ACCELERATED CONSTRUCTION OF THE HIGHWAY STEEL OVERHEAD SIGN TRUSS (SOST) THROUGH THE IMPLEMENTATION OF U-BOLT CONNECTIONS

Quarterly Progress Report
For the period ending September 1st, 2023

Submitted by:
Zhengyu Liu; Brent M. Phares
Graduate Student - Abdalla Alomari

Bridge Engineering Center
Iowa State University

ACCELERATED BRIDGE CONSTRUCTION
UNIVERSITY TRANSPORTATION CENTER

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Florida International University
Miami, FL

1. Background and Introduction

In the past decades, many states (including Iowa, Illinois and Wisconsin, etc.) have implemented U-bolt connections (such as Highway steel overhead sign truss) to replace the traditional wield or group bolts connections. For example, the current Iowa DOT steel overhead sign truss (SOST) design standards utilize U-bolt connections to anchor a four-chord horizontal space truss to supporting 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 use of the U-bolt connection on the ancillary support structures allows for a simple and quick onsite assembling of the large steel pieces. With that, the engineers could prefabricate and assemble the small steel pieces into large steel frames (components) off-site, and then quickly connect these large pieces on field by utilizing one or two U-bolt. This manner has been proved significantly accelerating the onsite construction (assembling). The avoid of tightening the group bolts or doing the welding also reduces the on-site labor cost.

The previous phase of this research work (Phares and Liu 2019, Liu and Phares 2020) served as a starting point to determine the load capacity of U-bolt connections used on highway overhead sign trusses. Three laboratory tests were conducted on two types of U-bolt connections. Finite element (FE) models were developed to investigate the internal stress development in the U-bolt subject to loadings in various directions. The data collected from the tests were analyzed and then used to calibrate the FE models. The calibrated models were then used in the parametric study to calculate the yield and ultimate capacities of the target U-bolt connections with various material properties and loading directions. Finally, interaction diagrams were developed for capacity estimation of both U-bolt connections. The results from both laboratory tests and analytical solutions indicated that different failure modes occurred when the specimen was loaded in different directions. Although this work represents a major step toward developing a better understanding of the behavior and design of U-bolt connections, several questions were raised and additional work was recommended to perform additional laboratory tests 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.

2. Problem Statement

The load capacities of the U-bolt connections on the SOST structures are not known because they are used in ways that do not match available manufacturer data. Although these U-bolt connections appear to have performed satisfactorily in the past, in recent years there has been a growing safety concern because of the need for overhead sign trusses to support larger signs at greater span lengths. As indicated by the Bridges and Structures Bureau (BSB) at the Iowa DOT, it is imperative to determine if the U-bolt connections have adequate strength to safely perform in current overhead sign support structures as well as in future ones that will need to resist even greater loads.

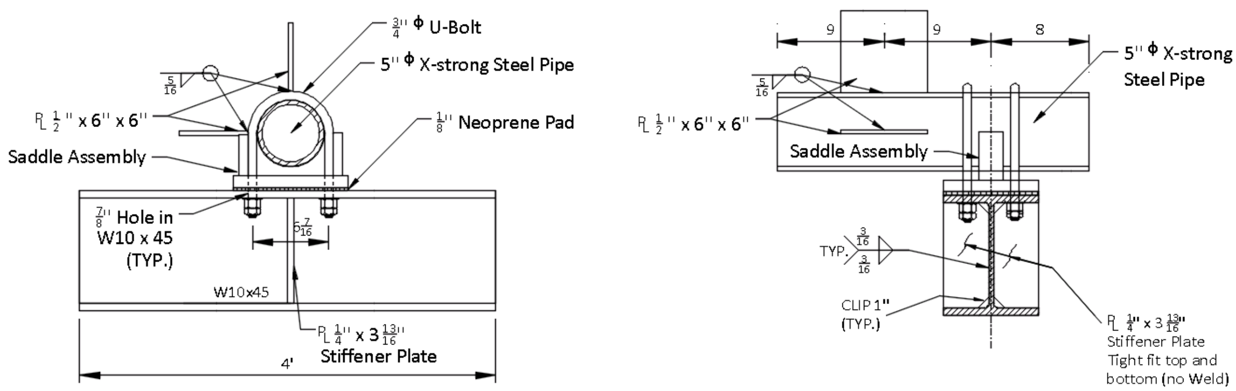
3. Objectives and Research Approach

The objectives of this project will be built on the work conducted by Phares and Liu (2019). The objectives of the proposed research are to:

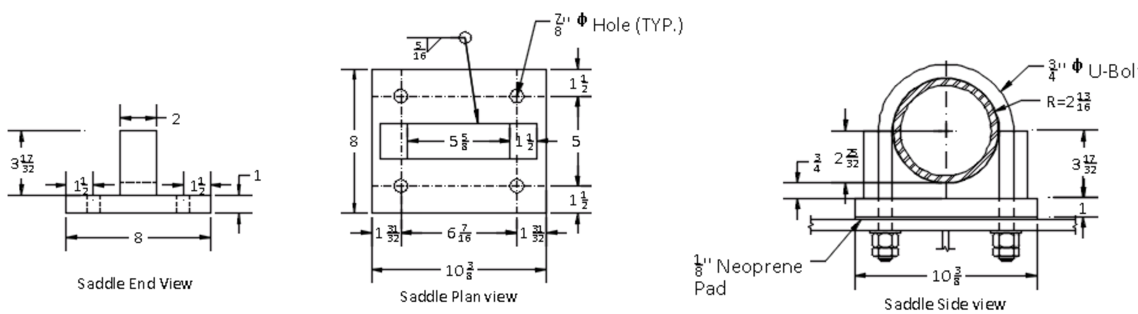
1. Investigate the structural behavior of the U-bolt connections and evaluate the capacity of the U-bolt connections subject to various loading directions

2. Validate the analytical results developed in Phares and Liu (2019).

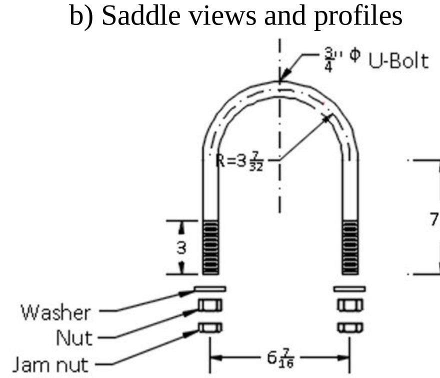
Consistent with the work conducted by Phares and Liu (2019), two types of critical U-bolt connections will be evaluated: 1) Type A U-bolt connection − used to anchor the bottom chords of the horizontal space truss to supporting columns at each end of the space truss, and 2) Type B U-bolt connection ─ used to attach vertical sign-support members to the front-top and front-bottom chords of the space truss. The details and dimensions of Type A and Type B specimens are shown in Figures 1 and 2, respectively. As indicated in Figure 1, the Type A specimen consists of a W-shaped steel beam, a saddle assembly, a steel pipe, two steel plates, and U-bolt components. As indicated in Figure 2, the Type B specimen consists of an L-shaped steel angle, a steel pipe, two steel plates, and U-bolt components.



a) Specimen views and profiles

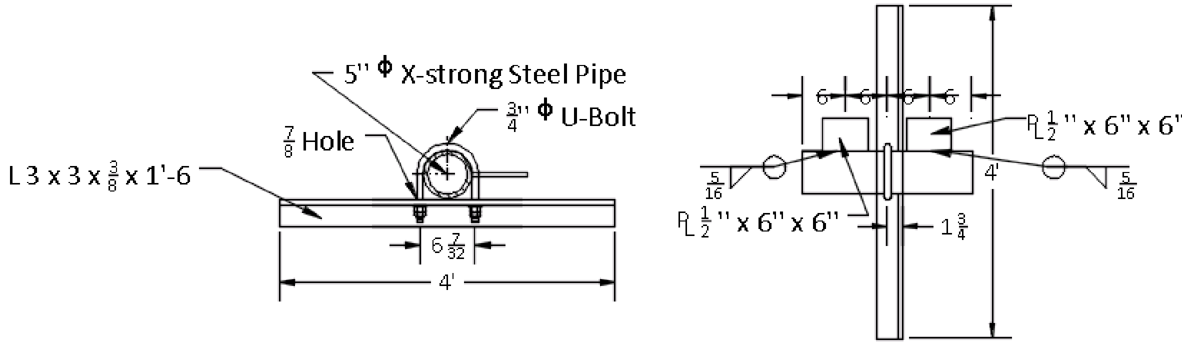


b) Saddle views and profiles



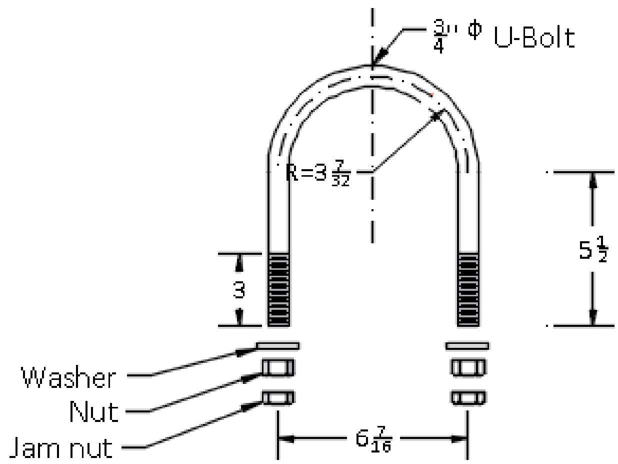
c) U-bolt details

Figure 1 Type A U-bolt Connection Specimen



>>> U-bolt leg spacing is 6 7/16", not 6 7/32" as currently shown above left <<<

a) Specimen views and profiles



b) U-bolt details

Figure 2 Type B U-bolt Connection Specimen

4. Description of Research Project Tasks

The following is a description of tasks carried out to date.

Task 1 – Literature Review

The completion of the previous phase (Phares and Liu 2019) of this project has produced a comprehensive literature review. An additional literature search will be conducted to collect information that was not uncovered in the previous phase research, mostly focusing on the review on the state DOT's use of the same or similar system.

The research team is doing the literature review. About 99% of the review work is completed by March 1, 2023.

Task 2 – Laboratory Tests

The proposed laboratory tests consist of two components: material property tests (Task 2.1), additional static tests to those performed in research Phase I (Task 2.2). Table 1 shows the test matrix for each phase. All specimens tested in Task 2 will be appropriately designed with the identical material and geometric properties as used in the actual SOST design standards.

Table 1 Test Matrix in Task 2

Task I.D.	Test type	Load type	No. of tests
Task 4.1 Material Property Tests	U-bolt Coupon	Static Tension	3
	Tube Coupon	Static Tension	At least 2
Task 4.2 U-bolt Static Tests	Type A-S1	45°	1
	Type A-S2	135°	1
	Type A-S3	180°	1
	Type B-S1	0°	1
	Type B-S2	45°	1
	Type B-S3	135°	1
	Type B-S4	180°	1

* The intent here is to run 3 million cycles per specimen, the test will stop if the system fails during the test or if nothing in the system fails after 3 million cycle loads.

Task 2.1 – Material property tests

The goal of the material property tests is to capture the stress-strain relationship of the tested U-bolt and the tube material when they are subject to the static tensile loading. These material properties are needed in order to understand the overall structural behavior of the U-bolt connections. In these tests, three specimens that are made with the same material as used on the tested U-bolt will be prepared and tested following ASTM A370 to capture the static stress-strain behavior. At least one tension coupon will be tested from each tube size (assuming all full-scale test specimens come from the same mother tube), and the Type B angles. All these coupons tested in this task will be in the "galvanized" condition.

Task 2.2 – Additional static tests

Although Phares and Liu (2019) provided the capacities of the U-bolt connection when the load is in different directions, most of the results were predicted by the analytical approach and never validated by the experimental tests. It was found that analytical simulation results show different failure modes when the loads are in different directions. Additional experimental validation was recommended for loading in the 45°, 135° and 180° directions. See Figure 3 for the loading orientations. The objective of this step is to conduct additional static tests to validate the predication results in Phares and Liu (2019). In total, seven tests will be conducted in this step including three on the Type A connection with loading directions of 45°,135° and 180° and four on the Type B connection with loading directions of 0°, 45°, 135° and 180°. Each test will be performed on a new U-bolt setup and loaded until either ultimate capacity or the desired capacity is achieved.

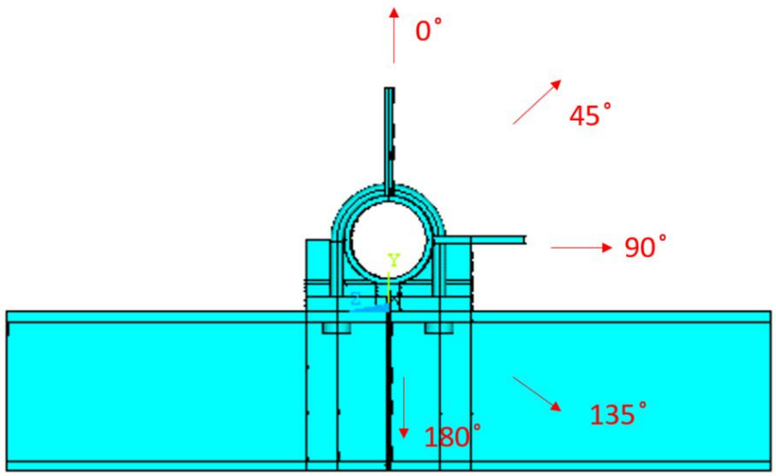


Figure 3 Load Direction on Type A Specimen

Before testing, all the specimens will be galvanized since this is a specified practice performed on the SOST structures. Similar to the work conducted by Phares and Liu (2019), the U-bolt response will be measured during each test. In order to compare the results with those in Phares and Liu (2019), a similar instrumentation plan used in the previous research phase will be adopted in this task. Five uniaxial strain gages will be attached along the exterior of each U-bolt. Displacement transducers will be installed to measure the displacement at the loading point and a load cell will be used to measure the loading increment. Since the previous research indicated that the rosette gages installed on the saddle (Type A connection) shows minimal response, no instrumentation will be installed on the saddles in this step.

10% of this task is completed by September 1, 2023. All the Type A and Type B specimens have been designed and fabricated. They are ready for the test. Instrumentation plan has been finalized and all the instrumentation needed have been purchased. The research team is still waiting for the availability for lab space. We will keep track with lab people to make this test happen as soon as possible.

In addition, one Iowa DOT SOST structure was selected to perform a more than one year of field monitoring. Although the field monitoring in Task 3 will provide data on the wind direction and speed, which could be used to calculate the wind pressure acting on the SOST structure, the load experienced by the U-bolt connections is unknown, and it is impossible to measure the load transferred through the U-bolt connections utilizing the field monitoring approach directly. The goal of this work is to determine the loading that is experienced by an onsite SOST structure in Iowa. The data collected during the field monitoring will be used to validate the FE model.

A data acquisition system and associated instrumentation was designed with the goal of capturing the wind load acting on the SOST and the associated structural response to wind loading. In order to achieve this, multiple types of sensors, including strain gauge, anemometer, thermal sensor were included in the instrumentation design. The anemometer was placed on the top of the space truss to measure the wind direction and speed. The data collected from the anemometer will be used to evaluate the wind pressure experienced by the SOST structures. The strain gages were placed at a few locations from mid-span to support, where at each location, multiple gages around the circumference of the chord within a plane will be installed. Such instrumentation allows measurement of the strain in the major directions, including vertical, horizontal, and in-between. The data is being collected during the monitoring work. Once the anticipated data are collected, the rainflow-counting technique will be performed to calculate an effective stress range. The results obtained from this Task will be used to calibrate the analytical model and determine the maximum load experienced on a field U-bolt connection. The final design of the instrumentation will be submitted to the TAC for approval before the initiation of the fieldwork.

A full-scale FE model is being developed based on the design of the field-monitored SOST structures utilizing mainly beam elements for the truss members and shell elements for the signs. The U-bolt connections was idealized with beam/spring elements to allow for load transfer from the lower-front and lower-back chords of the horizontal space truss to the W-section that is part of the supporting vertical planar truss (for Type A connection), and from vertical sign-support members to the front-top and front-bottom chords of the space truss (for Type B connection). The model will be loaded by the wind pressure calculated based on the wind speed/direction data collected, and then validated utilized field-collected strain data. Once the model is validated, the internal forces/moments in the beam/spring elements used to simulate the U-bolt connections will be output to determine the load experienced by U-bolt connection.

Task 3- Validation of Interaction Diagrams

In the previous research phase (Phares and Liu 2019), interaction diagrams were developed with limitations for design usage to estimate the capacity of the U-bolt connections with different material types and load directions. These diagrams were developed based on a parametric study performed on the calibrated FE models. However, these results were not validated through laboratory tests.

In this task, the capacity results obtained from Task 2.2 will be used to compare with the prediction from the interaction diagrams developed by Phares and Liu (2019). The difference between the experimental results and the results predicted by the interaction diagrams will be discussed if any discrepancies are found.

0% completed

Task 4- Recommendation Development

Based on results from the laboratory tests, the recommendation for the design subsequently will be derived to accurately estimate the capacity of the U-bolt connections under different loading conditions for the two types of U-bolts connections.

0% completed

Task 5- Final Report

A final report will be prepared as the final product of this project. Prior to report finalization all the review comments properly addressed.

0% completed

5. Expected Results and Specific Deliverables

The output of this research will provide guidance on selection, design and implementation of the U-bolt connection, which is commonly used on SOST to accelerate the onsite construction (assemble) of the truss frame and reduce the field labor cost. The research results will assist contractors in effectively and efficiently designing SOST structures without concern for the capacity and safety of the U-bolt connections. This research will also help to verify the safety of existing overhead sign support structures and ensure that the U-bolt connections are structurally adequate for future trusses that will support larger signs at greater span lengths.

6. Schedule

Progress of tasks in this project is shown in the table below.

Item	% Completed
Percentage of Completion of this project to Date	30%

Research Task	2022		2023								
	11	12	1	2	3	4	5	6	7	8	9
Task 1 – Literature Review											
Task 2.1 – Material property tests											
Task 2.2 – Additional static tests											
Task 3 - Validation of Interaction Diagrams											
Task 4 - Recommendation Development											
Task 5 - Final Report											

Work Performed

Work To be Performed

7. References

Phares, Brent M., Zhengyu Liu. "Determination of U-Bolt Connection Load Capacities in Overhead Sign Support Structures". No. IHRB Project TR-902 (2019).

Liu, Zhengyu, and Brent M. Phares. "Determination of U-bolt connection load capacities in overhead sign support structures." Journal of Constructional Steel Research 170 (2020): 106096.