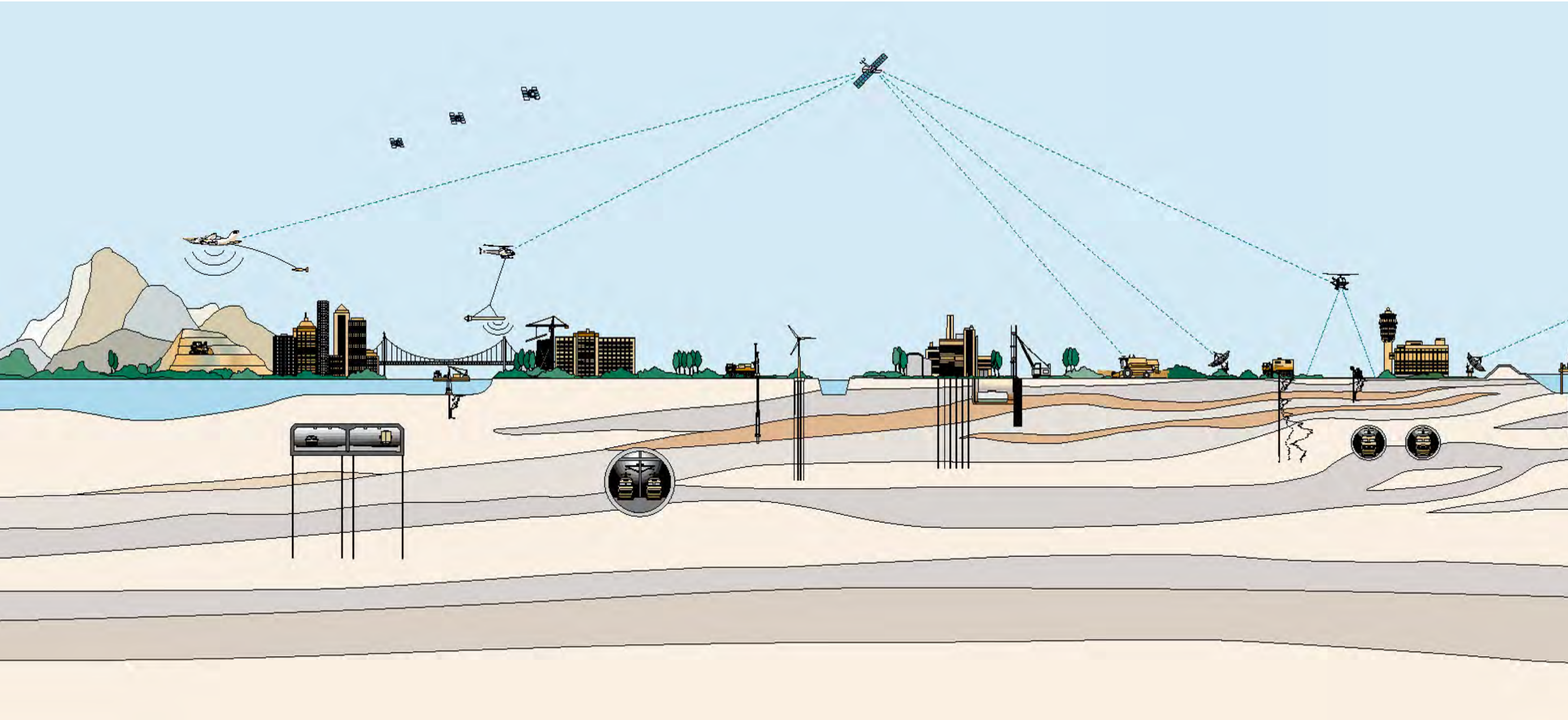
FUGRO USA LAND, INC.

# PRELIMINARY GEOTECHNICAL REPORT
# STORM SURGE SUPPRESSION STUDY - GCCPRD
# BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON AND ORANGE COUNTIES, TEXAS

DANNENBAUM ENGINEERING CORPORATION

HOUSTON, TEXAS



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Report No. 04.10160148
October 18, 2017

**DANNENBAUM ENGINEERING CORPORATION**
3100 West Alabama Street
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Attention: Mr. Christopher Sallese, PMP

**Preliminary Geotechnical Report**
**Storm Surge Suppression Study - GCCPRD**
**Brazoria, Chambers, Galveston, Harris, Jefferson and Orange Counties, Texas**

Fugro USA Land, Inc. (Fugro) is pleased to present this report of our geotechnical services for the Gulf Coast Community Protection and Recovery District (GCCPRD) Storm Surge Suppression Study. This study covers the coastal areas of Brazoria, Chambers, Galveston, Harris, Jefferson and Orange Counties in Texas. These coastal areas are also known as the six-county region. Mr. Christopher Sallese, PMP of Dannenbaum Engineering Corporation (Dannenbaum) requested our services on July 1, 2016. Our services were performed in general accordance with Fugro Proposal No. 04.10160148p dated September 8, 2016. Our services were authorized by the *Subcontract for Professional Services* document executed on November 8, 2016.

After authorization, Mr. Sallese requested that Fugro include preliminary geotechnical engineering recommendations as a part of the report. As requested, we have included a summary of interpreted subsurface conditions, preliminary geotechnical recommendations, and a future geotechnical investigation plan as a part of this report. This report includes our review of the local geology and existing geotechnical information, field exploration activities, laboratory testing program, summary of interpreted subsurface conditions, preliminary geotechnical recommendations, and a future geotechnical investigation plan for the above-reference project. We anticipate that future geotechnical services will be authorized for this project and a final geotechnical report will be issued at a later date.

A draft of this report was submitted to Dannenbaum dated August 1, 2017. Mr. Larry S. Marr, P.E. of Dannenbaum provided comments in a meeting with Ms. Gouri Mohan, P.E. of Fugro on September 8, 2017. This report addresses the comments and supersedes all previously provided geotechnical information.

We appreciate the opportunity to be of continued service to Dannenbaum. Please call us at 713-369-5400 if you have any questions or comments concerning this report or when we may be of further assistance.

Sincerely,
**FUGRO USA LAND, INC.**
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## EXECUTIVE SUMMARY

The Storm Surge Suppression Study was initiated by the Gulf Coast Community Protection and Recovery District (GCCPRD) for investigating mitigation measures to reduce the impact of future storm surges and flooding damages along the coastal areas of Brazoria, Chambers, Galveston, Harris, Jefferson, and Orange Counties in Texas. These coastal areas are also known as the six-county region. This study is separated into four processes: Initial Study (Phases 1 through 3), Development (Phases 4 through 6), Refinement (Phases 7 and 8), and Recommendations (Phase 9). This study is currently within Phase 4 of the development process.

We understand that Phase 4 involves the development of alternatives for surge protection systems along the six-county region. Structural alternatives are being considered for this study and may include flood gates with flood walls and levees. We understand that Dannenbaum Engineering Corporation (Dannenbaum) was contracted by GCCPRD to assist in providing engineering services for the proposed Storm Surge Suppression Study in the coastal areas of the six-county region. Fugro was contracted by Dannenbaum to assist in their efforts by providing services to integrate existing geotechnical data into a GIS soil model and collect new geotechnical data at strategic locations along the six-county region. We also understand that detailed engineering services are not part of this study.

A geological site assessment, review of existing geotechnical information, field exploration, laboratory testing program, slope stability analyses and deep foundation recommendations were performed as part of our preliminary geotechnical engineering services. The geological site assessment includes our review of the regional geology, stratigraphy, soils, surface faulting, subsidence, salt domes, regional seismicity, expansive soils, karst, and collapsible soils within the six-county region along the Texas Gulf Coast. A review of existing geotechnical information was performed during the initial phase of our geotechnical study to identify data gaps along the proposed North Recommended Alignment, Central Recommended Alignment (Coastal Spine), and South Recommended Alignments of the GCCPRD Storm Suppression Study. A GIS database was created for the existing borings that were collected along the alignments. Several areas with data gaps were addressed by performing 8 geotechnical borings and 54 CPT soundings during our field exploration investigation. Laboratory testing was performed on selected soil samples from our borings for evaluating the classification properties, undrained shear strength, and compressibility of the subsurface cohesive soils. Based on information provided to us, we understand that earthen levees, T-walls, sector gates, and other proposed structures are planned for the storm surge protection system. Therefore, slope stability analyses and deep foundation recommendations were performed at this time to provide preliminary engineering data.

Additional geotechnical investigation, consisting of field exploration, laboratory testing, engineering analyses and pile load test program, is discussed to guide the next phase of geotechnical study.

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# 1.0 INTRODUCTION

## 1.1 Program Description

The Gulf Coast Community Protection and Recovery District (GCCPRD) was formed by the six-county region to perform studies and develop mitigation measures for future storm surge and flooding caused by storm events. The Storm Surge Suppression Study was initiated by GCCPRD for investigating mitigation measures to reduce the impact of future storm surges and flooding damages along the coastal areas of Brazoria, Chambers, Galveston, Harris, Jefferson and Orange Counties in Texas. These coastal areas are also known as the six-county region. This study is divided into three alignments along the six-county region: North Recommended Alignment, Central Recommended Alignment (Coastal Spine), and South Recommended Alignment. The *Overall Site Map* of the proposed alignments along the six-county region is presented on Plate 1a. These alignments were developed for future placement of proposed structures to mitigate the impact of storm surges and flood damage along the coastal areas of Brazoria, Chambers, Galveston, Harris, Jefferson and Orange Counties in Texas. Details of each alignment are presented on Plates 1b through 1d. The Storm Surge Suppression Study is separated into four processes: Initial Study (Phases 1 through 3), Development (Phases 4 through 6), Refinement (Phases 7 and 8), and Recommendation (Phase 9).

We understand that Phase 4 involves the development of alternatives for surge protection systems along the six-county region. Structural alternatives are being considered for this study and may include, flood gates with flood walls and levees. We understand that the Dannenbaum Engineering Corporation (Dannenbaum) was contracted by GCCPRD to assist in providing engineering services along the six-county region. Fugro was contracted by Dannenbaum to assist in their efforts by providing services to integrate existing geotechnical data into a GIS soil model and collect new geotechnical data at strategic locations along the six-county region. We also understand that detailed engineering services are not part of Phase 4 for the Storm Surge Suppression Study.

## 1.2 Purpose and Scope of Services

The purpose of our services was to assist Dannenbaum in their preliminary engineering design efforts for this study. We accomplished this purpose by:

- Reviewing existing geotechnical and geologic information in the public domain, including information from GCCPRD, Texas Department of Transportation (TxDOT), US Army Corps of Engineers (USACE), Texas General Land Office (GLO), Ports and Counties.
- Reviewing geotechnical information from Fugro's Project Library for the North Recommended Alignment, Central Recommended Alignment (Coastal Spine), and South Recommended Alignment areas along the six-county region.

- Developing a GIS model using existing and collected soil data in and around the North Recommended Alignment, Central Recommended Alignment (Coastal Spine), and South Recommended Alignment areas along the six-county region.
- Performing 6 soil borings to depth of 50 ft and 2 soil borings to a depth of 400 ft below existing grade within the limits of the six-county region. These borings were performed in general accordance with local geotechnical practice for the Texas Gulf Coast region.
- Performing 54 Piezocone Penetration Tests (CPT) to a depth of about 60 ft below existing grade to explore the subsurface conditions.
- Identifying geotechnical concerns and developing a conceptual interpretation of subsurface conditions along the six-county region.
- Developing geotechnical considerations for the surge protection system.

Environmental assessments, compliance with State and Federal Regulatory requirements, and/or environmental analyses including those with mold, fungi, and other biologic agents were beyond the scope of our services.

### 1.3 Applicability of Report

The scope of the field exploration, tests, and analyses for this study, as well as the conclusions and recommendations presented in this report, were selected or developed on the basis of our understanding of the project, as described above and in later sections of this report. If pertinent details of the project have changed or otherwise differ from our descriptions, we request that we be notified and authorized to review the changes and, if necessary, to modify our conclusions and recommendations.

We prepared this data report exclusively for Dannenbaum Engineering Corporation and the Gulf Coast Community Protection and Recovery District (GCCPRD) for their evaluation and preliminary engineering design for the Storm Surge Suppression Study. We have conducted this study using the standard level of care and diligence normally practiced by recognized engineering firms now performing similar services under similar circumstances. We intend for this report, including all illustrations, to be used in its entirety. Furthermore, this report should not be construed to represent a warranty of subsurface conditions, nor should this report be used, whether in whole or part, as a stand-alone construction specification document. Fugro makes no claim or representation concerning any activity or condition falling outside the specified purposes to which this report is directed.

## 2.0 GEOLOGIC SITE ASSESSMENT

### 2.1 Regional Geology

The Gulf of Mexico Basin, which includes the Texas Gulf Coast, was formed by tectonic activities of the Paleozoic basement rocks during the separation of the supercontinent, Pangaea. Sediments were primarily deposited into the Texas Gulf Coast due to fluvial-deltaic to shallow-marine environments during the Miocene-age and the Pleistocene-age. The Texas Gulf Coast is prominent for supporting agriculture and stores significant petroleum reservoirs.

There are 10 major rivers that divides the Texas Gulf Coast and runs nearly perpendicular into the Gulf of Mexico Basin. These rivers are the Sabine, Neches, Trinity, San Jacinto, Brazos, Colorado, Lavaca, Guadalupe, San Antonio, and the Nueces. Figure 2-1[1] shows a map of major rivers that are within the Texas Gulf Coast.


**Figure 2-1[1]:** Major rivers along the Texas Gulf Coast (Not to Scale).

[1] Chowdhury, A.H., Turco, M.J. (2006), “Geology of the Gulf Coast Aquifer, Texas”, Texas Water Development Board, Report 365: Aquifers of the Gulf Coast of Texas, p. 23-50.

These rivers primarily have broad alluvial valleys and deposit sediments in the basin. It was suggested that structural features in the Gulf of Mexico Basin were formed by differential movements of the basin floor and sediments that flowed as viscous fluids on sloping surfaces[2]. These structural features include arches, embayments, numerous growth faults, and salt domes that are spread across the Texas Gulf Coast.

The State of Texas is divided into several physiographic provinces. The province of the Texas Gulf Coast is called the Gulf Coastal Plains. The surface elevations of the Gulf Coastal Plains gradually rise from the sea level in the east to as much as 1,000 ft in the north from east to west. The Gulf Coastal Plains is divided in three subprovinces known as the Coastal Prairies, the Interior Coastal Plains, and the Blackland Prairies. Figure 2-2[3] shows the Physiographic Map of Texas.

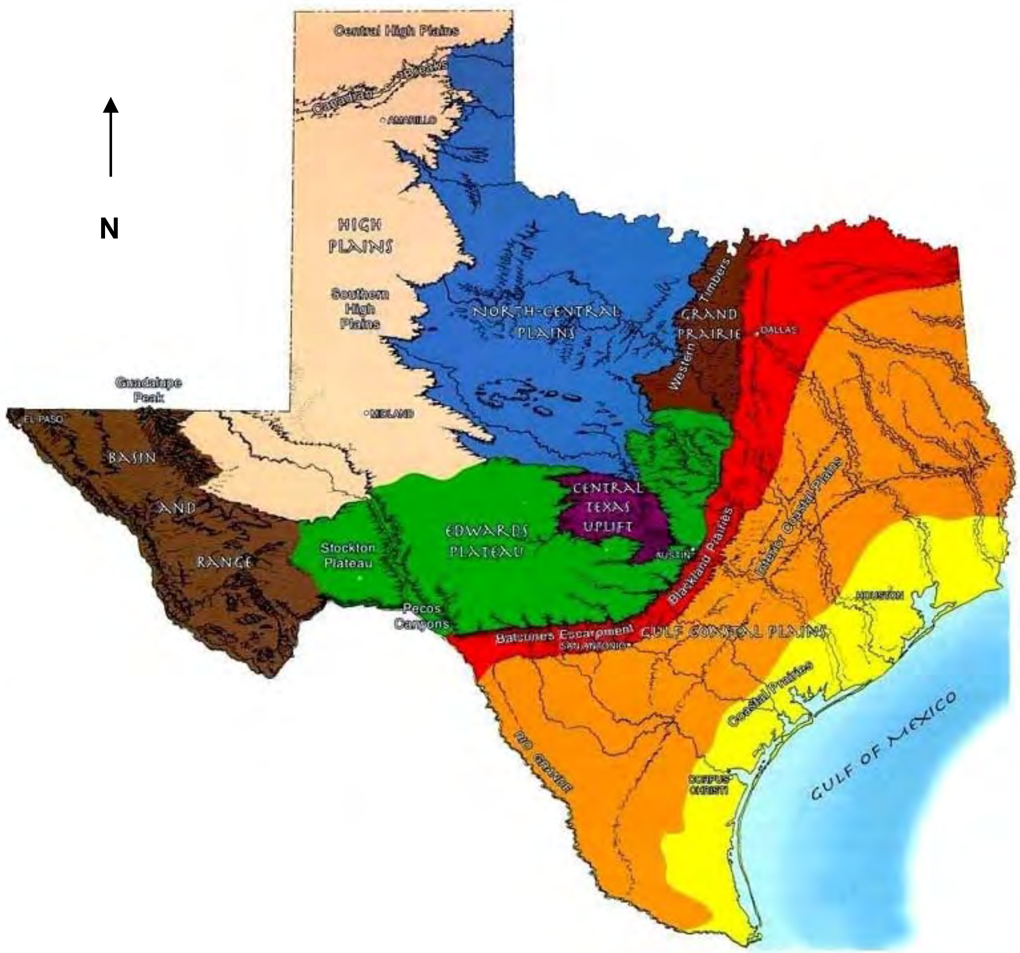



**Figure 2-2[3]:** Physiographic Map of Texas (Not to Scale)

[2] Bornhauser, M. (1958), "Gulf Coast Tectonics", American Association of Petroleum Geologists Bulletin, V. 42, p. 339-370.

[3] The University of Texas at Austin (1996), "Physiographic Map of Texas," Bureau of Economic Geology.

The counties of Brazoria, Chambers, Galveston, Harris, Jefferson, and Orange, also known as the six-county region, fall within the boundaries of the Coastal Prairies. The Coastal Prairies is near the shoreline of the Gulf of Mexico Basin. The Trinity River, San Jacinto River, Brazos River, Sabine Arch, Houston Embayment, San Marcos Arch are the major water and land features within the six-county region. In addition, numerous growth faults and salt domes are common features within the six-county region.

## 2.2 Stratigraphy

The surface geology of the Coastal Prairies is defined by Quaternary period, which is the youngest period of the Cenozoic Era. The Quaternary period is divided into the Holocene and Pleistocene series. Geological cross sections were developed from numerous well logs to define the stratigraphy across the Texas Gulf Coast. Sedimentary deposits of the Holocene and Pleistocene series range in depths of about 400 ft to 3,200 ft from the ground surface within the Coastal Prairies[4]. The deposits of the Holocene and Pleistocene series primarily include the alluvium deposits, Beaumont Formation, and Lissie Formation.

The alluvium deposits are underlain by Beaumont Formation, which is underlain by the Lissie Formation. The layer thickness and presence of these stratigraphies vary across the Coastal Prairies. The alluvium deposits are prominent for the Holocene series and are common in areas near rivers and streams. The alluvium deposits consist primarily of sand and gravel soils with lower content of silt and clay soils.

The Beaumont Formation spans from the Sabine River in the east through Kleberg County in the south of the Coastal Prairies. This formation consists primarily of overconsolidated stiff to hard clays that are interbedded with silt and sand layers. The clay soils of this formation are commonly dark in color with secondary features including calcium carbonate, calcareous nodules, ferrous nodules, and slickensides. Typically, the clays within this formation were deposited on broad, flat deltaic flood plains during periods of overflow. During dry seasons, the clays contracted and networks of surface cracks developed. As each flood occurred, new sediments of various grain sizes were deposited in the open fissures. This cyclic wetting and drying continued and produced fissures which are commonly observed in the Beaumont clays. These fissures are randomly oriented and their occurrence within the formation is highly variable.

The Lissie Formation spans from the Sabine River in the east through the Rio Grande in the south of the Coastal Prairies. The sediments of this formation are composed of continental and fluvial deposits. The continental deposits were laid down as flood-plain deposits along rivers and creeks. The fluvial deposits were formed of delta sands, bottom silts, and muds. In general, this formation is composed of interbedded clays, silts, clayey and/or silty sands. The sand deposits are typically clayey or silty but may also include clean, poorly graded sand, gravel, and even random cobbles or

[4] Baker, Jr. E.T., Turco, M.J. (1995), "Stratigraphic Nomenclature and Geologic Sections of the Gulf Coastal Plain of Texas", U.S. Geological Survey: Open-File Report 94-461.

boulders. Buried stream channel may occur sporadically within finer grained deposits throughout the Lissie formation.

The Beaumont and Lissie Formations are dominant divisions of the Pleistocene series.

### 2.3 Soils

The United States Department of Agriculture Soil Conservation Services (USDA SCS) in conjunction with other governmental agencies have compiled detailed soil surveys over the years for the six-county region. These surveys include, but not limited to, soil maps, soil properties, soil classifications, and soil formations for the counties. Soil scientists developed the soil surveys by observing the steepness, length, and shape of slopes; the size of streams and drainage features; and the kinds of native crops and plants. They also generated soil profiles by digging test pits to a depth of less than 10 ft below the ground surface and obtaining soil samples for field and laboratory testing. Please note that the soil description obtained for the six-county region are applicable only to surficial soils within the upper 10 ft below the ground surface. The encountered soils are named and classified and area boundary lines are drawn on aerial photographs. The soil maps are derived from the aerial photographs and are divided into map units or map associations. Each unit or association consists of primary, higher percentage soils, and secondary, lower percentage soils. The general soil maps for the six-county region are presented on Plates A-1 through A-5 in Appendix A[5]. The information presented in the following subsections are based on our review of the soil survey data provided by the USDA SCS for Brazoria, Chambers, Galveston, Harris, Jefferson and Orange Counties in Texas.

#### 2.3.1 Brazoria County

Brazoria County is defined by 2 general landscapes for interpretation purposes: the deep nonsaline soils and deep saline soils in the top 10 ft. The soils are grouped into 9 units: Lake Charles, Pledger-Brazoria, Bernard-Edna, Asa-Norwood, Enda-Aris, Surfside-Velasco, Harris-Veston, Francitas-Narta, and Mustang-Veston. These soils primarily have a low corrosion potential for concrete and a high corrosion potential for uncoated steel. In general, these soils have severe limitations for re-use as embankment material: (1) hard to compact, (2) wetness, (3) piping, and (4) seepage.

The deep nonsaline soils consist of the Lake Charles, Pledger-Brazoria, Bernard-Edna, Asa-Norwood, and Enda-Aris units. The Lake Charles unit is formed from clay deposits. The general soil description is very dark gray to gray in color with slickensides. The Pledger-Brazoria unit is formed from clayey fluvial deposits. The general soil description is reddish brown in color, alkaline, with calcium carbonate, and calcareous deposits. The Bernard-Edna unit is formed from ancient clayey coastal deposits. The general soil description is very dark gray to light brownish gray in color, acidic to alkaline, with calcium carbonate. The Asa-Norwood unit is from recent loamy fluvial deposits. The general soil description is very dark grayish brown to yellowish red in color, alkaline, with calcium

[5] United States Department of Agriculture Soil Conservation Services (1969-1996), “General Soil Map”, Brazoria County, Chambers County, Galveston County, Harris County, and Jefferson and Orange Counties.

carbonate and calcareous deposits. The Edna-Aris unit is formed from ancient fluvial deposits. The general soil description is primarily dark gray in color, neutral to alkaline, with calcium carbonate. The Lake Charles and the Pledger-Brazoria units have a high shrink-swell potential, while the Bernard-Edna and Asa-Norwood units have a low to high shrink-swell potential. In addition, the nonsaline soils have low permeability and poor drainage characteristics.

The deep saline soils consist of the Surfside-Velasco, Harris-Veston, Francitas-Narta, and Mustang-Veston units. The Surfside-Velasco unit is formed from recent clayey fluvial deposits. The general soil description is very dark gray to dark reddish brown in color, mildly alkaline, with calcium carbonates. The Harris-Veston unit is formed from recent clayey marine deposits. The general soil description is very dark gray to gray in color, mildly to strongly alkaline. The Francitas-Narta unit is formed from ancient clayey coastal deposits. The general soil description is very dark gray to light brown in color, alkaline, with calcium carbonates and slickensides. The Mustang-Veston unit is formed from recent sandy coastal deposits. The general soil description is light gray in color and alkaline. The saline soils along the coast are influenced by the salt deposits and tides from the Gulf of Mexico. They have high erosion potential and are vulnerable to flood events. Besides the Mustang-Veston unit, the saline soils primarily have a high shrink-swell potential, low permeability and poor drainage characteristics.

### 2.3.2 Chambers County

The soils of Chambers County are grouped into 6 associations: Beaumont-Morey-Lake Charles, Harris-Veston-Ijam, Anahuac-Morey-Frost, Vaiden-Acadia-Calhoun, Harris-Kaufman, and Stowell-Clodine. These soils primarily have a moderate to high corrosion potential for concrete and a high corrosion potential for uncoated steel. They also have a low to high shrink-swell potential, low permeability and poor drainage characteristics. In general, these soils primarily have moderate limitations for re-use as embankment material: (1) good to fair resistance to piping and erosion, (2) fair slope stability, and (3) medium to high compressibility.

The Beaumont-Morey-Lake Charles association is clayey and loamy in nature. The general soil description is very dark gray to dark gray in color, acidic to neutral, with iron oxides, calcium carbonates, and slickensides.

The Harris-Veston-Ijam association is clayey and loamy in nature. The general soil description is very dark gray to dark gray in color, alkaline and saline, with iron oxides, calcium carbonates, and calcareous deposits.

The Anahuac-Morey-Frost association is loamy in nature. The general soil description is very dark gray to dark gray in color, acidic, with calcium carbonates and slickensides.

The Vaiden-Acadia-Calhoun association is clayey and loamy in nature. The general soil description is dark grayish brown and dark gray in color, acidic, with slickensides.

The Harris-Kaufman association is clayey in nature. The general soil description is very dark gray to black in color, neutral to alkaline.

The Stowell-Clodine association is sandy and loamy in nature. The general soil description is very dark gray to gray in color, acidic, alkaline.

**2.3.3 Galveston County**

Galveston County is defined by 3 general landscapes for interpretation purposes. The deep nonsaline soils of the mainland, deep saline soils of the marshland, and deep nonsaline soils of the barrier island in the top 10 ft. The soils are grouped into 9 units: Mocarey-Leton-Algoa, Lake Charles-Bacliff, Bernard-Verland, Kemah-Edna-Leton, Bernard-Edna, Placedo-Tracosa-Veston, Narta-Francitas, Ijam, and Mustang-Galveston. These soils have a low to high corrosion potential for concrete and a high corrosion potential for uncoated steel. In general, these soils have severe limitations for re-use as embankment material: (1) hard to compact, (2) wetness, (3) piping, (4) seepage, and (5) excess salt and sodium.

The deep nonsaline soils of the mainland consists of the Mocarey-Leton-Algoa, Lake Charles-Bacliff, Bernard-Verland, Kemah-Edna-Leton, and Bernard-Edna units. The Mocarey-Leton-Algoa unit is loamy in nature. The general soil description is very dark gray, alkaline, with calcium carbonate and calcareous deposits. The Lake Charles-Bacliff unit is clayey in nature. The general soil description is very dark gray to gray in color, acidic to alkaline. The Bernard-Verland unit is clayey in nature. The general soil description is very dark gray to gray and acidic to alkaline. The Kemah-Edna-Leton unit is clayey in nature. The general soil description is dark grayish brown to dark gray in color, acidic to alkaline. The Bernard-Edna unit is clayey in nature. The general soil description is very dark gray to gray and acidic to alkaline. These soils primarily have a low to high shrink-swell potential, low permeability and poor drainage characteristics.

The saline soils of the marshland consist of the Placedo-Tracosa-Veston, Narta-Francitas, Ijam units. The Placedo-Tracosa-Veston unit is loamy and clayey in nature. The general soil description is dark gray and alkaline. The Nara-Francitas unit is loamy and clayey in nature. The general soil description is very dark gray to dark gray and alkaline. The Ijam unit is clayey in nature. The general soil description is dark grayish brown, neutral to alkaline. The saline soils of the marshland are influenced by the salt deposits and tides from the Gulf of Mexico. These soils primarily have a high shrink-swell potential, high erosion potential, low permeability, poor drainage characteristics and are vulnerable to flood events.

The nonsaline soils of the barrier island consist of the Mustang-Galveston unit. They are primarily located on Galveston Island and Bolivar Peninsula, where the landscape consists of beaches and barrier sand dunes. The Mustang-Galveston unit is sandy in nature. The general soil description is dark gray and grayish brown and alkaline. These soils primarily have a high erosion potential and high permeability. This is evident by past storm surge and flooding events negatively impacting Galveston Island and Bolivar Peninsula throughout the years.

**2.3.3 Harris County**

Harris County is defined by 4 general landscapes for interpretation purposes. The nearly level clayey and loamy prairie soils, nearly level loamy prairie soils, nearly level to gently sloping loamy forested soils and nearly level forested bottom land soils. The soils are grouped into 8 associations: Lake Charles-Bernard, Midland-Beaumont, Clodine-Addicks-Gessner, Wockley-Gessner, Katy-Aris, Aldine-Ozan, Segno-Hockley and Nahatche-Voss-Kaman. These soils primarily have a low to moderate corrosion potential for concrete and a high corrosion potential for uncoated steel. In general, these soils have moderate limitations for re-use as embankment material: (1) low strength, (2) unstable, (3) compressible, (4) piping, and (5) seepage.

The nearly level clayey and loamy prairie soils consist of Lake Charles-Bernard and Midland-Beaumont associations. The general soil description for Lake Charles-Bernard association is very dark gray to gray, neutral to alkaline, with calcium carbonate, calcareous deposits, and slickensides. The general soil description for the Midland-Beaumont association is dark gray to yellowish brown, acidic, with slickensides. The Lake Charles-Bernard and Midland-Beaumont associations are located within urban and rural areas across the county. Throughout the county, the moderate to high shrink-swell potential of these soils is problematic for slabs-on-grade and pavement structures. In addition, these soils primarily have a low permeability and poor drainage characteristics. These soils have a low to moderate corrosion potential for concrete and a high corrosion potential for uncoated steel.

The nearly level loamy prairie soils consist of Clodine-Addicks-Gessner, Wockley-Gessner, and Katy-Aris associations. The general soil description for Clodine-Addicks-Gessner association is dark gray to light gray in color, neutral to moderately alkaline, with calcium carbonates. The general soil description for the Wockley-Gessner association is dark grayish brown to light gray, acidic to alkaline. The general soil description for the Katy-Aris association is dark grayish brown to brown and acidic. Throughout the county, these soils primarily have a low to moderate shrink-swell potential, low permeability and poor drainage characteristics.

The nearly level to gentle sloping loamy forested soils consist of the Aldine-Ozan and Segno-Hockley associations. The general soil description for the Aldine-Ozan association is dark grayish brown to light gray in color and acidic. The general soil description for the Segno-Hockley association is dark grayish brown to yellowish brown and gray and acidic. These soils primarily have a low to moderate shrink-swell potential, low permeability and poor drainage characteristics.

The nearly level forested bottom land soils consist of the Nahatche-Voss-Kaman association. They are in areas within the 100-year flood plain. The Nahatche-Voss-Kaman association is clayey, loamy, and sandy in nature. The general soil for this association from the ground surface to a depth of about 6 ft is dark grayish brown to dark gray, acidic to alkaline, with calcium carbonate and slickensides. These soils primarily have a moderate to high shrink-swell potential, are vulnerable to flood events, and are erodible. These soils also have a moderate corrosion potential for concrete and a high corrosion potential for uncoated steel.

### 2.3.4 Jefferson and Orange Counties

The soils of Jefferson and Orange Counties are grouped into 15 units: League-Beaumont-China, Labelle-Morey-Meaton, Leerco-Zummo-Caplen, Texla-Evadale, Orcadia-Aris, Bancker-Creole-

Veston, Anahuac-Aris-Leton, Ijam-Neel-Neches, Estes-Fausse, Craigen-Mollco, Camptown-Spurger-Bienville, Franeau-Harris, Vamont-Bevil, Barbary, and Sabine-Baines. The soils of Jefferson and Orange Counties primarily have a moderate to high corrosion potential for concrete and a high corrosion potential for uncoated steel. They also have high shrink-swell potential, high seasonal water table, low permeability, and poor drainage characteristics. In general, these soils primarily have severe limitations for re-use as embankment material: (1) hard to compact, (2) wetness, (3) piping, and (4) seepage.

The League-Beaumont-China, Labelle-Morey-Meaton, Leerco-Zummo-Caplen, Bancker-Creole-Veston, Anahuac-Aris-Leton, Franeau-Harris, and Sabine-Baines units are located primarily in Jefferson County. The League-Beaumont-China unit is clayey in nature. The general soil description is very dark gray to gray in color and acidic. The Labelle-Morey-Meaton map unit is clayey and loamy in nature. The general soil description is dark grayish brown to gray in color, neutral to alkaline. The Leerco-Zummo-Caplen unit is along a coastal marsh area and is mucky and clayey in nature. The general soil description is very dark gray to dark gray in color, acidic, saline. The Bancker-Creole-Veston unit is along a coastal area and is mucky, clayey, loamy, and sandy in nature. The general soil description is gray in color, acidic to alkaline, saline. The Anahuac-Aris-Leton unit is clayey, loamy, and sandy in nature. The general soil description is grayish brown to light gray in color, acidic. The Franeau-Harris unit is along a coastal marsh area and is clayey in nature. The general soil description is very dark gray in color, acidic to alkaline, saline. The Sabine-Baines unit is along the Sabine Lake and is loamy and sandy in nature. The general soil description is very dark brown and gray in color, acidic to alkaline, saline.

The Texla-Evadale, Orcadia-Aris, and Barbary units are primarily located in Orange County. The Texla-Evadale unit is clayey and loamy in nature. The general soil description is grayish brown and light brownish gray in color, acidic. The Orcadia-Aris unit is clayey and loamy in nature. The general soil description is very dark grayish brown to light brownish gray in color, acidic. The Barbary unit is along a coastal swamp area and is mucky and clayey in nature. The general soil description is gray in color, acidic.

The Ijam-Neel-Neches, Estes-Fausse, Craigen-Mollco, Camptown-Spurger-Bienville, and Vamont-Bevil units are primarily located in both Jefferson and Orange Counties. The Ijam-Neel-Neches unit is mainly adjacent to the Intracoastal Waterway, Sabine Lake, and the Neches River. This unit is clayey and sandy in nature. The general soil description is dark gray to light gray in color, acidic to neutral, saline. The Estes-Fausse unit is clayey in nature. The general soil description is gray to light gray in color, acidic. The Craigen-Mollco unit is clayey, loamy, and sandy in nature. The general soil description is dark grayish brown to gray in color, acidic. The Camptown-Spurger-Bienville unit is clayey, loamy, and sandy in nature. The general soil description is dark gray, red, pale brown, and light brownish gray in color, acidic. The Vamont-Bevil unit is clayey in nature. The general soil description is brown and gray in color, acidic to neutral.

## 2.4 Surface Faulting

In the Gulf Coastal Plains of Texas, several hundred faults are known or suspected to be active. These are known as growth faults which run parallel to the coast. Most of these faults are located within the Houston-Galveston (Texas) area subsidence bowl. Evidence of modern activity of these faults includes: changes in elevation of the ground surface, sharp linears on remote imagery (aerial photographs and LIDAR), offsets in pavements, and damage to buildings and other structures.

These faults are manifestations of subsurface movements, which began several miles below the ground surface. They were formed by extremely slow movement of the very thick sediments under the Gulf Coastal Plains toward the Gulf of Mexico and by the rise of very deep salt into domes at lesser depths.

Although these faults are all ancient, natural features, most of the modern fault activity is induced by man's actions. Nearly all the faults that have moved since the early 1900's are in areas where decline in pressures of groundwater, oil, or gas have been sufficient to cause subsidence of the ground surface. The percentage of faults now moving in subsidence areas is far greater than elsewhere in the coastal plain and modern fault movements greatly exceed average rates over geologic time.

In the mid 1970's various users in parts of Galveston, Chambers, Brazoria, and southeastern Harris Counties of Texas began ongoing programs to reduce groundwater pumpage. Those reductions have caused groundwater levels in affected portions of the principal aquifers to stop declining or even rebound substantially, and several faults in those areas are known to have responded by slowing or stopping their current movements. In the northern and western parts of Harris County and in parts of adjacent counties, pumpage is continuing or increasing and the faults are continuing to move. In addition, newly activated or previously undetected faults or fault segments are occasionally discovered, particularly in areas where pumpage is continuing or accelerating.

Movements of faults in the coastal plains tend to be small and frequent and do not cause earthquakes, because the sediments are not hard rock and are not able to store significant amounts of strain energy. There is evidence to suggest that some faults may move slightly in response to surface waves from large, distant earthquakes. In the case of the Mexico City earthquake of September 19, 1985, some faults that had not moved appreciably for several years appeared to have moved one-quarter inch or so in response to the earthquake[6]. Some faults that were moving might have slipped more, and other faults clearly remained stable during the event.

According to the traditional definition used in the Gulf Coastal Plains, a fault that has broken or displaced man-made structures or has a clear, well-defined scarp is active. Faults that reach the surface or offset the shallowest stratum breaks in the subsurface are considered to have the potential to become active. Experience has shown that these criteria are appropriate throughout the outcrop

[6] Mastroiani, J. J. (1991), "A Study of Active Fault Movement, Houston, Texas and Vicinity," unpublished Master of Science Thesis, University of Houston, pp. 53 – 55.

of Pleistocene and younger deposits, regardless of whether there are any indications of activity in the past 10,000 years. The vertical movements of typical active faults averaged over many years range from less than 0.1 inch to slightly more than 1.0 inch per year. Horizontal movements are extensional and are thought to depend upon the dip of the fault. The most common dips should produce horizontal movements in the range of about one-sixth to one-third the vertical movement. The surface movements generally occur in a band of significant width, which is likely to be different for each fault and to vary along the length of a fault. Bandwidths of 30 ft to 50 ft are common, but wider or narrower bands are also found.

A map of surface faulting is shown on Plate 2 of this report. Based on our review, it appears that the locations of the North Recommended Alignment, Central Recommended Alignment (Coastal Spine), and South Recommended Alignment are not in proximity to known growth faults observed within the six-county region.

**2.5 Subsidence**

For much of the 1900's, groundwater was the principal source of water for municipal, domestic, and industrial demands throughout the Gulf Coastal Plains of Texas. By the 1930's, groundwater pumpage was sufficient to cause major drawdowns of groundwater levels in the artesian aquifers, particularly in the heavily industrialized areas near the Houston Ship Channel in Harris County, Texas. The reductions in groundwater pressures caused similar increases in the intergranular stresses in the aquifers, resulting in consolidation of the sediments and subsidence of the ground surface. Subsidence is the lowering of the ground surface in response to the drawdowns of the groundwater levels.

The State of Texas is divided into 14 groundwater management areas. One objective of the groundwater management areas is to control subsidence caused by withdrawal of water from groundwater reservoirs within Texas. The location of the six-county region is within Groundwater Management Area 14. This area has 2 subsidence districts: The Fort Bend Subsidence District and the Harris-Galveston Subsidence District. The subsidence area monitored by the Harris-Galveston Subsidence District (HGSD) is within the six-county region for this study.

The HGSD was form in 1975 by the Texas legislature. The district is currently monitoring subsidence several sites throughout 9 counties: Harris County, Galveston County, Brazoria County, Chambers County, Jefferson County, Montgomery County, Liberty County, Fort Bend County, and Waller County. Subsidence data from 1906-2000 was gathered by the district and the National Geodetic Survey (NGS) which reported subsidence in Harris County had reached up to 10 ft and in Galveston County up to 6 ft[7]. These values were observed in central Harris County, east Harris County, south Harris County, and on the mainland of Galveston County. By 2016, subsidence in Harris County and Galveston County had increased on the order of 3 inches, a modest increase reflective of the

[7] Harris Galveston Subsidence District, "Subsidence Contour Map 1906-2000", http://hgsubsidence.org

reductions in groundwater pumpage[8]. In addition, monitoring data at selected sites shows a cumulative subsidence on the order of 2 inches between 2002 and 2016 within Brazoria, Chambers, and Jefferson Counties. Based on our review of the HGSD subsidence observations, we do not anticipate significant subsidence in the future for the above-mentioned counties, if groundwater pumpage and oil and gas withdrawal are maintained at current levels.

### 2.6 Salt Domes

Salt domes are structures that form vertical stocks of crystalline rock salt (halite) within the subsurface. These structures are scattered throughout the Gulf Coastal Plains of Texas. The salt dome formation within the coast occurred in the basin where sedimentary rocks and deposits overlies the salt layer[9]. Salt domes provide underground storage facilities for natural resources such as petroleum, salt, and sulfur. However, ground surface structures can form when these natural resources are extracted from the subsurface. The growth of salt domes has caused numerous growth faults, fractures, and subsidence within the coast. Their growth is attributed to extraction of natural resources from the subsurface. The extraction of these natural resources creates localized cavities within the subsurface. In some cases, these cavities could collapse causing massive ground settlement. Based on previous studies, the growth rate of mature salt domes within the Gulf Coastal Plains of Texas have steadily declined to less than 0.1 mm per year[10].

A map of salt domes is shown on Plate 3 of this report. Based on our review, it appears that the portions of the North Recommended Alignment, Central Recommended Alignment (Coastal Spine), and South Recommended Alignment are in proximity to known salt domes observed within the six-county region.

### 2.7 Regional Seismicity

The Texas Gulf Coast is in a zone of relatively low seismicity, with very few earthquakes being reported in recorded history. We reviewed the seismic maps prepared by the United States Geological Survey (USGS) in conjunction with other agencies and organizations. The USGS seismic maps are time-dependent hazard maps that produce information on the occurrences of future earthquake activities. The seismic maps were developed based on extensive scientific research on past earthquakes which occurred over 100 years ago. The maps present earthquake ground-shaking levels for peak horizontal ground acceleration. Several seismic maps are presented on Plates B-1 through B-4 in Appendix B[11]. Based upon a review of the seismic site class definitions

[8] Harris Galveston Subsidence District, “Subsidence Monitor Charts”, http://hgsubsidence.org

[9] Hamlin, H.S., (2006), “Salt Domes in the Gulf Coast Aquifer”, Texas Water Development Board, Report 365: Aquifers of the Gulf Coast of Texas, p. 217-230.

[10] Seni, S.J. and Jackson, M.P.A., (1983a and 1983b), “Evolution of Salt Structures, East Texas Diapir Provinces”, American Association of Petroleum Geologists Bulletin, v. 67, no. 8, p. 1219-1247.

[11] International Building Code (2012), Chapter 16: Structural Design, Section 1613 Earthquake Loads.

and associated values, in accordance with *Section 1613 Earth Quake Loads* of the 2012 International Building Code, we have summarized the following information for the six-county region:

- **Soil Site Classification:** Class D (per Table 1613.5.2).
- **Maximum Considered Earthquake Ground Motion for 0.2 Second Spectral Response:** $S_s$=7% g. (per Figure 1613.5(1)). *Note that the value taken from Figure* 1613.5(1) *is based on Site Class B Classification and must be adjusted per Section 1613.5.3 for Site Class D.*
- **Maximum Considered Earthquake Ground Motion for 1.0 Second Spectral Response:** $S_1$=4% g. (per Figure 1613.5(2)). *Note that the value taken from the* per Figure 1613.5(2) *is based on Site Class B Classification and must be adjusted per Section 1613.5.3 for Site Class D.*

### 2.8 Expansive Soils

Expansive clay soils are commonly found in the near-surface stratigraphy throughout the Coastal Plain of Texas. These soils have a high potential for swelling and shrinking with seasonal fluctuations in moisture content. High shrink-swell potential was reported throughout the near-surface soils within the six-county region based on our review of the USDA SCS soil surveys.

The primary source of distress is generally soil movements associated with shrink-swell potential behavior of subgrade soils beneath roadway pavements, slabs-on-grade, foundations, and other structures. Our experience on previous projects throughout the Texas Gulf Coast has reported high shrink-swell behavior of the near-surface soils. Therefore, we generally recommend the following activities to mitigate the high shrink-swell behavior of the near-surface soils:

- Removal of at least the upper 2 ft of subgrade soil and replacing with structural clay fill or lime-stabilized clay fill prior to placement of structures.
- Removal and replacement activities should extend laterally at least 5 ft beyond the edges of the footprint of structures.
- Grade the site to provide positive drainage away from the structures. Water should not be allowed to pond adjacent to the structures.

### 2.9 Karst

Karst features are generally developed within the subsurface by the dissolution of carbonate rocks and minerals such as limestone, gypsum, and dolomite by groundwater. When drainage of the groundwater occurs, karst features are characterized by voids within the subsurface. Davies, et al.[12] reported karst features along West and Central Texas. Several geologists suggest that thick

[12] Davies, W. W., Simpson, J. H., Olmacher, G. C., Kirk, W. S., and Newton, E. G., (1984), “Engineering Aspects of Karst,” USGS.

limestone deposits were formed during the Permian period (last period of the Paleozoic Era) in West and Central Texas. Karst features are not common to the Gulf Coastal Plains of Texas.

### 2.10 Collapsible Soils

Collapsible soils are soils that experience significant volume change caused by wetting, external loading, or a combination of both. Collapsible soils are characterized by the following geotechnical engineering properties: high void ratio and porosity, low bulk density and water content, high dry density and stiffness, high percentage of fine-grained particles, and low plasticity[13]. These soils are generally associated with an open microstructure and experience brittle behavior during deformation. Collapsible soils can be compacted fill soils or natural soils such as aeolian deposits, alluvial deposits, colluvial deposits, residual deposits, and volcanic tuff. Loess, an aeolian deposit, is the most common soil that exhibits collapsible behavior during deformation. Loess is not common to the Coastal Plain of Texas.

[13] Howayek, A.E., Huang, P.T., Bisnett, R., Santagata, M.C. (2011), "Identification and Behavior of Collapsible Soils, Publication FHWA/IN/JTRP-2011/12, Joint Transportation Research Program, Indian Department of Transportation and Purdue University.

## 3.0 REVIEW OF EXISTING GEOTECHNICAL INFORMATION

The existing geotechnical information along the North Recommended Alignment, Central Recommended Alignment (Coastal Spine), and South Recommended Alignment for the Storm Surge Suppression Study was assembled and reviewed during the initial stage of our geotechnical study. The existing information was used to develop a GIS soil model to generate generalized subsurface profiles for identifying areas with data gaps. Fugro submitted an electronic database file to Dannenbaum for generating the GIS soil model. Several areas with data gaps were addressed by performing eight (8) geotechnical borings and 54 CPT soundings during our field investigation. In addition, laboratory testing was performed on select soil samples from the eight (8) geotechnical borings. Refer to Section 4.0 *Field Investigation* and Section 5.0 *Laboratory Testing* for more details.

This section provides an abridged listing of the existing geotechnical information that are located near or along the proposed alignments. The information presented herein were obtained from the public domain, including but not limited to the Gulf Coast Community Protection and Recovery District (GCCPRD), the Texas Department of Transportation (TxDOT), Port Freeport, US Army Corps of Engineers (USACE), Texas General Land Office (GLO), and Galveston County. Additional geotechnical information was obtained from Fugro's Project Library. A detailed listing of all the reviewed reference documents along the proposed alignments is presented on Plates C-1 through C-10 in Appendix C.

### 3.1 North Recommended Alignment

The reference documents below provided existing geotechnical information that are located near or along the alignment:

- Tolunay-Wong Report No. 59755 dated August 29, 2013, Geotechnical Engineering Study, HFPL System Evaluation, Jefferson County Drainage District No. 7, Jefferson County, Texas. GIS Naming Convention: HFPL System Evaluation – Jefferson County DD7 2013.
- Texas Department of Transportation Project No. NH 2003 (411) dated 1996-2001, Drilling Logs for the IH 10 Reconstruction from Neches River Bridge to West of Dewitt Road, Beaumont, Texas.
  GIS Naming Convention: 20-181-0028-09-237-254_AsBuilt_2006.
- US Corps of Engineers Drawing Nos. F-4 through F-6 dated 1973, Feasibility Study for Sabine Neches Waterway, Texas.
  GIS Naming Convention: Sabine Neches Waterway – Feasibility Study 1973.

### 3.2 Central Recommended Alignment (Coastal Spine)

The reference documents below provided existing geotechnical information that are located near or along the alignment:

- Tolunay-Wong Project No. 08.18.920 dated April 2008, Boring Logs for Galveston Channel and San Jacinto PA, Galveston, Texas.
  GIS Naming Convention: Galveston Channel and San Jacinto PA.
- Fugro Report No. 0415-0851 dated June 10, 2003, Geotechnical Study for Solids Handling Building Placement, City of Galveston, Galveston, Texas.
  GIS Naming Convention: GALVESTON COUNTY – Solids Handling Building.
- Gulf Coast Coring Project No. C 367-9-1 dated October 1987, Drilling Logs for State Highway No. 168, Control No. 0367-09-001, Galveston, Texas.
  GIS Naming Convention: SH 168 Galveston County.
- US Army Corps of Engineers File No. GALV. 313-69 dated July 1986, Locations and Logs of Borings (Plates 12 and 13) for Clear Creek, Texas, Flood Control, Second Outlet. GIS Naming Convention: Clear Lake 2nd Outlet-1987.
- McBride-Ratcliff and Associates File No. 85-345 dated October 9, 1985, Geotechnical Investigation, Clear Lake Second Outlet Channel, Clear Lake City, Texas.
  GIS Naming Convention: RR Bridge and Pline Crossing Clear Lake 2$^{nd}$ Outlet Channel - 1985.
- McBride-Ratcliff and Associates File No. 84-583 dated March 14, 1985, Geotechnical Investigation, Railroad Bridge and Pipeline Crossing, Clear Lake Second Outlet Channel, Clear Lake City, Texas.
  GIS Naming Convention: Clear Lake Second Outlet Channel - 1985.
- McBride-Ratcliff and Associates File No. 82-430 dated December 6, 1982, Geotechnical Investigation, Feasibility Study of Proposed Second Outlet for Clear Lake, Houston, Texas. GIS Naming Convention: Feasibility Study – 2nd Outlet for Clear Lake - 1982.
- Frank G. Bryant & Associates Job No. 3633 dated May 1979, Subsurface Exploration Logs for the Baytown High Level Bridge.
  GIS Naming Convention: TX146 at Houston Ship Channel-1980.
- US Army Corps of Engineers drawing dated January 27, 1972, Soil Plan and Profile for Texas Coast Hurricane Study, Galveston Entrance, Channel Structure.
  GIS Naming Convention: Galveston Entrance Channel 1972.
- The County of Galveston, Galveston, Texas sheets dated September 14, 1964, Boring Logs (Sheet Nos. 22 through 24) for San Luis Pass Bridge.
  GIS Naming Convention: San Luis Pass Bridge.
- US Army Corps of Engineers File No. GALV. 305-129 dated December 1959, Boring Layout and Soil Profile (Sta. 129+00 to 163+00) for Galveston Harbor and Channel, Galveston, Texas, Seawall Extension.
  GIS Naming Convention: Geotech Seawall EXT 1959 II.

- US Army Corps of Engineers File No. GALV. 305-127 dated December 1958, Boring Layout and Soil Profile for Galveston Harbor and Channel, Galveston, Texas, Seawall Extension. GIS Naming Convention: Geotech Seawall EXT 1958 II.
- Greer and McClelland Report dated August 21, 1952, Foundation Investigation for Piers 39, 40, & 41 – Galveston Wharves, Galveston, Texas.
  GIS Naming Convention: GALVESTON WHARVES – Piers 39, 40, & 41.
- US Army Corps of Engineers File No. GALV. 305-123 dated February 1951, Foundation Borings (Sta. 0+00 to 35+00 and Sta. 35+00 to 70+00) for Galveston Harbor and Channel, Galveston, Texas, Seawall Extension.
  GIS Naming Convention: Sewall Extension Plans-1951.
- US Army Corps of Engineers File No. I.W.W. 1101-85 dated January 1943, Cross Sections and Borings (Sheet Nos. 1 through 15), Louisiana and Texas, Intracoastal Waterway, Highland to Port Bolivar, Dredging, Galveston, Texas.
  GIS Naming Convention: High Island to Pt. Bolivar.

### 3.3 South Recommended Alignment

The reference documents below provided existing geotechnical information that are located near or along the alignment:

- PSI Report No. 291-601 dated March 24, 2013, Geotechnical Evaluation Report No. II – Old River North Levee, Freeport Hurricane Storm Levee Protection System, Freeport, Texas. GIS Naming Convention: 291-106_evaluation_report_orn.
- PSI Report No. 0291-100-2 – Volume 5 dated July 7, 2011, Geotechnical Evaluation Report for Freeport Hurricane Storm Levee Protection System, Brazoria County, Texas.
  GIS Naming Convention: PSI Report Volume 5 (ES, OC, EOC).
- PSI Report No. 0291-100-2 – Volume 4 dated July 7, 2011, Geotechnical Evaluation Report for Freeport Hurricane Storm Levee Protection System, Brazoria County, Texas.
  GIS Naming Convention: PSI Report Volume 4 (DBCN, DBCS, DTB).
- PSI Report No. 0291-100-2 – Volume 3 dated July 7, 2011, Geotechnical Evaluation Report for Freeport Hurricane Storm Levee Protection System, Brazoria County, Texas.
  GIS Naming Convention: PSI Report Volume 3 (ORN, ORS, NWB, SWB).
- PSI Report No. 0291-100-2 – Volume 2 dated July 7, 2011, Geotechnical Evaluation Report for Freeport Hurricane Storm Levee Protection System, Brazoria County, Texas.
  GIS Naming Convention: PSI Report Volume 2 (EBO, EBT, CB, SS).
- Drilling Logs dated November 1965 and June 1966, Brazos River Compression Study. GIS Naming Convention: Brazos River Comprehensive Study.

## 4.0 FIELD INVESTIGATION

Our field exploration activities for the geotechnical study are discussed in this section. We have included discussions relating to drilling methods, sampling methods, depth-to-water observations, cone penetration tests (CPT), and borehole/CPT completion.

### 4.1 General

We developed the field exploration program prior to initiating our field activities. The soil boring and CPT sounding locations were selected, marked, and staked in the field by Fugro at the proposed segments along the Central Recommended Alignment (Coastal Spine) and South Recommended Alignment. <u>Due to anticipated difficulty of obtaining access permits to locations along the North Recommended Alignment, field exploration was not planned along the North Recommended Alignment at this phase of the study.</u> The approximate soil boring and CPT sounding locations are shown on the *Plan of Explorations* on Plates 4a and 4b.

A total of eight (8) geotechnical soil borings, designated BH-01 through BH-08 were drilled between April 19 and May 12, 2017. Among the soil borings, six (6) of the soil borings, designated BH-01 and BH-04 through BH-08, were drilled to the termination depth of 50 ft and two (2) of the soil borings, designated BH-02 and BH-03, were drilled to the termination depth of 400 ft below existing grade. The soil boring ID, GPS coordinates, alignment name, and associated proposed structure description are summarized in Table 4-1.

**Table 4-1. Summary of Soil Borings**

<table>
<tr><th rowspan="2">Alignment Name</th><th rowspan="2">Proposed Structure Description</th><th rowspan="2">Boring ID</th><th rowspan="2">Depth (ft)</th><th colspan="2">GPS Coordinates</th></tr>
<tr><th>Northing</th><th>Easting</th></tr>
<tr><td rowspan="5">Central Recommended Alignment (Coastal Spine)</td><td rowspan="5">High Island to San Luis Pass Coastal Spine with Galveston Ring Levee</td><td>BH-01</td><td>50</td><td>29°26'36.66"</td><td>94°39'56.52"</td></tr>
<tr><td>BH-02</td><td>400</td><td>29°21'49.24"</td><td>94°45'31.77"</td></tr>
<tr><td>BH-03</td><td>400</td><td>29°20'02.72"</td><td>94°45'21.14"</td></tr>
<tr><td>BH-04</td><td>50</td><td>29°15'25.58"</td><td>94°52'30.35"</td></tr>
<tr><td>BH-05</td><td>50</td><td>29°10'23.95"</td><td>94°59'42.43"</td></tr>
<tr><td rowspan="3">South Recommended Alignment</td><td>GCCPRD Alternative Route East of Plants, Proposed</td><td>BH-06</td><td>50</td><td>29°11'24.28"</td><td>95°23'04.83"</td></tr>
<tr><td rowspan="2">Reach 3, Jones Creek Levee</td><td>BH-07</td><td>50</td><td>28°58'38.12"</td><td>95°31'32.18"</td></tr>
<tr><td>BH-08</td><td>50</td><td>28°58'14.14"</td><td>95°26'24.91"</td></tr>
</table>

In addition, a total of fifty-four (54) CPT soundings, designated CPT-01 through CPT-03 and CPT-05 through CPT-55, were performed to a maximum depth of approximately 60 ft below existing grade between May 3 and May 17, 2017. CPT-04 was canceled due to difficulty in accessing the location. The CPT sounding ID, GPS coordinates, alignment name, and associated structure description are summarized in Table 4-2.

**Table 4-2. Summary of CPT Soundings**

| Alignment Designation | Proposed Structure Description | Sounding ID | Approximate Depth (ft) | GPS Coordinates | |
|---|---|---|---|---|---|
| | | | | Northing | Easting |
| Central Recommended Alignment (Coastal Spine) | High Island to San Luis Pass Coastal Spine with Galveston Ring Levee | CPT-01 | 61 | 29°33'05.80" | 94°23'20.47" |
| | | CPT-02 | 60 | 29°32'39.03" | 94°24'14.77" |
| | | CPT-03 | 60 | 29°32'17.61" | 94°25'09.86" |
| | | CPT-04 | NA | NA | NA |
| | | CPT-05 | 60 | 29°31'37.71" | 94°26'57.20" |
| | | CPT-06 | 60 | 29°31'15.32" | 94°27'58.51" |
| | | CPT-07 | 60 | 29°30'54.23" | 94°28'56.47" |
| | | CPT-08 | 60 | 29°30'04.02" | 94°31'10.60" |
| | | CPT-09 | 60 | 29°29'42.97" | 94°32'11.10" |
| | | CPT-10 | 60 | 29°29'22.61" | 94°33'06.77" |
| | | CPT-11 | 60 | 29°28'57.54" | 94°34'15.34" |
| | | CPT-12 | 60 | 29°28'35.22" | 94°35'14.61" |
| | | CPT-13 | 60 | 29°28'14.86" | 94°36'11.90" |
| | | CPT-14 | 60 | 29°27'55.10" | 94°37'06.21" |
| | | CPT-15 | 60 | 29°27'33.32" | 94°38'05.60" |
| | | CPT-16 | 60 | 29°27'03.74" | 94°39'05.03" |
| | | CPT-17 | 60 | 29°26'04.63" | 94°40'46.27" |
| | | CPT-18 | 60 | 29°25'35.84" | 94°41'35.50" |
| | | CPT-19 | 60 | 29°25'05.71" | 94°42'26.22" |
| | | CPT-20 | 60 | 29°24'23.24" | 94°43'09.85" |
| | | CPT-21 | 60 | 29°23'33.33" | 94°43'51.16" |

**Table 4-2. Summary of CPT Sounding Locations (Continued)**

| Alignment Designation | Structure Description | Sounding ID | Approximate Depth (ft) | GPS Coordinates | |
|---|---|---|---|---|---|
| | | | | Northing | Easting |
| Central Recommended Alignment (Coastal Spine) | High Island to San Luis Pass Coastal Spine with Galveston Ring Levee | CPT-22 | 60 | 29°22'56.95" | 94°44'34.35" |
| | | CPT-23 | 60 | 29°22'25.38" | 94°45'12.32" |
| | | CPT-24 | 60 | 29°14'33.70" | 94°52'21.68" |
| | | CPT-25 | 60 | 29°13'59.65" | 94°53'32.30" |
| | | CPT-26 | 60 | 29°13'21.17" | 94°54'22.09" |
| | | CPT-27 | 60 | 29°13'04.06" | 94°54'57.01" |
| | | CPT-28 | 60 | 29°12'43.40" | 94°55'40.83" |
| | | CPT-29 | 60 | 29°12'18.55" | 94°56'35.81" |
| | | CPT-30 | 60 | 29°11'45.18" | 94°57'22.06" |
| | | CPT-31 | 60 | 29°10'59.76" | 94°58'21.03" |
| | | CPT-32 | 60 | 29°09'34.17" | 95°00'41.89" |
| | | CPT-33 | 60 | 29°08'52.87" | 95°01'47.92" |
| | | CPT-34 | 60 | 29°08'22.59" | 95°02'33.69" |
| | | CPT-35 | 60 | 29°07'54.78" | 95°03'17.35" |
| | | CPT-36 | 60 | 29°07'24.33" | 95°04'03.32" |
| | | CPT-37 | 60 | 29°06'47.12" | 95°04'56.79" |
| | | CPT-38 | 60 | 29°06'25.08" | 95°05'44.22" |
| | | CPT-39 | 60 | 29°05'37.20" | 95°06'34.87" |

**Table 4-2. Summary of CPT Sounding Locations (Continued)**

| Alignment Designation | Structure Description | Sounding ID | Approximate Depth (ft) | GPS Coordinates | |
|---|---|---|---|---|---|
| | | | | Northing | Easting |
| South Recommended Alignment | GCCPRD Alternative Route East of Plants, Proposed | CPT-40 | 60 | 29°10'27.86" | 95°23'30.50" |
| | | CPT-41 | 60 | 29°09'34.20" | 95°23'28.24" |
| | | CPT-42 | 60 | 29°08'39.04" | 95°23'40.30" |
| | | CPT-43 | 60 | 29°07'48.79" | 95°23'24.63" |
| | | CPT-44 | 60 | 29°07'10.92" | 95°22'52.96" |
| | | CPT-45 | 60 | 29°06'24.81" | 95°22'18.49" |
| | | CPT-46 | 60 | 29°05'20.99" | 95°22'04.97" |
| | | CPT-47 | 60 | 29°04'40.66" | 95°21'50.12" |
| | | CPT-48 | 60 | 29°03'52.25" | 95°21'03.09" |
| | GCCPRD South End of Alternative Route, Proposed | CPT-49 | 60 | 29°03'09.91" | 95°20'06.77" |
| | | CPT-50 | 60 | 29°02'19.51" | 95°20'02.40" |
| | | CPT-51 | 62 | 29°01'19.84" | 95°19'42.90" |
| | Reach 3, Jones Creek Levee and Reach 4, Tank Farm Levee | CPT-52 | 60 | 28°59'07.26" | 95°29'44.47" |
| | | CPT-53 | 60 | 28°59'06.09" | 95°28'07.58" |
| | | CPT-54 | 60 | 28°58'02.83" | 95°27'36.17" |
| | | CPT-55 | 60 | 28°58'05.17" | 95°29'47.60" |

Detailed description of the soils encountered in the soil borings drilled for this study are presented in the boring logs shown on Plates D-1 through D-8 in Appendix D. A key to the terms and symbols used on the boring logs is presented on Plates D-9a and D-9b. CPT logs and associated shear strength correlation results for this project are presented on Plates E-1 through E-3 and E-5 through E-55 in Appendix E. CPT-04 was canceled due to difficulty in accessing the location.

## 4.2 Drilling Methods

The borings were drilled with our truck-mounted drilling rigs using a combination of dry-auger and wet-rotary drilling techniques. All borings were initially drilled using dry-auger techniques in an effort to identify the short-term depth-to-water conditions. When free water was encountered, or as required due to caving and weak soil conditions, the borings were advanced to their completion depths using wet-rotary techniques. Additional information relating to the applicable drilling methods for each boring is presented on the boring logs on Plates D-1 through D-8 in Appendix D.

## 4.3 Soil Sampling Methods

Soil samples were generally taken at about 2-ft intervals to a depth of 10 ft below existing grade, at 5-ft intervals to a depth of 100 ft, and at 10-ft intervals thereafter to the completion depth of the borings. Soil samples were generally obtained following the procedures described below. Detailed descriptions of the soils encountered are presented on the boring logs presented on Plates D-1 through D-8 in Appendix D.

Undisturbed samples of cohesive soils were generally obtained by hydraulically pushing a 3-inch diameter, thin-walled tube sampler a distance of about 24 inches. Our field procedure for sampling cohesive soils was conducted in general accordance with ASTM D1587 (*Standard Practice for Thin-Walled Tube Sampling of Soils for Geotechnical Purposes*). These samples were extruded in the field and visually classified by our field technicians. We obtained field estimates of the undrained shear strength of the recovered cohesive samples using a pocket penetrometer. Portions of each recovered soil sample were packaged and transported to our laboratory for testing.

Granular soil samples were generally obtained using the Standard Penetration Test (SPT) as described on Plate D-9b. Our field procedure for granular soil sampling was in general accordance with the *Standard Method for Penetration Test and Split-Barrel Sampling of Soils* (ASTM D1586). This testing was performed with 140-lb, automatic hammers with a drop height of 2.5 ft. Our technicians recorded the hammer blows for each 6-inch sampling interval. The N-value, as described on Plate D-9b, is recorded on each boring log. Soil samples obtained with the split-barrel sampler were visually classified and placed in plastic bags for transportation to our laboratory.

## 4.4 Depth-to-Water Measurements

All borings performed for this study were initially drilled employing the dry-auger technique in an effort to identify the depth-to-water. Once water was encountered, drilling was temporarily halted and depth-to-water measurements in the open boreholes were recorded. Additional observations were generally made and recorded at about 5-minute intervals for about 10 to 15 minutes. Drilling was then resumed to the boring completion depths using wet-rotary drilling techniques. Depth-to-water measurements are noted on the boring logs on Plates D-1 through D-8 in Appendix D. Further discussion on our depth-to-water observations is presented later in the 6.0 *General Site Conditions* Section of this report.

### 4.5 Cone Penetration Tests

The CPTs for this project were conducted using our truck mounted CPT rig. A CPT unit utilizes the self-weight of the equipment to push a cylindrical steel probe into the ground. We obtained CPT data by pushing a series of cylindrical rods, with an instrumented probe at the base, into the soil at a constant rate. The probe consists of a piezocone tip element and a side-friction sleeve element. Continuous measurements of penetration resistance at the cone tip, friction along the friction sleeve, and pore water pressure were recorded during the penetration tests. During testing, the results were saved electronically for further data reduction in our office. CPT logs and associated shear strength correlation results for this project are presented on Plates E-1 through E-3 and E-5 through E-55 in Appendix E. CPT-04 was canceled due to difficulty in accessing the location.

### 4.6 Borehole/CPT Completion

Borings/CPTs drilled for this study were backfilled with cement-bentonite grout upon completion. The boreholes/CPTs were grouted from the bottom up using a tremie pipe. When grout returned to the surface, the tremie pipe was removed and the boreholes were topped-off by pouring grout from the surface.

## 5.0 LABORATORY TESTING

The laboratory testing program for this geotechnical study was directed towards evaluating the classification properties, undrained shear strength, compressibility, and dispersive nature of the subsurface cohesive soils. Our laboratory tests were performed in general accordance with the appropriate ASTM standards as presented at the end of this section.

### 5.1 Classification Tests

The classification tests included tests for natural water content, liquid and plastic limits (collectively termed Atterberg limits), and material finer than the No. 200 sieve (percent fines). These tests aid in classifying the soils and are used to correlate the results of other tests performed on samples taken from different borings and/or different depths. Results of these classification tests are recorded on the boring logs in Appendix D.

### 5.2 Shear Strength of Cohesive Soils

The undrained shear strength of selected undisturbed samples of cohesive soils by performing unconfined compression and unconsolidated-undrained triaxial compression tests. The natural water content and dry unit weights were determined as routine parts of the shear strength tests. The results of the laboratory shear strength tests are presented on the boring logs on Plates D-1 through D-8 in Appendix D.

### 5.3 Soil Compressibility Tests

One-dimensional, incrementally-loaded consolidation tests were performed on selected samples to obtain the compressibility characteristics of the cohesive subsurface soils. Each consolidation test underwent a rebound-reload cycle. Natural moisture content and dry unit weight were determined as routine portions of the consolidation tests. The results of the consolidation tests are presented on Plates F-1 through F-8 in Appendix F.

### 5.4 Dispersive Clay Testing

Most clayey soils are moderately to highly resistant to erosion by water. To a large extent, this is due to the surface chemistry of the clay particles, causing them to be attracted to each other in the presence of water. However, some clayey soils have the tendency for individual particles to repel each other in the presence of water. Particles of these clayey soils, when exposed to freshwater, have a tendency to go into suspension in the water by a process called “dispersion.” Such clayey soils are collectively called “dispersive clays.”

To determine the presence of dispersive soils for this project, we performed crumb dispersion tests on select recovered soil samples. We generally selected a representative sample within the upper 35 ft depth below existing ground surface in borings BH-01 and BH-05 through BH-09 explored for this study.

The crumb dispersion tests provide a qualitative indication of the natural dispersion characteristics of clayey soils. This test method consists of placing a crumb of natural soil approximately the size of a cube with 15 mm sides on the bottom of a white porcelain dish containing 250 mL of distilled water. Visual determinations of the dispersion grade are made and recorded at various times. Determination of grade is based on the formation, extent, and turbidity of a dense "cloud" or halo of colloidal-sized particles extending from the soil crumb. Table 5-1 presents general guidelines for estimating the dispersive potential from crumb test results per the requirements of ASTM D6572.

**Table 5-1. General Guidelines for Crumb Tests (ASTM D6572)**

| Dispersive Classification | Reaction | Description |
|---|---|---|
| Grade 1 | Nondispersive | No reaction; the soil may crumble, slake, diffuse, and spread out, but there is no turbid water created by colloids suspended in the water. All particles settle during the first hour. |
| Grade 2 | Intermediate | Slight reaction; this is the transition grade. A faint, barely visible colloidal suspension causes turbid water near portions of the soil crumb surface or all around the surface. If the cloud is easily visible, assign Grade 3. If the cloud is faintly seen in only one small area, assign Grade 1. |
| Grade 3 | Dispersive | Moderate reaction; an easily visible cloud of suspended clay colloids is seen around all of the outside soil crumb surface. The cloud may extend up to 10 mm (3/4 in.) away from the soil crumb mass along the bottom of the dish. |
| Grade 4 | Highly Dispersive | Strong reaction; a dense, profuse cloud of suspended clay colloids is seen around the entire bottom of the dish. Occasionally, the soil crumb dispersion is so extensive that it is difficult to determine the interface of the original soil crumb and the colloidal suspension. Often, the colloidal suspension is easily visible on the sides of the dish. |

The results of the crumb dispersion tests performed on three representative soil samples are presented in Table 5-2. The samples were tested and classified using the ASTM D6572-Method A procedure. The results of the crumb tests suggest that the soils are dispersive in nature. We intend to perform pinhole dispersion tests, which presents a qualitative measurement of the dispersiveness of clayey soils, during the detailed design of this study.

**Table 5-2. Summary of Crumb Test Results**

| Boring No. | Depth (ft) | Soil Sample Material Description | Test Grade | | |
|---|---|---|---|---|---|
| | | | At 2 min. | At 60 min. | At 360 min. |
| BH-01 | 20 | Sandy Clay, olive gray, with shell fragments | 1 | 1 | 1 |
| BH-01 | 34 | Sandy Clay, olive gray | 1 | 4 | 4 |
| BH-05 | 29 | Sandy Clay, greenish gray, with shell fragments | 1 | 2 | 4 |
| BH-06 | 5 | Clay, gray, with calcareous nodules | 1 | 1 | 1 |
| BH-06 | 14 | Clay, tan and gay, with calcareous nodules | 2 | 3 | 4 |
| BH-07 | 7 | Silty Clay, red | 4 | 4 | 4 |
| BH-07 | 19 | Clay, brown and gray, with calcareous nodules | 1 | 1 | 1 |
| BH-08 | 2 | Clay, dark gray, with shell fragments and gravel | 1 | 1 | 1 |
| BH-08 | 9 | Clay, dark gray and brown | 1 | 4 | 4 |

### 5.5 Summary of Laboratory Tests

Table 5-3 summarizes the types and number of laboratory tests as well as the test standards performed for this study.

**Table 5-3. Summary of Laboratory Testing Program**

| Laboratory Test | Quantity | Test Method |
|---|---|---|
| Moisture Content | 28 | ASTM D2216 |
| Atterberg Limit | 42 | ASTM D4318 |
| Percent Passing No. 200 Sieve | 46 | ASTM D1140 |
| Dry Unit Weight | 25 | ASTM D7263 |
| Unconfined Compression | 6 | ASTM D2166 |
| Unconsolidated-Undrained Triaxial Compression | 19 | ASTM D2850 |
| One-Dimensional Consolidation (CRS) | 7 | ASTM D4186 |
| Crumb Dispersion | 9 | ASTM D6572 |

## 6.0 GENERAL SITE CONDITIONS

Our focus for this geotechnical study pertains to the Central Recommended Alignment (Coastal Spine) and South Recommended Alignment with actual geotechnical soil borings and Cone-Penetrometer Tests (CPTs). An *Overall Site Map* showing the approximate proposed structures and levee layout is presented on Plates 1a through 1d and a layout of the Central Recommended Alignment (Coastal Spine) and South Recommended Alignment is presented on the *Plan of Explorations* on Plates 4a and 4b. Our soil boring and CPT locations corresponding to the proposed structures and levee layout were also summarized in Tables 4-1 and 4-2 of this report. As mentioned earlier, due to anticipated difficulty of obtaining access permits to locations along the North Recommended Alignment, field exploration was not planned along the North Recommended Alignment at this phase of the study. Therefore, this section does not include information on general site conditions for the North Recommended Alignment.

### 6.1 Subsurface Conditions

The generalized subsurface conditions are based on the review of available geotechnical information from the public domain, Fugro's Project Library, and actual field exploration and laboratory testing conducted for this phase of the project. Schematics of the general stratigraphy along the Central Recommended Alignment (Coastal Spine) and South Recommended Alignment are presented on the *Generalized Subsurface Profiles* on Plates 5a through 5e.

Additional information of the subsurface conditions encountered during our studies is presented on the boring logs on Plates D-1 through D-8 in Appendix D and the CPT logs on Plates E-1 through E-3 and Plates E-5 through E-55 in Appendix E of this report. CPT-04 was canceled due to difficulty in accessing the location.

#### 6.1.1 Central Recommended Alignment (Coastal Spine) – Bolivar Peninsula

This alignment starts from the intersection of Highway 124 and Highway 87 and spans southwestward along the peninsula's long axis for about 25 miles and ends at the southwestern tip of the peninsula. The subsurface conditions presented in this subsection are based on the actual field investigation and results from associated laboratory tests conducted on soil samples from the borings drilled along this alignment. Our interpretation of the soil stratigraphy observed in soil borings BH-01 and BH-0-2 and CPT soundings CPT-01 through CPT-03 and CPT-05 through CPT-23 is summarized below. CPT-04 was canceled due to difficulty in accessing the location. The *Generalized Subsurface Profile Section A-A'* is shown on Plate 5a.

Stratum I: In general, granular soils were encountered from existing grade to a depth of about 3 ft on the northeastern end and from existing grade to a depth of about 20 ft on the southwestern tip along the long axis of the peninsula. The granular soils consist of sands, silty sands, sandy silts, and clayey sands. Based on our interpretation, loose to medium dense granular soils were primarily observed in this stratum and increased gradually in thickness from CPT-09, CPT-10, CPT-14 to CPT-23, BH-01 and BH-02. SPT N-values ranged from 6 to 24 blows per ft, indicating loose to medium dense in situ relative density of the granular soil. Isolated clay pockets with correlated undrained shear strength less than 250 psf (very soft) were encountered in some CPT locations.

Stratum II: Natural cohesive soils with interbedded sand layers are encountered below Stratum I to a depth of about 60 ft below existing grade. The cohesive soils typically consisted of clays with shell fragments and sand seams. The undrained shear strength of the cohesive materials, obtained from field and laboratory testing and CPT empirical correlations, generally ranged from about 250 psf (very soft) to greater than 2,000 psf (very stiff). The Atterberg Limits testing indicated measured liquid limits ranging from about 72 to 76 percent and plastic limits ranging from about 15 to 21 percent, resulting in calculated plasticity indices ranging from about 55 to 57 percent. The measured natural water content of the cohesive soils was approximately 28 percent.

Soil boring BH-02 was explored to a maximum depth of 400 ft below existing grade. Alternating layers of granular soils and cohesive soils were encountered below a depth of 47 ft. Granular soils were encountered at a depth of 47 ft and extends to 78 ft. The granular soils consisted of medium dense sands. The SPT N-values of the sands primarily ranged from 13 to 21 blows per ft at depths between 47 ft to 73.5 ft. However, a SPT N-value of 9 blows per ft was encountered at depths between 73.5 ft to 78 ft. Firm to very stiff cohesive soils were encountered at a depth of 78 ft and extends to about 93.5 ft. The undrained shear strength of clays, obtained from field and laboratory testing, generally ranged from 550 psf (firm) to greater than 2,000 psf (very stiff). The Atterberg Limits testing indicated measured liquid limit of 57 percent and plastic limit of 14 percent, resulting in the calculated plasticity index of 43. The measured natural water content of the clays was approximately 21 percent. Granular soils were encountered at a depth of 93.5 ft and extends to a depth of about 108 ft. These granular soils consisted of medium dense to dense sands. The SPT N-values of these sands ranged from 30 to 35 blows per ft. Stiff to very stiff cohesive soils consisting of sandy clays and clays with sand and silt seams are encountered at a depth of 108 ft and extends to about 400 ft. These cohesive soils consisted of sandy clays and clays. The undrained shear strength of the sandy clays and clays ranged from about 1,000 psf (stiff) to greater than 2,000 psf (very stiff). The Atterberg Limits testing indicated measured liquid limits ranging from 24 to 88 percent and plastic limits ranging from 13 to 24 percent, resulting in the calculated plasticity indices ranging from 9 to 64 percent. The measured natural water contents of the sandy clays and clays ranged from 20 to 34 percent.

Detailed descriptions of the subsurface conditions encountered in the borings BH-03 and BH-04 drilled and the CPT soundings CPT-24 through CPT 39 performed along this alignment are presented on the boring logs in Appendix D and the CPT logs in Appendix E of this report. The generalized subsurface cross section and associated subsurface shear strength profile are presented on Plate 5a and Plate 6a of this report, respectively.

### 6.1.2 Central Recommended Alignment (Coastal Spine) – Galveston Island

This alignment starts from the northern end of Highway 3005 and spans southwestward along the island's long axis for about 20 miles and ends at the southern tip of the island (i.e., where the road changes to Highway 257). The subsurface conditions presented in this subsection are based on actual field investigation and results from associated laboratory tests conducted on soil samples from the borings drilled along the alignment. Our interpretation of the soil stratigraphy observed in soil borings BH-03 through BH-05 and CPT sounding CPT-24 through CPT-39 is summarized below. The *Generalized Subsurface Profile Section B-B'* is shown on Plate 5b.

Stratum I: In general, granular soils were encountered from existing grade to a depth about 38 ft on the northeastern end and from existing grade to a depth of about 20 ft on the southwestern end of the island along the long axis of the island. The granular soils consist of sands, silty sands, sandy silts, and clayey sands. Based on our interpretation, very loose to medium dense granular soils were primarily observed in this stratum. SPT N-values ranged from 1 to 22 blows per ft, indicating very loose to medium dense granular soil.

Stratum Ia: Natural cohesive soils were encountered between CPT-35 and CPT-39 from a depth of about 8 ft and extending to about 16 ft. The undrained shear strength of the cohesive soils, obtained primarily from CPT empirical correlations, generally ranged from 250 psf (very soft) to 1,200 psf (stiff).

Stratum II: Natural cohesive soils with interbedded granular sand layers were encountered below Stratum I to a depth of about 60 ft below existing grade. The cohesive soils typically consisted of clays with shell fragments, calcareous nodules, sand seams, and sand pockets. The undrained shear strength of the cohesive materials, obtained primarily from field and laboratory testing and CPT empirical correlations, generally ranged from 250 psf (very soft) to greater than 2,000 psf (very stiff).

Soil boring BH-03 was explored to a maximum depth of 400 ft below existing grade. Cohesive soils with sand seams were encountered from a depth of 60 ft and extending to about 120 ft. The undrained shear strength of the clays generally ranged from about 500 psf (firm) to 1,900 psf (stiff). The Atterberg Limits testing indicated measured liquid limits ranging from 60 to 95 percent and plastic limits ranging from 16 to 21 percent, resulting in the calculated plasticity indices ranging from 44 to 74 percent. The measured natural water contents of the clays ranged from about 28 to 56 percent. Medium dense to very dense granular soils were encountered beneath the clays. The granular soils consisted of silty sands and sands and were encountered from a depth of 120 ft and extends to about 198 ft. The SPT N-values of the sands primarily ranged from 28 to greater than 50 blows per ft at depths between 120 ft to 178 ft. However, loose to medium dense silty sands with SPT N-values ranging from 10 to 28 blows per ft were encountered at between depths of 178 ft to 198 ft. Stiff to very stiff cohesive soils were encountered beneath the loose to medium dense silty sands from a depth of 198 ft and extending to about 400 ft. These cohesive soils cohesive primarily of clays. The undrained shear strength of the clays generally ranged from about 1,200 psf (stiff) to greater than

2,000 psf (very stiff). The Atterberg Limits testing indicated measured liquid limits ranging from 30 to 87 percent and plastic limits ranging from 12 to 21 percent, resulting in the calculated plasticity indices ranging from 17 to 68 percent. The measured natural water contents of the clays range from about 19 to 37 percent.

Detailed descriptions of the subsurface conditions encountered in the borings drilled and the CPTs performed along this segment are presented on the boring logs in Appendix D and the CPT logs in Appendix E of this report. The generalized subsurface cross section and associated subsurface shear strength profile are presented on Plate 5b and Plate 6b of this report, respectively.

### 6.1.3 South Recommended Alignment – East of Plants

This alignment starts from the intersection of Highway 171 and Highway 523 and spans southward along Highway 523 for about 13 miles and ends at the intersection of Highway 523 and Highway 792. The subsurface conditions presented in this subsection are based on actual field investigation and results from associated laboratory tests conducted on soil samples from the borings drilled along the segment. Our interpretation of the soil stratigraphy observed in the soil boring BH-06 and CPT soundings CPT-40 through CPT-51 is summarized below. The *Generalized Subsurface Profile Section C-C'* is shown on Plate 5c.

Stratum I: Natural cohesive soils were primarily encountered from existing grade to the maximum exploration depth of about 60 ft. The cohesive soils typically consisted of clays with shell fragments, calcareous nodules, sand seams, sand pockets, and slickensides. The undrained shear strength of the cohesive materials, obtained primarily from field and laboratory testing and CPT empirical correlations, generally ranged from about 250 psf (very soft) to greater than 2000 psf (very stiff). The Atterberg Limits testing indicated measured liquid limits ranging from about 52 to 81 percent and plastic limits ranging from about 13 to 21 percent, resulting in calculated plasticity indices ranging from about 39 to 60 percent. The measured natural water contents of the cohesive soils were about 22 percent to 35 percent. It should be noted that quite a few isolated sand layers of varying thickness were encountered between depths of about 20 ft and 60 ft below existing grade.

Detailed descriptions of the subsurface conditions encountered in the borings drilled and the CPTs performed along this segment are presented on the boring logs in Appendix D and the CPT logs in Appendix E of this report. The generalized subsurface cross section and associated subsurface shear strength profile are presented on Plate 5c and Plate 6c of this report, respectively.

### 6.1.4 South Recommended Alignment – Jones Creek Levee and Buffalo Camp System

This alignment starts from south of the intersection of Highway 2004 and Highway 36 and spans eastward for about 5 miles and ends at the approximate end of Stephen F. Austin Street. The subsurface conditions presented in this subsection are based on actual field investigation and results from associated laboratory tests conducted on soil samples from the borings drilled along the segment. Our interpretation of the soil stratigraphy observed in soil borings BH-07 and BH-08 and

CPT soundings CPT-52 through CPT-55 is summarized below. The *Generalized Subsurface Profile Section D-D'* is shown on Plate 5d.

Stratum I: Natural cohesive soils were primarily encountered at grade to a depth of about 30 ft below existing grade. The cohesive soils typically consisted of clays with shell fragments, calcareous nodules, ferrous nodules, sand seams, and sand pockets. The undrained shear strength of the cohesive materials, obtained primarily from field and laboratory testing and CPT empirical correlations, generally ranged from about 350 psf (soft) to greater than 2000 psf (very stiff). The Atterberg Limits testing indicated measured liquid limits ranging from about 42 to 94 percent and plastic limits ranging from about 12 to 24 percent, resulting in calculated plasticity indices ranging from about 28 to 70 percent. The measured natural water contents of the cohesive soils were about 22 to 38 percent. It should be noted that a sandy fill layer of about 2 ft to 3 ft in thickness was generally encountered at grade.

Stratum II: In general, granular soils were encountered beneath Stratum I from a depth of about 30 ft and extends to 60 ft below grade. The granular soils consist of sand, silty sand, sandy silt, and clayey sand. Based on our interpretation, medium dense granular soils were primarily observed in this stratum. SPT N-values ranged from 14 to 20 blows per ft, indicating medium dense in situ relative density of the granular soil.

Stratum IIa: Natural cohesive soils were primarily encountered from soil boring BH-07 and CPT-55 between depths of about 40 ft and 50 ft. The cohesive soils typically consisted of clays with shell fragments, calcareous nodules, ferrous nodules, sand seams, and sand pockets. The undrained shear strength of the cohesive materials, obtained primarily from field and laboratory testing and CPT empirical correlations, generally ranged from about 1,750 psf (stiff) to greater than 2000 psf (very stiff). The Atterberg Limits testing indicated measured liquid limit being 55 percent and plastic limits being 15 percent, resulting in calculated plasticity index of 40 percent. The measured natural water content of the cohesive soils was approximately 25 percent.

Detailed descriptions of the subsurface conditions encountered in the borings drilled and the CPTs performed along this segment are presented on the boring logs in Appendix D and the CPT logs in Appendix E of this report. The generalized subsurface cross section and associated subsurface shear strength profiles are presented on Plate 5d and Plate 6d of this report, respectively.

Based on our review of the existing geotechnical information, the subsurface conditions adjacent to the Buffalo Camp System seem to be in general agreement with that of the Jones Creek Levee.

### 6.1.5 South Recommended Alignment – Federal System

The current exploration does not include soil borings or CPT soundings conducted along the Freeport Hurricane Flood System Modernization - Federal System (Federal System) of the South Recommended Alignment. We reviewed the existing geotechnical information presented in Section

3.3 *South Recommended Alignment* for understanding the generalized subsurface conditions along the Federal System of the South Recommended Alignment.

Cohesive fill soils were generally encountered to a depth of about 10 ft to 30 ft below the ground surface along the Federal System. The consistency of the cohesive fill soils varies from soft to firm. Natural soils consisting of alternating layers of cohesive and granular soils were primarily observed from about 30 ft to 100 ft below the ground surface. The consistency of the natural cohesive soils varies from soft to stiff. The granular soils had medium dense to dense in-situ relative density with recorded SPT N-values ranged from 11 blows per ft to 41 blows per ft.

The existing geotechnical information along the Federal System was used to develop Profile E-E’ for performing slope stability analyses and providing deep foundation recommendations. Refer to Section 8.0 *Slope Stability Analyses* and Section 9.0 *Deep Foundation Recommendations*.

#### 6.1.6 Galveston Bay Floating Sector Gate

We understand that a proposed floating sector gate is planned for the Storm Surge Suppression Study. Borings BH-02 and BH-03 were explored to a depth of 400 ft below existing grade at Bolivar Peninsula and Galveston Island, respectively. A generalized subsurface profile along Galveston Bay where the floating sector gate is proposed is shown on Plate 5e of this report. A detailed subsurface description along Galveston Bay is not provided at the time of this report. We recommend that additional marine borings/CPTs be performed along Galveston Bay to better interpret the subsurface conditions along the proposed sector gate.

### 6.2 Depth-to-Water Conditions

Short-term depth-to-water measurements were performed for the borings during drilling operations. As mentioned previously, all borings were initially drilled using dry-auger techniques in an effort to identify the short-term depth-to-water conditions. Initial free-water was encountered in the borings from depths ranging from about 1.0 to 5.2 ft below existing grade at the time of our drilling operations along the Central Recommended Alignment (Coastal Spine). After about 5 to 35 minutes of observation, water levels in the open boreholes ranged from about 1.0 ft to 5.2 ft below existing grade along the Central Recommended Alignment (Coastal Spine). Initial free water was not encountered at the time of our drilling operations along the South Recommended Alignment. For borings where initial free water was not encountered to a depth of 25 ft, wet-rotary drilling operations were used to complete these boreholes. The short-term water depth observations are presented on the boring logs in the Remarks section on Plates D-1 through D-8 in Appendix D and in Table 6-1.

**Table 6-1. Summary of Groundwater Observations**

| Alignment Designation | Structure Description | Boring ID | Groundwater Depth (ft) | |
|---|---|---|---|---|
| | | | Initial Encounter | 15 Minutes after Initial Encounter |
| Central Recommended Alignment (Coastal Spine) | High Island to San Luis Pass Coastal Spine with Galveston Ring Levee | BH-01 | 3.0 | 3.0 |
| | | BH-02 | 5.2 | 5.2 |
| | | BH-03 | 3.0 | 3.0 |
| | | BH-04 | 1.0 | 1.0 |
| | | BH-05 | 3.0 | 3.0 |
| South Recommended Alignment | GCCPRD Alternative Route East of Plants, Proposed | BH-06 | Not Observed | Not Observed |
| | Reach 3, Jones Creek Levee and Reach 4, Tank Farm Levee | BH-07 | Not Observed | Not Observed |
| | | BH-08 | Not Observed | Not Observed |

### 6.3 Variations in Subsurface Conditions

Our interpretations of soil and depth-to-water conditions, as described in this report, are based on our review of the soil borings, CPT data, laboratory tests, and our local experience. Although we have allowed for minor variations in the subsurface conditions, our recommendations may not be appropriate for subsurface conditions other than those reported herein. It is possible that some undisclosed variations in soil or groundwater conditions will occur outside the boring and CPT locations, especially with respect to the depth, consistency, and lateral extent of fill material. We recommend careful observations during construction to verify our interpretations. Should variations from our interpretations be found, we recommend that we be notified and authorized to evaluate what, if any, revisions should be made to our recommendations.

## 7.0 TYPES OF SURGE PROTECTION AND GEOTECHNICAL DESIGN CRITERIA

This section discusses conceptual plans of the proposed surge protection system and associated geotechnical design criteria that are applicable to the project based on our experience with similar projects in the Gulf Coast region. The conceptual plans were provided by engineering design firms, which include Arcadis, U.S., Inc. (Arcadis), LJA Engineering, Inc. (LJA), and RPS Group (RPS).

### 7.1 Surge Protection System – North Recommended Alignment

The North Recommended Alignment is located in Orange and Jefferson Counties, Texas. Based on the drawings provided by LJA, we understand that the proposed structures along the North Recommended Alignment consist of an earth levee and T-wall combination of approximately 85 to 90 miles in length, the Neches River Sector Gate system, bulkhead closure structures, and ancillary structures such as box culverts and pump stations.

#### 7.1.1 Earth Levee and T-wall

The earth levee has a minimum crest width of 20 ft with levee net heights ranging from 10 ft to 20 ft and levee base width varying from 110 ft to 200 ft. The design heights of the levees are summarized in Table 7-1. We assigned identification numbers, designated ID No. 1 through 4, for the structures listed in Table 7-1.

**Table 7-1. Design Height of Levees**

| Alignment | ID No. | Levee Location | Max Height (ft) | Min Height (ft) |
|---|---|---|---|---|
| North Recommended Alignment | 1 | Reach 1, Orange-Sabine River Levee | 18.1 | 9.8 |
| | 2 | Reach 2, East Bank of the Neches River | 17.6 | 4.0 |
| | 3 | Reach 3, Modernization of the Port Arthur Federal Levee System | 18.5 | 1.2 |
| | 4 | Reach 4, West Bank of the Neches River | 16.1 | 0.7 |

The slope inclination is 4-horizontal to 1-vertical (4H:1V) for the protected side and 5H:1V for the flood side. The T-wall system consists of two typical configurations based on the natural grade elevations as follows,

a. Natural Grade at El. +7 ft: The wall stems reaching an elevation of El. +16 ft, slab base being 3 ft in thickness, battered concrete piles of 16 inches square, and continuous vertical sheet piles.

b. Natural Grade at El. +10 ft: The wall stems reaching an elevation of El. +13 ft, slab base being 1.5 ft in thickness, battered concrete piles of 16 inches square, and continuous vertical sheet piles.

### 7.1.2 Bulkhead Closure System

The bulkhead closure system consists of a mobile bulkhead, a crane and associated pedestal, and storage and closure slabs. The top elevation of the bulkhead closure reaches El. +14 ft. The bulkhead storage platform is approximately 3 ft in thickness and supported by concrete piles of 14 inches square driven to the design penetration of El. -68 ft. The bulkhead closure foundation base slab is 6.5 ft in thickness and supported by H-Piles driven to the design penetration of El. -120 ft.

### 7.1.3 Neches River Sector Gate System

Based on the drawings provided by Arcadis, it consists of two (2) steel gate assemblies of 32 ft in radius, four (4) vertical lift gates, combi-walls, and associated bulkheads on two sides of the Neches River. The sector gates will be supported on a concrete slab of 15 ft in thickness to be installed at El. -62 ft. Steel pipe piles will likely be used to support the concrete slab and sector gates. Each of the vertical lift gates will be 50 ft wide supported by the gate piers and piles at El. -52 ft. The Neches River combi-wall will be installed from the existing bay floor reaching the design elevation of El. +21 ft. The wall will be supported by a combination of battered steel pipe piles of 3 ft in diameter, cylinder piles of 5.5 ft in diameter, and closure piles of 1.5 ft in diameter.

## 7.2 Surge Protection System – Central Recommended Alignment (Coastal Spine)

The Central Recommended Alignment is located in Chambers County and Galveston County, Texas. The proposed structures along the Central Recommended Alignment consist of an earth levee and T-wall combination of approximately 45 miles long: the Galveston Ring Levee of T-walls (approximately 20 miles long), the Houston Ship Channel Floating Sector Gate, and the Clear Lake Gate.

### 7.2.1 Earth Levee and T-wall

The proposed earth levee has net heights ranging from 10 to 20 ft. The design heights of the levees are summarized in Table 7-2. We assigned identification numbers, designated ID No. 5 through 7, for the structures listed in Table 7-2.

**Table 7-2. Design Height of Levees**

| Alignment | ID No. | Levee Location | Max Height (ft) | Min Height (ft) |
|---|---|---|---|---|
| Central Recommended Alignment (Coastal Spine) | 5 | Clear Lake Gate | 12.0 | 12.0 |
| | 6 | Galveston Ring Levee | 15.4 | 6.2 |
| | 7 | High Island to San Luis Coastal Spine | 14.7 | 8.0 |

Other information related to the levee configuration is not available at the time of this report.

### 7.2.2 Houston Ship Channel Floating Sector Gate System

Based on the drawings provided by Arcadis, it consists of two (2) floating steel gate assemblies of approximately 550 ft in radius, 25 vertical lift gates, combi-walls, and associated support islands in the Ship Channel. The floating sector gates will be partially hinge supported by ball-points of 75 ft in diameter, a sill slab at the mudline of approximately El. -60 ft. Steel pipe piles will likely be used to support the vertical gate structures. The combi-wall will be installed from the existing bay floor reaching the design elevation of El. +18 ft. The wall will be supported by a combination of battered steel pipe piles of 3 ft in diameter, cylinder piles of 5.5 ft in diameter, and closure piles of 1.5 ft in diameter.

In addition, each of the supported islands for the floating sector gates facility will be constructed using 7 cofferdams of 101 ft in diameter and 26 cofferdams of 75 ft in diameter. We understand that it is in the phase of preliminary design and a few other options are also being considered.

### 7.3 Surge Protection System – South Recommended Alignment

The South Recommended Alignment is located in Brazoria County, Texas. Per layout plans provided by RPS, the proposed structures along the South Recommended Alignment consist of a continuous earthen levee of approximately 45 to 60 miles long and T-walls at selected locations along the levee segments. In addition, a continuous earthen levee of approximately 15 to 20 miles long is proposed along with a vertical lift gate in the middle of the proposed *GCCPRD Alternative route East of Plants*.

### 7.3.1 Earth Levee and T-wall

The proposed earth levee has net heights ranging from 10 ft to 20 ft. The design heights of the levees are summarized in Table 7-3. We assigned identification numbers, designated ID No. 8 through 14, for the structures listed in Table 7-3.

**Table 7-3. Design Height of Levees**

| Alignment | ID No. | Levee Location | Max Height (ft) | Min Height (ft) |
|---|---|---|---|---|
| South Recommended Alignment | 8 | GCCPRD south end of alternative route, proposed | 20.4 | 13.3 |
| | 9 | GCCPRD alternative route east of plants, proposed | 13.5 | 0.7 |
| | 10 | Reach 1, Freeport Hurricane Flood Protection System Modernization - Buffalo Camp Local System | 0.8 | 0.3 |
| | 11 | Reach 1, Freeport Hurricane Flood Protection System Modernization - Federal System | 4.7 | 0.3 |

**Table 7-3. Design Height of Levees**

| Alignment | ID No. | Levee Location | Max Height (ft) | Min Height (ft) |
|---|---|---|---|---|
| South Recommended Alignment | 12 | Reach 3, Jones Creek Levee | 12.7 | 1.7 |
| | 13 | Reach 4, Tank Farm Levee | 16.3 | 16.3 |
| | 14 | Reach 5, Chocolate Bayou Ring Levee | 19.0 | 2.4 |

Other information related to the levee configuration is not available at the time of this report.

### 7.4 Geotechnical Design Criteria

Based on our understanding of the proposed structures for surge protection and the available design information, we have included slope stability and associated settlement analyses and deep foundation recommendations in this report.

#### 7.4.1 Slope Stability Analysis for the Earth Levees

The stability of the levees is analyzed using the Spencer's Method per each generalized subsurface soil profile and assumed levee cross section configurations, which include the slope inclination of 3H:1V on the protected side and flood side and the maximum height of each segment. The analysis included end of construction, long term, and rapid drawdown and associated Factors of Safety (FOS). Discussions of design methodology and calculated factors of safety are provided in Section 8.0 *Slope Stability Analysis*. It is noted that we have listed some segments of "as-built" levees and recommend associated analyses be performed once the complete grade information is available.

#### 7.4.2 Settlement Estimates for the Earth Levees

Settlement analyses were performed to evaluate consolidation of a levee section due to the grade change. Our analyses used the Boussinesq's theories of stress distribution and compressibility parameters measured from the consolidation tests performed for this study and empirically correlated soil parameters. Discussions of the settlement analyses methodology and associated results are provided in Section 8.0 *Slope Stability Analysis*.

#### 7.4.3 Deep Foundation Recommendations

For the proposed structures, we have evaluated the axial capacities in compression and tension and lateral capacity using H-Piles, pre-cast pre-stressed concrete piles, and steel pipe piles. Discussions of the methodology and results are provided in Section 9.0 *Deep Foundation Recommendations*.

Once additional design information becomes available, additional geotechnical evaluation should be performed as discussed in Section 10.0 *Additional Geotechnical Evaluation*.

## 8.0 SLOPE STABILITY ANALYSES

We understand that the GCCPRD is planning to construct levees as part of the Storm Surge Suppression Study. Based on information provided us, there are 13 levees. Several levees are existing structures that are proposed for rehabilitation. At the time of this report, the alignment, description, existing ground elevations, and design elevations are available for the levees. However, cross sections and station numbers for the levees were not available. Table 8-1 provides a summary of the available information for the levees.

**Table 8-1. Summary of Levee Information**

| Alignment | ID No. | Description | Existing Ground Elevation, (ft) | | Design Elevation, (ft) | |
|---|---|---|---|---|---|---|
| | | | Min. | Max. | Min. | Max. |
| North Recommended Alignment | 1 | Reach 1, Orange-Sabine River Levee | 3 | 6.8 | 16 | 22 |
| | 2 | Reach 2, East Bank of the Neches River | 4.2 | 14.6 | 15 | 22.5 |
| | 3 | Reach 3, Modernization of the Port Arthur Federal Levee System | 4 | 23.5 | 17 | 22.5 |
| | 4 | Reach 4, West Bank of the Neches River | 4.6 | 17.6 | 17.5 | 22 |
| Central Recommended Alignment (Coastal Spine) | 5 | Clear Lake Gate | 5 | 5 | 17 | 17 |
| | 6 | Galveston Ring Levee | 3.1 | 6.3 | 12.5 | 18.5 |
| | 7 | High Island to San Luis Pass Coastal Spine | 3.3 | 22.1 | 17 | 21 |
| South Recommended Alignment | 8 | GCCPRD South End of Alternative Route, Proposed | 3.1 | 9.2 | 22.5 | 23.5 |
| | 9 | GCCPRD Alternative Route East of Plants, Proposed | 6.5 | 18.8 | 19.5 | 20 |
| | 10 | Reach 1, Freeport Hurricane Flood Protection System Modernization – Buffalo Camp Local System | 16.2 | 21.6 | 15.5 | 17 |
| | 11 | Reach 1, Freeport Hurricane Flood Protection System Modernization – Federal System | 14.3 | 20.3 | 16 | 23.5 |

**Table 8-1. Summary of Levee Information (Continued)**

| Alignment | ID No. | Description | Existing Ground Elevation, (ft) | | Design Elevation, (ft) | |
|---|---|---|---|---|---|---|
| | | | Min. | Max. | Min. | Max. |
| South Recommended Alignment | 12 | Reach 3, Jones Creek Levee | 6.9 | 20.7 | 16.5 | 20 |
| | 13 | Reach 4, Tank Farm Levee | 4.7 | 4.7 | 21 | 21 |
| | 14 | Reach 5, Chocolate Bayou Ring Levee | 4 | 19.1 | 20.5 | 24.5 |

As mentioned earlier, new borings and CPT soundings were not performed along the North Recommended Alignment in Orange and Jefferson Counties. At the time of this report, slope stability analyses were not performed for the proposed levees along the North Recommended Alignment.

The following sections discuss the method of analysis, design soil parameters, loading conditions, global stability analyses, erosion protection, and levee settlements.

### 8.1 Method of Analysis

The global stability was analyzed to evaluate the potential for slope failure. We performed slope stability analyses for the proposed levees with the aid of a computer program SLIDE 6.0. The SLIDE computer program generates slip surfaces and evaluates the factor of safety for each slip surface. The program allows a large number and shape of potential slip surfaces to be investigated to determine the critical slip surface for each of the analyzed levee configuration. The results of our analyses are presented on Plates H-1 through H-27 in Appendix H.

Our analyses were performed using the Spencer's method, which uses the method of slices to evaluate the stability along a series of circular slip surfaces. The computed factor of safety is the ratio of the forces resisting movement to the driving forces. Acceptable factor of safety depends upon many factors such as loading conditions, selection criteria used for strength parameters, risk of failure, etc.

### 8.2 Design Soil Parameters

We reviewed plots of the undrained shear strength versus depth (refer to Plates 6a and 6b) and nearby existing geotechnical data along the South Recommended Alignment in Brazoria County to determine the design soil parameters for the global stability analyses. The soil parameters for Profile A-A', B-B', C-C', D-D', and E-E' are presented in Tables 8-2 through 8-6. We assumed that compacted embankment fill composed of fat clays or lean clays will be used to construct the proposed levees. Therefore, the soil parameters for the compacted embankment fill are presented in Table 8-7[14].

**Table 8-2. Soil Parameters for Slope Stability Analysis - Profile A-A'**

| Depth, ft | Soil | Total Unit Weight, pcf | Short-Term (Undrained) | | Long-Term (Drained) | | Rapid Drawdown | |
|---|---|---|---|---|---|---|---|---|
| | | | Cohesion (c), psf | Friction Angle ($\phi$), degrees | Cohesion (c'), psf | Friction Angle ($\phi$'), degrees | Cohesion ($c_{cu}$), psf | Friction Angle ($\phi_{cu}$), degrees |
| 0 to 5 | Sand | 115 | 0 | 25 | 0 | 25 | 0 | 25 |
| 5 to 15 | Soft Clay | 105 | 300 | 0 | 50 | 17 | 75 | 12 |
| 15 to 60 | Soft to Stiff Clay | 125 | Top: 300 Bottom: 1,000 | 0 | Top: 50 Bottom: 200 | Top: 17 Bottom: 21 | Top: 75 Bottom: 250 | Top: 12 Bottom: 16 |

**Table 8-3. Soil Parameters for Slope Stability Analysis - Profile B-B'**

| Depth, ft | Soil | Total Unit Weight, pcf | Short-Term (Undrained) | | Long-Term (Drained) | | Rapid Drawdown | |
|---|---|---|---|---|---|---|---|---|
| | | | Cohesion (c), psf | Friction Angle ($\phi$), degrees | Cohesion (c'), psf | Friction Angle ($\phi$'), degrees | Cohesion ($c_{cu}$), psf | Friction Angle ($\phi_{cu}$), degrees |
| 0 to 8 | Sand | 115 | 0 | 25 | 0 | 25 | 0 | 25 |
| 8 to 16 | Soft Clay | 105 | 300 | 0 | 50 | 17 | 75 | 12 |
| 16 to 20 | Sand | 115 | 0 | 30 | 0 | 30 | 0 | 30 |
| 20 to 45 | Soft to Firm Clay | 105 | Top: 300 Bottom: 800 | 0 | Top: 50 Bottom: 200 | Top: 17 Bottom: 21 | Top: 75 Bottom: 250 | Top: 12 Bottom: 16 |
| 45 to 60 | Stiff Clay | 125 | 1,200 | 0 | 250 | 21 | 300 | 16 |

[14] US Army Corps of Engineers, "Hurricane and Storm Damage Risk Reduction System Design Guidelines", New Orleans District Engineering Division (Interim Document dated June 2012)

**Table 8-4. Soil Parameters for Slope Stability Analysis - Profile C-C'**

| Depth, ft | Soil | Total Unit Weight, pcf | Short-Term (Undrained) | | Long-Term (Drained) | | Rapid Drawdown | |
|---|---|---|---|---|---|---|---|---|
| | | | Cohesion (c), psf | Friction Angle ($\phi$), degrees | Cohesion (c'), psf | Friction Angle ($\phi'$), degrees | Cohesion ($c_{cu}$), psf | Friction Angle ($\phi_{cu}$), degrees |
| 0 to 14 | Firm Clay | 105 | 700 | 0 | 140 | 20 | 190 | 15 |
| 14 to 25 | Stiff Clay | 125 | 1,600 | 0 | 320 | 23 | 370 | 18 |
| 25 to 40 | Stiff Clay | 125 | 2,000 | 0 | 400 | 25 | 400 | 20 |
| 40 to 60 | Stiff Clay | 125 | 1,600 | 0 | 320 | 23 | 370 | 17 |

**Table 8-5. Soil Parameters for Slope Stability Analysis - Profile D-D'**

| Depth, ft | Soil | Total Unit Weight, pcf | Short-Term (Undrained) | | Long-Term (Drained) | | Rapid Drawdown | |
|---|---|---|---|---|---|---|---|---|
| | | | Cohesion (c), psf | Friction Angle ($\phi$), degrees | Cohesion (c'), psf | Friction Angle ($\phi'$), degrees | Cohesion ($c_{cu}$), psf | Friction Angle ($\phi_{cu}$), degrees |
| 0 to 15 | Firm Clay | 115 | 750 | 0 | 150 | 20 | 200 | 15 |
| 15 to 30 | Stiff Clay | 125 | 1,500 | 0 | 300 | 23 | 350 | 18 |
| 30 to 43 | Sand | 115 | 0 | 30 | 0 | 30 | 0 | 30 |
| 43 to 50 | Stiff Clay | 125 | 1,800 | 0 | 360 | 24 | 400 | 19 |
| 50 to 60 | Sand | 115 | 0 | 30 | 0 | 30 | 0 | 30 |

**Table 8-6. Soil Parameters for Slope Stability Analysis - Profile E-E'**

| Depth, ft | Soil | Total Unit Weight, pcf | Short-Term (Undrained) | | Long-Term (Drained) | | Rapid Drawdown | |
|---|---|---|---|---|---|---|---|---|
| | | | Cohesion (c), psf | Friction Angle ($\phi$), degrees | Cohesion (c'), psf | Friction Angle ($\phi'$), degrees | Cohesion ($c_{cu}$), psf | Friction Angle ($\phi_{cu}$), degrees |
| 0 to 15 | Soft Clay | 105 | 300 | 0 | 50 | 17 | 75 | 12 |
| 15 to 50 | Firm Clay | 115 | 700 | 0 | 140 | 20 | 190 | 15 |
| 50 to 80 | Stiff Clay | 125 | 1,500 | 0 | 300 | 23 | 350 | 18 |

**Table 8-7. Soil Parameters for Compacted Clay (Fat Clay or Lean Clay) Fill**

| Depth, ft | Total Unit Weight, pcf | Short-Term (Undrained) | | Long-Term (Drained) | | Rapid Drawdown | |
|---|---|---|---|---|---|---|---|
| | | Cohesion (c), psf | Friction Angle ($\phi$), degrees | Cohesion (c'), psf | Friction Angle ($\phi'$), degrees | Cohesion ($c_{cu}$), psf | Friction Angle ($\phi_{cu}$), degrees |
| Varies | 115 | 600 | 0 | 120 | 20 | 170 | 15 |

### 8.3 Loading Conditions

For satisfactory performance, the levees should have an acceptable factor of safety during their entire projected time of service. Factors of safety for the potential loading conditions and modes of failure should be considered. In our analysis, we computed factors of safety for the critical cross section of the levees along the Central Recommended Alignment (Coastal Spine) and South Recommended Alignment. The following paragraphs the stability conditions analyzed in our study.

#### 8.3.1 Short-Term (Undrained) Condition

The short-term, or undrained, condition is applicable to situations before pore water pressures have dissipated, such as during and shortly following construction, as well as shortly following any significant loading. Analyses for this condition involve the use of undrained shear strength parameters as tabulated in a previous section. The water level is assumed at the existing grade elevations. Required minimum factor of safety for short-term condition is 1.3 per USACE EM 1110-

2-1913[15]. In the short-term condition analyses, we assumed a surface load of 250 psf along the crown width.

### 8.3.2 Long-Term (Drained) Condition

The long-term, or drained, condition models the condition in which the pore pressures generated during construction and operation have dissipated. Analyses for this condition involve the use of drained shear strength parameters as tabulated in the previous section. The water level is assumed at the existing grade elevations. Required minimum factor of safety for long-term condition is 1.4 per the guidelines of the US Army Corps of Engineers.

### 8.3.3 Rapid Drawdown Condition

The rapid drawdown condition models the case in which the water level saturates a major part of the levee and drops faster than the soil can drain. This causes excess pore water pressure to develop which may result in failure. The initial water level was assumed at the full height of the levee. The final water level was assumed at the existing grade elevation. Analyses for this condition involves using drained strength parameters (c' and $\phi$') and undrained strength parameters ($c_{cu}$ and $\phi$). Required minimum factor of safety for flooded condition is 1.0 to 1.2 per the guidelines of the US Army Corps of Engineers.

## 8.4 Global Stability Analyses

Tables 8-8 and 8-9 contain a summary of the results from our analyses at critical locations along the levees planned for the Central Recommended Alignment (Coastal Spine) and South Recommended Alignment. We assumed a crown width of 10 ft and 3H:1V inclination along the side slopes of the levees. Graphical representations of our analyses are presented on Plates H-1 through H-27 in Appendix H.

**Table 8-8. Summary of Global Stability Analyses – Central Recommended Alignment (Coastal Spine)**

| ID No. | Cross Section | Height, (ft) | Computed Factors of Safety | | |
|---|---|---|---|---|---|
| | | | Short Term Condition | Long Term Condition | Rapid Drawdown Condition |
| 6 | B-B' | 15.4 | 1.46 | 1.59 | 1.13 |
| 7 | B-B' | 12.2 | 1.51 | 1.49 | 1.20 |
| | A-A' | 14.7 | 1.32 | 1.39 | **0.99** |
| | A-A' | 13.5 | 1.35 | 1.37 | 1.01 |

[15] US Army Corps of Engineers, "Design and Construction Levee", Engineer Manual (EM 1110-2-1913 dated April 30, 2000).

**Table 8-9. Summary of Global Stability Analyses – South Recommended Alignment**

| ID No. | Cross Section | Height, (ft) | Computed Factors of Safety | | |
|---|---|---|---|---|---|
| | | | Short-Term Condition | Long-Term Condition | Rapid Drawdown Condition |
| 8 | C-C’ | 20.4 | 1.88 | 1.62 | 1.05 |
| 9 | C-C’ | 13.5 | 2.57 | 1.73 | 1.26 |
| 11 | E-E’ | 4.7’ | 2.56 | 1.49 | 1.19 |
| 12 | D-D’ | 12.7 | 2.85 | 1.79 | 1.33 |
| 13 | D-D’ | 16.3 | 2.78 | 1.93 | 1.19 |

### 8.5 Erosion Protection

The stability of levees will be dependent upon the ability of the slopes to maintain their integrity during repeated flood and runoff events. Erosion usually increases over time due to seepage flow, flood, and runoff events. The loss of soil along the toe of the levees or at inlet and outlet structures along levee systems could jeopardize the performance of the protection system. Therefore, isolated areas may need some type of erosion protection, especially in areas where granular soils and shallow dispersive cohesive soils are exposed along the structures and outside the toe of the slopes. Observations should also be performed during construction activities to further identify those areas that will require additional erosion protection.

The aim of erosion protection should be to reduce surface erosion due to runoff and weathering. An engineered approach should be used to applying erosion control measures at this site. Applicable erosion protection systems include: the use of engineered concrete rip-rap, articulated concrete blocks, concrete revetment mats, lime/cement treated soil, or gabions. Sodding and other surficial vegetation may also be used per the USACE EM 1110-2-1913 or equivalent specifications to protect the slopes from surface erosion.

The Geotechnical Engineer-of-Record should have the opportunity to review the engineered surface erosion protection design. A Hydraulic Engineer should be consulted to provide insight into the hydraulic influences from flooding and runoff on the design and performance of any proposed erosion protection systems.

### 8.6 Levee Settlements

Construction of the levees along the project alignments will incur settlements within the proposed levee embankment and the underlying supporting soils. We anticipate that settlements within the proposed levee embankment is due to the self-weight of the fill material. The self-weight settlements (about 60 to 80 percent) will primarily will occur during proper placement and compaction of clay fill used to construct the proposed levees. In addition, consolidation settlements of the underlying supporting soils will occur throughout the life of the proposed levees and may vary along these structures due to variation in the subsurface conditions. The consolidation settlement is dependent on several factors such as the levee configuration and the compressibility characteristics of supporting soils.

### 8.6.1 Self-Weight Settlement of Levee Embankment

It is anticipating that proper placement and compacted clay fill will be used to construct the proposed levees. Therefore, we anticipated that clay fill may settlement about 2 to 3 percent of its height due to its own self weight. Table 8-10 provides estimated settlements based on the anticipated maximum height of the proposed levees presented in Section 8.4 along the Central Recommended Alignment (Coastal Spine) and South Recommended Alignment.

**Table 8-10. Estimated Settlement within Compacted Clay (Fat Clay or Lean Clay) Fill**

| Alignment | ID No. | Description | Maximum Height, (ft) | Estimated Settlement, (in) |
|---|---|---|---|---|
| Central Recommended Alignment (Coastal Spine) | 6 | Galveston Ring Levee | 15.4 | 3.7 to 4.4 |
| | 7 | High Island to San Luis Pass Coastal Spine | 14.7 | 3.5 to 5.3 |
| South Recommended Alignment | 8 | GCCPRD South End of Alternative Route, Proposed | 20.4 | 4.9 to 7.3 |
| | 9 | GCCPRD Alternative Route East of Plants, Proposed | 13.5 | 3.2 to 4.9 |
| | 11 | Reach 1, Freeport Hurricane Flood Protection System Modernization – Federal System | 4.7 | 1.1 to 1.7 |
| | 12 | Reach 3, Jones Creek Levee | 12.7 | 3.0 to 4.6 |
| | 13 | Reach 4, Tank Farm Levee | 16.3 | 3.9 to 5.9 |

### 8.6.2 Settlement of Supporting Soil Due to Levee Embankment

The settlement analyses of the supporting soils were primarily performed along the Central Recommended Alignment (Coastal Spine) and South Recommended Alignment at sections with maximum heights. Cross sections of the levees were not available at the time of this report. Therefore, we assumed a crown width of 10 ft and 3H:1V inclination of the side slopes. Additional recommendations for the levees will be provided during the detailed design phase of this study.

We calculated the settlements of the supporting soils due to the weight of the levee using the computer program Settle3D developed by Rocscience. The software program uses Boussinesq's theories of stress distribution, the soil compressibility parameters and elastic modulus values for the supporting soils. We anticipate that the immediate settlement of the soils would occur during the construction period and consolidation settlement of the cohesive soils would occur throughout the life of the levees.

Soil compressibility parameters used in our analyses were developed based on the laboratory consolidation test results, available correlations with soil index parameters, and our experience from projects with similar soil conditions. The rate of settlement is directly related to the excess pore water pressure dissipation. The change in thickness (settlement) of the layer after the beginning of loading was determined using the theory of consolidation, which predicts the pore pressure at any point in time and space in the consolidating layer. The design soil parameters for our settlement analyses at Profile A-A', B-B', C-C', D-D', and E-E' are presented in Tables 8-11 through 8-15.

**Table 8-11. Soil Parameters for Settlement Analysis - Profile A-A'.**

| Depth, (ft) | Soil Description | Total Unit Weight (pcf) | Compressibility Parameters | | | |
|---|---|---|---|---|---|---|
| | | | CR(1) | RR(2) | OCR(3) | $C_v$(5), ($ft^2$/yr) |
| 0 to 5 | Loose Sand | 115 | E(6): 300 ksf | -- | -- | 300 |
| 5 to 15 | Soft Clay | 105 | 0.15 | 0.03 | 10 | 7 |
| 15 to 60 | Soft to Stiff Clay | 125 | 0.20 | 0.02 | 3 | 7 |

**Notes:**

1. Strain-based compression index.
2. Strain-based re-compression index.
3. Over-consolidation ratio.
4. Pre-Consolidation Pressures
5. Coefficient of Consolidation.
6. Modulus of Elasticity.

**Table 8-12.Soil Parameters for Settlement Analysis - Profile B-B'**

| Depth, (ft) | Soil Description | Total Unit Weight, (pcf) | Compressibility Parameters | | | |
|---|---|---|---|---|---|---|
| | | | CR(1) | RR(2) | OCR(3) | $C_v$(5), ($ft^2/yr$) |
| 0 to 8 | Loose Sand | 115 | E(6): 300 ksf | -- | -- | 300 |
| 8 to 16 | Soft Clay | 105 | 0.15 | 0.03 | 10 | 7 |
| 16 to 20 | Medium Dense Sand | 115 | E(6): 450 ksf | -- | -- | 300 |
| 20 to 45 | Soft to Firm Clay | 105 | 0.20 | 0.02 | 3 | 7 |
| 45 to 60 | Stiff Clay | 125 | 0.20 | 0.02 | 3 | 7 |

**Table 8-13.Soil Parameters for Settlement Analysis - Profile C-C'**

| Depth, (ft) | Soil Description | Total Unit Weight, (pcf) | Compressibility Parameters | | | |
|---|---|---|---|---|---|---|
| | | | CR(1) | RR(2) | OCR(3) | $C_v$(5), ($ft^2/yr$) |
| 0 to 14 | Firm Clay | 105 | 0.15 | 0.03 | 10 | 7 |
| 14 to 60 | Stiff Clay | 125 | 0.20 | 0.02 | 3 | 7 |

**Notes:**

1. Strain-based compression index.
2. Strain-based re-compression index.
3. Over-consolidation ratio.
4. Pre-Consolidation Pressures
5. Coefficient of Consolidation.
6. Modulus of Elasticity.

**Table 8-14.Soil Parameters for Settlement Analysis - Profile D-D'**

| Depth, (ft) | Soil Description | Total Unit Weight, (pcf) | Compressibility Parameters | | | |
|---|---|---|---|---|---|---|
| | | | CR(1) | RR(2) | OCR(3) | $C_v$(5), ($ft^2$/yr) |
| 0 to 15 | Firm Clay | 115 | 0.15 | 0.03 | 10 | 7 |
| 15 to 30 | Stiff Clay | 125 | 0.20 | 0.02 | 3 | 7 |
| 30 to 43 | Medium Dense Sand | 115 | E(6): 450 ksf | -- | -- | 300 |
| 43 to 50 | Stiff Clay | 125 | 0.20 | 0.02 | 3 | 7 |
| 50 to 60 | Medium Dense Sand | 115 | E(6): 450 ksf | -- | -- | 300 |

**Table 8-15.Soil Parameters for Settlement Analysis - Profile E-E'**

| Depth, (ft) | Soil Description | Total Unit Weight, (pcf) | Compressibility Parameters | | | |
|---|---|---|---|---|---|---|
| | | | CR(1) | RR(2) | OCR(3) | $C_v$(5), ($ft^2$/yr) |
| 0 to 5 | Soft Clay | 105 | 0.15 | 0.03 | 10 | 7 |
| 5 to 15 | Stiff Clay | 115 | 0.20 | 0.02 | 3 | 7 |
| 15 to 60 | Stiff Clay | 125 | 0.20 | 0.02 | 3 | 7 |

**Notes:**

1. Strain-based compression index.
2. Strain-based re-compression index.
3. Over-consolidation ratio.
4. Pre-Consolidation Pressures
5. Coefficient of Consolidation.
6. Modulus of Elasticity.

Based on our preliminary settlement analysis, we expect that the loading resulting from levee grade raising will induce consolidation settlements of the supporting soils as presented in Tables 8-16 and 8-17. Due to variation of soil properties, additional compressibility tests should be performed and used in the final settlement analysis.

**Table 8-16. Calculated Levee Settlement – Central Recommended Alignment (Coastal Spine)**

| ID No. | Soil Profile | Max. Height, ft | Estimated Consolidation Settlement at Ground Surface(1) (inch) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | End of Levee Construction(2) | 3 Months(3) | 6 Months(3) | 1 Year(3) | 5 Years (3) | 50 Years (3) |
| 6 | B-B' | 15.4 | 0.5 | 0.7 | 0.8 | 1.0 | 1.7 | 3.0 |
| 7 | B-B' | 12.2 | 0.4 | 0.6 | 0.7 | 0.8 | 1.4 | 2.5 |
| | A-A' | 14.7 | 0.7 | 0.9 | 1.1 | 1.3 | 2.0 | 3.6 |

**Notes:**

1. The compacted clay fill will settle under its own weight primarily during the construction phase.
2. The construction period for the levee was assumed to be 3 months.
3. Time is reference after end of levee construction.
4. Surcharge loads were calculated assuming a total unit weight of 115 pcf for the compacted clay fill material.

**Table 8-17. Calculated Levee Settlement – South Recommended Alignment**

| ID No. | Soil Profile | Max. Height, ft | Estimated Consolidation Settlement at Ground Surface (1) (inch) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | End of Construction(2) | 3 Months(3) | 6 Months(3) | 1 Year(3) | 5 Years (3) | 50 Years (3) |
| 8 | C-C' | 20.4 | 4.4 | 5.2 | 5.8 | 6.5 | 8.1 | 10.6 |
| 9 | C-C' | 13.5 | 3.6 | 4.3 | 4.6 | 5.2 | 6.4 | 8.2 |
| 11 | E-E' | 4.7 | 2.0 | 2.2 | 2.2 | 2.3 | 2.7 | 3.2 |
| 12 | D-D' | 12.7 | 3.4 | 3.9 | 4.2 | 4.5 | 5.5 | 7.1 |
| 13 | D-D' | 16.3 | 3.6 | 4.2 | 4.6 | 5.1 | 6.4 | 8.2 |

**Notes:**

1. The compacted clay fill will settle under its own weight primarily during the construction phase.
2. The construction period for the levee was assumed to be 3 months.
3. Time is referenced after the end of levee construction.
4. Surcharge loads were calculated assuming a total unit weight of 115 pcf for the compacted clay fill material.

We performed a preliminary settlement analysis using our interpreted design parameters based on the soil conditions encountered during this study, the review of existing geotechnical studies performed by others, and the anticipated loading from the fill placement. However, actual compressibility characteristics of subgrade soils may vary and differ from what we assumed in our analyses. The actual post-construction settlements will vary depending on several factors such as construction period, field permeability of subgrade soils, and other soil parameters.

### 8.7 Additional Considerations

We understand that several levees are existing structures that are proposed for rehabilitation as part of the mitigation measures for this study. As such, we should be given the opportunity in the detailed design phase to review available as-built drawings, cross sections, and any other pertinent information to verify our above recommendations.

## 9.0 DEEP FOUNDATION RECOMMENDATIONS

This section presents our deep recommendations for the proposed T-walls along the Central Recommended Alignment (Coastal Spine) and South Recommended Alignment which include design soil parameters, static axial capacity, axial group effects, lateral capacity, lateral group effects, and estimated settlement. Deep foundation recommendations for the remaining structures as described in Section 7.0 *Types of Surge Protection and Geotechnical Design Criteria* will be addressed during the detailed design phase of this study.

### 9.1 Soil Parameters

Soil parameters were selected based on the review of existing geotechnical information, our laboratory data, and field test data collected from the current soil borings and CPTs performed at the site. The undrained shear strength profile is presented on Plates 6a through 6d. The shear strength profile was developed based on CPTs and field and laboratory testing performed as a part of the project. The soil parameters used for axial capacity and lateral capacity analysis for the proposed alignments are presented on Plates G-1 through G-3 in Appendix G.

### 9.2 Static Axial Capacity

The ultimate axial capacity, in both compression and tension were computed using the static method of analysis. In this method, the ultimate compressive capacity of a pile is taken as the sum of the skin friction on the pile wall and the end bearing on the pile tip. When computing tensile capacity, the end bearing component is neglected. The weight of the pile and the soil plug, if applicable, are also neglected in the computations. In general, we neglected the strength of upper 4 ft of soil from the final grade for the computation of axial pile capacity. The ultimate pile capacity curves for individual 14 X 73 H-piles and 14- and 18-inch driven pre-cast square concrete piles (PCP) are presented on Plates G-4 through G-12 in Appendix G. The ultimate pile capacity curves are for vertical piles. We understand that current plan calls for the use of battered piles for this study. Refer to Plate G-13 in Appendix G for the computation of the *Ultimate Capacity of Battered Piles*.

We recommend a factor of safety of 2.0 be applied to the ultimate axial capacity of piles loaded in compression (transient and sustained) and transient tension. A factor of safety of 3.0 should be applied for sustained tension loads. The weight of the pile was neglected in the computation of ultimate tension capacity, but it may be included once the penetration is determined. In such an instance, the buoyant weight of the piles should be used. Buoyant unit weights of 430 pcf and 90 pcf are typically used for steel and concrete, respectively. A factor of safety of 1.2 should be applied to the pile weight.

### 9.3 Axial Group Effects

The overall allowable axial load carrying capacity of a group of piles may, in some cases, be less than the sum of the individual allowable capacities. Piles in a group can either fail as individual piles or as a group in a "block failure" mode. A reduction in the individual pile capacity, to allow for group effects, is usually not necessary for piles having a center-to-center spacing of 3 or more pile diameters. The reduction in individual capacity depends on many factors including the configuration of the group, number of piles in the group, pile size, the depth of installation, and the pile spacing. We recommend that newly installed piles be spaced at least 3 pile diameters (center-to-center) to reduce substantial axial group effects. We would be pleased to review the pile group configuration and perform axial group analyses during the detailed design phase of this study.

### 9.4 Lateral Capacity

We evaluated the lateral resistance of individual 14 X 73 H-piles and 14- and 18-inch square precast concrete piles for the encountered soil conditions. We performed our lateral capacity analyses for a single, isolated pile using the computer program LPILE Version 6.0, developed by Ensoft, Inc. This program uses finite difference numerical techniques to compute lateral deflections and bending moments induced in a pile due to lateral and axial loads applied at the top of the pile.

The pile-soil system is modeled as a series of finite segments that represent the pile and the soil. Soil resistance is provided using p-y curves developed from a distribution of input soil unit weights and strength parameters specific to the subsurface conditions at the project site. If the piles are structurally tied together with a rigid concrete cap and the pile caps are embedded within the soil, the lateral resistance from the pile caps may be added to the lateral resistance of the individual piles provided in the Tables 9-1 through 9-3.

The following assumptions were made in our lateral capacity analyses of single isolated piles:

- Young's modulus for steel piles equals 29,000 ksi.
- Young's modulus of square concrete piles equals 4,000 ksi.
- Top of the H-piles and precast concrete piles for the proposed T-walls was taken to be at existing grade.
- Lateral loads were only applied at the top of the pile.
- No external loads or moments were applied at the top of the pile.

We analyzed both free-head and fixed-head conditions with lateral loads (shear force) applied at the top of the piles. We performed our analyses using limiting deflections of ½ and 1 inch at the top of the piles. We also evaluated the maximum bending moment in the pile section. We analyzed each case using both "uncracked" and "cracked" stiffness (EI) for the concrete piles. A "cracked" stiffness of 35 percent of the actual stiffness was used for our calculations as recommended by ACI 318-08. The computed maximum shear force, the maximum bending moment, and the depth of maximum bending moment for isolated, individual piles are presented in Tables 9-1 through 9-3. Individual, isolated piles are representative of a free-head condition. A group of piles structurally tied together with a rigid concrete cap is more closely representative of a fixed-head condition.

**Table 9-1. Individual Lateral Pile Capacities – Central Recommended Alignment (Coastal Spine) (Profile A-A')**

| Pile Size | Pile Top Fixity | Lateral Deflection[1] (inch) | Shear Force at the Surface (kips) | | Maximum Bending Moment (kips-inch) | | Depth of Maximum Bending Moment[2] (ft) | |
|---|---|---|---|---|---|---|---|---|
| | | | Uncracked | Cracked | Uncracked | Cracked | Uncracked | Cracked |
| **Pre-Cast Concrete Pile (PCP)** | | | | | | | | |
| 14-inch square | Free Head | ½ | 4.3 | 2.9 | 320 | 176 | 10.2 | 7.8 |
| | | 1 | 6.1 | 4.1 | 522 | 284 | 11.4 | 9.0 |
| | Fixed Head | ½ | 9.7 | 6.6 | 834 | 458 | 0 | 0 |
| | | 1 | 14.0 | 9.4 | 1,354 | 737 | 0 | 0 |
| 18-inch square | Free Head | ½ | 6.9 | 4.8 | 596 | 326 | 12.6 | 9.6 |
| | | 1 | 9.9 | 6.8 | 977 | 530 | 13.8 | 10.8 |
| | Fixed Head | ½ | 15.3 | 10.5 | 1,571 | 862 | 0 | 0 |
| | | 1 | 22.3 | 15.1 | 2,564 | 1,393 | 0 | 0 |
| **Steel H-Pile (Weak Axis)** | | | | | | | | |
| 14X73 | Free Head | ½ | 3.5 | | 237 | | 9.0 | |
| | | 1 | 5.0 | | 387 | | 10.2 | |
| | Fixed Head | ½ | 7.9 | | 618 | | 0 | |
| | | 1 | 11.4 | | 998 | | 0 | |
| **Steel H-Pile (Strong Axis)** | | | | | | | | |
| 14X73 | Free Head | ½ | 5.3 | | 428 | | 11.4 | |
| | | 1 | 7.5 | | 697 | | 12.6 | |
| | Fixed Head | ½ | 11.8 | | 1,114 | | 0 | |
| | | 1 | 17.1 | | 1,813 | | 0 | |

**Notes:**
(1) Lateral deflection at the top of the pile.
(2) The depth of maximum bending moment is referenced from the top of pile.

**Table 9-2. Individual Lateral Pile Capacities – Central Recommended Alignment (Coastal Spine) (Profile B-B')**

| Pile Size | Pile Top Fixity | Lateral Deflection[1] (inch) | Shear Force at the Surface (kips) | | Maximum Bending Moment (kips-inch) | | Depth of Maximum Bending Moment[2] (ft) | |
|---|---|---|---|---|---|---|---|---|
| | | | Uncracked | Cracked | Uncracked | Cracked | Uncracked | Cracked |
| **Pre-Cast Concrete Pile (PCP)** | | | | | | | | |
| 14-inch square | Free Head | ½ | 5.7 | 3.7 | 399 | 226 | 7.8 | 7.2 |
| | | 1 | 7.9 | 5.5 | 603 | 369 | 9.6 | 7.8 |
| | Fixed Head | ½ | 12.5 | 8.8 | 989 | 566 | 0 | 0 |
| | | 1 | 17.7 | 11.8 | 1,606 | 857 | 0 | 0 |
| 18-inch square | Free Head | ½ | 8.9 | 6.1 | 674 | 408 | 10.2 | 7.8 |
| | | 1 | 12.4 | 8.6 | 1,093 | 623 | 12.6 | 8.4 |
| | Fixed Head | ½ | 19.8 | 13.5 | 1,870 | 1,014 | 0 | 0 |
| | | 1 | 30.0 | 18.7 | 3,202 | 1,619 | 0 | 0 |
| **Steel H-Pile (Weak Axis)** | | | | | | | | |
| 14X73 | Free Head | ½ | 4.6 | | 303 | | 7.2 | |
| | | 1 | 6.5 | | 472 | | 7.8 | |
| | Fixed Head | ½ | 10.4 | | 739 | | 0 | |
| | | 1 | 14.1 | | 1,154 | | 0 | |
| **Steel H-Pile (Strong Axis)** | | | | | | | | |
| 14X73 | Free Head | ½ | 6.9 | | 504 | | 8.4 | |
| | | 1 | 9.4 | | 779 | | 10.8 | |
| | Fixed Head | ½ | 15.1 | | 1,318 | | 0 | |
| | | 1 | 22.2 | | 2,210 | | 0 | |

**Notes:**
(1) Lateral deflection at the top of the pile.
(2) The depth of maximum bending moment is referenced from the top of pile.

**Table 9-3. Individual Lateral Pile Capacities – Central Recommended Alignment (Coastal Spine) (Profile E-E')**

| Pile Size | Pile Top Fixity | Lateral Deflection[1] (inch) | Shear Force at the Surface (kips) | | Maximum Bending Moment (kips-inch) | | Depth of Maximum Bending Moment[2] (ft) | |
|---|---|---|---|---|---|---|---|---|
| | | | Uncracked | Cracked | Uncracked | Cracked | Uncracked | Cracked |
| **Square Pre-Cast Concrete Pile (PCP)** | | | | | | | | |
| 14-inch square | Free Head | ½ | 4.2 | 2.7 | 327 | 171 | 10.4 | 8.0 |
| | | 1 | 6.4 | 4.1 | 558 | 284 | 12.0 | 8.8 |
| | Fixed Head | ½ | 10.2 | 6.4 | 893 | 456 | 0 | 0 |
| | | 1 | 15.9 | 9.9 | 1,522 | 770 | 0 | 0 |
| 18-inch square | Free Head | ½ | 6.8 | 4.3 | 652 | 324 | 13.6 | 10.4 |
| | | 1 | 10.5 | 6.6 | 1,139 | 550 | 15.2 | 11.2 |
| | Fixed Head | ½ | 17.0 | 10.5 | 1,773 | 889 | 0 | 0 |
| | | 1 | 26.7 | 16.3 | 3,024 | 1,517 | 0 | 0 |
| **Steel H-Pile (Weak Axis)** | | | | | | | | |
| 14X73 | Free Head | ½ | 3.3 | | 236 | | 9.6 | |
| | | 1 | 5.1 | | 399 | | 10.4 | |
| | Fixed Head | ½ | 8.1 | | 638 | | 0 | |
| | | 1 | 12.5 | | 1,082 | | 0 | |
| **Steel H-Pile (Strong Axis)** | | | | | | | | |
| 14X73 | Free Head | ½ | 5.2 | | 453 | | 12.0 | |
| | | 1 | 8.0 | | 780 | | 12.6 | |
| | Fixed Head | ½ | 12.9 | | 1,234 | | 0 | |
| | | 1 | 20.2 | | 2,106 | | 0 | |

**Notes:**
(1) Lateral deflection at the top of the pile.
(2) The depth of maximum bending moment is referenced from the top of pile.

## 9.5 Lateral Group Effects

Lateral load capacity of a single isolated pile is generally based on acceptable lateral deflection. In general, for the same lateral deflection, the lateral load carrying capacity of a pile within a group will be less than that of an individual pile. Leading row piles generally experience less reduction in lateral capacity as compared to trailing row piles for the same head deflection criteria. The pile group arrangement and, more importantly, the center-to-center spacing between adjacent piles, have a significant impact on lateral group effects. Piles spaced greater than about 5 to 6 times the pile width or pile diameter, center-to-center, generally have limited group effects. We would be pleased to review the pile group configuration and perform lateral group analyses during the detailed design phase of this study.

### 9.6 Recommended Pile Penetrations

We recommend that the piles be installed to a depth sufficient enough to develop the axial capacity required to support the proposed structures with a factor of safety as recommended in Section 9.2. In addition, piles should be installed to a minimum depth to provide sufficient lateral support. If lateral loads are not applicable to the design, tip penetrations can be reduced in accordance with the required pile capacities. However, additional penetration may be required to satisfy the axial capacity or other design requirements. Table 9-4 presents our recommended pile penetrations based on our lateral capacity analysis.

**Table 9-4. Minimum Required Pile Penetrations Based on Lateral Capacity**

| Alignment | Area | Pile Type | Pile Size | Penetration Below Pile Top (ft) |
|---|---|---|---|---|
| Central Recommended Alignment (Coastal Spine) | Profile A-A’ | Steel H-Pile | 14 X 73 | 41 |
| | | Pre-Cast Concrete Pile | 14-inch square | 38 |
| | | | 18-inch square | 44 |
| South Recommended Alignment | Profile B-B’ | Steel H-Pile | 14 X 73 | 39 |
| | | Pre-Cast Concrete Pile | 14-inch square | 36 |
| | | | 18-inch square | 42 |
| | Profile E-E’ | Steel H-Pile | 14 X 73 | 33 |
| | | Pre-Cast Concrete Pile | 14-inch square | 40 |
| | | | 18-inch square | 36 |

### 9.7 Pile Settlement Considerations

A detailed settlement analysis for piles was not performed at the time of this report. However, based on the subsurface soil conditions at the site and our experience with similar soils, we expect that the total consolidation settlement of single, isolated piles, properly designed and installed following our recommendations, will be on the order of less than 1 inch. Groups of pile foundations will likely settle more than individual piles subject to the same load per pile. The increase in settlement between individual piles and groups is generally small for small sized groups (less than about a 5 by 5 group).

The settlement of pile groups is dependent on several variables including: dimension of the pile group, pile length, the sustained structural load, and the compressibility characteristics of the foundation soils. We would be pleased to perform a detailed group settlement analysis on a case-by-case basis during the detailed design phase of this study.

## 10.0 ADDITIONAL GEOTECHNICAL CONSIDERATIONS

This section discusses our recommendations for additional geotechnical study for the next phase of design per USACE publications such as the *Hurricane and Storm Damage Risk Reduction System Interim Design Guidelines* authored by the New Orleans District Engineering Division, dated June 2012.

### 10.1 Geotechnical Exploration Program

Based on the review of the available drawings provided by Arcadis, LJA Engineering, Inc., and RPS, we recommend that a geotechnical exploration plan be developed for additional land and marine borings/CPTs in the next phase of the study. Additional borings should be considered along the alignment where data gaps are present as well as at locations where the final alignment of the levee/T-wall and associated structures have a significant offset from the current drilling locations. In addition, Fugro recommends borings/CPTs at an interval of 250 ft along the levee for the next phase of the study.

Marine borings should be performed for the proposed facilities and structures that will be constructed in rivers, creeks, and channels. Prior to performing marine borings, it is important that bathymetry of the waterbodies is available to facilitate the selection of boring locations and barge equipment. These borings should be performed for the Galveston Bay Floating Sector Gates system, Galveston Combi-Walls, Neches River Sector Gates system, and the Bulkhead Closure Structure.

### 10.2 Geotechnical Study

Detailed analyses for the proposed and as-built levees and T-walls, sector gates, vertical lift gates, and associated facilities should be planned and performed.

#### 10.2.1 Levee and T-wall

Global slope stability should be performed to determine any unbalanced forces or need for stability berms to overcome driving forces. Typically, both the Spencer's Method and MVD Method of Planes should be used in order to meet USACE's criteria. The analyses should include wedge-shaped failure surface and critical optimized wedge surface block searches. In cases where tension is encountered in slices near the ground surface of the slip surface, tension cracks should be inserted accordingly.

Determination of T-wall pile capacities. Based on our knowledge, T-wall piles used for segments of the New Orleans levee system were driven to 90 ft to 100 ft deep. As per structural design requirement, we anticipate that some soil borings may be warranted to a depth greater than 60 ft below grade. The foundation support piles shall be designed such that settlement of the pile cap and horizontal deflection of the pile cap be less than 0.5 inch and 0.75 inches, respectively.

Seepage analysis to determine sheet-pile wall embedment elevation. Along the alignments with large amount of granular soils below grade, seepage erosion (piping) along the levee and T-wall system needs to be performed. Seepage below a floodwall is a very important consideration in the design.

Excessive underseepage could result in sand boils or heaving on the landside of the wall, which could possibly lead to loss of foundation support. If a large amount of granular soil is present immediately below grade, the pressure head at various locations below the wall needs to be determined in order to estimate the uplift force acting against the base of the T-wall. Several measures have been used to safely control and distribute seepage below a floodwall. Sheet-pile cutoffs are added many times when there is a pervious stratum below the wall. Toe drains at the landside bottom of the base slab have been used to help safely distribute underseepage and prevent the formation of sand boils. The analyses should include the gradient of seepage below and through the cross sections and upward gradients for piping safety evaluation.

<u>Longitudinal slope stability.</u> Determination of the levee slopes/T-wall tie-in, which typically defines the slope transition from the levee section to the T-wall.

<u>Downdrag or the effect of longitudinal levee slopes on the T-wall piles</u>. The grade changes and proximity of the proposed levee to T-walls along the levee alignment could cause downdrag effects on the T-wall piles. Based on the amount of levee fill and associated settlements estimated at the neutral plane per Fellenius' Method, T-wall settlements should be analyzed in the long term. T-walls consist of structural members on intervals to help support the stem of the wall. T-walls settlement analysis should be performed in accordance with EM 1110-1-1904. Depending upon the loading combination on the wall system, piles consisting of cutoff sheet piles and battered piles are usually used to support the weight and provide stability to the wall system. The piles transfer load to better soil conditions founded below the unsuitable foundation soils near the grade.

T-wall failure modes, including global stability, structural performance, and underseepage/piping, are typically considered viable for levee T-walls. Among the modes relating to the geotechnical investigation, global instability, consisting of overturning, sliding, and bearing capacity should be checked per the design criteria.

<u>Overturning analysis</u>. When assessing the overturning stability of a T-wall, the resultant location of the vertical force acting along the base slab of the wall needs to be determined. This information is used to determine how much of the base slab is acting in compression. If the resultant is located outside the limits of the base slab, then it is no longer acting in compression and the traditional limit state for overturning is exceeded. Moments are taken about the toe end of the base slab. Resisting moments include the weight of the structure (stem and slab), weight of material resting upon the structure, resisting soil pressure, and resisting water pressure. Driving moments include uplift, soil pressure, and water pressure. The overturning analysis may have to be evaluated for both drained and undrained soil conditions depending upon the type of soil, duration of loading, etc. Specific information related to how to assess T-walls with keys is provided in *EM 1110-2-2502 Retaining and Flood Walls*.

<u>Sliding analysis</u>. The same forces that contribute to or resist overturning failures also contribute to or resist sliding failures. Lateral forces (earth pressure, water pressure) push the wall in one direction or the other and vertical forces (concrete weight, soil weight, uplift, etc.) either add to or take away

from the normal force that supplies the frictional resistance along the sliding plane. When there is a key present, the sliding resistance at the base should be calculated using an estimate of the actual shear strength parameters of the soil. Limit equilibrium is used to assess the stability against sliding. The traditional limit state for a sliding analysis is when the shear force acting along the sliding plane exceeds the shear capacity of that plane. The shear plane (slip surface) can be a combination of planes or surfaces but is usually simplified as a plane for analysis purposes. Only force equilibrium is satisfied, not moment equilibrium (which is analyzed as part of the overturning analysis).

Bearing Capacity. The loading conditions used to assess the overturning analysis are used for assessing bearing capacity. The bearing capacity should be analyzed for the same plane analyzed as part of the sliding analysis. A normal and tangent force is computed for the structural wedge along the bearing plane. These forces are used to check the bearing capacity. The normal component of the ultimate bearing capacity is compared to the effective normal force (demand) applied to the structural wedge in a traditional limit state analysis.

**10.2.2 Floating Sector Gates**

We understand that for the Floating Sector Gates, two man-made islands will be constructed for supporting the gate system in Galveston Bay. A total of 33 sheet pile cellular cofferdams of the size of 75 ft and 101 ft in diameter are planned for forming a continuous bulkhead wall along the perimeter of each support island. The cofferdams will be filled with a combination of sand and concrete. The geotechnical investigation program should be conducted in general reference to *EM 1110-2-2503 Design of Sheet Pile Cellular Structures Cofferdams and Retaining Structures*. The geotechnical analysis should consider the failure modes including slope sliding stability, overturning, rotation, bearing capacity, and deep-seated sliding analyses.

Slope Sliding Stability. The overall stability should be evaluated for the potential of a global-type slope failure. The computed factor of safety is the ratio of the forces resisting movement to the driving forces. A factor of safety of 1.0 or less implies the slope is unstable, while a factor of safety greater than 1.0 implies that the slope is computed to be stable. Acceptable factors of safety depend upon many factors such as loading conditions, selection criteria used for strength parameters, risk of failure etc.

Seismic sliding stability. The sliding stability of a sheet pile cofferdam for an earthquake-induced base motion should be checked by assuming that the specified horizontal earthquake acceleration, and the vertical earthquake acceleration, if in the analysis, will act in the most unfavorable direction.

Overturning Potential. Soil-filled cellular cofferdams may fail by overturning or tilting about the toe of the inboard side while water load is built up on the onboard side.

Rotation Potential. Soil-filled cellular cofferdams may fail by rotating along a circular sliding surface in the cell fill or in the foundation soil intercepting the toe of the sheet piles. The analysis can be performed by using the Hansen's Method to assume failure surfaces to be convex or concave by trial until the minimum factor of safety is determined.

Bearing Capacity. Soil-filled cellular cofferdams must rest on a base of firm material that possesses the bearing capacity to sustain the weight of the filled cellular structure. The bearing capacity of both cohesive and granular soils supporting cellular structures can be determined by Terzaghi's method and Hansen's method.

Deep-Seated Sliding. The soil-filled cellular cofferdam may fail by sliding along any weak seam below the cellular structure before other types of failure could occur. The deep-seated sliding analysis can be performed by using the Approximate Method, which is usually applicable when the weak seam exists near the bottom of the cellular structure.

Per the USACE publications, the following analyses should also be performed,

a. Lateral capacities of the sheet piles in responding to fill inside the cofferdams.

b. Pile foundations for sector gate design checked for stability using the same procedures as T-walls.

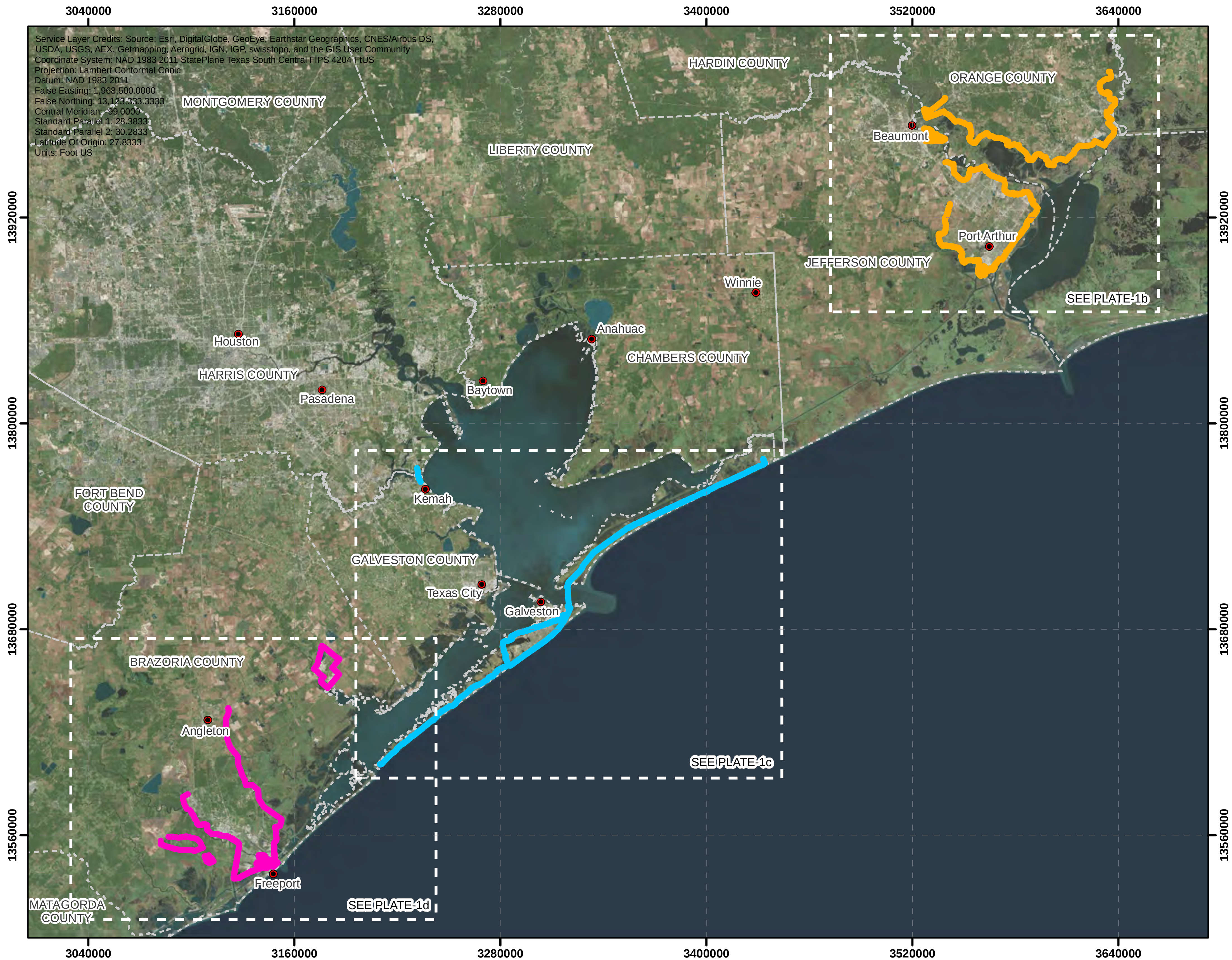
c. Settlement estimates for the man-made island and associated individual cofferdam fill and sheet pile cofferdam. Due to complexity of the structure and soil conditions, it is usually necessary to use finite element program such as PLAXIS to incorporate the soil-pile interaction and negative skin friction due to the placement of fill for forming the support islands.

d. Seepage analysis: Generally, two types of seepage are considered for designing a sheet pile cofferdam: seepage through the cell fill and foundation underseepage.

### 10.2.3 Pile Load Test Program

Preconstruction and production static and dynamic pile testing program should be developed to verify the geotechnical capacity and pile length reaching the design elevations. Pile drivability studies using the GRLWEAP software should also be included for various pile-hammer systems suitable for the subsurface soil profile. Pile restrikes should be performed after initial installation to assess soil set up and consequent gain in pile capacity with time.

# ILLUSTRATIONS

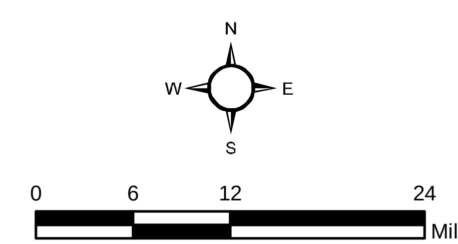



**LEGEND**

- North Recommended Alignment
- Central Recommended Alignment (Coastal Spine)
- South Recommended Alignment

**NOTES:**

1. ALIGNMENTS PROVIDED BY DANNENBAUM.
2. SEE PLATES 1b-1d FOR DETAILS ON THE ALIGNMENTS.




**OVERALL SITE MAP**

STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS
JEFFERSON AND ORANGE COUNTIES, TEXAS

PLATE 1a

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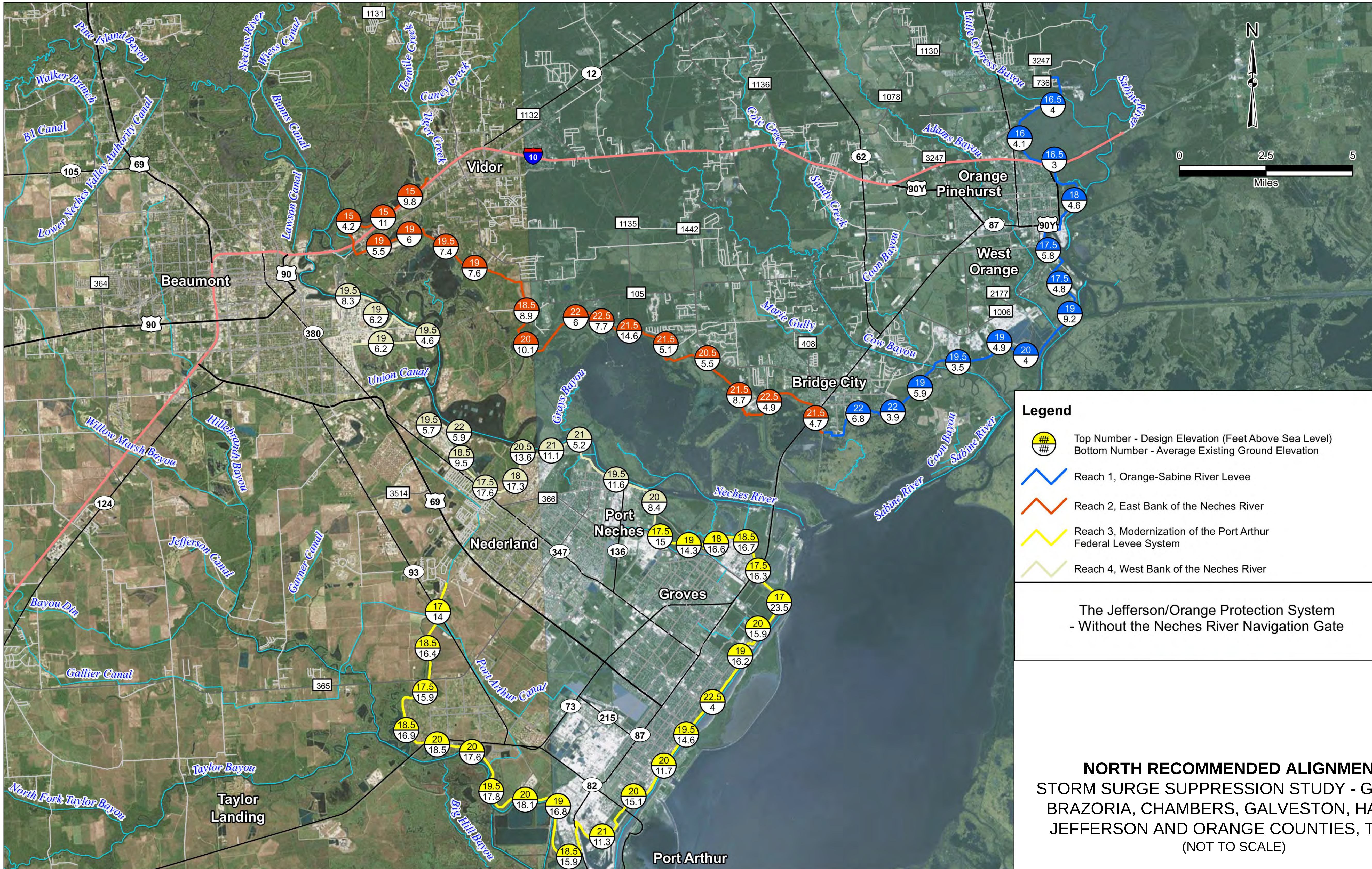


# NORTH RECOMMENDED ALIGNMENT

STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS
(NOT TO SCALE)

PLATE 1b

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REVISION: 0

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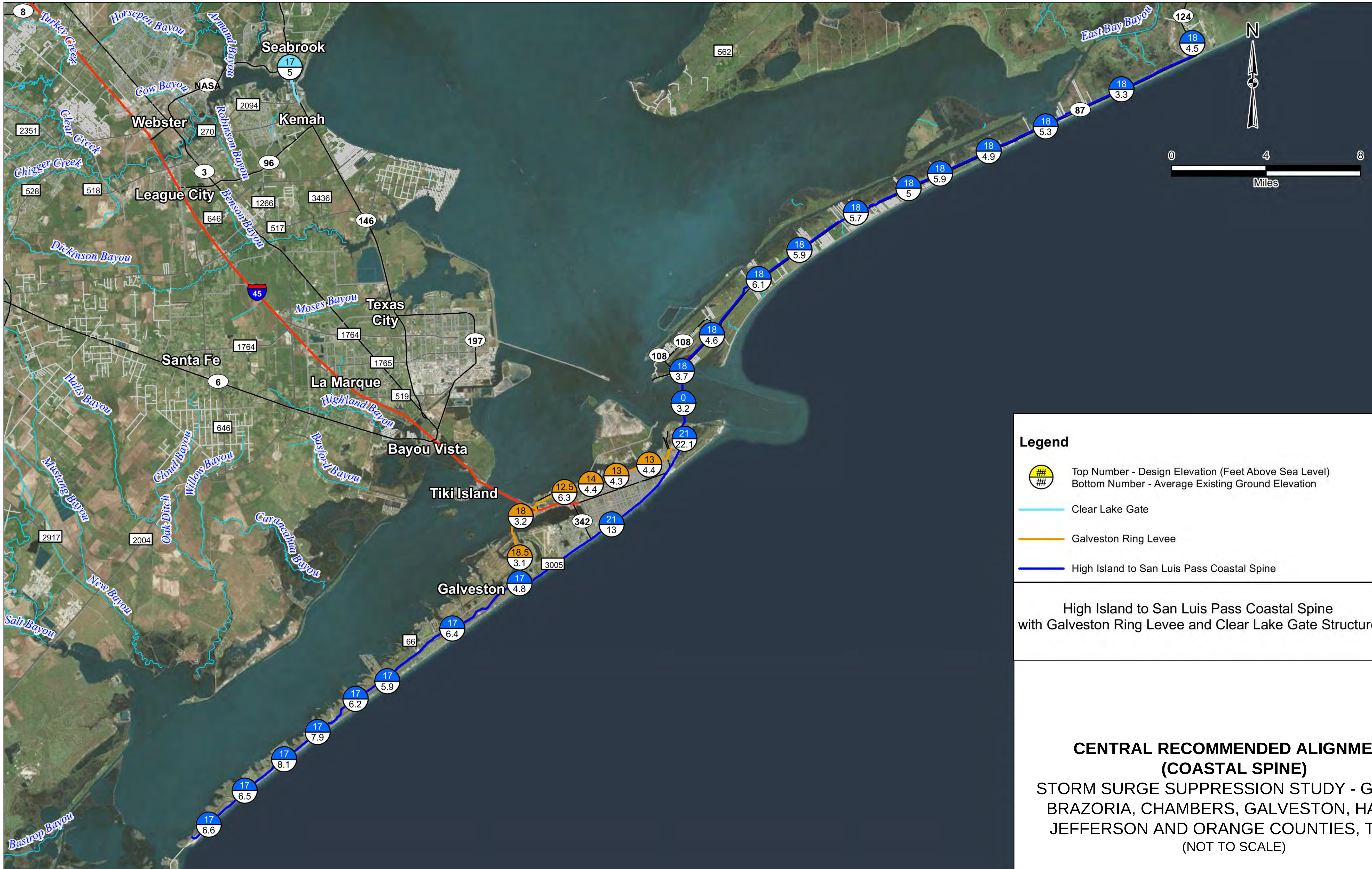


**CENTRAL RECOMMENDED ALIGNMENT (COASTAL SPINE)**

STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON AND ORANGE COUNTIES, TEXAS
(NOT TO SCALE)

PLATE 1c

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REVISION: 0

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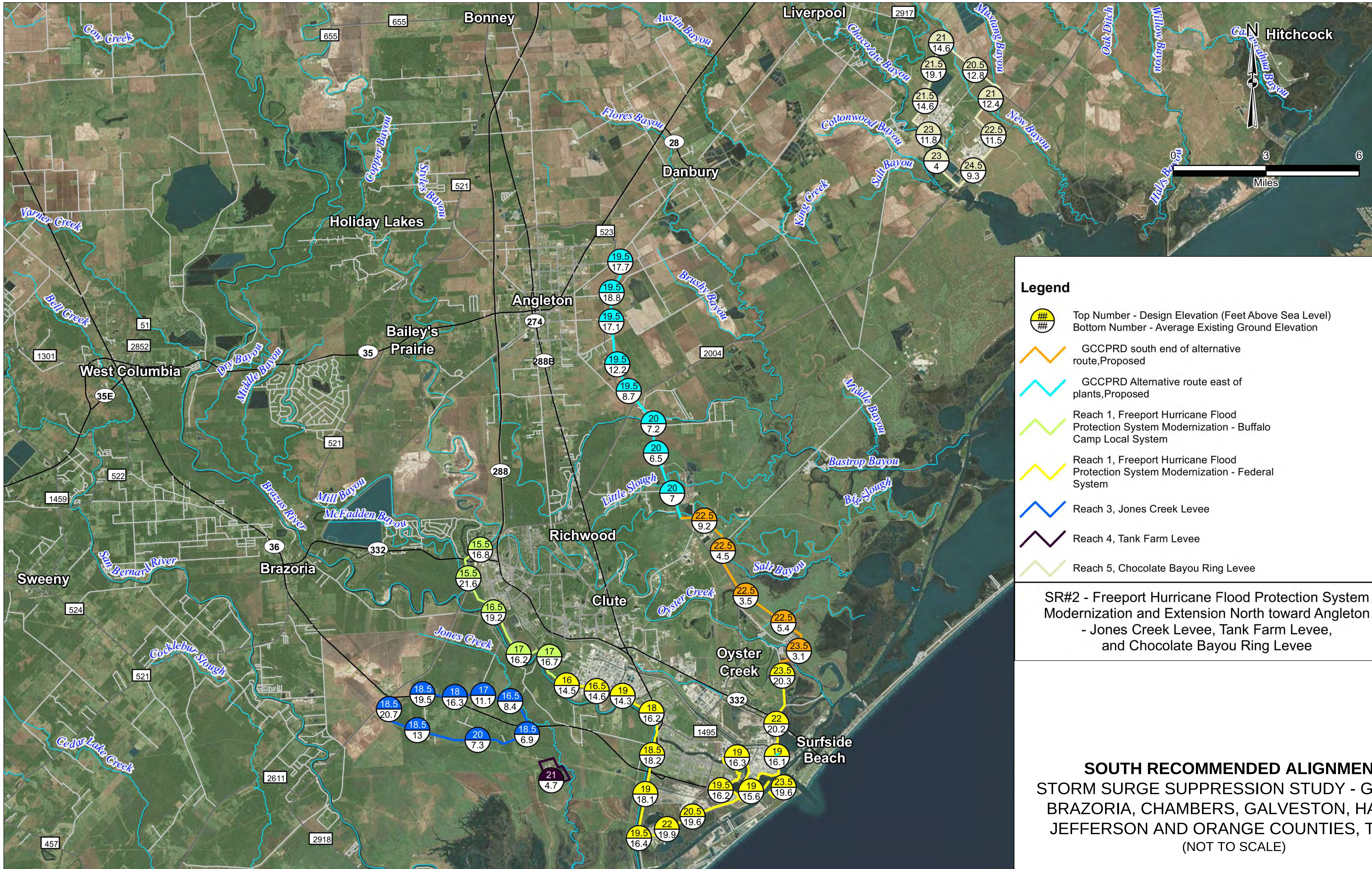


**SOUTH RECOMMENDED ALIGNMENT**

STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON AND ORANGE COUNTIES, TEXAS
(NOT TO SCALE)

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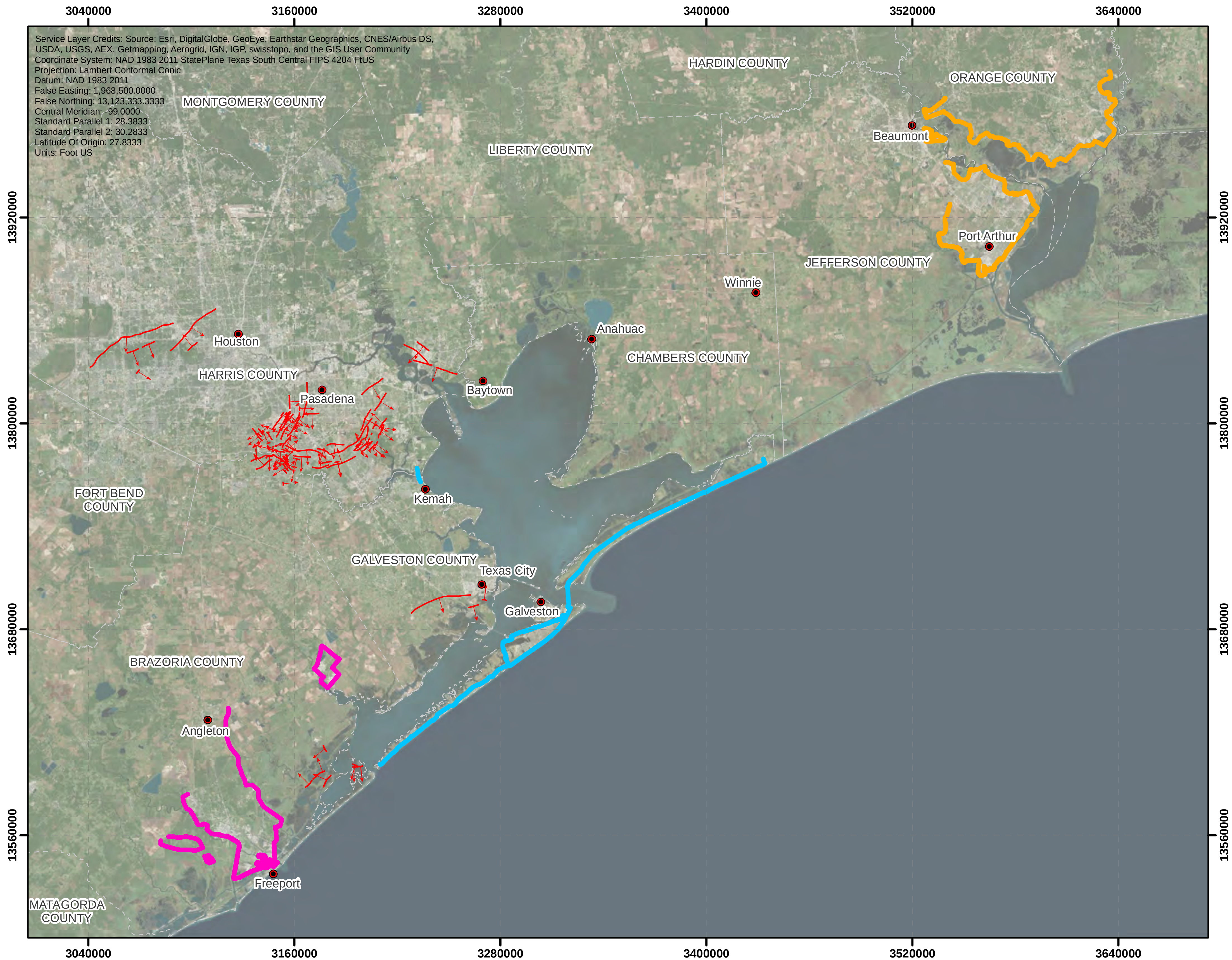



**LEGEND**

North Recommended Alignment

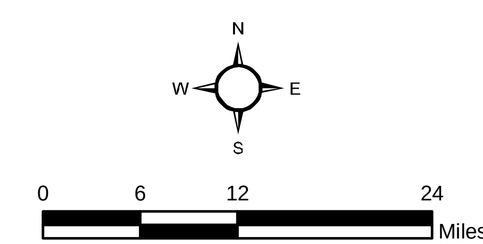
Central Recommended Alignment (Coastal Spine)

South Recommended Alignment

Normal Faults

**NOTES:**

1. ALIGNMENTS PROVIDED BY DANNENBAUM.
2. REFERENCE : GEOLOGIC DATABASE OF TEXAS (https://tnris.org/data-catalog/entry/geologic-database-of-texas/)

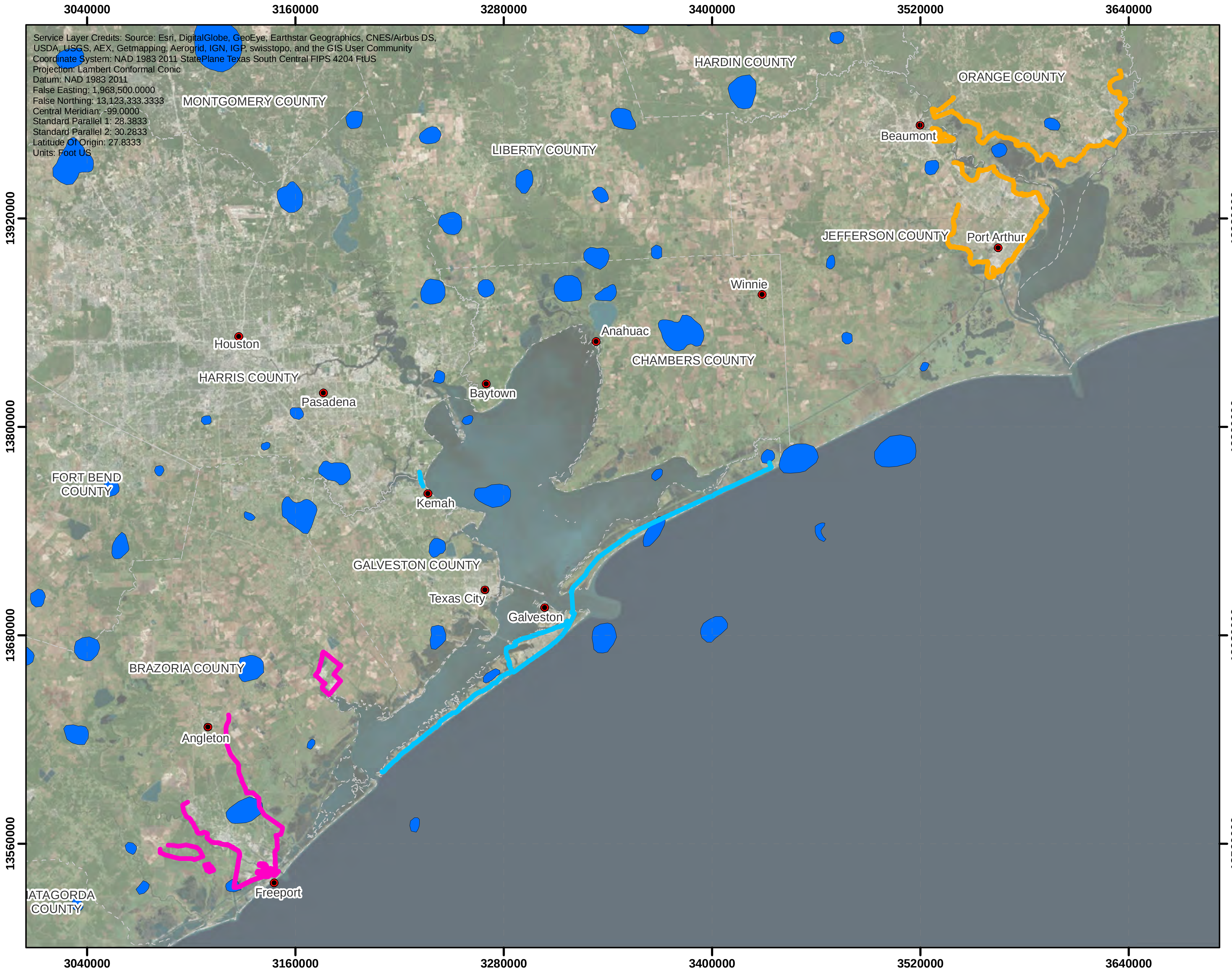



**MAP OF SURFACE FAULTING**

STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS
JEFFERSON AND ORANGE COUNTIES, TEXAS

PLATE 2

R:\04100\2016 Projects\0100-0199\04.10160148 - GCCPRD Storm Surge Phase 4\00_GIS\MXD\Report\Plate-2_Map of Surface Faulting.mxd, 10/12/2017, k.kim




**LEGEND**

- North Recommended Alignment
- Central Recommended Alignment (Coastal Spine)
- South Recommended Alignment
- Salt Domes

**NOTES:**

1. ALIGNMENTS PROVIDED BY DANNENBAUM.
2. REFERENCE : Huffman, A. C. et al., 2004. Salt Diapirs in the Gulf Coast. U.S. Geological Survey, DS-90, version 1.0.

N
W E
S

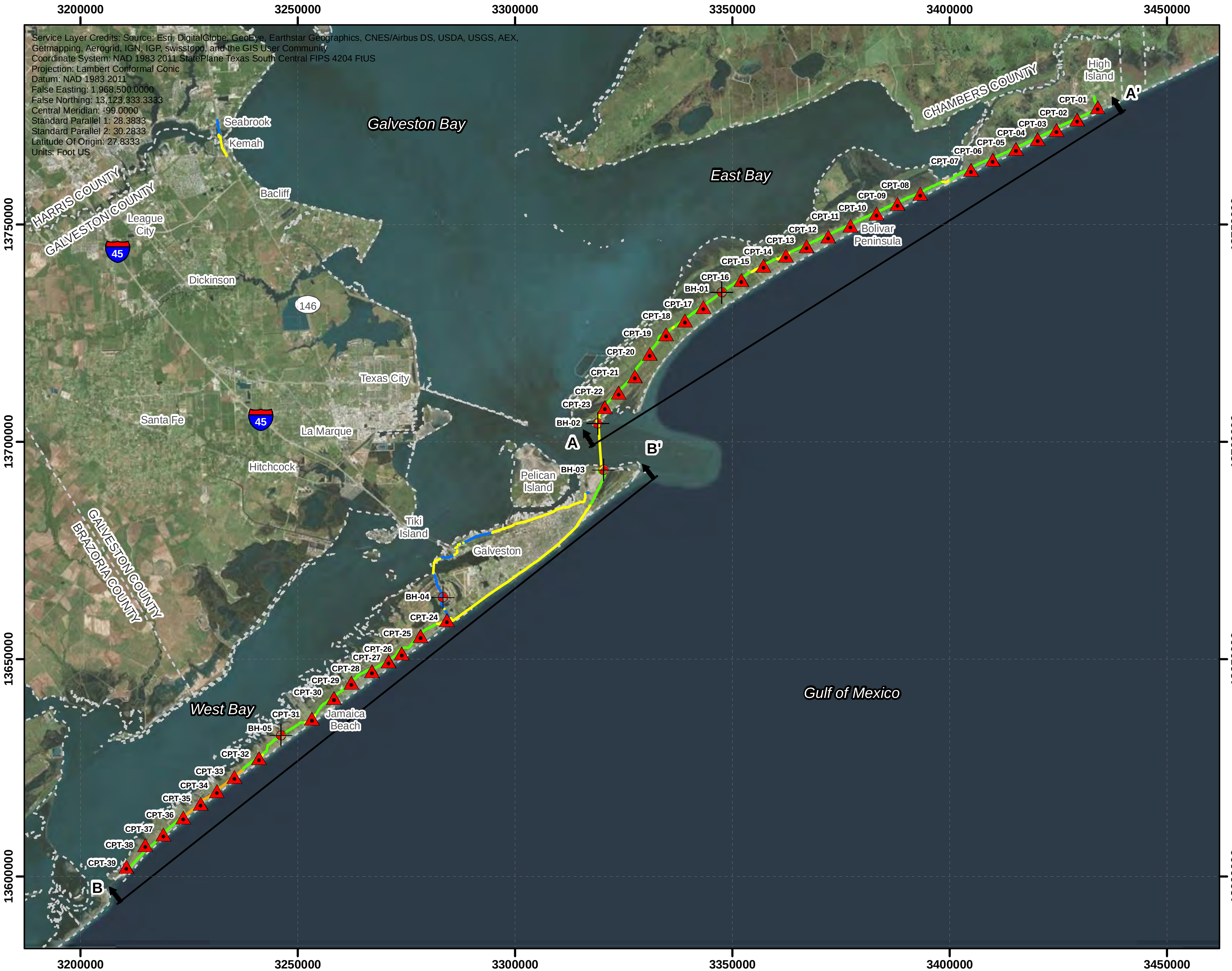
0 6 12 24
Miles

**MAP OF SALT DOMES**

STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS
JEFFERSON AND ORANGE COUNTIES, TEXAS

PLATE 3

R:\04100\2016 Projects\0100-0199\04.10160148 - GCCPRD Storm Surge Phase 4\00_GIS\MXD\Report\Plate-3_Map of Salt Domes.mxd, 10/12/2017, k.kim




**LEGEND**

GEOTECHNICAL BORINGS (CURRENT)

CONE PENETRATION TEST (CURRENT)

SUBSURFACE PROFILE

**LOCATION OF T-WALL / LEVEE**

ELEVATED HIGHWAY

LEVEE WITH BERM

LEVEE WITHOUT BERM

VERTICAL WALL

**NOTES:**

1. EXPLORATION LOCATIONS ARE APPROXIMATE.
2. PROPOSED ALIGNMENTS PROVIDED BY DANNENBAUM.

N
W
E
S

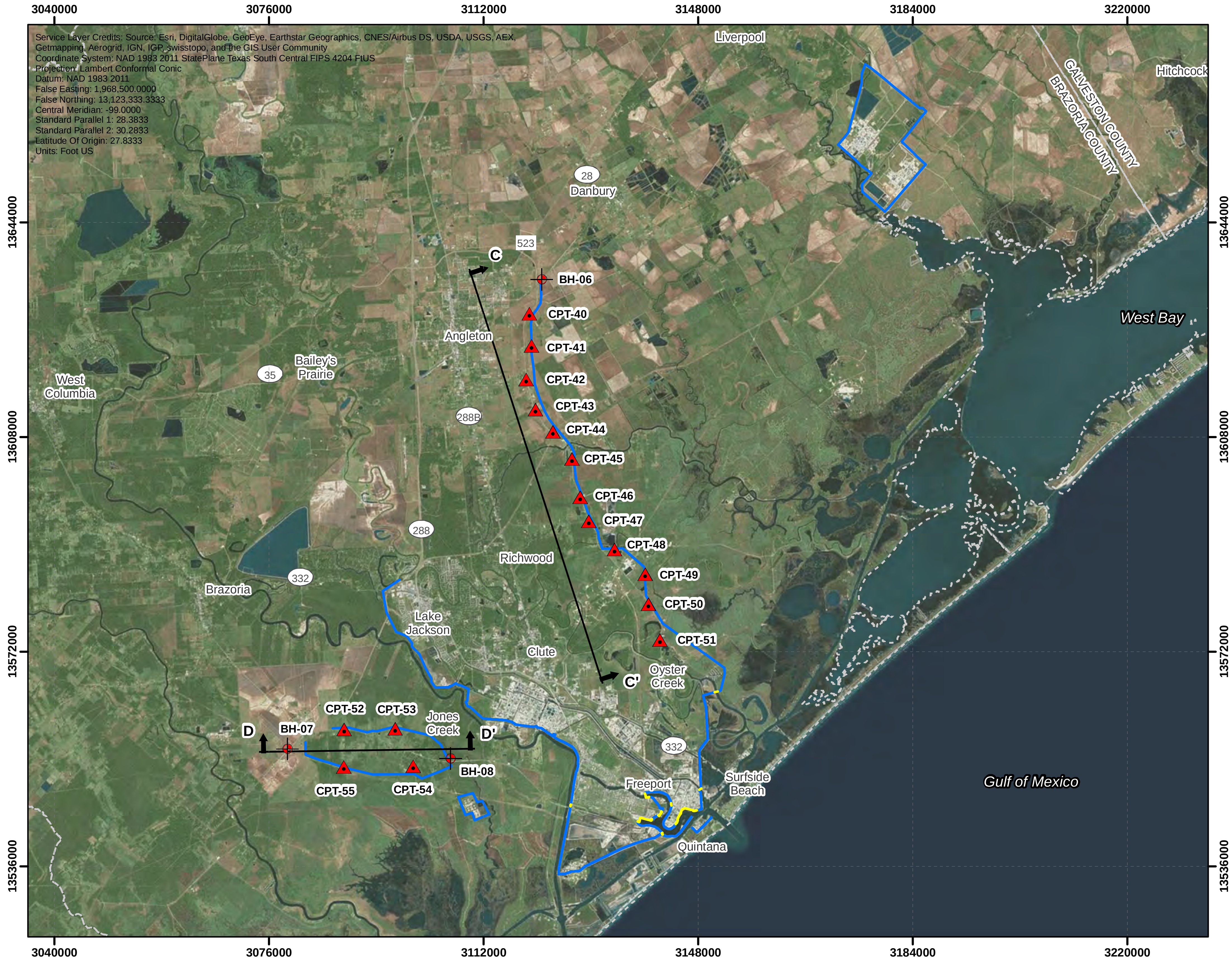
0 12,500 25,000 50,000
Feet

**PLAN OF EXPLORATIONS - CENTRAL RECOMMENDED ALIGNMENT (COASTAL SPINE)**

STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS
JEFFERSON AND ORANGE COUNTIES, TEXAS

PLATE 4a

R:\04100\2016 Projects\0100-0199\04.10160148 - GCCPRD Storm Surge Phase 4\00_GIS\MXD\Report\Plate-4a_Plan of Exploration.mxd, 10/16/2017, k.kim




## LEGEND

GEOTECHNICAL BORINGS (CURRENT)

CONE PENETRATION TEST (CURRENT)

SUBSURFACE PROFILE

### LOCATIONS OF T-WALL / LEVEE

ELEVATED HIGHWAY

LEVEE WITH BERM

LEVEE WITHOUT BERM

VERTICAL WALL

**NOTES:**

1. EXPLORATION LOCATIONS ARE APPROXIMATE.
2. PROPOSED ALIGNMENTS PROVIDED BY DANNENBAUM.

N
W E
S

0 9,000 18,000 36,000
Feet

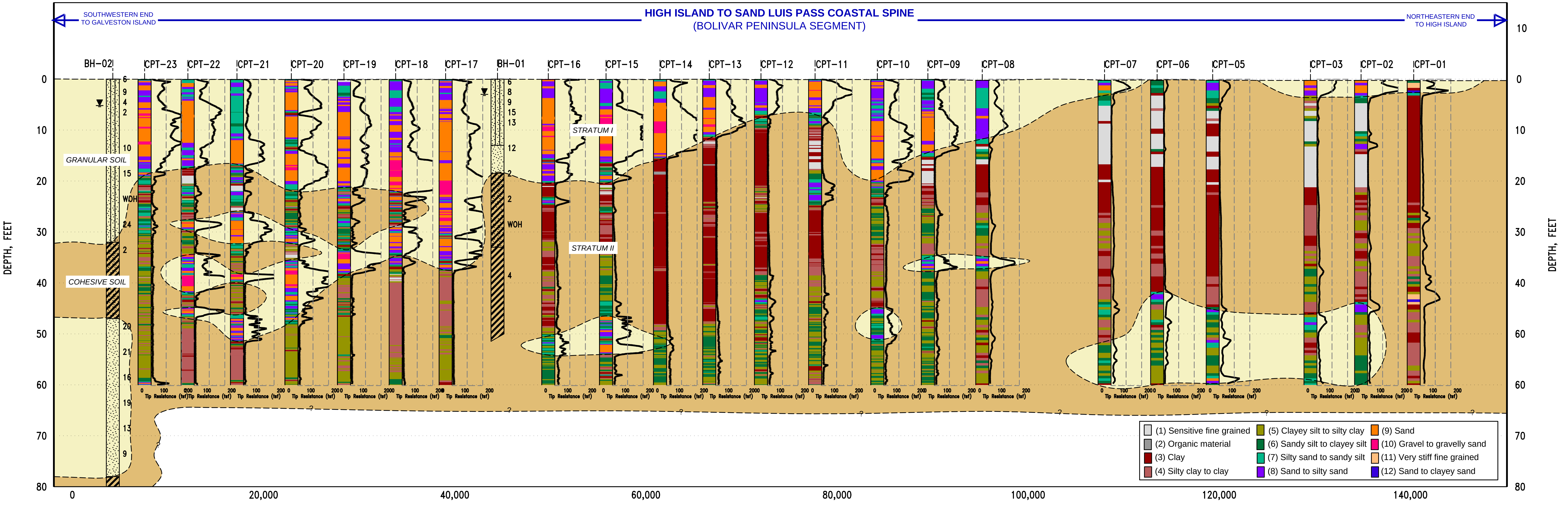
**PLAN OF EXPLORATIONS -**
**SOUTH RECOMMENDED ALIGNMENT**

STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS
JEFFERSON AND ORANGE COUNTIES, TEXAS

PLATE 4b

R:\04100\2016 Projects\0100-0199\04.10160148 - GCCPRD Storm Surge Phase 4\00_GIS\MXD\Report\Plate-4b_Plan of Exploration.mxd, 10/16/2017, k.kim

FUGRO

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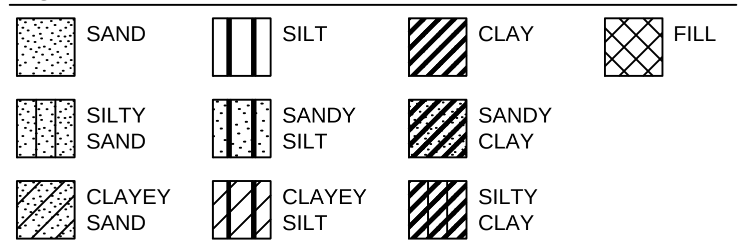


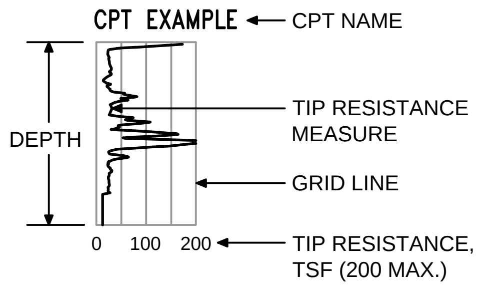


**NOTES:**

1. DATA CONCERNING SUBSURFACE CONDITIONS HAVE BEEN OBTAINED AT BORING AND CPT LOCATIONS ONLY. ACTUAL CONDITIONS AT LOCATIONS BETWEEN BORINGS AND CPT LOCATIONS MAY VARY FROM THE GENERALIZED SOIL PROFILE SHOWN HERE.
2. THE MAXIMUM DEPTH OF BORING BH-02 IS 400 FEET.
3. SEE PLATE 4a FOR EXPLORATIONS AND SUBSURFACE LINE LOCATIONS.
4. HORIZONTAL NOT TO SCALE.

**GENERALIZED SUBSURFACE PROFILE SECTION A-A'**
**CENTRAL RECOMMENDED ALIGNMENT**
**(COASTAL SPINE) - BOLIVAR PENINSULA**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS

0 15 30 FEET
VERTICAL SCALE

PLATE 5a

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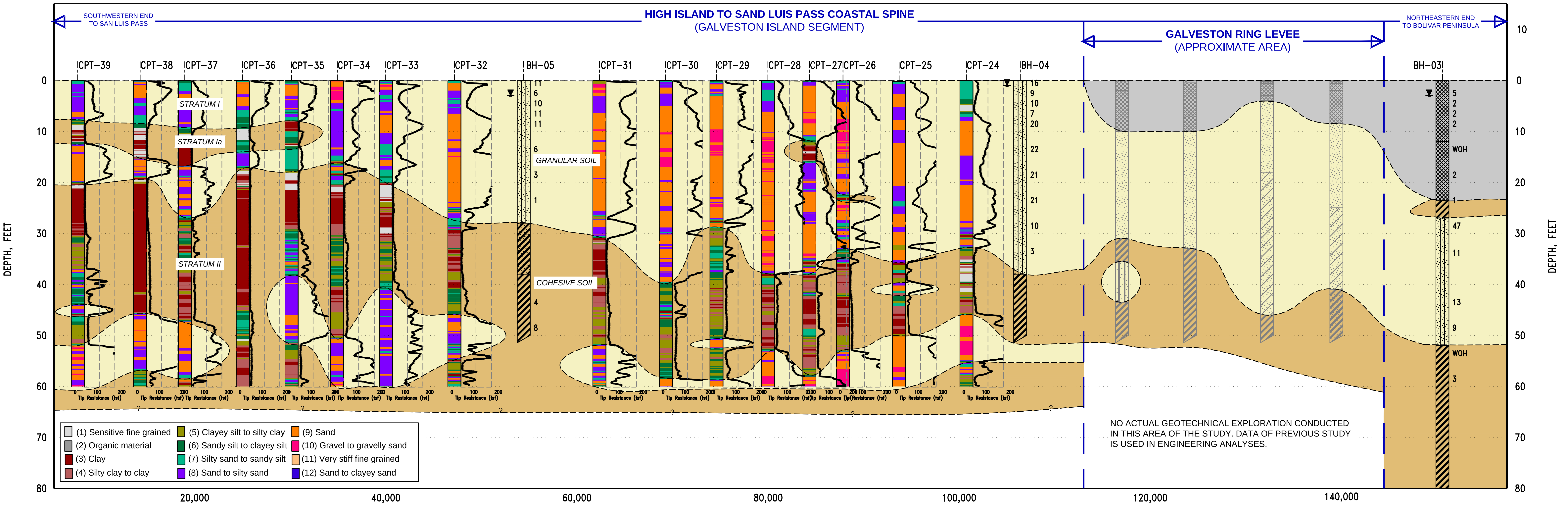
REVISION: 0

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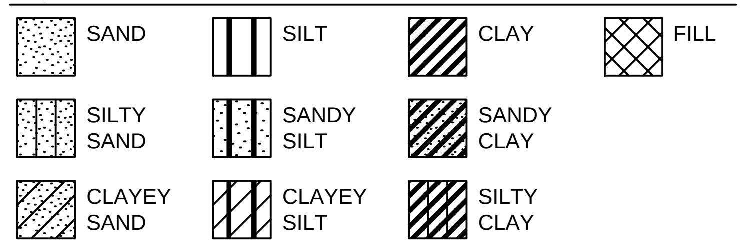


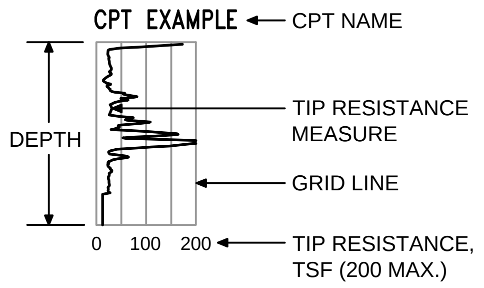


**NOTES:**
1. DATA CONCERNING SUBSURFACE CONDITIONS HAVE BEEN OBTAINED AT BORING AND CPT LOCATIONS ONLY. ACTUAL CONDITIONS AT LOCATIONS BETWEEN BORINGS AND CPT LOCATIONS MAY VARY FROM THE GENERALIZED SOIL PROFILE SHOWN HERE.
2. THE MAXIMUM DEPTH OF BORING BH-03 IS 400 FEET.
3. SEE PLATE 4a FOR EXPLORATIONS AND SUBSURFACE LINE LOCATIONS.
4. HORIZONTAL NOT TO SCALE.

**GENERALIZED SUBSURFACE PROFILE SECTION B-B'**
**CENTRAL RECOMMENDED ALIGNMENT**
**(COASTAL SPINE) - GALVESTON ISLAND**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON AND ORANGE COUNTIES, TEXAS

0 15 30 FEET
VERTICAL SCALE



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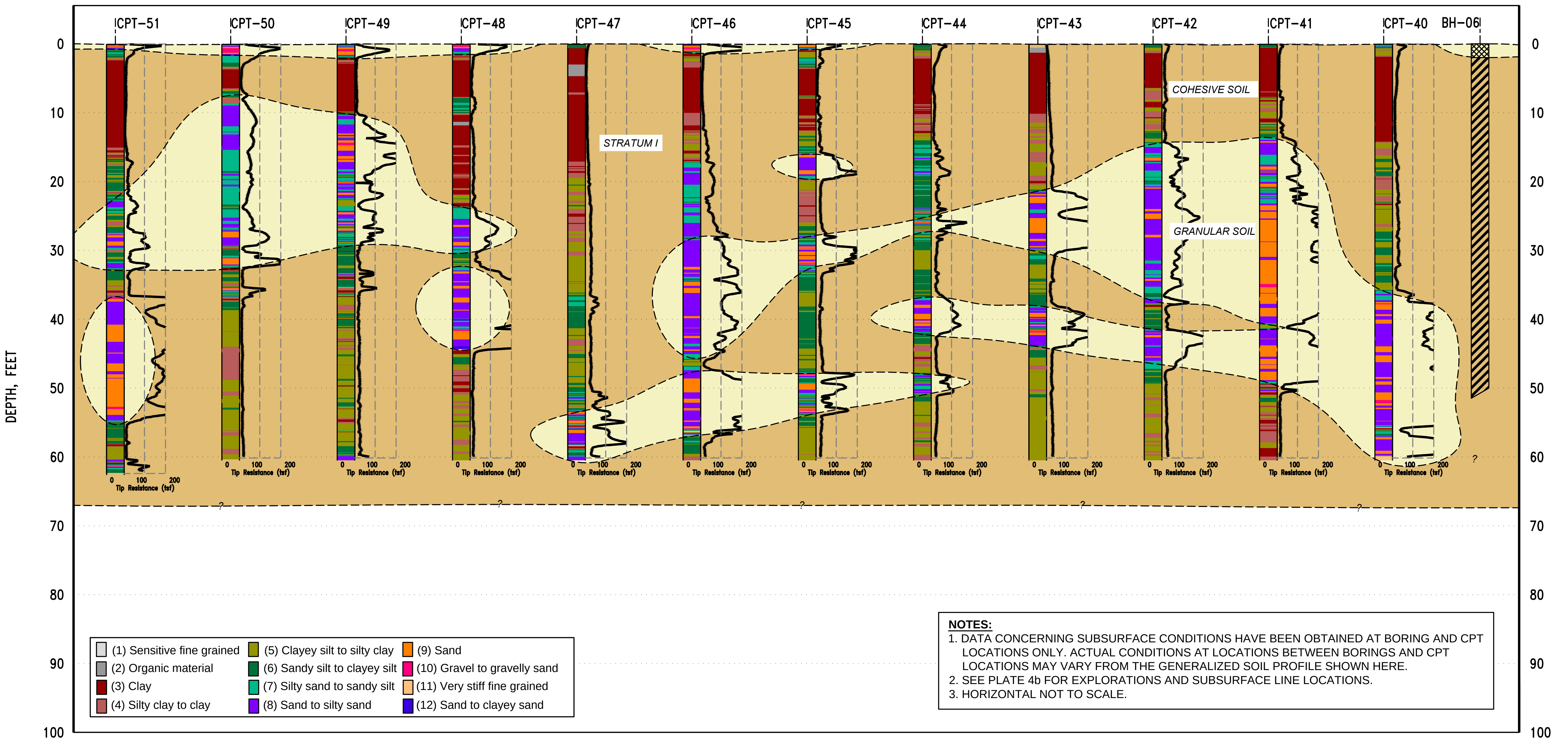
REVISION: 0

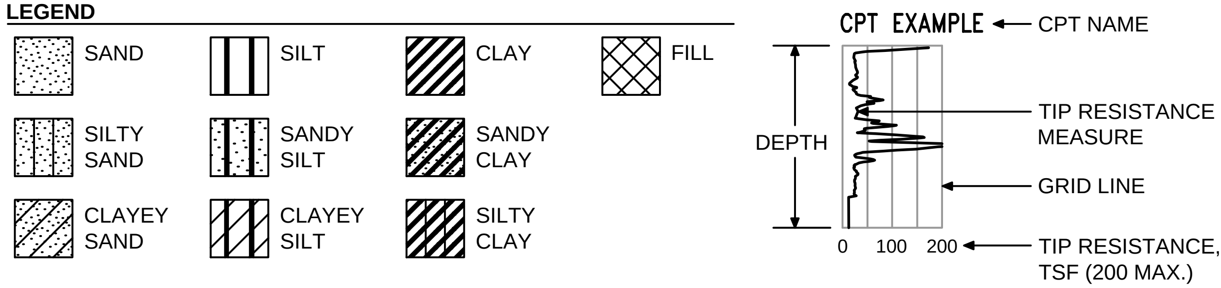
Report No. 04.10160148




**NOTES:**

1. DATA CONCERNING SUBSURFACE CONDITIONS HAVE BEEN OBTAINED AT BORING AND CPT LOCATIONS ONLY. ACTUAL CONDITIONS AT LOCATIONS BETWEEN BORINGS AND CPT LOCATIONS MAY VARY FROM THE GENERALIZED SOIL PROFILE SHOWN HERE.
2. SEE PLATE 4b FOR EXPLORATIONS AND SUBSURFACE LINE LOCATIONS.
3. HORIZONTAL NOT TO SCALE.

**LEGEND**




**GENERALIZED SUBSURFACE PROFILE SECTION C-C'**
**SOUTH RECOMMENDED ALIGNMENT**
**EAST OF PLANTS**

STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON AND ORANGE COUNTIES, TEXAS

0 15 30 FEET
VERTICAL SCALE

PLATE 5c

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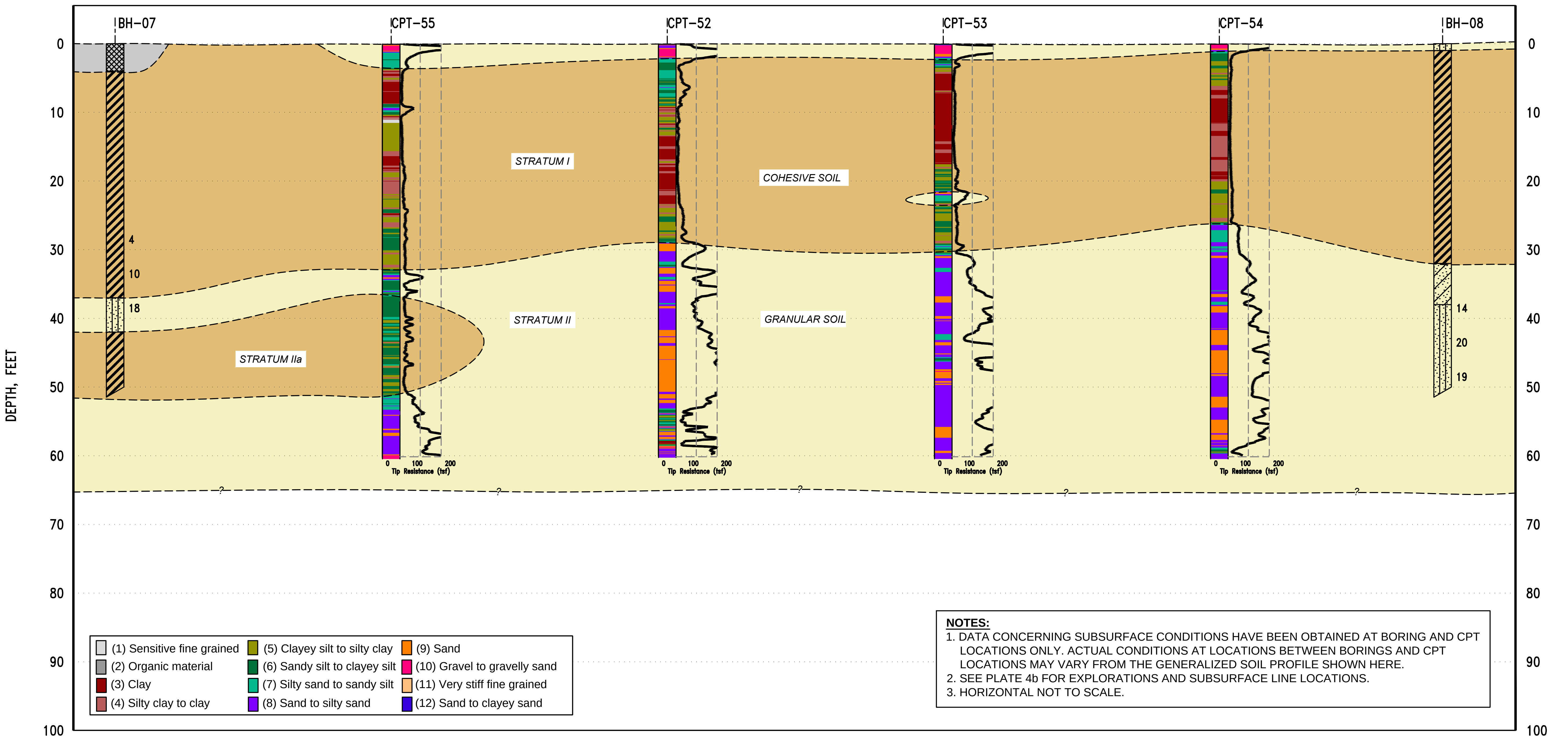
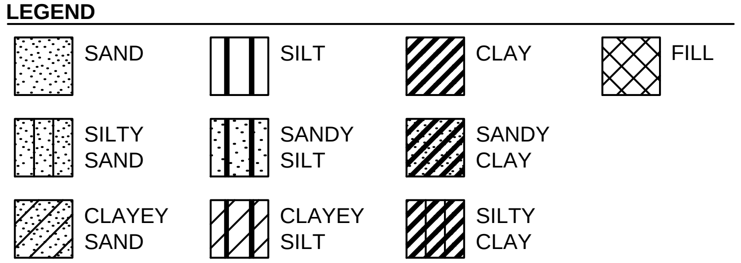
REVISION: 0

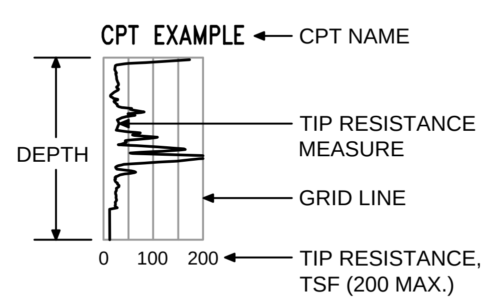



**NOTES:**

1. DATA CONCERNING SUBSURFACE CONDITIONS HAVE BEEN OBTAINED AT BORING AND CPT LOCATIONS ONLY. ACTUAL CONDITIONS AT LOCATIONS BETWEEN BORINGS AND CPT LOCATIONS MAY VARY FROM THE GENERALIZED SOIL PROFILE SHOWN HERE.
2. SEE PLATE 4b FOR EXPLORATIONS AND SUBSURFACE LINE LOCATIONS.
3. HORIZONTAL NOT TO SCALE.

**LEGEND**




**GENERALIZED SUBSURFACE PROFILE SECTION D-D'**
**SOUTH RECOMMENDED ALIGNMENT**
**JONES CREEK LEVEE AND BUFFALO CAMP SYSTEM**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON AND ORANGE COUNTIES, TEXAS

0 15 30 FEET
VERTICAL SCALE

PLATE 5d

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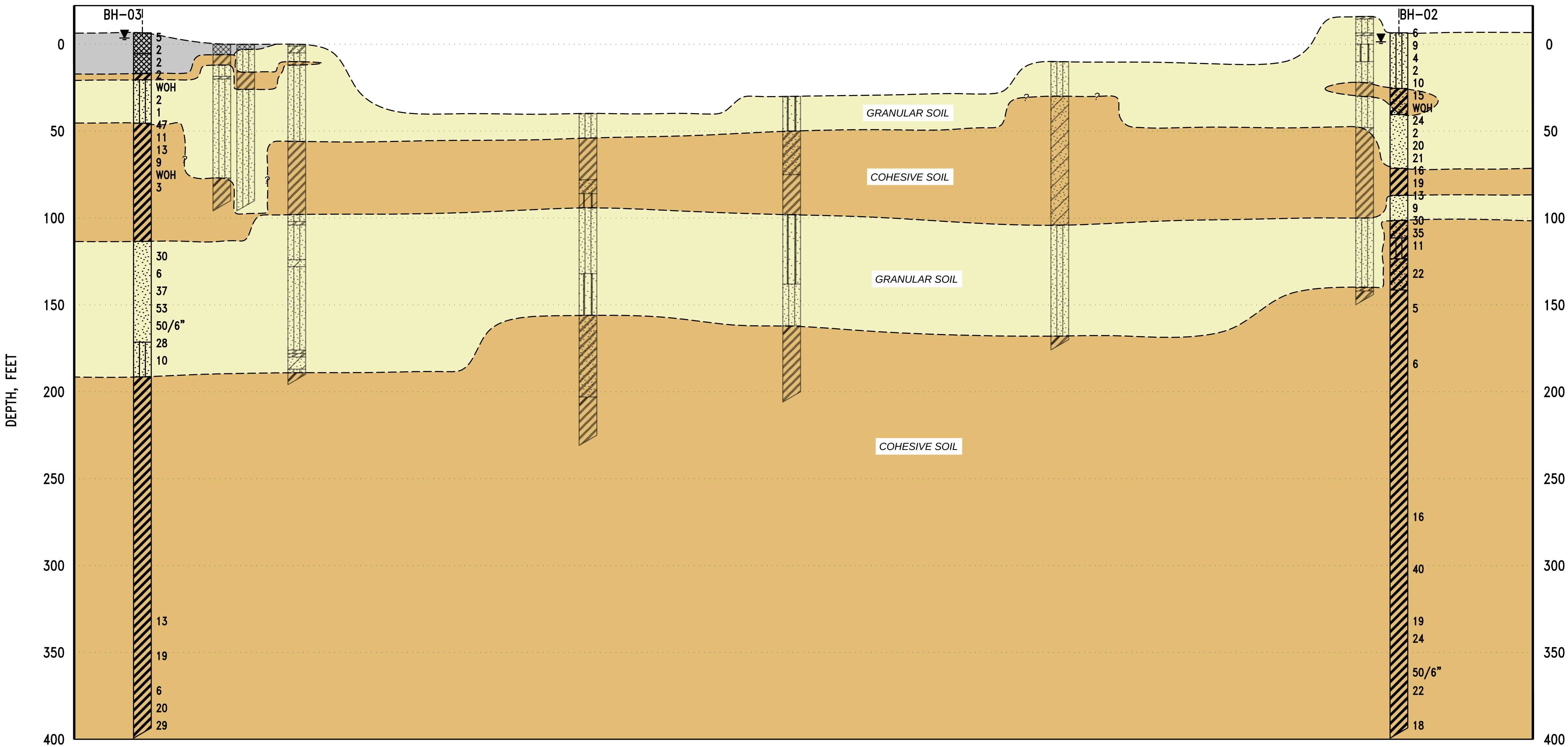
REVISION: 0

Report No. 04.10160148




**LEGEND**

SAND | SILT | CLAY | FILL
SILTY SAND | SANDY SILT | SANDY CLAY
CLAYEY SAND | CLAYEY SILT | SILTY CLAY

NOTES:
1. DATA CONCERNING SUBSURFACE CONDITIONS HAVE BEEN OBTAINED AT BORING LOCATIONS ONLY. ACTUAL CONDITIONS AT LOCATIONS BETWEEN BORING LOCATIONS MAY VARY FROM THE GENERALIZED SOIL PROFILE SHOWN HERE.
2. SEE PLATE 4b FOR EXPLORATIONS AND SUBSURFACE LINE LOCATIONS.
3. HORIZONTAL NOT TO SCALE.

**GENERALIZED SUBSURFACE PROFILE**
**GALVESTON BAY FLOATING SECTOR GATE**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON AND ORANGE COUNTIES, TEXAS

0 60 120 FEET
VERTICAL SCALE

PLATE 5e

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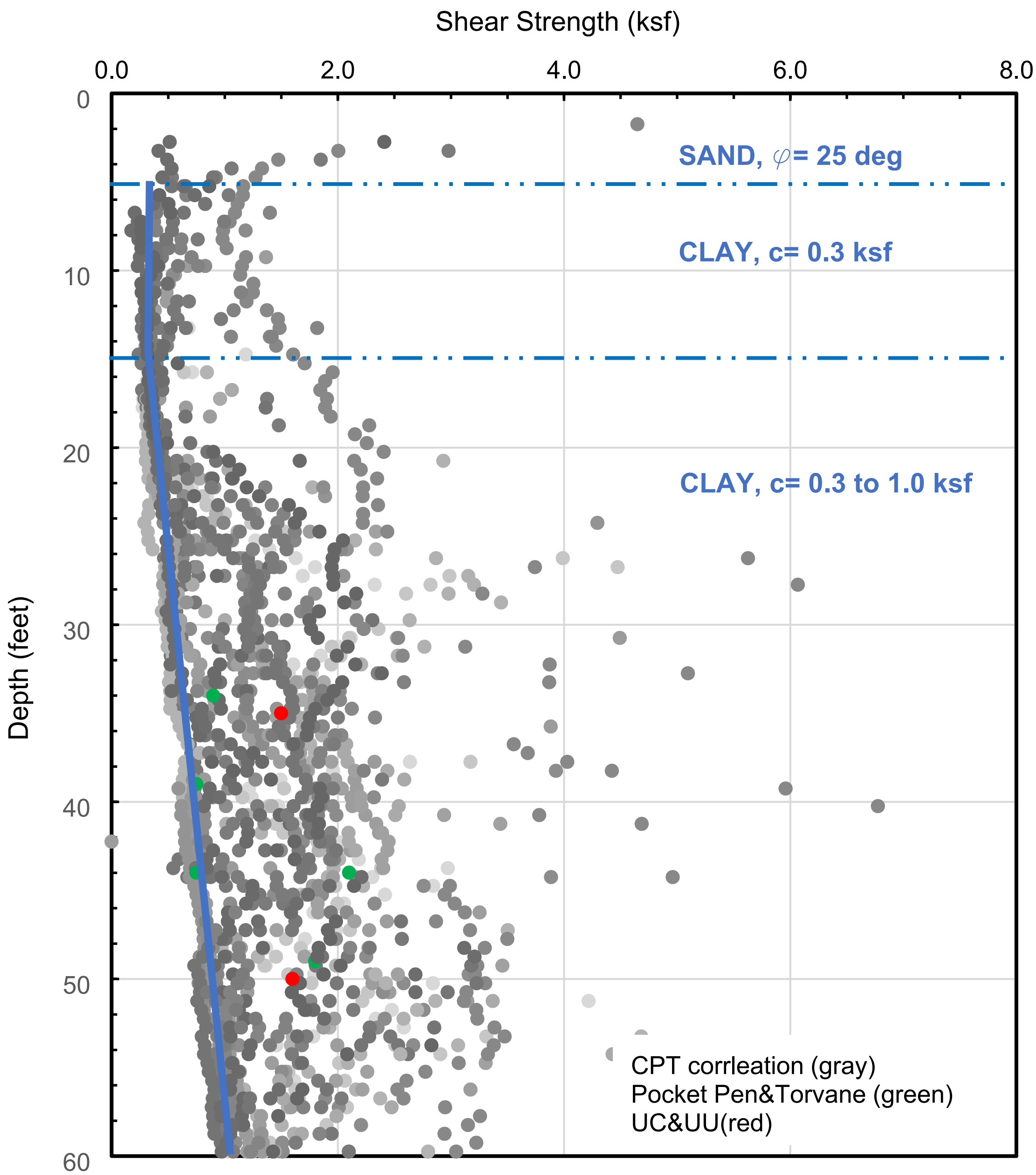
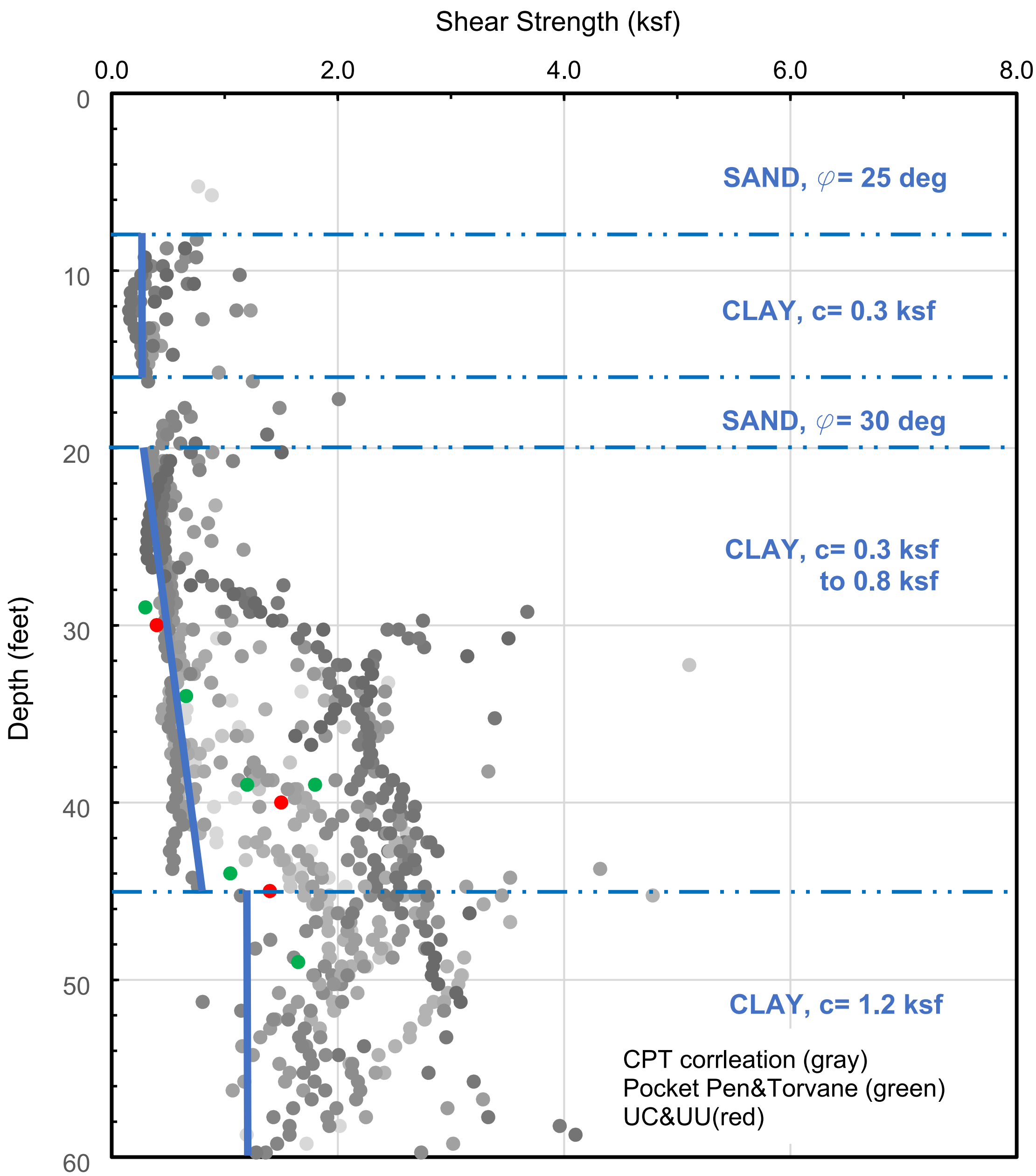
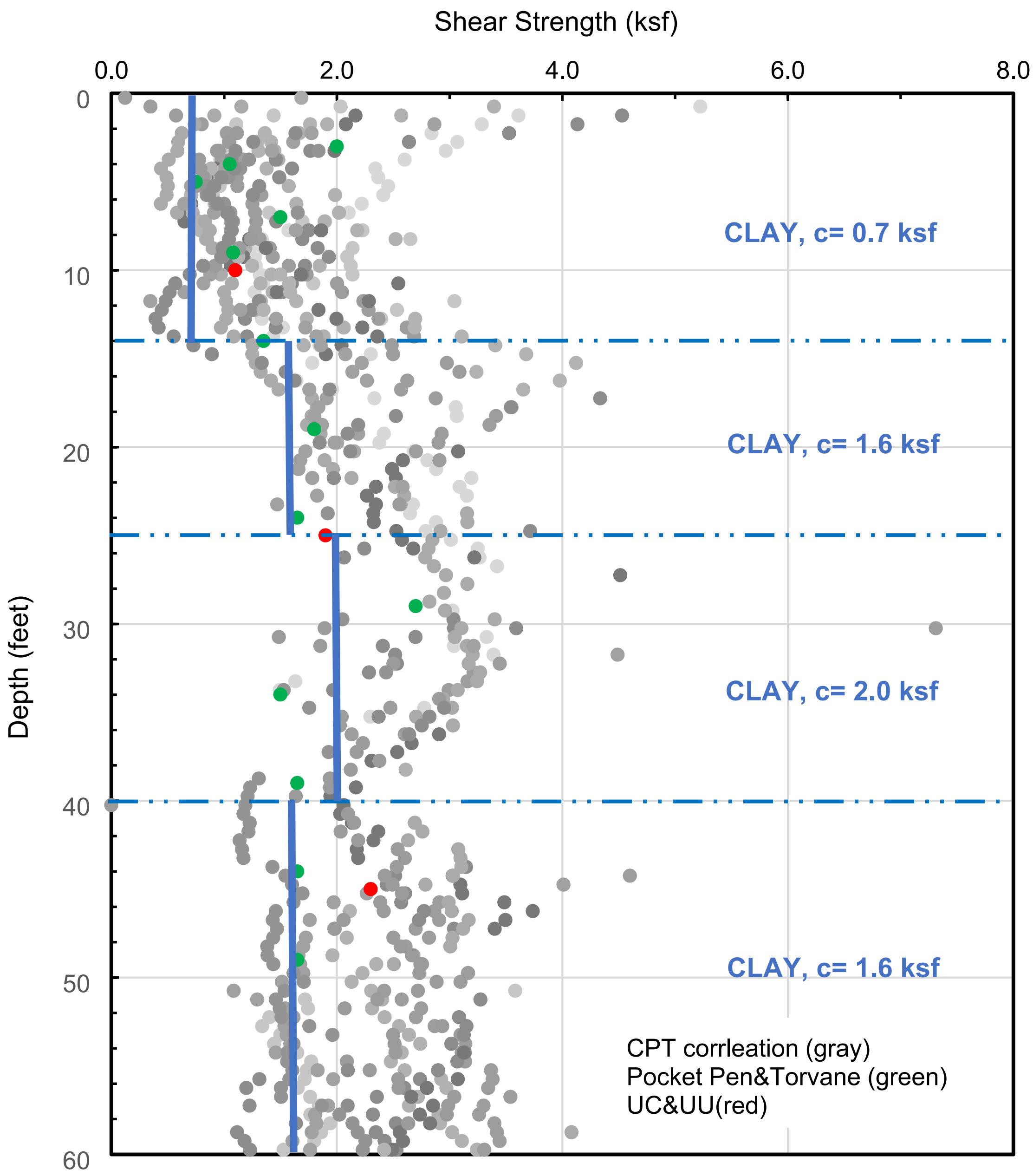



**SHEAR STRENGTH PROFILE A-A'**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON, AND
ORANGE COUNTY, TEXAS

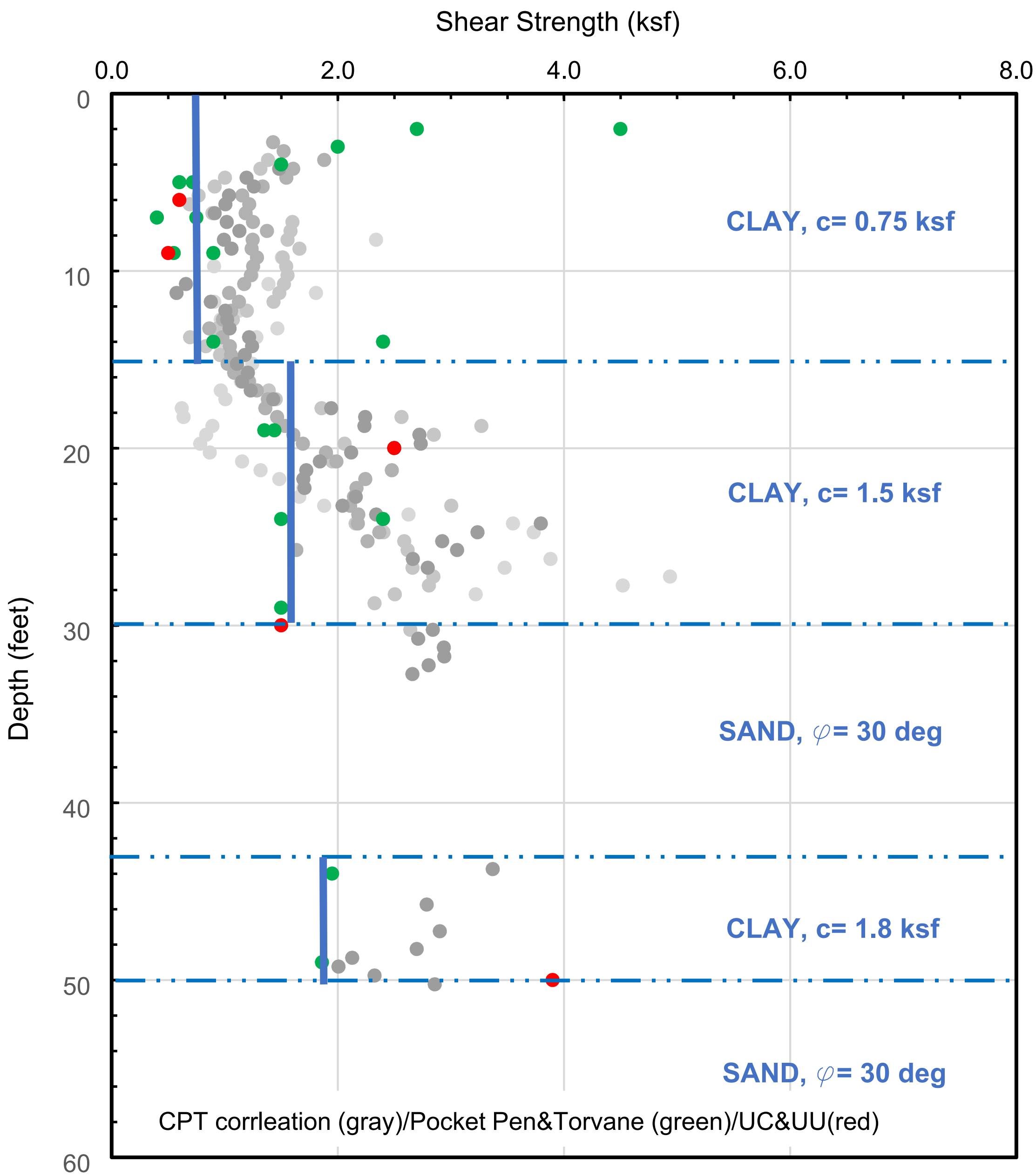



**SHEAR STRENGTH PROFILE B-B'**

STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON, AND ORANGE COUNTY, TEXAS



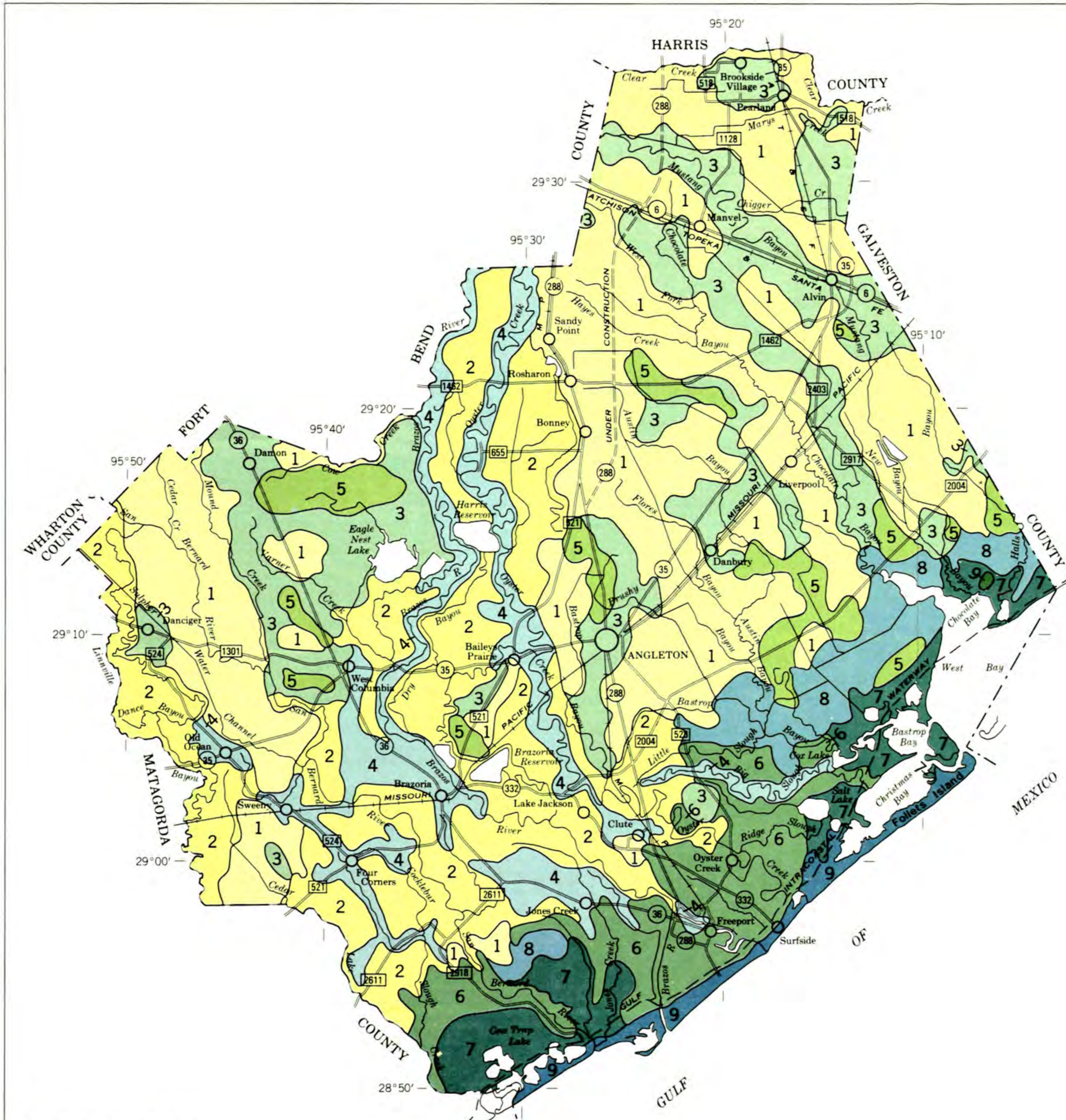

**SHEAR STRENGTH PROFILE C-C'**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON, AND
ORANGE COUNTY, TEXAS




**SHEAR STRENGTH PROFILE D-D'**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON, AND
ORANGE COUNTY, TEXAS

# APPENDIX A

# GENERAL SOIL MAPS




LEGEND 1/

DEEP, NONSALINE SOILS

| | |
|---|---|
| 1 | Lake Charles: Clayey, somewhat poorly drained, very slowly permeable soils; on coastal terraces |
| 2 | Pledger-Brazoria: Clayey, somewhat poorly drained, very slowly permeable soils; on bottom lands |
| 3 | Bernard-Edna: Loamy, somewhat poorly drained and poorly drained, very slowly permeable soils; on coastal terraces |
| 4 | Asa-Norwood: Loamy, well drained, moderately permeable soils; on bottom lands |
| 5 | Edna-Aris: Loamy, poorly drained and somewhat poorly drained, very slowly permeable soils; on coastal terraces |

DEEP, SALINE SOILS

| | |
|---|---|
| 6 | Surfside-Velasco: Clayey, poorly drained and very poorly drained, very slowly permeable soils; in marshes |
| 7 | Harris-Veston: Clayey and loamy, very poorly drained and poorly drained, very slowly permeable and slowly permeable soils; in marshes |
| 8 | Francitas-Narta: Clayey and loamy, poorly drained and somewhat poorly drained, very slowly permeable soils; on coastal terraces |
| 9 | Mustang-Veston: Sandy and loamy, poorly drained, rapidly permeable and slowly permeable soils; in marshes |

1/ The texture given in the descriptive headings refers to the surface layer of the major soils.

Compiled 1979

*Each area outlined on this map consists of more than one kind of soil. The map is thus meant for general planning rather than a basis for decisions on the use of specific tracts.*

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
BRAZORIA COUNTY COMMISSIONERS COURT
TEXAS AGRICULTURAL EXPERIMENT STATION

# GENERAL SOIL MAP

## BRAZORIA COUNTY, TEXAS

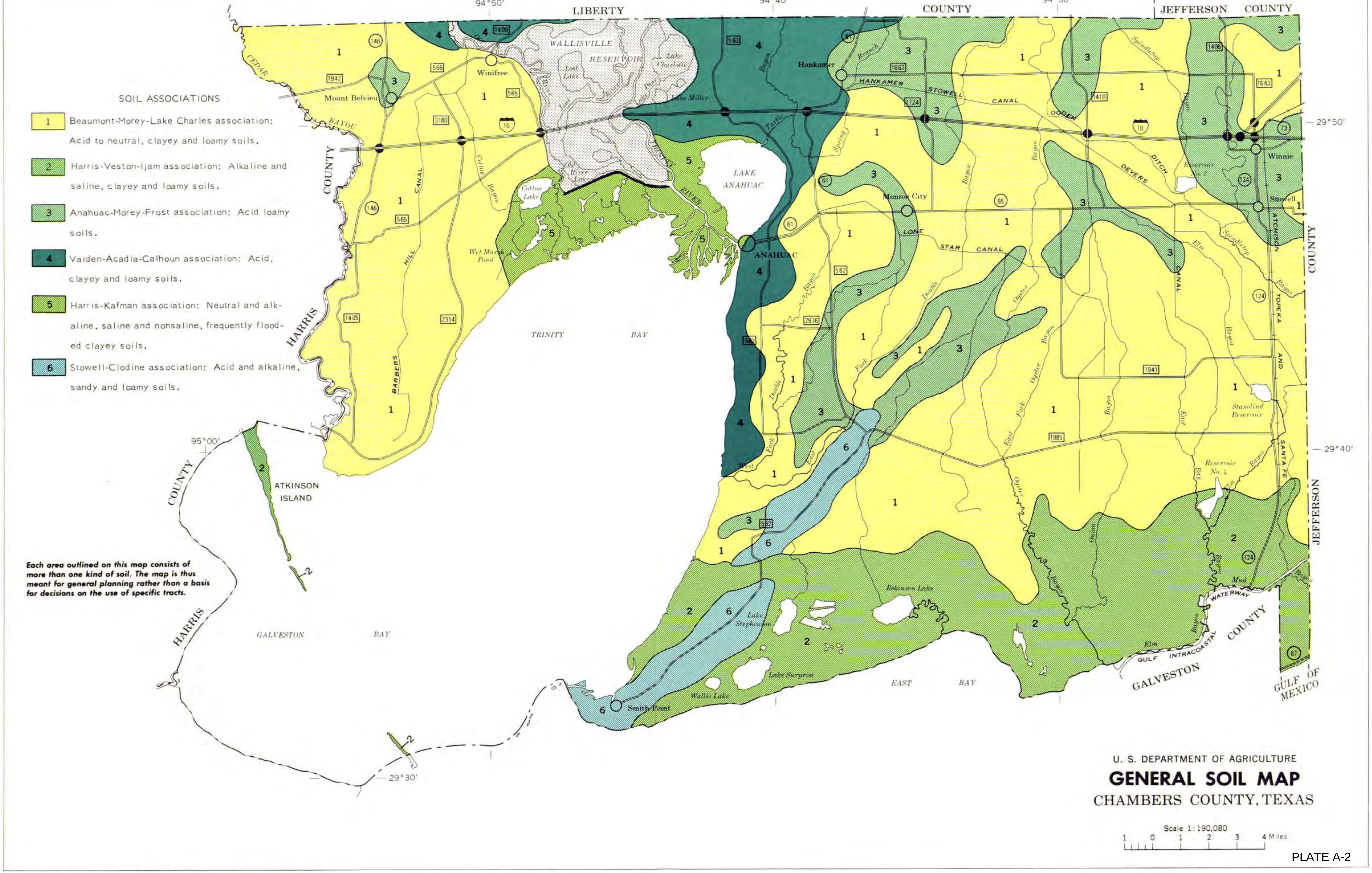
N

Scale 1:380,160

1 0 1 2 3 4 5 6 Miles

1 0 5 10 Km

PLATE A-1

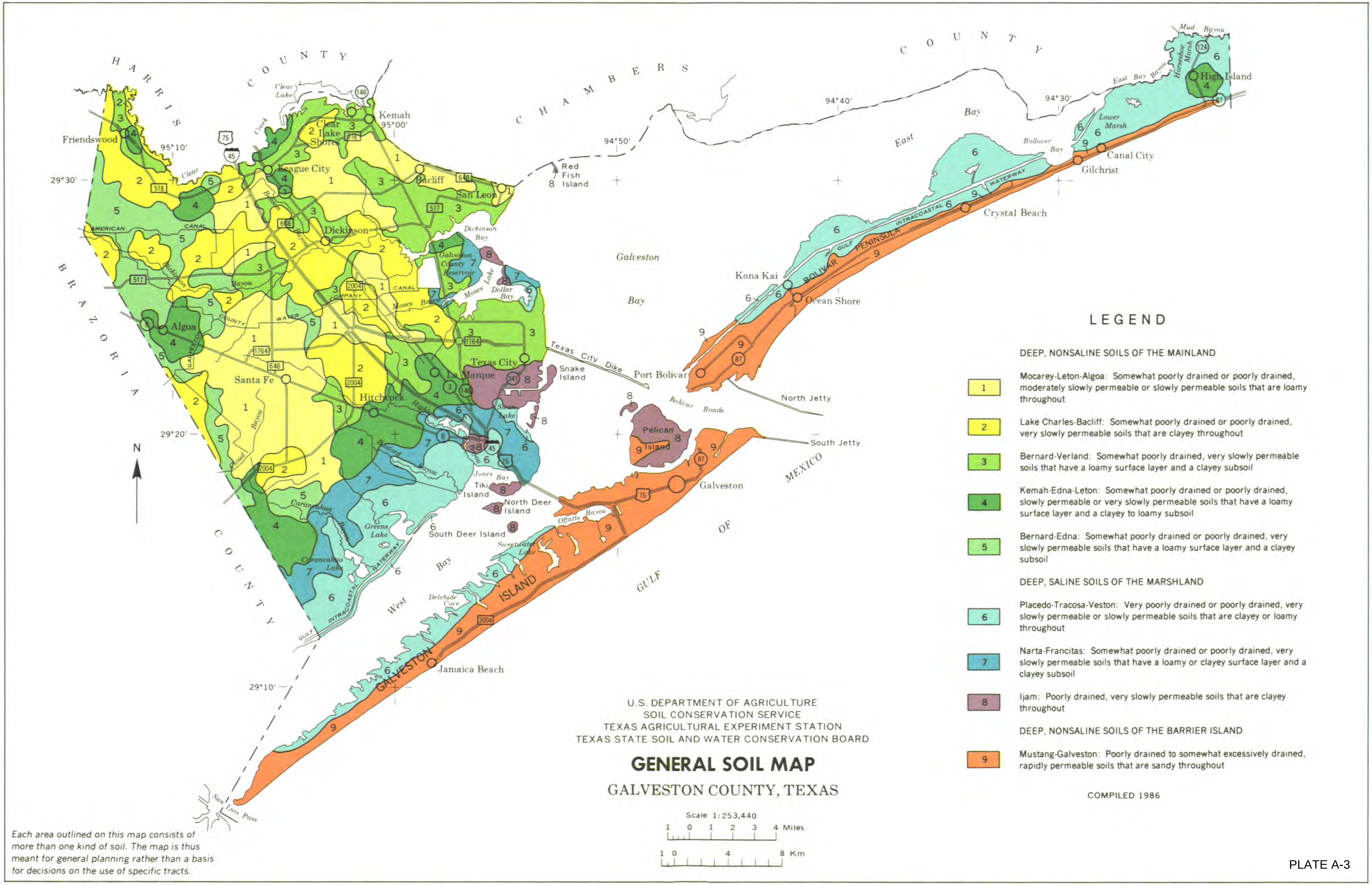



U. S. DEPARTMENT OF AGRICULTURE

**GENERAL SOIL MAP**

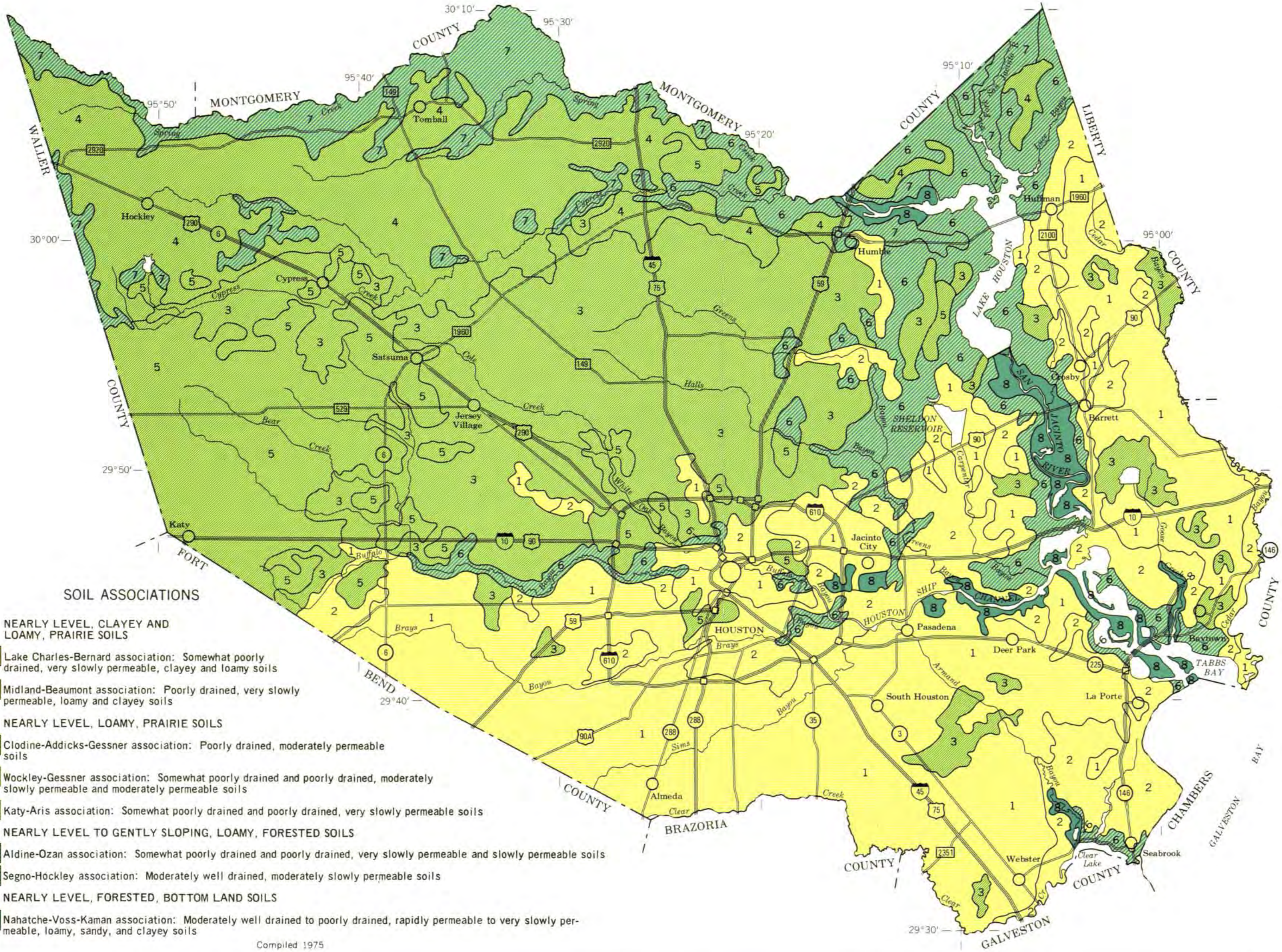
CHAMBERS COUNTY, TEXAS

PLATE A-2



U.S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
TEXAS AGRICULTURAL EXPERIMENT STATION
TEXAS STATE SOIL AND WATER CONSERVATION BOARD
GENERAL SOIL MAP
GALVESTON COUNTY, TEXAS
Scale 1:253,440
1 0 1 2 3 4 Miles
1 0 4 8 Km
LEGEND
DEEP, NONSALINE SOILS OF THE MAINLAND
1 Mocarey-Leton-Algoa: Somewhat poorly drained or poorly drained, moderately slowly permeable or slowly permeable soils that are loamy throughout
2 Lake Charles-Bacliff: Somewhat poorly drained or poorly drained, very slowly permeable soils that are clayey throughout
3 Bernard-Verland: Somewhat poorly drained, very slowly permeable soils that have a loamy surface layer and a clayey subsoil
4 Kemah-Edna-Leton: Somewhat poorly drained or poorly drained, slowly permeable or very slowly permeable soils that have a loamy surface layer and a clayey to loamy subsoil
5 Bernard-Edna: Somewhat poorly drained or poorly drained, very slowly permeable soils that have a loamy surface layer and a clayey subsoil
DEEP, SALINE SOILS OF THE MARSHLAND
6 Placedo-Tracosa-Veston: Very poorly drained or poorly drained, very slowly permeable or slowly permeable soils that are clayey or loamy throughout
7 Narta-Francitas: Somewhat poorly drained or poorly drained, very slowly permeable soils that have a loamy or clayey surface layer and a clayey subsoil
8 Ijam: Poorly drained, very slowly permeable soils that are clayey throughout
DEEP, NONSALINE SOILS OF THE BARRIER ISLAND
9 Mustang-Galveston: Poorly drained to somewhat excessively drained, rapidly permeable soils that are sandy throughout
COMPILED 1986
Each area outlined on this map consists of more than one kind of soil. The map is thus meant for general planning rather than a basis for decisions on the use of specific tracts.
HARRIS COUNTY
CHAMBERS COUNTY
BRAZORIA COUNTY
GULF OF MEXICO
Galveston Bay
East Bay
West Bay
Friendswood
League City
Kemah
Clear Lake Shores
Bacliff
San Leon
Dickinson
Algoa
Santa Fe
Hitchcock
La Marque
Texas City
Texas City Dike
Port Bolivar
North Jetty
South Jetty
Bolivar Roads
Pelican Island
Galveston
Jamaica Beach
Kona Kai
Ocean Shore
Crystal Beach
Gilchrist
Canal City
High Island
Red Fish Island
Snake Island
Tiki Island
North Deer Island
South Deer Island
Jones Bay
Dickinson Bay
Dollar Bay
Moses Lake
Galveston County Reservoir
Swan Lake
Greens Lake
Carancahua Lake
Sweetwater Lake
Delehide Cove
Offatts Bayou
Rollover Bay
Lower Marsh
Horseshoe Marsh
Mud Bayou
East Bay Bayou
Clear Lake
Clear Creek
San Luis Pass
BOLIVAR PENINSULA
GALVESTON ISLAND
GULF INTRACOASTAL WATERWAY
AMERICAN CANAL
GALVESTON COUNTY WATER COMPANY CANAL
95°10′
95°00′
94°50′
94°40′
94°30′
29°30′
29°20′
29°10′
N


PLATE A-3




Each area outlined on this map consists of more than one kind of soil. The map is thus meant for general planning rather than a basis for decisions on the use of specific tracts.

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
TEXAS AGRICULTURAL EXPERIMENT STATION
AND
HARRIS COUNTY FLOOD CONTROL DISTRICT

# GENERAL SOIL MAP
## HARRIS COUNTY, TEXAS

Scale 1:316,800

1 0 1 2 3 4 5 Miles

### SOIL ASSOCIATIONS

NEARLY LEVEL, CLAYEY AND LOAMY, PRAIRIE SOILS

1 Lake Charles-Bernard association: Somewhat poorly drained, very slowly permeable, clayey and loamy soils

2 Midland-Beaumont association: Poorly drained, very slowly permeable, loamy and clayey soils

NEARLY LEVEL, LOAMY, PRAIRIE SOILS

3 Clodine-Addicks-Gessner association: Poorly drained, moderately permeable soils

4 Wockley-Gessner association: Somewhat poorly drained and poorly drained, moderately slowly permeable and moderately permeable soils

5 Katy-Aris association: Somewhat poorly drained and poorly drained, very slowly permeable soils

NEARLY LEVEL TO GENTLY SLOPING, LOAMY, FORESTED SOILS

6 Aldine-Ozan association: Somewhat poorly drained and poorly drained, very slowly permeable and slowly permeable soils

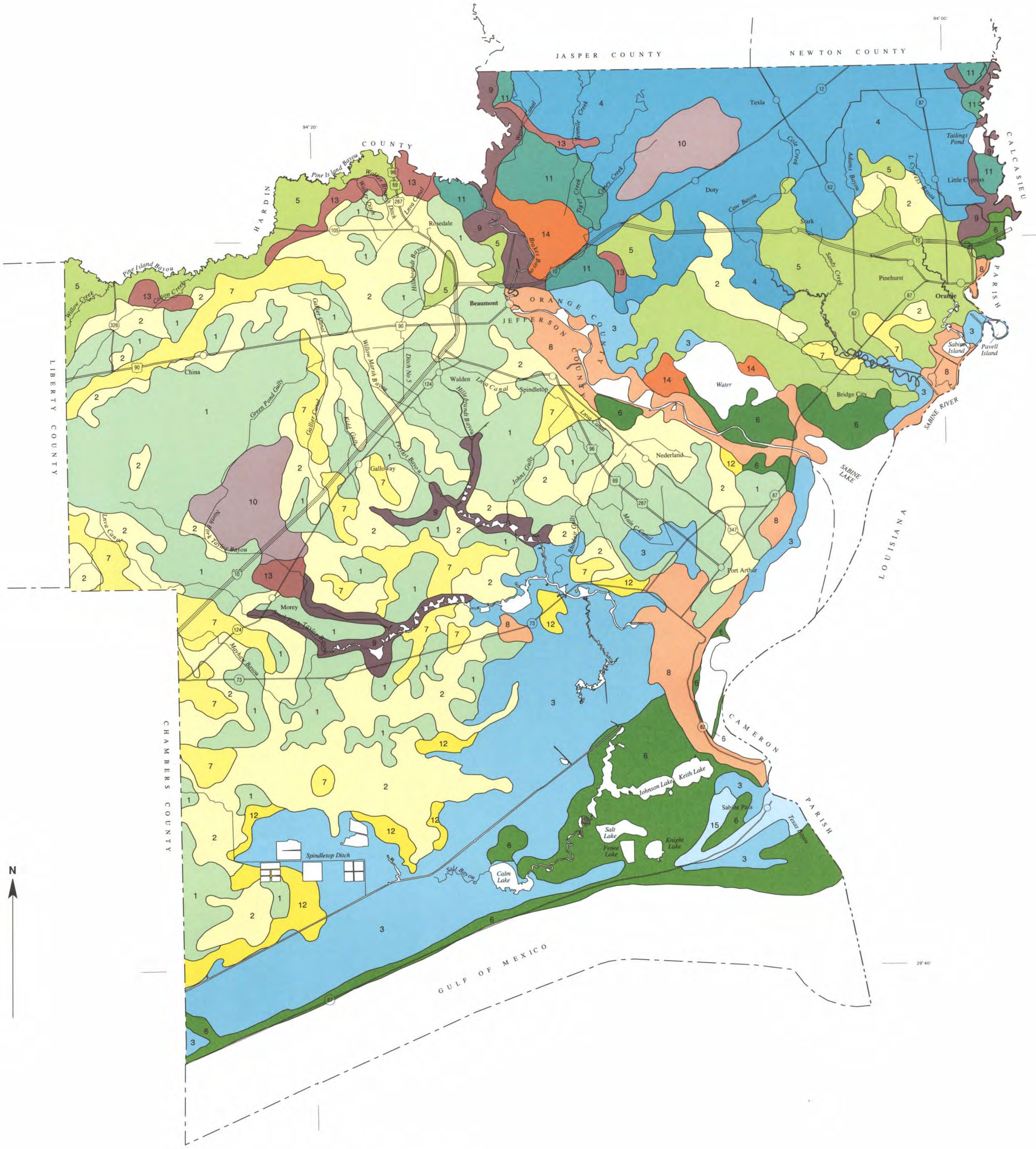
7 Segno-Hockley association: Moderately well drained, moderately slowly permeable soils

NEARLY LEVEL, FORESTED, BOTTOM LAND SOILS

8 Nahatche-Voss-Kaman association: Moderately well drained to poorly drained, rapidly permeable to very slowly permeable, loamy, sandy, and clayey soils

Compiled 1975

PLATE A-4




## SOIL LEGEND*

| | |
|---|---|
| 1 | League-Beaumont-China |
| 2 | Labelle-Morey-Meaton |
| 3 | Leerco-Zummo-Caplen |
| 4 | Texla-Evadale |
| 5 | Orcadia-Aris |
| 6 | Bancker-Creole-Veston |
| 7 | Anahuac-Aris-Leton |
| 8 | Ijam-Neel-Neches |
| 9 | Estes-Fausse |
| 10 | Craigen-Mollco |
| 11 | Camptown-Spurger-Bienville |
| 12 | Franeau-Harris |
| 13 | Vamont-Bevil |
| 14 | Barbary |
| 15 | Sabine-Baines |

*The units on this legend are described in the text under the heading "General Soil Map Units."

Compiled 1996

UNITED STATES DEPARTMENT OF AGRICULTURE
NATURAL RESOURCES CONSERVATION SERVICE
TEXAS AGRICULTURAL EXPERIMENT STATION

# GENERAL SOIL MAP
## Jefferson and Orange Counties TEXAS

Scale 1:190080

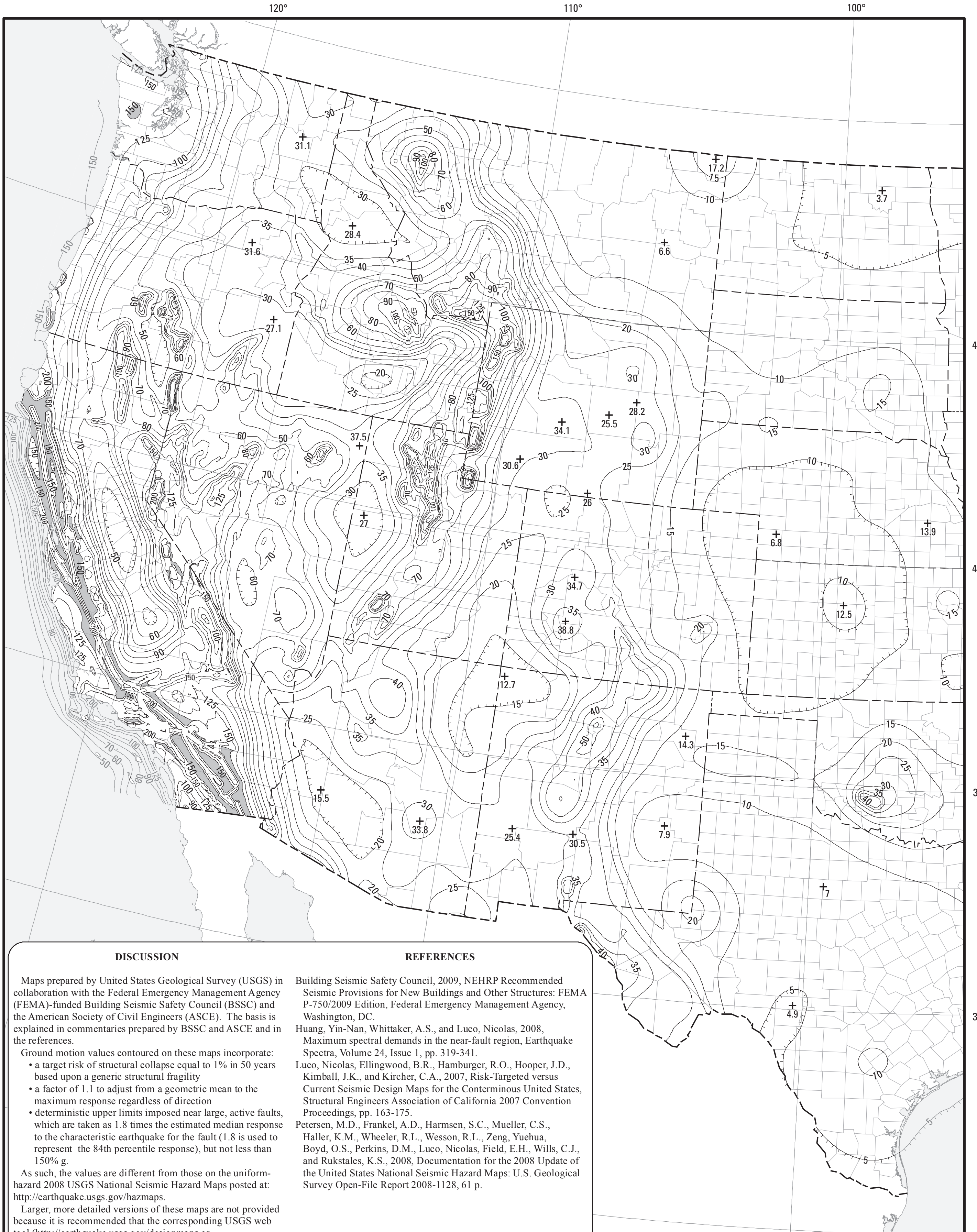
MILES

KILOMETERS

*Each area outlined on this map consists of more than one kind of soil. The map is thus meant for general planning rather than a basis for decisions on the use of specific tracts.*

# APPENDIX B

# USGS SEISMIC MAPS




**DISCUSSION**

Maps prepared by United States Geological Survey (USGS) in collaboration with the Federal Emergency Management Agency (FEMA)-funded Building Seismic Safety Council (BSSC) and the American Society of Civil Engineers (ASCE). The basis is explained in commentaries prepared by BSSC and ASCE and in the references.

Ground motion values contoured on these maps incorporate:

- a target risk of structural collapse equal to 1% in 50 years based upon a generic structural fragility
- a factor of 1.1 to adjust from a geometric mean to the maximum response regardless of direction
- deterministic upper limits imposed near large, active faults, which are taken as 1.8 times the estimated median response to the characteristic earthquake for the fault (1.8 is used to represent the 84th percentile response), but not less than 150% g.

As such, the values are different from those on the uniform-hazard 2008 USGS National Seismic Hazard Maps posted at: http://earthquake.usgs.gov/hazmaps.

Larger, more detailed versions of these maps are not provided because it is recommended that the corresponding USGS web tool (http://earthquake.usgs.gov/designmaps or http://content.seinstitute.org) be used to determine the mapped value for a specified location.

**REFERENCES**


Building Seismic Safety Council, 2009, NEHRP Recommended Seismic Provisions for New Buildings and Other Structures: FEMA P-750/2009 Edition, Federal Emergency Management Agency, Washington, DC.

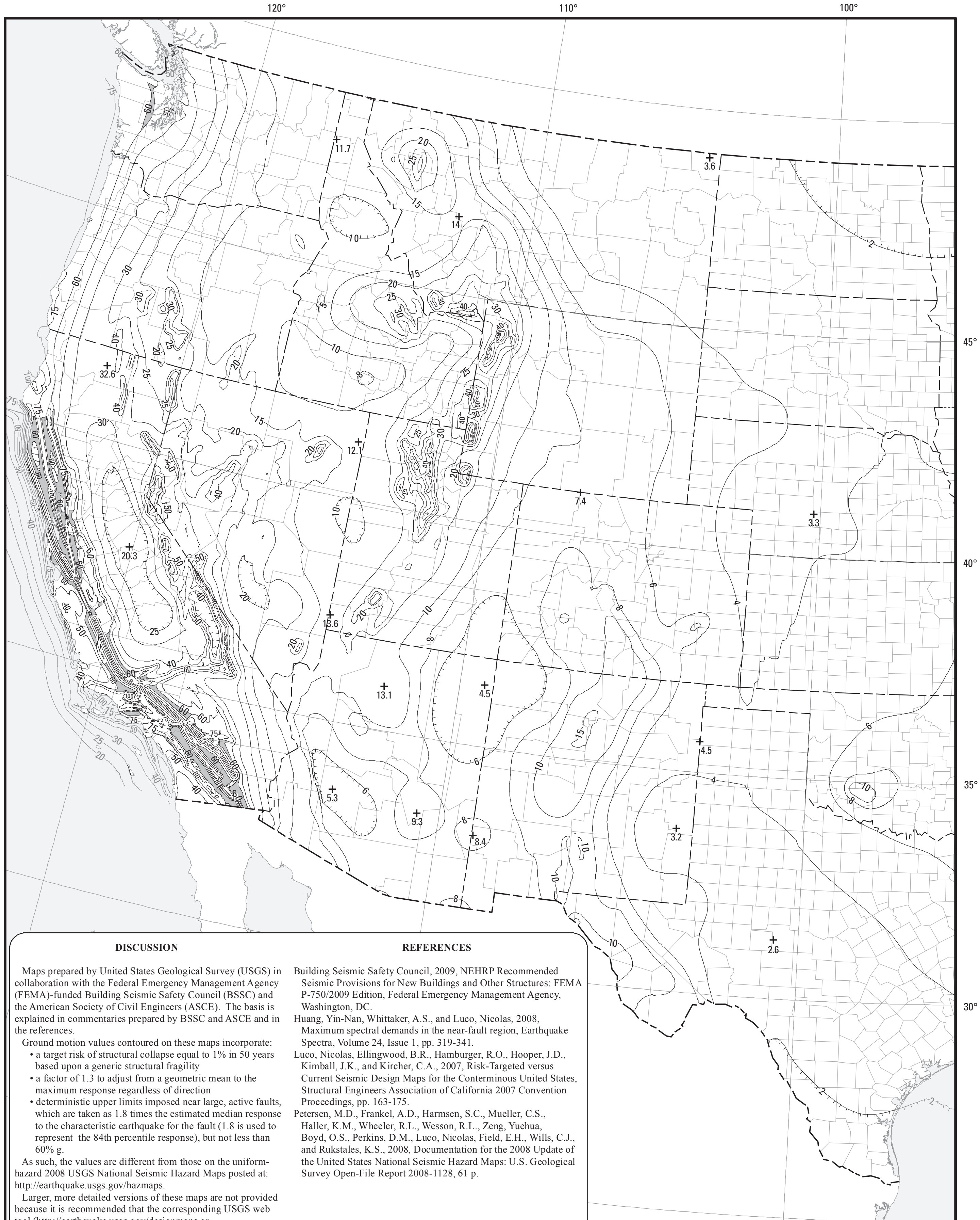
Huang, Yin-Nan, Whittaker, A.S., and Luco, Nicolas, 2008, Maximum spectral demands in the near-fault region, Earthquake Spectra, Volume 24, Issue 1, pp. 319-341.

Luco, Nicolas, Ellingwood, B.R., Hamburger, R.O., Hooper, J.D., Kimball, J.K., and Kircher, C.A., 2007, Risk-Targeted versus Current Seismic Design Maps for the Conterminous United States, Structural Engineers Association of California 2007 Convention Proceedings, pp. 163-175.

Petersen, M.D., Frankel, A.D., Harmsen, S.C., Mueller, C.S., Haller, K.M., Wheeler, R.L., Wesson, R.L., Zeng, Yuehua, Boyd, O.S., Perkins, D.M., Luco, Nicolas, Field, E.H., Wills, C.J., and Rukstales, K.S., 2008, Documentation for the 2008 Update of the United States National Seismic Hazard Maps: U.S. Geological Survey Open-File Report 2008-1128, 61 p.


**Figure 1613.3.1(1) Risk-Targeted Maximum Considered Earthquake ($MCE_R$) Ground Motion Response Accelerations for the Conterminous United States of 0.2-Second Spectral Response Acceleration (5% of Critical Damping), Site Class B *(continued)***


**Figure 1613.3.1(1)-continued Risk-Targeted Maximum Considered Earthquake ($MCE_R$) Ground Motion Response Accelerations for the Conterminous United States of 0.2-Second Spectral Response Acceleration (5% of Critical Damping), Site Class B**




**DISCUSSION**

Maps prepared by United States Geological Survey (USGS) in collaboration with the Federal Emergency Management Agency (FEMA)-funded Building Seismic Safety Council (BSSC) and the American Society of Civil Engineers (ASCE). The basis is explained in commentaries prepared by BSSC and ASCE and in the references.

Ground motion values contoured on these maps incorporate:

- a target risk of structural collapse equal to 1% in 50 years based upon a generic structural fragility
- a factor of 1.3 to adjust from a geometric mean to the maximum response regardless of direction
- deterministic upper limits imposed near large, active faults, which are taken as 1.8 times the estimated median response to the characteristic earthquake for the fault (1.8 is used to represent the 84th percentile response), but not less than 60% g.

As such, the values are different from those on the uniform-hazard 2008 USGS National Seismic Hazard Maps posted at: http://earthquake.usgs.gov/hazmaps.

Larger, more detailed versions of these maps are not provided because it is recommended that the corresponding USGS web tool (http://earthquake.usgs.gov/designmaps or http://content.seinstitute.org) be used to determine the mapped value for a specified location.

**REFERENCES**

Building Seismic Safety Council, 2009, NEHRP Recommended Seismic Provisions for New Buildings and Other Structures: FEMA P-750/2009 Edition, Federal Emergency Management Agency, Washington, DC.

Huang, Yin-Nan, Whittaker, A.S., and Luco, Nicolas, 2008, Maximum spectral demands in the near-fault region, Earthquake Spectra, Volume 24, Issue 1, pp. 319-341.

Luco, Nicolas, Ellingwood, B.R., Hamburger, R.O., Hooper, J.D., Kimball, J.K., and Kircher, C.A., 2007, Risk-Targeted versus Current Seismic Design Maps for the Conterminous United States, Structural Engineers Association of California 2007 Convention Proceedings, pp. 163-175.

Petersen, M.D., Frankel, A.D., Harmsen, S.C., Mueller, C.S., Haller, K.M., Wheeler, R.L., Wesson, R.L., Zeng, Yuehua, Boyd, O.S., Perkins, D.M., Luco, Nicolas, Field, E.H., Wills, C.J., and Rukstales, K.S., 2008, Documentation for the 2008 Update of the United States National Seismic Hazard Maps: U.S. Geological Survey Open-File Report 2008-1128, 61 p.

**Figure 1613.3.1(2) Risk-Targeted Maximum Considered Earthquake ($MCE_R$) Ground Motion Response Accelerations for the Conterminous United States of 1-Second Spectral Response Acceleration (5% of Critical Damping), Site Class B *(continued)***


**Figure 1613.3.1(2)-continued Risk-Targeted Maximum Considered Earthquake ($MCE_R$) Ground Motion Response Accelerations for the Conterminous United States of 1-Second Spectral Response Acceleration (5% of Critical Damping), Site Class B**

# APPENDIX C

## DETAILED LIST OF REFERENCE DOCUMENTS

| COUNTY | GIS NAMING CONVENTION | YEAR | TYPE OF DATA | NO. and MAX. DEPTH OF BORINGS/CPTS | ISSUED BY |
|---|---|---|---|---|---|
| Brazoria | #84 New Administration Building Cherry St. Terracon No. 91145004 | 2014 | Borings | 4 Borings- 50 ft | Terracon Consultants, Inc. |
| Brazoria | psi_report_291-104__dbcs_levee-phase_ii_ | 2013 | CPTs and Borings | 29 CPT- 60 ft; 51 Borings-60 ft | Professional Services Industries, Inc. |
| Brazoria | psi_report_291-105__dbcn_levee-phase_ii_ | 2013 | CPTs and Borings | 28 CPTs- 60 ft; 51 Borings- 60 ft | Professional Services Industries, Inc. |
| Brazoria | 291-106_evaluation_report_orn | 2011 | CPTs and Borings | 16 CPTs- 100 ft; 2 Borings- 100 ft | Professional Services Industries, Inc. |
| Brazoria | PSI Report Volume 2 (EBO, EBT, CB, SS) | 2011 | Borings | 37 Borings- 80 ft | Professional Services Industries, Inc. |
| Brazoria | PSI Report Volume 3 (ORN, ORS, NWB, SWB) | 2011 | Borings | 15 Borings- 80 ft | Professional Services Industries, Inc. |
| Brazoria | PSI Report Volume 4 (DBCN, DBCS, DTB) | 2011 | Borings | 38 Borings- 80 ft | Professional Services Industries, Inc. |
| Brazoria | PSI Report Volume 5 (ES, OC, EOC) | 2011 | Borings | 31 Borings- 80 ft | Professional Services Industries, Inc. |
| Brazoria | #82 Report 92115100 VT Backland Development Phase 2 | 2011 | Borings | 27 Borings- 100 ft | Terracon Consultants, Inc. |
| Brazoria | #74 Report No. 92075660 HMLP 25 Phase II FBST E. FM 1495 Terracon | 2008 | Borings | 15 Borings- 40 ft | Terracon Consultants, Inc. |
| Brazoria | Chocolate Bayou Placement Area | 2008 | Borings | 6 Borings- 20 ft | Tolunay-Wong Engineers, Inc. |
| Brazoria | #81 Report 286-75040 High Mast Light Poles | 2007 | Borings | 7 Borings- 45 ft | Professional Services Industries, Inc. |
| Brazoria | #73 Report No. 286-65066 Proposed Radar Towers | 2006 | Borings | 2 Borings- 50 ft | Professional Services Industries, Inc. |
| Brazoria | FM 2004 at SH 288 | 2005 | Borings | 11 Borings- 77 ft | Texas Department of Transportation |
| Brazoria | Corp. of Eng. Freeport- TWE | 2005 | Borings | 3 Borings- 40 ft | Tolunay-Wong Engineers, Inc. |
| Brazoria | FM 2917 - SH 35 to New Bayou | 2000 | Borings | 4 Borings- 77 ft | Texas Department of Transportation |
| Brazoria | FM 1495 at Intercostal Waterway | 1998 | Borings | 14 Borings- 125 ft | Texas Department of Transportation |
| Brazoria | FM 523 - Mound Rd. to Oyster Creek | 1993 | Borings | 2 Borings- 100 ft | Texas Department of Transportation |
| Brazoria | TX 332 at Intercoastal Waterway - 1988 | 1988 | Borings | 9 Borings- 150 ft | Woodward - Clyde Consultants |
| Brazoria | FM 523 - FM 2004 to Hoskins Mound Rd | 1987 | Borings | 2 Borings- 80 ft | Texas Department of Transportation |
| Brazoria | FM 2004 at Oyster Creek | 1987 | Borings | 4 Borings- 80 ft | Texas Department of Transportation |
| Brazoria | Freeport Channel, GLO | 1970 | Borings | 8 Borings- 16 ft | U.S Army Corps of Engineers |
| Brazoria | Freeport Harbor and Channel | 1969 | Borings | 2 Borings- 16 ft | U.S Army Corps of Engineers |
| Brazoria | Brazos River Comprehensive Study | 1966 | Borings | 8 Borings- 100 ft | U.S Army Corps of Engineers |

**DETAILED LIST OF REFERENCE DOCUMENTS**

STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS

| COUNTY | GIS NAMING CONVENTION | YEAR | TYPE OF DATA | NO. and MAX. DEPTH OF BORINGS/CPTS | ISSUED BY |
|---|---|---|---|---|---|
| Galveston | Embankment and Foundation Stability | 2013 | CPTs and Borings | 21 Borings-100 ft/ 17 CPTs- 100 ft | Paradigm / Fugro |
| Galveston | Galveston Channel Deepinging, TO-0010 | 2010 | Borings | 19 Borings- 80 ft | Terracon Consultants, Inc. |
| Galveston | San Jacinto PA | 2010 | CPTs | 9 Borings- 80 ft | Terracon Consultants, Inc. |
| Galveston | US COAST GUARD - ATON Rebuild | 2009 | Borings | 2 Borings- 100 ft | Fugro |
| Galveston | SH 146 - LP 197 Overpass SB. | 2009 | Borings | 6 Borings- 142 ft | Texas Department of Transportation |
| Galveston | Anchorage Basin Sand Source Investigation | 2009 | Borings | 7 Borings- 14 ft | Rock Engineering and Testing Lab, Inc. |
| Galveston | GALVESTON COUNTY - Ramp on Seawall Blvd | 2008 | Borings | 1 Boring- 50 ft | Fugro |
| Galveston | Galveston Channel and San Jacinto PA | 2008 | Borings | 13 Borings- 40 ft | Tolunay-Wong Engineers, Inc. |
| Galveston | CITY OF GALVESTON - Bar Screen | 2003 | Borings | 1 Boring- 40 ft | Fugro |
| Galveston | GALVESTON COUNTY - Solids Handling Building | 2003 | Borings | 2 Borings- 35 ft | Fugro |
| Galveston | GALVESTON COUNTY - Wastewater Detention Pond | 2000 | Borings | 6 Borings- 35 ft | Fugro |
| Galveston | ENSCO - Offshore Energy Museum | 1995 | Borings | 1 Boring- 100 ft | Fugro |
| Galveston | GALVESTON COUNTY - Clear Creek Flood Control Channel | 1989 | Borings | 4 Borings- 36 ft | McClelland Consultants |
| Galveston | CITY OF GALVESTON - Hughes Road | 1988 | Borings | 10 Borings- 15 ft | McClelland Engineers Inc. |
| Galveston | USACE - Disposal Area San Jac | 1988 | Borings | 6 Borings- 90 ft | McClelland Engineers Inc. |
| Galveston | USACE - Pelican Island | 1988 | Borings | 12 Borings- 70 ft | McClelland Engineers Inc. |
| Galveston | USACE - New District Headquarters Building | 1987 | Borings | 4 Borings- 150 ft | McClelland Engineers Inc. |
| Galveston | SH 168 Galveston County | 1987 | Borings | 26 Borings- 40 ft | Texas Department of Transportation |
| Galveston | Jadwin Building 1985 | 1985 | Borings | 14 Borings- 90 ft | U.S. Army Corps of Engineers |
| Galveston | TC 350 HFP Bayou Rd | 1984 | Borings | 13 Borings/ 70 ft | U.S. Army Corps of Engineers |
| Galveston | TC 336 HFP Structure N. of TC Gated Drainge Structure | 1981 | Borings | 14 Borings/ 30 ft | U.S. Army Corps of Engineers |
| Galveston | CITY OF GALVESTON - Moody Parking Garage | 1979 | Borings | 4 Borings- 100 ft | McClelland Engineers Inc. |
| Galveston | TC 327 HFP Structures N. of TC | 1979 | Borings | 13 Borings/ 26 ft | U.S. Army Corps of Engineers |
| Galveston | TC 329 SW Leg Gated Drainage Structure Construction | 1979 | Borings | 15 Borings/ 40 ft | U.S. Army Corps of Engineers |
| Galveston | TC_HFP DM 13 789+00 to 927+00 | 1978 | Borings | 58 Borings- 70 ft | U.S. Army Corps of Engineers |
| Galveston | UTMB - Ambulatory Facility | 1977 | Borings | 4 Borings-140 ft | McClelland Engineers Inc. |
| Galveston | UTMB - Ambulatory Parking Facility | 1977 | Borings | 2 Borings- 100 ft | McClelland Engineers Inc. |
| Galveston | UTMB - Learning Center | 1976 | Borings | 3 Borings- 145 ft | McClelland Engineers Inc. |

| COUNTY | GIS NAMING CONVENTION | YEAR | TYPE OF DATA | NO. and MAX. DEPTH OF BORINGS/CPTS | ISSUED BY |
|---|---|---|---|---|---|
| Galveston | UTMB - Additional Animal facility | 1975 | Borings | 2 Borings- 30 ft | McClelland Engineers Inc. |
| Galveston | UTMB - Thermal Plant Expansion | 1974 | Borings | 5 Borings- 62 ft | McClelland Engineers Inc. |
| Galveston | UTMB - Marine Biomedical Building | 1972 | Borings | 3 Borings- 50 ft | McClelland Engineers Inc. |
| Galveston | Galveston Entrance Channel 1972 | 1972 | Borings | 6 Borings- 190 ft | U.S. Army Corps of Engineers |
| Galveston | UTMB - Admin Building | 1971 | Borings | 1 Boring- 140 ft | McClelland Engineers Inc. |
| Galveston | UTMB - Sealy Hospital 2 | 1971 | Borings | 5 Borings- 129.5 ft | McClelland Engineers Inc. |
| Galveston | TC_HFP DM 07 655+00 to 790+00 | 1971 | Borings | 41 Borings- 40 ft | U.S. Army Corps of Engineers |
| Galveston | TC 265 HFP Bay Street Drainage Diversion Structures | 1968 | Borings | 8 Borings/ 16 ft | U.S. Army Corps of Engineers |
| Galveston | TC 349 HFP Local Interests Pumping Station | 1966 | Borings | 8 Borings- 32 ft | US Army Engineering District |
| Galveston | HC - Bayport Ship Channel | 1966 | Borings | 8 Borings- 60 ft | McClelland Engineers Inc. |
| Galveston | UTMB - Animal Research Lab | 1966 | Borings | 4 Borings- 30 ft | McClelland Engineers Inc. |
| Galveston | UTMB - Basic Sciences Building | 1966 | Borings | 3 Borings- 145 ft | McClelland Engineers Inc. |
| Galveston | TC 256 HFP Gravity and Waste Water Culverts Sta 629 to 657-2 | 1966 | Borings | 40 Borings/ 40 ft | U.S. Army Corps of Engineers |
| Galveston | TC 260 HFP TC Pumping Station | 1966 | Borings | 16 Borings/ 70 ft | U.S. Army Corps of Engineers |
| Galveston | TC_HFP DM 10 477+50 to 535+00 | 1964 | Borings | 42 Borings- 76 ft | U.S. Army Corps of Engineers |
| Galveston | TC_HFP DM 12 535+00 to 655+00 | 1964 | Borings | 47 Borings- 60 ft | U.S. Army Corps of Engineers |
| Galveston | San Luis Pass Bridge | 1964 | Borings | 12 Borings/ 151.0 ft | Howard, Needles, Tammen, and Bergendoff |
| Galveston | 01 - TC 237 Levee Sta. 0+00 to Sta 7+50 | 1964 | Borings | 17 Borings/25 ft | U.S. Army Corps of Engineers |
| Galveston | TC_HFP DM 05 142+00 to 490+00 | 1963 | Borings | 70 Borings- 70 ft | U.S. Army Corps of Engineers |
| Galveston | CITY OF GALVESTON - City Hall | 1962 | Borings | 2 Borings- 50 ft | McClelland Engineers Inc. |
| Galveston | CITY OF GALVESTON - Courthouse | 1962 | Borings | 2 Borings- 75 ft | McClelland Engineers Inc. |
| Galveston | TC 339 LaMarque Pumping Station Dicharge Culvert and Outlet | 1962 | Borings | 17 Borings/ 40 ft | U.S. Army Corps of Engineers |
| Galveston | 02 - TC 222 Levee Sta. 7+50 to Sta 84+00 | 1962 | Borings | 12 Borings/ 30 ft | U.S. Army Corps of Engineers |
| Galveston | CITY OF GALVESTON - Cotton Route | 1961 | Borings | 15 Borings- 60 ft | McClelland Engineers Inc. |
| Galveston | CITY OF GALVESTON - Drainage District No.4 | 1961 | Borings | 12 Borings- 60 ft | McClelland Engineers Inc. |
| Galveston | GALVESTON WHARVES - Proposed Truck Dump | 1961 | Borings | 6 Borings- 50 ft | McClelland Engineers Inc. |
| Galveston | UTMB - Outpatient Building | 1961 | Borings | 2 Borings- 115 ft | McClelland Engineers Inc. |
| Galveston | TC_HFP DM 02 000+00 to 360+00 | 1961 | Borings | 61 Borings- 75 ft | U.S. Army Corps of Engineers |

**DETAILED LIST OF REFERENCE DOCUMENTS**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS

| COUNTY | GIS NAMING CONVENTION | YEAR | TYPE OF DATA | NO. and MAX. DEPTH OF BORINGS/CPTS | ISSUED BY |
|---|---|---|---|---|---|
| Galveston | CITY OF GALVESTON - Memorial Hospital No.1 | 1960 | Borings | 9 Borings- 60 ft | McClelland Engineers Inc. |
| Galveston | GALVESTON COUNTY - Jail | 1960 | Borings | 2 Boring- 50 ft | McClelland Engineers Inc. |
| Galveston | UTMB - Central Chilling Plant | 1960 | Borings | 5 Borings- 100 ft | McClelland Engineers Inc. |
| Galveston | Geotech Seawall EXT 1959 II | 1959 | Borings | 20 Borins- 76.4 ft | U.S. Army Corps of Engineers |
| Galveston | Geotech Seawall EXT 1959 | 1959 | Borings | 10 Borins- 76.9 ft | U.S. Army Corps of Engineers |
| Galveston | Geotech Seawall EXT 1958 II | 1958 | Borings | 31 Borings- 93 ft | U.S. Army Corps of Engineers |
| Galveston | Geotech Seawall EXT 1958 | 1958 | Borings | 16 Borings- 58.9 ft | U.S. Army Corps of Engineers |
| Galveston | CITY OF GALVESTON - Elevated Water Tank 2 | 1957 | Borings | 1 Boring- 55 ft | McClelland Engineers Inc. |
| Galveston | GALVESTON WHARVES - Pier 14 | 1956 | Borings | 15 Borings- 110 ft | McClelland Engineers Inc. |
| Galveston | GALVESTON WHARVES - Piers 39, 40 & 41 | 1952 | Borings | 11 Borings- 84 ft | Greer and McClelland |
| Galveston | Geotech Seawall EXT 1951 | 1951 | Borings | 21 Borings- 61.9 ft | U.S. Army Corps of Engineers |
| Galveston | Sewall Extention Plans-1951 | 1951 | Borings | 21 Borings/ 64.0 ft | U.S. Army Corps of Engineers |
| Galveston | CITY OF GALVESTON - Municipal Incinerator | 1950 | Borings | 2 Borings- 49.5 ft | Greer and McClelland |
| Galveston | GALVESTON WHARVES - Pier 35 | 1950 | Borings | 7 Borings- 61 ft | Greer and McClelland |
| Galveston | CITY OF GALVESTON - Bridge at Offat's Bayou | 1949 | Borings | 2 Borings- 80 ft | Greer and McClelland |
| Galveston | CITY OF GALVESTON - Memorial Hospital No.2 | 1949 | Borings | 3 Borings- 30 ft | Greer and McClelland |
| Galveston | UTMB - Zeigler Hospital | 1949 | Borings | 5 Borings- 110 ft | Greer and McClelland |
| Galveston | CITY OF GALVESTON - Reservoir | 1948 | Borings | 2 Borings- 101.5 ft | Greer and McClelland |
| Galveston | High Island to Pt. Bolivar | 1943 | Borings | 71 Borings- 22 ft | U.S. Army Corps of Engineers |
| Galveston | SH 146 at Drainage Ditch 7B. | Not Available | Borings | 4 Borings- 90 ft | Texas Department of Transportation |
| Galveston | 04 - TC 278 Levee 2nd Stage Sta. 141+50 to Sta. 199+00 | Not Available | Borings | 37 Borings/ 30ft | U.S. Army Corps of Engineers |
| Galveston | 06 - TC 224 Levee Sta. 203+00 to Sta 290+00 | Not Available | Borings | 17 Borings/ 25ft | U.S. Army Corps of Engineers |
| Galveston | 07 - TC 229 Levee Sta. 290+00 to Sta 367+50 | Not Available | Borings | 61 Borings/ 45ft | U.S. Army Corps of Engineers |

| COUNTY | GIS NAMING CONVENTION | YEAR | TYPE OF DATA | NO. and MAX. DEPTH OF BORINGS/CPTS | ISSUED BY |
|---|---|---|---|---|---|
| Galveston | 08 - TC 273 Levee 2nd Stage Sta.292+00 to 332+00 & 367+50 to 446+10 | Not Available | Borings | 19 Borings/ 15ft | U.S. Army Corps of Engineers |
| Galveston | 09 - TC 241 Levee Sta. 367+75 to Sta. 459+50 | Not Available | Borings | 7 Borings/ 40ft | U.S. Army Corps of Engineers |
| Galveston | 10-TC 268 Levee Sta. 446+10 to Sta. 477+27 Dike to Monsanto Fill | Not Available | Borings | 14 Borings/ 48ft | U.S. Army Corps of Engineers |
| Galveston | 11-TC 277 Concrete Floodwall Sta. 477+60 to Sta.504+99 Plans and Specs | Not Available | Borings | 7 Borings/ 75ft | U.S. Army Corps of Engineers |
| Galveston | 12-TC 293 Floodwall and cont. alterations of structures Sta. 504+99 to Sta. 538+55 | Not Available | Borings | 13 Borings/ 65ft | U.S. Army Corps of Engineers |
| Galveston | 13-TC 271 Levee Sta.537+50 to Sta. 629+00 | Not Available | Borings | 9 Borings/ 12ft | U.S. Army Corps of Engineers |
| Galveston | Record Drawings and Design Memo | Not Available | Borings | 8 Borings- 76 ft | US Army Engineering District |
| Galveston | Houston - Galveston Nav Channels, San Jacinto PA | Not Available | Borings | 5 Borings- 35 ft | U.S. Army Corps of Engineers |
| Galveston | Rice University Coastal Research Group | Not Available | Borings | 5 Borings- 30 ft | Rice University |
| Galveston | TC Levee Local Interest Pump Station-Borrow Area | Not Available | Borings | 8 Borings/ 30 ft | U.S. Army Corps of Engineers |

| COUNTY | GIS NAMING CONVENTION | YEAR | TYPE OF DATA | NO. and MAX. DEPTH OF BORINGS/CPTS | ISSUED BY |
|---|---|---|---|---|---|
| Harris | TX146 at Houston Ship Channel-1986 | 1986 | Borings | 2 Borings- 150 ft | McClelland Engineers, Inc. |
| Harris | Clear Creek 2nd Outlet-1987 | 1986 | Borings | 21 Borings- 100 ft | U.S. Army Corps of Engineers |
| Harris | Clear Lake Second Outlet Channel - 1985 | 1985 | Borings | 11 Borings - 100 ft | McBride-Ratcliff and Associates, Inc. |
| Harris | RR Bridge and Pline Crossing Clear Lake 2nd Outlet Channel - 1985 | 1985 | Borings | 4 Borings - 90 ft | McBride-Ratcliff and Associates, Inc. |
| Harris | Feasibility Study - 2nd Outlet for Clear Lake - 1982 | 1982 | Borings | 9 Borings - 75 ft | McBride-Ratcliff and Associates, Inc. |
| Harris | TX146 at Houston Ship Channel-1980 | 1980 | Borings | 4 Borings - 160 ft | Frank G. Bryant & Associates, Inc. |

| COUNTY | GIS NAMING CONVENTION | YEAR | TYPE OF DATA | NO. and MAX. DEPTH OF BORINGS/CPTS | ISSUED BY |
|---|---|---|---|---|---|
| Jefferson | Alligator Bayou at SH 82_AsBuilt_2013 | 2013 | Borings | 2 Borings | Texas Department of Transportation |
| Jefferson | HFPL System Evaluation - Jefferson County DD7 2013 | 2012 | Borings | 84 Borings- 70 ft | Tolunay-Wong Engineers, Inc. |
| Jefferson | Main C Canal at FM 365_AsBuilt_2012 | 2012 | Borings | 2 Borings | Texas Department of Transportation |
| Jefferson | Alligator Bayou - PStation and Cofferdam 2011 | 2011 | Borings | 17 Borings- 150 ft | Fugro |
| Jefferson | LNVA Canal at 27th St_AsBuilt_2011 | 2011 | Borings | 1 Boring | Texas Department of Transportation |
| Jefferson | Main A Canal at SH 347_OrigPlans_2010 | 2010 | Borings | 2 Borings | Texas Department of Transportation |
| Jefferson | Main B Canal at US 69_OrigPlans_2010 | 2010 | Borings | 2 Borings | Texas Department of Transportation |
| Jefferson | Rhodair Gully at US 69 SB_OrigPlans_2006 | 2006 | Borings | 2 Borings | Texas Department of Transportation |
| Jefferson | Rhodair Gully at US 69_Widening_2006 | 2006 | Borings | 1 Boring | Texas Department of Transportation |
| Jefferson | Rhodair Gully at Spur 93_OrigPlans_2003 | 2003 | Borings | 2 Borings | Texas Department of Transportation |
| Jefferson | Taylors Bayou Saltwater Barrier - 2003 | 2003 | Borings | 3 Borings- 70 ft | Tolunay-Wong Engineers, Inc. |
| Jefferson | Port Arthur Boat Basin - 2003 | 2003 | Borings | 7 Borings- 51 ft | Geotest Engineering, Inc. |
| Jefferson | Main A Canal at US 69_OrigPlans_2001 | 2001 | Borings | 2 Borings | Texas Department of Transportation |
| Jefferson | Taylors Bayou at SH 73 EB_AsBuilt_2000 | 2000 | Borings | 8 Borings | Texas Department of Transportation |
| Jefferson | Taylors Bayou at SH 73 WB_AsBuilt_2000 | 2000 | Borings | 8 Borings | Texas Department of Transportation |
| Jefferson | Crane Bayou at Main Ave_AsBuilt_1999 | 1999 | Borings | 2 Borings | Texas Department of Transportation |
| Jefferson | Main B Canal at SH 73_AsBuilt_1999 | 1999 | Borings | 2 Borings | Texas Department of Transportation |
| Jefferson | Star Lake Ditch at Atalantic Rd _AsBuilt_1998 | 1998 | Borings | 2 Borings | Texas Department of Transportation |
| Jefferson | Drainage Ditch at Orchard Rd._AsBuilt_1996 | 1996 | Borings | 2 Borings | Texas Department of Transportation |
| Jefferson | Main B Canal at 9th Ave_AsBuilt_1993 | 1993 | Borings | 2 Borings | Texas Department of Transportation |
| Jefferson | Atlantic Main Bridge at Taft Ave_AsBuilt_1989 | 1989 | Borings | 2 Borings | Texas Department of Transportation |
| Jefferson | Main A Canal at 60th St_AsBuilt_1989 | 1989 | Borings | 2 Borings | Texas Department of Transportation |
| Jefferson | Crane Bayou at Proctor St_AsBuilt_1988 | 1988 | Borings | 2 Borings | Texas Department of Transportation |
| Jefferson | Disposal Area No. 23 - 1988 | 1988 | Borings | 7 Borings- 30 ft | McClelland Engineers Inc. |
| Jefferson | Irving Ave. Underpass_Widening_1987 | 1987 | Borings | 2 Borings- 76 ft | Texas Department of Transportation |
| Jefferson | DMemo No 4 Taylors Bayou 1986 | 1986 | Borings | 58 Borings- 30 ft | U.S. Army Corps of Engineers |
| Jefferson | 75th St at US 69_ConstrPlans_1986 | 1986 | Borings | 2 Borings | Texas Department of Transportation |

| COUNTY | GIS NAMING CONVENTION | YEAR | TYPE OF DATA | NO. and MAX. DEPTH OF BORINGS/CPTS | ISSUED BY |
|---|---|---|---|---|---|
| Jefferson | DMemo No 3 Taylors Bayou 1985 | 1985 | Borings | 12 Borings- 20 ft (+180 Borings- 36 ft) | U.S. Army Corps of Engineers |
| Jefferson | Main A Canal at 9th Ave_AsBuilt_1983 | 1983 | Borings | 1 Boring | Texas Department of Transportation |
| Jefferson | SH 347 Overpass at Spur 136_OrigPlans_1983 | 1983 | Borings | 5 Borings | Texas Department of Transportation |
| Jefferson | Main B Canal at US 69_AsBuilt_1980 | 1980 | Borings | 1 Boring | Texas Department of Transportation |
| Jefferson | S Port Acres Ditch at SH 73_AsBuilt_1980 | 1980 | Borings | 1 Boring | Texas Department of Transportation |
| Jefferson | Main D Canal at 25th St_AsBuilt_1978 | 1978 | Borings | 1 Boring | Texas Department of Transportation |
| Jefferson | Alligator Bayou - PStation & GDS and OMM 1978 | 1978 | Borings | 27 Borings- 80 ft | U.S. Army Corps of Engineers |
| Jefferson | Beauxart Garden Overpass_ConstrPlans_1975 | 1975 | Borings | 2 Borings | Texas Department of Transportation |
| Jefferson | Sabine Neches Waterway - Feasability Study 1973 | 1975 | Borings | 14 Borings- 60 ft | U.S. Army Corps of Engineers |
| Jefferson | FM 366 KCS RR North _OrigPlans_1972 | 1972 | Borings | 2 Borings | Texas Department of Transportation |
| Jefferson | FM 366 KCS RR South _OrigPlans_1972 | 1972 | Borings | 2 Borings | Texas Department of Transportation |
| Jefferson | Taft Ave at SH 73_OrigPlans_1972 | 1972 | Borings | 4 Borings | Texas Department of Transportation |
| Jefferson | Intracoastal Canal SH 87_AsBuilt_1971 | 1971 | Borings | 14 Borings | Texas Department of Transportation |
| Jefferson | DMemo No 1 Taylors Bayou 1969 | 1969 | Borings | 112 Borings- 26 ft | U.S. Army Corps of Engineers |
| Jefferson | 25th St and SH 73 Left_AsBuilt_1969 | 1969 | Borings | 2 Borings | Texas Department of Transportation |
| Jefferson | 25th St and SH 73 Right_AsBuilt_1969 | 1969 | Borings | 2 Borings | Texas Department of Transportation |
| Jefferson | 39th St at SH 73 Left_AsBuilt_1969 | 1969 | Borings | 2 Borings | Texas Department of Transportation |
| Jefferson | 39th St at SH 73 Right_AsBuilt_1969 | 1969 | Borings | 2 Borings | Texas Department of Transportation |
| Jefferson | Main Ave at 32nd Left_AsBuilt_1969 | 1969 | Borings | 2 Borings | Texas Department of Transportation |
| Jefferson | Main Ave at 32nd Right_AsBuilt_1969 | 1969 | Borings | 2 Borings | Texas Department of Transportation |
| Jefferson | Southern Pacific RR EB_ConstrPlans_1969 | 1969 | Borings | 2 Borings | Texas Department of Transportation |
| Jefferson | Southern Pacific RR WB_ConstrPlans_1969 | 1969 | Borings | 2 Borings | Texas Department of Transportation |
| Jefferson | 20-124-0200-14-085_AsBuilt_1969 | 1969 | Borings | 2 Borings- 70 ft | Texas Department of Transportation |
| Jefferson | 20-124-0065-08-098_AsBuilt_1968 | 1968 | Borings | 2 Borings | Texas Department of Transportation |
| Jefferson | 20-124-0065-08-099_AsBuilt_1968 | 1968 | Borings | 2 Borings | Texas Department of Transportation |
| Jefferson | 9th Ave at SH 73_OrigPlans_1968 | 1968 | Borings | 4 Borings | Texas Department of Transportation |
| Jefferson | KCS RR at SH 73_OrigPlans_1968 | 1968 | Borings | 5 Borings | Texas Department of Transportation |
| Jefferson | SH 347 at SH 73_AsBuilt_1968 | 1968 | Borings | 4 Borings | Texas Department of Transportation |

**DETAILED LIST OF REFERENCE DOCUMENTS**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS

| COUNTY | GIS NAMING CONVENTION | YEAR | TYPE OF DATA | NO. and MAX. DEPTH OF BORINGS/CPTS | ISSUED BY |
|---|---|---|---|---|---|
| Jefferson | Sabine Neches Waterway - 1967 | 1967 | Borings | 12 Borings- 60 ft | U.S. Army Corps of Engineers |
| Jefferson | Spur 380 at US 69_ConstrPlans_1966 | 1966 | Borings | 2 Borings | Texas Department of Transportation |
| Jefferson | Spur 380 Overpass_ConstrPlans_1966 | 1966 | Borings | 2 Borings- 86 ft | Texas Department of Transportation |
| Jefferson | Sulphur Plant Rd. Underpass_ConstrPlans_1966 | 1966 | Borings | 2 Borings- 70 ft | Texas Department of Transportation |
| Jefferson | Airport Rd Overpass_1965 | 1965 | Borings | 3 Borings | Texas Department of Transportation |
| Jefferson | FM 365 at US 69_AsBuilt_1965 | 1965 | Borings | 2 Borings | Texas Department of Transportation |
| Jefferson | KC&S Overpass_AsBuilt_1965 | 1965 | Borings | 3 Borings | Texas Department of Transportation |
| Jefferson | Rhodair Gully at US 69_OrigPlans_1965 | 1965 | Borings | 2 Borings | Texas Department of Transportation |
| Jefferson | Rhodair Gully at US 69-1_OrigPlans_1965 | 1965 | Borings | 2 Borings | Texas Department of Transportation |
| Jefferson | FM 366 at SH 347_AsBuilt_1964 | 1964 | Borings | 3 Borings | Texas Department of Transportation |
| Jefferson | Sabine Neches Spoil Disposal Area 1964 | 1964 | Borings | 4 Borings- 20 ft | U.S. Army Corps of Engineers |
| Jefferson | SH 73 at US 69_OrigPlans_1963 | 1963 | Borings | 2 Borings | Texas Department of Transportation |
| Jefferson | Sabine Pass Anchorage Basin - 1963 | 1963 | Borings | 3 Borings- 56 ft | U.S. Army Corps of Engineers |
| Jefferson | Main A Canal at SH 73_OrigPlans_1961 | 1961 | Borings | 2 Borings | Texas Department of Transportation |
| Jefferson | Main Outfall Canal at Spur 215_AsBuilt_1961 | 1961 | Borings | 2 Borings | Texas Department of Transportation |
| Jefferson | Hwy 69 and SH 73_OrigPlans_1960 | 1960 | Borings | 2 Borings | Texas Department of Transportation |
| Jefferson | Spur 214 at SH 73_OrigPlans_1960 | 1960 | Borings | 2 Borings | Texas Department of Transportation |
| Jefferson | Spur 215 at SH 73_OrigPlans_1958 | 1958 | Borings | 2 Borings | Texas Department of Transportation |
| Jefferson | Rhodair Gully at FM 365_AsBuilt_1953 | 1953 | Borings | 3 Borings | Texas Department of Transportation |
| Jefferson | 20-124-0508-04-035_AsBuilt_1951 | 1951 | Borings | 1 Boring | Texas Department of Transportation |
| Jefferson | 20-124-0508-04-036_AsBuilt_1951 | 1951 | Borings | 1 Boring | Texas Department of Transportation |
| Jefferson | Sportsman Club Ditch at SH 73_AsBuilt_1951 | 1951 | Borings | 2 Borings | Texas Department of Transportation |
| Jefferson | Interim Report Hurricane Survey Pt Arthur & Vicinity - 1961 | Not Available | Borings | 17 Borings- 65 ft | U.S. Army Corps of Engineers |
| Jefferson | CPTs from GLO - 2001 | Not Available | CPTs | 18 CPTs-60 ft | Not Available |

**DETAILED LIST OF REFERENCE DOCUMENTS**

STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS

| COUNTY | GIS NAMING CONVENTION | YEAR | TYPE OF DATA | NO. and MAX. DEPTH OF BORINGS/CPTS | ISSUED BY |
|---|---|---|---|---|---|
| Orange | August 2013 Boring Rpt | 2013 | Borings | 5 Borings- 40 ft | Fugro |
| Orange | November 2007 Boring Rpt | 2007 | Borings | 1 Boring- 60 ft | Tolunay-Wong Engineers, Inc. |
| Orange | 20-181-AA06-91-001_AsBuilt_2007 | 2007 | Borings | 1 Boring- 60 ft | Texas Department of Transportation |
| Orange | 20-181-0028-09-237-254_AsBuilt_2006 | 2006 | Borings | 82 Borings- 24 ft | Texas Department of Transportation |
| Orange | August 2004 Boring Rpt | 2004 | Borings | 3 Borings- 40 ft | Fugro |
| Orange | 20-181-0028-14-243_AsBuilt_2002 | 2002 | Borings | 34 Borings- 55 ft | Texas Department of Transportation |
| Orange | 20-181-0306-02-029_AsBuilt_1997 | 1997 | Borings | 2 Borings- 50 ft | Texas Department of Transportation |
| Orange | 20-181-AA03-67-001_AsBuilt_1991 | 1991 | Borings | 1 Boring- 33 ft | Texas Department of Transportation |
| Orange | 20-181-0784-06-009_WideningPlans_1988 | 1988 | Borings | 2 Borings- 70 ft | Texas Department of Transportation |
| Orange | 20-181-0784-06-010_Widening_1988 | 1988 | Borings | 2 Borings- 55 ft | Texas Department of Transportation |
| Orange | USACE14080-25 | 1980 | Borings | 1 Boring- 50 ft | U.S. Army Corps of Engineers |
| Orange | USACE14080-26 | 1980 | Borings | 1 Boring- 45 ft | U.S. Army Corps of Engineers |
| Orange | 20-181-0305-07-042_Widening_1976 | 1976 | Borings | 2 Borings- 61 ft | Texas Department of Transportation |
| Orange | 20-181-0306-01-021_AsBuilt_1972 | 1972 | Borings | 8 Borings- 76 ft | Texas Department of Transportation |
| Orange | 20-181-0028-09-144-147_AsBuilt_1969 | 1969 | Borings | 2 Borings- 84 ft | Texas Department of Transportation |
| Orange | 20-181-1284-02-004_AsBuilt_1962 | 1962 | Borings | 1 Boring- 40 ft | Texas Department of Transportation |
| Orange | 20-181-0028-14-108_OrigPlans_1961 | 1961 | Borings | 2 Borings- 60 ft | Texas Department of Transportation |
| Orange | 20-181-AA26-90-006_OrigPlans_1961 | 1961 | Borings | 4 Borings- 60 ft | Texas Department of Transportation |
| Orange | 20-181-0028-14-101_AsBuilt_1959 | 1959 | Borings | 2 Borings- 155 ft | Texas Department of Transportation |
| Orange | 20-181-0028-14-068_AsBuilt_1953 | 1953 | Borings | 3 Borings- 80 ft | Texas Department of Transportation |
| Orange | 20-181-0028-14-069_AsBuilt_1953 | 1953 | Borings | 4 Borings- 60 ft | Texas Department of Transportation |
| Orange | 20-181-0028-15-071_AsBuilt_1953 | 1953 | Borings | 5 Borings- 70 ft | Texas Department of Transportation |
| Orange | 20-181-0028-14-070_AsBuilt_1951 | 1951 | Borings | 5 Borings- 60 ft | Texas Department of Transportation |
| Orange | 20-181-0883-02-001_AsBuilt_1951 | 1951 | Borings | 1 Boring- 32 ft | Texas Department of Transportation |
| Orange | 20-181-0882-02-001_AsBuilt_1948 | 1948 | Borings | 2 Borings- 52 ft | Texas Department of Transportation |
| Orange | 20-181-0028-15-061_AsBuilt_1943 | 1943 | Borings | 5 Borings- 70 ft | Texas Department of Transportation |
| Orange | 20-181-0306-01-017_OrigPlans_1939 | 1939 | Borings | 11 Borings- 55 ft | Texas Department of Transportation |

**DETAILED LIST OF REFERENCE DOCUMENTS**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS

# APPENDIX D

# LOGS OF BORINGS

| DEPTH, FT | WATER LEVEL | SYMBOL | SAMPLES | BLOWS PER FOOT | LOCATION: See Plate 4a<br>COORDINATES: N 29°6'36.66" W 94°9'56.52"<br>SURFACE EL.: Not Available<br>STRATUM DESCRIPTION | STRATUM DEPTH, FT | UNIT DRY WT, PCF | PASSING NO. 200 SIEVE, % | WATER CONTENT, % | LIQUID LIMIT | PLASTIC LIMIT | PLASTICITY INDEX (PI) | SHEAR STRENGTH (KIPS PER SQ FT) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 6 | SILTY SAND, loose, brown | | | | | | | | |
| | ▼ | | | 8 | | | | | | | | | |
| 5 | | | | 9 | | | | 20 | 38 | 21 | 12 | 9 | |
| | | | | 15 | - with clay seams at 6'<br>- medium dense, olive gray, with shell fragments below 6.5' | | | | | | | | |
| 10 | | | | 13 | | | | | | | | | |
| 15 | | | | 12 | SAND, medium dense, fine-grained, olive gray, with shell fragments | 13.0 | | 6 | | | | | |
| 20 | | | | 2 | SANDY CLAY, very soft, olive gray, with shell fragments | 18.5 | | | | | | | |
| 25 | | | | 2 | | | | 66 | | 27 | 15 | 12 | |
| 30 | | | | WOH | | | | | | | | | |
| 35 | | | | | CLAY, firm to stiff, olive gray | 33.0 | 97 | 85 | 28 | 72 | 15 | 57 | □ Penetrometer; ▼ Unconfined |
| | | | | 4 | - soft, tan and greenish gray, with sand seams, 38.5' to 43' | | | | | | | | |

Shear strength legend: □ Penetrometer, ◇ Torvane, △ Field Vane; Unconfined ▼, Triaxial ●, Miniature Vane ▲. KIPS PER SQ FT: 0.5, 1.0, 1.5, 2.0, 2.5

NOTES:
1. ▽: Water First Noticed. ▼: Depth To Water after 15 minutes.
2. WOH: Weight of Hammer.
3. Boring coordinates were obtained with a hand-held GPS device.
4. Terms and symbols are presented on Plates D-9a and D-9b.

DATE: May 12, 2017
TOTAL DEPTH: 50'
CAVED DEPTH: 3'
DRY AUGER: Surface to 6'
WET ROTARY: 6' to 50'
BACKFILL: Cement-Bentonite Grout
LOGGER: E. Schulak

**LOG OF BORING NO. BH-01**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON AND ORANGE COUNTIES, TEXAS

| DEPTH, FT | WATER LEVEL | SYMBOL | SAMPLES | BLOWS PER FOOT | LOCATION: See Plate 4a<br>COORDINATES: N 29°6'36.66" W 94°9'56.52"<br>SURFACE EL.: Not Available<br>STRATUM DESCRIPTION | STRATUM DEPTH, FT | UNIT DRY WT, PCF | PASSING NO. 200 SIEVE, % | WATER CONTENT, % | LIQUID LIMIT | PLASTIC LIMIT | PLASTICITY INDEX (PI) | SHEAR STRENGTH (KIPS PER SQ FT) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | CLAY, soft, tan and greenish gray<br>- with sand seams to 43'<br>- stiff to very stiff below 43'<br>- brown and gray, 43' to 48'<br>- brown below 48' | 50.0 | 97 | 98 | 28 | 76 | 21 | 55 | |

SHEAR STRENGTH legend: □ Penetrometer; ◇ Torvane; △ Field Vane; Unconfined ▼; Triaxial ●; Miniature Vane ▲. KIPS PER SQ FT: 0.5, 1.0, 1.5, 2.0, 2.5

NOTES:

1. ▽: Water First Noticed. ▼: Depth To Water after 15 minutes.
2. WOH: Weight of Hammer.
3. Boring coordinates were obtained with a hand-held GPS device.
4. Terms and symbols are presented on Plates D-9a and D-9b.

DATE: May 12, 2017
TOTAL DEPTH: 50'
CAVED DEPTH: 3'
DRY AUGER: Surface to 6'
WET ROTARY: 6' to 50'
BACKFILL: Cement-Bentonite Grout
LOGGER: E. Schulak

**LOG OF BORING NO. BH-01**

STORM SURGE SUPPRESSION STUDY - GCCPRD

BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON AND ORANGE COUNTIES, TEXAS

| DEPTH, FT | WATER LEVEL | SAMPLES | BLOWS PER FOOT | STRATUM DESCRIPTION | STRATUM DEPTH, FT | UNIT DRY WT, PCF | PASSING NO. 200 SIEVE, % | WATER CONTENT, % | LIQUID LIMIT | PLASTIC LIMIT | PLASTICITY INDEX (PI) | SHEAR STRENGTH (KIPS PER SQ FT) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 6 | SILTY SAND, very loose to loose, brown, with shell fragments | | | | | | | | |
| | | | 9 | | | | | | | | | |
| 5 | ▼ | | 4 | | | | 13 | 25 | | | | |
| | | | 2 | - dark gray, 6.5' to 8' | | | | | | | | |
| | | | | - olive gray, with clay seams below 8' | | | | | | | | |
| 10 | | | | | | | 27 | | 21 | 18 | 3 | |
| 15 | | | 10 | | | | | | | | | |
| 20 | | | 15 | - medium dense below 18.5' | | | | | | | | |
| 25 | | | WOH | - very loose at 24' | | | 26 | | 24 | 22 | 2 | |
| 30 | | | 24 | | | | | | | | | |
| | | | | SANDY CLAY, soft to firm, olive gray | 32.0 | | | | | | | |
| 35 | | | 2 | | | | 56 | | 33 | 18 | 15 | |
| | | | | | | | | | | | | □ |

LOCATION: See Plate 4a
COORDINATES: N 29°1'49.24" W 94°5'31.77"
SURFACE EL.: Not Available

SHEAR STRENGTH: □ Penetrometer, ◇ Torvane, △ Field Vane, Unconfined ▼, Triaxial ●, Miniature Vane ▲; KIPS PER SQ FT: 0.5, 1.0, 1.5, 2.0, 2.5

NOTES:
1. ▽: Water First Noticed. ▼: Depth To Water after 15 minutes.
2. WOH: Weight of Hammer.
3. Boring coordinates were obtained with a hand-held GPS device.
4. Terms and symbols are presented on Plates D-9a and D-9b.

DATE: April 25, 2017
TOTAL DEPTH: 400'
CAVED DEPTH: Not Applicable
DRY AUGER: Surface to 8'
WET ROTARY: 8' to 400'
BACKFILL: Cement-Bentonite Grout
LOGGER: E. Schulak

**LOG OF BORING NO. BH-02**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON AND ORANGE COUNTIES, TEXAS
PLATE D-2a

| DEPTH, FT | WATER LEVEL | SYMBOL | SAMPLES | BLOWS PER FOOT | LOCATION: See Plate 4a<br>COORDINATES: N 29°1'49.24" W 94°5'31.77"<br>SURFACE EL.: Not Available<br>STRATUM DESCRIPTION | STRATUM DEPTH, FT | UNIT DRY WT, PCF | PASSING NO. 200 SIEVE, % | WATER CONTENT, % | LIQUID LIMIT | PLASTIC LIMIT | PLASTICITY INDEX (PI) | SHEAR STRENGTH (KIPS PER SQ FT) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 45 | | | | | SANDY CLAY, firm, olive gray<br>- with shell fragments below 45' | | | | | | | | □ |
| 50 | | | | 20 | SAND, medium dense, fine-grained, olive gray | 47.0 | | | | | | | |
| 55 | | | | 21 | | | | | | | | | |
| 60 | | | | 16 | | | | 6 | | | | | |
| 65 | | | | 19 | | | | | | | | | |
| 70 | | | | 13 | - with shell fragments below 68' | | | | | | | | |
| 75 | | | | 9 | - loose below 73.5' | | | | | | | | |
| | | | | | CLAY, firm, dark gray, with sand pockets | 78.0 | | | | | | | □ |

Shear strength legend: □ Penetrometer; ◇ Torvane; △ Field Vane; Unconfined ▼; Triaxial ●; Miniature Vane ▲. Scale: 0.5, 1.0, 1.5, 2.0, 2.5

NOTES:
1. ▽: Water First Noticed. ▼: Depth To Water after 15 minutes.
2. WOH: Weight of Hammer.
3. Boring coordinates were obtained with a hand-held GPS device.
4. Terms and symbols are presented on Plates D-9a and D-9b.

DATE: April 25, 2017
TOTAL DEPTH: 400'
CAVED DEPTH: Not Applicable
DRY AUGER: Surface to 8'
WET ROTARY: 8' to 400'
BACKFILL: Cement-Bentonite Grout
LOGGER: E. Schulak

**LOG OF BORING NO. BH-02**

STORM SURGE SUPPRESSION STUDY - GCCPRD

BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON AND ORANGE COUNTIES, TEXAS

| DEPTH, FT | SAMPLES / BLOWS PER FOOT | STRATUM DESCRIPTION | STRATUM DEPTH, FT | UNIT DRY WT, PCF | PASSING NO. 200 SIEVE, % | WATER CONTENT, % | LIQUID LIMIT | PLASTIC LIMIT | PLASTICITY INDEX (PI) | SHEAR STRENGTH, KIPS PER SQ FT |
|---|---|---|---|---|---|---|---|---|---|---|
| | | CLAY, firm, dark gray, with sand pockets | | | | | | | | |
| | | - stiff to very stiff below 83' | | | | | | | | |
| 85 | | - greenish gray, 83' to 88' | | 107 | 87 | 21 | 57 | 14 | 43 | 3.0 (Triaxial) |
| | | - gray below 88' | | | | | | | | |
| 90 | | | | | | | | | | |
| 95 | 30 | SAND, medium dense to dense, fine-grained, gray | 93.5 | | | | | | | |
| 100 | 35 | | | | 6 | | | | | |
| 105 | | | | | | | | | | |
| 110 | | SANDY CLAY, stiff, greenish gray, with calcareous nodules | 108.0 | | 59 | | 46 | 13 | 33 | |
| 115 | | | | | | | | | | |
| | 11 | SILTY CLAY, stiff, gray, with sand seams | 118.0 | | 81 | | 23 | 17 | 6 | |

LOCATION: See Plate 4a
COORDINATES: N 29°1'49.24" W 94°5'31.77"
SURFACE EL.: Not Available

Legend: □ Penetrometer, ◇ Torvane, △ Field Vane, Unconfined ▼, Triaxial ●, Miniature Vane ▲

NOTES:
1. ▽: Water First Noticed. ▼: Depth To Water after 15 minutes.
2. WOH: Weight of Hammer.
3. Boring coordinates were obtained with a hand-held GPS device.
4. Terms and symbols are presented on Plates D-9a and D-9b.

DATE: April 25, 2017
TOTAL DEPTH: 400'
CAVED DEPTH: Not Applicable
DRY AUGER: Surface to 8'
WET ROTARY: 8' to 400'
BACKFILL: Cement-Bentonite Grout
LOGGER: E. Schulak

**LOG OF BORING NO. BH-02**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON AND ORANGE COUNTIES, TEXAS

| DEPTH, FT | WATER LEVEL | SYMBOL | SAMPLES | BLOWS PER FOOT | STRATUM DESCRIPTION | STRATUM DEPTH, FT | UNIT DRY WT, PCF | PASSING NO. 200 SIEVE, % | WATER CONTENT, % | LIQUID LIMIT | PLASTIC LIMIT | PLASTICITY INDEX (PI) | SHEAR STRENGTH (KIPS PER SQ FT) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | SILTY CLAY, firm, gray, with sand seams | | | | | | | | |
| 125 | | | | | | | | | | | | | |
| 130 | | | | | SANDY CLAY, very stiff, gray | 130.0 | | | | | | | |
| 135 | | | | | | | | | | | | | |
| | | | | 22 | | | | 56 | 22 | | | | |
| 140 | | | | | | | | | | | | | |
| 145 | | | | | | | | | | | | | |
| | | | | | CLAY, very stiff, greenish gray | 148.0 | | | | | | | |
| 150 | | | | | | | 106 | 75 | 22 | 59 | 13 | 46 | 3.4 |
| 155 | | | | | | | | | | | | | |
| | | | | 5 | - firm, tan, with calcium nodules, 158.5' to 168' | | | | | | | | |

LOCATION: See Plate 4a
COORDINATES: N 29°1'49.24" W 94°5'31.77"
SURFACE EL.: Not Available

SHEAR STRENGTH legend: □ Penetrometer, ◇ Torvane, △ Field Vane, Unconfined ▼, Triaxial ●, Miniature Vane ▲. KIPS PER SQ FT: 0.5, 1.0, 1.5, 2.0, 2.5

NOTES:
1. ▽: Water First Noticed. ▼: Depth To Water after 15 minutes.
2. WOH: Weight of Hammer.
3. Boring coordinates were obtained with a hand-held GPS device.
4. Terms and symbols are presented on Plates D-9a and D-9b.

DATE: April 25, 2017
TOTAL DEPTH: 400'
CAVED DEPTH: Not Applicable
DRY AUGER: Surface to 8'
WET ROTARY: 8' to 400'
BACKFILL: Cement-Bentonite Grout
LOGGER: E. Schulak

# LOG OF BORING NO. BH-02
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON AND ORANGE COUNTIES, TEXAS

| DEPTH, FT | BLOWS PER FOOT | STRATUM DESCRIPTION | STRATUM DEPTH, FT | UNIT DRY WT, PCF | PASSING NO. 200 SIEVE, % | WATER CONTENT, % | LIQUID LIMIT | PLASTIC LIMIT | PLASTICITY INDEX (PI) |
|---|---|---|---|---|---|---|---|---|---|
| | | LOCATION: See Plate 4a<br>COORDINATES: N 29°1'49.24" W 94°5'31.77"<br>SURFACE EL.: Not Available | | | | | | | |
| | | CLAY, firm, tan<br>- with calcium nodules to 168' | | | | | | | |
| 165 | | | | | | | | | |
| | | - greenish gray and tan, 168' to 178'<br>- stiff, 169' to 219' | | | | | | | |
| 170 | | | | | 97 | | 79 | 19 | 60 |
| 175 | | | | | | | | | |
| | | - greenish gray, 178' to 191' | | | | | | | |
| 180 | | | | | | | | | |
| 185 | | | | | | | | | |
| 190 | | | | | | | | | |
| | 6 | - firm at 191'<br>- tan and gray, 191' to 198'<br>- with silt seams, 191' to 208' | | | | | | | |
| 195 | | | | | | | | | |
| | | - gray, 198' to 208'<br>- very stiff at 199' | | | | | | | |

SHEAR STRENGTH, KIPS PER SQ FT: 0.5 1.0 1.5 2.0 2.5
□ Penetrometer ◇ Torvane △ Field Vane Unconfined ▼ Triaxial ● Miniature Vane ▲

NOTES:
1. ▽: Water First Noticed. ▼: Depth To Water after 15 minutes.
2. WOH: Weight of Hammer.
3. Boring coordinates were obtained with a hand-held GPS device.
4. Terms and symbols are presented on Plates D-9a and D-9b.

DATE: April 25, 2017
TOTAL DEPTH: 400'
CAVED DEPTH: Not Applicable
DRY AUGER: Surface to 8'
WET ROTARY: 8' to 400'
BACKFILL: Cement-Bentonite Grout
LOGGER: E. Schulak

## LOG OF BORING NO. BH-02
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON AND ORANGE COUNTIES, TEXAS

| DEPTH, FT | WATER LEVEL | SYMBOL | SAMPLES | BLOWS PER FOOT | LOCATION: See Plate 4a; COORDINATES: N 29°1'49.24" W 94°5'31.77"; SURFACE EL.: Not Available — STRATUM DESCRIPTION | STRATUM DEPTH, FT | UNIT DRY WT, PCF | PASSING NO. 200 SIEVE, % | WATER CONTENT, % | LIQUID LIMIT | PLASTIC LIMIT | PLASTICITY INDEX (PI) | SHEAR STRENGTH (KIPS PER SQ FT) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | CLAY, very stiff, gray,<br>- with silt seams to 208' | | | | | | | | |
| 208 | | | | | - olive gray, 208' to 218' | | | | | | | | □ |
| 218 | | | | | - greenish gray, 218' to 228'<br>- with sand pockets and seams, 218' to 278'<br>- very stiff below 219' | | 88 | 98 | 34 | 88 | 24 | 64 | □; ● 3.2 |
| 228 | | | | | - gray, 228' to 238'<br>- with calcareous nodules, 228' to 268' | | | | | | | | □+ |
| 238 | | | | | - gray and tan, 238' to 258' | | | | | | | | □ |

Shear strength legend: □ Penetrometer; ◇ Torvane; △ Field Vane; Unconfined ▼; Triaxial ●; Miniature Vane ▲. Scale: 0.5, 1.0, 1.5, 2.0, 2.5

NOTES:
1. ▽: Water First Noticed. ▼: Depth To Water after 15 minutes.
2. WOH: Weight of Hammer.
3. Boring coordinates were obtained with a hand-held GPS device.
4. Terms and symbols are presented on Plates D-9a and D-9b.

DATE: April 25, 2017
TOTAL DEPTH: 400'
CAVED DEPTH: Not Applicable
DRY AUGER: Surface to 8'
WET ROTARY: 8' to 400'
BACKFILL: Cement-Bentonite Grout
LOGGER: E. Schulak

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# LOG OF BORING NO. BH-02

STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON AND ORANGE COUNTIES, TEXAS

| DEPTH, FT | WATER LEVEL | SYMBOL | SAMPLES | BLOWS PER FOOT | LOCATION: See Plate 4a<br>COORDINATES: N 29°1'49.24" W 94°5'31.77"<br>SURFACE EL.: Not Available<br>STRATUM DESCRIPTION | STRATUM DEPTH, FT | UNIT DRY WT, PCF | PASSING NO. 200 SIEVE, % | WATER CONTENT, % | LIQUID LIMIT | PLASTIC LIMIT | PLASTICITY INDEX (PI) | SHEAR STRENGTH (KIPS PER SQ FT) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | CLAY, very stiff, gray and tan<br>- with calcareous nodules to 268'<br>- with sand pockets and seams to 278' | | | | | | | | |
| 245 | | | | | | | | | | | | | |
| 250 | | | | | | | | | | | | | |
| 255 | | | | | | | | | | | | | |
| | | | | | - tan and greenish gray, 258' to 268'<br>- stiff at 259' | | | | | | | | |
| 260 | | | | | | | | | | | | | |
| 265 | | | | | | | | | | | | | |
| | | | | | - red and greenish gray, 268' to 278.5' | | | | | | | | |
| 270 | | | | | | | | | | | | | |
| 275 | | | | | | | | | | | | | |
| | | | | 16 | - greenish gray, 278.5' to 288' | | | | | | | | |

Shear strength legend: □ Penetrometer, ◇ Torvane, △ Field Vane, Unconfined ▼, Triaxial ●, Miniature Vane ▲. KIPS PER SQ FT: 0.5, 1.0, 1.5, 2.0, 2.5

NOTES:
1. ▽: Water First Noticed. ▼: Depth To Water after 15 minutes.
2. WOH: Weight of Hammer.
3. Boring coordinates were obtained with a hand-held GPS device.
4. Terms and symbols are presented on Plates D-9a and D-9b.

DATE: April 25, 2017
TOTAL DEPTH: 400'
CAVED DEPTH: Not Applicable
DRY AUGER: Surface to 8'
WET ROTARY: 8' to 400'
BACKFILL: Cement-Bentonite Grout
LOGGER: E. Schulak

# LOG OF BORING NO. BH-02

STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON AND ORANGE COUNTIES, TEXAS

| DEPTH, FT | WATER LEVEL | SYMBOL | SAMPLES | BLOWS PER FOOT | STRATUM DESCRIPTION | STRATUM DEPTH, FT | UNIT DRY WT, PCF | PASSING NO. 200 SIEVE, % | WATER CONTENT, % | LIQUID LIMIT | PLASTIC LIMIT | PLASTICITY INDEX (PI) | SHEAR STRENGTH (KIPS PER SQ FT) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | CLAY, very stiff, greenish gray | | | | | | | | |
| 285 | | | | | | | | | | | | | |
| 288–290 | | | | | - brownish gray, 288' to 298'<br>- with silt partings, 288' to 308'<br>- with shell fragments, 288' to 298' | | 94 | 100 | 30 | 74 | 20 | 54 | □+ ; 3.7 ● |
| 295 | | | | | | | | | | | | | |
| 298–300 | | | | | - red and greenish gray, 298' to 308' | | | | | | | | □+ |
| 305 | | | | | | | | | | | | | |
| 308–310 | | | | 40 | - brown and greenish gray, 308' to 314'<br>- with sand seams, 308' to 314' | | | 91 | | 24 | 15 | 9 | □+ |
| 315 | | | | | - greenish gray and red, with calcareous nodules, 314' to 338' | | | | | | | | |

Shear strength legend: □ Penetrometer; ◇ Torvane; △ Field Vane; Unconfined ▼; Triaxial ●; Miniature Vane ▲. Scale: 0.5, 1.0, 1.5, 2.0, 2.5

NOTES:
1. ▽: Water First Noticed. ▼: Depth To Water after 15 minutes.
2. WOH: Weight of Hammer.
3. Boring coordinates were obtained with a hand-held GPS device.
4. Terms and symbols are presented on Plates D-9a and D-9b.

LOCATION: See Plate 4a
COORDINATES: N 29°1'49.24" W 94°5'31.77"
SURFACE EL.: Not Available

DATE: April 25, 2017
TOTAL DEPTH: 400'
CAVED DEPTH: Not Applicable
DRY AUGER: Surface to 8'
WET ROTARY: 8' to 400'
BACKFILL: Cement-Bentonite Grout
LOGGER: E. Schulak

# LOG OF BORING NO. BH-02

STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON AND ORANGE COUNTIES, TEXAS

LOCATION: See Plate 4a
COORDINATES: N 29°1'49.24" W 94°5'31.77"
SURFACE EL.: Not Available

| DEPTH, FT | BLOWS PER FOOT | STRATUM DESCRIPTION | UNIT DRY WT, PCF | PASSING NO. 200 SIEVE, % | WATER CONTENT, % | LIQUID LIMIT | PLASTIC LIMIT | PLASTICITY INDEX (PI) |
|---|---|---|---|---|---|---|---|---|
| | | CLAY, very stiff, greenish gray and red<br>- with calcareous nodules to 338' | | | | | | |
| 325 | | | | | | | | |
| 330 | | | | | | | | |
| 335 | | | | | | | | |
| | 19 | - olive gray, 338' to 348'<br>- with silt pockets and seams below 338' | | | | | | |
| 340 | | | | | | | | |
| 345 | | | | | | | | |
| | 24 | - greenish gray below 348' | | 97 | | 40 | 14 | 26 |
| 350 | | | | | | | | |
| 355 | | | | | | | | |
| | | - with sand pockets, 358' to 378' | 108 | 91 | 20 | 25 | 16 | 9 |

SHEAR STRENGTH (KIPS PER SQ FT: 0.5, 1.0, 1.5, 2.0, 2.5)
□ Penetrometer ◇ Torvane △ Field Vane; Unconfined ▼ Triaxial ● Miniature Vane ▲

NOTES:
1. ▽: Water First Noticed. ▼: Depth To Water after 15 minutes.
2. WOH: Weight of Hammer.
3. Boring coordinates were obtained with a hand-held GPS device.
4. Terms and symbols are presented on Plates D-9a and D-9b.

DATE: April 25, 2017
TOTAL DEPTH: 400'
CAVED DEPTH: Not Applicable
DRY AUGER: Surface to 8'
WET ROTARY: 8' to 400'
BACKFILL: Cement-Bentonite Grout
LOGGER: E. Schulak

## LOG OF BORING NO. BH-02

STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON AND ORANGE COUNTIES, TEXAS

| DEPTH, FT | WATER LEVEL | SYMBOL | SAMPLES | BLOWS PER FOOT | STRATUM DESCRIPTION | STRATUM DEPTH, FT | UNIT DRY WT, PCF | PASSING NO. 200 SIEVE, % | WATER CONTENT, % | LIQUID LIMIT | PLASTIC LIMIT | PLASTICITY INDEX (PI) | SHEAR STRENGTH (KIPS PER SQ FT) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | CLAY, very stiff, greenish gray, with silt pockets and seams<br>- with sand pockets to 378' | | | | | | | | |
| 365 | | | | | | | | | | | | | |
| | | | | 50/6" | | | | | | | | | |
| 370 | | | | | | | | | | | | | |
| 375 | | | | | | | | | | | | | |
| | | | | 22 | - with shell fragments, 378' to 388' | | | | | | | | |
| 380 | | | | | | | | | | | | | |
| 385 | | | | | | | | | | | | | |
| | | | | | | | 114 | 79 | 17 | 36 | 15 | 21 | 7.2 (Triaxial); Penetrometer + |
| 390 | | | | | - hard at 390' | | | | | | | | |
| 395 | | | | | | | | | | | | | |
| | | | | 18 | | | | | | | | | |

LOCATION: See Plate 4a
COORDINATES: N 29°1'49.24" W 94°5'31.77"
SURFACE EL.: Not Available

Shear strength legend: □ Penetrometer, ◇ Torvane, △ Field Vane, Unconfined ▼, Triaxial ●, Miniature Vane ▲
KIPS PER SQ FT: 0.5, 1.0, 1.5, 2.0, 2.5

NOTES:
1. ▽: Water First Noticed. ▼: Depth To Water after 15 minutes.
2. WOH: Weight of Hammer.
3. Boring coordinates were obtained with a hand-held GPS device.
4. Terms and symbols are presented on Plates D-9a and D-9b.

DATE: April 25, 2017
TOTAL DEPTH: 400'
CAVED DEPTH: Not Applicable
DRY AUGER: Surface to 8'
WET ROTARY: 8' to 400'
BACKFILL: Cement-Bentonite Grout
LOGGER: E. Schulak

**LOG OF BORING NO. BH-02**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON AND ORANGE COUNTIES, TEXAS

Report No. 04.10160148

| DEPTH, FT | WATER LEVEL | SYMBOL | SAMPLES | BLOWS PER FOOT | LOCATION: See Plate 4a<br>COORDINATES: N 29°0'02.72" W 94°5'21.14"<br>SURFACE EL.: Not Available<br>STRATUM DESCRIPTION | STRATUM DEPTH, FT | UNIT DRY WT, PCF | PASSING NO. 200 SIEVE, % | WATER CONTENT, % | LIQUID LIMIT | PLASTIC LIMIT | PLASTICITY INDEX (PI) | SHEAR STRENGTH (KIPS PER SQ FT) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | FILL: SAND, very loose to loose, with shell fragments | | | | | | | | |
| | ▼ | | | 5 | | | | | | | | | |
| 5 | | | | 2 | - with clay pockets, 4.5' to 8' | | | | | | | | |
| | | | | 2 | | | | | | | | | |
| 10 | | | | 2 | | | | | | | | | |
| | | | | | FILL: SANDY CLAY, very soft, greenish gray, with sand seams and shell fragments | 12.0 | | | | | | | |
| 15 | | | | WOH | | | | 62 | | 34 | 14 | 20 | |
| 20 | | | | 2 | | | | | | | | | |
| | | | | 1 | CLAY, very soft, olive gray | 23.5 | | | | | | | |
| 25 | | | | | | | | 90 | | 100 | 26 | 74 | |
| | | | | | SILTY SAND, medium dense to dense, greenish gray, with shell fragments | 27.0 | | | | | | | |
| 30 | | | | 47 | | | | | | | | | |
| 35 | | | | 11 | | | | | | | | | |
| | | | | | - with clay pockets and seams below 38' | | | | | | | | |

SHEAR STRENGTH legend: □ Penetrometer ◇ Torvane △ Field Vane; Unconfined ▼ Triaxial ● Miniature Vane ▲; KIPS PER SQ FT 0.5 1.0 1.5 2.0 2.5

NOTES:
1. ▽: Water First Noticed. ▼: Depth To Water after 15 minutes.
2. WOH: Weight of Hammer.
3. NR: Not Recorded.
4. Boring coordinates were obtained with a hand-held GPS device.
5. Terms and symbols are presented on Plates D-9a and D-9b.

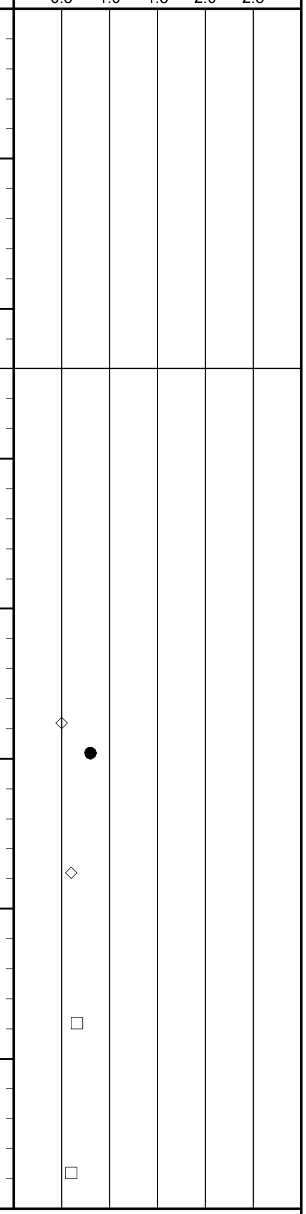
DATE: May 4, 2017
TOTAL DEPTH: 400'
CAVED DEPTH: Not Applicable
DRY AUGER: Surface to 6'
WET ROTARY: 6' to 400'
BACKFILL: Cement-Bentonite Grout
LOGGER: E. Schulak

**LOG OF BORING NO. BH-03**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON AND ORANGE COUNTIES, TEXAS

| DEPTH, FT | WATER LEVEL | SYMBOL | SAMPLES | BLOWS PER FOOT | STRATUM DESCRIPTION | STRATUM DEPTH, FT | UNIT DRY WT, PCF | PASSING NO. 200 SIEVE, % | WATER CONTENT, % | LIQUID LIMIT | PLASTIC LIMIT | PLASTICITY INDEX (PI) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 45 | | | | 13 | SILTY SAND, loose to medium dense, greenish gray, with shell fragments, clay pockets and seams | | | | | | | |
| 50 | | | | 9 | | | | 15 | | | | |
| 55 | | | | WOH | CLAY, very soft to soft, olive gray, with shell fragments<br>- with sand seams to 68' | 52.0 | | | | | | |
| 60 | | | | 3 | | | | | | | | |
| 65 | | | | | - firm, 63' to 108' | | 65 | 85 | 56 | 95 | 21 | 74 |
| 70 | | | | | | | | | | | | |
| 75 | | | | | | | | | | | | |

LOCATION: See Plate 4a
COORDINATES: N 29°0'02.72" W 94°5'21.14"
SURFACE EL.: Not Available

SHEAR STRENGTH, KIPS PER SQ FT (0.5, 1.0, 1.5, 2.0, 2.5)
□ Penetrometer ◇ Torvane △ Field Vane — Unconfined ▼ Triaxial ● Miniature Vane ▲



NOTES:
1. ▽: Water First Noticed. ▼: Depth To Water after 15 minutes.
2. WOH: Weight of Hammer.
3. NR: Not Recorded.
4. Boring coordinates were obtained with a hand-held GPS device.
5. Terms and symbols are presented on Plates D-9a and D-9b.

DATE: May 4, 2017
TOTAL DEPTH: 400'
CAVED DEPTH: Not Applicable
DRY AUGER: Surface to 6'
WET ROTARY: 6' to 400'
BACKFILL: Cement-Bentonite Grout
LOGGER: E. Schulak

# LOG OF BORING NO. BH-03
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON AND ORANGE COUNTIES, TEXAS



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| DEPTH, FT | WATER LEVEL | SYMBOL | SAMPLES | BLOWS PER FOOT | LOCATION: See Plate 4a<br>COORDINATES: N 29°0'02.72" W 94°5'21.14"<br>SURFACE EL.: Not Available<br>STRATUM DESCRIPTION | STRATUM DEPTH, FT | UNIT DRY WT, PCF | PASSING NO. 200 SIEVE, % | WATER CONTENT, % | LIQUID LIMIT | PLASTIC LIMIT | PLASTICITY INDEX (PI) | SHEAR STRENGTH (KIPS PER SQ FT) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | CLAY, firm, olive gray, with shell fragments | | | | | | | | |
| 85 | | | | | | | | | | | | | |
| 90 | | | | | | | | 93 | | 93 | 22 | 71 | |
| 95 | | | | | | | | | | | | | |
| 100 | | | | | | | | | | | | | |
| 105 | | | | | | | | | | | | | |
| | | | | | - stiff below 108' | | | | | | | | |
| 110 | | | | | | | 95 | 98 | 28 | 60 | 16 | 44 | |
| 115 | | | | | | | | | | | | | |
| | | | | | - with sand seams below 118' | | | | | | | | |

Shear strength legend: □ Penetrometer; ◇ Torvane; △ Field Vane; Unconfined ▼; Triaxial ●; Miniature Vane ▲

KIPS PER SQ FT: 0.5 1.0 1.5 2.0 2.5

NOTES:

1. ▽: Water First Noticed. ▼: Depth To Water after 15 minutes.
2. WOH: Weight of Hammer.
3. NR: Not Recorded.
4. Boring coordinates were obtained with a hand-held GPS device.
5. Terms and symbols are presented on Plates D-9a and D-9b.

DATE: May 4, 2017
TOTAL DEPTH: 400'
CAVED DEPTH: Not Applicable
DRY AUGER: Surface to 6'
WET ROTARY: 6' to 400'
BACKFILL: Cement-Bentonite Grout
LOGGER: E. Schulak

**LOG OF BORING NO. BH-03**

STORM SURGE SUPPRESSION STUDY - GCCPRD

BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON AND ORANGE COUNTIES, TEXAS

LOCATION: See Plate 4a
COORDINATES: N 29°0'02.72" W 94°5'21.14"
SURFACE EL.: Not Available

| DEPTH, FT | SAMPLES | BLOWS PER FOOT | STRATUM DESCRIPTION | STRATUM DEPTH, FT | UNIT DRY WT, PCF | PASSING NO. 200 SIEVE, % | WATER CONTENT, % | LIQUID LIMIT | PLASTIC LIMIT | PLASTICITY INDEX (PI) | SHEAR STRENGTH (KIPS PER SQ FT) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 120 | | | SAND, medium dense to very dense, fine-grained, greenish gray, with sand seams<br>- with clay seam at 119.5' | 120.0 | | | | | | | |
| 129.5 | X | 30 | - pale brown below 128.5' | | | 7 | | | | | |
| 139.5 | X | 6 | - coarse-grained, 138.5' to 158'<br>- loose at 139' | | | | | | | | |
| 149.5 | X | 37 | | | | | | | | | |
| 159.5 | X | 53 | - fine-grained below 158' | | | | | | | | |

Shear strength legend: □ Penetrometer; ◇ Torvane; △ Field Vane; Unconfined ▼; Triaxial ●; Miniature Vane ▲. Scale: 0.5, 1.0, 1.5, 2.0, 2.5

NOTES:
1. ▽: Water First Noticed. ▼: Depth To Water after 15 minutes.
2. WOH: Weight of Hammer.
3. NR: Not Recorded.
4. Boring coordinates were obtained with a hand-held GPS device.
5. Terms and symbols are presented on Plates D-9a and D-9b.

DATE: May 4, 2017
TOTAL DEPTH: 400'
CAVED DEPTH: Not Applicable
DRY AUGER: Surface to 6'
WET ROTARY: 6' to 400'
BACKFILL: Cement-Bentonite Grout
LOGGER: E. Schulak

**LOG OF BORING NO. BH-03**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON AND ORANGE COUNTIES, TEXAS

LOCATION: See Plate 4a
COORDINATES: N 29°0'02.72" W 94°5'21.14"
SURFACE EL.: Not Available

| DEPTH, FT | BLOWS PER FOOT | STRATUM DESCRIPTION | STRATUM DEPTH, FT | UNIT DRY WT, PCF | PASSING NO. 200 SIEVE, % | WATER CONTENT, % | LIQUID LIMIT | PLASTIC LIMIT | PLASTICITY INDEX (PI) | SHEAR STRENGTH (KIPS PER SQ FT) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | SAND, medium dense to very dense, fine-grained, pale brown | | | | | | | | |
| 168.5 | 50/6" | - with shell fragments below 168.5' | | | | | | | | |
| 178 | 28 | SILTY SAND, loose to medium dense, olive gray, with clay pockets, shell fragments, and gravel | 178.0 | | 16 | | | | | |
| 188.5 | 10 | | | | | | | | | |
| 198 | | CLAY, stiff to very stiff, greenish gray<br>- with sand pockets to 205' | 198.0 | 108 | 72 | 20 | 39 | 14 | 25 | 3.0 (Triaxial); ~1.5 (Penetrometer) |

Depth scale: 165, 170, 175, 180, 185, 190, 195

Shear strength legend: □ Penetrometer, ◇ Torvane, △ Field Vane, Unconfined ▼, Triaxial ●, Miniature Vane ▲. Scale: 0.5, 1.0, 1.5, 2.0, 2.5

NOTES:
1. ▽: Water First Noticed. ▼: Depth To Water after 15 minutes.
2. WOH: Weight of Hammer.
3. NR: Not Recorded.
4. Boring coordinates were obtained with a hand-held GPS device.
5. Terms and symbols are presented on Plates D-9a and D-9b.

DATE: May 4, 2017
TOTAL DEPTH: 400'
CAVED DEPTH: Not Applicable
DRY AUGER: Surface to 6'
WET ROTARY: 6' to 400'
BACKFILL: Cement-Bentonite Grout
LOGGER: E. Schulak

**LOG OF BORING NO. BH-03**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON AND ORANGE COUNTIES, TEXAS

LOCATION: See Plate 4a
COORDINATES: N 29°0'02.72" W 94°5'21.14"
SURFACE EL.: Not Available

| DEPTH, FT | STRATUM DESCRIPTION | UNIT DRY WT, PCF | PASSING NO. 200 SIEVE, % | WATER CONTENT, % | LIQUID LIMIT | PLASTIC LIMIT | PLASTICITY INDEX (PI) | SHEAR STRENGTH, KIPS PER SQ FT |
|---|---|---|---|---|---|---|---|---|
| 200 | CLAY, stiff to very stiff, greenish gray<br>- with sand pockets to 205' | | | | | | | |
| 210 | | | 100 | | 54 | 18 | 36 | Penetrometer ≈1.6 |
| 219 | | | | | | | | Penetrometer ≈2.5 |
| 228 | - with silt partings and shell fragments, 228' to 248' | | | | | | | Penetrometer ≈2.5+ |
| 238 | - olive gray, 238' to 258' | | | | | | | Penetrometer ≈1.1 |
| 240 | | 85 | 99 | 37 | 31 | 14 | 17 | Triaxial 3.2 |

NOTES:
1. ▽: Water First Noticed. ▼: Depth To Water after 15 minutes.
2. WOH: Weight of Hammer.
3. NR: Not Recorded.
4. Boring coordinates were obtained with a hand-held GPS device.
5. Terms and symbols are presented on Plates D-9a and D-9b.

DATE: May 4, 2017
TOTAL DEPTH: 400'
CAVED DEPTH: Not Applicable
DRY AUGER: Surface to 6'
WET ROTARY: 6' to 400'
BACKFILL: Cement-Bentonite Grout
LOGGER: E. Schulak

**LOG OF BORING NO. BH-03**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON AND ORANGE COUNTIES, TEXAS

| DEPTH, FT | WATER LEVEL | SYMBOL | SAMPLES | BLOWS PER FOOT | LOCATION: See Plate 4a<br>COORDINATES: N 29°0'02.72" W 94°5'21.14"<br>SURFACE EL.: Not Available<br>STRATUM DESCRIPTION | STRATUM DEPTH, FT | UNIT DRY WT, PCF | PASSING NO. 200 SIEVE, % | WATER CONTENT, % | LIQUID LIMIT | PLASTIC LIMIT | PLASTICITY INDEX (PI) | SHEAR STRENGTH (KIPS PER SQ FT) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | CLAY, very stiff, olive gray<br>- with silt partings and shell fragments to 248' | | | | | | | | |
| 245 | | | | | | | | | | | | | |
| | | | | NR | - with wood fragments, 248' to 249.5' | | | | | | | | |
| 250 | | | | | | | | | | | | | |
| 255 | | | | | | | | | | | | | |
| | | | | | - greenish gray, 258' to 278'<br>- with sand pockets and seams, 248' to 289' | | | 60 | | 30 | 12 | 18 | Penetrometer ≈ 2.2 |
| 260 | | | | | | | | | | | | | |
| 265 | | | | | | | | | | | | | |
| | | | | | | | | | | | | | Penetrometer ≈ 2.8 |
| 270 | | | | | | | | | | | | | |
| 275 | | | | | | | | | | | | | |
| | | | | | - tan and brown, 278' to 288' | | | | | | | | Penetrometer 2.8+ |

Shear strength legend: □ Penetrometer, ◇ Torvane, △ Field Vane, ▼ Unconfined, ● Triaxial, ▲ Miniature Vane. KIPS PER SQ FT: 0.5, 1.0, 1.5, 2.0, 2.5

NOTES:
1. ▽: Water First Noticed. ▼: Depth To Water after 15 minutes.
2. WOH: Weight of Hammer.
3. NR: Not Recorded.
4. Boring coordinates were obtained with a hand-held GPS device.
5. Terms and symbols are presented on Plates D-9a and D-9b.

DATE: May 4, 2017
TOTAL DEPTH: 400'
CAVED DEPTH: Not Applicable
DRY AUGER: Surface to 6'
WET ROTARY: 6' to 400'
BACKFILL: Cement-Bentonite Grout
LOGGER: E. Schulak

**LOG OF BORING NO. BH-03**

STORM SURGE SUPPRESSION STUDY - GCCPRD

BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON AND ORANGE COUNTIES, TEXAS

LOCATION: See Plate 4a
COORDINATES: N 29°0'02.72" W 94°5'21.14"
SURFACE EL.: Not Available

| DEPTH, FT | STRATUM DESCRIPTION | UNIT DRY WT, PCF | PASSING NO. 200 SIEVE, % | WATER CONTENT, % | LIQUID LIMIT | PLASTIC LIMIT | PLASTICITY INDEX (PI) | SHEAR STRENGTH (KIPS PER SQ FT) |
|---|---|---|---|---|---|---|---|---|
| | CLAY, very stiff, tan and brown<br>- with sand pockets and seams to 289' | | | | | | | |
| 288–290 | - red, with silt partings, 288' to 308'<br>- stiff to hard at 289' | 108 | 99 | 21 | 51 | 21 | 30 | Penetrometer 1.4; Triaxial 5.5 |
| 298–300 | | | 100 | | 87 | 19 | 68 | Penetrometer + |
| 308–310 | - greenish gray below 308' | | | | | | | Penetrometer + |
| 318– | - with shell fragments, 318' to 328' | | | | | | | Penetrometer 2.3 |

Legend: □ Penetrometer, ◇ Torvane, △ Field Vane, Unconfined ▼, Triaxial ●, Miniature Vane ▲

NOTES:
1. ▽: Water First Noticed. ▼: Depth To Water after 15 minutes.
2. WOH: Weight of Hammer.
3. NR: Not Recorded.
4. Boring coordinates were obtained with a hand-held GPS device.
5. Terms and symbols are presented on Plates D-9a and D-9b.

DATE: May 4, 2017
TOTAL DEPTH: 400'
CAVED DEPTH: Not Applicable
DRY AUGER: Surface to 6'
WET ROTARY: 6' to 400'
BACKFILL: Cement-Bentonite Grout
LOGGER: E. Schulak

**LOG OF BORING NO. BH-03**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON AND ORANGE COUNTIES, TEXAS

| DEPTH, FT | WATER LEVEL | SYMBOL | SAMPLES | BLOWS PER FOOT | LOCATION: See Plate 4a<br>COORDINATES: N 29°0'02.72" W 94°5'21.14"<br>SURFACE EL.: Not Available<br>STRATUM DESCRIPTION | STRATUM DEPTH, FT | UNIT DRY WT, PCF | PASSING NO. 200 SIEVE, % | WATER CONTENT, % | LIQUID LIMIT | PLASTIC LIMIT | PLASTICITY INDEX (PI) | SHEAR STRENGTH, KIPS PER SQ FT (□ Penetrometer, ◇ Torvane, △ Field Vane, Unconfined ▼, Triaxial ●, Miniature Vane ▲) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | CLAY, very stiff, greenish gray<br>- with silt partings to 308'<br>- with shell fragments to 328' | | | | | | | | |
| 325 | | | | | | | | | | | | | |
| 330 | | | | | | | | | | | | | □+ |
| 335 | | | | | | | | | | | | | |
| | | | | 13 | - with sand pockets, 338.5' to 348' | | | | | | | | |
| 340 | | | | | | | | | | | | | |
| 345 | | | | | | | | | | | | | |
| | | | | | - with calcareous nodules, 348' to 358.5' | | | | | | | | |
| 350 | | | | | - hard at 350' | | 113 | 85 | 19 | 51 | 14 | 37 | 5.9 ● |
| 355 | | | | | | | | | | | | | |
| | | | | 19 | - with shell fragments, 358.5' to 368' | | | | | | | | |

NOTES:
1. ▽: Water First Noticed. ▼: Depth To Water after 15 minutes.
2. WOH: Weight of Hammer.
3. NR: Not Recorded.
4. Boring coordinates were obtained with a hand-held GPS device.
5. Terms and symbols are presented on Plates D-9a and D-9b.

DATE: May 4, 2017
TOTAL DEPTH: 400'
CAVED DEPTH: Not Applicable
DRY AUGER: Surface to 6'
WET ROTARY: 6' to 400'
BACKFILL: Cement-Bentonite Grout
LOGGER: E. Schulak

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**LOG OF BORING NO. BH-03**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON AND ORANGE COUNTIES, TEXAS

LOCATION: See Plate 4a
COORDINATES: N 29°0'02.72"
W 94°5'21.14"
SURFACE EL.: Not Available

| DEPTH, FT | BLOWS PER FOOT | STRATUM DESCRIPTION | STRATUM DEPTH, FT | UNIT DRY WT, PCF | PASSING NO. 200 SIEVE, % | WATER CONTENT, % | LIQUID LIMIT | PLASTIC LIMIT | PLASTICITY INDEX (PI) | SHEAR STRENGTH (KIPS PER SQ FT) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | CLAY, very stiff, greenish gray, with silt seams<br>- with shell fragments to 368' | | | | | | | | |
| 365 | | | | | | | | | | |
| 370 | | | | | | | | | | |
| 375 | | | | | | | | | | |
| | 6 | - firm at 379' | | | | | | | | |
| 380 | | | | | | | | | | |
| 385 | | | | | | | | | | |
| | 20 | | | | | | | | | |
| 390 | | | | | | | | | | |
| 395 | | | | | | | | | | |
| | 29 | | | | | | 37 | 13 | 24 | |

SHEAR STRENGTH legend: □ Penetrometer, ◇ Torvane, △ Field Vane, Unconfined ▼, Triaxial ●, Miniature Vane ▲
KIPS PER SQ FT: 0.5 1.0 1.5 2.0 2.5

NOTES:
1. ∇: Water First Noticed. ▼: Depth To Water after 15 minutes.
2. WOH: Weight of Hammer.
3. NR: Not Recorded.
4. Boring coordinates were obtained with a hand-held GPS device.
5. Terms and symbols are presented on Plates D-9a and D-9b.

DATE: May 4, 2017
TOTAL DEPTH: 400'
CAVED DEPTH: Not Applicable
DRY AUGER: Surface to 6'
WET ROTARY: 6' to 400'
BACKFILL: Cement-Bentonite Grout
LOGGER: E. Schulak

**LOG OF BORING NO. BH-03**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON AND ORANGE COUNTIES, TEXAS



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| DEPTH, FT | WATER LEVEL | SYMBOL | SAMPLES | BLOWS PER FOOT | LOCATION: See Plate 4a<br>COORDINATES: N 29°5'25.58" W 94°2'30.35"<br>SURFACE EL.: Not Available<br>STRATUM DESCRIPTION | STRATUM DEPTH, FT | UNIT DRY WT, PCF | PASSING NO. 200 SIEVE, % | WATER CONTENT, % | LIQUID LIMIT | PLASTIC LIMIT | PLASTICITY INDEX (PI) | SHEAR STRENGTH (KIPS PER SQ FT) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ▼ | | | 16 | SILTY SAND, loose to medium dense, brown, with shell fragments | | | | | | | | |
| | | | | 9 | | | | | | | | | |
| 5 | | | | 10 | | | | | | | | | |
| | | | | 7 | | | | | | | | | |
| | | | | 20 | - brownish gray, 8.5' to 13.5' | | | | | | | | |
| 10 | | | | | | | | | | | | | |
| | | | | 22 | - gray, 13.5' to 28.5' | | | | | | | | |
| 15 | | | | | | | | | | | | | |
| | | | | 21 | | | | | | | | | |
| 20 | | | | | | | | | | | | | |
| | | | | 21 | | | | | | | | | |
| 25 | | | | | | | | | | | | | |
| | | | | 10 | - olive gray below 28.5' | | | | | | | | |
| 30 | | | | | | | | | | | | | |
| | | | | 3 | - very loose below 33.5' | | | | | | | | |
| 35 | | | | | | | | | | | | | |
| | | | | | CLAY, stiff, red and greenish gray | 38.0 | | | | | | | □ (Penetrometer) ~1.4 |

Shear strength legend: □ Penetrometer; ◇ Torvane; △ Field Vane; Unconfined ▼; Triaxial ●; Miniature Vane ▲. KIPS PER SQ FT: 0.5, 1.0, 1.5, 2.0, 2.5

NOTES:
1. ▽: Water First Noticed. ▼: Depth To Water after 15 minutes.
2. Boring coordinates were obtained with a hand-held GPS device.
3. Terms and symbols are presented on Plates D-9a and D-9b.

DATE: May 8, 2017
TOTAL DEPTH: 50'
CAVED DEPTH: Not Applicable
DRY AUGER: Surface to 50'
WET ROTARY: Not Applicable
BACKFILL: Cement-Bentonite Grout
LOGGER: E. Schulak

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**LOG OF BORING NO. BH-04**

STORM SURGE SUPPRESSION STUDY - GCCPRD

BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON AND ORANGE COUNTIES, TEXAS

| DEPTH, FT | WATER LEVEL | SYMBOL | SAMPLES | BLOWS PER FOOT | LOCATION: See Plate 4a<br>COORDINATES: N 29°5'25.58" W 94°2'30.35"<br>SURFACE EL.: Not Available<br>STRATUM DESCRIPTION | STRATUM DEPTH, FT | UNIT DRY WT, PCF | PASSING NO. 200 SIEVE, % | WATER CONTENT, % | LIQUID LIMIT | PLASTIC LIMIT | PLASTICITY INDEX (PI) | SHEAR STRENGTH (KIPS PER SQ FT) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | CLAY, stiff, red and greenish gray | | | | | | | | |
| 45 | | | | | - with shell fragments at 44' | | 84 | | 38 | 94 | 23 | 71 | |
| | | | | | - red below 48' | | | | | | | | |
| 50 | | | | | | 50.0 | | | | | | | |
| 55 | | | | | | | | | | | | | |
| 60 | | | | | | | | | | | | | |
| 65 | | | | | | | | | | | | | |
| 70 | | | | | | | | | | | | | |
| 75 | | | | | | | | | | | | | |

Shear strength legend: □ Penetrometer; ◇ Torvane; △ Field Vane; Unconfined ▼; Triaxial ●; Miniature Vane ▲. Scale: 0.5, 1.0, 1.5, 2.0, 2.5

NOTES:

1. ▽: Water First Noticed. ▼: Depth To Water after 15 minutes.
2. Boring coordinates were obtained with a hand-held GPS device.
3. Terms and symbols are presented on Plates D-9a and D-9b.

DATE: May 8, 2017
TOTAL DEPTH: 50'
CAVED DEPTH: Not Applicable
DRY AUGER: Surface to 50'
WET ROTARY: Not Applicable
BACKFILL: Cement-Bentonite Grout
LOGGER: E. Schulak

**LOG OF BORING NO. BH-04**

STORM SURGE SUPPRESSION STUDY - GCCPRD

BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON AND ORANGE COUNTIES, TEXAS

LOCATION: See Plate 4a
COORDINATES: N 29°0'23.95" W 94°9'42.43"
SURFACE EL.: Not Available

| DEPTH, FT | WATER LEVEL | BLOWS PER FOOT | STRATUM DESCRIPTION | STRATUM DEPTH, FT | UNIT DRY WT, PCF | PASSING NO. 200 SIEVE, % | WATER CONTENT, % | LIQUID LIMIT | PLASTIC LIMIT | PLASTICITY INDEX (PI) | SHEAR STRENGTH (KIPS PER SQ FT) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 11 | SILTY SAND, loose to medium dense, brown | | | | | | | | |
| | ▼ | 6 | | | | | | | | | |
| 5 | | 10 | | | | | | | | | |
| | | 11 | - brownish gray, 6.5' to 8.5' | | | | | | | | |
| | | 11 | - light olive gray, 8.5' to 13.5' | | | | | | | | |
| 10 | | | | | | | | | | | |
| | | 6 | - greenish gray, 13.5' to 18.5' | | | | | | | | |
| 15 | | | | | | | | | | | |
| | | 3 | - very loose, gray, with shell fragments below 18.5' | | | | | | | | |
| 20 | | | | | | | | | | | |
| | | 1 | | | | | | | | | |
| 25 | | | | | | | | | | | |
| | | | SANDY CLAY, soft, greenish gray, with shell fragments, and calcareous nodules | 28.0 | | | | | | | |
| 30 | | | | | 89 | 56 | 33 | 52 | 13 | 39 | |
| | | | - firm, greenish gray and dark brown below 33' | | | | | | | | |
| 35 | | | | | | 53 | | | | | |
| | | | CLAY, stiff, tan and greenish gray, with sand pockets and calcareous nodules | 38.0 | 104 | 73 | 23 | 51 | 12 | 39 | |

SHEAR STRENGTH legend: □ Penetrometer; ◇ Torvane; △ Field Vane; Unconfined ▼; Triaxial ●; Miniature Vane ▲. KIPS PER SQ FT: 0.5, 1.0, 1.5, 2.0, 2.5

NOTES:
1. ▽: Water First Noticed. ▼: Depth To Water after 15 minutes.
2. Boring coordinates were obtained with a hand-held GPS device.
3. Terms and symbols are presented on Plates D-9a and D-9b.

DATE: May 9, 2017
TOTAL DEPTH: 50'
CAVED DEPTH: 3'
DRY AUGER: Surface to 4'
WET ROTARY: 4' to 50'
BACKFILL: Cement-Bentonite Grout
LOGGER: E. Schulak

# LOG OF BORING NO. BH-05
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON AND ORANGE COUNTIES, TEXAS

| DEPTH, FT | WATER LEVEL | SYMBOL | SAMPLES | BLOWS PER FOOT | LOCATION: See Plate 4a<br>COORDINATES: N 29°0'23.95" W 94°9'42.43"<br>SURFACE EL.: Not Available<br>STRATUM DESCRIPTION | STRATUM DEPTH, FT | UNIT DRY WT, PCF | PASSING NO. 200 SIEVE, % | WATER CONTENT, % | LIQUID LIMIT | PLASTIC LIMIT | PLASTICITY INDEX (PI) | SHEAR STRENGTH (KIPS PER SQ FT) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | CLAY, stiff, tan and greenish gray, with sand pockets and calcareous nodules | | | | | | | | |
| | | | | 4 | - firm below 43.5' | | | | | | | | |
| 45 | | | | | | | | | | | | | |
| | | | | 8 | | | | | | | | | |
| 50 | | | | | | 50.0 | | | | | | | |
| 55 | | | | | | | | | | | | | |
| 60 | | | | | | | | | | | | | |
| 65 | | | | | | | | | | | | | |
| 70 | | | | | | | | | | | | | |
| 75 | | | | | | | | | | | | | |

SHEAR STRENGTH legend: □ Penetrometer, ◇ Torvane, △ Field Vane, Unconfined ▼, Triaxial ●, Miniature Vane ▲. KIPS PER SQ FT: 0.5, 1.0, 1.5, 2.0, 2.5

NOTES:
1. ▽: Water First Noticed. ▼: Depth To Water after 15 minutes.
2. Boring coordinates were obtained with a hand-held GPS device.
3. Terms and symbols are presented on Plates D-9a and D-9b.

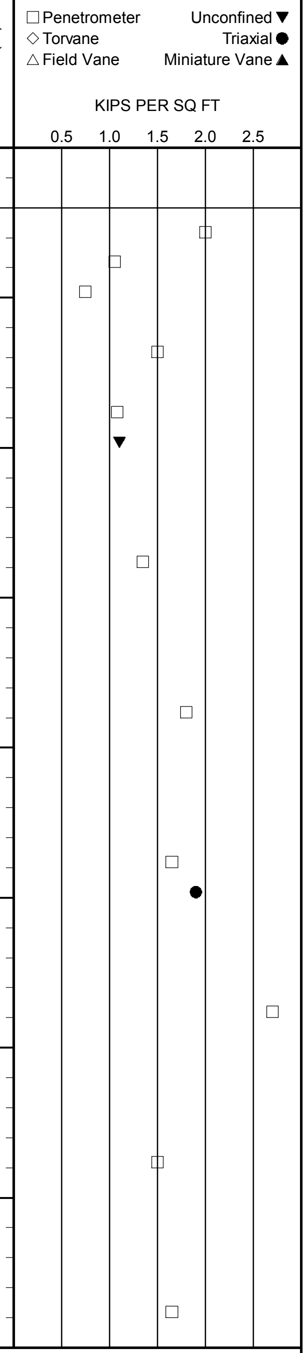
DATE: May 9, 2017
TOTAL DEPTH: 50'
CAVED DEPTH: 3'
DRY AUGER: Surface to 4'
WET ROTARY: 4' to 50'
BACKFILL: Cement-Bentonite Grout
LOGGER: E. Schulak

**LOG OF BORING NO. BH-05**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON AND ORANGE COUNTIES, TEXAS

LOCATION: See Plate 4b
COORDINATES: N 29°1'24.28" W 95°3'04.83"
SURFACE EL.: Not Available

| DEPTH, FT | STRATUM DESCRIPTION | STRATUM DEPTH, FT | UNIT DRY WT, PCF | PASSING NO. 200 SIEVE, % | WATER CONTENT, % | LIQUID LIMIT | PLASTIC LIMIT | PLASTICITY INDEX (PI) |
|---|---|---|---|---|---|---|---|---|
| | FILL: SANDY CLAY, dark brown to gray, with calcareous nodules | 2.0 | | | | | | |
| | CLAY, stiff, gray<br>- with calcareous nodules to 18'<br>- with ferrous nodules to 13' | | | | | | | |
| 5 | - firm at 5' | | | | | | | |
| | - gray and tan, 7' to 18' | | | | | | | |
| 10 | | | 87 | 95 | 35 | 81 | 21 | 60 |
| 15 | | | | | | | | |
| | - greenish gray and tan, slickensided, 18' to 23' | | | | | | | |
| 20 | | | | | | | | |
| | - tan and gray, 23' to 28' | | | | | | | |
| 25 | | | 102 | | 25 | 52 | 13 | 39 |
| | - red to greenish gray, 28' to 33'<br>- very stiff at 29'<br>- with sand pockets below 29' | | | | | | | |
| 30 | | | | | | | | |
| | - red below 33' | | | | | | | |
| 35 | | | | | | | | |

SHEAR STRENGTH




NOTES:

1. Free water was not encountered during drilling to a depth of 25'.
2. Boring coordinates were obtained with a hand-held GPS devices.
3. Terms and symbols are presented on Plates D-9a and D-9b.

DATE: May 11, 2017
TOTAL DEPTH: 50'
CAVED DEPTH: Not Applicable
DRY AUGER: Surface to 25'
WET ROTARY: 25' to 50'
BACKFILL: Cement-Bentonite Grout
LOGGER: E. Schulak

# LOG OF BORING NO. BH-06

STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON AND ORANGE COUNTIES, TEXAS

LOCATION: See Plate 4b
COORDINATES: N 29°1'24.28" W 95°3'04.83"
SURFACE EL.: Not Available

| DEPTH, FT | STRATUM DESCRIPTION | STRATUM DEPTH, FT | UNIT DRY WT, PCF | PASSING NO. 200 SIEVE, % | WATER CONTENT, % | LIQUID LIMIT | PLASTIC LIMIT | PLASTICITY INDEX (PI) |
|---|---|---|---|---|---|---|---|---|
| | CLAY, stiff, red, with sand pockets | | | | | | | |
| | - stiff to very stiff below 43' | | | | | | | |
| 45 | | | 103 | | 22 | 67 | 18 | 49 |
| 50 | | 50.0 | | | | | | |
| 55 | | | | | | | | |
| 60 | | | | | | | | |
| 65 | | | | | | | | |
| 70 | | | | | | | | |
| 75 | | | | | | | | |

SHEAR STRENGTH: □ Penetrometer, ◇ Torvane, △ Field Vane, Unconfined ▼, Triaxial ●, Miniature Vane ▲
KIPS PER SQ FT: 0.5 1.0 1.5 2.0 2.5

NOTES:
1. Free water was not encountered during drilling to a depth of 25'.
2. Boring coordinates were obtained with a hand-held GPS devices.
3. Terms and symbols are presented on Plates D-9a and D-9b.

DATE: May 11, 2017
TOTAL DEPTH: 50'
CAVED DEPTH: Not Applicable
DRY AUGER: Surface to 25'
WET ROTARY: 25' to 50'
BACKFILL: Cement-Bentonite Grout
LOGGER: E. Schulak

**LOG OF BORING NO. BH-06**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON AND ORANGE COUNTIES, TEXAS

LOCATION: See Plate 4b
COORDINATES: N 28°8'38.12" W 95°1'32.18"
SURFACE EL.: Not Available

| DEPTH, FT | BLOWS PER FOOT | STRATUM DESCRIPTION | STRATUM DEPTH, FT | UNIT DRY WT, PCF | PASSING NO. 200 SIEVE, % | WATER CONTENT, % | LIQUID LIMIT | PLASTIC LIMIT | PLASTICITY INDEX (PI) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | | FILL: SANDY CLAY, stiff to hard, dark brown | | | | | | | |
| | | - red below 2' | | | | | | | |
| 4 | | CLAY, soft to firm, red | 4.0 | | | | | | |
| 8 | | | | 88 | 95 | 35 | 42 | 14 | 28 |
| 13 | | - dark brown, 13' to 18' | | | | | | | |
| 18 | | - stiff to very stiff, 18' to 28.5'<br>- brown and greenish gray, with ferrous nodules, 18' to 23'<br>- with calcareous nodules below 18' | | | | | | | |
| 20 | | | | 107 | 91 | 22 | 47 | 12 | 35 |
| 23 | | - red, tan and brown, with sand pockets and seams below 23' | | | | | | | |
| 28.5 | 4 | - firm to stiff below 28.5' | | | | | | | |
| 33.5 | 10 | | | | | | | | |
| 37 | | SILTY SAND, medium dense, brown | 37.0 | | | | | | |
| 38.5 | 18 | | | | | | | | |

SHEAR STRENGTH (KIPS PER SQ FT: 0.5, 1.0, 1.5, 2.0, 2.5)
□ Penetrometer ◇ Torvane △ Field Vane — Unconfined ▼ Triaxial ● Miniature Vane ▲
4.5+

NOTES:
1. Free water was not encountered during drilling to a depth of 25'.
2. Boring coordinates were obtained with a hand-held GPS devices.
3. Terms and symbols are presented on Plates D-9a and D-9b.

DATE: May 11, 2017
TOTAL DEPTH: 50'
CAVED DEPTH: Not Applicable
DRY AUGER: Surface to 25'
WET ROTARY: 25' to 50'
BACKFILL: Cement-Bentonite Grout
LOGGER: E. Schulak

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**LOG OF BORING NO. BH-07**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON AND ORANGE COUNTIES, TEXAS

LOCATION: See Plate 4b
COORDINATES: N 28°8'38.12" W 95°1'32.18"
SURFACE EL.: Not Available

| DEPTH, FT | WATER LEVEL | SYMBOL | SAMPLES | BLOWS PER FOOT | STRATUM DESCRIPTION | STRATUM DEPTH, FT | UNIT DRY WT, PCF | PASSING NO. 200 SIEVE, % | WATER CONTENT, % | LIQUID LIMIT | PLASTIC LIMIT | PLASTICITY INDEX (PI) | SHEAR STRENGTH (KIPS PER SQ FT) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | SILTY SAND, medium dense, brown | | | | | | | | |
| | | | | | CLAY, stiff, red | 42.0 | | | | | | | |
| 50 | | | | | - very stiff at 50' | 50.0 | 101 | | 25 | 55 | 15 | 40 | 3.9 (Triaxial) |

SHEAR STRENGTH legend: □ Penetrometer; ◇ Torvane; △ Field Vane; Unconfined ▼; Triaxial ●; Miniature Vane ▲

KIPS PER SQ FT: 0.5 1.0 1.5 2.0 2.5

Depth scale: 45, 50, 55, 60, 65, 70, 75

NOTES:
1. Free water was not encountered during drilling to a depth of 25'.
2. Boring coordinates were obtained with a hand-held GPS devices.
3. Terms and symbols are presented on Plates D-9a and D-9b.

DATE: May 11, 2017
TOTAL DEPTH: 50'
CAVED DEPTH: Not Applicable
DRY AUGER: Surface to 25'
WET ROTARY: 25' to 50'
BACKFILL: Cement-Bentonite Grout
LOGGER: E. Schulak

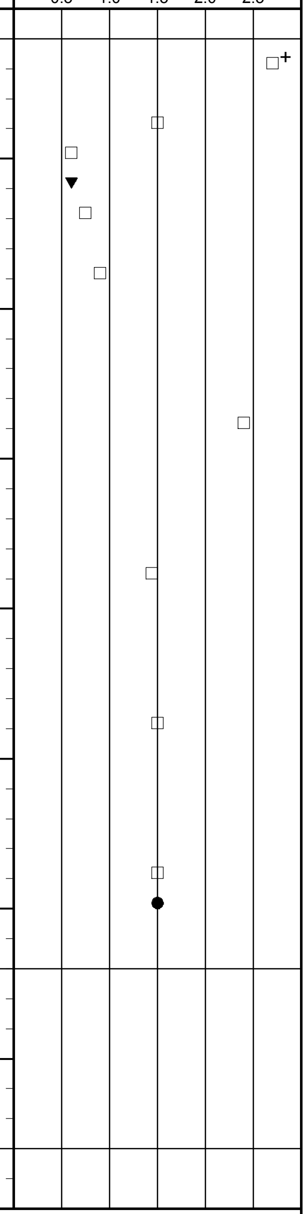
**LOG OF BORING NO. BH-07**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON AND ORANGE COUNTIES, TEXAS

LOCATION: See Plate 4b
COORDINATES: N 28°8'14.14" W 95°6'24.91"
SURFACE EL.: Not Available

| DEPTH, FT | BLOWS PER FOOT | STRATUM DESCRIPTION | STRATUM DEPTH, FT | UNIT DRY WT, PCF | PASSING NO. 200 SIEVE, % | WATER CONTENT, % | LIQUID LIMIT | PLASTIC LIMIT | PLASTICITY INDEX (PI) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | | SILTY SAND, tan | 1.0 | | | | | | |
| 1 | | CLAY, firm to very stiff, dark brown, - with shell fragments to 2' | | | | | | | |
| 6 | | - red and brown, 6' to 8' | | 100 | 91 | 23 | 44 | 15 | 29 |
| 8 | | - dark brown, 8' to 13' - with calcareous nodules below 8' - with ferrous nodoules, 8' to 23' | | 83 | | 38 | | | |
| 13 | | - red and greenish gray below 13' - very stiff at 14' | | | | | | | |
| 18 | | - stiff below 18' | | | | | | | |
| 30 | | | | | | | 94 | 24 | 70 |
| 32 | | CLAYEY SAND, brown and gray | 32.0 | | | | | | |
| 38 | 14 | SILTY SAND, medium dense, brown | 38.0 | | | | | | |

SHEAR STRENGTH (KIPS PER SQ FT: 0.5, 1.0, 1.5, 2.0, 2.5)

□ Penetrometer ◇ Torvane △ Field Vane Unconfined ▼ Triaxial ● Miniature Vane ▲



NOTES:
1. Free water was not encountered during drilling to a depth of 25'.
2. Boring coordinates were obtained with a hand-held GPS devices.
3. Terms and symbols are presented on Plates D-9a and D-9b.

DATE: May 10, 2017
TOTAL DEPTH: 50'
CAVED DEPTH: Not Applicable
DRY AUGER: Surface to 25'
WET ROTARY: 25' to 50'
BACKFILL: Cement-Bentonite Grout
LOGGER: E. Schulak

**LOG OF BORING NO. BH-08**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON AND ORANGE COUNTIES, TEXAS

| DEPTH, FT | WATER LEVEL | SYMBOL | SAMPLES | BLOWS PER FOOT | LOCATION: See Plate 4b<br>COORDINATES: N 28°8'14.14" W 95°6'24.91"<br>SURFACE EL.: Not Available<br>STRATUM DESCRIPTION | STRATUM DEPTH, FT | UNIT DRY WT, PCF | PASSING NO. 200 SIEVE, % | WATER CONTENT, % | LIQUID LIMIT | PLASTIC LIMIT | PLASTICITY INDEX (PI) | SHEAR STRENGTH (KIPS PER SQ FT) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | SILTY SAND, medium dense, brown | | | | | | | | |
| 45 | | | | 20 | - pale brown below 43.5' | | | | | | | | |
| 50 | | | | 19 | | 50.0 | | | | | | | |
| 55 | | | | | | | | | | | | | |
| 60 | | | | | | | | | | | | | |
| 65 | | | | | | | | | | | | | |
| 70 | | | | | | | | | | | | | |
| 75 | | | | | | | | | | | | | |

SHEAR STRENGTH legend: □ Penetrometer, ◇ Torvane, △ Field Vane, Unconfined ▼, Triaxial ●, Miniature Vane ▲. KIPS PER SQ FT: 0.5, 1.0, 1.5, 2.0, 2.5

NOTES:
1. Free water was not encountered during drilling to a depth of 25'.
2. Boring coordinates were obtained with a hand-held GPS devices.
3. Terms and symbols are presented on Plates D-9a and D-9b.

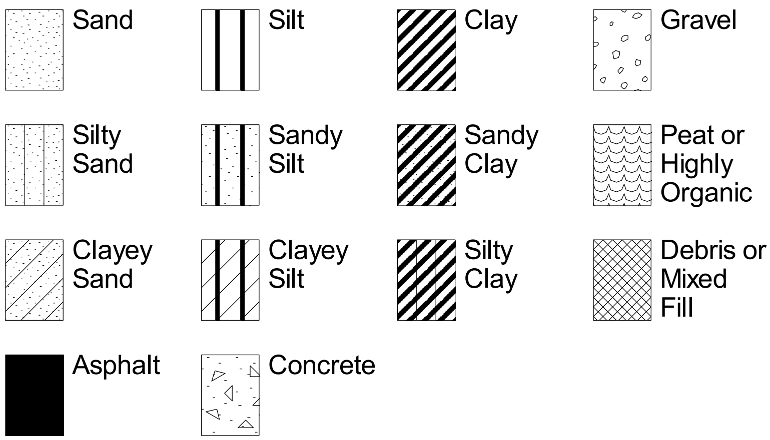
DATE: May 10, 2017
TOTAL DEPTH: 50'
CAVED DEPTH: Not Applicable
DRY AUGER: Surface to 25'
WET ROTARY: 25' to 50'
BACKFILL: Cement-Bentonite Grout
LOGGER: E. Schulak

**LOG OF BORING NO. BH-08**

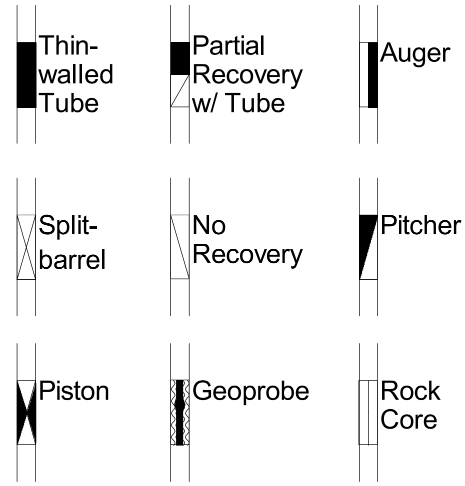
STORM SURGE SUPPRESSION STUDY - GCCPRD

BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON AND ORANGE COUNTIES, TEXAS

## SOIL TYPES




## SAMPLER TYPES

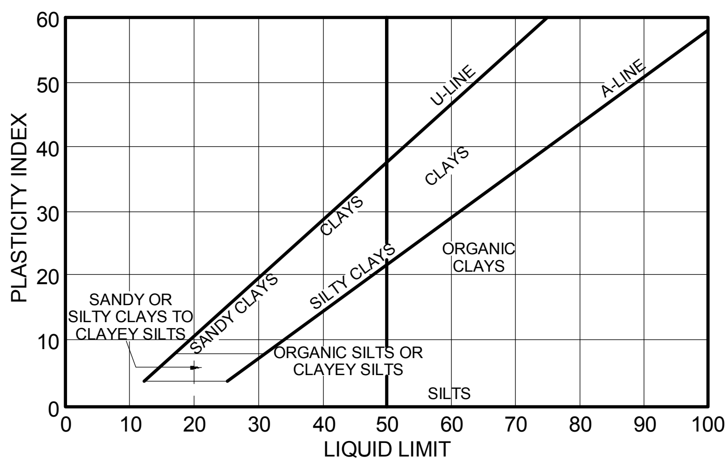



## SOIL GRAIN SIZE

U.S. Standard Sieve

| 6" | | 3" | 3/4" | 4 | 10 | 40 | 200 | | |
|---|---|---|---|---|---|---|---|---|---|
| Boulders | Cobbles | Gravel | | Sand | | | Silt | Clay | |
| | | Coarse | Fine | Coarse | Medium | Fine | | | |
| 152 | 76.2 | 19.1 | 4.76 | 2.00 | 0.420 | 0.074 | 0.002 | (mm) | |

## PLASTICITY CHART




## SOIL STRUCTURE

| | |
|---|---|
| Slickensided | Having planes of weakness that appear slick and glossy. |
| Fissured | Containing shrinkage or relief cracks, often filled with fine sand or silt; usually more or less vertical. |
| Pocket | Inclusion of material of different texture that is smaller than the diameter of the sample. |
| Parting | Inclusion less than 1/8 inch thick extending through the sample. |
| Seam | Inclusion 1/8 inch to 3 inches thick extending through the sample. |
| Layer | Inclusion greater than 3 inches thick extending through the sample. |
| Laminated | Soil sample composed of alternating partings or seams of different soil type. |
| Interlayered | Soil sample composed of alternating layers of different soil type. |
| Intermixed | Soil sample composed of pockets of different soil type and layered or laminated structure is not evident. |
| Calcareous | Having appreciable quantities of carbonate. |
| Carbonate | Having more than 50% carbonate content. |

# TERMS AND SYMBOLS USED ON BORING LOGS

SOIL CLASSIFICATION (1 of 2)

## STANDARD PENETRATION TEST (SPT)

A 2-in.-OD, 1-3/8-ID split spoon sampler is driven 1.5 ft into undisturbed soil with a 140-pound hammer free falling 30 in. After the sampler is seated 6 in. into undisturbed soil, the number of blows required to drive the sampler the last 12 in. is the Standard Penetration Resistance or "N" value, which is recorded as blows per foot as described below.

## SPLIT-BARREL SAMPLER DRIVING RECORD

| Blows Per Foot | Description |
|---|---|
| 25 | 25 blows drove sampler 12 inches, after initial 6 inches of seating. |
| 50/7" | 50 blows drove sampler 7 inches, after initial 6 inches of seating. |
| Ref/3" | 50 blows drove sampler 3 inches during initial 6-inch seating interval. |

NOTE: To avoid damage to sampling tools, driving is limited to 50 blows during or after seating interval.

## DENSITY OF GRANULAR SOILS

| Descriptive Term | *Relative Density, % | **Blows Per Foot (SPT) |
|---|---|---|
| Very Loose | < 15 | 0 to 4 |
| Loose | 15 to 35 | 5 to 10 |
| Medium Dense | 35 to 65 | 11 to 30 |
| Dense | 65 to 85 | 31 to 50 |
| Very Dense | > 85 | > 50 |

*Estimated from sampler driving record.
**Requires correction for depth, groundwater level, and grain size.

## STRENGTH OF COHESIVE SOILS

| Term | Undrained Shear Strength, ksf | Blows Per Foot (SPT) (approximate) |
|---|---|---|
| Very Soft | < 0.25 | 0 to 2 |
| Soft | 0.25 to 0.50 | 2 to 4 |
| Firm | 0.50 to 1.00 | 4 to 8 |
| Stiff | 1.00 to 2.00 | 8 to 16 |
| Very Stiff | 2.00 to 4.00 | 16 to 32 |
| Hard | > 4.00 | > 32 |

## SHEAR STRENGTH TEST METHOD

U - Unconfined Q = Unconsolidated - Undrained Triaxial

P = Pocket Penetrometer T = Torvane V = Miniature Vane F = Field Vane

## HAND PENETROMETER CORRECTION

Our experience has shown that the hand penetrometer generally overestimates the in-situ undrained shear strength of over consolidated Pleistocene Gulf Coast clays. These strengths are partially controlled by the presence of macroscopic soil defects such as slickensides, which generally do not influence smaller scale tests like the hand penetrometer. Based on our experience, we have adjusted these field estimates of the undrained shear strength of natural, overconsolidated Pleistocene Gulf Coast soils by multiplying the measured penetrometer reading by a factor of 0.6. These adjusted strength estimates are recorded in the "Shear Strength" column on the boring logs. Except as described in the text, we have not adjusted estimates of the undrained shear strength for projects located outside of the Pleistocene Gulf Coast formations.

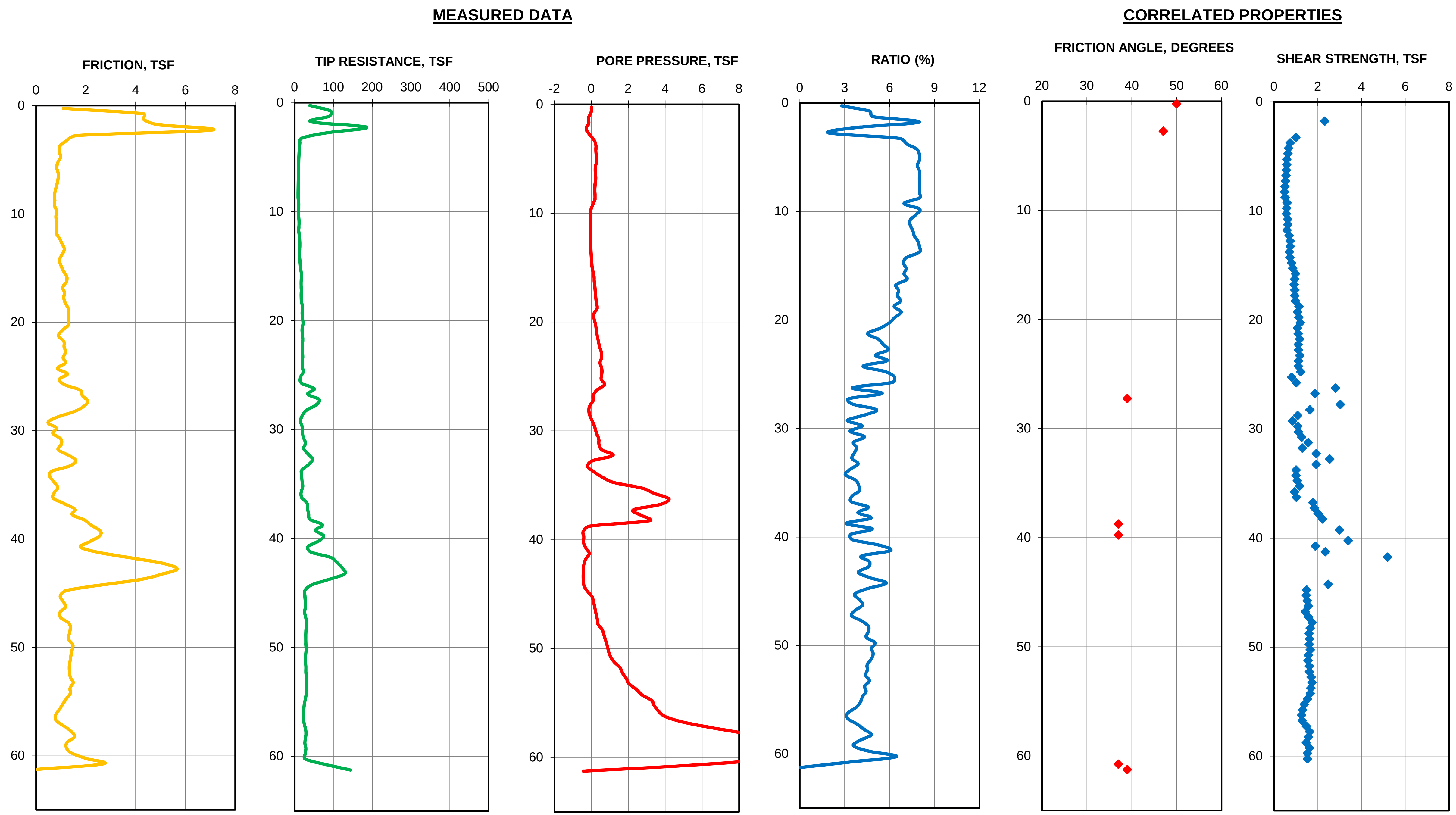
Information on each boring log is a compilation of subsurface conditions and soil or rock classifications obtained from the field as well as from laboratory testing of samples. Strata have been interpreted by commonly accepted procedures. The stratum lines on the logs may be transitional and approximate in nature. Water level measurements refer only to those observed at the time and places indicated, and can vary with time, geologic condition, or construction activity.

## TERMS AND SYMBOLS USED ON BORING LOGS
SOIL CLASSIFICATION (2 of 2)

# APPENDIX E

## CPT INFORMATION

Note: CPT-04 was canceled due to difficulty in accessing the location.

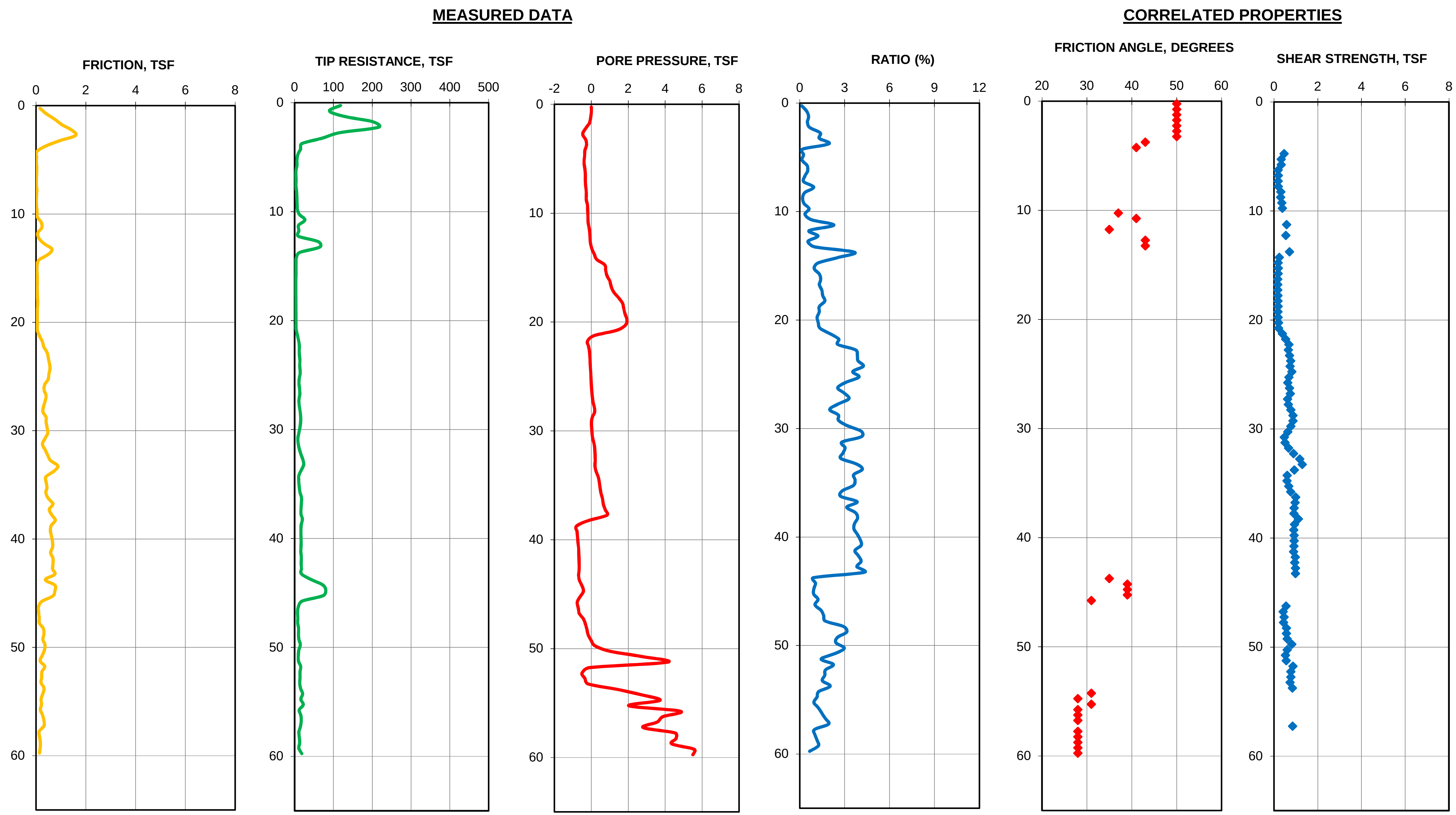



**NOTE:**

1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986).
   THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

**CONE PENETROMETER TEST: CPT-01**

STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS




**NOTE:**

1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986).
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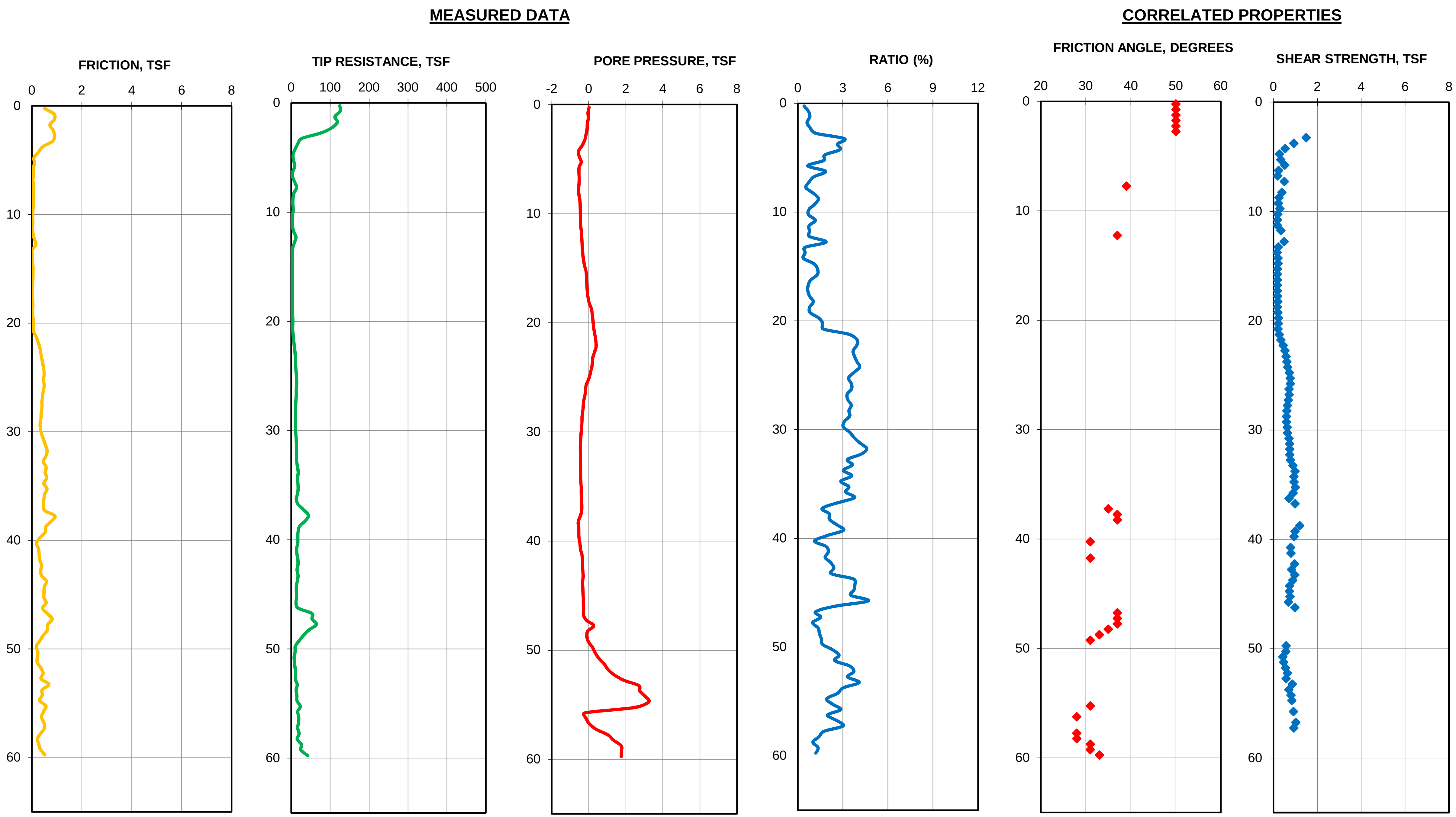
**CONE PENETROMETER TEST: CPT-02**

STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS



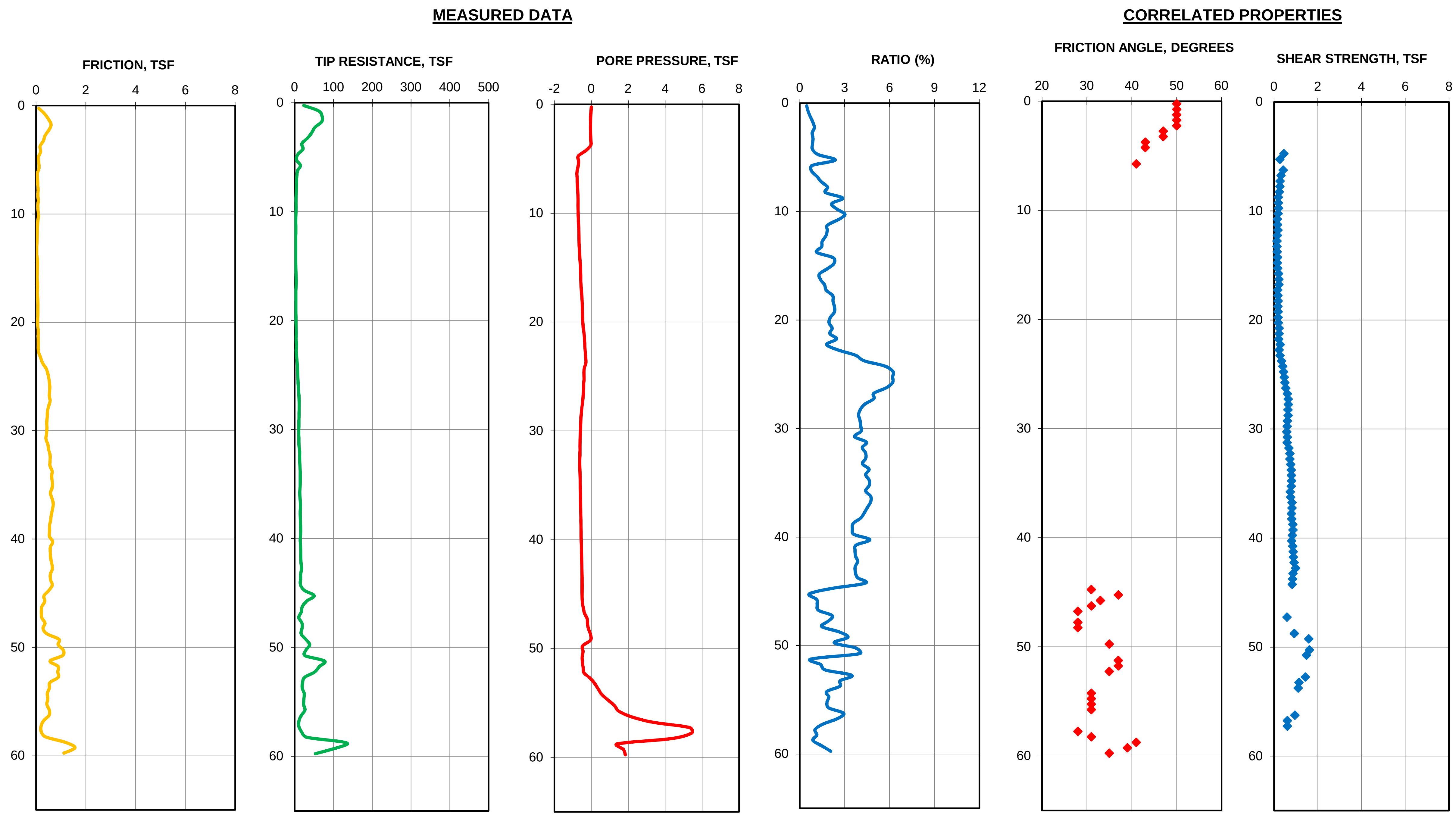

**NOTE:**

1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986).

THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

**CONE PENETROMETER TEST: CPT-03**

STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS

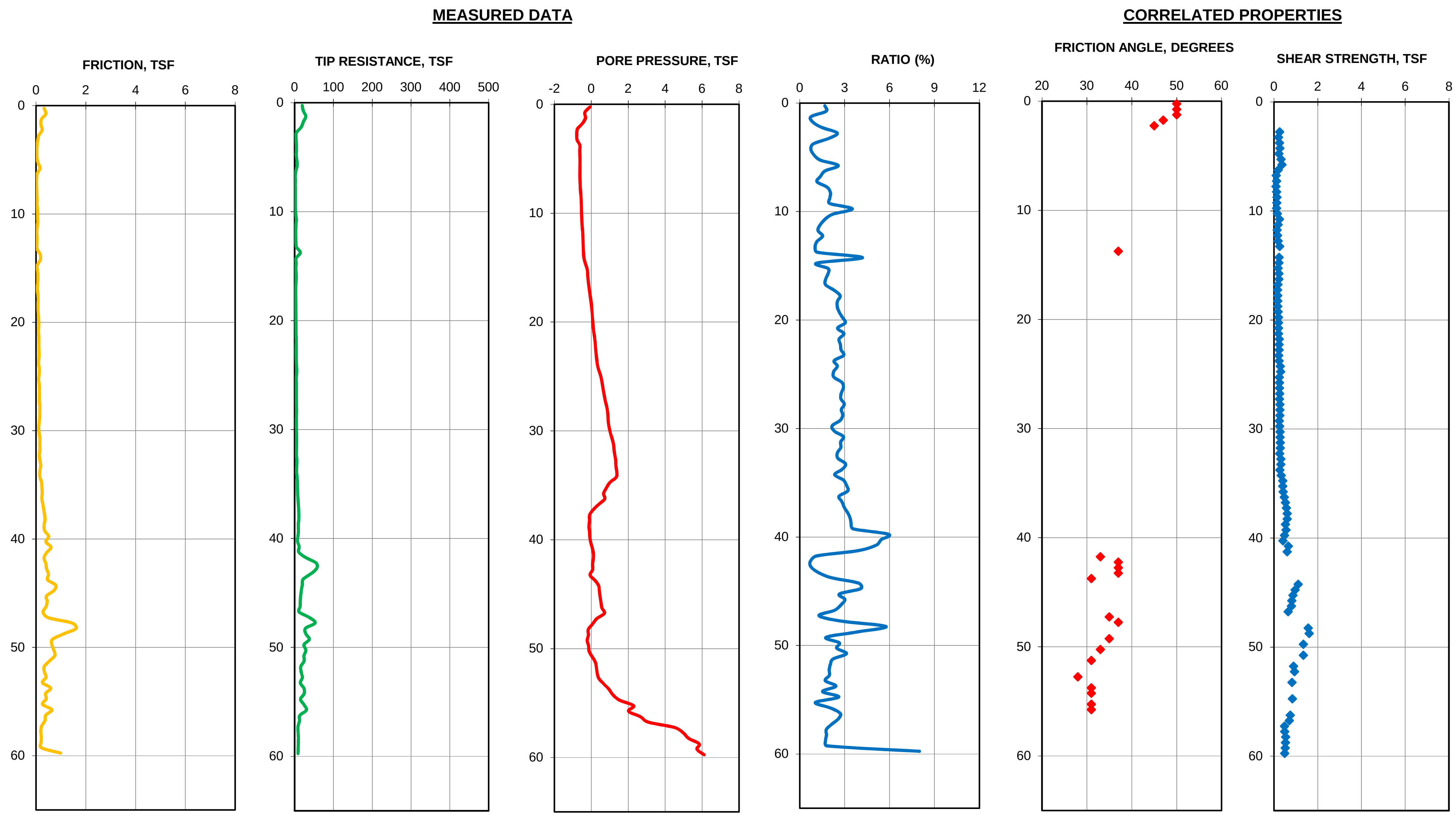



**NOTE:**

1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986).
   THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

**CONE PENETROMETER TEST: CPT-05**

STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS




**NOTE:**

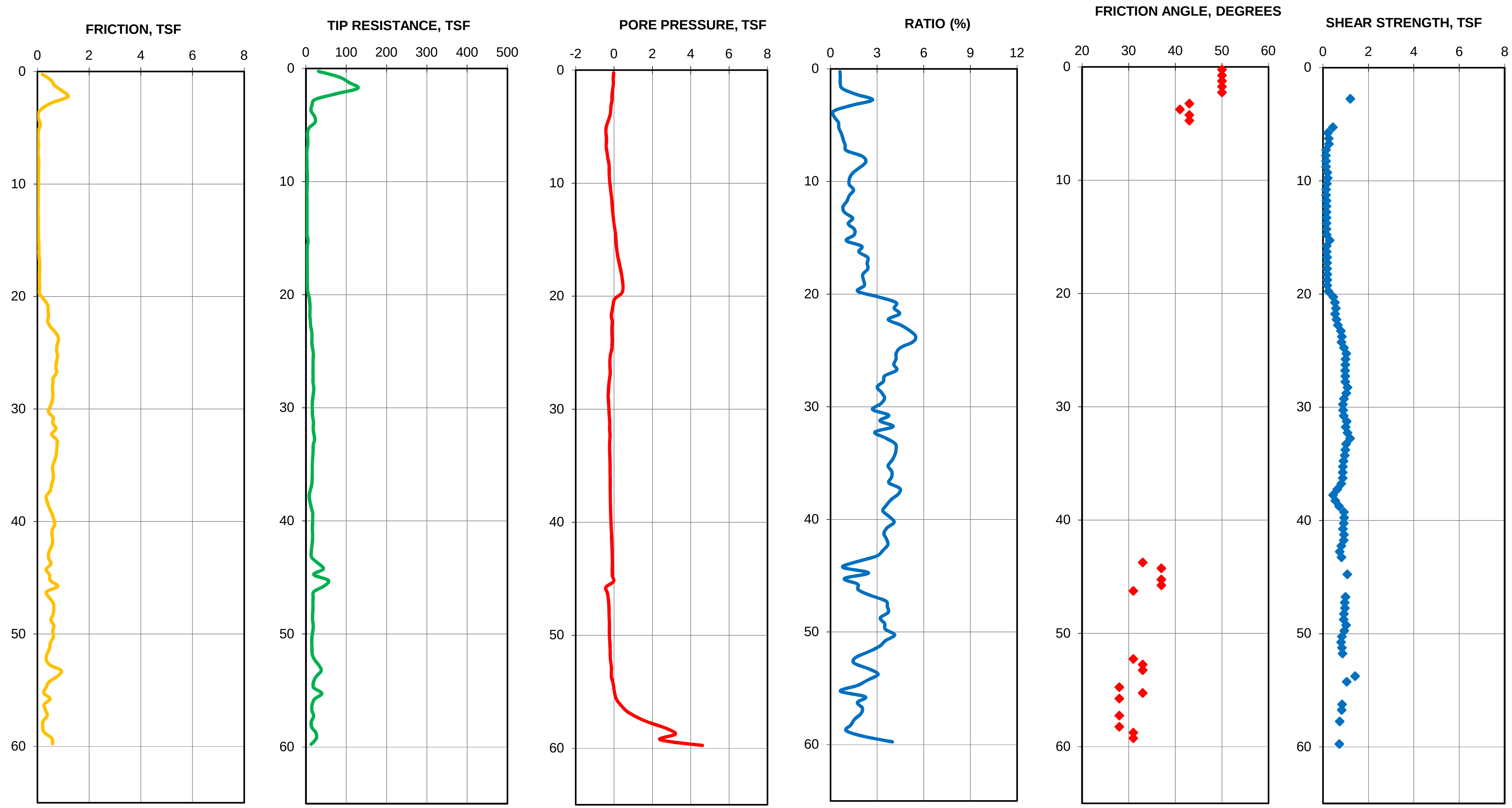
1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986). THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

**CONE PENETROMETER TEST: CPT-06**

STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON AND ORANGE COUNTIES, TEXAS

## MEASURED DATA

## CORRELATED PROPERTIES

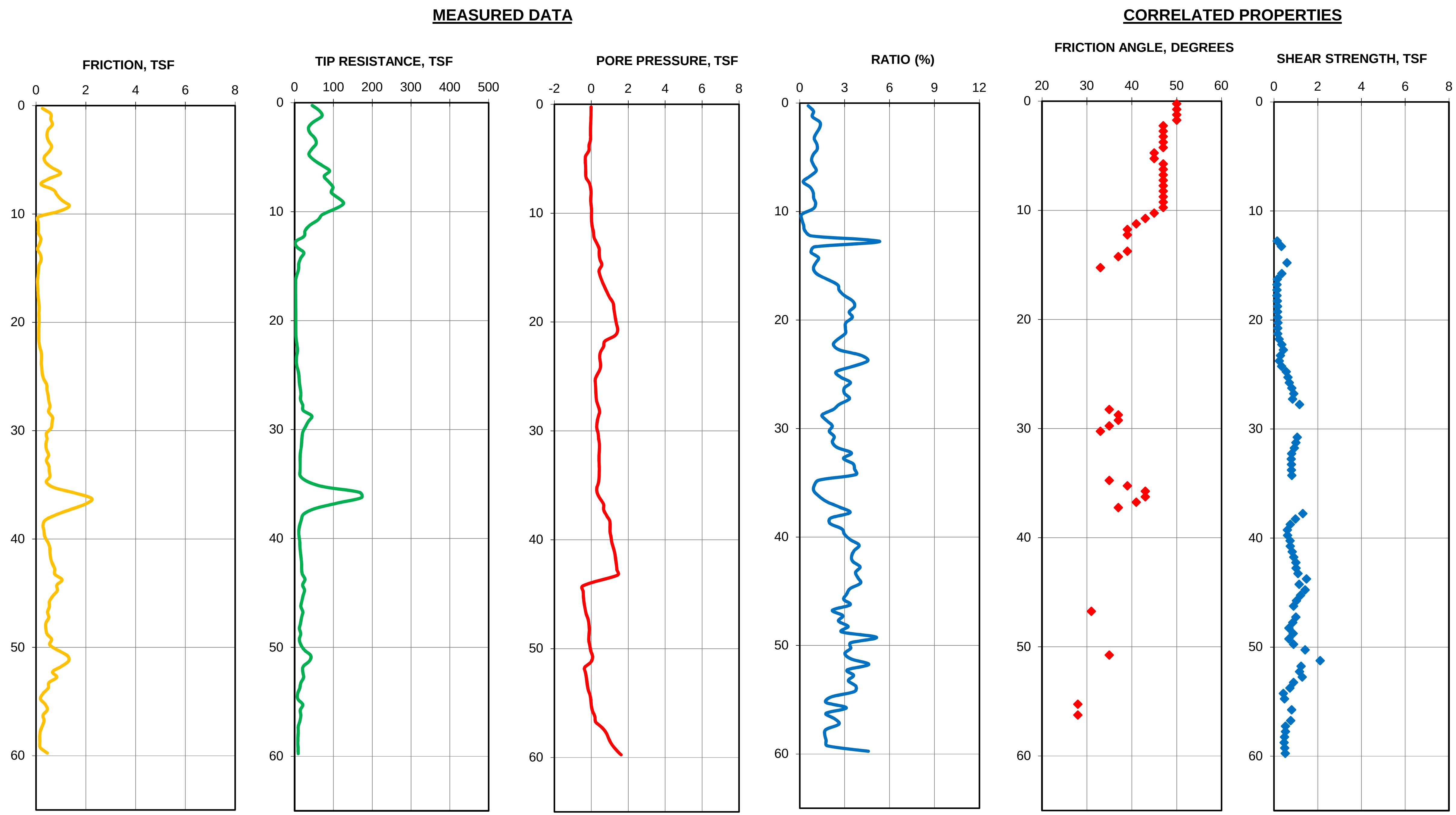



**NOTE:**

1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986). THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

**CONE PENETROMETER TEST: CPT-07**

STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS




**NOTE:**

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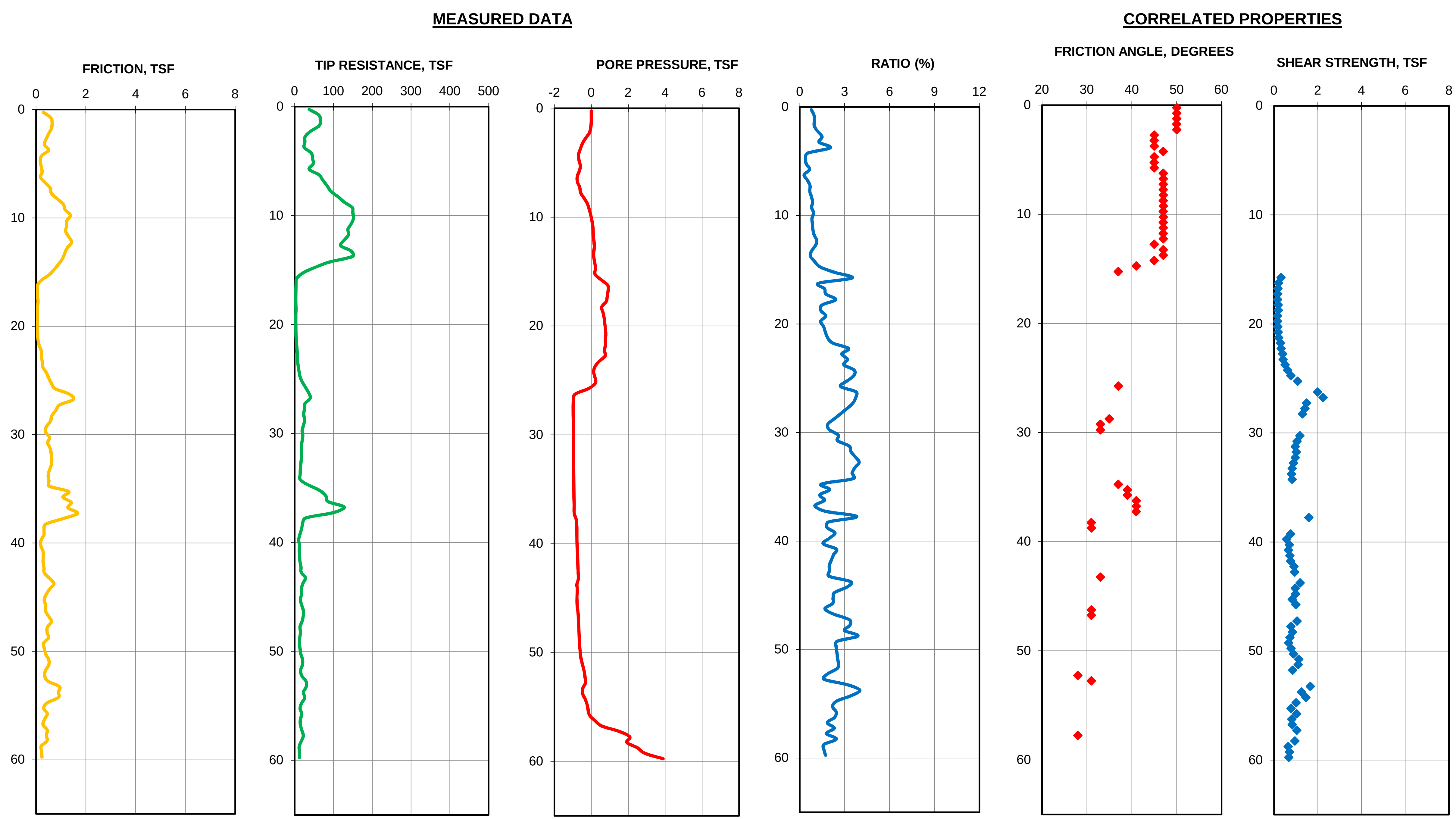
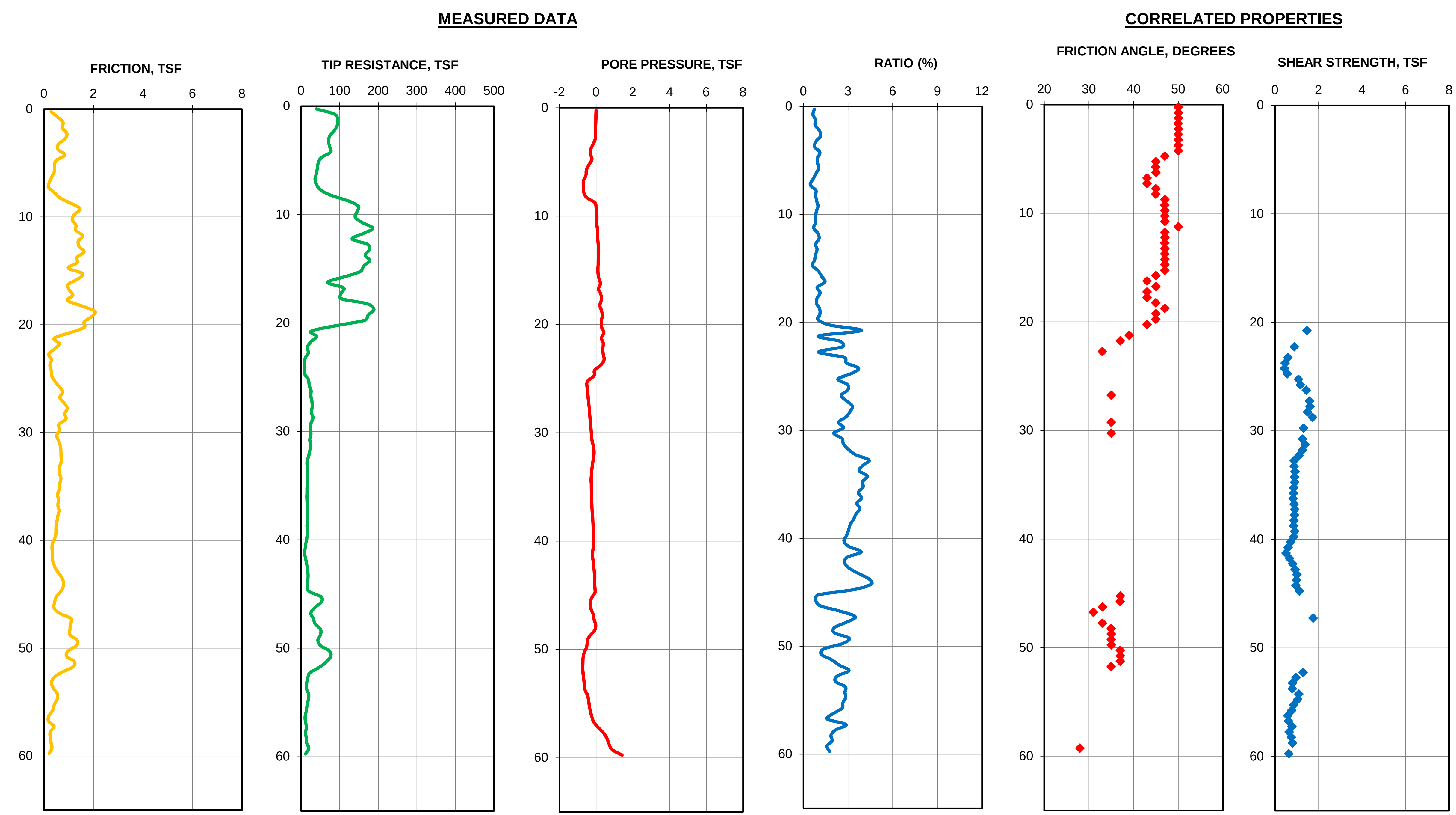
**CONE PENETROMETER TEST: CPT-08**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS




**NOTE:**

1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986).
   THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

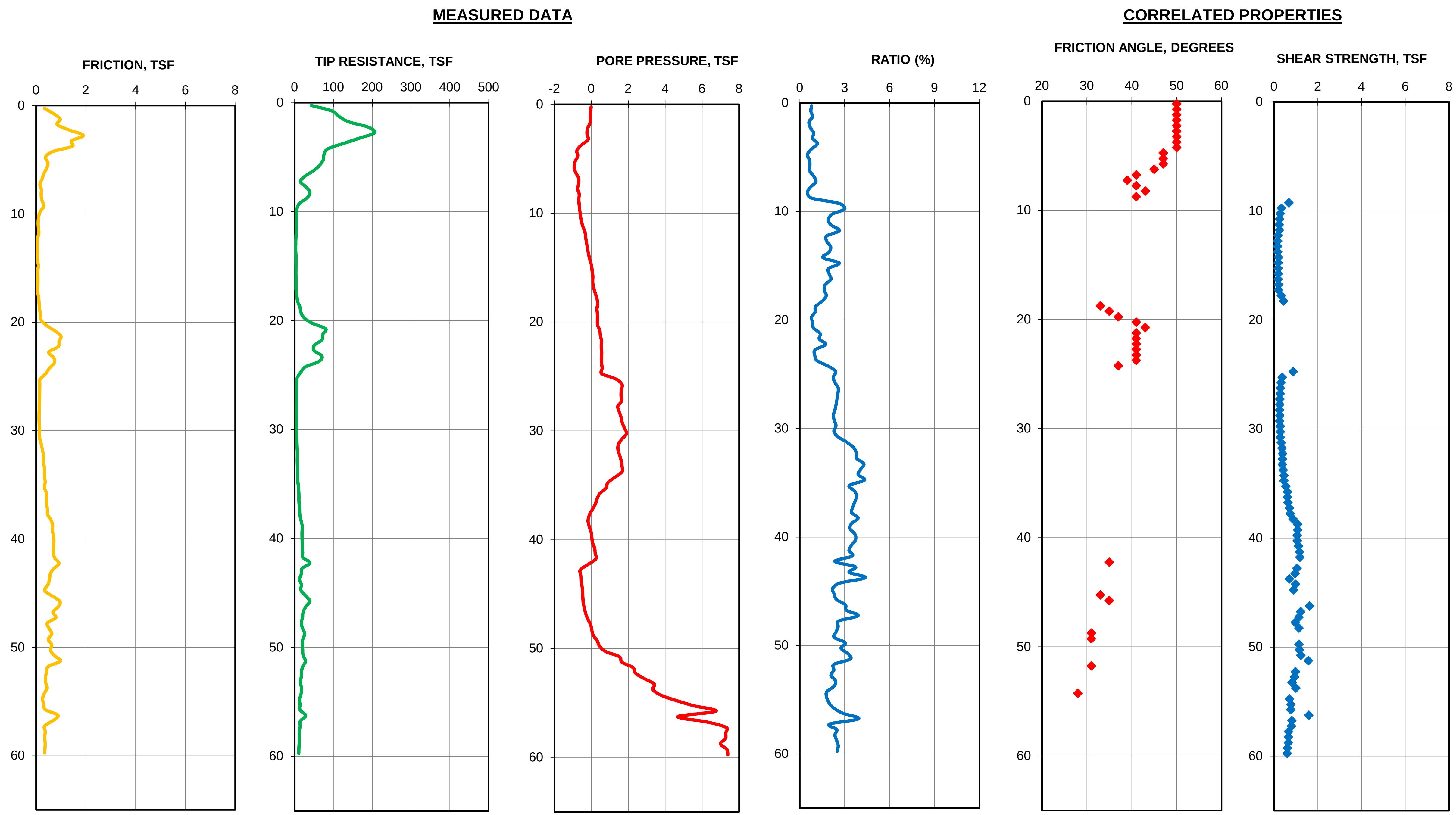
**CONE PENETROMETER TEST: CPT-09**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS




**NOTE:**

1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986).
   THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

**CONE PENETROMETER TEST: CPT-10**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS

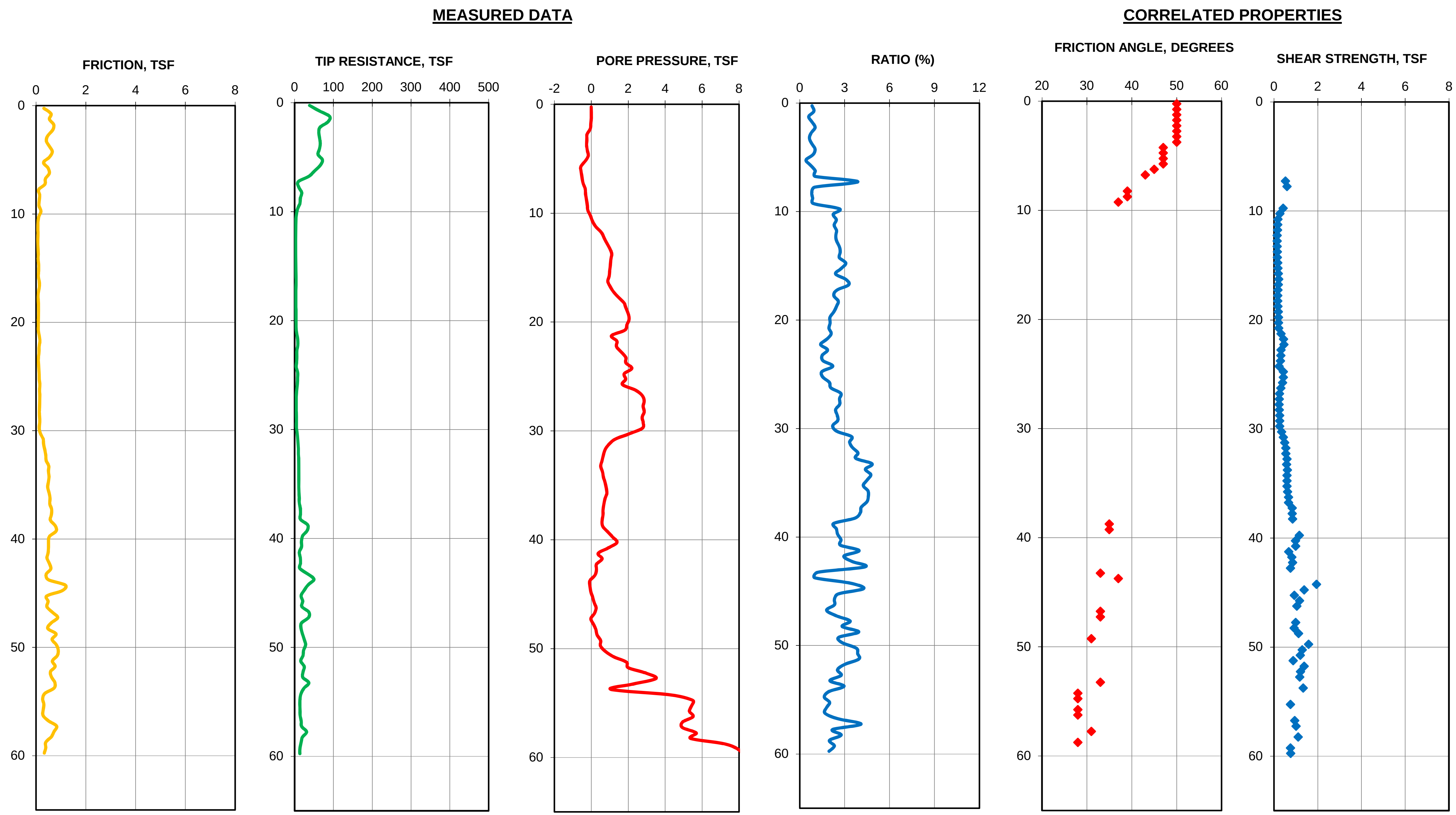



**NOTE:**

1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986).
   THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

**CONE PENETROMETER TEST: CPT-11**

STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS



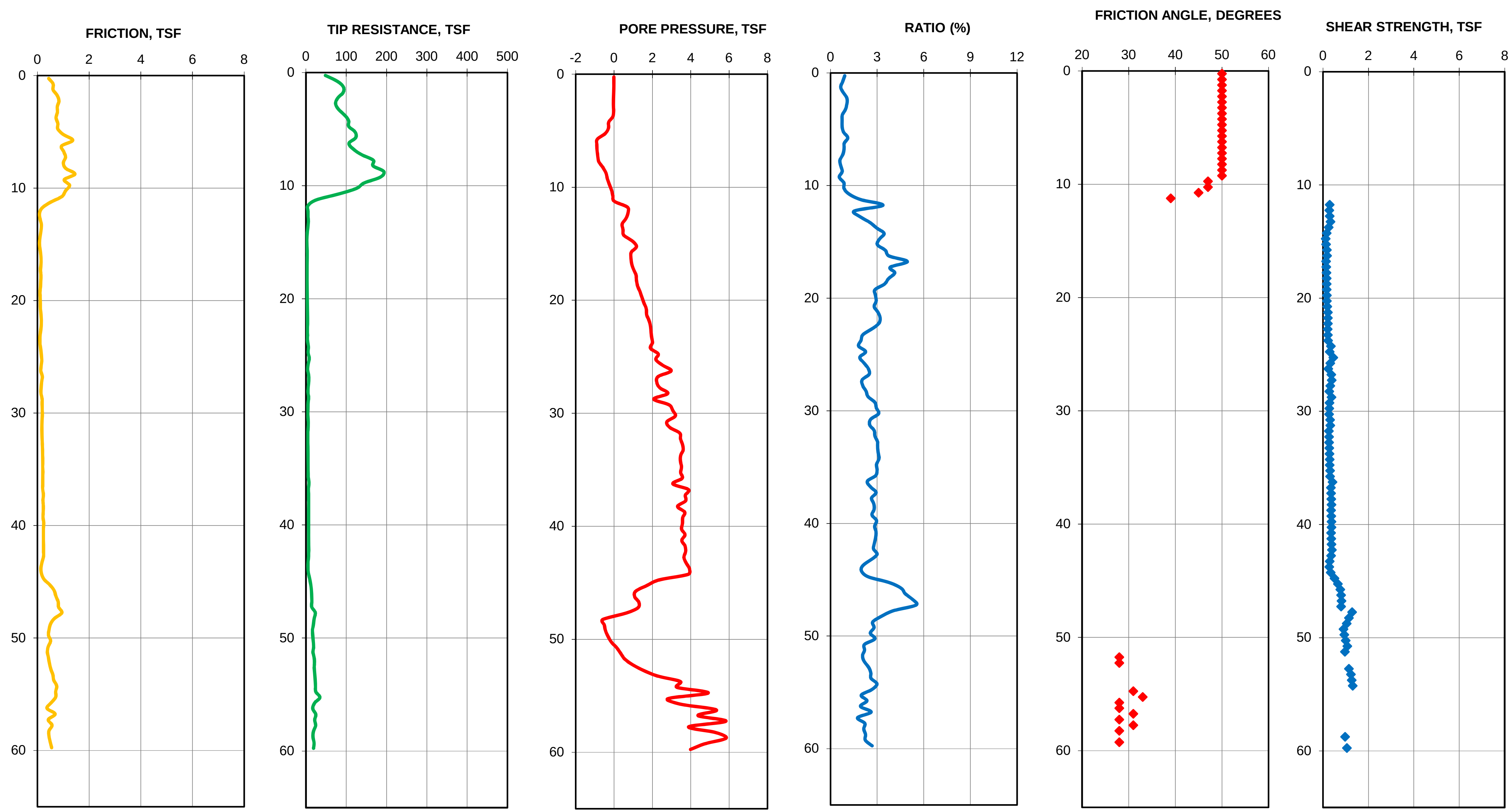

**NOTE:**

1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986).
   THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

**CONE PENETROMETER TEST: CPT-12**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS

## MEASURED DATA

## CORRELATED PROPERTIES




**NOTE:**

**1.** THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986).

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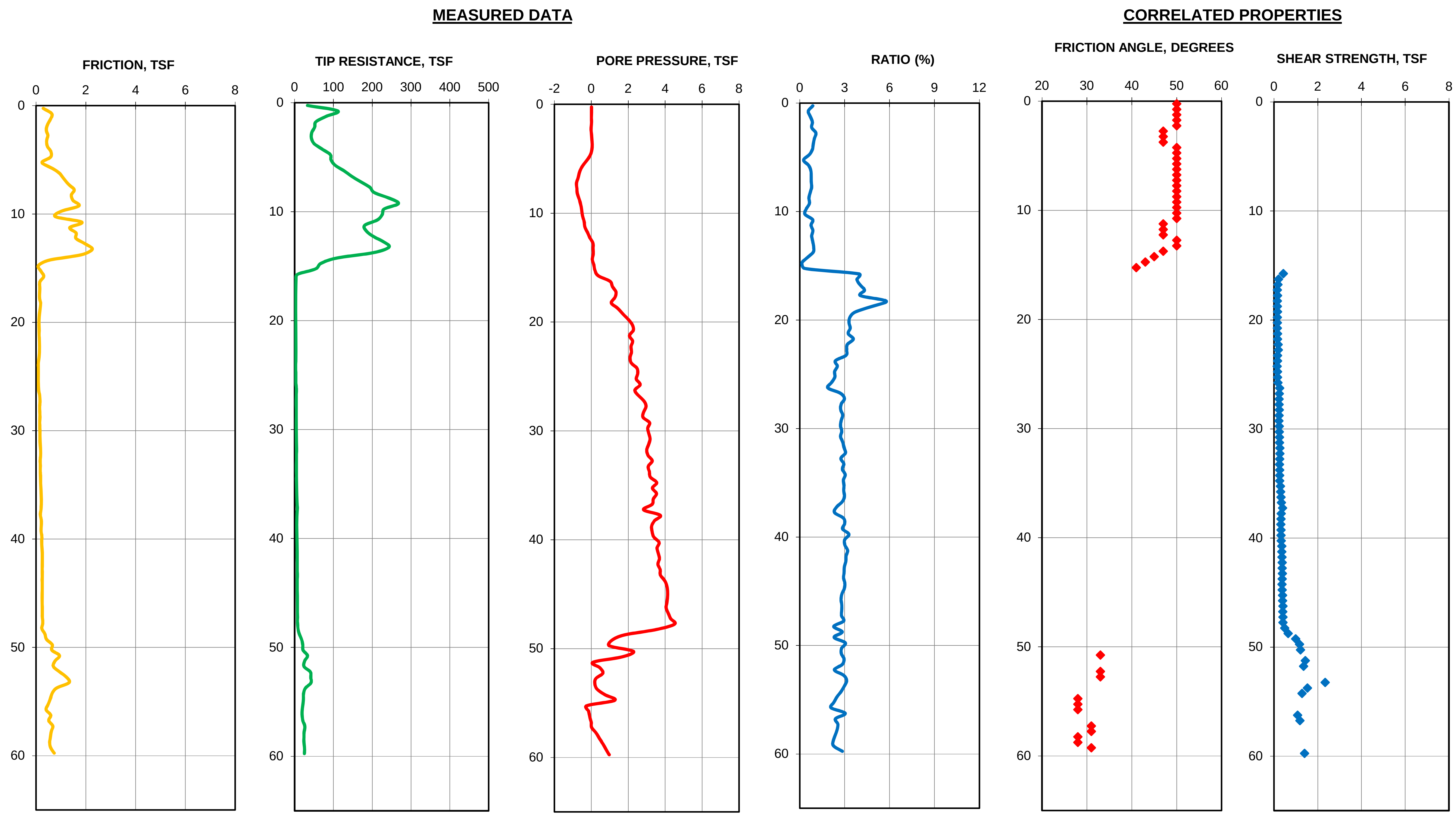
**CONE PENETROMETER TEST: CPT-13**

STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS




**NOTE:**

1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986).

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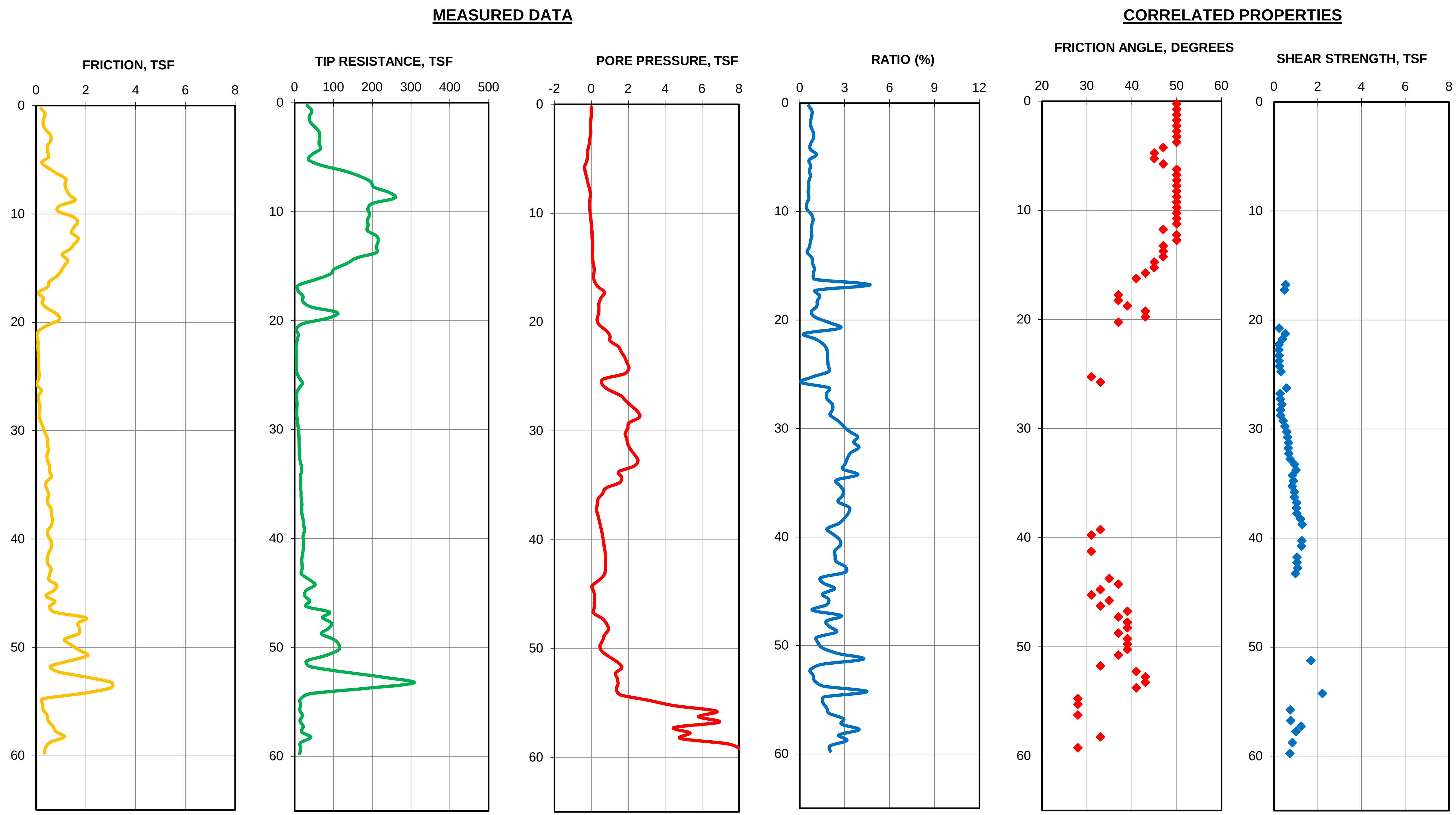
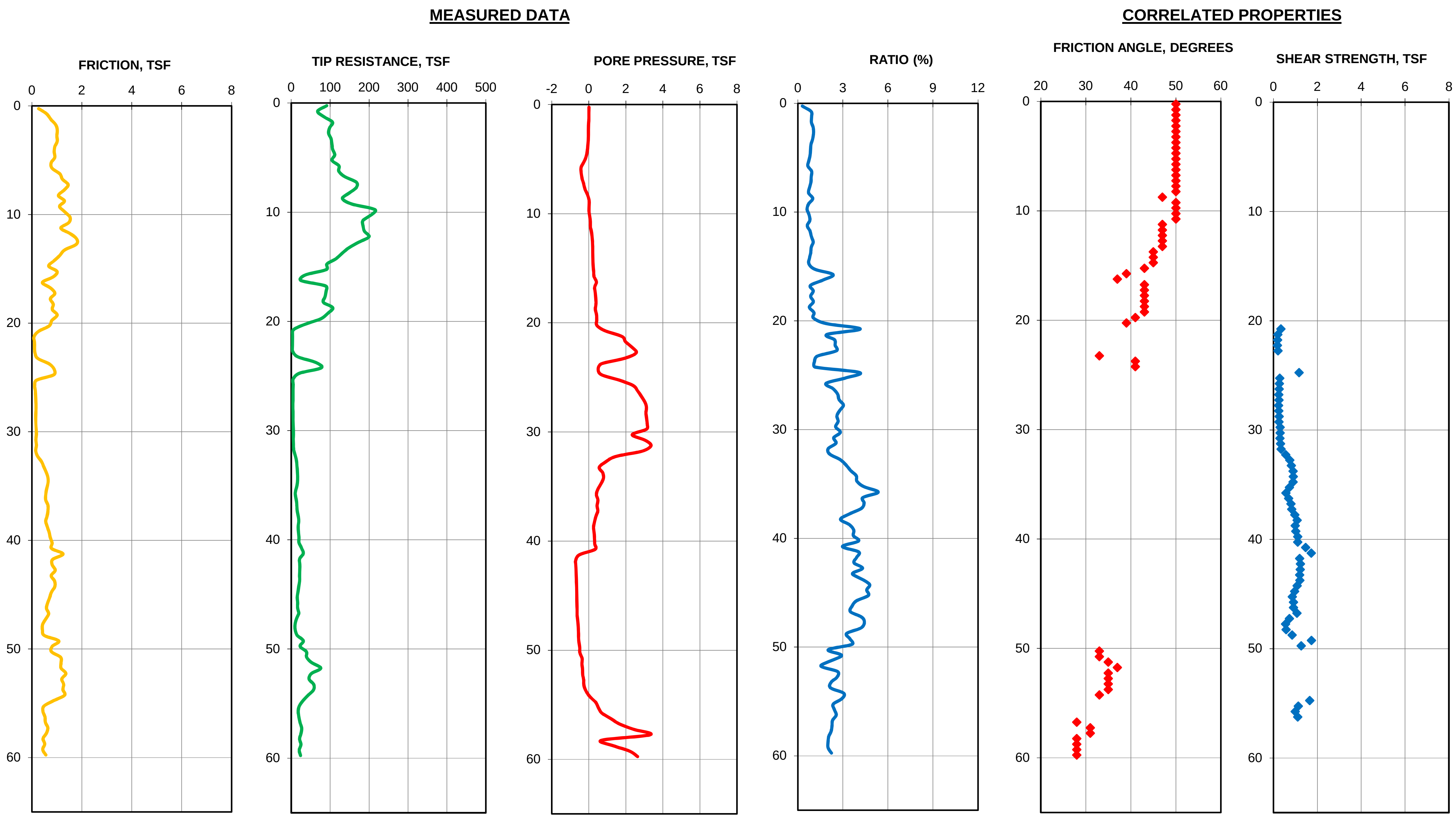
**CONE PENETROMETER TEST: CPT-14**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS




**NOTE:**

1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986). THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

**CONE PENETROMETER TEST: CPT-15**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON AND ORANGE COUNTIES, TEXAS

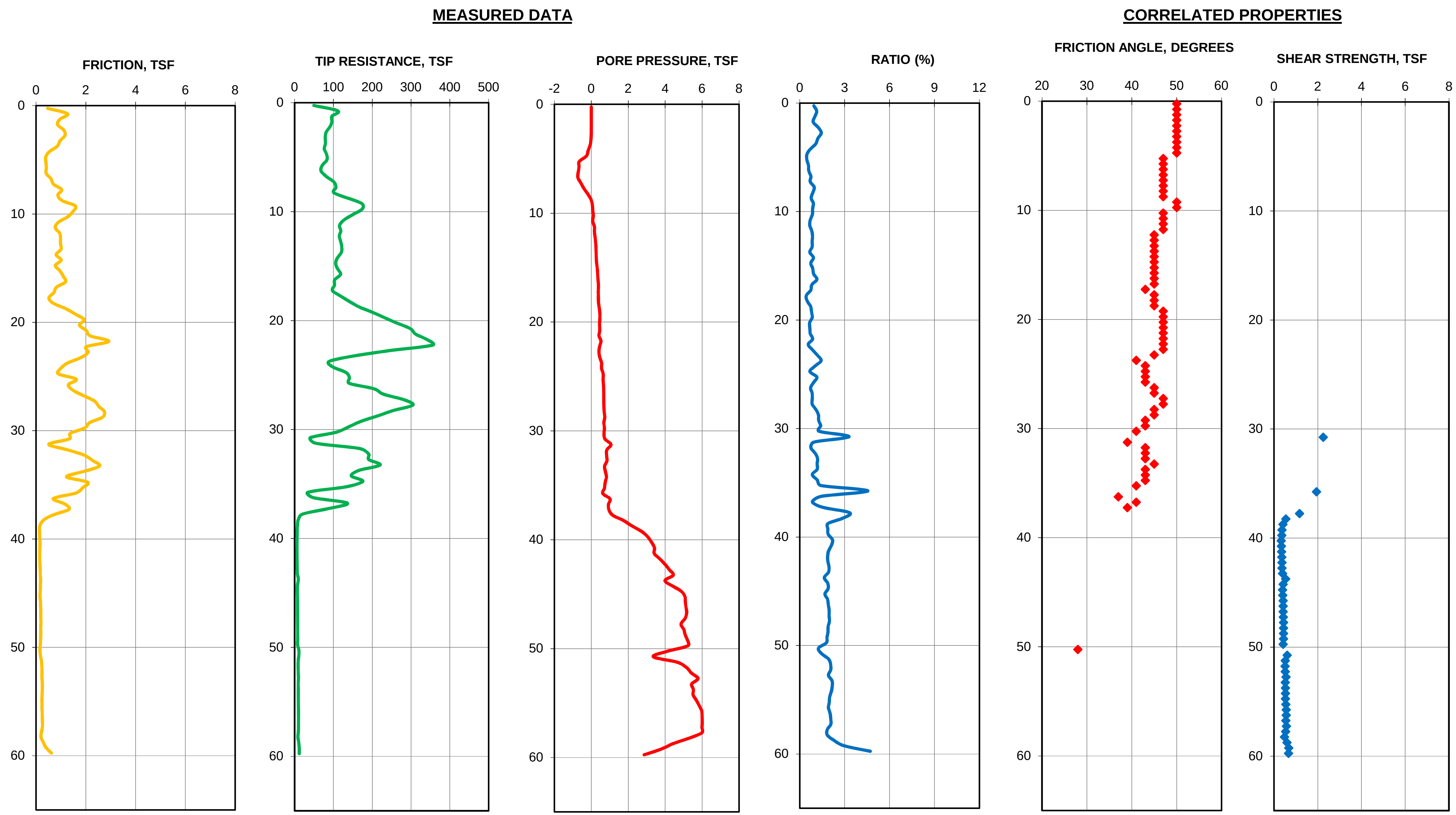



**NOTE:**

1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986). THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

**CONE PENETROMETER TEST: CPT-16**

STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS

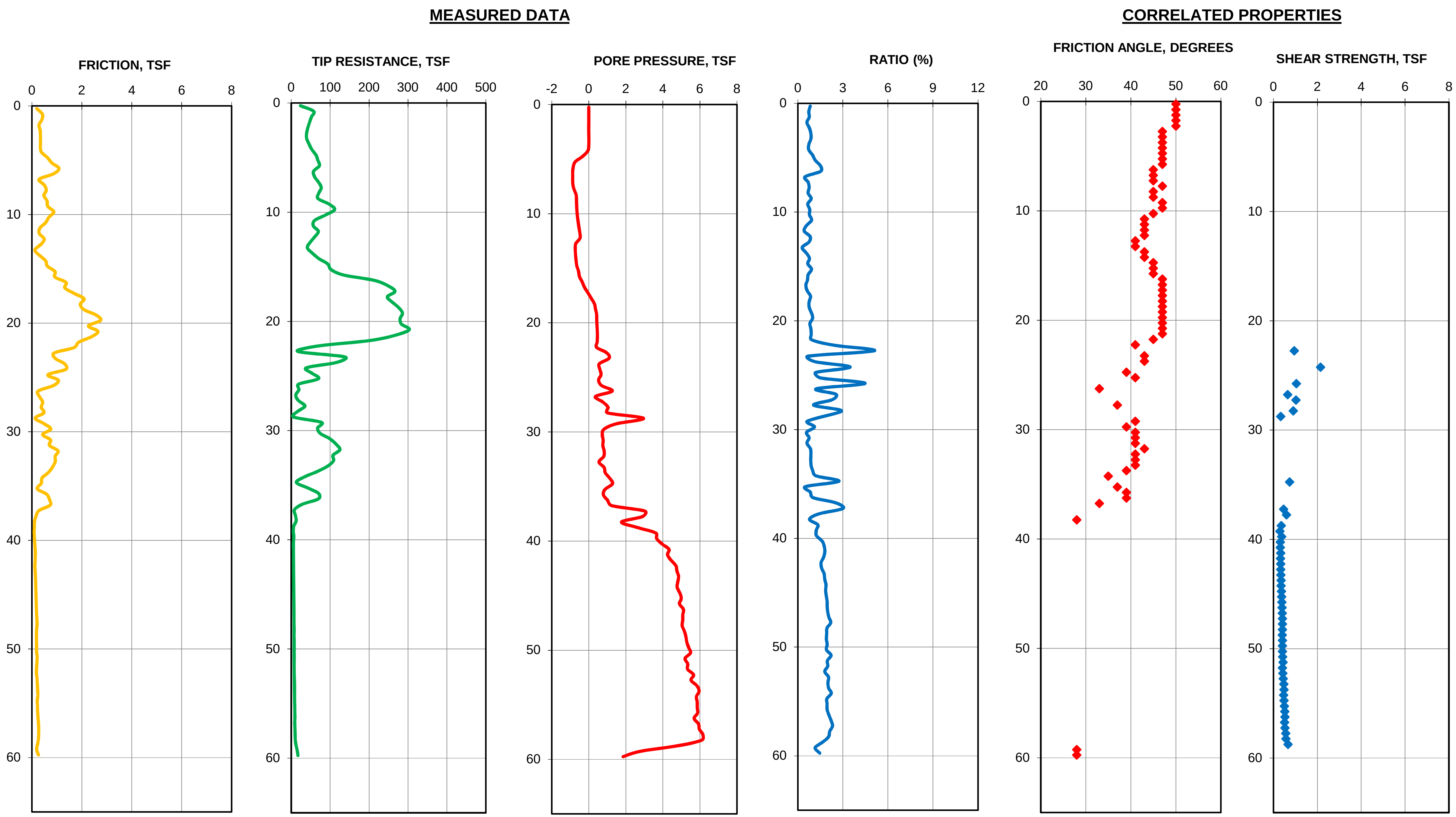



**NOTE:**

1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986).
   THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

**CONE PENETROMETER TEST: CPT-17**

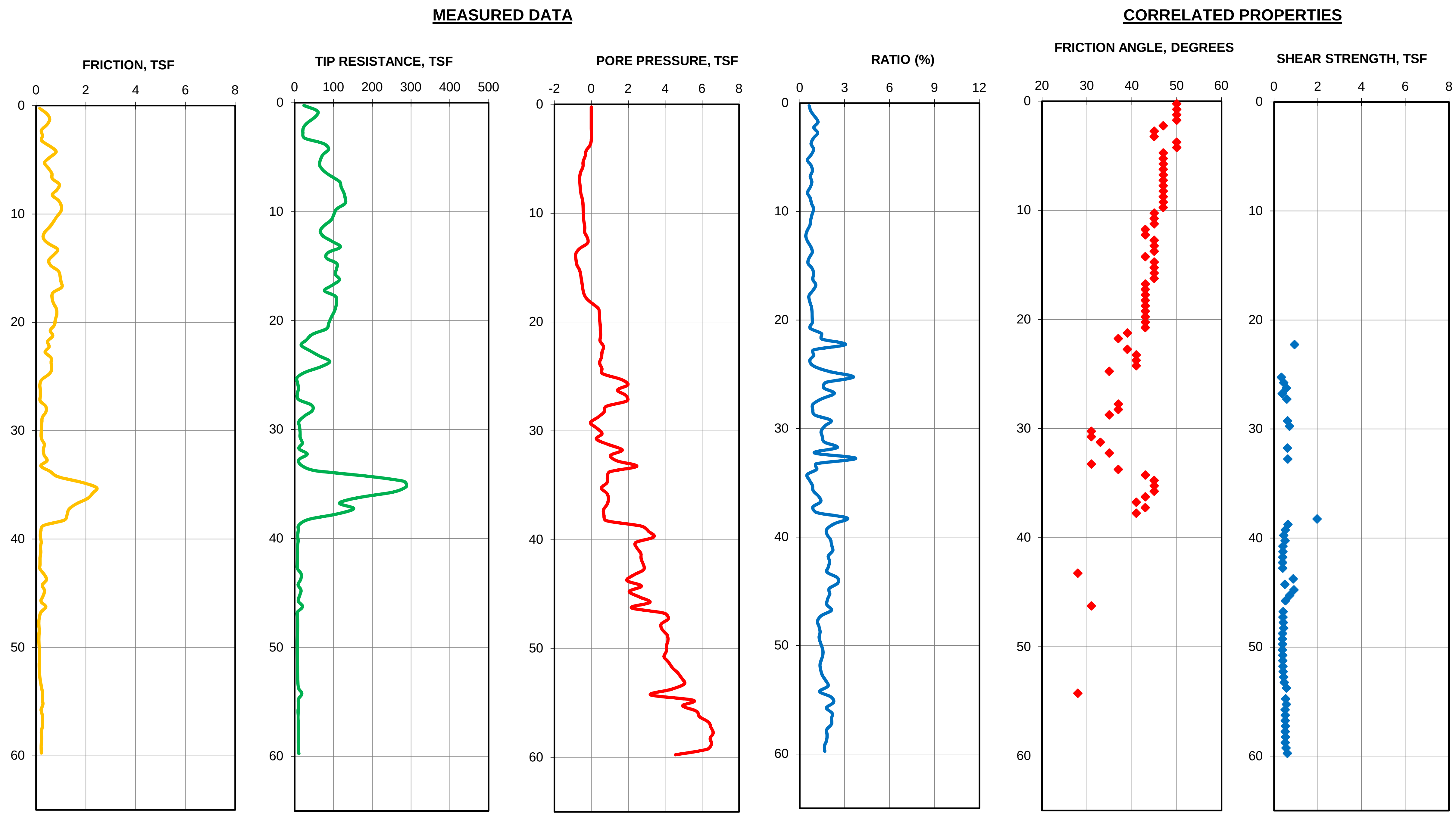
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS




**NOTE:**

1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986). THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

**CONE PENETROMETER TEST: CPT-18**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS



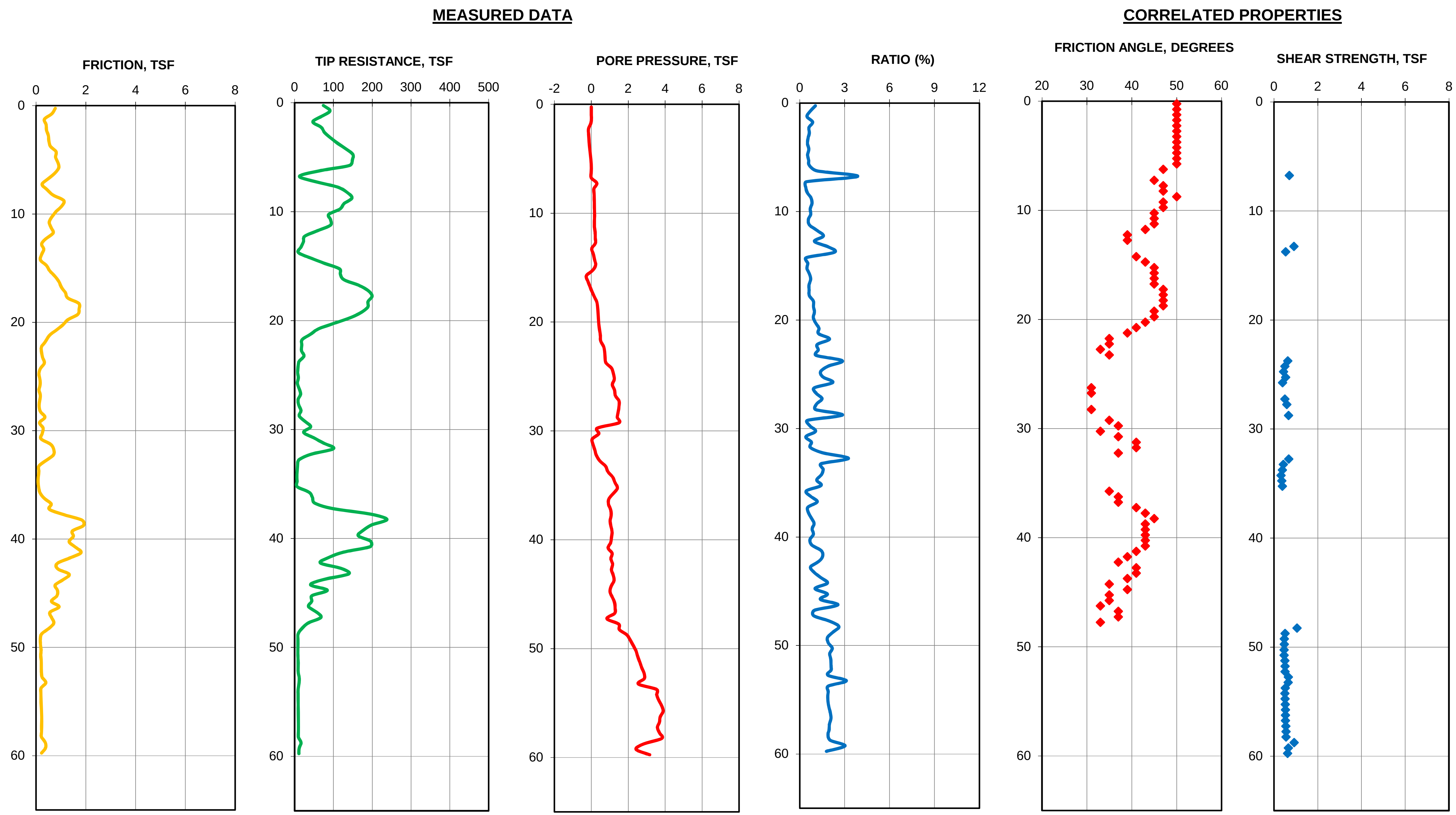

**NOTE:**

1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986). THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

**CONE PENETROMETER TEST: CPT-19**

STORM SURGE SUPPRESSION STUDY - GCCPRD

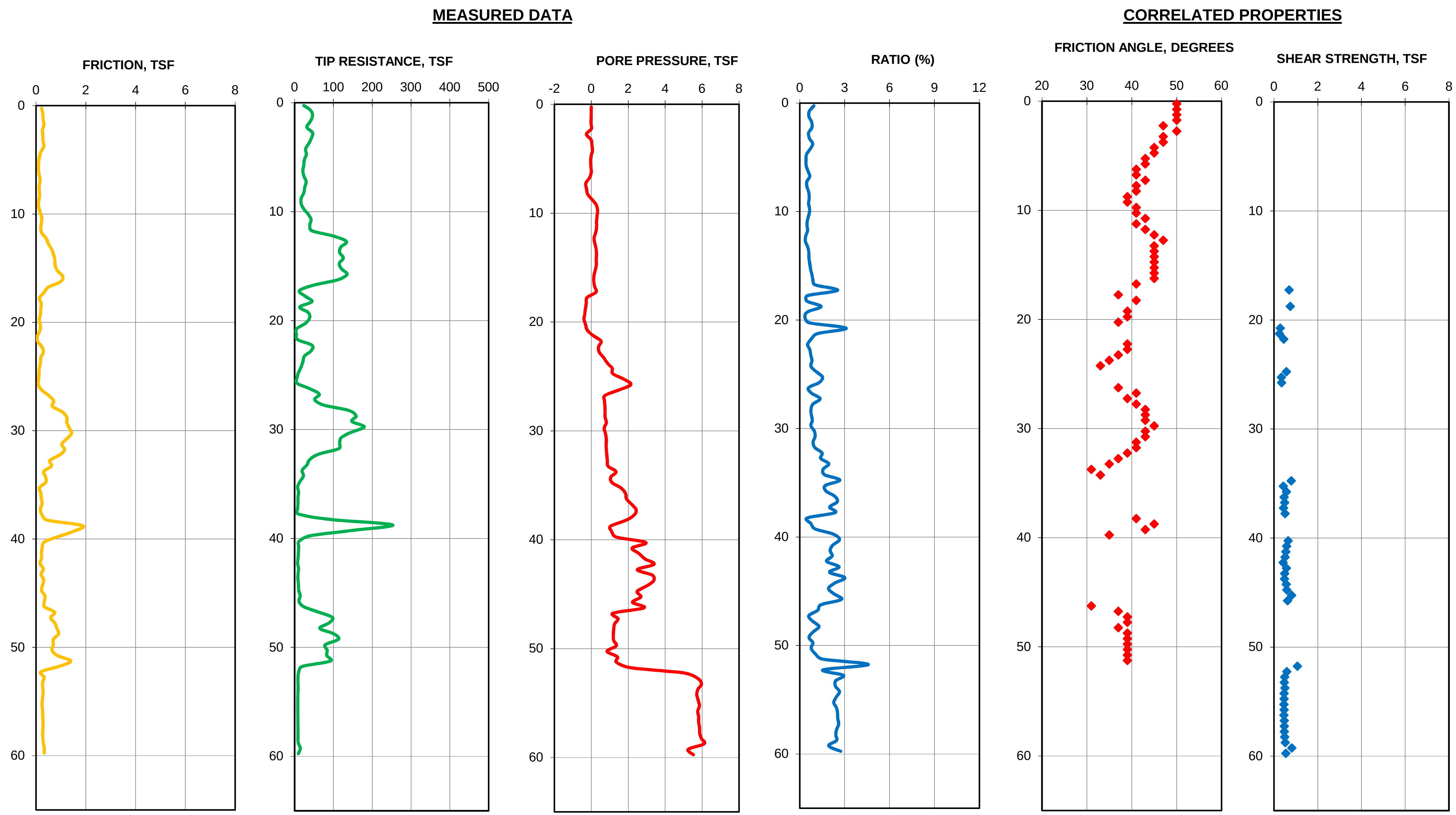
BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON AND ORANGE COUNTIES, TEXAS




**NOTE:**

1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986).
   THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

**CONE PENETROMETER TEST: CPT-20**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS

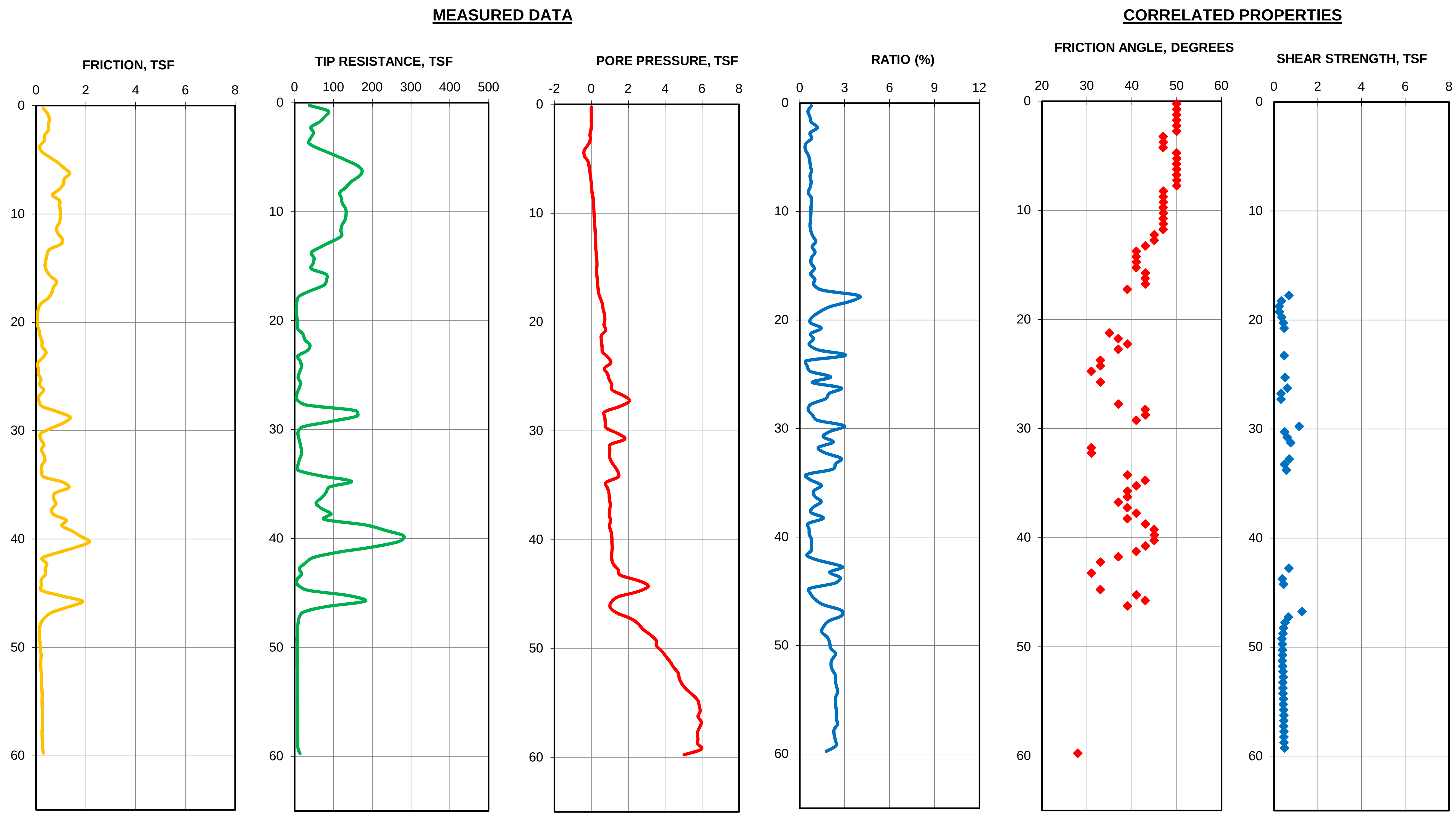



**NOTE:**

1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986). THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

**CONE PENETROMETER TEST: CPT-21**

STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS



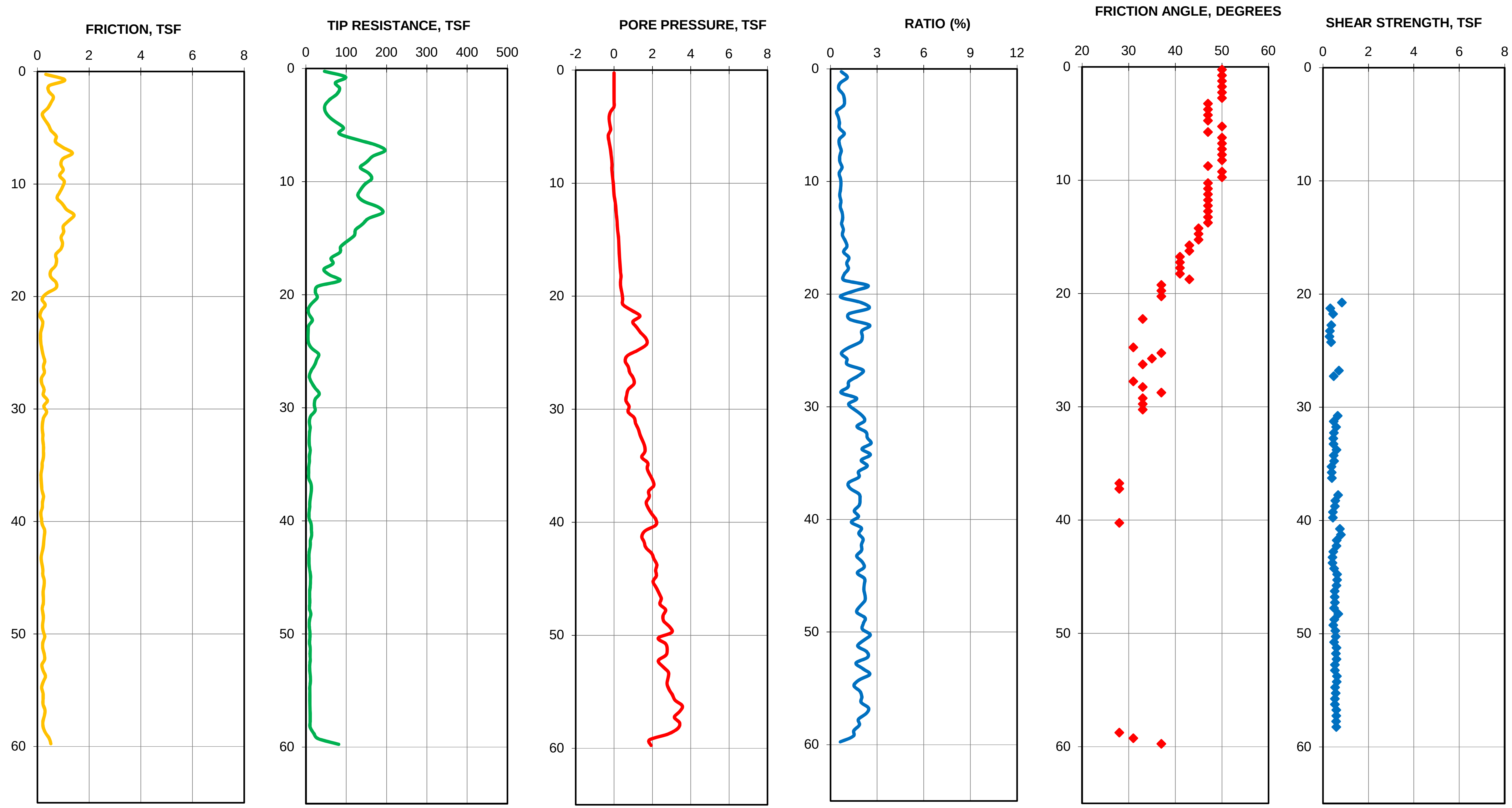

**NOTE:**

1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986).
THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

**CONE PENETROMETER TEST: CPT-22**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS

## MEASURED DATA

## CORRELATED PROPERTIES

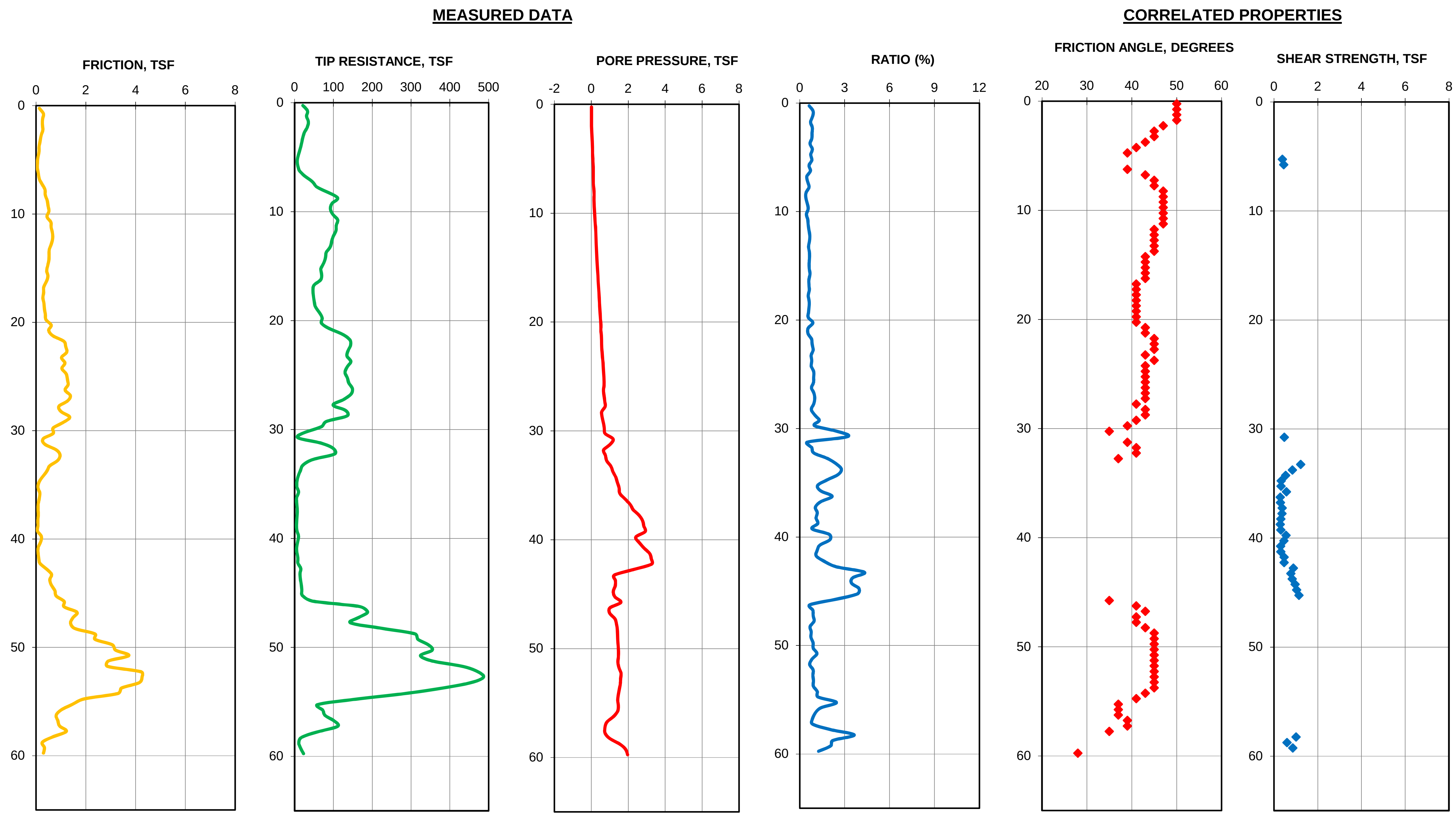



**NOTE:**

1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986).
   THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

**CONE PENETROMETER TEST: CPT-23**

STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS



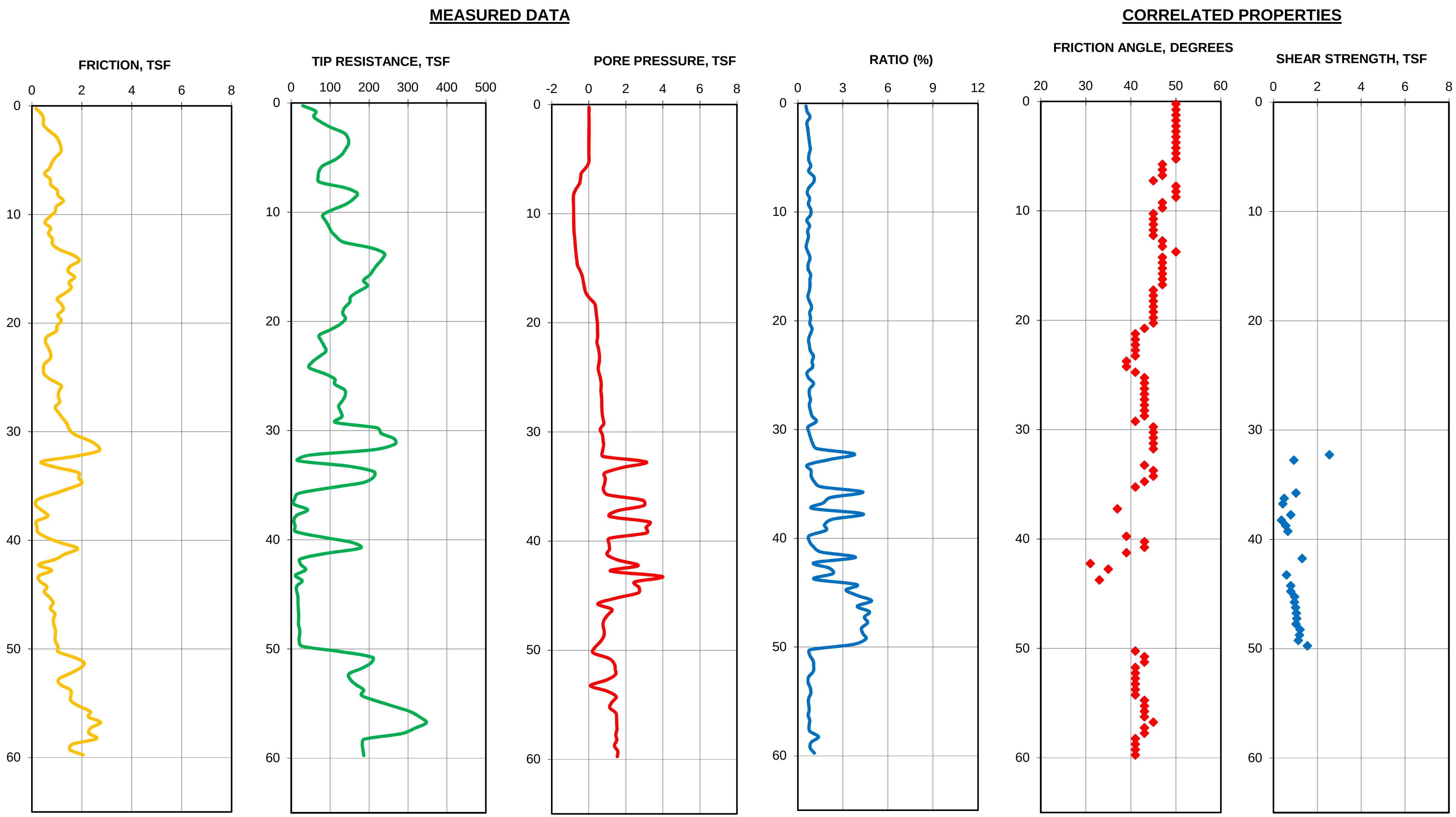

NOTE:

1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986).

THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

**CONE PENETROMETER TEST: CPT-24**

STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS



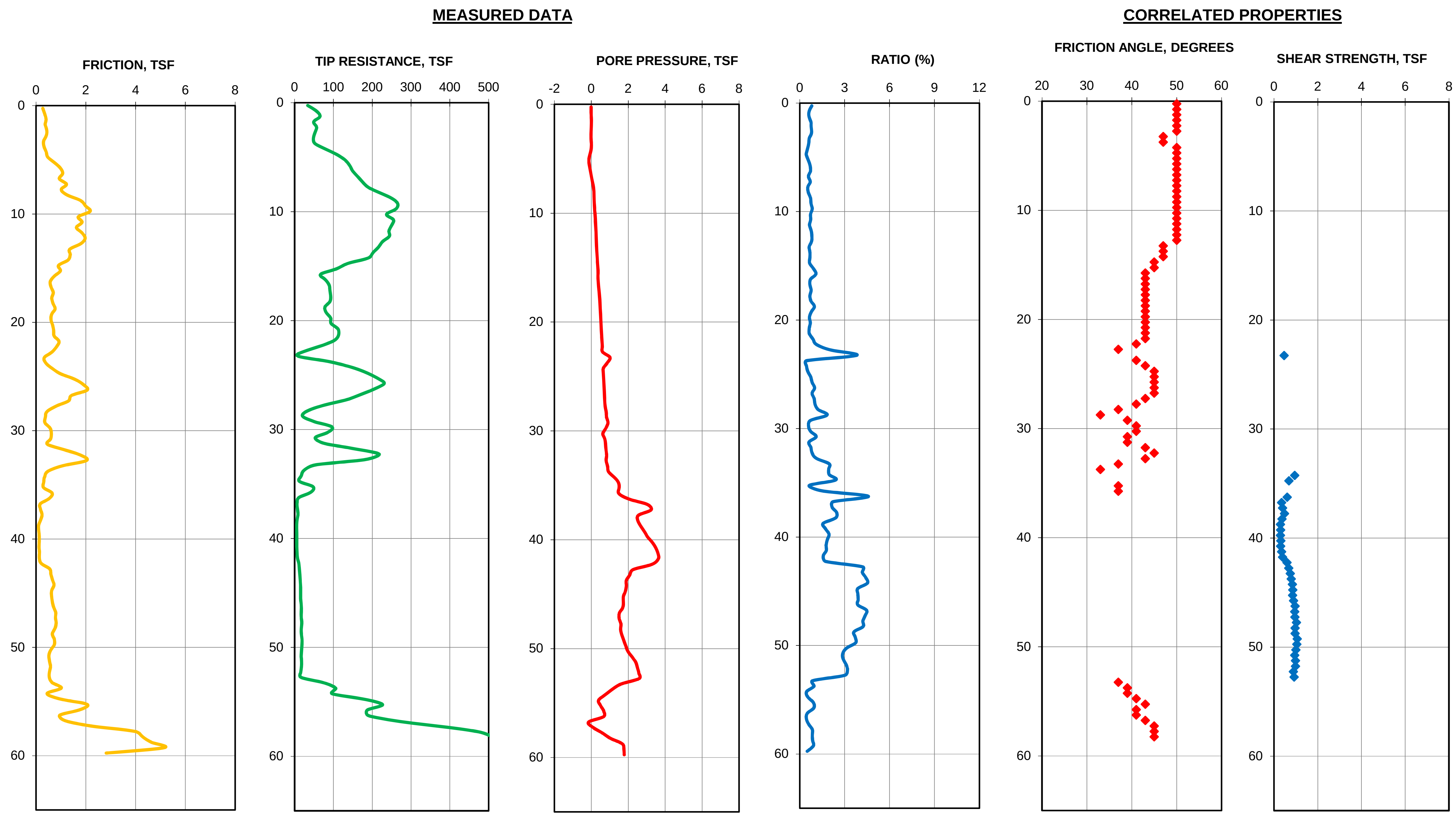

**NOTE:**

1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986).

   THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

**CONE PENETROMETER TEST: CPT-25**

STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS

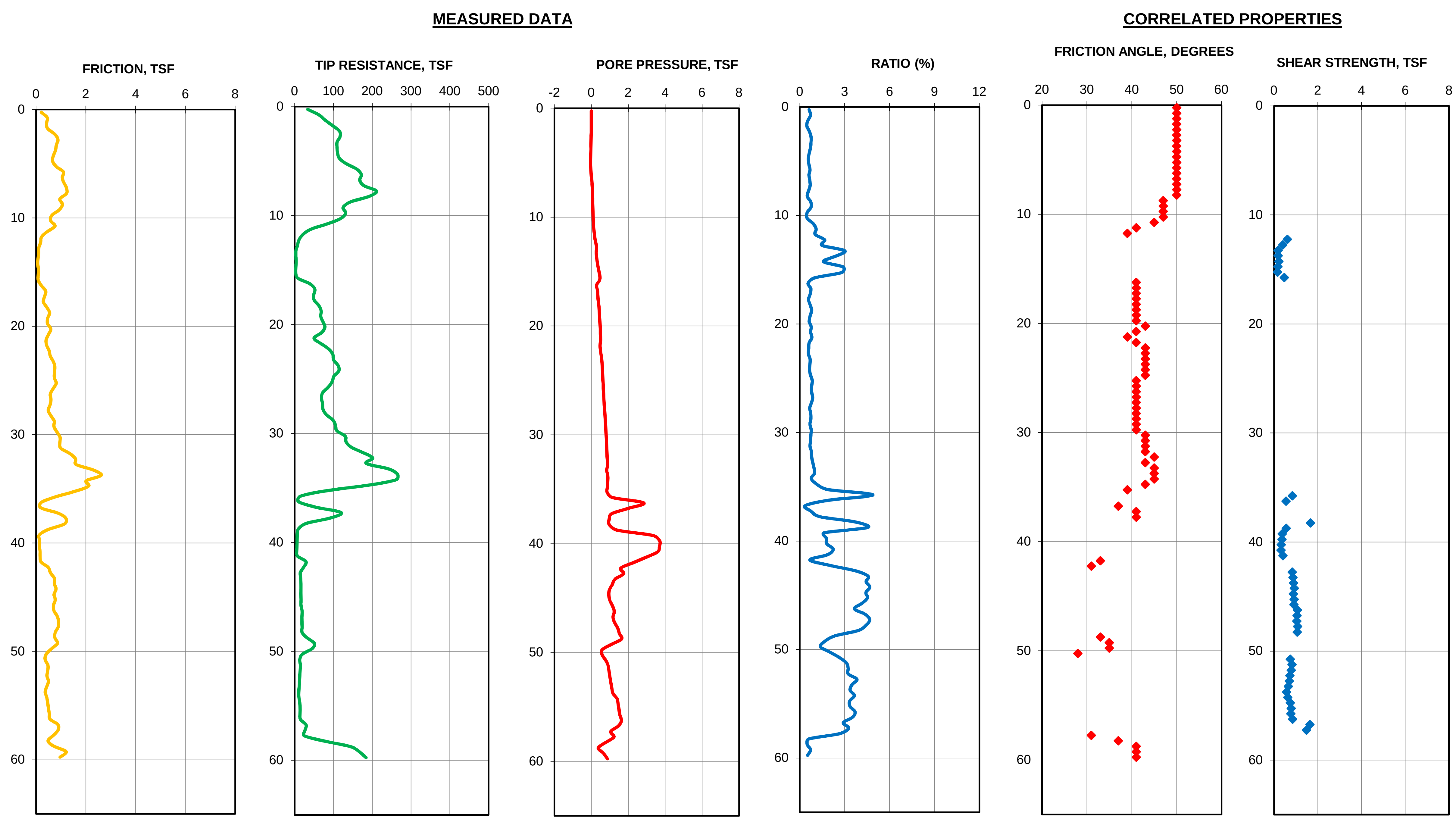



**NOTE:**

1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986).

THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

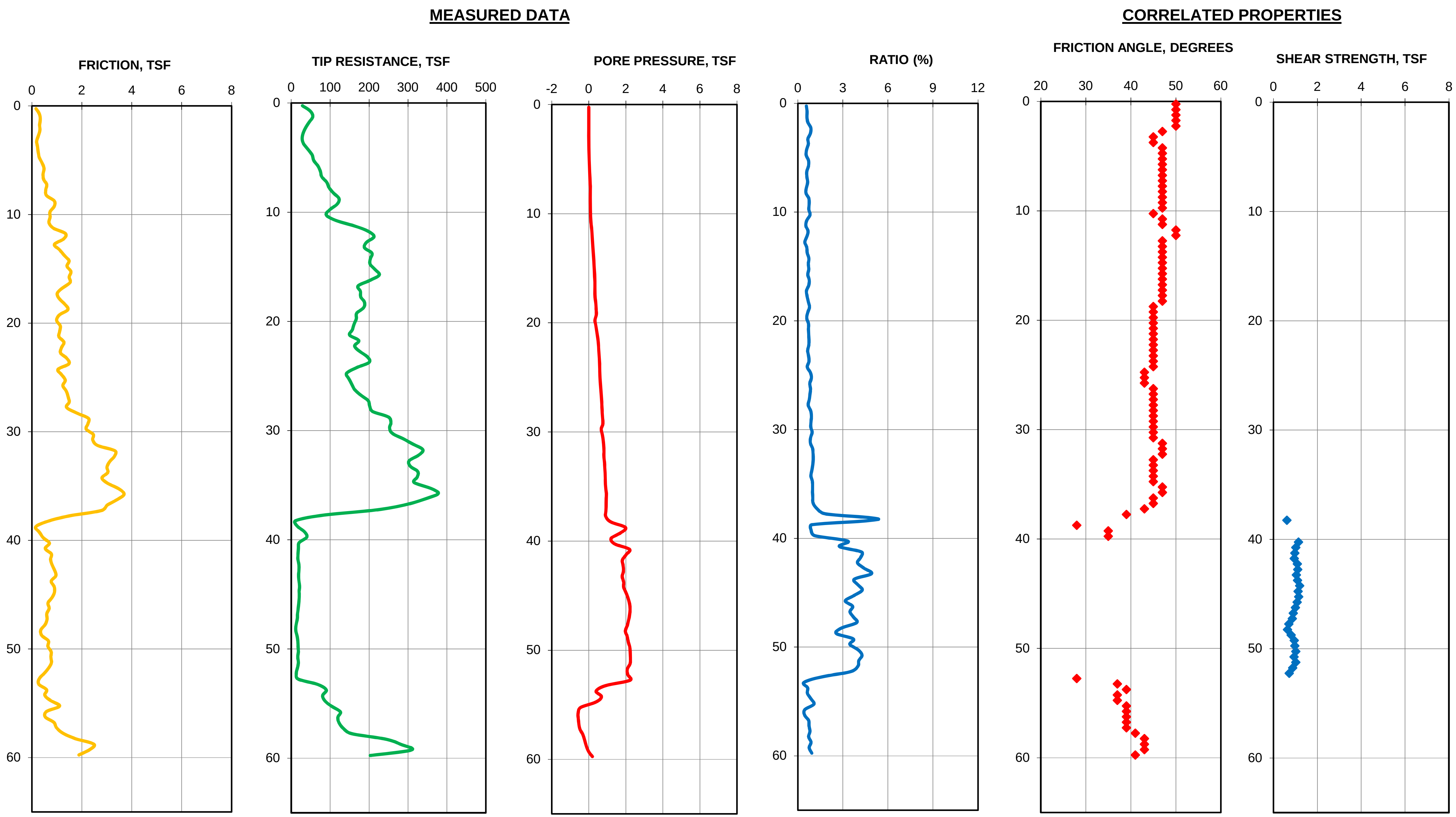
**CONE PENETROMETER TEST: CPT-26**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS




**NOTE:**

1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986). THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

**CONE PENETROMETER TEST: CPT-27**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS




**NOTE:**

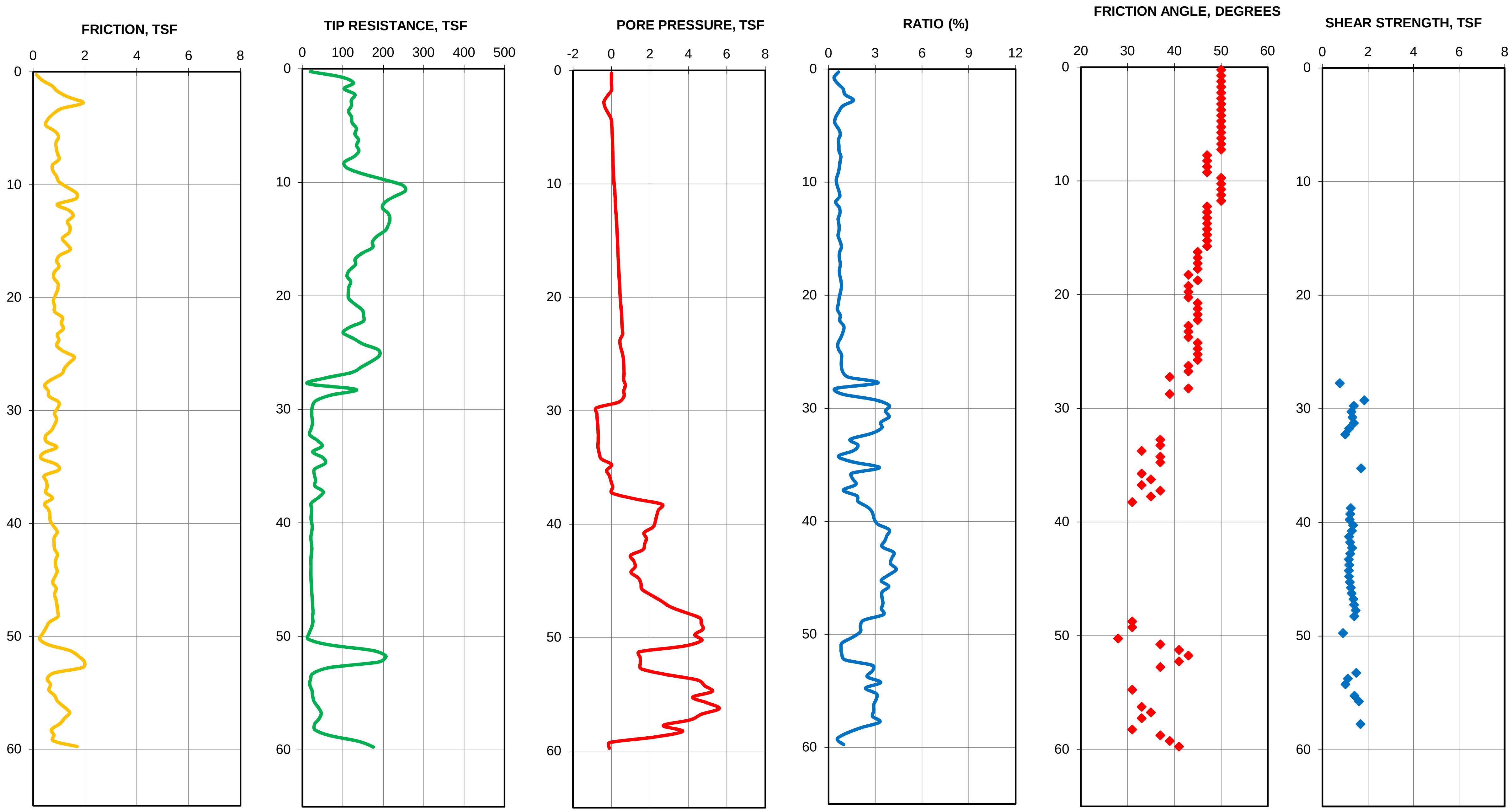
1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986).

   THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

**CONE PENETROMETER TEST: CPT-28**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS

MEASURED DATA

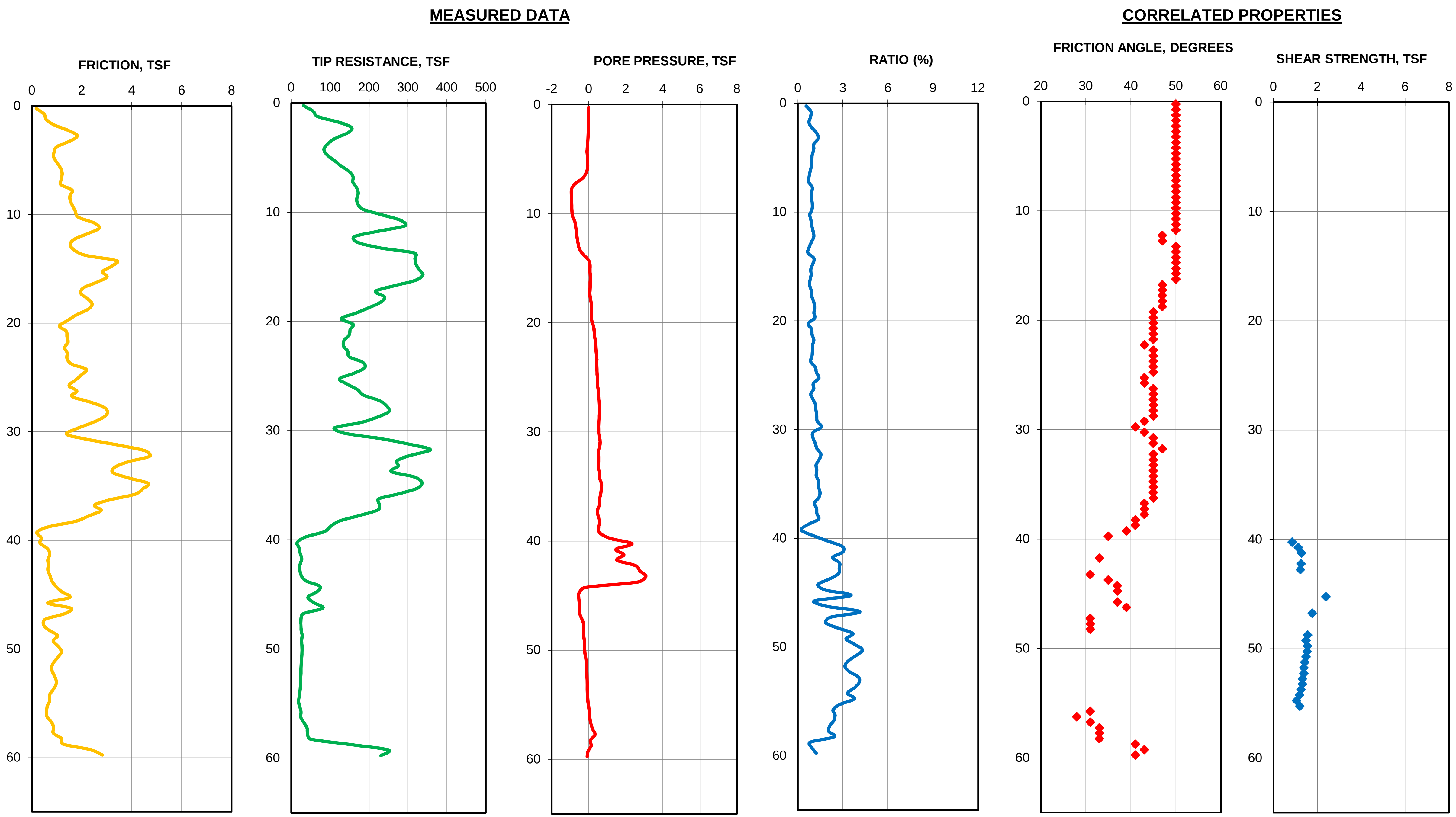
CORRELATED PROPERTIES




NOTE:

1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986).
THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

**CONE PENETROMETER TEST: CPT-29**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS




NOTE:

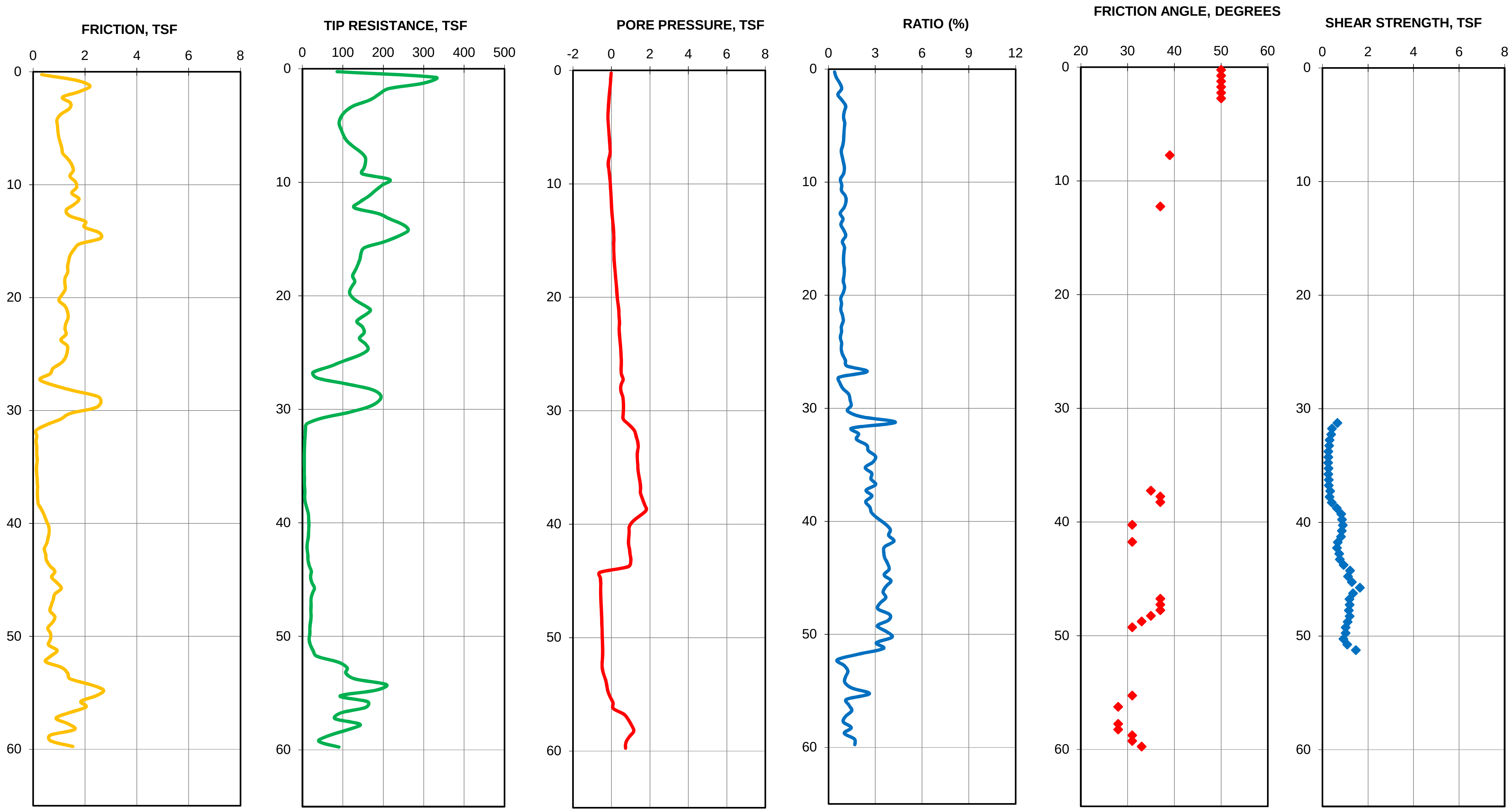
1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986).

THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

**CONE PENETROMETER TEST: CPT-30**

STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS

**MEASURED DATA** **CORRELATED PROPERTIES**

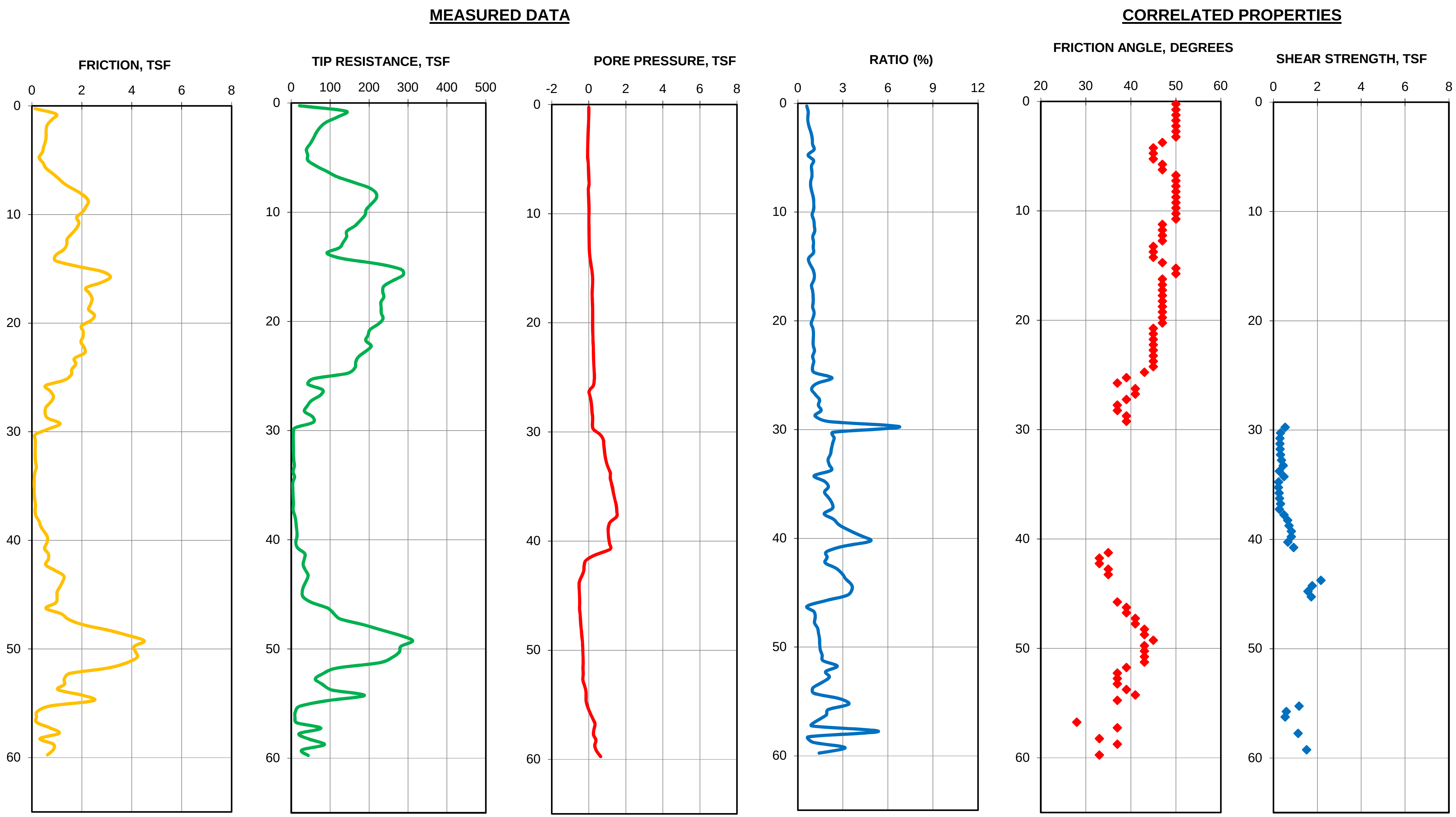



**NOTE:**

1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986).

   THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

**CONE PENETROMETER TEST: CPT-31**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS



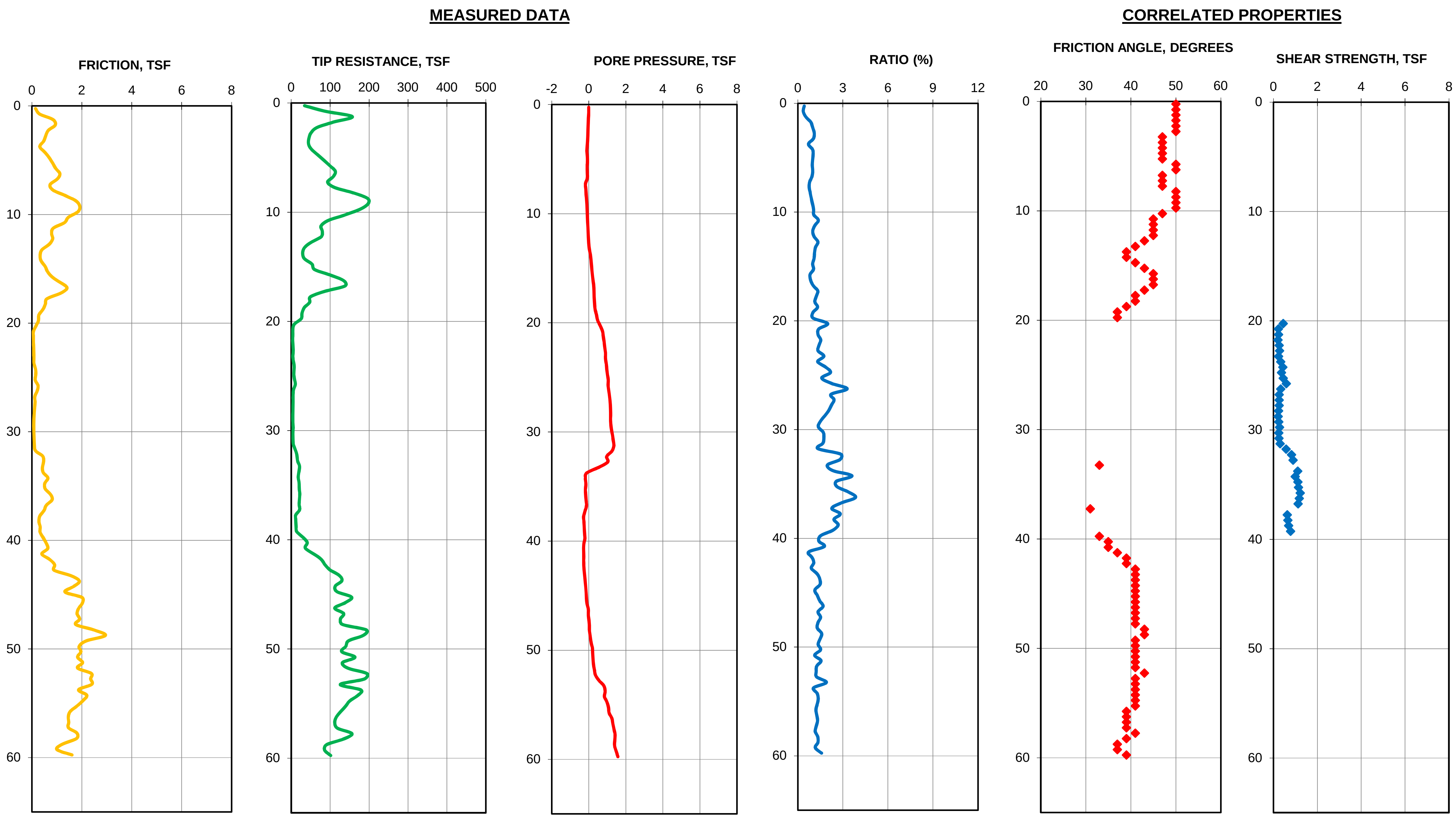

**NOTE:**

1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986).

THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

**CONE PENETROMETER TEST: CPT-32**

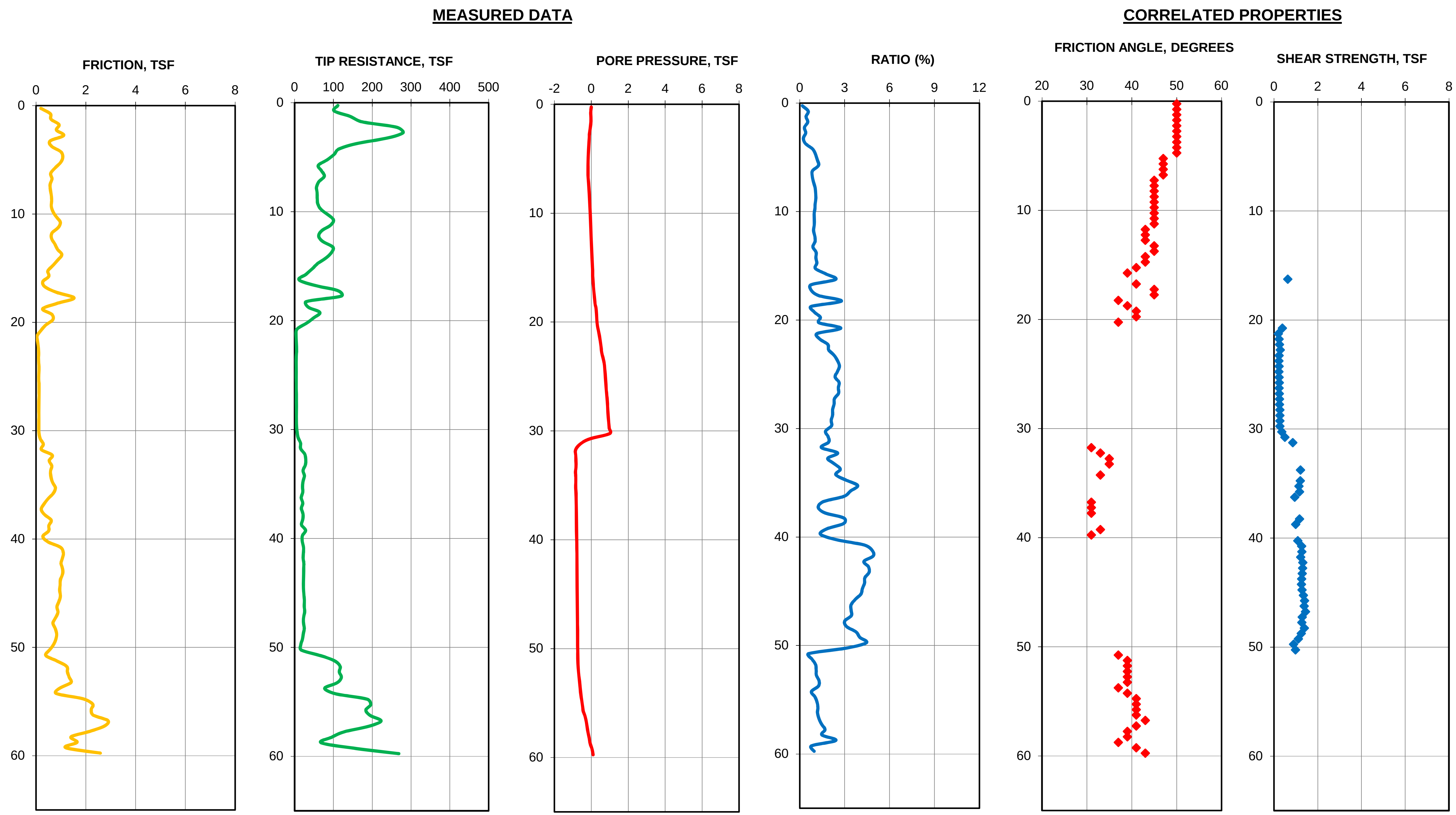
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS




**NOTE:**

1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986).
   THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

**CONE PENETROMETER TEST: CPT-33**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS

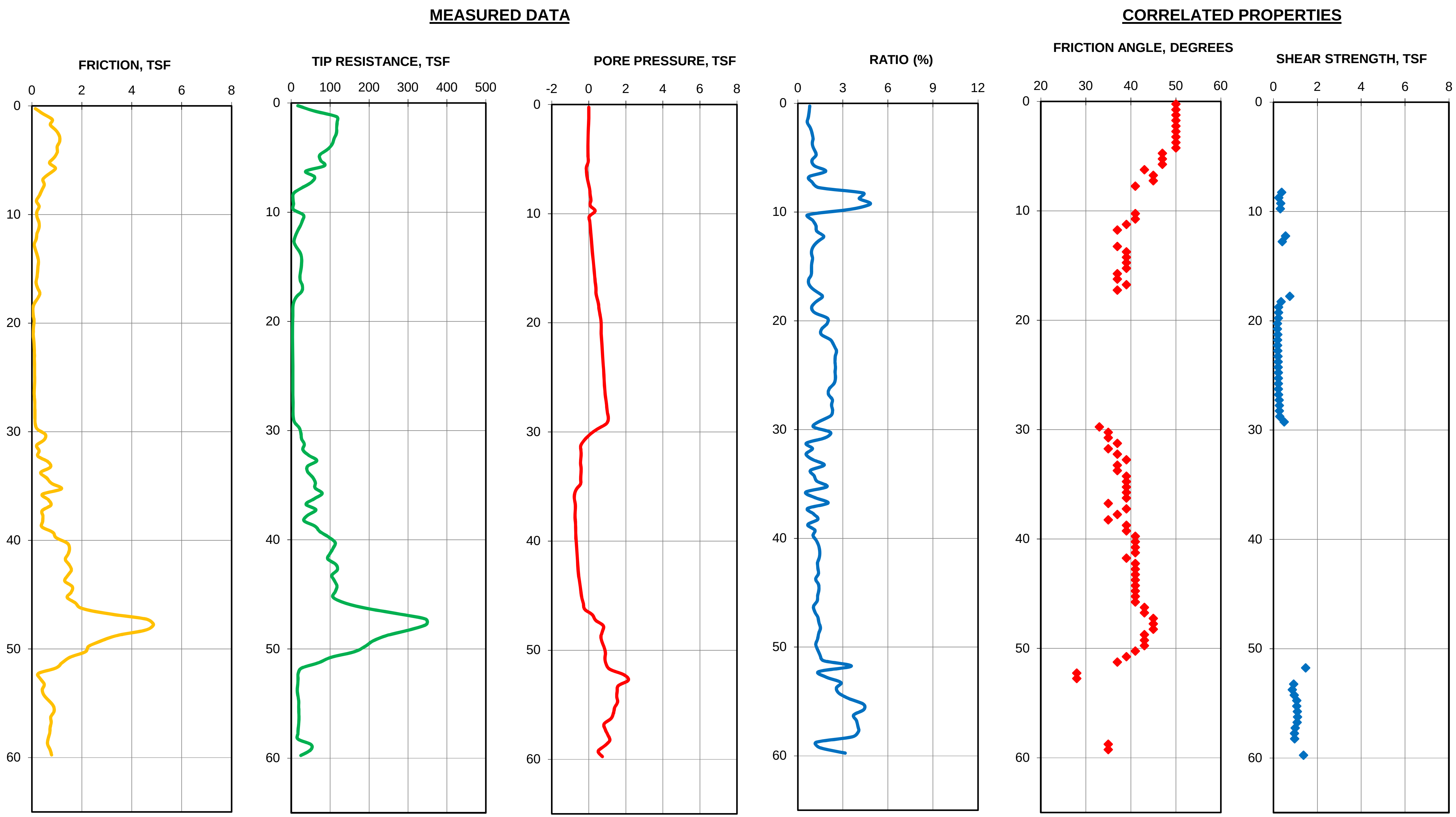



**NOTE:**

1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986).
   THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

**CONE PENETROMETER TEST: CPT-34**

STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS




NOTE:

1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986).

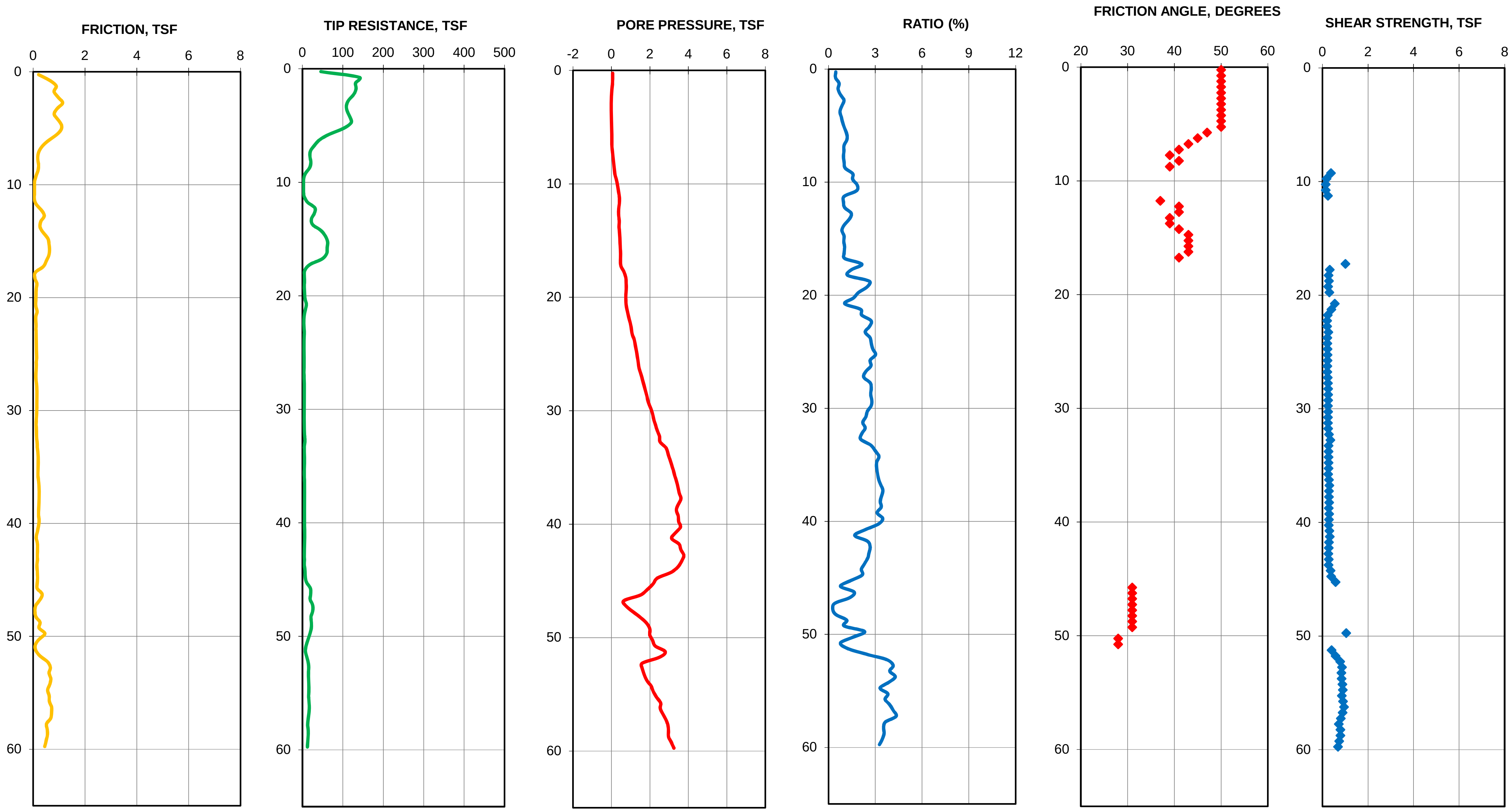
THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

**CONE PENETROMETER TEST: CPT-35**

STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS

## MEASURED DATA

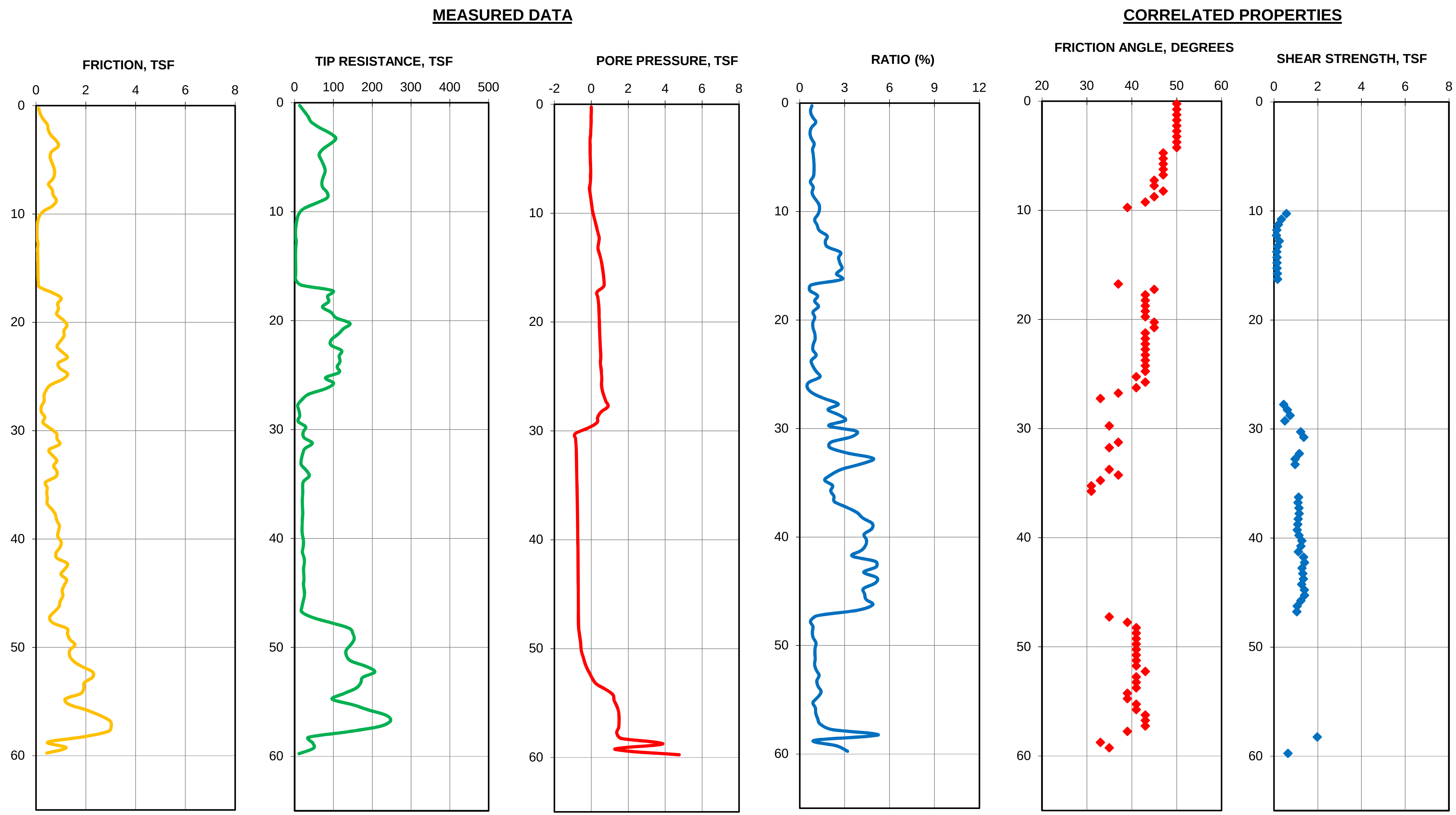
## CORRELATED PROPERTIES




**NOTE:**

1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986). THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

**CONE PENETROMETER TEST: CPT-36**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS



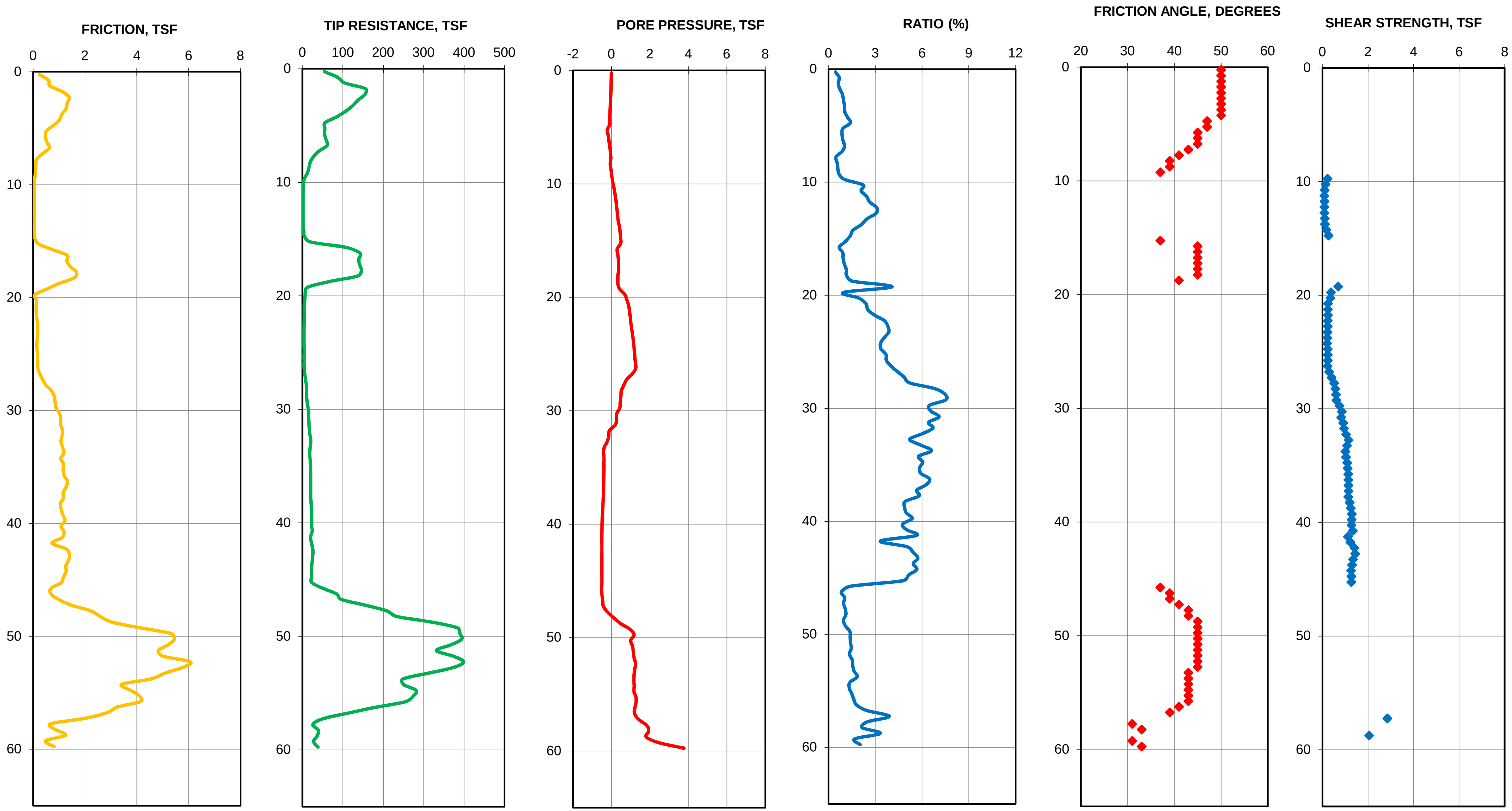

**NOTE:**

1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986). THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

**CONE PENETROMETER TEST: CPT-37**

STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON AND ORANGE COUNTIES, TEXAS

**MEASURED DATA** **CORRELATED PROPERTIES**



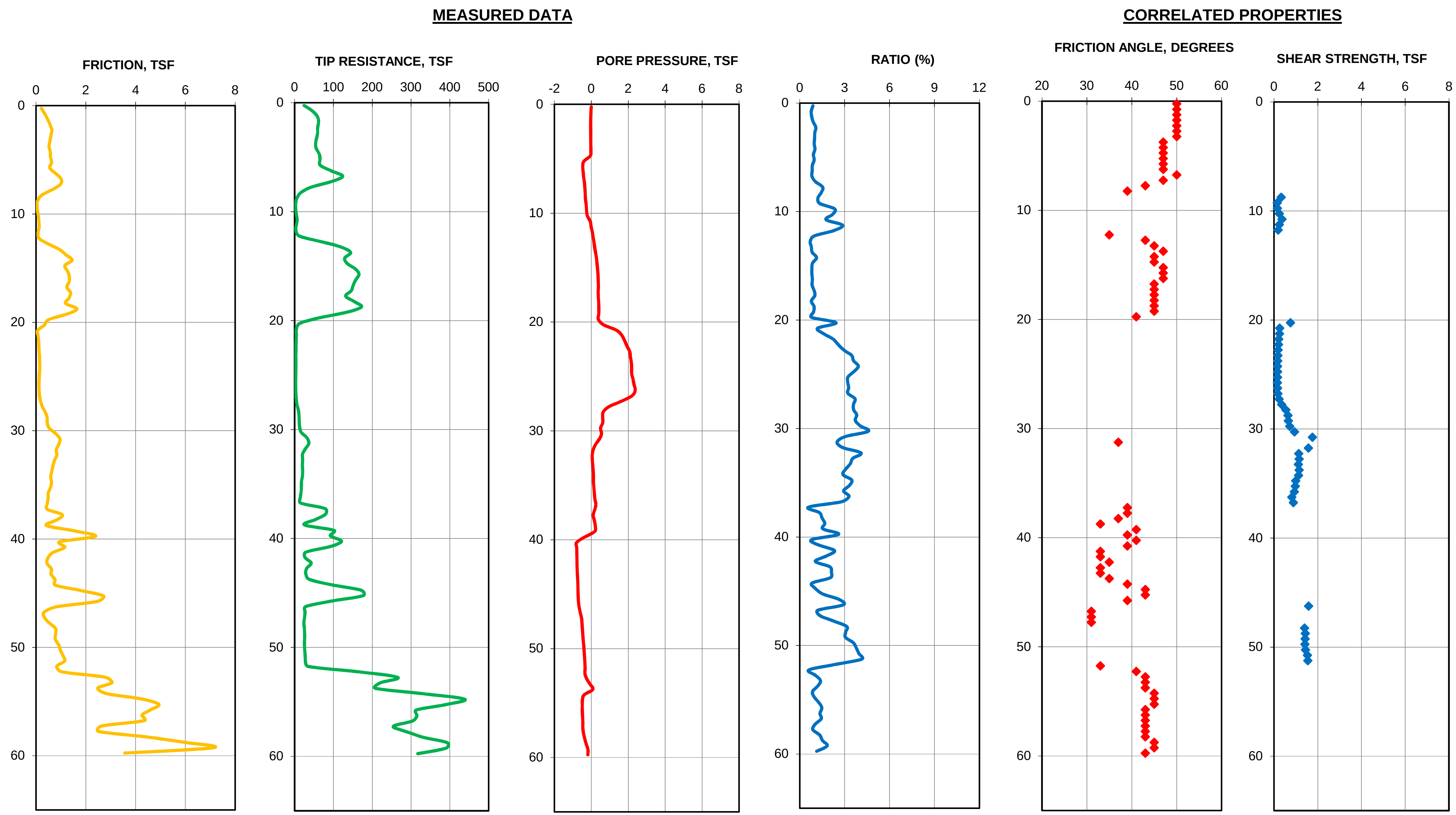

**NOTE:**

**1.** THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986).

THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

**CONE PENETROMETER TEST: CPT-38**

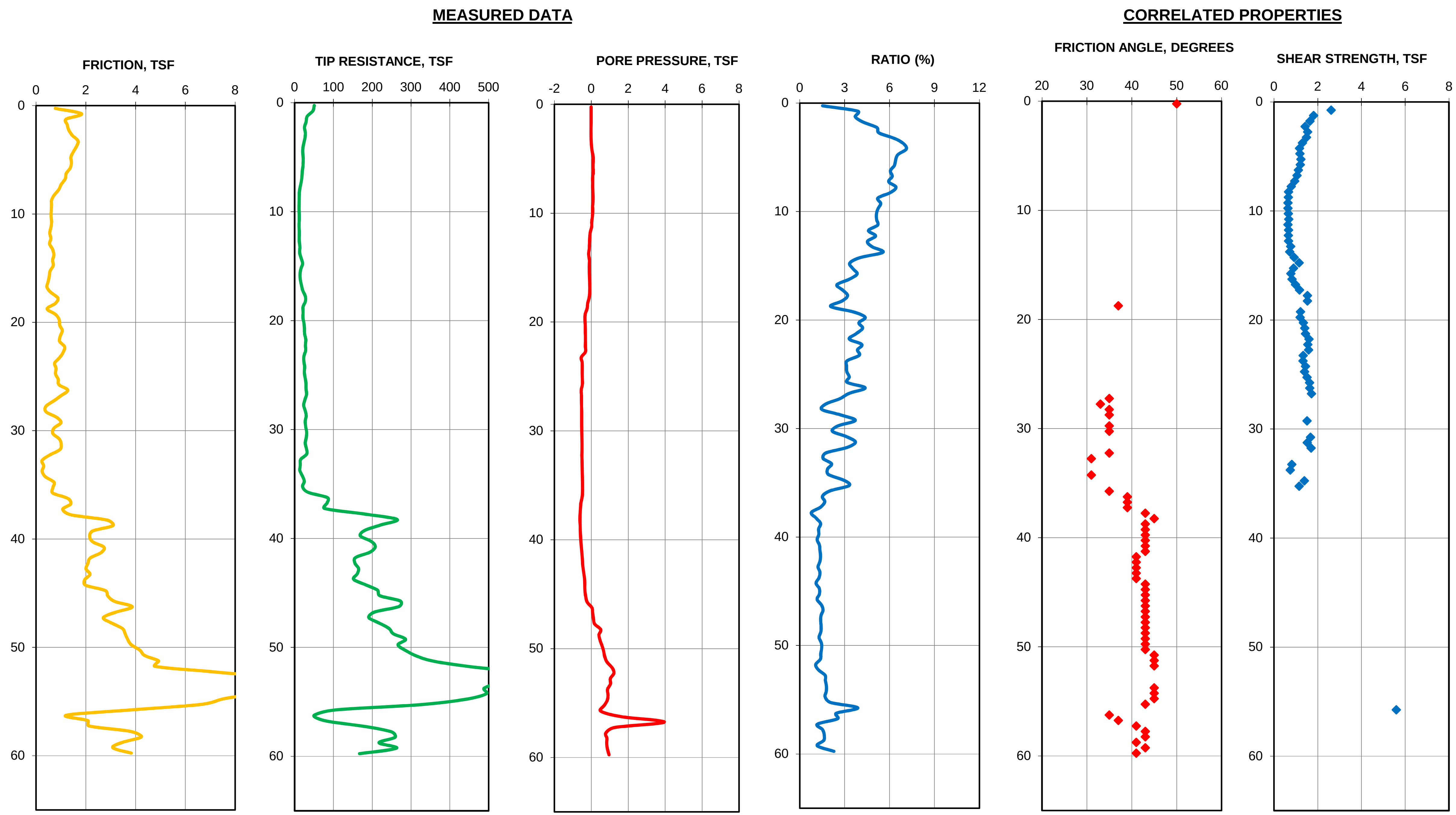
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS




**NOTE:**

1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986).
   THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

**CONE PENETROMETER TEST: CPT-39**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS

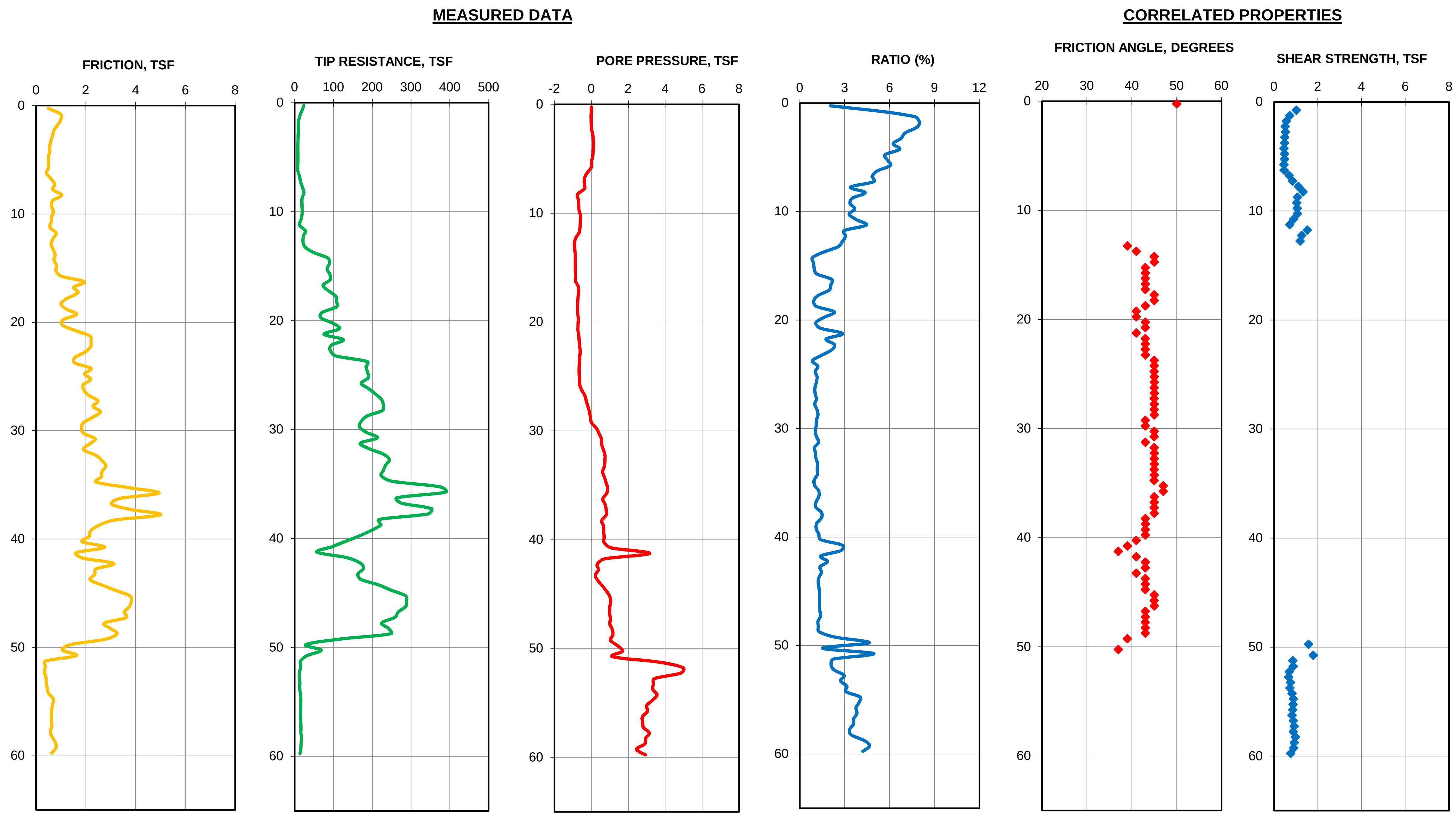



**NOTE:**

1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986). THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

**CONE PENETROMETER TEST: CPT-40**

STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS

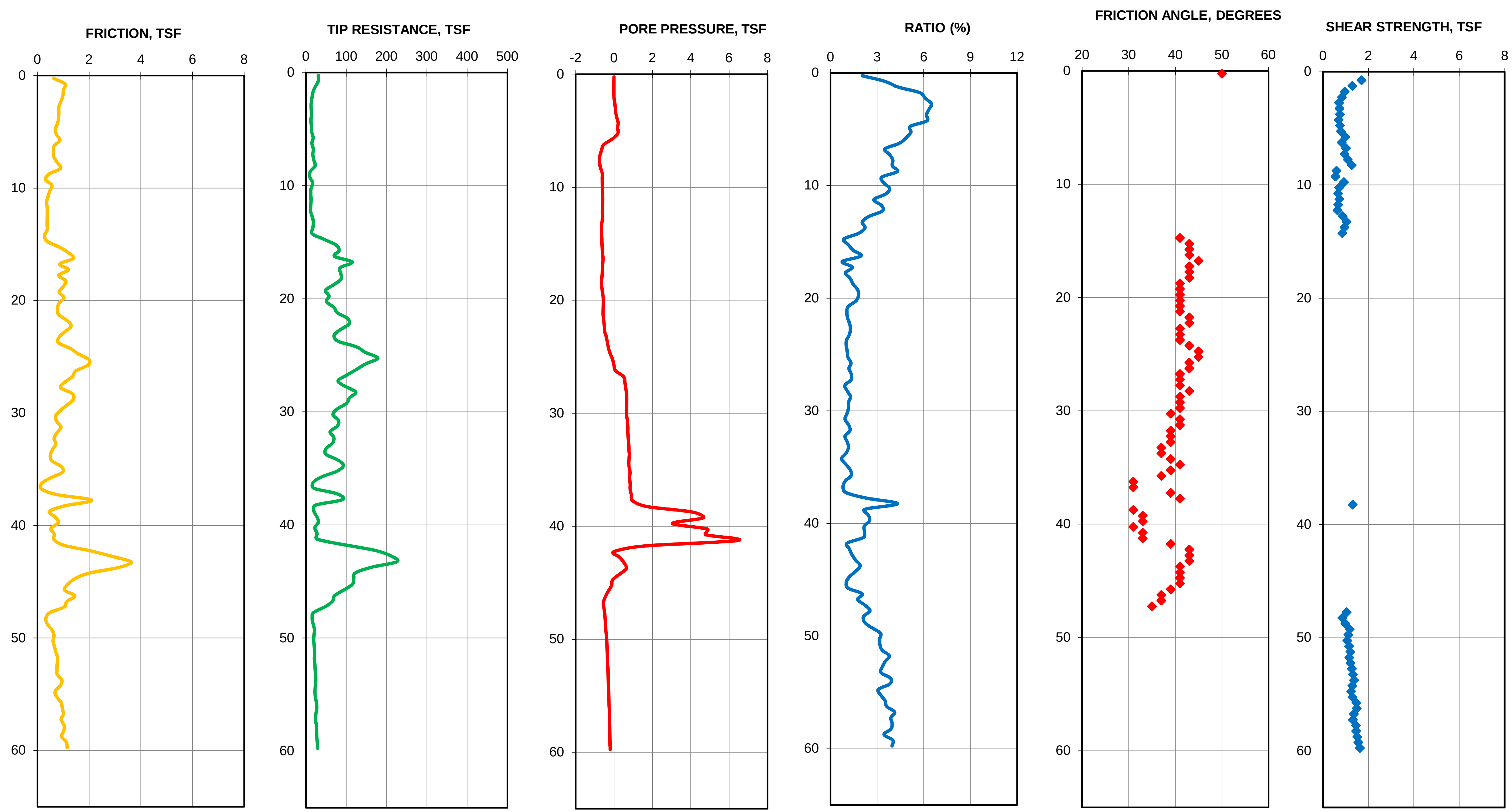



**NOTE:**

**1.** THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986).
THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

**CONE PENETROMETER TEST: CPT-41**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS

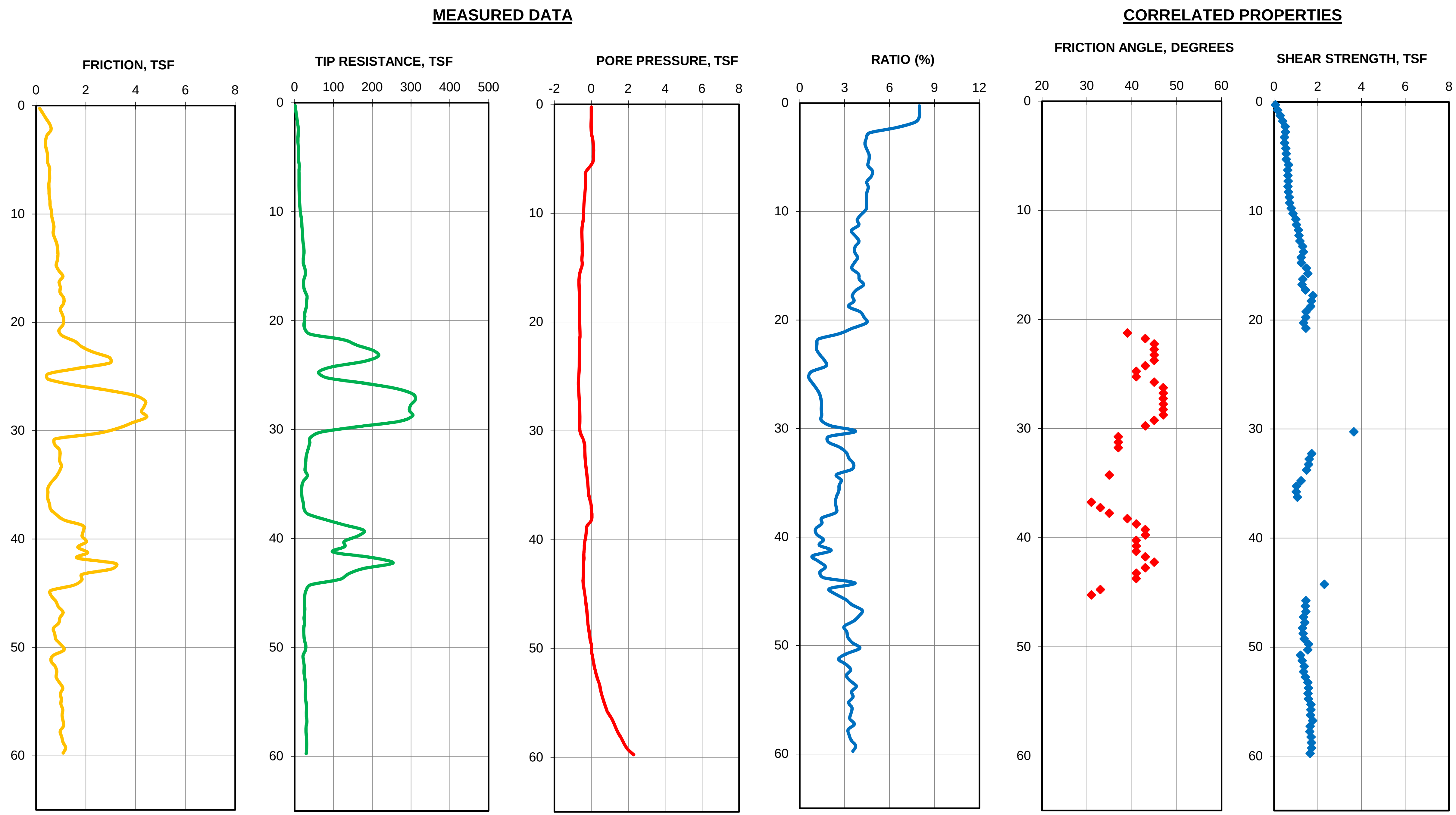
**MEASURED DATA** **CORRELATED PROPERTIES**




**NOTE:**

1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986).
   THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

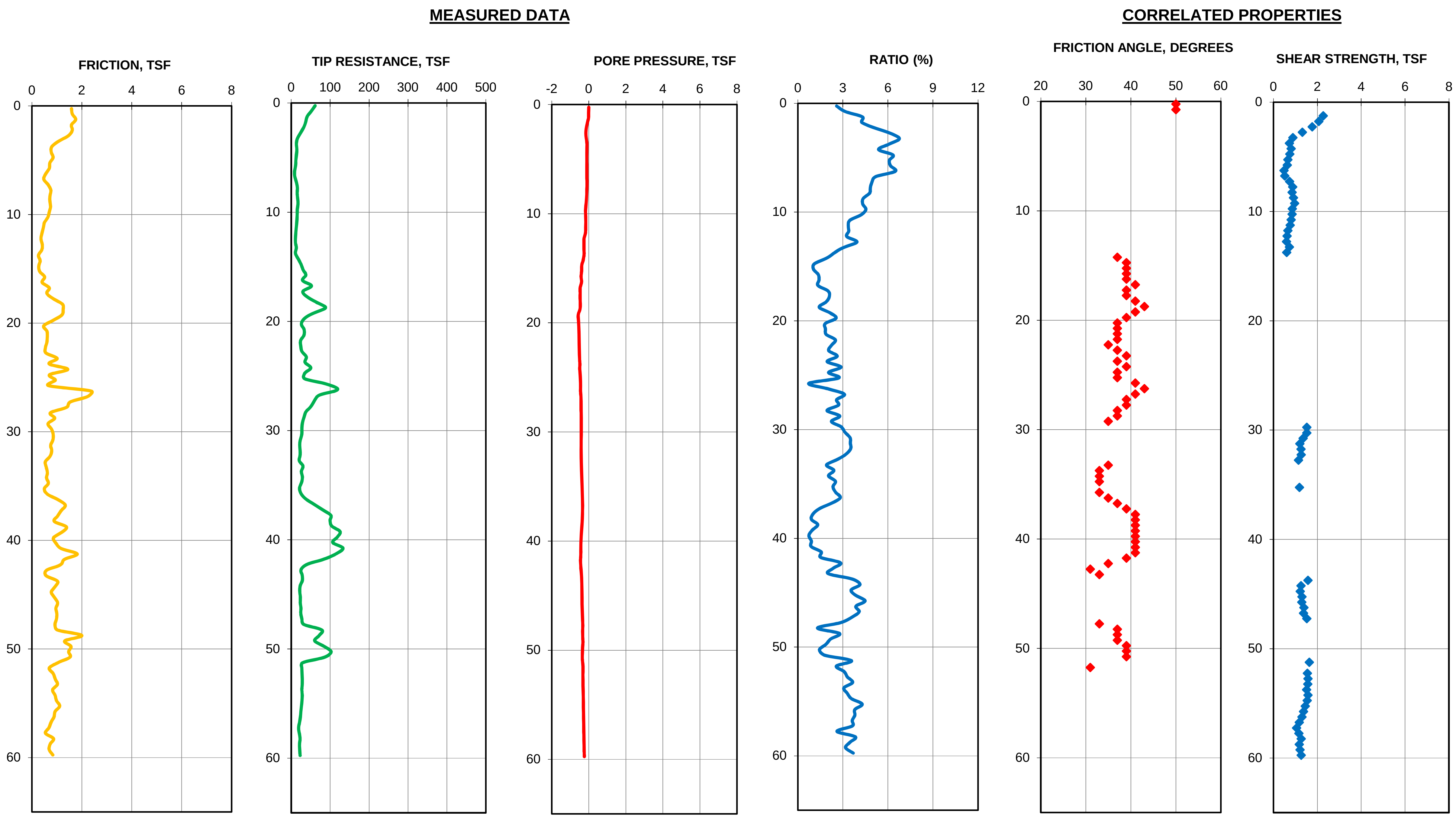
**CONE PENETROMETER TEST: CPT-42**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS




**NOTE:**

1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986).
   THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

**CONE PENETROMETER TEST: CPT-43**
STORM SURGE SUPPRESSION STUDY -GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS

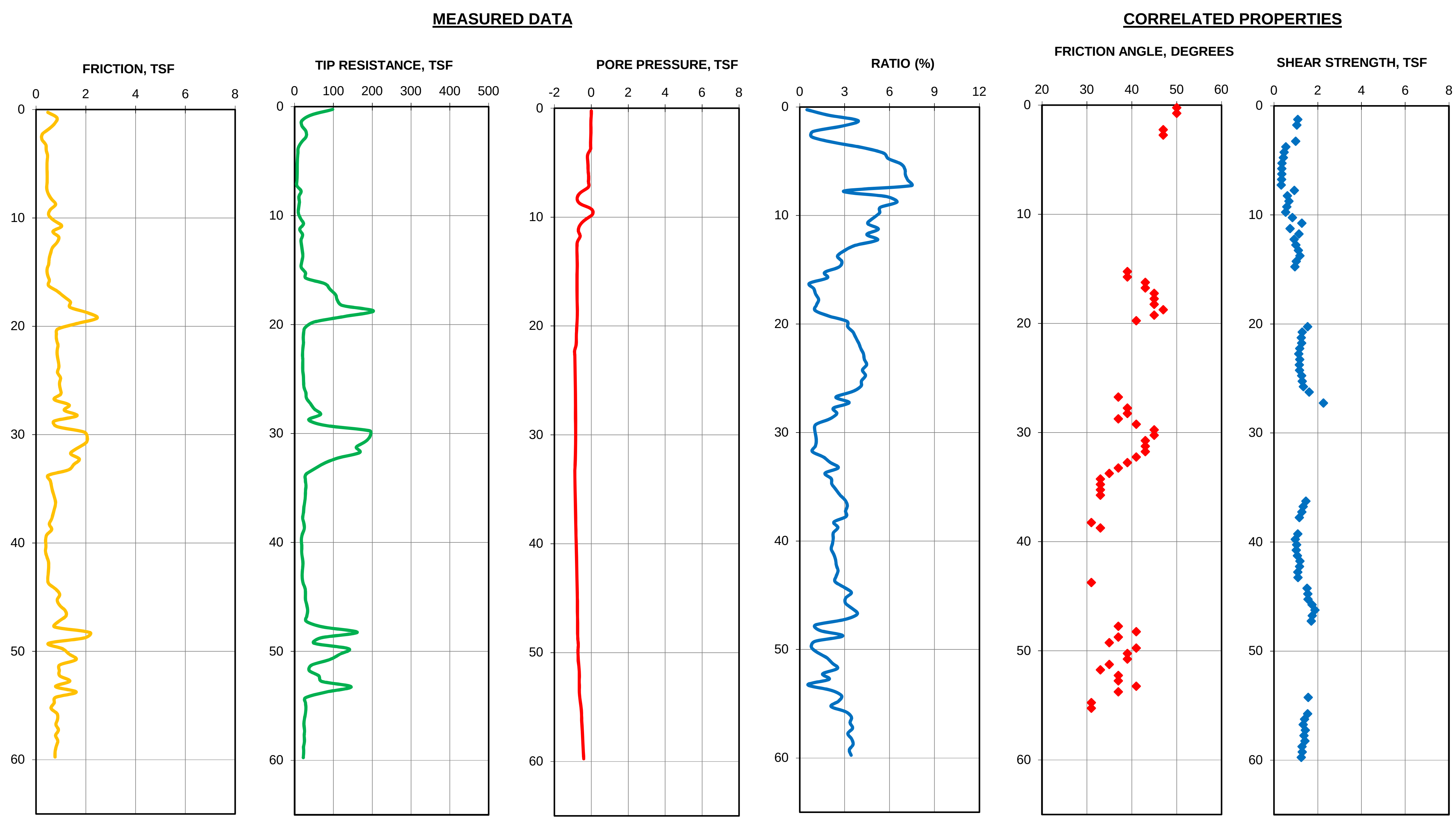



**NOTE:**

1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986). THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

**CONE PENETROMETER TEST: CPT-44**

STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON AND ORANGE COUNTIES, TEXAS

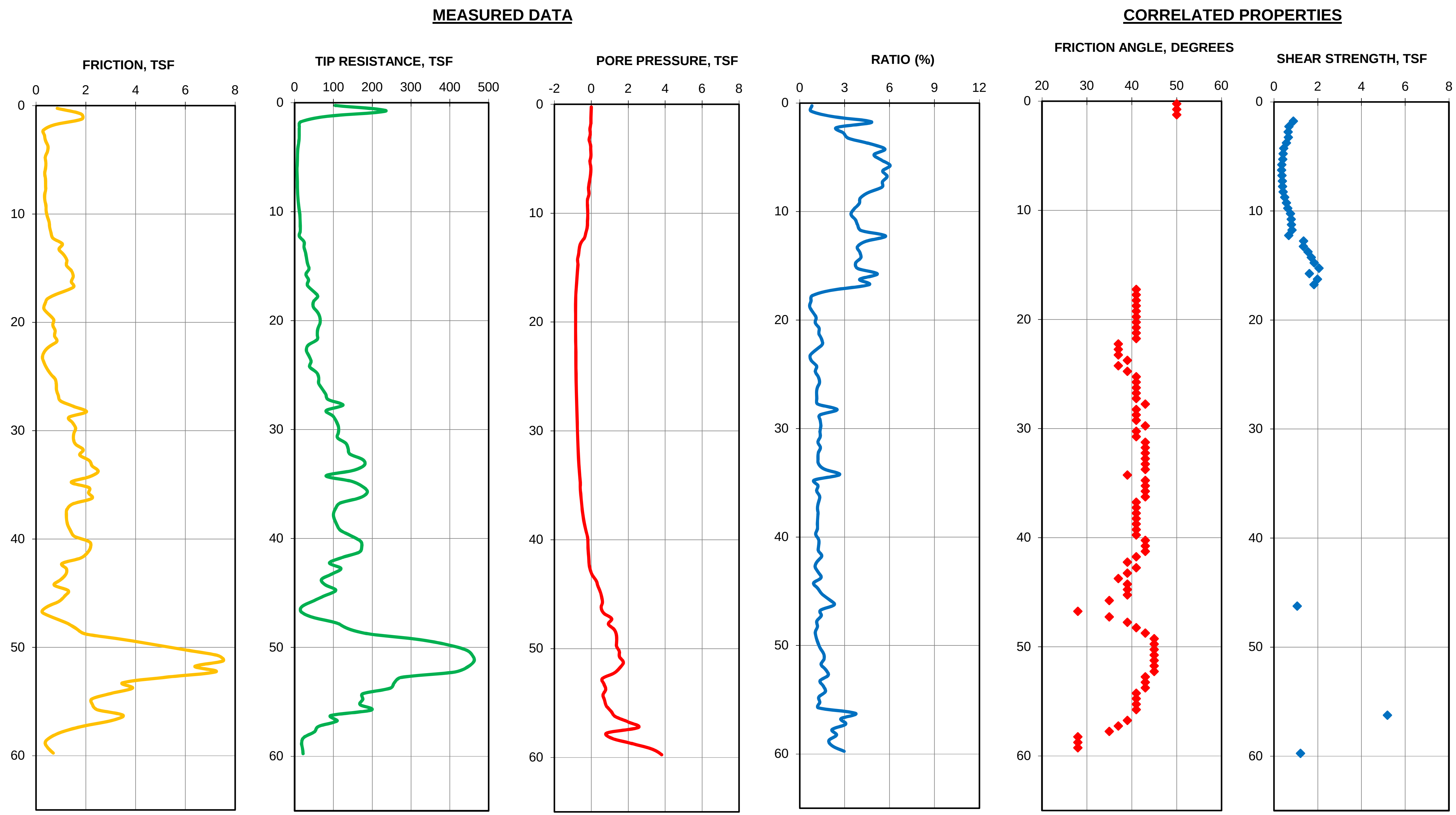



**NOTE:**

1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986).

   THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

**CONE PENETROMETER TEST: CPT-45**
STORM SURGE SUPPRESSION STUDY -GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS



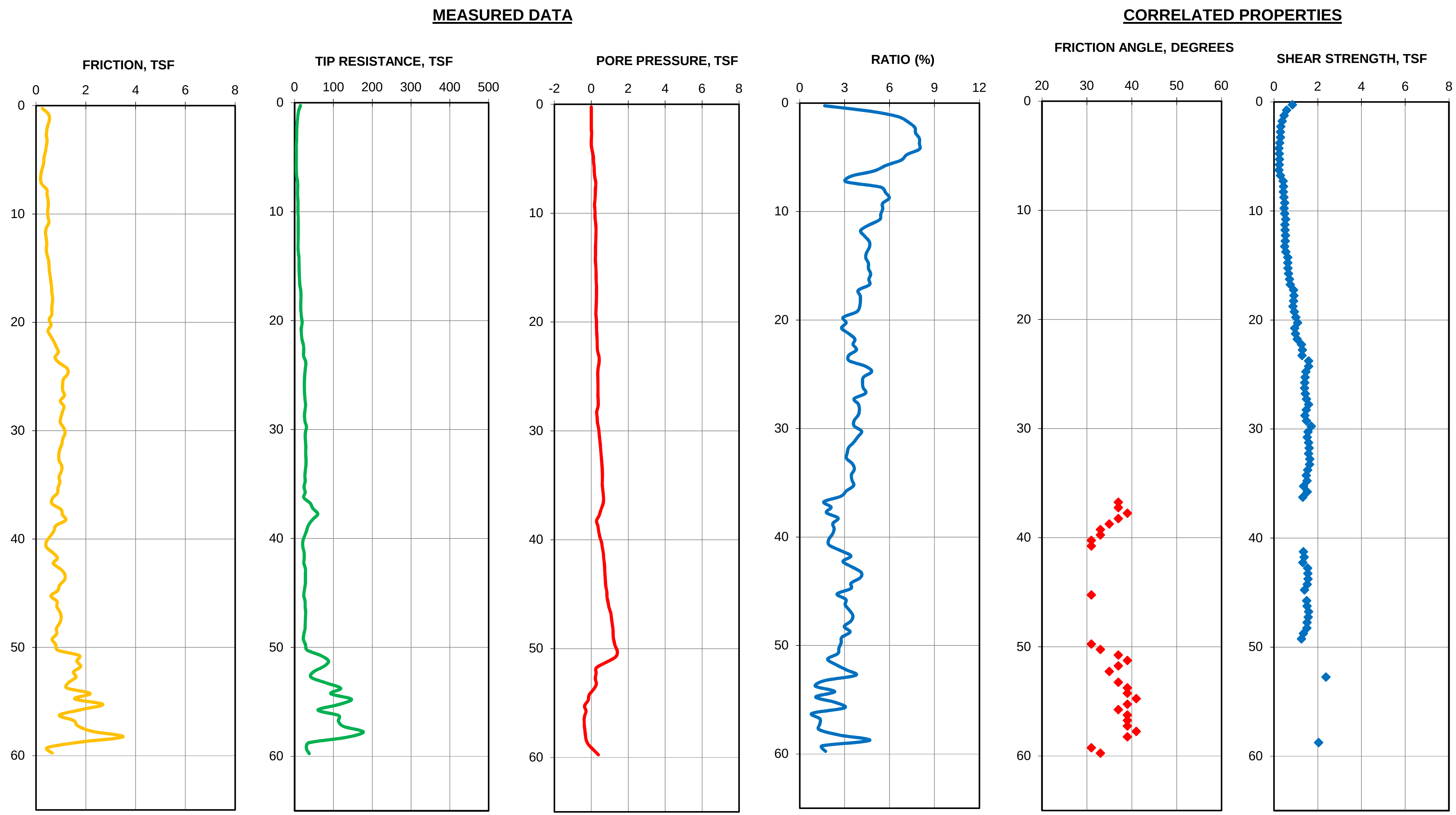

**NOTE:**

1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986).

   THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

**CONE PENETROMETER TEST: CPT-46**

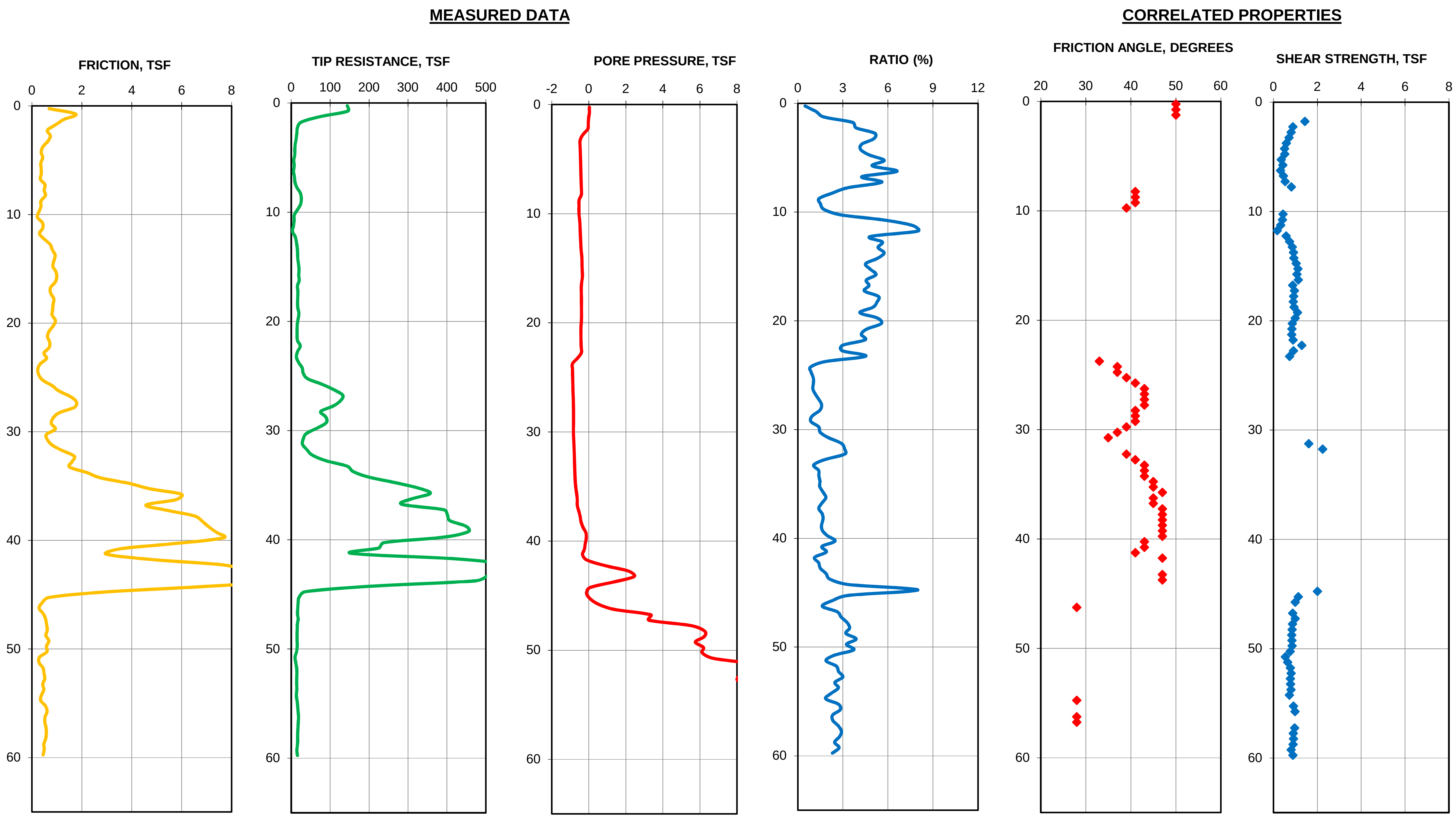
STORM SURGE SUPPRESSION STUDY -GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS




**NOTE:**

1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986).
   THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

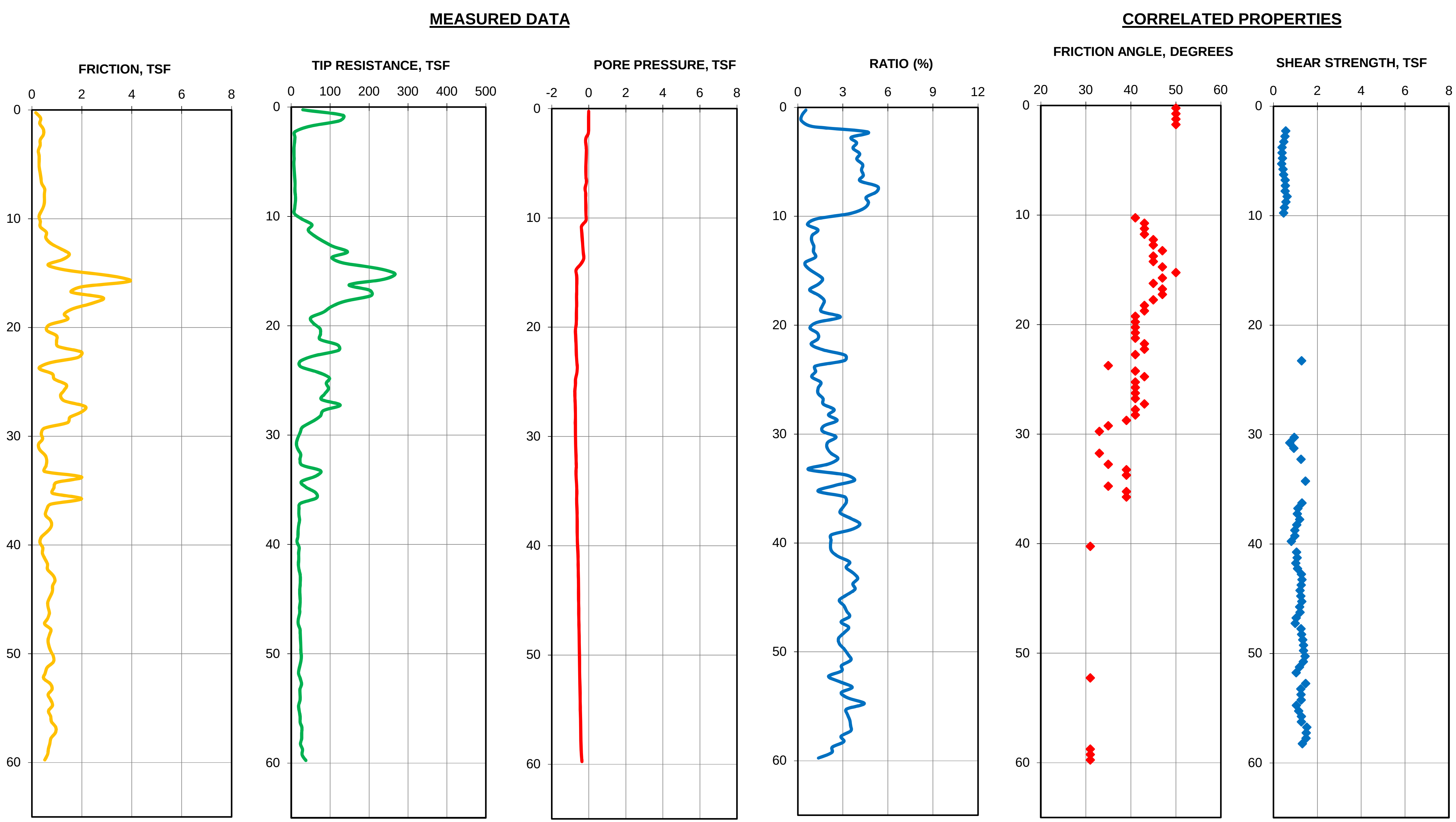
**CONE PENETROMETER TEST: CPT-47**
STORM SURGE SUPPRESSION STUDY -GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS




NOTE:

1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986).
   THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

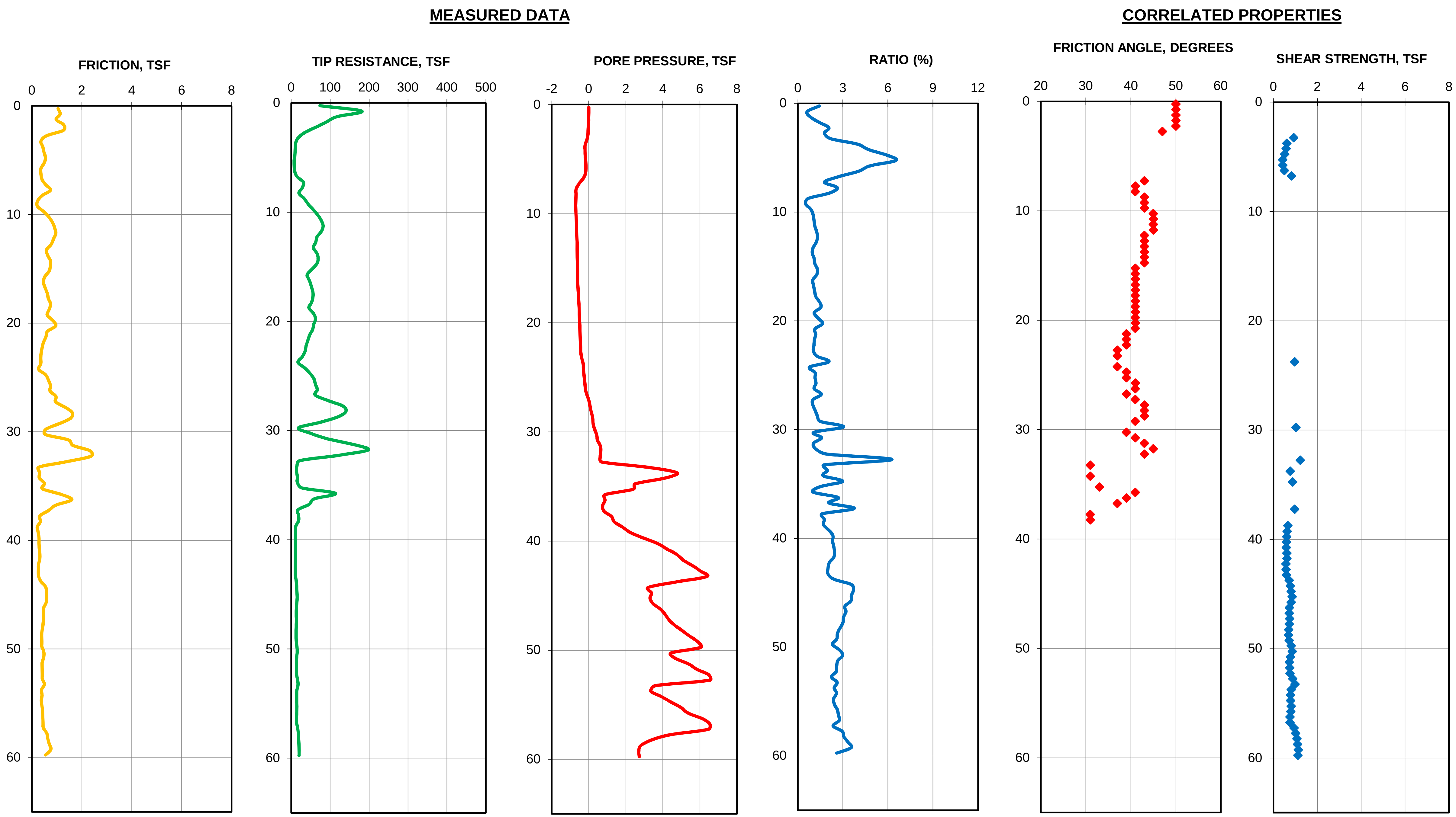
**CONE PENETROMETER TEST: CPT-48**
STORM SURGE SUPPRESSION STUDY -GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS




**NOTE:**

1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986).
   THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

**CONE PENETROMETER TEST: CPT-49**
STORM SURGE SUPPRESSION STUDY -GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS

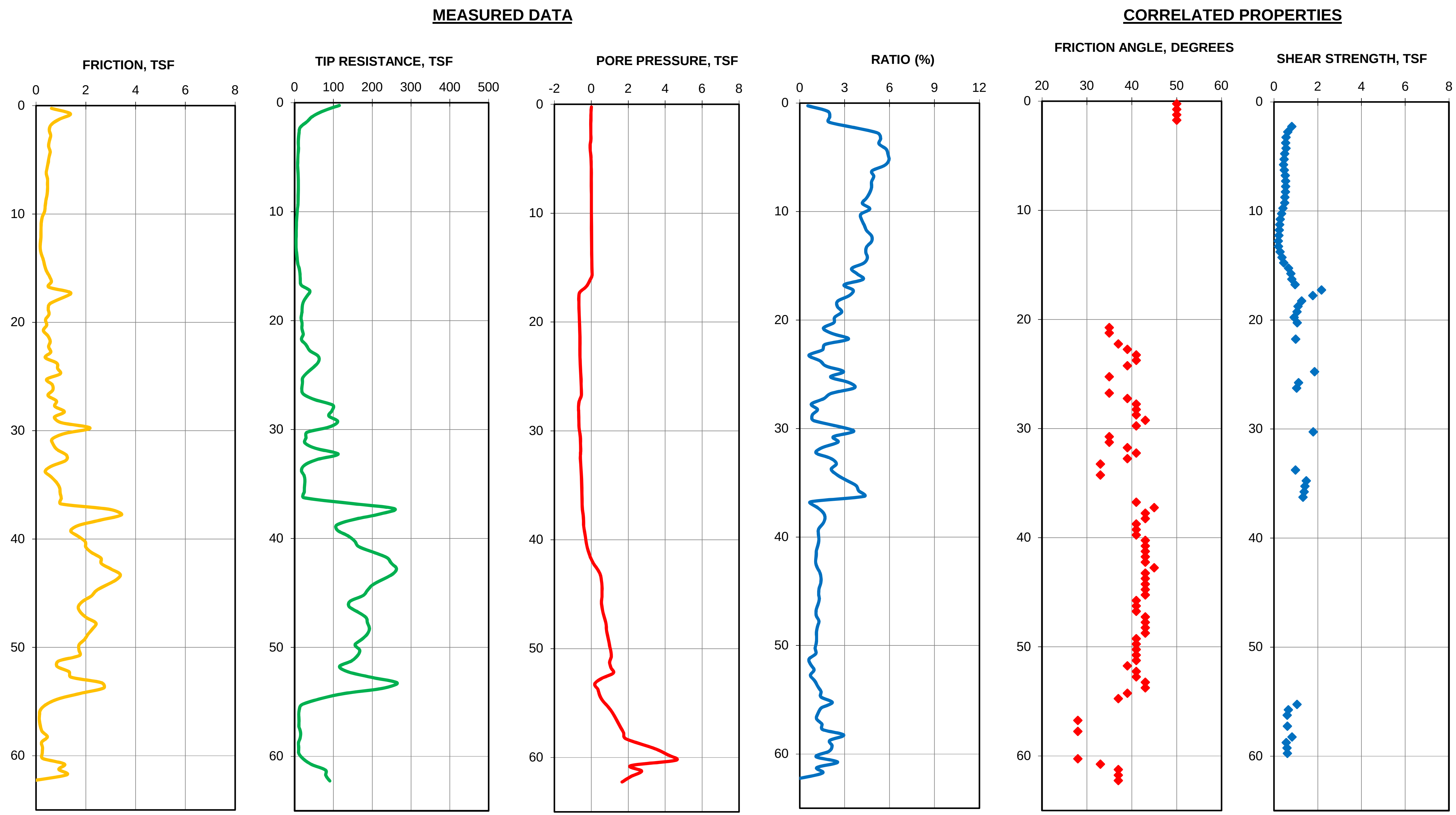



**NOTE:**

1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986). THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

**CONE PENETROMETER TEST: CPT-50**

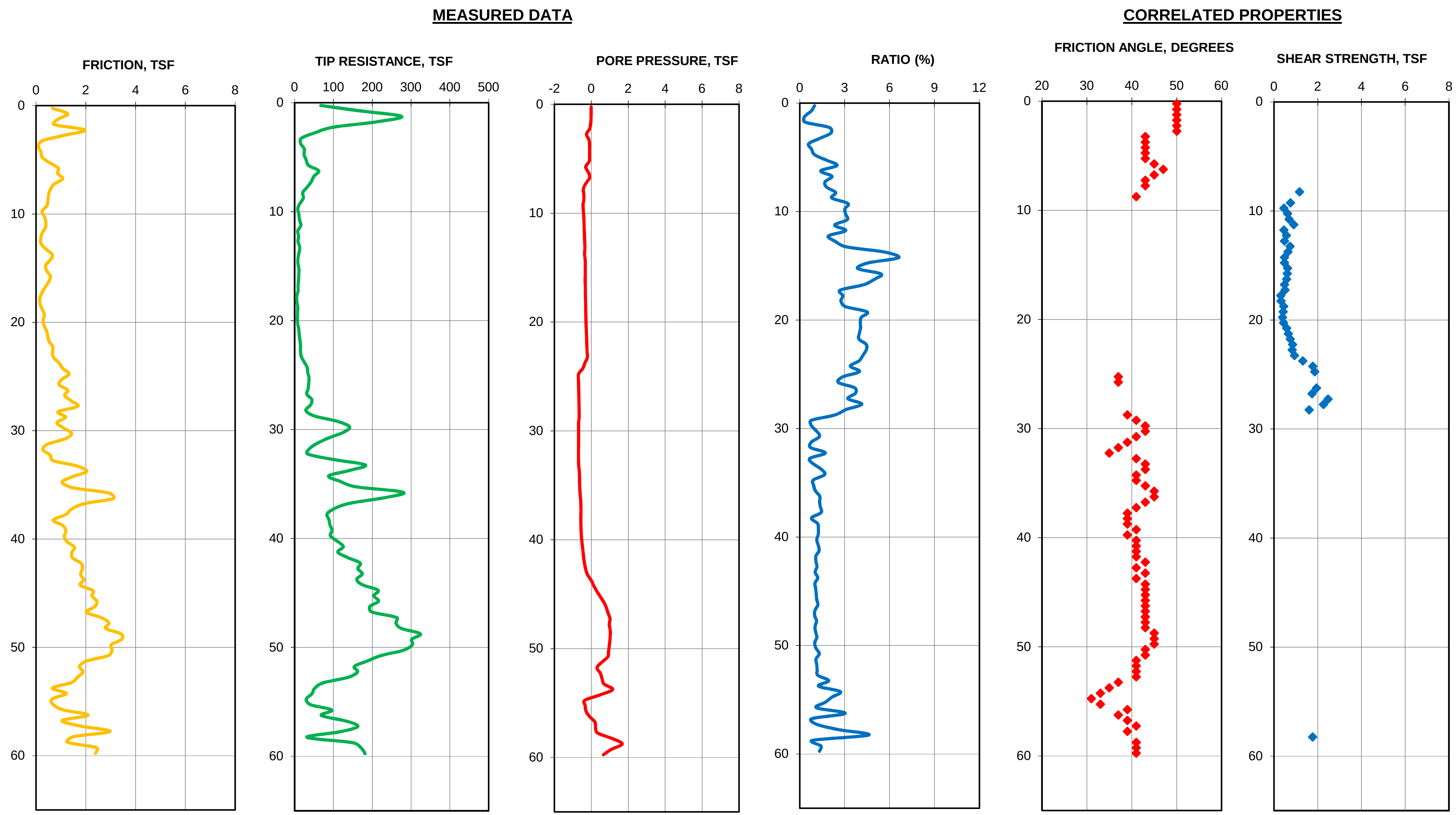
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON AND ORANGE COUNTIES, TEXAS




**NOTE:**

1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986).
   THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

**CONE PENETROMETER TEST: CPT-51**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS

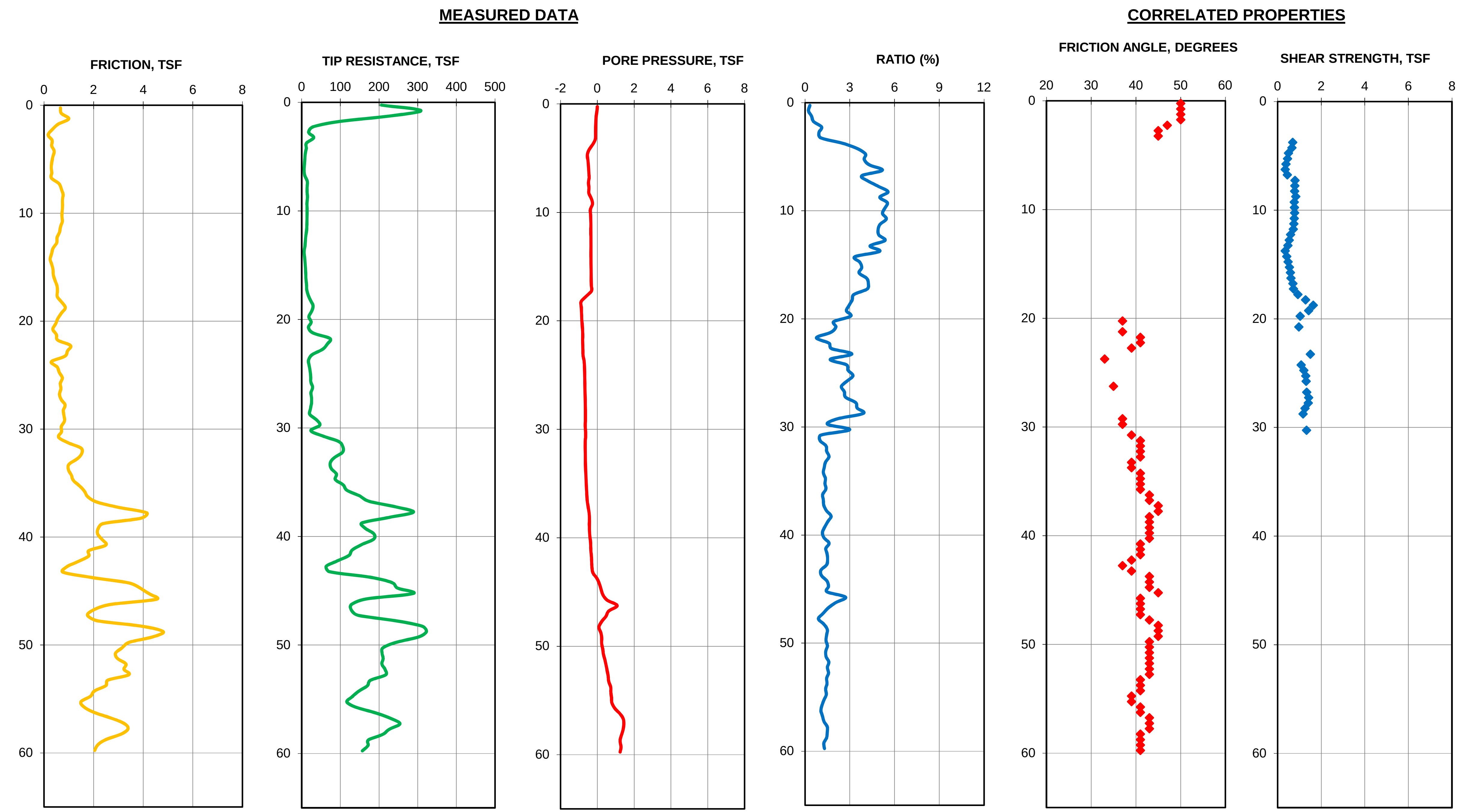



**NOTE:**

1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986). THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

**CONE PENETROMETER TEST: CPT-52**

STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS, JEFFERSON AND ORANGE COUNTIES, TEXAS




NOTE:

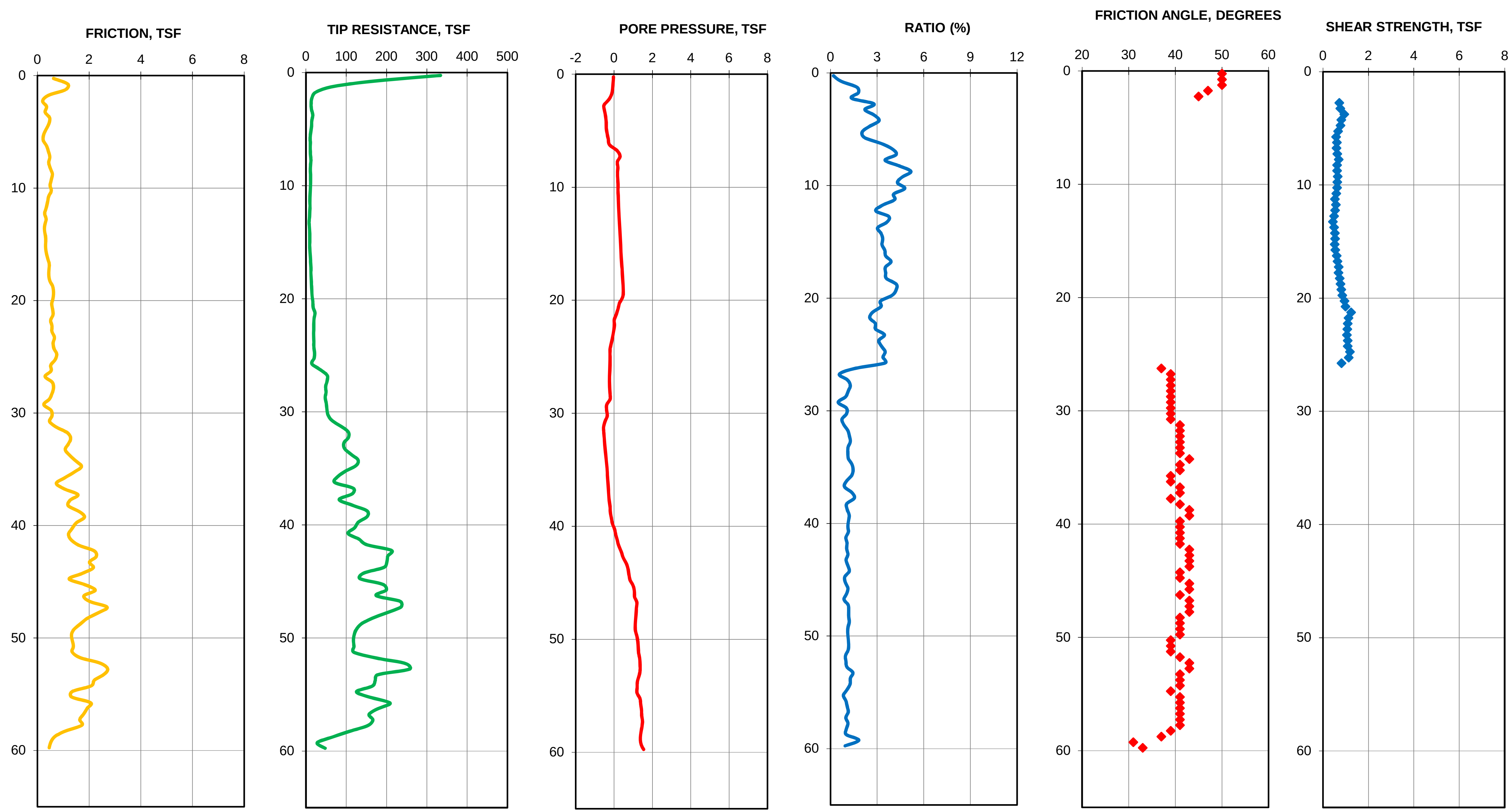
1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986).
THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

**CONE PENETROMETER TEST: CPT-53**

STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS

MEASURED DATA

CORRELATED PROPERTIES



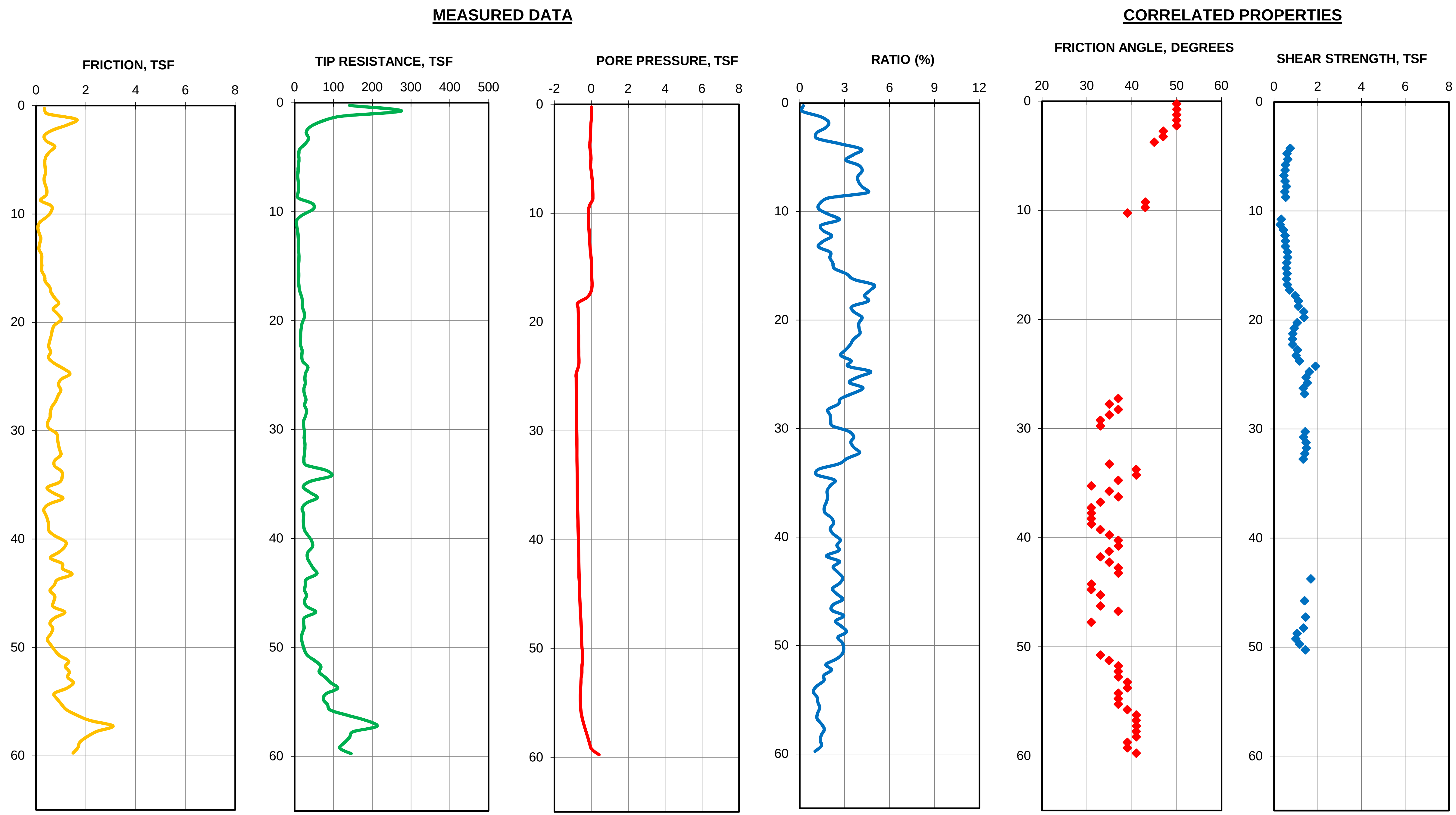

**NOTE:**

1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986).

THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

**CONE PENETROMETER TEST: CPT-54**

STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS




**NOTE:**

1. THE CORRELATED SOIL PROPERTIES (SHEAR STRENGTH AND FRICTION ANGLE) ARE BASED ON MODIFIED ROBERTSON AND CAMPANELLA METHOD (1986).

   THESE CORRELATED SOIL PROPERTIES SHOULD BE USED WITH PRUDENCE. PLEASE REFER TO REPORT TEXT FOR EXPLANATION.

**CONE PENETROMETER TEST: CPT-55**

STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS

# APPENDIX F

# LABORATORY CONSOLIDATION TEST RESULTS

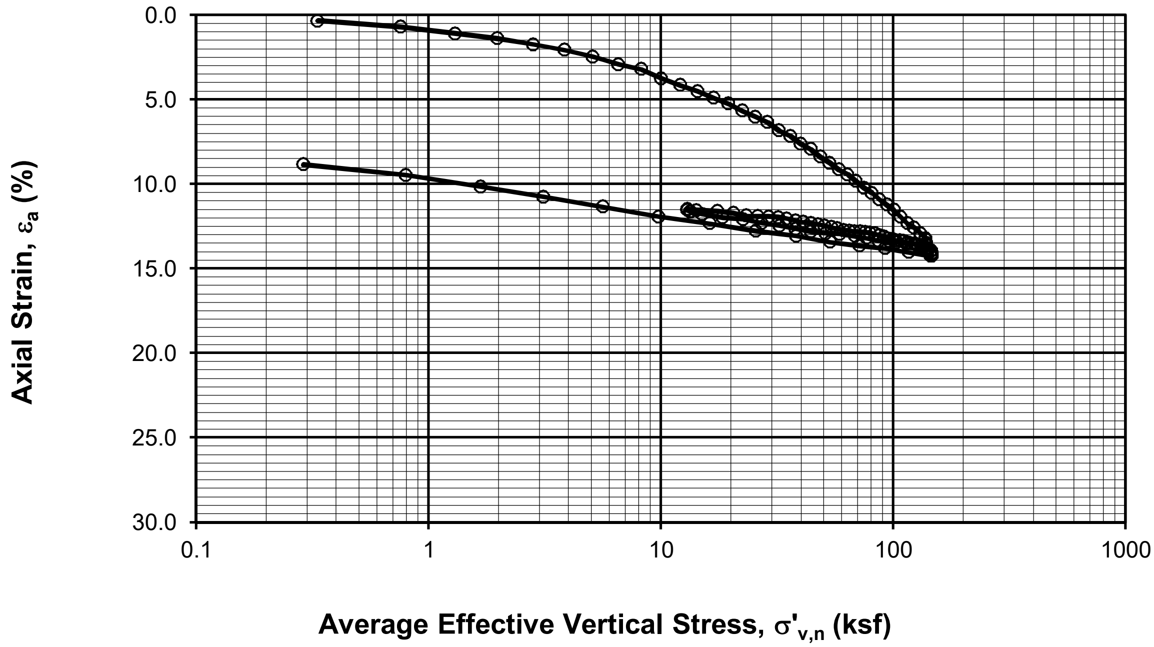
| Boring No. | Sample Depth (ft) | Type of Material | Total Unit Weight (pcf) | Initial Void Ratio | PCP(1) (ksf) | $C_{c\varepsilon}$(1) | $C_{r\varepsilon}$(1) | $C_v$ ($ft^2/y$) |
|---|---|---|---|---|---|---|---|---|
| BH-02 | 110 | Sandy Clay | 130 | 0.617 | 21.77 | 0.10 | 0.02 | 20 to 70 |
| BH-02 | 170 | Clay | 118 | 0.937 | 20.15 | 0.22 | 0.05 | 1 to 3 |
| BH-03 | 90 | Clay w/ shell fragments | 104 | 1.587 | 6.52 | 0.34 | 0.07 | 2 to 12 |
| BH-03 | 210 | Clay | 123 | 0.817 | 18.77 | 0.16 | 0.03 | 7 to 17 |
| BH-05 | 35 | Sandy Clay | 131 | 0.546 | 4.32 | 0.09 | 0.01 | 4 to 40 |
| BH-06 | 20 | Clay | 123 | 0.792 | 15.56 | 0.13 | 0.05 | 1 to 7 |
| BH-08 | 25 | Clay | 118 | 0.961 | 11.06 | 0.13 | 0.05 | 1 to 6 |

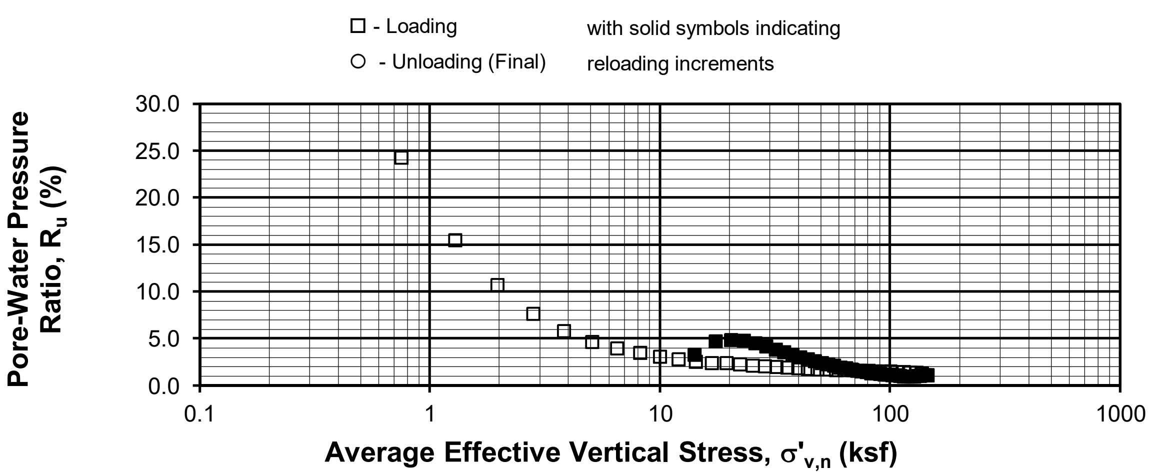
**Notes:**

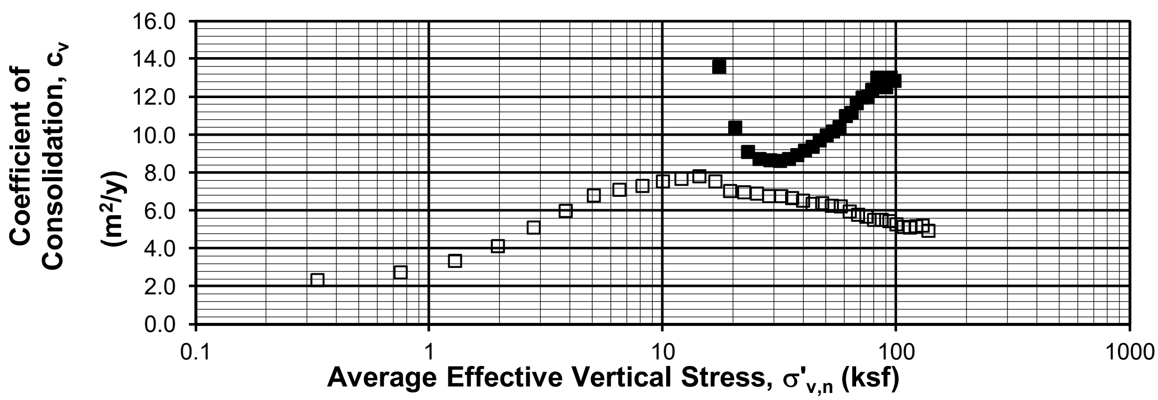
1. PCP- Pre-Consolidation Pressure, $C_{c\varepsilon}$ -Strain Based Compression Index, $C_{r\varepsilon}$ - Strain Based Recompression Index.
2. Sample disturbance was observed for Borings BH-02 at a depth of 110 ft and Boring BH-05 at a depth of 35 ft. Correction for disturbance was not performed and therefore empirical relationships were used to determine the soil compressibility parameters.

**SUMMARY OF CONSOLIDATION TEST RESULTS**

STORM SURGE SUPPRESSION STUDY – GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS




**1-D CONSOLIDATION TEST: CRS**

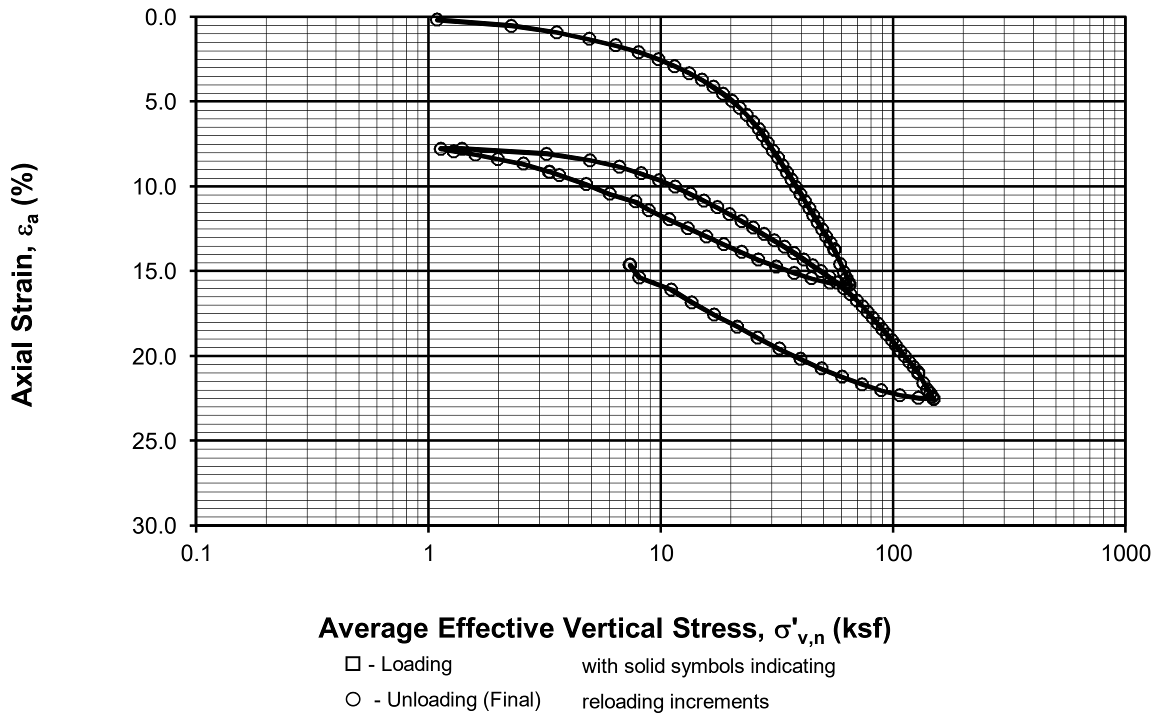
Sample No. 28b Depth 110 ft

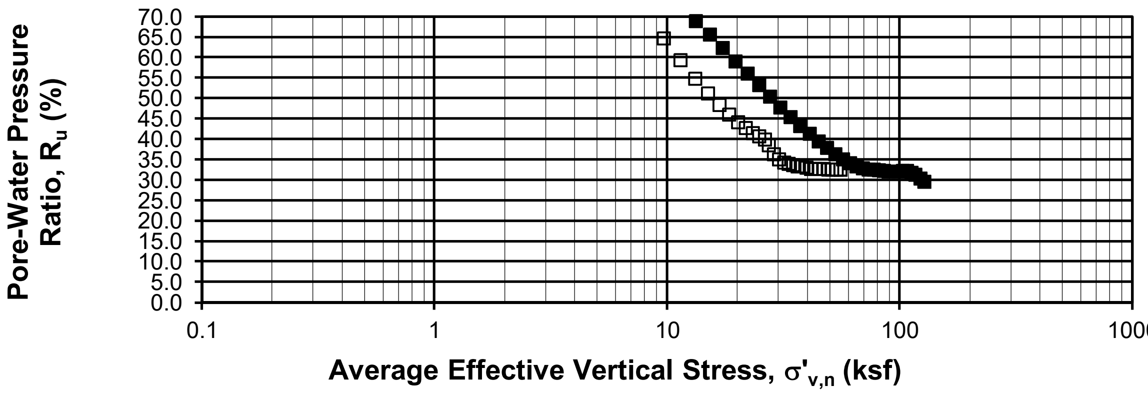
Boring BH-02

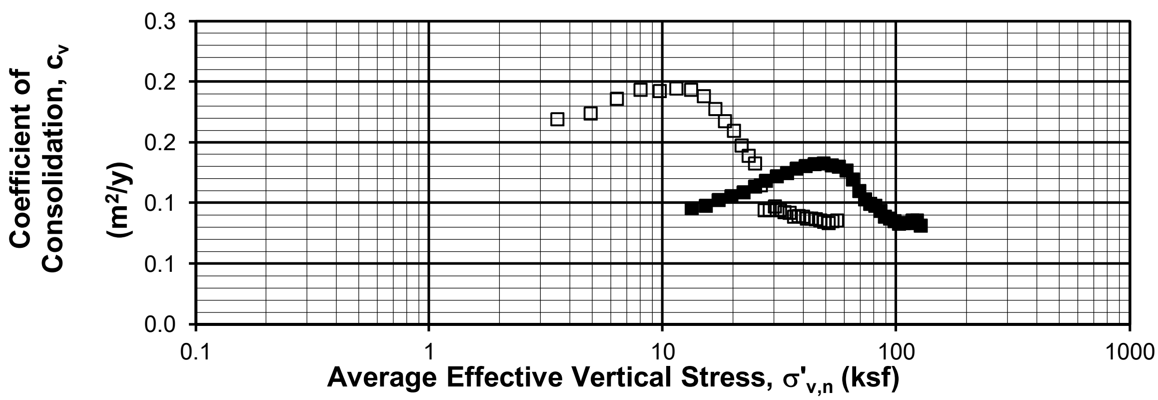
STORM SURGE SUPPRESSION STUDY - GCCPRD

BRAZORIA, CHAMBERS, GALVESTON, HARRIS

JEFFERSON AND ORANGE COUNTIES, TEXAS




**1-D CONSOLIDATION TEST: CRS**

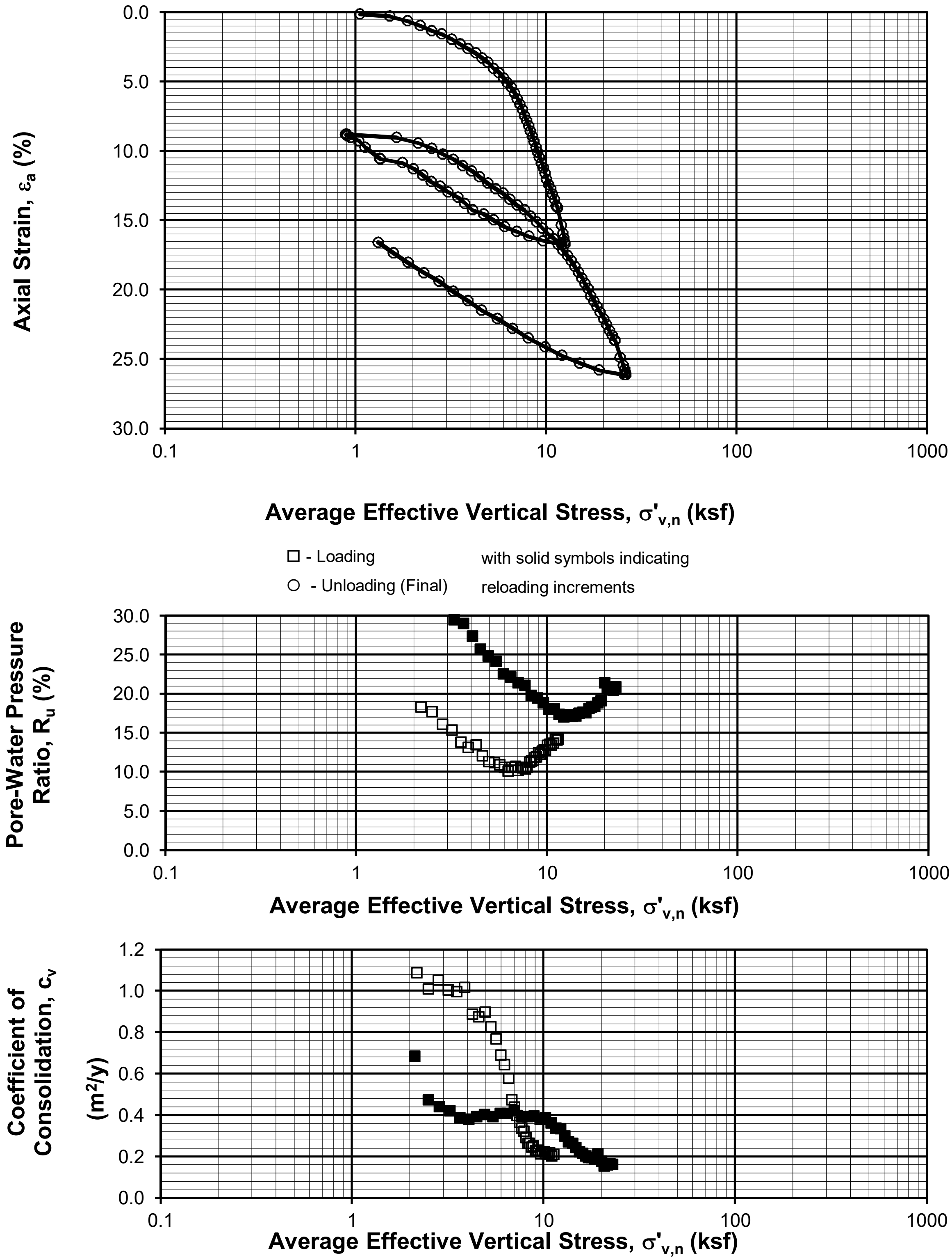
Sample No. 37b Depth 170 ft

Boring BH-02

STORM SURGE SUPPRESSION STUDY - GCCPRD

BRAZORIA, CHAMBERS, GALVESTON, HARRIS

JEFFERSON AND ORANGE COUNTIES, TEXAS




**1-D CONSOLIDATION TEST: CRS**

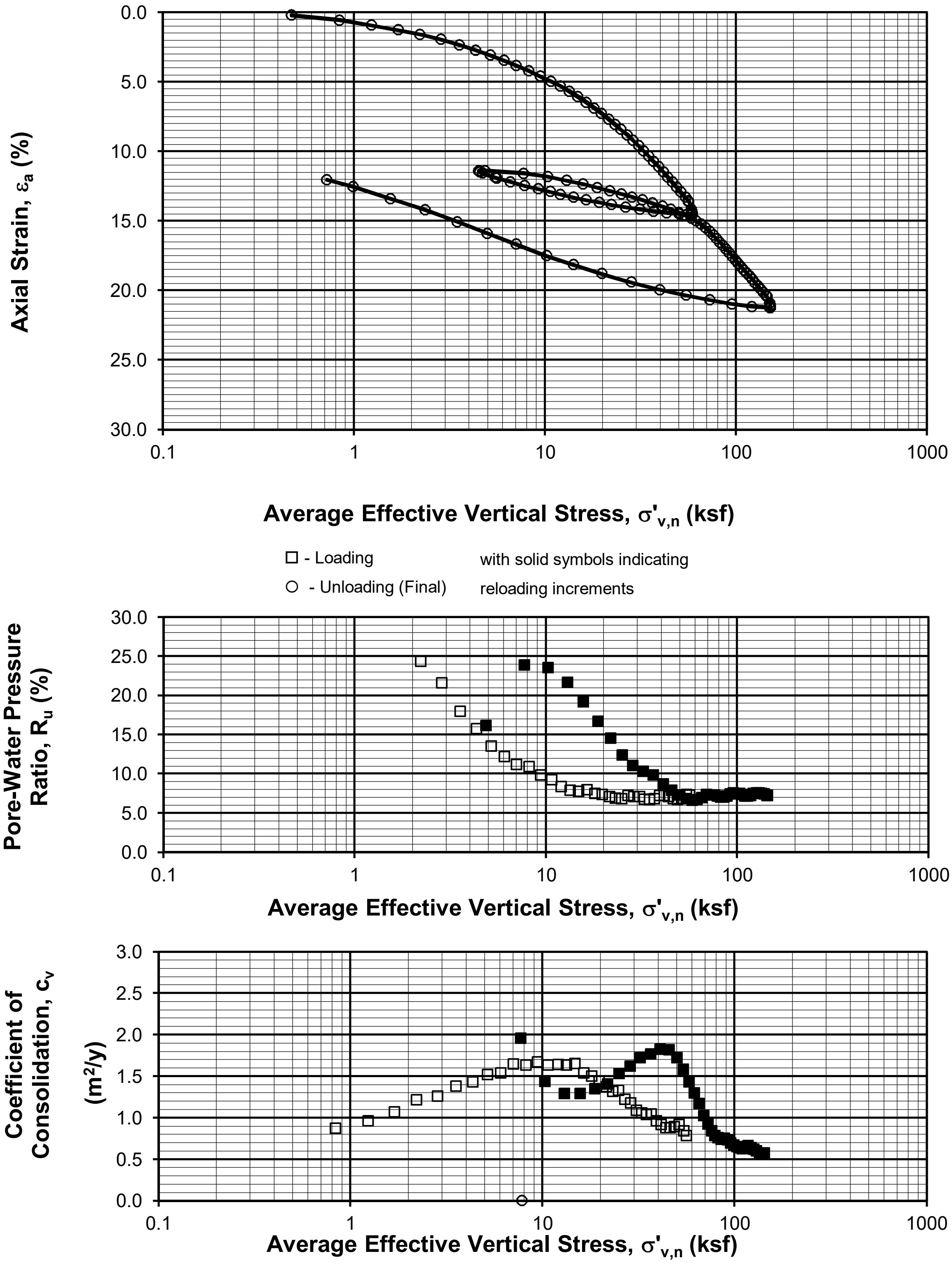
Sample No. 27b Depth 90 ft

Boring BH-03

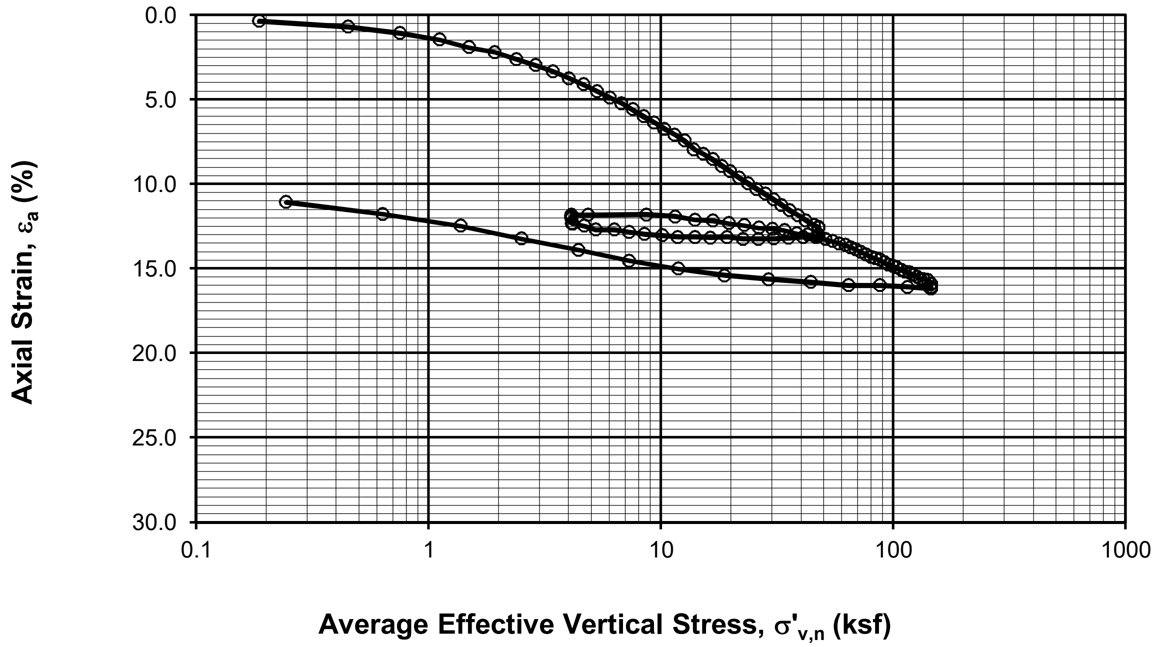
STORM SURGE SUPPRESSION STUDY - GCCPRD

BRAZORIA, CHAMBERS, GALVESTON, HARRIS

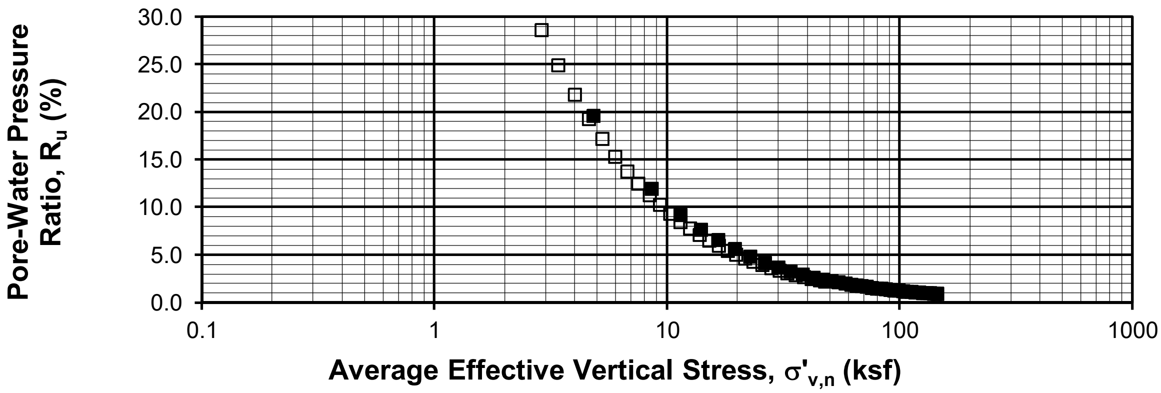
JEFFERSON AND ORANGE COUNTIES, TEXAS

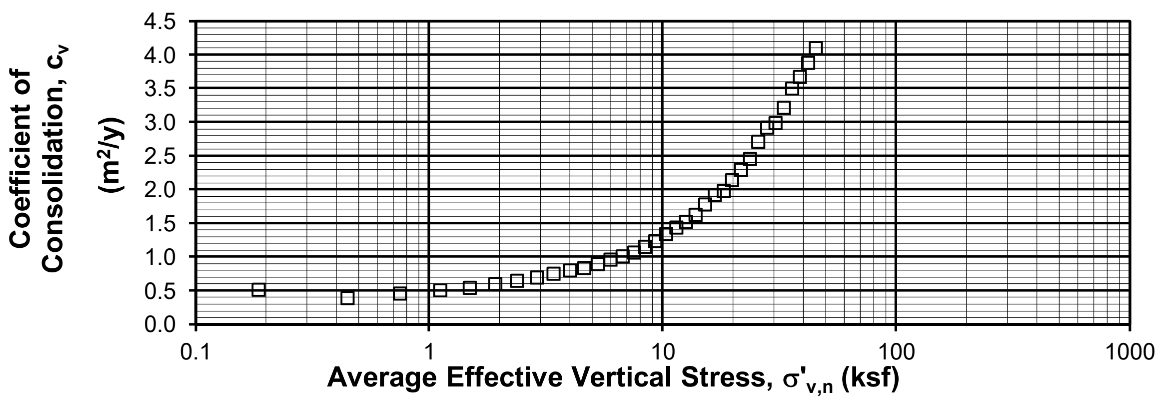



**1-D CONSOLIDATION TEST: CRS** Sample No.
44cRt Depth 209.85 ft
Boring BH-03
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS
JEFFERSON AND ORANGE COUNTIES, TEXAS




□ - Loading
○ - Unloading (Final)
with solid symbols indicating reloading increments




**1-D CONSOLIDATION TEST: CRS**

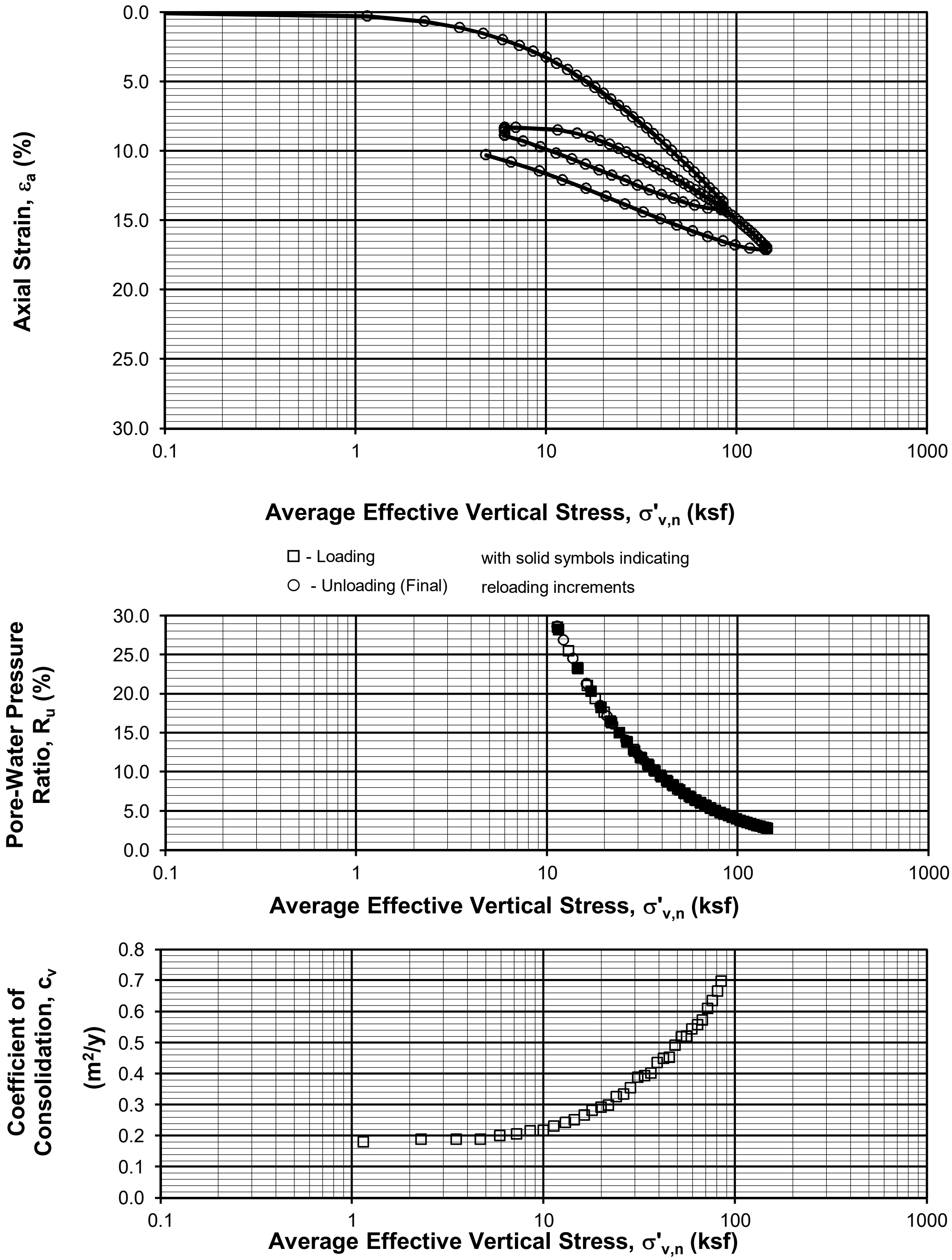
Sample No. 12b Depth 35 ft

Boring BH-05

STORM SURGE SUPPRESSION STUDY - GCCPRD

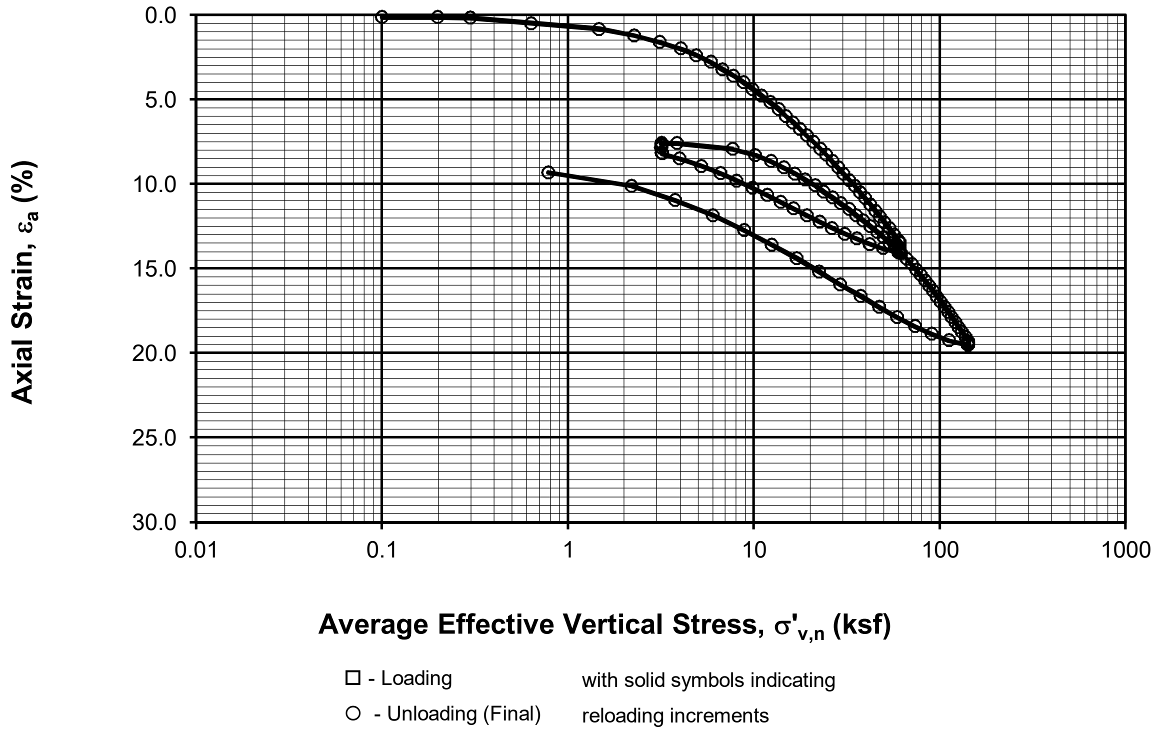
BRAZORIA, CHAMBERS, GALVESTON, HARRIS

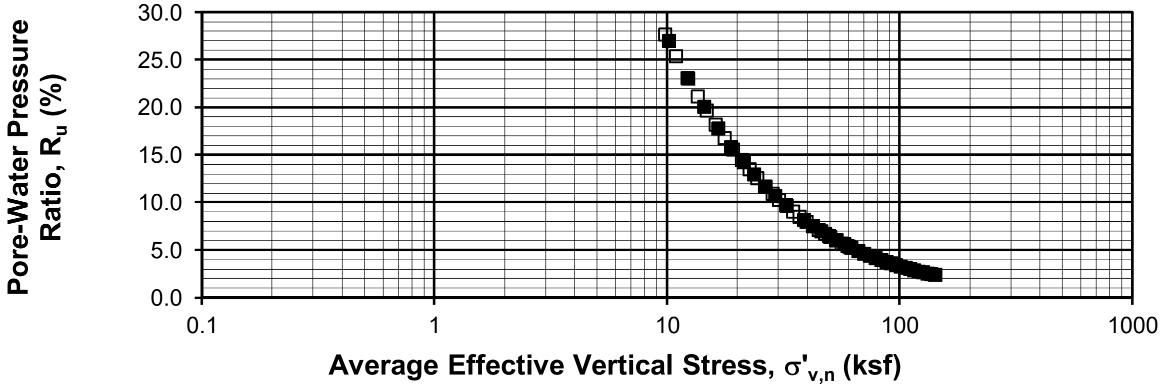
JEFFERSON AND ORANGE COUNTIES, TEXAS

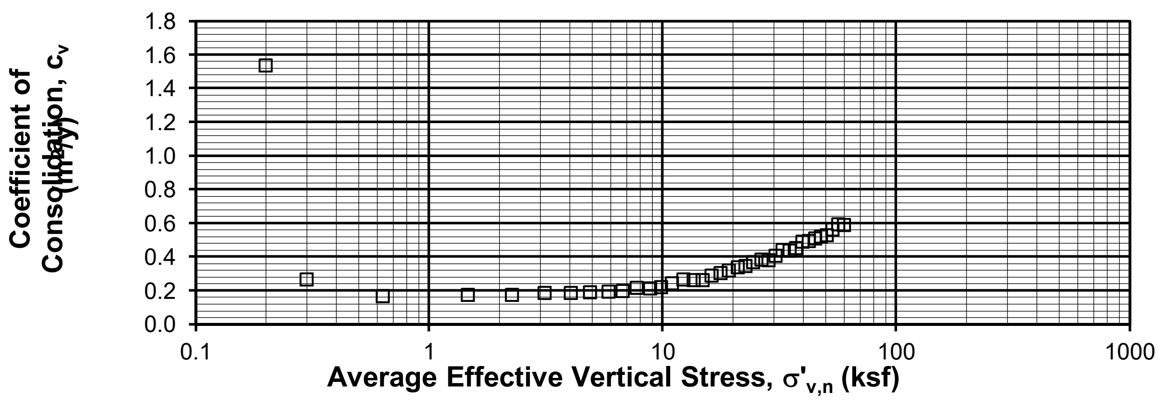



**1-D CONSOLIDATION TEST: CRS** Sample No. 13bRt
Depth 19.85 ft

Boring BH-06
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS
JEFFERSON AND ORANGE COUNTIES, TEXAS




**1-D CONSOLIDATION TEST: CRS**

Sample No. 15bRt Depth 24.85 ft

Boring BH-08

STORM SURGE SUPPRESSION STUDY - GCCPRD

BRAZORIA, CHAMBERS, GALVESTON, HARRIS

JEFFERSON AND ORANGE COUNTIES, TEXAS

# APPENDIX G

# PILE CAPACITY

## PILE CAPACITY DESIGN PARAMETERS – CENTRAL RECOMMENDED ALIGNMENT (COASTAL SPINE) – PROFILE A-A'

| Elevation, ft | Depth Below Existing Grade, ft | Soil Description | Total Unit Weight,(4) pcf | Axial Capacity | | | | | Lateral Capacity | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Cohesion, psf | Friction Angle (Φ),(3) degrees | Limiting Skin Friction,(3) ksf | $N_q$(3) | Limiting End Bearing,(3) ksf | Soil Type | Cohesion, psf | Friction Angle (Φ),(3) degrees | Subgrade Modulus,(6) pci | $\varepsilon_{50}$,(7) in/in |
| NA(2) | 0 to 2 | Dredge/Sand | 115 | Neglected to account for disturbance(5) | | | | | API Sand | Neglected to account for disturbance (5) | | | |
| NA | 2 to 4 | Dredge/Sand | 115 | Neglected to account for disturbance(5) | | | | | API Sand | - | 25 | 20 | - |
| NA | 4 to 5 | Dredge/Sand w/ Clay End Bearing | 115 | 300 | 25 | 1.4 | 12 | 60 | API Sand | - | 25 | 20 | - |
| NA | 5 to 15 | Soft Clay | 105 | 300 | - | 1.2(8) | - | - | Soft Clay | 300 | - | - | 0.03 |
| NA | 15 to 60 | Clay w/ Sand | 125 | Top: 300; Bottom: 1,000 | - | 1.2(8) | - | - | Soft Clay | Top: 300; Bottom: 1,000 | - | - | Top: 0.03 Bottom: 0.01 |

**NOTES:**

1. This table presents design parameters used for ultimate axial and lateral capacity analyses.
2. Survey for existing and final grade is not available.
3. Selection of undrained shear strength and other engineering parameters are based on the laboratory test results, SPT (N) values, and Pocket Penetrometer values from pertinent boring logs.
4. Groundwater table was assumed at the ground surface.
5. For axial capacity, we neglected soil strength in the upper 4 feet below finished grade to account for construction disturbance. For lateral capacity, we neglected soil strength in the upper 2 feet below finished grade to account for construction disturbance.
6. Subgrade Modulus values for lateral capacity analyses are based on API recommendations, and are correlated with the assumed friction angles. Modulus values are same for both static and cyclic loading conditions in sands.
7. Strains at 50% of maximum stress for lateral capacity analyses are based on the recommendation of L-Pile 6 (2010), and are correlated with the estimated undrained shear strength. The strains at 50% of maximum stress are same for both static and cyclic loading conditions in clays.
8. Based on our experience with cohesive soils in the Gulf Coast Region, we limited skin frictions to 1.2 ksf for pre-cast concrete piles.
9. API recommends using coefficients of lateral earth pressure for compression (kc) and tension (kt) equal to 1.0 and 0.7 for the precast concrete pile.
10. API recommends using coefficients of lateral earth pressure for compression (kc) and tension (kt) equal to 0.7 and 0.5 for the steel H-pile.

**PILE CAPACITY DESIGN PARAMETERS**
STORM SURGE SUPPRESSION STUDY – GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS
JEFFERSON AND ORANGE COUNTIES, TEXAS

**PILE CAPACITY DESIGN PARAMETERS – CENTRAL RECOMMENDED ALIGNMENT (COASTAL SPINE) – PROFILE B-B'**

| Elevation, ft | Depth Below Existing Grade, ft | Soil Description | Total Unit Weight,(4) pcf | Axial Capacity | | | | | Lateral Capacity | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Cohesion, psf | Friction Angle (Φ),(3) degrees | Limiting Skin Friction,(3) ksf | $N_q$(3) | Limiting End Bearing,(3) ksf | Soil Type | Cohesion, psf | Friction Angle (Φ),(3) degrees | Subgrade Modulus,(6) pci | $\varepsilon_{50}$,(7) in/in |
| NA(2) | 0 to 2 | Dredge/Sand | 115 | Neglected to account for disturbance(5) | | | | | API Sand | Neglected to account for disturbance (5) | | | |
| NA | 2 to 4 | Dredge/Sand | 115 | Neglected to account for disturbance(5) | | | | | API Sand | - | 25 | 20 | - |
| NA | 4 to 8 | Dredge/Sand w/ Clay End Bearing | 115 | 300 | 25 | 1.4 | 12 | 60 | API Sand | - | 25 | 20 | - |
| NA | 8 to 16 | Soft Clay | 105 | 300 | - | 1.2(8) | - | - | Soft Clay | 300 | - | - | 0.03 |
| NA | 16 to 20 | Sand w/ Clay End Bearing | 115 | 300 | 30 | 1.7 | 20 | 100 | API Sand | - | 30 | 20 | - |
| NA | 20 to 45 | Soft to Firm Clay w/ Sand | 105 | Top: 300; Bottom: 800 | - | 1.2(8) | - | - | Soft Clay | Top: 300; Bottom: 800 | - | - | Top: 0.03 Bottom: 0.01 |
| NA | 45 to 60 | Stiff Clay | 125 | 1200 | - | 1.2(8) | - | - | Stiff Clay (w/o Free Water) | 1,200 | - | - | 0.007 |

**NOTES:**

1. This table presents design parameters used for ultimate axial and lateral capacity analyses.
2. Survey for existing and final grade is not available.
3. Selection of undrained shear strength and other engineering parameters are based on the laboratory test results, SPT (N) values, and Pocket Penetrometer values from pertinent boring logs.
4. Groundwater table was assumed at the ground surface.
5. For axial capacity, we neglected soil strength in the upper 4 feet below finished grade to account for construction disturbance. For lateral capacity, we neglected soil strength in the upper 2 feet below finished grade to account for construction disturbance.
6. Subgrade Modulus values for lateral capacity analyses are based on API recommendations, and are correlated with the assumed friction angles. Modulus values are same for both static and cyclic loading conditions in sands.
7. Strains at 50% of maximum stress for lateral capacity analyses are based on the recommendation of L-Pile 6 (2010), and are correlated with the estimated undrained shear strength. The strains at 50% of maximum stress are same for both static and cyclic loading conditions in clays.
8. Based on our experience with cohesive soils in the Gulf Coast Region, we limited skin frictions to 1.2 ksf for pre-cast concrete piles.
9. API recommends using coefficients of lateral earth pressure for compression (kc) and tension (kt) equal to 1.0 and 0.7 for the precast concrete pile.
10. API recommends using coefficients of lateral earth pressure for compression (kc) and tension (kt) equal to 0.7 and 0.5 for the steel H-pile.

**PILE CAPACITY DESIGN PARAMETERS**
STORM SURGE SUPPRESSION STUDY – GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS
JEFFERSON AND ORANGE COUNTIES, TEXAS

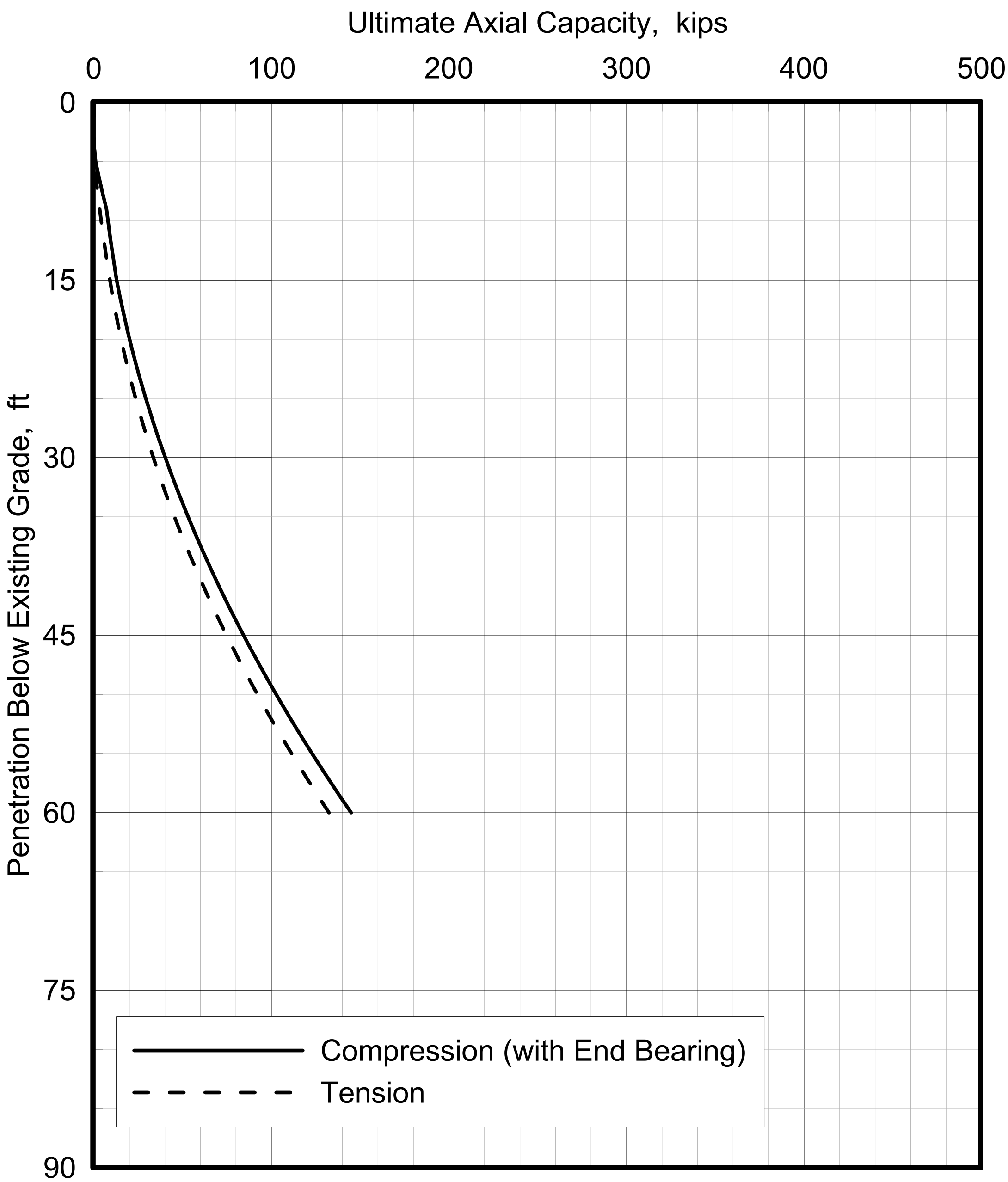
## PILE CAPACITY DESIGN PARAMETERS – SOUTH RECOMMENDED ALIGNMENT – PROFILE E-E'

| Elevation, ft | Depth Below Existing Grade, ft | Soil Description | Total Unit Weight,(4) pcf | Axial Capacity | | | | | Lateral Capacity | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Cohesion, psf | Friction Angle (Φ),(3) degrees | Limiting Skin Friction,(3) ksf | $N_q$(3) | Limiting End Bearing,(3) ksf | Soil Type | Cohesion, psf | Friction Angle (Φ),(3) degrees | Subgrade Modulus,(6) pci | $\varepsilon_{50}$,(7) in/in |
| NA(2) | 0 to 2 | Clay Fill with sand pockets and seams | 105 | Neglected to account for disturbance(5) | | | | | Soft Clay | Neglected to account for disturbance (5) | | | |
| NA | 2 to 4 | Clay Fill with sand pockets and seams | 105 | Neglected to account for disturbance(5) | | | | | Soft Clay | 300 | - | - | 0.03 |
| NA | 4 to 15 | Clay Fill with sand pockets and seams | 105 | 300 | - | 1.2(8) | - | - | Soft Clay | 300 | - | - | 0.03 |
| NA | 15 to 50 | Firm Clay with silt seams | 115 | 700 | - | 1.2(8) | - | - | Soft Clay | 700 | - | - | 0.01 |
| NA | 50 to 80 | Stiff Clay | 125 | 1,500 | - | 1.2(8) | - | - | Stiff Clay (w/o Free Water) | 1,500 | - | - | 0.007 |

**NOTES:**

1. This table presents design parameters used for ultimate axial and lateral capacity analyses.
2. Survey for existing and final grade is not available.
3. Selection of undrained shear strength and other engineering parameters are based on the review of available geotechnical studies performed by others.
4. Groundwater table was assumed at the ground surface.
5. For axial capacity, we neglected soil strength in the upper 4 feet below finished grade to account for construction disturbance. For lateral capacity, we neglected soil strength in the upper 2 feet below finished grade to account for construction disturbance.
6. Subgrade Modulus values for lateral capacity analyses are based on API recommendations, and are correlated with the assumed friction angles. Modulus values are same for both static and cyclic loading conditions in sands.
7. Strains at 50% of maximum stress for lateral capacity analyses are based on the recommendation of L-Pile 6 (2010), and are correlated with the estimated undrained shear strength. The strains at 50% of maximum stress are same for both static and cyclic loading conditions in clays.
8. Based on our experience with cohesive soils in the Gulf Coast Region, we limited skin frictions to 1.2 ksf for pre-cast concrete piles.
9. API recommends using coefficients of lateral earth pressure for compression (kc) and tension (kt) equal to 1.0 and 0.7 for the precast concrete pile.
10. API recommends using coefficients of lateral earth pressure for compression (kc) and tension (kt) equal to 0.7 and 0.5 for the steel H-pile.

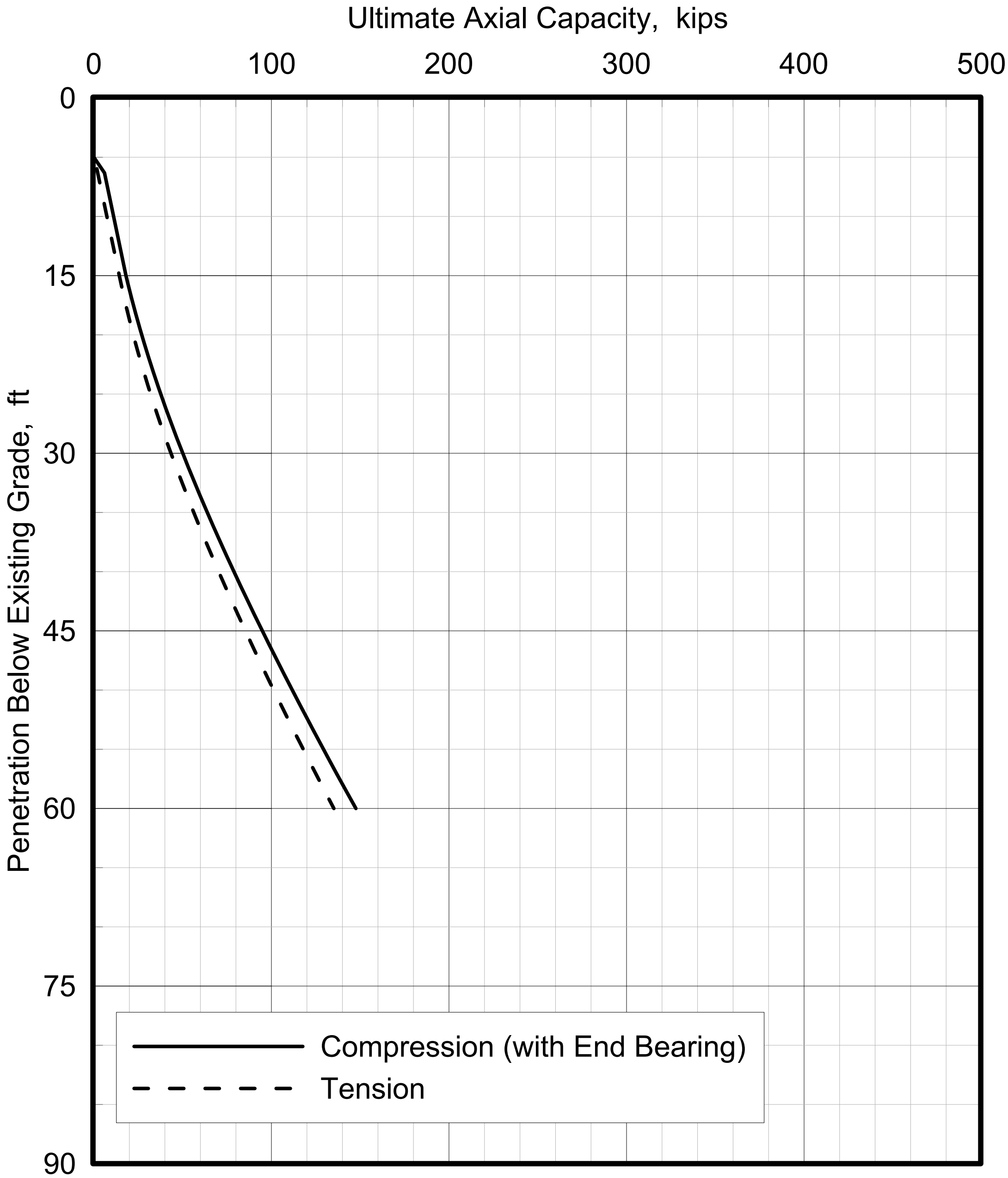
**PILE CAPACITY DESIGN PARAMETERS**
STORM SURGE SUPPRESSION STUDY – GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS
JEFFERSON AND ORANGE COUNTIES, TEXAS




**NOTES:**

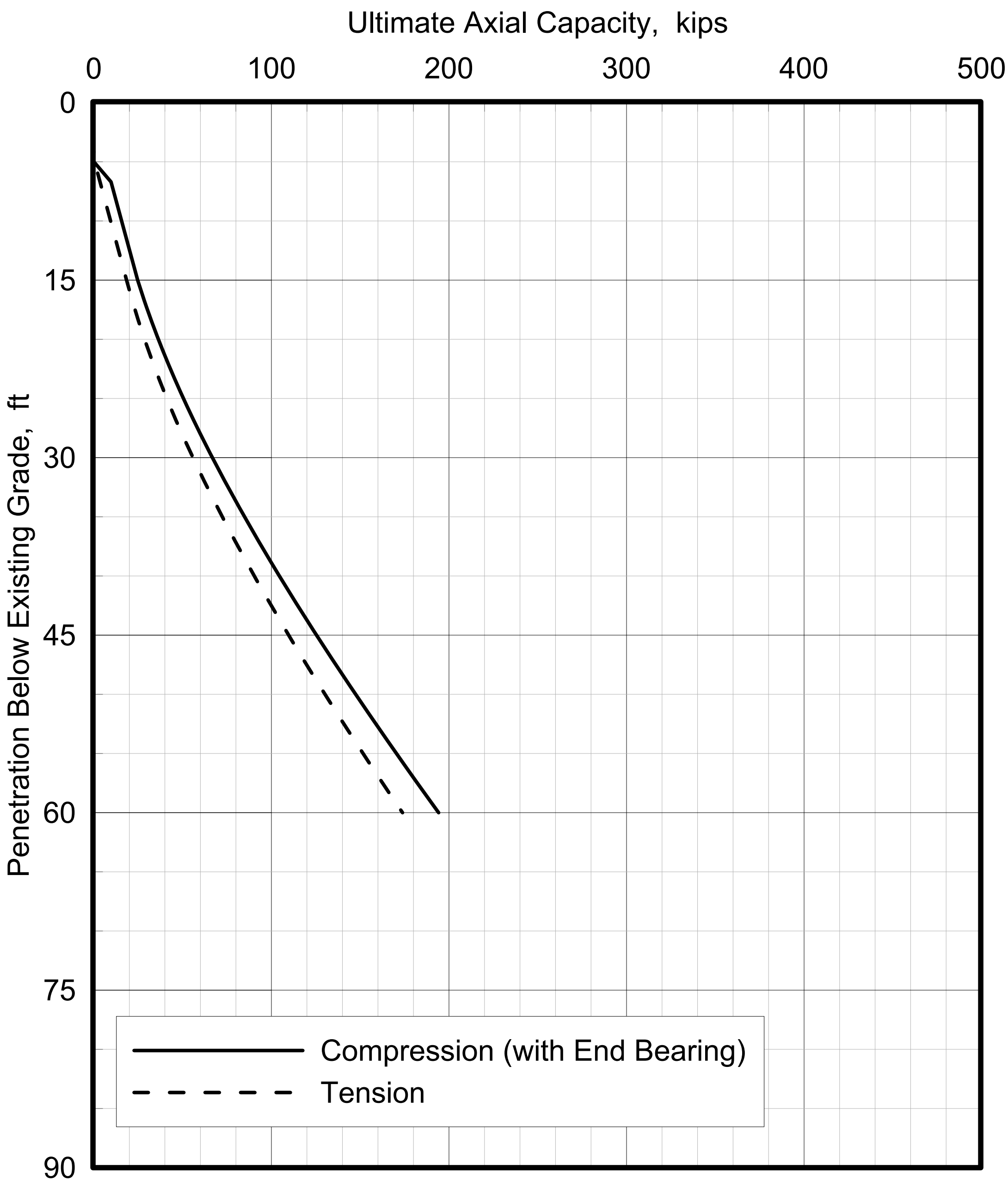
1. These curves represent ultimate values for compression and tension. A safety factor of 2.0 should be applied to sustained compressive loads or transient tensile loads and a safety factor of 3.0 should be applied for sustained tensile loads.
2. These curves are for a single isolated pile. Group effects will be discussed in the report text.

**ULTIMATE AXIAL CAPACITY**
**CENTRAL RECOMMENDED ALIGNMENT (COASTAL SPINE) - PROFILE A-A'**
**14 X 73 STEEL H-PILE**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS




**NOTES:**
1. These curves represent ultimate values for compression and tension. A safety factor of 2.0 should be applied to sustained compressive loads or transient tensile loads and a safety factor of 3.0 should be applied for sustained tensile loads.
2. These curves are for a single isolated pile. Group effects will be discussed in the report text.

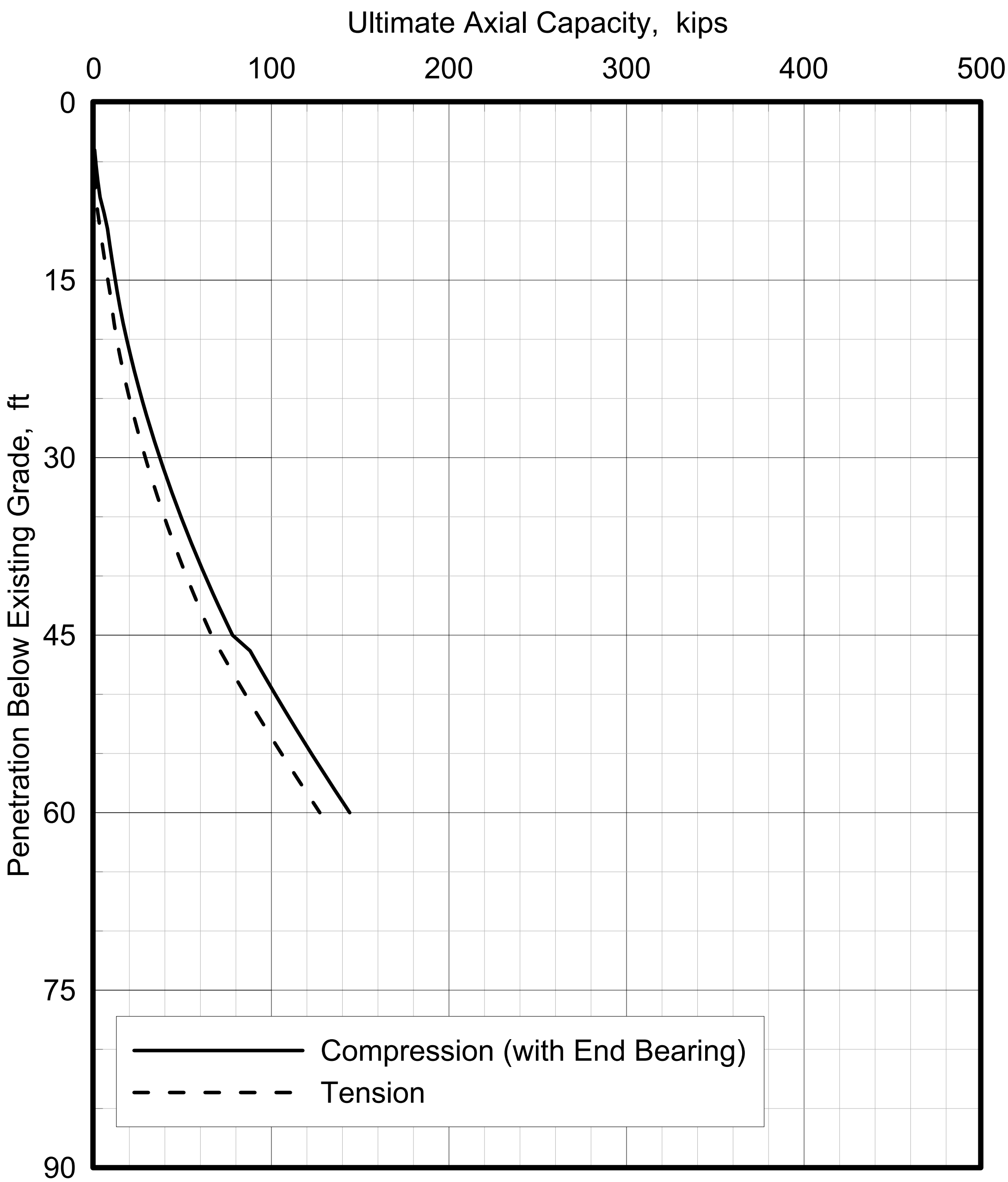
**ULTIMATE AXIAL CAPACITY**
**CENTRAL RECOMMENDED ALIGNMENT (COASTAL SPINE) - PROFILE A-A'**
**14-INCH SQUARE PRE-CAST CONCRETE PILE**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS




**NOTES:**

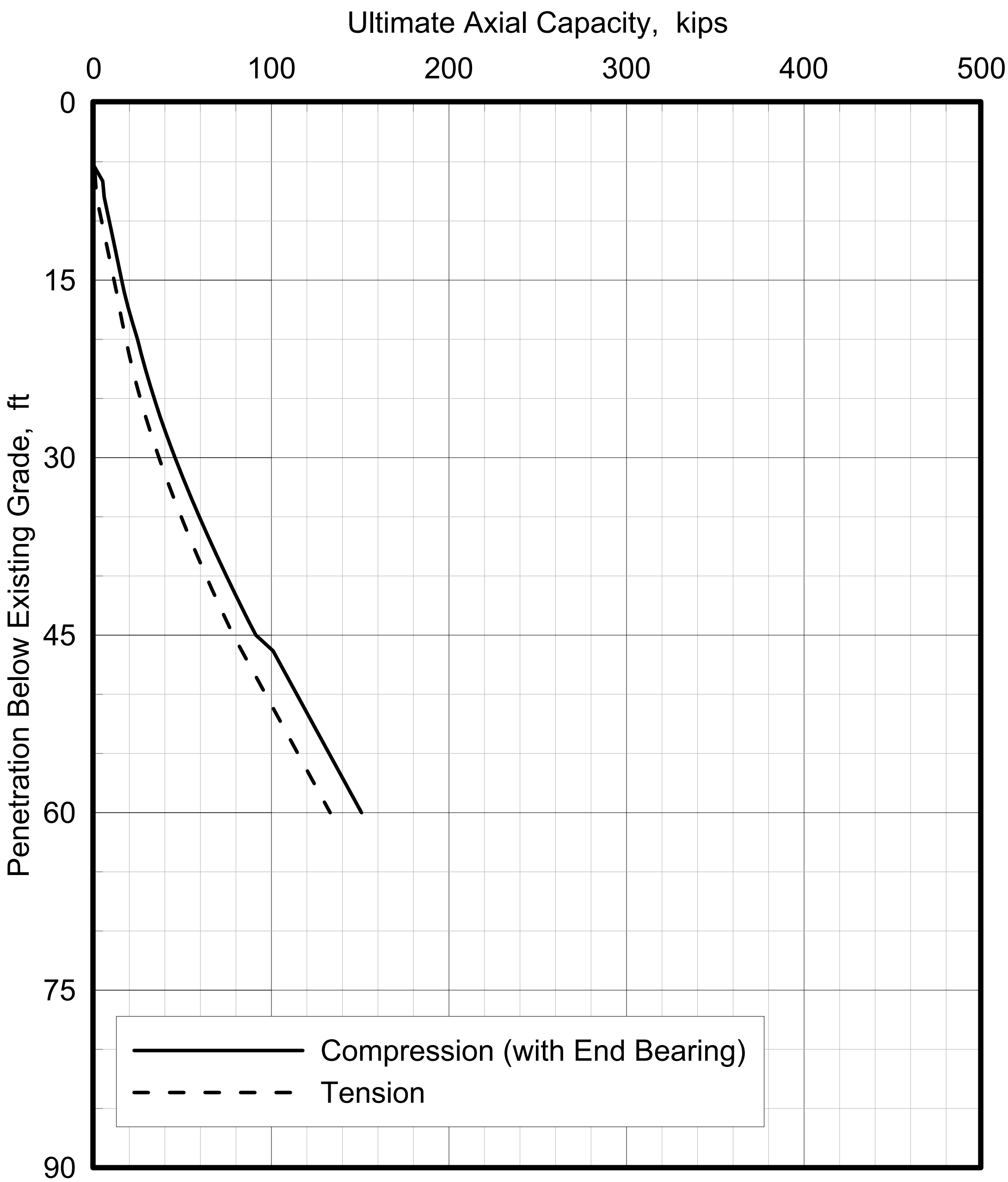
1. These curves represent ultimate values for compression and tension. A safety factor of 2.0 should be applied to sustained compressive loads or transient tensile loads and a safety factor of 3.0 should be applied for sustained tensile loads.
2. These curves are for a single isolated pile. Group effects will be discussed in the report text.

**ULTIMATE AXIAL CAPACITY**
**CENTRAL RECOMMENDED ALIGNMENT (COASTAL SPINE) - PROFILE A-A'**
**18-INCH SQUARE PRE-CAST CONCRETE PILE**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS




**NOTES:**
1. These curves represent ultimate values for compression and tension. A safety factor of 2.0 should be applied to sustained compressive loads or transient tensile loads and a safety factor of 3.0 should be applied for sustained tensile loads.
2. These curves are for a single isolated pile. Group effects will be discussed in the report text.

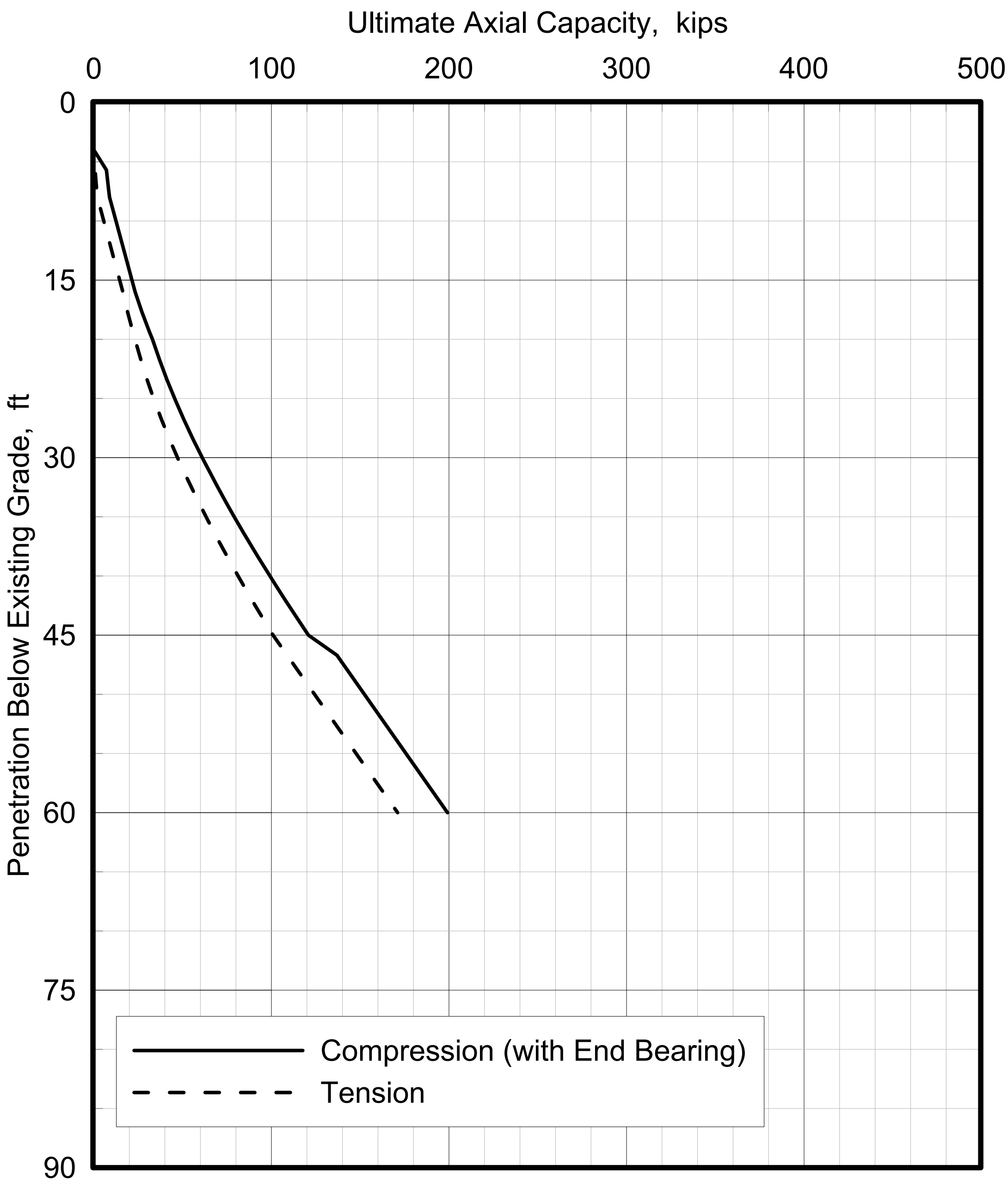
**ULTIMATE AXIAL CAPACITY**
**CENTRAL RECOMMENDED ALIGNMENT (COASTAL SPINE) - PROFILE B-B'**
**14 X 73 STEEL H-PILE**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS




**NOTES:**

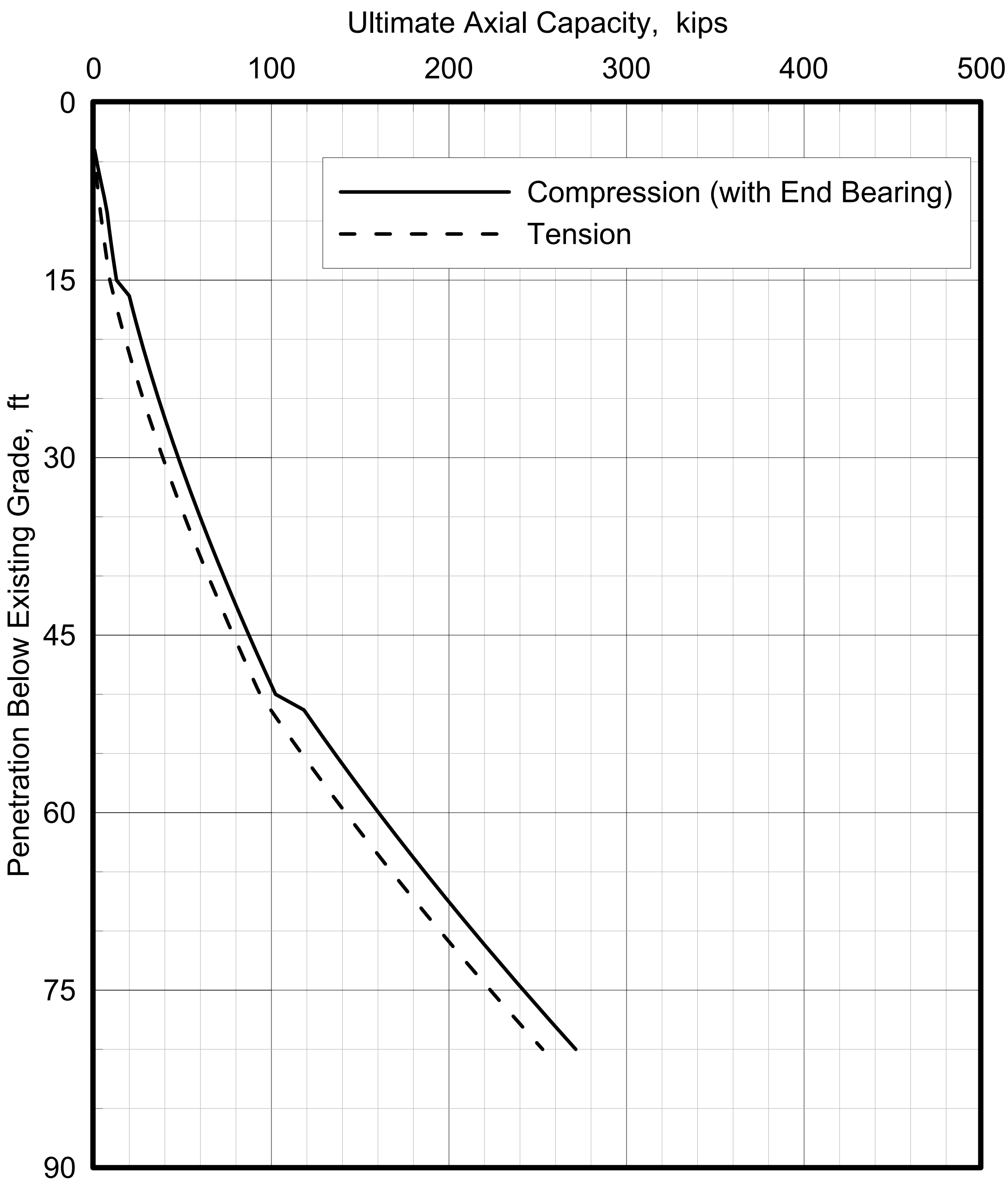
1. These curves represent ultimate values for compression and tension. A safety factor of 2.0 should be applied to sustained compressive loads or transient tensile loads and a safety factor of 3.0 should be applied for sustained tensile loads.
2. These curves are for a single isolated pile. Group effects will be discussed in the report text.

**ULTIMATE AXIAL CAPACITY**
**CENTRAL RECOMMENDED ALIGNMENT (COASTAL SPINE) - PROFILE B-B'**
**14-INCH SQUARE PRE-CAST CONCRETE PILE**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS




**NOTES:**
1. These curves represent ultimate values for compression and tension. A safety factor of 2.0 should be applied to sustained compressive loads or transient tensile loads and a safety factor of 3.0 should be applied for sustained tensile loads.
2. These curves are for a single isolated pile. Group effects will be discussed in the report text.

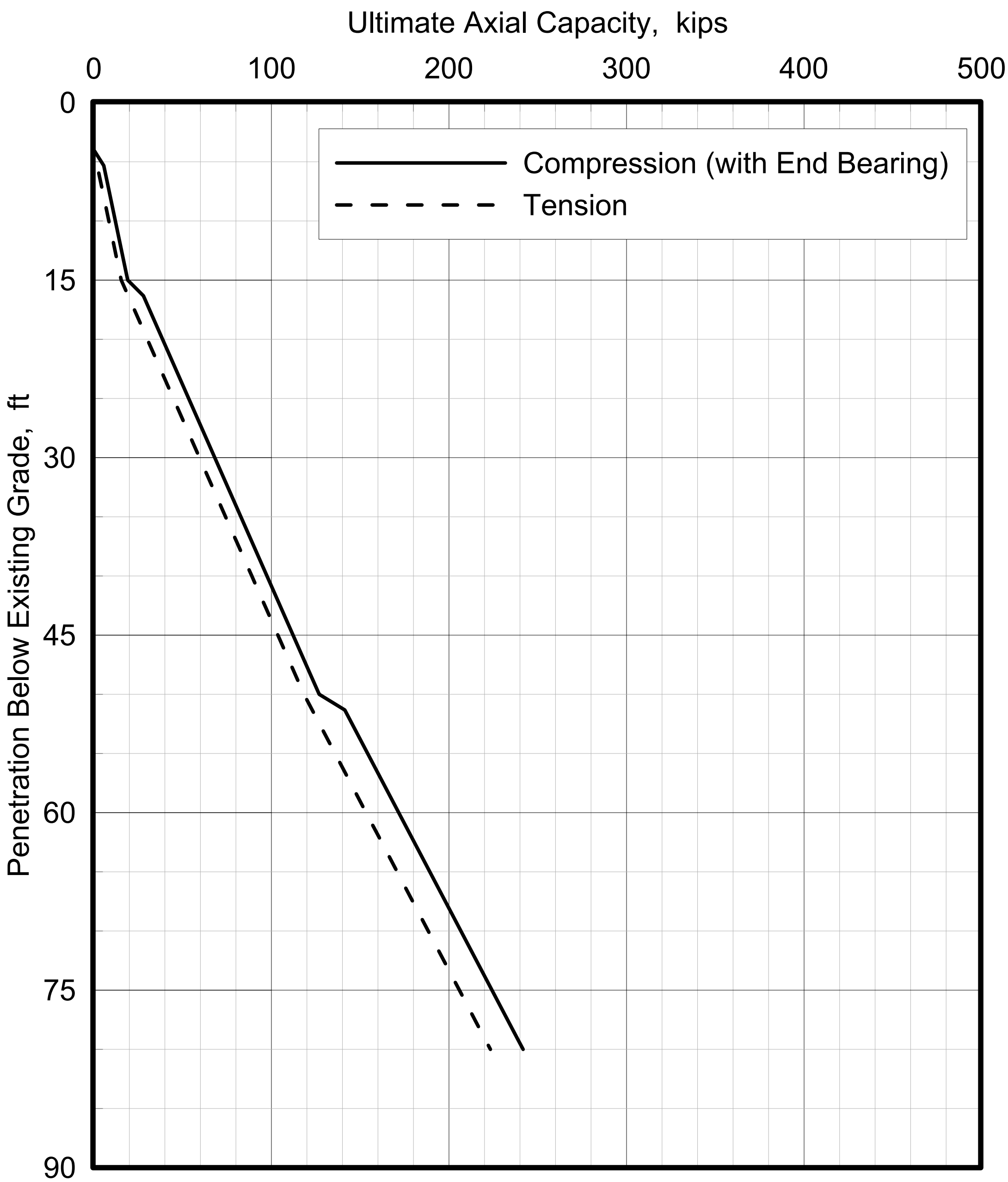
**ULTIMATE AXIAL CAPACITY**
**CENTRAL RECOMMENDED ALIGNMENT (COASTAL SPINE) - PROFILE B-B'**
**18-INCH SQUARE PRE-CAST CONCRETE PILE**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS




**NOTES:**

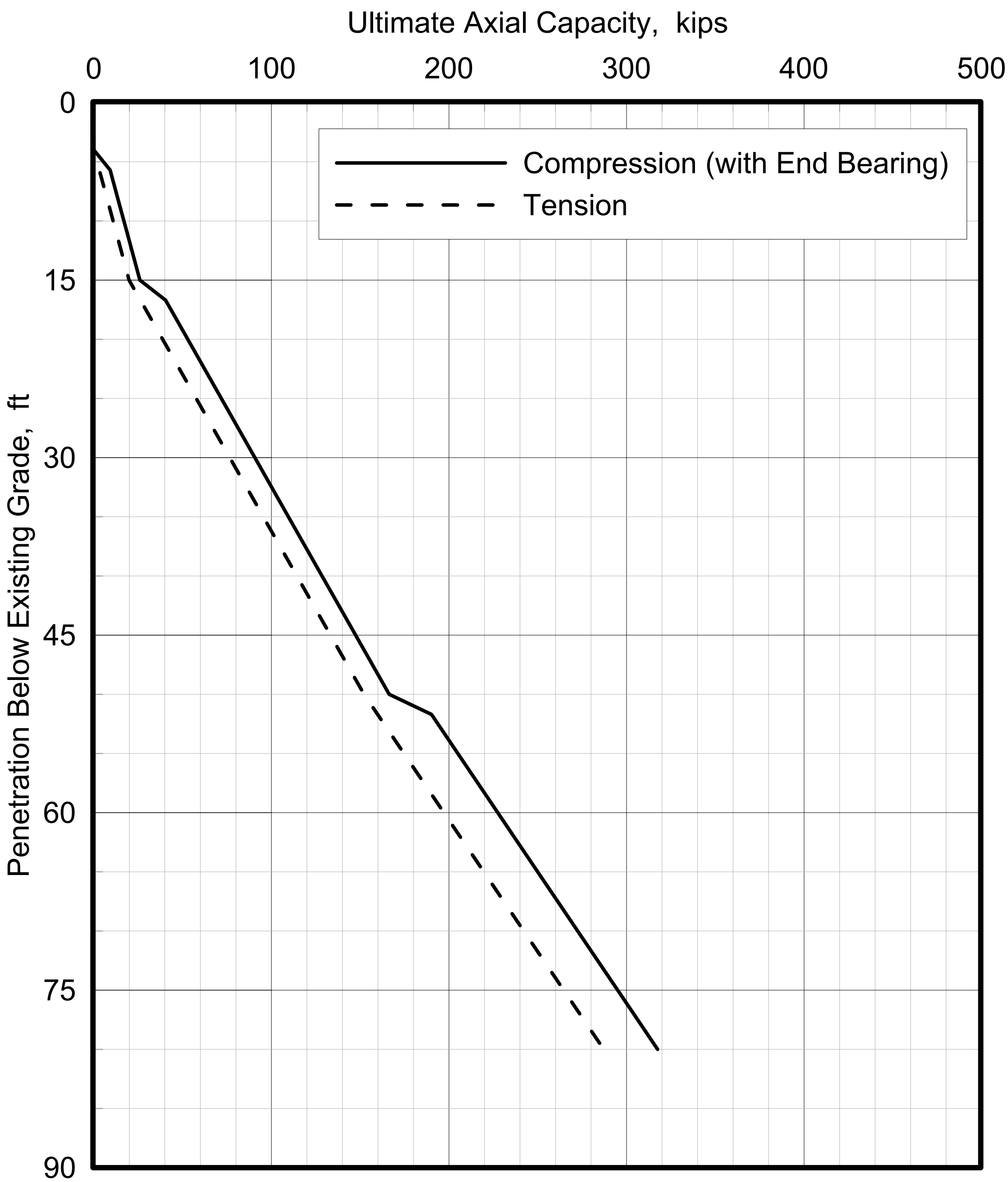
1. These curves represent ultimate values for compression and tension. A safety factor of 2.0 should be applied to sustained compressive loads or transient tensile loads and a safety factor of 3.0 should be applied for sustained tensile loads.
2. These curves are for a single isolated pile. Group effects will be discussed in the report text.

**ULTIMATE AXIAL CAPACITY**
**SOUTH RECOMMENDED ALIGNMENT - PROFILE E-E'**
**14 X 73 STEEL H-PILE**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS




**NOTES:**
1. These curves represent ultimate values for compression and tension. A safety factor of 2.0 should be applied to sustained compressive loads or transient tensile loads and a safety factor of 3.0 should be applied for sustained tensile loads.
2. These curves are for a single isolated pile. Group effects will be discussed in the report text.

**ULTIMATE AXIAL CAPACITY**
**SOUTH RECOMMENDED ALIGNMENT - PROFILE E-E'**
**14-INCH SQUARE PRE-CAST CONCRETE PILE**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS




**NOTES:**

1. These curves represent ultimate values for compression and tension. A safety factor of 2.0 should be applied to sustained compressive loads or transient tensile loads and a safety factor of 3.0 should be applied for sustained tensile loads.
2. These curves are for a single isolated pile. Group effects will be discussed in the report text.

**ULTIMATE AXIAL CAPACITY**
**SOUTH RECOMMENDED ALIGNMENT - PROFILE E-E'**
**18-INCH SQUARE PRE-CAST CONCRETE PILE**
STORM SURGE SUPPRESSION STUDY - GCCPRD
BRAZORIA, CHAMBERS, GALVESTON, HARRIS,
JEFFERSON AND ORANGE COUNTIES, TEXAS

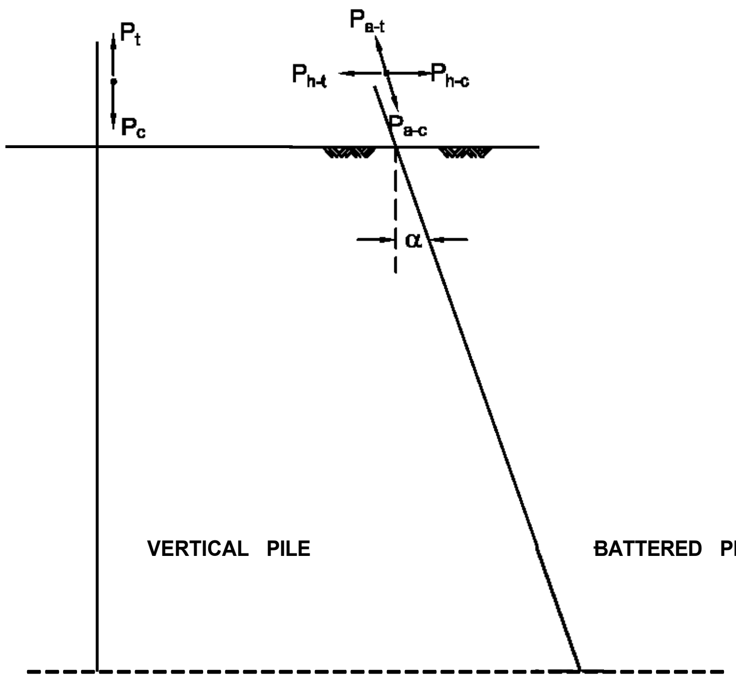
STEPS FOR COMPUTING BATTERED PILE CAPACITY

1. Determine ultimate tensile capacity ($P_t$) and ultimate compressive capacity ($P_c$) for vertical piles.
2. Compute ultimate end bearing capacity of vertical pile as $P_e = P_c - P_t$.
3. Compute skin friction component of battered pile ($P_s$) by multiplying $P_t$ by the secant of the batter angle (sec α).

4a. For battered piles loaded in compression, compute the ultimate axial capacity of the pile ($P_{a\text{-}c}$) by adding the skin friction ($P_s$) and end bearing ($P_e$) capacities.

4b. For battered piles loaded in tension, the ultimate axial capacity of the pile ($P_{a\text{-}t}$) is equal to the skin friction capacity ($P_s$).

5a/b. To compute the horizontal capacity ($P_h$) of the battered pile, multiply the ultimate axial capacity by the sine of the batter angle (sin α).



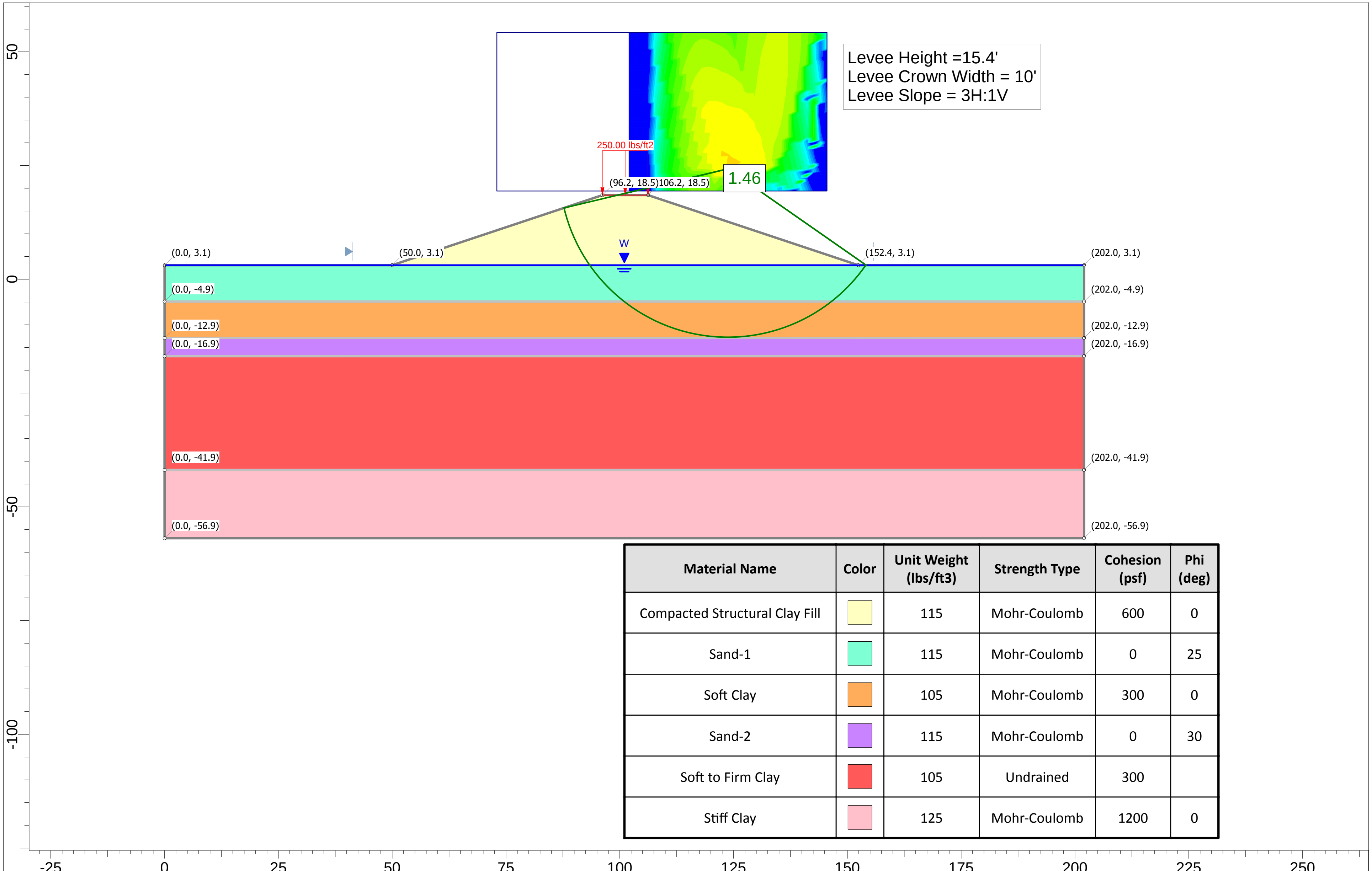

$$P_s = P_t \text{ SEC } \alpha$$
$$P_e = P_c - P_t$$
$$P_{a\text{-}c} = P_s + P_e$$
$$P_{a\text{-}t} = P_s$$
$$P_{h\text{-}c} = P_{a\text{-}c} \text{ SIN } \alpha$$
$$P_{h\text{-}t} = P_{a\text{-}t} \text{ SIN } \alpha$$

NOTES:
1. Vertical and battered piles must penetrate to equal elevations for this method to be applicable.
2. See text for other recommendations for battered piles.
3. Additional horizontal capacity can be developed due to flexural stiffness of battered pile. The method shown here does not include the flexural capacity of battered piles.

**ULTIMATE CAPACITY OF BATTERED PILES**
COMPUTATION METHOD

# APPENDIX H

# RESULTS OF SLOPE STABILITY ANALYSES




| Material Name | Color | Unit Weight (lbs/ft3) | Strength Type | Cohesion (psf) | Phi (deg) |
|---|---|---|---|---|---|
| Compacted Structural Clay Fill | | 115 | Mohr-Coulomb | 600 | 0 |
| Sand-1 | | 115 | Mohr-Coulomb | 0 | 25 |
| Soft Clay | | 105 | Mohr-Coulomb | 300 | 0 |
| Sand-2 | | 115 | Mohr-Coulomb | 0 | 30 |
| Soft to Firm Clay | | 105 | Undrained | 300 | |
| Stiff Clay | | 125 | Mohr-Coulomb | 1200 | 0 |

FUGRO

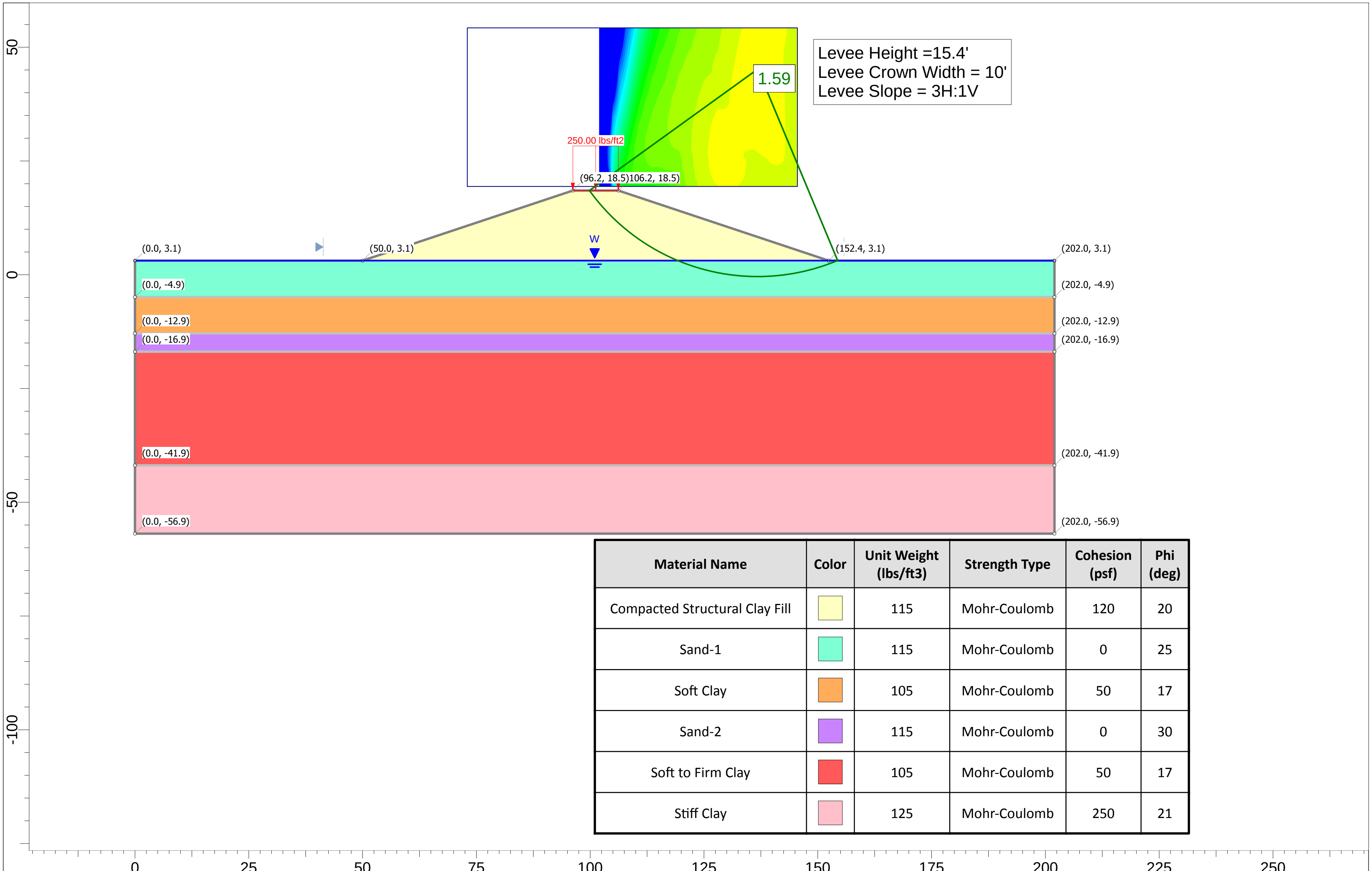
SLIDEINTERPRET 6.035

*Project* Storm Surge Suppression Study - GCCPRD

*Analysis Description* (ID No.6) Galveston Ring Levee - Profile B-B' - Short-Term Condition

*Drawn By* J. Clarke | *Scale* 1:360 | *Company* Fugro USA Land, Inc.

*Date* 07/31/2017 | PLATE H-1

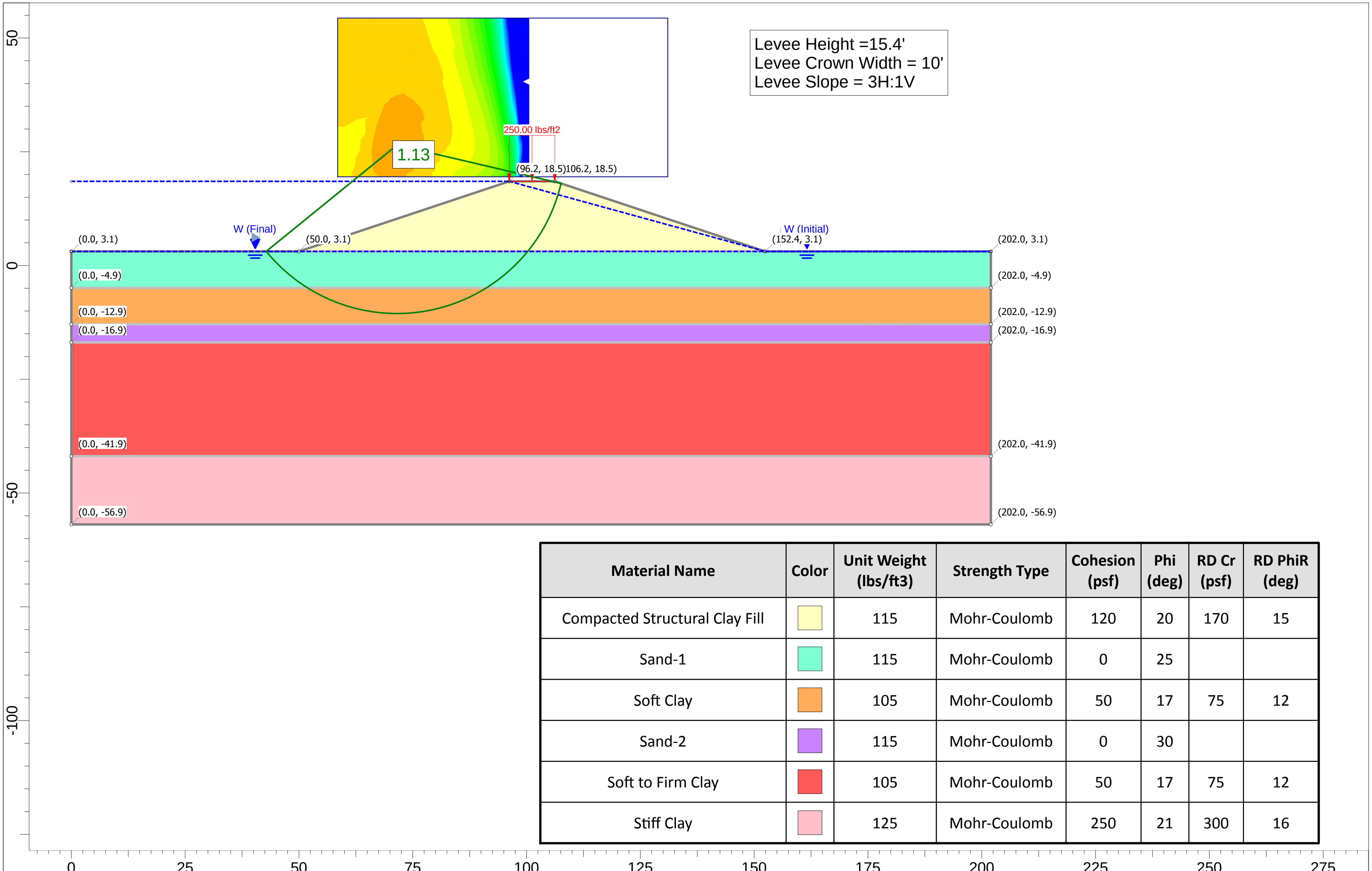



| Material Name | Color | Unit Weight (lbs/ft3) | Strength Type | Cohesion (psf) | Phi (deg) |
|---|---|---|---|---|---|
| Compacted Structural Clay Fill | | 115 | Mohr-Coulomb | 120 | 20 |
| Sand-1 | | 115 | Mohr-Coulomb | 0 | 25 |
| Soft Clay | | 105 | Mohr-Coulomb | 50 | 17 |
| Sand-2 | | 115 | Mohr-Coulomb | 0 | 30 |
| Soft to Firm Clay | | 105 | Mohr-Coulomb | 50 | 17 |
| Stiff Clay | | 125 | Mohr-Coulomb | 250 | 21 |

FUGRO

SLIDEINTERPRET 6.035

| | |
|---|---|
| *Project* | Storm Surge Suppression Study - GCCPRD |
| *Analysis Description* | (ID No.6) Galveston Ring Levee - Profile B-B' - Long-Term Condition |
| *Drawn By* | J. Clarke |
| *Scale* | 1:360 |
| *Company* | Fugro USA Land, Inc. |
| *Date* | 07/31/2017 |
| | PLATE H-2 |

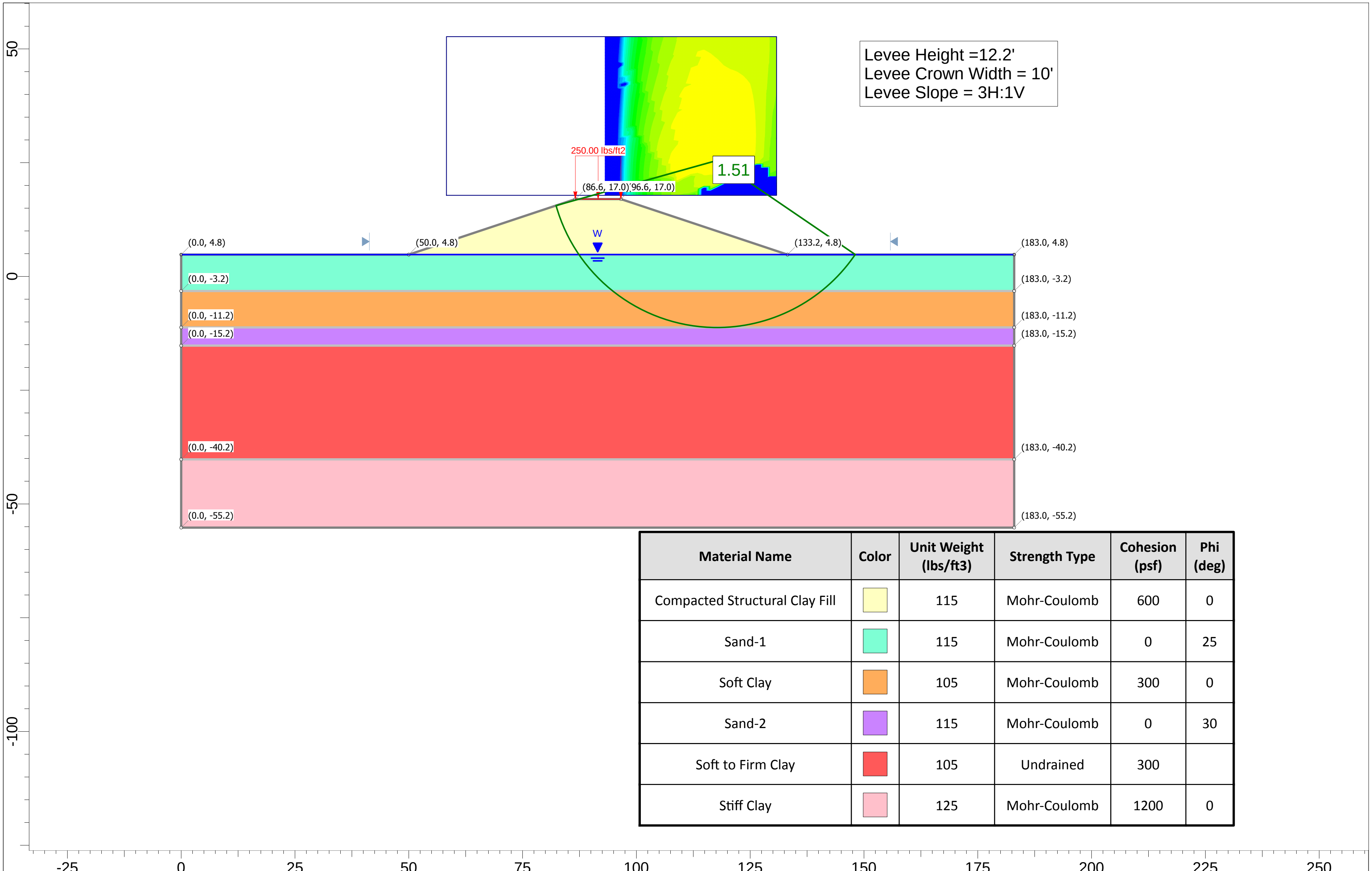



| Material Name | Color | Unit Weight (lbs/ft3) | Strength Type | Cohesion (psf) | Phi (deg) | RD Cr (psf) | RD PhiR (deg) |
|---|---|---|---|---|---|---|---|
| Compacted Structural Clay Fill | | 115 | Mohr-Coulomb | 120 | 20 | 170 | 15 |
| Sand-1 | | 115 | Mohr-Coulomb | 0 | 25 | | |
| Soft Clay | | 105 | Mohr-Coulomb | 50 | 17 | 75 | 12 |
| Sand-2 | | 115 | Mohr-Coulomb | 0 | 30 | | |
| Soft to Firm Clay | | 105 | Mohr-Coulomb | 50 | 17 | 75 | 12 |
| Stiff Clay | | 125 | Mohr-Coulomb | 250 | 21 | 300 | 16 |

FUGRO

SLIDEINTERPRET 6.035

| | |
|---|---|
| *Project* | Storm Surge Suppression Study - GCCPRD |
| *Analysis Description* | (ID No.6) Galveston Ring Levee - Profile B-B' - Rapid Drawdown Condition |
| *Drawn By* J. Clarke | *Scale* 1:360 |
| *Company* | Fugro USA Land, Inc. |
| *Date* 07/31/2017 | PLATE H-3 |

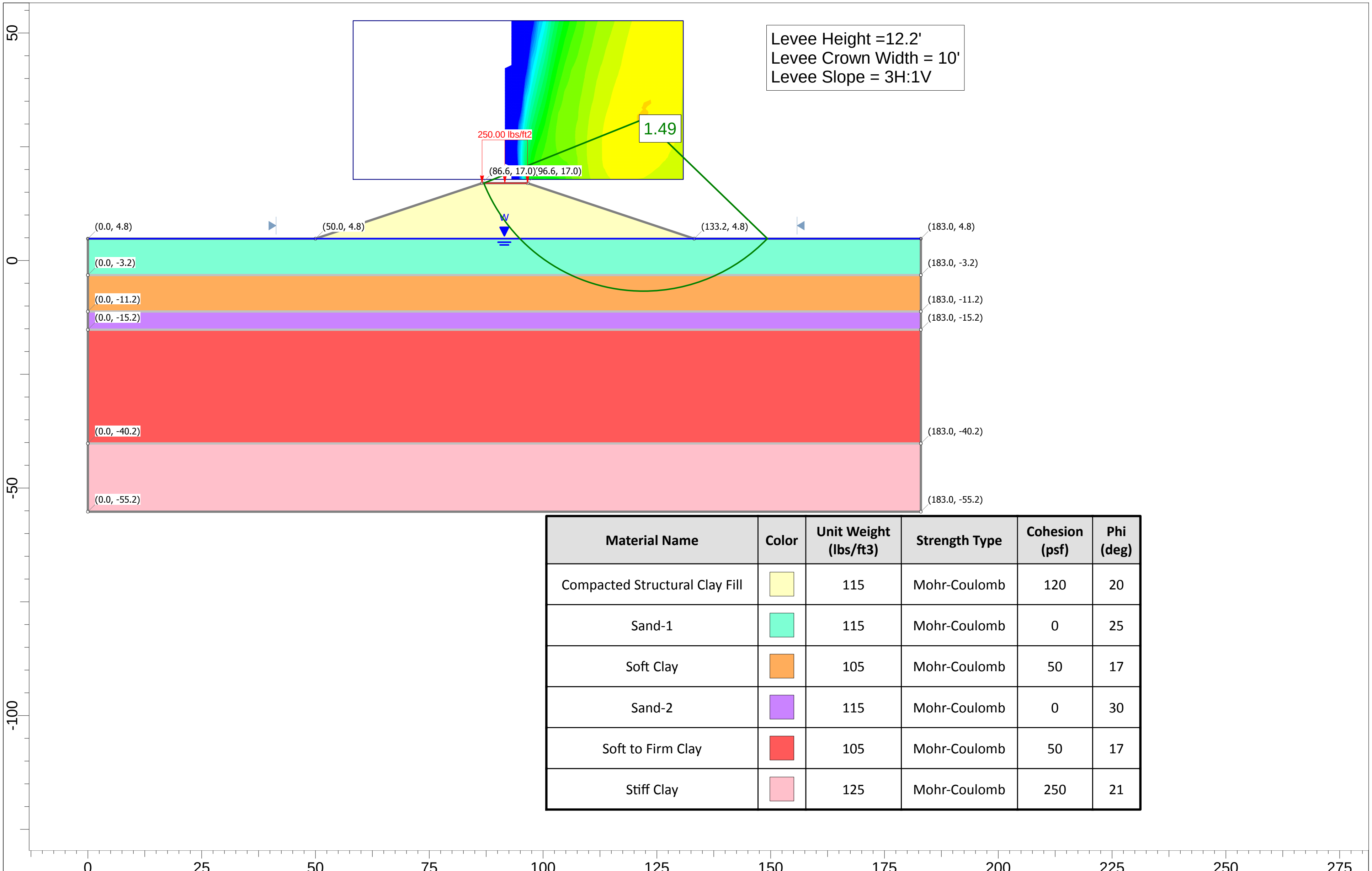



| Material Name | Color | Unit Weight (lbs/ft3) | Strength Type | Cohesion (psf) | Phi (deg) |
|---|---|---|---|---|---|
| Compacted Structural Clay Fill | | 115 | Mohr-Coulomb | 600 | 0 |
| Sand-1 | | 115 | Mohr-Coulomb | 0 | 25 |
| Soft Clay | | 105 | Mohr-Coulomb | 300 | 0 |
| Sand-2 | | 115 | Mohr-Coulomb | 0 | 30 |
| Soft to Firm Clay | | 105 | Undrained | 300 | |
| Stiff Clay | | 125 | Mohr-Coulomb | 1200 | 0 |

FUGRO

SLIDEINTERPRET 6.035

| | |
|---|---|
| *Project* | Storm Surge Suppression Study - GCCPRD |
| *Analysis Description* | (ID No.7) High Island to San Luis Pass Coastal Spine - Profile B-B' - Short-Term Condition |
| *Drawn By* | J. Clarke |
| *Scale* | 1:360 |
| *Company* | Fugro USA Land, Inc. |
| *Date* | 07/31/2017 |
| | PLATE H-4 |




| Material Name | Color | Unit Weight (lbs/ft3) | Strength Type | Cohesion (psf) | Phi (deg) |
|---|---|---|---|---|---|
| Compacted Structural Clay Fill | | 115 | Mohr-Coulomb | 120 | 20 |
| Sand-1 | | 115 | Mohr-Coulomb | 0 | 25 |
| Soft Clay | | 105 | Mohr-Coulomb | 50 | 17 |
| Sand-2 | | 115 | Mohr-Coulomb | 0 | 30 |
| Soft to Firm Clay | | 105 | Mohr-Coulomb | 50 | 17 |
| Stiff Clay | | 125 | Mohr-Coulomb | 250 | 21 |

FUGRO

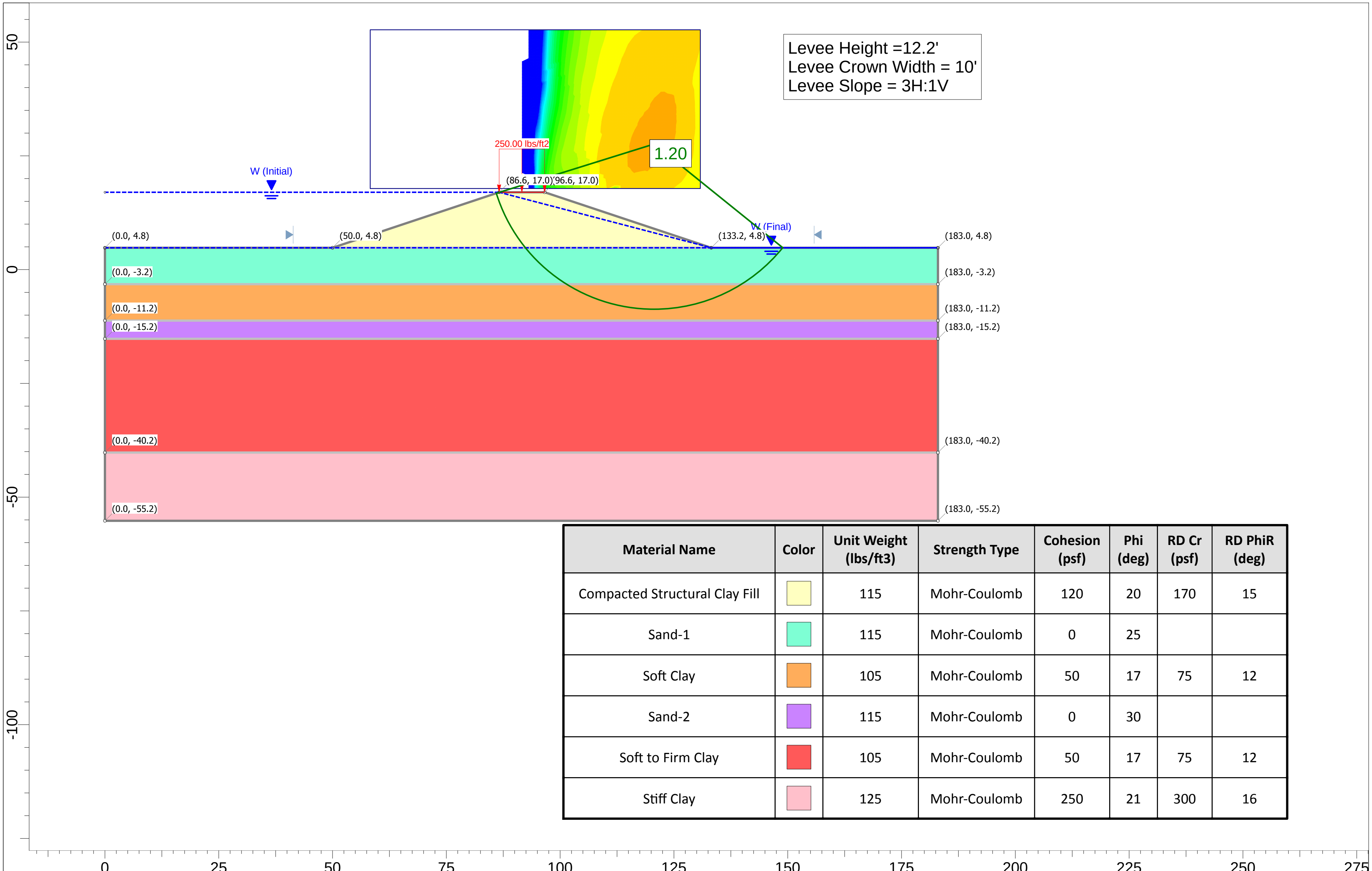
*Project*
Storm Surge Suppression Study - GCCPRD

*Analysis Description* (ID No.7) High Island to San Luis Pass Coastal Spine - Profile B-B' - Long-Term Condition

*Drawn By* J. Clarke | *Scale* 1:360 | *Company* Fugro USA Land, Inc.

*Date* 07/31/2017 | PLATE H-5

SLIDEINTERPRET 6.035




| Material Name | Color | Unit Weight (lbs/ft3) | Strength Type | Cohesion (psf) | Phi (deg) | RD Cr (psf) | RD PhiR (deg) |
|---|---|---|---|---|---|---|---|
| Compacted Structural Clay Fill | | 115 | Mohr-Coulomb | 120 | 20 | 170 | 15 |
| Sand-1 | | 115 | Mohr-Coulomb | 0 | 25 | | |
| Soft Clay | | 105 | Mohr-Coulomb | 50 | 17 | 75 | 12 |
| Sand-2 | | 115 | Mohr-Coulomb | 0 | 30 | | |
| Soft to Firm Clay | | 105 | Mohr-Coulomb | 50 | 17 | 75 | 12 |
| Stiff Clay | | 125 | Mohr-Coulomb | 250 | 21 | 300 | 16 |

FUGRO

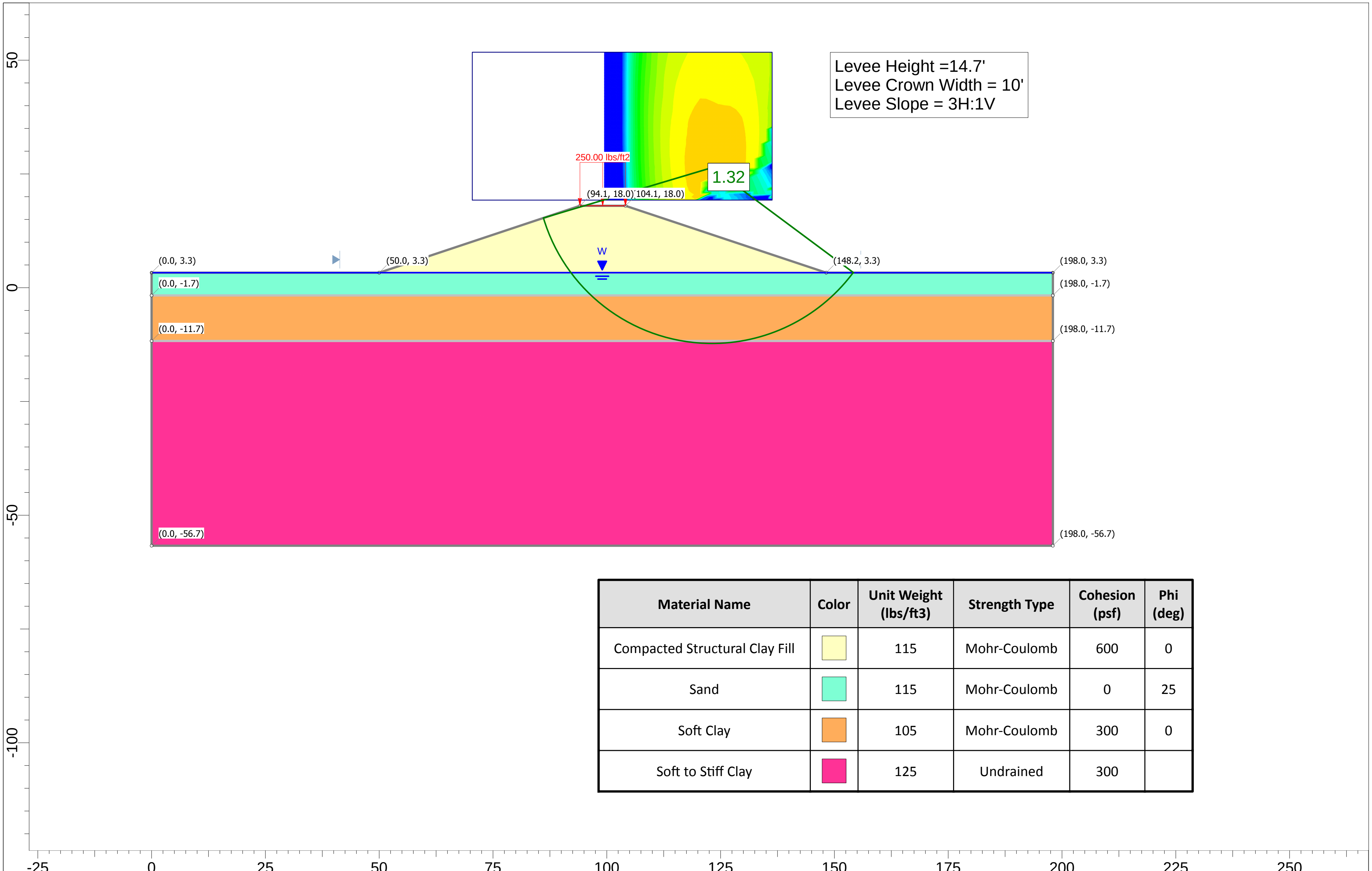
SLIDEINTERPRET 6.035

*Project* Storm Surge Suppression Study - GCCPRD

*Analysis Description* (ID No.7) High Island to San Luis Pass Coastal Spine - Profile B-B' - Rapid Drawdown Condition

*Drawn By* J. Clarke *Scale* 1:360 *Company* Fugro USA Land, Inc.

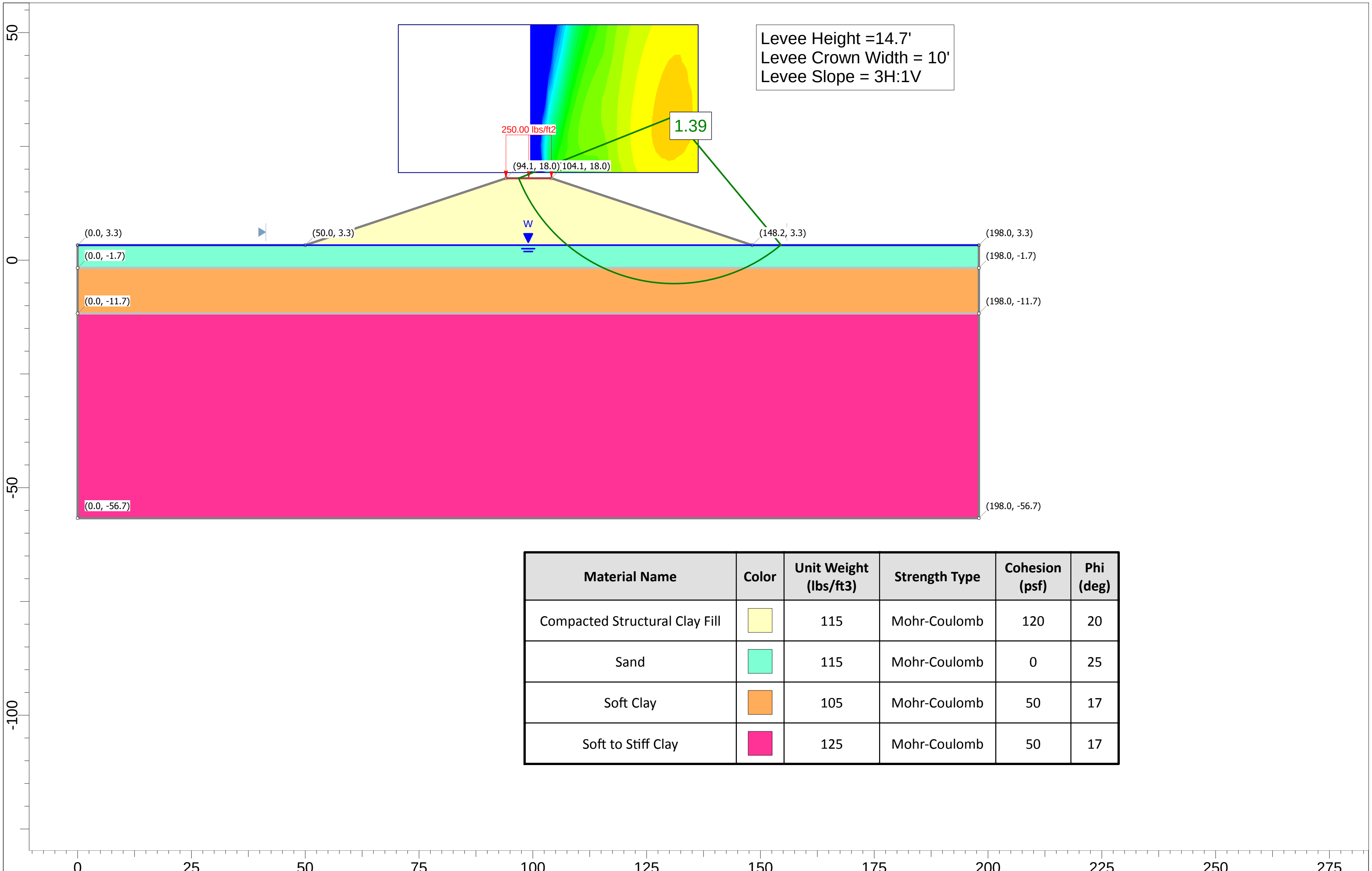
*Date* 07/31/2017 PLATE H-6




| Material Name | Color | Unit Weight (lbs/ft3) | Strength Type | Cohesion (psf) | Phi (deg) |
|---|---|---|---|---|---|
| Compacted Structural Clay Fill | | 115 | Mohr-Coulomb | 600 | 0 |
| Sand | | 115 | Mohr-Coulomb | 0 | 25 |
| Soft Clay | | 105 | Mohr-Coulomb | 300 | 0 |
| Soft to Stiff Clay | | 125 | Undrained | 300 | |

SLIDEINTERPRET 6.035

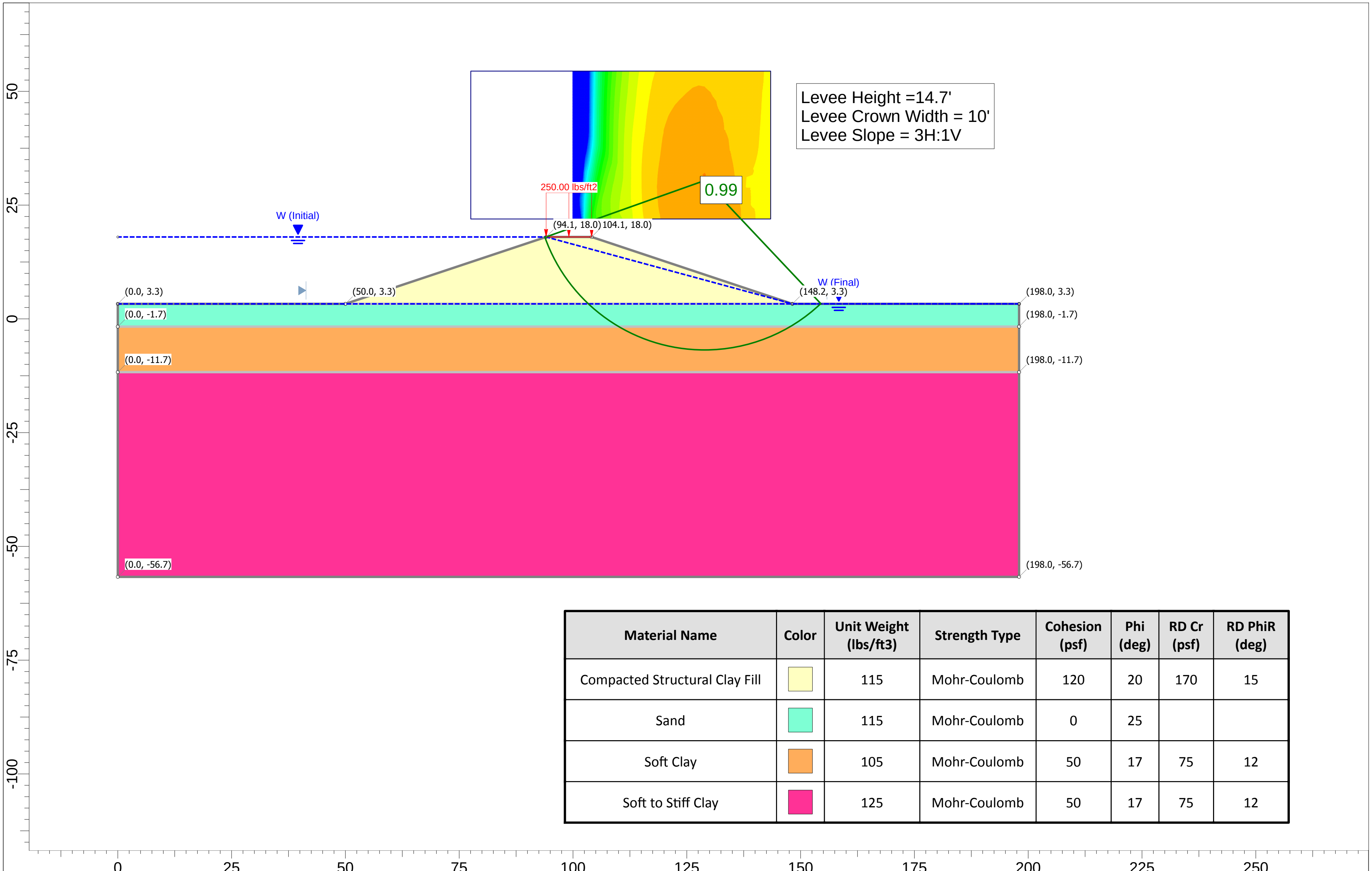
| | |
|---|---|
| *Project* | Storm Surge Suppression Study - GCCPRD |
| *Analysis Description* | (ID No.7) High Island to San Luis Pass Coastal Spine - Profile A-A' - Short-Term Condition |
| *Drawn By* | J. Clarke |
| *Scale* | 1:360 |
| *Company* | Fugro USA Land, Inc. |
| *Date* | 07/31/2017 |
| | PLATE H-7 |




| Material Name | Color | Unit Weight (lbs/ft3) | Strength Type | Cohesion (psf) | Phi (deg) |
|---|---|---|---|---|---|
| Compacted Structural Clay Fill | | 115 | Mohr-Coulomb | 120 | 20 |
| Sand | | 115 | Mohr-Coulomb | 0 | 25 |
| Soft Clay | | 105 | Mohr-Coulomb | 50 | 17 |
| Soft to Stiff Clay | | 125 | Mohr-Coulomb | 50 | 17 |

| | |
|---|---|
| *Project* | Storm Surge Suppression Study - GCCPRD |
| *Analysis Description* | (ID No.7) High Island to San Luis Pass Coastal Spine - Profile A-A' - Long-Term Condition |
| *Drawn By* | J. Clarke |
| *Scale* | 1:360 |
| *Company* | Fugro USA Land, Inc. |
| *Date* | 07/31/2017 |
| | PLATE H-8 |

SLIDEINTERPRET 6.035




| Material Name | Color | Unit Weight (lbs/ft3) | Strength Type | Cohesion (psf) | Phi (deg) | RD Cr (psf) | RD PhiR (deg) |
|---|---|---|---|---|---|---|---|
| Compacted Structural Clay Fill | | 115 | Mohr-Coulomb | 120 | 20 | 170 | 15 |
| Sand | | 115 | Mohr-Coulomb | 0 | 25 | | |
| Soft Clay | | 105 | Mohr-Coulomb | 50 | 17 | 75 | 12 |
| Soft to Stiff Clay | | 125 | Mohr-Coulomb | 50 | 17 | 75 | 12 |

FUGRO

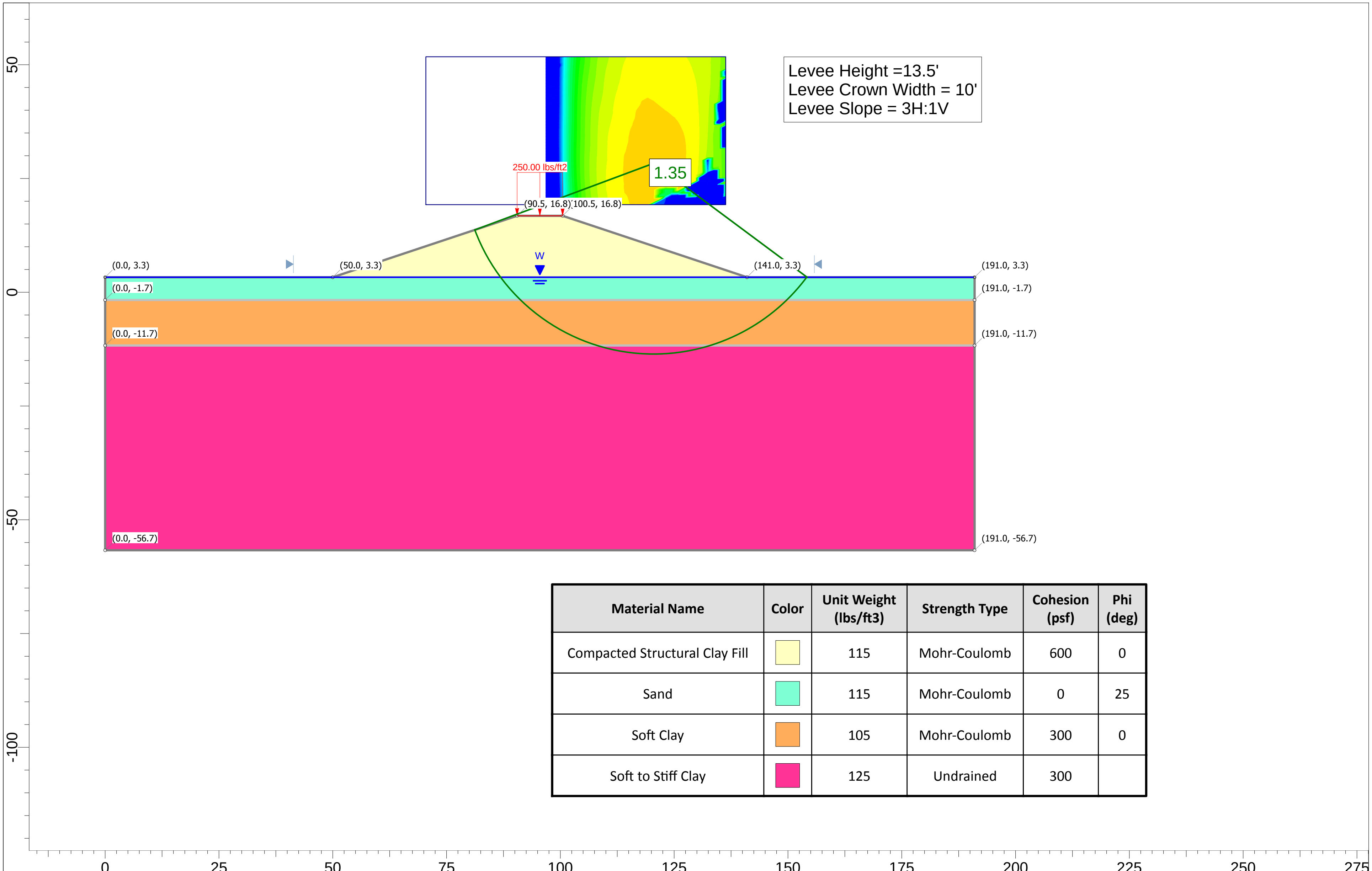
*Project* Storm Surge Suppression Study - GCCPRD

*Analysis Description* (ID No.7) High Island to San Luis Pass Coastal Spine - Profile A-A' - Rapid Drawdown Condition

*Drawn By* J. Clarke *Scale* 1:360 *Company* Fugro USA Land, Inc.

*Date* 07/31/2017 PLATE H-9

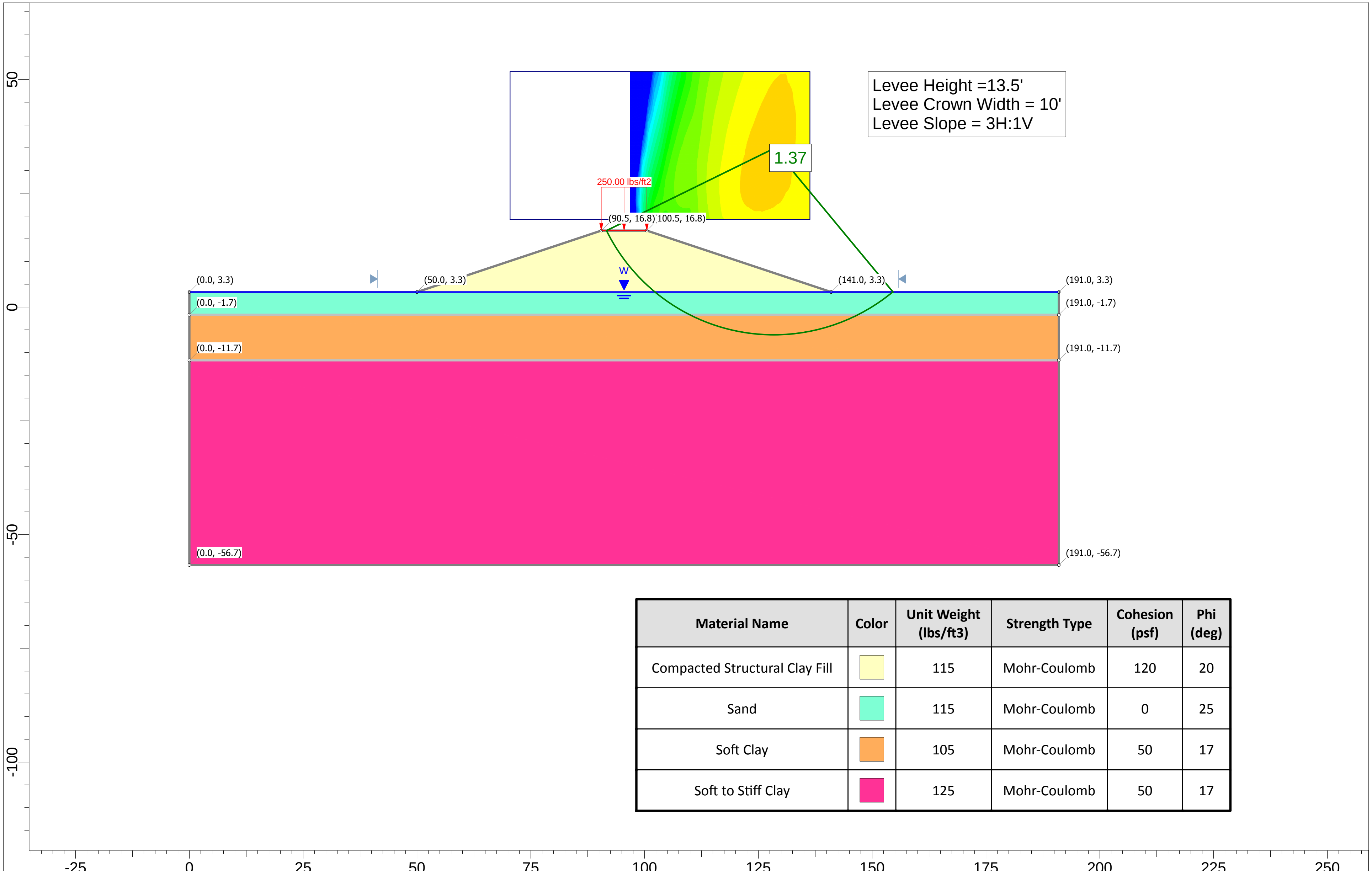
SLIDEINTERPRET 6.035




| Material Name | Color | Unit Weight (lbs/ft3) | Strength Type | Cohesion (psf) | Phi (deg) |
|---|---|---|---|---|---|
| Compacted Structural Clay Fill | | 115 | Mohr-Coulomb | 600 | 0 |
| Sand | | 115 | Mohr-Coulomb | 0 | 25 |
| Soft Clay | | 105 | Mohr-Coulomb | 300 | 0 |
| Soft to Stiff Clay | | 125 | Undrained | 300 | |

| | |
|---|---|
| *Project* | Storm Surge Suppression Study - GCCPRD |
| *Analysis Description* | (ID No.7) High Island to San Luis Pass Coastal Spine - Profile A-A' - Short-Term Condition |
| *Drawn By* | J. Clarke |
| *Scale* | 1:360 |
| *Company* | Fugro USA Land, Inc. |
| *Date* | 07/31/2017 |
| | PLATE H-10 |

SLIDEINTERPRET 6.035




| Material Name | Color | Unit Weight (lbs/ft3) | Strength Type | Cohesion (psf) | Phi (deg) |
|---|---|---|---|---|---|
| Compacted Structural Clay Fill | | 115 | Mohr-Coulomb | 120 | 20 |
| Sand | | 115 | Mohr-Coulomb | 0 | 25 |
| Soft Clay | | 105 | Mohr-Coulomb | 50 | 17 |
| Soft to Stiff Clay | | 125 | Mohr-Coulomb | 50 | 17 |

SLIDEINTERPRET 6.035

*Project*
Storm Surge Suppression Study - GCCPRD

*Analysis Description*
(ID No.7) High Island to San Luis Pass Coastal Spine - Profile A-A' - Long-Term Condition

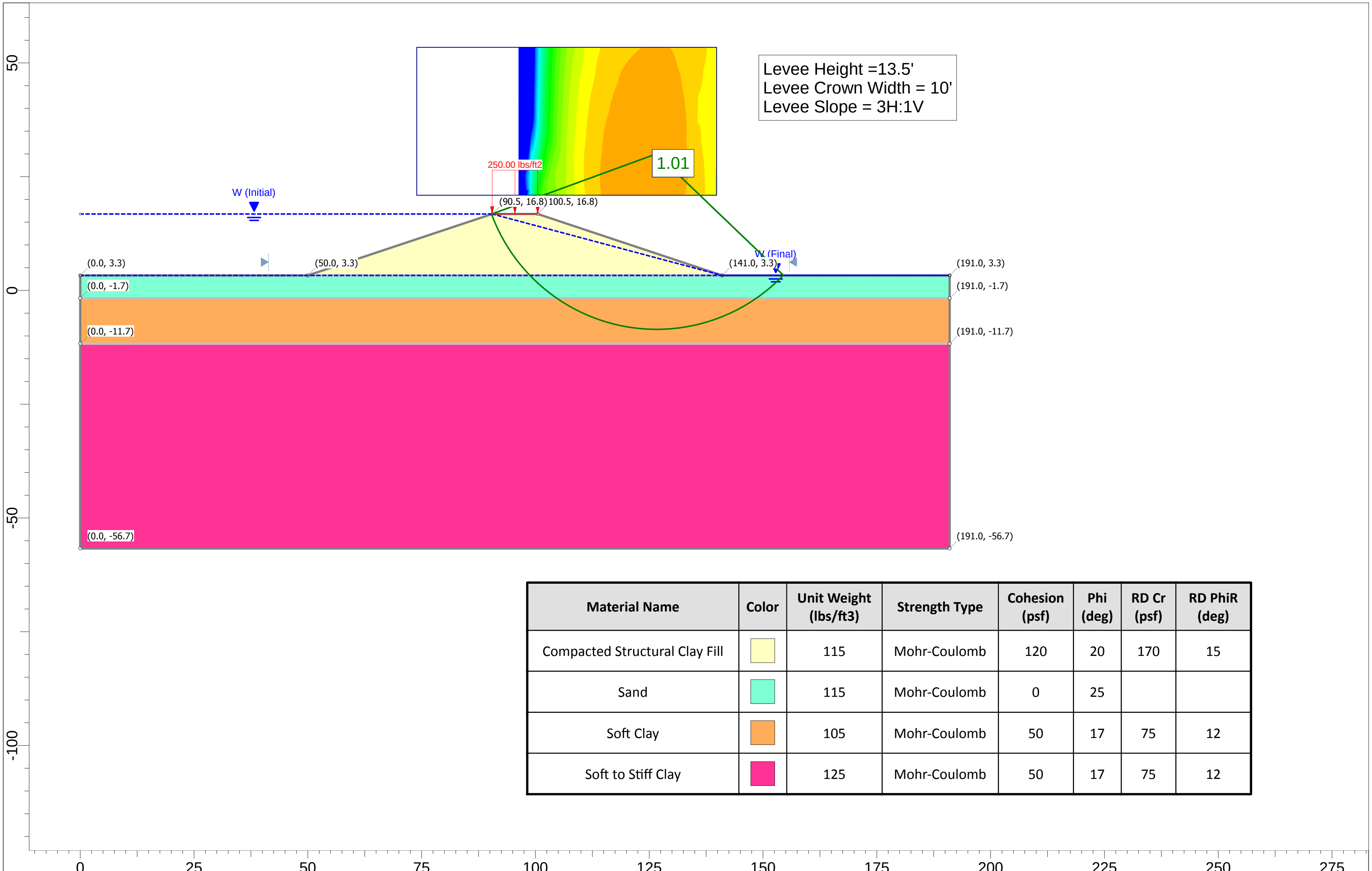
*Drawn By* J. Clarke

*Scale* 1:360

*Company* Fugro USA Land, Inc.

*Date* 07/31/2017

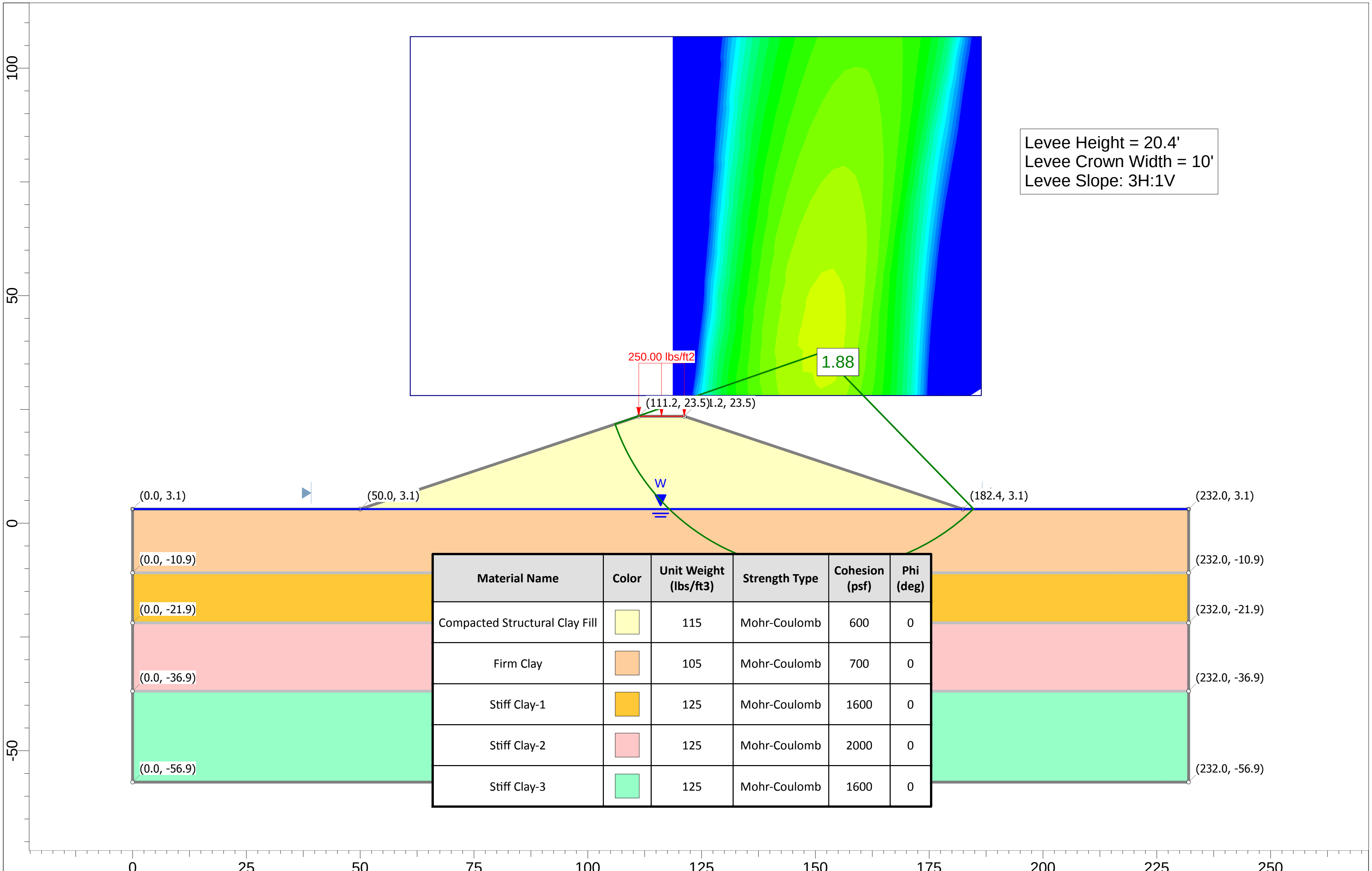
PLATE H-11




| Material Name | Color | Unit Weight (lbs/ft3) | Strength Type | Cohesion (psf) | Phi (deg) | RD Cr (psf) | RD PhiR (deg) |
|---|---|---|---|---|---|---|---|
| Compacted Structural Clay Fill | | 115 | Mohr-Coulomb | 120 | 20 | 170 | 15 |
| Sand | | 115 | Mohr-Coulomb | 0 | 25 | | |
| Soft Clay | | 105 | Mohr-Coulomb | 50 | 17 | 75 | 12 |
| Soft to Stiff Clay | | 125 | Mohr-Coulomb | 50 | 17 | 75 | 12 |

| | |
|---|---|
| *Project* | Storm Surge Suppression Study - GCCPRD |
| *Analysis Description* | (ID No.7) High Island to San Luis Pass Coastal Spine - Profile A-A' - Rapid Drawdown Condition |
| *Drawn By* | J. Clarke |
| *Scale* | 1:360 |
| *Company* | Fugro USA Land, Inc. |
| *Date* | 07/31/2017 |
| | PLATE H-12 |

SLIDEINTERPRET 6.035




| Material Name | Color | Unit Weight (lbs/ft3) | Strength Type | Cohesion (psf) | Phi (deg) |
|---|---|---|---|---|---|
| Compacted Structural Clay Fill | | 115 | Mohr-Coulomb | 600 | 0 |
| Firm Clay | | 105 | Mohr-Coulomb | 700 | 0 |
| Stiff Clay-1 | | 125 | Mohr-Coulomb | 1600 | 0 |
| Stiff Clay-2 | | 125 | Mohr-Coulomb | 2000 | 0 |
| Stiff Clay-3 | | 125 | Mohr-Coulomb | 1600 | 0 |

FUGRO

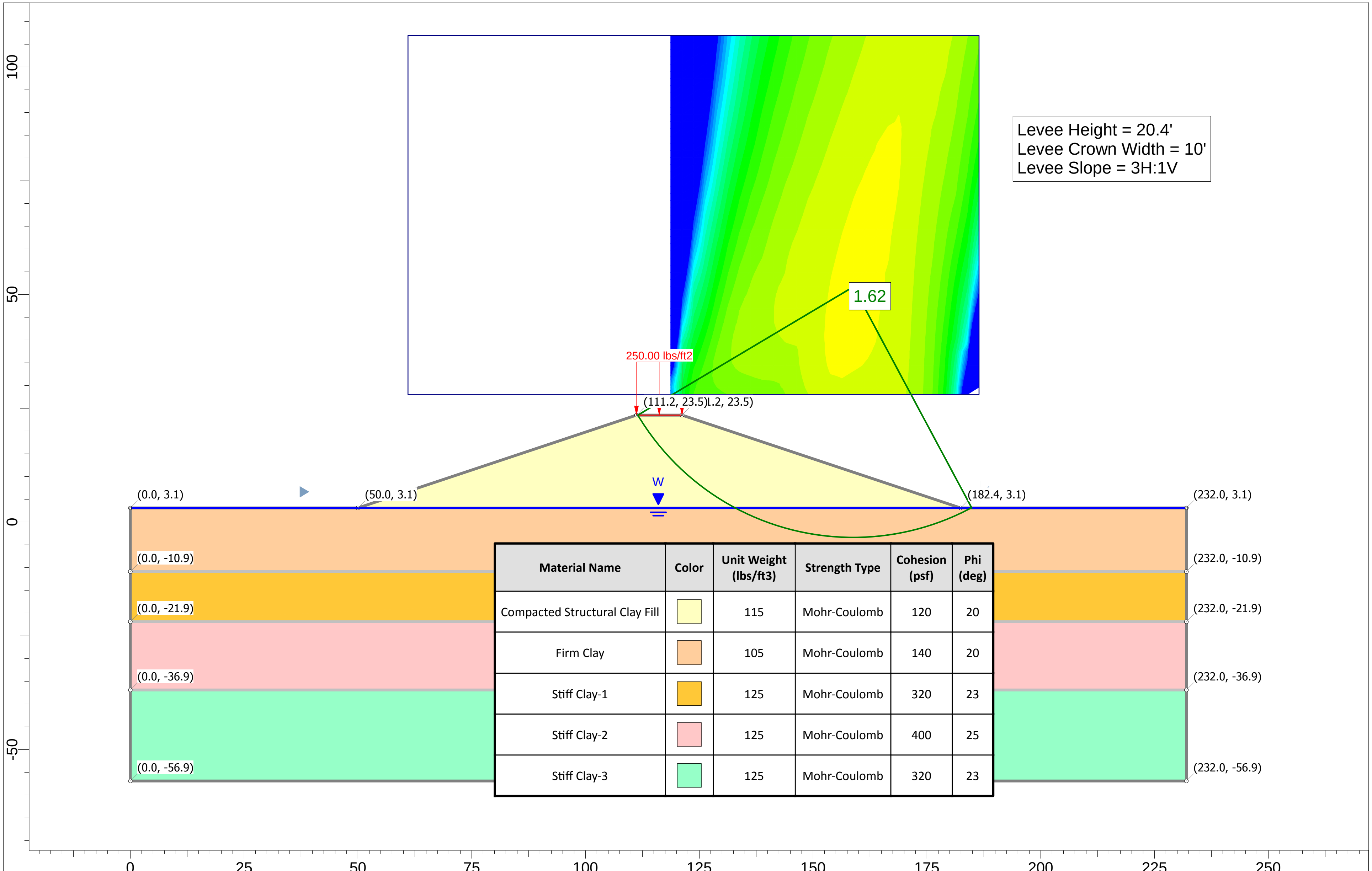
*Project* Storm Surge Suppression Study - GCCPRD

*Analysis Description* (ID No.8) GCCPRD South End of Alternative Route, Proposed - Profile C-C' - Short-Term Condition

*Drawn By* J. Clarke | *Scale* 1:360 | *Company* Fugro USA Land, Inc.

*Date* 07/31/2017 | PLATE H-13

SLIDEINTERPRET 6.035

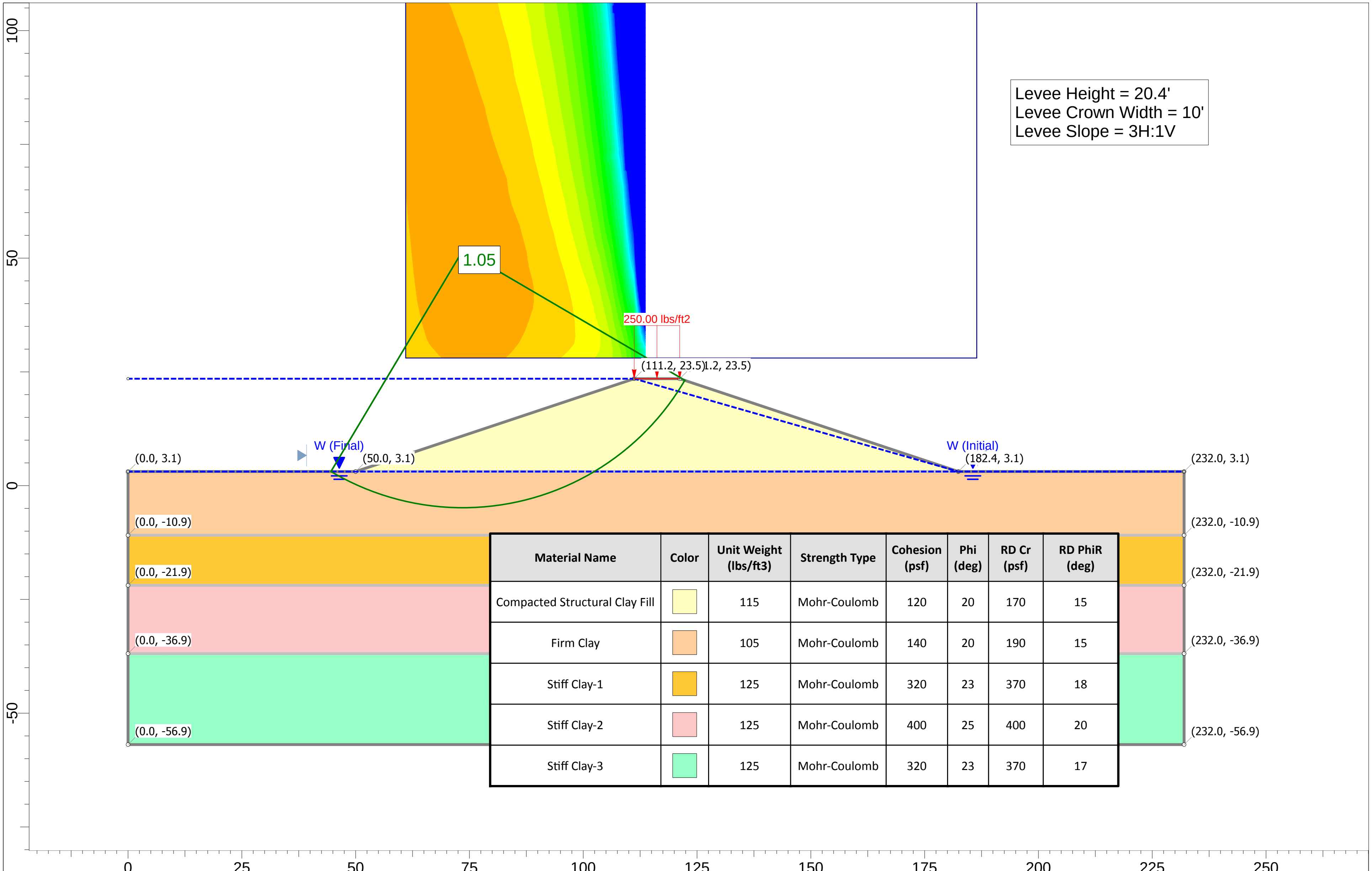



| Material Name | Color | Unit Weight (lbs/ft3) | Strength Type | Cohesion (psf) | Phi (deg) |
|---|---|---|---|---|---|
| Compacted Structural Clay Fill | | 115 | Mohr-Coulomb | 120 | 20 |
| Firm Clay | | 105 | Mohr-Coulomb | 140 | 20 |
| Stiff Clay-1 | | 125 | Mohr-Coulomb | 320 | 23 |
| Stiff Clay-2 | | 125 | Mohr-Coulomb | 400 | 25 |
| Stiff Clay-3 | | 125 | Mohr-Coulomb | 320 | 23 |

FUGRO

SLIDEINTERPRET 6.035

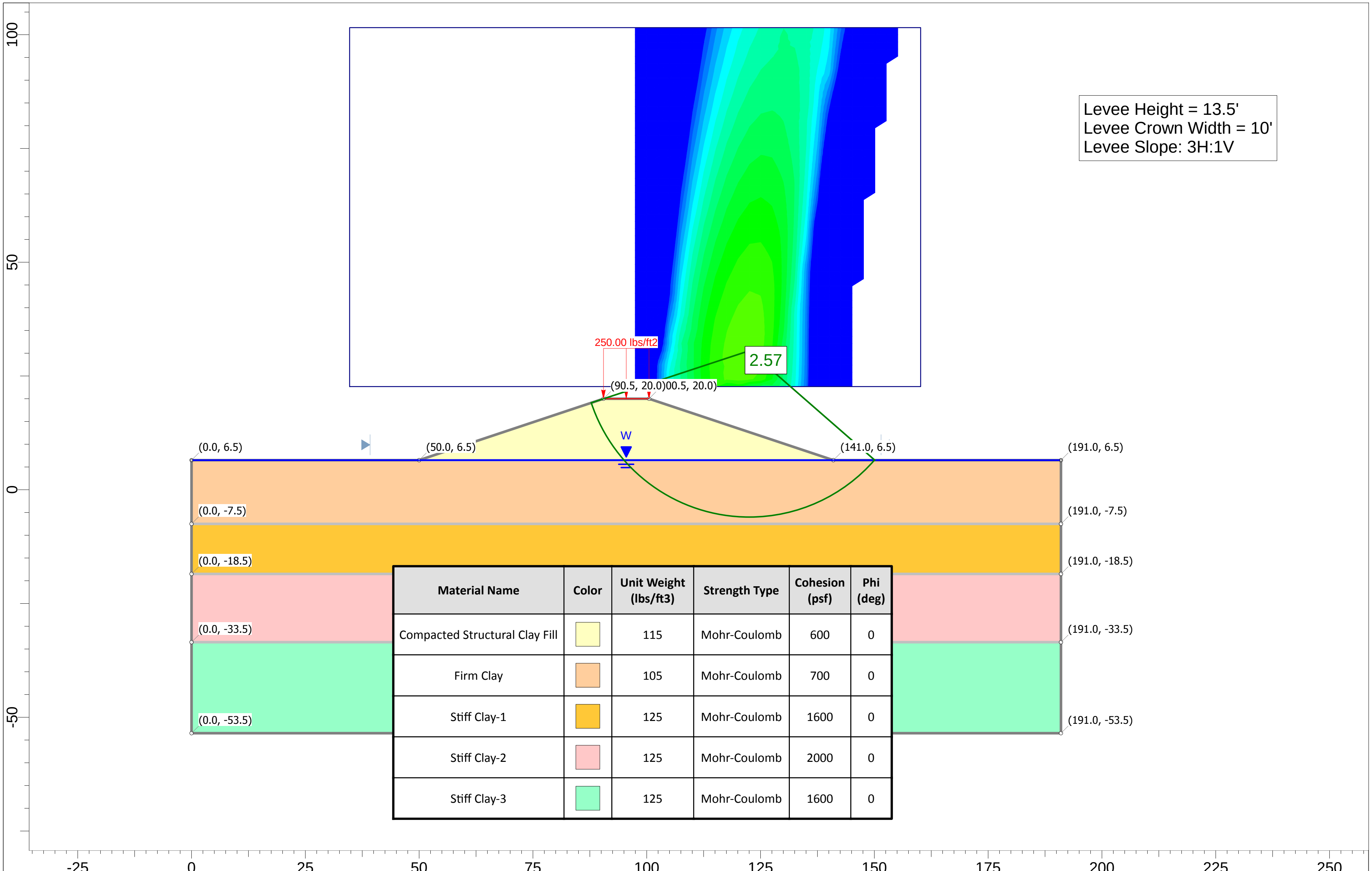
| | |
|---|---|
| *Project* | Storm Surge Suppression Study - GCCPRD |
| *Analysis Description* | (ID No.8) GCCPRD South End of Alternative Route, Proposed - Profile C-C' - Long-Term Condition |
| *Drawn By* | J. Clarke |
| *Scale* | 1:360 |
| *Company* | Fugro USA Land, Inc. |
| *Date* | 07/31/2017 |
| | PLATE H-14 |




| Material Name | Color | Unit Weight (lbs/ft3) | Strength Type | Cohesion (psf) | Phi (deg) | RD Cr (psf) | RD PhiR (deg) |
|---|---|---|---|---|---|---|---|
| Compacted Structural Clay Fill | | 115 | Mohr-Coulomb | 120 | 20 | 170 | 15 |
| Firm Clay | | 105 | Mohr-Coulomb | 140 | 20 | 190 | 15 |
| Stiff Clay-1 | | 125 | Mohr-Coulomb | 320 | 23 | 370 | 18 |
| Stiff Clay-2 | | 125 | Mohr-Coulomb | 400 | 25 | 400 | 20 |
| Stiff Clay-3 | | 125 | Mohr-Coulomb | 320 | 23 | 370 | 17 |

SLIDEINTERPRET 6.035

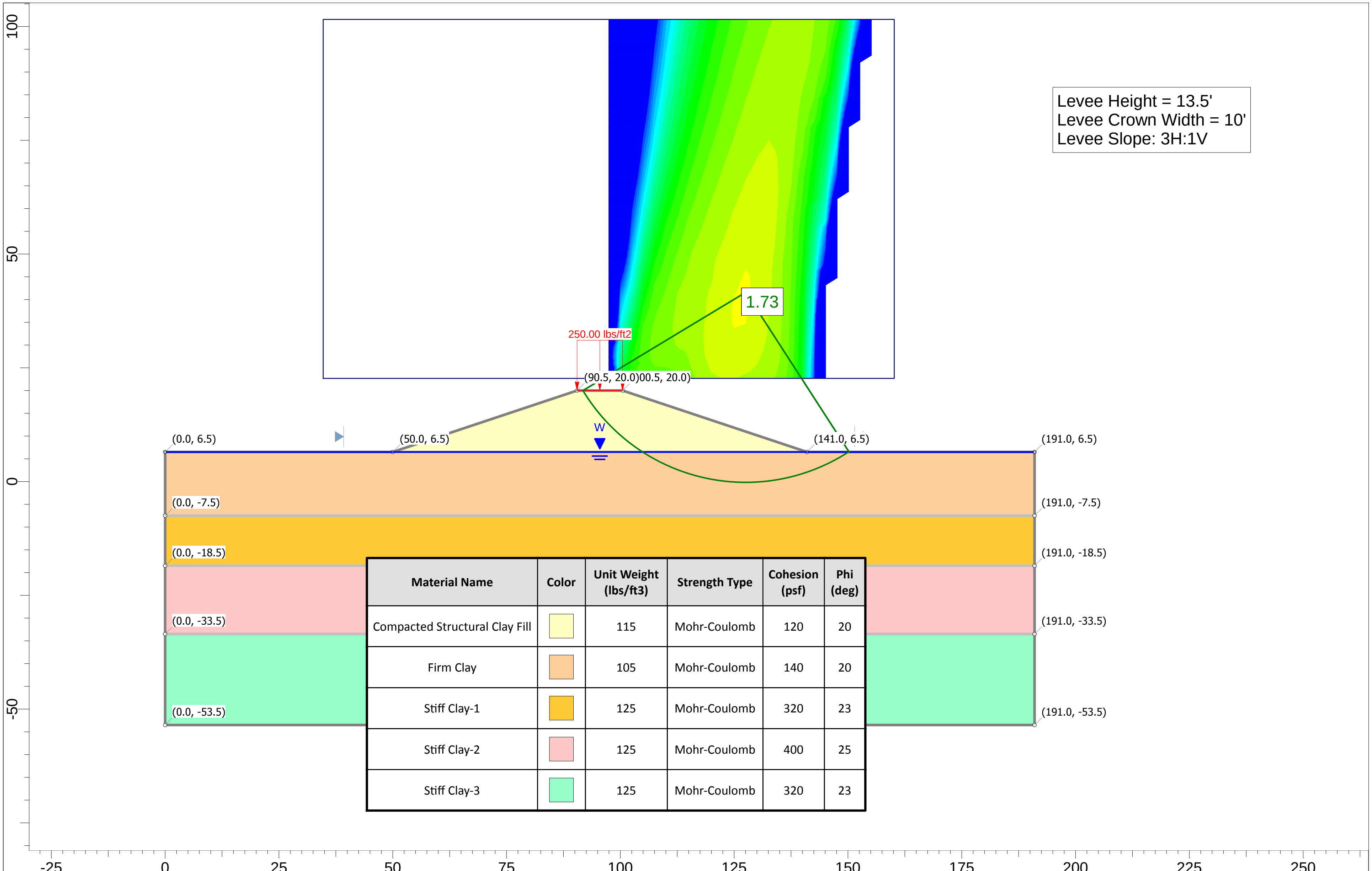
| | |
|---|---|
| *Project* | Storm Surge Suppression Study - GCCPRD |
| *Analysis Description* | (ID No.8) GCCPRD South End of Alternative Route, Proposed - Profile C-C' - Rapid Drawdown Condition |
| *Drawn By* | J. Clarke |
| *Scale* | 1:360 |
| *Company* | Fugro USA Land, Inc. |
| *Date* | 07/31/2017 |
| | PLATE H-15 |




| Material Name | Color | Unit Weight (lbs/ft3) | Strength Type | Cohesion (psf) | Phi (deg) |
|---|---|---|---|---|---|
| Compacted Structural Clay Fill | | 115 | Mohr-Coulomb | 600 | 0 |
| Firm Clay | | 105 | Mohr-Coulomb | 700 | 0 |
| Stiff Clay-1 | | 125 | Mohr-Coulomb | 1600 | 0 |
| Stiff Clay-2 | | 125 | Mohr-Coulomb | 2000 | 0 |
| Stiff Clay-3 | | 125 | Mohr-Coulomb | 1600 | 0 |

SLIDEINTERPRET 6.035

| | |
|---|---|
| *Project* | Storm Surge Suppression Study - GCCPRD |
| *Analysis Description* | (ID No.9) GCCPRD Alternative Route East of Plants, Proposed - Profile C-C' - Short-Term Condition |
| *Drawn By* | J. Clarke |
| *Scale* | 1:360 |
| *Company* | Fugro USA Land, Inc. |
| *Date* | 07/31/2017 |
| | PLATE H-16 |

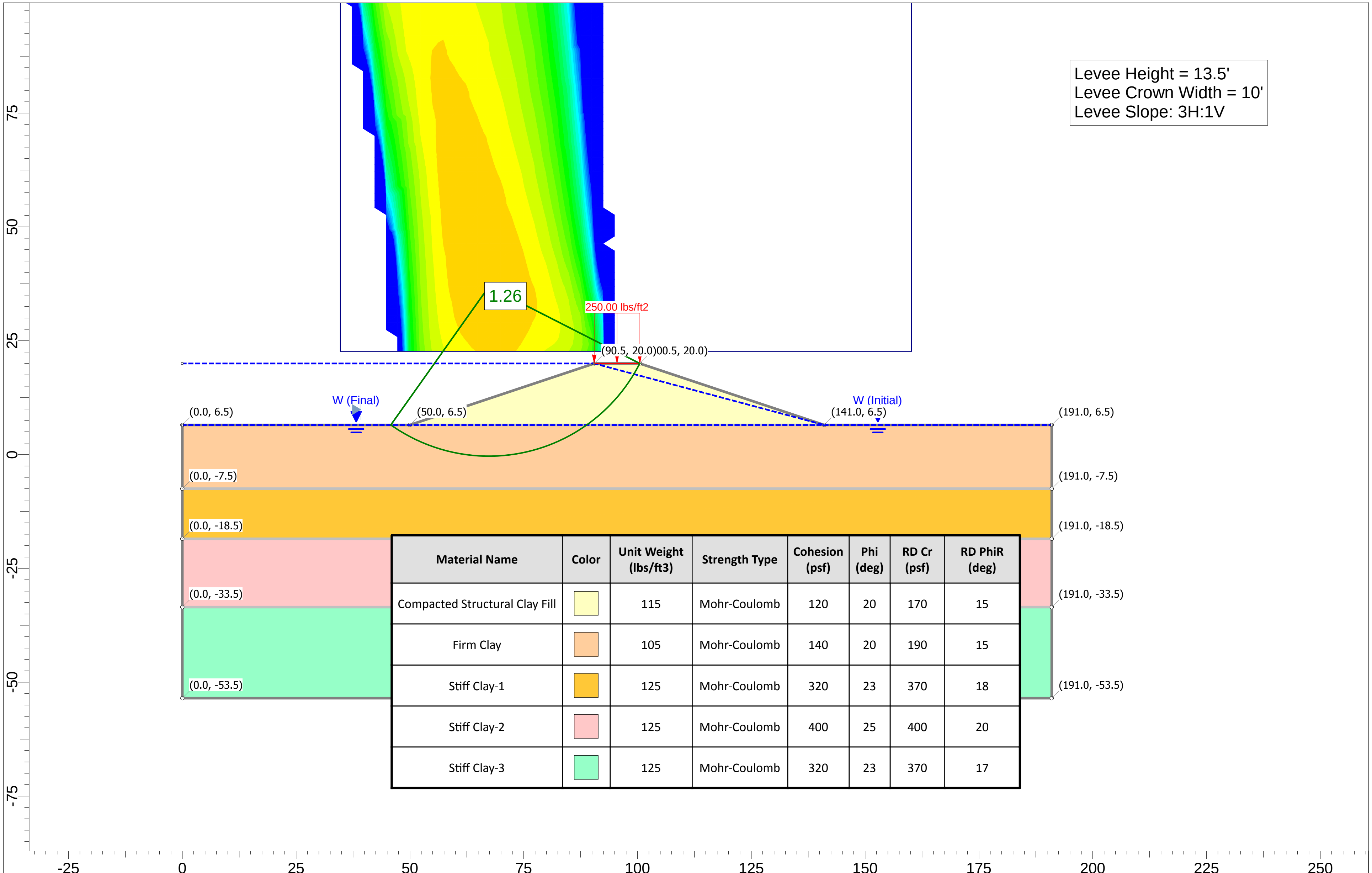



| Material Name | Color | Unit Weight (lbs/ft3) | Strength Type | Cohesion (psf) | Phi (deg) |
|---|---|---|---|---|---|
| Compacted Structural Clay Fill | | 115 | Mohr-Coulomb | 120 | 20 |
| Firm Clay | | 105 | Mohr-Coulomb | 140 | 20 |
| Stiff Clay-1 | | 125 | Mohr-Coulomb | 320 | 23 |
| Stiff Clay-2 | | 125 | Mohr-Coulomb | 400 | 25 |
| Stiff Clay-3 | | 125 | Mohr-Coulomb | 320 | 23 |

FUGRO

SLIDEINTERPRET 6.035

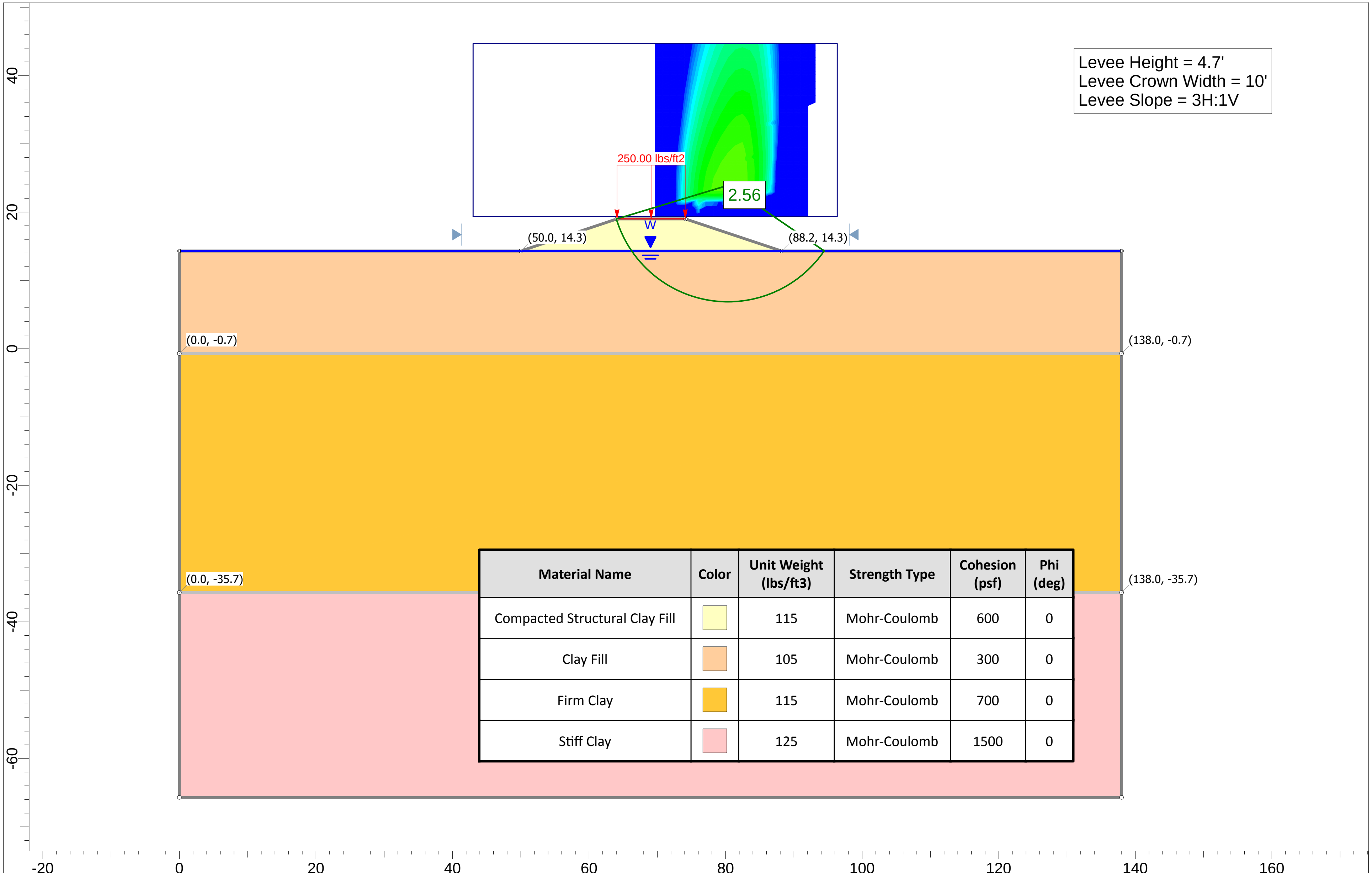
| | |
|---|---|
| *Project* | Storm Surge Suppression Study - GCCPRD |
| *Analysis Description* | (ID No.9) GCCPRD Alternative Route East of Plants, Proposed - Profile C-C' - Long-Term Condition |
| *Drawn By* | J. Clarke |
| *Scale* | 1:360 |
| *Company* | Fugro USA Land, Inc. |
| *Date* | 07/31/2017 |
| | PLATE H-17 |




| Material Name | Color | Unit Weight (lbs/ft3) | Strength Type | Cohesion (psf) | Phi (deg) | RD Cr (psf) | RD PhiR (deg) |
|---|---|---|---|---|---|---|---|
| Compacted Structural Clay Fill | | 115 | Mohr-Coulomb | 120 | 20 | 170 | 15 |
| Firm Clay | | 105 | Mohr-Coulomb | 140 | 20 | 190 | 15 |
| Stiff Clay-1 | | 125 | Mohr-Coulomb | 320 | 23 | 370 | 18 |
| Stiff Clay-2 | | 125 | Mohr-Coulomb | 400 | 25 | 400 | 20 |
| Stiff Clay-3 | | 125 | Mohr-Coulomb | 320 | 23 | 370 | 17 |

SLIDEINTERPRET 6.035

| | |
|---|---|
| *Project* | Storm Surge Suppression Study - GCCPRD |
| *Analysis Description* | (ID No.9) GCCPRD Alternative Route East of Plants, Proposed - Profile C-C' - Rapid Drawdown Condition |
| *Drawn By* | J. Clarke |
| *Scale* | 1:360 |
| *Company* | Fugro USA Land, Inc. |
| *Date* | 07/31/2017 |
| | PLATE H-18 |

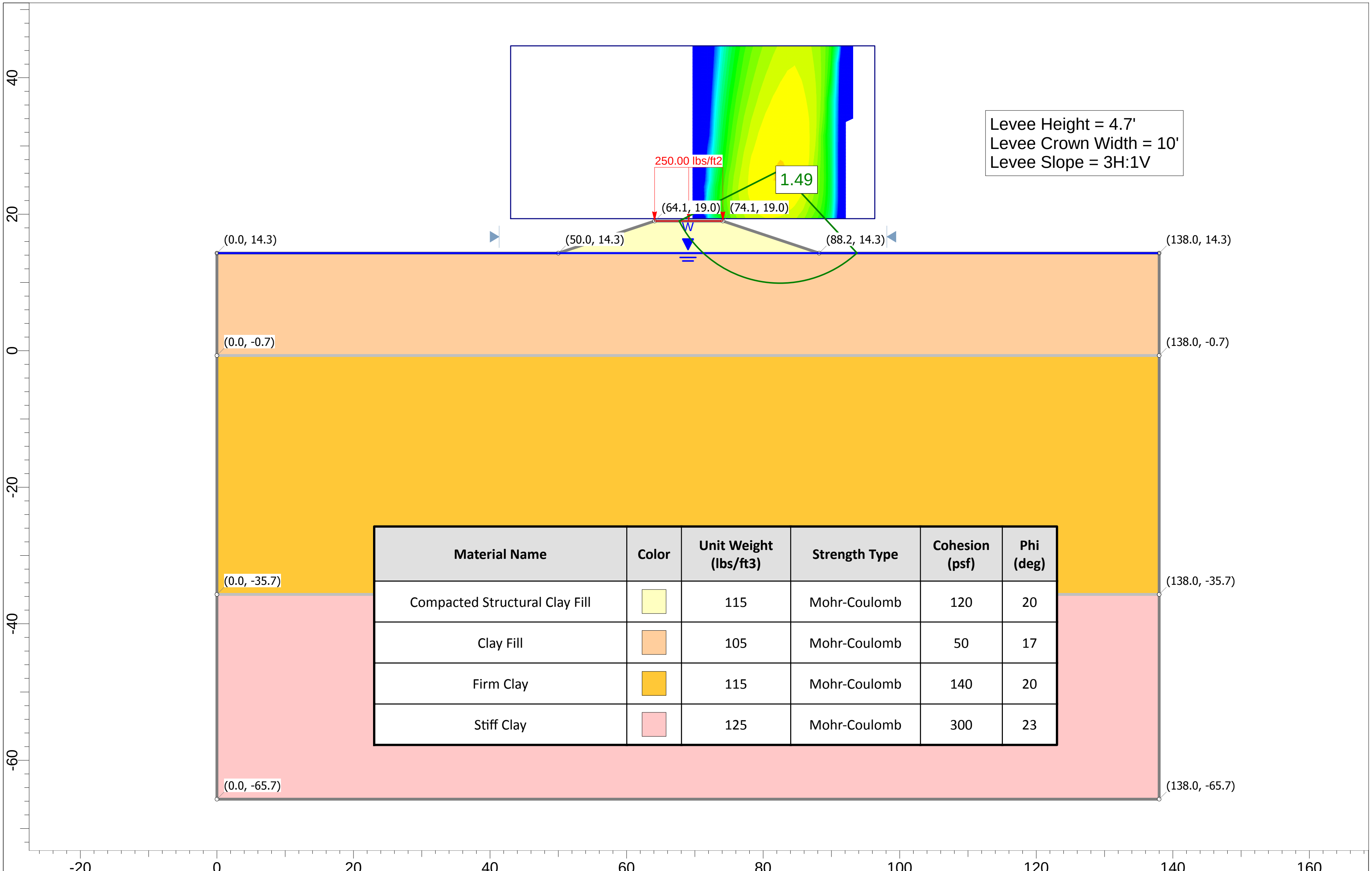



| Material Name | Color | Unit Weight (lbs/ft3) | Strength Type | Cohesion (psf) | Phi (deg) |
|---|---|---|---|---|---|
| Compacted Structural Clay Fill | | 115 | Mohr-Coulomb | 600 | 0 |
| Clay Fill | | 105 | Mohr-Coulomb | 300 | 0 |
| Firm Clay | | 115 | Mohr-Coulomb | 700 | 0 |
| Stiff Clay | | 125 | Mohr-Coulomb | 1500 | 0 |

FUGRO

SLIDEINTERPRET 6.035

| | |
|---|---|
| *Project* | Storm Surge Suppression Study - GCCPRD |
| *Analysis Description* | (ID No.11) Reach 1, Freeport Hurricane Flood Protection System Modernization - Federal System - Profile E-E' - Short-Term Condition |
| *Drawn By* | J. Clarke |
| *Scale* | 1:240 |
| *Company* | Fugro USA Land, Inc. |
| *Date* | 07/31/2017 |
| | PLATE H-19 |




| Material Name | Color | Unit Weight (lbs/ft3) | Strength Type | Cohesion (psf) | Phi (deg) |
|---|---|---|---|---|---|
| Compacted Structural Clay Fill | | 115 | Mohr-Coulomb | 120 | 20 |
| Clay Fill | | 105 | Mohr-Coulomb | 50 | 17 |
| Firm Clay | | 115 | Mohr-Coulomb | 140 | 20 |
| Stiff Clay | | 125 | Mohr-Coulomb | 300 | 23 |

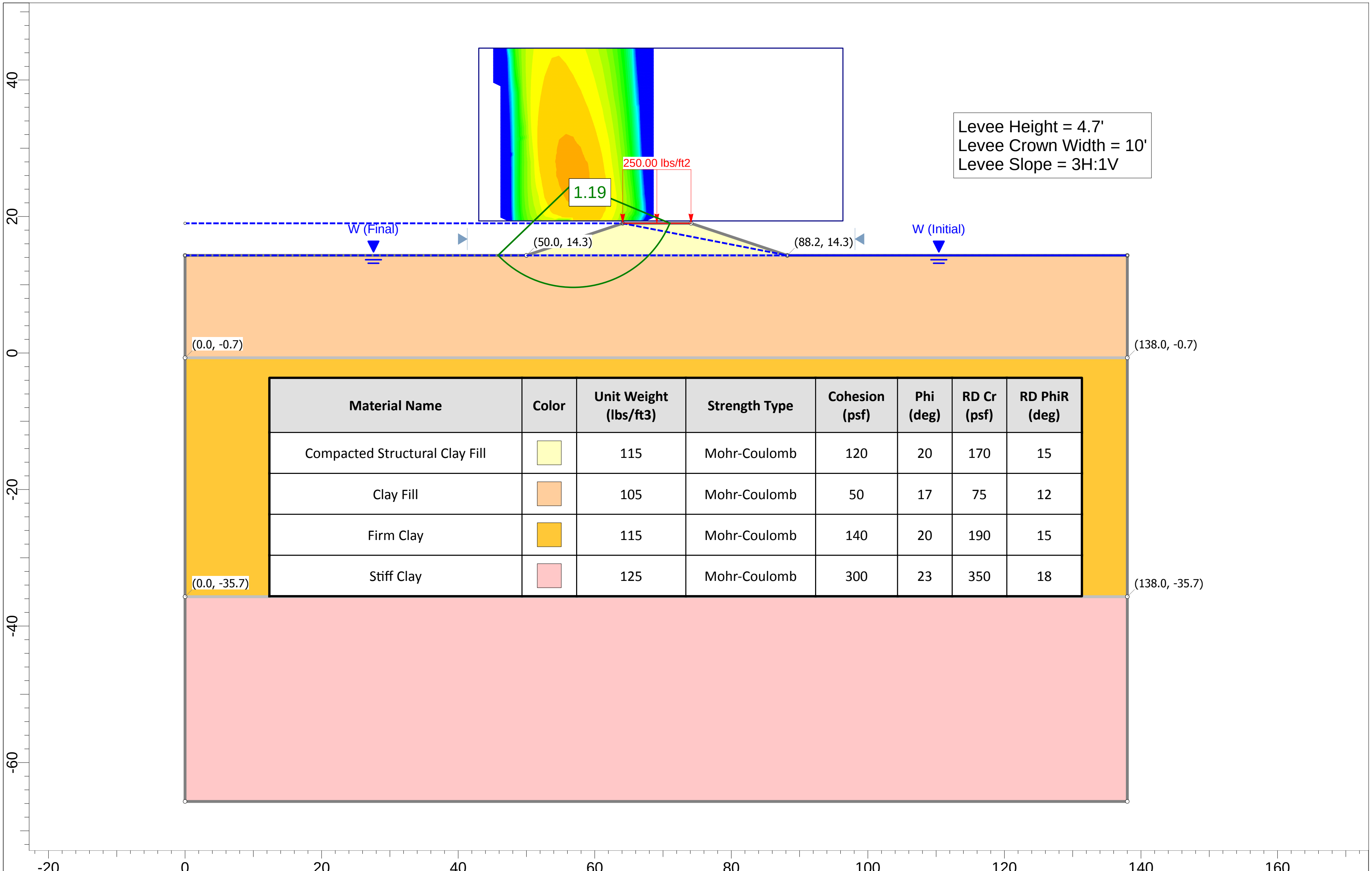
SLIDEINTERPRET 6.035

*Project*
Storm Surge Suppression Study - GCCPRD

*Analysis Description* (ID No.11) Reach 1, Freeport Hurricane Flood Protection System Modernization - Federal System - Profile E-E' - Long-Term Condition

*Drawn By* J. Clarke | *Scale* 1:240 | *Company* Fugro USA Land, Inc.

*Date* 07/31/2017 | PLATE H-20

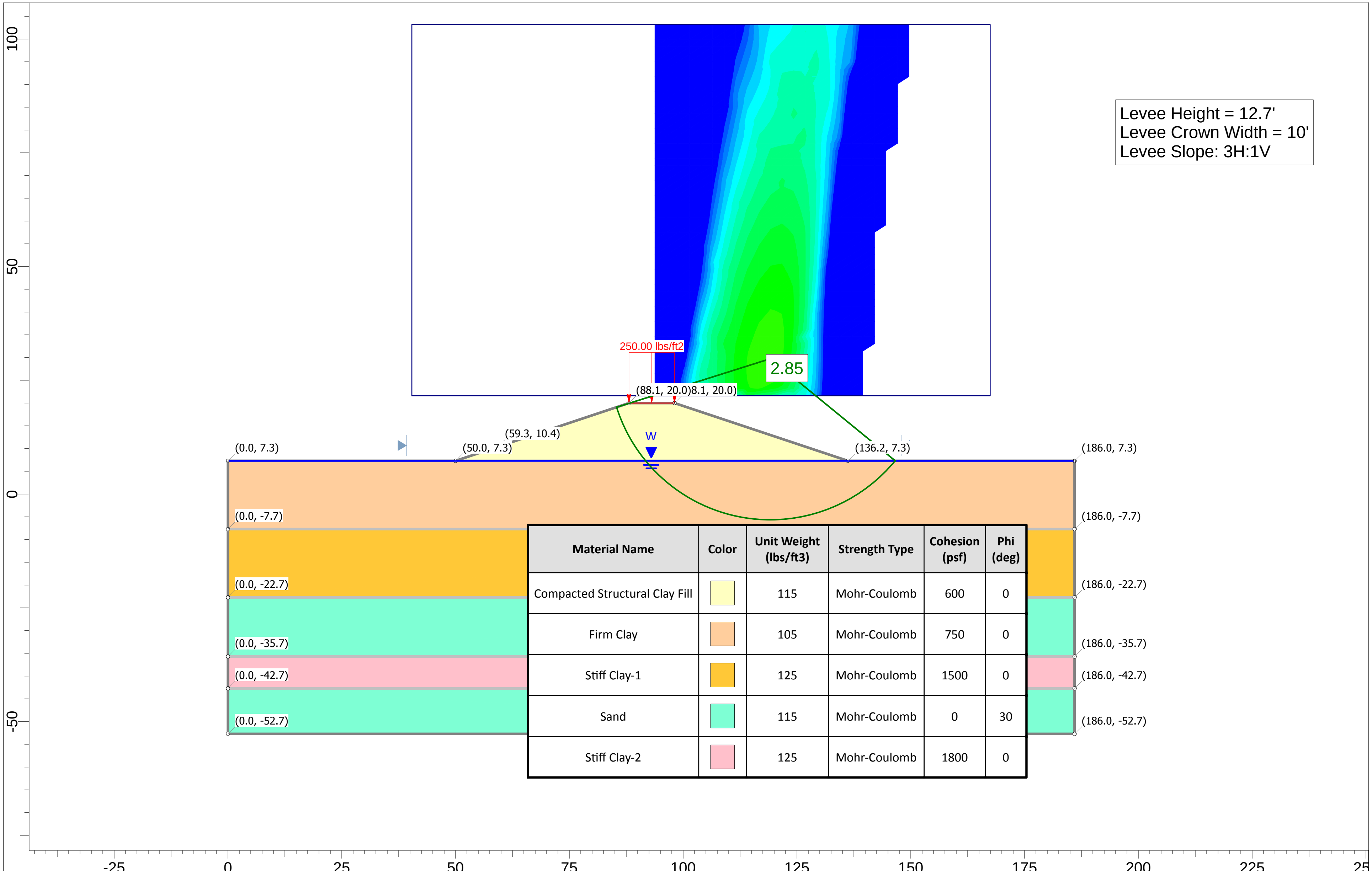



| Material Name | Color | Unit Weight (lbs/ft3) | Strength Type | Cohesion (psf) | Phi (deg) | RD Cr (psf) | RD PhiR (deg) |
|---|---|---|---|---|---|---|---|
| Compacted Structural Clay Fill | | 115 | Mohr-Coulomb | 120 | 20 | 170 | 15 |
| Clay Fill | | 105 | Mohr-Coulomb | 50 | 17 | 75 | 12 |
| Firm Clay | | 115 | Mohr-Coulomb | 140 | 20 | 190 | 15 |
| Stiff Clay | | 125 | Mohr-Coulomb | 300 | 23 | 350 | 18 |

FUGRO

SLIDEINTERPRET 6.035

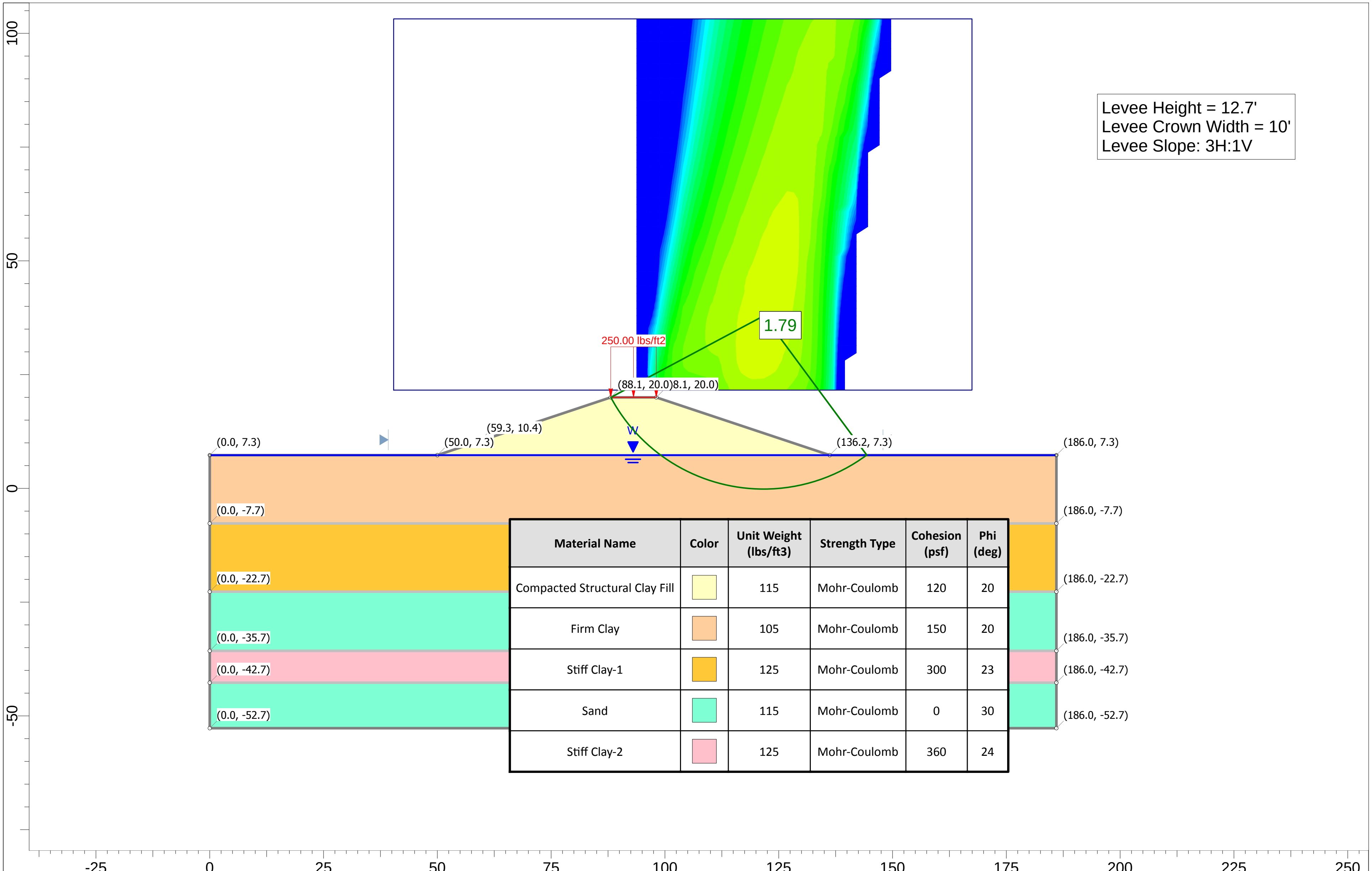
| | |
|---|---|
| *Project* | Storm Surge Suppression Study - GCCPRD |
| *Analysis Description* | (ID No.11) Reach 1, Freeport Hurricane Flood Protection System Modernization - Federal System - Profile E-E' - Rapid Drawdown Condition |
| *Drawn By* | J. Clarke |
| *Scale* | 1:240 |
| *Company* | Fugro USA Land, Inc. |
| *Date* | 07/31/2017 |
| | PLATE H-21 |




| Material Name | Color | Unit Weight (lbs/ft3) | Strength Type | Cohesion (psf) | Phi (deg) |
|---|---|---|---|---|---|
| Compacted Structural Clay Fill | | 115 | Mohr-Coulomb | 600 | 0 |
| Firm Clay | | 105 | Mohr-Coulomb | 750 | 0 |
| Stiff Clay-1 | | 125 | Mohr-Coulomb | 1500 | 0 |
| Sand | | 115 | Mohr-Coulomb | 0 | 30 |
| Stiff Clay-2 | | 125 | Mohr-Coulomb | 1800 | 0 |

| | |
|---|---|
| *Project* | Storm Surge Suppression Study - GCCPRD |
| *Analysis Description* | (ID No.12) Reach 3, Jones Creek Levee - Profile D-D' - Short-Term Condition |
| *Drawn By* | J. Clarke |
| *Scale* | 1:360 |
| *Company* | Fugro USA Land, Inc. |
| *Date* | 07/31/2017 |
| | PLATE H-22 |

SLIDEINTERPRET 6.035

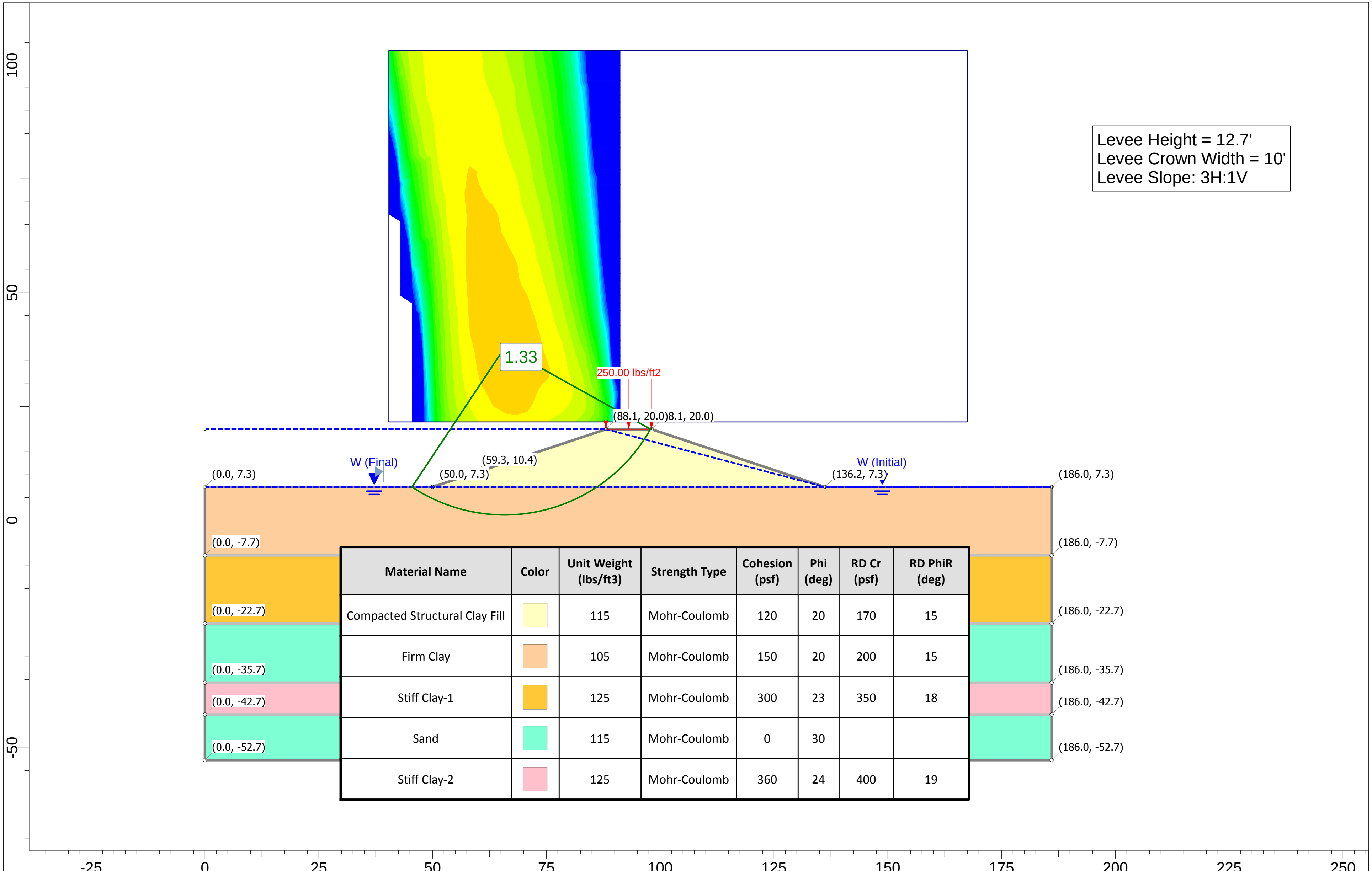



| Material Name | Color | Unit Weight (lbs/ft3) | Strength Type | Cohesion (psf) | Phi (deg) |
|---|---|---|---|---|---|
| Compacted Structural Clay Fill | | 115 | Mohr-Coulomb | 120 | 20 |
| Firm Clay | | 105 | Mohr-Coulomb | 150 | 20 |
| Stiff Clay-1 | | 125 | Mohr-Coulomb | 300 | 23 |
| Sand | | 115 | Mohr-Coulomb | 0 | 30 |
| Stiff Clay-2 | | 125 | Mohr-Coulomb | 360 | 24 |

FUGRO

| | |
|---|---|
| *Project* | Storm Surge Suppression Study - GCCPRD |
| *Analysis Description* | (ID No.12) Reach 3, Jones Creek Levee - Profile D-D' - Long-Term Condition |
| *Drawn By* | J. Clarke |
| *Scale* | 1:360 |
| *Company* | Fugro USA Land, Inc. |
| *Date* | 07/31/2017 |
| | PLATE H-23 |

SLIDEINTERPRET 6.035




Levee Height = 12.7'
Levee Crown Width = 10'
Levee Slope: 3H:1V

| Material Name | Color | Unit Weight (lbs/ft3) | Strength Type | Cohesion (psf) | Phi (deg) | RD Cr (psf) | RD PhiR (deg) |
|---|---|---|---|---|---|---|---|
| Compacted Structural Clay Fill | | 115 | Mohr-Coulomb | 120 | 20 | 170 | 15 |
| Firm Clay | | 105 | Mohr-Coulomb | 150 | 20 | 200 | 15 |
| Stiff Clay-1 | | 125 | Mohr-Coulomb | 300 | 23 | 350 | 18 |
| Sand | | 115 | Mohr-Coulomb | 0 | 30 | | |
| Stiff Clay-2 | | 125 | Mohr-Coulomb | 360 | 24 | 400 | 19 |

FUGRO

SLIDEINTERPRET 6.035

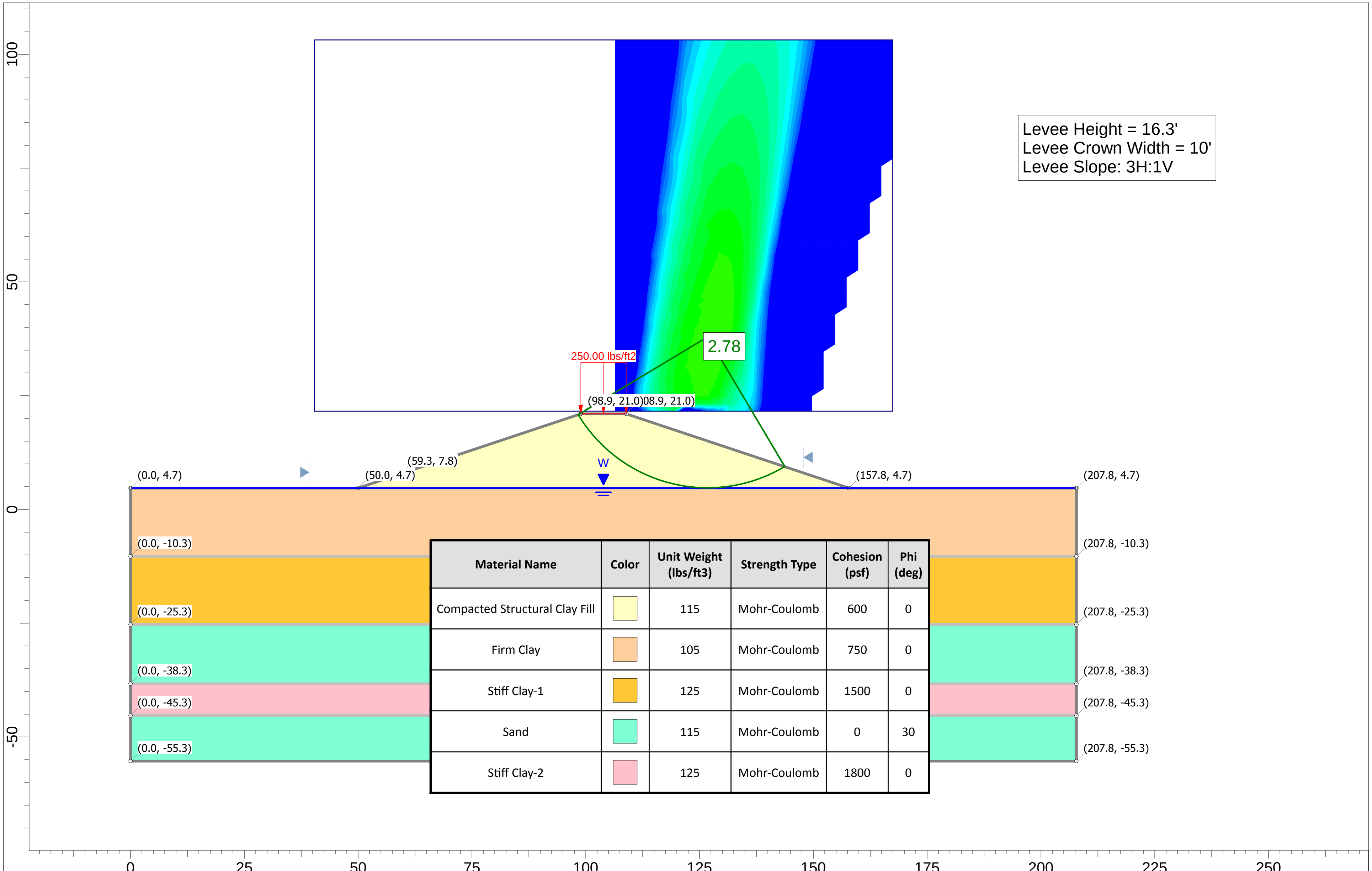
*Project*
Storm Surge Suppression Study - GCCPRD

*Analysis Description*
(ID No.12) Reach 3, Jones Creek Levee - Profile D-D' - Short-Term Condition

*Drawn By* J. Clarke | *Scale* 1:360 | *Company* Fugro USA Land, Inc.

*Date* 07/31/2017

PLATE H-24




| Material Name | Color | Unit Weight (lbs/ft3) | Strength Type | Cohesion (psf) | Phi (deg) |
|---|---|---|---|---|---|
| Compacted Structural Clay Fill | | 115 | Mohr-Coulomb | 600 | 0 |
| Firm Clay | | 105 | Mohr-Coulomb | 750 | 0 |
| Stiff Clay-1 | | 125 | Mohr-Coulomb | 1500 | 0 |
| Sand | | 115 | Mohr-Coulomb | 0 | 30 |
| Stiff Clay-2 | | 125 | Mohr-Coulomb | 1800 | 0 |

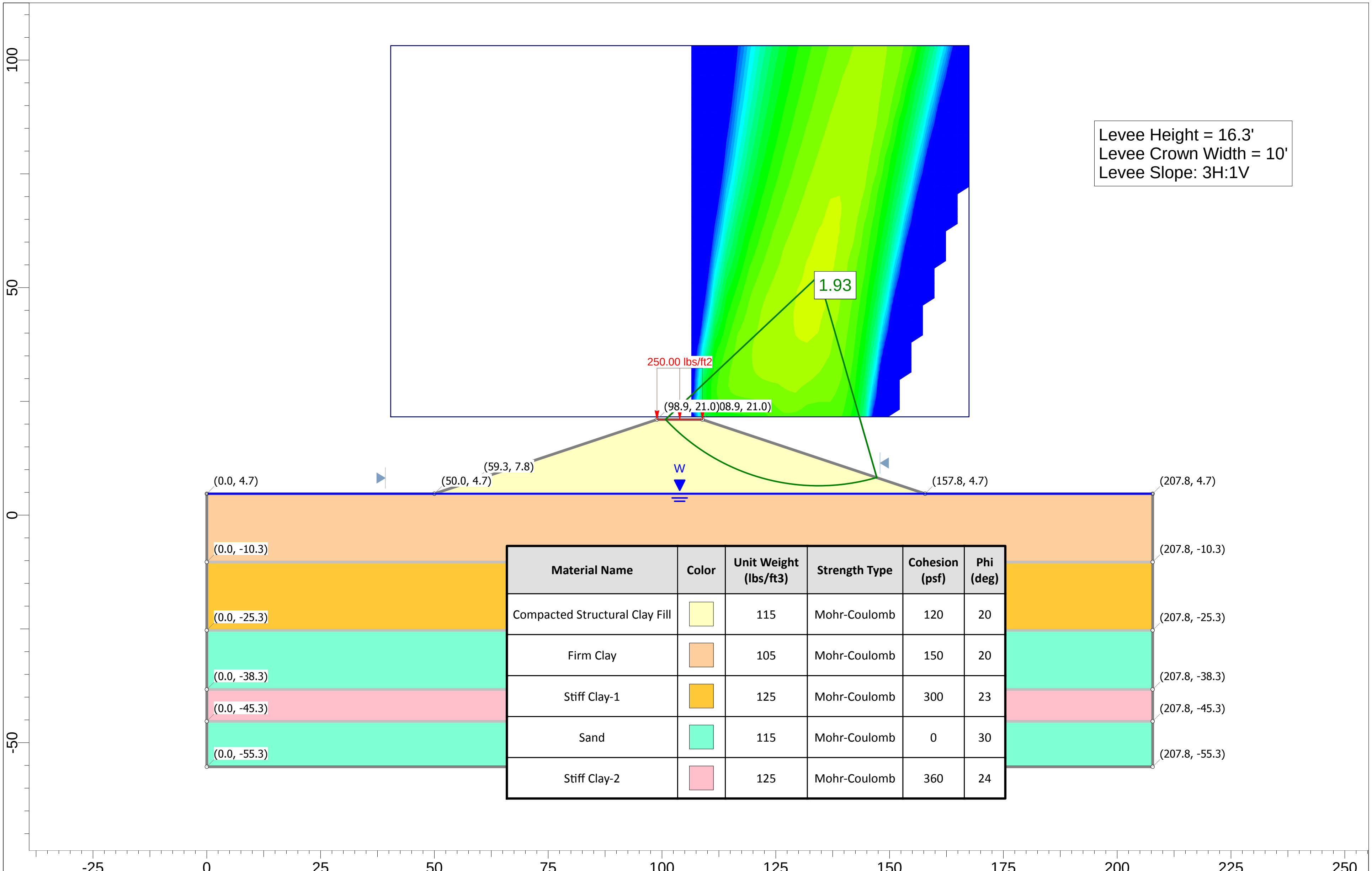
SLIDEINTERPRET 6.035

*Project*
Storm Surge Suppression Study - GCCPRD

*Analysis Description*
(ID No.13) Reach 4, Tank Farm Levee - Profile D-D' - Short-Term Condition

*Drawn By* J. Clarke | *Scale* 1:360 | *Company* Fugro USA Land, Inc.

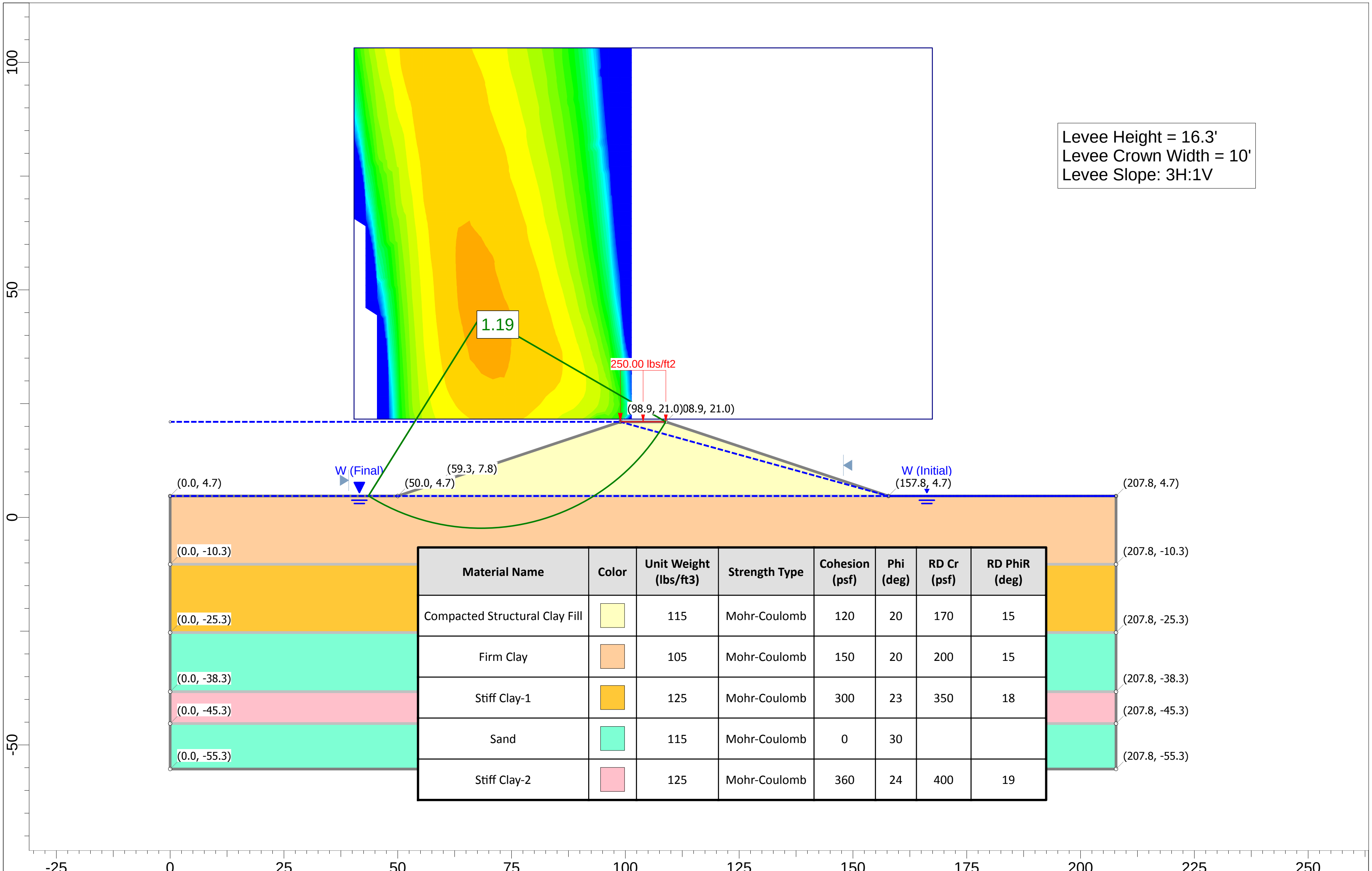
*Date* 07/31/2017 | PLATE H-25




| Material Name | Color | Unit Weight (lbs/ft3) | Strength Type | Cohesion (psf) | Phi (deg) |
|---|---|---|---|---|---|
| Compacted Structural Clay Fill | | 115 | Mohr-Coulomb | 120 | 20 |
| Firm Clay | | 105 | Mohr-Coulomb | 150 | 20 |
| Stiff Clay-1 | | 125 | Mohr-Coulomb | 300 | 23 |
| Sand | | 115 | Mohr-Coulomb | 0 | 30 |
| Stiff Clay-2 | | 125 | Mohr-Coulomb | 360 | 24 |

| | |
|---|---|
| *Project* | Storm Surge Suppression Study - GCCPRD |
| *Analysis Description* | (ID No.13) Reach 4, Tank Farm Levee - Profile D-D' - Long-Term Condition |
| *Drawn By* | J. Clarke |
| *Scale* | 1:360 |
| *Company* | Fugro USA Land, Inc. |
| *Date* | 07/31/2017 |
| | PLATE H-26 |

SLIDEINTERPRET 6.035




| Material Name | Color | Unit Weight (lbs/ft3) | Strength Type | Cohesion (psf) | Phi (deg) | RD Cr (psf) | RD PhiR (deg) |
|---|---|---|---|---|---|---|---|
| Compacted Structural Clay Fill | | 115 | Mohr-Coulomb | 120 | 20 | 170 | 15 |
| Firm Clay | | 105 | Mohr-Coulomb | 150 | 20 | 200 | 15 |
| Stiff Clay-1 | | 125 | Mohr-Coulomb | 300 | 23 | 350 | 18 |
| Sand | | 115 | Mohr-Coulomb | 0 | 30 | | |
| Stiff Clay-2 | | 125 | Mohr-Coulomb | 360 | 24 | 400 | 19 |

FUGRO

SLIDEINTERPRET 6.035

| | |
|---|---|
| *Project* | Storm Surge Suppression Study - GCCPRD |
| *Analysis Description* | (ID No.13) Reach 4, Tank Farm Levee - Profile D-D' -Rapid Drawdown Condition |
| *Drawn By* | J. Clarke |
| *Scale* | 1:360 |
| *Company* | Fugro USA Land, Inc. |
| *Date* | 07/31/2017 |
| | PLATE H-27 |