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Bridge Girder Testing on Norfolk Southern Railway

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Summary

Transportation Technology Center, Inc. (TTCI) tested three open-deck bridge spans on Norfolk Southern (NS) in a program to obtain loading history data under different train types on different span lengths. The results are being used to provide updated information on fatigue life estimation for steel deck girders. The focus is on continued service instead of potentially premature replacement.

Riveted steel deck girder spans of 30-, 64-, and 80-foot approximate overall lengths were tested at the eastern mega site between Roanoke, VA and Bluefield, WV. Data was obtained under normal revenue traffic at quarter points and mid-span on all three spans. Traffic included unit coal, unit grain, automotive, articulated double stack, and general merchandise for all bridges combined. Models for all three girder spans were also developed using finite element analysis (FEA).

Results from the test data and modeling indicate the following:

- For all train types measured during this testing, these three bridge spans have essentially infinite fatigue life assuming appropriate maintenance and inspection.
- Maximum stresses measured on all three test spans were all under 6 ksi, the limiting stress for riveted members for accumulative fatigue cycles.
- Finite element models including rail, deck ties, bracing, and realistic bearings were accurate compared with measured tension flange stresses. The models showed an upward shift in the neutral axis from the mid-height of the girder. The bearings also displayed additional stiffness compared to fully rotational, resulting in lower overall stresses than anticipated in design.
- Further analysis showed that measured stress ranges were consistent with simple classical beam analysis assuming simple point loads, no impact, and gross section properties. For these three spans, the stress reductions due to bearing fixity plus rail and deck contributions are similar to those obtained by not using net section properties.

For these particular spans, the results show that the bridges are performing well overall in current service under 286,000-pound loads without any accumulation of fatigue.

This work was performed as part of the Association of American Railroads' (AAR) Strategic Research Initiative on bridge life extension.

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TTCI
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INTRODUCTION

TTCI personnel performed revenue service testing on Norfolk Southern Railway (NS) steel deck plate girder bridges on their route between Roanoke, VA and Bluefield, WV. Three open-deck bridges were monitored for bottom flange stresses at mid-span and quarter points.

The testing was followed by FEA to compare theoretical results versus actual measured results. Measured stresses are close to those computed using FEA. The tests utilized portable gages, providing an efficient method for measurement in revenue service. One bridge required track time/occupancy over a waterway. Results from two years of testing were consistent.

BRIDGE V-264.70

Bridge V-264.70 is on the Whitethorne District near the station of Ironto, VA. The bridge is a multi-span separation above Bradshaw Creek and State Road 603. The tested span is the west end span (#4). The bridge is on tangent alignment in single main track territory of the old Virginian Railway main track. Measurements taken of the deck indicated that the span was approximately 1/2 inch off center (maximum) between track and girders.

The span has a 28′1″ center-to-center bearing distance. The two girders are spaced at 6′6″. The design is 1922 Cooper E75 with steam impact. Construction is two-girder riveted steel girders with built-up members and cover plates. Open-deck 10″×10″ timber ties comprise the deck. Bearings are 20″×20″ flat plates, resting on concrete substructure.

BRIDGE V-287.60

Bridge V-287.60 is on the Whitethorne District near the station of Whitethorne, VA, just east of the east siding switch, over Tom’s Creek. The bridge is located under a 0°40″ curve with 1-inch superelevation. The mid-ordinate distance of the curve is bisected by the bridge centerline. At mid-span, the outside rail of the curve is partially over the girder.

The bridge is a single-span two-girder riveted steel deck design, 1906 Cooper E60 with steam impact. The span measures 77′4″ center-to-center of bearings with a girder spacing of 7 feet. The deck is composed of 10″×12″ timbers with superelevation dapped into the ties. Bearings are rocker bearings designed to allow rotation. The span rests on concrete abutments.

BRIDGE N-354.13

Bridge N-354.13 is on the Christiansburg District near Blake, WV. The bridge is in two main track territory with the tested span under Main 2. The bridge is a single-span crossing on concrete abutments, with a length center-to-center over bearings of 61′9-1/2″. The design is two-girder riveted steel 1926 Cooper E70 with steam impact. The deck uses open-deck dapped timber ties a minimum 10-1/2″ deep × 14″ wide, varying the daps for the change in superelevation.

The bridge has a spiral alignment on the east end with a superelevation of 2 1/2 inches. The point of spiral to tangent is located at the western quarter point. The bridge itself is slightly skewed to accommodate the track alignment. The track-to-bridge center distance varies from 3 inches on the east end and is centered on the west end.

TESTING METHODOLOGY

This testing program marked the first use of portable strain gages for strain measurements for TTCI. Portable gages allow for more efficient installation and removal. The gages are attached with tabs with epoxy adhesive for connection to the girder steel. Surface preparation requires grinding the steel to obtain a clean, polished appearance before attachment.

The testing focused on obtaining tension stresses on the bottom flange. The gages were placed at mid-span and one of the quarter points on each girder on the bottom flange, a total of four channels. Total setup time from start to finish was two to three hours at each location. This setup time included the data acquisition system. Bridges V-264.70 and N-354.13 had low center heights, so installation by ladder was available. Bridge V-287.60 over Tom’s Creek required the use of a snooper truck. Installation time was the same for both methods.

Mid-span strain gage testing is established practice, but testing at quarter points is a recent addition. From theory and testing, it is evident that fatigue can occur across the length of cover plates, especially at cover plate cutoffs. Mid-span and quarter point data allows calculation of the rest of the length.

For load data, wheel impact load detector (WILD) data was available for some trains. Ongoing work merging WILD data with Umler® System data will use virtual trains for additional FEA to compare virtual and actual time histories.

TRAFFIC MIXTURE

The traffic on this line, historically primarily coal, currently includes a mixture of unit coal, unit grain, general manifest, automobile, and container intermodal. Coal and grain train data was obtained at all locations with the other train types captured at individual locations. WILD data was not available for all trains. Some additional data was available from train consist information without weight data.

DATA ANALYSIS

The data was captured as moment time histories. Figure 1 displays a typical unit train time history at mid-span.

The difference in stresses between north and south girders is due to the track centerline location relative to the bridge centerline for this particular span.

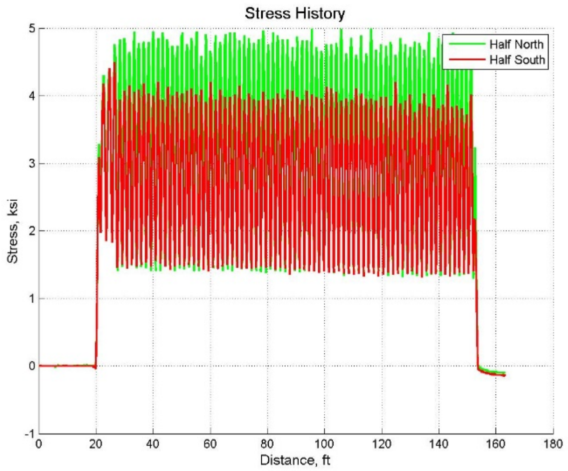

Figure 1. Typical Bending Moment Time History

Consistent results were obtained at all three bridges regarding the magnitude of maximum stresses. Typically, the stresses were below calculated stresses using American Railway Engineering and Maintenance-of-Way Association (AREMA) rating and fatigue provisions,[1] including impact. Essentially, the stresses were comparable to assuming two conditions for stress computation: (1) the assumption of static loading, or no impact reflected in the stresses, and (2) assuming gross section for section properties instead of the traditional net section. Comparisons of actual stresses to the use of static stress from gross section are shown in Figures 2 through 4 for the three bridges.

For use in fatigue design and evaluation, total design impact is reduced to 35 percent of its full value. The reduction is significant for shorter spans, with longer spans having very low overall anticipated impact stresses.

The assumption of gross section versus net section can be argued either way. What is apparent from the results is that regardless of the actual behaviors, the assessment of stress could be estimated using gross section and static loading. Checking the stresses against more thorough analysis was considered appropriate to determine if the stress magnitudes can be obtained computationally. This resulted in development of finite element models of all three bridge spans.

The finite element models were built and run using LUSAS® finite element software. The models include development of the girders, open-deck bridge ties, and rail for the bridge. Lateral bracing and cross frames were also included in the development of the models for each of the tested bridge spans.

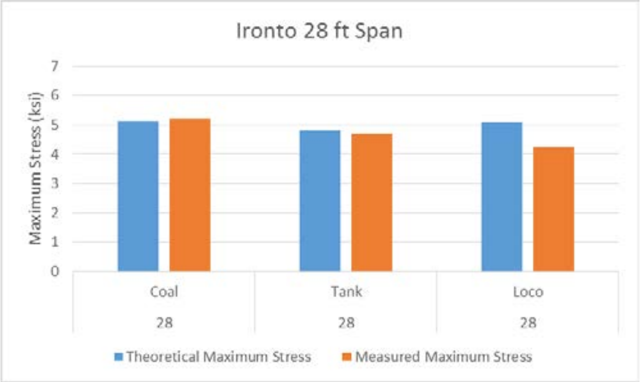

Figure 2. Maximum Stresses for Bridge V-264.70

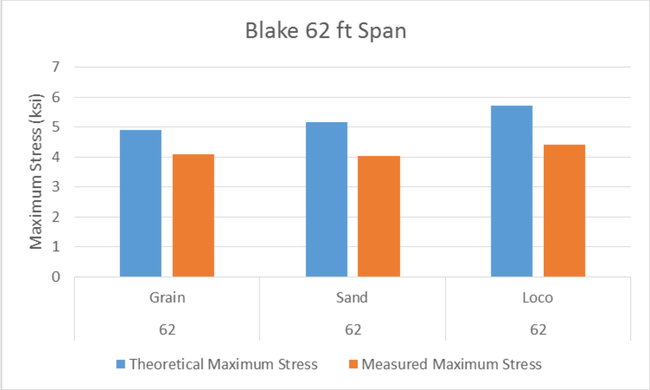

Figure 3. Maximum Stresses for Bridge N-354.13

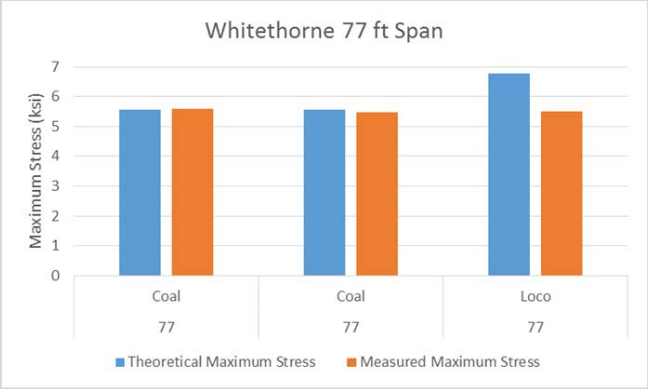

Figure 4. Maximum Stresses for Bridge V-287.60

The results of the finite element analysis for Bridge N-354.13 are shown in Figure 5. The finite element results for the other bridges are similar in nature. Two behaviors displayed in the FEA assumed in standard analysis are contrary to those assumptions: (1) apparent fixity from the bearings supporting the spans, and (2) the neutral axis located at the center of the symmetrical section of the girders during bending.

The apparent fixity from the bearings is likely due to resistance of rotation in the flat plate bearings. The resistance at the ends affects the shape of the elastic curve and the deflected shape. The assumption of standard analysis is a knife edge bearing allowing full rotation under any load. Bearings designed for rotation

(Bridge V 287.60) can also provide the same behavior when the bearings are frozen, which is a common occurrence.

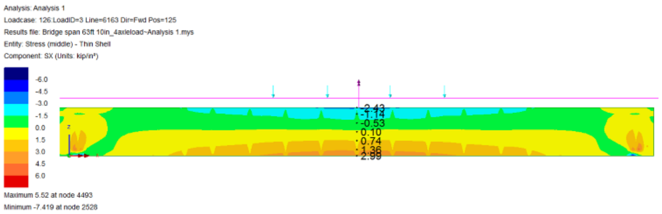

Figure 5. Typical Finite Element Results for Bridge N-354.13

The apparent shift in the neutral axis is displayed in the FEA. The shift for all three modeled spans was in the range of 5 to 7 percent upward. The FEA results match measured bottom flange stresses well. The shift of the neutral axis could be conjectured as the rail acting as part of the bridge span. This is currently only conjecture, but potential experimentation at the Facility for Accelerated Service Testing (FAST) could provide some insight.

The low stresses under fully loaded conditions must also be put into the context of the original designs. These spans were heavier than normal designs primarily for coal service in terrain requiring large motive power.

In relation to fatigue evaluation, the measured stresses are not sufficient for cycle accumulation in riveted girder sections at the locations measured on the spans. Location of maximum stress range can be evaluated by calculation. Fatigue evaluation is sensitive to stress range, so accuracy of actual values for different equipment is more critical than in determination of basic capacity ratings.

CONCLUSION

TTCI tested three open-deck bridge spans on NS in a program to obtain loading history data under different train types on different span lengths. The testing was limited to two-girder deck girder bridges. The results are being used to provide updated information on steel deck girders where focus is on continued service instead of potentially premature replacement.

The testing validated the use of portable strain gages. The gages resulted in efficient installation with consistent results from different testing periods. Use of these gages will continue to provide efficiencies for the TTCI bridge testing program.

This testing program incorporated measurements at the quarter points in addition to the mid-span for girder bridges. Measurement of quarter point stresses is essential for comprehensive fatigue assessment.

Maximum stresses measured on all three test spans were all under 6 ksi, the limiting stress for riveted members for accumulative fatigue cycles. For all train types measured during this testing, these bridge spans have essentially infinite fatigue life assuming appropriate maintenance and inspection.

The recorded time histories will be recreated virtually using obtained WILD data combined with UMLER® data. The trains can be processed to recreate the time history. Comparison between the actual and virtual versions may create potential for maintaining cycle counts on a real-time basis for train traffic.

Study of the virtual results of the FEA is warranted on a macro basis. Determining if the rail is part of the load-carrying structure is complex and likely inconclusive. Determination of fixity, however, can be performed at FAST.

Data from previous tests can be reexamined to see if the use of gross section and static loading produce similar results. While it provides a convenient shortcut for examination, it can only be considered a convenience until the entire loading mechanism is better understood. The mechanism transmitting loads from the track to the girders is not included. Deck design criteria in the AREMA recommendations[1] is a starting point since it assumes a spread of the load over a distance.

Additional reports from the testing will include examination of bending moment time histories, detailed results for each location, and estimates of traffic history to evaluate accumulated fatigue.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the support and assistance of Norfolk Southern Railway.

References

1. American Railway Engineering and Maintenance-of-Way Association. 2017. *Manual for Railway Engineering*, Chapter 15, “Steel Structures.” Lanham, MD.