



Determination of U-Bolt Connection Load Capacities in Overhead Sign Support Structures

tech transfer summary

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RESEARCH PROJECT TITLE

Determination of U-Bolt Connection Load Capacities in Overhead Sign Support Structures

SPONSORS

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The Bridge Engineering Center (BEC) is part of the Institute for Transportation (InTrans) at Iowa State University. The mission of the BEC is to conduct research on bridge technologies to help bridge designers/owners design, build, and maintain long-lasting bridges.

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The results of this research will assist engineers in designing overhead sign support sign structures with assurances for the capacity and safety of their U-bolt connections.

Objective

The objective of this project was to develop methodologies and/or guidance on how to estimate the capacity of the U-bolt connections specified in the Iowa Department of Transportation's (DOT's) steel overhead sign truss (SOST) design standards.

Problem Statement

The true load capacities of the U-bolt connections used to support the overhead signs are not known, because the bolts are used in ways that do not match the available manufacturer data or the way that manufacturers intended the bolts be used.

Although the Iowa DOT Office of Bridges and Structures is unaware of any U-bolt connection failures since the SOST standards were released in 2011, the load capacities of the U-bolt connections are not known.

Background

The current Iowa DOT SOST design standards utilize U-bolt connections to anchor a four-chord horizontal space truss to support columns at each end of the space truss. The SOST standards also utilize U-bolt connections to attach vertical sign-support members to the front-top and front-bottom chords of the space truss.

The SOST U-bolt dimensional and material properties are substantially the same as those used in the earlier STEel OverHead (STOH) sign truss design standards, which were utilized from about 1970–2011. It is reassuring that the current type of U-bolt connections appear to have performed satisfactorily for more than 40 years. However, there is a growing safety concern due to an ever-increasing need for the Iowa DOT's overhead sign trusses to support larger signs by trusses with even greater span lengths.



Dynamic message sign overhead support structure

Research Description

A comprehensive literature search on the utilization of and modeling of U-bolt connections was conducted for this project, which helped in confirming the research approach.

Using the current Iowa DOT SOST design standards and actual loading conditions, three laboratory tests were conducted on the following two types of critical U-bolt connections that were identified and selected:

- Type-A U-bolt connection used to anchor the bottom chords of the horizontal space truss to supporting columns at each end of the space truss
- Type-B U-bolt connection used to attach vertical sign support members to the front-top and front-bottom chords of the space truss

To simulate the critical load conditions applied on the two types of connections, two Type-A U-bolt connection specimens and one Type-B U-bolt connection specimen were designed with the material and geometric properties used in the SOST design standards. The specimens were fabricated, instrumented, and tested in the Iowa State University Structural Engineering Research Laboratory.

A numerical modeling program was developed to assist in understanding the actual behaviors and failure modes of the U-bolt connections. To further interpret the test results and provide a valid analytical tool for the parametric study to be conducted, finite element models (FEMs) were developed for the specimens.

The results from the FEMs were compared against the load test results to validate the modeling approach. The calibrated models were then used in the parametric study that was performed to understand the behavior of the U-bolt connections with different material properties and subject to various loading conditions.

Given that the laboratory tests on the specimens were conducted and the model calibration was performed based on the most frequently used 3/4-in. diameter U-bolt, the parametric study was also performed for the 3/4-in. diameter U-bolt connection. The parametric study was used to calculate the yield and ultimate capacities of both specimen types (with various material properties and load directions).



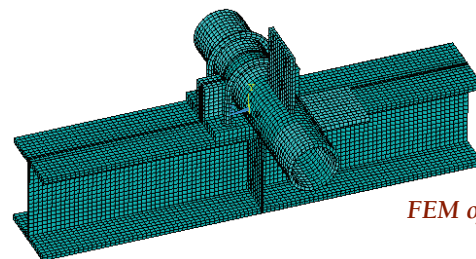
Type-A U-bolt connection



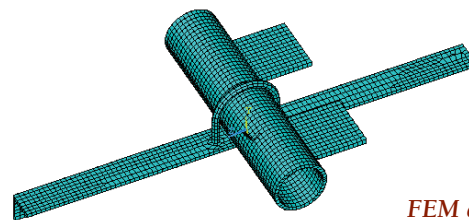
Type-B specimen



Type-A specimen



FEM of Type-A specimen



FEM of Type-B specimen

Finally, based on the experimental and numerical results, interaction diagrams were developed for designers and engineers to use in capacity estimation of their U-bolt connections under different loading conditions.

Key Findings

Literature Review Leading to Research Approach

- A comprehensive search of available literature indicated few research investigations on the capacity of U-bolt connection in civil engineering. However, related research was found in the fields of mechanical and vehicle engineering.
- Through the literature review, the researchers found that developing an FEM associated and calibrated with laboratory tests is the most commonly used approach to study the behavior of bolt-joined connections/U-bolt assemblies.
- The determination of the element type is a matter of computation time and computer capacity as related to model size. If enough computer time is available, the model with the solid element and surface contact element was found to provide the most accurate results.
- It was also found that model accuracy is sensitive to the definition of the contact behavior. It is essential to correctly model the contact interaction.
- Many approaches could be used to assign the preload (created by torque) to the FEM, including applying thermal strain on the shank or washers, or assigning an initial displacement onto the bottom of the bolt.

Research Results

- The results from both laboratory tests and analytical solutions indicate that different failure modes occur when the loading is in different directions.
- The results from the analytical study show a relatively low yield capacity, but indicate that the details have good ductility before reaching failure.
- The parametric study results indicate that the thread region is the most vulnerable location and that most of the failures start from that region.

Implementation Readiness and Benefits

This research helped to understand the structural behavior and stress distribution of the U-bolt connections used on the Iowa DOT's overhead sign structures subject to various loading conditions. The research results will benefit the Iowa DOT and other state DOTs that utilize similar U-bolt connections in overhead sign support structures.

This research resulted in interaction diagrams that Iowa DOT bridge designers and construction engineers, as well as other bridge owners, consultants, and contractors, can use for overhead sign support structures. The interaction diagrams were created for U-bolt connection capacity estimation under different loading conditions. Engineers can find the capacities by inputting the material type and load resultant direction.

Recommendations for Future Research

The research summarized in the final report represents a major step toward developing a better understanding of the behavior and design of U-bolt connections. However, several questions remain that could be answered by conducting additional research, as follows:

- Additional laboratory tests should be performed on high-strength U-bolts with loading directions of 135° and 180°, because the failure locations predicted by the FEM analyses with high-strength U-bolts are different from those captured in the laboratory tests.
- More experimental and analytical work should be conducted with various loading directions (e.g., 30°, 60°, 120°, and 150°) to study structural behavior subject to various loading directions.
- Given that almost all of the material types appear to have low yield capacity, the fatigue performance of the U-bolt connection should be investigated to understand the impact of repeated loads near the yield load. Additional laboratory tests are recommended to study the fatigue performance of the U-bolt connections.
- Given that both experimental and analytical work were conducted on the 3/4-in. diameter U-bolt, further research is recommended on U-bolt connections with other sizes to obtain the relationship between the U-bolt size and connection capacity.