June 30, 2009 Progress Report on Pooled Fund Study TPF-5(189):
"***Enhancement of Welded Steel Bridge Girders Susceptible to Distortion-Induced Fatigue***"

Introduction

There are significant developments to report for Transportation Pooled Fund study TPF-5(189) for the quarter ending June 31, 2009. The test frame has been erected in the KU Structures Lab, and the loading equipment has been received. Dimensions for the test girders have been finalized, and the initial connection geometry to be studied has been selected. A suite of finite element models are being performed to capture the expected behavior of the test assemblages. Component-level studies are continuing, and are also discussed.

Test Frame

The test frame was erected in mid-May, 2009 in the University of Kansas Structures Lab, and is pictured in Figures 1 and 2. The 400-kip MTS actuator and hydraulic pump also arrived in May, and are in the process of being installed.

Fig. 1. Test frame under construction

Fig. 2. Completed test frame in KU structures lab

Test Specimen Design

Sizing of the test girders is complete. Three girders spaced at 6 ft, each with dimensions as outlined in the March, 2009 progress report will be fabricated. The total bridge system will be 27 ft long between points of bearing. The first connection detail to be studied experimentally has been selected. The connection consists of a connection stiffener welded to the girders' webs, with a clip removed at the top and bottom flanges, as pictured in Figs. 5 and 6.

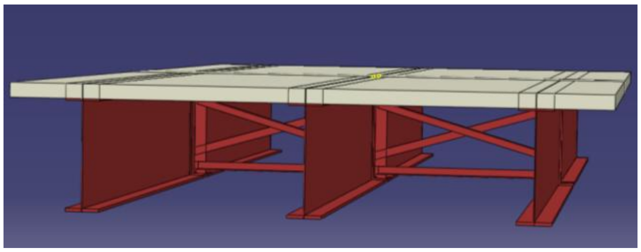

Fig. 3. View of overall model of three girder bridge assemblage

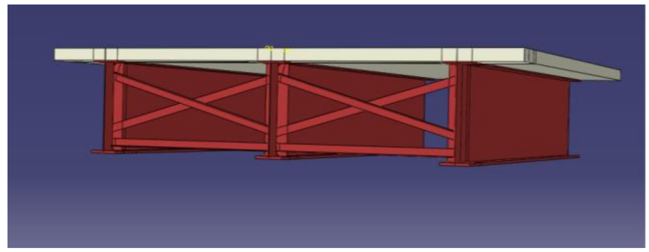

Fig. 4. Exposed view of lateral bracing at mid-span

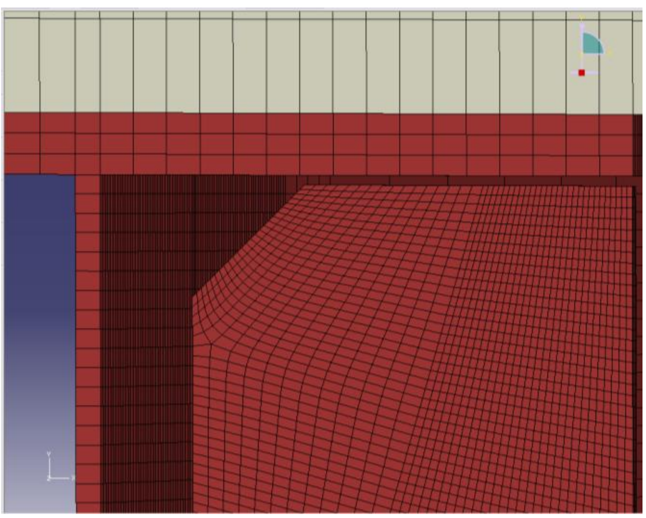

Fig. 5. View of clipped connection stiffener at the top flange

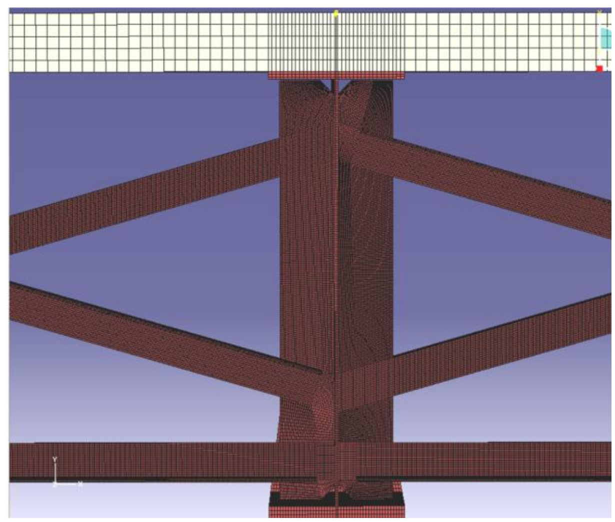

Fig. 6. View of internal girder with two connection stiffeners

The research team has begun to consider various regional bridge shops for fabrication of the girders. It is anticipated that the fabrication process of the first three-girder assemblage will be initiated within the next project quarter.

Component-Level Studies

Two parallel studies are being performed concurrent to the outlined activities that will feed directly into the pooled fund study activities once 3D testing commences. These studies are:

1. Characterization of sprayed chopped carbon fiber composite on steel fatigue details, and
2. Development and application of a PICK tool to treat the inside surface of undersized crack-stop holes.

In addition, results from the use of molded carbon fiber reinforced polymer (CFRP) composites to improve steel fatigue detail performance can be found in references 2 and 3.

Chopped-Fiber Application

Chopped carbon fibers have been sprayed onto flat bar fatigue specimens that contained an existing crack extending from a drilled hole. These retrofitted specimens have been subjected to fatigue loading in tension at a stress range of 24 ksi, and growth of the existing crack monitored. Additionally, continuous carbon fibers have also been applied to pre-cracked specimens, and propagation behavior at a stress range of 24 ksi observed. Although there are significant differences between stiffnesses of the two patch types, effect of both techniques on the propagation lives of pre-cracked fatigue specimens was similar. For specimens tested thus far, crack growth has been slowed substantially through use of the retrofits, when compared to fracture mechanics predictions. Experimental tests to determine the propagation life of uncoated specimens to serve as a baseline will be performed in the future.

A pre-cracked fatigue specimen coated with chopped fibers is pictured in Fig. 7. A finite element modeling effort has been undertaken to analytically investigate the behavior of a retrofitted specimen. Fig. 8 depicts the finite element model of the chopped fiber coated specimen. In the next quarter, additional chopped-fiber and continuous fiber tensile fatigue tests will be performed at a higher stress range of 32 ksi. Additionally, chopped fiber retrofits will be investigated on three-point bending cover-plated specimens.

Fig. 7. **Fatigue specimen with pre-existing crack, coated with chopped carbon fibers**

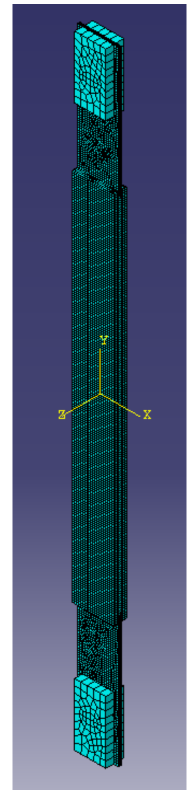

Fig. 8. **Finite element model of retrofitted fatigue specimen**

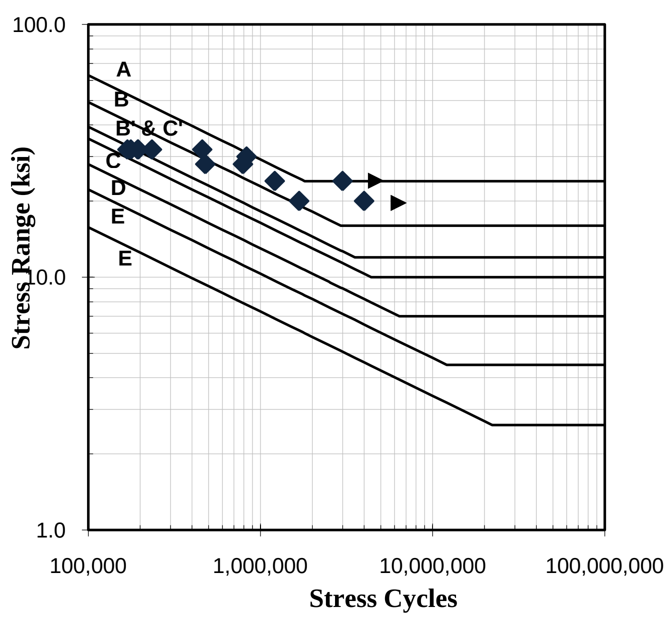

Fig. 9. **SN Diagram showing performance of control specimens**

Treatment of Undersized Crack Stop Holes

Thirteen fatigue specimens with undersized crack-stop holes have been tested as control specimens. Results are shown in Fig. 9. The PICK tool has been developed and applied to a fatigue specimen. The PICK treated hole was indeed expanded from its initial diameter. Fatigue testing did not show significant differences in performance between the treated specimen and untreated control specimens; however, this was not surprising at this stage of tool development. A photograph of a fatigue specimen is provided in Fig. 10. The PICK treatment is currently being refined, with the goals of eliminating potential crack initiation sites and creating more uniform treatment. Chamfered tool tips are being fabricated to help make the treatment process more uniform throughout the inner surface of the crack-stop hole.

To aid in refinement of the PICK tool, finite element modeling is being performed to better understand residual stress distributions in undersized crack stop holes due to cold expansion of the material. There is existing literature covering this topic for aluminum structures, but little exists aimed at structural steel. A series of finite element models have been developed to simulate residual stresses in the crack-stop hole after varying amounts of cold expansion. The finite element model of the full fatigue specimen is shown in Fig. 11. Fig. 12 depicts residual compressive stresses induced in the undersized crack-stop hole after 3% cold expansion. It is anticipated that in the next quarter, different sizes of crack-stop holes will be investigated analytically to determine the residual stresses needed to obtain performance similar to that of a correctly-sized crack-stop hole.

Fig. 10. **Fatigue specimen with undersized crack-stop hole**

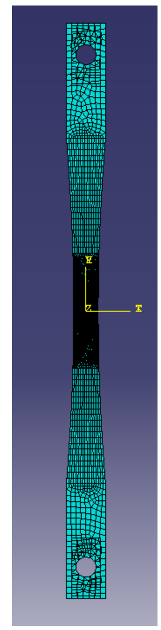

Fig. 11. **ABAQUS model of fatigue specimen with undersized crack-stop hole**

Upcoming Tasks

Given the current project activities, the following tasks are expected to occur in the next quarter:

1. Installation of the actuator and hydraulic pump on the test frame,
2. Post-tensioning of the test frame,
3. Selection of a shop for the test girders to be fabricated,
4. Order placed for first three-girder assemblage to be fabricated,
5. Selection of the next connection detail to be studied,
6. Continued fatigue testing of continuous and chopped-fiber retrofitted specimens at an increased stress range of 32 ksi,
7. Testing of chopped-fiber retrofit on three-point bending specimens, and
8. Analytical comparison of different undersized crack-stop holes with varying levels of cold-expansion.

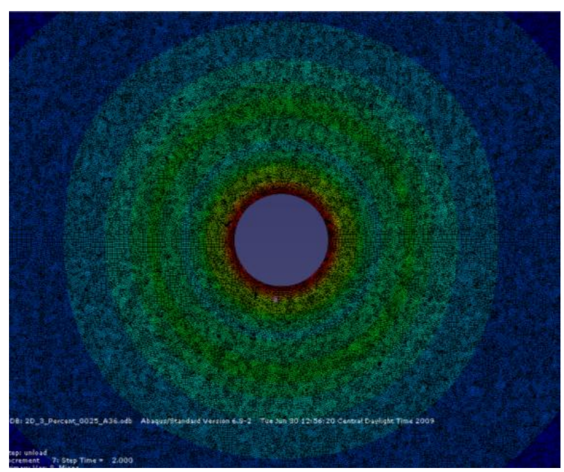

Fig. 12. **Von Mises residual stress fields for 3% expansion of crack-stop hole**

Conclusion

TPF-5(189) saw significant progress this quarter. The test set-up is nearing completion, and the test specimens have been designed to the point where it is prudent to begin preparations for fabrication of the first three-girder bridge assemblage. Component-level tests are also showing great promise. Chopped-fibers bonded to steel substrate have shown that crack propagation can be nearly halted in experimental fatigue tests under high stress ranges. Analytical studies of crack-stop holes under cold-expansion illustrate the potential for the PICK tool's success, and continued development of the PICK tool is being performed.

Contact Information

Please contact Caroline Bennett at (785)864-3235 or crb@ku.edu with any questions or discussion items.

References

1. Kaan, B.,‡ Barrett, R., Bennett, C., Matamoros, A., and Rolfe, S. (2008). "Fatigue enhancement of welded coverplates using carbon-fiber composites," Proceedings of the 2008 ASCE / SEI Structures Congress, Vancouver, BC, April 24 – 26, 2008.

2. Kaan, B. (2008). "Fatigue enhancement of category E' details in steel bridge girders using CFRP materials," thesis, presented to the University of Kansas, Lawrence, KS in partial fulfillment of the requirements for the degree of Masters of Science.