conference preview

RETROFIT MEASURES FOR DISTORTION-INDUCED FATIGUE

Using a combination of physical and virtual models, researchers are learning how to control cracking in bridge girders.

BY TEMPLE RICHARDSON, FATIH ALEMDAR, CAROLINE BENNETT, PH.D., ADOLFO MATAMOROS, PH.D., AND STAN ROLFE, P.E., PH.D.

DISTORTION-INDUCED FATIGUE is a serious problem in bridges and is thought to be the cause of the majority of fatigue cracking observed in steel bridges. This type of fatigue damage occurs in cross-frame-to-girder connections in an area called the *web gap* region, and is caused by the action of secondary stresses often neglected during the original design of the structure.

When this type of cracking occurs, engineers are faced with designing an appropriate retrofit measure to completely halt crack propagation, or at least reduce the rate of crack growth so the fatigue life of the bridge can be extended while other options are pursued. A "toolkit" of existing retrofit techniques for distortion-induced fatigue is currently available for this purpose, including drilling of crack-stop holes; providing a direct connection between the stiffener and the adjacent flange; and providing "backup" transverse stiffeners on the fascia side of an exterior girder. However, each of these techniques is not without problems. For example, providing positive connection between a connection stiffener and top flange may require removal of the concrete deck to bolt angles to the flange, resulting in significant expense and traffic disruption.

Retrofit Research

Given the challenges inherent to the repair of distortion-induced fatigue damage, there is a clear and immediate need to develop new retrofit measures that are cost-effective, are easy to install, minimize the disruptions to ongoing traffic and most importantly can be effective without introducing new vulnerabilities to fatigue damage.

Recent research performed at the University of Kansas has explored the merits of various retrofit techniques for distortion-induced fatigue damage in steel bridges. The research approach combined high-resolution numerical simulations of 3D finite element models and physical simulations of laboratory models, used in a complementary manner.

Physical models consisted of segments of plate girder proportioned to have a length of 112 in. and web dimensions of 34½ in. by ⅜ in. Girder specimens were rigidly connected to the laboratory floor such that the bottom flange of each specimen was restrained from lateral motion as it occurs in the top flange of a bridge girder made composite with a concrete deck (see Figure 1). Specimens were tested cyclically using load control, with loads applied by an actuator connected to a cross-frame assembly with a maximum load of 4.6 kips (tension) and a minimum of 0.8 kips (tension). The specimen and loading apparatus were modeled closely using the finite element analysis (FEA) software ABAQUS v6.10 (the model is shown in Figure 2). Cracks were explicitly simulated in some of the finite element models. The hot spot stress technique was used to quantify the stress demand near welds. The two fatigue-vulnerable details of particular interest were the connection stiffener-to-web weld and the web-to-bottom flange weld.

➤ Fig. 1: View of physical test setup.

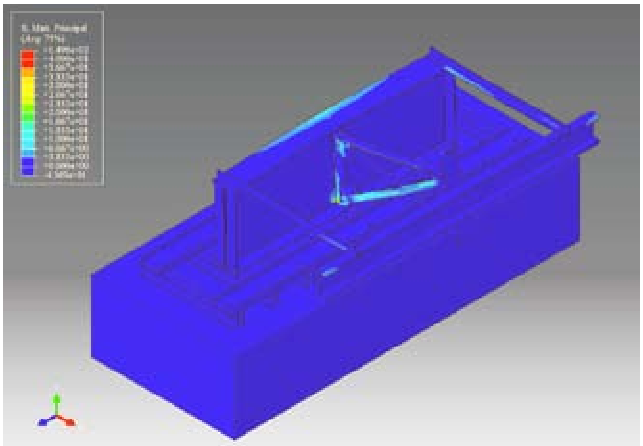

Fig. 2: View of overall finite element model.

To date, three specimens have been tested in the Structures Laboratory at the University of Kansas. Excellent agreement was observed between maximum principal stresses calculated using the finite element model and the experimentally observed crack locations. Cracks were first found at the connection stiffener-to-web weld and were horseshoe-shaped. After the formation of this crack, the bottom flange-to-web weld developed a horizontal crack that quickly propagated. In one specimen, the horseshoe-shaped and horizontal cracks were allowed to grow to lengths of 4 in. and 8 in., respectively. This particular crack configuration was analyzed in the models, examining pre- and post-retrofit responses. A small region of high-stress demand was also noted in the top web gap, on the fascia side of the web, during simulations of un-retrofitted specimens. During the test of Specimen 2, cracks were observed in the top web gap after cracks had initiated and propagated in the bottom web gap.

A total of six retrofit measures were investigated analytically: 1) drilling of crack-stop holes, 2) installation of tensioned bolts in crack-stop holes, 3) transverse back-up stiffeners, 4) composite blocks, 5) bolted angles connecting the stiffener to the flange and 6) bolted angles connecting the stiffener to the web, along with a steel backing plate. Retrofit measures 1 and 6 were also evaluated experimentally. The results of each are noted below.

1. The use of crack-stop holes as a retrofit measure for distortion-induced fatigue was studied both analytically and experimentally. Finite element results showed that the calculated value of the hot spot stress decreased 27% near the horseshoe-shaped crack and 16% near the horizontal crack after crack-stop holes were drilled. However, the calculated stress demand in the model without crack-stop holes was so high that the stress reduction was not expected to prevent cracks from re-initiating. In the physical simulation, cracks re-initiated following a relatively small number of cycles after holes were drilled. The length of the horseshoe-shaped crack before crack-stop holes were drilled was 4 in., and after the holes were drilled the crack grew by 2.75 in. over 39,700 cycles.

2. Use of fully tightened bolts and square plate washers was studied analytically. In this case, ¾-in.-diameter tensioned bolts were fitted in the crack-stop holes with the intent of applying a compressive stress to the crack tip. Square washers (1 in. by 1 in.) were included to investigate whether the compressive stress could be distributed over a larger area. This method did not significantly reduce the stress demand at the connection stiffener-to-web weld.

3. Use of two different back-up stiffeners—a full-depth stiffener and a partial-depth stiffener—was considered analytically. Both back-up stiffeners were effective at reducing stresses in the vicinity of the cracks; 40% to 85% stress reduction was noted for the various geometries studied. It was also found that applying backup stiffeners as a preventative measure before cracking initiated resulted in significantly higher stress demands near the horizontal crack.

4. Use of a composite block bonded to the web, connection stiffener and flange was studied analytically on a cracked model. A 5-in. by 5-in. carbon fiber reinforced polymer (CFRP) composite block was designed to fill the entire web gap region. The maximum stress in the horseshoe crack in the region directly covered by the CFRP material was reduced by 93%.

5. Use of bolted angles connecting the stiffener to the flange was studied analytically. The configuration evaluated consisted of two angles bolted to the flange and welded to the connection stiffener. Implementing this measure in an actual bridge would require either drilling through the concrete deck to install the bolts or welding threaded studs to the inside face of the top flange; both cases were modeled. While this measure caused the hot spot stress near the horseshoe-shaped crack to decrease by 95%, a new fatigue-vulnerable detail was introduced in the flange when a welded stud was used instead of a bolt.

6. Use of two bolted angles (2L6×6×¾) connecting the web to the stiffener and a backing plate (18-in. by 6-in. by ¾-in.) on the fascia side of the web was studied both analytically

Temple Richardson (left) is a graduate research assistant, **Caroline Bennett**, Ph.D., and **Adolfo Matamoros**, Ph.D. (center), are associate professors, and **Stan Rolfe**, P.E., Ph.D. (right), is the Albert P. Learned Distinguished Professor, all in the Department of Civil, Environmental and Architectural Engineering at the University of Kansas, Lawrence, Kan. Not pictured: **Fatih Alemdar**, who is also a graduate research assistant.

From left: Richardson, Bennett, Matamoros and Rolfe

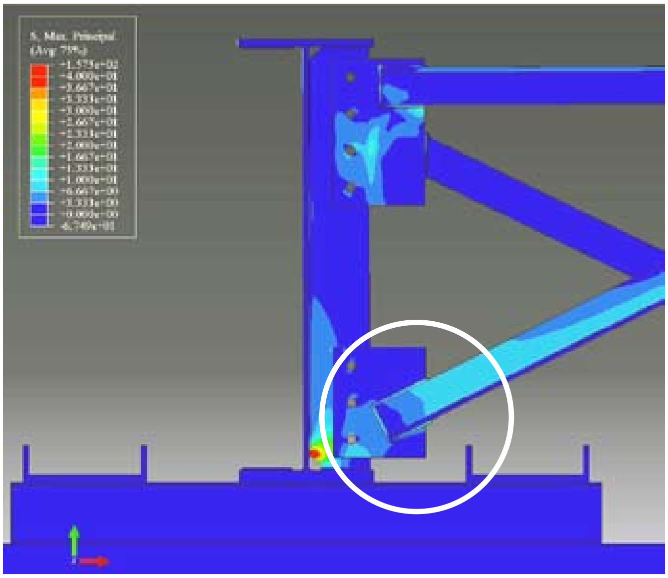

Fig. 3: Cross-sectional view of unretrofitted specimen, with web gap shown in circle.

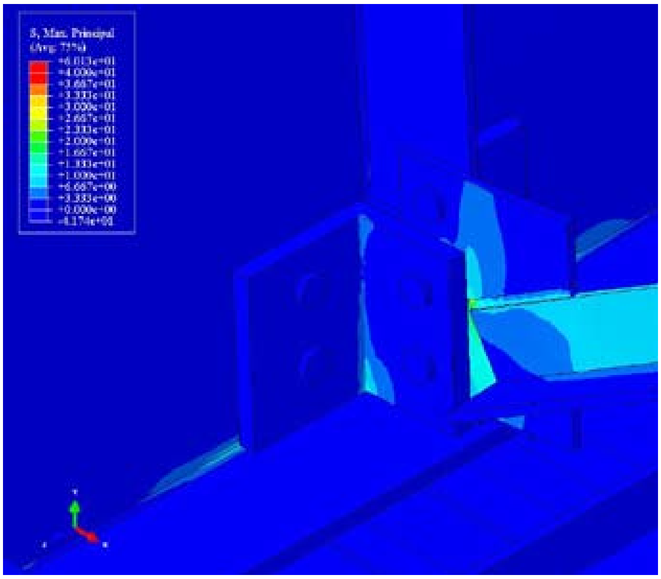

Fig. 4: Interior side of girder shown with bolted angles connecting the web to the stiffener.

and experimentally. This measure caused the calculated stress demands in the web gap region to decrease by 98% near the horseshoe-shaped crack and 95% near the horizontal crack (see Figures 3 and 4). This was an important finding because this technique is expected to be inexpensive and easy to install in the field, without significant disruptions to traffic or removal of a concrete deck. It should be noted that additional research on the behavior of this retrofit measure is warranted before implementation in the field, and that this measure is the subject of ongoing research at the University of Kansas. MSC

The authors would like to acknowledge funding provided by the Kansas Department of Transportation's KTRAN program, as well as Transportation Pooled Fund Study TPF-5(189), which includes support from FHWA and the state DOTs of California, Iowa, Illinois, Kansas, Louisiana, New Jersey, New York, Oregon, Pennsylvania, Tennessee, Washington, Wisconsin and Wyoming.

This article provides a preview of some of what the authors will present in Session B8 at the World Steel Bridge Symposium, April 18-20 in Dallas. Learn more about the World Steel Bridge Symposium and NASCC:The Steel Conference at ***www.aisc.org/nascc****.*