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Member-Level Redundancy for Steel Bridge Girders

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Summary

Transportation Technology Center, Inc. (TTCI) has four steel railway bridge spans located at the Facility for Accelerated Service Testing (FAST) that are being tested for fatigue performance. The bridges carry approximately 150 MGT per year of heavy axle load (HAL) traffic. TTCI is using these bridges to investigate life extension methods and improved life estimates for common riveted steel railway bridge spans. This *Technology Digest* presents initial results of a member-level redundancy test that is currently ongoing at TTCI.

- For test purposes, three notch defects were intentionally cut into the bottom cover plate of the 32-foot steel girder span at FAST in September 2015.
- The notched girder continues to perform well with 154 MGT (968,000 cycles) accumulated after the notches were introduced.
- There are cracks visible in each of the three notches. However, no cracks have propagated beyond the notches to date.
- The stresses near the center of the bottom cover plate at mid-span are remaining at the same level since February 2015.
- Multiple safety and monitoring systems are in place on this span to detect changes in bridge behavior and limit deflection in case of changes.

The presence of more than one cover plate in a built-up steel girder provides a level of redundancy within a bridge member. If a single component develops a crack, there will be redistribution of stresses into other components of the built-up member. The bridge will continue to be monitored, inspected frequently, and evaluated for repair should crack growth or a fracture occur.

This research is being conducted as part of the AAR's Strategic Research Initiative on bridge life extension.

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INTRODUCTION

To investigate member-level redundancy in the field, a test at FAST was designed to provide an in-service evaluation of the potential benefit that is thought to be present in riveted girders fabricated from multiple components, including web plates, flange angles, and cover plates. Three notch defects were installed in the bottom partial length cover plate (tension flange) of the 32-foot span. Objectives of this testing are threefold: (1) determine crack growth rate, which provides information regarding suitable inspection intervals; (2) determine critical crack length at which fracture might occur; and (3) determine whether fracture propagates to additional components of the built-up girder, or the number of additional cycles required to do so.[1] Laboratory tests to date on full-scale specimens have shown the crack propagation and fracture of a member element (cover plate, for example) to remain confined to that element rather than to introduce defects into adjoining members upon fracture. Testing at FAST on an actual bridge span under actual train loadings will serve to provide further information about this behavior, which has the potential to greatly extend calculated span life.

LITERATURE REVIEW

Connor et al.[2] reported that, during a period surveyed from 1960 to 2005, no fracture critical bridge with built-up members is known to have failed due to the fracture of one single component propagating a fracture to an adjacent component. In contrast, there are examples of several highway and railroad bridges containing component failures (i.e., failures of one component of a built-up member, such as an angle or plate) which have continued to sustain service loads in the 'failed' state. Substantial safe service life remains in a built-up steel girder with a failed component because of member-level redundancy. Laboratory investigations at Purdue University have shown that in at least 20 experiments, fracture of a single riveted girder component has not resulted in propagation of a crack to an adjacent component.[3,4] When a fatigue crack initiates in one cover plate in a built-up section, redistribution of stresses into the uncracked components can occur. The potential for stress redistribution during the crack growth process means the safe service life of the member is greater than the life to crack initiation of a single element.

BRIDGE DESCRIPTION

The investigated railway bridge has two riveted steel deck plate girder (DPG) spans with open decks. The bridge is located at FAST at the Transportation Technology Center (TTC) near Pueblo, Colorado. The two short steel DPG bridge spans were installed in December 2014. A 33-foot span built in 1904 was donated by Canadian Pacific Railway (CP) from near Fernie, BC. This span was shortened by ~7 inches at each end to fit the existing opening. Figure 1 shows both DPG spans in the west steel bridge at FAST. The bridge is in a 5-degree curve with 4 inches of superelevation. The open deck spans are also superelevated by the same amount.[5]

Figure 1. 24-foot and 32-foot Riveted DPG Spans in the West Steel Bridge at FAST

Both spans are being overloaded by the HAL train (with primarily 315 kip cars) at FAST. The normal rating of the 32-foot span is Cooper E-54 as provided by CP. At FAST, the loading on the high rail girder of this span is Cooper E-72 at the normal operating speed. To date these spans have performed well with no maintenance required nor defects noted during the 269 MGT of HAL traffic accumulated.

Figure 2 shows mid-span tension flange stresses as measured using strain gages in the 32-foot span, under normal FAST train operations at 40 mph.

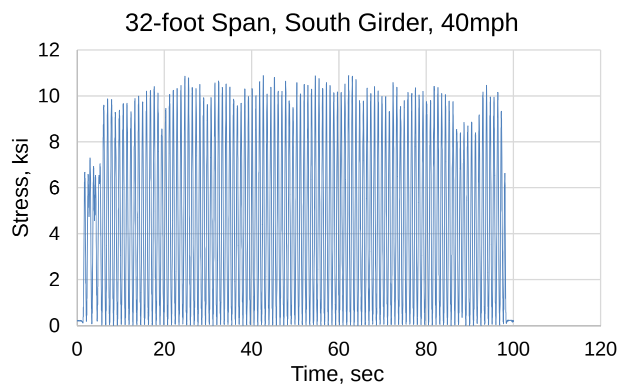


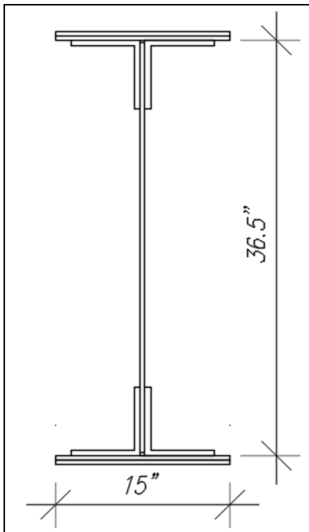
Figure 2. Tension Flange Stress at Mid-Span of 32-foot Span under FAST Train Loading

The measurements shown are for the south girder or high rail girder of the span. Note that the span unloads completely (stress goes down to zero) between the lead and trail trucks of each car. This is expected, because the span length is less than the inside axle spacing on the cars;

so there is a brief period beneath each car when there are no axles on the span.

CALCULATION FOR BUILT-UP GIRDER IN 32-FOOT SPAN

The 32-foot DPG span at FAST has two main girders that are built-up sections including web plates, flange angles, two top cover plates, and two bottom cover plates as shown in the Figure 3.



Top partial length cover plate (15” x 7/16” PL x 22’4”)

Top full length cover plate (15” x 3/8” PL x 31’10”)

Top flange angles (6” x 6” x ½” L x 31’10”)

Web (36” x 3/8” PL x 31’10”)

Bottom flange angles (6” x 6” x ½” L x 31’10”)

Bottom full length cover plate (15” x 3/8” PL x 31’10”)

Bottom partial length cover plate (15” x 7/16” PL x 22’4”)

Figure 3. Built-up Section of Main Girder of 32-foot Span

Mid-span moment due to 53-foot cars of 315 kips on the 32-foot span is about 1,522.5 kip-ft under static load conditions. The calculated stresses using gross section due to bending moment are presented in Table 1. AREMA[6] recommends the use of net section; however, the gross section stresses are closer to the measured values.

Table 1. Calculated Stresses Using Gross Section

Gross Section	Moment of Inertia, in^4	Ys, in	Stress, ksi
With all bottom cover plates	16,395.80	19.06	10.6
With one bottom cover plate	13,784.95	20.94	13.9
Without both bottom cover plates	11,095.43	22.90	18.9

The stress level with a section without one cover plate is still below the AREMA allowable stress of 18.15 ksi. The stresses get higher if the section loses both bottom cover plates; then, it is exceeding allowable design stresses. However, losing a cover plate is not very common. Even with a fatigue crack on the plate, the plate can still carry some load. If the crack is detected by an inspector in a timely manner and the condition is repaired, the bridge can be operated safely.

MODIFICATIONS TO 32-FOOT RIVETED STEEL SPAN AND SAFETY MEASURES

Defects were installed in the bottom partial length cover plate (tension flange) of the 32-foot span. The girder cross section at mid-span is shown in Figure 3. Defects were introduced in the partial length bottom cover plate of the most heavily loaded girder (south side, high rail) in order to provide stress concentrations in which cracks might initiate and propagate. Defects were installed at locations near centerline. Defects consist of three notches ground in the bottom cover plate (Figure 4).

Figure 4. Three Notches Cut into Bottom Cover Plate of 32-foot Span South Girder

Safety cribbing, shown in Figure 5, was installed to limit the deflection of the span should a fracture occur. In addition, a deflection limit switch was installed and connected to the signal system. Deflection indicators are also used for periodic monitoring of maximum deflection during train operations.

Figure 5. Safety Cribbing installed under 32-foot Span of FAST West Steel Bridge

MEASUREMENTS AND DATA RESULTS TO DATE

For the 32-foot span, the following measurements are collected under normal FAST train operations:

- Mid-span tension flange strain in axial direction, on bottom cover plate, for each girder.

- For the south (high rail) girder which is most heavily loaded, and containing the introduced defect(s), strain gages are applied to each tension flange element (flange angles, each side of the full length of the cover plate, and both sides of the web about 1 inch above the flange angles).
- For the south and north girder, tension flange strain gages at the quarter span location are also used.
- Mid-span vertical deflections, on the south girder.

Data collection is triggered automatically as the train approaches the bridge.

The defects on the bottom flange were introduced in September 2015. Since that time, 154 MGT has been accumulated. There are cracks visible in each of the three notches (Figure 6). However, no cracks have propagated beyond the notches to date.

Figure 6. Crack in the Notch

The stresses near the center of the bottom cover plate at mid-span are remaining at the same level since February 2015 (Figure 7).

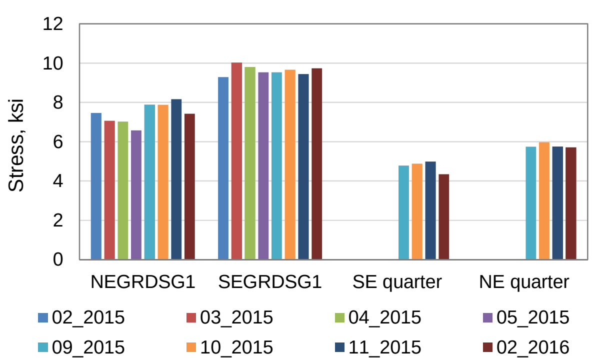


Figure 7. Mid-Span and Quarter Location Stress Comparison of North and South Girder, Train Speed 40 mph

Figure 8 shows stresses on the south girder since September 2015, and they also are at the same level since the defects were introduced. The bridge will continue to be monitored, inspected frequently, and evaluated for repair should crack growth or a fracture occur.

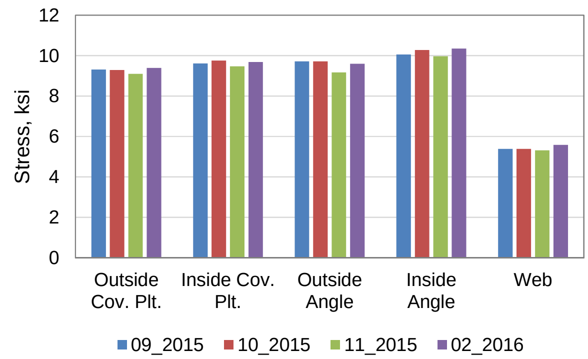


Figure 8. Stress Comparison of Various Locations on South Girder, Train Speed 40 mph

CONCLUSION

To date, the 32-foot span at FAST has performed well with no maintenance required, no defects noted, and total accumulated tonnage of at least 1,969 MGT with over 269 MGT of HAL traffic. The presence of more than one cover plate in a built-up steel girder provides a level of redundancy within a bridge member. If a single component develops a crack, there will be redistribution of stresses into other components of the built-up member. The notched girder continues to perform well with 154 MGT and 968,000 load cycles accumulated after the notches were introduced. The bridge will continue to be monitored, inspected frequently, and evaluated for repair should crack growth or a fracture occur.

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