

## **Fatigue Assessment of Highway Bridges with K-type Bracing System**

\*Chung C.Fu<sup>1)</sup>, Gengwen Zhao<sup>2)</sup>, Tim Saad<sup>3)</sup>, Yunfeng Zhang<sup>4)</sup>  
and Ed Zhou<sup>5)</sup>

<sup>1),2), 3), 4)</sup> *The Bridge Engineering Software and Technology (BEST) Center, Department of Civil and Environmental Engineering, University of Maryland, College Park, MD, 20742 USA*

<sup>1)</sup> *ccfu@umd.edu*

<sup>5)</sup> *URS Corporation, Germantown, MD, USA*

### **ABSTRACT**

Fatigue-induced cracking is a common failure mode in many steel bridges reaching their original design life. These aging bridge structures have experienced increasing traffic volume and weight, deteriorating components as well as a large number of stress cycles.

This paper studies a case of a currently monitored interstate bridge on fatigue assessment of highway bridges under truck loads. This single span composite steel I-girder bridge with K-type bracing system was numerically studied by 3D global and local finite element models of the bridge. Based on the simulated traffic flow, the statistical dynamic responses such as displacements and stress-ranges of bridge girders were studied for the cause of fatigue cracks of a certain bracing system.

Meanwhile, field long-term monitoring test has also been conducted. Based on the information from field tests, simulated numerical analytical results were verified. Thus, the performance of highway bridges under truck load can be predicted in a more realistic way to estimate the fatigue performance of highway bridges.

### **1. INTRODUCTION**

Intermediate cross-frame diaphragms of composite steel girder bridges can serve two distinct functions. They can (1) brace the girders' compression flanges, and (2) distribute loads among the girders. The truly essential function of traditional cross-frame diaphragms is to stabilize the girders' compression flanges. Many different configurations of cross-frame diaphragms have been employed in the construction of steel plate-girder bridges (Mertz 2001). Generally speaking, there are four (4) types of cross-frames to be selected:

1. X-frame without top chord (X-frame w/o top)
2. X-frame with top and bottom chords (X-frame w/top)
3. K-frame without top chord (K-frame w/o top)
4. K-frame with top chord (K-frame w/top)

The aspect ratio, girder spacing / girder depth, is the key factor in choosing economical crossframeconfiguration. In general, following rule-of-thumb is adopted:

---

<sup>1), 4)</sup> Professor

<sup>2), 3)</sup> Graduate Student

- X-frames good for aspect ratios  $< 1$
- K-frames good for aspect ratios  $> 1.5$
- $1 < \text{Aspect ratio} < 1.5$  - more subjective - client standard details or preferences may control selection of frame type

Transverse connection plates for cross-frame diaphragms, or transverse stiffeners used as connection plates, based on AASHTO LRFD Specification (2012), must be welded or bolted to both the compression and tension flanges of the plate girders for distortion-induced fatigue-cracking considerations. Usually, the connection of the cross-frame members with the plate girder is considered a working point as a truss joint, with the lines of action of the cross-frame members coincident with the junction of the flange and the web.

## 2. FATIGUE CRACKS AND BRIDGE TESTING

Middlebrook Bridge is a simple span structure consisting of 17 welded steel plate girders and carries I-270 with three traffic lanes in the southbound roadway and five traffic lanes in the Northbound roadway (Figure 1 for photo view and Figure 2 for plan view of the bridge with the instrumentation plan). Four fatigue cracks were reported in the June 2011 Bridge Inspection Report, all in the welded connection between the lower end of the diaphragm connection plate and the girder bottom flange. Figures 3 and 4 show two of the four crack locations at G3B2D3(Girder 3 Bay 3 Diaphragm 3) and G4B3D3 (Girder 4 Bay 3 Diaphragm 3) and their sensor placement.

A research project sponsored by the US Department of Transportation's Research and Innovative Technology Administration (RITA), under The Commercial Remote Sensing and Spatial Information (CRS&SI) Technologies Program required a pilot testing bridge to develop and field test a Wireless Integrated Structural Health Monitoring (ISHM) System and Middlebrook Road Bridge with active fatigue cracks was selected and complete pilot testing was performed by using acoustic emission (AE), accelerometer, deflection and strain sensors for bridge information collection. Maximum stress range measured above the diaphragm on girder web in the longitudinal direction is 1.6 ksi due to regular traffic, which is low comparatively. Girder displacement and stress range records due to truck traffic were part of the collection for this study.

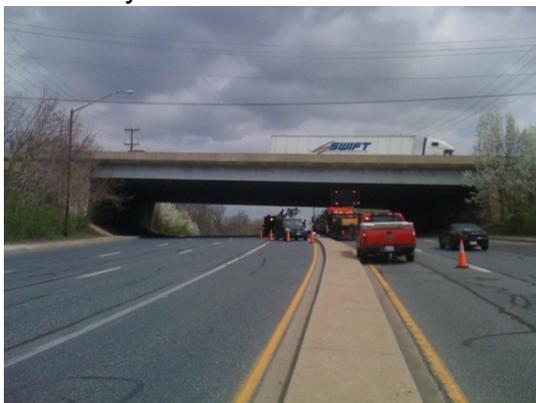


Fig.1 Elevation and close-up views of the Middlebrook Bridge

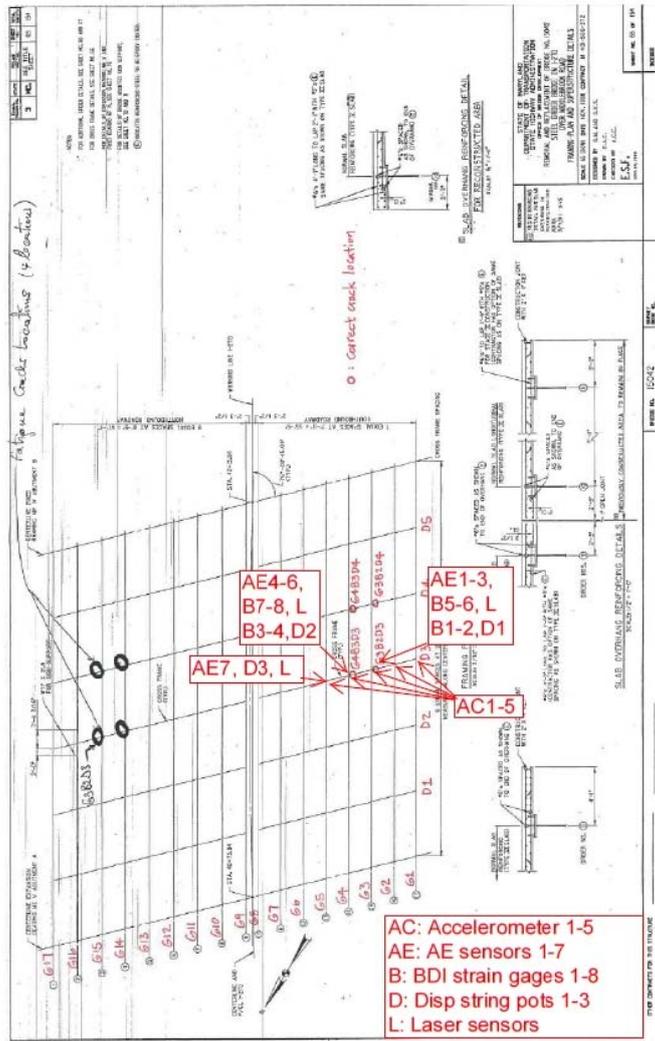


Fig.2 Crack locations and sensor placement on the framing plan

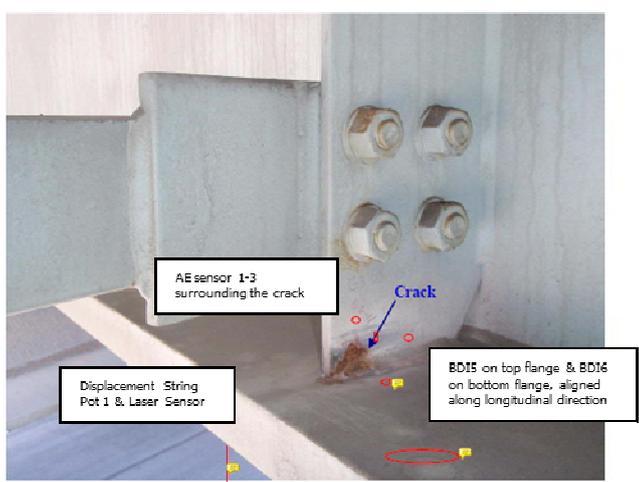


Fig.3 Crack at G3B2D3(Girder 3 Bay 2 Diaphragm 3) and sensor locations

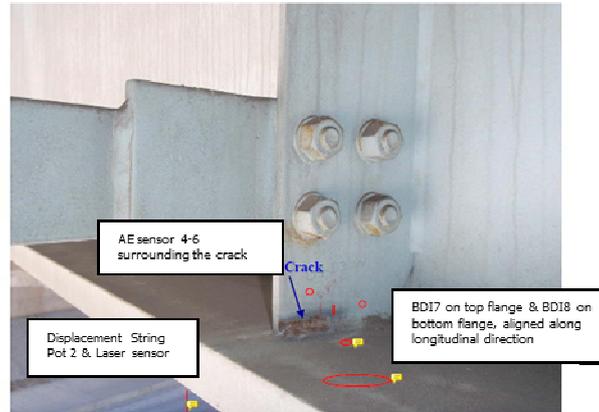


Fig.4 Crack at G4B3D3 (Girder 4 Bay 3 Diaphragm 3) and sensor locations

### 3. FIELD TEST RESULTS

In bridge fatigue evaluation, one key component is to accurately determine the live load-induced stress range. Compared with analytical methods, field test is the most accurate method since no assumptions need to be made for uncertainties in load distribution such as unintended composite action between structural components, contribution of nonstructural members, stiffness of various connections, and behavior of concrete deck in tension. The actual strain histories experienced by bridge components are directly measured by strain gages at the areas of concern. The effects of varying vehicle weights and their random combinations in multiple lanes are also reflected in the measured strains (Zhou 2006).

#### 3.1 Bridge Deflection Monitoring

Both laser sensor and ultrasonic distance sensors were used to measure the dynamic deflection of the bridge. Only one laser sensor and one ultrasonic distance sensor were used each time. The data from laser sensor is shown in Figure 5.

Table.1 Maximum deflection measured by laser sensor

Girder #	3	4	5
MaxD (m)	0.0066	0.0069	0.0063

Note: MaxD=average(Disp)-minimum(Disp)

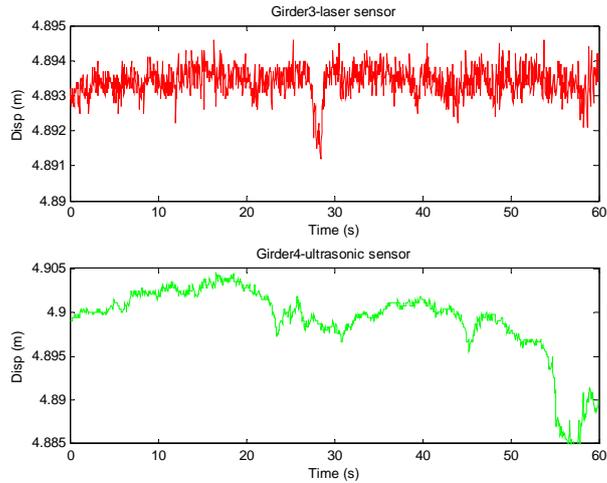


Fig.5 Bridge deflection data by laser sensor (upper) and ultrasonic sensor (lower) (The measured value is the distance between the sensor and girder bottom surface)

### 3.2 String Pots

String pots were placed on girders 3 and 4, synchronized with strain and acoustic emission results (Figure 6). The maximum measurements within the testing period are 0.231" on girder 3 and 0.205" on girder 4, respectively, which are very closed to the laser results, though laser was independently measured. (This short-term measurement is lower than previously measured up to 0.5" or 0.75".)

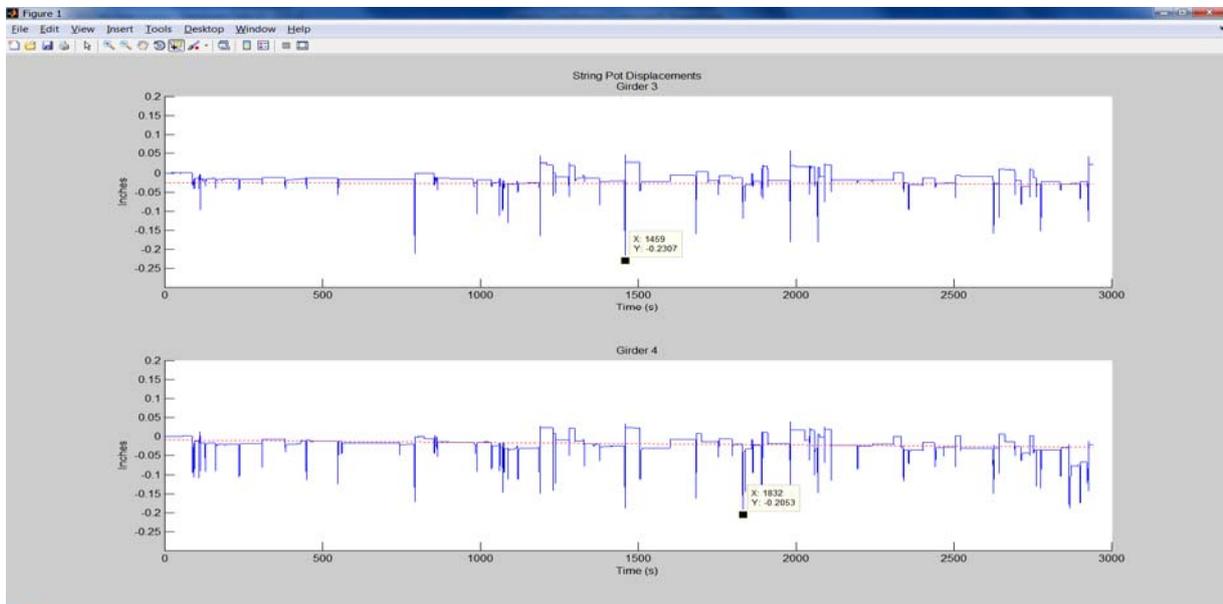


Fig.6 String pot deflection results on girders 3 and 4

### 3.3 BDI Strain Transducers

BDI 1-4 strain transducers were placed on both sides of the connection plates while BDI 5- 8 were placed on the top and bottom flanges on Girders 3 and 4. Figure 7 shows the stresses on the connection plates. As for the connection plates, the

maximum stresses are 16.18 ksi in tension for BDI 1641 on girder 3 and 16.1 ksi in tension for BDI 1644 on girder 4. In comparison, the maximum stress measured on the bottom flange is 1.604 ksi in tension for BDI 3215 on the bottom flange of girder 3.

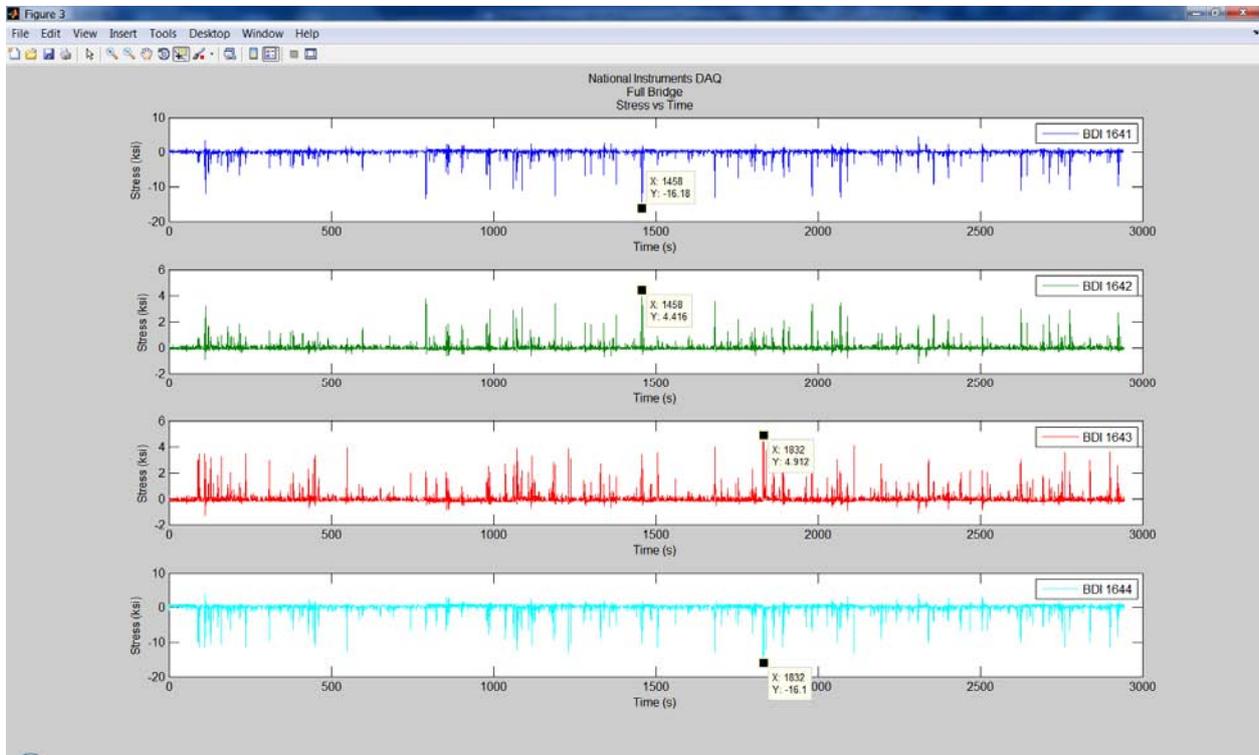


Fig.7 BDI strain transducer connection plate measurements  
(Positive indicates compression; 1641 G3 crack side; 1642 G3 uncrack side, 1643 G4 crack side and 1644 G4 uncrack side)

## 4. FEM SIMULATION

### 4.1 Traffic Data

The traffic data that was used to simulate traffic flow is the time varying vehicle count data from Internet Traffic Monitoring System operated by Maryland Department of Transportation State Highway Administration. The simulation procedure could be summarized in four steps. (1) Build the simulation network in TSIS 5.1 around the MD Bridge No. 1504200 I-270 over Middlebrook Road based on the background map obtained from Google Map. (2) Use the time varying vehicle count data collected from nearby detectors as the input data for the simulation model. The truck count data is converted to truck percentage. (3) Install three loop detectors at the bridge in the created simulation network, one for each lane in order to record the speed, type and passage time of the detected vehicles. (4) Run the simulation. The passage time, speed and lane occurred of trucks could be recorded, just like virtual WIM data.

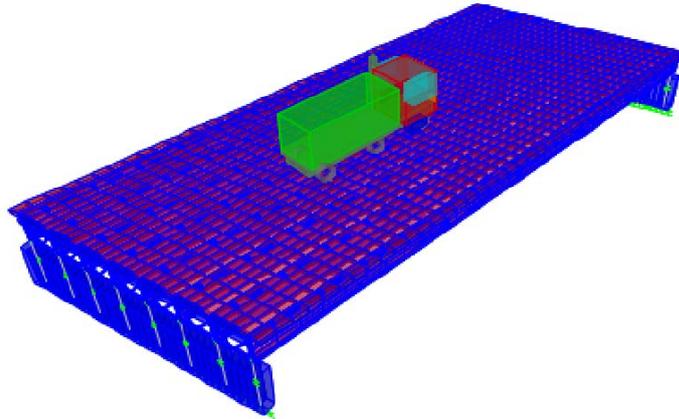


Fig.8 Bridge under Traffic Loading

#### 4.2 Finite Element Model

To simulate the bridge behavior under traffic load, global and local models were built where global model was used to monitor the global behavior and stresses near the crack area while local model was used finding the stress concentration factor (SCF) at the exact crack location, or called hot spot.

Global Model-Once the truck information is collected, it can be converted to truck loading and will be simulated to the bridge model by the CSiBridge program. As part of the results, Figure 9 shows the time history curves of two hot spots of the connection plate, located at Girder 3 Diaphragm 3. Shell element 252 is on the G3 crack side, and shell element 250 is on G3 uncrack side. Both of them are on the same face. As an example of the graphic results, Figure 10 show a zoom-in stress contour of connection plates on Girder 4 Diaphragm 3 at T=283second.

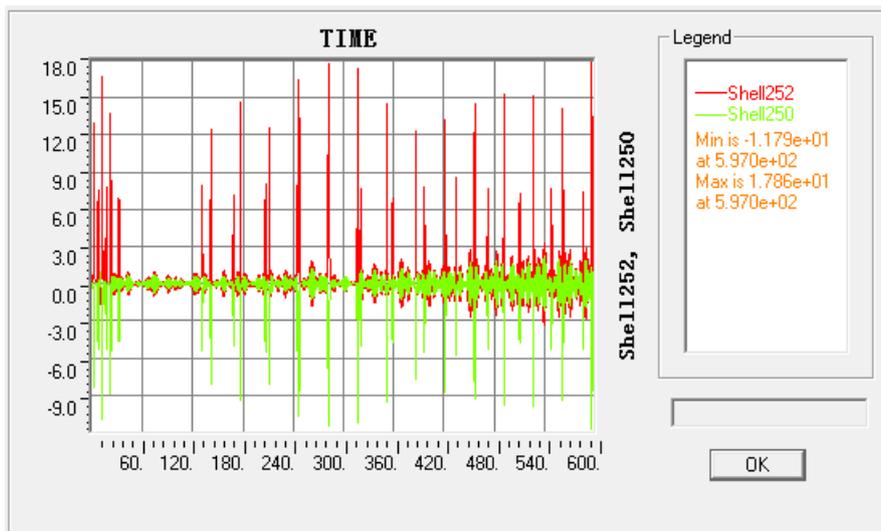


Fig.9 Stress of Hot Spot (Shell252-G3crack side, shell250-G3uncrack side)  
unit-ksi

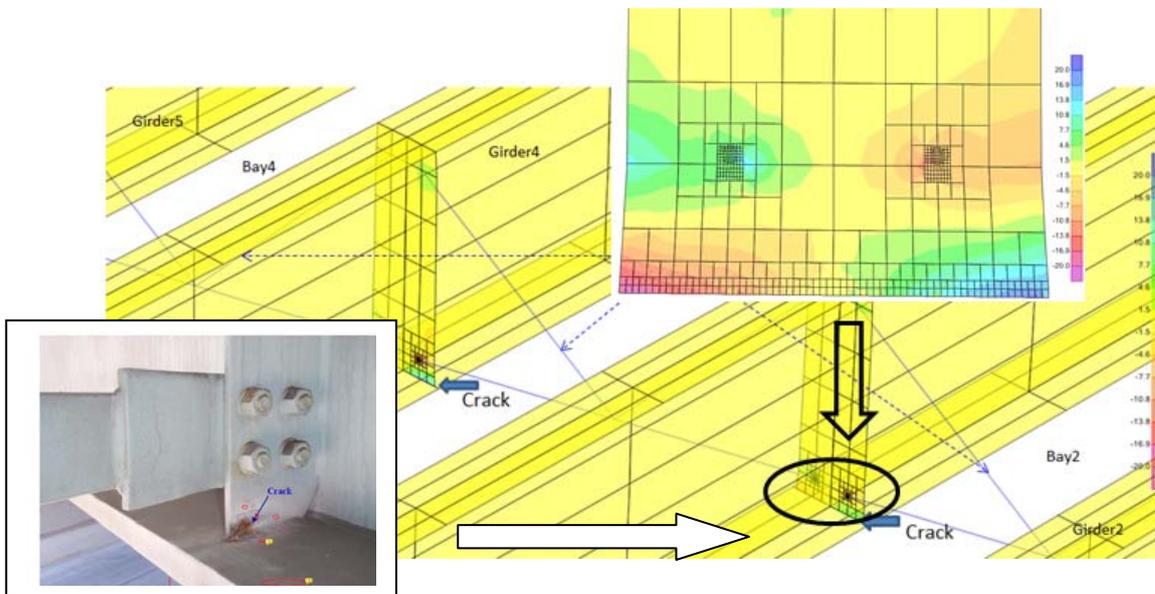


Fig.10 Zoom-in Stress Contour of Connection Plate (Girder 3 Diaphragm 3) at T=597second

Local Model-For a typical K-type cross frame, Figure 11 shows the finite element local model in SAP 2000. The model and its results are summarized below:

- 1) Local Model – portion of girder with K-type crossframes on both sides (Figure 12)
- 2) Boundary condition - pin supported (Figure 12)
- 3) Loading - 0.2in downward displacement on the left end and 0.4in upward displacement at the right end were applied (Figure 12)
- 4) Maximum stress around bottom chord and connection plate connection (Figure 13)

Compressive stress -1.7ksi on the left connection plate and tensile stress +4.07ksi on the right connection plate are shown in this model.

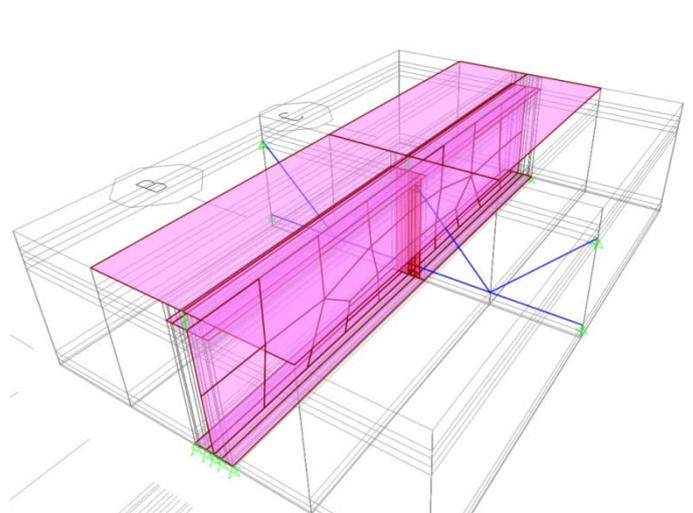


Fig.11 Local model at mid span girder three

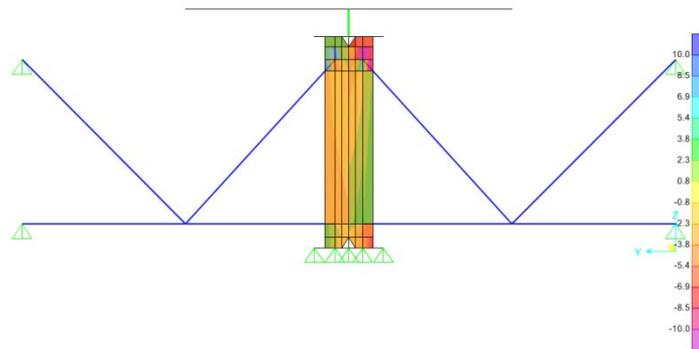


Fig.12 Local model stress contour on connection plate

## 5. CONCLUSION

It can be concluded that among all types of cross-frames, X-type with top and bottom chords is the stiffest of all, then the K-type with top and bottom chords, then the X-type with bottom only and the flexible one is the K-type with bottom chord only. Differential displacement between girders will cause one diagonal in tension and one in compression. Since the working point of the diagonal is not at the junction of girder web and top flange plus no help from the top chord, one side of the connection plate will be under tension and one under compression. Measured 16.1 ksi in tension is not surprising with the flexibility of the cross-frame and the girder system (with up to 0.5" to 0.75" vertical deflections due to live load observed.) Fatigue cracks is inevitable on the tension side of the connection plate with differential girder displacement.

## ACKNOWLEDGEMENT

The work is partially supported through a research grant from the US Department of Transportation's RITA Program (Grant No. RITARS11HUMD; Program Director: Caesar Singh) with professional assistance from Maryland State Highway Administration. However, the opinions and conclusions expressed in this paper are solely those of the writers and do not necessarily reflect the views of the sponsors.

## REFERENCES

- AASHTO LRFD Bridge Design Specifications, 6<sup>th</sup> Ed. (2012), American Association of State Highway and Transportation Officials (AASHTO), Washington, D.C.
- CSI Bridge (2010), *Integrated 3D Bridge Design Software*, Computer and Structures, Inc., Berkeley, CA.
- Mertz, D. R. (2001), *Designers' Guide to Cross-Frame Diaphragms*, American Iron and Steel Institute.
- SAP2000, C. S. I., (2007), *Integrated software for structural analysis & design*, Computer and Structures, Inc., Berkeley, CA.
- Zhou, Y.E. (2006), "Assessment of bridge remaining fatigue life through field strain measurement." *Journal of Bridge Engineering (ASCE)*, Vol. 11(6), 737-744.