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Federal Highway Administration

CORPUS CHRISTI MPO METROPOLITAN PLANNING ORGANIZATION

LAGUNA SHORES ROAD IN CORPUS CHRISTI, TX RESILIENCE DURABILITY TO EXTREME WEATHER PILOT PROJECT

REPORT JUNE 8, 2021

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DISCLAIMER

This report was developed by the Corpus Christi Metropolitan Planning Organization (Corpus Christi MPO) in accordance with a research grant from the Federal Highway Administration (FHWA). The statements, findings, conclusions, and recommendations are those of the authors and do not necessarily reflect the views of FHWA or the U.S. Department of Transportation.

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EXHIBITS

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16. Abstract

The Corpus Christi Metropolitan Planning Organization (MPO) received support from the Federal Highway Administration (FHWA) to deploy a nature-based shoreline protection feature to enhance the resilience to extreme weather of a roadway along the western shore of the Laguna Madre in Corpus Christi, Texas. The MPO was awarded $110,770 from FHWA to support design of an innovative, nature-based shoreline protection feature as part of an applied research deployment. A total of $22,154 (20%) was leveraged as in-kind, non-federal match in the form of partner staff time. Construction of the pilot nature-based shoreline protection feature, estimated to be $180,000, will be funded by the City of Corpus Christi but is not being proposed as match.

Laguna Shores Road, which runs along the western shoreline of the Laguna Madre between SH 358 and the Barney M. Davis Energy Center, is a major north-south thoroughfare in the Flour Bluff neighborhood of Corpus Christi. Laguna Shores Road may eventually provide an alternative for connectivity to Segment A of the seven-segment Regional Parkway Mobility Corridor (Regional Parkway), for which a Planning and Environmental Linkages (PEL) study was completed in 2016. The Regional Parkway will be a multi-modal facility that will help alleviate congestion on SH 358, will serve as a second route for evacuation of the most vulnerable parts of the City, and will enhance connectivity to the fastest growing portions of the community. This roadway was identified as a priority multi-modal corridor in the community's Strategic Plan for Active

Mobility, Phase 1 – Bicycle Mobility (2016).

The City of Corpus Christi is currently initiating the design phase of a project to rebuild three separate portions of Laguna Shores Road to improve the level of service and reduce susceptibility to inundation; construction was expected to begin in Spring of 2019. Under existing conditions, several locations along Laguna Shores Road are subject to periodic inundation under spring tide and other typical (non-storm) conditions. Likewise, shoreline erosion has historically undermined the roadway in multiple locations, which has direct negative impacts on project lifecycle, maintenance costs, and public safety. These locations are particularly susceptible to the impacts of storm surge and extreme weather events, and this vulnerability will increase in the face of sea level rise.

The southern end of Segment 1 of the reconstruction project is particularly vulnerable to extreme weather. At this location, there is no habitat buffer between the roadway and the open water of the Laguna Madre; the toe of the slope on the eastern side of the roadway is literally in the intertidal zone. This location is representative of significant portions of Laguna Shores Road, making it an ideal site for a pilot implementation of innovative shoreline protection techniques.

The Local Government led a collaborative effort and has:

- Assessed baseline habitat and shoreline conditions.
- Identified one or more innovative shoreline protection strategies that integrate engineering and ecological (habitat restoration/living shoreline) techniques.
- Constructed a pilot shoreline protection project as part of the roadway reconstruction project.
- Monitored project effectiveness in terms of habitat development and shoreline condition while evaluating the utility of pilot technique(s) used to enhance the durability of other segments of Laguna Shores Road and other, similarly vulnerable transportation infrastructure.

This project was a collaborative effort, wherein staff at the MPO managed an interdisciplinary team of specialized experts from the academic, environmental non-profit, municipal, and private sectors.

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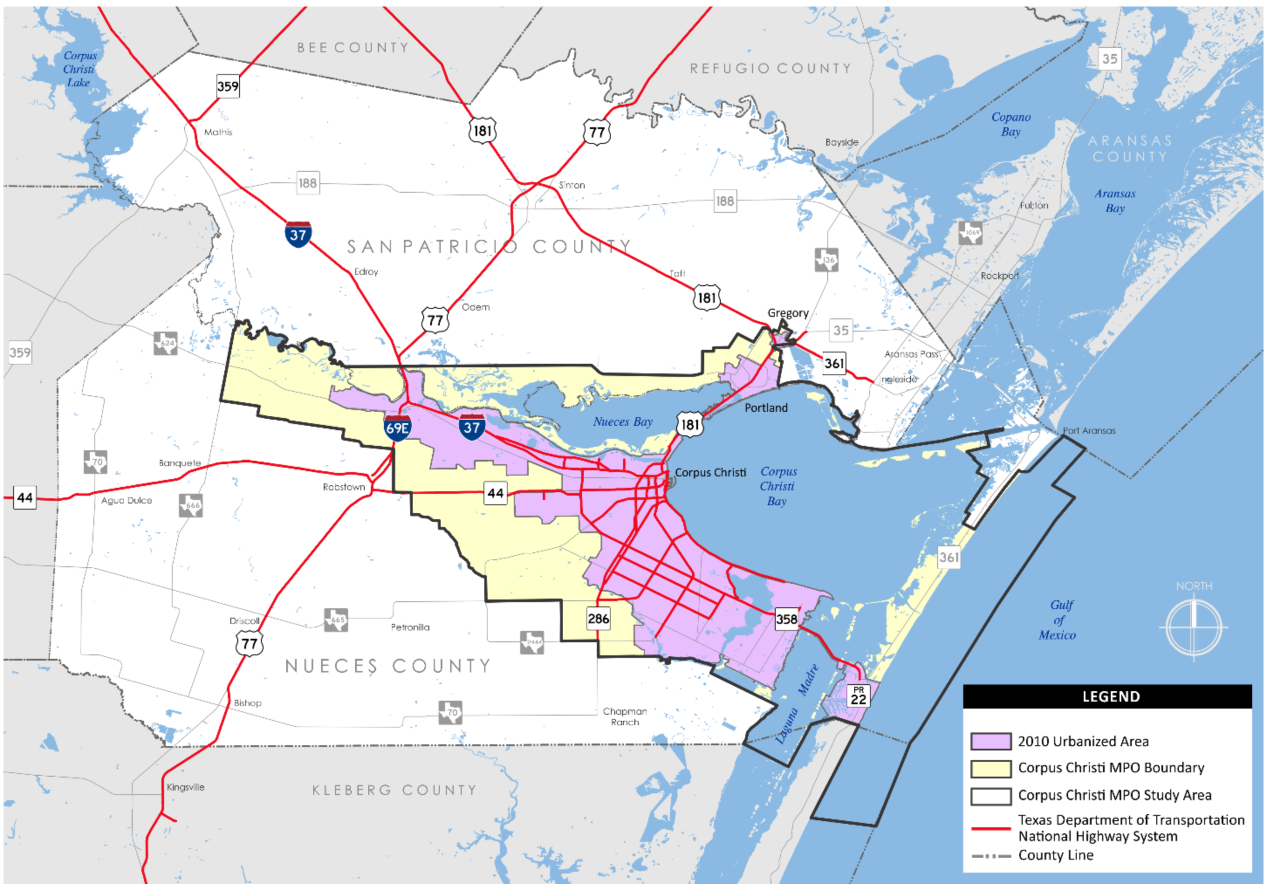
I. Introduction

a. Description of the Project Area

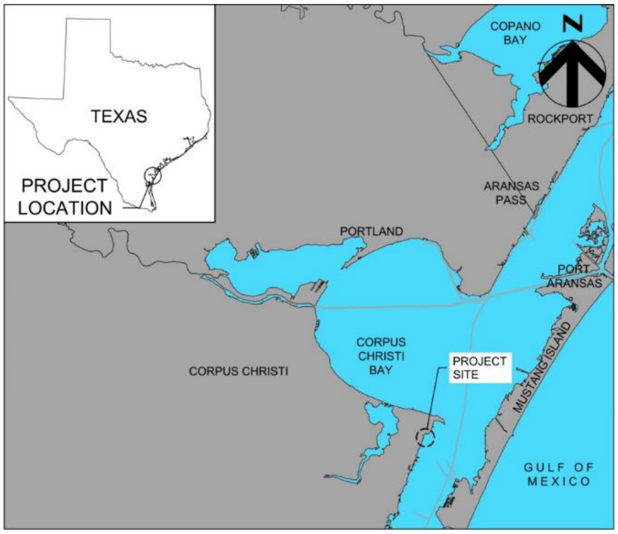
Laguna Shores Road, which runs along the western shoreline of the Laguna Madre between SH 358 and the Barney M. Davis Energy Center, is a major north-south thoroughfare in the Flour Bluff neighborhood of Corpus Christi (see Exhibits 1-3). Laguna Shores Road may eventually provide an alternative for connectivity to Segment A of the seven-segment Regional Parkway Mobility Corridor (Regional Parkway), for which a Planning and Environmental Linkages (PEL) study was completed in 2016. The Regional Parkway will be a multi-modal facility that will help alleviate congestion on SH 358, will serve as a second route for evacuation of the most vulnerable parts of the City, and will enhance connectivity to the fastest growing portions of the community. This roadway was identified as a priority multi-modal corridor in the community's Strategic Plan for Active Mobility, Phase 1 – Bicycle Mobility (2016).

Exhibit 1. Map of the Corpus Christi Metropolitan Planning Organization Area



The southern end of Segment 1 of the reconstruction project is particularly vulnerable to extreme weather. At this location, there is no habitat buffer between the roadway and the open water of the Laguna Madre; the toe of the slope on the eastern side of the roadway is in the intertidal zone. This location is representative of significant portions of Laguna Shores Road, making it an ideal site for a pilot implementation of innovative shoreline protection techniques.

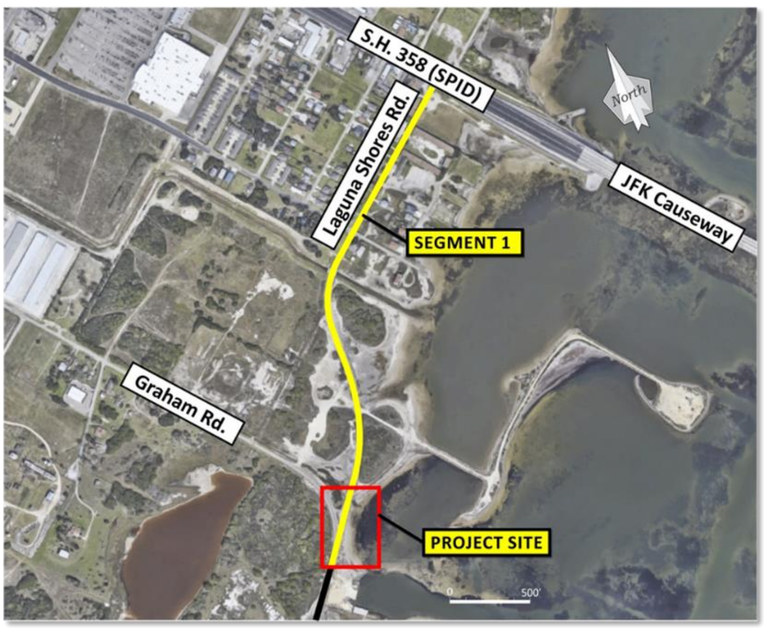
Exhibit 2. Maps of Laguna Shores Road Site Layout



Vicinity Map

Location Map

Exhibit 3. Map of Laguna Shores Road Project Location and Scope



- The pilot project is located on Laguna Shores Road, a major north-south thoroughfare in the Flour Bluff neighborhood of Corpus Christi, TX.
- Roadway runs along the western shoreline of Laguna Madre.
- Roadway is vulnerable to erosion, inundation, and other chronic and acute impacts from rising sea levels and coastal storm activity.
- Efforts to construct a nature-based shoreline protection feature of a shellfish habitat and saltwater marsh. This will help to create a more resilient roadway and improve level of service and reduce susceptibility to inundation.

b. General Approach/Project Description

The Corpus Christi Metropolitan Planning Organization (MPO) requested support from the Federal Highway Administration (FHWA) to deploy a nature-based shoreline protection feature to enhance the resilience to extreme weather of a roadway along the western shore of the Laguna Madre in Corpus Christi, Texas. The MPO received $110,770 from FHWA to support design of an innovative, nature-based shoreline protection feature as part of an applied research deployment. A total of $22,154 (20%) was leveraged as an in-kind, non-federal match in the form of partner staff time. Construction of the pilot nature-based shoreline protection feature, estimated to be $180,000, was funded by the City of Corpus Christi but was not proposed as a match.

Exhibit 4. Images of Pilot Project Initial Condition

Looking south at the project location on Laguna Shores Road under typical (non-storm) conditions. Photo credit: Corpus Christi MPO.

Close-up, note the irregular edge of pavement and proximity to open water. Photo credit: Corpus Christi MPO.

The City of Corpus Christi initiated the design phase of a project to rebuild three separate portions of Laguna Shores Road to improve the level of service and reduce susceptibility to inundation; construction was expected to begin in Spring of 2019. Under existing conditions, several locations along Laguna Shores Road are subject to periodic inundation under spring tide and other typical (non-storm) conditions. Likewise, shoreline erosion has historically undermined the roadway in multiple locations, which has direct negative impacts on the roadway's useable life, maintenance costs, and public safety. These locations are particularly susceptible to the impacts of storm surge and extreme weather events, and this vulnerability will increase in the face of sea level rise.

The Resiliency Project Schedule is provided below.

PROJECT PHASE	2018												2019											
	Q1			Q2			Q3			Q4			Q1			Q2			Q3			Q4		
Pilot selection announced by FHWA																								
Solicitation prepared/published by Corpus Christi MPO																								
Submittals received/service provider selected by Corpus Christi MPO																								
Scope negotiation complete /contract established/NTP delivered to service provider																								
Task 2 – Data Gathering																								
Task 3 – Shoreline/Baseline Habitat Assessment																								
Task 4 – Develop and Evaluate Alternatives for Shoreline Protection Project																								
Task 5 – Engineering Design of Shoreline Protection Project /Coordination with Roadway Design Team																								
Task 6 – Support construction of Shoreline Protection Project (Synched with bond-funded roadway reconstruction)																								
Task 7 – Monitoring and Evaluation																								
Task 8 – Dissemination of Findings												*				*			*			*		

PROJECT PHASE	2020												2021											
	Q1			Q2			Q3			Q4			Q1			Q2			Q3			Q4		
Pilot selection announced by FHWA																								
Solicitation prepared/published by Corpus Christi MPO																								
Submittals received/service provider selected by Corpus Christi MPO																								
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Task 7 – Monitoring and Evaluation																								
Task 8 – Dissemination of Findings	*			*			*			*			*			*			*			*		

PROJECT PHASE	2022											
	Q1			Q2			Q3			Q4		
Pilot selection announced by FHWA												
Solicitation prepared/published by Corpus Christi MPO												
Submittals received/service provider selected by Corpus Christi MPO												
Scope negotiation complete /contract established/NTP delivered to service provider												
Task 2 – Data Gathering												
Task 3 – Shoreline/Baseline Habitat Assessment												
Task 4 – Develop and Evaluate Alternatives for Shoreline Protection Project												
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Task 6 – Support construction of Shoreline Protection Project (Synched with bond-funded roadway reconstruction)												
Task 7 – Monitoring and Evaluation												
Task 8 – Dissemination of Findings	*			*			*			*		

* Indicates report of findings to FHWA

Exhibit 5. Image of Pilot Project Initial Problem

Water spill over Laguna Shores Road after Hurricane Hanna made landfall south of Corpus Christi on Padre Island at 5 p.m., July 25, 2020. A Category 2 storm Hanna made a second landfall at 6:15 p.m. in Kennedy County, south of Corpus Christi. Photo credit: Corpus Christi Caller-Times. Photographer Courtney Sacco. Used by permission.

The Local Government led a collaborative effort to:

- Assessed baseline habitat and shoreline conditions.
- Identified one or more innovative shoreline protection strategies that integrate engineering and ecological (habitat restoration/living shoreline) techniques.
- Constructed a pilot shoreline protection project as part of the roadway reconstruction project.
- Monitored project effectiveness in terms of habitat development and shoreline condition to evaluate the utility of the pilot technique(s) to enhance the durability of other segments of Laguna Shores Road and other, similarly vulnerable transportation infrastructure.

This pilot was a collaborative effort, wherein staff at the MPO managed an interdisciplinary team of specialized experts from the academic, environmental non-profit, municipal, and private sectors.

II. Parties Involved

a. Roles and Responsibilities

The Corpus Christi MPO as the local government for the TxDOT contract and the FHWA Resilience Durability Pilot Project coordinates the delivery of the overall project with our regional and project specific projects. The regional partners are on the following page.

Project Partners include:

In the research program in the Coastal Conservation and Restoration Ecology Lab at Texas A&M University – Corpus Christi (TAMU-CC), Dr. Jennifer Beseres Pollack explored how climate and human-caused changes in environmental conditions affect benthic communities as well as how restoration can play a role in recovering ecosystem services lost due to habitat degradation. She specializes in oyster reef restoration projects in the Coastal Bend area. Dr. Pollack created and oversaw an oyster shell recycling and reef restoration project that has become a prominent vehicle for community engagement in coastal conservation issues. They committed to assist with habitat characterization, identification of target locations within the study area, and development of engineering alternatives. Dr. Pollack and her students employed the Texas General Land Office Rapid Assessment Method (RAM) as part of their Marine Ecology course, which produced high quality, replicable results for the project and yielded a unique, applied, hands-on learning opportunity for the students.

Assistant Professor, Dr. Michael Starek in the Geographic Information Sciences Program at Texas A&M University – Corpus Christi is the Director of the Measurement Analytics Lab in the Conrad Blucher Institute for Surveying and Science. Their foci include geospatial remote sensing and analytics, including LiDAR and UAV approaches, for study of natural and built systems with emphasis on coastal-environmental domains. Dr. Starek and his students committed to utilizing unmanned autonomous vehicle (UAV) technology to collect aerial photogrammetry (including subtidal bathymetric data) as part of the shoreline and habitat surveys.

Rosario Martinez oversees and manages habitat enhancement and water quality projects for the Coastal Bend Bays and Estuaries Program (CBBEP). The Texas General Land Office (TGOL) and CBBEP have undertaken numerous marsh restoration and shoreline protection projects, including the creation of 170 acres of intertidal marsh complex in Nueces Bay, shoreline protection of critical habitat and seagrass meadows in Corpus Christi Bay, and protection of a critical bird rookery island in Corpus Christi Bay. Ms. Martinez is committed to providing technical assistance with habitat assessment and alternatives development and helped identify opportunities for synergy in terms of public outreach and dissemination of findings from this effort.

The City of Corpus Christi Engineering Department committed staff time of their engineers to the project. Most original named engineers left the city before the Laguna Shores Road project started the design and construction phases. The primary staff member assisting in the Resiliency Project coordination was Mr. Larijai (Lj) Francis. He led the city's efforts in the following tasks:

- Assisted with preliminary data collection.
- Evaluated design alternatives for the shoreline protection feature.
- Facilitated incorporation of the engineering plans and specifications for the pilot shoreline protection project into the design and regulatory permitting of the larger roadway reconstruction project.
- Managed procurement of a contractor to construct the pilot shoreline protection project.
- Reviewed/contributed to monitoring reports.

The Corpus Christi MPO hired a consultant team to identify one or more innovative shoreline protection strategies and generate engineering plans and specifications for inclusion in the City's broader roadway reconstruction permitting and construction project. For this service provider, the Corpus Christi MPO hired a firm with interdisciplinary environmental science and coastal engineering capabilities, including demonstrable experience in:

- Evaluating shoreline geomorphology.
- Modeling the influence of wave action to inform scenario-based planning.
- Designing shoreline protection of various types with an emphasis on integrating ecological (living shoreline) components.
- Integrating stakeholders and technical experts from other sectors to produce creative and collaborative solutions.

MPO staff managed the selected consultant and facilitated the integration of the other collaborators into the workflow.

The MPO selected a coastal engineering service provider to identify one or more innovative shoreline protection strategies and generate engineering plans and specifications for inclusion in the City's broader roadway reconstruction permitting and construction project for Laguna Shores Road in the Flour Bluff neighborhood of Corpus Christi, TX.

In support of the City of Corpus Christi's construction activities, the MPO, through the consulting engineer, provided technical assistance to the City of Corpus Christi with regulatory permitting and construction administration of the shoreline protection feature(s).

The Corpus Christi MPO staff coordinated the integration of the project team members from the private, academic, environmental non-profit, and municipal sectors. MPO staff implemented a procurement process to select a private sector consultant to lead the technical scope of work. The MPO staff worked with the selected service provider to refine the project scope, and the selected consultant shared in project management responsibilities.

The Corpus Christi MPO was responsible for selecting the consulting team and project partners TAMU-CC and CBBEP collected a variety of data about historical and existing conditions, including (but not limited to):

- Determining frequency of roadway inundation at project location.
- Gathering/reviewing readily available reports, data (tide, wind, and storm surge), historical aerial photographs, survey, and geophysical data for initial characterization of existing site conditions (MPO and contracted consultant).

The estuarine habitat specialists from the academic and non-profit sectors will develop or adapt a standardized monitoring protocol and will assess the existing (baseline) habitat condition within the project area in order to characterize the dominant vegetative community, including elevation regimes for target marsh species. The team will also identify unique ecological features, opportunities, and/or challenges that may influence evaluation/selection of context-appropriate shoreline protection alternative(s).

The MPO used unmanned aerial vehicle technology to capture aerial photogrammetry and subtidal bathymetric data to inform engineering design of the shoreline protection features. The MPO was responsible for Geotechnical data that was collected in the project location to inform engineering design.

The consulting engineer used as a pattern for prevailing wave conditions and utilize that information, along with available aerial photography and other data, to estimate erosion rates for the study area.

III. Description of the Work Performed

a. Data Gathering for Laguna Shores Road Project Area

The selected consulting team and project partners (TAMU-CC and CBBEP) collected a variety of data about historical and existing conditions, including:

- With City staff, the consultant and MPO determined the frequency of roadway inundation at the project location.
- The consultant and MPO gathered/reviewed readily available reports, data (tide, wind, and storm surge), historical aerial photographs, survey, and geophysical data for the initial characterization of existing site conditions.

A coastal engineering firm was hired to develop the necessary documents and coordinate the resiliency project design with the City of Corpus Christi Engineering Services staff. They received the final topographic and bathymetric survey information collected by TAMU-CC and Coastal Bend and Bay Estuaries Program (CBBEP) that supplements the habitat assessment survey provided by TAMU-CC earlier this year. The information is described below.

The Laguna Shores Digital Elevation Model Report Brief Workflow: The Terrestrial Laser Scanner (TLS) survey was completed on December 1, 2018. The decision was made to do multiple scan positions to be able to capture as much of the exposed shoreline as possible within the 4.7-acre study area. The point cloud was then georeferenced in the scanner's software RiSCAN by using eight tie points collected at the time of the survey. The control points were surveyed at 1-minute occupation times using Virtual Reference Station (VRS), a system composed of hardware and software designed to facilitate real-time Global Positioning System (GPS)/Global Navigation Satellite System (GNSS) positing based on a set of reference stations. VRS corrected the Real Time Kinematic (RTK) GPS, a releative positioning technique that measures the position of two GNSS antennas relative to each other in real-time. The point cloud then had any transitory objects removed before it was exported out of RiSCAN.

The Unmanned Aircraft System (UAS) flight was completed on December 16, 2018 using a DJI Phantom 4 Pro. The flight had eight ground control points with a GSD of 0.47 inches or 0.083 US survey foot (ft-US) with a sidelap and frontlap of 80%. After collection, the Structure-from-Motion (SfM) photogrammetric processing was completed in Pix4dMapper. This resulted in the creation of a 3D point cloud and Digital Surface Model (DSM). Through a series of processing modules using the software LAStools, the remaining noise was removed from the TLS and UAS point clouds. The point clouds were also filtered using a classification algorithm to identify ground versus non-ground points. For the TLS, the ground classified points stemming from the single and last returns were used to interpolate a Digital Terrain Model (DTM) of the bare-earth surface. Similarly, the single and last return points were also used to create a TLS-DSM. Due to the UAS platform being a photogrammetric method, it is considered a single return system.

Therefore, all points were used to attempt to classify ground points. Those points classified as ground were interpolated to generate a UAS DTM. It is important to mention that the ground point classification does not mean those points truly stem from the ground surface. The algorithm employed is an automated method and over the densely vegetated areas of the study site it is very challenging to filter the non-vegetated points. Therefore, the DTMs should only be treated as representing the exposed ground in places not covered by vegetation or landcover. For exposed ground areas the DSMs and DTMs provide very similar elevation values as observed in the tables below.

Exhibit 6. Table of Laguna Shores Digital Elevation

Point Desity				
Platform	Point Density Per Square Survey Foot			
TLS	141.73			
UAS	75.57			
Basic DSM statistics:				
Platform	Min (ft-US)	Max (ft-US)	Mean (ft-US)	Std dev (ft-US)
TLS	0.05000	8.74916	2.47486	1.25416
UAS	-0.45800	8.91497	3.2674	1.81877
Basic DTM statistics:				
Platform	Min (ft-US)	Max (ft-US)	Mean (ft-US)	Std dev (ft-US)
TLS	-0.47244	5.97686	2.29812	1.09244
UAS	-0.48500	6.38200	2.87820	1.44684
DSM Root Mean Square Error:				
Categories	DSM TLS RMSE (ft-US)	DSM UAS RMSE (ft-US)		
Overall Accuracy	1.051974451	0.413533696		
Exposed Beach	0.262161658	0.114489927		
Vegetation	1.923916324	0.697720908		
DTM Root Mean Square Error:				
Categories	DSM TLS RMSE (ft-US)	DSM UAS RMSE (ft-US)		
Overall Accuracy	0.699071096	0.239281908		
Exposed Beach	0.18536735	0.114154315		
Vegetation	1.27457872	0.381713348		

<u>Report prepared by:</u>
Christopher Reynolds, Gradute Research Assisant – Measure Analytics Lab Conrad Blucher Institute for Sureveying
and Science, Texas A&M University – Corpus Christi
Date of Preparation: March 1, 2019. Reviewed and Edited by Dr. Michael Straek on March 21, 2019.

The spatial interpolation method used by LAStools is a TIN interpolation that takes a weighted average based on nearest neighbors using a Delaunay triangulation. The resolution of the interpolation and size of triangles are adjustable to remove areas where point density is low. These DSMs and DTMs were created at a resolution of 0.25 US survey foot (ft-US). All products are referenced to NAD 1983 (2011) State Plane Texas South FIPS 4205 Ft-US and NAVD88 height (ft-US). The DSMs and DTMs were clipped to represent only the main study area and shoreline of interest.

The TLS data had occlusions in certain areas and was clipped to a smaller size than the UAS data. Statistical Results for UAS and TLS DEM accuracy are presented in the Tables above, measured relative to the RTK GPS field survey topo points collected at the study site. When viewing the results, we can see that both the UAS and TLS did not perform well over vegetation due to the occlusion of the ground surface. This is particularly evident in the dense vegetation located in the northern portion of the study area. Although multiple methods were attempted to filter the vegetation out, it was not successful due to the nature of these scanning and imaging techniques. This means that areas over vegetation will have significant elevation error relative to the exposed shoreline or road surface. In contrast, elevation accuracy on the exposed ground surfaces and shoreline is high with approximately a tenth of a foot for both the DSMs and DTMs.

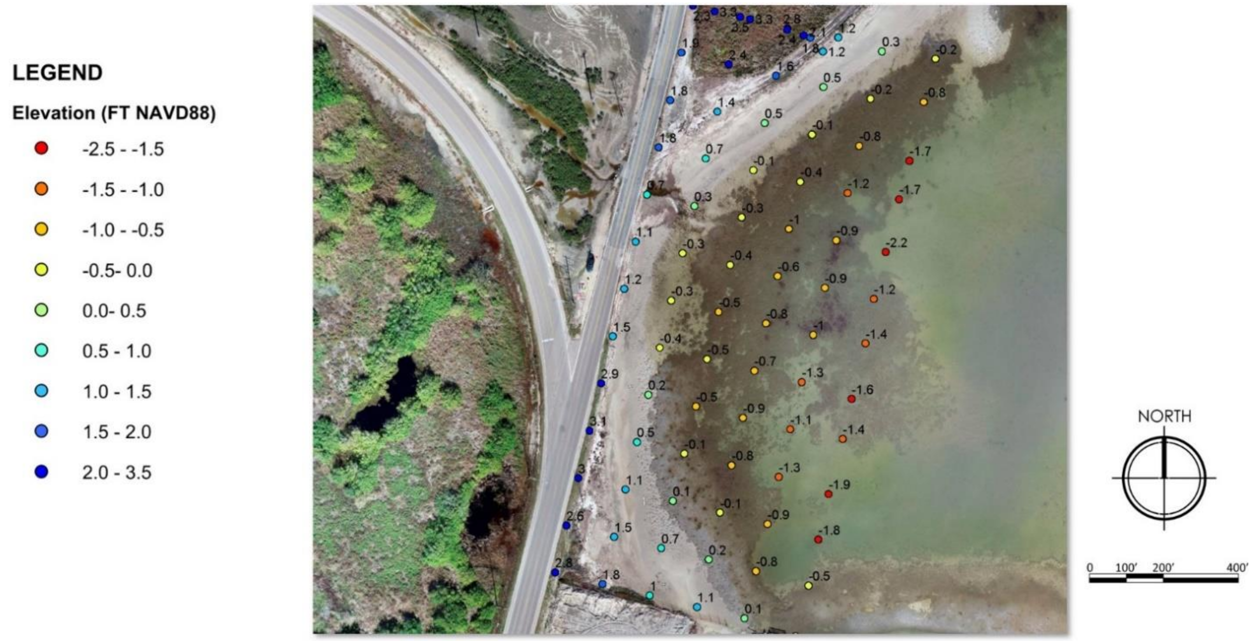
The Quality Report/Calibration Report of the aerial data collection equipment is provide as Appendix A.

The results of the data collection is presented in the following Exhibits 7 through 9.

Exhibit 7. Aerial of Data Collection Locations for Condition Assessment

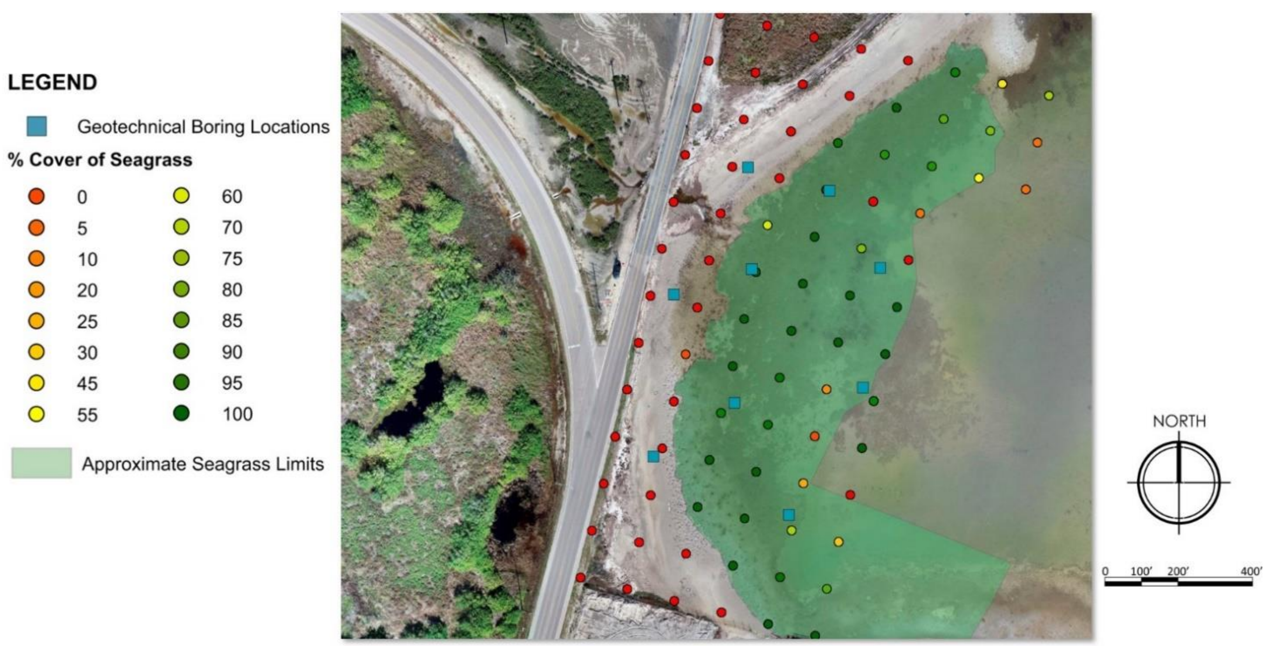
Transets were surveyed at approximately 50 ft spacing perpendicular to Laguna Shores Road and extended approximately 200 ft past the existing shoreline. The annual high tide line and mean low water Cline were also surveyed. The consultant then determined the definition of the annual high tide line and coordinated with surveyors in the field.

Exhibit 8. Aerial of Locations of Elevation Data Collected



Transects included quadrats to note species present and percent cover. The edge of seagrass was delineated. A biologist was on site to assist TAMU-CC. The estuarine habitat specialists from TAMU-CC and BBEP developed/adapted a standardized monitoring protocol and assessed the existing (baseline) habitat condition within the project area in order to characterize the dominant vegetative community, including elevation regimes for target marsh species.

Exhibit 9. Aerial of the Data Collection for Seagrass and Boring Locations



The purpose of the survey was to document the elevations of Spartina alterniflora and associated health at sites adjacent to the proposed project location. A surveyor accompanied a biologist to gather elevation data from the bayward edge of the Spartina through the landward edge.

The geotechnical conditions report in the project area is provided as Appendix B.

b. Lessons Learned

1. The collection of the data required a thoughtful process to allocate resources to determine what information existed and what information was required for the project. The use of students was a great learning experience for them and provided inexpensive labor for the collection of data in an expeditious manner. The students were eager participants in the wading through the water and grassy areas to enable the professionals to collect the data quickly and accurately.
2. The use of the City project information regarding the condition of the roadway and the causes of the damage to the roadway and drainage infrastructure due to wave and tide actions were important in narrowing the focus of this pilot resiliency project to the location selected. The fact that the City was preparing reconstruction in this area was an advantageous opportunity to combine their improvements of raising the roadway and upgraded drainage systems with the added value of the proposed solution identified through the FHWA resiliency project.
3. The application of the process used in this project could be applied easily to other projects being planned in the City and region with similar infrastructure damage along the water that have constant damage from rising tides and wave action. The identification of the possible area and likely applications to make these portions of the infrastructure more resilient is a beneficial undertaking for the local governments in this coastal region. An inventory would be the first step in this process.

c. Alternative Analysis of Shoreline Protections Systems Using Climate Data

The following report documents the alternatives analysis performed for the Laguna Shores Living Shoreline Project. The project is being performed for the Corpus Christi Metropolitan Planning Organization (MPO) and is part of a Federal Highway Administration (FHWA) pilot program that includes applied research and monitoring coordination with TAMU-CC and the CBBEP. The Laguna Shores Living Shoreline Project is also being conducted in coordination with the City of Corpus Christi as part of their Laguna Shores Segment 1 roadway project, which involves raising the roadway elevation between South Padre Island Drive and Graham Road. The intent of the living shoreline component is to provide nature-based shoreline protection to reduce erosion adjacent to Laguna Shores Road, which is currently exposed to the Laguna Madre. This report summarizes the data collection, design criteria development, and design alternatives considered for this project. See Exhibit 10 and Exhibit 11 for project vicinity and location maps.

Exhibit 10. Map of Project Vicinity

Exhibit 11. Map of Project Location

Exisiting Conditions (1)

This section summarizes habitat, survey, and geotechnical investigations, along with data gathering of meteorological and oceanographic conditions near the project site.

Habitat Assessment (1.1)

Habitat assessments were conducted by Harte Research Institute (HRI) of TAMU-CC and by the engineering consultant in November 2018. Habitat assessments identified the limits of seagrass (Halodule wrightii) growth and the percentage of seagrass coverage within 1 square meter quadrangles placed on a 50 ft grid (RTK GPS survey points were taken at the same locations). The landward extent of seagrass was typically located between -1.0 ft and 0.0 ft NAVD1.

Smooth cordgrass (Spartina alterniflora) is the intertidal vegetation species typically targeted for marsh restoration. The ground elevation that supports Spartina growth is sensitive to the local intertidal elevation range. Spartina was not found at the immediate project site, but a reference marsh survey found Spartina 0.2 miles north of the project site growing between elevations +0.8 ft and +1.2 ft. Other natural resources that would influence the living shoreline design were not found in the project area. See Exhibit 12 for a summary of the habitat assessment.

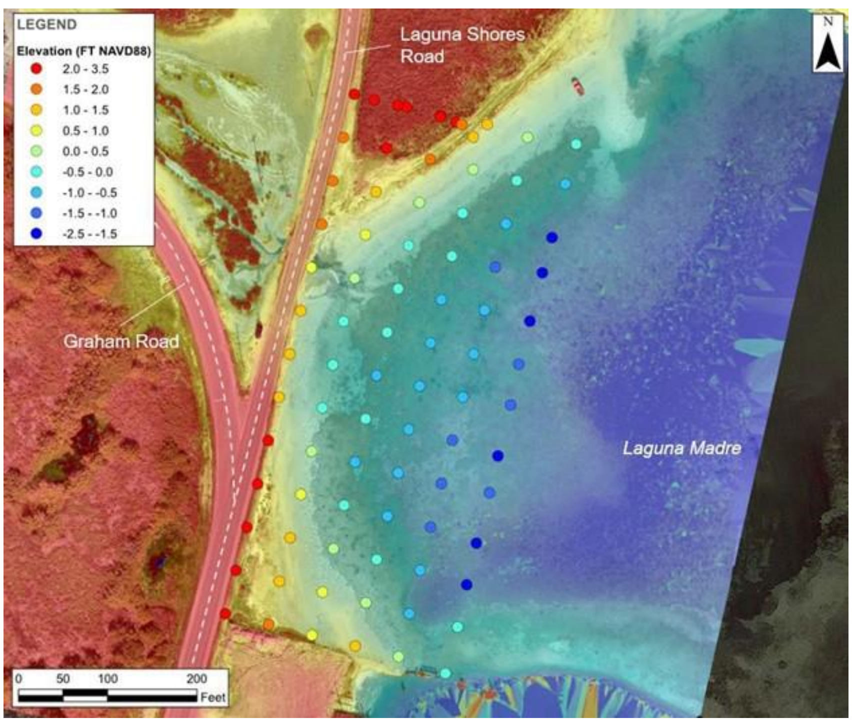
Bathymetric and Topographic Surveys and Aerial Photography (1.2)

Bathymetric and topographic surveys were conducted by the Conrad Blucher Institute for Surveying and Science (CBI) of TAMU-CC in December 2018. RTK GPS survey points were collected on the same 50 ft grid that the habitat assessments were made. Additional data was collected via terrestrial laser scanner to provide high resolution topographic data. The bathymetry near the project site is generally shallow (between 0.0 ft and -2.0 ft) and mildly sloped (100H:1V to 200H:1V). Exhibit 13 displays bathymetric and topographic data collected by TAMU-CC. Points denoted with a circle were collected via RTK and the rest were collected via terrestrial laser scanner and an unmanned aircraft system. Note that terrestrial laser scanner has limited penetration through the water column and data collected below the waterline may have increased vertical error.

[1] Elevations listed in this document are referenced to the North American Vertical Datum of 1988 (NAVD) Geoid 12B unless otherwise noted.

Exhibit 12. Aerial of Habitat Assessment Conducted by TAMU-CC and Engineering Consultant

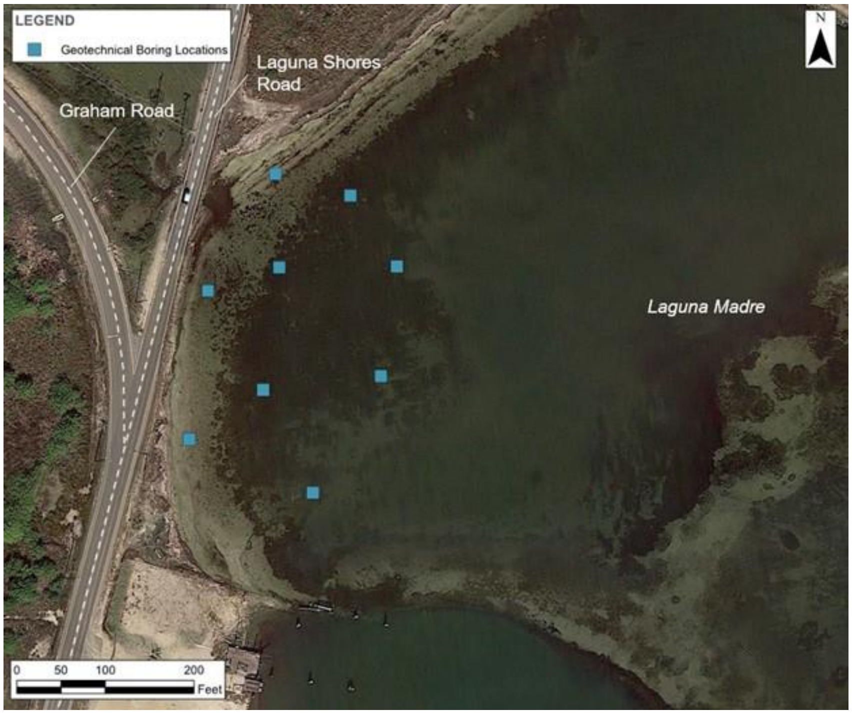
Exhibit 13. Image of Bathymetric and Topographic Survey Data



Geotechnical Investigation (1.3)

A geotechnical investigation was performed and documented in a report dated April 25, 2019. Nine borings were performed in the project area to identify soil types and to provide foundation recommendations. Based on the findings of the investigation, soil types in the project area are generally poorly graded sand and silty sand, with generally sandier soils along the shoreline. 0.5 ft to 1.0 ft of initial settlement should be expected after construction. Findings recommend that the soils should provide a suitable foundation for a low-crested rock breakwater of the type described in this alternatives analysis. Exhibit 14 provides the locations of the borings.

Exhibit 14. Aerial of Geotechnical boring locations



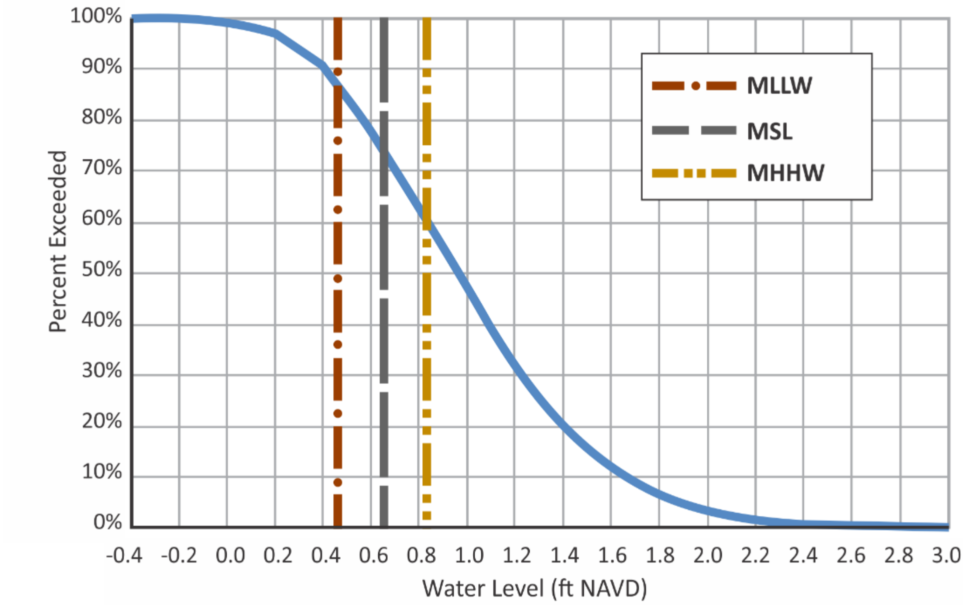
Water Level (1.4)

Water level data were obtained from the National Oceanographic and Atmospheric Administration (NOAA) Station located at Packery Channel, TX (ID: 8775792), 3 miles southeast of the project site. Tidal datums are shown in Table 1. Hourly water level data were obtained for 2012 – 2018 and used to create an exceedance plot (Exhibit 16). Water level exceeded +0.9 ft approximately 50% of the data record, +1.7 ft for 10% of the record, and +2.3 ft for 1% of the record. The highest recorded water level was +5.4 ft during Hurricane Harvey in August 2017. Based on tidal datums at Packery Channel station, MHHW was exceeded over 50% of the time since 2012.

Exhibit 15. Table of Tidal Datums at Packery Channel NOAA Station (ID 8775792)

Datum	Elevation (ft-NAVD)
Mean Higher High Water (MHHW)	0.83
Mean High Water (MHW)	0.83
Mean Tide Level (MTL)	0.65
Mean Sea Level (MSL)	0.65
Mean Low Water (MLW)	0.46
Mean Lower Low Water (MLLW)	0.46

Exhibit 16. Chart of Water Level Exceedance Plot for Packery Channel NOAA Station 8775792 for 2012-2018



Wind and Wave Climate (1.5)

The project site is exposed to waves generated by wind blowing across the open fetch of the Laguna Madre (Exhibit 17), but wave data is not readily available in the project area. To develop wave conditions at the project site, one dimensional wave modeling was performed using the Automated Coastal Engineering System (ACES) module of the Coastal Engineering & Design Analysis System (CEDAS) developed by the United States Army Corps of Engineers (USACE). A range of wind speeds and water levels were used to calculate the significant wave height and peak wave period for multiple scenarios. Hourly wind data obtained from the Packery Channel NOAA Station for 2008 to 2018 is summarized in an exceedance plot (Exhibit 18). All winds were assumed to approach from the southeast, which is both the predominant wind direction at the site and the direction of the longest fetch. Water levels above +3.0 ft are high enough above typical Spartina planting elevation that wave energy is expected to pass over and not reduce vegetation health. Exhibit 19 summarizes the wave analysis results. The largest significant wave height calculated is 1.9 ft with a peak wave period of 2.7 seconds.

Exhibit 17. Aerial of Longest Exposed Fetch

Exhibit 18. Chart of Wind Speed Exceedance Plot for Packery Channel NOAA Station for 2008-2018

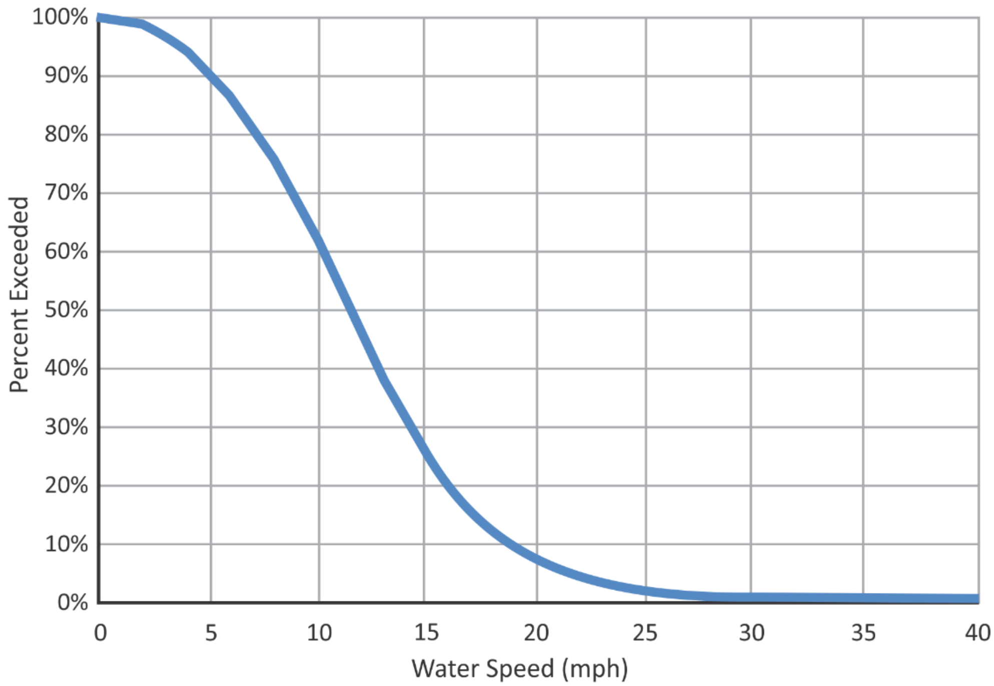


Exhibit 19. Table of Results from ACES Wave Model

Water Level (ft-NAVD)	Wind Speed Description	Wind Speed (mph)	Significant Wave Height (ft)	Peak Wave Period (s)
+2.5	25% Exceedance	13	0.5	1.5
	10% Exceedance	23	0.9	1.9
	0.1% Exceedance	30	1.1	2.1
	Max Recorded	53	1.7	2.7
+3.0	25% Exceedance	13	0.5	1.5
	10% Exceedance	23	0.9	1.9
	0.1% Exceedance	30	1.2	2.1
	Max Recorded	53	1.9	2.7

Alternatives Analysis (2)

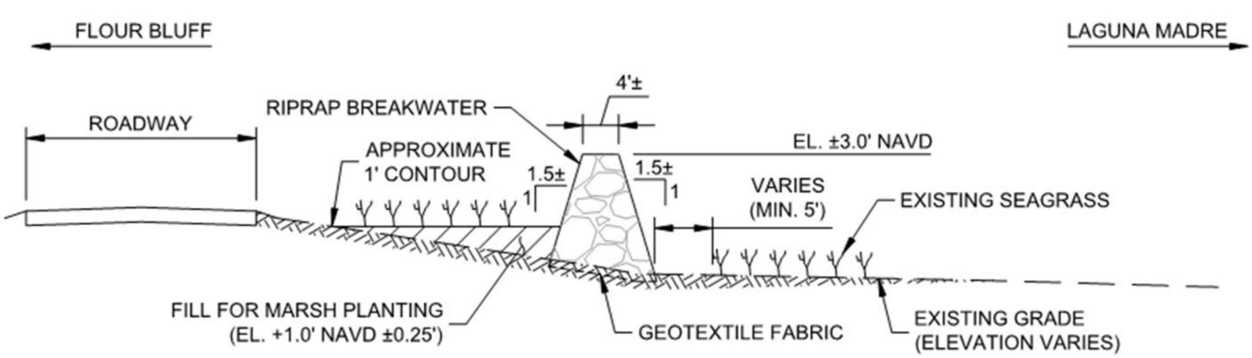
Laguna Shores Road is exposed to open fetches from the southeast. During high tide events, water levels reach the articulated mat currently being used as erosion control on the road slopes. Repeated exposure to wave attack during these high tide events will likely cause scour below the articulated mat and lead to undermining. Waves approaching the shoreline run-up onto the existing roadway and will likely run-up onto the proposed roadway. Lastly, during significant storm events, waves can reach the roadway and areas landward. To address erosion along the existing project shoreline and provide increased protection to the road, two living shoreline protection alternatives were considered. The living shoreline alternatives include a breakwater system and imported fill for marsh planting that provide wave attenuation benefits and increased habitat. The shoreline protection feature alignment was developed to avoid impacts to existing seagrass beds, allow room for marsh fill, and be constructed with land-based equipment rather than water-based equipment such as barges. The proposed breakwater alignment is between the 0.0 ft and +1.0 ft contours. It features a 35 ft gap near the existing culverts under Laguna Shores Road to facilitate drainage and flow through the culverts. The southern breakwater is 400 ft and the northern breakwater is 100 ft for a total length of 500 ft.

Exhibit 20. Aerial of Proposed Breakwater Alignment

Riprap Breakwater Option (2.1)

Riprap breakwaters can significantly reduce the transmitted wave height in both deep and shallow depths and can be used effectively in high or low energy environments. Riprap also provides hard substrate habitat for encrusting species including oysters and barnacles and serves as habitat for juvenile fish, crabs, and other invertebrates. A stone stability analysis using modeled wave conditions was conducted and resulted in a recommended median stone weight (W50) of 150 lbs and a median stone diameter (D50) of 1.0 ft. A design crest elevation of +3.0 ft and crest width of 4.0 ft was selected to reduce the wave energy transmitted through the structure to levels acceptable for vegetation growth. The crest elevation will allow for estimated long-term settlement of up to 6 inches while still providing wave reduction and attenuation in storm conditions. Side slopes of 1.5H:1V were selected to minimize the breakwater footprint and allow for more marsh fill area. A geotextile fabric will be placed under the structure to help limit scour and settling. A riprap breakwater would be constructible using equipment typically on site for roadway construction. Approximately 800 tons of graded riprap will be required to construct the breakwater. Exhibit 21 depicts a typical riprap breakwater section along with the marsh planting area for the Laguna Shores project site.

Exhibit 21. Schematic of Typical RipRap Breakwater Section



Reef Ball Breakwater Option (2.2)

Reef balls are hollow, hemispherical shaped artificial reef units cast from concrete with randomly placed holes to allow for wave energy dissipation and habitat creation. Reef balls come in a variety of sizes with heights ranging from 1 ft to 5 ft and weights ranging from 45 lbs to 6,000 lbs. Reef balls provide excellent habitat for marine animals, but have varied effectiveness at reducing wave transmission, making them more suited to shallow water, low energy environments. Guidance recommends that reef ball breakwaters consist of at least three rows of units to adequately reduce wave transmission. However, monitoring results at other project sites have shown that the first row of reef balls can be undercut and that 4 rows provides better long-term stability and wave reduction. Considering that the horizontal area available for a breakwater feature at the Laguna Shores site is limited due to the close proximity of seagrass adjacent to the roadway, multiple rows of reef balls may not be feasible and could also reduce the area available for marsh fill and planting. Reef balls also have more stability and habitat value with lower crest elevations, which reduces the wave attenuation properties as more wave energy passes over the semi-submerged breakwaters when compared to higher elevation structures. Lastly, the bottom elevations along the proposed breakwater alignment are variable, which would result in variation of breakwater height due to consistent elevations of the reef ball units. Graded riprap breakwaters are better suited to variable bottom depths and can more readily achieve a consistent crest elevation. The reef balls would be placed on a geotextile fabric and/or geogrid.

Exhibit 22. Image of Reef Ball Breakwater

Example of a reef ball breakwater in Oyster Lake in West Galveston Bay, TX. Note that the first row of reef balls on the right is leaning forward due to undermining. Photo credit: Consultant.

Marsh Fill (2.3)

Existing conditions including site location and orientation, benthic and bottom conditions, and meteorological and oceanographic conditions were considered for marsh creation. Additional criteria used in the conceptual design and alternatives analysis include project site access, constructability, construction cost, and material availability. Based on the findings of the geotechnical investigation and site visits, soil near the shoreline is sandy and firm enough to support marsh fill. There are no existing natural resources such as marsh grass or oyster beds landward of the seagrass beds that would need to be avoided. Spartina was located 0.2 miles north of the project site between the elevations of +0.8 ft and +1.2 ft. Given the narrow elevation range that local Spartina grows in, the proposed marsh fill elevation is +1.0 ft to fall within the middle of the range. All marsh fill is located behind the proposed breakwaters to reduce wave energy damages on the new marsh. The fill extends from the landward side of the breakwaters up to the existing +1.0 ft contour. Marsh fill is not proposed in the breakwater gap to avoid blocking the nearby culverts. Approximately 200 CY of sandy material is required for marsh fill. Marsh fill of this quantity is typically easily obtainable and would be constructible with standard roadway equipment. After construction, Spartina sprigs would be planted on approximately 3 ft centers. Factors influencing the success of the marsh fill living shoreline component include timing of sprig planting and protection from pedestrian and vehicle traffic. Additional planting may be needed after the initial project construction.

Opinion of Probable Construction Cost

Conceptual level opinion of probable construction costs (OPCC) for both the riprap breakwater and reef ball breakwater plus marsh fill component area shown in Exhibit 23 and Exhibit 24, respectively.

Exhibit 23. Table of Conceptual OPCC: Riprap Breakwater

Item	Description	Quantity	Unit	Unit Price	Extended Price
1	Mobilization / Demobilization	1	LS	$25,000	$25,000
2	Construction Surveying	1	LS	$10,000	$10,000
3	Riprap Breakwater (500 LF)				
3.1	Armor Stone	800	TON	$100	$80,000
3.2	Geotextile Fabric	1,200	SY	$6	$8,000
4	Marsh Area				
4.1	Fill for Marsh Planting	200	CY	$45	$9,000
4.2	Planting	1,200	EACH	$4	$5,000
				Subtotal:	$137,000
				Contingency (30%):	$42,000
				Total:	**$179,000**

Exhibit 24. Table of Conceptual OPCC: Reef Ball Breakwater

Item	Description	Quantity	Unit	Unit Price	Extended Price
1	Mobilization / Demobilization	1	LS	$25,000	$25,000
2	Construction Surveying	1	LS	$10,000	$10,000
3	Reef Ball Breakwater (500 LF)				
3.1	Reef Ball	500	EACH	$250	$125,000
3.2	Geotextile Fabric	1,200	SY	$6	$8,000
4	Marsh Area				
4.1	Fill for Marsh Planting	200	CY	$45	$9,000
4.2	Planting	1,200	EACH	$4	$5,000
				Subtotal:	$182,000
				Contingency (30%):	$55,000
				Total:	**$237,000**

Summary and Conclusion

This alternatives analysis was conducted to assess the living shoreline component of the Laguna Shores Segment 1 roadway project intended to reduce erosion and provide increased resiliency to Laguna Shores Road. Data gathering including a metocean analysis, a site visit and habitat assessment by consultant, hydrographic surveying, and preliminary geotechnical testing were completed. Two breakwater concepts, a riprap breakwater and a reef ball breakwater, were developed to provide wave protection to Laguna Shores Road and to provide hard substrate habitat. A marsh fill concept was also developed to provide additional habitat and living shoreline benefits. Both of the breakwater concepts and marsh fill concept were developed to be constructed with equipment typical for roadway construction and will not require additional specialized equipment. Opinions of probable construction cost were developed for each breakwater concept.

Based on the findings of the alternatives analysis, the recommended alternative is a riprap breakwater with imported fill for marsh grass planting placed along the landward side of the breakwater. Riprap breakwaters generally provide greater wave attenuation compared to reef ball breakwaters. Additionally, riprap can be placed on uneven or sloped surfaces and can still be stable whereas reef balls require flat surfaces to avoid leaning after placement. To provide sufficient wave reduction, multiple rows of reef balls must be placed along a shoreline. At Laguna Shores Road, the bayward extent of breakwater construction is limited due to the presence of seagrass near the shoreline. The intent of the living shoreline project is that all components will be constructed with equipment typical for the roadway replacement portion of the project, which also limits the distance offshore that the breakwater can be placed. Lastly, the opinion of probable construction cost of a riprap breakwater of $179,000 is within the existing project budget of $180,000.

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USACE, 2005. Coastal Engineering Manual. Engineer Manual 1110-2-1100 (Part VI), U.S. Army Corps of Engineers, Washington, D.C.

Leenknecht, D.A., Szuwalski, A. and Sherlock, A.R. (1992). Automated Coastal Engineering System: User’s Guide. U.S. Army Corps of Engineers, Coastal Engineering Research Center, Waterways Experiment Station, Vicksburg, MS.

National Oceanic and Atmospheric Association (NOAA). (2019). Packery Channel, TX - Station ID: 8775792. NOAA Tides and Currents.

Rock Engineering and Testing Laboratory, Inc. (RETL). (2019). *Geotechnical Subsurface Investigation for the Proposed Laguna Madre Breakwater Project, Laguna Shores Road and Graham Road, Corpus Christi, Texas. Geotechnical Study.* Prepared for HDR Engineering, Inc.

During the initial conversations for the proposed resilience and durability project, we anticipated that the success of the project would require the following:

- Integrated partners perspectives for planning, design and construction of the Laguna Shores Road project
- Communicate often to ensure the resiliency components were incorporated into the planning, design of on-going construction project
- As the lead convener of the project partners, the Corpus Christi MPO added value for resiliency design, permitting and application to be part of the City of Corpus Christi’s base bid construction package. This was more certain of an actual project rather than the resilience project being a possible “alternate” bid item. An alternate item in the bidding process could have been eliminated due to construction costs and funding availability from the City to complete the resilience portion of the project.

IV. Recommendations for future actions (or planned next steps)

The next steps in the project are identified below and are scheduled over the next few years as construction concludes and monitoring of the installation continues.

Monitoring and Evaluation

The estuarine habitat specialists from the academic and non-profit will utilize the habitat assessment protocol defined during preconstruction habitat evaluation to monitor the efficacy of the project in terms of habitat development and shoreline stabilization. The team will conduct an initial post-construction assessment within 60 days of completion of construction and will repeat their evaluation annually at one- and two-years post-construction.

Generate and Disseminate Report of Findings

At 24 months post award, the project team will generate an interim report in 508-compliant format that complies with FHWA standards for research reports. Annual monitoring reports will be submitted for four years post-construction; the monitoring report in the fourth year will be part of a final report of findings (in a 508-compliant format that complies with FHWA standards for research reports).

All findings will be presented to all the member agencies in the MPO who oversee transportation infrastructure projects (cities of Corpus Christi and Portland, TxDOT – Corpus Christi District, Nueces and San Patricio counties, and the Port of Corpus Christi Authority) to inform future fortification of other sections of Laguna Shores Road and of other transportation facilities. The team will identify potential opportunities to share findings with other community members and other stakeholders (regional and beyond), possibly including the Flour Bluff Business Association, the local chapter of the American Society of Civil Engineers, and the Texas Chapter of the American Shore and Beach Preservation Association.

In March 2021, the construction project is being implemented by the City of Corpus Christi in accord with the original resiliency project timeline. The construction schedule for the overall duration timeline for the Laguna Shores Road Project is provided below.

Laguna Shores Road: Projected Timeline: Construction duration is expected to be 16 months.

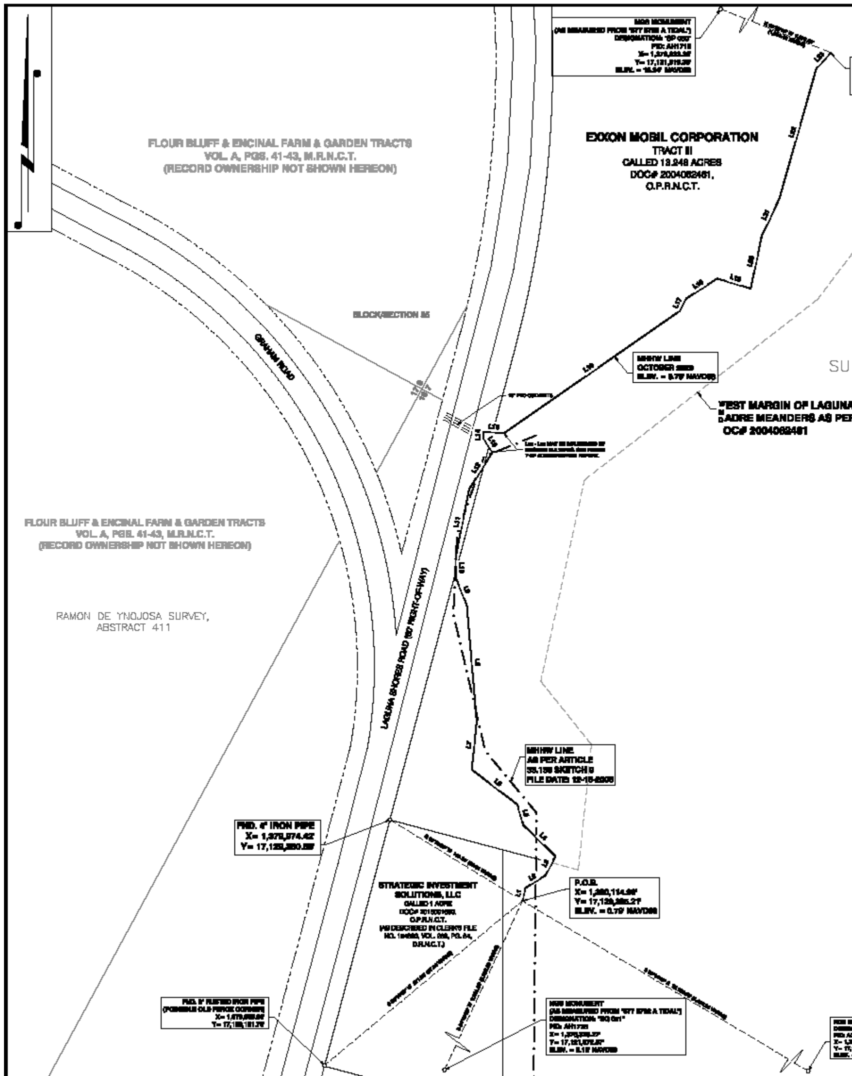
Anticipated Construction Start: October 2020

Anticipated Completion: August 2021

Segment 1: Graham Road to South Padre Island Drive - June/July 2021 with MPO Resiliency Project

The city is completing the permits required for their construction project and includes the permits for the resiliency project. Permits with the Army Corps of Engineers and the Texas General Land Office (GLO) are nearing completion as well as the companion Letter of No Objection from the landowner that has land that intersects the construction of the barrier breakwater and associated planting areas. The owner is ExxonMobil, and this project is expected to help them meet their environmental stewardship goals.

Exhibit 25. Plan of the Required Boundary Survey for Submerged Parcel per GLO Requirements



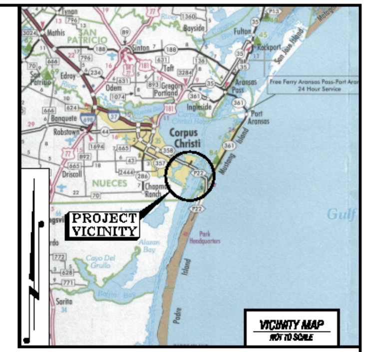
LEGEND:

FND.	FOUND
P.O.B.	POINT OF BEGINNING
P.O.T.	POINT OF TERMINATION
R.O.W.	RIGHT-OF-WAY
MHHW	MEAN HIGHER HIGH WATER

MHHW LINE, OCTOBER 2020, ELEV. = 0.79' NAVD88

MHHW LINE AS PER ARTICLE 33.136 SKETCH 9, FILE DATE: 12-15-2005

LINE	BEARING	DISTANCE	VARAS
L1	N 12°21'17" E	13.98'	5.03V
L2	N 57°33'51" E	25.39'	9.14V
L3	N 27°14'22" E	22.72'	8.18V
L4	N 45°56'41" W	47.08'	16.95V
L5	N 16°09'40" W	22.54'	8.11V
L6	N 52°31'42" W	60.60'	21.82V
L7	N 05°46'17" E	51.46'	18.53V
L8	N 04°51'57" W	123.02'	44.29V
L9	N 21°50'39" W	29.80'	10.73V
L10	N 01°53'23" W	22.47'	8.09V
L11	N 11°11'53" E	73.26'	26.38V
L12	N 32°07'00" E	46.45'	16.72V
L13	N 33°04'46" W	18.12'	6.52V
L14	N 01°10'14" E	6.46'	2.33V
L15	S 65°39'32" E	21.93'	7.89V
L16	N 55°10'42" E	225.77'	81.28V
L17	N 25°25'02" E	13.80'	4.97V
L18	N 57°01'03" E	40.12'	14.44V
L19	S 73°15'43" E	36.88'	13.28V
L20	N 11°53'18" E	56.74'	20.43V
L21	N 25°14'50" E	43.41'	15.63V
L22	N 15°51'49" E	143.05'	51.50V
L23	N 42°30'27" E	22.42'	8.07V



NOTES:

1. ALL COORDINATES REFER TO THE TEXAS STATE PLANE COORDINATE SYSTEM, SOUTH ZONE (#4205), NORTH AMERICAN DATUM OF 1983 (2011 ADJUSTMENT), US FEET. ALL BEARINGS ARE LAMBERT GRID BEARINGS AND ALL DISTANCES GRID. THE COMBINED SCALE FACTOR IS 0.99995967 AND CONVERGENCE ANGLE IS +00° 34' 24.2".
2. COORDINATES AND ELEVATIONS ARE BASED ON NGS MONUMENT:

   NGS MONUMENT "B77 5792 A TIDAL" (PUBLISHED)
   N: 17,121,538.35
   E: 1,393,149.44
   EL: 2.76' NAVD88
3. ALL OTHER MONUMENTS ARE REFERENCED AS MEASURED AND SHOWN HEREON.
4. ALL POSITIONS AND ELEVATIONS RECORDED USING SURVEY GRADE, RTK GPS. EQUIPMENT: TRIMBLE R10.
5. THE STATE OWNERSHIP BOUNDARY IS BASED ON THE MEAN HIGHER HIGH WATER (MHHW) CONTOUR. MHHW ELEVATION OF 0.79' NAVD88 FOR LAGUNA MADRE WAS DETERMINED BY MEASUREMENTS TAKEN FROM A LOCAL TIDE GAUGE AND CALCULATED AGAINST AN EXISTING TIDE GAUGE LOCATED NEAR THE INTRACOASTAL WATER WAY AND THE J.F.K. CAUSEWAY, OPERATED BY THE CONRAD BLUCHER INSTITUTE FOR SURVEYING AND SCIENCE AND DESIGNATED AS "PACKERY CHANNEL". THE LOCAL AND PUBLISHED GAUGES PRODUCED AGREEABLE TIDAL RANGES OVER THE COURSE OF THE FIVE DAY MONITORING PERIOD. THUS, THE PUBLISHED MHHW ELEVATION OF 0.79' NAVD88 WAS UTILIZED FOR THIS SURVEY.
6. TO CONVERT FEET TO VARAS MULTIPLY BY 0.36.
7. REFERENCE ACCOMPANYING REPORT CONTAINING FIELD NOTES DATED OCTOBER 2020 FOR ADDITIONAL INFORMATION.

I, JAMES M. NAISMITH, HEREBY STATE THAT THIS DRAWING REPRESENTS A SURVEY THAT IS CORRECT; IN ACCORDANCE WITH SECTION 21.042 TEXAS NATURAL RESOURCES CODE, WAS MADE ACCORDING TO LAW; WAS MADE IN THE FIELD UNDER MY DIRECT CONTROL AND SUPERVISION; WAS MADE UTILIZING METHODOLOGY APPROVED BY THE GLO; AND IS RECORDED IN

NOTICE: THIS SURVEY WAS PERFORMED IN ACCORDANCE WITH SECTION 33.136, NATURAL RESOURCES CODE, FOR THE PURPOSE OF EVIDENCING THE LOCATION OF THE SHORELINE IN THE AREA DEPICTED IN THIS SURVEY AS THAT SHORELINE EXISTED BEFORE COMMENCEMENT OF EROSION RESPONSE ACTIVITY, AS REQUIRED BY CHAPTER 33, NATURAL RESOURCES CODE. THE LINE DEPICTED ON THIS SURVEY FIXES THE SHORELINE FOR THE PURPOSE OF LOCATING A SHORELINE BOUNDARY, SUBJECT TO MOVEMENT LANDWARD AS PROVIDED BY SECTION 33.136, NATURAL RESOURCES CODE.

THIS SHORELINE SURVEY OF MEAN HIGHER HIGH WATER ALONG THE WESTERN SHORE OF THE LAGUNA MADRE EXTENDS NORTHEASTERLY ALONG LAGUNA SHORES ROAD NEAR THE VICINITY OF ITS INTERSECTION WITH GRAHAM ROAD.

SURVEYED: OCTOBER 15, 2020

SURVEY PERSONNEL: SCOTTY RALL, SR. AND SCOTTY RALL, JR.

PRELIMINARY, THIS DOCUMENT SHALL NOT BE RECORDED FOR ANY PURPOSE AND SHALL NOT BE USED OR VIEWED OR RELIED UPON AS A FINAL SURVEY DOCUMENT.

JAMES M. NAISMITH
LICENSED STATE LAND SURVEYOR

Naismith Marine Services, Inc.

NOTES:

REV. NO:	REV. DATE:	REV. DESCRIPTION:	REV. BY:
00	--/--		

REVISIONS

Naismith Marine Services, Inc.
now a part of TBS T. BAKER SMITH

DRAWN BY: JTR | APPROVED BY: JMN
DATE: 10/20/2020 | JOB NO: 2020.0637
PROJECTION: TEXAS SOUTH ZONE
GEO. DATUM: NAD83 (2011) | VERT. DATUM: NAVD88
GRID UNITS: US SURVEY FEET
SHEET NO: 1 OF 1

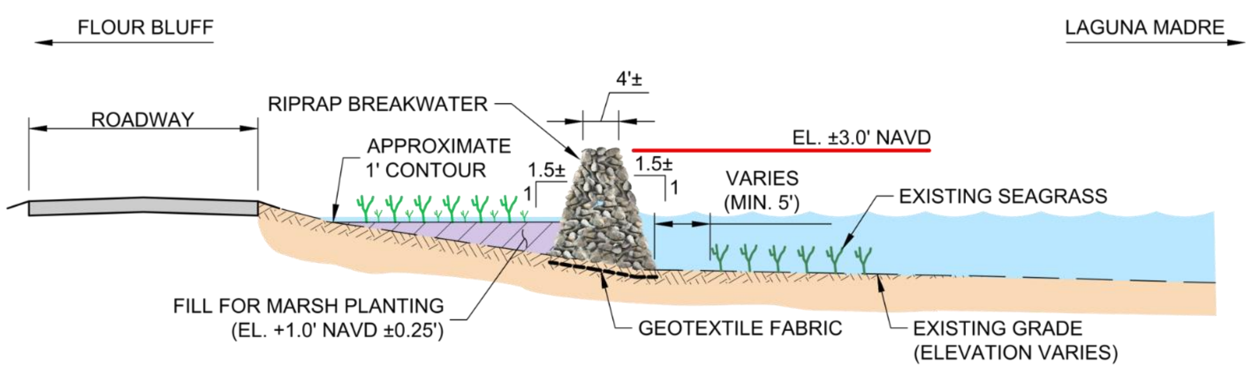
LAGUNA SHORES LIVING SHORELINE

HDR ENGINEERING, INC.
SHORELINE SURVEY OF A PORTION OF THE WESTERN SHORELINE OF THE LAGUNA MADRE SITUATED IN LAGUNA MADRE SUBMERGED LAND TRACT 15 APPROXIMATELY TWELVE MILES SOUTHEASTERLY OF THE CITY OF CORPUS CHRISTI, NUECES COUNTY, TEXAS

Exhibit 26. Construction at Laguna Shores Road in the Vicinity of the Future Breakwater

This photo shows the new drainage element in the vicinity of the Laguna Shores Road future breakwater. Photo credit: Corpus Christi MPO.

Exhibit 27. Schematic Section of the Proposed Breakwater. Color detail by the Corpus Christi MPO



V. Recommendations for improvements to FHWA resources used (if applicable)

The FHWA employees were critical in the success of this project. Their guidance along the development of the initial application to the checkpoints along the way were helpful in assisting the local agency in moving the project forward with local staff changes over the duration of the project. Additional assistance for directing the local agency to resources related to the development of the application, contracting and best practices of other similar resilience projects. The recommendation is to provide the local agency a comprehensive review of the process at the application and award stages. This would assist the local agency in being more knowledgeable on the requirements and proceed more expeditiously in the delivery of the projects.

Appendix A: Consultant Aerial Camera Quality Report/Calibration Details

Appendix B: Geotechnical Subsurface Investigation for the Proposed Laguna Madre Breakwater Project Laguna Shores Road and Graham Road Corpus Christi, Texas

APPENDIX A

Consultant Aerial Camera Quality Report/Calibration Details

Quality Report

Generated with Pix4Dmapper version 4.3.31

Important: Click on the different icons for:

Help to analyze the results in the Quality Report

Additional information about the sections

Click here for additional tips to analyze the Quality Report

Summary

Project	Chris_Reynolds_12_16_2018_Process
Processed	2019-01-24 15:05:46
Camera Model Name(s)	FC6310_8.8_5472x3648 (RGB)
Average Ground Sampling Distance (GSD)	1.19 cm / 0.47 in

Quality Check

Images	median of 51200 keypoints per image	
Dataset	611 out of 625 images calibrated (97%), all images enabled	
Camera Optimization	2.17% relative difference between initial and optimized internal camera parameters	
Matching	median of 18553 matches per calibrated image	
Georeferencing	yes, 8 GCPs (8 3D), mean RMS error = 0.014 ft	

Calibration Details

Number of Calibrated Images	611 out of 625
Number of Geolocated Images	625 out of 625

Initial Image Positions

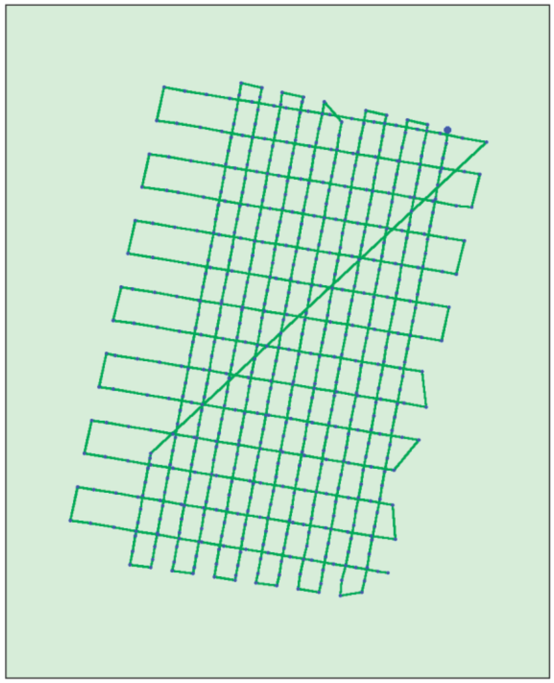
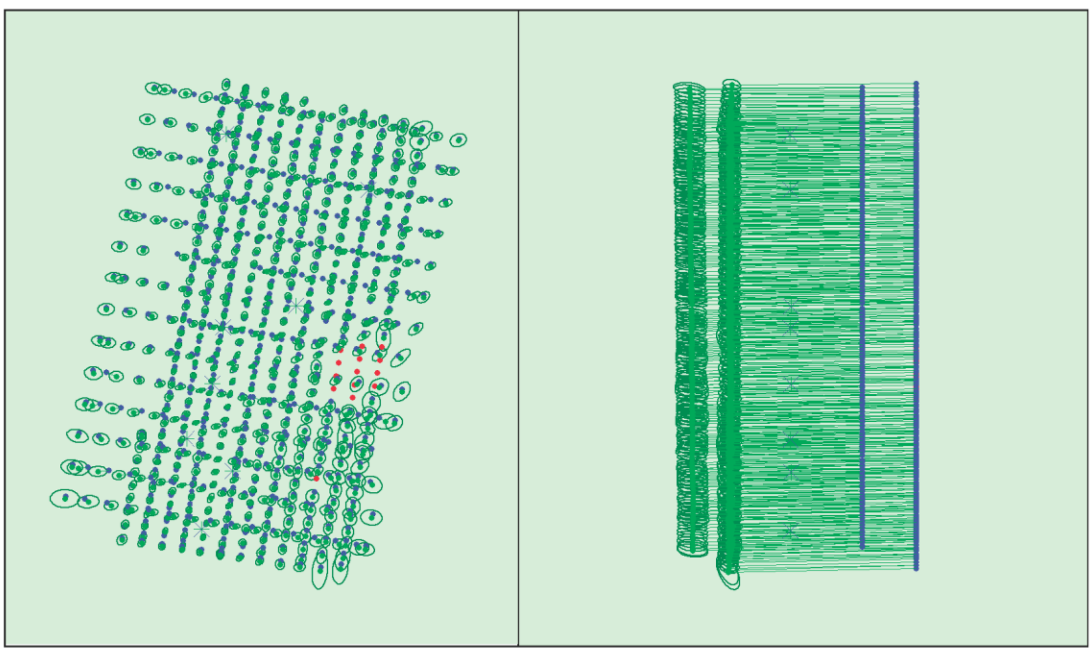
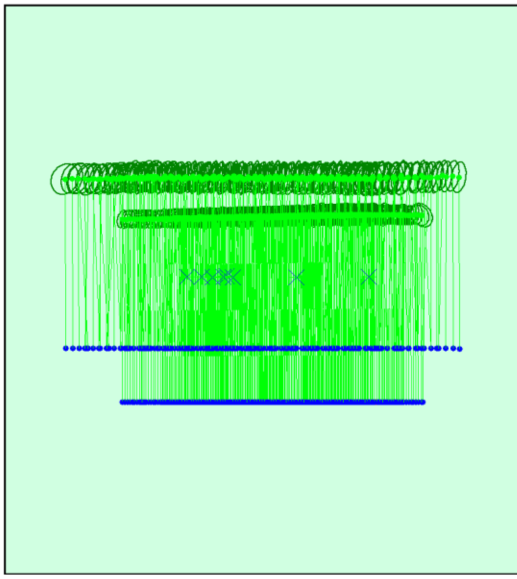


Figure 2: Top view of the initial image position. The green line follows the position of the images in time starting from the large blue dot.

Computed Image/GCPs/Manual Tie Points Positions





Uncertainty ellipses 500x magnified

Figure 3: Offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCPs initial positions (blue crosses) and their computed positions (green crosses) in the top-view (XY plane), front-view (XZ plane), and side-view (YZ plane). Red dots indicate disabled or uncalibrated images. Dark green ellipses indicate the absolute position uncertainty of the bundle block adjustment result.

Absolute camera position and orientation uncertainties

	X [ft]	Y [ft]	Z [ft]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.021	0.021	0.051	0.006	0.006	0.003
Sigma	0.007	0.008	0.012	0.003	0.002	0.002

Bundle Block Adjustment Details

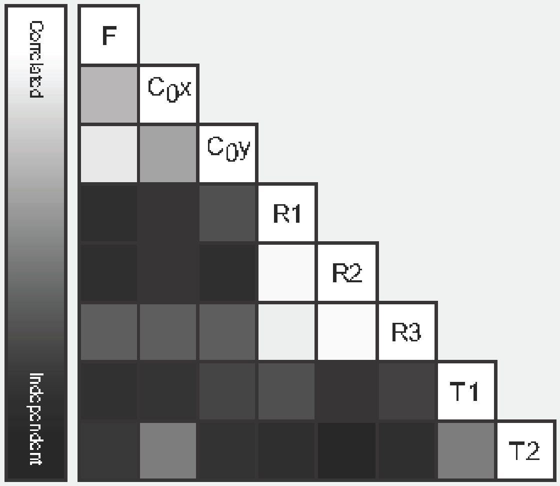
Number of 2D Keypoint Observations for Bundle Block Adjustment	9870628
Number of 3D Points for Bundle Block Adjustment	2712194
Mean Reprojection Error [pixels]	0.174

Internal Camera Parameters

FC6310_8.8_5472x3648 (RGB). Sensor Dimensions: 12.833 [mm] x 8.556 [mm]

EXIF ID: FC6310_8.8_5472x3648

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	3668.759 [pixel] 8.604 [mm]	2736.001 [pixel] 6.417 [mm]	1823.999 [pixel] 4.278 [mm]	0.003	-0.008	0.008	-0.000	0.000
Optimized Values	3588.801 [pixel] 8.417 [mm]	2737.172 [pixel] 6.419 [mm]	1834.578 [pixel] 4.303 [mm]	0.002	-0.005	0.004	0.000	0.002
Uncertainties (Sigma)	1.089 [pixel] 0.003 [mm]	0.131 [pixel] 0.000 [mm]	0.197 [pixel] 0.000 [mm]	0.000	0.000	0.000	0.000	0.000



The correlation between camera internal parameters determined by the bundle adjustment. White indicates a full correlation between the parameters, ie. any change in one can be fully compensated by the other. Black indicates that the parameter is completely independent, and is not affected by other parameters.

The number of Automatic Tie Points (ATPs) per pixel, averaged over all images of the camera model, is color coded between black and white. White indicates that, on average, more than 16 ATPs have been extracted at the pixel location. Black indicates that, on average, 0 ATPs have been extracted at the pixel location. Click on the image to the see the average direction and magnitude of the re-projection error for each pixel. Note that the vectors are scaled for better visualization. The scale bar indicates the magnitude of 1 pixel error.

2D Keypoints Table

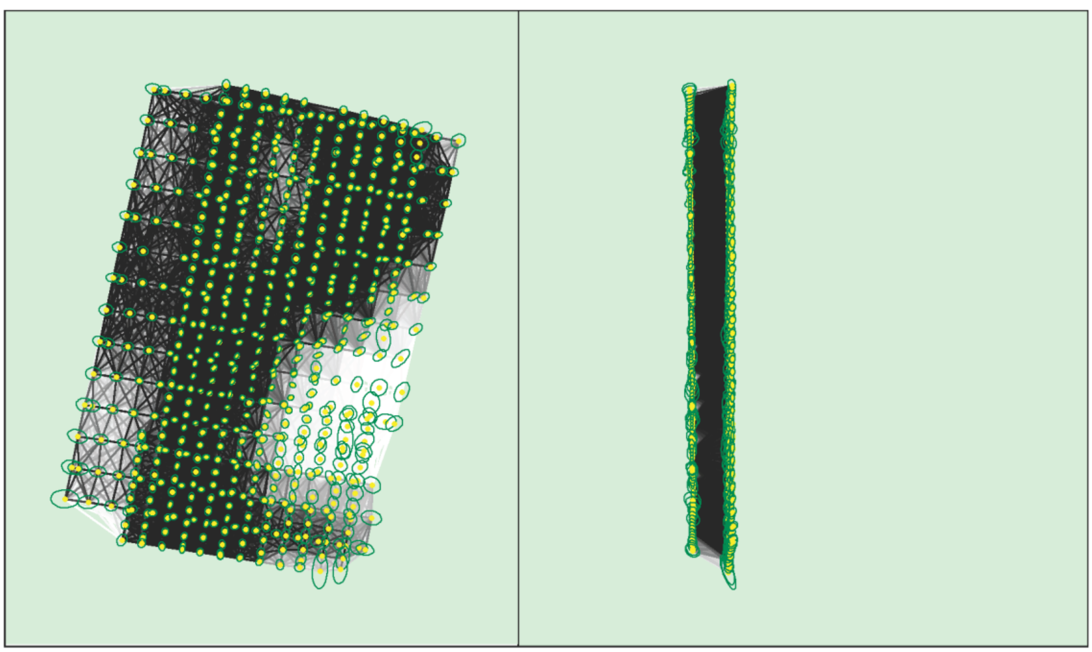
	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	51200	18553
Min	18369	94
Max	79684	39826
Mean	48483	16155

3D Points from 2D Keypoint Matches

	Number of 3D Points Observed
In 2 Images	1616897
In 3 Images	437020
In 4 Images	199759
In 5 Images	114369
In 6 Images	71715
In 7 Images	50616
In 8 Images	37361
In 9 Images	28297
In 10 Images	23292
In 11 Images	18407
In 12 Images	15212
In 13 Images	12696
In 14 Images	10633
In 15 Images	9060
In 16 Images	7886
In 17 Images	6680
In 18 Images	5856
In 19 Images	5118
In 20 Images	4552
In 21 Images	3923
In 22 Images	3491
In 23 Images	3081

In 24 Images	2679
In 25 Images	2378
In 26 Images	2216
In 27 Images	1983
In 28 Images	1797
In 29 Images	1617
In 30 Images	1441
In 31 Images	1389
In 32 Images	1297
In 33 Images	1160
In 34 Images	1096
In 35 Images	973
In 36 Images	930
In 37 Images	766
In 38 Images	679
In 39 Images	639
In 40 Images	533
In 41 Images	435
In 42 Images	353
In 43 Images	292
In 44 Images	211
In 45 Images	160
In 46 Images	108
In 47 Images	72
In 48 Images	42
In 49 Images	13
In 50 Images	4

2D Keypoint Matches



Uncertainty ellipses 500x magnified

Number of matches

25 222 444 666 888 1111 1333 1555 1777 2000

Figure 5: Computed image positions with links between matched images. The darkness of the links indicates the number of matched 2D keypoints between the images. Bright links indicate weak links and require manual tie points or more images. Dark green ellipses indicate the relative camera position uncertainty of the bundle block adjustment result.

Relative camera position and orientation uncertainties

	X [ft]	Y [ft]	Z [ft]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.019	0.020	0.014	0.008	0.006	0.003
Sigma	0.007	0.008	0.006	0.003	0.002	0.001

Geolocation Details

Ground Control Points

GCP Name	Accuracy XY/Z [ft]	Error X [ft]	Error Y [ft]	Error Z [ft]	Projection Error [pixel]	Verified/Marked
1500 (3D)	0.020/ 0.020	0.004	-0.021	-0.012	0.405	19 / 19
1501 (3D)	0.020/ 0.020	0.015	0.011	0.006	0.353	43 / 43
1502 (3D)	0.020/ 0.020	0.018	-0.012	0.029	0.375	34 / 34
1503 (3D)	0.020/ 0.020	-0.009	0.030	-0.017	0.428	23 / 23
1504 (3D)	0.020/ 0.020	-0.025	-0.011	-0.021	0.401	32 / 32
1505 (3D)	0.020/ 0.020	-0.010	-0.010	0.005	0.363	28 / 28
1506 (3D)	0.020/ 0.020	-0.004	0.012	-0.002	0.351	10 / 10
1507 (3D)	0.020/ 0.020	0.008	0.003	-0.000	0.420	28 / 28
Mean [ft]		-0.000318	0.000182	-0.001444		
Sigma [ft]		0.013651	0.015760	0.015024		
RMS Error [ft]		0.013655	0.015762	0.015093		

0 out of 2 check points have been labeled as inaccurate.

Check Point Name	Accuracy XY/Z [ft]	Error X [ft]	Error Y [ft]	Error Z [ft]	Projection Error [pixel]	Verified/Marked
1508		0.0252	-0.0195	-0.0430	0.5827	11 / 11
1509		-0.0421	-0.0881	-0.0235	0.5933	11 / 11
Mean [ft]		-0.008446	-0.053810	-0.033273		

Sigma [ft]		0.033608	0.034310	0.009739		
RMS Error [ft]		0.034653	0.063818	0.034669		

Localisation accuracy per GCP and mean errors in the three coordinate directions. The last column counts the number of calibrated images where the GCP has been automatically verified vs. manually marked.

Absolute Geolocation Variance

Min Error [ft]	Max Error [ft]	Geolocation Error X [%]	Geolocation Error Y [%]	Geolocation Error Z [%]
-	-49.21	0.00	0.00	0.00
-49.21	-39.37	0.00	0.00	0.00
-39.37	-29.53	0.00	0.00	0.00
-29.53	-19.68	2.29	0.00	0.00
-19.68	-9.84	6.71	11.29	47.46
-9.84	0.00	36.17	27.99	16.86
0.00	9.84	45.99	60.72	0.00
9.84	19.69	6.71	0.00	10.31
19.69	29.53	2.13	0.00	25.37
29.53	39.37	0.00	0.00	0.00
39.37	49.21	0.00	0.00	0.00
49.21	-	0.00	0.00	0.00
Mean [ft]		0.902731	4.650414	-403.608978
Sigma [ft]		7.897604	6.098228	16.413970
RMS Error [ft]		7.949030	7.669077	403.942601

Min Error and Max Error represent geolocation error intervals between -1.5 and 1.5 times the maximum accuracy of all the images. Columns X, Y, Z show the percentage of images with geolocation errors within the predefined error intervals. The geolocation error is the difference between the initial and computed image positions. Note that the image geolocation errors do not correspond to the accuracy of the observed 3D points.

Geolocation Bias	X	Y	Z
Translation [ft]	0.902731	4.650414	-403.608978

Bias between image initial and computed geolocation given in output coordinate system.

Relative Geolocation Variance

Relative Geolocation Error	Images X [%]	Images Y [%]	Images Z [%]
[-1.00, 1.00]	87.23	100.00	100.00
[-2.00, 2.00]	100.00	100.00	100.00
[-3.00, 3.00]	100.00	100.00	100.00
Mean of Geolocation Accuracy [ft]	16.404167	16.404167	32.808333
Sigma of Geolocation Accuracy [ft]	0.000002	0.000002	0.000005

Images X, Y, Z represent the percentage of images with a relative geolocation error in X, Y, Z.

Geolocation Orientational Variance	RMS [degree]
Omega	1.091
Phi	1.045
Kappa	4.544

Geolocation RMS error of the orientation angles given by the difference between the initial and computed image orientation angles.

Initial Processing Details

System Information

Hardware	CPU: Intel(R) Core(TM) i9-7940X CPU @ 3.10GHz RAM: 128GB GPU: NVIDIA GeForce GTX 1080 Ti (Driver: 25.21.14.1694)
Operating System	Windows 10 Enterprise, 64-bit

Coordinate Systems

Image Coordinate System	WGS 84
Ground Control Point (GCP) Coordinate System	NAD_1983_StatePlane_Texas_South_FIPS_4205_Feet (2D)
Output Coordinate System	NAD_1983_StatePlane_Texas_South_FIPS_4205_Feet (2D)

Processing Options

Detected Template	No Template Available
Keypoints Image Scale	Full, Image Scale: 1
Advanced: Matching Image Pairs	Aerial Grid or Corridor
Advanced: Matching Strategy	Use Geometrically Verified Matching: no
Advanced: Keypoint Extraction	Targeted Number of Keypoints: Automatic
Advanced: Calibration	Calibration Method: Standard Internal Parameters Optimization: All External Parameters Optimization: All Rematch: Auto, no

Point Cloud Densification details

Processing Options

Image Scale	multiscale, 1/2 (Half image size, Default)
Point Density	Optimal
Minimum Number of Matches	3
3D Textured Mesh Generation	no
LOD	Generated: no
Advanced: Image Groups	group1
Advanced: Use Processing Area	yes
Advanced: Use Annotations	yes
Time for Point Cloud Densification	45m:41s
Time for Point Cloud Classification	NA
Time for 3D Textured Mesh Generation	NA

Results

Number of Generated Tiles	4
Number of 3D Densified Points	56096115
Average Density (per ft^3)	47.19

DSM, Orthomosaic and Index Details

Processing Options

DSM and Orthomosaic Resolution	1 x GSD (1.19 [cm/pixel])
DSM Filters	Noise Filtering: yes Surface Smoothing: yes, Type: Sharp

Raster DSM	Generated: yes Method: Inverse Distance Weighting Merge Tiles: yes
Orthomosaic	Generated: yes Merge Tiles: yes GeoTIFF Without Transparency: yes Google Maps Tiles and KML: yes
Contour Lines Generation	Generated: yes Contour Base [ft]: 0 Elevation Interval [ft]: 1 Resolution [cm]: 100 Minimum Line Size [vertices]: 20
Time for DSM Generation	14m:19s
Time for Orthomosaic Generation	36m:46s
Time for DTM Generation	00s
Time for Contour Lines Generation	49s
Time for Reflectance Map Generation	00s
Time for Index Map Generation	00s

APPENDIX B

Geotechnical Subsurface Investigation for the Proposed Laguna Madre Breakwater Project Laguna Shores Road and Graham Road Corpus Christi, Texas

• GEOTECHNICAL ENGINEERING
• MATERIALS ENGINEERING & TESTING
• SOILS • ASPHALT • CONCRETE

GEOTECHNICAL SUBSURFACE INVESTIGATION FOR THE PROPOSED LAGUNA MADRE BREAKWATER PROJECT LAGUNA SHORES ROAD AND GRAHAM ROAD CORPUS CHRISTI, TEXAS

RETL REPORT NUMBER: G119127

PREPARED FOR:

HDR ENGINEERING, INC.
555 NORTH CARANCAHUA, SUITE 1600
CORPUS CHRISTI, TEXAS 78401-0849

APRIL 25, 2019

PREPARED BY:

ROCK ENGINEERING & TESTING LABORATORY, INC.
6817 LEOPARD STREET
CORPUS CHRISTI, TEXAS 78409
P: (361) 883-4555; F: (361) 883-4711
TBPE FIRM NO. 2101

• Geotechnical Engineering
• Construction Materials
Engineering & Testing
• Soils • Asphalt • Concrete

April 25, 2019

HDR Engineering, Inc.
555 North Carancahua, Suite 1600
Corpus Christi, TX 78401-0849

Attention: Mr. Christian LaPann-Johannessen

SUBJECT: **SUBSURFACE INVESTIGATION, LABORATORY TESTING PROGRAM, AND FOUNDATION RECOMMENDATIONS FOR THE PROPOSED LAGUNA MADRE BREAKWATER PROJECT**
Laguna Shores Road and Graham Road
Corpus Christi, Texas
RETL Job No. – G119127

Dear Mr. LaPann-Johannessen,

In accordance with our agreement, we have conducted a subsurface investigation, laboratory testing program, and foundation evaluation for the above referenced project. The results of this investigation, together with our recommendations, are to be found in the accompanying report, one electronic copy of which is being transmitted herewith for your records and distribution to the design team.

Often, because of design and construction details that occur on a project, questions arise concerning soil conditions, and Rock Engineering and Testing Laboratory, Inc. (RETL), Texas Professional Engineering Firm No. – 2101, would be pleased to continue its role as Geotechnical Engineer during the project implementation.

RETL also has great interest in providing materials testing and observation services during the construction phase of this project. If you will advise us of the appropriate time to discuss these engineering services, we will be pleased to meet with you at your convenience. If you have any questions, or if we can be of further assistance, please contact us at (361) 883-4555.

Sincerely,

Mark C. Rock, P.E.
Vice President of Operations

Rock Engineering & Testing Laboratory, Inc.
www.rocktesting.com
6817 Leopard Street • Corpus Christi, Texas 78409-1703
Office: (361) 883-4555 • Fax: (361) 883-4711
10856 Vandale St • San Antonio, Texas 78216-3625
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SUBSURFACE INVESTIGATION, LABORATORY TESTING PROGRAM, AND FOUNDATION RECOMMENDATIONS FOR THE PROPOSED LAGUNA MADRE BREAKWATER PROJECT LAGUNA SHORES ROAD AND GRAHAM ROAD CORPUS CHRISTI, TEXAS

RETL REPORT NUMBER: G119127

PREPARED FOR

HDR ENGINEERING, INC.
555 N. CARANCAHUA, SUITE 1600
CORPUS CHRISTI, TEXAS 78401-0849

APRIL 25, 2019

PREPARED BY:

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TEXAS PROFESSIONAL ENGINEERING FIRM NO. 2101

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BRIAN J GEIGER
118991
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PROFESSIONAL ENGINEER

STATE OF TEXAS
MARK C. ROCK
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Brian J. Geiger, P.E.
Geotechnical Engineer
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Vice President of Operations
Cell: 361 438 8755

ENGINEERING & TESTING ROCK LABORATORY INCORPORATED

TABLE OF CONTENTS

INTRODUCTION

This report presents the results of a soils exploration, laboratory testing program, and foundation analysis for the proposed Laguna Madre Breakwater Project located in Laguna Madre near the intersection of Laguna Shores Road and Graham Road in Corpus Christi, Texas.

Authorization

The work for this project was performed in accordance with RETL proposal number P061418A dated June 25, 2018. The original scope of work and fee was approved and incorporated into a HDR SUBCONSULTANT AGREEMENT for HDR Project 10053908. The SUBCONSULTANT AGREEMENT was returned to RETL via e-mail transmission.

Purpose and Scope

The purpose of this exploration was to evaluate the soil and groundwater conditions at the site and to provide foundation recommendations suitable for the proposed project.

The scope of the exploration and analysis included the subsurface exploration, field and laboratory testing, engineering analysis and evaluation of the subsurface soils, provision of recommendations, and preparation of this report for the proposed Laguna Madre Breakwater Project located in Laguna Madre near the intersection of Laguna Shores Road and Graham Road in Corpus Christi, Texas. Based on information provided to RETL, the project will include the construction of a rock breakwater. The proposed breakwater will be approximately 3-feet in height.

The scope of services did not include an environmental assessment. Any statements in this report, or on the boring logs, regarding odors, colors, unusual or suspicious items or conditions are strictly for the information of the client.

General

The exploration and analysis of the subsurface conditions reported herein are considered sufficient in detail and scope to provide foundation recommendations for the proposed project. The information submitted for the proposed project is based on project details provided by HDR and the soil information obtained at the boring locations. If the designers require additional soil parameters to complete the design of the proposed foundation systems, and this information can be obtained from the soil data and laboratory tests performed within the scope of work included in our proposal for this project, RETL will provide the additional information requested as a supplement to this report.

The Geotechnical Engineer states that the findings, recommendations, specifications or professional advice contained herein have been presented after being prepared in a manner consistent with that level of care and skill ordinarily exercised by reputable members of the Geotechnical Engineer's profession practicing contemporaneously under similar conditions in the locality of the project. RETL operates in general accordance with "*Standard Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction*, (ASTM D3740)." No other representations are expressed or implied, and no warranty or guarantee is included or intended.

This report has been prepared for the exclusive use of HDR for the specific application for the proposed Laguna Madre Breakwater Project located in Laguna Madre near the intersection of Laguna Shores Road and Graham Road in Corpus Christi, Texas.

DESCRIPTION OF SITE

The proposed project site is located off of Laguna Shores Road in Flour Bluff along the west shoreline of the Laguna Madre in Corpus Christi, Texas. The site was accessible by boat or by wading. The drillers indicated that the bay bottom was generally very soft in the upper 6-inches to 1-foot.

FIELD EXPLORATION

Scope

The field exploration, to evaluate the engineering characteristics of the subsurface materials, included reconnaissance of the project site, performing the boring operations and obtaining disturbed samples. During the sample recovery operations, the soils encountered were classified and recorded on the boring logs in accordance with "*Standard Guide for Field Logging of Subsurface Exploration of Soil and Rock*, (ASTM D5434)."

Nine borings were performed at this site for the purpose of providing geotechnical information. The table below provides the boring identifications, boring depths, and GPS coordinates at the boring locations:

Boring	Sampling Depth (ft)	GPS Coordinates
B-1	8½	N 27.65762° W 97.27674°
B-2	6	N 27.65740° W 97.27699°
B-3	7½	N 27.65740° W 97.27658°
B-4	5	N 27.65702° W 97.27705°
B-5	5	N 27.65706° W 97.27664°
B-6	5	N 27.65670° W 97.27688°
B-7	3½	N 27.65769° W 97.27700°
B-8	5	N 27.65733° W 97.27724°
B-9	3½	N 27.65687° W 97.27731°

The GPS coordinates, obtained at the boring locations using a commercially available GPS, are provided in this report and on the boring logs. RETL, in coordination with HDR determined the scope of the field work. RETL staked the borings in the field and performed the drilling operations. A Boring Location Plan is provided in the Appendix.

The borings performed for this project were used to determine the classification and strengths of the subgrade soils. The information provided on the boring logs includes boring locations, boring depths, soil classifications, soil strengths, and laboratory test results. The boring logs are included in the Appendix.

Drilling and Sampling Procedures

The borings were advanced using a Russian Sampler driven into the soil to the desired sampling depth and then implemented to obtain a disturbed soil sample. The sampling operations were performed in general accordance with the procedures for "*Standard Practice for Soil Exploration and Sampling by Auger Borings,* (ASTM D1452)."

The soil samples obtained were placed in plastic bags, marked according to boring number, depth and any other pertinent field data, stored in special containers and delivered to the laboratory for testing.

Field Tests and Observations

Static Cone Penetrometer Tests - Portable static cone penetrometer tests were performed at each sampling interval. The portable static cone penetrometer is a device used for measuring soil consistency. The device is equipped with dual rods enabling the cone stress to be measured directly. Soil friction on the outer rod does not influence the reading. The cone is forced into the soil in increments and retracted slightly after each increment to zero the gauge, and then the cone is advanced to obtain the cone index (Qc). The cone index is always read directly from the gauge. It has units of kg/cm^2, which is essentially equal to $tons/ft^2$. The results of the portable static cone penetrometer tests are provided on the boring logs using the notation Qc.

The correlation between the cone index and soil constants is not absolute. The following empirical formulas were provided by the portable static cone penetrometer manufacturer, Boart Longyear Company, and have been determined through extensive field use of the unit:

1. Standard Penetration Test Value "N"
   N = Qc/4
2. Unconfined Compressive Strength "Qu" (tsf)
   Uniform clay and silty clays: Qu = Qc/5
   Clayey silts: Qu = Qc/(10 to 20)
3. Cohesion "C" or Undrained Shear Strength (tsf)
   Uniform clay and silty clays: C = Qc/10
   Clayey silts: C = Qc/(20 to 40)

Water Level Observations – All borings were performed in a marine environment and the areas were inundated with seawater.

Bay Bottom Elevations – The bay bottom elevations at the boring locations were not provided at the time of this report. The depths of water at the boring locations was recorded and is presented on the boring logs provided in the Appendix.

LABORATORY TESTING PROGRAM

In addition to the field investigation, a laboratory testing program was conducted to determine additional pertinent engineering characteristics of the subsurface materials necessary in analyzing the behavior of the foundation system for the proposed project.

The laboratory testing program included supplementary visual classification (ASTM D2487) and water content tests (ASTM D2216) on the samples. In addition, selected samples were subjected to Atterberg limits tests (ASTM D4318) and percent material finer than the #200 sieve tests (ASTM D1140).

The laboratory testing program was conducted in general accordance with applicable ASTM Specifications. The results of these tests are to be found on the accompanying boring logs provided in the Appendix.

SUBSURFACE CONDITIONS

General

The types of foundation bearing materials encountered in the test borings have been visually classified and are described in detail on the boring logs. The results of the static cone penetrometer, and other laboratory tests are presented on the boring logs in numerical form. Representative samples of the soils were placed in polyethylene bags and are now stored in the laboratory for further analysis, if desired. Unless notified to the contrary, the samples will be disposed of three months after issuance of this report.

The stratification of the soil, as shown on the boring logs, represents the soil conditions at the actual boring locations. Variations may occur between, or beyond, the boring locations. Lines of demarcation represent the approximate boundary between different soil types, but the transition may be gradual, or not clearly defined.

It should be noted that, whereas the test borings were drilled and sampled by experienced drillers, it is sometimes difficult to record changes in stratification within narrow limits. In the absence of foreign substances, it is also difficult to distinguish between discolored soils and clean soil fill.

Soil Conditions

The soil conditions encountered at the project site have been summarized and soil properties including soil classification, undrained shear strength, angle of internal friction, and effective unit weight are provided in the following tables:

Soil Profile 1: Borings B-1 through B-6

D	Generalized Soil Description	C	ϕ	γ_e	-#200	Q_c
	Average Water Depth 1.8'	Not Applicable				
0-4	Poorly Graded **SAND** & Silty **SAND**	0	28	50	4-19	5-25
4-8	Poorly Graded **SAND** & Silty **SAND**	0	28	50	5-15	20-35

Soil Profile 2: Borings B-7 through B-9

D	Generalized Soil Description	C	ϕ	γ_e	-#200	Q_c
	Average Water Depth 0.6	Not Applicable				
0-5	Poorly Graded **SAND**	0	28	50	5-8	15-33

Where:
D = Depth in feet below existing bay bottom
C = Soil Cohesion, psf (undrained)
ϕ = Angle of Internal Friction, deg. (undrained)
γ_e = Effective soil unit weight, pcf
-#200 = Percent passing the No. 200 sieve (%)
Q_c = Cone Index (tsf)

It should be noted that the upper 6-inches to 1-foot of the bay bottom was very soft and that the first sample was obtained between the 1 and 2½-foot depth. Detailed descriptions of the soils encountered at the boring locations are provided on the boring logs included in the Appendix.

FOUNDATION DISCUSSION AND RECOMMENDATIONS

Based on information provided to RETL, the proposed Laguna Madre Breakwater Project located is located in Laguna Madre near the intersection of Laguna Shores Road and Graham Road in Corpus Christi, Texas. The project will include the construction of a rock breakwater. The proposed breakwater will be approximately 3-feet in height with a base width of 23-feet and a crest width of 5-feet. The side slopes of the breakwater will be constructed at a slope of 3 Horizontal to 1 Vertical. A breakwater with the proposed measurements results in a ground contact pressure, assuming a SSD Unit Weight of the rock material of 160 pcf, of approximately 480 psf. The breakwater will exert a line load similar to that of a strip footing foundation.

It is RETL's opinion that during the initial placement of the first course of stone approximately ½ to 1-foot of displacement of the soft bay bottom will occur. **Once the initial settlement occurs the ultimate bearing pressure is on the order of 800 psf resulting in a safety factor for the effective unit weight of the stone breakwater on the supporting substrate is on the order of 1.5, a sufficient safety factor for this type of project.** Immediate settlements, settlements that will occur within a week, warrants that the contractor top off the breakwater with additional stone after a minimum of one week after the initial construction of the breakwater to the proposed grades. Assuming that the soils are sand soils to depths of 2-times the average width of the cross-sectional dimension of the breakwater, long term consolidation settlements are not expected. A more detailed settlement analysis can be performed, but, based on the dimensions of the breakwater, will require additional data from supplemental field investigation.

GENERAL COMMENTS

If significant changes are made in the character or location of the proposed project, a consultation should be arranged to review any changes with respect to the prevailing soil conditions. At that time, it may be necessary to submit supplementary recommendations.

APPENDIX

• GEOTECHNICAL ENGINEERING
• CONSTRUCTION MATERIALS ENGINEERING & TESTING
• SOILS • ASPHALT • CONCRETE

BORING LOCATION PLAN

April 25, 2019
Attn: Mr. Christian LaPann-Johannessen
RETL Job No.: G119127

LAGUNA MADRE BREAKWATER PROJECT
Laguna Shores Road and Graham Road
Corpus Christi, Texas

ROCK ENGINEERING & TESTING LABORATORY, INC.
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LOG OF BORING B-1

SHEET 1 of 1

Rock Engineering and Testing Laboratory, Inc.
6817 Leopard St
Corpus Christi, TX 78409
Telephone: 361-883-4555
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CLIENT: HDR Engineering, Inc.
PROJECT: Laguna Shores Living Shoreline Project
LOCATION: Laguna Shores Rd. & Graham Rd.; C.C., TX
NUMBER: G119127

DATE(S) DRILLED: 3/18/19 - 3/18/19

DRILLING METHOD(S):
Russian Sampler

GROUNDWATER INFORMATION:
Boring was performed under 2-feet of water.

SURFACE ELEVATION: N/A

SOIL SYMBOL	DEPTH (FT)	SAMPLE NUMBER	SAMPLES	N: BLOWS/FT P: TONS/SQ FT Tv: TONS/SQ FT Qc: TONS/SQ FT	MOISTURE CONTENT (%)	LIQUID LIMIT LL	PLASTIC LIMIT PL	PLASTICITY INDEX PI	DRY DENSITY POUNDS/CU.FT	COMPRESSIVE STRENGTH (TONS/SQ FT)	MINUS NO. 200 SIEVE (%)	DESCRIPTION OF STRATUM
	1–2	AUGER S-1		Qc= 6	28							**POORLY GRADED SAND WITH SILT**, wet, light gray, very loose.
	3.5–5	AUGER S-2		Qc= 5	28	NP	NP	NP			10	Same as above. (SP-SM)
	6–7.5	AUGER S-3		Qc= 30	25							Same as above, gray, loose.
												Sampling refusal was encountered at a depth of approximately 8½-feet.

N - STANDARD PENETRATION TEST RESISTANCE
Qc - STATIC CONE PENETROMETER TEST INDEX
Tv - TORVANE RESISTANCE

REMARKS:
Boring depth and location were determined by RETL. Drilling operations were performed by RETL at GPS Coordinates N 27.65762° W 97.27674°.

LOG OF BORING B-2

SHEET 1 of 1

Rock Engineering and Testing Laboratory, Inc.
6817 Leopard St
Corpus Christi, TX 78409
Telephone: 361-883-4555
Fax: 361-883-4711

CLIENT: HDR Engineering, Inc.
PROJECT: Laguna Shores Living Shoreline Project
LOCATION: Laguna Shores Rd. & Graham Rd.; C.C., TX
NUMBER: G119127

DATE(S) DRILLED: 3/18/19 - 3/18/19

DRILLING METHOD(S):
Russian Sampler

GROUNDWATER INFORMATION:
Boring was performed under 1½-feet of water.

SURFACE ELEVATION: N/A

FIELD DATA				LABORATORY DATA							
DEPTH (FT)	SAMPLE NUMBER	SAMPLES	N: BLOWS/FT P: TONS/SQ FT Tv: TONS/SQ FT Qc: TONS/SQ FT	MOISTURE CONTENT (%)	LIQUID LIMIT LL	PLASTIC LIMIT PL	PLASTICITY INDEX PI	DRY DENSITY POUNDS/CU.FT	COMPRESSIVE STRENGTH (TONS/SQ FT)	MINUS NO. 200 SIEVE (%)	DESCRIPTION OF STRATUM
1–2.5	AUGER S-1		Qc= 25	27	NP	NP	NP			5	**POORLY GRADED SAND**, wet, brown and gray, loose. (SP)
3.5–5	AUGER S-2		Qc= 20	20							Same as above.
6			Qc= 25								Sampling refusal was encountered at a depth of approximately 6-feet.

N - STANDARD PENETRATION TEST RESISTANCE
Qc - STATIC CONE PENETROMETER TEST INDEX
Tv - TORVANE RESISTANCE

REMARKS:
Boring depth and location were determined by RETL. Drilling operations were performed by RETL at GPS Coordinates N 27.65740° W 97.27699°.

LOG_OF_BORING GINT G119127.GPJ ROCK_ETL.GDT 4/12/19

LOG OF BORING B-3

Rock Engineering and Testing Laboratory, Inc.
6817 Leopard St
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Telephone: 361-883-4555
Fax: 361-883-4711

CLIENT: HDR Engineering, Inc.
PROJECT: Laguna Shores Living Shoreline Project
LOCATION: Laguna Shores Rd. & Graham Rd.; C.C., TX
NUMBER: G119127
DATE(S) DRILLED: 3/18/19 - 3/18/19

DRILLING METHOD(S):
Russian Sampler

GROUNDWATER INFORMATION:
Boring was performed under 2-feet of water.

SURFACE ELEVATION: N/A

DEPTH (FT)	SAMPLE NUMBER	N: BLOWS/FT / P: TONS/SQ FT / Tv: TONS/SQ FT / Qc: TONS/SQ FT	MOISTURE CONTENT (%)	LIQUID LIMIT LL	PLASTIC LIMIT PL	PLASTICITY INDEX PI	DRY DENSITY POUNDS/CU.FT	COMPRESSIVE STRENGTH (TONS/SQ FT)	MINUS NO. 200 SIEVE (%)	DESCRIPTION OF STRATUM
1–2.5	AUGER S-1	Qc= 13	35	NP	NP	NP			19	**SILTY SAND**, wet, light brown and gray, with shell, very loose. (SM)
3.5–5	AUGER S-2	Qc= 10	25							Same as above.
6–7.5	AUGER S-3	Qc= 35	25	NP	NP	NP			15	Same as above, loose. (SM)
										Sampling refusal was encountered at a depth of approximately 7½-feet.

N - STANDARD PENETRATION TEST RESISTANCE
Qc - STATIC CONE PENETROMETER TEST INDEX
Tv - TORVANE RESISTANCE

REMARKS:
Boring depth and location were determined by RETL. Drilling operations were performed by RETL at GPS Coordinates N 27.65740° W 97.27658°.

LOG OF BORING B-4

Rock Engineering and Testing Laboratory, Inc.
6817 Leopard St
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Telephone: 361-883-4555
Fax: 361-883-4711

CLIENT: HDR Engineering, Inc.
PROJECT: Laguna Shores Living Shoreline Project
LOCATION: Laguna Shores Rd. & Graham Rd.; C.C., TX
NUMBER: G119127

DATE(S) DRILLED: 3/18/19 - 3/18/19

DRILLING METHOD(S):
Russian Sampler

GROUNDWATER INFORMATION:
Boring was performed under 1½-feet of water.

SURFACE ELEVATION: N/A

DEPTH (FT)	SAMPLE NUMBER	SAMPLES	N: BLOWS/FT P: TONS/SQ FT Tv: TONS/SQ FT Qc: TONS/SQ FT	MOISTURE CONTENT (%)	LIQUID LIMIT LL	PLASTIC LIMIT PL	PLASTICITY INDEX PI	DRY DENSITY POUNDS/CU.FT	COMPRESSIVE STRENGTH (TONS/SQ FT)	MINUS NO. 200 SIEVE (%)	DESCRIPTION OF STRATUM
1–2	AUGER S-1		Qc= 25	28	NP	NP	NP			4	**POORLY GRADED SAND**, wet, light brown, loose.
3.5–5	AUGER S-2		Qc= 35	27							Same as above.
5											Sampling refusal was encountered at a depth of approximately 5-feet.

N - STANDARD PENETRATION TEST RESISTANCE
Qc - STATIC CONE PENETROMETER TEST INDEX
Tv - TORVANE RESISTANCE

REMARKS:
Boring depth and location were determined by RETL. Drilling operations were performed by RETL at GPS Coordinates N 27.65702° W 97.27705°.

LOG_OF_BORING GINT G119127.GPJ ROCK_ETL.GDT 4/12/19

LOG OF BORING B-5

Rock Engineering and Testing Laboratory, Inc.
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Telephone: 361-883-4555
Fax: 361-883-4711

CLIENT: HDR Engineering, Inc.
PROJECT: Laguna Shores Living Shoreline Project
LOCATION: Laguna Shores Rd. & Graham Rd.; C.C., TX
NUMBER: G119127

DATE(S) DRILLED: 3/18/19 - 3/18/19

DRILLING METHOD(S):
Russian Sampler

GROUNDWATER INFORMATION:
Boring was performed under 2-feet of water.

SURFACE ELEVATION: N/A

SOIL SYMBOL	DEPTH (FT)	SAMPLE NUMBER	SAMPLES	N: BLOWS/FT P: TONS/SQ FT Tv: TONS/SQ FT Qc: TONS/SQ FT	MOISTURE CONTENT (%)	LIQUID LIMIT LL	PLASTIC LIMIT PL	PLASTICITY INDEX PI	DRY DENSITY POUNDS/CU.FT	COMPRESSIVE STRENGTH (TONS/SQ FT)	MINUS NO. 200 SIEVE (%)	DESCRIPTION OF STRATUM
	1			Qc= 18								**POORLY GRADED SAND**, wet, dark gray and brown, with shell, loose.
		AUGER S-1			40							
	2											
	3											
				Qc= 30								Same as above, light brown. (SP)
	4	AUGER S-2			25	NP	NP	NP			5	
	5											Sampling refusal was encountered at a depth of approximately 5-feet.
	6			Qc= 35								

N - STANDARD PENETRATION TEST RESISTANCE
Qc - STATIC CONE PENETROMETER TEST INDEX
Tv - TORVANE RESISTANCE

REMARKS:
Boring depth and location were determined by RETL. Drilling operations were performed by RETL at GPS Coordinates N 27.65706° W 97.27664°.

LOG OF BORING B-6

Rock Engineering and Testing Laboratory, Inc.
6817 Leopard St
Corpus Christi, TX 78409
Telephone: 361-883-4555
Fax: 361-883-4711

CLIENT: HDR Engineering, Inc.
PROJECT: Laguna Shores Living Shoreline Project
LOCATION: Laguna Shores Rd. & Graham Rd.; C.C., TX
NUMBER: G119127
DATE(S) DRILLED: 3/18/19 - 3/18/19

DRILLING METHOD(S):
Russian Sampler

GROUNDWATER INFORMATION:
Boring was performed under 2-feet of water.

SURFACE ELEVATION: N/A

FIELD DATA				LABORATORY DATA							
DEPTH (FT)	SAMPLE NUMBER	SAMPLES	N: BLOWS/FT P: TONS/SQ FT Tv: TONS/SQ FT Qc: TONS/SQ FT	MOISTURE CONTENT (%)	ATTERBERG LIMITS: LIQUID LIMIT LL	PLASTIC LIMIT PL	PLASTICITY INDEX PI	DRY DENSITY POUNDS/CU.FT	COMPRESSIVE STRENGTH (TONS/SQ FT)	MINUS NO. 200 SIEVE (%)	DESCRIPTION OF STRATUM
1 – 2.5	AUGER S-1		Qc= 10	22	NP	NP	NP			8	**POORLY GRADED SAND WITH SILT**, wet, light brown, very loose. (SP-SM)
3.5 – 5	AUGER S-2		Qc= 30	23							Same as above, loose.
5											Sampling refusal was encountered at a depth of approximately 5-feet.
6			Qc= 35								

N - STANDARD PENETRATION TEST RESISTANCE
Qc - STATIC CONE PENETROMETER TEST INDEX
Tv - TORVANE RESISTANCE

REMARKS:
Boring depth and location were determined by RETL. Drilling operations were performed by RETL at GPS Coordinates N 27.65670° W 97.27688°.

LOG_OF_BORING GINT G119127.GPJ ROCK_ETL.GDT 4/12/19

LOG OF BORING B-7

Rock Engineering and Testing Laboratory, Inc.
6817 Leopard St
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Telephone: 361-883-4555
Fax: 361-883-4711

CLIENT: HDR Engineering, Inc.
PROJECT: Laguna Shores Living Shoreline Project
LOCATION: Laguna Shores Rd. & Graham Rd.; C.C., TX
NUMBER: G119127
DATE(S) DRILLED: 4/10/19 - 4/10/19

DRILLING METHOD(S):
Russian Sampler

GROUNDWATER INFORMATION:
Boring was performed under 6-inches of water.

SURFACE ELEVATION: N/A

SOIL SYMBOL	DEPTH (FT)	SAMPLE NUMBER	SAMPLES	N: BLOWS/FT P: TONS/SQ FT Tv: TONS/SQ FT Qc: TONS/SQ FT	MOISTURE CONTENT (%)	LIQUID LIMIT LL	PLASTIC LIMIT PL	PLASTICITY INDEX PI	DRY DENSITY POUNDS/CU.FT	COMPRESSIVE STRENGTH (TONS/SQ FT)	MINUS NO. 200 SIEVE (%)	DESCRIPTION OF STRATUM
	1			Qc= 33								**POORLY GRADED SAND WITH SILT**, wet, brown, loose.
	2	AUGER S-1			20						8	
	3											
				Qc= 45								Sampling refusal was encountered at a depth of approximately 3½-feet.
	4											
	5											
	6			Qc= 53								

N - STANDARD PENETRATION TEST RESISTANCE
Qc - STATIC CONE PENETROMETER TEST INDEX
Tv - TORVANE RESISTANCE

REMARKS:
Boring depth was determined by RETL and location was determined by HDR Engineering Inc. Drilling operations were performed by RETL at GPS Coordinates N 27.65769° W 97.27700°.

LOG_OF_BORING GINT G119127.GPJ ROCK_ETL.GDT 4/12/19

LOG OF BORING B-8

Rock Engineering and Testing Laboratory, Inc.
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Telephone: 361-883-4555
Fax: 361-883-4711

CLIENT: HDR Engineering, Inc.
PROJECT: Laguna Shores Living Shoreline Project
LOCATION: Laguna Shores Rd. & Graham Rd.; C.C., TX
NUMBER: G119127
DATE(S) DRILLED: 4/10/19 - 4/10/19

DRILLING METHOD(S):
Russian Sampler

GROUNDWATER INFORMATION:
Boring was performed under 1-foot of water.

SURFACE ELEVATION: N/A

SOIL SYMBOL	DEPTH (FT)	SAMPLE NUMBER	SAMPLES	N: BLOWS/FT P: TONS/SQ FT Tv: TONS/SQ FT Qc: TONS/SQ FT	MOISTURE CONTENT (%)	ATTERBERG LIMITS LIQUID LIMIT LL	PLASTIC LIMIT PL	PLASTICITY INDEX PI	DRY DENSITY POUNDS/CU.FT	COMPRESSIVE STRENGTH (TONS/SQ FT)	MINUS NO. 200 SIEVE (%)	DESCRIPTION OF STRATUM
	1	AUGER S-1		Qc= 15	21							**POORLY GRADED SAND WITH SILT**, wet, light brown, very loose.
	2											
	3											
	4	AUGER S-2		Qc= 23	24	NP	NP	NP			5	Same as above, loose. (SP-SM)
	5											Sampling refusal was encountered at a depth of approximately 5-feet.
	6			Qc= 49								

N - STANDARD PENETRATION TEST RESISTANCE
Qc - STATIC CONE PENETROMETER TEST INDEX
Tv - TORVANE RESISTANCE

REMARKS:
Boring depth was determined by RETL and location was determined by HDR Engineering Inc. Drilling operations were performed by RETL at GPS Coordinates N 27.65733° W 97.27724°.

LOG OF BORING B-9

Rock Engineering and Testing Laboratory, Inc.
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Telephone: 361-883-4555
Fax: 361-883-4711

CLIENT: HDR Engineering, Inc.
PROJECT: Laguna Shores Living Shoreline Project
LOCATION: Laguna Shores Rd. & Graham Rd.; C.C., TX
NUMBER: G119127

DATE(S) DRILLED: 4/10/19 - 4/10/19

DRILLING METHOD(S):
Russian Sampler

GROUNDWATER INFORMATION:
Boring was performed under 3-inches of water.

SURFACE ELEVATION: N/A

SOIL SYMBOL	DEPTH (FT)	SAMPLE NUMBER	SAMPLES	N: BLOWS/FT P: TONS/SQ FT Tv: TONS/SQ FT Qc: TONS/SQ FT	MOISTURE CONTENT (%)	LIQUID LIMIT LL	PLASTIC LIMIT PL	PLASTICITY INDEX PI	DRY DENSITY POUNDS/CU.FT	COMPRESSIVE STRENGTH (TONS/SQ FT)	MINUS NO. 200 SIEVE (%)	DESCRIPTION OF STRATUM
	1			Qc= 15								**POORLY GRADED SAND WITH SILT**, wet, light brown, very loose. (SP-SM)
		AUGER S-1			18	NP	NP	NP			8	
	2											
	3											
				Qc= 23								Sampling refusal was encountered at a depth of approximately 3½-feet.
	4											
	5											
	6			Qc= 56								

N - STANDARD PENETRATION TEST RESISTANCE
Qc - STATIC CONE PENETROMETER TEST INDEX
Tv - TORVANE RESISTANCE

REMARKS:
Boring depth was determined by RETL and location was determined by HDR Engineering Inc. Drilling operations were performed by RETL at GPS Coordinates N 27.65687° W 97.27731°.

LOG_OF_BORING GINT G119127.GPJ ROCK_ETL.GDT 4/12/19

ROCK Engineering & Testing Laboratory Incorporated

Engineering & Testing
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KEY TO SOIL CLASSIFICATION AND SYMBOLS

UNIFIED SOIL CLASSIFICATION SYSTEM

MAJOR DIVISIONS		SYMBOL	NAME
COARSE GRAINED SOILS	GRAVEL AND GRAVELLY SOILS	GW	Well Graded Gravels or Gravel-Sand mixtures, little or no fines
		GP	Poorly Graded Gravels or Gravel-Sand mixtures, little or no fines
		GM	Silty Gravels, Gravel-Sand-Silt mixtures
		GC	Clayey Gravels, Gravel-Sand-Clay Mixtures
	SAND AND SANDY SOILS	SW	Well Graded Sands or Gravelly Sands, little or no fines
		SP	Poorly Graded Sands or Gravelly Sands, little or no fines
		SM	Silty Sands, Sand-Silt Mixtures
		SC	Clayey Sands, Sand-Clay mixtures
FINE GRAINED SOILS	SILTS AND CLAYS LL < 50	ML	Inorganic Silts and very fine Sands, Rock Flour, Silty or Clayey fine Sands or Clayey Silts
		CL	Inorganic Clays of low to medium plasticity, Gravelly Clays, Sandy Clays, Silty Clays, Lean Clays
		OL	Organic Silts and Organic Silt-Clays of low plasticity
	SILTS AND CLAYS LL > 50	MH	Inorganic Silts, Micaceous or Diatomaceous fine Sandy or Silty soils, Elastic Silts
		CH	Inorganic Clays of high plasticity, Fat Clays
		OH	Organic Clays of medium to high plasticity, Organic Silts
HIGHLY ORGANIC SOILS		PT	Peat and other Highly Organic soils

TERMS CHARACTERIZING SOIL STRUCTURE

SLICKENSIDED - having inclined planes of weakness that are slick and glossy in appearance

FISSURED - containing shrinkage cracks, frequently filled with fine sand or silt; usually more or less vertical

LAMINATED (VARVED) - composed of thin layers of varying color and texture, usually grading from sand or silt at the bottom to clay at the top

CRUMBLY - cohesive soils which break into small blocks or crumbs on drying

CALCAREOUS - containing appreciable quantities of calcium carbonate, generally nodular

WELL GRADED - having wide range in grain sizes and substantial amounts of all intermediate particle sizes

POORLY GRADED - predominantly of one grain size uniformly graded) or having a range of sizes with some intermediate size missing (gap or skip graded)

SYMBOLS FOR TEST DATA

- ▽ — Groundwater Level (Initial Reading)
- ▼ — Groundwater Level (Final Reading)
- — Shelby Tube Sample
- — SPT Samples
- — Auger Sample
- — Rock Core

TERMS DESCRIBING CONSISTENCY OF SOIL

COARSE GRAINED SOILS		FINE GRAINED SOILS		
DESCRIPTIVE TERM	NO. BLOWS/FT. STANDARD PEN. TEST	DESCRIPTIVE TERM	NO. BLOWS/FT. STANDARD PEN. TEST	UNCONFINED COMPRESSION TONS PER SQ. FT.
Very Loose	0 - 4	Very Soft	< 2	< 0.25
Loose	4 - 10	Soft	2 - 4	0.25 - 0.50
Medium	10 - 30	Firm	4 - 8	0.50 - 1.00
Dense	30 - 50	Stiff	8 - 15	1.00 - 2.00
Very Dense	over 50	Very Stiff	15 - 30	2.00 - 4.00
		Hard	over 30	over 4.00

Field Classification for "Consistency" is determined with a 0.25" diameter penetrometer