TRANSPORTATION POOLED FUND PROGRAM
QUARTERLY PROGRESS REPORT

Lead Agency (FHWA or State DOT): Kansas DOT

INSTRUCTIONS:
Project Managers and/or research project investigators should complete a quarterly progress report for each calendar quarter during which the projects are active. Please provide a project schedule status of the research activities tied to each task that is defined in the proposal; a percentage completion of each task; a concise discussion (2 or 3 sentences) of the current status, including accomplishments and problems encountered, if any. List all tasks, even if no work was done during this period.

Transportation Pooled Fund Program Project # *TPF-5(189)*	**Transportation Pooled Fund Program - Report Period:** ☐Quarter 1 (January 1 – March 31) ☐Quarter 2 (April 1 – June 30) X Quarter 3 (July 1 – September 30) ☐Quarter 4 (October 4 – December 31)

Project Title:
"***Enhancement of Welded Steel Bridge Girders Susceptible to Distortion-Induced Fatigue***"

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Lead Agency Project ID:	**Other Project ID (i.e., contract #):** **KAN00063732**	**Project Start Date:** 08/31/2008
Original Project End Date: **08/31/2011**	**Current Project End Date:** **08/31/2013**	**Number of Extensions:** **1**

Project schedule status:

☐ On schedule X On revised schedule ☐ Ahead of schedule ☐ Behind schedule

Overall Project Statistics:

Total Project Budget	**Total Cost to Date for Project**	**Total Percentage of Work Completed**
$1,060,000.00	$943,233.95	86%

Quarterly Project Statistics:

Total Project Expenses	**Total Amount of Funds**	**Percentage of Work Completed**

This Quarter	Expended This Quarter	This Quarter
$23,975.59	$23,975.59	5%

Project Description:

A large number of steel bridges within the national inventory are affected by distortion-induced fatigue cracks. Repairs for this type of failure can be very costly, both in terms of direct construction costs and indirect costs due to disruption of traffic. Furthermore, physical constraints inherent to connection repairs conducted in the field sometimes limit the type of technique that may be employed. The goal of the proposed research is to investigate the relative merit of novel repair techniques for distortion-induced fatigue cracks.

Progress this Quarter (includes meetings, work plan status, contract status, significant progress, etc.):

Project Meetings
Weekly research group meetings have continued to take place this quarter.

Contract Status
The contract is in-force and progressing toward an end date of August 31, 2013.

Technical Updates

1. 30 ft. Three-Girder Specimen

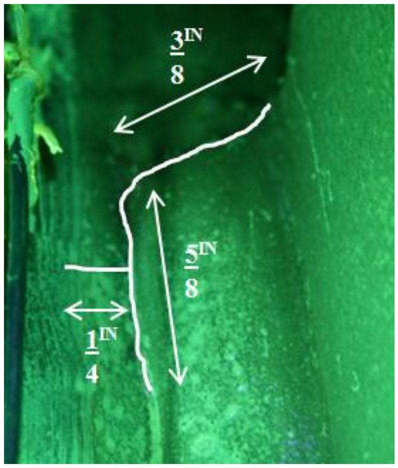
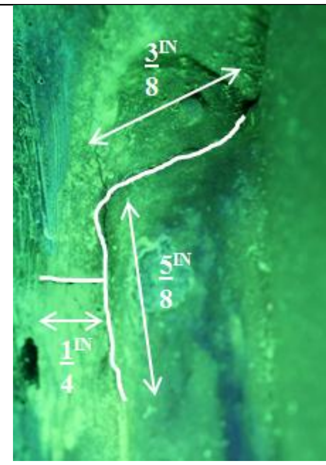
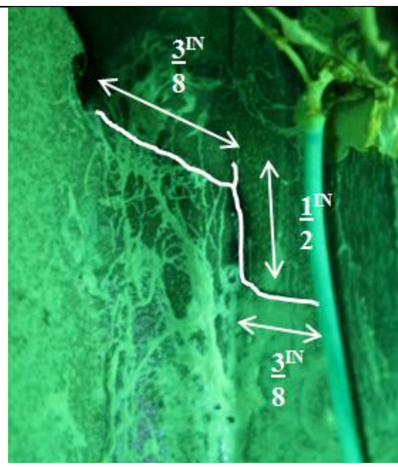
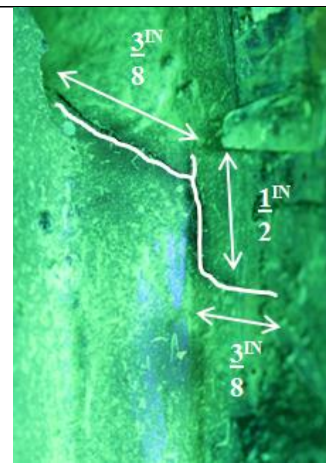
Fatigue testing of the 30-ft bridge has continued and progressed. After 150,000 cycles in the unretrofitted condition under a load range of 54-kips, the maximum individual crack length in the bridge was 1 in. Cracking to-date has occurred in the top web gaps of the exterior two girders (the north girder and the south girder).

At the end of the last reporting quarter, the first retrofit was applied to the bridge. The retrofit, termed the "double angles with backing plate" retrofit, consists of two 7-in. long L6x6x3/4 segments and one L8x18x3/4 backing plate. After the retrofit was applied, cyclic loading of the bridge was continued at a 54-kip load range (6 kips – 60 kips) for 1.2 million cycles, which is the cycle count used as run-out within this study.

After the 1.2 million cycles were completed, the retrofits were removed from the north and south girders, and cracks were inspected using a high-definition camera. The largest cracks prior to the retrofits had been found in the south girder. Cracking before and after the retrofit are compared in Table 1.

It can be seen that cracks did not propagate under the retrofit on the interior face of the girder. The crack on the fascia side of the girder experienced ¼-in. of crack growth while the retrofit was applied. This crack formed as a through-thickness crack from the spider cracking that can be seen on the interior side of the girder. The total length of the crack seen on the fascia side is $1^3/_8$-in. This crack length correlates with the total projected crack length on the interior side of the girder, including the spider crack length (3/8-in. + ¼-in.), stiffener width (3/8-in.) and weld width (3/8-in.). Therefore, it is likely that the change in the fascia crack length can be attributed to the existing interior crack propagating through the girder thickness.

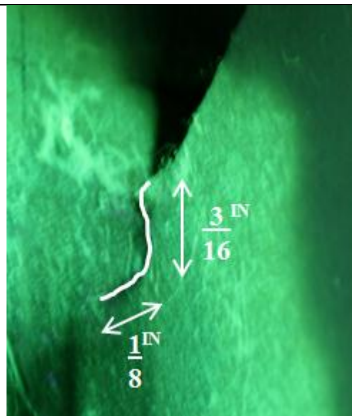
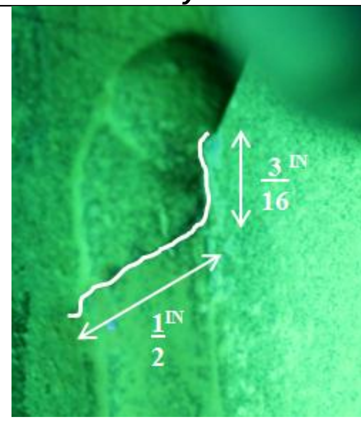
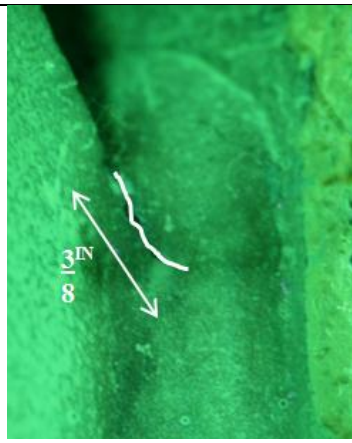
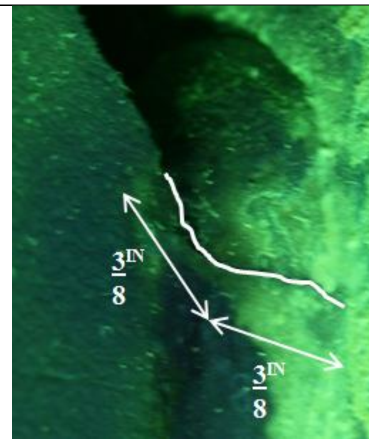
Table 1: Comparison of crack geometry in the south girder before and after retrofit application

<table>
<tr><th></th><th>Before Retrofit</th><th>After Retrofit – at 1.2 Million Cycles</th></tr>
<tr><td>Interior Face, Left Side</td><td>
</td><td>
</td></tr>
<tr><td>Interior Face, Right Side</td><td>
</td><td>
</td></tr>
<tr><td>Exterior Face</td><td>
</td><td>
</td></tr>
</table>

Cracking on the interior face of the north girder experienced low growth under the application of the retrofit, and crack geometries pre- and post- retrofit are presented in Table 2. No cracking was noted in the fascia side of the north girder.

While counterintuitive, finite element analyses performed by the researchers regarding field bridges and of the 9-ft. specimens have shown that very short crack lengths induce the most demanding stress condition in the web gap. Additionally, this test marks the first time this retrofit has been installed over crack lengths this small. Therefore, this is likely an extremely demanding scenario for the web gap and retrofit application.

Table 2: Comparison of crack geometry in the north girder before and after retrofit application

	Before Retrofit	***After Retrofit Cycled 1.2 Million***
Interior Face, Left Side		
Interior Face, Right Side		

Plots showing crack length over time (cycles) for both the north and south girders are shown in Figures 1 and 2.

To continue to assess the effectiveness of this retrofit, the applied stress range will be increased. A load range of 72 kips (8 kips – 80 kips) will be applied to the bridge in the retrofitted condition. This will further increase the demand placed upon the web gap region, and will be a very stringent test of the retrofit's effectiveness.

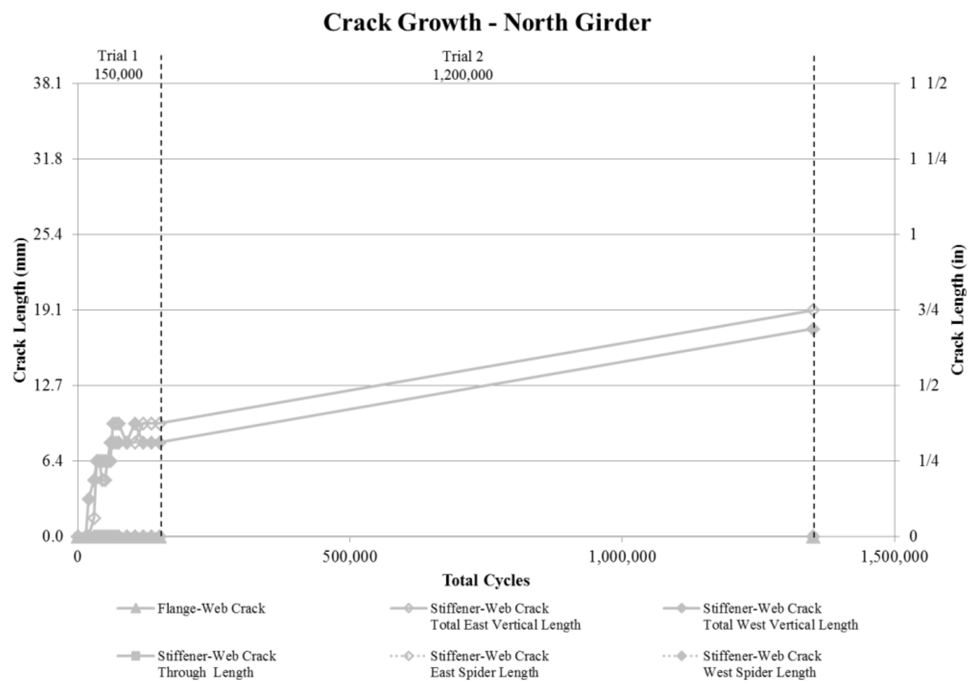


Figure 1: Crack growth plot for Trials 1 and 2 in the north girder

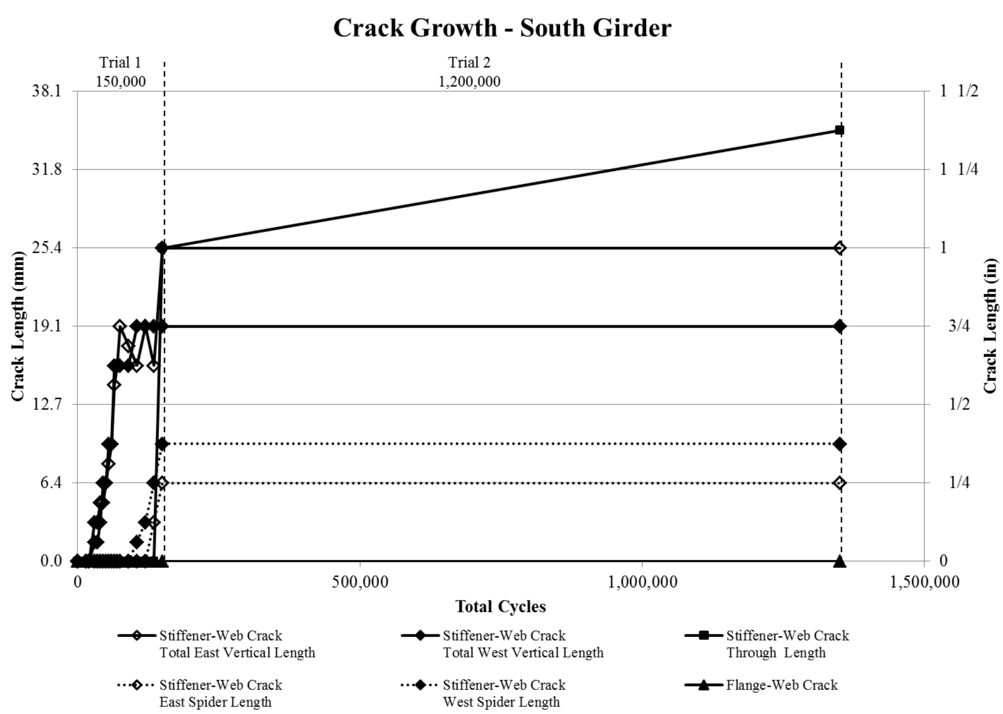


Figure 2: Crack growth plot for Trials 1 and 2 in the south girder

2. 9 ft. Girder Specimens

Testing of the 9-ft. specimens has continued and progressed. Two tests have been running concurrently – Specimen 3 and Specimen 4.

Specimen 3

Specimen 3 has undergone a significant testing series including various trials, and the crack lengths at the onset of the trial described in this progress report are quite significant. The horizontal web-to-flange crack had a total length of 21.5 in. at the onset of this new trial, and cracks emanating out of the web-to-stiffener weld extended approximately 14-in. into the web.

A version of the angles with backing plate repair was implemented on Specimen 3 in this highly-damaged state, in which two L6x6x3/4 segments 19-in. long were utilized with a backing plate having dimensions 24-in. x 24-in. x ½-in. This retrofit application covered the lengths of the horizontal and vertical cracks. Testing was performed until 1.2 million cycles were achieved, after which the specimen was inspected for crack growth. No additional crack growth was detected. The retrofit applied to Specimen 3 is shown in Figures 3 and 4.

Figure 3: View of backing plate used in most recent test trial of Specimen 3

Figure 4: View of double angles used in most recent test trial of Specimen 3

Specimen 4

The composite block retrofit discussed in the June, 2012 progress report was removed after 1.2 million cycles. The web gap region was inspected for crack growth, and it was found that the cracks had propagated modest amounts, with the greatest propagation occurring at the flange-to-web weld (1 5/16" growth over 1.2M cycles).

The CFRP block was removed from Specimen 4, and the cracks were allowed to grow freely for approximately 30,000 cycles. Then, to begin investigating the performance of crack-arrest holes under distortion-induced fatigue, very small 1/4-in. dia. crack-arrest holes were drilled at the tips of the cracks. The cracking patterns just prior to drilling the crack-arrest holes are shown in Figures 5 and 6.

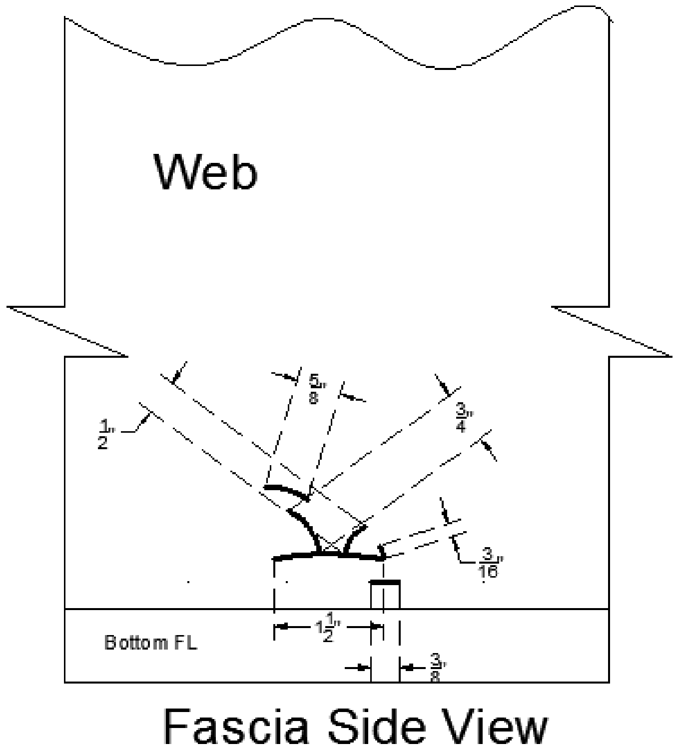


Figure 5: Cracking pattern in Specimen 4 on the fascia side of the web gap region

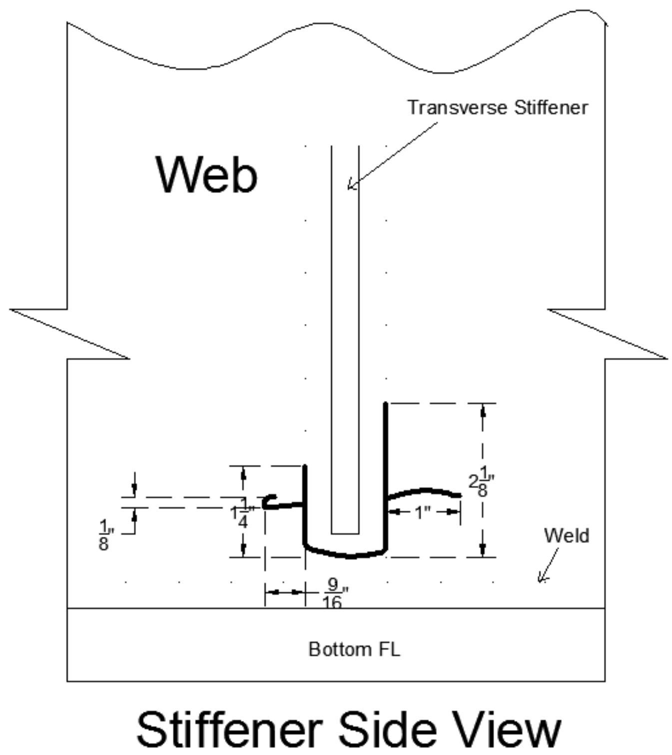


Figure 6: Cracking pattern in Specimen 4 on the interior side of the web gap region

Anticipated work next quarter:

- Fatigue testing of Specimen 30ft-1 in the retrofitted condition (double angles with backing plate) will continue in the next quarter.
- Fatigue testing of Specimen 3 and Specimen 4 in the 9-ft. girder test set-ups will continue.

Significant Results:

Fatigue cracking has initiated and propagated in the 30-ft. bridge test set-up, and has been repaired using the double-angles with backing plate retrofit. Some modest crack propagation was noted to have occurred with the retrofit in place under the demanding loading conditions provided to the test bridge. Testing of the double-angles with backing plate retrofit continues on 9-ft. Specimen 3, applied over very extreme crack lengths. Testing of composite blocks as a fatigue retrofit has been completed for 9-ft. Specimen 4.

A list of in-print publications produced by the project team in direct relation to TPF-5(189) is presented here, for the reader interested in further analysis of results to-date.

Richardson, T., Alemdar, F., Bennett, C., Matamoros, A., and Rolfe, S. "Evaluation of the Performance of Retrofit Measures for Distortion-Induced Fatigue Using Finite Element Analysis," National Steel Bridge Alliance (NSBA)

World Steel Bridge Symposium (WSBS) 2012 Proceedings, April 18-20, 2012.
Richardson, T., Alemdar, F., Bennett, C., Matamoros, A., and Rolfe, S. (2012). “Retrofit Measures for Distortion-Induced Fatigue,” *Modern Steel Construction*, American Institute of Steel Construction (AISC), 52 (4), 32-34.
Alemdar, F., Matamoros, A., Bennett, C., Barrett-Gonzalez, R., and Rolfe, S. (2012). “Use of CFRP Overlays to Strengthen Welded Connections under Fatigue Loading,” *Journal of Bridge Engineering*, American Society of Civil Engineers (ASCE), 17(3), 420-431.
Kaan, B*,* Alemdar, F., Bennett, C., Matamoros, A., Barrett-Gonzalez, R., and Rolfe, S. (2012). “Fatigue Enhancement of Welded Details in Steel Bridges Using CFRP Overlay Elements,” *Journal of Composites for Construction*, American Society of Civil Engineers (ASCE), 16(2) 138-149.
Hassel, H., Bennett, C., Matamoros, A., and Rolfe, S. (2012). “Parametric Analysis of Cross-Frame Layout on Distortion-Induced Fatigue in Skewed Steel Bridges,” Accepted for publication in the *Journal of Bridge Engineering*, American Society of Civil Engineers (ASCE).
Alemdar, F., Matamoros, A., Bennett, C., Barrett-Gonzalez, R., and Rolfe, S. (2011). "Improved Method for Bonding CFRP Overlays to Steel for Fatigue Repair," Proceedings of the ASCE/SEI Structures Congress, Las Vegas, NV, April 14-16, 2011.
Hartman, A., Hassel, H., Adams, C., Bennett, C., Matamoros, A., and Rolfe, S. “Effects of lateral bracing placement and skew on distortion-induced fatigue in steel bridges,” *Transportation Research Record: The Journal of the Transportation Research Board,* No. 2200, 62-68.
Crain, J., Simmons, G., Bennett, C., Barrett-Gonzalez, R., Matamoros, A., and Rolfe, S. (2010). “Development of a technique to improve fatigue lives of crack-stop holes in steel bridges,” *Transportation Research Record: The Journal of the Transportation Research Board,* No. 2200, 69-77.
Hassel, H., Hartman, A., Bennett, C., Matamoros, A., and Rolfe, S. "Distortion-induced fatigue in steel bridges: causes, parameters, and fixes," Proceedings of the ASCE/SEI Structures Congress, Orlando, FL, May 12-15, 2010.
Alemdar, F., Kaan., B., Bennett, C., Matamoros, A., Barrett-Gonzalez, R., and Rolfe, S. "Parameters Affecting Behavior of CFRP Overlay Elements as Retrofit Measures for Fatigue Vulnerable Steel Bridge Girders," Proceedings of the Fatigue and Fracture in the Infrastructure Conference, Philadelphia, PA, July 26-29, 2009.
Kaan, B., Barrett, R., Bennett, C., Matamoros, A., and Rolfe, S. “Fatigue enhancement of welded coverplates using carbon-fiber composites,” Proceedings of the ASCE / SEI Structures Congress, Vancouver, BC, April 24-26, 2008.

Circumstance affecting project or budget. (Please describe any challenges encountered or anticipated that might affect the completion of the project within the time, scope and fiscal constraints set forth in the agreement, along with recommended solutions to those problems).