TECHNOLOGY DIGEST

Timely Technology Transfer

LOADING SPECTRA AND RESPONSE OF A SHORT-SPAN RAILWAY BRIDGE

by

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TD95-012

Summary

A research project was initiated to develop loading spectra and response for railway bridges under current operating conditions. Evaluation of this loading spectra and response will assist in the assessment of the fatigue damage and the remaining fatigue life of the structure. This research will be useful in determining renovation and inspection needs for critical components of existing railway bridges and in designing new railway bridges.

Recent AAR testing of a short span through plate girder railway bridge has shown that the plate girder was loaded at only 50% of its original design loading. The stringer measurements were loaded at approximately 60% of their original design loading. Because of its short span, most of the cars could completely span the bridge. Test results verified this in that the plate girders were experiencing nearly one loading and unloading cycle for each typical car. And both plate girders experienced similar bending moment values indicating a relatively symmetrical load path on the bridge.

Experimental results from the analysis of the knee brace at the plate girder to floor beam connection showed that the knee brace carried almost no load. This demonstrates that the primary purpose of the knee brace is to prevent lateral buckling of the compression flanges in the plate girder. Analysis of the loading spectra developed from testing of this bridge showed that the vertical rail locations on and off the bridge recorded slight differences in the car loadings. The average total measured loads of the test train consist was approximately 12% higher for the 60 mph passage than for the 5 mph passage. This indicates a dynamic interaction between the bridge, train, and rail, possibly due to the difference in stiffness at the approach and on the bridge.

The bridge described in this digest is a 40-foot, open, through plate girder railway bridge. Measurements were recorded to determine the loading spectra and the bridge response from 209 revenue train passings. The revenue traffic consisted of unit-coal, unit-autorack, intermodal, and mixed freight trains. A special work train was also used to evaluate the loading patterns from a known consist at various speeds.

Suggested Distribution:

Operating/Engineering:

- ❑ Bridges and Roadway
- ❑ Maintenance Planning

Research and Development

Association of American Railroads
Research and Test Department
April 1995

INTRODUCTION AND CONCLUSIONS

The AAR's bridge program, which began in 1988, is designed to study in-service railway bridges under current loading conditions. This program has focused on two major concerns of the railway industry, the potential problems of the aging structures and the response of the bridges to increases in loadings. This digest describes a test on a 40-foot open deck, through plate girder railway bridge.

This bridge was chosen for testing because of the diverse revenue traffic mix. Traffic crossing over this 40-foot span bridge consists of unit-coal, unit-autorack, intermodal, and mixed freight trains. With the diverse speeds of the traffic, impact loads and dynamic effects due to train speed were also a consideration in the selection of this bridge.

Analysis of the loading spectra developed from the test shows that each rail location on and off the bridge was experiencing slightly different rail loads. This could be attributed to the dynamic interaction between the bridge, train, and rail. The difference in stiffness at the approach and on the bridge could affect the recorded measurements. In addition, the loading in the respective train's cars may not have been uniformly distributed. Differences in train speed could also have affected the rail loads.

A theoretical analysis of this bridge was used to examine different train consists. Some of the observations from the theoretical and experimental results are:

1) The plate girders experienced nearly one cycle for each typical car, and the bending moment response at the center span of both plate girders was almost the same. The bending strain in the north plate girder for a loaded coal train and an autorack train is shown in Exhibits 1 and 2, respectively. Even though the autorack cars cause the plate girder to totally unload, the peak-to-peak strain cycle is higher for the loaded coal train. This indicates that this bridge, because of its span length, responds to individual truck loadings, instead of entire car loadings. This also indicates that the loaded coal trains are of more concern than the autorack trains in terms of the reduction of fatigue life, for this particular span length.

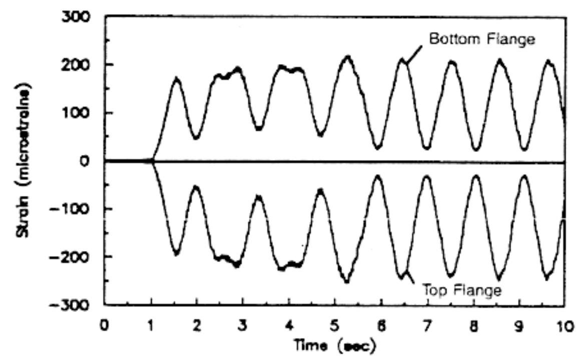

Exhibit 1. Bending Strain in North Plate Girder due to a Loaded Coal Train.

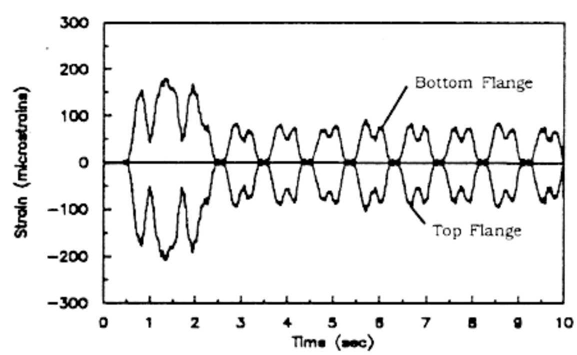

Exhibit 2. Bending Strain in North Plate Girder due to an Autorack Train.

2) In general, the average measured stress at the center span of the plate girders was below 6,500 pounds per square inch (psi), and the stress at the center span of the interior floor beam was below 8,500 psi. Based on the original design loading, the design stress for this bridge is 13,000 psi.

3) Even though the floor beam to plate girder connection was assumed to be rigid, the end moments in the floor beam were measured to be nearly zero. This is due to the lack of torsional stiffness in the plate girder.

4) The average total measured loads of the work train consist was approximately 12% higher for the 60 mile per hour passage than for the 5 mile per hour passage. Also, with regard to impact loading from the revenue trains, less than 1% of all of the vertical rail load counts were above 50,000 pounds.

The theoretical finite element and experimental responses of the connection between the floor beam and plate girder were also compared. Some tentative conclusions on the floor beam to plate girder connection are:

1) The applicability of simple bending theory does not hold in analyzing the floor beam to plate girder connection for this bridge.

2) The measured stresses at the strain rosette positions in the floor beam (Exhibit 3), matched closely with those predicted by the finite element method (FEM).

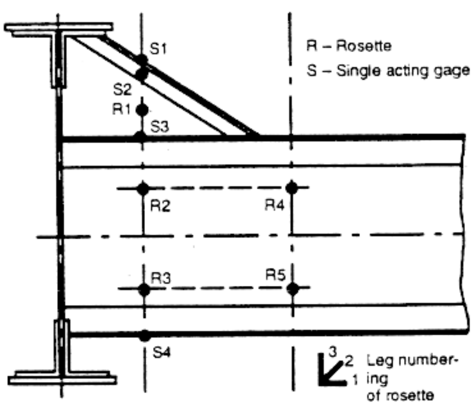

Exhibit 3. Strain Rosette Positions.

The experimental results indicated the moment at the end of the floor beam was nearly zero and that all of the shear was taken by the floor beam. This indicated that the knee brace is used only in preventing lateral torsional buckling of the compression flanges in the plate girder. However, the theoretical results showed that, under transverse loading, the knee brace transferred 30% of the vertical shear to the plate girder. The difference in the theoretical and experimental results of the knee brace indicate an inability to accurately model the knee brace to floor beam connection.

3) Both the measured and analytical stresses were well below the original design stresses for the plate girder and floor beam under current loading.

TEST PROGRAM

Bridge and Instrumentation Description

The bridge is located in Vonore, Tennessee, at Mile Post 311.5, approximately 40 miles southwest of Knoxville, Tennessee. It was built in 1905 with the majority of the construction being riveted. Bolts are used only in the stringer to floor beam connection, as specified in the original drawings. The bridge superstructure consists of plate girders that are 5'-9" in depth and are spaced 15'-6" center-to-center. The web stiffener spacing on the plate girders ranges from 2'-9" at the ends to 6'-6" at the center. The floor beams are 3'-0" in depth and are spaced 13'-4" on center. A knee brace is a part of each floor beam to plate girder connection. The stringers are 23.25" in depth and are spaced 9'-0" center-to-center.

The instrumentation of the track on this bridge consisted of eight vertical rail load measurements and one lateral rail load measurement on each rail. The vertical rail load measurements were collected at center span of the bridge, over an interior floor beam, and at each approach. The instrumentation of the bridge members consisted of single-acting strain gages, chevrons, linear variable differential transformers (LVDT's) and strain rosettes.

The members selected for the instrumentation were the plate girders, floor beams, stringers, and a knee brace. The floor beam to knee brace connection was instrumented only for the work train tests.

Loading Spectra

Of the 209 revenue trains that were collected for this test, 88 were loaded unit-coal trains, 44 were unloaded unit-coal trains, 39 were unit-autorack, 21 were mixed freight, and 17 were intermodal trains. The histogram in Exhibit 4 shows the vertical rail load percentage for each type of revenue train. The vertical rail loads of the unit-coal train were typically in the higher ranges, whereas those of the mixed-freight and intermodal trains tended to be spaced throughout all of the ranges. The vertical rail loads of the autorack trains, like the unit-coal, kept the same relative consistency in the histogram without much deviation, but in the lower ranges of the graph.

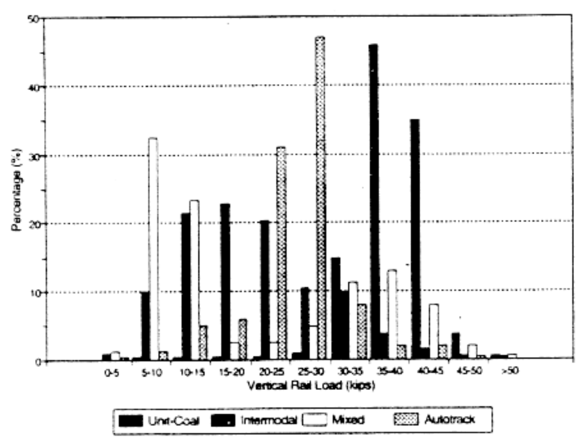

Exhibit 4. Vertical Rail Load Percentage for Each Type of Train.

Bridge Response

For each of the revenue and work train passages, the bending strains in the plate girders were recorded. Each flange strain of an interior floor beam was also collected. These floor beam strains were used to calculate the strong and weak axis bending, as well as any axial force. A structural analysis program was used to gain an understanding of connection behavior and load path from the measured strains.

Connection Response

The strain measurements on the floor beam and knee brace from the work train passages made it possible to evaluate the stress time histories at different strain rosette and strain gage positions. The stress time histories of normal stress, shear stress, principal stresses, and maximum and minimum shear stresses at different strain rosette positions were obtained using the strains measured at each rosette and strain transformation equations.

Finite Element Method

A finite element method (FEM) was used in this study to obtain the theoretical distribution of stresses and forces in the structure. Two models of a floor beam with and without a knee brace were developed for the FEM in order to study how the introduction of the knee brace affects the behavior of the connection.

Based on the symmetry of the bridge and the loading conditions, only half of the floor beam was analyzed using a symmetric boundary condition at the centerline. The loads used in the finite element analysis were the vertical, lateral and torsional loading. The loading used for the theoretical analysis was applied at the floor beam and stringer connection, as the loading is transferred from the stringers to the floor beam at that point. The model of the floor beam and knee brace connection for the finite element analysis was treated as a plane stress problem in which the stresses and strains are functions of x and y alone.

Note: Contact Bill Brantley at (312) 808-5417 with questions or comments about this document.

A more detailed report, which may contain revised information, will be available at a later date through the Document Distribution Center, Chicago Technical Center, 3140 South Federal Street, Chicago, Illinois 60616. A report list is available upon request.