Structural Vulnerability of Coastal Bridges under Extreme Hurricane Conditions

Identifying bridge configurations that enhance the resilience of coastal bridges against extreme weather events

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The main goal of this study is to evaluate the structural vulnerability of coastal bridge structures to hydrodynamic loads generated under extreme hurricane conditions along the Texas-Louisiana coastline. This research analyzes the most common bridge types (i.e. several girder bridge configurations) with the aim of identifying structures that are most and least resilient to hurricane waves and storm surge. Finite element-based simulations are being conducted to quantify the magnitude of the hydrodynamic loads under different hurricane sea states. Vulnerability curves will be developed to assess the potential damage of the bridge structures to specified hurricane scenarios. This information will be used to design and propose strategies that minimize structural damage during an extreme hurricane event, e.g. connections that prevent unseating of the superstructure.

Background

This project is in response to the severe hurricane events that have recently occurred, e.g. Harvey (2017) and Katrina (2005), along the Texas and Louisiana (TL) coastline. These hurricanes have caused significant damage to the infrastructure of the TL coast. Global climate change experts anticipate that the frequency and magnitude of severe hurricanes will increase in the coming years. Thus, there is a critical research need to develop methodologies that estimate the vulnerability of existing and future coastal bridges during extreme events. The strategies adopted to cope with extreme hurricane and tsunami events in the United States have been reactive rather than proactive. The cost of repairing and replacing bridges damaged during Hurricane Katrina exceeded $1 billion dollars. The most severe damage consisted of superstructure collapse due unseating of the deck, caused by the combined actions of storm surge and hydrodynamic forces from waves. This type of failure was observed both in bridges with integral and non-integral supports. It was also observed that in some cases, shear keys were sufficient to prevent unseating of the superstructure.

Project Summary

The main goal of this study is to predict the structural vulnerability of coastal bridge structures to hydrodynamic loads generated under extreme hurricane conditions along the TL coastline. The technical objectives include: (1) identifying current bridge configurations that are susceptible to severe damage due to extreme hurricanes and storm surge events and (2) design and propose strategies that minimize structural damages during extreme hurricanes and storm surges. UTSA researchers have made significant progress towards developing a high-resolution model capable of simulating the response of bridge structures to hydrodynamic loads under hurricane design conditions (i.e. surge height, wave height, and frequency) expected in the TL coast. The model is based on the Coupled Eulerian-Lagrangian approach for modeling wave-structure interaction, which is available in the commercial finite element software ABAQUS. This approach provides the foundation to study the vulnerability of bridge structures to natural hazards and achieve the aforementioned objectives. The main technical tasks of the project include: (1) modeling different bridge structural configurations under representative waves and surge conditions of the TL coastline and quantifying the magnitude of the hydrodynamic loads under different hurricane sea states, (2) establishing reliable quantifiable relationships between engineering parameters and damage levels, and (3) developing structural vulnerability curves and maps for the TL coastline.

Status Update

The response of coastal bridges due to hurricane induced waves has been simulated numerically using the Coupled Eulerian-Lagrangian (CEL) simulation approach available in the commercial finite element software ABAQUS. Different types of connectivity between the bridge superstructure and substructure have been considered. The results of a sample simulation are illustrated in Figure 1, in which it can be observed that the uplift forces generated by hurricane waves have the potential to overturn the bridge. The simulations performed to date have provided us confidence in our simulation approach and valuable information to update our models.

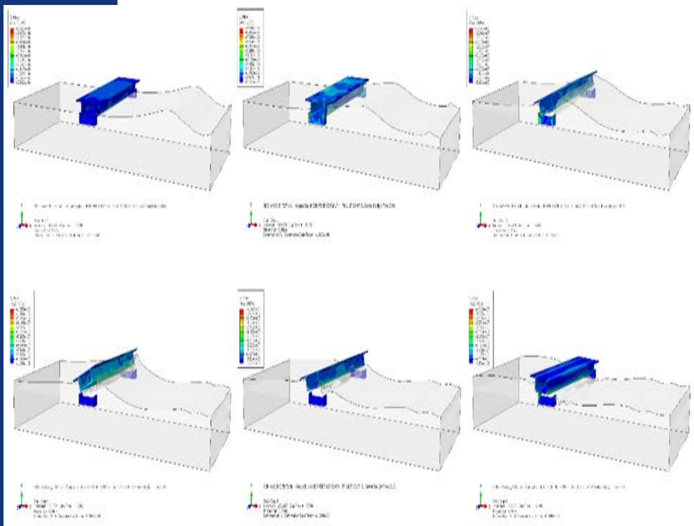

Figure 1. Sample simulation of a simply supported concrete box girder supported by shear keys.

In addition, the velocity and angle of impact of the wave have been varied to determine their effect on the response of coastal bridges. The simulation results have indicated that the response of the structure is highly dependent on the wave characteristics. The resultant shear and uplift forces increased with wave velocity, while the angle of impact only varied the magnitude of the resultant shear forces. In future work, variations to the bridge configuration will be performed in order to obtain a better understanding of the response of coastal bridges under hydrodynamic loads and propose design modifications that make them more resilient to extreme weather events.

Impacts

This study addresses several FAST Act research priorities, including: promoting safety, improving the durability and extending the life of transportation infrastructure, and preserving the existing transportation system. The potential impacts of this project include: (1) contributing to the resiliency of the transportation networks, particularly in the TL coastline, (2) ensuring the reliability of transportation routes needed to evacuate large populations along the coast during a hurricane, (3) minimizing the effects of extreme hurricanes on the US and local economies along the TL coastline, and (4) facilitating post-disaster recovery efforts and restoring economic activity.

Tran-SET

Tran-SET is Region 6's University Transportation Center. It is a collaborative partnership between 11 institutions (see below) across 5 states (AR, LA, NM, OK, and TX). Tran-SET is led by Louisiana State University. It was established in late November 2016 "to address the accelerated deterioration of transportation infrastructure through the development, evaluation, and implementation of cutting-edge technologies, novel materials, and innovative construction management processes".

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