INVESTIGATION OF FATIGUE-INDUCED CRACK WITH K-TYPE BRACING SYSTEM

by Chung C. Fu, Gengwen Zhao, Tim Saad & Yunfeng Zhang (UMD) and Y. Edward Zhou (URS)

Chung C. Fu, Ph.D., P.E.
University of Maryland, College Park, MD

Presented to
Istanbul Bridge Conference
August 11th ~ 13th, Istanbul, Turkey 2014
OUTLINE

• Introduction
• Fatigue cracks and bridge testing
• Filed test results
• Finite element model simulation
Distinct functions of intermediate cross-frame diaphragms of composite steel girder bridges

- Brace the girder’s compression flanges
- Distribute loads among girders
- Stabilize the girder’s
IN T R O D U C T I O N

C o n f i g u r a t i o n s o f c r o s s - f r a m e d i a p h r a g m s

• X-f r a m e w i t h o u t t o p c h o r d (X- f r a m e w / o t o p )

• X-f r a m e w i t h t o p a n d b o t t o m c h o r d s (X- f r a m e w / t o p )

• K - f r a m e w i t h o u t t o p c h o r d (K - f r a m e w / o t o p )

• K - f r a m e w i t h t o p a n d b o t t o m c h o r d s (K - f r a m e w / t o p )
Test Bridge - Middlebrook Bridge

- A single-span composite steel girder bridge with a span length of 46.76 m (140 ft)
- Consist of 17 welded steel plate girders
- Carry I-270 with 3 traffic lanes in the Southbound roadway (research subject)
Fatigue Cracks

- 4 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
Wireless Integrated Structural Health Monitoring (ISHM) System (sponsored by USDOT/RITA)

- Remote sensing capability
- Piezoelectric acoustic emission (AE) sensors
- Wind and solar based energy harvesting devices to power sensor network
FIELD TEST RESULTS

Bridge Deflection Monitoring

Both laser and ultrasonic distance sensors were used to measure the dynamic vertical deflections of the girder bottom flange. Only one laser sensor and one ultrasonic distance sensor were used.

<table>
<thead>
<tr>
<th>Girder Number</th>
<th>Maximum Deflection (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>0.0066</td>
</tr>
<tr>
<td>4</td>
<td>0.0069</td>
</tr>
<tr>
<td>5</td>
<td>0.0063</td>
</tr>
</tbody>
</table>
FIELD TEST RESULTS

String Pots

String pots were placed on Girders 3 and 4, synchronized with strain and acoustic emission. The maximum measurements within the testing period are 5.867 mm on Girdar 3 and 5.205 mm on Girdar 4, respectively.
FIELD TEST RESULTS

Strain Transducers

BDI 1-4 strain transducers were placed in the vertical direction on the connection plate on both sides of girder web while BDI 5-8 were placed in the longitudinal direction on the top and bottom flanges of Girder 3 and 4.

As for the connection plates, the maximum measured stresses are 111.557 MPa (16.18 ksi) in tension on Girder 3 and 111.006 MPa (16.1 ksi) in tension on Girder 4. In comparison, the maximum stress measured on the girder bottom...
FIELD TEST RESULTS
FINITE ELEMENT MODEL SIMULATION

Truck Loading

- Collect data from Hyattstown Weigh and Inspection Station and Maryland Internet Traffic Monitoring System (axle number/weight/spacing)

- Generate three types of fatigue trucks

- Use traffic commercial software (CORSIM-TSIS) to simulate real traffic

- Select the truck information from convert it to truck loading
FINITE ELEMENT MODEL SIMULATION

Three types of fatigue trucks:

2-Axle Truck Model

5-Axle Truck Model

6-Axle Truck Model
Finite Element Model Simulation

Traffic Simulation

Animation Results
Finite Element Model

- A 3D global model of the Southbound consisting of eight I-girders was generated by CSiBridge.
- The concrete deck, the eight I-girders, and connection plates were modeled by shell elements.
- The bridge diaphragms are inverted K-type braces with only bottom chords. All of them are.

<table>
<thead>
<tr>
<th>Mode Number</th>
<th>Field Test</th>
<th>CSiBridge</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.22</td>
<td>3.2451</td>
</tr>
<tr>
<td>2</td>
<td>5.5598</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>7.1363</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>7.805</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>8.4718</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>9.7479</td>
<td></td>
</tr>
</tbody>
</table>
Results

- The vertical stress near the welded edges of connection plates follows the same pattern; the western sides of the connection plates are under tension, and the eastern sides of the connection plates are under compression. Time history curves of vertical stress at the lower end of cross plating connection plate, located at Girder 3 Diaphragm 3. Shell element 252 is at the lower end of connection plate on the G3 cracked
A zoom-in vertical stress contour of connection plates on Girder 3 Diaphragm 3 at T-283
Connection Plates Configuration

- Skew (right) and non-skew (left)

Connection plates were parallel to the cross frames with the same angle of 76°

Connection plates were normal to the girders
The K-type bracing system was modeled for studying the influence of bracing system configuration on the stress distribution of connection plates. The cross section of diagonal and bottom chords employed for the K-frame with top chord (right) and K-frame without top chord (left).
## Bracing System Configuration

- Maximum vertical stress and axial force

<table>
<thead>
<tr>
<th>Connection plates configuration</th>
<th>Bracing system configuration</th>
<th>Max axial force (kip)</th>
<th>Max vertical stress of crack location (ksi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-skew connection plats</td>
<td>K-frame without top chord</td>
<td>-</td>
<td>13.50</td>
</tr>
<tr>
<td></td>
<td>K-frame with top chord</td>
<td>3.47</td>
<td>12.66</td>
</tr>
<tr>
<td>Skew connection plats</td>
<td>K-frame without top chord</td>
<td>-</td>
<td>0.33</td>
</tr>
<tr>
<td></td>
<td>K-frame with top chord</td>
<td>1.12</td>
<td>0.30</td>
</tr>
</tbody>
</table>
C O N C L U S I O N S

• Differential displacements between girders cause one diagonal in tension and one in compression. Since the working point of the diagonal is not at the junction of girders 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 under live load.

• Measured vertical tensile stresses up to 16.1 ksi in the connection plate explains why fatigue cracks have occurred at their connections to the girder bottom flange. Girders 3 and 4 are under the slow moving lane where most heavy trucks are using while Girders 1 and 2 support a shoulder and thus large differential deflections occurred between Girders 2 and 3 (with up to 0.5" to 0.75" vertical deflections due to live load observed).

• The connection plate configuration is a key factor for the stress distribution of the connection plates.
Acknowledgments

The work is partially supported through a research grant from the US Department of Transportation’s RITA Program (Grant No. RITARRS11HUMD; 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.