

FATIGUE EVALUATION OF A STEEL OPEN-DECK THROUGH- PLATE-GIRDER BRIDGE

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Summary

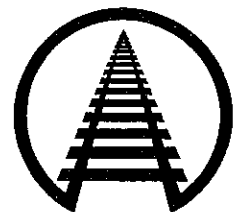
The Association of American Railroads (AAR) recently tested a steel open-deck through-plate-girder bridge with a span of 84 feet to evaluate its fatigue behavior and response under present day loading. The tests were conducted as a part of the AAR's ongoing research program to develop methodologies for extending the life of steel railroad bridges. Results revealed the following:

- Fatigue analysis, using the measured stresses, indicates that the interior floor beams are the most critical members. An estimated 74 percent of their fatigue life has been consumed since the construction of the bridge. The minimum remaining service life of the floor beams is about 4 to 7 years, depending on the volume of annual traffic.
- Stringers have expended approximately 51 percent of their life. They should last a minimum of 10 to 20 years, depending upon the traffic volume.
- The fatigue model developed by the AAR may be effectively used to predict the remaining life of various members of a steel bridge, and to help decide whether the life can be extended by strengthening a few critical members instead of replacing the whole bridge.

AAR researchers measured live load stresses under revenue service traffic and work trains and compared them with those from a finite element model. Using the measured stress data, the stress cycles for the various bridge members were computed. The minimum remaining life of the members was estimated by considering the past loading history as well as the current loadings.

Suggested Distribution:

- Maintenance Planning
- Research and Development
- Bridge Maintenance
- Maintenance of Way



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INTRODUCTION AND CONCLUSIONS

To study the effect of increased wheel loads on aging bridges, the Association of American Railroads (AAR) initiated a research project in 1988 which evaluated the loading spectra, fatigue behavior, structural integrity and impact loading spectra of steel railway bridges. The resulting work train and revenue service tests on bridges yielded a fatigue analysis model applicable to steel railway bridges.

Railway bridge infrastructure is a critical link in North America's transportation network. With the age of many railway bridges exceeding 50 years, and with the increasing axle loads in present day operating conditions, assessing remaining bridge life and taking appropriate action to ensure their longevity is a top priority for railway engineers.

As it is subjected to train traffic, the fatigue life of a railway bridge is slowly consumed. The rate at which this life is consumed is highly dependant on the weight and number of freight cars crossing the bridge at any given time. Due to expected increases in freight car axle loads of 10 to 25 percent in the coming years, some railway bridges may be approaching the end of their fatigue lives and may become candidates for replacement. In some cases, the life of an existing structure can be extended by strengthening only a few critical members, instead of replacing the entire structure.

To demonstrate the applicability of this strengthening methodology, and to obtain further information on the loading spectra and impact stress levels, the AAR has conducted revenue service and work train tests of an 84-foot, single track, open-deck, through-plate-girder bridge near Parsons, Kansas. Constructed in 1897 and operated by the Union Pacific Railroad, the bridge is on the railroad's replacement list for 1997.

The measured live-load stresses were compared to those calculated using a finite element model. The calculated bending stress values were found to be higher than the measured values, indicating continuity of the stringers and floor system. The measured live-load shear stress values were about the same as the calculated values.

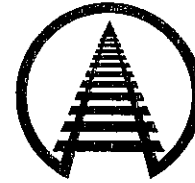
Using stress time history plots, the stress cycles for the various members were calculated using the rainflow cycle counting technique. The minimum remaining lives of various members of the bridge were evaluated based on past loading history and stress cycles imposed by present day loading on the railway bridge.

The maximum stresses for most members occurred during the passage of a revenue service train loaded with 110-ton cars. The maximum recorded live-load stresses indicate relatively short fatigue life for the existing stringers and floor beams.

The fatigue evaluation indicated that the interior floor beam was the most critical member, with only 26 percent of its fatigue life remaining. Under current and projected traffic conditions, the minimum remaining life of the interior floor beam would be 4 to 7 years. To increase the life of the floor beam, and consequently the life of the structure, a strengthening scheme using a cover plate added to the bottom flange is proposed. If implemented, the strengthened floor beam would have an estimated minimum remaining life of 9 to 18 years, depending on traffic conditions.

TEST TRAINS AND INSTRUMENTATION

The bridge was instrumented to measure the vertical wheel and axle loads at the approaches and at the mid-span. Strain gages measured bending stresses at the top and bottom flanges of the primary members (stringers, floor beams, girders). Shear gages



were attached to the webs of the primary members. Some gages were used to measure stress concentration effects at the ends of the stringers.

Two work trains were used to load the bridge at various speeds. The first train consisted of a 6-axle locomotive, followed by eight cars (two loaded 100-ton cars, two empty 100-ton cars, two loaded 110-ton cars, and two empty 100-ton cars). The second train consisted of the first train plus two additional loaded 125-ton cars in the rear.

To determine the maximum stresses and impact factors, the work train tests were conducted at speeds of 5, 10, 20, 30, 40 and 50 miles per hour, in addition to the crawl speed. Axle load impact factors up to 28 percent were recorded in the speed range of 5 to 50 mph.

The tests also included data from seven revenue trains. Based on their composition and average car weight, these trains were classified as 100-ton (average car weight 250-275 kips), 110-ton (average car weight 275-300 kips) or mixed traffic trains. There were three 110-ton trains, two 100-ton trains, and two mixed/unloaded trains. Exhibit 1 presents the details of these seven revenue service trains.

Exhibit 1. Revenue Train Data

Train No.	No. Cars	Gross Wt. (Tons)	Avg. Wt./Car (Kips)	Train Designation (Tons)	Speed (mph)
001	115	17009	295.8	110	43
002	109	16044	294.4	110	49
003	113	16808	297.5	110	49
004	114	15358	269.4	100	29
005	116	15886	273.9	100	43
006	90	8125	180.6	Mixed	42
007	43	3186	148.2	Mixed	52

FATIGUE ANALYSIS RESULTS

The extent of fatigue damage in various members of the bridge under the revenue trains was evaluated using the rainflow method, for counting the number of stress cycles, and Miner's rule of cumulative fatigue damage, to assess the damage per train crossing. These figures were converted to damage values per 10 million gross tons (MGT).

Different types of construction details in a structure are assigned a fatigue category based on their susceptibility to fatigue damage. These categories range from A to E', with A being the least prone to fatigue damage and E' being the most prone. Fatigue category D was used for the main girder and the floor beams (built-up riveted construction), and category C was used for the stringers (rolled sections). The interior floor beams had the highest fatigue damage rates. (See Exhibit 2.)

Exhibit 2. Fatigue Damage Rates and Minimum Remaining Life

	Main Girder	Stringer	Inter Fl. Beam	End Fl. Beam
Damage/10 MGT of 100-Ton Traffic	0.010%	0.41%	0.60%	0.12%
Damage/10 MGT of 110-Ton Traffic	0.030%	0.48%	0.73%	0.13%
Cumulative Damage 1897-1995	1%	51%	74 %	15%
Remaining Life (years)	>100	10-20	4-7	>50

In order to evaluate the total fatigue life of the bridge consumed since its construction, the past loading history of the bridge was estimated based on information provided by the railroad. Using these figures, the



consumed fatigue life through 1995 for various members of the bridge was evaluated using the methodology explained above. Results indicate that the interior floor beam is the most critical member, with an estimated 74 percent of its life consumed. This translates to a minimum remaining life of about 4 years, assuming 100 MGT/year of 110-ton traffic (or 7 years, assuming the current 52 MGT/year of 110-ton traffic). Exhibit 2 presents results for the primary members. These results are based on the fatigue curves found in Chapter 15 of the AREA manual, which represented a minimum fatigue life.

STRENGTHENING

To increase the life of the existing structure, a strengthening scheme for the interior floor beam has been developed. By adding a cover plate to the bottom flange of the floor beam, the level of tensile stress in the bottom flange is reduced. This reduced stress is estimated to increase the minimum remaining fatigue life of the floor beam to 9 years (from 4 years), assuming 100 MGT/year of 110-ton traffic (or 18 years assuming 52 MGT/year of 110-ton traffic). The floor beams would then reach the end of their useful lives at about the same time as the stringers. At that point, the entire floor system would need to be replaced, but the main girders would still have significant life remaining. Exhibit 3 presents the data for the minimum remaining life of the floor beam under various traffic conditions, before and after strengthening.

MAXIMUM STRESSES

The maximum stress experienced under the different work and revenue train runs was evaluated from the measured data for the various members. The maximum stresses were recorded under a 110-ton revenue train run. The maximum recorded tensile stresses

in the main girder, the stringer, and the interior floor beam are 5.5 ksi, 8.7 ksi, and 7.1 ksi respectively. The maximum compressive stresses in these members are 6.3 ksi, 7.5 ksi and 10.1 ksi, respectively. These measurements support the estimated fatigue lives calculated.

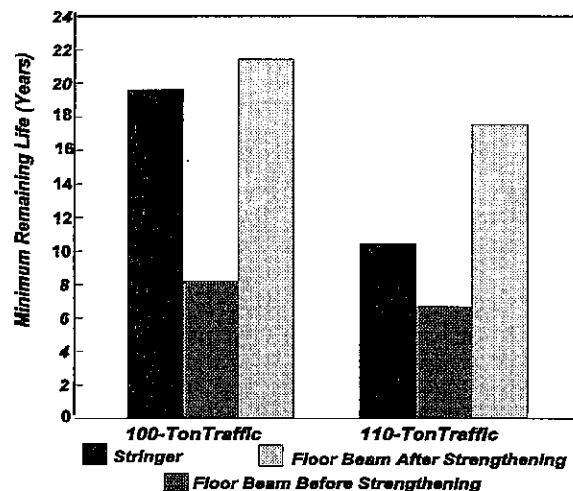


Exhibit 3. Minimum Remaining Life of Interior Floor Beam Before and After Strengthening

BRIDGE DESCRIPTION

The bridge has been rated E49-50 by the railroad. The rail over the bridge is 133 CWR and is box anchored off each end of the bridge. Current traffic on the bridge, approximately 52 MGT per year, consists primarily of coal trains, with a small amount of mixed freight, auto-rack and intermodal trains.

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