TECHNOLOGY DIGEST

Timely Technology Transfer — 00-010

Investigation of Fatigue Cracking of Open Deck DPG Spans

by A.S. Uppal, and D.E. Otter
A.M. Itani,[*] E.M. Maragakis,[*]

Summary

Under service conditions, fatigue cracks have been observed in the upper portion of some open deck, deck plate girder (DPG) spans. These cracks are attributed to tensile stresses generated by the out-of-plane displacements resulting from the dynamic loads of trains in locations that are normally regarded as part of compression zones. To investigate the nature and magnitude of these stresses, Transportation Technology Center, Inc., in conjunction with University of Nevada at Reno, conducted a three-dimensional finite-element analysis on a short DPG span. The analytical results were then compared to the experimental tests conducted on a same size specimen. The conclusions drawn from the investigation were as follows:

- The analytical model indicated that tensile stresses can in fact occur in a DPG span in locations that are normally regarded as compression zones. This was further confirmed by strain measurements taken on a full-size specimen.
- These tensile stresses are caused by out-of-plane displacements under dynamic loads of the train.
- Several factors appear to influence the out-of-plane displacements and hence the magnitude of tensile stresses generated. While it is thought that in some instances these tensile stresses could be high enough to cause fatigue cracking, none appeared in the laboratory test.

Based on the information in this digest, railroads may want to include criteria in their inspection procedures to determine whether a thorough examination of the top flange and upper portion of web is needed due to the possibility of fatigue cracks and loose rivets.

[*] University of Nevada at Reno

Suggested Distribution:

☐ Maintenance of Way
☐ Bridges
☐ Track Maintenance
☐ Engineering

Work performed by TTCI Transportation Technology Center, Inc.
a subsidiary of the Association of American Railroads
July 2000

INTRODUCTION

A deck plate girder (DPG) span is the most common type of span used in construction of steel railway bridges. A DPG is usually a maximum of about 120 feet in length and consists of two girders. The depth of the span is approximately 1/12th of its length. A plate girder is essentially a built up I-beam in which flanges are composed of shapes (generally plates and angles), that are connected to a solid web plate. The girder flanges are composed of two angles and one or more cover plates. The two girders are connected by transverse frames, called cross frames, and by lateral bracing in the plane of the upper flanges, and frequently, also, in the plane of lower flanges. Except in cases of very shallow girders, the web plate is stiffened at intervals by angles called intermediate stiffeners. Stiffeners are also provided at points of force concentrations, such as at the ends, called bearing stiffeners. In a girder of this cross-section, most of the bending moment is assumed to be resisted by the top and bottom flanges and most of the shear resisted by the web. Exhibit 1 shows a general view of a typical open deck DPG span.

For the lateral system to be effective, the centers of girders of a single-track bridge are spaced at 1/10th of the span length or more. A common practice is to use a minimum spacing of 6 feet, 6 inches, for shorter spans, and use a wider spacing of up to 10 feet for longer spans. The wider spacing, however, requires a heavier deck that increases the cost and thus affects the overall economy of the plate girder spans.

The track is secured to the deck of the span that consists of timber ties. The ties are designed to carry axle load distributed over three consecutive ties. The ties are spaced with clear openings not more than 6 inches between them and are secured by means of spacing timbers or steel bars against bunching. For shorter spans (less than 50 feet), the lateral bracing of a deck plate girder consists of an upper lateral system and transverse bracing at the ends and at intermediate points (i.e., cross frames). This arrangement furnishes a theoretically complete lateral bracing, but requires the lateral forces acting along the lower part of the girder to be transferred to the bearings in a less direct manner than when a lower lateral system is used. However, for longer spans, both an upper and a lower lateral system are employed, which with the transverse bracing are quite effective in transferring lateral loads.

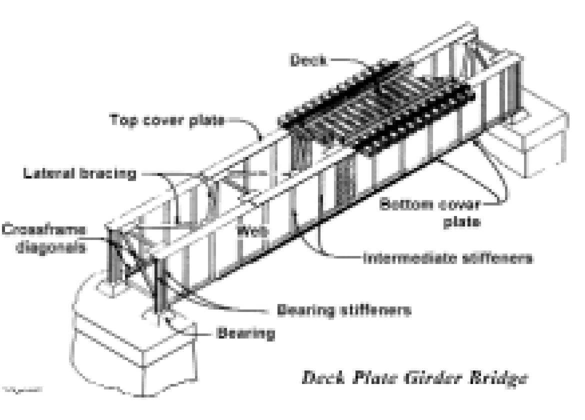

Exhibit 1. **Typical Open Deck DPG Span**

BEHAVIOR OF DPG SPAN

Generally, the top half of the cross-section of the deck plate girder (i.e., above the neutral axis) is in compression and the bottom half cross-section (i.e., below the neutral axis) is in tension. However, under dynamic loading, in addition to normal in-plane displacements, the girders can also experience out-of-plane displacements that could generate tensile stresses in localized areas of the top flange and the upper portions of web. These out-of-plane displacements appear to depend on several factors, some of which are the stiffness of the component (flange or web), depth and spacing of the girders, size and spacing of ties, design of lateral bracing system, and the magnitude of the imposed loads, etc.

The locations on the open deck DPG spans where such tensile stresses have been observed (in some revenue service bridges, but not in the TTCI tests described here) to cause fatigue cracking are as follows:

- **Fillet of top flange angles.** Deflection of ties creates eccentric loading on the flange angles, resulting in their outstanding legs moving up and down under train loading. With the accumulation of sufficient cycles of reversible loading, this could cause the fillet of the angles to crack. Exhibit 2 shows a fatigue crack initiated under the ties in the fillet of the top flange angle.
- **Transverse cracks in upper areas of webs.** Out-of-plane displacement of the top flange and the upper area of the web generate localized tensile stresses in a compression zone. These stresses could be aggravated by rivet or bolt holes that act as stress raisers. Fatigue cracks have initiated at rivet holes and propagated into the interior of the web. Also, depending on the magnitude of the tensile stress and the load cycles, fatigue cracks have occurred in the top flanges. Exhibit 3 shows a crack in the top flange that initiated at a bolt hole.

TTCI = Transportation Technology Center, Inc.; AAR = Association of American Railroads

Exhibit 2. Fatigue Crack in the Fillet of Outside Flange Angle

Exhibit 3. Fatigue Crack in Top Flange Initiated at a Bolt Hole

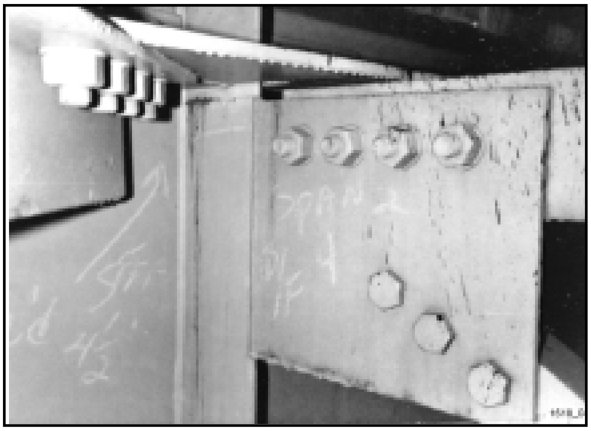

Exhibit 4. Fatigue Crack in Cross Frame, Stiffener and Web Connection

- **Rigid Connections.** Welds connecting a cross frame to the web in the welded girder span sometimes create a very rigid connection preventing out-of-plane movements. This together with poor weld details sometimes sets up high tensile stresses that with accumulation of sufficient load cycles can result in fatigue cracks. Exhibit 4 shows a fatigue crack that initiated in the weld at top of cross frame to web stiffener connection.

ANALYTICAL INVESTIGATION

The purpose of the analytical investigation was to determine the nature and the magnitude of the out of plane stresses. The model used for the analytical study was a DPG span 15 feet long and had two main girders 5 feet, 6 inches deep and spaced 7 feet apart. Each girder consisted of a 3/8-inch thick web and two 6"x6"x 9/16" angles back to back at top and bottom flanges with one 14"x 7/16" cover plate. It had lateral bracing attached to the top and bottom flanges, and cross frames at 12 feet on centers. The deck of the span consisted of 10"x10" timber ties spaced at 15 inches on center. The ties were alternately secured to the top flanges by hook bolts.

A three-dimensional finite element analysis was conducted to determine the location and the magnitude of the maximum principle tensile stresses due to train loading.

The model was subjected to a two point load condition. The loads were 65 kips each, applied to the ties, one foot away from the centerline of the girder to simulate actual train loading. Under this loading, which approximately corresponds to the fatigue endurance limit Category D detail of 7 ksi, the maximum tensile stress values found were 6.12 ksi in the upper part of the web and 13.75 ksi in the top of the top flange.

COMPARISON WITH EXPERIMENTAL STUDY

The results of the analysis were compared to the tensile stresses measured on a specimen of the same size and under the same loading conditions that was tested in the laboratory. Exhibit 5 shows the location of rosettes for measuring strains.

The maximum principle tensile stress values measured at 5.5 million cycles of loading in the upper part of the web and in the top of top flange were 7.64 ksi and 12.41 ksi respectively. No fatigue cracking occurred at this point. However, several bridge ties cracked and a number of rivets became loose near the load points. Exhibit 6 gives a comparison of the analytical and experimental values of the tensile stresses found from the analytical model and laboratory testing.

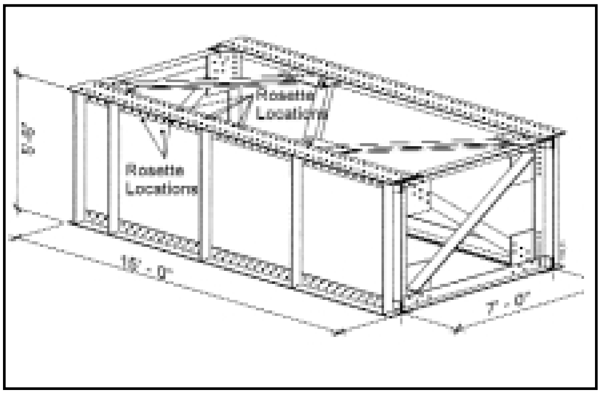

Exhibit: 5. Location of Rosettes for Strain Measurements

Area:		Maximum Stress Tensile (ksi): $\sigma1$		
		Maximum Tensile Stress 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%

Exhibit: 6. Comparison between Analytical and Measured Tensile Stresses

CONCLUSIONS

The following conclusions are drawn from the results of analytical modeling and their comparison with the measurements taken during the laboratory testing of a specimen of the same configuration.

- The analytical model indicated that tensile stresses can in fact occur in a DPG span in locations that are normally regarded as part of its compression zone. This was further confirmed by measurements taken on a full size specimen.
- These tensile stresses are caused by out-of-plane displacements under dynamic loads of the train.
- Several factors appear to influence the out-of-plane displacements, and hence the magnitude of tensile stresses generated. While it is thought in some instances these tensile stresses could be large enough to cause fatigue cracking, none occurred in the laboratory test.

Based on the information in this digest, railroads may want to include criteria in their inspection procedures to determine whether a thorough examination of the top flange and upper portion of web is needed due to the possibility of fatigue cracks and loose rivets.

REFERENCE

He, P.C., Itani, A. M., and Maragakis, E.M., “Fatigue Behavior of Riveted Open Deck Railroad Bridge Girders,” Report No. CCEER 99-10, Engineering Research and Development Center, College of Engineering, University of Nevada, Reno, August 1999.

ACKNOWLEDGMENT

The authors thankfully acknowledge the information provided by Messrs. R. A. P. Sweeney of Canadian National, W.G. Byers of Burlington Northern Santa Fe, and C.T. Goewey of Norfolk Southern.

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

A MORE DETAILED REPORT, WHICH MAY CONTAIN REVISED INFORMATION, MAY BE AVAILABLE AT A LATER DATE THROUGH AAR/TTCI, PUBLICATIONS, P.O. Box 79780, BALTIMORE, MD, 21279-0780.