Monitoring and Evaluation of a Plate Girder Bridge

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ABSTRACT

Many of Iowa's multiple steel girder bridges are experiencing fatigue cracking of the girder webs at diaphragm connections. The state, along with Iowa State University, has been investigating a retrofit method involving bolt loosening in the diaphragm/girder connection. Testing of this retrofit has included continuous monitoring of a demonstration bridge to assess the impact of the retrofit over an extended period of time.

A continuous monitoring system was designed and installed at a bridge site and connected to instrumentation to monitor the bridge's response to the retrofit. Electrical and telephone utilities were installed at the site to power the unit and to allow for remote control of the system with data transfer capabilities. The data collection software was fully programmable and could be adjusted and reprogrammed as needed. The data downloaded from the system were used to determine the effectiveness and stability of the retrofit over an extended period of time.

The continuous monitoring testing was a pilot project for health monitoring bridges in Iowa. The developed data acquisition system can be easily adapted to a variety of remote monitoring applications. The robustness of the system and its ability to be controlled remotely make it a useful tool for future remote monitoring activities.

Key words: continuous monitoring— fatigue—girder bridges—retrofit—web gap

INTRODUCTION

Bridge 4048.2S017, shown in Fig. 1, is a three span bridge crossing the Boone River on Highway 17 in central Iowa. As shown in Fig. 2, the end spans are 29.7 m and the interior span is 38.1 m. The girders are labeled as G1 to G5 and the diaphragms in each span are labeled as D0 to D5. The bridge has five main plate girders with an integral concrete deck as shown in Fig. 3. The 1.5 m deep girders are connected by X-type diaphragms every 6.1 m. A visual inspection revealed no fatigue cracking in the girder webs near the connections to the diaphragms. However, many multiple steel girder bridges with this diaphragm connection detail in Iowa have experienced cracking in that region.

FIGURE 1. Photographs of Bridge Deck and Profile

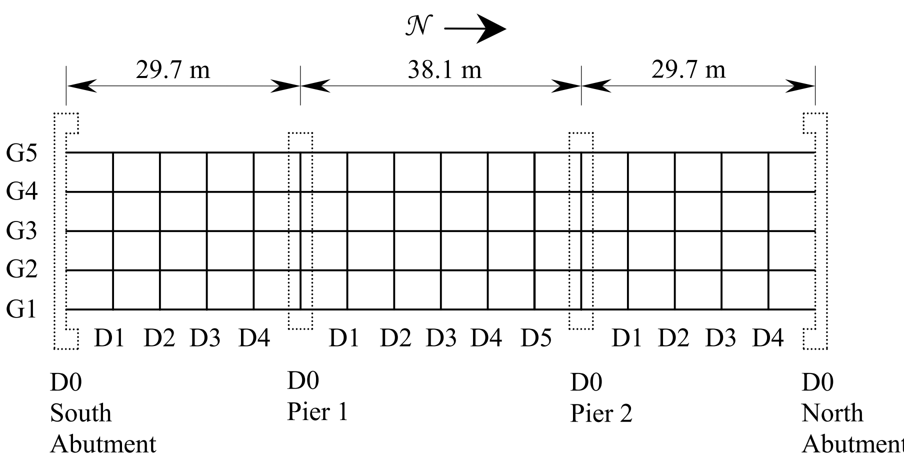

FIGURE 2. Plan View Illustration of Superstructure

The bridge was selected for study because visual inspections have not yet identified signs of fatigue cracking in the web. A bolt loosening retrofit designed to eliminate web cracking was installed on the bridge [1,2,3]. The retrofit consists of loosening bolts connecting the negative moment diaphragms to the main girders. Ambient truck loading behavior data (i.e. web strain, out-of-plane displacement, etc.) were collected over several months before and after installing the retrofit to study the effectiveness and stability of the retrofit.

The on-site remote monitoring system was constructed from off the shelf components to record data from the bridge. The stand alone Data Acquisition System (DAS) was used in conjunction with strain, displacement, and temperature sensors to monitor the bridge continuously. The system was controlled remotely and relayed data back to the laboratory for reduction and interpretation. Data were collected only when significant loading was present on the bridge to save storage space and to simplify analysis.

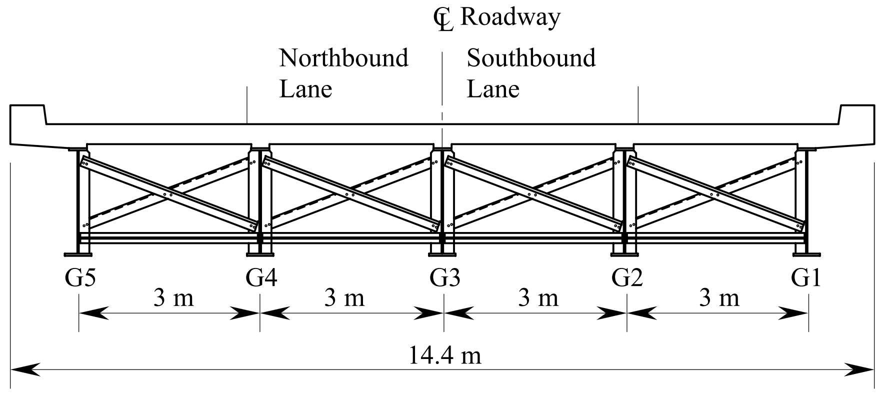

FIGURE 3. Illustration of Bridge Cross Section at Negative Moment Diaphragm

DESCRIPTION OF PROBLEM

Many existing steel girder bridges in Iowa had the same connection design between the diaphragms and webs. Fatigue cracking has occurred in the web gaps of this design, especially in the negative moment region, because the stiffener is not attached to the girder top flange which allows out-of-place distortion. The web gap is defined as the region of the web between the top flange fillet weld and the stiffener weld and is typically only an inch in length in the vertical direction. Typically the cracks found in this region are horizontal, parallel to the top flange, and extend up to a few inches away on either side of the web gap.

The Iowa Department of Transportation (DOT) has attempted to control the cracking in the web gaps by drilling holes at the crack tips to reduce the stress intensity factor [4,5]. The hole drilling technique has not always proved successful and cracking has continued past the holes in some cases. Cracking past the drilled holes can be caused by inaccurate placement of the hole with respect to the crack tip, or by stresses high enough to continue crack propagation.

Fatigue cracking in the web gap is a result of differential deflection of the adjacent girders due to asymmetric traffic loading on the bridge deck. As vehicles cross a bridge, the adjacent girders deflect differently at the same cross section and the diaphragms between the girders are distorted. This is especially true on bridges with skewed piers. Forces created in the diaphragms cause a rotation at the connection between the girder and the diaphragms. The force is transferred to the girder by the web stiffener, which causes the web gap to displace out-of-plane. The stiffener pulls at the web, but the top flange, being integral with the deck, resists movement and the result is out-of-plane displacement as illustrated in Fig. 4. Continued cycles of this out-of-plane displacement result in fatigue cracking in the web gap. Exterior girders are especially prone to fatigue cracking because, unlike interior girders, they do not have a diaphragm on both sides of the girder to oppose the out-of-plane forces.

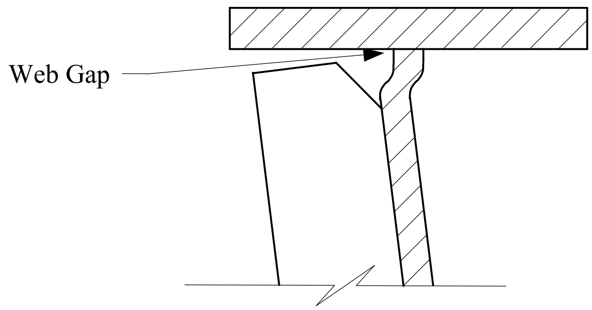

FIGURE 4. Out-of-plane Distortion in Web Gap

SYSTEM DESCRIPTION AND USE

A Campbell Scientific CR 9000 was selected as the base for the remote continuous monitoring data collection system. The system was set up in an environmental enclosure on Pier 2, which provided the system protection from the weather and vandalism as shown in Fig. 5. The system has an input capacity of 24 channels with further expansion possible. Thermocouples, strain gages, and displacement transducers were used in this study, but the system is capable of supporting many different sensor types. Instrumentation was focused at a diaphragm in the negative moment region near Pier 2 as illustrated in Fig. 6.

Four thermocouples were used to monitor the bridge steel temperature, the temperature in the enclosure, and the ambient temperature. These sensors were the standard K type thermocouples.

Two gradient strain gages were installed in the G1 and G2 web gaps as shown in Fig. 7. These gradient gages consist of five small, foil backed strain gages placed within the web gap to collect a detailed strain profile. For this study the strain in the web gap was the most important indicator of the effectiveness of the retrofit.

FIGURE 5. Photographs of Environmental Enclosure and CR 9000

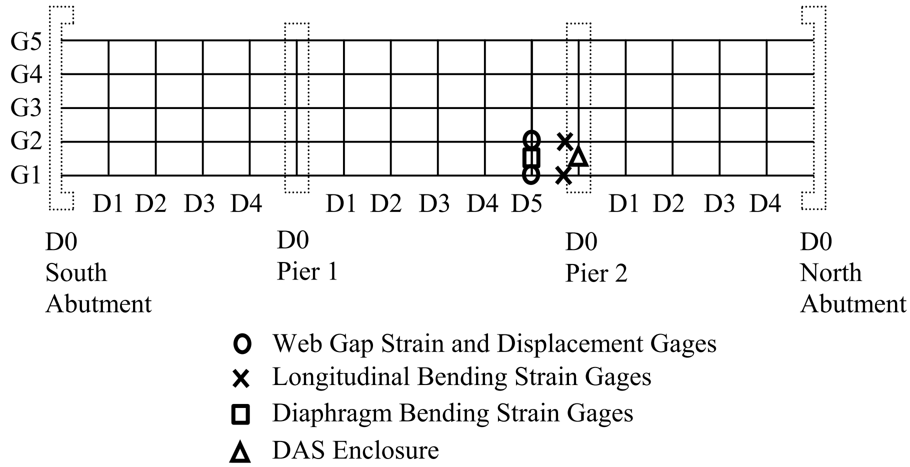

FIGURE 6. Illustration of Instrumentation Locations on the Superstructure

Three weldable strain gages were mounted on the diaphragm members between G1 and G2 as pictured in Fig. 7. The gages were encased in plastic to provide protection from the environment.

Four Direct Current Displacement Transducers (DCDT) were installed at the stiffener connection of D5. Two were placed on G1 and two were placed on G2 as shown in Fig. 8. One transducer measured out-of-plane displacement of the web gap and the other measured vertical movement of the flange relative to the stiffener. Out-of-plane displacement of the web was indicated by the change in horizontal position of the stiffener with respect to the top flange, which was integral with the deck. The out-of-plane displacement of the web is an indicator similar to the strain in the web gap of the effectiveness of the retrofit.

Two weldable strain gages were also used to measure the strain in the bottom flange of G1 and G2 at 0.9 m from the bearing at Pier 2 as pictured in Fig. 8. The strain in the girders reflects the global effect the retrofit has on the bridge and was also used as a trigger for the DAS as described below.

FIGURE 7. Photographs of Diaphragm and Web Gap Strain Gages

FIGURE 8. Photographs of Longitudinal Strain Gages and Out-Of-Plane Transducers

The DAS collected data in a unique manner. The system monitored the bridge continuously and stored approximately 20 minutes of data in temporary memory. These data were not used in the analysis. As more data was collected it recorded over the previously recorded data to update the temporary memory. In order for the system to record data to its permanent memory the data had to be considered useful to analysis. A trigger threshold, which reflected the magnitude of the load, had to be reached by a selected input channel. In this case, a strain gage on the bottom flange of G2 was used as the trigger channel. The system was programmed to recognize any value greater than 20 microstrain in the bottom flange to be a truck of notable size at which time the data was recorded to the permanent memory. Eight seconds of data prior to the trigger value being reached and eight seconds after were stored permanently, allowing the event to include all data involving the trigger load crossing the bridge.

The data stored in the permanent memory of the DAS were retrievable via modem connection. All parameters involving control of the unit were also accessible through the modem connection. Data collection programs could be uploaded to the unit and turned off and on remotely. The system was also capable of generating real time plots of data so that important channels could be visibly monitored if needed.

Data generated by Iowa DOT load trucks of known weight and dimension were recorded with and without the retrofit in place. These load trucks were used as base line data for evaluating the ambient data. The 20 microstrain trigger threshold was determined using the DOT load truck data so trucks of similar loading could be collected. Twenty microstrain is equivalent to a truck weighing approximately 22,680 kg, which is the loading of the DOT trucks.

Four months of ambient data were collected with the bolts in the tight condition (no retrofit) and another four months were collected with the bolts in the loose condition (retrofit installed). The four months of data were used to evaluate the effectiveness of the retrofit over an extended period of time following implementation.

RESULTS

Typical plots of the 16 seconds of data for the DOT trucks are shown in Fig. 9 before and after implementation of the retrofit. The DOT load trucks showed a substantial (nearly 90 percent) reduction in strain in the G1 web gap following implementation of the retrofit. Other sensors in the web gap region also showed similar reductions with the exception of the bottom flange strain in the girders. The girder strain showed very little change due to implementation of the retrofit, and because of this the bottom flange strain was useful as a trigger.

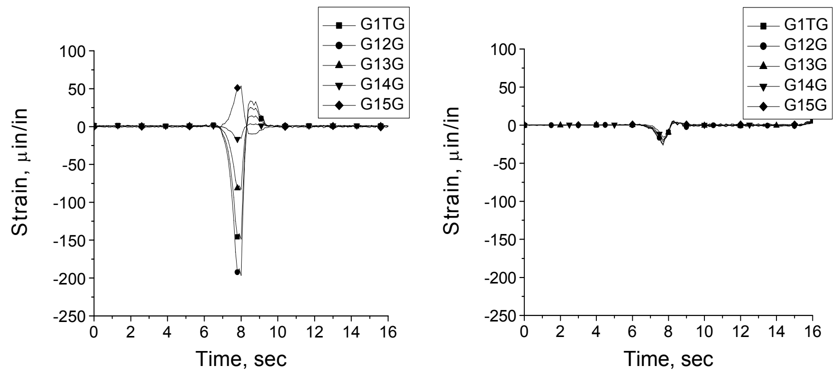

FIGURE 9. Web gap Strain Vs. Time Plots before and after the Retrofit

The girder strain showed very little change after implementation of the retrofit so that the bottom flange strain was useful as a trigger. The strain in the girders during the DOT truck loading was similar with and without the retrofit, about 20 microstrain as shown in Fig. 10, even thought the trucks were of slightly different weights. To correct for the difference in weight the plots from before the retrofit were normalized to represent equal loads of approximately 22680 kg in both tests. The longitudinal strain was used to identify load size of ambient trucks before and after the retrofit was installed.

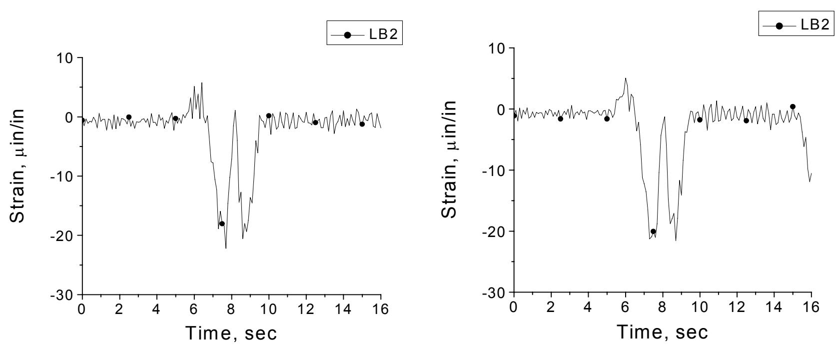

FIGURE 10. Longitudinal strain vs. time plots before and after the retrofit

A sample ambient truck similar to the DOT load trucks as far as causing similar longitudinal strain patterns and peak strains was selected for each of the four months before and after the retrofit was implemented. The longitudinal strain and web gap strain for each of these trucks is plotted in Fig. 11. Web gap strains for each of these trucks and the DOT trucks are similar both before and after the retrofit was implemented suggesting that the reduction in web gap strain does not change over time.

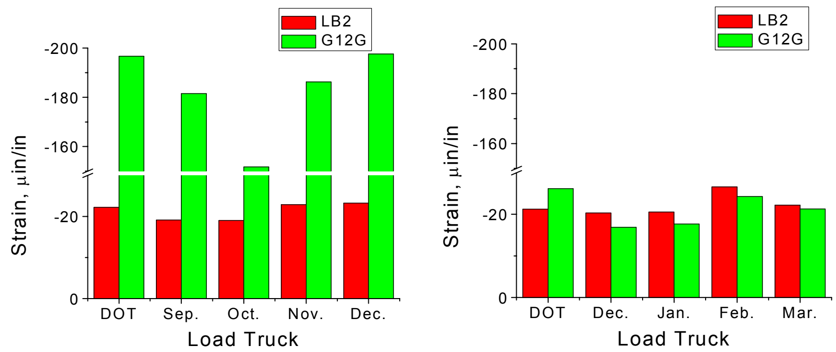

FIGURE 11. Long Term Web Gap and Longitudinal Strain before and after the Retrofit

CONCLUSION

The results of the testing show that the strain in the web gap is significantly reduced with the implementation of the bolt loosening retrofit. The exterior girder web gaps show the greatest reductions, but all web gap and diaphragm instrumentation showed reductions of over 50 percent.

The long term testing program revealed that the overall results (the peak strain and displacement associated with a loading) did not change over time when the retrofit was implemented. This suggests that the retrofit will be effective in reducing or eliminating fatigue cracking in the web gap and the effectiveness will not deteriorate over time.

The long term data from ambient loading also highlights the performance of the DAS. The system continuously recorded the needed data for analysis of the retrofit and withstood the rigors of on-site installation. The ability of the system to be controlled remotely saved time when data downloads or new program uploads were needed. The system segmented the truck loadings so the files could be input into a spreadsheet program as separate events. The system also counted the number of events since the last download and showed basic statistics on the data. The capabilities of the Campbell Scientific CR 9000 were instrumental in the completion of this project.

The DAS had other untapped uses that were not employed on this project. The software could be programmed to collect only peak values, instead of timed quantities of data surrounding a trigger. The peaks could be set up in a statistical analysis of traffic crossing the bridge by the system as it collects the data. This would provide an easily accessible overview of how many different size trucks crossed the bridge and the strain in the web gap, or damage, they caused.

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The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Iowa Department of Transportation.

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