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Fitness for Service Analysis for 65-foot Steel Girder Bridge Span at FAST

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Summary

Transportation Technology Center, Inc. (TTCI) is testing intermediate-length, steel deck plate girder bridge spans at the Facility for Accelerated Service Testing (FAST) in Pueblo, CO. The spans were removed from revenue service and are of riveted fabrication. The spans are being loaded at or above their normal rated capacity by the FAST train. TTCI is using these spans to investigate life extension and service life estimates for common steel spans as part of the Association of American Railroads' (AAR) Strategic Research Initiatives (SRI) program on bridge life extension.

Preliminary measurements and analysis of a 65-foot span built in 1954 indicate:

- Spans that are longer than the inside axle spacing of the cars, such as these intermediate length spans at FAST, do not experience full unloading under each car. Thus, the stress range cycles for each car are less than the maximum stress. If this is properly accounted for, it can be of tremendous benefit in a service life analysis.
- A simple fatigue life estimate, based on theoretical maximum stress near midspan and one full loading and unloading cycle per car, is only 196 million gross tons (MGT).
- Accounting for partial unloading cycles, the theoretical service life estimated using American Railway Engineering and Maintenance of Way Association (AREMA) rating provisions[1] is nearly 1,500 MGT.
- Estimated service life, based on strain gage measurements, is essentially infinite for this 65-foot span using the loading provided by the FAST train.
- Estimated service life based on proposed adjustments to theoretical stress range also is essentially infinite for this span.
- The AREMA service life rating recommendations[1] can provide a much longer life estimate compared to simple use of the basic fatigue design Category D.
- More than 650 MGT of heavy axle load (HAL) traffic has been accumulated on this span at FAST.

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INTRODUCTION

TTCI has installed intermediate length steel deck plate girder bridge spans at FAST. A 65-foot span, built in 1954, was donated by a Class I railroad in 2013. Figure 1 shows the span in the East Steel Bridge at FAST. It was installed in 2013 and has been described in detail in a previous *Technology Digest*.[2]

Figure 1. A 65-foot riveted deck plate girder span in the East Steel Bridge at FAST

Span Loading and Performance

The span is loaded about 25 percent above its normal rated capacity by the HAL train at FAST. The normal rating of the 65-foot span is Cooper E-45. The FAST train loading on this span is E-57. At more than 650 MGT of HAL traffic thus far, this span has performed well, with no defects noted and no maintenance required.

Bridge Service Life Estimates

The service life of this span can be estimated in a number of ways, yielding varying results. Normally, bridge service life estimates are first made using theoretical calculations. If the theoretical estimate comes up shorter than is desired, improvements in analysis and strain gage measurements of the bridge under traffic are options that can often lead to a longer estimated service life.[1]

Life Estimate Based on Theoretical Calculated Maximum Stress

The most expedient and conservative estimate — which also yields the shortest estimated service life — uses the maximum stress in the span, with one cycle per car and fatigue Category D. The FAST train consists primarily of 53-foot rotary dump cars with a truck axle spacing of 6 feet and a truck center spacing of 40.5 feet. The loading from these cars is used for the service life estimate. The Cooper E-80 design load is not appropriate for estimating service life as actual loads should be used.

The effective span length (center-to-center of bearings) of this girder span is approximately 63 feet. The maximum bending moment from the HAL train loading is increased to account for impact at the normal 40 mph train operating speed at FAST. Maximum stress is computed using the net section modulus of the girder. These calculations are all made in the same fashion as is done for a load capacity rating. For a service life estimate for girder spans, AREMA recommends 35 percent of the design impact be used for the mean impact for fatigue rating (the same as the mean impact used for fatigue design).

The magnitude of the live load stress range is the most influential parameter for service life calculations. It is conservative to assume the number of load cycles produced per train to be the same as the number of cars plus locomotives in the train. The theoretical maximum live load stress (including fatigue design impact, 35 percent of design impact) near midspan under the HAL train is 12.07 ksi.

For stress ranges above 9 ksi, AREMA recommends the standard Category D fatigue life (S-N) curve.[1] The service life is estimated at 1.2 million cycles for this 65-foot span. For the 315,000-pound cars at FAST, this number corresponds to only 196 MGT of HAL traffic. With more than 600 MGT accumulated at FAST, this estimate is too conservative. Using maximum stress is a quick, easy way to avoid doing a stress range calculation on spans that are not even close to being a problem. If such a calculation shows a potential fatigue problem then a proper stress range analysis is in order, as is the case here.

Life Estimates Based on Theoretical Calculated Stress Range

For spans that do not experience full unloading under each car, the stress range for most of the load cycles is normally less than the maximum live load stress. Unlike maximum bending moment, which always is near midspan (for simply supported intermediate length bridge spans subjected to typical North American railroad loadings), the location of the maximum moment range can vary considerably depending on car length and span length.[3] A further complication is the consideration of the partial length cover plates commonly found in riveted railroad girders. The resulting variation in girder cross section properties also must be taken into account when computing stress range for a fatigue life analysis.

The moment range is calculated as the difference between maximum and minimum moments. The stress range at each location is computed using the section modulus at that location. See Figure 2. The calculated static maximum stress range for the HAL cars on this span is 6.53 ksi near midspan. Adjusting the stress range to account for fatigue design impact gives 7.52 ksi.

For a typical unit train traversing an intermediate length span, there is one cycle at the maximum stress, and approximately one cycle per car at the stress range. The total number of load cycles per train is approximately the same as the number of cars plus locomotives in the train.

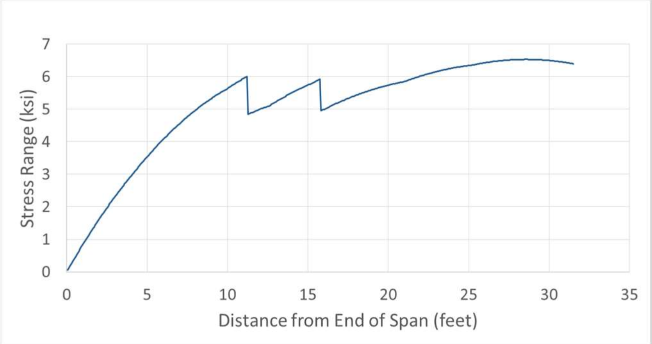

Figure 2. Stress range along tension flange of 65-foot girder span under 53-foot HAL cars

For a typical pass of the FAST train, with three locomotives and 110 HAL cars, there will be one cycle at the maximum stress of 12.07 ksi, and approximately 112 cycles of 7.52 ksi at midspan. This is much less severe than the maximum stress for all cycles. The equivalent stress range (root-mean-cube) for a Category D fatigue analysis is 7.58 ksi. Category D fatigue life for this stress range is 5.0 million load cycles (792 MGT) of HAL traffic. While computation of the maximum stress range is more extensive, the resulting service life estimate using this method is four times the estimate using theoretical midspan maximum stress.

Most of the stress range cycles for this 65-foot span are below 9 ksi, so a further option is available using the AREMA rating guidelines. For riveted spans and stress range cycles below 9 ksi, Category C may be used for those cycles. Category D is still used for the one large cycle per train. In order to properly implement this AREMA provision, the cycles need to be evaluated against different portions of the S-N curve using the Palmgren-Miner rule as described in the *NSBA Fatigue Primer*.[4] The equivalent stress range equation (root-mean-cube) given in AREMA cannot be used. The resulting fatigue life estimate using this provision is 9.4 million cycles (1,486 MGT), or more than seven times the estimate using theoretical maximum midspan stress.

AREMA Chapter 15 has a provision, 7.3.2.2.d(2), to allow continued operation of a span with equivalent stress range less than 9 ksi provided certain requirements are met for lateral bracing and frequency of inspection. This provision could be applied in this situation.

Life Estimates Based on Measured Stress Range

One method for improving a service life estimate is to use strain gage measurements under actual traffic. Comparison of the theoretical stresses and stress ranges noted above to the measured data in Figure 3 indicates that the measured stresses are considerably lower. Therefore, use of the measured stress ranges should produce an increased life estimate for this span.

Figure 3 shows midspan tension flange stresses in one of the girders as measured using strain gages in the 65-foot span under normal FAST train operations at 40 mph. The train on the day of these measurements had three locomotives (6-axle) and 108 cars, with a total weight of 17,395 tons. As predicted in the theoretical computations, the stress does not return completely to zero between the lead and trail trucks of each car. Since cycles with stress range below 6 ksi need not be included when using the AREMA life estimation method, Figure 3 shows that there is only one cycle (the entire train) that must be considered.

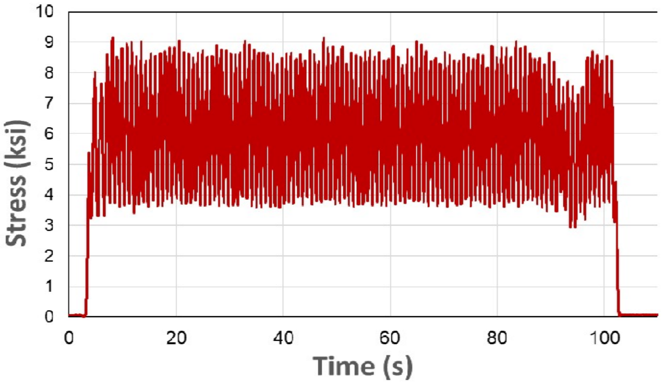

Figure 3. Tension flange stress at midspan of 65-foot span under FAST train loading

The magnitude of that cycle is the maximum recorded stress of 9.2 ksi. Based on the AREMA rating provisions, using Category D for a stress range greater than 9 ksi, the number of cycles to a 2.5 percent probability of crack initiation is 2.8 million. With only one cycle per train, it would take about 48,000 MGT of the HAL train to accumulate this many cycles, which is more than 300 years at FAST.

Comparison of Service Life Estimates

Vast improvements in service life estimates using strain gage measurements suggest that there is tremendous potential benefit in developing an improved theoretical stress range calculation that agrees more closely with the measured values. There are several possible factors contributing to measured stress range being less than that calculated using basic beam theory: 1) distribution of wheel loads by the rail and deck; 2) partial fixity of the bearings in translation and rotation; 3) partial section contribution from the rail and deck; 4) actual impact (due to smooth continuous welded rail) being less than that assumed; 5) all components of the girders acting in unison; and 6) effective span length. The first three factors require a detailed finite element model to estimate. Work is underway to develop improved methods to evaluate these effects for better bridge life estimates.

Some industry experts have proposed using an impact of 15 percent of the design value for purposes of estimating fitness for service.[5] They have also proposed using 85 percent of the live-load stress ranges, based on extensive test data. With these reductions, the theoretical stress range per car is less than 6 ksi for this span. This results in an estimated service life of 2.6 million cycles and more than 40,000 MGT.

Comparison of the various life estimates is shown in Figure 4. Note that both the use of stress range rather than midspan maximum and measured stresses rather than theoretical stresses lead to more favorable fatigue life estimates.

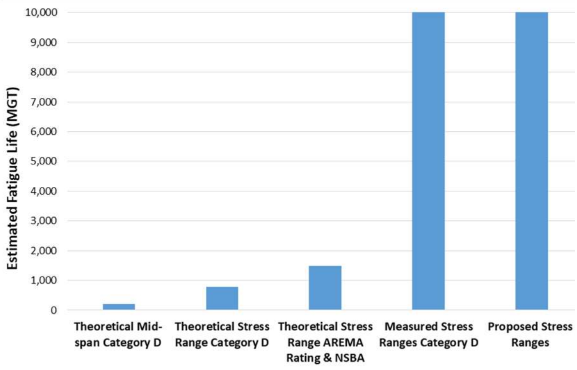

Figure 4. Comparison of fatigue life estimates for FAST 65-foot span using various stress cycle ranges and rating provisions (bars to 10,000 MGT are truncated)

CONCLUSIONS

TTCI has performed service life estimates for a 65-foot span at FAST. Measurements and analyses indicate:

- For spans that do not experience full unloading under each car, stress range cycles for each car are less than the maximum stress. If this is properly accounted for, it can be of tremendous benefit in a service life analysis.
- A simple fatigue life estimate based on theoretical maximum stress using design criteria near midspan is too conservative for an intermediate length span. The tonnage carried by this span at FAST already is more than three times the estimated life using this conservative method.
- The theoretical service life estimate using AREMA rating provisions is more than seven times higher than the simple midspan analysis for this span.
- Estimated service life based on strain gage measurements is essentially infinite for this span.
- Estimated fatigue life based on proposed guidelines is essentially infinite for this span.

Further analysis and testing is needed to determine the effects of rating methods on spans of other lengths and spans subjected to different train loadings. Further analysis also is needed to estimate cycle accumulation over the service history of various bridges.

ACKNOWLEDGEMENTS

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