Structures Research Services
2015-2017
(Task 2 Final Report –Aluminum Truss Overhead Sign Support Flange Damage Assessment)

Eric P. Steinberg, Ph.D., P.E.
Civil Engineering Department
Ohio University - ORITE
Athens, OH 45701-2979

Richard A. Miller, Ph.D., P.E.
Department of Civil & Environmental Engineering
University of Cincinnati
Cincinnati, Ohio 45221-0071

Douglas K. Nims, Ph.D., P.E.
Department of Civil Engineering
University of Toledo
Toledo, Ohio 43606

Kevin White, P.E.
E.L. Robinson
1801 Watermark Drive, Suite 310
Columbus, OH 43215

January 2019

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/OH-2019-21		

4. Title and Subtitle	5. Report Date (Month and Year)
Structural Engineering Research On-Call Services **Task 2 - Aluminum Truss Overhead Sign Support Flange Damage Assessment**	**September 2019**
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Doug Nims, Eric Steinberg	
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Ohio University **222 Stocker Center** **Athens, OH 45701**	11. Contract or Grant No. **SJN 135250**
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Ohio Department of Transportation **Office of Statewide Planning and Research** **1980 West Broad St., MS 3280** **Columbus, OH 43223**	**Final Report**
	14. Sponsoring Agency Code

15. Supplementary Notes

Prepared in cooperation with the Ohio Department of Transportation (ODOT) and the U.S. Department of Transportation, Federal Highway Administration

16. Abstract

A variety of structural supports exist to mount signs along highways. One type of support is a truss that spans the width of the highway that allows for the placement of overhead signs. These trusses are subject primarily to wind and gravity loads. The connections between the chords and the diagonals are typical fillet welded. Fillet welds are a fatigue prone detail and the welding potentially can leave a heat affected zone which affects the strength of the joints and the members.
A truss with severe cracking near Obetz, Ohio was identified by the Ohio Department of Transportation and removed from service.

Research team members inspected the trusses in the field on March 14, 2018 after they were removed from service. The cracking was mapped and elements of the truss including cracked and undamaged joints were removed from the truss and transported to the University of Toledo. Figure 1 shows a cracked horizontal chord member.

17. Key Words	18. Distribution Statement
	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	**Unclassified**	**10**	

Form DOT F 1700.7 (8-72) **Reproduction of completed pages authorized**

Structures Research Services 2015-2017

(Task 2 Final Report – Aluminum Truss Overhead Sign Support Flange Damage Assessment)

Principal Investigators:

Eric P. Steinberg, Ph.D., P.E.
Kenneth Walsh, Ph.D.
Issam Khoury, Ph.D., P.E.
Civil Engineering Department
Ohio University - ORITE
Athens, OH 45701-2979
Phone: (740) 593-1465
e-mail: steinber@ohio.edu

Douglas K. Nims, Ph.D., P.E.
Department of Civil Engineering
Joseph Lawrence
Center for Materials and Sensor Characterization
University of Toledo
Toledo, Ohio 43606

January 2019

Introduction:

Routine maintenance of overhead signs by ODOT District 12 revealed cracking in the flange connectors for several aluminum support trusses. Figure 1 shows some cracked flanges. All the trusses with cracked flanges had six bolt hexagonal flanges instead of the circular eight bolt flanges shown on the standard drawings. The trusses with severely cracked flanges were immediately taken out of service and placed near the side of the roadway. The removed trusses were visited by the part of the research team in October of 2015 in order to review and catalog the cracked flanges prior to the trusses being cut up into more manageable sizes for removal from the site and future testing. Each flange position in terms of sign placement was recorded in case any of the cracking could be attributed to position based on loading. Documentation of the observations consisted of filling out a form to identify the truss, flange location, and map the cracking. It was noted that all the observed cracking originated at the bolt holes and propagated outward. A total of seven truss sections, approximately 12 feet long were delivered to Ohio University during November for future evaluation. The trusses were estimated to have been in service since the late 1970's.

Figure 1: Typical Cracking (left) and Severe Cracking (right)

Objectives:

There were two primary objectives of the study.

1. Determine if damaged joints of the truss could sustain design loads
2. Determine the cause of the cracking

To meet these objectives, sections of the trusses were analyzed and tested. Ohio University tested two truss sections under loading and the University of Toledo investigated the materials of the joint around the bolts at cracking locations on two joints.

Assessment:

The project started with visual inspection of the trusses in the field. A Damage Index was established in order to rank the level of damage for the truss joint and individual flange connections within the joint. The severity of the damage was defined by the number and of size of the cracks, and a weighting factor was included. The Joint Damage Index (JDI) was simply the sum of the four flange Damage Indices. Two truss sections were tested to determine if the joint could sustain expected design loads. Truss 100 containing Joint B was tested first followed by Truss 315 which contained Joint A. Truss 100 with Joint B was tested first because of the high JDI. The results of Truss 100 with Joint B resulted in the testing of Truss 315 with Joint A which showed even a higher amount of damage based on the JDI. The top front flange (TF) for Truss 43 and the bottom back (BB) flange for Truss 315 Joint B were used by the University of Toledo to perform material testing. These joints had the same flange damage index and had approximately the average level of damage for all the flange connections.

Analytical Modeling:

In order to determine if a damaged flange could withstand expected design loads, testing was carried out. However, pretest analyses were required. The expected forces and stresses of a complete truss subjected to design loads were determined from an analytical study. Then an analytical study of the approximately 12 foot section of the truss was also necessary to determine testing support conditions and loading configuration in order to assure the test generated forces and stresses similar to those expected on the complete full scale truss.

The bottom flanges of the joint were the biggest concern since they were subjected to tension from self-weight and depending on wind direction, were also subjected to additional tension. After several versions of different models were attempted for the 12 foot section of the truss, it was determined that a cantilevered support condition could be utilized to create tension forces in the bottom chords similar to the actual truss in service. In addition to cantilevering the truss from a support frame, an additional support was required at one of the bottom flanges and an additional diagonal member was necessary. Applied loads of 10,000 lbs at the free end of the cantilever on each bottom chord produced the necessary tension forces in the bottom chords and flanges connecting the bottom chord members.

Section Testing:

Once the analytical studies were completed, the actual testing was performed in a manner as close as possible to the analytical modeling. Figure 2 shows the test set up for the truss section. Note that the two bottom flanges were the primary test flanges as these flanges were primarily subjected to tension. To produce the results of the section modeling, the flange near the wall was supported. A variety of instrumentation was installed on the truss sections that were tested to measure deformations, strains, and the applied load from hydraulic cylinders.

Truss 100 section Joint B was the first section to be tested. This truss was originally located over East bound IR 480 at mile marker 17.6. The truss was chosen for testing because of the high overall Joint Damage Index. The tested flanges had damage indices of 11 which were slightly higher than average. The truss was position for testing by placing the back bottom flange in the support flange location and the top back flange in the unsupported flange position. Both cylinders reached the 10,000 lbs that was determined from the analytical modeling. No failure was observed in either of the bottom joints.

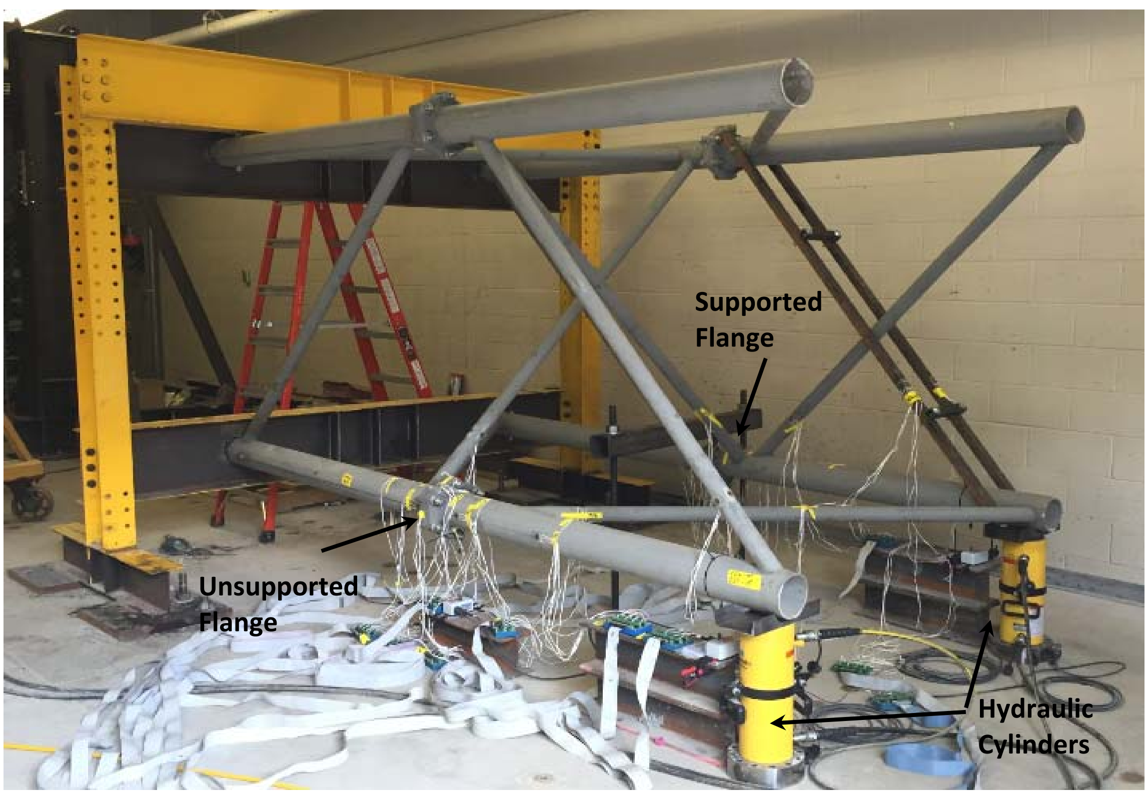

Figure 2: Truss Section Test

Since the Truss 100 Section Joint B achieved the load determined to generate design loads in the joint without failure, Truss 315 Section Joint A was tested next. This second truss had existed above IR 90 westbound at mile marker 173.2. It had the highest overall joint damage. The bottom back flange was placed in the unsupported flange location and the bottom front flange was placed in the supported flange location during testing. The bottom front flange had one of the highest Joint Damage Index values (27). Both cylinders reached approximately 8,000 lbs before the test was stopped. The bottom back flange at the supported flange location failed when a crack near a bottom bolt propagated around the welded joint connecting the flange to the chord. Though the Truss 315 flange failed prior to the 10,000 lbs load being reached by each hydraulic cylinder, the tensile stresses generated in the truss members adjacent to the flanges exceeded the stresses expected from analytical modeling.

Material Testing

The goals of the material testing were to:

1. Determine the nature of the corrosion products between the bolt and the flange.
2. If possible, develop and experimentally validate a hypothesis about the time varying failure mechanism that lead to the cracks in the flanges.
3. Suggest inspection and remediation steps to assess the cracking or mitigate the damage.

Component Inspection of the Flanges

Following up on the field inspections, two flanges were sent to the University of Toledo for laboratory inspection and material testing. Visual inspection and material characterization tests were carried out on the fracture surfaces, ejected pieces and sawn parts. The flanges, bolts, nuts and washers were inspected.

Energy Dispersive X-Ray spectroscopy (EDS) established the bolt and washers are stainless steel (typical 18% Cr and 8% Ni) and the flange is an aluminum alloy (most likely cast). The visual inspection found that the failure surfaces and spaces near the bolt are packed with a dense corrosion product.

Material Tests

Based on the component inspection, it was hypothesized that galvanic corrosion is taking place between the aluminum flange and the stainless-steel bolts and washers. Aluminum is the anode and corrodes more quickly. This corrosion resulted in the buildup of corrosion product, loss of aluminum section and stress corrosion cracking. Four types of tests were carried out at the University of Toledo Center for Material and Sensor Characterization. The test results were:

1. The Fourier Transform Infrared Spectroscopy (FTIR) analysis showed the corrosion product contained no organic components.
2. Energy Dispersive X-Ray spectroscopy (EDS) analysis showed oxygen was diffusing into the aluminum and aluminum section was being lost and replaced by corrosion product.
3. X-Ray Powder Diffraction (XRD) analysis showed aluminum oxides were the dominate corrosion products.
4. Scanning Electron Microscope (SEM) inspection of the surfaces showed the following:
    a. Crack patterns consistent with stress corrosion cracking.
    b. More corrosion near the bolt and diminishing corrosion as the distance from the bolt increased
    c. Indications of ductile fracture at the outer surface.

Material Testing – Conclusion

At the level of investigation carried out, the hypothesis was confirmed. Evidence of galvanic corrosion between the stainless-steel bolt and washer and the aluminum flange was observed. The corrosion product was an aluminum oxide. Stress corrosion cracking was observed near the bolt. Ductile cracking on the outer surface was part of the evidence the stress corrosion cracking was localized near the bolt.

This leads to a postulated failure mechanism. Galvanic corrosion led to a reduction in density and strength of the aluminum, the anodic metal, and the initiation of stress corrosion cracking. The combination of section loss and stress corrosion cracking on the inner surface of the bolt hole combined with the cyclic loading of wind and truck’s induced gusts caused the flanges to crack. The cracks propagated from the inner surface of the bolt hole to the outer surface.

A detailed discussion of the tests and their results and a finite element analysis of the flange is provided in Rezaei, 2017.

Potential Fixes

- Remove one of the factors that contributes to galvanic corrosion (bimetallic joint, environment or electrolyte).
- The technique chosen depends on the number of cracks and their size. Some of the following are suggested:
    - If no cracking is visible and no mitigation measures have been carried out, coat the joint to eliminate the electrolyte
    - If moderate cracking and there are no mitigation measures, coat the joint to eliminate the electrolyte and shorten the inspection interval.
    - If extensive cracking, put a mechanical jacket on the joint and take steps to arrest corrosion.

Possible additional exploration

- Identify a practical field inspection technique to determine the state of other flanges in the field. Particularly, for flanges with no visible cracking.
- Determine why the eight bolt circular flanges not exhibit the dramatic cracking. Possibly obtain an eight bolt flange that has been removed from service.
- Conduct analytical and experimental investigations to determine acceptable crack size or expected crack growth rate and setting inspection schedule.