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Validation Test of New Steel Bridge Fatigue Considerations

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Summary

Transportation Technology Center, Inc. tested a steel railroad bridge to validate a recent development in fatigue theory that is particularly applicable to unit trains on steel railroad bridges. The test results show the need to evaluate fatigue ratings at quarter-span locations, in addition to the traditional mid-span location for many typical railroad spans.

While the mid-span location is usually the area that governs steel girder design for bending, and is most commonly checked for rating, this study shows that the quarter-span area should also be checked when fatigue is considered.

Results further indicate:

- Fatigue life of steel bridges depends on the ratio of the car-to-span length. Thus, a certain bridge span may have different fatigue lives depending on the length of the cars operating in unit trains over the bridge.
- For certain spans of steel bridges, fatigue life at quarter-span locations could be less than half that at midspan locations; e.g., quarter-spans of the 115-foot steel bridge tested under this program appear to have 4 to 5 times less fatigue life than midspan.
- Spans approximately twice the length of a common unit train car are most likely affected by fatigue near the quarter point.
- Girder spans of about 70 to 130 feet are most affected by typical unit train cars.
- Bridges with partial length cover plate flanges are most affected.

Lower fatigue life at quarter-span locations in existing steel railroad bridges might not be an immediate concern. However, many railroad bridge girders fall in the affected range of span lengths and need careful inspection.

This study was performed as part of an effort to update the Association of American Railroads' (AAR) bridge fatigue models under the AAR Strategic Research Initiatives on railroad bridge life extension.



INTRODUCTION AND CONCLUSIONS

The understanding of the fatigue life of steel railroad bridge components is of particular importance; some steel girders may have reduced section areas at or near quarter-span locations. The designers might not have anticipated today’s heavier axle loads or considered fatigue.

Fatigue life depends on the size and number of load cycles. For a certain car-to-span length ratio, the number of cycles may be higher at quarter-span locations than at midspan locations. In that case, the bridge components at or close to a quarter-span location may accumulate higher fatigue over the service life of the bridge than those components at or close to a midspan location. The effect of the car-to-span length ratio on fatigue life is a recent theory and has been discussed in detail in references 1 and 2.

Theoretical fatigue life due to unit trains was studied for spans up to 160 feet. This study provides a range of spans in which the fatigue life may be lower for typical unit trains. For certain bridge spans, unit coal and grain trains appear to reduce fatigue life at quarter-span locations more than 50 percent compared to midspan locations.

To validate the theory, a 115-foot span bridge over the Fountain River in Pueblo, Colorado, was instrumented and strain histories were measured under unit trains. As expected, fatigue life of the bridge at quarter-span locations was up to four times lower than at midspan locations under grain and coal train traffic. No appreciable difference in midspan and quarter-span fatigue life was observed under unit tank train traffic.

The fatigue accumulation due to unit trains appears to be higher at quarter-span locations than at midspan locations for a range of span-to-car length ratios near 2.

AFFECTED BRIDGE SPAN RANGES

To determine the bridge span range that might have higher fatigue damage at quarter-span locations than at midspan locations, fatigue calculations were performed for unit trains operating over span lengths up to 160 feet. Unit trains analyzed include those with 53-foot cars (typical for rotary dump coal cars), 59-foot cars (typical for grain cars), and 44-foot cars (for some shorter cars). Fatigue cycles and stress ranges at both quarter-span and midspan locations were accumulated using the AREMA Chapter 15 root-mean-cube calculation.³ Fatigue lives at quarter-span locations were normalized based on the fatigue lives at midspan locations.

This analysis was performed for girders with a uniform cross section (see Figure 1), as well as a variable cross section (see Figure 2). The variable cross section analysis assumes the quarter-span location has a section modulus equal to 75 percent of the midspan section modulus.

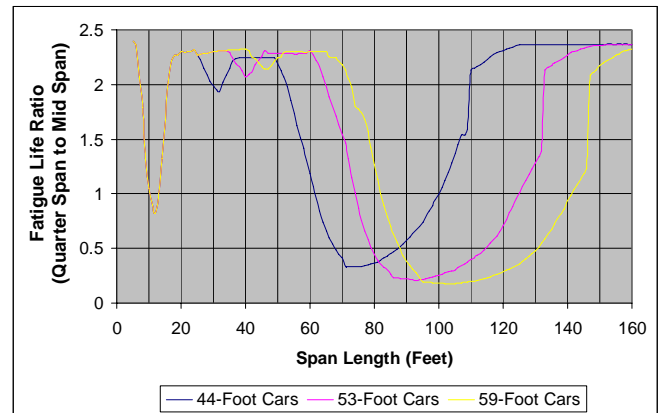


Figure 1. Relative Fatigue Life under Unit Trains for Girders with Uniform Cross Section

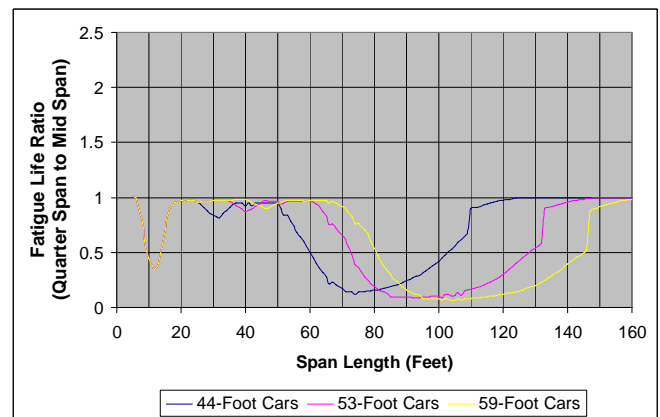


Figure 2. Relative Fatigue Life under Unit Trains for Girders with Variable Cross Section

The results of these calculations show that a wide range of girders was affected, particularly girders with variable cross sections. The effects are most significant for ~100-foot girders. This span length is approximately twice that of common unit train cars.

TEST BRIDGE

Figure 3 shows the BNSF bridge over the Fountain River in Pueblo, Colorado. It is conveniently located to TTCL, accessible, with span lengths of 115 feet overall. (Span length is under 113 feet from center-to-center of bearings). The bridge has several deck plate girders with a ballasted deck. The girders are of riveted fabrication with flanges made of several cover plates. The girder cross section varies, changing at cover plate cutoff locations. Traffic over the bridge includes numerous unit coal trains, occasional unit grain trains, and unit tank trains, as well as manifest freight trains.



Figure 3: BNSF Fountain River Bridge Used for Validation Testing

Strain gages were attached to both girders of the easternmost span. Gages were located near the midspan location and also near the east quarter points of the girders. Data was collected under the passage of unit coal, grain and tank trains, as Figure 4 shows. The different car lengths in these trains provided the opportunity to make additional comparisons to the theory regarding the ratio of car-to-span length.



Figure 4: Unit Grain Train Crossing 115-Foot Test Span

TEST RESULTS

Figures 5, 6, and 7 show strain data, converted to girder stresses, from the passage of a coal train, a grain train, and a tank train, respectively. The coal train had uniform car lengths of 53 feet. The coal cars also appear to have been uniformly loaded. All cars in the coal train were stenciled for 286,000 pounds gross rail load (GRL).

The grain train had car lengths of about 58 feet to 61 feet. Some cars in the grain train were stenciled for 286,000 pounds GRL, while others were stenciled for 263,000 pounds GRL. Some variation in car loading is evident in the data, likely corresponding to the differences in car capacity.

The tank train had car lengths of about 43 feet to 45 feet. As with the grain train, some cars in the tank train were stenciled for 286,000 pounds GRL, while others were stenciled for 263,000 pounds GRL. Again, some variation in car loading is evident in the data, likely corresponding to the differences in car capacity.

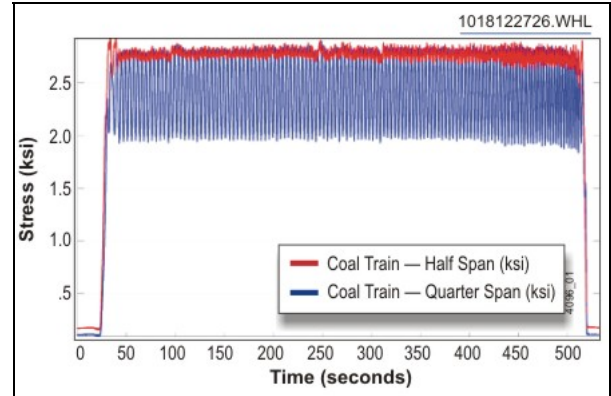


Figure 5: Girder Stresses under Coal Train with 53-Foot Cars

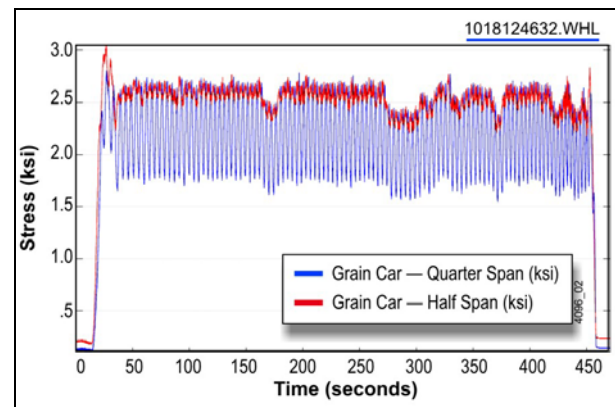


Figure 6: Girder Stresses under Grain Train with 58- to 61-Foot Cars

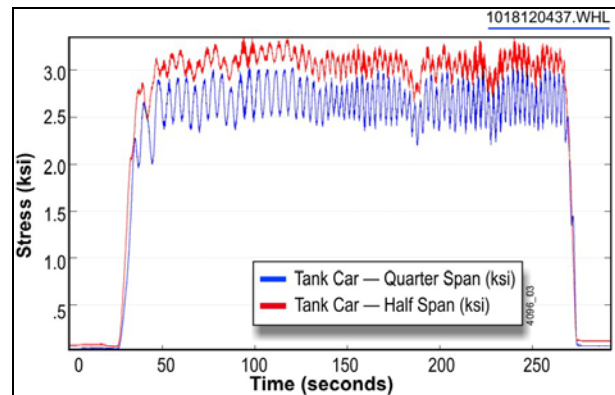


Figure 7: Girder Stresses under Tank Train with 43- to 45-Foot Cars

DISCUSSION AND FATIGUE COMPARISONS

The data collected under the coal and grain trains (Figures 5 and 6) illustrate the phenomenon predicted by the theory.¹ The cars in both of these trains are very close to half the span length. Based on the span length from center-to-center of bearings, the car-to-span length ratio is 0.47 for the coal cars, and about 0.52 for the grain cars. The car-to-span length ratio for the tank cars is about 0.39.

As expected, the shorter cars in the tank train produce the highest strains at the midspan location. They also generate the largest per-car cyclical stress variations at the midspan location. It is reasonable to expect that they will accumulate the greatest amount of fatigue at the midspan location. Figure 8 compares fatigue life calculations from both theoretical and measured stress ranges for the three car types at the midspan of the 115-foot girder. As expected, the shorter tank cars produced the shortest fatigue life at the midspan location. The longer grain cars produced the longest fatigue life at the midspan location. For ease of comparison, all fatigue life calculations were normalized to those for the common 53-foot coal car at the midspan location.

The comparisons between measured and theoretical fatigue life for the midspan location are reasonably good, considering some of the assumptions made in the analysis. The measured fatigue life estimates were made using the measured stress histories for the three train types. The theoretical calculations assumed uniform trains of 286,000-pound cars for all three train types, and uniform car lengths of 44 feet for tank cars, 53 feet for coal cars, and 59 feet for grain cars. As noted above, the actual trains had some variations in car lengths and weights, particularly for the tank and grain trains. These differences likely contribute to the variations between the theoretical and measured values, as Figure 8 shows.

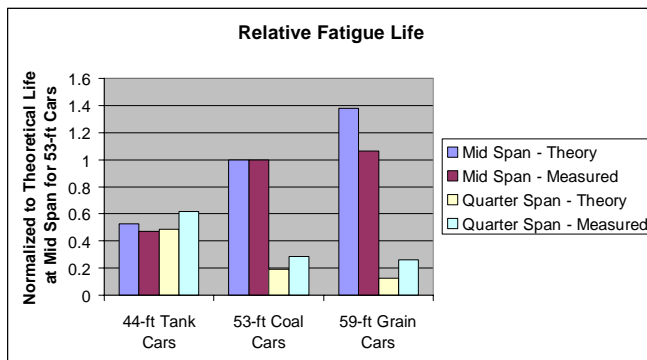


Figure 8: Relative Fatigue Life for a 115-Footer Girder Span under Three Unit Train Types

Note that in Figures 5 and 6 for the coal and grain trains, the peak stresses at the quarter-span locations are nearly as high as those at the midspan location, due to the reduced cross section of the cover-plated girder at the quarter points. And there is more cyclic activity, adding to the amount of fatigue experienced at the quarter-span locations. One might expect the fatigue life at the quarter points to be less than that at the midspan location for the coal and grain trains. Figure 8 also shows the computed fatigue life at the quarter-span locations for all three train types on this 115-foot girder span.

The fatigue life at the quarter-span locations for the unit coal and grain trains is significantly less than that at the midspan location for those trains. In fact, the fatigue life for the coal and grain trains at the quarter-span locations is less than that shown for the midspan location for the tank train.

Assumptions and Caveats

The above analysis is only for the 115-foot span tested under the three train types shown. Results may vary with spans and cars of different lengths.

For this particular bridge, the design is quite heavy and the peak stresses are relatively low. Since the stresses are so low compared to the constant amplitude fatigue limit, most of the stress cycles at the quarter point would not normally be counted. But for a bridge of lighter design, most or all of the stress cycles might be appropriately counted. So, for purposes of illustration, the above analysis included all stress cycles greater than 0.5 ksi in the fatigue stress computations. Depending on the type of detail, peak stress levels, and other factors, stress cycles of magnitude less than half of the constant amplitude fatigue limit might be ignored.

Railroad Bridge Design and Rating Implications

While the midspan location is usually the area that governs girder design for bending and is most commonly checked for rating, this study shows that the quarter-span area should also be analyzed when fatigue is considered. The car-to-span length ratio is a key parameter that controls the potential for fatigue to govern near the quarter-span locations rather than the midspan location. For light bridge designs and certain car-to-span length ratios, the fatigue life at the quarter-span locations might be less than that at the midspan location by a significant amount. Built-up girders with cover plate cut-offs are more likely to be affected than girders with a constant cross section.

ACKNOWLEDGEMENT

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REFERENCES

- Dick, Stephen M. 2002. "Bending Moment Approximation for Use in Fatigue Life Evaluation of Steel Railway Girder Bridges." Ph.D. Dissertation, Department of Civil, Environmental and Architectural Engineering, University of Kansas, Lawrence, Kansas.
- Dick, Stephen M., and Steven L. McCabe. 2002. "Fatigue Analysis of Steel Railway Girder Bridges." American Railway Engineering & Maintenance of Way Association 2002 Annual Conference.
- American Railway Engineering and Maintenance of Way Association. 2008. *Manual for Railway Engineering*, "Chapter 15 – Steel Structures," Lanham, Maryland.

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