	MHW+ESLR	MLW+ESLR
	ft	ft
2020	0.796	0.414
2021	0.816	0.434
2022	0.837	0.455
2023	0.858	0.476
2024	0.879	0.497
2025	0.901	0.519
2026	0.923	0.541
2027	0.946	0.564
2028	0.969	0.587
2029	0.992	0.61
2030	1.016	0.634
2031	1.04	0.658
2032	1.065	0.683
2033	1.09	0.708
2034	1.115	0.733
2035	1.141	0.759
2036	1.167	0.785
2037	1.194	0.812
2038	1.221	0.839
2039	1.248	0.866
2040	1.276	0.894

Description	Elev
	ft
Existing mudline	-2.0
End of Construction	3.0
Mean tide water, during construction	0.6
Final Fill Height, ft	5

	Elevation, ft	
	Low	High
2020 target	0.9	1.3

Notes:
Elevation Reference: NAVD88.
MHW = mean high water.
MLW = mean low water.
ESLR = estimated sea level rise.

	mm	ft	in
Subsidence Rate	7.0	0.023	0.276

CPRA-Provided Water Elevations, Subsidence Rate, and Marsh Fill Surface Target Elevations

Number	Type	Elev, ft		Thick.	Sublyrs	Sublyr Thick	Mid El	p'_p	e_o	$C_{\varepsilon r}$	C_r	$C_{\varepsilon r}/C_{\varepsilon c}$	$C_{\varepsilon c}$	C_c	Matl ID
		top	bottom	ft		ft	ft	psf							
7	Compr	-2	-5	3	6	0.500	-3.5	1.50	1.00	0.025	0.050	0.170	0.147	0.294	7
6	Compr	-5	-10	5	10	0.50	-7.5	1.50	1.00	0.025	0.050	0.170	0.147	0.294	6
5	Compr	-10	-15	5	10	0.50	-12.5	1.50	1.00	0.025	0.050	0.170	0.147	0.294	5
4	Compr	-15	-20	5	10	0.50	-17.5	1.50	1.00	0.025	0.050	0.170	0.147	0.294	4
3	Compr	-20	-30	10	10	1.00	-25.0	1.55	1.00	0.025	0.050	0.170	0.147	0.294	3
2	Compr	-30	-45	15	10	1.50	-37.5	2.00	1.20	0.025	0.055	0.170	0.147	0.324	2
1	Compr	-45	-60	15	10	1.50	-52.5	2.50	1.60	0.025	0.065	0.170	0.147	0.382	1
	Incompr	-60													
			Totals	58	66										

Matl ID	Elevation Range		Initial Condition	Initial Void Ratio	Past Max Pressure	Compression Indices		Δe/ LOG(k/k_o)			C_r*log(σ'_p/σ')	C_c*log(σ'_p/σ')	Void Ratio		Stress	Permeability, k	
	Bot	Top		e_o	σ'_p	C_r	C_c	C_k	k_o	Pt	e_{oc}	e_{nc}	Calc	Plotted	σ'	Calc	Plotted
	ft	ft			psf				ft/day						psf	ft/day	ft/day
1	-60	-45	OC	1.6	2500	0.065	0.382	0.25	0.005	1	0.286	0.000	1.886	1.886	1.00E-01	5.000E-03	5.00E-03
	-52.5					C_r/C_c	0.170			2	0.190	0.000	1.790	1.790	3.00E+00	2.065E-03	2.06E-03
Bottom layer						$C_{\varepsilon r}$	$C_{\varepsilon c}$			3	0.156	0.000	1.756	1.756	1.00E+01	1.51E-03	1.51E-03
						0.025	0.147			4	0.125	0.000	1.725	1.725	3.00E+01	1.13E-03	1.13E-03
										5	0.091	0.000	1.691	1.691	1.00E+02	8.30E-04	8.30E-04
										6	0.060	0.000	1.660	1.660	3.00E+02	6.24E-04	6.24E-04
										7	0.026	0.000	1.626	1.626	1.00E+03	4.56E-04	4.56E-04
										8	0.000	0.000	1.600	1.600	2.50E+03	3.59E-04	3.59E-04
										9	0.000	0.230	1.370	1.370	1.00E+04	4.32E-05	4.32E-05
										10	0.000	0.412	1.188	1.188	3.00E+04	8.06E-06	8.06E-06
										11	0.000	0.612	0.988	0.988	1.00E+05	1.28E-06	1.28E-06
2	-45	-30	OC	1.2	2000	0.055	0.324	0.25	0.005	1	0.237	0.000	1.437	1.437	1.00E-01	5.00E-03	5.00E-03
	-37.5					C_r/C_c	0.170			2	0.155	0.000	1.355	1.355	3.00E+00	2.37E-03	2.37E-03
						$C_{\varepsilon r}$	$C_{\varepsilon c}$			3	0.127	0.000	1.327	1.327	1.00E+01	1.82E-03	1.82E-03
						0.025	0.147			4	0.100	0.000	1.300	1.300	3.00E+01	1.43E-03	1.43E-03
										5	0.072	0.000	1.272	1.272	1.00E+02	1.09E-03	1.09E-03
										6	0.045	0.000	1.245	1.245	3.00E+02	8.59E-04	8.59E-04
										7	0.000	0.000	1.200	1.200	2.00E+03	5.66E-04	5.66E-04
										8	0.000	0.057	1.143	1.143	3.00E+03	3.35E-04	3.35E-04
										9	0.000	0.226	0.974	0.974	1.00E+04	7.03E-05	7.03E-05
										10	0.000	0.381	0.819	0.819	3.00E+04	1.69E-05	1.69E-05
										11	0.000	0.550	0.650	0.650	1.00E+05	3.56E-06	3.56E-06
3	-30	-20	OC	1.0	1550	0.050	0.294	0.25	0.005	1	0.210	0.000	1.210	1.210	1.00E-01	5.00E-03	5.00E-03
	-25					C_r/C_c	0.170			2	0.136	0.000	1.136	1.136	3.00E+00	2.53E-03	2.53E-03
						$C_{\varepsilon r}$	$C_{\varepsilon c}$			3	0.110	0.000	1.110	1.110	1.00E+01	1.99E-03	1.99E-03
						0.025	0.147			4	0.086	0.000	1.086	1.086	3.00E+01	1.60E-03	1.60E-03
										5	0.060	0.000	1.060	1.060	1.00E+02	1.26E-03	1.26E-03
										6	0.036	0.000	1.036	1.036	3.00E+02	1.01E-03	1.01E-03
										7	0.000	0.000	1.000	1.000	1.55E+03	7.26E-04	7.26E-04
										8	0.000	0.084	0.916	0.916	3.00E+03	3.34E-04	3.34E-04
										9	0.000	0.238	0.762	0.762	1.00E+04	8.10E-05	8.10E-05
										10	0.000	0.378	0.622	0.622	3.00E+04	2.23E-05	2.23E-05
										11	0.000	0.532	0.468	0.468	1.00E+05	5.40E-06	5.40E-06

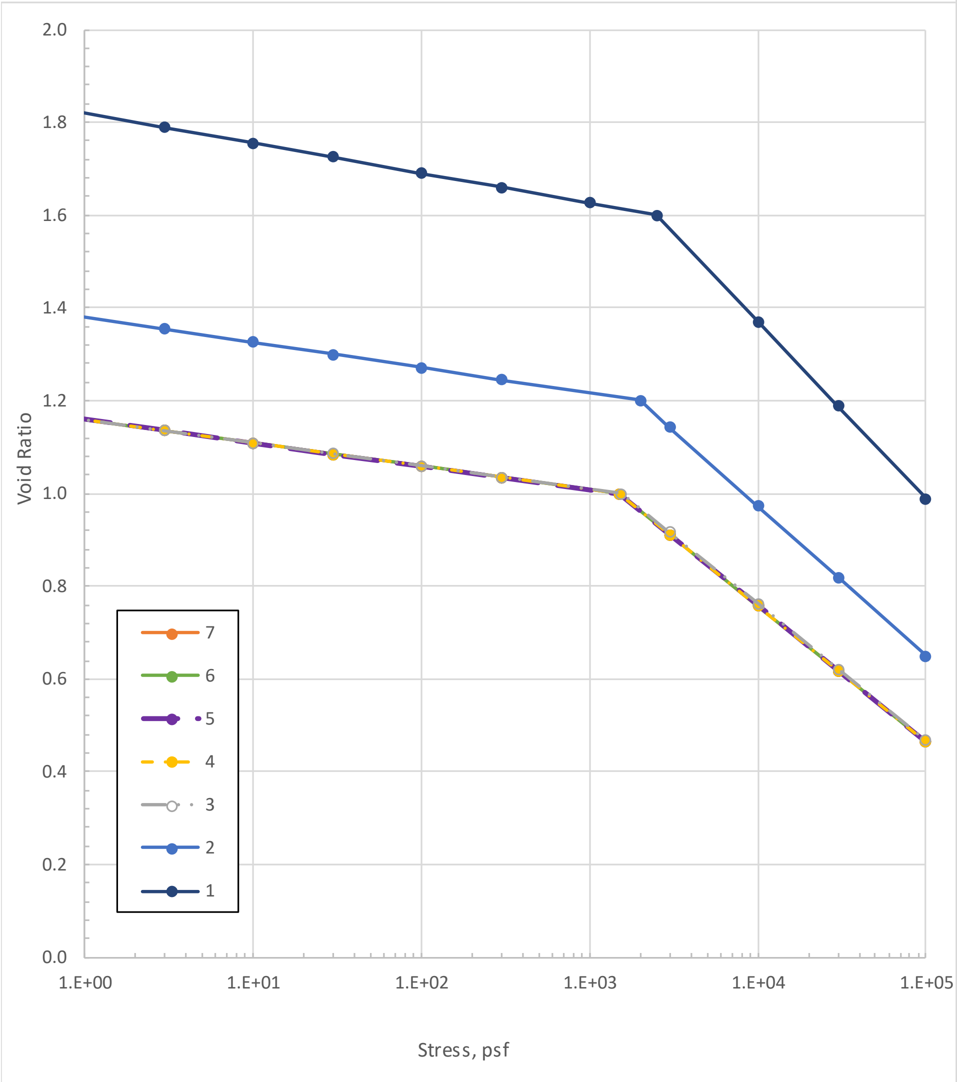
Calculated Void Ratio versus Vertical Effective Stress and Permeability for Foundation Soils, 1/3

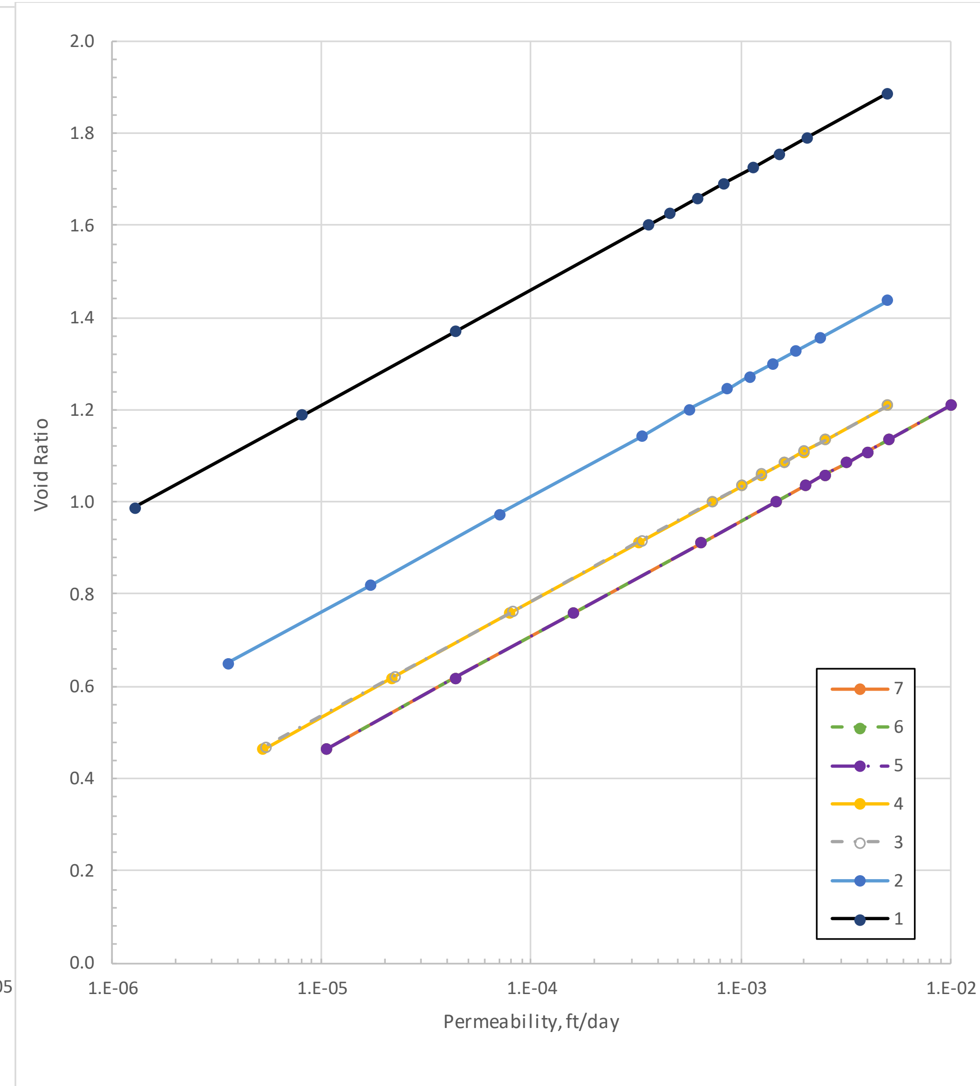
	Elevation Range		Initial Condition	Initial Void Ratio	Past Max Pressure	Compression Indices		Δe/LOG(k/k_o)			C_r*log(σ'_p/σ')	C_c*log(σ'_p/σ')	Void Ratio		Stress	Permeability, k	
Matl ID	Bot	Top		e_o	σ'_p	C_r	C_c	C_k	k_o	Pt	e_{oc}	e_{nc}	Calc	Plotted	σ'	Calc	Plotted
	ft	ft			psf				ft/day						psf	ft/day	ft/day
4	-20	-15	OC	1.0	1500	0.050	0.294	0.25	0.005	1	0.209	0.000	1.209	1.209	1.00E-01	5.00E-03	5.00E-03
	-17.5					C_r/C_c	0.170			2	0.135	0.000	1.135	1.135	3.00E+00	2.53E-03	2.53E-03
						$C_{\varepsilon r}$	$C_{\varepsilon c}$			3	0.109	0.000	1.109	1.109	1.00E+01	1.99E-03	1.99E-03
						0.025	0.147			4	0.085	0.000	1.085	1.085	3.00E+01	1.60E-03	1.60E-03
										5	0.059	0.000	1.059	1.059	1.00E+02	1.26E-03	1.26E-03
										6	0.035	0.000	1.035	1.035	3.00E+02	1.01E-03	1.01E-03
										7	0.000	0.000	1.000	1.000	1.50E+03	7.31E-04	7.31E-04
										8	0.000	0.089	0.911	0.911	3.00E+03	3.23E-04	3.23E-04
										9	0.000	0.242	0.758	0.758	1.00E+04	7.85E-05	7.85E-05
										10	0.000	0.383	0.617	0.617	3.00E+04	2.16E-05	2.16E-05
										11	0.000	0.536	0.464	0.464	1.00E+05	5.23E-06	5.23E-06
5	-15	-10	OC	1.0	1500	0.050	0.294	0.25	0.01	1	0.209	0.000	1.209	1.209	1.00E-01	1.00E-02	1.00E-02
	-12.5					C_r/C_c	0.170			2	0.135	0.000	1.135	1.135	3.00E+00	5.06E-03	5.06E-03
						$C_{\varepsilon r}$	$C_{\varepsilon c}$			3	0.109	0.000	1.109	1.109	1.00E+01	3.98E-03	3.98E-03
						0.025	0.147			4	0.085	0.000	1.085	1.085	3.00E+01	3.20E-03	3.20E-03
										5	0.059	0.000	1.059	1.059	1.00E+02	2.51E-03	2.51E-03
										6	0.035	0.000	1.035	1.035	3.00E+02	2.02E-03	2.02E-03
										7	0.000	0.000	1.000	1.000	1.50E+03	1.46E-03	1.46E-03
										8	0.000	0.089	0.911	0.911	3.00E+03	6.47E-04	6.47E-04
										9	0.000	0.242	0.758	0.758	1.00E+04	1.57E-04	1.57E-04
										10	0.000	0.383	0.617	0.617	3.00E+04	4.31E-05	4.31E-05
										11	0.000	0.536	0.464	0.464	1.00E+05	1.05E-05	1.05E-05
6	-10	-5	OC	1.0	1500	0.050	0.294	0.25	0.01	1	0.209	0.000	1.209	1.209	1.00E-01	1.00E-02	1.00E-02
	-7.5					C_r/C_c	0.170			2	0.135	0.000	1.135	1.135	3.00E+00	5.06E-03	5.06E-03
						$C_{\varepsilon r}$	$C_{\varepsilon c}$			3	0.109	0.000	1.109	1.109	1.00E+01	3.98E-03	3.98E-03
						0.025	0.147			4	0.085	0.000	1.085	1.085	3.00E+01	3.20E-03	3.20E-03
										5	0.059	0.000	1.059	1.059	1.00E+02	2.51E-03	2.51E-03
										6	0.035	0.000	1.035	1.035	3.00E+02	2.02E-03	2.02E-03
										7	0.000	0.000	1.000	1.000	1.50E+03	1.46E-03	1.46E-03
										8	0.000	0.089	0.911	0.911	3.00E+03	6.47E-04	6.47E-04
										9	0.000	0.242	0.758	0.758	1.00E+04	1.57E-04	1.57E-04
										10	0.000	0.383	0.617	0.617	3.00E+04	4.31E-05	4.31E-05
										11	0.000	0.536	0.464	0.464	1.00E+05	1.05E-05	1.05E-05

Calculated Void Ratio versus Vertical Effective Stress and Permeability for Foundation Soils, 2/3

	Elevation Range		Initial Condition	Initial Void Ratio	Past Max Pressure	Compression Indices		$\Delta e / LOG(k/k_o)$			C_r*log(σ'$_p$/σ')	C_c*log(σ'$_p$/σ')	Void Ratio		Stress	Permeability, k	
Matl ID	Bot	Top		e_o	σ'_p	C_r	C_c	C_k	k_o	Pt	e_{oc}	e_{nc}	Calc	Plotted	σ'	Calc	Plotted
	ft	ft			psf				ft/day						psf	ft/day	ft/day
7	-5	-2	OC	1.0	1500	0.050	0.294	0.25	0.01	1	0.209	0.000	1.209	1.209	1.00E-01	1.00E-02	1.00E-02
	-3.5					C_r / C_c	0.170			2	0.135	0.000	1.135	1.135	3.00E+00	5.06E-03	5.06E-03
Top layer						$C_{\varepsilon r}$	$C_{\varepsilon c}$			3	0.109	0.000	1.109	1.109	1.00E+01	3.98E-03	3.98E-03
						0.025	0.147			4	0.085	0.000	1.085	1.085	3.00E+01	3.20E-03	3.20E-03
										5	0.059	0.000	1.059	1.059	1.00E+02	2.51E-03	2.51E-03
										6	0.035	0.000	1.035	1.035	3.00E+02	2.02E-03	2.02E-03
										7	0.000	0.000	1.000	1.000	1.50E+03	1.46E-03	1.46E-03
										8	0.000	0.089	0.911	0.911	3.00E+03	6.47E-04	6.47E-04
										9	0.000	0.242	0.758	0.758	1.00E+04	1.57E-04	1.57E-04
										10	0.000	0.383	0.617	0.617	3.00E+04	4.31E-05	4.31E-05
										11	0.000	0.536	0.464	0.464	1.00E+05	1.05E-05	1.05E-05

Calculated Void Ratio versus Vertical Effective Stress and Permeability for Foundation Soils, 3/3

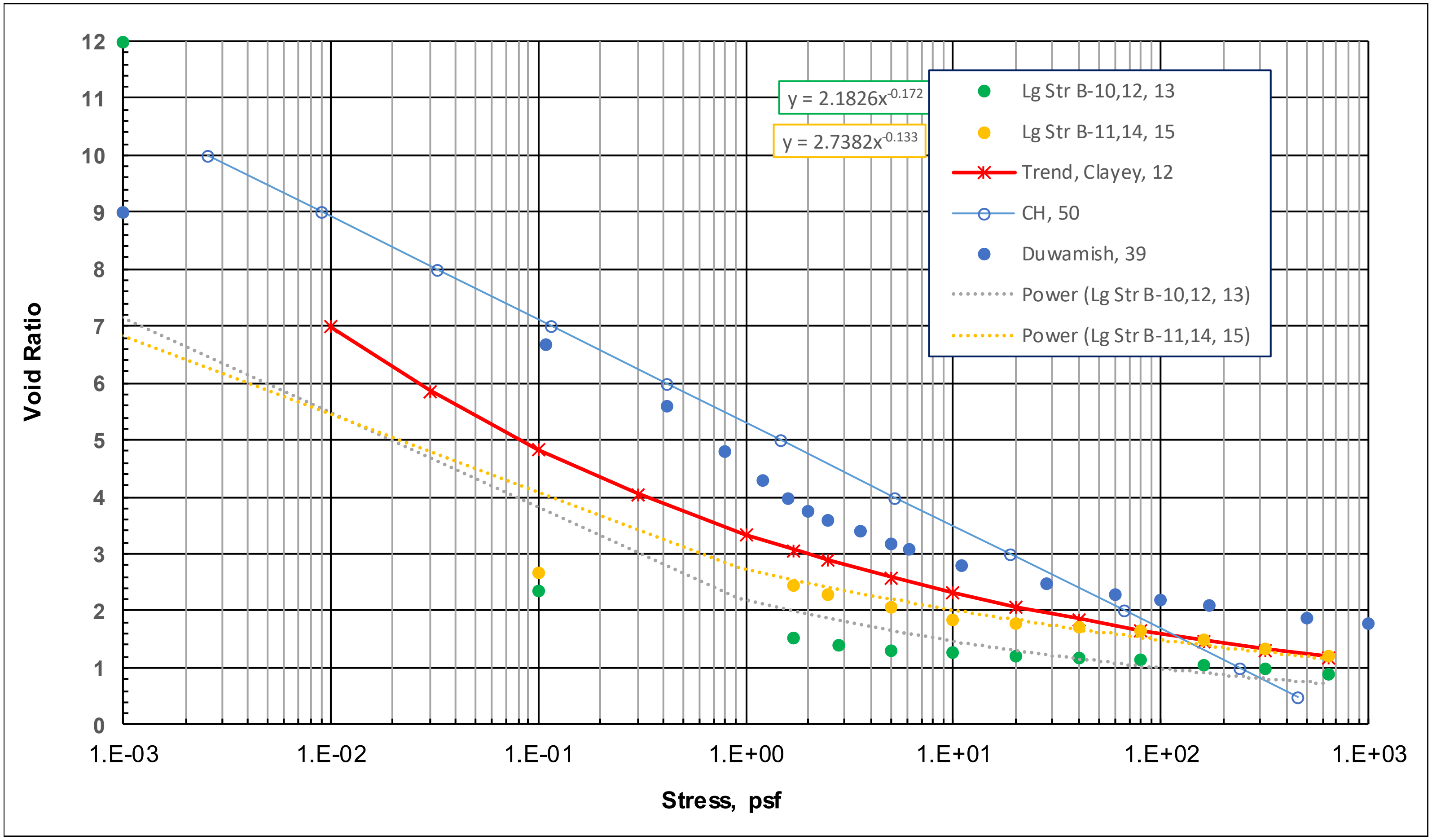




Calculated Void Ratio versus Vertical Effective Stress and Permeability for Foundation Soils

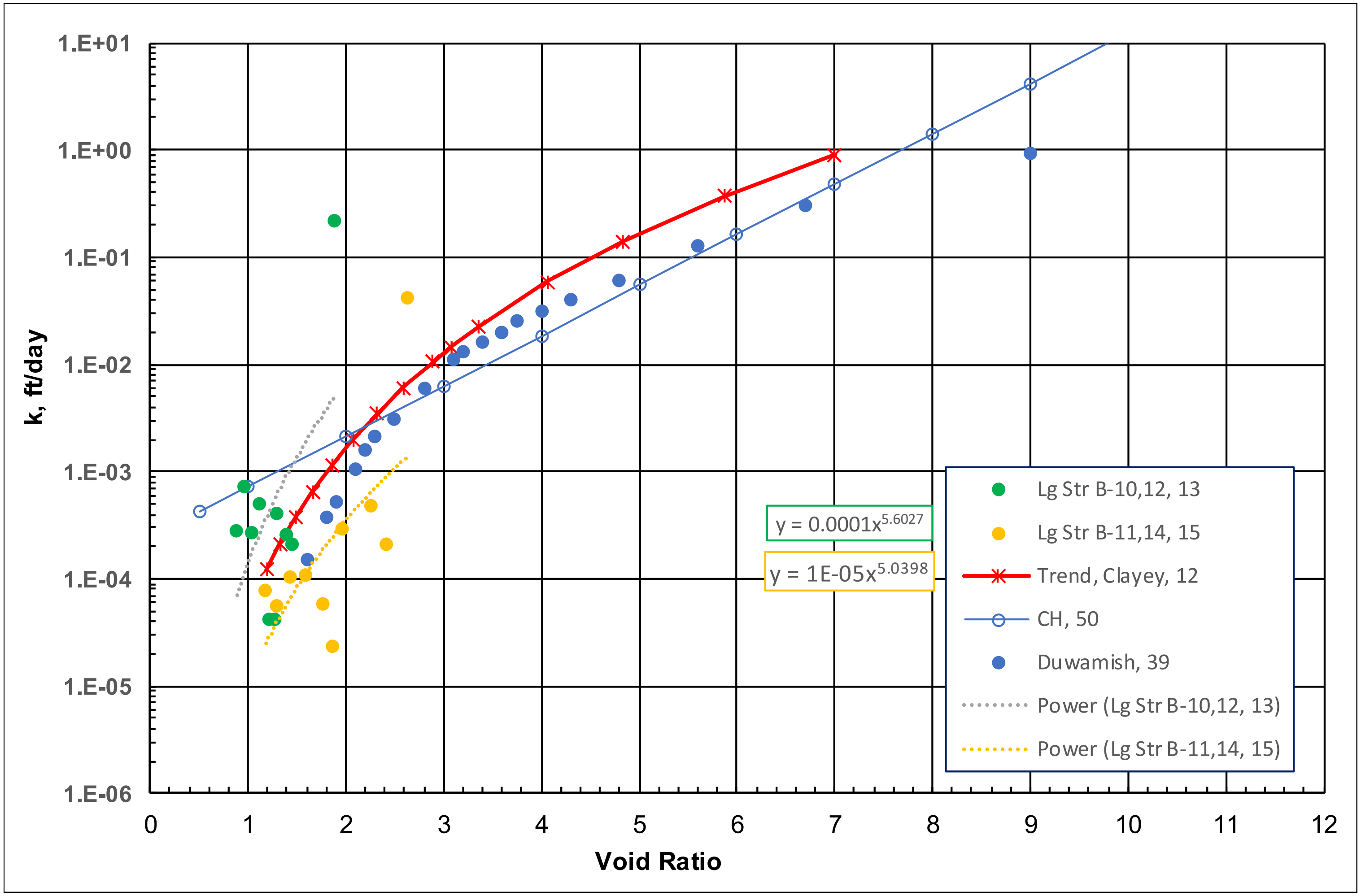
Print No.	Time		Lift No	Lift Thickness	Fill Thickness	Day Dessication Starts	Month Dessication Starts
	days	yrs		ft	ft		
	0.01	0	1	2	2	150	6
1	1	0.00274			2	150	6
2	15	0.0411	2	1	3	150	6
3	30	0.0822	3	1	4	150	6
4	45	0.123	4	1	5	150	6
5	60	0.164	5	1	6	150	6
6	75	0.205	6	1	7	150	6
7	90	0.247	7	1	8	150	6
8	120	0.329	8	1	9	150	6
9	150	0.411	9	1	10	150	6
10	180	0.493			10	180	7
11	270	0.740			10	270	10
12	365	1.0			10	365	1
13	548	1.5			10	548	7
14	730	2.0			10	730	1
15	1095	3.0			10	1095	1
16	1825	5.0			10	1825	1
17	3650	10.0			10	3650	1
18	5475	15.0			10	5475	1
19	7300	20.0			10	7300	1
20	9125	25.0			10	9125	1
21	10950	30.0			10	10950	1

Dredge Fill Placement and Print Time Input



Notes:
1) Red trendline used for settlement evaluation, i.e,. PSDDF input.
2) Duwamish, 39 and CH, 50 data from Stark (2005) database.

Borrow Area/Dredge Fill Material Void Ratio Versus Stress



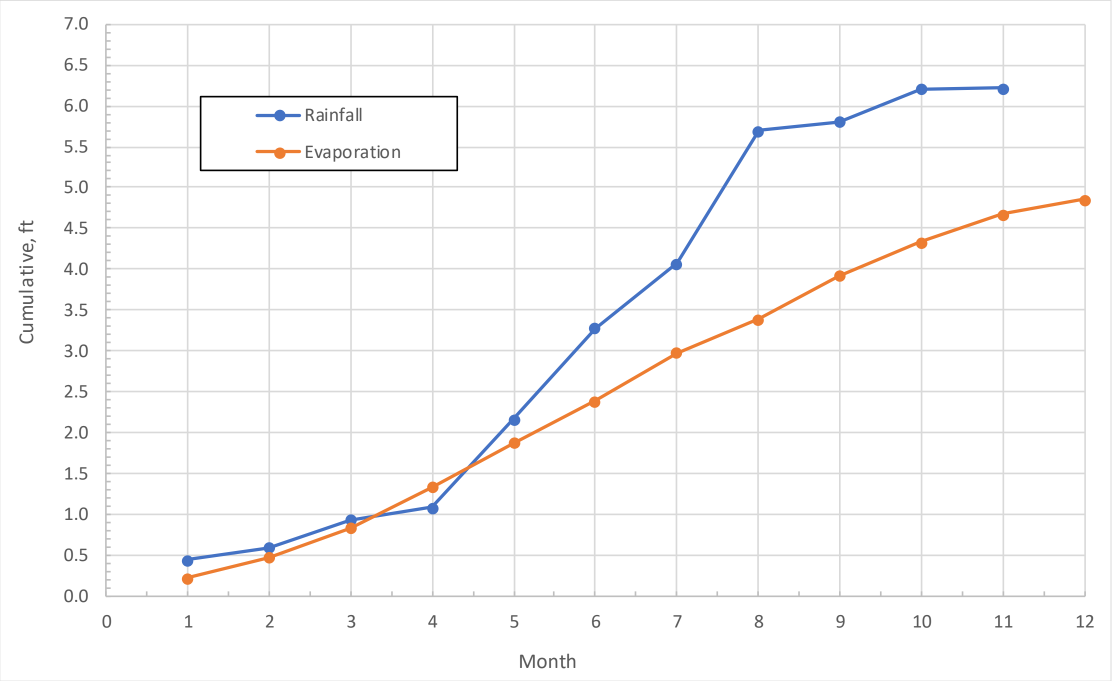
Notes:
1) Red trendline used for settlement evaluation, i.e., PSDDF input.
2) Duwamish, 39 and CH, 50 data from Stark (2005) database.

Borrow Area/Dredge Fill Material Permeability Versus Void Ratio

Pt	e	σ'	k	
		psf	ft/day	cm/sec
1	7.00	0.01	9.08E-01	3.20E-04
2	5.87	0.03	3.74E-01	1.32E-04
3	4.84	0.1	1.42E-01	5.00E-05
4	4.06	0.3	5.85E-02	2.06E-05
5	3.35	1.0	2.21E-02	7.81E-06
6	3.08	1.7	1.44E-02	5.09E-06
7	2.89	2.5	1.06E-02	3.73E-06
8	2.59	5	6.05E-03	2.13E-06
9	2.32	10	3.46E-03	1.22E-06
10	2.07	20	1.98E-03	6.98E-07
11	1.86	40	1.13E-03	3.99E-07
12	1.66	80	6.46E-04	2.28E-07
13	1.49	160	3.70E-04	1.30E-07
14	1.33	320	2.11E-04	7.46E-08
15	1.19	640	1.21E-04	4.26E-08

Tabulated Borrow Area/Dredge Fill Material Compressibility and Permeability Input

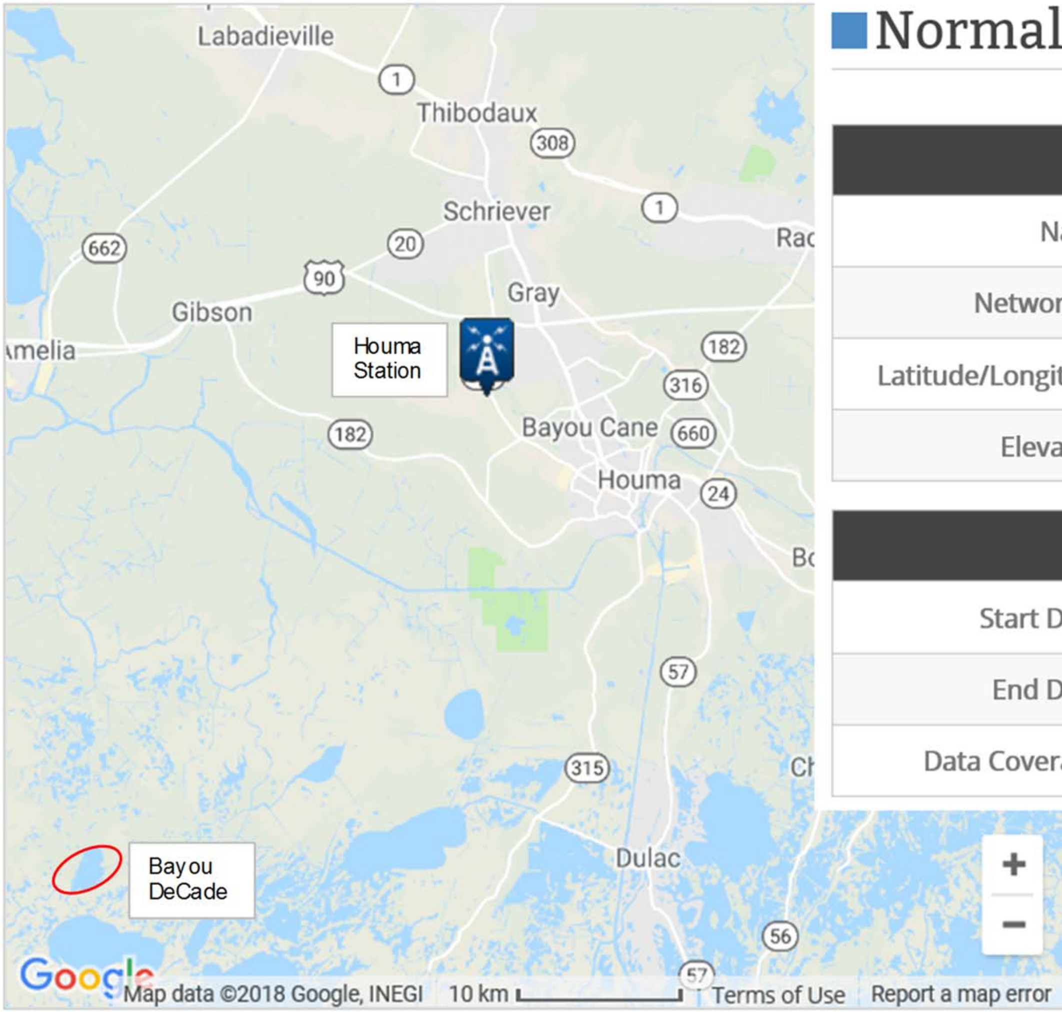
ID	Month	Precipitation				Evaporation		PSDDF Input		Cumulative	
		2010 Houma		1917-2017 Thibodeau		Estimated Jennings		Evaporation	Rainfall	Evaporation	Rainfall
		in	ft	in	ft	in	ft	ft	ft	ft	ft
1	January	4.97	0.41	5.33	0.44	2.67	0.22	0.22	0.44	0.22	0.44
2	February	4.77	0.40	1.87	0.16	2.98	0.25	0.25	0.16	0.47	0.60
3	March	4.8	0.40	4.04	0.34	4.37	0.36	0.36	0.34	0.84	0.94
4	April	3.6	0.30	1.78	0.15	6.05	0.50	0.50	0.15	1.34	1.09
5	May	4.31	0.36	12.96	1.08	6.52	0.54	0.54	1.08	1.88	2.17
6	June	7.32	0.61	13.36	1.11	6.09	0.51	0.51	1.11	2.39	3.28
7	July	7.86	0.66	9.47	0.79	7.03	0.59	0.59	0.79	2.98	4.07
8	August	7.37	0.61	19.53	1.63	5.04	0.42	0.42	1.63	3.40	5.70
9	September	5.62	0.47	1.31	0.11	6.3	0.53	0.53	0.11	3.92	5.80
10	October	3.82	0.32	4.79	0.40	4.97	0.41	0.41	0.40	4.34	6.20
11	November	3.67	0.31	0.12	0.01	4.02	0.34	0.34	0.01	4.67	6.21
12	December	4.14	0.35	6.01	0.50	2.19	0.18	0.18	0.50	4.85	6.71
		62.25	5.19	80.57	6.71	58.23	4.85	4.85	6.71		
	Average							0.40	0.56		



Notes:

1) 2010 precipitation for Houma: https://www.ncdc.noaa.gov/cdo-web/datatools/normal.
2) 1917-2017 precipitation for Thibodeau and evaporation estimates from NOAA (2017) "Climatological Data Annual Summary, Louisiana, Vol 122, No. 1.

Rain and Evaporation Input



Normals Monthly Station Details

STATION DETAILS	
Name	HOUMA, LA US
Network:ID	GHCND:USC00164407
Latitude/Longitude	29.6407°, -90.816°
Elevation	2.4 m

PERIOD OF RECORD	
Start Date[1]	2010-01-01
End Date[1]	2010-12-01
Data Coverage[2]	100%

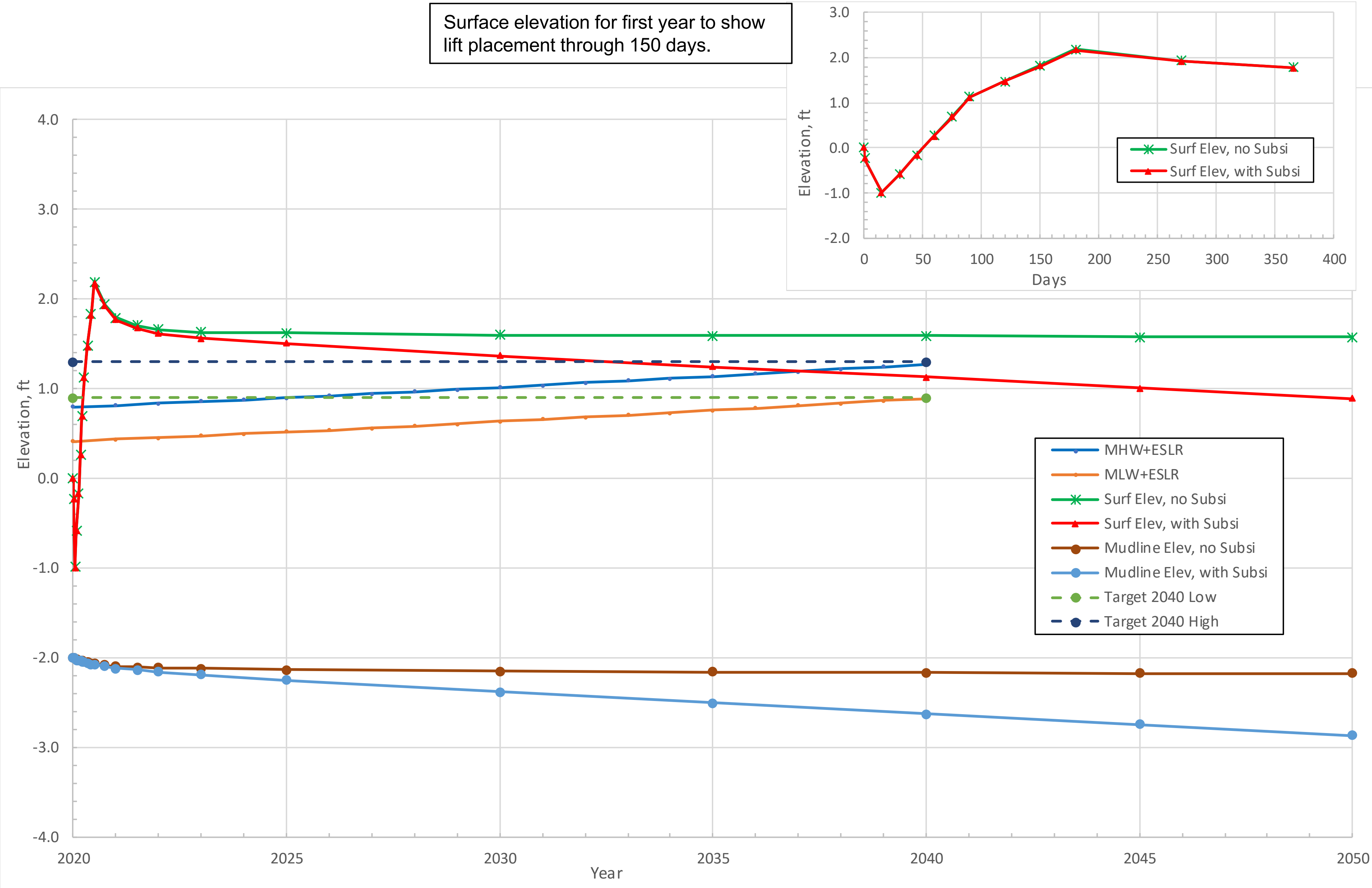
Rainfall Station Location

ID	Boring	Depth	LL	PL	PI
		ft			
1	B-10	6	25	24	1
2	B-10	10	81	27	54
3	B-11	4	84	25	59
4	B-11	12	56	20	36
7	B-12	2	61	23	38
8	B-13	10	123	38	86
9	B-14	2	79	26	53
10	B-14	12	165	47	119
5	B-15	4	87	26	61
6	B-15	12	87	28	59

	Averages			mc, %		G_s	S	e	
Composite	LL	PL	PI	DL= 1.2*PL	SL= 1.8*LL		DL	DL	SL
10,12,13	73	28	45	33	131	2.517	0.4	2.1	3.3
11,14,15	93	29	64	34	167	2.514	0.4	2.2	4.2
Avg	83	28	55	34	149	2.515	0.4	2.1	3.7
Selected								2.2	4.3

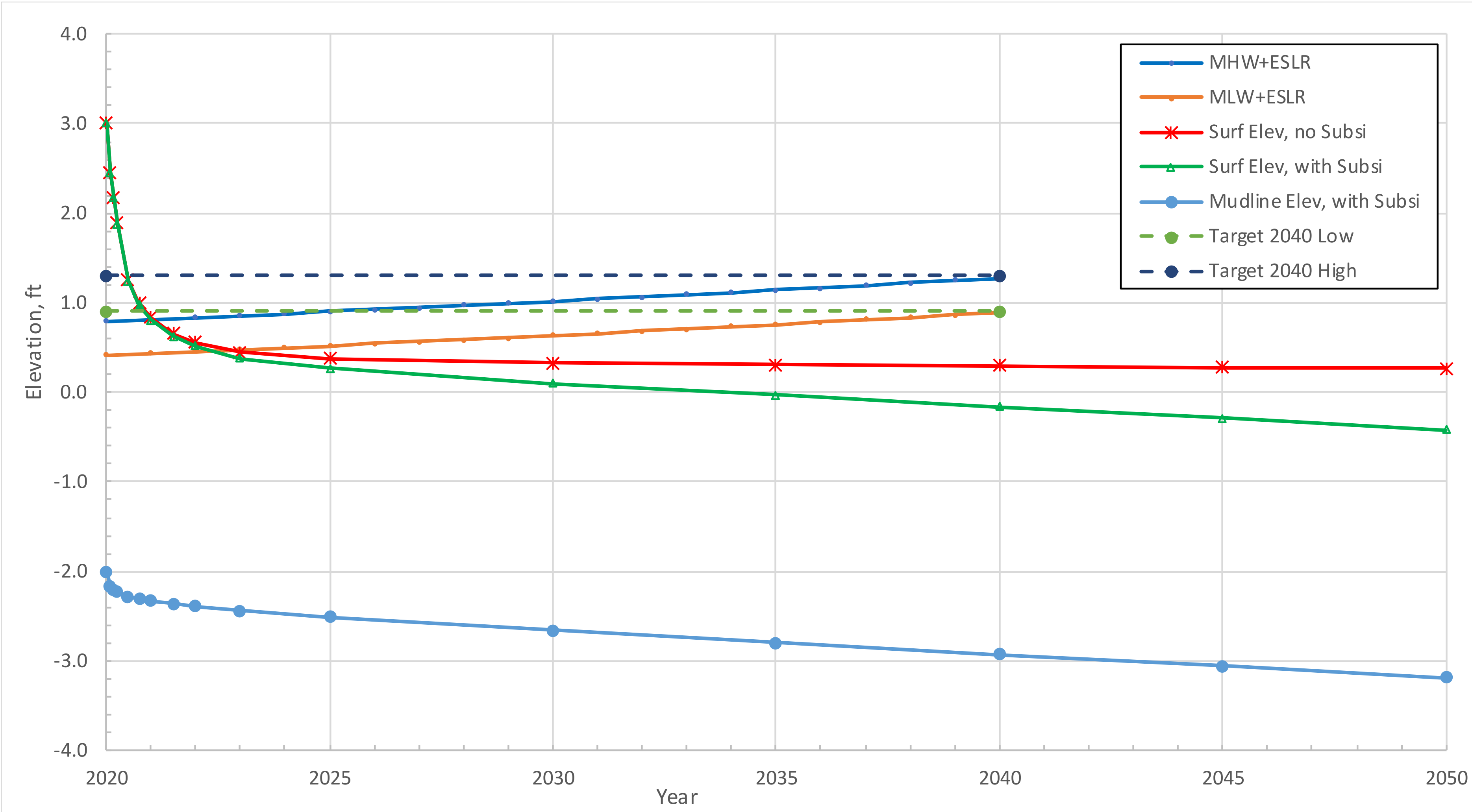
Notes:
1) Samples noted in red comprise Composite 10, 12, 13 sample.
2) Samples note in blue comprise Composite 11, 14, 15 sample.
3) Composite 10, 12, 13, more sandy that Composite 11, 14, 15, but fines used for column settling test.
4) SL = saturation limit, void ratio at or above where material remains saturated and buoyant, drying occurs via evaporation but material remains saturated.
5) DL = desiccation limit, void ratio at which shrinkage from evaporation ceases.
6) Moisture content, mc, and void ratio, e, for desiccation and saturation limits estimated from correlations in Stark et al (2005).

Estimated Saturation and Desiccation Limits



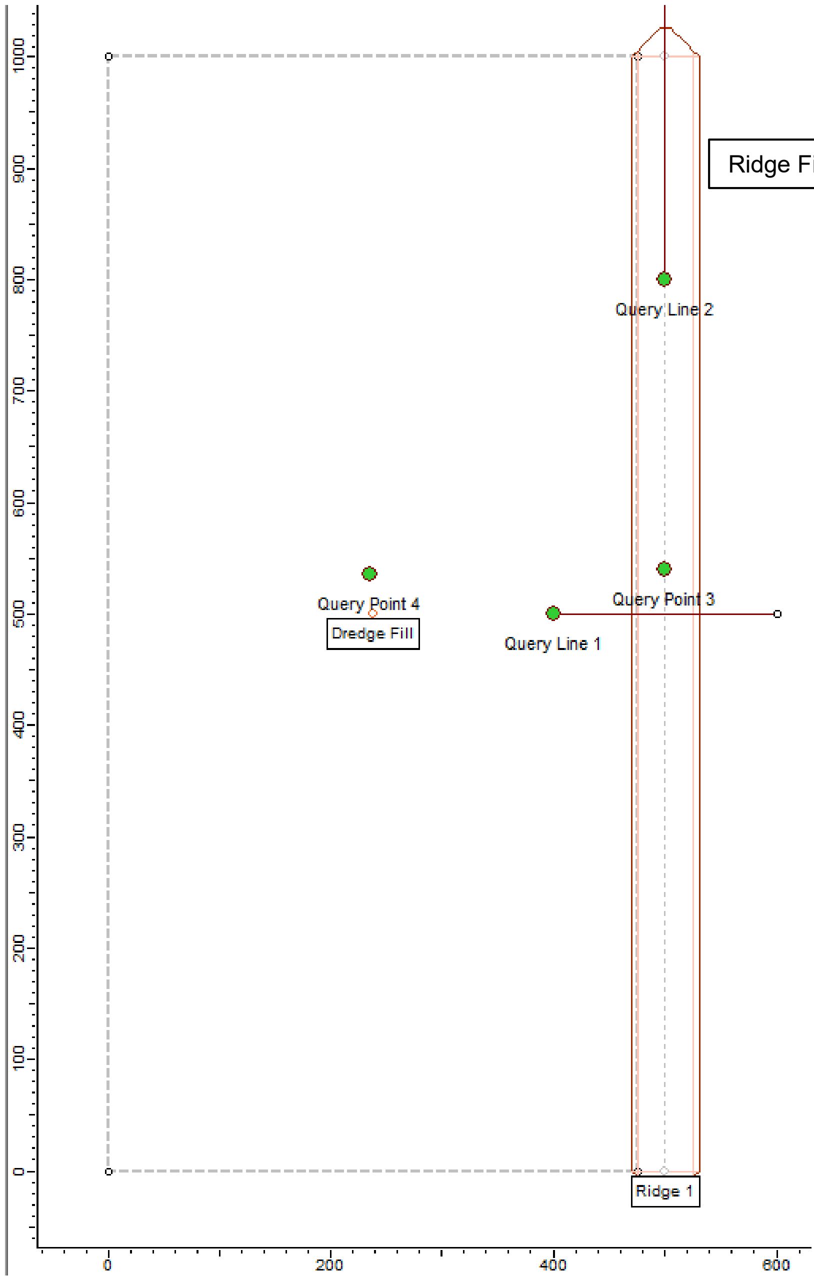
Estimated Dredge Fill and Mudline (El-2 ft) Settlement versus Year,
One 2-ft-thick Lift Followed by Eight 1-ft-thick Lifts

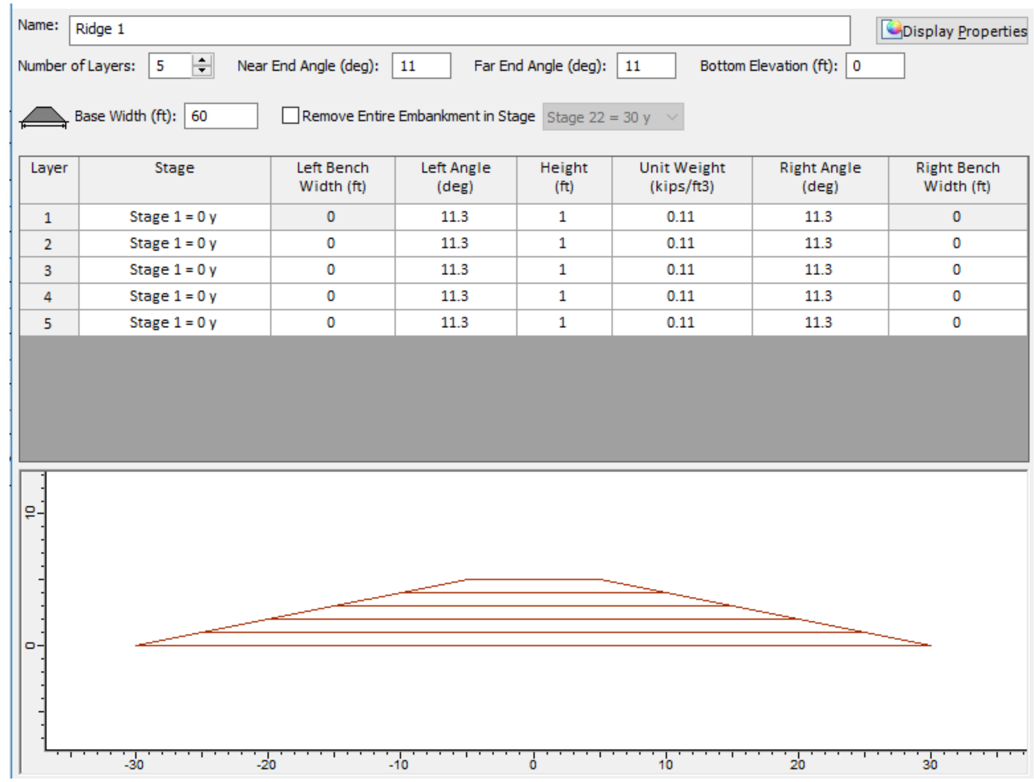
Plate B-15



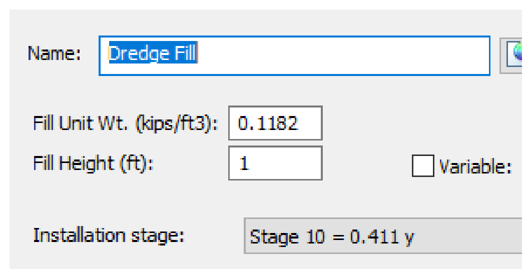
Estimated Dredge Fill and Mudline (El-2 ft) Settlement versus Year, One 5-ft-thick Lift

Containment Ridge/Dike Settlement



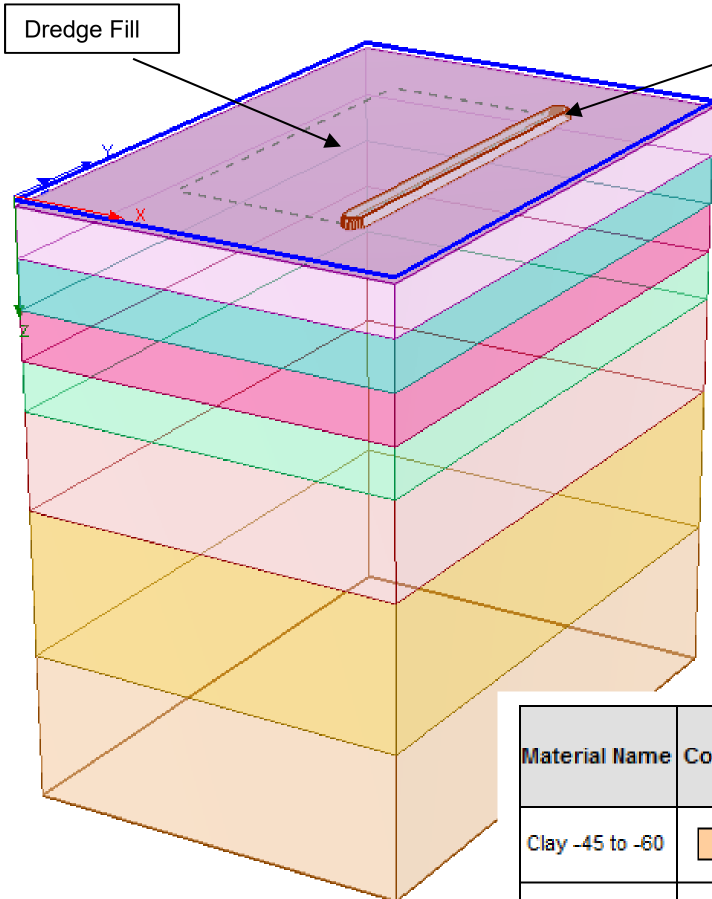


Layer	Stage	Left Bench Width (ft)	Left Angle (deg)	Height (ft)	Unit Weight (kips/ft3)	Right Angle (deg)	Right Bench Width (ft)
1	Stage 1 = 0 y	0	11.3	1	0.11	11.3	0
2	Stage 1 = 0 y	0	11.3	1	0.11	11.3	0
3	Stage 1 = 0 y	0	11.3	1	0.11	11.3	0
4	Stage 1 = 0 y	0	11.3	1	0.11	11.3	0
5	Stage 1 = 0 y	0	11.3	1	0.11	11.3	0

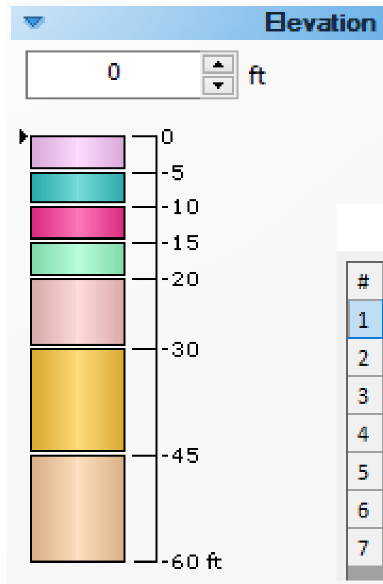


Notes:
1) Ridge fill placed as one, 5-ft-thick, lift at time zero.
2) Dredge fill placed as buoyant unit weight of height of solids x 1 ft at 0.411 yrs = 150 days.

Settle3D Model for Ridge Settlement, Section T-21, Southeast End, Plan View of Fill Geometry and Loads



Note:
1) Mudline set at El 0 ft.
2) Water piezometric level set at El+0.6 ft.
3) Soil parameters mimic those used for PSDDF.
4) Permeability modeled using variable permeability with void ratio using C_k = 0.25 and initial permeability (K_o) equal to permeability at e_o.
5) Allowed drainage at bottom of lower two layers to because of interbedded sandy zones, see CPT logs

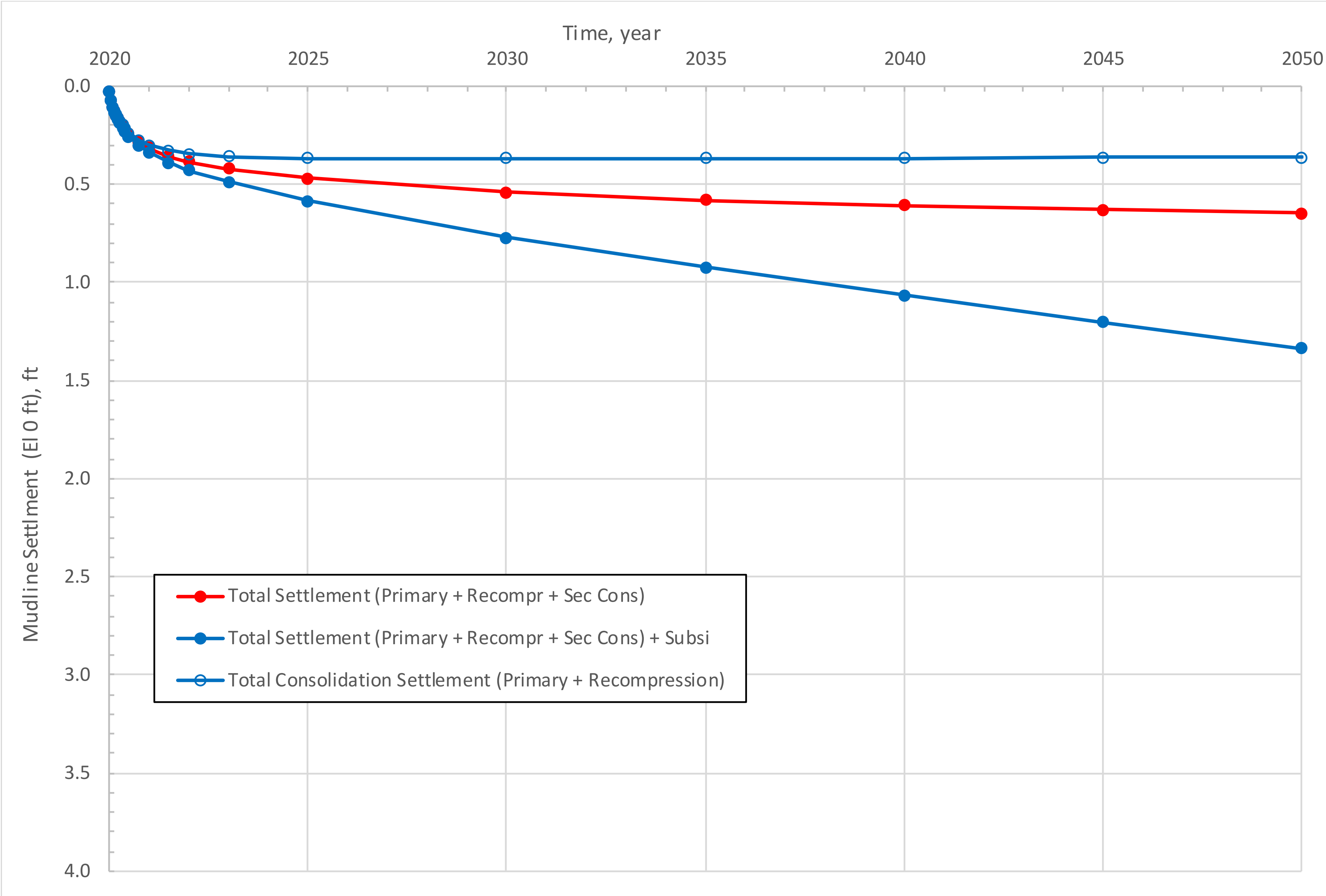


Soil Drainage Conditions

#	Name	Drained at Bottom
1	Clay 0 to -5	☐
2	Clay -5 to -10	☐
3	Clay -10 to -15	☐
4	Clay -15 to -20	☐
5	Clay -20 to -30	☐
6	Clay -30 to -45	☑
7	Clay -45 to -60	☑

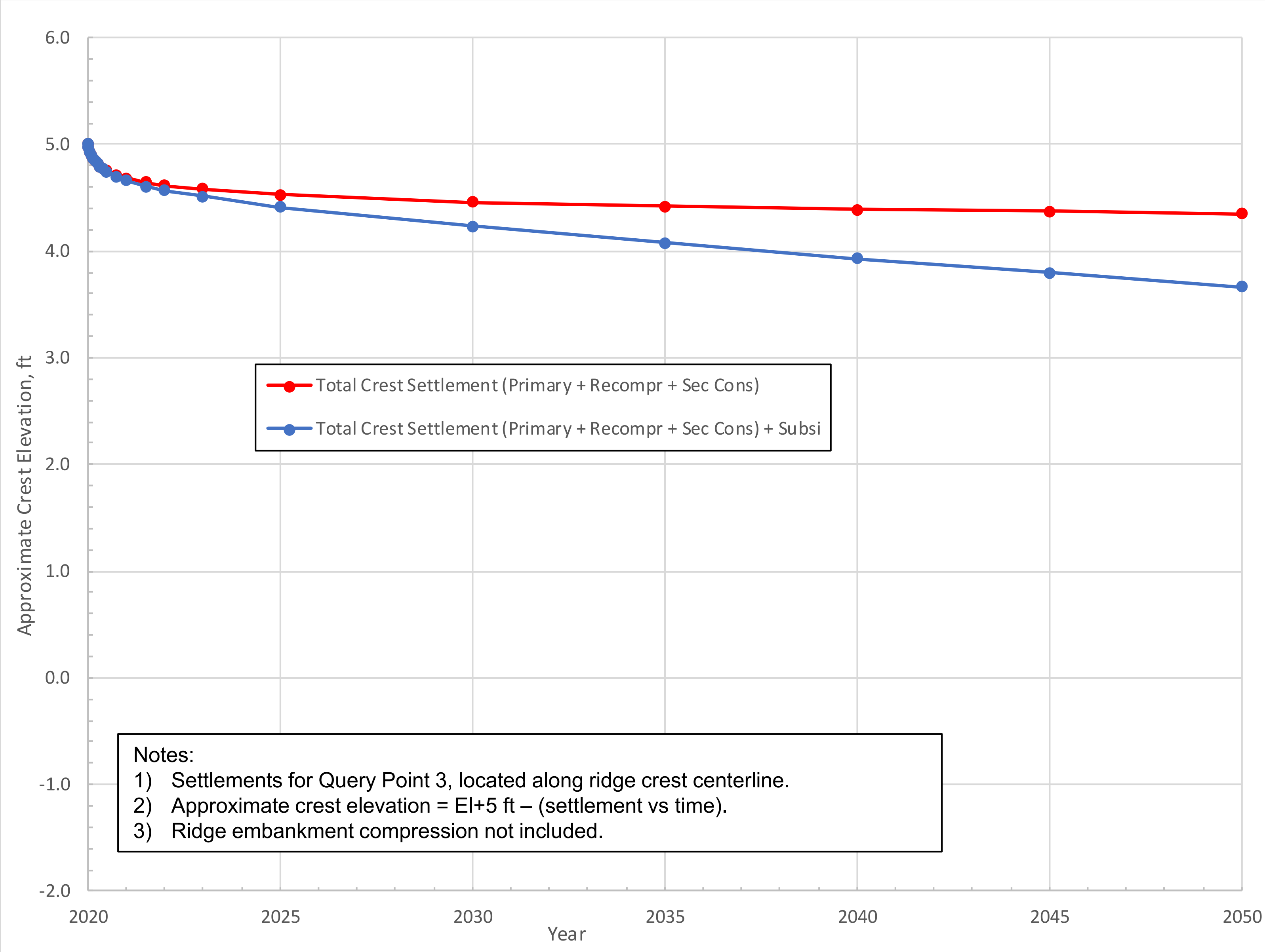
Material Name	Color	Unit Weight (kips/ft3)	Sat. Unit Weight (kips/ft3)	Material Type	Cc	Cr	Pc (ksf)	e0	K (ft/d)	Kr (ft/d)	Secondary Consol. Method	Ca/Cc	Mesri Material Type
Clay -45 to -60		0.115	0.115	Non-Linear	0.382	0.065	2.5	1.6	0.000359	0.000359	Mesri	0.04	Soft Clay
Clay -30 to -45		0.115	0.115	Non-Linear	0.324	0.055	2	1.2	0.000566	0.000566	Mesri	0.04	Soft Clay
Clay -20 to -30		0.115	0.115	Non-Linear	0.294	0.05	1.55	1	0.000726	0.000726	Mesri	0.04	Soft Clay
Clay -10 to -15		0.115	0.115	Non-Linear	0.294	0.05	1.5	1	0.00146	0.00146	Mesri	0.04	Soft Clay
Clay -5 to -10		0.115	0.115	Non-Linear	0.294	0.05	1.5	1	0.00146	0.00146	Mesri	0.04	Soft Clay
Clay 0 to -5		0.115	0.115	Non-Linear	0.294	0.05	1.5	1	0.00146	0.00146	Mesri	0.04	Soft Clay

Settle3D Subsurface Material Thicknesses and Properties



Note: Settlement for Query Point 3, located along ridge crest centerline.

Mudline Settlement (El 0 ft) Beneath Ridge Crest, Section T-21, Southeast End



Approximate Ridge Crest Settlement, Section T-21, Southeast End

APPENDIX C

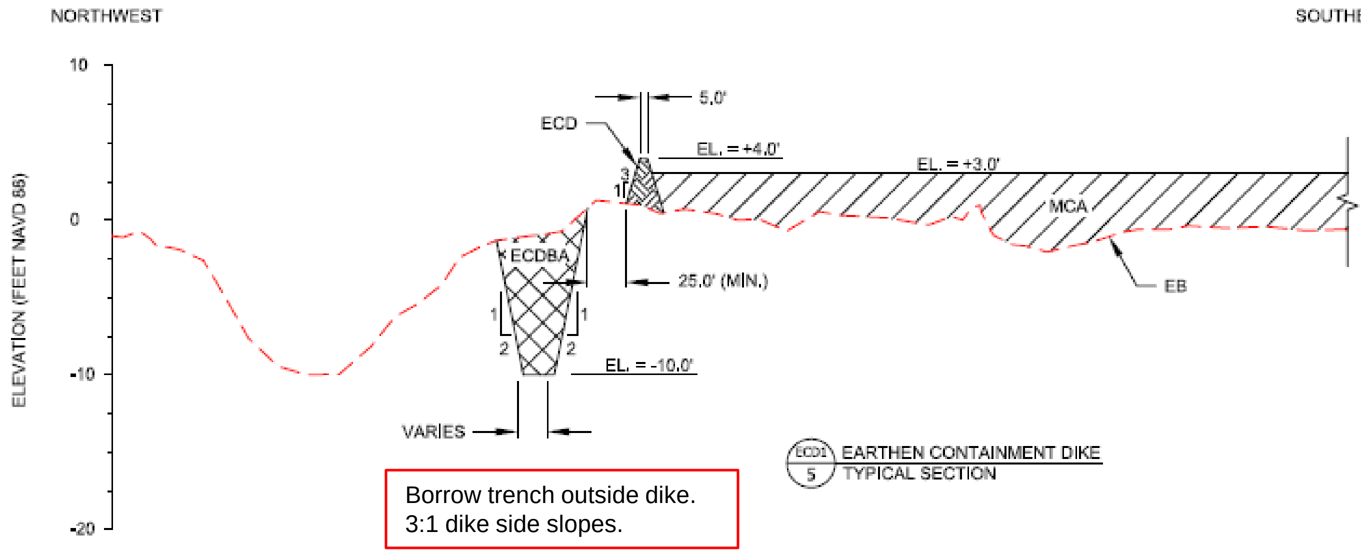
SLOPE STABILITY EVALUATIONS

Section	Water Elev	Crest Elev	Configuration	Factor of Safety, F_s									
				Without Marsh						Without Marsh, with Equipment Load		With Marsh	
				Dike to Outside Borrow Trench	Dike to Inside Borrow Trench	Outside Borrow Trench Slope	Inside Borrow Trench Slope	Inside Dike Slope	Outside Dike Slope	Outside Borrow Trench Slope	Inside Borrow Trench Slope	Dike to Outside Borrow Trench	Outside Dike Slope
	ft	ft		Undrained Shear Strength									
T21-SE	0.6	5	Earthen Ridge	2.10	NA	2.65	NA	1.93	NP	2.19	NA	2.10	NP
T25-NW	0.6	4	Earthen Containment Dike	2.29	NA	2.20	NA	3.18	NP	NP	NA	NP	2.98
T33-NW	0.6	4	Earthen Containment Dike	NA	2.65	NA	3.23	1.96	2.62	NA	2.86	NA	2.61
				Drained Shear Strength									
T21-SE	0.6	5	Earthen Ridge	NA	NA	1.02	NP	NP	NP	NP	NP	NP	NP

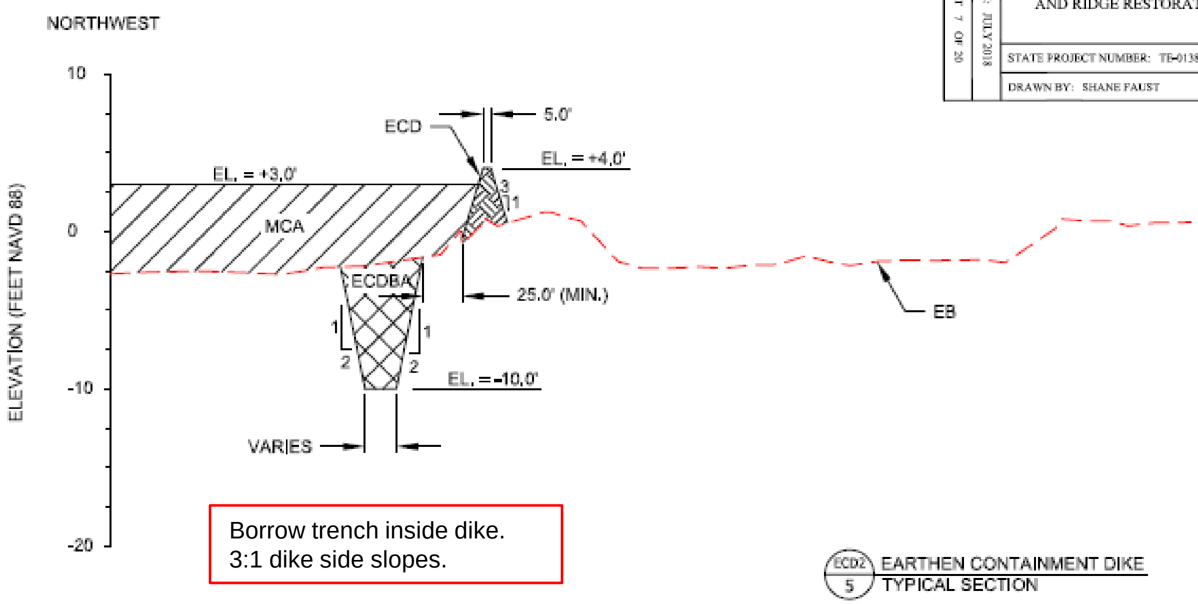
Notes:
1) See section slope stability figures for configurations.
2) NA = Not Applicable
3) NP = Analysis not performed.
4) Shallow, water-filled, tension crack line used where needed to eliminate negative base slice or interslice forces.
5) All results are for optimized potential failure surface using entry-exit slip surface option and Morgenstern Price method with a half-sine interslice function (SLOPE/W default).
6) Equipment loading applicable to construction conditions using undrained strength, with load placed between dike and trench.
7) Equipment loading not applicable for long term condition using drained strength.

Summary of Slope Stability Analyses

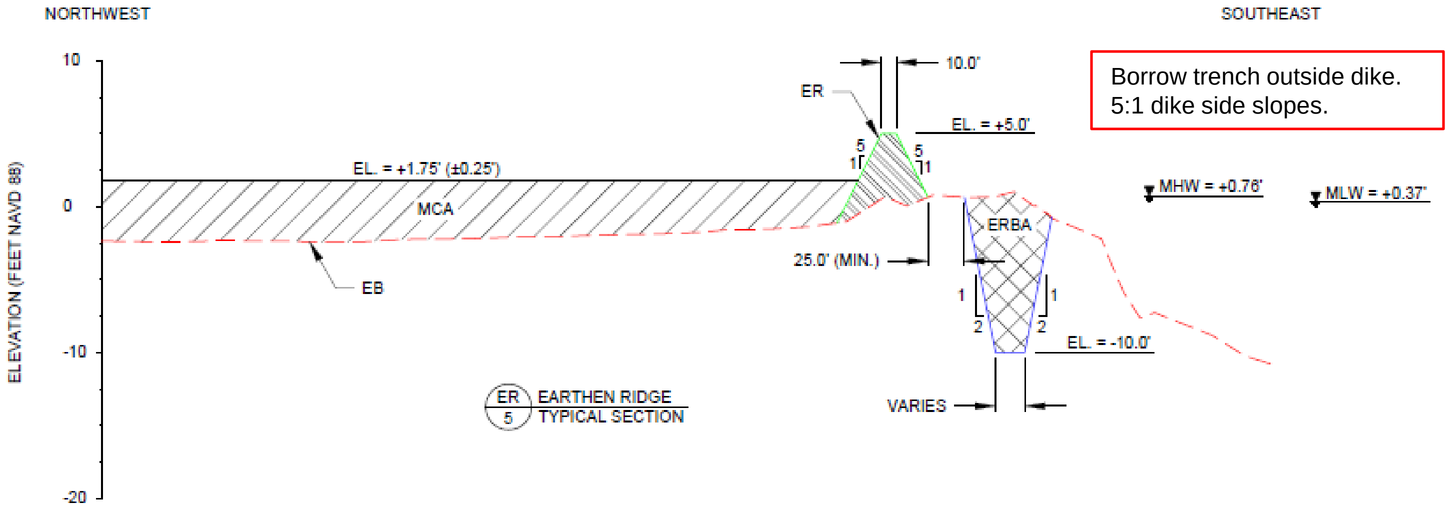
Sections Selected for Slope Stability Evaluations

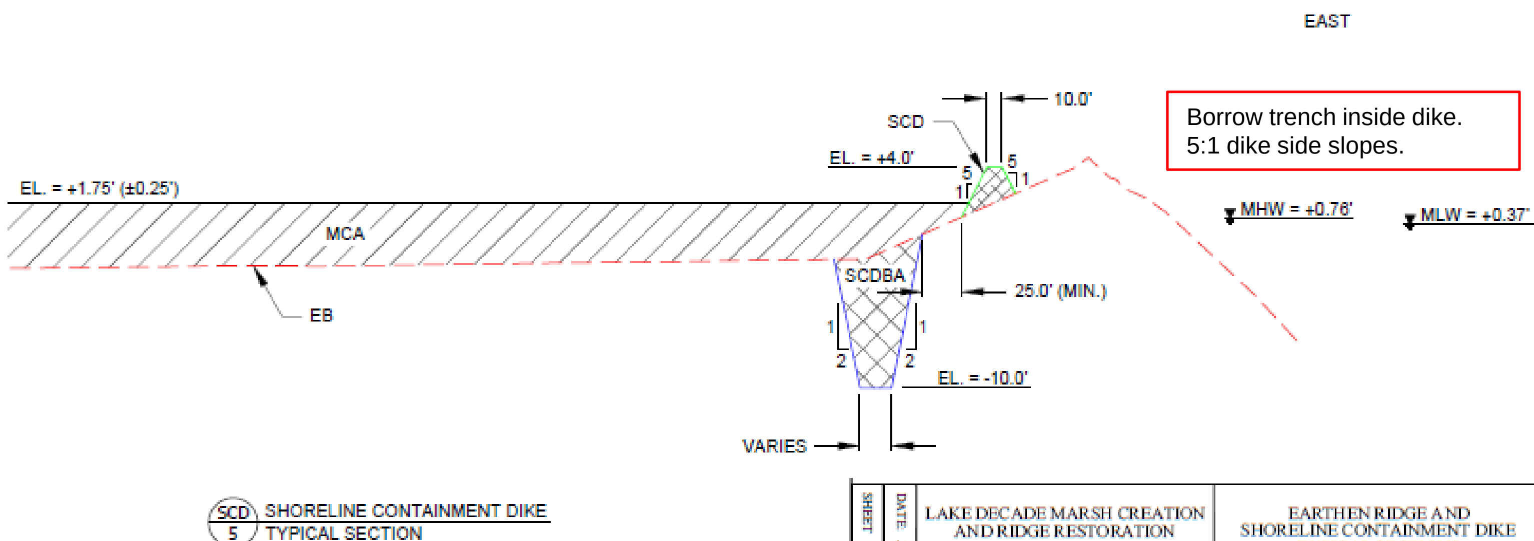


SHEET 7 OF 20	DATE: JULY 2018	LAKE DECADE MARSH CREATION AND RIDGE RESTORATION	EARTHEN CONTAINMENT DIKE TYPICAL SECTIONS	COASTAL PROTECTION AND RESTORATION AUTHORITY 150 TERRACE AVENUE BATON ROUGE, LOUISIANA 70802
		STATE PROJECT NUMBER: TE-0138	DESIGNED BY: TRAVIS BYLAND, P.E. -	
		DRAWN BY: SHANE FAUST	APPROVED BY:	



Typical Sections for Earth Containment Dike and Trench Borrow Areas





SHEET 8 OF 20

DATE: JULY 2018

LAKE DECADE MARSH CREATION AND RIDGE RESTORATION

EARTHEN RIDGE AND SHORELINE CONTAINMENT DIKE TYPICAL SECTIONS

COASTAL PROTECTION AND RESTORATION AUTHORITY
150 TERRACE AVENUE
BATON ROUGE, LOUISIANA 70802

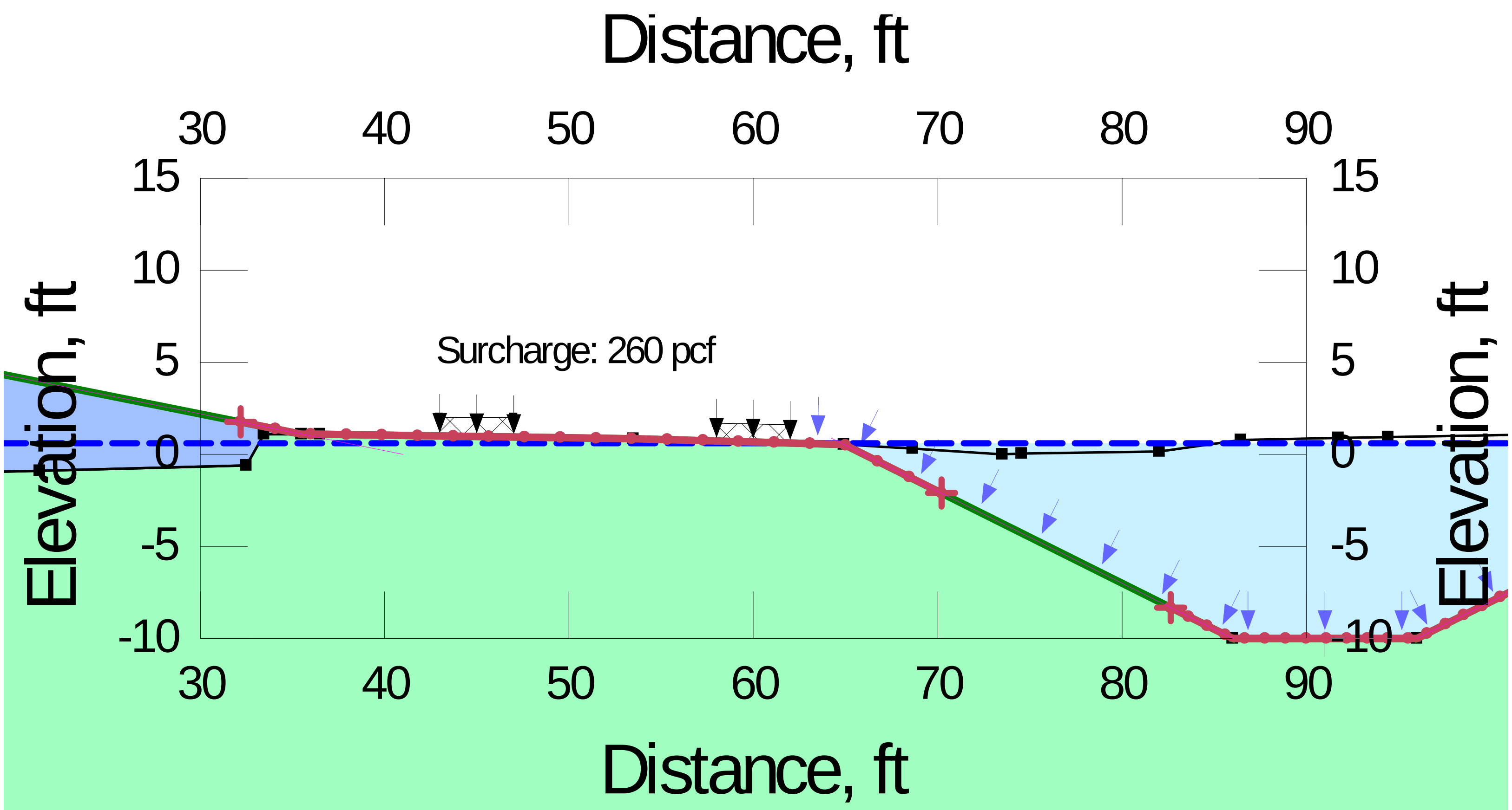
STATE PROJECT NUMBER: TE-0138

DESIGNED BY: TRAVIS BYLAND, P.E. -

DRAWN BY: SHANE FAUST

APPROVED BY:

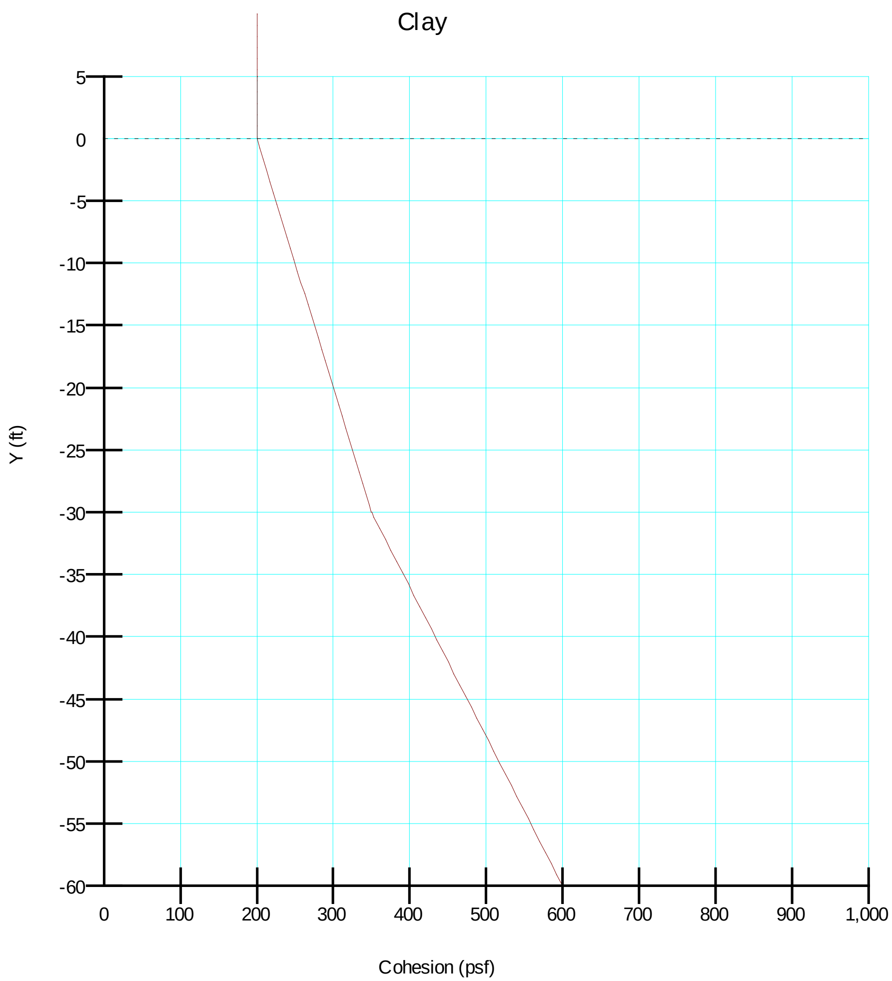
Typical Sections for Earth Ridge and Shoreline Containment Dikes and Trench Borrow Areas

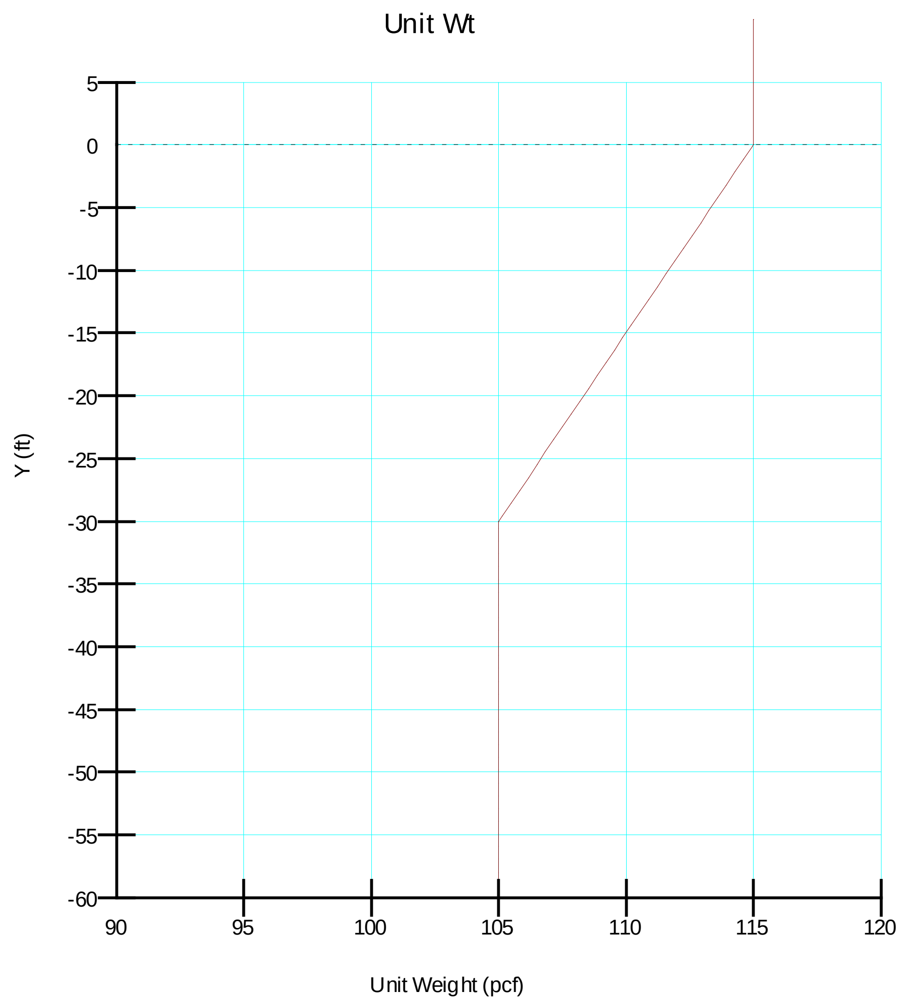


Notes:

1) CPRA provided information for excavator load configuration.
2) Loads consist of two, 4-ft-wide tracks with a uniform contact pressure of 260 psf.
3) Track center-to-center spacing is 15 ft.
4) If water level is above ground surface, contact pressure is reduced for buoyancy equal to 62.4 pcf x water depth (ft).
5) Excavator width is about 19 ft and with an assumed length of 40 ft.
6) In SLOPE/W, surcharge loads are two-dimensional, extending perpendicular to the section plane; so loading is conservative, i.e., too high, compared to a three-dimensional load distribution with depth for a three-dimensional load applied at the surface.
7) Surcharge loads were applied as a unit weight x 1 ft, e.g., 260 pcf x 1 ft = 260 psf.

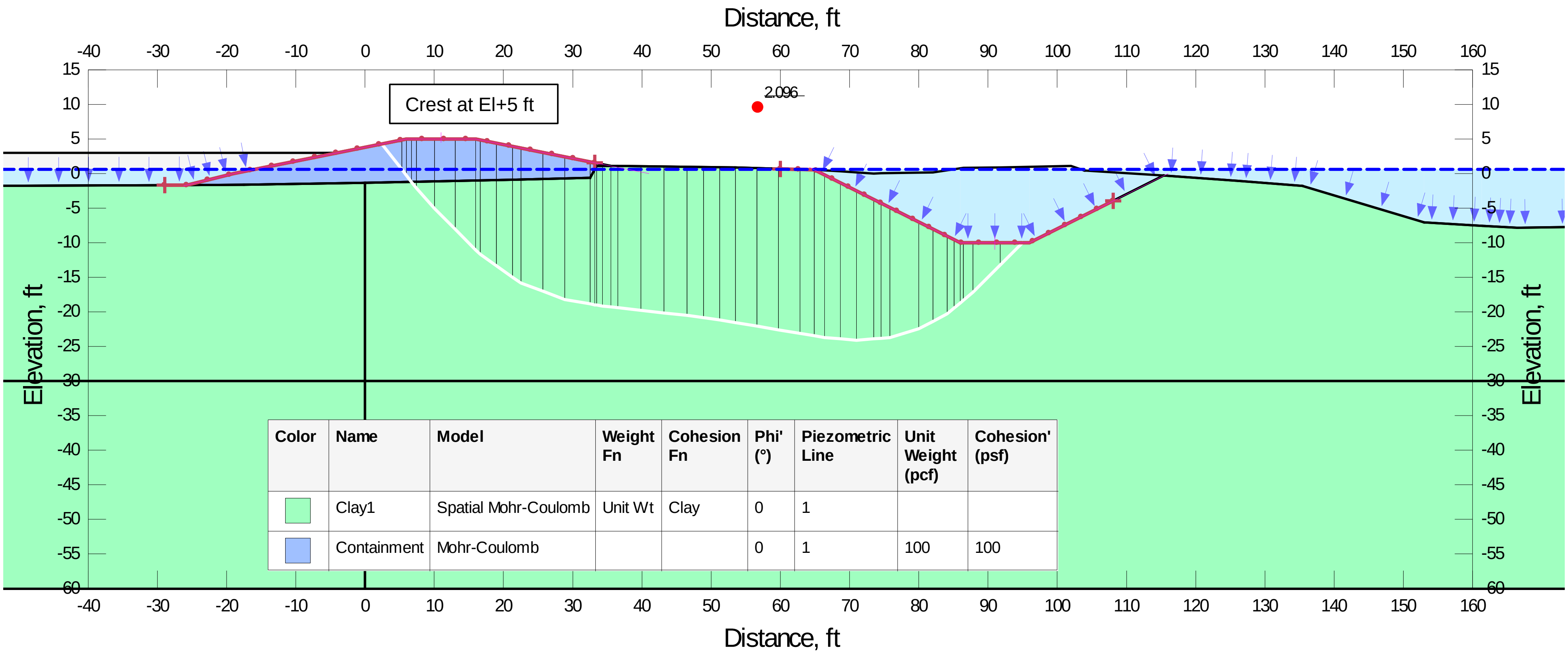
Equipment Loading Configuration





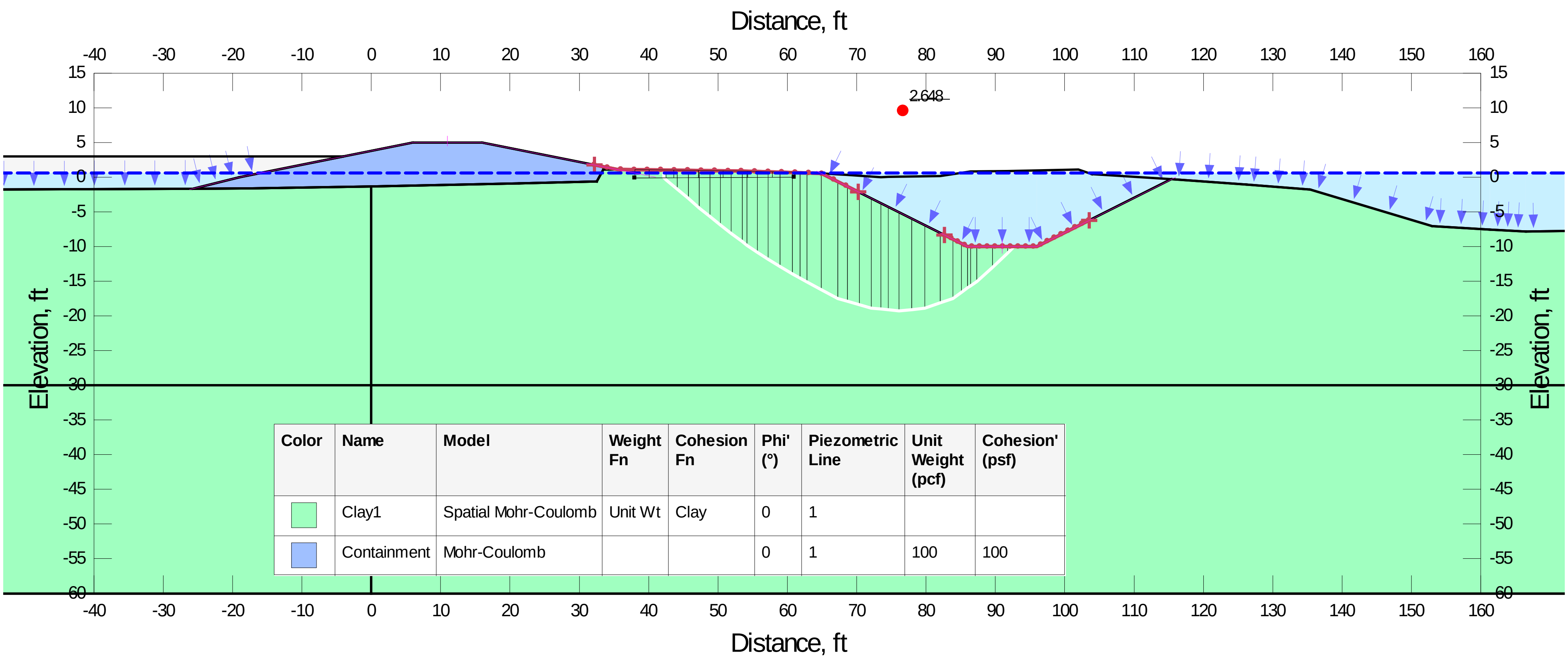
SLOPE/W, Undrained Shear Strength and Unit Weight, Foundation Soils

Section T-21, Southeast End



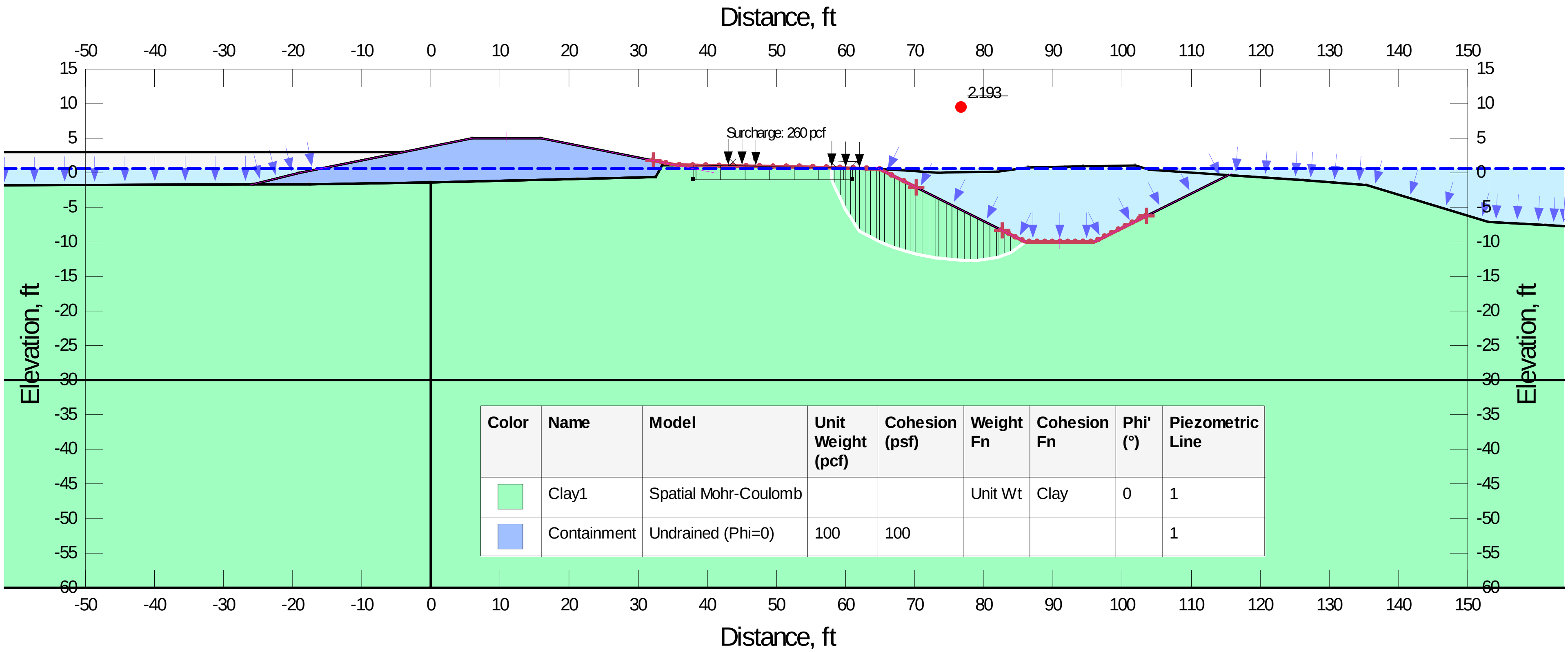
Color	Name	Model	Weight Fn	Cohesion Fn	Phi' (°)	Piezometric Line	Unit Weight (pcf)	Cohesion' (psf)
	Clay1	Spatial Mohr-Coulomb	Unit Wt	Clay	0	1		
	Containment	Mohr-Coulomb			0	1	100	100

Section T-21, Southeast End, Dike to Outside Borrow Trench without Marsh



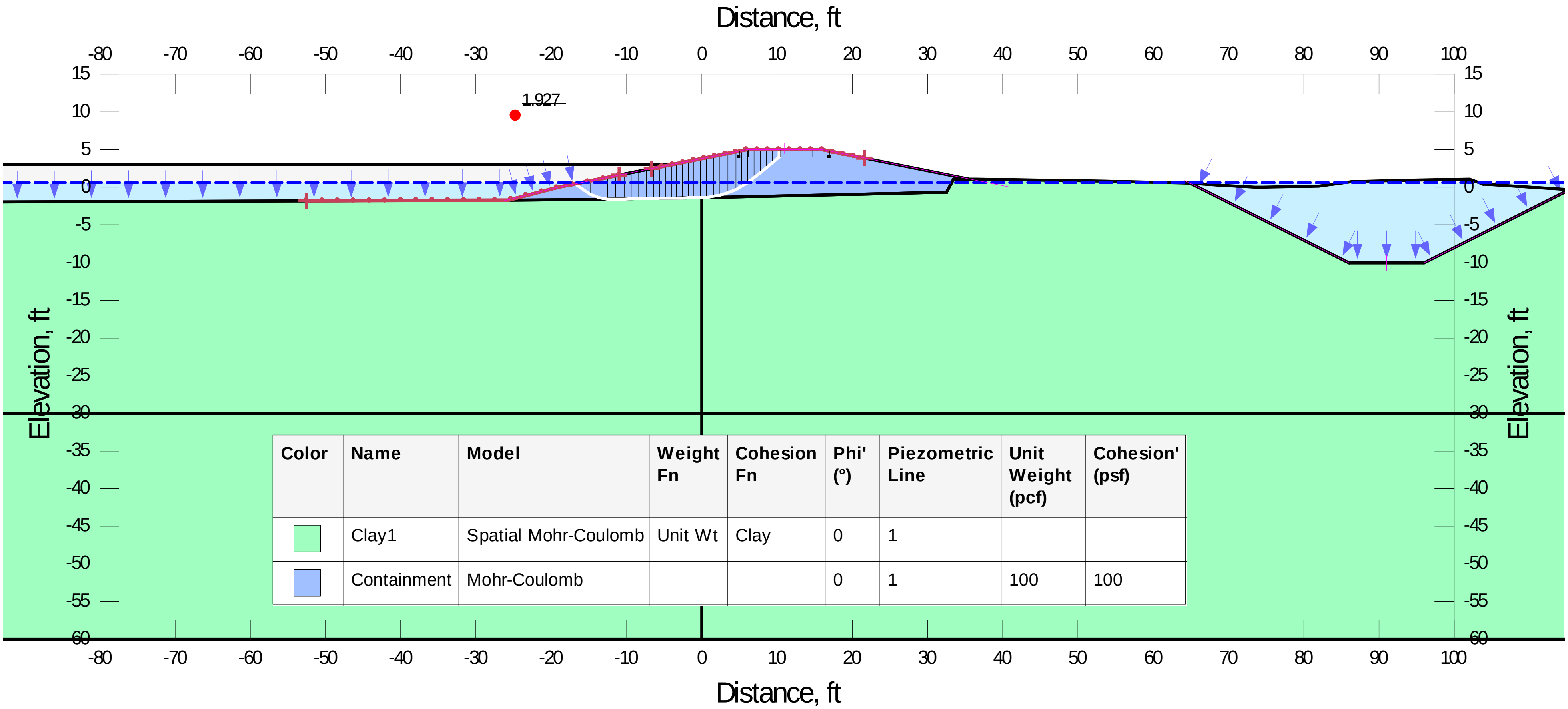
Color	Name	Model	Weight Fn	Cohesion Fn	Phi' (°)	Piezometric Line	Unit Weight (pcf)	Cohesion' (psf)
	Clay1	Spatial Mohr-Coulomb	Unit Wt	Clay	0	1		
	Containment	Mohr-Coulomb			0	1	100	100

Section T-21, Southeast End, Outside Borrow Trench Slope without Marsh



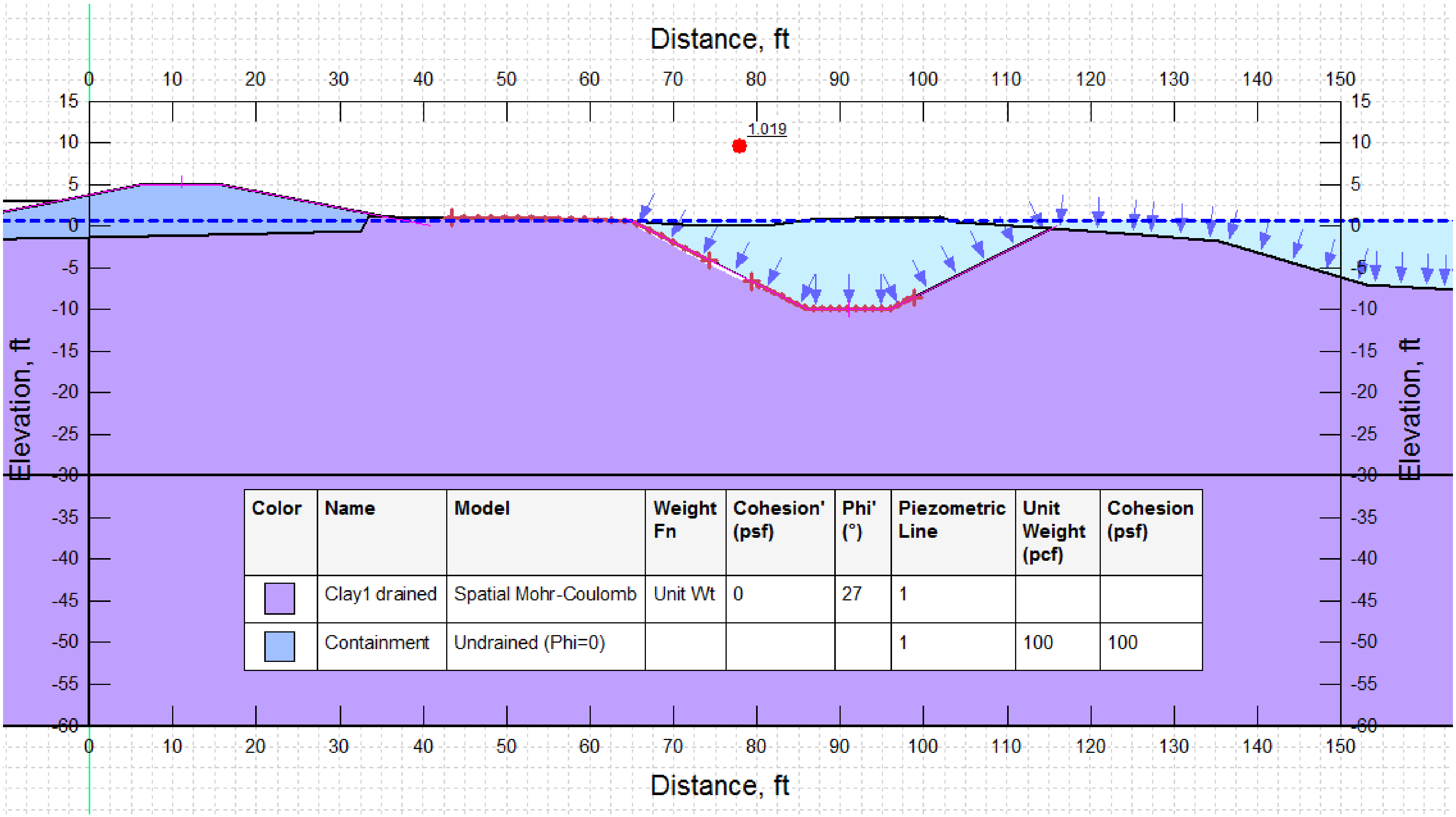
Color	Name	Model	Unit Weight (pcf)	Cohesion (psf)	Weight Fn	Cohesion Fn	Phi' (°)	Piezometric Line
	Clay1	Spatial Mohr-Coulomb			Unit Wt	Clay	0	1
	Containment	Undrained (Phi=0)	100	100				1

Section T-21, Southeast End, Outside Borrow Trench Slope with Equipment Load and without Marsh



Color	Name	Model	Weight Fn	Cohesion Fn	Phi' (°)	Piezometric Line	Unit Weight (pcf)	Cohesion' (psf)
	Clay1	Spatial Mohr-Coulomb	Unit Wt	Clay	0	1		
	Containment	Mohr-Coulomb			0	1	100	100

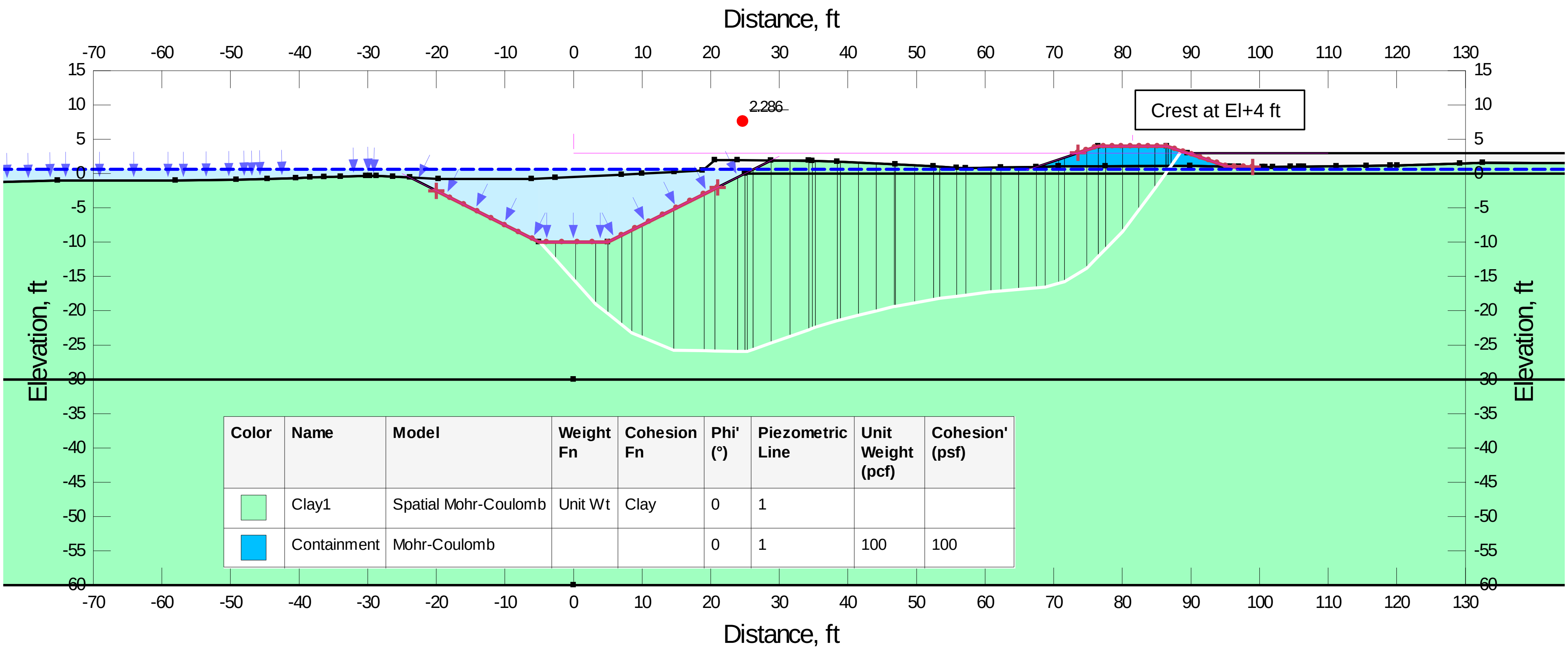
Section T-21, Southeast End, Inside Dike Slope without Marsh



Color	Name	Model	Weight Fn	Cohesion' (psf)	Phi' (°)	Piezometric Line	Unit Weight (pcf)	Cohesion (psf)
	Clay1 drained	Spatial Mohr-Coulomb	Unit Wt	0	27	1		
	Containment	Undrained (Phi=0)				1	100	100

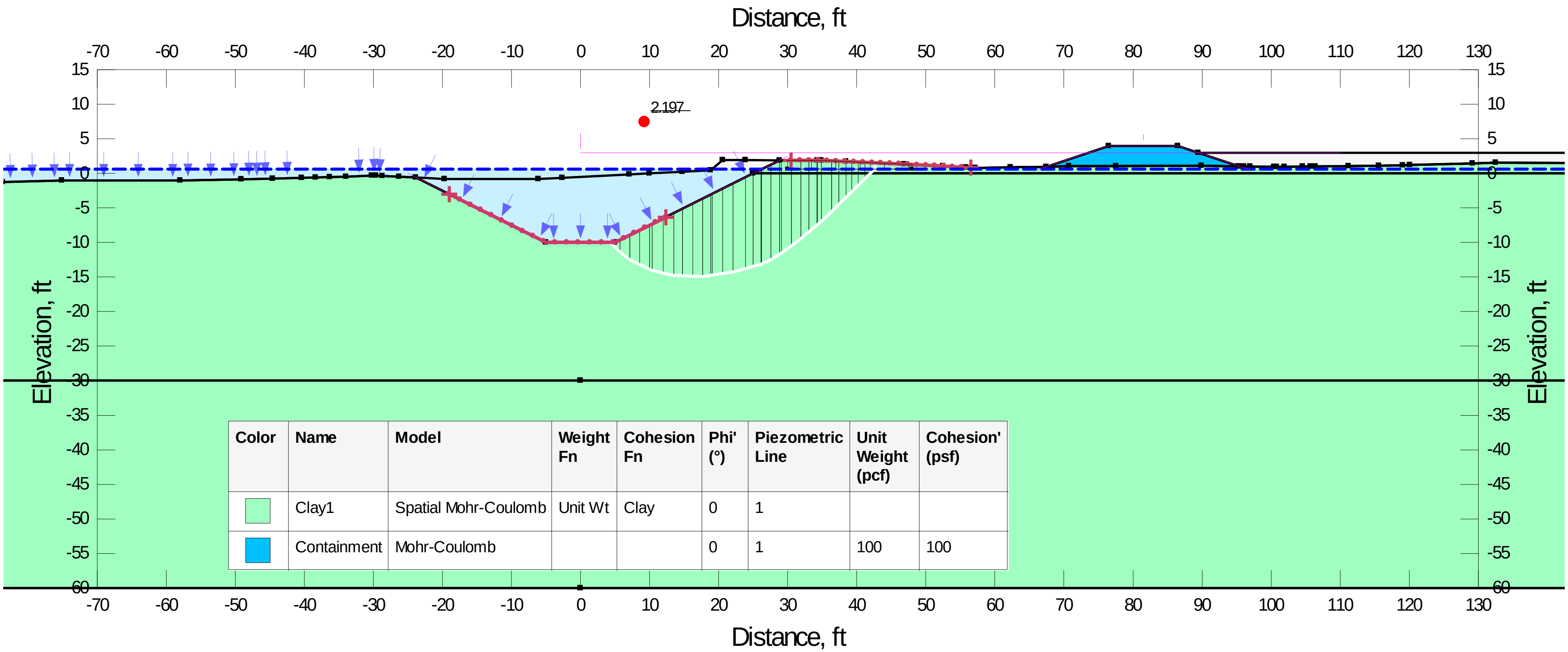
Section T-21, Southeast End, Trench Slope using Drained Strength Parameters

Section T-25, Northwest End



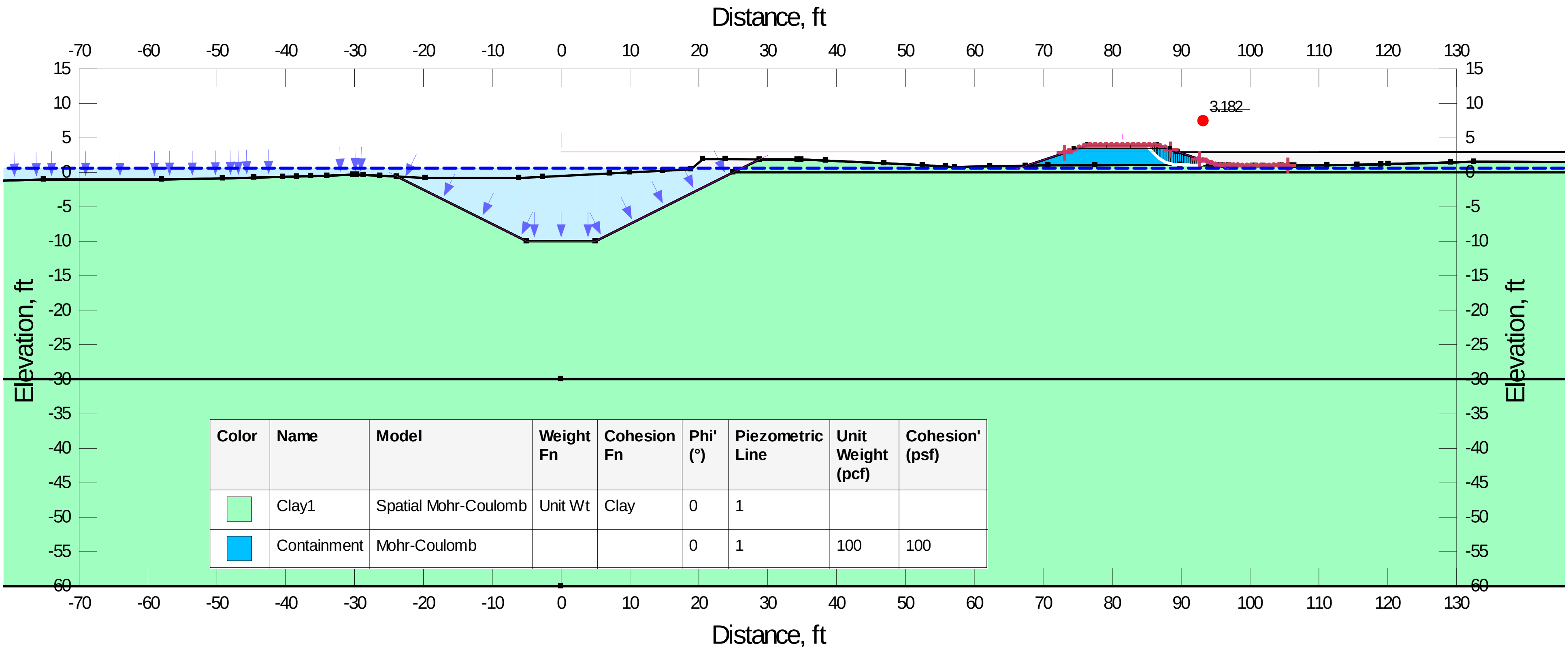
Color	Name	Model	Weight Fn	Cohesion Fn	Phi' (°)	Piezometric Line	Unit Weight (pcf)	Cohesion' (psf)
	Clay1	Spatial Mohr-Coulomb	Unit Wt	Clay	0	1		
	Containment	Mohr-Coulomb			0	1	100	100

Section T-25, Northwest End, Dike to Outside Borrow Trench without Marsh

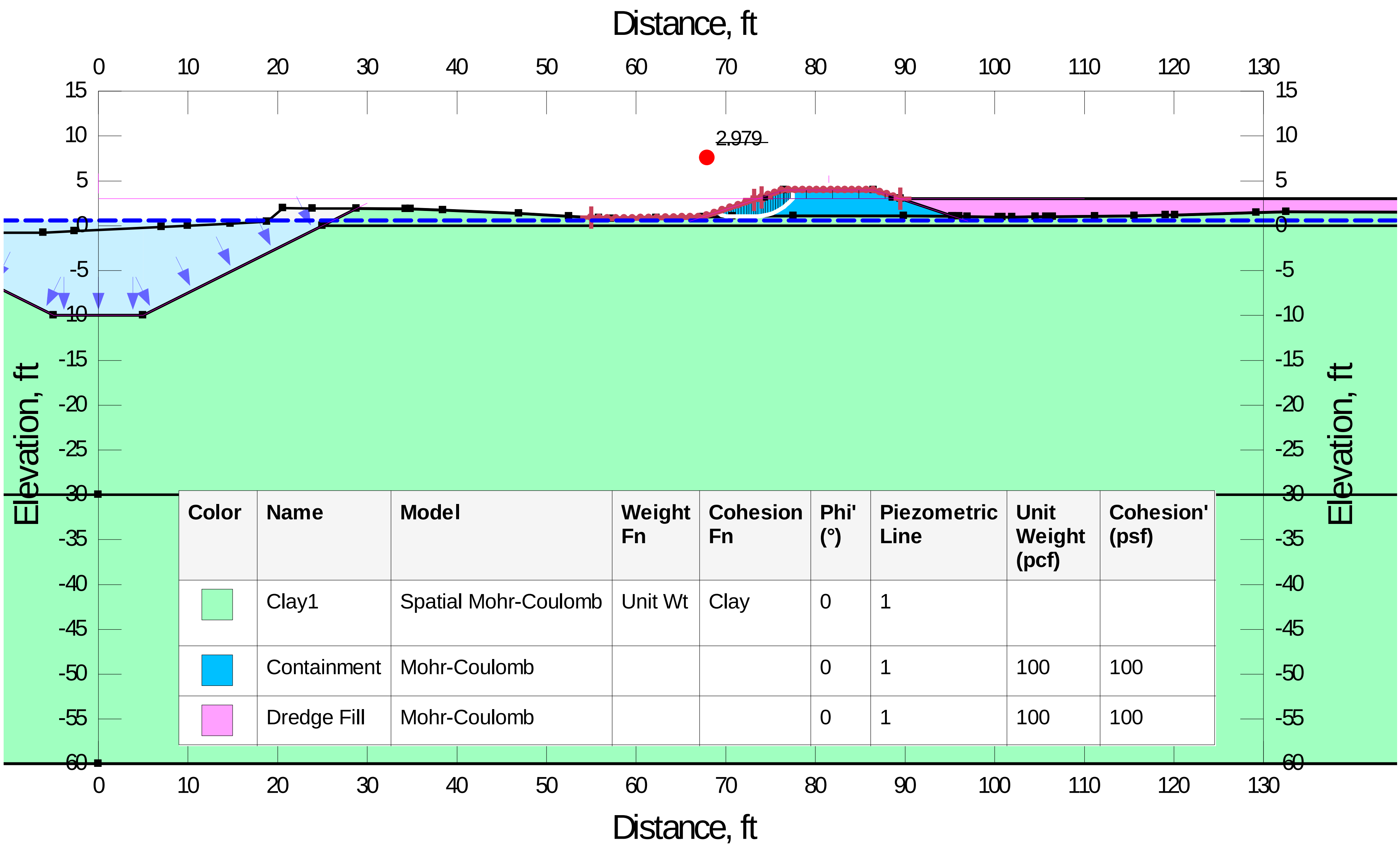


Color	Name	Model	Weight Fn	Cohesion Fn	Phi' (°)	Piezometric Line	Unit Weight (pcf)	Cohesion' (psf)
	Clay1	Spatial Mohr-Coulomb	Unit Wt	Clay	0	1		
	Containment	Mohr-Coulomb			0	1	100	100

Section T-25, Northwest End, Outside Borrow Trench Slope without Marsh



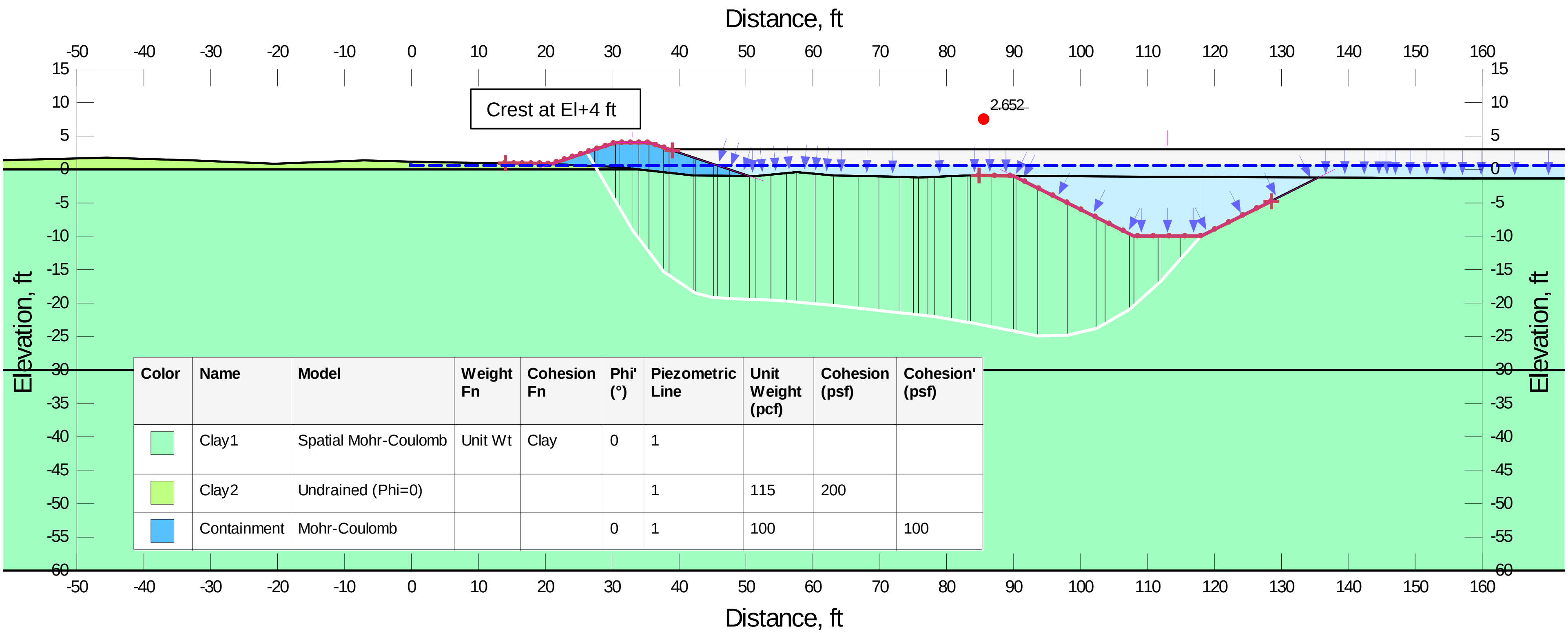
Section T-25, Northwest End, Inside Dike Slope without Marsh



Color	Name	Model	Weight Fn	Cohesion Fn	Phi' (°)	Piezometric Line	Unit Weight (pcf)	Cohesion' (psf)
	Clay1	Spatial Mohr-Coulomb	Unit Wt	Clay	0	1		
	Containment	Mohr-Coulomb			0	1	100	100
	Dredge Fill	Mohr-Coulomb			0	1	100	100

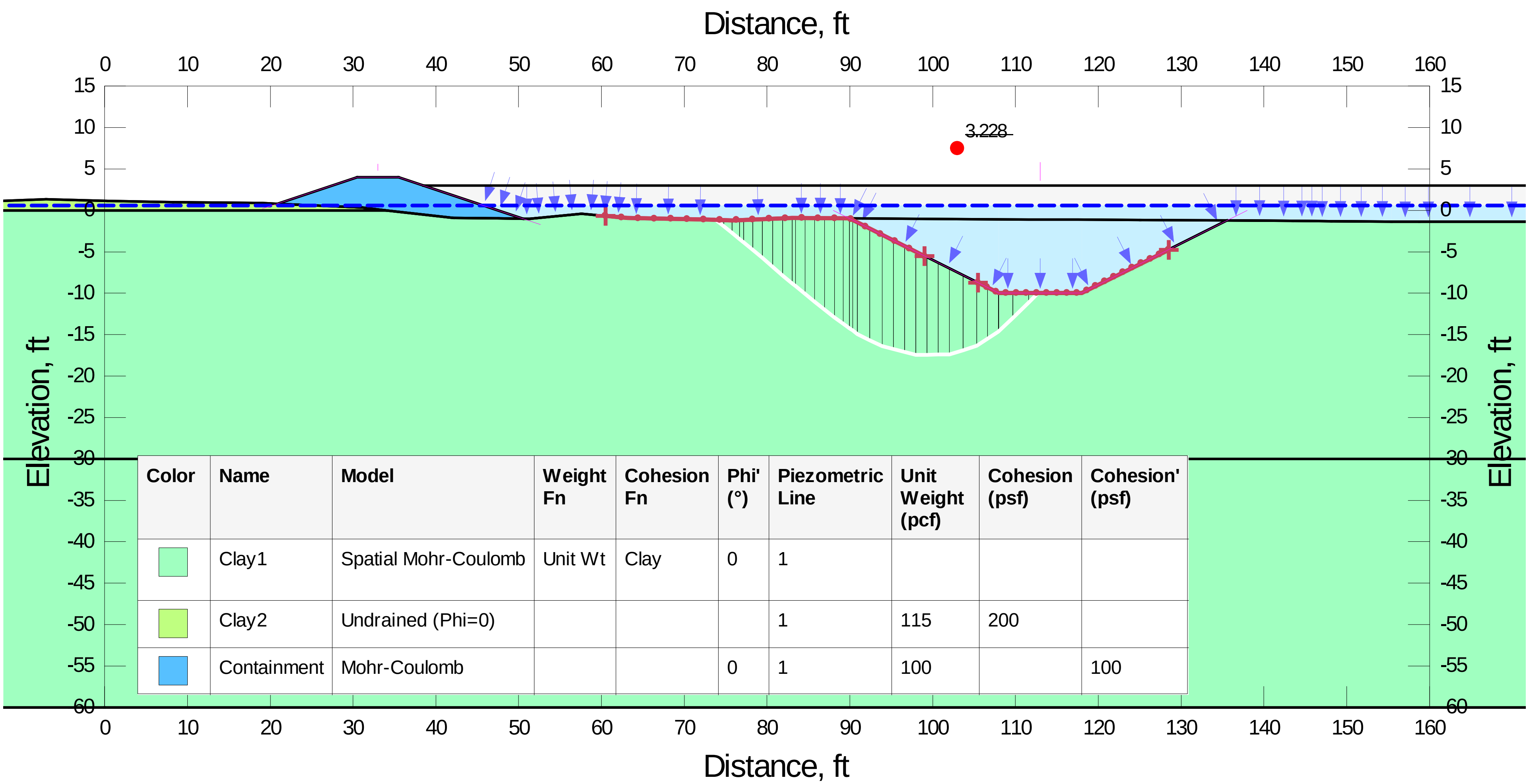
Section T-25, Northwest End, Outside Dike Slope with Marsh

Section T-33, Northwest End



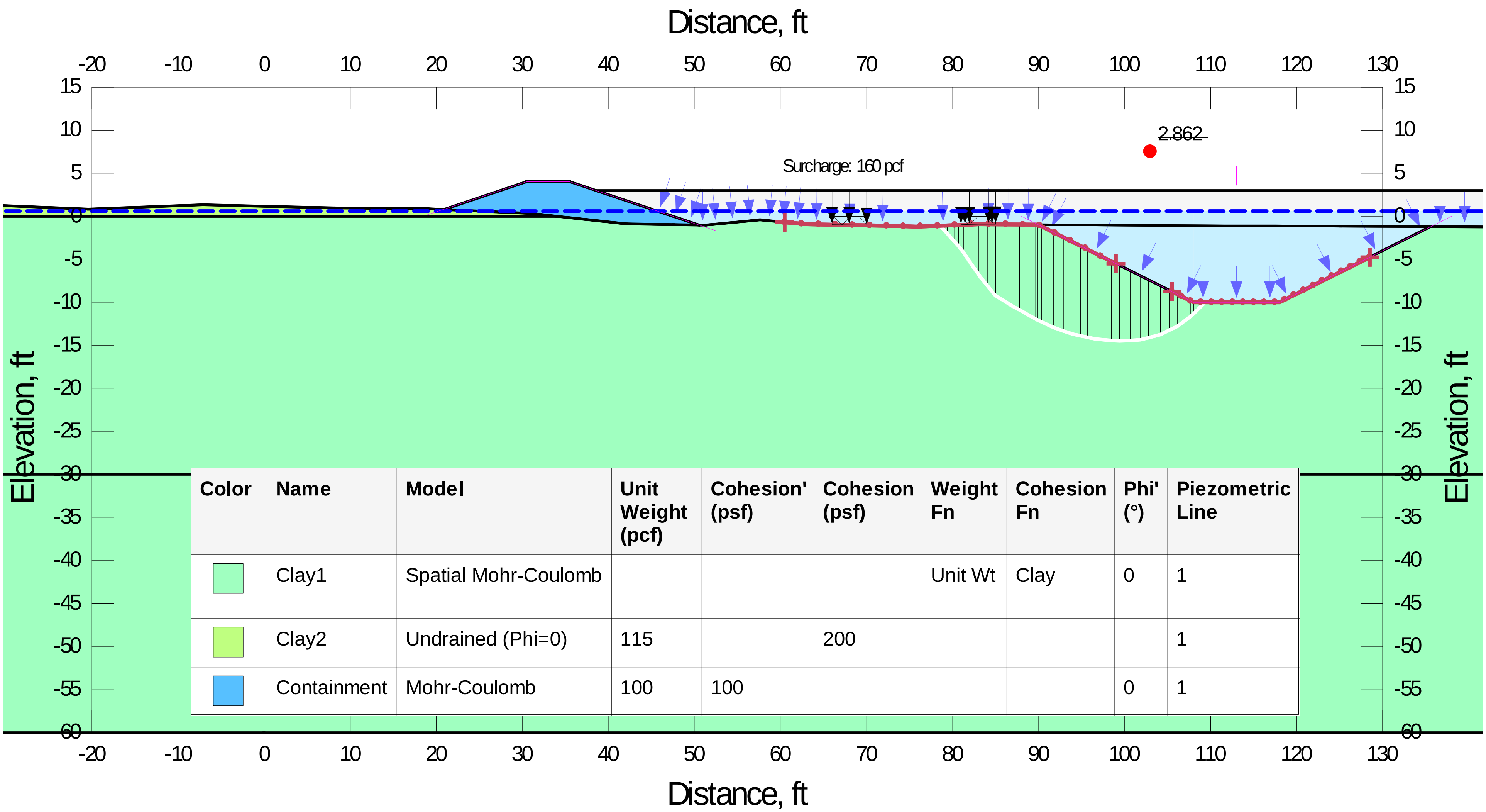
Color	Name	Model	Weight Fn	Cohesion Fn	Phi' (°)	Piezometric Line	Unit Weight (pcf)	Cohesion (psf)	Cohesion' (psf)
	Clay1	Spatial Mohr-Coulomb	Unit Wt	Clay	0	1			
	Clay2	Undrained (Phi=0)				1	115	200	
	Containment	Mohr-Coulomb			0	1	100		100

Section T-33 Northwest End, Dike to Inside Borrow Trench without Marsh



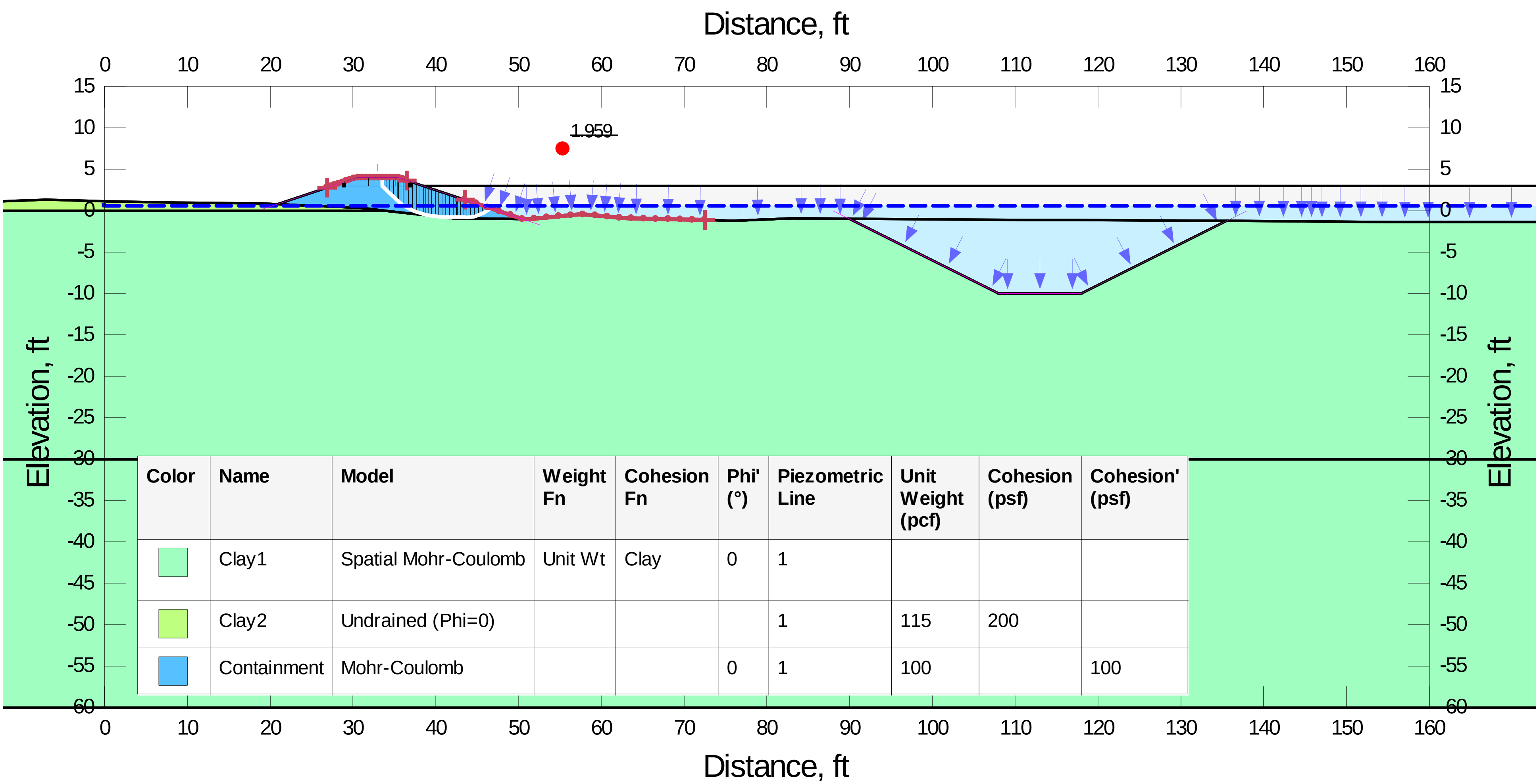
Color	Name	Model	Weight Fn	Cohesion Fn	Phi' (°)	Piezometric Line	Unit Weight (pcf)	Cohesion (psf)	Cohesion' (psf)
	Clay1	Spatial Mohr-Coulomb	Unit Wt	Clay	0	1			
	Clay2	Undrained (Phi=0)				1	115	200	
	Containment	Mohr-Coulomb			0	1	100		100

Section T-33, Northwest End, Inside Borrow Trench Slope without Marsh



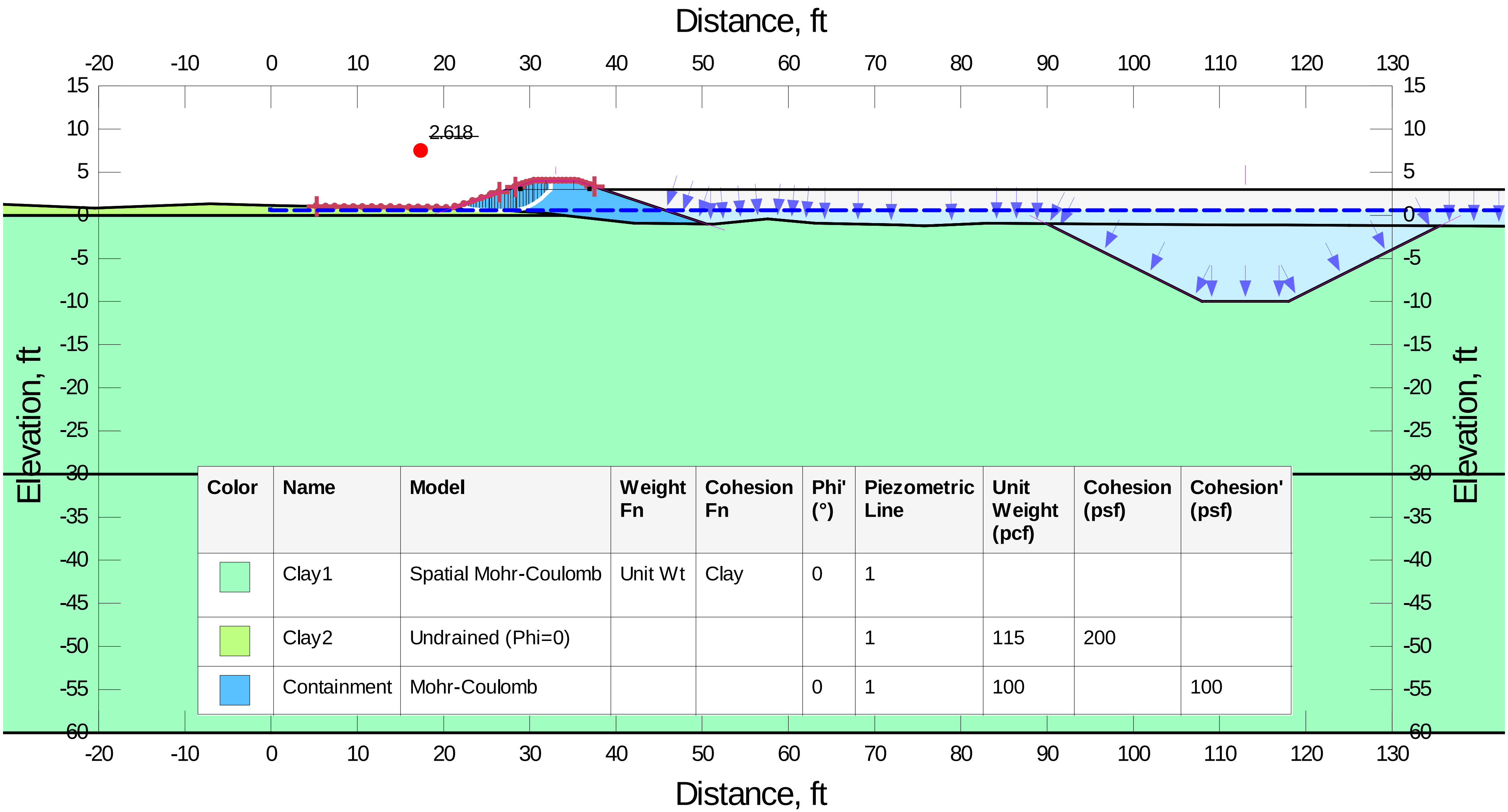
Color	Name	Model	Unit Weight (pcf)	Cohesion' (psf)	Cohesion (psf)	Weight Fn	Cohesion Fn	Phi' (°)	Piezometric Line
	Clay1	Spatial Mohr-Coulomb				Unit Wt	Clay	0	1
	Clay2	Undrained (Phi=0)	115		200				1
	Containment	Mohr-Coulomb	100	100				0	1

Section T-33, Northwest End, Inside Borrow Trench Slope without Marsh with Equipment Load



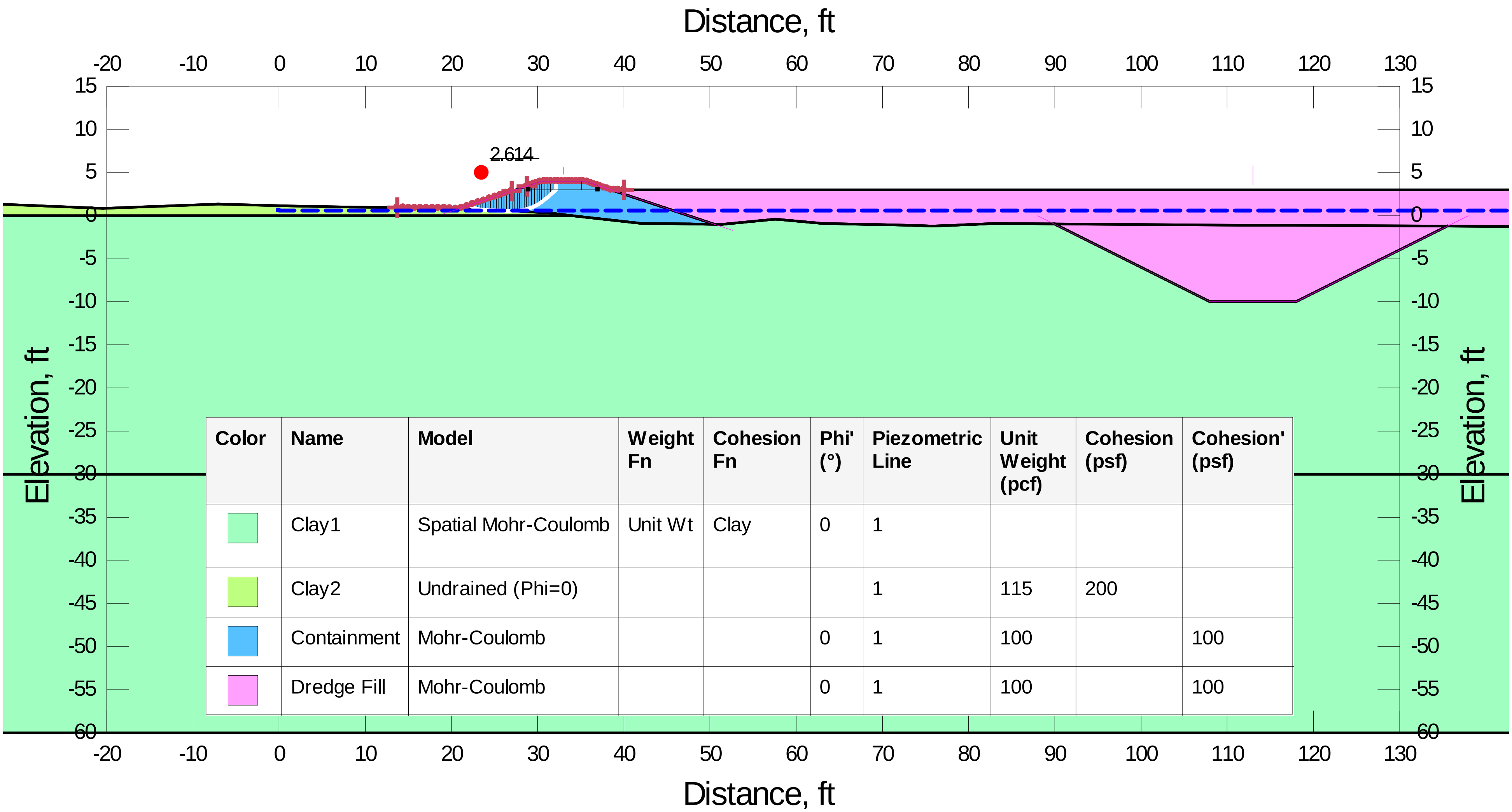
Color	Name	Model	Weight Fn	Cohesion Fn	Phi' (°)	Piezometric Line	Unit Weight (pcf)	Cohesion (psf)	Cohesion' (psf)
	Clay1	Spatial Mohr-Coulomb	Unit Wt	Clay	0	1			
	Clay2	Undrained (Phi=0)				1	115	200	
	Containment	Mohr-Coulomb			0	1	100		100

Section T-33, Northwest End, Inside Dike Slope without Marsh



Color	Name	Model	Weight Fn	Cohesion Fn	Phi' (°)	Piezometric Line	Unit Weight (pcf)	Cohesion (psf)	Cohesion' (psf)
	Clay1	Spatial Mohr-Coulomb	Unit Wt	Clay	0	1			
	Clay2	Undrained (Phi=0)				1	115	200	
	Containment	Mohr-Coulomb			0	1	100		100

Section T-33, Northwest End, Outside Dike Slope without Marsh



Color	Name	Model	Weight Fn	Cohesion Fn	Phi' (°)	Piezometric Line	Unit Weight (pcf)	Cohesion (psf)	Cohesion' (psf)
	Clay1	Spatial Mohr-Coulomb	Unit Wt	Clay	0	1			
	Clay2	Undrained (Phi=0)				1	115	200	
	Containment	Mohr-Coulomb			0	1	100		100
	Dredge Fill	Mohr-Coulomb			0	1	100		100

Section T-33, Northwest End, Outside Dike Slope with Marsh