Stopping fatigue cracking in steel bridge components

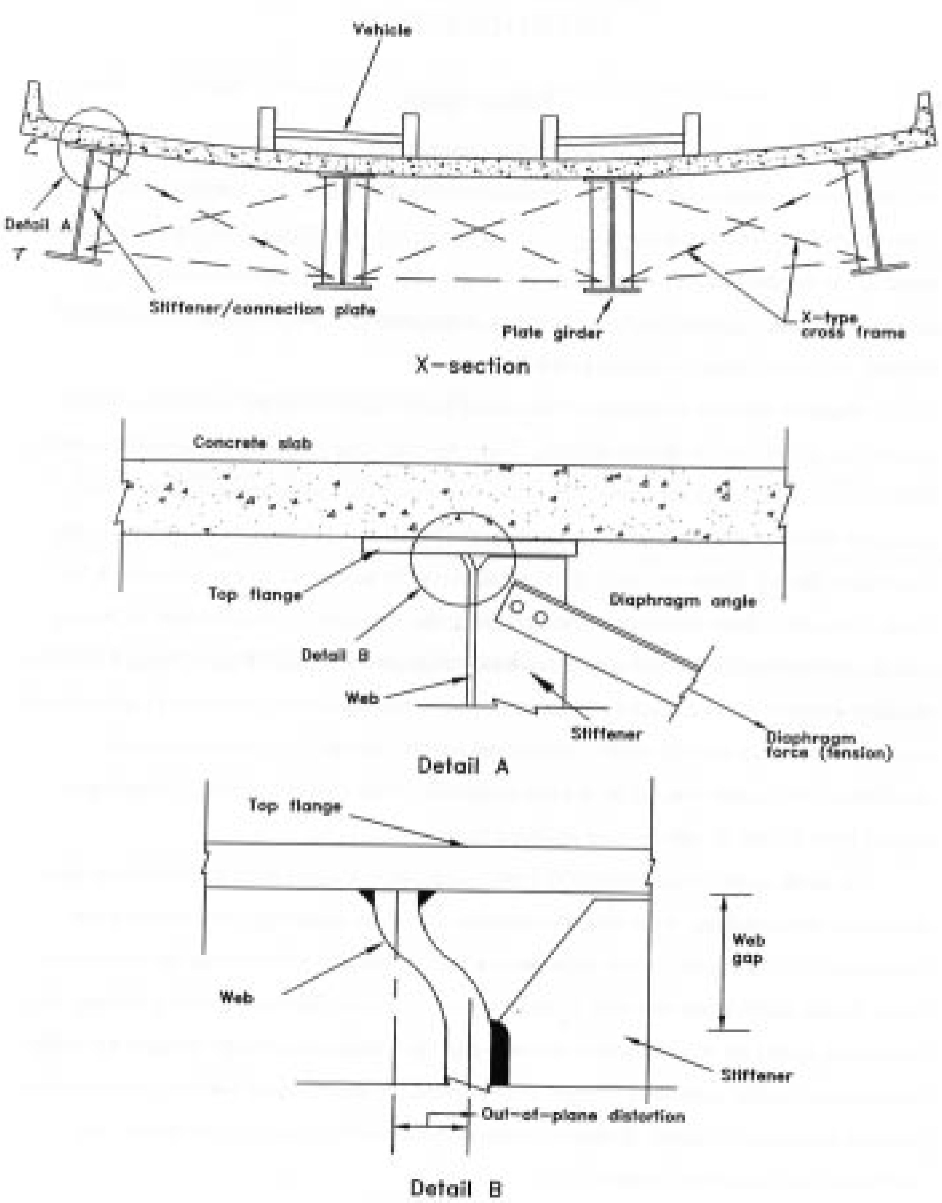
Project partners: Iowa Department of Transportation and the Iowa Highway Research Board (Project HR-393)

The problem

Fatigue cracks in some components of older, multiple-girder steel bridges is a common phenomenon in many states. Iowa's cracking problems are primarily concentrated in the web area of the steel girders.

The top detail of the figure below shows a cross-section of such a bridge, with steel diaphragms and girders. The girders consist of a vertical web, the upper flange, and the lower flange, with a connection plate welded to the web and the lower

BRIDGE CRACKING . . . continued on page 10



This figure represents out-of-plane girder web distortion in the gap region.

BRIDGE CRACKING . . . continued from page 9

flange. (Before AASHTO specifications required that connection plates be welded to both flanges, Iowa did not generally weld the plates to the upper flange.) Over an intermediate support, the upper flange is in tension. The upper flanges are rigidly connected to the bridge deck. The diaphragms are bolted to the connection plates.

Under typical vehicle loads, forces develop in the diaphragms that cause out-of-plane loading on the girder web (see Detail A in the figure on page 9). Without a rigid connection between the connection plate and upper flange, this loading causes out-of-plane distortion of the web in the gaps adjacent to the upper flange, resulting in bending and cracking (see Detail B in the figure).

Various solutions to the cracking problems—drilling holes at the crack tip, increasing the web gap length, welding or bolting the stiffening plate to the top flange, even removing unnecessary diaphragms to eliminate the source of cracking—are destructive in nature, and some of them require stopping traffic during the retrofit.

A possible solution

The Iowa Department of Transportation (Iowa DOT) Office of Bridge Maintenance has proposed a simpler, nondestructive retrofit: loosening the bolts at selected connections between the diaphragms and the girders.

Under CTRE's research program with the Iowa DOT, and with the support of the Iowa Highway Research Board, Iowa State University staff in civil and construction engineering, Professors Terry Wipf and Lowell Greimann and Structures Laboratory Manager Doug Wood, investigated the proposed retrofit.

Their study included field tests on five continuous-span steel bridges, including both X-type (depicted in the figure on page 9) and K-type diaphragm bridges. One of the bridges in particular, an X-type on Interstate 80, has extensive fatigue cracking in the web gap regions.

The experiments

To assess the proposed retrofit, researchers measured bridge responses under vehicle loads before and after loosening bolts connecting the diaphragms to the girder connection plates. Two sets of bolts, an upper and lower set, connect each diaphragm diagonal to a connection plate, with two bolts per set on X-type diaphragms and three bolts per set on K-type diaphragms.

On X-type diaphragms, loosening either set would produce the same effect, so researchers loosened the lower bolts because of their easy access. With K-type diaphragms, loosening upper bolts was expected to have a greater effect on web gap areas, so the top bolts were loosened. Researchers also evaluated the effects of loosening both upper and lower diaphragm bolts.

Forces in the diaphragms cause most of the problematic distortions and cracking. Researchers constructed a finite element model using the software program ANSYS to determine at which diaphragm/connection plate connections the greatest distortion develops. The bridges were then instrumented at the web gaps in those areas. Two types of instrumentation were used: displacement transducers and foil strain gages.

BRIDGE CRACKING . . . continued on page 11

BRIDGE CRACKING . . . continued from page 10

During tests on two of the bridges, regular traffic was restricted while one (sometimes two) rear-tandem axle truck was driven over the bridge at various speeds. Heavy traffic on the other three bridges made stopping regular traffic impossible, so tests were conducted with the loaded truck(s) running at traffic speeds.

Conclusions

The results of loosening diaphragm-girder connection bolts varied widely from girder to girder and bridge to bridge. In general, however, tests demonstrated that loosening these bolts substantially reduced diaphragm diagonal forces, the main cause of out-of-plane distortion-induced cracking.

The method reduced maximum stress ranges by at least 25 percent for all but one web gap (in a K-type diaphragm bridge). Such reductions would result in significantly extending the web gap fatigue life.

The researchers recommend the retrofit for steel bridges with X-type diaphragms but believe that more research should be conducted before implementing the method on K-type diaphragm bridges.

The final report, "Preventing Cracking at Diaphragm/Plate Girder Connections in Steel Bridges," is online at www.ctre.iastate.edu/reports/CTRE_rep.htm. •

CTRE welcomes new staff

Keith Knapp

CTRE is pleased to welcome Keith Knapp. Keith has a split appointment with CTRE, where he manages traffic engineering and traffic safety programs, and ISU's Department of Civil and Construction Engineering, where he is an assistant professor.

Keith has a Ph.D. in civil engineering from Texas A&M and has spent several years as a transportation engineer for CH2M Hill, Inc. The majority of his background includes systematic functional analysis of design-related impacts at a roadway corridor level, including the operational and safety impacts of new developments, traffic control, signing, and marking. In addition, he has a special interest in the systematic analysis (supply, demand, and design) of parking—the sometimes forgotten, but always important, land-use/transportation connection.

Keith's overriding principle in transportation work is that of "perpetual impact": Any project, no matter how small, will have positive and negative impacts, and it is our job to identify the impacts before they occur. •