1-2014

Making Bridges Outlast Rising Waters

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OTREC
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MAKING BRIDGES OUTLAST RISING WATERS

A large-scale laboratory model helps researchers determine the strength of a highway bridge subassembly to resist horizontal and vertical wave forces.

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 by wave forces. The spans of these bridges typically rested on bent column supports, and were attached to the supports by a variety of connection methods. Failure of these connections caused bridge spans to be washed away when the water rose high enough to lift them off. To build bridges that can withstand such forces, engineers must be able to estimate the effects the forces will have.

Investigator Daniel Cox of Oregon State University has conducted wave loading research on highway bridge superstructures in the past (see OTREC projects 30 and 161). In this project, he turned his attention to the supporting substructures of bridges, examining the effects of wave forces on a bent column assembly substructure. The focus of this project was to determine the strongest types of connections that would withstand hydrodynamic force.

Cox and co-investigator Tim Maddux, also of OSU, worked with a team of graduate students to conduct large-scale experiments in OSU's Structural Engineering Research Laboratory. They used full-size prototypes of a prestressed concrete cylinder pile (PCCP) supported bent-column assembly, testing the connections using different loading cycles to determine the causes and modes of their failure.

The Research

The experiment was designed to simulate hurricane-induced wave loading on bridge superstructure-to-substructure connections. Two identical laboratory specimens were created, each a full-size prototype of a bent-column assembly. Forces were applied to these specimens to reproduce the effects of hurricane waves.

To determine the most commonly used anchorages in coastal infrastructure, researchers conducted a survey of state transportation agencies. They contacted representatives from

THE ISSUE

To build hurricane-resistant highway bridges in coastal areas, bridge designers must have accurate predictions of the behavior of the structural connection between the superstructure and substructure.

THE RESEARCH

This project used a large-scale laboratory model to calculate the effects of wave forces that would act on a full-sized bridge. The experiments tested:

- How the bridge responds to pressure under different loading conditions;
- How the bridge responds to pressure when already in a state of moderate damage;
- How the bridge responds to pressure once it has been retrofitted to rigidly attach the girders to the bent columns.

THE IMPLICATIONS

This research provides empirical data about the way a bridge's subassembly supports the deck during high water and wave forces. These data are necessary for designing strong connections for coastal bridges, which may be subjected to those forces in the event of a tropical storm.

Photo: Damage at Escambia Bay, Fla, after Hurricane Ivan (Courtesy W. Nickas).

PROJECT INFORMATION

TITLE: Laboratory Performance of Highway Bridge Girder Anchorages Under Simulated Hurricane-Induced Wave Loading

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PROJECT NUMBER: 2009-252

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MORE INFORMATION
http://otrec.us/project/252

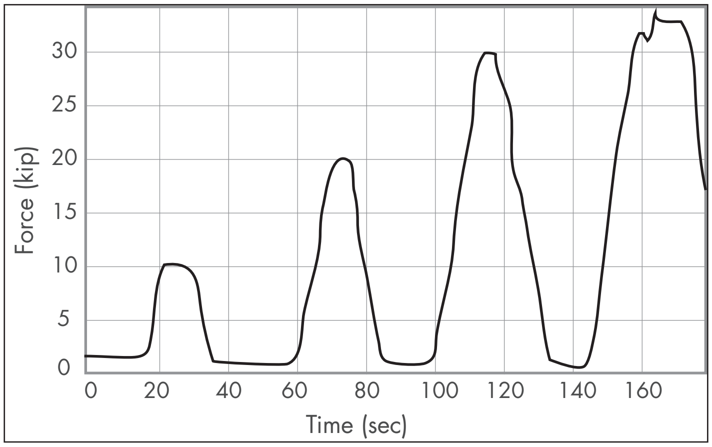
RELATED RESEARCH
http://otrec.us/project/30
http://otrec.us/project/161

the Florida, Alabama and Louisiana transportation departments and requested details of the anchorages used on existing bridges that could be susceptible to hurricane loadings, or were damaged by past hurricanes. From this survey, three anchorage designs emerged as the most common: the headed stud, clip bolt, and through bolt.

Each one of these anchorage types was attached to a concrete cylinder and subjected to four different loading conditions: vertical pseudostatic cyclic loading; horizontal pseudo-static cyclic loading; simultaneous horizontal and vertical pseudo-static cyclic loading; and dynamic loading (with simultaneous vertical and horizontal forcing). This resulted in 12 tests, each designed to isolate and then combine the force components that could potentially cause damage to the connection.

The three quasi-static cyclic test types applied their loads in increasing amplitude, starting with 100% Katrina conditions, until the specimen failed. The fourth type, the dynamic loading test, used the applied loads (both horizontal and vertical) taken from reduced-scale hydraulic model tests and transformed them to full-scale forces acting on the connections. During each test, researchers observed how and when damage occurred to the concrete around the inserts as well as how and when the connection itself failed.

The headed stud exhibited the most robust performance of the three anchorages considered. It had the highest load capacity, failing at 180% of Katrina conditions, and exhibited minimal ancillary damage to the prestressed concrete girders even at failure. The clip bolt connection failed at the lowest load, during 100% Katrina conditions, and the through bolt connection demonstrated higher strength than the clip bolt connection, ultimately failing at 160% of Katrina conditions. The damage sustained by the girder, however, was much more extensive in the through bolt connection than in either of the other two.



Vertical load history for anchorage specimens.

Each anchorage was subjected to psuedo-statically increasing cyclic load amplitudes until it failed. A typical load history is shown here, with an increased force about every forty seconds.

Implications

For the first time in the field of ocean structural engineering, full-size structural connection wave load responses have been measured through hybrid testing. These experimental results should enable bridge owners to better evaluate the vulnerability of their existing infrastructures. Moreover, now that the behavior of typical substructure-superstructure bridge connections has been recorded, the findings from this study stand to improve anchor designs, enabling future bridges to better withstand wave forces.