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Steel Bridge Life Extension for Welded Girder Span at FAST

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Summary

Transportation Technology Center, Inc. has used a number of techniques to safely extend the service life of two steel bridge spans located at the Facility for Accelerated Service Testing (FAST). A welded girder span with a critical tension flange crack was kept in service for over 2,100 MGT, at which time it was removed from service at FAST. This digest focuses on findings from the welded girder span while in service at FAST.

Overall keys for extending service life of this bridge span at FAST are:

- Stress State Reduction: Smooth rail surface and good track geometry are maintained on bridge and approaches.
- Inspections: Regular overall inspections, frequent focused inspections of critical details, targeted use of nondestructive testing, and frequent cursory inspections.
- Repairs: Simple and effective bolted repairs to bracing systems.
- Monitoring Systems: Installation of simple deflection limit devices and automated monitoring of basic bridge responses.

Many of these techniques can be employed in revenue service in one form or another to extend the safe service life of bridges. Stress state reduction, inspection, and targeted monitoring techniques can be employed to extend the service life of concrete and timber bridges in addition to steel bridges. When compared to the capital cost of bridge replacement, some of these techniques can be cost effective for extending the service life of existing bridges.

This work has been conducted under the Association of American Railroads' Strategic Research Initiative on Bridge Life Extension, as well as the FAST Program.

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INTRODUCTION

The steel bridge at FAST has two deck plate girder spans with lengths of 65 and 55.5 feet. Both spans have carried considerable amounts of heavy axle load (HAL) traffic at FAST with the use of several bridge life extension techniques. Successful methods have included:

- Stress State Reduction
- Inspections
- Repairs
- Monitoring Systems

These life extension methods and safety measures allowed years of continuing train operations over the spans in spite of conditions that were not up to current recommended practice. The 65-foot welded deck plate girder span had a partial depth crack in the tension flange near the middle of the span. With over 16 years of HAL traffic, it has also developed dozens of other cracks, including several broken bracing members. Figure 1 shows the two spans of the steel bridge at FAST.

Figure 1: Steel Bridge at FAST with 65-foot Welded Deck Plate Girder Span (left) and 55.5-foot Riveted Deck Plate Girder Span (right)

65-Foot Welded Span

The 65-foot span is a fully welded span fabricated in 1957, with several weld details that do not conform to current recommended practice.[1] This span developed a tension flange crack after only 82 MGT of HAL traffic. The tension flange crack grew from a constraint induced fracture crack that originated at a gusset to stiffener weld.[2,3,4] The original crack was first noted after 37 MGT of traffic at FAST. At that time, the crack was only in the web of the girder. After 45 MGT of additional traffic, it was found to have grown into the tension flange. Upon finding the tension flange crack, a crib bent was installed beneath the span to provide additional support and to prevent the crack from growing. The bridge was operated with this crib support for an additional 63 MGT. During this time, several other cracks also developed in the span, primarily cracks beneath intermediate stiffeners, as will be discussed below.

The 65-foot welded girder span was designed for Cooper E-72 loading with diesel locomotive impact. The test train at FAST provides the equivalent of an E-57 loading on the span. Numerous cracks developed in the span in spite of the loading only being 79 percent of the design capacity of the span. In each case, the cracks appear to have initiated at weld details.

At the recommendation of the Association of American Railroads' Heavy Axle Load Engineering Research Committee, after a total accumulated tonnage of 144 MGT, shims were removed from the crib bent to allow at least 1 inch of deflection for this welded span. The intent was to monitor the growth and growth rate of the tension flange crack.

Table 1 provides a timeline overview of the most significant test events and changes in test configuration for the 65-foot welded steel span during its testing at FAST.

Table 1: Timeline of Significant Test Events for the 65-foot Welded Bridge Span at FAST

65-foot Welded Steel Span Timeline			
Date	MGT	Cycles (millions)	Event
11/19/1997	0	0.00	Span installed
1/8/1998	14	0.09	First web cracks beneath stiffener
1/27/1998	26	0.17	Additonal web cracks, first stop drill holes
2/10/1998	37	0.23	Large web crack near mid span
5/1/1998	82	0.52	Large web crack growth into tension flange Crib bent installed beneath span
1/19/1999	144	0.91	Full deflection of span allowed
7/12/2012	1930	12.22	Second large web crack near quarter point
9/12/2012	1930	12.22	Second large crack removed, repair completed
11/12/2013	2107	13.34	Span removed

Repairs and Maintenance to the 65-foot Welded Girder Span

During the 16 years that the 65-foot welded girder span was in service at FAST, more than 40 cracks developed. Many of the cracks initiated at the bottom of the intermediate stiffeners, just above the tension flange, as Figure 2 shows. Cracking of this type has been commonly noted in welded steel girder spans.[5] In three cases during the early years, crack stop holes were drilled at the crack tips to halt crack propagation.[2] In each case, no further crack growth was noted after more than a decade of service. In many cases, the ends of the cracks were simply marked and monitored for further crack growth. In many cases for these below-the-stiffener cracks, crack growth halted with a crack length of about 2 inches or less on either side of a stiffener. For most of these cracks, routine inspection turned out to be sufficient for keeping the span in service for regular train operations; as long as the crack did not continue to grow, no remedial action was taken.

Figure 2: Web Crack beneath Intermediate Stiffener Just Above Tension Flange

Testing of movable bridge rail joints introduced dynamic vertical wheel load impacts into the steel bridge spans. Some of the rail joint assemblies tested were attached to the adjoining running rails with bolted rail joints rather than with welds, introducing even more wheel impact locations. The impacts increased the rate of crack growth at locations near the joints. Cracks also developed in top lateral bracing members near joints.[6,7] Cracks in the top lateral bracing members tended to propagate quickly. In some cases, the cracks grew from partial to complete in a matter of only one or two days of train operations. In other cases, the cracks were not discovered until they were completely through the cross section of the member. Over the 16 years of train operations, a total of five lateral braces developed complete cracks. In each case, the crack appeared to initiate at the weld connecting the brace to the top flange of the girder.

In each case of a cracked top lateral brace, the brace was repaired using a simple bolted splice on one leg of the angle, as Figure 3 shows. Due to the location of the cracks, it was not feasible to splice the other leg of the angle in a similar fashion. In each case, the bolted splice performed well. Two of the splices served for over 1,500 MGT and two more served for over 1,200 MGT. The fifth splice was installed much more recently. These simple splice repairs are much easier and quicker to make than a full member replacement.

Figure 3: Simple Bolted Splice Repair to Top Lateral Brace

The broken braces that appeared beneath rail joints as well as the increased crack growth rate in other cracks near joints point out the importance of maintaining a smooth rail surface, thereby reducing the stress state.

More recently, the running rail on this span developed corrugations. The result was an increase in crack development and crack growth throughout the span. The corrugated rail resulted in increased dynamic vertical wheel loads and increased stresses in the girders. The resulting increase in fatigue life consumption per train pass was nearly 50 percent.[3,4,8] Grinding the rail surface to a smooth condition significantly reduced the stresses and resulting fatigue accumulation.

In addition, maintenance of good track geometry on the bridge and bridge approaches minimizes vehicle dynamics, which could also contribute to an increase in the stress state. The approaches to the steel bridge at FAST are constructed of compacted, well-draining backfill material, with broad slopes. After initial settlement, the approach track has required minimal geometry maintenance. With smooth rail and smooth geometry on bridge approaches, the dynamic vertical wheel loads on the FAST steel bridge are considerably less than those predicted using AREMA's recommended practice.[1]

Monitoring Systems for Continued Operation of Span with Tension Flange Crack

For safety purposes, the crib bent beneath the 65-foot welded span with the tension flange crack was left in place to limit deflection in case the crack grew quickly. Additionally, three separate monitoring systems were installed:

- A deflection limit switch, which tripped a signal alarm when exceeded
- A deflection and strain monitoring system, which provided warnings when levels (described below) were reached
- Resettable "fish scale" maximum deflection device to provide visual indication to test controller.

These monitoring systems are all very simple and provide actionable data or indications. The operation of the limit switch was checked each night before operation. The deflection and strain gage monitoring system provided continuous data that could be checked and monitored as desired, and provided "yellow light" and "red light" warnings at predetermined deflection levels. The fish scales were checked manually by the test controller several times during train operations. (The fish scales have been used at FAST for many years to provide a visual indication of rail movement in curves.) The fish scales are a very simple mechanical device requiring no electrical power, no batteries, and no data download interface complications. The fish scales have subsequently been used on other spans at FAST to provide a simple visual indication of peak span deflection for test personnel. Typical peak deflection for this span under the test train at FAST was about 0.5 inch. The maximum deflection recommended by American Railway Engineering and Maintenance of Way Association (AREMA) for a span of this length is about 1.2 inches.[1] Warning levels for deflection during train operation were set at 0.63 inch (25 percent above normal/yellow light) and 0.75 inch (50 percent above normal/red light).

With the start of full span loading on the tension flange crack, nondestructive testing (NDT) methods were added to the inspection routine. Whenever ultrasonic rail flaw inspection was conducted at FAST, the inspection crew performed a manual ultrasonic inspection on the tension flange crack to determine the size and check for growth. The inspection interval varied from about 5 MGT (weekly) in the early years to between 10 and 14 MGT (biweekly) in the later years. In terms of load cycles, 16 MGT of the FAST train equals about 100,000 load cycles on this span. Over nearly 15 years, the 65-foot welded span accumulated 1,963 MGT and 12.4-million load cycles of HAL traffic while allowing full deflection on the tension flange crack. No growth in the tension flange crack was noted by ultrasonic inspection during this period. An x-ray inspection of the tension flange crack was performed at one point to confirm the ultrasonic readings.

The crack remained in an arc shape about 4 to 5 inches across and about 1 inch deep for over 2,000 MGT. The tension flange cross section is 18 inches across by 2.625 inches deep. The crack represented about 7 percent of the tension flange area.

Additional NDT at times included the use of electrochemical fatigue sensors[9] and acoustic emissions.[10] Both of these technologies are intended to provide an indication of crack growth activity. While both technologies identified crack growth activity in web and stiffener cracks at various locations, neither noted any significant crack growth activity associated with the tension flange crack during the periods they were in use.

Complete bridge inspections were conducted about every 30 MGT or about every 200,000 load cycles. In addition, the bridge was the subject of frequent cursory inspections, being at eye level in a location frequented by numerous track workers, measurement specialists, and engineers. Strain gage readings from the tension flanges were monitored on a regular basis.

CONCLUSIONS

A welded steel girder bridge span served 16 years (2,107 MGT) at FAST under HAL traffic. For more than 15 years, the span had a tension flange crack and developed dozens of other cracks over its service life. Keys to extending the service life of this span included:

- Stress state reduction through
  - Maintaining a smooth rail surface (elimination of rail joints, grinding of corrugated rail)
  - Maintaining good track geometry on bridge and approaches to minimize vehicle dynamics
- Inspections
  - Regular overall inspections
  - Frequent focused inspections of critical details
  - Targeted use of NDT where appropriate
  - Frequent cursory inspections
- Repairs
  - Simple and effective bolted splice repairs for bracing
  - No failures in over 1,500 MGT
- Monitoring Systems
  - Simple bridge safety detection systems (limit switch, fish scale) on cracked span
  - Automated monitoring of basic strains and deflections

All cracks in this span appear to have initiated at weld details. The weld details in this span are not in compliance with current recommended practice.[1] The FAST train loading on this span was about 79 percent of the design capacity for this span. The capacity calculations do not take into account welded fabrication details.

Some of these life extension techniques might be cost effective for extending the life of bridge spans in revenue service. Part of the decision process for implementing any of these would include amount and type of traffic on the line, location of the bridge in the network, capacity of adjacent tracks or routes, and the condition of the span relative to others on the system.

After this span was removed from service at FAST, it was moved to Purdue University for additional analysis and training of bridge inspectors.

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