Retrofit Solution for Out-of-Plane Distortion of X-Type Diaphragm Bridges

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Some of the Iowa Department of Transportation's (Iowa DOT) welded continuous steel plate girder bridges have developed cracks in the negative moment regions at the web gaps with diaphragm connection plates. A method to prevent cracking in bridges with X-type or K-type diaphragms had been suggested by the Iowa DOT, which consists of loosening the bolts in some of the connections between the diaphragm diagonals and the connection plates. The objective of the paper is to investigate the effectiveness of this method in X-type diaphragm bridges. The research was sponsored by and performed in cooperation with the Iowa DOT. The experimental investigation included selecting and testing three bridges: two skew and one non-skew. The finite element method was used to choose the testing locations at which strain gages and displacement transducers were attached. The response at these locations was collected before and after implementing the method. Bridges were subjected to truck loading in different lanes with different speeds. The preliminary results show that the behavior of the web gaps in X-type diaphragm bridges was greatly enhanced by the suggested method as the stress range and out-of-plane distortion were reduced by at least 42% at exterior girders. Based on the results of the study, it is recommended to implement the method in bridges with X-type diaphragms. Key words: out-of-plane distortion, fatigue, plate girder bridge, cracking, diaphragm connections.

INTRODUCTION

A number of localized failures have developed in steel bridge components due to fatigue during the past several decades. Some of these have resulted in brittle fracture. Out-of-plane distortions in a small gap at the diaphragm connection plates are the cause of the largest category of cracking in steel bridges (*1*). The problem has developed in different types of bridges, including suspension bridges, girder floor beam bridges, multiple girder bridges, tied arch bridges, and box girder bridges.

Figure 1 shows a schematic of the out-of-plane distortion at the end of transverse diaphragm connection plates in plate girder bridges. Under typical vehicle loading, differential vertical deflection of adjacent girders causes forces to develop in the diaphragm elements, which cause the out-of-plane loading on the girder web (Detail A). Without the stiffener attachment to the top flange and with the top flange rigidly connected to the bridge deck by shear connectors, these forces pass through girder web causing out-of-plane distortion and, hence, bending of the web gap immediately adjacent to the top flange (Detail B). In the negative moment regions, high cyclic stresses due to this distortion cause cracking in the web gap region typically parallel to the longitudinal tensile stresses (*2*).

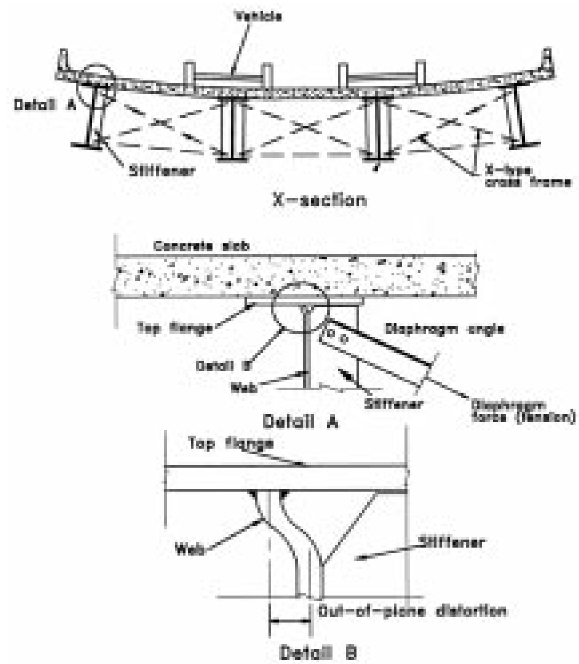

FIGURE 1 Description of out-of-plane girder web distortion in the gap region.

Current AASHTO Specifications (*3*) require a positive attachment between transverse connection plates for the diaphragms and both girder flanges. However, for many in-service bridges, the connection plates are welded only to the web and the compression flange. This was done because bridge specifications, at the time these bridges were constructed, discouraged welding of connection plates to the tension flange.

The primary objective of this work is to investigate a method suggested by the Iowa DOT to prevent web cracking. This method consists of loosening the bolts in some of the connections between the diaphragm diagonals and the stiffeners, which are welded to

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FIGURE 2 I-80 Bridge No. 7804.8L080.

either the girder bottom, compression flange, and the web or to the web only.

DESCRIPTION OF THE BRIDGE

The experimental phase of the study involved testing five bridges (three with X-type diaphragms and two with K-type diaphragms). However, only the results of one bridge with X-type diaphragms will be described in this paper due to space limitations. This bridge is located in Pottawattamie County (Iowa), 6 km west of the junction of Interstate 80 (I-80) with U.S. 6 road. The bridge was constructed in 1965. A photo of the bridge is shown in Figure 2. The superstructure consists of four continuous steel plate girders topped by a reinforced concrete deck slab. The girders have three spans of 27.89, 35.66, and 27.89 m, respectively with a lateral spacing of 2.95 m and are skewed 30 degrees with the bridge substructure. Between the supports, girders are braced using X-type diaphragms at an approximate spacing of 6.71 m. Vertical web stiffeners are closely fitted to the tension flange with a diagonal cope at approximately 50 mm from the web-girder intersection. At locations of intermediate diaphragms, two-bolt connections are used to connect diaphragm elements to the stiffeners.

Fatigue cracks have been suspected or confirmed in the web gap region at nine locations of the bridge. Eight of these locations were in the negative moment region and only one was in the positive moment region. As a retrofit, holes were drilled. However, the cracks extended beyond the drilled holes in some of these locations. Crack extensions were treated by drilling holes at the new crack tip locations.

RESEARCH METHOD

Two sets of bolts connect the diaphragm diagonals to the girder webs near the top and bottom flanges. The lower set of bolts is easily accessed in the field and, hence, the method was examined by loosening these bolts. The Iowa DOT provided two rear-tandem-axle loaded test trucks. Each weighed approximately 220 kN. Due to the high traffic volume, traffic was allowed to flow during testing. However, sufficient distance separated the test truck, running at the traffic flow speed, from other vehicles on the bridge to ensure sound interpretation of results.

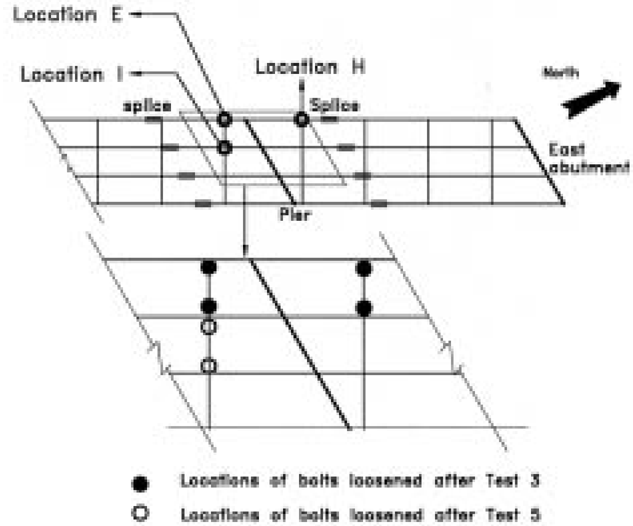

FIGURE 3 Schematic plan showing the instrumentation locations.

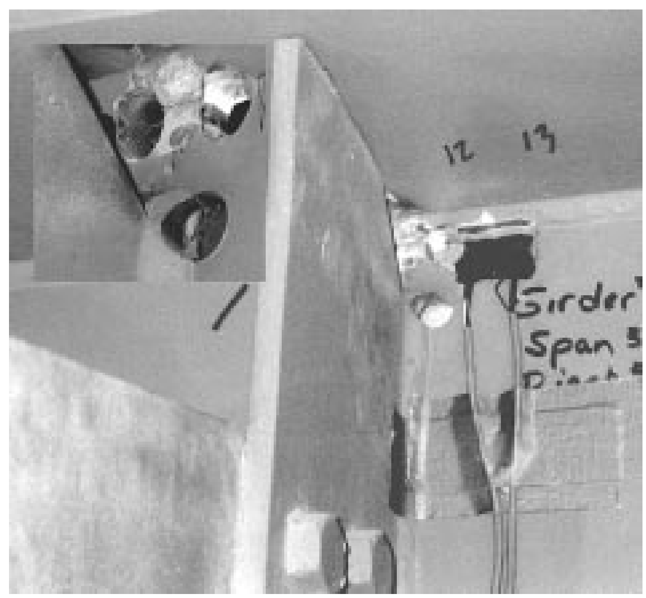

FIGURE 4 Cracks and drilled holes at Location H.

With the bolts tight, Tests 1-3 (tight condition tests) were conducted with the test truck traveling in the driving lane, passing lane and between lanes. Later, the lower connection bolts attaching both exterior panel diaphragm diagonals to the stiffeners at Locations E and H were completely loosened. Next, Tests 4-5 (partial loose condition tests) were conducted with the truck in the driving and passing lanes, respectively. These tests allowed an investigation of the effects of partial loosening of the diaphragm bolts (by partial loosening it is meant completely loosening the lower connection bolts of the exterior diaphragm panel) on the web gap behavior of

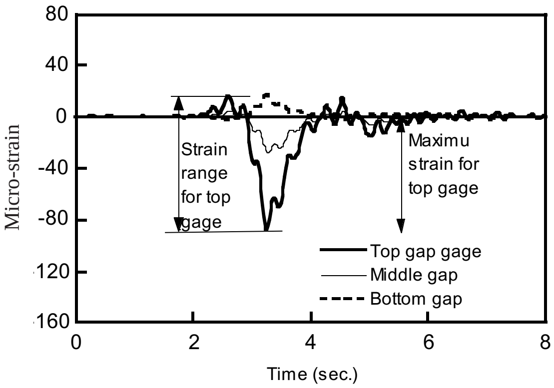

FIGURE 5 Strain data in the web gaps of Locations E, I and H during Test 3.

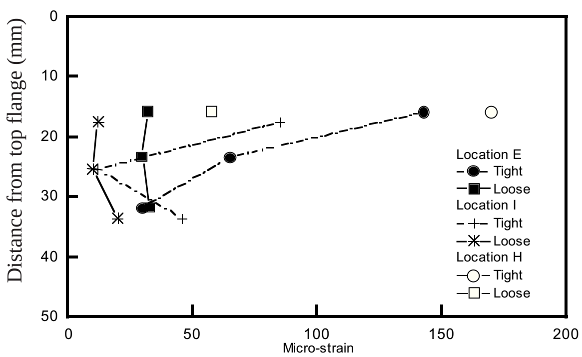

FIGURE 6 Strain range at Locations E, I, and H.

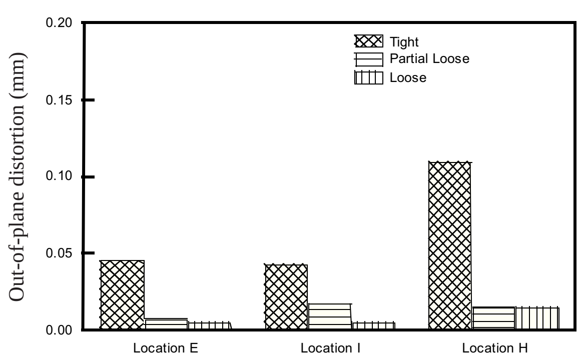

FIGURE 7 Maximum out-of-plane distortion at Locations E, I, and H during tight, partial loose and loose condition tests.

both exterior and interior girders. Later, the lower connection bolts of the interior panel at Location I were loosened and Tests 6-7 (loose condition tests) were conducted with the truck in the driving and passing lane, respectively. During testing, truck speed ranged from 88 to 100 km/h. Although not reported here, additional data were collected with ambient traffic.

Figure 3 shows a schematic half plan of the bridge showing the instrumented locations. Strains and out-of-plane distortion were measured in three web gaps: (1) at an exterior girder with no cracking (Location E), (2) at an interior girder with no cracking (Location I), and at an exterior girder where cracks were detected and holes were drilled (Location H-Figure 4). Diaphragm diagonal strains at location E were also measured. Other locations were instrumented; however, they are outside the scope of this paper.

RESULTS

Web Gap Strains

Figure 5 shows the strain reading of the gages installed in the web gap of Location E during Test 3 (tight condition). This figure further shows how the maximum strain and the strain range are defined. Figure 6 shows the maximum strain ranges computed at Locations E, I, and H in both tight and loose conditions. Obviously, the strain ranges in the web gap at Location H were slightly higher than the corresponding values at Location E implying that drilling holes technique may not prevent crack extension. The maximum computed strain ranges during tight condition tests at Locations E, I, and H were 143, 85, and 170 micro-strain, respectively. In the loose condition tests, there was a significant reduction in the strain ranges, as the maximum strain ranges were 32, 12, and 56 micro-strain, respectively with at least 65% reduction compared to the tight condition tests. It should be noted that the reported values in this paper are those obtained directly from the strain gage readings without extrapolation inside the web gap.

Web Gap Out-of-Plane Distortion

In the tight condition, the maximum out-of-plane distortion at Locations E, I and H (as shown in Figure 7) were 0.046, 0.043, and 0.110 mm, respectively. The out-of-plane distortion at Location H (with cracks and drilled holes) is more than twice those occurred at either Location E or Location I. This conforms to what was reported by Fisher et al. (*4*) where it was mentioned that the amount of the out-of-distortion increased with the existence of cracks. This implies that cracks and drilling holes reduced the lateral stiffness of the web gap significantly. Note, however, that the maximum values of strains were of comparable magnitude at the three locations.

Generally, loosening bolts reduced the web gap out-of-plane distortion at all the three locations. As illustrated in Figure 6, loosening only the exterior diaphragm panel bolts (partial loose condition) produced effects comparable to complete loosening both exterior and interior panel bolts (loose condition) on the web gap at Locations E and H. For Location I, there was a significant reduction in the out-of-plane distortion between the partial loose and loose condition tests.

Diaphragm Diagonal Forces

In the tight condition, the peak forces in the diaphragm diagonal (D1) showed variation with the transverse truck position with a peak magnitude of approximately 6 kN. The forces nearly diminished upon either loosening the exterior panel bolts (partial loose condition) or both exterior and interior panel bolts (loose condition). During the loose condition tests, the maximum force was within 0.5 kN.

SUMMARY

The general out-of-plane deformation behavior of the web gaps was enhanced as the nondestructive retrofit method was applied. For this bridge, the strain range in all tested web gaps was reduced by at least 65%. A similar trend was noticed for the out-of-plane distortion for which maximum values at exterior and interior girders decreased by at least 83% and 88%, respectively. Tests on other X-type diaphragm bridges yielded similar results. Considering the experimental results of this study, it is recommended to adopt the proposed method (loosening diaphragm bolts in the negative moment region) as a retrofit technique to prevent cracking from out-of-plane distortion of web gaps in X-type diaphragm bridges. Nevertheless, the design steps as presented in (*5*) should be performed before implementing the method.

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