PERFORMANCE OF COASTAL INFRASTRUCTURE UNDER WAVE AND WIND EFFECTS

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Abstract: Recent hurricane induced damage in the United States revealed that coastal structures are very vulnerable to destructive natural hazards. During the hurricanes, many low-rise bridge superstructures were dislocated under wave actions and residential houses were damaged under both wind and wave actions along the coastal line. Meanwhile, high-rise bridges, especially long-span flexible bridges along with the on-going traffic, are sensitive to wind effects. This presentation introduces issues and recent works of our research group related to high-rise long-span bridges, low-rise (low-lying) short span bridges, traffic safety, and residential houses along coastal lines under wind and/or wave actions. The information will help engineers, emergency response teams, transportation planning and management personnel, and the general public and communities in the process of prior disaster preparation and post-event recovery.

1.0 Introduction

By many measures, hurricane-induced winds and floods are the most devastating ones of all the catastrophic natural hazards that affect the United States. Coastal counties along the Gulf and Atlantic seaboards are experiencing great population growth and development. The metropolitan area of New Orleans is a prime example. Research predicted that a direct hit by a Category 3 or larger hurricane would ‘fill the bowl,’ submerging most of the city in deep water. New Orleans escaped catastrophic hurricane hits a few times in the last few decades. However, the predicted nightmare scenario unfortunately happened when Hurricane Katrina hit New Orleans in August 29, 2005. This disaster along with the “near-misses” in New Orleans area served to reinforce the concerns that how vulnerable our coastal cities are, and how important it is to prepare for the landfall of major hurricanes.

Coastal bridges are often the backbones of transportation lines and bottlenecks controlling traffic capacity. As demonstrated with the Katrina case in New Orleans, maintaining the highest transportation capacity and safety of these bridges is vital to support hurricane evacuations, emergency rescue response, reconstruction activities, and economic development of coastal cities. On one hand, though new bridges can be built with higher profiles (and more money) without being inundated, there are many low-lying existing bridges along the coastal lines. If the global warning assumption holds true, then more and more existing and new bridges will face the threats of hurricane induced wave loading. On the other hand, high-rise bridges, especially long-span flexible bridges along with the on-going traffic, are sensitive to wind effects. Meanwhile, low-rise residential buildings, the most common surface buildings, have been repeatedly witnessed as the most vulnerable structures after strong windstorms.

2.0 Damage Predictions of a Typical Low-Rise Building Under Hurricane Loads

The economic loss induced by hurricanes is around $5 billion annually, which has far outweighed the loss caused by earthquakes and other natural hazards (Pinelli et al. 2004). Low-rise residential buildings, the most common surface buildings, have been repeatedly witnessed as the most vulnerable structures after strong windstorms. The typical damaged envelope components, e.g., roof shingles or sheathing panels, not only allow the rainwater intrusion to cause additional content damages, but also produce flying debris that threatens neighboring buildings. Both reliable damage predictions and efficient mitigation measures for residential buildings need a better understanding of the structural responses, including system responses and component responses, under realistic hurricane loads.

The prototype structure used in the present study is a one-story 5:12 pitched gable roof house with the dimensions of 18.3×13.4×3.0 m for length, width, and overhang height, respectively, (Cope 2000, Pan et al. (2013). In the present study, the building is modeled as a timber structure since the light-framed wood structures account for about 90% of the existing residential house stock in US and approximately 95% of new homes (Martin et al. 2011). The general-purpose structural analysis software, ANSYS, is used to develop an analytical model of the selected prototype house. Wind tunnel tests on a 1:50 scaled model was conducted at the Boundary Layer Wind Tunnel of Louisiana State University as shown in Fig. 1 to determine the wind pressures on both sides of the building envelope.

At a 72 m/s (160 mph) wind speed, a Category 4 hurricane event, the Von Mises stresses develop significantly at the nail spots where the nail connections constrain the deformation of the leeward roof sheathing, windward gable end wall, and the windward wall edges as shown in Fig. 2 (a) and agree well with the observed failures of roof edge sheathings, gable end walls, and side walls shown in Figs. 2 (b) and (c). Further investigations on each of the seven failure modes and the corresponding initial failure wind speed are conducted to link the potential damage areas indicated by the Von Mises stresses to a specific failure mode.

3.0 Issues Related to Long-Span Bridges

Under strong winds, bridges may exhibit large dynamic and static responses. Wind may also endanger the safety of moving vehicles on the roadways as well as on bridges. For regular *aerodynamic* study of long-span bridges, no traffic load is typically considered, assuming that bridges will be closed to traffic at high wind speeds. Therefore, bridges are usually tested in wind tunnels or analyzed numerically without considering moving vehicles on them. However, coastal bridges may be occupied by stalled or moving traffic in modest or high wind during the arrival of tropical storm/hurricane winds. No adequate research has been performed on the dynamic interaction of vehicle-bridge and vehicle-road in hurricane type of high and large turbulent wind considering the safety of both bridges and vehicles. Although emergency management officials generally plan to halt evacuations such that the roads are cleared shortly before the onset of tropical storm-force winds, there are numerous possible scenarios under which vehicles may still be on the bridge when higher wind speeds occur. These scenarios include unexpected increase in hurricane forward speed or intensity, evacuation traffic gridlock, accidents/stalled vehicles or rainfall flooding blocking the road ahead, etc. To quantify the wind effects on vehicles, both experimental study and computational fluid dynamics (CFD) simulations were carried out.

4.0 Hurricane Induced Damage of Low-Rise Coastal Bridges

Recent hurricane damages in the United States revealed that coastal bridges are very vulnerable to destructive natural hazards. During the hurricanes, many bridge superstructures were dislocated; some of them even fell into the water after the bearing connections failed, as shown in Fig. 3. In the numerical part of this research, a wave model based on solitary wave theory was conducted to investigate the time history of wave forces on the Biloxi Bay Bridge. Investigation of effects of submersion depth on the wave force on the Biloxi Bay Bridge decks was conducted. The experimental part of this research is about determining the impact that the different parts of a bridge have on the total forces experienced by the bridge models. Research and tests have been performed on some of the recommended methods of mitigating the damage that bridges experience during hurricane events. Some techniques can be implemented only on new bridges, and others may be able to be implemented on existing bridges. Five different clearances were tested along with eight different bridge models that ranged from a flat plate to a fully developed slab-on-girder bridge model as shown in Fig. 4. Two different support systems were also tested: a fixed support system and a system that allowed for some horizontal and rotational movement. It was found that the girders of a bridge play the largest role in increasing the experienced forces, with variability of open, closed, and vented girder systems changing this increase in forces. It was also determined that the different support systems do have an effect on the wave forces, with the fixed support system showing more wave force for certain deck clearances and less wave force for others.

5.0 Conclusions

The present study discussed issues of both long-span high-rise and short-span low-rise coastal bridges as well as residential houses in coastal lines. Both numerical and experimental works were conducted on low-rise bridge deck to understand the wave forces. A refined 3D FEM with in-depth construction details was developed and analyzed to evaluate the building envelope performance that is the primary reason for the hurricane loss but not well addressed so far.

6.0 Acknowledgements

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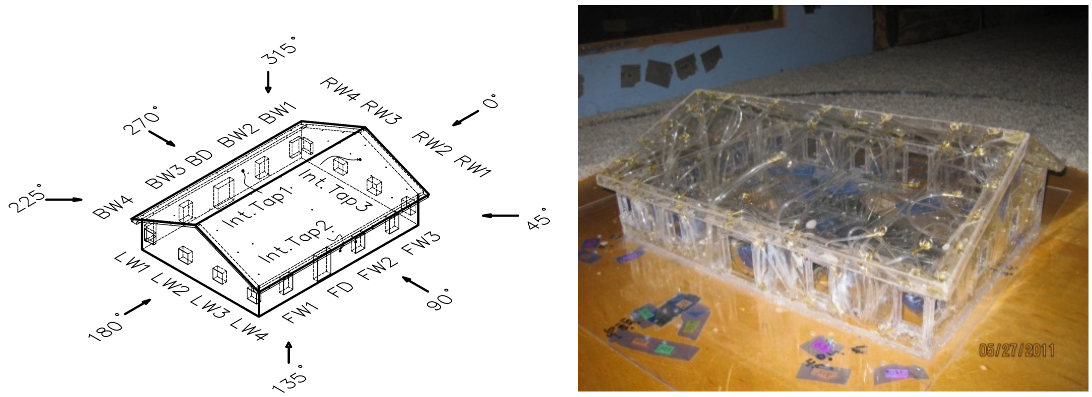

(a) Wind incidence angles **(b) Scaled model details**

Fig. 1 Scaled wind tunnel model (1:50)

(a) Von Mises stresses at 160 mph in WT load case

(b) Gable end wall and roof edge sheathing (arrows) failure in Katrina (FEMA 2006)

(c) Gable end and side wall failure in Andrew (FEMA 1992)

Fig. 2 Comparison of predicted potential damage areas and observed building damage

Fig. 3 Span Unseating of US-90 Biloxi-Ocean Springs Bridge

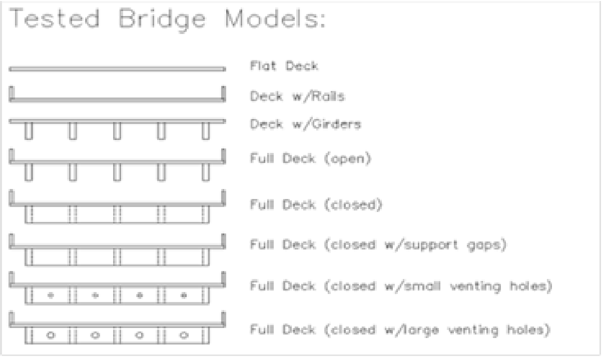

Fig. 4 Tested deck configurations