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## Stress-State Evaluation of Lateral Braces in Open Deck Steel Girder Bridge at FAST

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### Summary

Steel bridges on some Heavy Axle Load (HAL) routes are being subjected to unprecedented levels of traffic. In less than 2 years, some components of these steel bridges encounter more than 2 million cycles of fatigue, which is a criteria used for the fatigue life design of bridges. This load environment has prompted a review of the current fatigue design criteria for steel bridges subjected to HAL traffic.

Under the Association of American Railroads' Strategic Research Initiative Program, Transportation Technology Center, Inc. (TTCI) is studying the stress state and techniques to extend the life of the steel bridge at the Facility for Accelerated Service Testing (FAST). TTCI measured and analyzed the strains in the bridge members using strain gages and a special test train, which includes 315,000 pound cars.

As a result of this test, the design and rating of steel bridge bracing members under HAL traffic are expected to be reviewed. Also, economical and more reliable bracing repair techniques are expected to evolve. Heavy axle loads and continuing load cycles have particularly increased the maintenance requirements of lateral braces. Today, the repair of bracing members makes up a major portion of the steel bridge maintenance budget. Better design criteria for bracing members will reduce the cost of future maintenance.

This study has led to the following conclusions:

- Bracing members in both spans of the steel bridge at FAST meet the current strength and stability design criteria of AREMA guidelines.
- Stresses computed from measured strains in some bracing members of the steel bridge, especially at or near the midspans, exceeded the fatigue design criteria of current AREMA guidelines. It should be noted that bracing members are not generally designed with any fatigue considerations.
- In addition to direct axial stresses, the bracing members are also subjected to significant bi-axial bending stresses.
- All of the cracks experienced in braces and stiffeners of the steel bridge at FAST appear to have initiated at weld details.
- While the strains in the tension flanges of the tested bridge increased with train speed, the strains in bracing members remained nearly unchanged.
- Finite Element Analysis results conformed to the measured strains, for the most part.

This study only considered vertical wheel loads, impact loads, and lateral loads due to equipment as recommended by AREMA. Strains due to dead load, thermal effects, wind loads, and fabrication were not considered.



**Introduction and Conclusions**

The bridges on some Heavy Axle Load (HAL) routes are being subjected to unprecedented traffic. For example; 30 trains per day, each with 120 286,000-pound cars, may produce more than 200 MGT of traffic and about 1.3 million stress cycles per year on some components of medium span bridges. That means, in less than 2 years, some steel bridge components complete more than 2 million cycles of fatigue, which is a criteria used for the fatigue life design of bridges. This load environment has prompted a review of the current fatigue design criteria of steel bridges subjected to HAL traffic.

Lateral braces are designed for axial loads imparted to the bridge from lateral forces of equipment and wind loads. The current codes of practice ignore the bending stresses in the braces. It is appreciated that rising train speeds and car loads may cause considerable rotation of flanges, unequal deflection of girders, out-of-plane bending of girders, and displacement-induced bending of braces. All of these factors may create significant bending stresses in addition to direct axial stresses.

As compared to the steel bridge at the Facility for Accelerated Service Testing (FAST), the lateral forces imparted to bridges in revenue service can be much higher.<sup>1, 2</sup> This is particularly due to hunting cars, wheelset misalignments, high-impact wheels, steering forces, centrifugal forces, track irregularities, and the lateral component of braking forces.

Both spans of the bridge at FAST experienced numerous cracks. To measure the level of stresses and investigate the cause of cracks in the compression zone, various bracing members were instrumented. The top lateral braces and horizontal members of the diaphragms experienced maximum stresses. This is where most of the cracked and broken braces were observed. The minimum stresses were observed in bottom lateral braces and X-members of the diaphragms. No cracks were noticed in these members.

The bracing member weld details of both the spans are predominantly of fatigue design Category E. The maximum axial stresses for all of the members were lower than the fatigue stress limit of this category. But, the sum of maximum bending and axial stresses of some braces exceeded the limit at 45 mph.

The analytical stress results were conformal to measured strain in tension flanges, but were not conformal to actual strains in some bracing members. Using AREMA design loads in Finite Element (FE) modeling might be a good way to predict axial and bending stresses in braces.

**Bridge Description**

The steel bridge at FAST has two deck plate girder spans: 65- and 55.5-foot spans. All of the members are welded. The braces are of angles or T-sections. Except the horizontal braces that have both legs welded, only one leg of all other braces is welded at the ends. Top and bottom lateral braces are welded to every other opposite stiffener. The bottom lateral braces are connected to gusset plates, which are welded to the web. Top lateral braces are directly welded to the flanges.

The 65-foot span was designed in 1956 for a Cooper E-72 loading with diesel impact. For comparison, the HAL train is equivalent to about an E-56 loading on the main member of this span, although for individual components, this can be higher due to the 79,000 pound axle loads of the test train at FAST. The diaphragms are at 16-foot spacing. All bracing members are 4" X 4" X 1/2" angles.

The 55.5-foot span was designed in 1967 for a Cooper E-72 loading with diesel impact. The HAL train is equivalent to about an E-61 for the main member of this span, although for individual components, this can be higher due to the 79,000 pound axle loads of the test train at FAST. The diaphragms are at 11-foot spacing and all the diaphragm members are of L-Section 5" X 5" X 1/2". Top and bottom lateral braces are ST 6 X 20.4. A moveable bridge joint is at the center of bridge with parts on each span.<sup>3</sup>

**Crack Development History**

Figures 1 a and b show that the 65-foot span was subjected to a higher rate of crack initiation than the 55.5-foot span. This might be attributed to the relatively lower lateral stiffness of the span as well as the different weld details and fabrication practices. It might also be due to the differences in bracing the two spans. The lower lateral stiffness of the 65-foot span, due to greater diaphragm spacing, may have allowed more out-of-plane bending that contributed to initiation of cracks in the regions normally considered as the compression zone. Material fatigue may also be responsible for initiation of cracks.

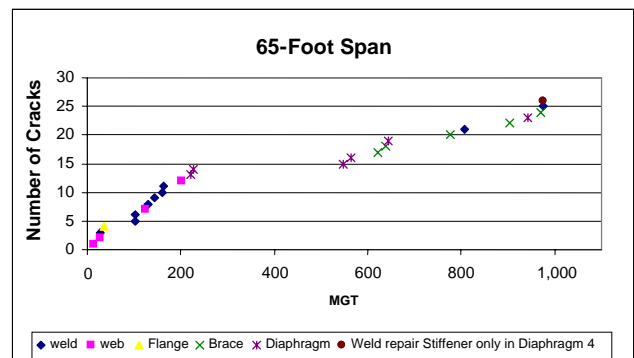


Figure 1a. Crack Development History of the 65-Foot Span

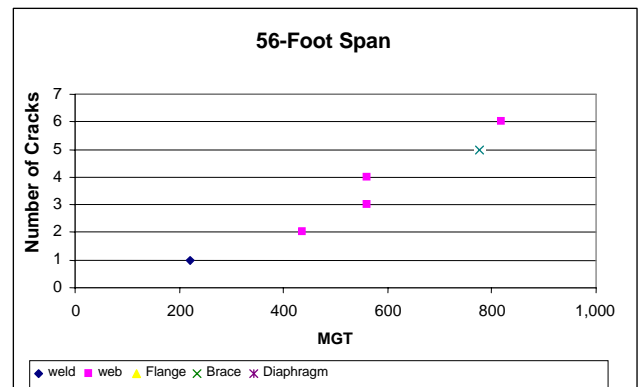


Figure 1b. Crack Development History of the 55.5-Foot Span

The cracked and broken braces were repaired using bolted splice connections and by drilling holes. Figure 2 shows a typical broken lateral brace after bolted repair. Figure 3 shows a stiffener with additional weld metal on cracks.



Figure 2. A Lateral Brace in the 65-Foot Span after Repair



Figure 3. A Stiffener Repaired with Drilled Holes and Additional Weld

## Methodology

The selected members at end and midspan diaphragms of both spans, as shown in Figures 4 and 5, were strain gaged at the following locations:

- Top and bottom lateral braces – x and y bending at ¼ and ½ spans
- Top lateral braces (at mid diaphragm only) – x and y bending at 1 inch from welds
- Horizontal Diaphragm members – x and y bending at ¼ and axial force at ½ spans
- Cross Diaphragm members – x and y bending at 6 inches from connection and axial force at ¼ span

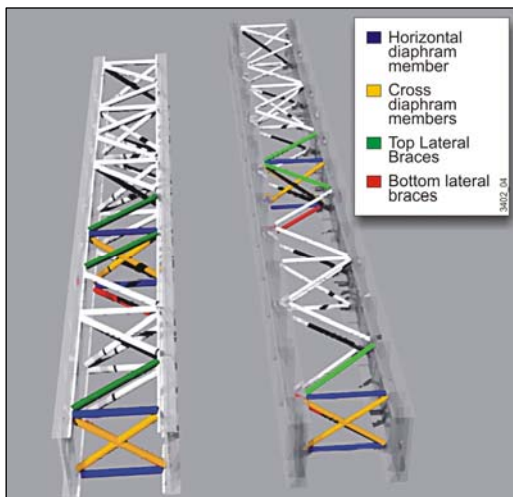


Figure 4. Strain Gaged Members. 65-Foot Span (right) and 55.5-Foot Span (left)



Figure 5. Bending and Axial Circuits at 1/2 Span (left), Bending Strain at 1/4 Span (right)

All of the strain gage circuits were full Wheatstone bridges with compensation for thermal changes. The axial strain gages were installed at the neutral axes of the sections. The bending circuits were installed at 0.75 inch from the edges.

A test train passed at 2 mph in each direction, and then the speed was increased at 5 mph increments starting with 5 mph and ending at 45 mph. The test train had two 4-axle locomotives on each end. The train had two 263-kip and 14 315-kip cars. The train had some flat and out-of-round wheels. One truck had higher vertical loads.

## Combined Stresses

Figures 6 a and b show the combined effect of maximum bending and axial stresses in the instrumented members of both the bridge spans. Some members exceeded the fatigue criteria of Stress Category E members for bridges subjected to more than 2 million cycles. These members were at, or close, to the midspan, where most cracked and broken braces were observed. The bottom lateral braces and cross members experienced the least combined stresses and thus experienced no cracks.

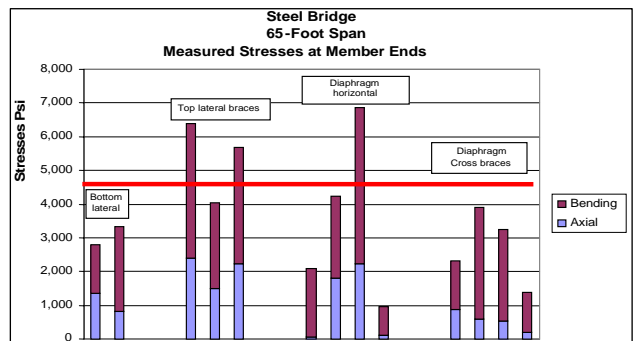


Figure 6a. Measured Axial and Bending Stresses in Lateral Braces and Diaphragm Members for the 65-Foot Span

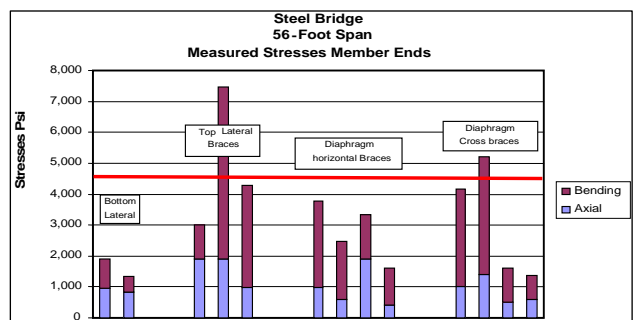


Figure 6b. Measured Axial and Bending Stresses in Lateral Braces and Diaphragm Members for the 55.5-Foot Span

### Finite Element Modeling

Both spans of the bridge were analyzed using the 3-dimensional elastic finite element capability of ANSYS®. The objective was to compare results of stress analysis using AREMA design loads with the measured stresses. The heaviest static axle load arrangement producing the highest moment in the flanges with impact loads was used in the model. In order to replicate car hunting and rocking effects of vehicles, vertical load on one girder was increased by 10 percent and reduced on the other by the same amount.

The flanges, webs, and stiffeners were modeled with shell elements. The lateral braces and diaphragms were modeled with asymmetrical beam elements. These beam elements are capable of evaluating direct axial and biaxial bending stresses.

As shown in Figures 7a and b, the bending strain results in the bottom flange were reasonably close to the measured strains. This is expected. Static flexural analysis of steel members provides reasonably accurate results. The predicted maximum bending and axial stresses in the braces were about 50 percent lower than the measured values. Although the design lateral loads were applied, they may not replicate the actual load the spans experience. The lateral movement of vehicles, track irregularities, and wheel slipping may create additional lateral forces in the braces, which are difficult to model.

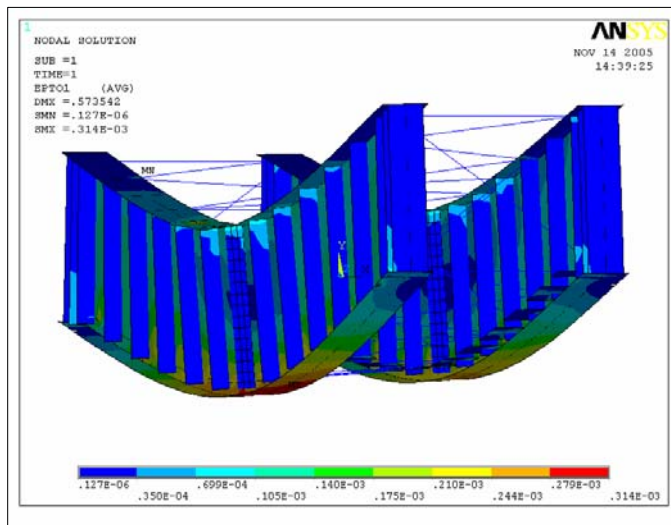


Figure 7a. Strain Contours in Tension Flange

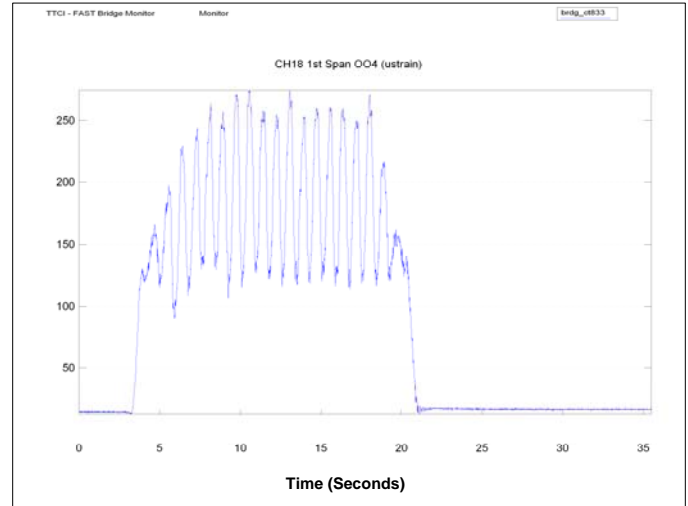


Figure 7b. Measured Strains in Tension Flange

The model was also exercised using the design criteria for bracing members; that is, applying 2.5 percent of compression chord load laterally. This model yielded lower stresses than the model with the design loads.

### Future Work

In order to better understand the behavior of bracing members and develop a possible proposed revision to current AREMA guidelines, the test will be repeated after replacing the bridge joint with smooth rail. The results will then be compared with the current test.

### References

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2. Otter, D., B. Doe, and S. Belpont, January 2005. "Rail Car Lateral Forces for Bridge Design and Rating." *Technology Digest*. TD-05-002. Association of American Railroads, Transportation Technology Center, Inc., Pueblo, CO.
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