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HELPING BRIDGES WITHSTAND HURRICANE WAVES

A large-scale laboratory model helps researchers determine horizontal and vertical wave forces on a highway bridge superstructure.

The Issue

During Hurricanes Ivan in 2004 and Katrina in 2005, at least 11 highway and railroad bridges along the U.S. Gulf Coast were damaged. When the water rose during the storms, wave forces slammed into the bridges' supporting substructures, and when it rose high enough, the water's buoyancy had enough power to lift off sections of a bridge's superstructure and lay them aside like giant Legos.

To build bridges that can withstand the force of hurricane waves, engineers must be able to estimate the effects those waves will have on bridge structures. An OTREC project led by Oregon State University (OSU) professor Daniel Cox examined the effects of wave loading on highway bridge superstructures.

Cox and co-investigators Chris Higgins and Solomon Yim, also of OSU, worked with a team of graduate students to conduct experiments in the Large Wave Flume at the O.H. Hinsdale Wave Research Laboratory at OSU. They used a 1:5 scale concrete model of a section of the Interstate 10 Bridge over Escambia Bay, Fla, which failed during Hurricane Ivan. The problem addressed by this project is that while calculating the force of buoyancy, or hydrostatic force, is a straightforward analytical process, accurate estimation of the force of moving water —hydrodynamic force —is far more difficult.

The Research

When designing any structure, engineers often use analytical models: mathematical functions which help calculate the forces that will act on the structure, and the shape and strength it will need to have to withstand them. Highway bridge superstructures, however, have complex geometries. Their response to multidirectional forces can be difficult to estimate. When the added complexities of trapped air, turbulence, and the reactive movements of the bridge's structure are considered, analytical solutions become impractical and empirical models are the only way to go.

THE ISSUE
To build hurricane-resistant highway bridges in coastal areas, bridge designers must have accurate predictions of the vertical and horizontal wave forces that will be acting on their structures.

THE RESEARCH
This project used a large-scale laboratory model to calculate the wave forces that would act on a full-sized bridge. The model bridge section used in this project was:

- Made of the same materials as a full-sized bridge;
- Built on a 1:5 scale using Froude criteria to ensure it moved like the real thing;
- Subjected to a variety of measured wave forces in a controlled environment.

THE IMPLICATIONS
This research provides empirical data about the way a bridge's superstructure responds to high water and wave forces. These data are necessary for designing stronger coastal bridges, which may be subjected to those forces in the event of a tropical storm.

Photo: Damage to the U.S. 90 Biloxi Bay Bridge caused by Hurricane Katrina

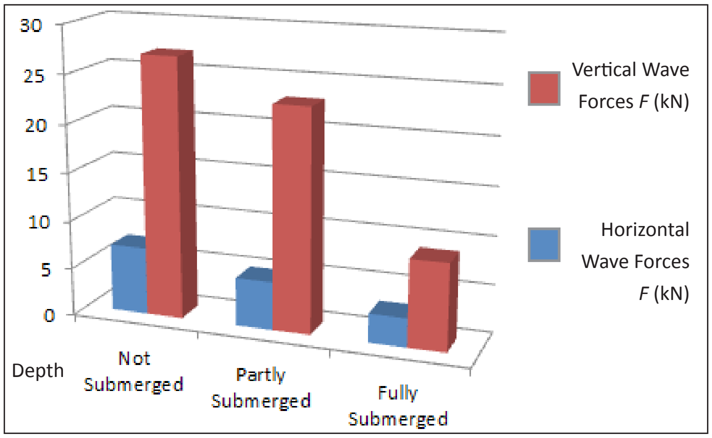
Small-scale models have been designed in the past, but there are limitations to working small. Real-world bridges are made of reinforced concrete, as was the one used in this project. Previous models have been fabricated from wood, plastic, or metal, due to difficulties working with concrete at small scales. The difference in size and material makes the water affect the model differently than a real bridge. Moreover, previous bridge models treated the structure as rigid, with no dynamic response to the forces. This also led to inaccurate results.

The model the research team used was designed to move like a full-size bridge using Froude scaling, so that the velocities acting on the 1:5 scale model had the same ratio as the velocities acting on the full scale. This assured that the model and the full-size version which was its prototype would have geometrically similar motions. The experimental setup also incorporated a roller and rail system, which allowed the model bridge section to move back and forth, simulating the way a real bridge would respond to the waves.

Using the flume to generate different sizes of waves, the researchers measured wave conditions along with the resulting forces, pressures, and structural responses. The data they collected will help to calibrate future numerical simulations, leading to the potential for bridge designs that can withstand stronger hydrodynamic forces.

Implications

The team also compared the measured forces to guidelines recently published by the American Association of State Highway and Transportation Officials (AASHTO). AASHTO has developed a series of equations to calculate design loads on coastal bridges due to waves. The equations predict the horizontal and vertical wave forces that will be acting on the bridges.



Measured forces for regular wave trials at a wave period of 2.5 seconds.

The above graph shows horizontal and vertical wave forces at varying depths, where the interval between waves remains constant. The graph shows that wave forces at shallower water levels are stronger than those in deeper water.

In cases where the still water level was at or below the low chord of the bridge, the horizontal and vertical forces predicted by the AASHTO guidelines compared reasonably well to the forces measured in OSU's wave flume.

Once the bridge was partially submerged, however, the measured forces leveled out or even decreased compared to those at lower water levels. At these higher water levels, AASHTO guidelines appear to over-predict the forces. According to this research, designers should exercise caution when using these guidelines if their design conditions result in partial or complete submergence of the bridge.

PROJECT INFORMATION

TITLE: Hurricane Wave Forces on Highway Bridge Superstructure

LEAD INVESTIGATOR: Daniel Cox, Ph.D., Oregon State University

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MORE INFORMATION
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