Fatigue Life of Bridges

As attention is once again being paid to increasing axle loads and traffic densities, the ability of existing railway bridges to carry increasing loads has become an area of concern. As was pointed out in a previous Tracking R&D article (*RT&S,* April 1990, p. 10), increasing the loading of a steel railway bridge will result in a reduction in its fatigue life. However, the extent of that reduction, and the ability to extend bridge life by structural modifications, remain issues to be addressed by ongoing research.

One set of studies involved a detailed set of fatigue investigations on seven steel bridges on a major North American railway (1). By using a combination of field measurements and theoretical analyses, a detailed set of fatigue life predictions was made for actual in-service railway bridges, as a function of past, present and future (projected) traffic loadings (l, 2). The sequence of analysis steps carried out under these studies is as follows:

—Field measurements.
—Theoretical model analysis.
—Traffic analysis.
—Estimate of fatigue damage.
—Evaluation of fatigue detail category.
—Estimate of remaining life.
—Action required.

Table 1. Impact from work train test (2)

Member	**RMS Stress**	**Average Measured Impact % at Speed:** 40 mph	**Average Measured Impact % at Speed:** 50 mph	**Maximum Impact % "Area Code"**
North hanger	axial	4.6	7.5	43.3
South hanger	axial	7.0	8.3	
North hanger	rivet at f.b.	11.4	14.3	
South hanger	rivet at f.b.	15.5	14.5	
North stringer	bending	5.0	7.4	51.5
South stringer	bending	9.0	4.2	
Floor beam	at N. stringer	3.5	6.6	43.3
Floor beam	at S. stringer	6.3	7.1	

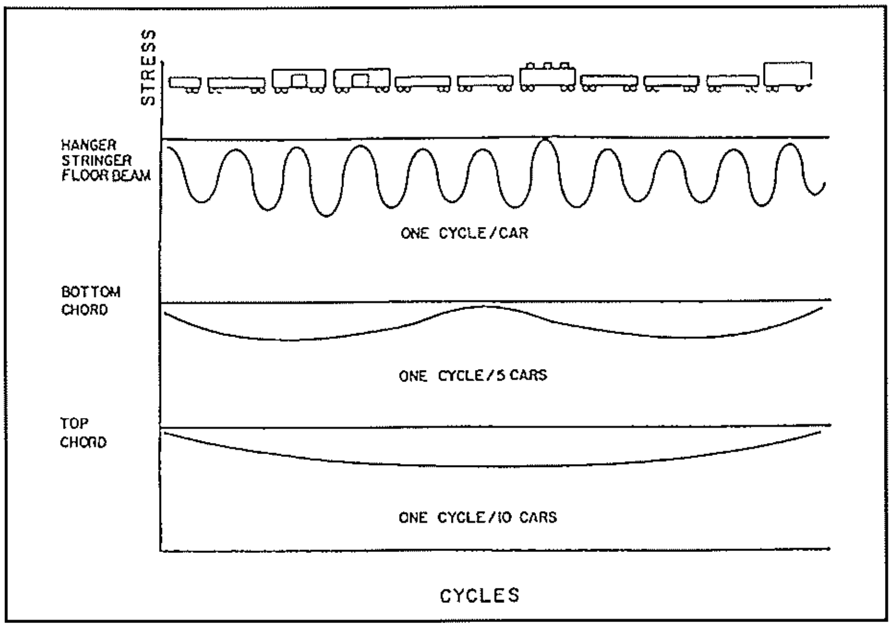

Figure 1 — Frequency of critical loading cycles (2).

By examining up to seven days worth of actual traffic data, using strain gauges to measure stress levels on critical bridge elements (top and bottom chords, hangers, floor beams, stringers, etc.), the effect of loading sequence, sample size and impact loadings were studied. It was determined that 24 hours of continuous data was sufficient, that the effect of car sequence was not critical (thus allowing the use of car-history data) and that the effect of speed-related impacts were lower than those predicted by the present design code (Table 1) (2).

Critical loading cycles

Combining measured stress data with theoretical analysis of the structures also allowed for the determination of the frequency of critical loading cycles, as a function of the number of cars passing over the bridge. This

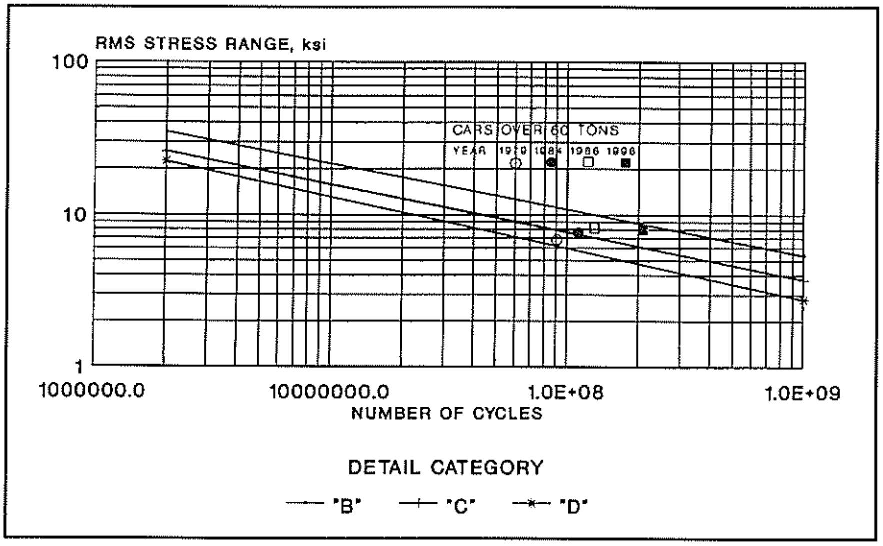

Figure 2 — Frequency versus stress range, past and future traffic (2).

TABLE 2
Estimated Fatigue Life of Bridge Members (2)

	Stress Range	Fatigue Life Category		
	Ksi	D	C	B
Hanger at F.B.	7.3	1980-	1984	1998
Stringer	5.7	1982	1991	2000+
Floor Beam	4.4	1993	2000	2000+

is illustrated in Figure 1, which shows that for the bridge hangers, stringers and floor beams, there was one critical loading cycle per car; for the bottom chord there was one critical loading cycle per five cars; for the top chord, there was one critical loading cycle per 10 cars.

Using an appropriate fatigue damage analysis, such as Miner's Rule or the Root-Mean-Square (RMS) procedure, the fatigue life of the different structural members was carried out on a specific steel railway bridge as a function of the specific fatigue details (2). The effect of these details is illustrated in Figure 2, which presents an S-N curve (relating stress to the number of cycles to failure) for three different bridge-detail categories. Detail B includes high-strength, bolted connections, Detail C includes riveted connections where the rivets are tight and have a proper level of clamping force, while Detail D includes riveted connections where the clamping force levels are less than normal, i.e. loose rivets. As can be seen in this Figure, there is a significant reduction in life (defined by the number of cycles to failure) between these three categories, which are representative of the different connections on railway bridges.

Table 2 presents these estimated fatigue life values in a tabular format, showing the year at which the bridge member is calculated to have "failed." At riveted connections (C and D) where failure was predicted (at the hangers), subsequent field inspections verified the presence of fatigue cracks, thus verifying the validity of the analysis approach (2). Furthermore, noting the relative lives of the different connectors, and in particular the extended life of the high-strength bolted connections, it was determined that retrofitting the existing rivets with high-strength bolts would extend the fatigue life of the bridge in service.

Thus, it appears that fatigue analysis techniques can be used to examine the remaining "life" of existing railway bridges, as well as to examine the effect of changes in traffic loadings, and the effect of structural modifications on these lives.

References

(1) Szeliski, Z. L., "Bridge Fatigue Studies," Bulletin of the American Railway Engineering Association, Volume 83, Bulletin 688, March 1982.
(2) Szeliski, Z. L. and Elkholy, I. A., "Fatigue Investigation of a Railway Truss Bridge," Canadian Journal of Civil Engineering, Volume 11, 1984.