Project Summary
Texas Department of Transportation

9-5498: Methods of Evaluating the Redundancy of Steel Bridges

Background

Bridges that are classified as *fracture critical* by AASHTO require more frequent inspections than other types of bridges, resulting in greater costs for their maintenance. Several historical events—including the girder failures in the I-79 Bridge at Neville Island and in the Hoan Bridge in Milwaukee—have shown, however, that severe damage can occur without necessarily resulting in bridge collapse. Thus, a primary objective of this research project was to characterize the redundancy that exists in twin steel box-girder bridges, which are widely used in Texas and are classified as fracture critical. The main goal of the research was to develop guidelines for modeling a bridge's behavior in the event that a fracture of a critical tension flange takes place.

What the Researchers Did

The research included laboratory testing, experimental evaluation of a full-scale box-girder bridge, and computational modeling. The laboratory tests investigated the behavior of shear studs embedded in a concrete deck under loading conditions consistent with those that occur following the fracture of a girder. The three tests performed using the full-scale bridge were the first of their kind. The first two tests were used to evaluate the response of the bridge resulting from a sudden release of load. In the third test, the damaged bridge with a fractured girder was loaded statically until it collapsed, allowing for the ultimate strength to be determined. Finally, simulation models were developed to predict the response of a twin steel box-girder bridge following the fracture of one girder. Simplified models suitable for implementation in spreadsheet software or through the use of hand calculations were developed, as were detailed finite element models.

What They Found

Results from the laboratory tests demonstrated that the shear stud embedment depth, number of shear studs, shear stud orientation, and presence of a haunch can all greatly influence the pullout strength of shear studs embedded in a concrete deck. When studs in a haunch are not sufficiently tall to engage the bottom mat of reinforcing steel in the bridge deck, which was the case for the full-scale bridge that was tested—as well as in many other such bridges in Texas—the resulting mode of failure is brittle.

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When the studs do engage the bottom mat of reinforcement, the mode of failure is ductile. Based on the results of forty-eight tests, researchers on this project developed modified equations to use with the current ACI provisions (ACI 318, Appendix D) for estimating the breakout strength of shear studs embedded in reinforced concrete. The findings of the research were detailed in report 9-5498-2 "The Tensile Capacity of Welded Shear Studs."

Findings from the full-scale bridge tests revealed the inherent redundancy of the bridge evaluated during this research program. From a perspective of redundancy, the bridge considered during this project represented one of the worst cases. It was simply supported and therefore did not possess any inherent redundancy that is attributed to structures that are statically indeterminate. Consistent with standard TxDOT practice, all external braces that could have assisted in redistributing loads from the fractured girder to the intact one were removed following the completion of bridge construction. In addition, the bridge rails were constructed with expansion joints that limited the capacity of these components. Finally, the bridge was horizontally curved in plan, and the exterior girder was the one that was fractured. All of these effects combined to make the bridge less redundant than it might have otherwise been. Yet, despite these limitations, the bridge tested in this study performed remarkably well, carrying a load of 363,000 lbs.—more than three times greater than the legal truck load—with a full-depth fracture in the exterior girder.

Finally, experimental data collected through the laboratory tests and the full-scale bridge tests were used to develop validated analysis models that can be used to predict the capacity of twin steel box-girder bridges following the fracture of one girder. Because of the large deformations, inelastic material response, contact, and localized failures that occur when a fracture critical bridge responds near the point of collapse, modeling such behavior is very challenging, and overcoming numerical convergence problems represented a significant effort. Guidelines developed from this research provide information on how to conduct such analyses in a manner that minimizes the potential for numerical convergence problems while still providing accurate assessments of performance.

What This Means

Findings from this study suggest that twin steel box-girder bridges may have more capacity than the AASHTO specifications currently give them credit. Because of the research carried out on this project, engineers now have tools that can be used to analyze the response of twin steel box-girder bridges following the fracture of one of its girders. The simplified evaluation procedure is appropriate for the vast majority of cases; detailed finite element models can be used when results from the simplified model are inconclusive or require further refinement. Results obtained from these analysis models can be used to demonstrate the level of redundancy that exits in a given bridge system, which may eventually lead to reduced inspection requirements.

For More Information:
9-5498-2 The Tensile Capacity of Welded Shear Studs

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