Addressing Resilience in Project Development

U.S. Department of Transportation
Federal Highway Administration

Sea Level Rise and Storm Surge Impacts on a Coastal Bridge

This study based in Mobile Bay, Alabama focused on the vulnerability of a coastal bridge to sea level rise, storm surge, and waves.[1]

Site Context and Facility Overview

The I-10 Bridge, or "the Bayway," crosses the northern end of Mobile Bay, Alabama and the southern end of the Mobile-Tensaw River Delta. Mobile Bay is a large, shallow estuary, much of which is less than 12 feet deep. The bridge is part of the major east-west interstate highway along the Gulf Coast and is one of the most heavily traveled roadways in the Mobile metropolitan area. State officials are currently planning to widen the bridge to increase the capacity of the highway.

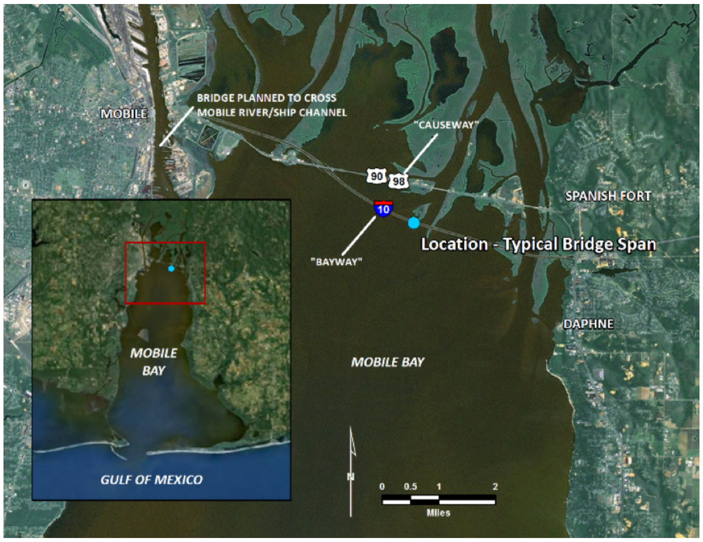

Figure 1: Map of project location.
Image Source: South Coast Engineers and Ersi's World Imagery

Tropical storms and hurricanes regularly impact the Mobile Bay area and cause coastal flooding and wave damage. Storm surge has exceeded 12 feet in the northern end of the Bay at the bridge.

An alternate route to the Bayway is provided by U.S. 90/98, also known locally as "the Causeway," which runs roughly parallel to the bridge but is much more susceptible to flooding from storm surge due to its low elevation on an earthen embankment.

Environmental Stressors and Scenarios

The primary stressors of concern at this site are sea level rise, storm surge, and waves. Higher sea levels will increase the magnitude and extent of inundation from storms and increase exposure to loads from wave action. Wave-induced loads can be extremely sensitive to storm surge elevation.

The analysis team developed a scenario for this assessment based on Hurricane Katrina characteristics, except shifted to make landfall closer to Mobile with +75 cm (29.5 in.) of sea level rise (adjusted to reflect local conditions) above mean sea-level (MSL). High-resolution storm surge and wave models (ADCIRC and STWAVE) were used to simulate this storm scenario.

Figure 2 shows scenario modeling results for time-varying storm surge stillwater levels (SWL) at the bridge location (+22.3 feet). Waves will add an additional 5.6 feet during this scenario based on the wave model results.

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[1] This snapshot summarizes one of nine engineering-informed adaptation studies conducted under the Transportation Engineering Approaches to Climate Resiliency (TEACR) Project. See https://www.fhwa.dot.gov/environment/sustainability/resilience/publications/ for more about this study and *Synthesis of Approaches for Addressing Resilience in Project Development*.

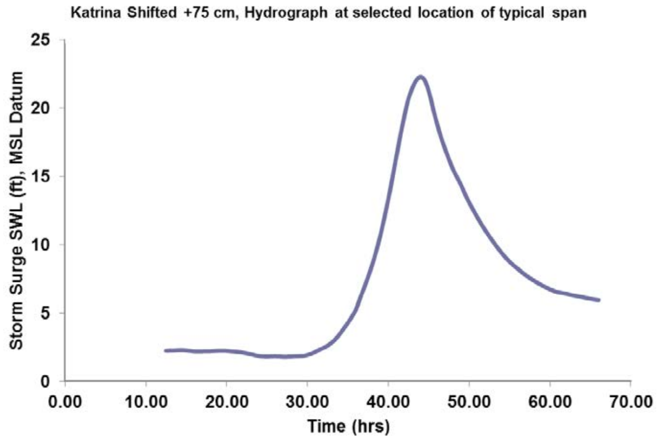

Figure 2: ADCIRC modeling of storm surge SWL. Waves could add 5.6 feet to this SWL in the storm scenario.

Analytical Approach

Overview

The research team analyzed how the existing bridge would perform under the selected storm scenario. The team estimated the wave-induced loading from this scenario using FHWA methods described in HEC-25 (2nd ed.).[2] The structural capacity of the existing bridge was computed based on evaluation of the construction plans. With bridge structural element elevations ranging from +16.5 to +22.8 feet and a peak storm surge elevation of +22.3 feet and wave height of 5.6 feet, the bridge will be exposed to extreme wave-induced loads during the scenario storm.

One concern was the bridge's connections between the superstructure and the substructure. On similar bridges, this connection has typically failed when the concrete around the bolts at the connection breaks with exposure to hurricane wave loads.

Results

Table 1 shows a summary of the estimated wave loading under the future scenario and the performance of the current bridge.

Summary of loads, capacity, and expected performance	Vertical Direction (kips)	Horizontal Direction (kips)
Wave-induced loads on bridge deck	1,550	530
Capacity of existing connections between the girders and the bent beams	520	110
Failure (yes/no)	Yes	Yes

Table 1: Summary of the loads, capacity, and expected performance of the bridge in the selected storm scenario.

Based on this analysis, the storm scenario would cause the bridge to fail. The connections between the superstructure and substructure would fail under the extreme loads. The team also determined the bridge would fail under a storm surge level of +14.9 feet, significantly less than the +22.3 feet of the original storm scenario. Figure 3 shows the failure of the bridge at both these SWL elevations.

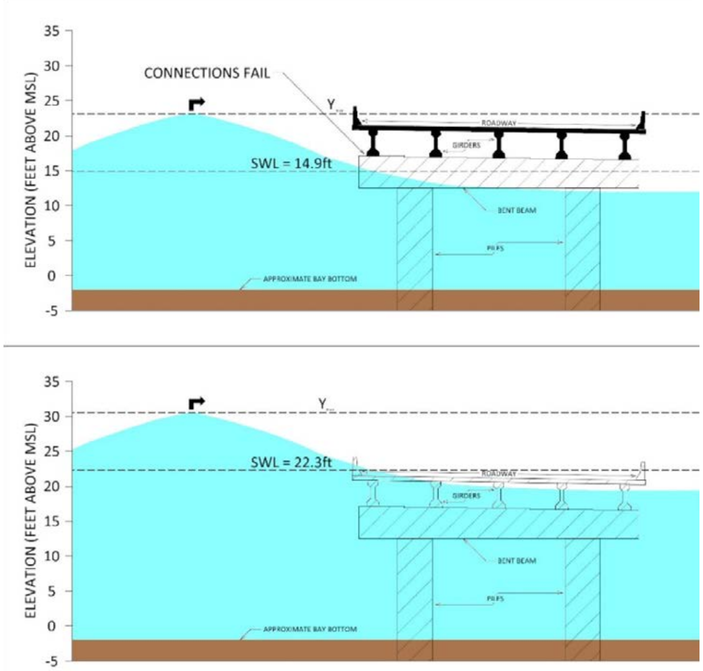

Figure 3. Analysis results showing bridge connection failures at SWL +14.9 feet and bridge failure at the storm scenario SWL +22.3 feet.

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[2] FHWA, HEC 25 (2nd ed), Highways in the Coastal Environment

Adaptation Options

The research team considered four possible adaptation options: 1) strengthen connections between the superstructure and substructure, 2) improve span continuity, 3) modify the bridge shape, and 4) increase deck elevations. Figure 4 shows a visual summary of the first two adaptation options.

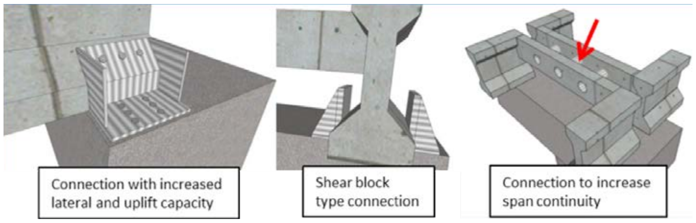

Figure 4: Examples of potential retrofit options for several of the adaptations considered.

Strengthen Connections

A key finding of this assessment is that if the connections are strengthened (a logical approach given past failures) then the bridge would likely still be destroyed by uplift-induced negative bending, which the deck and girders are not designed to withstand. Negative bending is the upward flexing due to the upward load acting on the bottom of the deck which is restrained at each end. Most bending, due to weight on the bridge, is in the other (positive) direction.

Improved Span Continuity

Improving the continuity between adjacent spans through retrofits of the existing bridge would improve performance by increasing the effective dead load of the overall structure, but it does not address potential failures in the superstructure and foundation or substructure.

Modified Bridge Shape

The bridge (see Figure 5) is concave on the seaward side of the structure and this can trap air as waves impact the structure.

Very high, short duration loads can be generated when a small air pocket is trapped between a rigid structure and a breaking wave. Altering the shape of this cross-section may reduce horizontal loads in storm events, but there is no standard design guidance for retrofits, and more research would be needed.

Figure 5: Outside edge of bridge showing concave configuration which traps an air pocket when a wave strikes it and potentially increases lateral loads.

Increased Deck Elevation Combination

Increasing the bridge's deck elevation in combination with one or more of the previous adaptation options could be an option during bridge reconstruction, but would be difficult as a retrofit. A new construction design could raise the deck elevation significantly to avoid wave loads.

Economic Analysis

To estimate the economic impacts of a potential bridge closure on the regional economy, the research team used the economic impact modeling software IMPLAN. Economic impacts included direct impacts to primary industries affected, indirect impacts to suppliers that interact with the primary industries, and induced impacts to other sectors from changes in industry activity.

The research team found that the failure of the bridge could result in significant costs to daily users of the bridge as well as the region-wide economy of the greater Mobile area. These costs come primarily in the form of direct costs to passenger and freight vehicles and indirect costs to the broader economy. Loss of the bridge could directly cost primary users $1,130,800 per day and result in a daily loss of up to $323,900 in industry activity.

Approximately 25 percent of the estimated economic costs associated with a bridge closure can be attributed to the loss of non-business (leisure) trips. The remaining 75 percent of the losses come from direct loss of economic activity, including increased commuter travel time and distance, and increased freight travel time.

Recommended Course of Action

Elevating the bridge, potentially in conjunction with structural adaptations, appears to be the only course of action that would allow it to survive an extreme storm condition such as the one evaluated here.

Lessons Learned

- High-resolution storm surge and wave modeling is a valuable tool for quantifying the vulnerability of coastal infrastructure. Such modeling is recommended in FHWA guidance, such as HEC-25 (2nd ed.).
- The design of engineering adaptations for coastal bridges requires following the load path implications through the entire structure and not just considering one type of possible bridge failure mechanism.
- Retrofit adaptation options that strengthen the connections between the decks and substructure can be designed to avoid the primary, historical damage mechanism (separation of the decks from substructure). However, such measures alone leave the bridge vulnerable to destruction due to other, secondary failure mechanisms (e.g. deck-girder damage due to negative bending and pile damage).
- Strengthening the connections alone may provide a limited increase in resilience, less than one additional foot of storm surge elevation, for this bridge.
- The team found none of the adaptation options, with the exception of increasing the deck elevation, to be adequate in avoiding the failure of this structure in this storm scenario.

For More Information

Resources:

Transportation Engineering Approaches to Climate Resiliency (TEACR) project website
www.fhwa.dot.gov/environment/sustainability/resilience/ongoing_and_current_research/teacr/index.cfm

HEC 25 Volume 2: Assessing Extreme Events
www.fhwa.dot.gov/engineering/hydraulics/library_arc.cfm?pub_number=192&id=158

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