A ccumulated fatigue damage in steel bridges presents a particularly insidious challenge to bridge designers and engineers. Because the effects of fatigue are difficult to quantify before identifiable cracks occur, bridge engineers try to design bridges with infinite fatigue lives. Many details that were considered good practice three decades ago, however, have proved detrimental to the fatigue performance of steel bridges.

Distortion-induced fatigue is one of the most difficult fatigue-related problems to address. The phenomenon occurs when adjacent girders at the same cross-section of a bridge undergo different deflections. Because of the difference in the deflections, the brace elements induce out-of-plane deformations and stresses on the girders they connect. The effect of these stresses on the bridge’s fatigue life is difficult to quantify and was not a consideration in bridge design practice three decades ago. The use of connection details that are prone to fatigue cracking in the vulnerable girder web-gap region (see Figure 1a), therefore, was widespread.

Different approaches have been developed to repair girders that are vulnerable to distortion-induced fatigue. One method is to modify the connection between brace elements and the girder so that distortion occurs over a relatively long segment of the web, reducing the stress demand in the area that is prone to fatigue cracking. A second repair method takes the opposite approach and modifies the connection to engage the girder flange directly, avoiding the load path through the vulnerable web-gap region.

Choosing the wrong technique, however, can accelerate bridge damage. Because choosing the repair method that is best suited to an individual bridge is difficult, tailored research studies often are necessary to identify the appropriate repair technique.

The Kansas State Bridge Office (KSBO) employs a bridge management approach similar to that used by other agencies—bridges are inspected at regular intervals, and repairs and replacements are prioritized by the availability of resources and the level of need. Whether or not a bridge is to be replaced depends on the level of deterioration and on the level of use by the traveling public.

K-TRANS, a research program sponsored by the Kansas Department of Transportation (DOT), undertakes research projects to address challenges faced by agency engineers. Many of the program’s research projects have contributed to the KSBO’s bridge management activities. The KSBO identifies the challenges, and universities are encouraged to submit proposals to K-TRANS to develop solutions.

Two steel bridges experienced distortion-induced fatigue cracking and were repaired successfully by applying results from K-TRANS research. The case studies follow. The success of the repairs has saved Kansas DOT millions of dollars in bridge replacement costs and has provided proven retrofit techniques that can be applied in the future.
Problem

Two Kansas highway bridges, K-96 over the Little Arkansas River in Hutchinson, and K-16 over the Tuttle Creek Reservoir in Riley County, revealed many distortion-induced fatigue cracks during several inspection cycles.

Constructed in 1955, the Little Arkansas River Bridge is a 17-span, 1,020-ft long, steel floor, beam-and-stringer structure. Cracking was found in the connecting plates between the stringers and floor beams, as shown in Figure 1.

The Tuttle Creek Bridge, constructed in 1962, is a 38-span structure, 5,350-ft long, with two girders. Figure 2 shows the typical cracking patterns found in the Tuttle Creek Bridge. Because the structure was nonredundant and fracture-critical, failure of a primary member could have caused a complete structural collapse; this heightened concerns about the cracking.

Solution

The University of Kansas (KU) and the KSBO formed a partnership to determine and evaluate retrofit solutions for each of the two bridges. The KSBO developed preliminary analytical models for initial understanding and for the retrofit development. KU evaluated the proposed repairs with sophisticated analysis tools and experimental field techniques. KU and Kansas DOT then partnered in field evaluations of each of the structures, before and after the repairs, to estimate the performance of the new details.

The Arkansas River Bridge repairs focused on reducing restraint in the damaged connections, after the KU analyses found that additional restraint would have concentrated forces at the horizontal welds and exacerbated the bridge's problems. The chosen retrofit is shown in Figure 1b.

KU also evaluated the repairs developed by the KSBO for the Tuttle Creek Bridge. The repairs used angle sections to connect the stiffeners to the top flange of the girder, as shown in Figure 2. Threaded studs were welded to the bottom of the girder's top flange. Angle sections were welded to each side of the connection stiffener and were nutted to the threaded stud on the top flange. This detail offered two advantages: it could be installed without disrupting traffic, and it did not create a fatigue-prone detail on the primary member.

Benefits

The stress ranges in the repaired details at the Arkansas River Bridge decreased significantly, resulting in an estimated fatigue life of 25 to 65 years, depending on traffic. The repair work performed on the structure cost $500,000, in contrast to the estimated $5 million for bridge replacement, which also would have inconvenienced the traveling public.

The calculated fatigue life of the retrofitted details in the Tuttle Creek Bridge exceeds the useful life of the structure. The repair and retrofit work cost $700,000, with bridge replacement estimates ranging from $26.5 million to $62.6 million. Because of the high cost of replacement, the only viable alternative to repair would have been closure, forcing residents to detour almost 50 miles.

Moreover, the repair to the Tuttle Creek Bridge could be performed under traffic. Many alternative repair methods commonly used to engage the top flange with the web-gap region require replacing part of the concrete bridge deck to allow access to the top of the top flange.

The benefits of this research partnership to the agency, taxpayers, and the traveling public were substantial. Repair was a much more economical alternative than replacement, and travelers and local residents did not have to make excessive—and possibly permanent—detours. These retrofit methods can be used on many Kansas bridges of similar design, as well as on other U.S. bridges with similar fatigue damage.

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