Final Geotechnical Data Assessment Memo

December 31, 2018
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## Issue and revision record

<table>
<thead>
<tr>
<th>Revision</th>
<th>Date</th>
<th>Originator</th>
<th>Checker</th>
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<tr>
<td>A</td>
<td>08/30/2018</td>
<td>M.J.Walker</td>
<td>C.Brodbaek, P.McLaughlin</td>
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1 Purpose

The Tentatively Selected Plan for the Texas Coastal Protection and Restoration project calls for construction a coastal flood barrier along portions of Galveston Island and Bolivar Peninsula. This barrier is being designed to reduce risk of inundation from storm surge. This memorandum presents the results of axial pile design calculations and provide those results as recommendations for feasibility-level design. Pile axial capacities have been developed using available historical geotechnical data at the following locations:

- Clear Creek
- Dickinson Bayou
- City of Galveston Pump Stations (East and West)

Additionally, this memorandum includes a discussion of nearby pipeline data, and a summary of the available geotechnical data and the interpreted soil profiles.
2 Data Collection

2.1 Geotechnical Data

Mott MacDonald has compiled a GIS database of the available geotechnical information in the region of the proposed improvements. The historical geotechnical reports date from the 1950s through the early 2000s. Few cone penetration tests are available in the data, and soil sampling typically used standard penetration tests without hammer energy measurements. Some locations include geotechnical data to depths appropriate for design of foundations for the Coastal Texas project, but many are for shallow improvements such as roadways or low levees.

Geotechnical data to support foundation design would include boreholes with sampling at regular intervals or cone penetration tests extending below specified pile tip elevations.

2.1.1 Vertical Datums

The various sources use various datums for reference. Some refer to the National Geodetic Vertical Datum (NGVD29), North American Vertical Datum (NAVD88), or simply depth below mudline. During subsequent phases of the project, these datums should be reconciled.

2.1.2 Borings

The available data for four flood protection and pump station sites have been evaluated: Clear Creek, Dickinson Bayou, Galveston East, and Galveston West. The data available for each site are described in Table 1 below. See the references section of this memorandum for details regarding each report. Generally, only the Clear Creek and Dickinson geotechnical conditions are well characterized for the purposes of feasibility level pile capacity estimates. The proximity of the available data to the proposed facilities is shown in Figure 1 through Figure 3.

<table>
<thead>
<tr>
<th>Site Name</th>
<th>Geotechnical Data</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear Creek</td>
<td>Site-specific boreholes to 75 feet below onshore grade.</td>
<td>McBride-Ratcliff and Associates (1982)</td>
</tr>
<tr>
<td>Clear Creek</td>
<td>Site-specific boreholes to 90 feet below onshore grade.</td>
<td>McBride-Ratcliff and Associates (1985)</td>
</tr>
<tr>
<td>Clear Creek</td>
<td>Site-specific boreholes to -80 feet, NGVD. Stratigraphy and unconfined compression strength.</td>
<td>USACE (1987)</td>
</tr>
<tr>
<td>Dickinson Bayou</td>
<td>Boreholes to approximately 20 feet below grade located greater than 2,500 feet away. No SPT N values.</td>
<td>USACE (1962)</td>
</tr>
<tr>
<td>Dickinson Bayou</td>
<td>Site specific boreholes for SH146 Bridge over Dickinson Bayou.</td>
<td>Geotest Engineering (2000)</td>
</tr>
<tr>
<td>Galveston West</td>
<td>Site-specific boreholes to 27.5 feet depth below mudline.</td>
<td>USACE (1958)</td>
</tr>
<tr>
<td>Galveston East</td>
<td>Site-specific boreholes to 35 feet depth below nearby site grade.</td>
<td>Fugro South (2003)</td>
</tr>
<tr>
<td>Galveston East</td>
<td>Boreholes to 5 feet below nearby site grade approximately 1,500 feet to the south. Generally not relevant for this study.</td>
<td>McLellend Engineers (1961)</td>
</tr>
</tbody>
</table>
Figure 1: Aerial image showing location of proposed Dickenson Pump Station and available geotechnical information from Geotest Engineering (GT). Borehole locations from USACE (1962) are approximately 2500 feet southward.

Figure 2: Aerial image showing location of proposed Clear Creek Pump Station and available geotechnical information from McBride Ratcliff and Associates (1982, 1985).
2.1.3 Soil Samples

The soil sampling documented in the historical geotechnical reports comprises standard penetration tests (SPT), which yield generally disturbed samples not appropriate for advanced laboratory testing and strength characterization. For the Clear Creek Site the USACE (1987) work included unconfined compression test profiles. This profile indicates a relatively weak (unconfined compressive strength values between 400 and 800 psf), near-surface clay layer overlying stiff to very stiff clays (unconfined compressive strength values between 1,200 and 3,000 psf).

For locations with geotechnical investigation information that did not reach sufficient depth, the conditions documented in the available data were extended for the analysis. For instance, the generally sandy profiles at Galveston east and west sites are extrapolated from data extending only to about 35 feet. Data at Clear Creek and Dickinson Bayou extend to approximately 100 feet.

2.2 Bathymetry and Topography

Generally, the available geotechnical data were collected referencing the onshore ground surface, NGVD29 vertical datum, or the mudline. A generalized stratigraphy has been developed at each location for depth below surface grade or mudline and does not consider depth of water above.

2.3 Pipelines

Mott MacDonald has performed a preliminary analysis of all pipelines in the vicinity of the Clear Creek Gate and Wall, Dickinson Bayou Gate and Wall, and Galveston Pump Station. A pipeline database showing pipelines in the Galveston, Chambers, and Brazoria County portion of the National Pipeline Mapping System was provided by the USACE (USACE, 2018). This database was used to flag areas all potential pipelines in the project footprint. To delineate pipelines within the footprint of ER measures outside of Galveston, Chambers, and Brazoria Counties, the Texas Railroad Commission (GIS Database) was used to delineate pipelines within the project footprint. It is anticipated that a magnetometer survey will be conducted to verify the location of...
all pipelines with the ER and CSRM measure project footprints before final design of these features is conducted.

2.3.1 CSRM Measures

Pipeline locations within the Clear Creek and Dickinson Bayou structures were identified from the USACE, 2018 data. A summary of all pipelines identified in the vicinity of this structure are shown below in Table 2 and Table 3.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Size/Type</th>
<th>Owner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear Creek</td>
<td>6” Propylene</td>
<td>ExxonMobil</td>
</tr>
<tr>
<td>Clear Creek</td>
<td>12” Gas</td>
<td>NuStar Logistics</td>
</tr>
<tr>
<td>Clear Creek</td>
<td>12” Pipeline</td>
<td>Magellan Pipeline Co</td>
</tr>
<tr>
<td>Clear Creek</td>
<td>6” Ethylene</td>
<td>UCAR Pipeline Incorp.</td>
</tr>
<tr>
<td>Clear Creek</td>
<td>Unknown</td>
<td>Enterprise Texas Pipeline</td>
</tr>
<tr>
<td>Clear Creek</td>
<td>12”</td>
<td>Seadrift Pipeline Corp</td>
</tr>
</tbody>
</table>

Table 2: Pipelines identified within Clear Creek Gate and Wall footprint

<table>
<thead>
<tr>
<th>Feature</th>
<th>Size/Type</th>
<th>Owner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dickinson Bayou</td>
<td>6” Propylene</td>
<td>Flint Hills Resources</td>
</tr>
<tr>
<td>Dickinson Bayou</td>
<td>12” Gas</td>
<td>NuStar Logistics</td>
</tr>
<tr>
<td>Dickinson Bayou</td>
<td>12” Pipeline</td>
<td>Magellan Pipeline Co</td>
</tr>
<tr>
<td>Dickinson Bayou</td>
<td>6” Ethylene</td>
<td>UCAR Pipeline Incorp.</td>
</tr>
<tr>
<td>Dickinson Bayou</td>
<td>Unknown</td>
<td>Enterprise Texas Pipeline</td>
</tr>
<tr>
<td>Dickinson Bayou</td>
<td>12”</td>
<td>Seadrift Pipeline Corp</td>
</tr>
<tr>
<td>Dickinson Bayou</td>
<td>Unknown</td>
<td>Lavaca Pipeline Co.</td>
</tr>
</tbody>
</table>

Table 3: Pipelines identified within Dickinson Bayou Gate and Wall footprint

The high number of pipelines within the project footprint will likely require relocation. It is anticipated that the pipelines will be relocated via a trenching and horizontal directional drilling methodology to install the pipelines at a deeper depth. It is assumed that this will be done prior to construction of the Clear Creek and Dickinson Features.

Based on the pipeline database provided by the USACE, no pipelines were identified at any of the proposed Galveston Pump station locations footprints. It is recommended that the USACE separately investigate any pipelines within the proposed Ring Levee footprint.

2.3.2 ER Measures

Mott MacDonald has also performed a preliminary pipeline investigation for the Ecosystem restoration measures. Mott MacDonald has identified potential pipeline conflicts for all Measures. Note that the available pipeline database provided by the USACE (USACE, 2018) only covered ER measures in Brazoria, Galveston, and Chambers County. To identify any potential pipeline conflicts in other counties, Mott MacDonald used the Texas Railroad Commission Pipeline viewer tool (TXRR GIS Database, 2018). All pipelines identified within the proposed project footprints are listed below. Note that no pipelines were identified within the proposed project footprint measures B-2 or W-3.
Table 4: Pipelines Identified within Measure G-5

<table>
<thead>
<tr>
<th>Feature</th>
<th>Size/Type</th>
<th>Owner</th>
</tr>
</thead>
<tbody>
<tr>
<td>ER Measure G-5</td>
<td>Unknown/ Natural Gas</td>
<td>Centana Intrastate Pipeline, LLC</td>
</tr>
<tr>
<td>ER Measure G-5</td>
<td>Unknown/ Natural Gas</td>
<td>Impact Midstream, LLC</td>
</tr>
<tr>
<td>ER Measure G-5</td>
<td>Unknown/Petroleum Products</td>
<td>Cameron Highway Oil Pipeline Company</td>
</tr>
<tr>
<td>ER Measure G-5</td>
<td>Unknown/ Natural Gas</td>
<td>Black Marlin Pipeline Company</td>
</tr>
<tr>
<td>ER Measure G-5</td>
<td>Unknown/ Natural Gas</td>
<td>Impact Midstream, LLC</td>
</tr>
<tr>
<td>ER Measure G-5</td>
<td>Unknown/ Oil/Natural Gas/Condensate</td>
<td>Emerald Gathering and Transportation, L.L.C.</td>
</tr>
<tr>
<td>ER Measure G-5</td>
<td>Unknown/ Hazardous Material</td>
<td>Chevron Pipe Line Company</td>
</tr>
</tbody>
</table>

Source: USACE, 2018

Table 5: Pipelines Identified within Measure G-28

<table>
<thead>
<tr>
<th>Feature</th>
<th>Size/Type</th>
<th>Owner</th>
</tr>
</thead>
<tbody>
<tr>
<td>ER Measure G-28</td>
<td>24”/ Crude Oil</td>
<td>ENTERPRISE PRODUCTS OPERATING LLC</td>
</tr>
<tr>
<td>ER Measure G-28</td>
<td>Unknown/Natural Gas</td>
<td>Gulf Energy Exploration Corp.</td>
</tr>
</tbody>
</table>

Source: USACE, 2018

Table 6: Pipelines Identified within Measure B-12

<table>
<thead>
<tr>
<th>Feature</th>
<th>Size/Type</th>
<th>Owner</th>
</tr>
</thead>
<tbody>
<tr>
<td>ER Measure G-28</td>
<td>16”/Natural Gas</td>
<td>ENERGY TRANSFER COMPANY</td>
</tr>
<tr>
<td>ER Measure G-28</td>
<td>8”/Natural Gas</td>
<td>ENERGY TRANSFER COMPANY</td>
</tr>
<tr>
<td>ER Measure B-12</td>
<td>20”/Natural Gas</td>
<td>BLUE DOLPHIN PIPELINE COMPANY</td>
</tr>
<tr>
<td>ER Measure B-12</td>
<td>12”/Natural Gas</td>
<td>AMERICAN MIDSTREAM (SEACREST), LP</td>
</tr>
<tr>
<td>ER Measure B-12</td>
<td>42”/Natural Gas</td>
<td>FREEPORT LNG DEVELOPMENT, L.P.</td>
</tr>
<tr>
<td>ER Measure B-12</td>
<td>24”/Crude Oil</td>
<td>EXXONMOBIL PIPELINE CO</td>
</tr>
<tr>
<td>ER Measure B-12</td>
<td>Unknown/Gas</td>
<td>ABANDONED</td>
</tr>
<tr>
<td>ER Measure B-12</td>
<td>30”/Crude Oil</td>
<td>EXXONMOBIL PIPELINE CO</td>
</tr>
<tr>
<td>ER Measure B-12</td>
<td>42”/Crude Oil</td>
<td>ENTERPRISE CRUDE PIPELINE LLC</td>
</tr>
<tr>
<td>ER Measure B-12</td>
<td>8”/Hydrogen</td>
<td>PHILLIPS 66 COMPANY - SWEENY REFINERY</td>
</tr>
<tr>
<td>ER Measure B-12</td>
<td>12”/Liquid Propane</td>
<td>DOW PIPELINE CO</td>
</tr>
<tr>
<td>ER Measure B-12</td>
<td>8”/Methane</td>
<td>DOW PIPELINE CO</td>
</tr>
<tr>
<td>ER Measure B-12</td>
<td>8”/Natural Gas</td>
<td>AMERICAN MIDSTREAM (SEACREST), LP</td>
</tr>
</tbody>
</table>

Source: TXRR GIS Database, 2018

Table 7: Pipelines Identified within ER Measure M-8

<table>
<thead>
<tr>
<th>Feature</th>
<th>Size/Type</th>
<th>Owner</th>
</tr>
</thead>
<tbody>
<tr>
<td>ER Measure M-8</td>
<td>30”/Natural Gas</td>
<td>Transcontinental Gas Co.</td>
</tr>
<tr>
<td>ER Measure M-8</td>
<td>16”/Natural Gas</td>
<td>Panther Pipeline, LLC</td>
</tr>
<tr>
<td>ER Measure M-8</td>
<td>8.63”/Natural Gas</td>
<td>Houston Pipeline Company, LLC</td>
</tr>
<tr>
<td>ER Measure M-8</td>
<td>8.63”/Natural Gas</td>
<td>HARVEST PIPELINE COMPANY</td>
</tr>
<tr>
<td>Feature</td>
<td>Size/Type</td>
<td>Owner</td>
</tr>
<tr>
<td>-----------------</td>
<td>-------------------</td>
<td>--------------------------------------------</td>
</tr>
<tr>
<td>ER Measure M-8</td>
<td>3.5”/Natural Gas</td>
<td>MILAGRO EXPLORATION, LLC</td>
</tr>
</tbody>
</table>

Source: TXRR GIS Database, 2018

**Table 8: Pipelines Identified within ER Measure CA-5**

<table>
<thead>
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<th>Feature</th>
<th>Size/Type</th>
<th>Owner</th>
</tr>
</thead>
<tbody>
<tr>
<td>ER Measure CA-5</td>
<td>2.38”/Natural Gas</td>
<td>COX, EDWIN L.</td>
</tr>
<tr>
<td>ER Measure CA-5</td>
<td>4.5”/Natural Gas</td>
<td>ONYX PIPELINE COMPANY</td>
</tr>
<tr>
<td>ER Measure CA-5</td>
<td>3.5”/Natural Gas</td>
<td>CHESAPEAKE OPERATING, LLC</td>
</tr>
<tr>
<td>ER Measure CA-5</td>
<td>2.38-3.5”/Natural Gas</td>
<td>NEUMIN PRODUCTION COMPANY</td>
</tr>
</tbody>
</table>

Source: TXRR GIS Database, 2018

**Table 9: Pipelines Identified within ER Measure CA-6**

<table>
<thead>
<tr>
<th>Feature</th>
<th>Size/Type</th>
<th>Owner</th>
</tr>
</thead>
<tbody>
<tr>
<td>ER Measure CA-6</td>
<td>16”/Natural Gas</td>
<td>HIGH ISLAND GAS LLC</td>
</tr>
<tr>
<td>ER Measure CA-6</td>
<td>Unknown/Natural Gas</td>
<td>LAVACA PIPE LINE COMPANY</td>
</tr>
<tr>
<td>ER Measure CA-6</td>
<td>8.63”/Natural Gas</td>
<td>COASTLAND OPERATIONS, LLC</td>
</tr>
<tr>
<td>ER Measure CA-6</td>
<td>8.63/Crude Oil</td>
<td>BUTTES RESOURCES COMPANY</td>
</tr>
</tbody>
</table>

Source: TXRR GIS Database, 2018

**Table 10: Pipelines Identified within ER Measure SP-1**

<table>
<thead>
<tr>
<th>Feature</th>
<th>Size/Type</th>
<th>Owner</th>
</tr>
</thead>
<tbody>
<tr>
<td>ER Measure SP-1</td>
<td>16”/Natural Gas</td>
<td>ENBRIDGE PIPELINES (TX INTRA) LP</td>
</tr>
<tr>
<td>ER Measure SP-1</td>
<td>12.75”/Natural Gas</td>
<td>CINCO NATURAL RESOURCES CORP.</td>
</tr>
<tr>
<td>ER Measure SP-1</td>
<td>12.75”/Natural Gas</td>
<td>SOUTHCROSS CCNG GATHERING LTD.</td>
</tr>
<tr>
<td>ER Measure SP-1</td>
<td>4.5”/Natural Gas</td>
<td>LAMAR OIL &amp; GAS, INC.</td>
</tr>
<tr>
<td>ER Measure SP-1</td>
<td>12.75”/Natural Gas</td>
<td>SOUTHCROSS CCNG TRANSMISSION LTD</td>
</tr>
</tbody>
</table>

Source: TXRR GIS Database, 2018

All pipelines identified within the ER measure footprints are listed in Table 7 - Table 10. The construction activities specific to each measure will dictate whether pipeline relocation is necessary. It is recommended that pipeline relocation be investigated on a measure by measure basis during final design. It is anticipated that a magnetometer survey will be conducted to verify the location of all pipelines with the ER measure project footprints before final design of these features is conducted.
3 Geotechnical Design Parameter Development

Soil profiles have been developed for axial capacity evaluations. Inputs to the pile capacity calculations include soil strength (either undrained shear strength, \( s_u \), or friction angle, \( \varphi \)), unit weight (\( \gamma \)), and a soil-pile interface coefficient related to the soil type and pile diameter (\( \alpha \) or \( K_S \)). For this feasibility level evaluation, the API (2000) recommendations have been applied. In accordance with that approach, a limiting unit skin friction value is applied for each soil type and consistency. Later stages of design should refine pile capacity estimates based on new geotechnical borings, sampling and testing and allow for pile capacity estimates from cone penetration test data.

At the Clear Creek site, the available historical geotechnical information is sufficiently detailed to support a refinement of a typically clay profile with a sand layer. Dickinson has a similar clay profile with a sandy soil layer. The local available data show the sand layer to be dense to very dense and of sufficient thickness to provide a bearing layer. Additional checks for settlement and consolidation for end bearing piles should be completed at later stages of design as the clay layer underlying the sand is stiff and likely normally consolidated to slightly over consolidated.

At the Galveston Pump Station sites (East and West), the available geotechnical information extends to a maximum depth of 35 feet below grade, and shows a profile comprising silty sand. To derive axial pile capacity values beyond that depth, the stratum has been assumed to extend to 100 feet. Only with further geotechnical data (collected in later project phases or identifying other historical sources) can this estimate be refined.

The resulting axial pile capacity curves are not adjusted for downdrag, scour, or localized site issues such as zones of hard driving or gravels. Pile capacities developed require pilings be driven with an impact hammer to generate specified capacity. As a result, they should be used solely to develop feasibility level design and concept verification. The capacities presented are “ultimate” and should be factored down by a Factor of Safety in accordance with the Hurricane and Storm Damage Risk Reduction System Design Guidelines (HSDRRS, USACE 2012), or other governing design criteria as appropriate. A minimum Factor of Safety of 2.0 is recommended for both tension and compression cases for this feasibility evaluation.

Pile capacities have been developed for the pile types identified in Table 2.

Table 11: Pile Types Used for Axial Pile Calculations

<table>
<thead>
<tr>
<th>Reinforced Concrete Pile Types</th>
<th>Steel Pipe Pile Sizes</th>
</tr>
</thead>
<tbody>
<tr>
<td>12-inch diameter round</td>
<td>12.75-inch outside diameter</td>
</tr>
<tr>
<td>24-inch diameter round</td>
<td>18-inch outside diameter</td>
</tr>
<tr>
<td>36-inch diameter round</td>
<td>24-inch outside diameter</td>
</tr>
<tr>
<td></td>
<td>36-inch outside diameter</td>
</tr>
</tbody>
</table>
3.1 Clear Creek

The Clear Creek soil profile is described in Table 12 below. See Plates 1-a through 1-g for the resulting pile capacities. The soil profile has been developed from information found in McBride-Ratcliff (1982), McBride-Ratcliff (1985), and USACE (1987).

Table 12: Interpreted Soil Profile for Clear Creek Site

<table>
<thead>
<tr>
<th>Layer Depth (ft)</th>
<th>Soil Type</th>
<th>Su (psf)</th>
<th>(\varphi (^{\circ}))</th>
<th>((K_s \text{ or } \alpha)^1)</th>
<th>(N_q^2)</th>
<th>Skin/Tip Limit (ksf)(^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-45</td>
<td>Soft Clay</td>
<td>0.22*(\varphi')</td>
<td>--</td>
<td>(\alpha = 1.0)</td>
<td>9</td>
<td>--</td>
</tr>
<tr>
<td>45-59</td>
<td>Stiff Clay</td>
<td>1500</td>
<td>--</td>
<td>(\alpha = 0.5-0.6)</td>
<td>9</td>
<td>--</td>
</tr>
<tr>
<td>59-100</td>
<td>Very Dense Sand</td>
<td>--</td>
<td>36</td>
<td>(K_s = 0.8-1.0)</td>
<td>16</td>
<td>2 / 200</td>
</tr>
</tbody>
</table>

Notes:
1. Soil-Pile Interface Factor \(K_s\) for sands, adhesion factor \(\alpha\) for clays. \(K_s\) increases for large displacement piles.
2. End-bearing tip factor \(N_q\)
3. Skin friction limit and tip resistance limit per API 2000

3.2 Dickinson Bayou

The Dickinson Bayou soil profile is described in Table 13 below. See Plates 2-a through 2-g for the resulting pile capacities. The soil profile has been developed from geotechnical borehole logs completed for the design of the State Highway 146 Bridge over Dickinson Bayou dated February and March 2000, by Geotest Engineering, Inc. The logs, profile, and location portions of the report were provided on August 10, 2018, as the result of an information request made to the Texas Department of Transportation.

Table 13: Interpreted Soil Profile for Dickinson Site

<table>
<thead>
<tr>
<th>Layer Depth (ft)</th>
<th>Soil Type</th>
<th>Su (psf)</th>
<th>(\varphi (^{\circ}))</th>
<th>((K_s \text{ or } \alpha)^1)</th>
<th>(N_q^2)</th>
<th>Skin/Tip Limit (ksf)(^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-20</td>
<td>Soft Clay</td>
<td>250</td>
<td>--</td>
<td>(\alpha = 1.0)</td>
<td>9</td>
<td>--</td>
</tr>
<tr>
<td>20-65</td>
<td>Stiff Clay</td>
<td>0.242*(\varphi')</td>
<td>--</td>
<td>(\alpha = 0.3-0.8)</td>
<td>9</td>
<td>--</td>
</tr>
<tr>
<td>65-70</td>
<td>Very Dense Sand</td>
<td>--</td>
<td>36</td>
<td>(K_s = 0.8-1.0)</td>
<td>40</td>
<td>2 / 75</td>
</tr>
<tr>
<td>75-85</td>
<td>Very Dense Sand</td>
<td>--</td>
<td>36</td>
<td>(K_s = 0.8-1.0)</td>
<td>40</td>
<td>2 / 200</td>
</tr>
<tr>
<td>85-90</td>
<td>Very Dense Sand</td>
<td>--</td>
<td>36</td>
<td>(K_s = 0.8-1.0)</td>
<td>40</td>
<td>2 / 50</td>
</tr>
<tr>
<td>90-100</td>
<td>Stiff Clay</td>
<td>0.22*(\varphi')</td>
<td>--</td>
<td>(\alpha = 1.0)</td>
<td>9</td>
<td>--</td>
</tr>
</tbody>
</table>

Notes:
1. Soil-Pile Interface Factor \(K_s\) for sands, adhesion factor \(\alpha\) for clays. \(K_s\) increases for large displacement piles.
2. End-bearing tip factor \(N_q\)
3. Skin friction limit and tip resistance limit per API 2000. End bearing limited intentionally at top and bottom of sand layer due to softer clay material above and below.

3.3 Galveston Pump Station Locations

The Galveston Island soil profile is described in Table 14 below. See Plates 3-a through 3-g for the resulting pile capacities. The soil profile has been developed from geotechnical borehole logs by McLellend Engineers (1961) and Fugro South (2003). The references do not include data deeper than 35 feet below site grades at the time of investigation, so the soil conditions have been extrapolated to depths. Both references indicate a relatively sandy profile. The assumed soil profile must be validated by site-specific geotechnical investigation, which should extend to depths beyond estimated pile toe elevations.
### Table 14: Interpreted Soil Profile for Galveston Sites

<table>
<thead>
<tr>
<th>Layer Depth (ft)</th>
<th>Soil Type</th>
<th>Su (psf)</th>
<th>(\phi) (°)</th>
<th>(Ks or (\alpha))(^1)</th>
<th>N(_q)^2</th>
<th>Skin/Tip Limit (ksf)^3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-100</td>
<td>Loose- to Medium-Dense Silty Sand</td>
<td>--</td>
<td>30</td>
<td>K(_s) = 0.8-1.0</td>
<td>12</td>
<td>1.4 / 60</td>
</tr>
</tbody>
</table>

Notes:
1. Soil-Pile Interface Factor K\(_s\) for sands, adhesion factor \(\alpha\) for clays. K\(_s\) increases for large displacement piles.
2. End-bearing tip factor N\(_q\)
4 Conclusions

Axial pile capacity curves have been developed from available geotechnical data for the planned sites in Galveston County, Texas.

For the Clear Lake Pump Station site and Dickinson Bayou site, sufficient geotechnical data are available to develop stratigraphy that would support a concept level design estimate of pile axial capacities. At Galveston sites the available data are more sparse, and actual ground conditions may vary considerable once detailed soils investigations are performed.

For larger concrete pile sizes, pile driving may require a driving shoe or other driving aids to achieve penetration depths, as large hammers necessary to achieve penetration can cause spalling at the pile head, and cracking in tension lower in the piles as the wave energy propagates through the piles. Driven piles relying on end bearing often require pile head displacements of 2-4% or more of pile diameter to engage full end bearing after driving. Hence, larger diameter piles may require larger pile head displacements than permissible to engage this end bearing capacity, and this should be considered in structural design as applicable for the pump stations and flood protection structures.

Steel pipe piles may require additional thickness for corrosivity in saline environments. The axial pile capacities provided have taken the lower of the plugged and unplugged driving conditions.
5 References


USACE. (2018). *NPMS Database for Chambers, Galveston, and Brazoria Counties*. NPMS.


A. Feasibility Level Pile Capacity Curves
NOTES:
1. REDUCE ULTIMATE PILE CAPACITY WITH FACTOR OF SAFETY (FoS) PER HSDRRS, WITH MINIMUM FoS OF 2.0 FOR TENSION AND COMPRESSION.
2. PILE CAPACITIES CALCULATED PER API RP 2A.
4. CAPACITIES PROVIDED FOR FEASIBILITY DESIGN ONLY. NOT FOR CONSTRUCTION OR DETAILED DESIGN.
NOTES:
1. REDUCE ULTIMATE PILE CAPACITY WITH FACTOR OF SAFETY (FoS) PER HSDRRS, WITH MINIMUM FoS OF 2.0 FOR TENSION AND COMPRESSION.
2. PILE CAPACITIES CALCULATED PER API RP 2A.
4. CAPACITIES PROVIDED FOR FEASIBILITY DESIGN ONLY. NOT FOR CONSTRUCTION OR DETAILED DESIGN.
NOTES:
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4. CAPACITIES PROVIDED FOR FEASIBILITY DESIGN ONLY. NOT FOR CONSTRUCTION OR DETAILED DESIGN.
NOTES:
1. REDUCE ULTIMATE PILE CAPACITY WITH FACTOR OF SAFETY (FoS) PER HSDRRS, WITH MINIMUM FoS OF 2.0 FOR TENSION AND COMPRESSION.
2. PILE CAPACITIES CALCULATED PER API RP 2A.
4. CAPACITIES PROVIDED FOR FEASIBILITY DESIGN ONLY. NOT FOR CONSTRUCTION OR DETAILED DESIGN.
PILE DIAMETER: 18-IN
PILE TYPE: PRE-CAST CONCRETE CIRCULAR PILE

NOTES:
1. REDUCE ULTIMATE PILE CAPACITY WITH FACTOR OF SAFETY (FoS) PER HSDRRS, WITH MINIMUM FoS OF 2.0 FOR TENSION AND COMPRESSION.
2. PILE CAPACITIES CALCULATED PER API RP 2A.
4. CAPACITIES PROVIDED FOR FEASIBILITY DESIGN ONLY. NOT FOR CONSTRUCTION OR DETAILED DESIGN.
PILE DIAMETER: 24-IN  PILE TYPE: PRE-CAST CONCRETE CIRCULAR PILE

NOTES:
1. REDUCE ULTIMATE PILE CAPACITY WITH FACTOR OF SAFETY (FoS) PER HSDRRS, WITH MINIMUM FoS OF 2.0 FOR TENSION AND COMPRESSION.
2. PILE CAPACITIES CALCULATED PER API RP 2A.
4. CAPACITIES PROVIDED FOR FEASIBILITY DESIGN ONLY. NOT FOR CONSTRUCTION OR DETAILED DESIGN.
NOTES:
1. REDUCE ULTIMATE PILE CAPACITY WITH FACTOR OF SAFETY (FoS) PER HSDRRS, WITH MINIMUM FoS OF 2.0 FOR TENSION AND COMPRESSION.
2. PILE CAPACITIES CALCULATED PER API RP 2A.
4. CAPACITIES PROVIDED FOR FEASIBILITY DESIGN ONLY. NOT FOR CONSTRUCTION OR DETAILED DESIGN.
5. DRIVABILITY OF LARGE DIAMETER SOLID SECTION CIRCULAR PILES SHOULD BE CONSIDERED. PILES LONGER THAN 80 FEET MAY BE INFEASIBLE.
NOTES:
1. REDUCE ULTIMATE PILE CAPACITY WITH FACTOR OF SAFETY (FoS) PER HSDRRS, WITH MINIMUM FoS OF 2.0 FOR TENSION AND COMPRESSION.
2. PILE CAPACITIES CALCULATED PER API RP 2A.
3. REFERENCE GEOTECH REPORT: GEOTEST ENGINEERING, INC. BOREHOLES COMPLETED FEB 2000. SH146 DICKINSON BAYOU BRIDGE.
4. CAPACITIES PROVIDED FOR FEASIBILITY DESIGN ONLY. NOT FOR CONSTRUCTION OR DETAILED DESIGN.
5. GROUND SURFACE IDENTIFIED APPROXIMATELY ELEVATION 0.
6. CAPACITY INTENTIONALLY LIMITED IN UPPER AND LOWER 5 FEET OF DENSE SAND LAYER.
NOTES:
1. REDUCE ULTIMATE PILE CAPACITY WITH FACTOR OF SAFETY (FoS) PER HSDRRS, WITH MINIMUM FoS OF 2.0 FOR TENSION AND COMPRESSION.
2. PILE CAPACITIES CALCULATED PER API RP 2A.
3. REFERENCE GEOTECH REPORT: GEOTEST ENGINEERING, INC. BOREHOLES COMPLETED FEB 2000. SH146 DICKINSON BAYOU BRIDGE.
4. CAPACITIES PROVIDED FOR FEASIBILITY DESIGN ONLY. NOT FOR CONSTRUCTION OR DETAILED DESIGN.
5. GROUND SURFACE IDENTIFIED APPROXIMATELY ELEVATION 0.
6. CAPACITY INTENTIONALLY LIMITED IN UPPER AND LOWER 5 FEET OF DENSE SAND LAYER.
NOTES:
1. REDUCE ULTIMATE PILE CAPACITY WITH FACTOR OF SAFETY (FoS) PER HSDRRS, WITH MINIMUM FoS OF 2.0 FOR TENSION AND COMPRESSION.
2. PILE CAPACITIES CALCULATED PER API RP 2A.
3. REFERENCE GEOTECH REPORT: GEOTEST ENGINEERING, INC. BOREHOLES COMPLETED FEB 2000. SH146 DICKINSON BAYOU BRIDGE.
4. CAPACITIES PROVIDED FOR FEASIBILITY DESIGN ONLY. NOT FOR CONSTRUCTION OR DETAILED DESIGN.
5. GROUND SURFACE IDENTIFIED APPROXIMATELY ELEVATION 0.
6. CAPACITY INTENTIONALLY LIMITED IN UPPER AND LOWER 5 FEET OF DENSE SAND LAYER.
NOTES:
1. REDUCE ULTIMATE PILE CAPACITY WITH FACTOR OF SAFETY (FoS) PER HSDRRS, WITH MINIMUM FoS OF 2.0 FOR TENSION AND COMPRESSION.
2. PILE CAPACITIES CALCULATED PER API RP 2A.
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NOTES:
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2. PILE CAPACITIES CALCULATED PER API RP 2A.
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4. CAPACITIES PROVIDED FOR FEASIBILITY DESIGN ONLY. NOT FOR CONSTRUCTION OR DETAILED DESIGN.
5. GROUND SURFACE IDENTIFIED APPROXIMATELY ELEVATION 0.
6. CAPACITY INTENTIONALLY LIMITED IN UPPER AND LOWER 5 FEET OF DENSE SAND LAYER.
PILE DIAMETER: 24-IN  
PILE TYPE: PRE-CAST CONCRETE CIRCULAR PILE

NOTES:
1. REDUCE ULTIMATE PILE CAPACITY WITH FACTOR OF SAFETY (FoS) PER HSDRRS, WITH MINIMUM FoS OF 2.0 FOR TENSION AND COMPRESSION.
2. PILE CAPACITIES CALCULATED PER API RP 2A.
3. REFERENCE GEOTECH REPORT: GEOTEST ENGINEERING, INC. BOREHOLES COMPLETED FEB 2000. SH146 DICKINSON BAYOU BRIDGE.
4. CAPACITIES PROVIDED FOR FEASIBILITY DESIGN ONLY. NOT FOR CONSTRUCTION OR DETAILED DESIGN.
5. GROUND SURFACE IDENTIFIED APPROXIMATELY ELEVATION 0.
6. CAPACITY INTENTIONALLY LIMITED IN UPPER AND LOWER 5 FEET OF DENSE SAND LAYER.
PILE DIAMETER: 36-IN

PILE TYPE: PRE-CAST CONCRETE CIRCULAR PILE

NOTES:
1. REDUCE ULTIMATE PILE CAPACITY WITH FACTOR OF SAFETY (FoS) PER HSDRRS, WITH MINIMUM FoS OF 2.0 FOR TENSION AND COMPRESSION.
2. PILE CAPACITIES CALCULATED PER API RP 2A.
3. REFERENCE GEOTECH REPORT: GEOTEST ENGINEERING, INC. BOREHOLES COMPLETED FEB 2000. SH146 DICKINSON BAYOU BRIDGE.
4. CAPACITIES PROVIDED FOR FEASIBILITY DESIGN ONLY. NOT FOR CONSTRUCTION OR DETAILED DESIGN.
5. GROUND SURFACE IDENTIFIED APPROXIMATELY ELEVATION 0.
6. CAPACITY INTENTIONALLY LIMITED IN UPPER AND LOWER 5 FEET OF DENSE SAND LAYER.
7. DRIVABILITY OF LARGE DIAMETER SOLID SECTION CIRCULAR PILES SHOULD BE CONSIDERED. PILES LONGER THAN 80 FEET MAY BE INFEASIBLE.
NOTES:
1. REDUCE ULTIMATE PILE CAPACITY WITH FACTOR OF SAFETY (FoS) PER HSDRRS, WITH MINIMUM FoS OF 2.0 FOR TENSION AND COMPRESSION.
2. PILE CAPACITIES CALCULATED PER API RP 2A.
4. CAPACITIES PROVIDED FOR FEASIBILITY DESIGN ONLY. NOT FOR CONSTRUCTION OR DETAILED DESIGN.
NOTES:
1. REDUCE ULTIMATE PILE CAPACITY WITH FACTOR OF SAFETY (FoS) PER HSDRRS, WITH MINIMUM FoS OF 2.0 FOR TENSION AND COMPRESSION.
2. PILE CAPACITIES CALCULATED PER API RP 2A.
4. CAPACITIES PROVIDED FOR FEASIBILITY DESIGN ONLY. NOT FOR CONSTRUCTION OR DETAILED DESIGN.

FILE: Galveston E-W PP 18 Final.xlsx
NOTES:
1. REDUCE ULTIMATE PILE CAPACITY WITH FACTOR OF SAFETY (FoS) PER HSDRRS, WITH MINIMUM FoS OF 2.0 FOR TENSION AND COMPRESSION.
2. PILE CAPACITIES CALCULATED PER API RP 2A.
4. CAPACITIES PROVIDED FOR FEASIBILITY DESIGN ONLY. NOT FOR CONSTRUCTION OR DETAILED DESIGN.
NOTES:
1. REDUCE ULTIMATE PILE CAPACITY WITH FACTOR OF SAFETY (FoS) PER HSDRRS, WITH MINIMUM FoS OF 2.0 FOR TENSION AND COMPRESSION.
2. PILE CAPACITIES CALCULATED PER API RP 2A.
4. CAPACITIES PROVIDED FOR FEASIBILITY DESIGN ONLY. NOT FOR CONSTRUCTION OR DETAILED DESIGN.

File: Galveston E-W PP 36 Final.xlsx
NOTES:
1. REDUCE ULTIMATE PILE CAPACITY WITH FACTOR OF SAFETY (FoS) PER HSDRRS, WITH MINIMUM FoS OF 2.0 FOR TENSION AND COMPRESSION.
2. PILE CAPACITIES CALCULATED PER API RP 2A.
4. CAPACITIES PROVIDED FOR FEASIBILITY DESIGN ONLY. NOT FOR CONSTRUCTION OR DETAILED DESIGN.
ULTIMATE PILE CAPACITY 24-IN CONCRETE PILE, GALVESTON EAST AND WEST SITES

NOTES:
1. REDUCE ULTIMATE PILE CAPACITY WITH FACTOR OF SAFETY (FoS) PER HSDRRS, WITH MINIMUM FoS OF 2.0 FOR TENSION AND COMPRESSION.
2. PILE CAPACITIES CALCULATED PER API RP 2A.
4. CAPACITIES PROVIDED FOR FEASIBILITY DESIGN ONLY. NOT FOR CONSTRUCTION OR DETAILED DESIGN.

PILE DIAMETER: 24-IN
PILE TYPE: PRE-CAST CONCRETE CIRCULAR PILE
NOTES:
1. REDUCE ULTIMATE PILE CAPACITY WITH FACTOR OF SAFETY (FoS) PER HSDRRS, WITH MINIMUM FoS OF 2.0 FOR TENSION AND COMPRESSION.
2. PILE CAPACITIES CALCULATED PER API RP 2A.
4. CAPACITIES PROVIDED FOR FEASIBILITY DESIGN ONLY. NOT FOR CONSTRUCTION OR DETAILED DESIGN.
B. Lateral Pile and SOE Analysis
Preliminary Lateral Pile Capacity and Shoring Evaluation Memorandum

November 6, 2018
Preliminary Lateral Pile Capacity and Shoring Evaluation Memorandum

November 6, 2018
Issue and revision record

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<th>Checker</th>
<th>Approver</th>
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<td>10/18/2018</td>
<td>M.J.Walker</td>
<td>C.Brodaek, P.McLaughlin</td>
<td>J.Carter</td>
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<td>S Von Stockhausen</td>
<td>M J Walker</td>
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<td>S Von Stockhausen</td>
<td>M J Walker</td>
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Document reference: 393582-C1

Information class: Standard

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A. Lateral Pile Analysis Results 10
1 Purpose

The Tentatively Selected Plan for the Texas Coastal Protection and Restoration project calls for construction a coastal flood barrier along portions of Galveston Island and Bolivar Peninsula. This barrier is being designed to reduce risk of inundation from storm surge. This memorandum presents the results of lateral pile design calculations and provides those results as recommendations for feasibility-level design. Pile lateral capacities have been developed using available historical geotechnical data at the following locations:

- Clear Creek
- Dickinson Bayou
- City of Galveston Pump Stations (East and West)

This memorandum uses the same stratigraphic information developed for a similar feasibility-level analysis of axial pile capacities, published under separate cover. Additionally, this memorandum includes a cursory evaluation of the depth of support of excavation (SOE) that would be required to function as a cutoff for seepage flow, and provides recommendations for the lateral loads to be exerted on those walls.
2 Data Collection

2.1 Geotechnical Data

Mott MacDonald has compiled a GIS database of the available geotechnical information in the region of the proposed improvements. The historical geotechnical reports date from the 1950s through the early 2000s. Few cone penetration tests are available in the data, and soil sampling typically used standard penetration tests without hammer energy measurements. Some locations include geotechnical data to depths appropriate for design of foundations for the Coastal Texas project, but many are for shallow improvements such as roadways or low levees.

Geotechnical data to support foundation design would include boreholes with sampling at regular intervals or cone penetration tests extending below specified pile tip elevations.

2.1.1 Vertical Datums

The various sources use various datums for reference. Some refer to the National Geodetic Vertical Datum (NGVD29), North American Vertical Datum (NAVD88), or simply depth below mudline. During subsequent phases of the project, these datums should be reconciled.

2.1.2 Borings

The available data for four flood protection and pump station sites have been evaluated: Clear Creek, Dickinson Bayou, Galveston East, and Galveston West. The data available for each site are described in Table 1 below. See the references section of this memorandum for details regarding each report. Generally, only the Clear Creek and Dickinson geotechnical conditions are well characterized for the purposes of feasibility level lateral pile capacity estimates.

Table 1: Source Geotechnical Information for Site.

<table>
<thead>
<tr>
<th>Site Name</th>
<th>Geotechnical Data</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear Creek</td>
<td>Site-specific boreholes to 75 feet below onshore grade.</td>
<td>McBride-Ratcliff and Associates (1982)</td>
</tr>
<tr>
<td>Clear Creek</td>
<td>Site-specific boreholes to 90 feet below onshore grade.</td>
<td>McBride-Ratcliff and Associates (1985)</td>
</tr>
<tr>
<td>Clear Creek</td>
<td>Site-specific boreholes to -80 feet, NGVD. Stratigraphy and unconfined compression strength.</td>
<td>USACE (1987)</td>
</tr>
<tr>
<td>Dickinson Bayou</td>
<td>Boreholes to approximately 20 feet below grade located greater than 2,500 feet away. No SPT N values.</td>
<td>USACE (1962)</td>
</tr>
<tr>
<td>Dickinson Bayou</td>
<td>Site specific boreholes for SH146 Bridge over Dickinson Bayou.</td>
<td>Geotest Engineering (2000)</td>
</tr>
<tr>
<td>Galveston West</td>
<td>Site-specific boreholes to 27.5 feet depth below mudline.</td>
<td>USACE (1958)</td>
</tr>
<tr>
<td>Galveston East</td>
<td>Site-specific boreholes to 35 feet depth below nearby site grade.</td>
<td>Fugro South (2003)</td>
</tr>
<tr>
<td>Galveston East</td>
<td>Boreholes to 5 feet below nearby site grade approximately 1,500 feet to the south. Generally not relevant for this study.</td>
<td>McLellend Engineers (1961)</td>
</tr>
</tbody>
</table>
2.1.3 Soil Samples

The soil sampling documented in the historical geotechnical reports comprises standard penetration tests (SPT), which yield generally disturbed samples not appropriate for advanced laboratory testing and strength characterization. For the Clear Creek site, the USACE (1987) work included unconfined compression test profiles. This profile indicates a relatively weak (unconfined compressive strength values between 400 and 800 psf), near-surface clay layer overlying stiff to very stiff clays (unconfined compressive strength values between 1,200 and 3,000 psf).

For locations with geotechnical investigation information that did not reach sufficient depth, the conditions documented in the available data were extended for the analysis. For instance, the generally sandy profiles at Galveston east and west sites are extrapolated from data extending only to about 35 feet. Data at Clear Creek and Dickinson Bayou extend to approximately 100 feet.

2.2 Bathymetry and Topography

Generally, the available geotechnical data were collected referencing the onshore ground surface, NGVD29 vertical datum, or the mudline. A generalized stratigraphy has been developed at each location for depth below surface grade or mudline and does not consider depth of water above.
3 Geotechnical Design Parameter Development

Soil profiles have been developed for axial capacity evaluations. Inputs to the pile capacity calculations include soil strength (either undrained shear strength, $s_u$, or friction angle, $\varphi$), unit weight ($\gamma$), and lateral soil stiffness parameters. For this feasibility level evaluation, the suggested values provided by ENSOFT in the Technical Manual for LPile 2015 (2015) have been used with adjustments based on soil type and strength results. With additional geotechnical investigation, including cone penetration tests, it may be possible to refine these values.

At the Clear Creek site, the available historical geotechnical information is sufficiently detailed to support a refinement of a typically clay profile with a sand layer. Dickinson has a similar clay profile with a sandy soil layer. The local available data show the sand layer to be dense to very dense and of sufficient thickness to provide a bearing layer for axial pile capacity. This has been incorporated in the Clear Creek soil model for lateral pile analysis.

At the Galveston Pump Station sites (East and West), the available geotechnical information extends to a maximum depth of 35 feet below grade, and shows a profile comprising silty sand. To derive axial pile capacity values beyond that depth, the stratum was assumed to extend to 100 feet. This model has been applied to the lateral pile analysis. Only with further geotechnical data (collected in later project phases or identifying other historical sources) can this estimate be refined.

The resulting lateral pile capacity (shear), moments developed in the piles, and resulting displacements assume the load is applied at the pile head and the pile head is at the soil surface. Thus, if the piles are immersed or extend above the mudline to support the superstructure, the cantilevered rotation and displacement will be larger. No scour has been incorporated into the soil model. These results should be used solely to develop feasibility level design and concept verification. The capacities presented are “ultimate” and should be factored down by a Factor of Safety in accordance with the Hurricane and Storm Damage Risk Reduction System Design Guidelines (HSDRRS, USACE 2012), or other governing design criteria as appropriate. For groups of piles, the use of ENSOFT GROUP can be used with the soil parameters presented in the tables below. GROUP would be used to identify the reductions in pile lateral capacities for shadowing effects caused by rows of piles.

Pile capacities have been developed for the pile types identified in Table 2. The stratigraphic models are described in subsequent sections. The results of the analyses are attached to this memorandum for these piles pushed in free head conditions to 0.25 inches, 0.5 inches, 1.0 inches, and 2.0 inches.

Table 2: Pile Types Used for Lateral Pile Calculations

<table>
<thead>
<tr>
<th>Pile Types</th>
<th>Structural Properties</th>
<th>Pile Sizes</th>
</tr>
</thead>
<tbody>
<tr>
<td>12-inch dia. steel pipe</td>
<td>$E = 30,000$ksi, $F_y = 50$ksi</td>
<td>12.75-inch OD, 3/8-inch thickness</td>
</tr>
<tr>
<td>24-inch dia. steel pipe</td>
<td>$E = 30,000$ksi, $F_y = 50$ksi</td>
<td>24-inch OD (nominal) 1/2-inch thickness</td>
</tr>
<tr>
<td>24-inch dia. concrete</td>
<td>$F_c' = 4,000$psi, 2% steel, 3-inches concrete cover</td>
<td>24-inch outside diameter, round</td>
</tr>
</tbody>
</table>

Note: All pile lengths were assumed 80 feet for this analysis. Actual lengths to be determined by structural engineer.
3.1 Clear Creek

The Clear Creek soil profile is described in Table 3 below. The soil profile has been developed from information found in McBride-Ratcliff (1982), McBride-Ratcliff (1985), and USACE (1987).

**Table 3: LPile Soil Profile for Clear Creek Site**

<table>
<thead>
<tr>
<th>Layer Depth (ft)</th>
<th>Soil Type</th>
<th>Su (psf)(^1)</th>
<th>(\varphi) ((^{\circ}))</th>
<th>(\gamma'^1) (pcf)(^2)</th>
<th>LPILE Soil Type</th>
<th>k (pci)</th>
<th>(\varepsilon_{50})</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-45</td>
<td>Soft Clay</td>
<td>0.22*(\gamma_{vo}') (225)</td>
<td>--</td>
<td>45</td>
<td>Stiff Clay w/ Free Water</td>
<td>300</td>
<td>0.02</td>
</tr>
<tr>
<td>45-59</td>
<td>Stiff Clay</td>
<td>1500</td>
<td>--</td>
<td>45</td>
<td>Stiff Clay w/ Free Water</td>
<td>500</td>
<td>0.02</td>
</tr>
<tr>
<td>59-100</td>
<td>Very Dense Sand</td>
<td>--</td>
<td>36</td>
<td>65</td>
<td>Reese Sand</td>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>

Notes:
1 For a shear strength varying with depth, an average value was calculated using \(\gamma^v\)' at the midpoint of the layer. The average value is reported in parentheses.
2 Effective Unit Weight is denoted by \(\gamma^v\)'

3.2 Dickinson Bayou

The Dickinson Bayou soil profile is described in Table 4 below. The soil profile has been developed from geotechnical borehole logs completed for the design of the State Highway 146 Bridge over Dickinson Bayou dated February and March 2000, by Geotest Engineering, Inc. The logs, profile, and location portions of the report were provided on August 10, 2018, as the result of an information request made to the Texas Department of Transportation.

**Table 4: Interpreted Soil Profile for Dickinson Site**

<table>
<thead>
<tr>
<th>Layer Depth (ft)</th>
<th>Soil Type</th>
<th>Su (psf)(^1)</th>
<th>(\varphi) ((^{\circ}))</th>
<th>(\gamma'^1) (pcf)(^2)</th>
<th>LPILE Soil Type</th>
<th>k (pci)</th>
<th>(\varepsilon_{50})</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-20</td>
<td>Soft Clay</td>
<td>250</td>
<td>--</td>
<td>45</td>
<td>Stiff Clay w/ Free Water</td>
<td>250</td>
<td>0.02</td>
</tr>
<tr>
<td>20-65</td>
<td>Stiff Clay</td>
<td>0.242*(\gamma_{vo}') (460)</td>
<td>--</td>
<td>45</td>
<td>Stiff Clay w/ Free Water</td>
<td>400</td>
<td>0.02</td>
</tr>
<tr>
<td>65-75</td>
<td>Very Dense Sand</td>
<td>--</td>
<td>36</td>
<td>65</td>
<td>Reese Sand</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>75-85</td>
<td>Very Dense Sand</td>
<td>--</td>
<td>36</td>
<td>65</td>
<td>Reese Sand</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>85-90</td>
<td>Very Dense Sand</td>
<td>--</td>
<td>36</td>
<td>65</td>
<td>Reese Sand</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>90-100</td>
<td>Stiff Clay</td>
<td>0.22*(\gamma_{vo}') (1050)</td>
<td>--</td>
<td>45</td>
<td>Stiff Clay w/ Free Water</td>
<td>500</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Notes:
1 For a shear strength varying with depth, an average value was calculated using \(\gamma^v\)' at the midpoint of the layer. The average value is reported in parentheses.
2 Effective Unit Weight is denoted by \(\gamma^v\)'

3.3 Galveston Pump Station Locations

The Galveston Island soil profile is described in Table 5 below. The soil profile has been developed from geotechnical borehole logs by McLelland Engineers (1961) and Fugro South (2003). The references do not include data deeper than 35 feet below site grades at the time of investigation, so the soil conditions have been extrapolated to depths. Both references indicate
a relatively sandy profile. The assumed soil profile must be validated by site-specific geotechnical investigation, which should extend to depths beyond estimated pile toe elevations.

Table 5: Interpreted Soil Profile for Galveston Sites

<table>
<thead>
<tr>
<th>Layer Depth (ft)</th>
<th>Soil Type</th>
<th>Su (psf)</th>
<th>φ (°)</th>
<th>γ11 (pcf)²</th>
<th>LPile Soil Type</th>
<th>k (pci)</th>
<th>ε50</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-100</td>
<td>Loose-to Medium-Dense Silty Sand</td>
<td>--</td>
<td>30</td>
<td>55</td>
<td>Reese Sand</td>
<td>20</td>
<td>--</td>
</tr>
</tbody>
</table>

Notes:
1 Effective Unit Weight is denoted by γ'
4 Shoring Recommendations

Feasibility-level analyses were performed for a sand and clay profile in order to evaluate approximate minimum depth of embedment to form a water seepage cut-off. The objective of the analysis was to identify the depth of embedment required to reduce the seepage head \( i \) below the critical exit gradient \( i_{\text{crit}} \). With \( i/i_{\text{crit}} \) less than unity, the bottom of excavation is anticipated to be stable from seepage. The volume of seepage may still require dewatering systems, particularly for the sandy soil profile at the Galveston sites. At this stage of design and with the limited available geotechnical information, determination of groundwater flow volumes is premature, but should be considered once excavation geometry is finalized. Using simplified manual flow net procedures, assumed permeability values, and simplified geometry, we have estimated the depth of embedment to lower the exit gradient below the critical exit gradient.

The Rankine lateral pressures acting on anticipated temporary SOE have also been calculated. The resulting active pressures assume that the walls will be free to rotate sufficiently to mobilize the active condition. Internal bracing may alter these loads and would need to be evaluated during later stages of design. The results from the feasibility-level analyses for shoring recommendations are presented in Table 6.

Table 6: Shoring Embedment and Lateral Pressure Recommendations

<table>
<thead>
<tr>
<th>Profile</th>
<th>Embedment Depth for Flow Net Analysis</th>
<th>Active Below GWT (psf/foot)</th>
<th>Active Above GWT (psf/foot)</th>
<th>Passive* Below GWT (psf/foot)</th>
<th>Passive* Above GWT (psf/foot)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>30 ft</td>
<td>80</td>
<td>40</td>
<td>225</td>
<td>350</td>
</tr>
<tr>
<td>Clay</td>
<td>30 ft</td>
<td>85</td>
<td>55</td>
<td>155</td>
<td>220</td>
</tr>
</tbody>
</table>

Notes:
- Assumed excavation depth is 35 feet below surrounding site grades.
- Assumed excavation with is 100 feet for purposes of developing the flow net.
- *Neglect the first two feet of embedment for passive pressure development.
- GWT = groundwater table. For the calculation of lateral loads, this can be assumed to be equivalent to the mean higher high water determined locally.
5 Conclusions

Lateral pile analyses have been developed from available geotechnical data for the planned sites in Galveston County, Texas. Lateral loads on temporary SOE have been estimated, and the

For the Clear Lake Pump Station site and Dickinson Bayou site, sufficient geotechnical data are available to develop stratigraphy that would support a concept level design estimate of pile lateral capacities. At Galveston sites the available data are more sparse, and actual ground conditions may vary considerable once detailed soils investigations are performed.

Steel pipe piles may require additional thickness for corrosivity in saline environments. The lateral pile capacities provided have considered nominal wall thicknesses only, and are not reduced for corrosion section loss.
6 References


USACE. (2018). *NPMS Database for Chambers, Galveston, and Brazoria Counties*. NPMS.


A. Lateral Pile Analysis Results
24-INCH CONCRETE
CLEAR CREEK
(0.25'', 0.5'', 1'', 2'')
Lateral Pile Deflection (inches)

Bending Moment (in-kips)

Shear Force (kips)

Depth (ft)

24inch concrete - 0.25inch

Stf. Cl. W

Sand
24-INCH CONCRETE

DICKINSON

(0.25", 0.5", 1", 2")
Lateral Pile Deflection (inches)

Bending Moment (in-kips)

Shear Force (kips)

- 24inch concrete - 0.25 inch

Stf. Cl. W

Sand
24-INCH CONCRETE

GALVESTON

(0.25'', 0.5'', 1'', 2'')
Lateral Pile Deflection (inches)

Bending Moment (in-kips)

Shear Force (kips)

Depth (ft)

24inch concrete - 0.25 inch

Sand
24 inch concrete - 1 inch Sand
12.75-INCH STEEL PIPE

CLEAR CREEK

(0.25", 0.5", 1", 2")
12.75-INCH STEEL PIPE

DICKINSON

(0.25'', 0.5'', 1'', 2'')
- Lateral Pile Deflection (inches)
- Bending Moment (in-kips)
- Shear Force (kips)

- Depth (ft)

- 12.75 inch steel - 0.25 inch

- Stf. Cl. W

- Sand
12.75 inch steel - 0.5 inch

Lateral Pile Deflection (inches)

Bending Moment (in-kips)

Shear Force (kips)

Stf. Cl. W

Sand
Lateral Pile Deflection (inches)

Bending Moment (in-kips)

Shear Force (kips)

Depth (ft)

12.75inch steel - 2 inch

Stf. Cl. W

Stf. Cl. W

Sand
12.75-INCH STEEL PIPE

GALVESTON

(0.25", 0.5", 1", 2")
12.75 steel - 0.25 inch

Sand
Lateral Pile Deflection (inches)

Bending Moment (in-kips)

Shear Force (kips)

Depth (ft)

-0.1 0 0.1 0.2 0.3 0.4

-100 0 100 200 300 400 500

-4 -2 0 2 4 6 8

12.75 inch steel - 0.5 inch

Sand
Lateral Pile Deflection (inches)

Bending Moment (in-kips)

Shear Force (kips)

- 12.75 inch steel - 1 inch

Sand
Lateral Pile Deflection (inches)

Bending Moment (in-kips)

Shear Force (kips)

\[
\begin{align*}
\text{Depth (ft)} & = 0, 0.5, 1, 1.5 \\
\text{Lateral Pile Deflection (inches)} & = 0, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80 \\
\text{Bending Moment (in-kips)} & = 0, 200, 400, 600, 800, 1000, 1200, 1400 \\
\text{Shear Force (kips)} & = -20, -10, 0, 10, 20, 30 \\
\end{align*}
\]

12.75 inch steel - 2 inch

Sand
24-INCH STEEL PIPE

CLEAR CREEK

(0.25", 0.5", 1", 2")
24-INCH STEEL PIPE

DICKINSON

(0.25", 0.5", 1", 2")
Lateral Pile Deflection (inches)

Bending Moment (in-kips)

Shear Force (kips)

Depth (ft)

24 inch steel - 0.5 inch

Stf. Cl. W

Sand
Lateral Pile Deflection (inches)

Bending Moment (in-kips)

Shear Force (kips)

Depth (ft)

24inch steel - 1 inch

Stf. Cl. W

Sand
Lateral Pile Deflection (inches)

Bending Moment (in-kips)

Shear Force (kips)

Depth (ft)

Depth (ft)

Depth (ft)

0
0.5
1
1.5
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
-1000
0
1000
2000
3000
4000
-20
-10
0
10
20
30
40
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80

24 inch steel - 2 inch

Stf. Cl. W

Sand
24-INCH STEEL PIPE

GALVESTON

(0.25", 0.5", 1", 2")
Lateral Pile Deflection (inches)

Bending Moment (in-kips)

Shear Force (kips)

Depth (ft)

-2000
-1000
0
1000
2000
3000
4000

-30
-20
-10
0
10
20
30
40

24inch steel - 1 inch

Sand