<u>September 30, 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 June 30, 2009 and September 30, 2009 includes the following highlights:

- Post-tensioning of the test frame columns,
- Analytical investigation into the effects of specific retrofit techniques on performance of the test girders,
- Experimental investigation on the effects of chopped and continuous CFRP fibers on the propagation life of cracked specimens, and
- Refinement of the PICK tool intended to treat undersized, drilled crack-stop holes.

Test Frame

The test frame was post-tensioned this project quarter. Eight $1^3/_8$" diameter all-thread bars were each subjected to a locked-in tension force of 105 kips, placing the columns of the frame in compression. Since all specimens will be loaded in positive bending from an actuator suspended from test frame, the columns will be subjected to cyclic tensile stresses. Post-tensioning the frame will help to reduce the tensile stress range felt by the columns.

In the next quarter of the project, brace connections will be fully-tightened (this task was reserved until post-tensioning was complete to eliminate locking-in brace stresses). Following this task, the actuator will be suspended from the frame. The hydraulics and controller will be routed and tested with the actuator in-place. The hydraulic pump was successfully installed this project quarter.

Test Specimen Design

As discussed in the June 30, 2009 quarterly report, sizing of the geometry of the test specimens is complete. The research team is working with fabricators to ensure that the current geometry is constructible.

In this reporting quarter, steps have been taken to investigate the potential effects of retrofit techniques applied to the test girder geometry. Models have been constructed in ABAQUS to examine the behavior of the connection stiffener with different restraint conditions. Additionally, the effect of chopped fibers coating the web-gap region was examined in the models.

Figs. 1, 2, and 3 show the model geometry with no retrofit in the web-gap region. Fig. 3 shows the stress distribution in the web gap region. Figs. 4, 5, and 6 depict other retrofit techniques studied, including the slotted web gap retrofit, and two variations of CFRP material applied in the web gap region. Fig. 7 illustrates the stress distribution in the web gap region underneath the CFRP overlay. Comparing the unretrofitted web-gap region to the CFRP-retrofitted web gap stresses, it is apparent that the retrofit is successful in reducing the stress demand at the web gap. This is illustrated further in the plot shown in Fig. 8, comparing the various retrofits' effectiveness in reducing stress demand at the web gap.

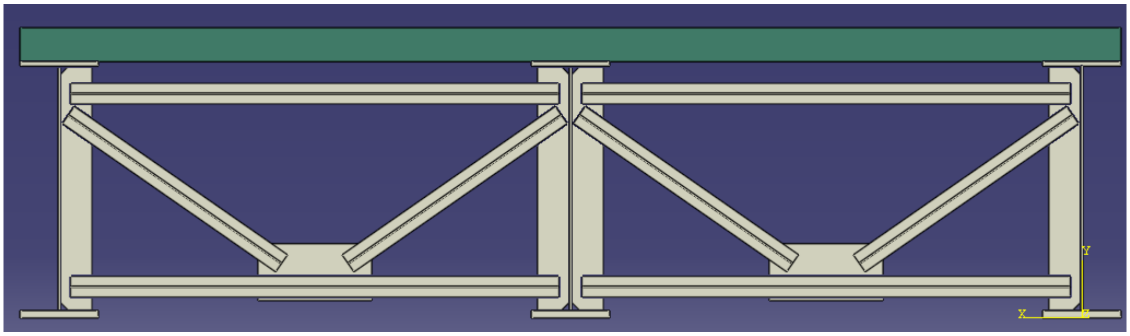

Fig. 1. Section view of test bridge geometry with un-retrofitted web-gap region

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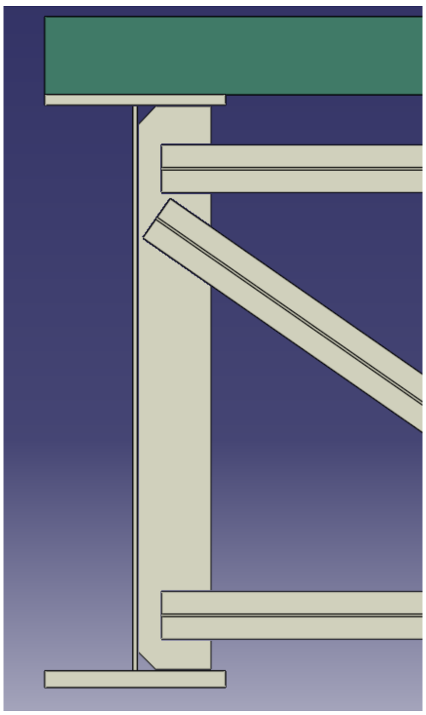

Fig. 2. Section view of test girder geometry with un-retrofitted clipped web-gap region

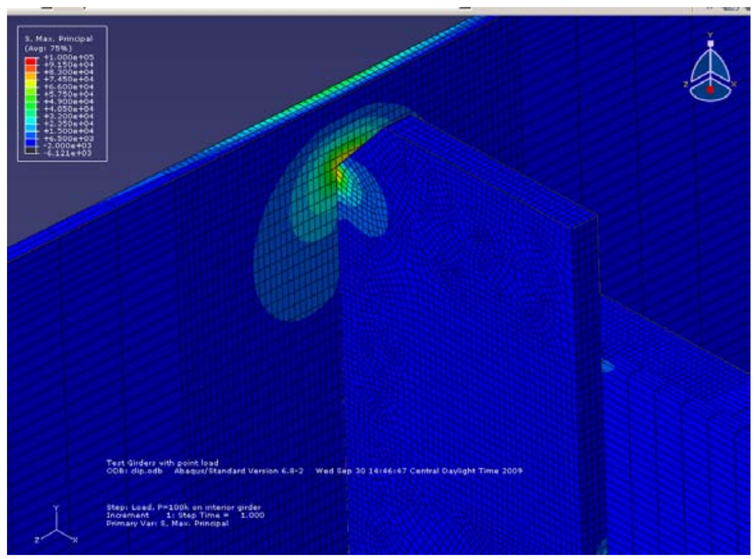

Fig. 3. View of maximum principal stress distribution in un-retrofitted clipped web-gap region (top flange removed from view for clarity)

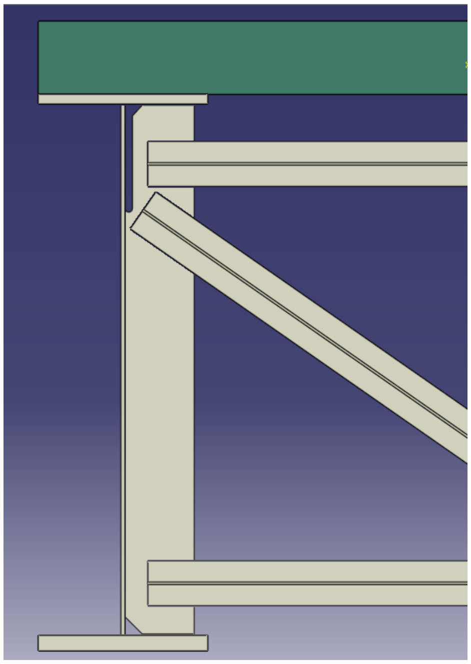

Fig. 4. Section view of test girder geometry with slot retrofit in web-gap region

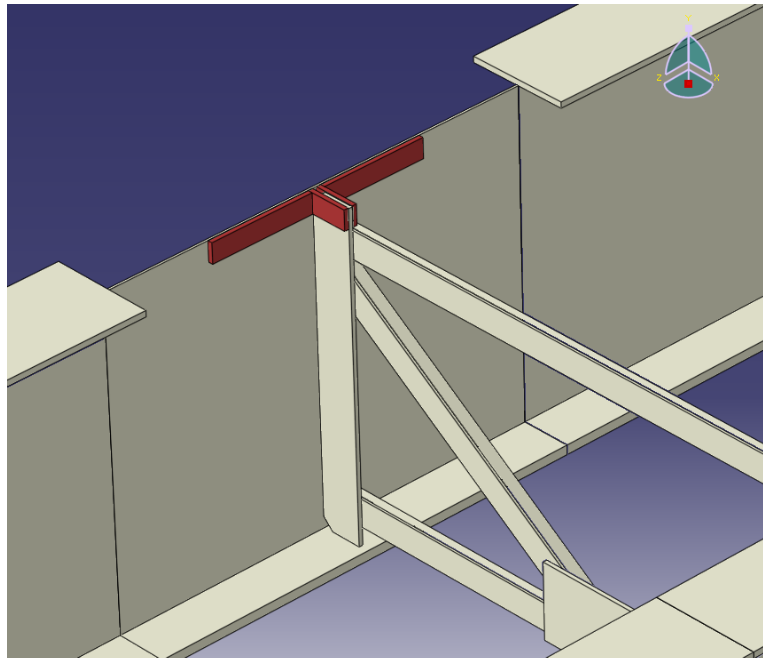

Fig. 5. View of test girder retrofitted with CFRP material surrounding web-gap region (portion of top flange removed from view for clarity)

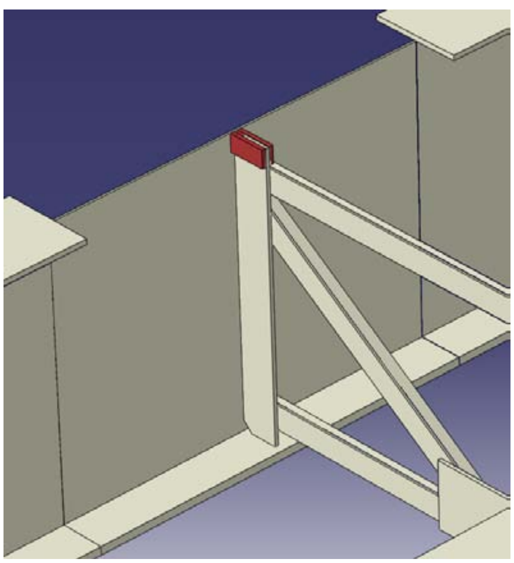

Fig. 6. View of test girder retrofitted with CFRP material surrounding web-gap region on connection stiffener (portion of top flange removed from view for clarity)

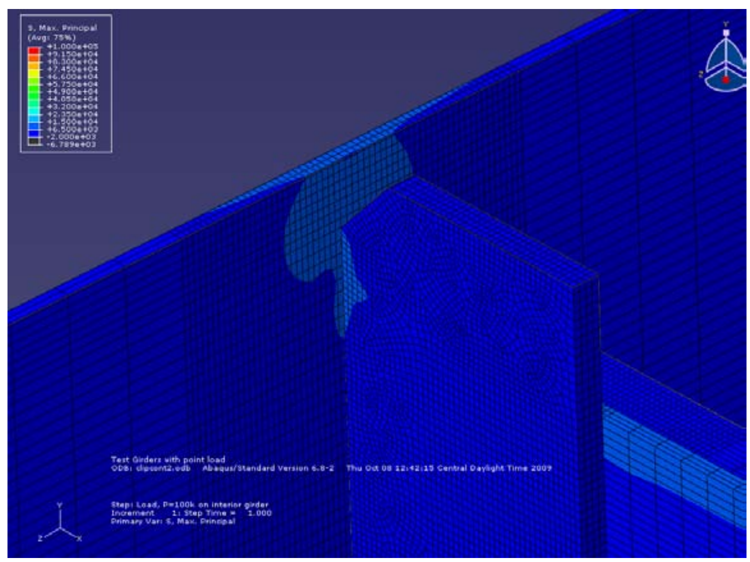

Fig. 7. View of maximum principal stress distribution in clipped web-gap region with CFRP retrofit on connection stiffener (top flange and CFRP material removed from view to expose web gap stresses)

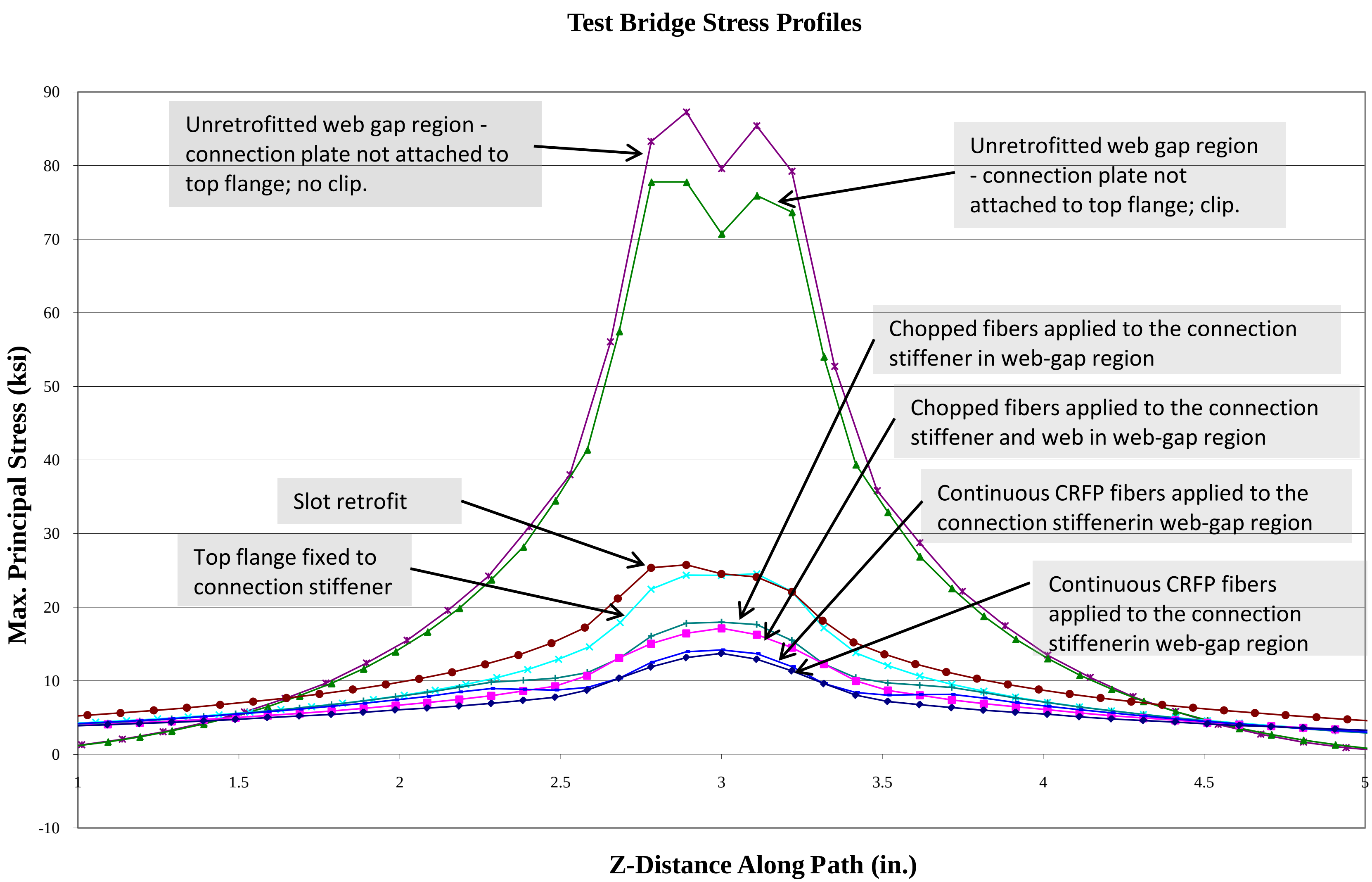

Fig. 8. Maximum principal stresses in web gap region of test girder under various retrofit conditions

Component-Level Studies

Chopped-Fiber Application

In addition to tensile fatigue specimens described in the June 30, 2009 quarterly report, in which non-cracked specimens were coated with chopped carbon fibers, pre-cracked specimens have also been retrofitted with CFRP material and tested in fatigue. Chopped fibers and continuous carbon fibers were applied to pre-cracked specimens, and propagation behavior observed for each system.

Although there are significant differences between stiffnesses of the two patch types, the effects of both techniques on the propagation lives of pre-cracked fatigue specimens were found to be similar. For specimens tested thus far, crack growth was 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.

The plot shown in Fig. 9 illustrates the predicted propagation lives of untreated specimens for different stress ranges (black continuous curves), as well as measured propagation lives for three treated, pre-cracked specimens tested at stress ranges between 24 ksi and 32 ksi. It is apparent that significant gains were made by coating the cracked specimens with CFRP materials. Specimens tested at these high stress ranges (24 ksi and 32 ksi) performed similar to predictions that would have occurred in bare specimens subjected to stress ranges of 4 ksi to 7 ksi.

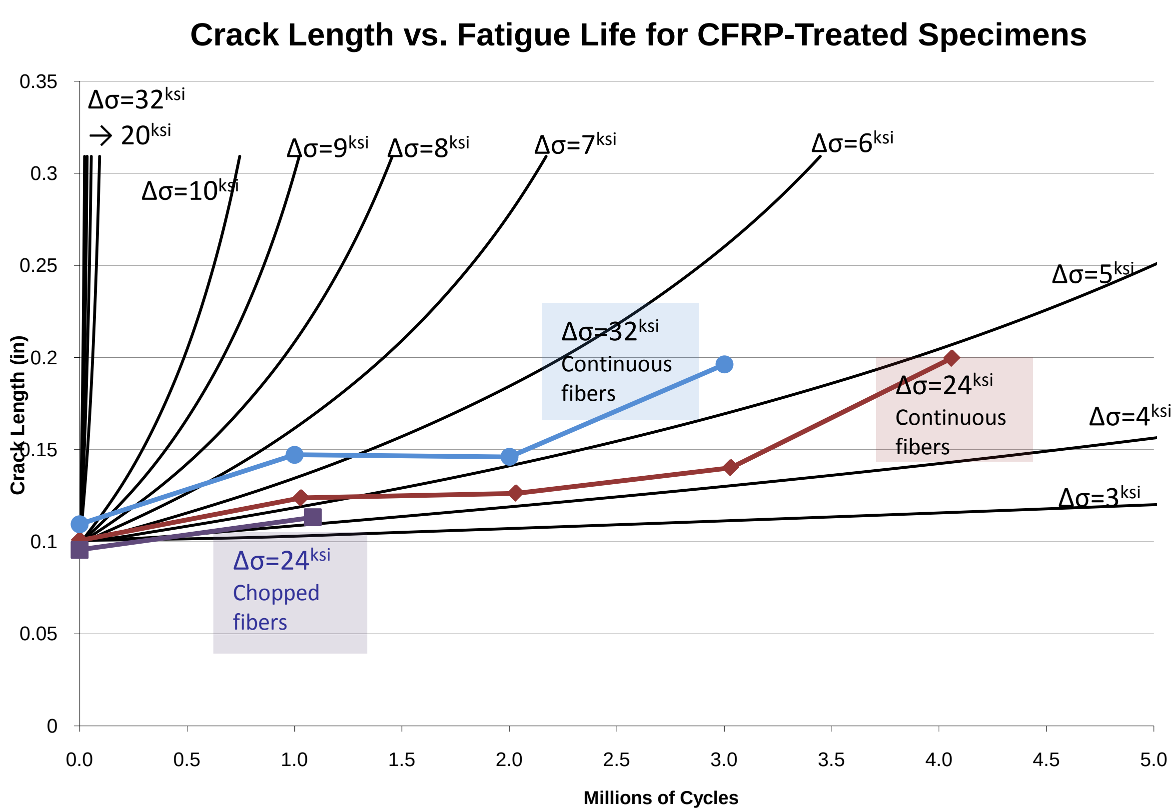

Fig. 9. Plot showing propagation lives of pre-cracked specimens coated with CFRP materials against fracture-mechanics predicted propagation lives for untreated, pre-cracked specimens.

Treatment of Undersized Crack Stop Holes

Twenty 1/4" thick fatigue specimens were fabricated this quarter. These additional specimens will be used to assess effectiveness of the PICK technique when scaled for higher loads and more realistic crack-stop hole geometry. Experimental testing progress slowed this quarter, as both load frames experienced damage and required maintenance. When one of the load frames was operational, tension specimens for 1/4" plate material were tested. The first 1/4" thick control fatigue specimen is currently being tested.

Chamfered tool tips were received from the fabricator, and have been installed in the PICK tool. The intent of chamfering the tool tips is to more uniformly treat the inner surface of the crack-stop holes.

In addition to finite element modeling uniform expansion of crack stop holes as previously reported (June 2009), a finite element model was created to examine interactions between the tool tips, plate, and aluminum plug. The plug-plate-tool interaction was modeled in ABAQUS, a general-purpose finite element program capable of solving nonlinear, large-deflection, plastic analyses. The 3-D model (Figs. 10 and 11) showed that the tool deformed the aluminum plug well into the plastic range, causing the plug to develop a barrel shape as is produced in a standard compression test (Fig. 12). As a result of the lateral expansion of the plug, the inside of the hole was expanded plastically also. However, the hole was not expanded uniformly. As the top and bottom of the plug contracted, the plug no longer contacted the entire surface of the hole. These analytical results corroborated laboratory observations.

The nonuniform expansion of the plug and plate is being corrected by changing the shape of the tip of the tool from a cylinder to a truncated cone. With this new geometry it is thought that the inside of the hole will be uniformly expanded sufficiently into the plastic region of the material's stress-strain curve so that when the plug is removed compressive residual stresses will exist on the inside of the hole.

In the upcoming project quarter, additional fatigue tests of PICK-treated specimens will be performed using the refined version of the PICK tool. Fatigue tests on the 1/4" thick fatigue specimens will be continued. Finite element analyses will be continued, with the goal of better understanding the stress distributions imparted by the refined version of the PICK tool.

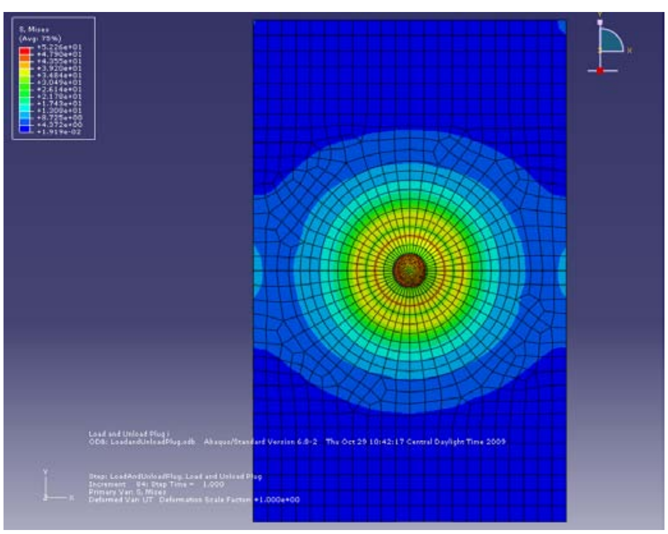

Fig. 10. View of the overall plug-plate-tool interaction model

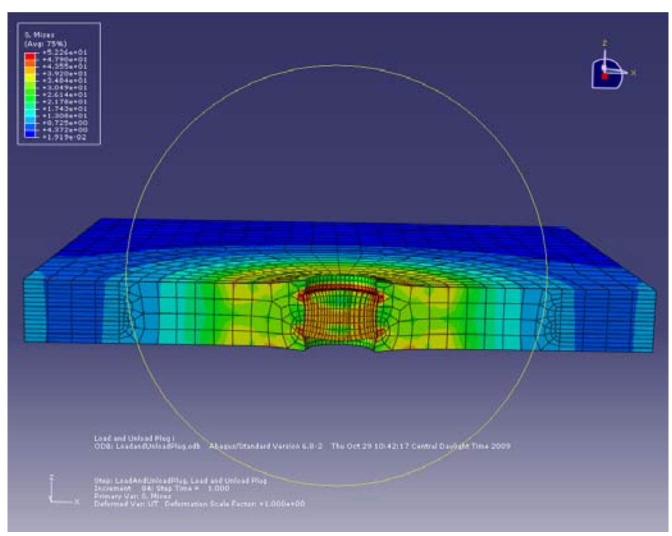

Fig. 11. Section view showing the deformed, treated hole and resulting Von Mises stress distribution

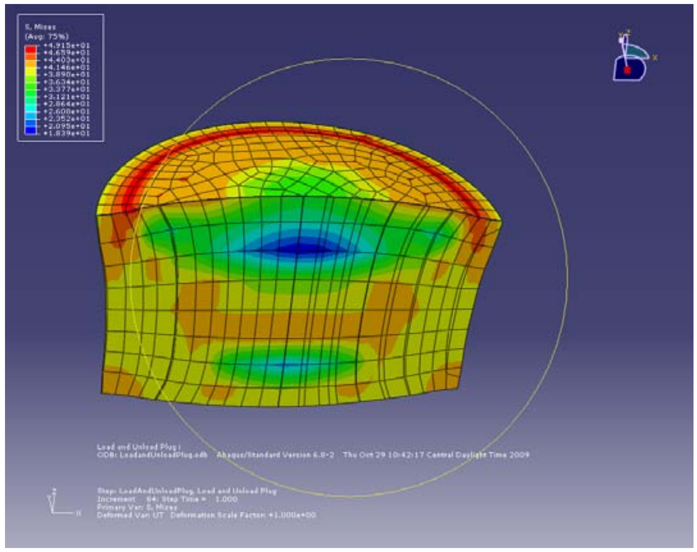

Fig. 12. Section view of the deformed plug

Upcoming Tasks

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

1. Installation of the actuator in the test frame,
2. Final selection of a fabricator to construct the test girders
3. Continued fatigue testing of CFRP-treated specimens (tensile and bending fatigue)
4. Continued fatigue testing of control and experimental specimens to further develop treatment of undersized crack-stop holes.

Conclusion

Meaningful progress was made on Study TPF 5(189) this reporting quarter. The test frame was post-tensioned and the hydraulic pump installed, making the frame ready for the actuator to be suspended. A significant analytical investigation was performed examining different retrofit effects on the performance of the web gap region in the test girder geometry. Fatigue tests performed on cracked tensile specimens treated with CFRP materials showed that the CFRP retrofits significantly extended the propagation lives of the cracked specimens. Finally, a better understanding of the plug-plate-PICK tool interaction behavior was gained by performing a highly nonlinear analysis.

Contact Information

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