

LABORATORY INVESTIGATION OF FATIGUE BEHAVIOR OF A RIVETED OPEN-DECK RAILROAD DECK PLATE GIRDER SPAN

by P.C. He,* A.M. Atani,* E.M. Maragakis,* and A.S. Uppal

Summary

Transportation Technology Center, Inc., in conjunction with University of Nevada at Reno, conducted studies on an open-deck, deck plate girder (DPG) railway span to determine its fatigue behavior under repeated heavy axle loads.

In these tests, a full-scale specimen that represented an existing railway bridge with a reduced span length was subjected to 5.5 million cycles of dynamic loading (approximately 200 million gross tons of traffic). The top flange and the web experienced out-of-plane deformations due to eccentric location of the applied load from the centerline of the plate girder. This out-of-plane deformation caused local tensile stresses in a region that is normally assumed to be under compressive stresses. After 5.5-million cycles of dynamic testing, the plate girder did not experience any visible cracks. However, several bridge ties cracked and a number of rivets lost their initial pretension and became loose due to the repeated dynamic loading.

A two-part experimental and analytical program was carried out with the following conclusions:

- A number of rivets near the point of load application became loose in the specimen.
- The test specimen did not experience any visible fracture even though it was subjected to relatively high tensile stresses over 5.5-million cycles of dynamic loading.
- Other factors that were not investigated at this time were variations in the quality of the rivet holes and riveting process which are often contributors to the variation in test results.
- A 3-D finite element analysis predicted the behavior of the DPG span. The flange stresses obtained from the mathematical model were relatively close to the experimental values.

* University of Nevada, Reno

Suggested Distribution:

- Maintenance of Way
- Planning & Analysis
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INTRODUCTION

Riveted bridges were built over a period of more than 150 years, concluding in the 1970s, when high-strength bolts and welding became the most commonly used connection methods. While for many of these bridges, maximum stresses in recent decades have not yet reached the levels caused by heavy steam locomotive axle loads with hammer blow, some of these bridges are subject to increasing load cycles at higher stresses due to increases in traffic and freight car axle loads. Riveted railway bridges still provide excellent service today. However, the age and condition of some particular bridges that are experiencing increases in traffic and axle loads have raised concerns about their performance. Therefore to ensure continued service, it is important to identify and assess fatigue behavior, estimate fatigue life, and determine retrofit requirements. These concerns were emphasized by reports of cracks in some open-deck, deck plate girder (DPG) spans. These spans were on heavy axle load coal lines. The cracks initiated at rivet holes in the web plate and its connection to the top flange angles and propagated beyond the toes of the flange angles towards the interior of the web of the plate girders. This type of cracking was attributed to the out-of-plane movement resulting from the slenderness of the web of the girder.

The propagation of these cracks into flange members could significantly reduce the load carrying capacity of the spans. To understand the fatigue behavior of DPG spans, this study was conducted in two parts. The experimental investigations involved testing a full-scale riveted DPG span in four-point bending to simulate the passage of a

train car. The analytical investigation utilized a three-dimensional finite-element model to analyze the specimen and compare these stresses to the experimental values.

EXPERIMENTAL STUDY

The test specimen was 15 feet long and consisted of two 1'2"-wide and 5'6"-deep girders each comprising a 3/8" x 66" web plate, two 6"x 6" x9/16" angles, and a 14"x 7/16" cover plate at top and bottom flanges. The material used was ASTM A 36 open-hearth type steel, and rivets were A502-1 with 7/8" diameter. One girder was fabricated with punched holes, and the other one with drilled rivet holes. The girders were connected together by a riveted cross frame. The track consisted of 133 RE rails seated on tie plates and spiked to 10"x10"x10' No. 1 Douglas fir ties. Every second tie was secured to top flanges of the girders of the span by means of 1/2" diameter hook bolts.

Exhibit 1 is a diagram of the test set-up, while Exhibit 2 is a photo of the tests in progress. The test set-up comprises a reaction frame with a spreader beam to transfer the load from a single actuator to two-point loads. The instrumentation included 11 rosettes at different locations (six on the web

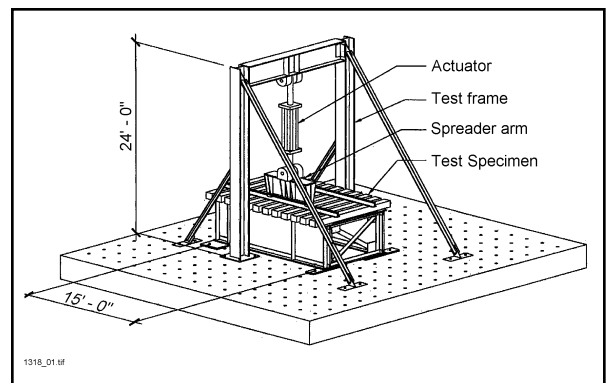
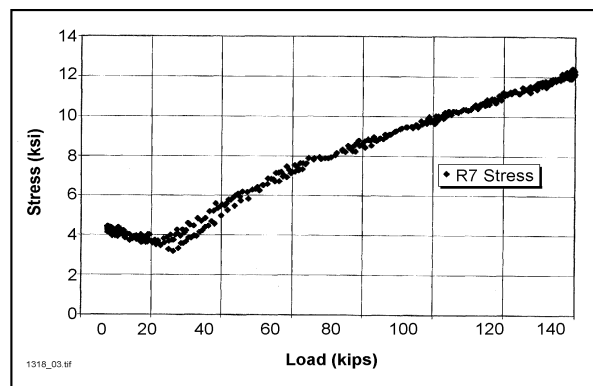


Exhibit 1. Test Set-up

**Exhibit 2. View of Test in Progress**

and vertical legs of top flange angles, and six on top of top flange) of the girder with punched holes and two wire potentiometers to measure vertical displacements in timber ties.

The load application varied between 0 to 130 kips in 0.4 seconds. The maximum principal tensile stresses measured in the web, connection angle and top flange were 8.71, 12.6, and 17.8 ksi respectively. The specimen was subjected to 5.5-million cycles with an average stress of 12 ksi at a maximum of 140 kip load as shown in Exhibit 3 without any visible sign of fatigue cracking. However, several bridge ties cracked and a number of rivets close to the loading points lost their initial pretension and became loose. The out-of-plane movement that resulted in loosening of rivets did not cause cracks to initiate in the specimen to the termination of the test at 5.5 million cycles. A number of factors were not investigated at this time including variations in the quality of the rivet holes and riveting process which are contributors to the variation in test results.

**Exhibit 3. Principal Stresses of Rosette 7**

As a reference, the equation given in the American Railway Engineering and Maintenance of Way, Manual for Railway Engineering states that a fatigue crack may occur when the load cycle exceeds 1.3-million cycles at stress range of 12 ksi. The AREMA equation is for a 2.5 percent probability of occurrence.

ANALYTICAL INVESTIGATION

A three-dimensional finite-element analysis was performed using the Automatic Dynamic Incremental Non-Linear Analysis (ADINA) program. Two-point loads were assumed located a foot away from the centerline of one of the girders, cross wise and centered about mid span, length wise. The point loads were considered to be 40 kips each, to approximately simulate a car loading as well as 65 kips each to obtain a principle stress of 7 ksi at rivet holes. Exhibit 4 shows the deformed shape under a 40-kip load and Exhibit 5 shows the maximum principal stresses under a 65-kip load.

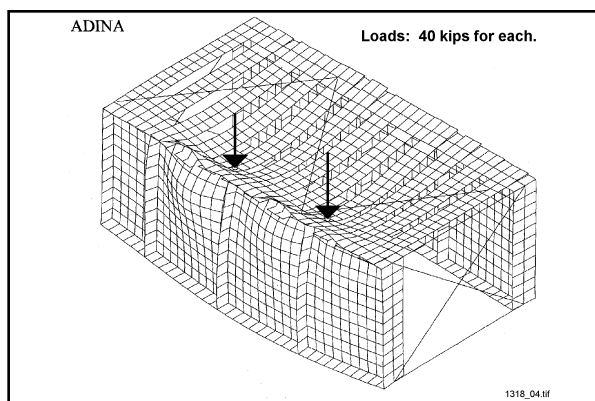


Exhibit 4. Deformed Shape of the Specimen

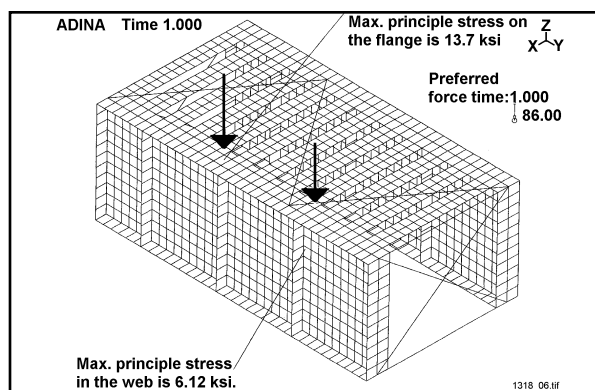


Exhibit 5. Test Specimen under Two 65-Kip Vertical Loads

COMPARISON BETWEEN EXPERIMENTAL AND ANALYTICAL RESULTS

Exhibit 6 shows the stress values from both the experimental and analytical results at 5.5 million cycles of loading. The greatest difference in the two values is in the web, which is attributed to the out-of-plane deformation in the web. The analytical results suggest that the model overestimated the out-of-plane deformations in the web.

METHOD OF RETROFIT

The method of retrofit used on the railroad bridge spans representing the test specimen involved welding the cracks, then plating the areas covering the cracks with high-strength bolts. This method extended the life of the spans for several years.

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Note: Please contact Shakoor Uppal at (719) 584-0749 with questions or comments about this document.

E-mail: shakoor_uppal@ttci.aar.com Web site: www.ttci.aar.com

Exhibit 6. Comparison between Analysis and Test Results

Area:	Max.stress tensile (ksi): σ_1			
	Max. tensile stresses from analysis:	Stresses from test result:	Percentage of stress difference	
Web:	Rosette 1:	4.35	2.32	-47%
	Rosette 2:	3.50	7.64	118%
	Rosette 3:	5.00	8.43	69%
	Rosette 4:	5.63	2.45	-57%
	Rosette 5:	6.12	2.06	-66%
Top Flange	Rosette 7:	13.75	12.41	-10%
	Rosette 8:	13.75	9.30	-32%
	Rosette 9:	5.50	5.37	-2%
	Rosette 10:	4.25	4.88	15%
	Rosette 11:	9.50	10.16	7%

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