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U.S. DOT Gulf Coast Study, Phase 2

Engineering Case Study 5: Bridge Segment Exposure to Storm Surge

This is one of 11 engineering case studies conducted under the Gulf Coast, Phase 2 Project. This case study focused on the vulnerability of a bridge to storm surge and associated wave forces.

Description of the Site and Facility

Storm surge can cause a bridge to fail via three different mechanisms: (1) a wave uplifting and washing away the superstructure (bridge deck), (2) failure of the substructure (bridge piers) due to the lateral forces of the wave, and (3) failure of the substructure due to excessive scour. This case study evaluated these three failure modes using the US 90/98 Ramp to I-10 as an example bridge.

I-10 and US 90/98 are two major routes that cross the Mobile Bay. Exit 30 on I-10 is an important interchange between the two routes; in the event that an incident disrupts traffic on one of the roads, motorists can use Exit 30 to access an alternate route across the Bay. Located approximately midway across the Bay, this interchange is exposed to storm surge during major storms.

The case study analysis focused on the portion of the interchange bridge between Bents 9 and 14 (out of a total of 29 bents) due to damages incurred on this segment during Hurricanes Katrina and Georges. The superstructure consists of a concrete slab deck and four concrete beams. The superstructure is connected to the bents with bolts that provide some resistance to both vertical uplift and lateral forces from surge. The bridge is relatively low-lying; the study segment ranges from just to 2.3 feet (0.7 meter) to 9.6 feet (2.9 meters) above Mean Higher High Water (MHHW).

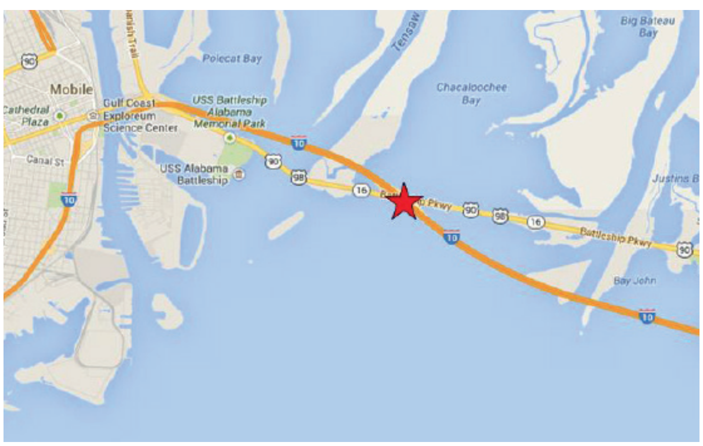

Figure 1: Location of Exit 30 within the Mobile Metropolitan Area

Climate Stressors and Scenarios Evaluated and Impacts on the Facility

This case study focused on sea level rise and coastal storm surge as the primary climate drivers that could damage the bridge. To assess a range of possible storm surge impacts, this analysis considered three storm scenarios, including:

- Hurricane Katrina Base Case Scenario: This scenario represents the surge conditions that actually occurred in Mobile during Hurricane Katrina.
- Hurricane Katrina Shifted Scenario: This scenario estimates the surge levels that could have occurred if Hurricane Katrina's path was shifted east to make landfall directly in Mobile.
- Hurricane Katrina Shifted + Intensified + Sea Level Rise (SLR) Scenario: This scenario estimates the surge levels that would occur if Hurricane Katrina made landfill directly on Mobile, intensified with stronger winds, and came on top of 2.5 feet (0.8 meters) of sea level rise.

Under all three scenarios, the superstructure and substructure of the bridge would be inundated.

The case study analyzed whether the bridge would likely fail due to the following failure mechanisms:

- **Failure Mode 1:** Superstructure fails by wave uplifting and it washes away
- **Failure Mode 2:** Substructure fails due to lateral forces applied from the waves or gets uprooted by the upward vertical forces acting on the superstructure
- **Failure Mode 3:** Substructure fails due to excessive scour

The results of the analysis concluded that the most substantial superstructure loadings occurred under the second storm scenario, while the greatest substructure loadings occurred under the first scenario. These results are interesting because it is the third scenario that represented the most extreme storm surge conditions, yet the loading on the bridge was less extreme under this third scenario. These results are due to the fact that the greater inundation that would occur under scenario 3 causes the damaging wave action to occur above the deck. Thus, deeper inundation can actually spare the structure from the more damaging forces of waves.

The analysis concluded that the bridge is likely not vulnerable to Failure Mode 1, but could be vulnerable to Failure Modes 2 and 3. However, actual performance during Hurricane Katrina showed that the reverse was true: the superstructure was displaced, but the substructure was not damaged. This discrepancy is potentially due to the lack of detailed condition information on the anchor bolts or more detailed geotechnical data, such as the shear strength parameters and physical properties (e.g., plasticity characteristics, unit weight) of soils in the vicinity.

Figure 2: Location of the Ramp to I-10 Eastbound within the Exit 30 Interchange

Identification and Evaluation of Adaptation Options

Adaptation measures can help protect against one or more of the failure modes. When considering adaptation measures, it is important to note that replacing the superstructure can be less costly and time intensive than replacing the substructure. Therefore, some adaptation options focus on allowing a controlled failure of the superstructure in order to limit the damaging forces on the substructure. Example adaptation options include:

- Design the superstructure to break away from the substructure in a significant storm surge. A breakaway superstructure would allow for a much shorter and less expensive rebuild period than if the substructure was allowed to be damaged.
- Design the anchor bolts and horizontal through girder bolts to fail at a lower load level, resulting in lower loads transmitted to the piles in a significant storm surge.
- Conversely, improve the connection between the superstructure and substructure and also investigate if the substructure foundations require strengthening after obtaining all geotechnical information.
- Investigate the use or partial use of installing open grid decks to possibly reduce the vertical loads imposed by a storm surge.
- Replace the bridge with a raised/protected embankment section up to a point high enough along the ramp where a bridge section can be used.
- Remove the interchange the next time it is seriously damaged, and do not allow for traffic to cross between the two routes in the middle of the Bay.

Potential Course of Action

Resource limitations did not allow for a comprehensive analysis of all adaptation options, so a recommendation was not made. To identify the appropriate action, it would be important to ensure that geotechnical characteristics are fully accounted for. Furthermore, the costs and benefits of protecting the superstructure must be fully assessed, as some superstructure protection measures could increase the likelihood that the substructure would fail, and the substructure could be far more costly to replace than the superstructure.

Lessons Learned

More extreme storm surges do not necessarily translate to more extreme forces on the bridge. In this case study, the less extreme storm scenarios sometimes exerted more forces on the structure.

The discrepancy between calculated results and historical record shows that incomplete datasets can dramatically influence results. Before taking action, it is important to ensure that the analysis takes into account all possible factors, including geotechnical properties (which were missing from this case study).

For More Information

Resources:
Gulf Coast Study:
Engineering Assessments of Climate Change Impacts and Adaptation Measures

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