

Report on
Evaluation of Interstate 80 Sign Truss

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**Office of Bridges and Structures
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Prepared by:

Terry J. Wipf
Brent M. Phares

The Bridge Engineering Center
at the
Center for Transportation Research and Education-
Iowa State University



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TABLE OF CONTENTS

LIST OF FIGURES	ii
LIST OF TABLES	iii
BACKGROUND	1
EXPERIMENTAL PROGRAM	1
EXPERIMENTAL RESULTS	3
FINITE ELEMENT MODELING	3
COMPARISON OF EXPERIMENTAL AND ANALYTICAL RESULTS	7
DISCUSSION	10
SUMMARY	11
DISCUSSION	11

LIST OF FIGURES

Figure 1. Photographs of Sign Truss before Removal.....	2
Figure 2. Deterioration of Bottom Chord Member of the Truss.....	3
Figure 3. Experimental Setup	4
Figure 4. Sign Truss after Cutting the Bottom Chord Member	5
Figure 5. View of Truss Showing Strain Gage Locations	5
Figure 6. Sign Truss Loaded with Four Concrete Blocks.....	6
Figure 7. 3D Finite Element Model of the Truss	7
Figure 8. Analytical Element Axial Strains Undamaged/Damaged	8
Figure 9. Experimental and Analytical Results for Undamaged Truss	9
Figure 10. Experimental and Analytical Results for Damaged Truss	9

LIST OF TABLES

Table 1. Field Strain Readings Before and After Cutting Bottom Chord Member	6
Table 2. Analytical Results (3D) Damaged and Undamaged Conditions	8
Table 3. Experimental and Analytical Results Before and After Member Cut	10

BACKGROUND

A sign support truss over eastbound I-80 about 2 miles west of the west I-35/I-80/I-235 interchange near Des Moines, IA was removed in the spring of 2000. A routine inspection of the truss found that one of the bottom chord members was severely deteriorated. Corrosion of the bottom chord has caused significant thickness loss of cross section area of many members. This deterioration led to a concern about the structural adequacy of the truss.

The truss is a galvanized steel, four chord truss with a span of approximately 60 ft and carries a single 14 ft x 40 ft sign and associated lighting as shown in Fig. 1. Figure 2 shows a photograph of the deterioration of one of the bottom chord members near mid span.

The Iowa DOT initiated this investigation to evaluate the structural behavior of sign support trusses that have structural deficiencies and to assess the urgency to remove or retrofit these trusses. The primary objectives of this investigation are:

- (1) Perform a load test of a damaged truss to assess the impact of the damaged members on the overall performance of the truss.
- (2) Compare the load test results with the results of structural analysis of the truss with the intent of assessing the accuracy of predicting the structural behavior of damaged and undamaged sign support trusses.
- (3) Provide recommendations for managing damaged trusses.

EXPERIMENTAL PROGRAM

Two load tests were conducted in March and April of 2000. Both tests were performed at the Iowa DOT maintenance garage facility after removing the damaged truss from service. Figure 3 shows photos of the test set-up. Note that the truss was rotated 90 degrees from its normal orientation so that the effect of wind loads could be simulated by applying vertical loads.

The first tests conducted were intended to assess the structural behavior of the undamaged and damaged truss with a specific interest in structural redundancy. These tests were conducted in March 2000. Figure 4 shows a photograph of the truss after cutting the bottom chord member. The second set of tests were conducted in April 2000. These test were intended to assess the impact of removing other critical members from the truss. The second set of tests covered several cases. Each case involved removing additional truss members at critical locations. The results of this series of tests are not presented herein but further reified the conclusions developed from the tests conducted in March, 2000.

Before the test, the truss was instrumented with strain gages. The strain gages were mounted on sixteen truss members and oriented such that only axial load was measured. Figure 5 shows a schematic of the truss with the instrumented members highlighted.



a. Overview of the Sign Truss Site



b. Close-up view

Figure 1. Photographs of Sign Truss before Removal.



Figure 2. Deterioration of Bottom Chord Member of the Truss

The tests were conducted by applying four concrete blocks weighing 5.0 kips each to the top of the truss (simulating horizontal wind load). Figure 6 shows a photo of the loaded truss. During the test, strain readings were taken after each concrete block was added.

EXPERIMENTAL RESULTS

The first load tests were completed to determine how the truss behaved after removing one of its most heavily loaded members as compared with an undamaged truss. This comparison will demonstrate the impact of having severely damaged truss members. The experimental results for these tests (i.e., undamaged and damaged) are summarized in Table 1.

FINITE ELEMENT MODELING

A three-dimensional finite element model of the truss was developed using ANSYS. Each member was represented by three-dimensional beam elements (Beam44 element in ANSYS). The geometrical properties of the members were based on the cross sectional dimensions of the truss members given in the design plans. The Beam44 element has six degrees of freedom at each node: translations in the nodal X, Y, Z directions and rotations about the nodal X, Y, Z axes. The loads consisted of 4 concentrated forces applied equally on the north and south trusses. The boundary conditions at the truss ends were considered to be pinned at the west end and a roller at the east end. Figure 7 shows the finite element idealization of the truss structure.



a. 3D View of the Sign Support Truss Before Testing



b. Side View of the Sign Truss
Figure 3. Experimental Setup.



Figure 4. Sign Truss after Cutting the Bottom Chord Member.

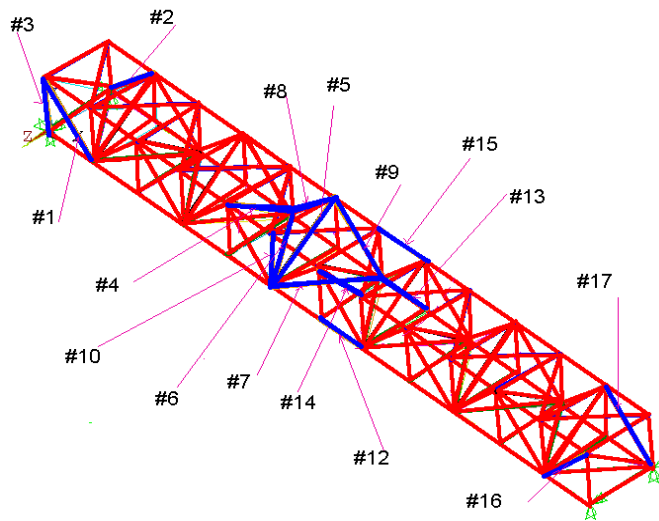


Figure 5. View of Truss Showing the Strain Gage Locations



Figure 6: Sign Truss Loaded with Four Concrete Blocks

Table 1: Field Strain Readings Before and After Cutting Bottom Chord Member

Location	Undamaged, Microstrain	Damaged, Microstrain	Change, Microstrain
1 (diagonal)	170	200	+30
2 (diagonal)	-168	-148	+20
3 (vertical)	-158	-174	+16
4 (out of plane)	-40	-14	+26
5 (out of plane)	-40	-202	-162
6 (bottom bracing)	32	146	+114
7 (bottom bracing)	30	130	+100
8 (diagonal)	-78	60	+138
9 (diagonal)	-2	100	+102
10 (vertical)	-64	-40	+24
11			
12 (bottom chord)	256	390	+134
13 (bottom chord)	236	94	-142
14 (top chord)	-258	-378	-120
15 (top chord)	-238	-74	+164
16 (diagonal)	174	188	14
17 (diagonal)	-196	-176	+20

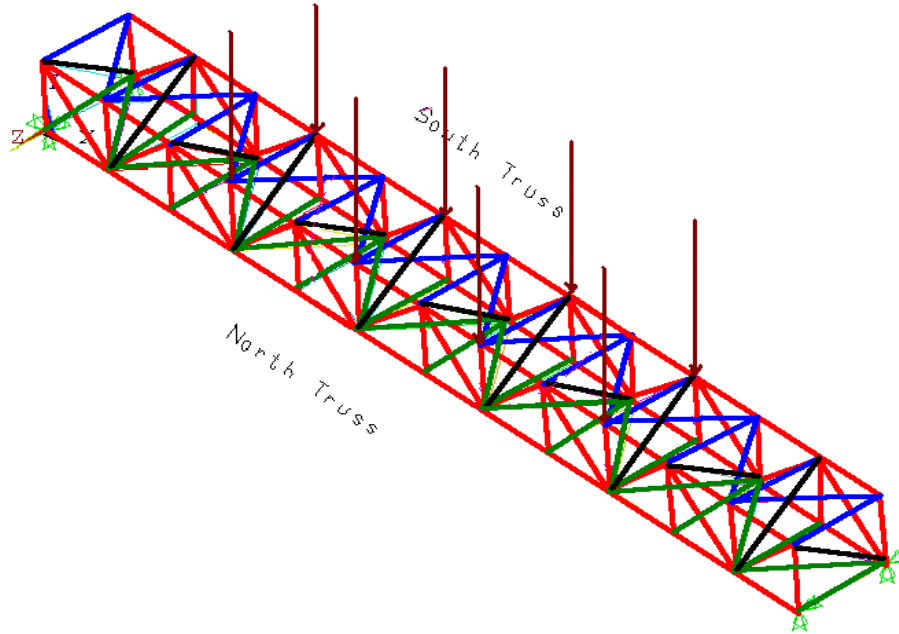


Figure 7. 3D Finite Element Model of the Truss.

The model was analyzed for both test cases (i.e., undamaged and damaged {element 29 in the model}). The maximum deflection before removing the cut member was found to be 0.59 in.; after removal the deflection was 0.87 in. For comparison purposes, a simple 2D model of the structure was developed and analyzed. The results of the 2D model were found to be very close to those of the 3D model for the undamaged truss. This means that using simple 2D models would be sufficient to assess the overall structural behavior of the truss. However, it was found that a 2D model would not accurately predict the behavior of the damaged truss. The 3D analysis strain results are summarized in Table 2. Figure 8 shows the results for members in the vicinity of the removed member.

For comparison purposes, two variations of the 3D model were also developed to assess the joint conditions (rigid or pinned). The first variation was to model the top and bottom chord members using beam elements as was done for the original model, while modeling the other elements (e.g., diagonals, bottom bracing, and out-of-plane) as truss elements. The second variation was to model the entire structure using truss elements. The member forces and maximum deflections of both variations were found to be very close to the original model.

COMPARISON OF EXPERIMENTAL AND ANALYTICAL RESULTS

One objective of this project was to develop an analytical model that accurately represents the structural behavior of trusses so that the performance can be evaluated. To accomplish this, the results of the developed analytical model were validated using strain measurements from the load tests. Table 3 shows the experimental and analytical results before and after the bottom chord element cut. Figures 9 and 10 show the results in the vicinity of the cut member.

Table 2: Analytical Results (3D) Damaged and Undamaged Conditions.

Strain Gage Location	Element #	Undamaged, microstrain	Damaged, microstrain
1 (diagonal)	49	196	165
2 (diagonal)	61	-201	-234
3 (vertical)	100	-140	-126
4 (out of plane)	153	-45	-61
5 (out of plane)	154	-49	-403
6 (bottom bracing)	77	20	115
7 (bottom bracing)	78	25	167
8 (diagonal)	65	-86	24
9 (diagonal)	66	15	128
10 (vertical)	109	-102	-101
11			
12 (bottom chord)	7	268	447
13 (bottom chord)	31	262	155
14 (top chord)	19	-266	-337
15 (top chord)	43	-272	-196
16 (diagonal)	60	199	205
17 (diagonal)	72	-197	-192

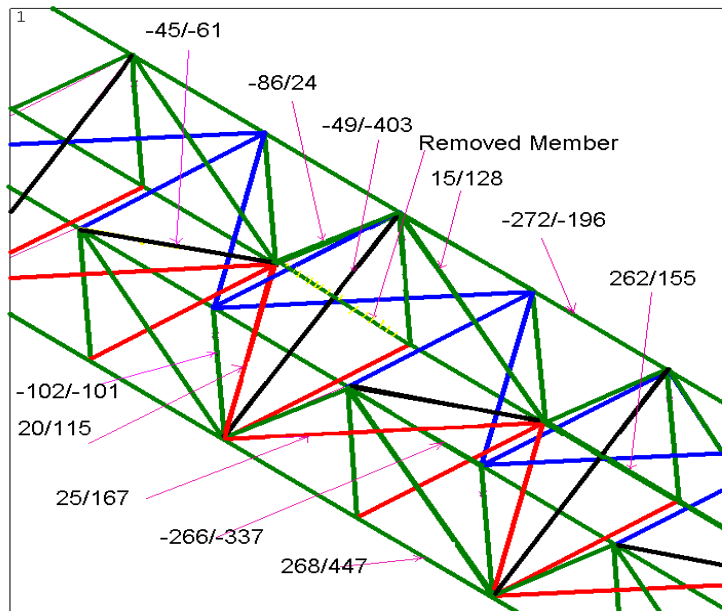


Figure 8. Analytical Element Axial Strains Undamaged/Damaged.

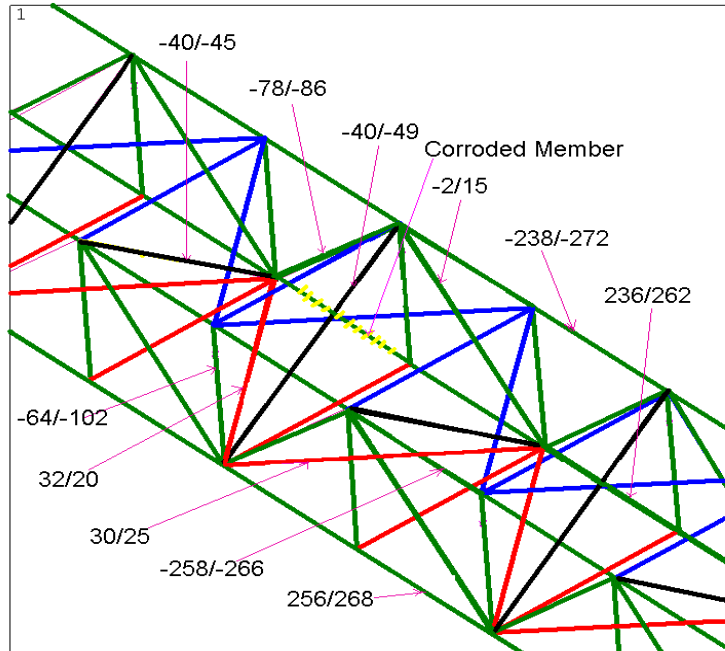


Figure 9. Experimental and Analytical Results for Undamaged Truss.

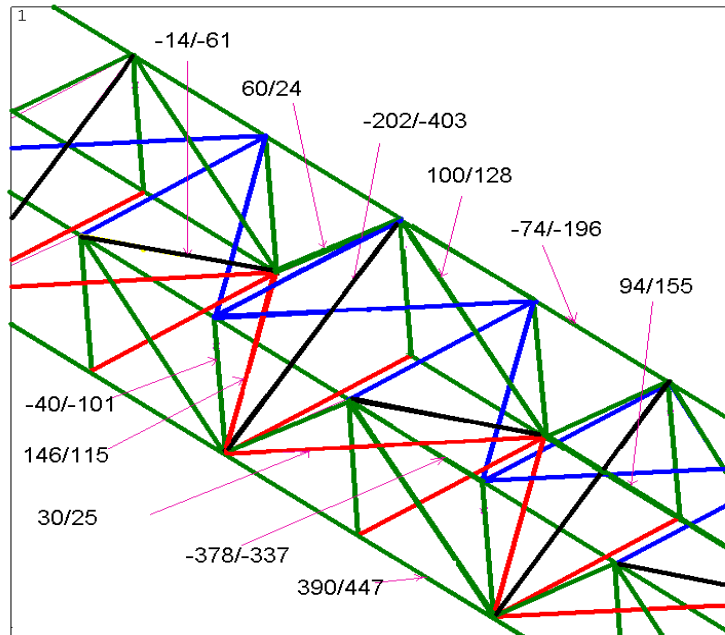


Figure 10. Experimental and Analytical Results for Damaged Truss

Table 3: Experimental and Analytical Results Before and After Member Cut

Strain Gage Location	Element#	Before Cutting Bottom Chord Member		After Cutting Bottom Chord Member	
		Field Strain Readings	3D Analysis Results	Field Strain Readings	3D Analysis Results
1 (diagonal)	49	170	196	200	165
2 (diagonal)	61	-168	-201	-148	-234
3 (vertical)	100	-158	-140	-174	-126
4 (out of plane)	153	-40	-45	-14	-61
5 (out of plane)	154	-40	-49	-202	-403
6 (bottom bracing)	77	32	20	146	115
7 (bottom bracing)	78	30	25	130	167
8 (diagonal)	65	-78	-86	60	24
9 (diagonal)	66	-2	15	100	128
10 (vertical)	109	-64	-102	-40	-101
11					
12 (bottom chord)	7	256	268	390	447
13 (bottom chord)	31	236	262	94	155
14 (top chord)	19	-258	-266	-378	-337
15 (top chord)	43	-238	-272	-74	-196
16 (diagonal)	60	174	199	188	205
17 (diagonal)	72	-196	-197	-176	-192

DISCUSSION

After the deteriorated member was cut (damaged condition), part of the load carried by the south truss near the removed member was transferred to the north truss by axial forces in the out of plane diagonals. This redistribution of load was evident from both the experimental and the analytical results. These results indicate a significant load redistribution property of the truss due to the highly redundant load paths in the structure.

The difference between the field and analytical results may be attributed to several factors. First, many members of the truss were corroded. This means that the theoretical values of section properties used in the analysis (which are taken from the design plans) are likely less than their actual values. Variations in elements properties would result in a load distribution different from that predicted from the analysis. More accurate analysis results may be obtained by modifying the properties of the corroded members in the

model to reflect the actual cross section properties at the time of the test. Also, some of the difference between the analytical and experimental results may be attributed to the possible variation in the Modulus of Elasticity (E) from the value assumed for the analysis (i.e., 29,000 ksi). For more accurate results, a lab test on a specimen of truss members may be needed to more accurately evaluate the Modulus of Elasticity of the members.

SUMMARY

The truss evaluated herein is highly redundant and a sufficient number of load paths exist to redistribute the loads in case a member becomes severely corroded. This means that corrosion or even complete failure of an individual truss member may not cause collapse of the truss. Even after the removal of one of the most heavily loaded members in the subject truss, the structure proved to have substantial reserve capacity and was able to sustain loads much larger than those typically induced by wind loads. After a bottom chord member was cut, most of the load carried by the south truss was transferred to the north truss through the out of plane diagonals. It was also found that the redistribution of load resulted in strain levels in the instrumented members below the yield strain of steel.

RECOMMENDATIONS

The investigated truss had a badly corroded bottom chord member located at mid span. Many other members were also corroded. This damage likely affects the performance of the truss. However, the experimental tests and an analytical investigation indicated that the truss did not need to be removed due to potential structural inadequacy. It was found that the truss has redundant load paths that allow redistribution of the loads. Due to this load path redundancy, if one or more members were to fail due to corrosion or other means (e.g., over height vehicle impact, etc.), the load will likely be redistributed to other members. From these tests, it was found that after load redistribution, the strain levels in other members were still below the yield strain of steel. It appears that for the subject truss, it may have been sufficient to simply repair the corroded member. However, in general, the extent of corrosion damage must be accurately assessed. The structural performance of the damaged structure can then be evaluated using an analytical model similar to the one discussed herein.

Although the analytical model presented herein was developed using ANSYS, the same model could be developed using other simpler analysis tools such as STAAD. Also, from analyzing both 2D and 3D models of the truss structure, it was found that either a 2D model or a 3D model is an acceptable idealization undamaged trusses. However, only a 3D model will be capable of representing the behavior of a damaged structure since the 2D model does not consider the out-of-plane members the two trusses.