COASTAL TEXAS STUDY

Coastal Texas Protection and Restoration Feasibility Study

Final Feasibility Report

Appendix D – Annex 24:

Life Safety Risk Assessment

August 2021

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Coastal Texas Study: Life Safety Risk Assessment

1.0 Introduction

A life safety risk assessment workshop was conducted as part of the Coastal Texas Study and a summary is included as an Annex to the Engineering Appendix. The life safety assessment is qualitative as it mainly focuses on failure modes of system components without consequence modeling.

2.0 Background

The Recommended Plan is a system of structural features that provide a comprehensive coastal storm risk reduction along Coastal Texas. The Recommended Plan was selected following comparison and screening of two initial project alternatives included elements of levees, floodwalls, pumping stations, and navigation gates. The alternatives evaluated are included in the Life Safety Measure/Plan Evaluation Matrix located at the end of this appendix. The alternatives are briefly described in the following sections. Main Report includes a map of all the components of the Recommended Plan and the Engineering Appendix provides full descriptions.

2.1 Alternative 1

No Action Alternative

In the No Action FWP condition, coastal forces continue natural erosion and accretion of sediment along shorelines and marshes; relative sea level change increases, storms will create extreme impacts with storm surge, wave attack and inundation, and create sudden shoreline reformation. Climate change may increase the frequency and intensity of storm characteristics.

2.2 Alternative 2

Alt A (Or Recommended Plan)

A gulfward system of structural measures will reduce the penetration of storm surge beyond the outermost coastal barrier island and peninsula, with a large gate across the inlet, a series of supporting beach, ring barrier and tie in levee features.

2.3 Alternative 3

Alt D2

An interior system of structural measures will reduce the penetration of storm surge past the bay shoreline with a series of connecting beach walls on the bay interior and connecting to existing CSRM features. A ring barrier is proposed for Galveston Island.

3.0 Approach

Quantitative consequence modeling was not conducted at the time of this life safety risk assessment. This life safety assessment is qualitative as it mainly focuses on potential failure modes of the various system components. The Project Delivery Team has made the determination to complete HEC-LifeSim modeling during Planning or Preconstruction Engineering and Design (PED) Phase.

3.1 Study Area and Consequence Centers

The Coastal Texas study area is home to two major metropolitan areas. The City of Galveston is situated on a barrier island between the Gulf of Mexico and Galveston Bay. The city is home to approximately 50 thousand people with about 16% of that population being over 65 years old (Census estimate July 1, 2019). The City of Houston sits on the northern end of Galveston Bay and is home to approximately 2.3 million people with about 10% of its population being over 65 years old (Census estimate July 1, 2019).

3.1 Population at Risk

Typically, Population at Risk (PAR) is defined as the number of people within a levee system's study area that would be subject to inundation during a flood hazard event. Since qualitative modeling has not been conducted to determine inundation extents for each potential failure scenario, PAR estimates are not available. A preliminary analysis was conducted using the hydraulic scenarios associated with the 1% Annual Exceedance Probability (AEP) event in the year 2085 to determine what the PAR would be without the project in place and with the project in place. While this analysis does not estimate any kind of breaching failure of the project, it does give a baseline idea of the maximum potentially impacted population in the study area. Since location-specific data for population expected to shelter in place was not available, data collected from emergency managers in the New Orleans metro area was utilized, which estimates 5% of the PAR remaining after a mandatory evacuation is ordered.

During HEC-LifeSim modeling, life loss is calculated for the population not fully evacuated based on a number of factors including velocity of flood waters, depth of flooding, structure stability, vertical evacuation within a structure, and age of the population. For this analysis, velocity of flood waters and structure stability were not accounted for. The depth of the flooding within a structure determines which life safety zone the population within the structure falls into based on the ability to vertically evacuate. These zones are “safe”, “compromised”, and “chance”. Populations classified as “safe” are unlikely to see life loss. Populations classified as “chance” are very likely to see life loss.

Life Safety Zones for With and Without Project in the 2085 1% AEP Event (5% of PAR Sheltering in Place)			
	Population in Safe Zone	Population in Compromised Zone	Population in Chance Zone
Without Project	51,089	770	3,066
With Project	53,641	606	678
Difference	2,553	165	2,388

Table 3.1 Estimated Population by Life Safety Zone

3.2 Emergency Preparedness Parameters

There are several factors considered when assessing potential time needed to evacuate an area and the percentage of the population likely to end up sheltering in place instead of evacuating.

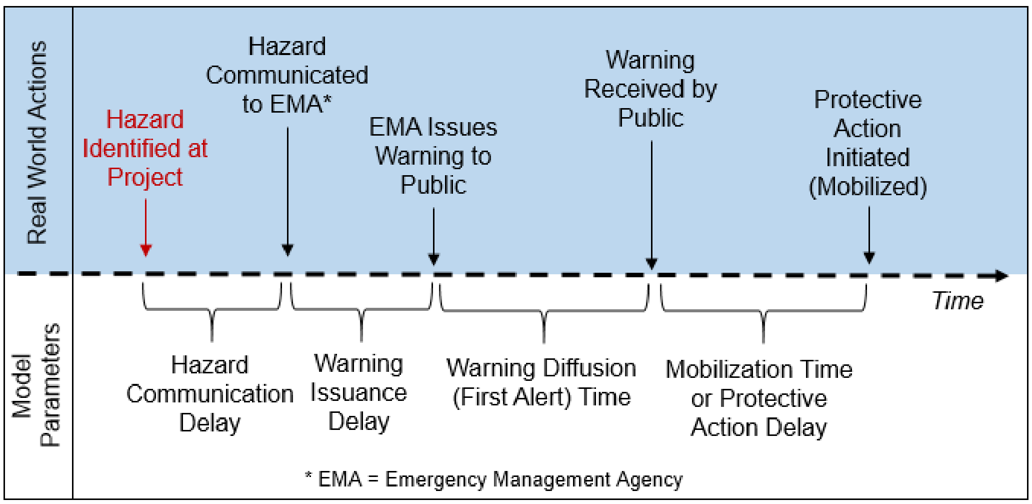

Figure 3.1 Standard Warning and Response Timeline

3.2.1 Hazard Communication Delay and Warning Issuance Delay

Hazard Communication Delay typically describes the time between a hazard being identified and that hazard being communicated to the local emergency managers. Warning Issuance Delay describes the time between the emergency manager being notified of a hazard and actually issuing a warning to the public. Due to the magnitude of the events required for overtopping and/or failure of the system, it was concluded by the risk assessment team that these events reflect surge associated with severe tropical storms and hurricanes. These events are typically well-predicted and monitored with standard language established and ready to push out to communicate the warning to the public. Since this is the case, Hazard Communication Delay and Warning Issuance Delay are not considered to be parameters that would make any kind of measurable impact on the overall evacuation and potential life loss seen in the study area.

3.2.2 Warning Diffusion Time

Warning Diffusion Time describes the time it takes for a warning issued by the local emergency managers to reach 100% of the population the warning pertains to. While severe tropical storms and hurricanes are well-forecasted and most people in the study area have the means to follow news coverage, the study area has a population of homeless and citizens living below the poverty line who may not have the technology necessary to receive warnings. These demographics may be harder to reach since there is not a loudspeaker or siren system in place for warning issuance and the main consequence centers like Galveston and Houston rely heavily on cell phone services to contact residents with emergency alerts.

3.2.3 Mobilization Time or Protective Action Delay

Mobilization Time or Protective Action Delay describes the time it takes between the public receiving the notice to evacuate and actually leaving their home. The two main factors of this timing are preparedness and perception of the population. Typically, the population in an area that experiences active hurricane seasons yearly is generally fairly well prepared to evacuate and has the perception that if a hurricane comes, they are likely to be impacted. This results in a population that is more likely to need less time to evacuate and is less likely to decide to shelter in place. These are the parameters the PDT recognizes may be negatively impacted by the project. Any time projects are put in place, the public is more likely to feel safe which results in being less prepared and/or willing to evacuate. In a failure situation, this change in mentality will result in higher life loss. This change in perception and its potential negative impact on life safety has been communicated to local officials.

3.3 Intended Impact of the Project

The project is not intended to promote sheltering in place instead of evacuating or have any impact on the evacuation orders typically given out in the study area currently. Any event that would result in an evacuation order without the project in place should still carry evacuation orders with the project in place. Communication with the public will be essential to combat the perception of safety once the project is in place to keep the population willing and ready to evacuate. Concerning life safety, the project is intended to provide risk reduction to critical infrastructure and evacuation routes so emergency services are available during and immediately after an event.

4.0 Major Drivers on System Performance

4.1 Storm Surge

The Texas coast is extremely vulnerable to hurricanes and tropical storms that continually place our coastal communities and natural resources at risk. As highlighted in the engineering Appendix (Table 2 1), tropical cyclones along the Texas Gulf Coast occur frequently, averaging once every 6 years along any stretch of the coastline. Hydrodynamic modeling suggests 100 year still water level in excess of 21ft using high sea level rise scenario with considerable wave loading which a protecting structure must withstand during an event.

4.2 Shoreline Change

The Texas coast is generally erosive except for areas on the updrift side of navigation jetties. Shoreline change has been monitored by the Bureau of Economic Geology (BEG) at 50-meter intervals through remote sensing techniques and is reported by Paine et al. (2014). Between the 1930s and 2012, the Texas coast lost on average 4 feet of shoreline per year. These changes are generally greater on the upper Texas coast (from the mouth of the Colorado River to Sabine Pass) than on the mid to lower coasts.

4.3 Sea Level Change

Along the Texas coast, RSLC variability is mainly due to ground settlement from compaction of soft ocean sediment. RSLC in Galveston Bay, as measured by the station at Pier 21, is about two times higher than elsewhere on the Texas Coast. Using Galveston Pier 21 gauge and USACE intermediate sea level rise scenario, RSLC is estimated to increase by 3 ft at the end of next 100 years. One consequence of the RSLC would be higher wave energy and storm surge resulting more frequent surge gate operation.

5.0 Qualitative Assessment of System Performance

The recommended plan is a comprehensive approach to coastal storm risk management along the Texas Coast. This risk assessment focuses on the Galveston Bay Storm Surge Barrier System (GBSSBS) that serves as the first line of a multiple-lines of defense strategy. Bay defenses in and around Galveston Bay are designed to perform in combination with the gulf-front components. Together, the defense lines operate as a system of systems to manage residual risk through redundancies. The system is focused on protecting property, critical infrastructure, roadways for evacuation, and facilitating recovery. The GBSSBS is divided into two lines of defense:

- Gulf Defenses – gates, beach/dune, seawall
- Bay Defenses – ring barrier, Clear Lake/Dickinson/non-structural, GIWW breakwaters, oyster reefs, ER features.

5.1 Bolivar Roads Gate System

The 2.08 mile gate system (Figure 1) crossing Galveston Harbor Entrance Channel consists of 16 shallow water environmental gates at elevation -5.0, 5 vertical lift gate at elevation -20.0, 3 vertical lift gates at elevation -40.0, 125’ sector gate at sill elevation of -40.0 for recreational traffic, 2 vertical lift gates at a sill elevation of -40.0, 2-650’ floating sector gate at a sill elevation of -60.0. The sill elevation across the ship channel will allow for any future deepening of the Galveston Harbor Entrance Channel, which is currently maintained at a depth of –48 feet MLLW. The sector gates across the ship channel are anchored and housed in man-made “islands” on either side of the Entrance Channel. The channel crossing continues with a 125’ sector gate at a sill elevation of

-40.0’ for recreational traffic, 2 vertical lift gates at a sill elevation of -40.0, and 3 vertical lift gates at a sill elevation of -20.0. The gate system than ties into the end of the existing seawall at the San Jacinto Placement Area on Galveston Island. The top elevation for the crossing is 21.5 feet NAVD 88.

The crossing starts on Bolivar Peninsula at the end of Biscayne Beach Road with 3.03 miles of earthen levee, as shown in Figure 5.1, and proceeds northwesterly to State Highway 87, where the levee turns south westerly to near the intersection of Keystone and 23rd Streets. The barrier continues southwest with combi-wall for 5,000 feet reaching the start of the gate system across the Galveston Entrance Channel.

Figure 5.1: HBolivar Roads Gate System and Tie-In Structures

Key features of the Bolivar Roads Gate System are:

- Combiwall similar to NOLA east area. Includes access road from levee/dunes.
- SWEG – includes road along back. Sluice gates that close for surge. Known technology that performs reliably.
- VLG – modeled after Hartel gate. Limited navigation through these structures. Shut with mechanical system. In event of malfunction, backup system allows closure with the weight of the structure.
- Sector gates – 125’ recreational navigation gate. Sill at -40’. Close by mechanical system.
- Sector gates – 650’ nav gates. Modeled after Saint Petersburg, Russia gates. Stored in islands when not in use to protect from environment, barges, and navigation traffic.

- Levee Tie-in: The crossing starts on Bolivar Peninsula at the end of Biscayne Beach Road with 3.03 miles of earthen levee, and proceeds northwesterly to State Highway 87, where the levee turns south westerly to near the intersection of Keystone and 23rd Streets. The levee will consist of a 1V:3H slope on the protected side and a 1V:6H slope on the unprotected side. The unprotected side of the levee will be armored with stone protection and the reminder of the levee will be turfed.
- Limitations in geotechnical analysis. Risk assessment regarding limited geotechnical data done during feasibility, applied conservative assumptions to feasibility analysis and the features. Risk associated with uncertainty can generally be mitigated with PED investigations.
- Risk exists based on limited/preliminary analysis and approach using analogous systems. Feasibility level analysis carrying medium to high risk.

Critical failure modes and design concerns are summarized below:

- Risk associated with gates not working. VLG large size could get bound up (could close under dead weight). Sector gates have many mechanical/electrical features that could malfunction, which are not fully developed to this point. Specific components will be identified for resilience/reliability during PED. Specific redundancy features not identified, however will incorporate features from comparable systems in place in the world where best practices/risk mitigation features could be gleaned.

- Design of these features included reliability features from other analogous gates which was a criterion during gate design workshop to mitigate this risk.

- Gate Design competition is proposed during PED phase to incorporate expert refinement of the optimum type of gate and components.

- Large sector gates likely most critical to a system malfunction (unlikely for VLGs to end up stuck with backup gravity closure).

- Consequence of damage to VLG stuck open- Wind load during event, scour at foundation and potential undermining of the structure. Wave action while stuck open (water under, wind/wave on VLG open) could lead to progressive failure of adjacent sections with wind/wave loading that are not intended in design.

- Failure of one gate is not anticipated to produce major life safety issues. Galveston Bay is big enough to absorb residual risks. The large sector gates would be the major risk driver here in that they are large enough to convey enough water to fill the bay. Additional modeling will evaluate the consequence of gate failure scenarios and cascading effects. Any surge barrier issue could result in more overtopping at the Galveston ring barrier, more loading to the pump stations. Similar risk to Clear

Lake and Dickinson Bay. Could have more loading than initial design.

- Potential stability issues with gate failure with scour behind system.
- What happens if both sides of the sector gate won't close entirely? An operations manual will need to describe timing and process for gate closure such that instabilities aren't an issue.
- Combi-Wall: Relatively standard floodwall construction. They have fewer failure modes associated with them than do other features. Failure during a storm would be unlikely to have progressive failure of the rest of the structure. Failure would likely be toward the peak of the storm, so the failed circumstance would be on the receding limb of the hydrograph.

5.2 Galveston Ring Barrier System

The Bay Defense System includes a ring barrier around the backside of Galveston, seawall improvements, storm surge gates at Clear Lake and Dickinson Bay (with pumping stations), and non-structural measures (raising buildings, flood-proofing, etc.) for mainland communities in the upper west side of Galveston Bay (Seabrook area).

Key features of the system are:

The proposed ring barrier (Figure 5.2) is a system of floodwalls, gates, pump stations, and levee sections that would provide flood risk management for approximately 15.8 square miles of the City of Galveston. The maximum height of the floodwall would be 14 feet, and it would contain numerous gates across roadways and railways, including a gated closure at Offatts Bayou. The gates would remain open until the system needs to be closed for storms. Drainage structures and pumping stations are included in the plan to remove excess water from the system.

Figure 5.2: Galveston Ring Barrier System

Critical failure modes and design concerns of the Galveston Ring Barrier System are summarized below:

- Offats Bayou has minimal fetch. Likely not a risk driver.
- Unlikely that rainfall to pose life safety risk inside the system.
- Joint probability of extreme surge and extreme rainfall is low. Pumps were designed assuming 100-yr surge and 25-yr rainfall.
- Low likelihood of vessel impacts throughout the alignment. Some near Offats Bayou, but somewhat unlikely.
- Risk at combiwall and navigation gate is similar to the risk of Large Bolivar Roads closure. SWEGs are the same type of Bolivar Roads but smaller in scale.
- Biggest life safety / property risk for ring barrier is getting water inside the system that cannot be handled by the pump stations. Will not be able to load all features to their maximum at the same time. E.g., if there is overtopping along the seawall it would be unlikely to also be having overtopping near Harborside (and the opposite). If area fills, it would be due to a significant exceedance event. Catastrophic failure considered unlikely; life safety issues most likely associated with an extreme event beyond the design storm, which would carry mandatory evacuation orders.

- Since the walls are built robustly, these wall features can be overtopped without catastrophic failure. Thus, from life safety perspectives, likelihood of catastrophic failure is low as a part of the system.
- Much of the system is manually operated, including ~100 gates. Failure could occur if they aren't closed, or if they fail during operation, which has potential for localized flooding.

5.3 Bolivar and West Galveston Beach and Dune System

The Recommended Plan proposes a 25-mile long beach and dune system along the Gulf-facing side of Bolivar Peninsula (from McFaddin National Wildlife Refuge to Bolivar Roads) and another 18-mile long beach and dune system along the Gulf-facing side of West Galveston Island (from the end of the seawall to San Luis Pass) [Figure 5.3].

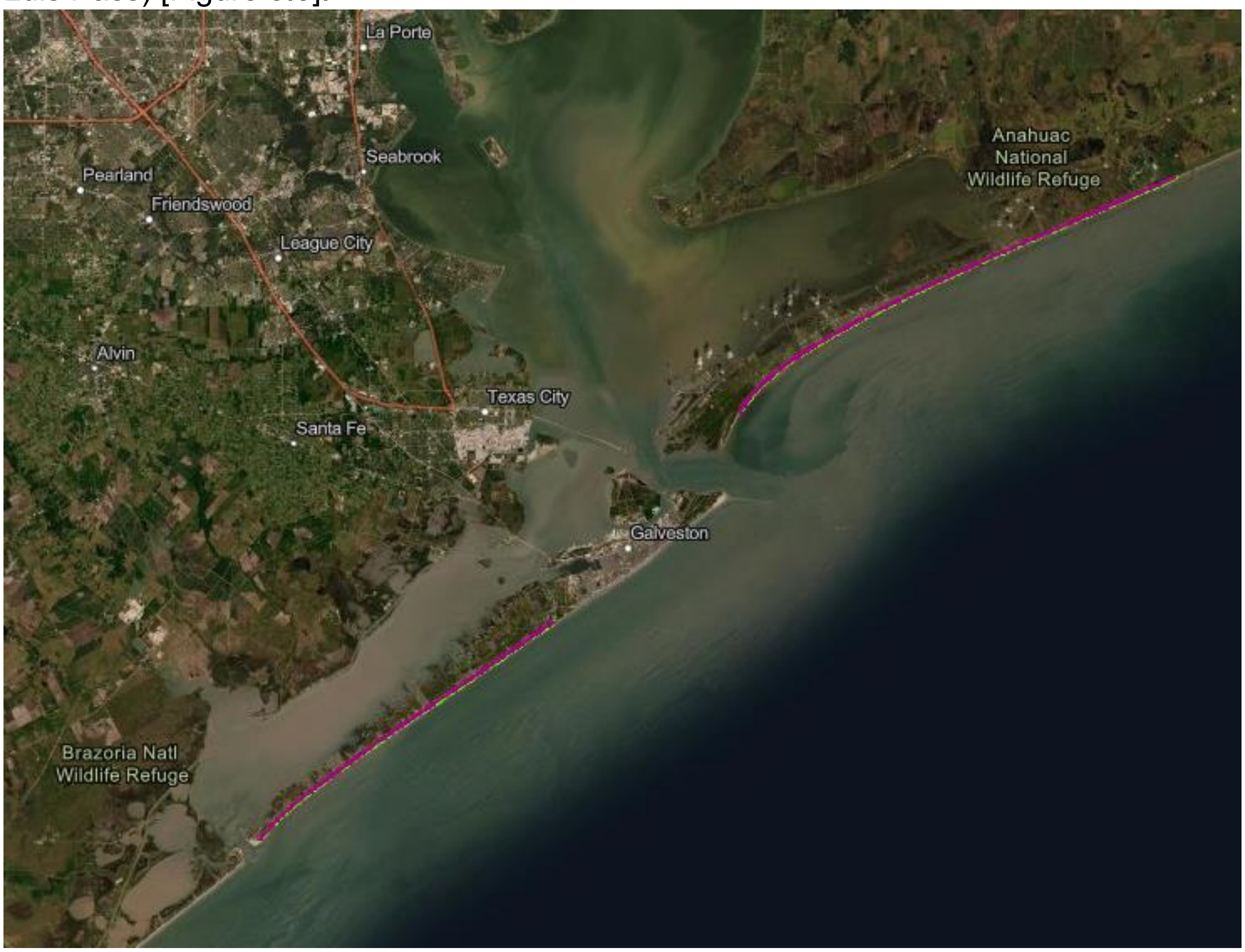

Figure 5.3: Bolivar and West Galveston Beach and Dune System

Key features of the system are:

A double-dune system with a beach on the Gulf-facing side. This would include a 14-foot landward dune, a 12 foot seaward dune, and a swale that separates the two. The dune system would be 185 feet wide with a 250 feet wide beach out front. The dunes would be planted with native vegetation to promote capture of wind-blown sand and provide habitat for coastal species. The widened beach would also increase resiliency of the dune system by providing time for vegetation to recover between severe storms.

Critical failure modes and design concerns of the Gate Tie In that transitions to the beach and dune feature are summarized below:

- Typical levee failure modes in play. Erosion on both front and back and under seepage (cut off wall hasn't been considered).
- There are concerns that there will be additional loading on the earthen levee because of surge being redirected away from the surge gates at Bolivar Roads.
- Breach would be catastrophic failure that would impact structures on the protected side.
- Catastrophic failure of this tie-in area perhaps the second-most likely opportunity behind some sort of mechanical failure of the surge gate system.
- If the tie-in fails, water is likely to head back toward Port Bolivar inland of the neighborhood behind the combiwall. Breach analysis would be needed to understand possible behavior.
- Transition between hard armoring and the earthen embankment likely area of high (if not highest) vulnerability. Could continue hardened (wall) as far as econ allows but would need to transition at some point.
- Similar point applies to the west end of the seawall and the transition to earthen levee.

- Levee Tie-in: Levee breaching due to seepage or overtopping is a major concern. Detail levee failure analyses and development of a monitoring protocol will be major tasks in PED.

    - Beach/dune system breaching– main consideration is water in the bay. The ring and other systems become susceptible with additional water in the bay.
    - Life safety risk is thought to be low overall with only the population sheltering in place instead of evacuating being at risk. The largest life safety concern is in areas where there is concentrated flow (high velocity) due to potential structure stability issues and collapse. Otherwise, structures generally have first floor elevations high enough that associated surge is unlikely to pose a threat to life safety just based on depth.

- Planned nourishments are distinct from catastrophic event. If catastrophic event and loss of dune in some critical sections, the period between the event and the restoration of the features would have additional risk. If dune is knocked down somewhat during a 50-yr event, potential for increased risk near the feature. For larger events where there is substantial overtopping and/or breaching, there a broader potential risk for the Galveston Bay system. PL84-99 mechanism could provide short contract to do spot maintenance. Stockpiles of sand could potentially be provided near hotspots to ensure sand available for restoration of a beach section following large event.
- Rollover Pass near to gulf. Roadway close to the gulf from Rollover and to the east. Loss of evacuation routes are the primary risk associated with this area.

5.4 Qualitative Risk Map

The consequences of life safety hazard due to structural failure modes as discussed above are visualized in figure 5.4. Life safety hazard ranking (high, moderate, low) shown in this figure is a rough order estimate of consequences due to failure (nonfunctioning) using engineering judgements. For example, it is estimated that failure of the Bolivar surge barrier during an event will have high consequences adjacent to this feature and across other system. However, the ring barrier system is a proven concept which will less likely generate life safety risk.

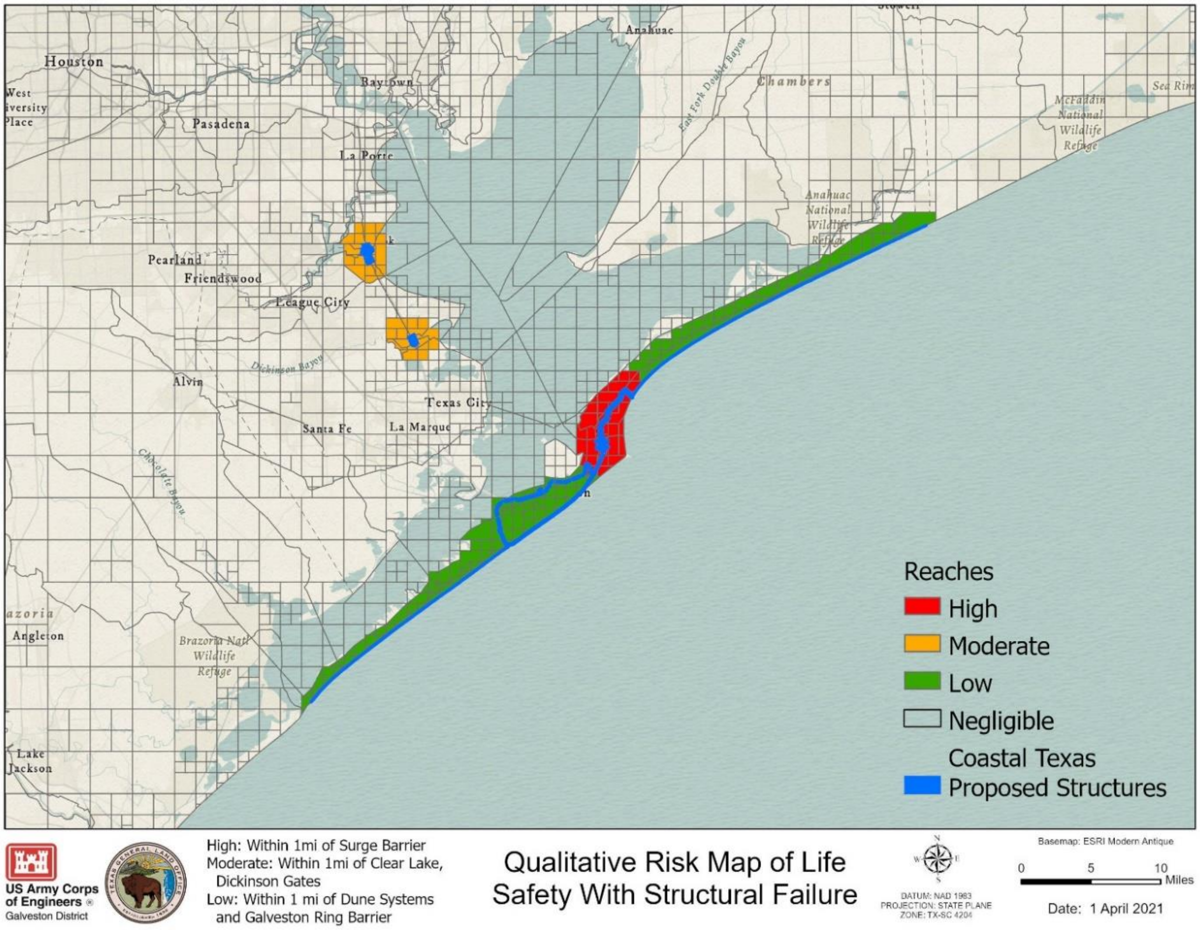

Figure 5.4: Qualitative Life Safety Risk Map due to Structural Failure

6.0 Life Safety Risk Assessment

6.1 The SQRA is currently targeted for completion early during PED, should the project be authorized and appropriated. A preliminary life safety matrix for the final array of alternatives is provided below.

Measure	Metric						
	Expected Annual LL[1]	Surge LLR[2]	Warning Time LLR[3]	Evacuation LLR[4]	Vulnerable Population[5]	Indirect LLR[6]	Incremental Risk[7]
No Action	Low	Medium	Low	Medium	3,836	Medium	Low
Alternative D2	Low	Medium	Low	Medium	1,379	Medium	Medium
Alternative A	Low	Low	Low	Low	1,284	Low	Medium

Notes: LL – Life Loss, LLR – Life Loss Risk

1. Expected annual life loss is assumed to be low for all scenarios. Events which would lead to breach or overtopping of either Alternative D2 or A would be large enough

that mandatory evacuation orders would be issued days in advance of the event. Those events would not carry any kind of official suggestion to shelter in place.

2. Life loss risk associated with surge is medium for both without-project and alternative D2 due to the unprotected nature of the barrier islands in both of these alternatives. Typically, most of the life loss seen is in vehicles and neither of these plans provide any protection for the evacuation routes leading out of Galveston and the barrier islands.
3. Warning time is low for all plans based on the tropical storm forecasting days in advance of event. Any potential breach or overtopping of either Alternative D2 or A would be large enough that mandatory evacuation orders would be issued days in advance of the event.
4. Evacuation life loss risk is medium for both the no action and Alternative D2 as neither of these plans provide risk reduction for evacuation routes. Some evacuation routes leading out of Galveston and the barrier islands are known to be inundated by tide events as well as surge events. Alternative A's alignment does provide protection to evacuation routes.
5. Population estimates for Alternative D2 were based on assuming with-project hydraulics associated with Alternative A for the reaches behind the D2 alignment (9-15, 36, 39-40, and 81-83) and without-project hydraulics for all other reaches. Population is considered vulnerable if the flooding above the first-floor elevation puts them in the chance or compromised life safety zones. Population assumes a 5% shelter in place rate for those who do not evacuate.
6. Indirect life loss is medium for both no action and Alternative D2 since neither plan provides protection of routes needed by emergency services to provide assistance immediately after an event. Alternative A is the only plan which provides significant protection to both routes used by emergency services and critical infrastructure points throughout the study area.
7. Incremental risk is based on evaluation of proposed flood control features and populations of protected areas (project performs as expected vs project overtops or fails). Both Alternatives D2 and A are medium incremental risk due to the perception of safety of the public within the high population area of Galveston Island. Citizens are more likely to ignore a mandatory evacuation order in favor of sheltering in place, so any overtopping or failure of the ring would lead to higher life loss.

6.2 Uncertainties

The life safety risk assessment was conducted by the PDT. Significant uncertainties and unknowns are incorporated into this assessment. The engineering unknowns, particularly the lack of geotechnical data resulting in major assumption in the foundation design, result in uncertainty with the potential long-term performance of the levees and floodwalls as currently planned. In addition, not enough data was available to the team for a quantitative assessment of consequences to estimate potential life loss associated with these potential failure modes. Assumptions were made about the performance and the potential consequences. Additional geotechnical, hydrological, and structural design work along with full consequence modeling would provide necessary information to reduce the uncertainty to tolerable levels.

Enclosure:

1. Workshop Agenda

Agenda and Goals for
Texas Coastal Protection Risk Screening and Probable Failure Mode Identification

Tuesday, March 2nd

Morning

-General discussion of project features, construction phasing and how that affects risk.

-Bolivar Roads Gate System
- -Briefing of primary features
- -Discussion of specific design and construction challenges of each feature
- -Listing of critical potential failure modes
- -Discussion of potential consequences of failure

Afternoon

-Continuation of the discussion of Bolivar Roads Gate System as needed

-Galveston Ring Barrier System
- -Briefing of primary features
- -Discussion of specific design and construction challenges of each feature
- -Listing of critical potential failure modes
- -Discussion of potential consequences of failure

Wednesday, March 3rd

Morning

-Continuation of the discussion of Galveston Ring Barrier System

-Clear Lake and Dickinson Bay Defenses
- -Briefing of primary features
- -Discussion of specific design and construction challenges of each feature
- -Listing of critical potential failure modes
- -Discussion of potential consequences of failure

Afternoon

-Continuation of the discussion of Clear Lake and Dickson Bay Gate Systems and Pump Stations as needed

-Beaches and Dunes (as time allows, could be done by teleconference later)
- -Briefing of primary features
- -Discussion of specific design and construction challenges of each feature
- -Listing of critical potential failure modes
- -Discussion of potential consequences of failure

-Wrap up and Path Forward