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Testing and Strengthening Bridge Connections

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TESTING AND STRENGTHENING BRIDGE CONNECTIONS

Researchers evaluate and improve the strength of gusset plate connections, essential pieces in bridge design that can fail due to buckling.

The Issue

Gusset plates — the riveted steel plates that attach two or more bridge elements — are commonly used as connections in steel truss bridges. The 2007 collapse of the Interstate 35W bridge in Minneapolis was the result of a failed gusset plate, and led to an additional set of bridge design guidelines from the Federal Highway Administration (FHWA). The new guidelines require gusset plate connections to be subject to load rating. Prior to the collapse, only truss members were considered for load rating, and the connections themselves were trusted because of conservative assumptions employed during their design. Inclusion of gusset plate connections in load ratings poses a significant challenge to bridge owners, because of the large number of connections in a bridge and the complexity of analysis required to accurately evaluate each connection. The complexity of stress fields and failure states found in bridge gusset plates is addressed in design by applying approximate methods to arrive at a rapid, conservative solution, but one that may lack accuracy. Thus, development of more refined techniques for conducting high-fidelity capacity evaluations on existing bridge connections is desirable.

The Research

The various methods for evaluating gusset plate buckling capacity all have room for improvement. They're generally based around a set of rule-of-thumb guidelines developed in the 1950s. The most common formulation used to describe the stress magnitude in a gusset plate is the Whitmore method, which estimates the maximum stress.

OTREC researchers found that, on average, the actual maximum compressive gusset plate stresses were larger in their experiments than those predicted by the Whitmore method. The project's lead researcher, Christopher Higgins of Oregon State University, along with co-investigators Peter Dusicka and Michael Scott, set out to develop more accurate methods of evaluating the strength of gusset plate connections, and to assess the effectiveness of the current guidelines using finite element analysis (FEA).

THE ISSUE

Gusset plates, the steel plates that attach bridge elements together, have historically not been included in load rating, leaving them vulnerable to failure due to design flaw. This project explores methods for load rating gusset plates.

THE RESEARCH

The researchers for this project developed an experimental setup that was designed to:

- Make sure failure occurred in the gusset plates in order to measure the maximum buckling capacity of the plates themselves;
- Resemble Node U10, the failed gusset plate from the 2007 I-35W bridge collapse;
- Measure the capacity and predict the buckling strength of gusset plates.

THE IMPLICATIONS

This research will allow bridge designers and safety inspectors to more accurately evaluate the strength and capacity of existing gusset plate connections, making bridge safety ratings more reliable.

Photo: "Node U-10," the connection responsible for the I-35W bridge collapse (courtesy NTSB)

In this research, the experimental work was conducted at Oregon State under the direction of Higgins, and the FEA studies were conducted at Portland State University under the direction of Dusicka.

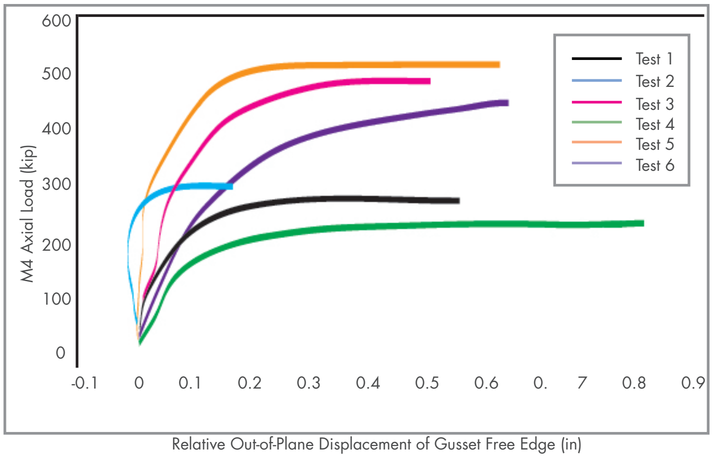
The research team conducted six large-scale experiments with a laboratory setup intended, by reinforcing the other bridge elements, to make sure failure occurred in the gusset plates. All six specimens failed due to sway buckling at the base of the diagonal compression member. The research team tested the contribution of factors like out-of-plane imperfection and plate thickness to predict the plate's buckling capacity, then compared their experimental results to existing load-rating techniques and the FHWA Guide to determine their effectiveness.

The experimental setup used in this project was inspired by connection U10 from the I-35W Bridge in Minnesota, shown in the image on the reverse. This is the connection reported to have failed and which prompted the professional community's interest in gusset plate performance and this research program.

Implications

Currently, the FHWA Guide is the protocol used by transportation agencies to evaluate gusset plates. A primary goal of this research effort was to develop a calibrated FEA model capable of evaluating gusset plate stresses, and their ultimate strength limit states, that would produce accurate load ratings for the gusset plate connections in existing bridges.

Connection-level finite element analysis was shown to be an effective method for evaluating the strength of steel bridge gusset plate connections, including member interactions. The model developed by this project has been validated with the experimental tests conducted at Oregon State University.



Displacement of the gusset plate under six loading tests

This graph shows how far (in inches) the free edge of the gusset plate moved, during six tests, in response to increasing loads. The more displacement, the more instability or "buckling" and the likelier the plate is to fail.

This research stands to help bridge designers and safety inspectors to evaluate the strength and capacity of existing gusset plate connections with greater accuracy than before. This will result in more reliable bridge safety ratings.

PROJECT INFORMATION

TITLE: Tools for Gusset Plate Evaluation

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PROJECT NUMBER: 2010-361, 2011-420

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MORE INFORMATION
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http://otrec.us/project/420