<u>December 31, 2009 Progress Report on Pooled Fund Study TPF-5(189):</u>
"***Enhancement of Welded Steel Bridge Girders Susceptible to Distortion-Induced Fatigue***"

Introduction

Progress made for the reporting quarter between September 30, 2009 and December 30, 2009 includes the following highlights:

- Hanging of the actuator and tightening of brace connections on the test frame;
- Analytical investigation concerning the effects of global bridge parameters on web gap stresses, including skew angle, cross-frame spacing, and cross-frame layout;
- Treatment of four specimens with PICK technology; and
- Analytical investigation concerning the effects of plate thickness and hole diameter and placement on the level of residual stresses achievable in cold-expanded crack-stop holes.

Experimental Test Set-Up

In this quarter of the project, brace connections were fully-tightened (this task was reserved until post-tensioning was complete to eliminate locking-in brace stresses). Following this task, the actuator was suspended from the frame. The hydraulics and controller were routed and tested with the actuator in-place. The final design of test specimens has been progressing through ongoing conversations with steel fabricators.

Effects of Global Bridge Parameters on Web Gap Stresses

An investigation was performed in this reporting quarter in which various parameters were investigated analytically to determine their effects on stresses in the web-gap region of a steel bridge. The bridge investigated was a two-span continuous structure with 90 ft spans. The finite element model was constructed using linear, solid elements for the steel girders, and linear shell elements for the composite concrete deck. At this stage, a strip loading was applied over one of the interior girders to produce differential deflection between it and adjacent girders. Global parameters that were investigated included the following:

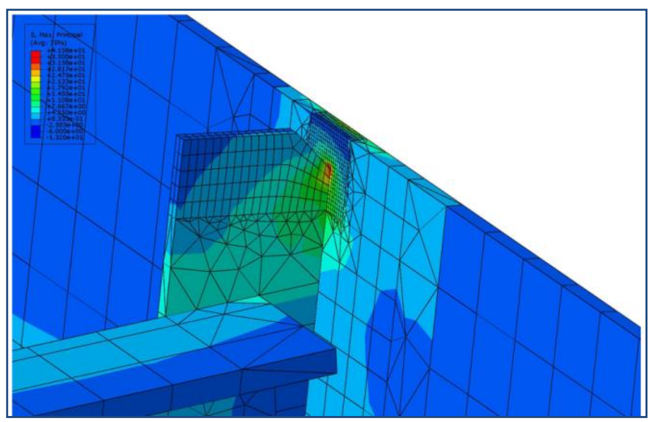


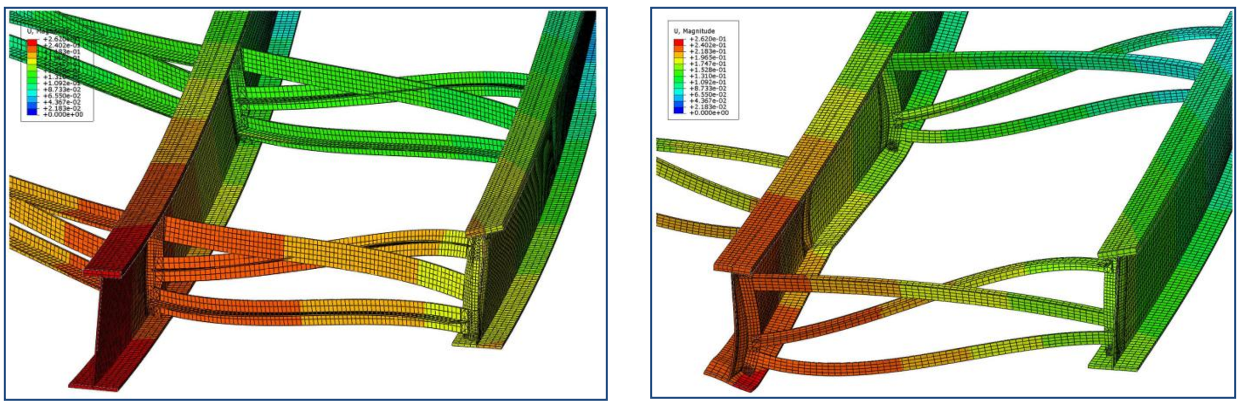
Fig. 1. View of ABAQUS model of web gap region in the connection detail studied analytically

- <u>Angle of bridge skew:</u> 0, 20, and 40 deg. skew angles were investigated.
- <u>Cross-frame spacing:</u> 15 and 30 ft crossframe spacings were investigated.
- <u>Cross-frame placement:</u> Cross-frames were placed parallel to the skew angle in some models, and perpendicular to the girders and staggered in other models.

The combination of parameters investigated in this phase of the analytical investigation is shown in Table 1. It was found in all models that the maximum stress in the web gap region occurred in the region of positive bending, but extremely different behavior was observed between the models with staggered cross frames perpendicular to the girder and cross frames placed parallel to skew. In the models with staggered cross frames, the region of maximum stress was the bottom web gap of the loaded girder, while in the models with cross frames place parallel to girder web maximum stress was found in the top web gap of the exterior girder adjacent to the loaded girder. In the models with cross frames place parallel to skew angle, both increasing skew angle and cross frame spacing increased the maximum stress found in the bridge, although neither had a significant effect.

Table 1. Finite Element Models Examined

Skew Angle	Parallel to Skew		Staggered	
	4.575 m (15 ft)	9.150 m (30 ft)	4.575 m (15 ft)	9.150 m (30 ft)
0	X	X		
20	X	X	X	X
40	X	X	X	X



(a) (b)

Fig. 2. Deflected shape of 40 deg. skewed bridge with 4.58 m (15.0 ft) cross frame spacing and: (a) Cross frames placed parallel to skew; (b) Staggered cross frames. Deck removed from view for clarity.

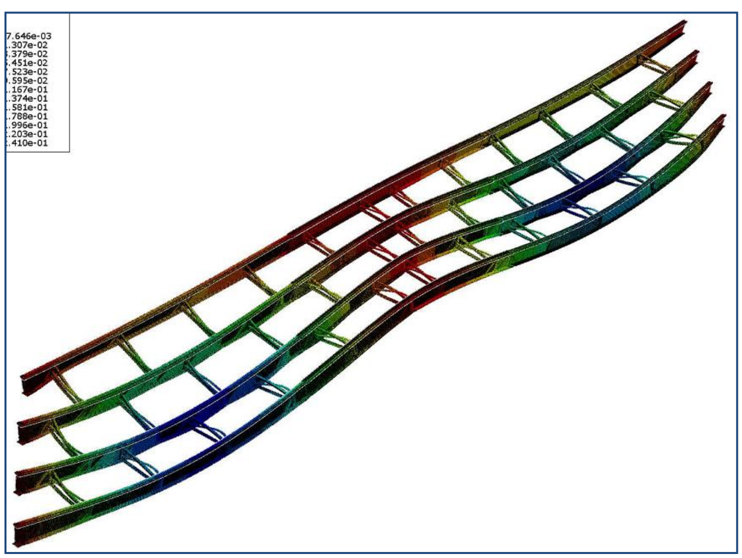


Fig. 3. Deflected shape of 40 deg. skewed bridge with staggered cross frames spaced at 15 ft. (Colored gradient represents vertical deflection values, with red being the smallest deflections, and blue representing the greatest values.)

Component-Level Studies

Component-level studies are continuing to move forward. These investigations focus primarily on the refinement of the following two retrofit techniques: (1) PICK technology to treat undersized crack-stop holes, and (2) use of CFRP materials to enhance fatigue life of cracked as well as un-cracked structural members.

Treatment of Undersized Crack-Stop Holes

Research concerning treatment of undersized crack stop holes in this reporting quarter focused on determining the effects of the following on residual stress distribution after cold expansion: (1) hole edge distance and hole diameter, and (2) plate thickness.

3-D, nonlinear, finite element models have been created to examine the levels of residual stress that may be achieved with cold expansion of crack-stop holes. This investigation has been important to determine the demands for the PICK tool development, as well as to compare efficacy of the PICK treatment against methods of cold expansion that are used in other fields, such as aerospace engineering.

The models described here focus on the effects of hole diameter, distance of the hole from the plate edge, and plate width to investigate the effects of those parameters on levels of compressive residual stresses. Fig. 4. shows the model geometry for a ratio of distance from hole center to plate edge, *e*, to hole diameter, *d*, of (*e*/*d*)=5.0.

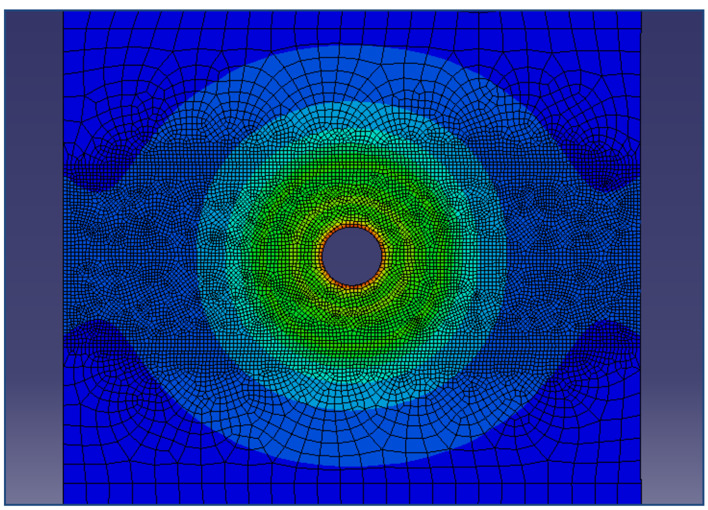


Fig. 4. Models based on specimens with thickness equal to 0.125 in., 4 percent uniform expansion, and mild-steel with σ_y = 40 ksi & σ_{ult} = 52 ksi

Results from the models showing the effect of edge distance, *e,* normalized with respect to hole diameter, *d,* are presented in Fig. 5. From the FEMs, investigating the effects edge distance ratio has on tangential residual stress fields, the following conclusions can be drawn:

- Once edge distance ratios exceed 3, where *e* is the distance from the center of the hole to the edge of the plate and *D* is the diameter of the hole, changes in edge distance ratio had minimal effect on the level or shape of the residual stress distribution that could be accomplished through uniform expansion. This e/D ratio of 3 can be defined as the point below which an insufficient amount of elastic material exists between the cold expanded hole and the free surface to constrain the plastic region and thus does not allow for proper “springback” of the elastically deformed region to occur.

- The lower level of beneficial residual stress corresponding with lower e/D ratios is likely to have a negative impact on the amount of fatigue life improvement that can be achieved through any method of cold expansion.

The results from the FEMs investigating the effects that increasing plate thickness will have on levels of tangential residual stress at plate mid-thickness are presented in Fig. 6. As plate thickness was increased, so too did the zone of residual compression, maximum compressive stress, and elastic plastic boundary. This occurred because as thickness increased the resulting material constraint or region of resistance behind the plastic zone increased as well. Consequently, the residual stresses produced after cold expansion became more compressive in thicker plates.

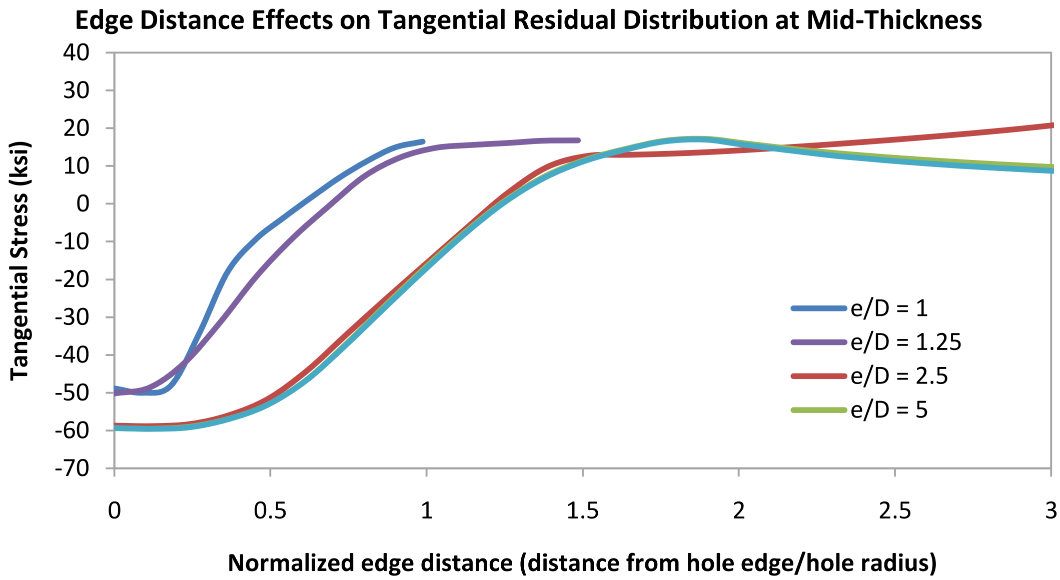


Fig. 5. Models based on specimens with thickness equal to 0.125 in., 4 percent uniform expansion, and mild-steel with σ_y = 40 ksi & σ_{ult} = 52 ksi

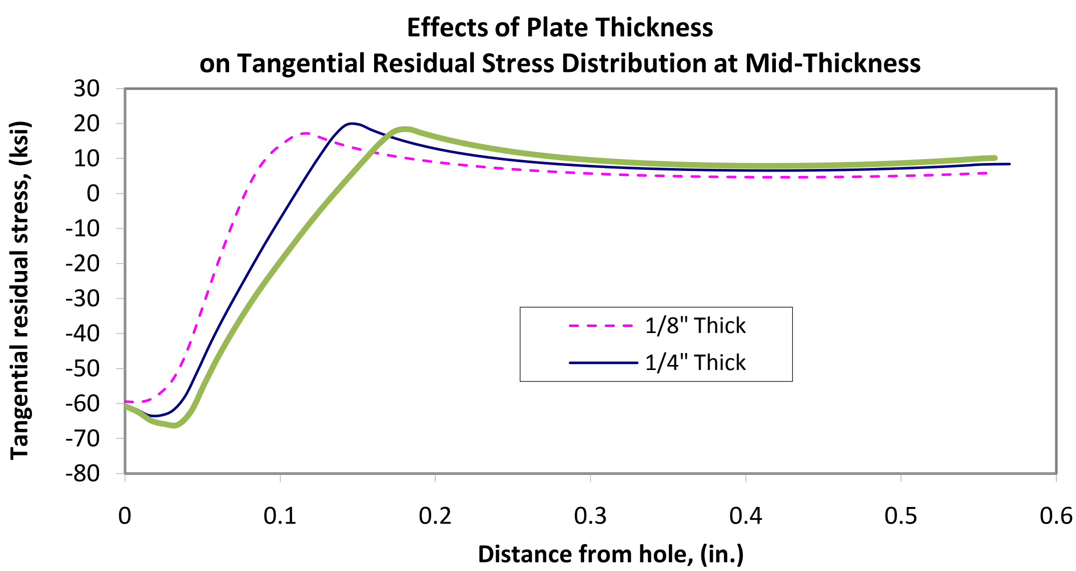


Fig. 6. Models based on specimens with equal widths, 4 percent uniform expansion, and mild-steel with σ_y = 40 ksi & σ_{ult} = 52 ksi

PICK Treatment

Four reduced-scale specimens have been treated with the PICK technology to date, and are currently being fatigue tested. Figures 7 through 9 show the laboratory set up while Figures 10 and 11 show typical results from the treatment. Figure 10 shows the Stresscoat, a brittle coating, applied to the specimen around the 1/8 in. hole and the resulting deformation as a result of the treatment. The Stresscoat cracks where it experiences elastic strain and disbonds with plastic strain. The extent of the disbonding indicates the plastic strain extends to a diameter of approximately 3/8-in.

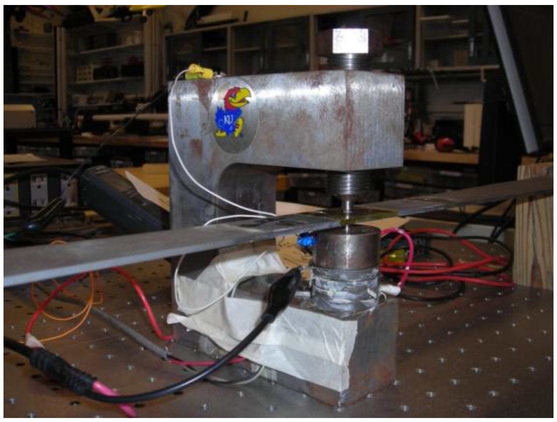


Fig. 7. Laboratory PICK Tool treating 1/8- specimen. Note piezoelectric transducers

Fig. 8. Signal generator, amplifier, and oscilloscope used to power and monitor signal to piezoelectric transducers.

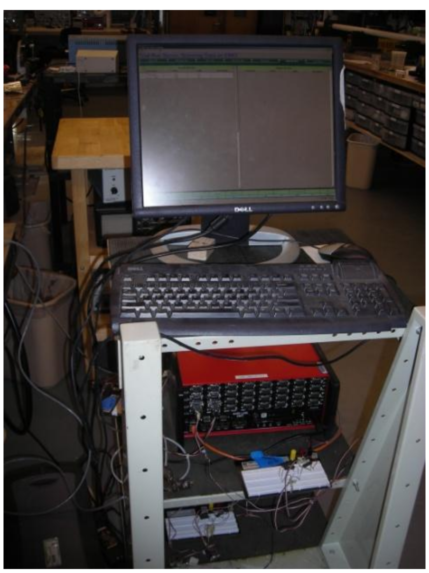


Fig. 9. Data Acquisition System (EBRT, Mars Labs) for recording strains obtained during PICK Testing

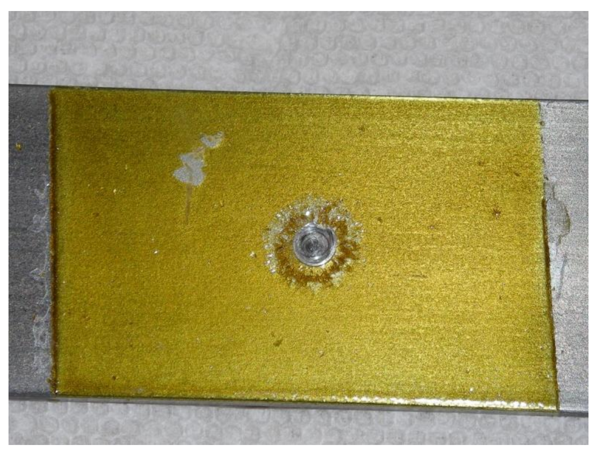


Fig. 10. Typical results from PICK treatment. The plug is still in the 1/8-in diameter hole. The yellow coating is a brittle coating. The region where it has flaked off shows the extent of the plastic deformation.

Fig. 11. Picture of treated hole with plug beside it.

Measurements of the inside of PICK-treated holes have shown that levels of 4% to 7% expansion can be obtained at the surfaces and in the center. This appears to correspond positively with the optimum level of expansion needed to provide the maximum improvement in a cold-expanded hole, based on comparisons with studies performed in the aerospace arena. Further refinement is underway to achieve expansion results in a more consistent manner.

Chopped-Fiber Application

Work has been progressing on investigating the use of CFRP to improve the fatigue lives of steel specimens. Chopped CFRP material has been applied to a three-point bending specimen, and fatigue testing of that specimen is currently ongoing. Please see previous progress reports for information on tensile fatigue testing of specimens coated with chopped-fiber CFRP materials.

Upcoming Tasks

The following tasks are anticipated to occur in the next project quarter:

1. Finalize design of connection details for experimental fatigue testing in three-girder assemblages, and
2. Testing of PICK-treated tensile fatigue specimens, and
3. Fatigue testing of CFRP-treated three-point bending specimens, and
4. Analytical investigation of the effectiveness of various retrofit techniques for distortion-induced fatigue susceptible details.

Conclusion

Meaningful progress was made on Study TPF 5(189) this reporting quarter. The brace connections on the test frame were fully-tightened, and the actuator was installed and is now operational. An analytical investigation was performed to study the effects of global bridge parameters on the severity of web gap stresses, including the effects of skew angle, cross-frame spacing, and cross-frame layout. An analytical study was performed examining factors that affect the level of beneficial compressive stresses that may be imparted in crack-stop holes through cold-expansion.

Contact Information

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