TECHNOLOGY DIGEST

Timely Technology Transfer

PROGRAM FOR ESTIMATING REMAINING FATIGUE LIFE OF STEEL RAILWAY BRIDGES

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Summary

Railway bridges are a critical link in our transportation network. Maintenance and replacement of railroad bridges costs millions of dollars each year in direct costs related to repair, restoration and replacement of bridges, and indirect costs related to the resultant disruption of transportation services.

The Association of American Railroads (AAR) has developed a computer program which will help maintenance planning, reduce maintenance expenses, and ensure extended bridge life. The program can be used by railroad bridge engineers for:

- *Estimating remaining service life of floor systems and other primary load carrying members of existing steel railway bridges. Many of the bridges built in the early 1900's were designed for heavy steel locomotives pulling lighter freight car loads of 50 tons or less. Modern locomotives are lighter, but freight cars are expected to haul 100 tons or more and can induce increased stresses in some bridge members; not all members are adversely affected. These increased stresses cause the fatigue life to be consumed at an increased rate and hence the need for a tool which can evaluate the fatigue related condition of steel bridges.*
- *Evaluating and quantifying adverse effects, if any, of increased car loads on the remaining useful life of steel bridges. For commodities such as coal, some railroads are already using freight car loadings to 286,000 lbs. gross. And it is expected that the future may bring 315,000 lb. gross load freight cars.*
- *Evaluating benefits of bridge strengthening projects.*
- *Determining the loss of load carrying capacity and the reduction in remaining life of bridge members because of loss of section due to rust.*
- *Resource allocation planning for repair, maintenance and upgrading of bridges in specific high volume corridors.*

The program uses guidelines from Chapter 15 "Steel Structures" of the American Railway Engineering Association (AREA) Manual. However, users also have the option of providing their own input parameters. The program features user interactive as well as menu driven inputs. Two types of output reports are produced, one has all the details which a bridge engineer might be interested in and the second is a summary report for resource management and maintenance planning.

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INTRODUCTION AND CONCLUSIONS

The AAR is currently conducting research to evaluate the behavior and structural integrity of railway bridges under today's operating environment. Railway bridges are a critical link in our transportation network. Maintenance and replacement of railroad bridges costs millions of dollars each year in direct costs related to repair, replacement and restoration of bridges, and indirect costs related to the resulting disruption of transportation services. Many existing railway bridges were built before 1950 and therefore range from 40 to 100 or more years old. These older bridges were designed for steam locomotive power and comparatively lighter car loads of 50 tons or less.

The modern freight environment consists of unit coal/grain trains with heavier load capacity freight cars: 100 ton capacity cars with wheel loads of 33,000 pounds and double stack service unit trains utilizing 125 ton capacity trucks with wheel loads of 39,000 pounds. Some railroads, for specific commodities such as coal, are already using freight car loadings to 286,000 lbs.gross weight, and it is expected that the future may bring 315,000 lb. gross load freight cars. Longer trains are also being operated. It is not uncommon to have double stack unit trains with 140 or more platforms and unit coal trains with 110 or more freight cars.

These heavier and longer trains induce higher stresses and impart more stress cycles to floor systems of most steel bridges, causing reduced remaining fatigue life. Long span members, such as plate girders, where the length is greater than truck center spacings, experience only one major stress cycle for every unit train passage and thus have minimal adverse affect. The major factors governing the fatigue resistance and remaining life of a steel bridge are:

1. The number of stress cycles,
2. The magnitude of these stress cycles, i.e. the stress ranges of these cycles, and
3. The type of construction (riveted or welded) and location of the bridge member or detail to be evaluated.

To evaluate the fatigue (reduction of remaining useful life) implications of today's and tomorrow's operating environment, the AAR has developed a computer program "Program for Estimating Remaining Fatigue Life of Steel Railway Bridges."

METHODOLOGY

The guidelines to calculate the fatigue damage to various members of a steel bridge due to the passage of a train are described in various sections of AREA Manual Chapter 15, "Steel Structures." The following factors are important in estimating the fatigue damage to a bridge member:

1.**Member Properties**
The properties of the member, such as the cross sectional area, length and the section modulus. Also, the state of stress eg., axial, bending stress or a combination of the two, is important to determine how the member behaves as a train passes over the bridge.

2.**Bridge Construction**
The type of construction of the bridge eg., whether built-up riveted members or welded members are used in construction. Most older (pre-1960) structures are of riveted construction. Welded members do not have the built-in redundancy of riveted members. The fatigue resistance properties of welded members are not the same as riveted members. The type of bridge deck (ballasted or open deck) is also important, because ballasted deck has inherently better impact load attenuation.

3. **Impact Factors**
The dynamic enhancement of loading from a train due to rolling effect of the equipment is dependent upon the type of power used in the train as well as track characteristics. Older steam locomotive trains had higher impact factors. The impact factor to be used for a member analysis also depends on the type of member, its length and

length of the bridge. Relevant equations for impact factors can be found in Section 1.3.5 of Chapter 15 of the AREA manual.

4. Member Fatigue Resistance

The fatigue resistance properties of a bridge member are dependent upon such factors as - whether the member is fracture critical or not. A fracture critical member is defined as one whose failure would cause the bridge to collapse or to lose its serviceability. All the bridge members for riveted or welded construction are assigned a certain fatigue category (Categories A through F), and each fatigue category has an S-N curve (Stress range versus Number of stress cycles to failure is called an S-N curve) associated with it. This S-N curve describes the fatigue performance of the member when subjected to stress cycles caused by passage of a train over the bridge. An example of the S-N curves used for welded members for various fatigue categories is shown in Exhibit 1. Other factors such as reduced cross-section due to rust, loose rivets, quality of welds etc. are also relevant and important.

5. Train Consist

The stress history cycles experienced by a bridge member are dependent upon the train make-up, the order of different locomotives and cars, axle weights, and axle spacing of each of the freight cars and locomotives. The stress history experienced by a member due to the passage of a given train can be synthesized into discrete stress cycles using cycle counting techniques. "Rainflow Counting" is one such technique and widely accepted and recommended. The computer program uses the rainflow counting technique and Miner's rule of cumulative fatigue damage.

6. Train Traffic over the Bridge

The remaining useful life of a bridge member depends on the train traffic experienced by the bridge since its construction. For older bridges, factors such as train make-up, number of trains per day since its construction, etc., are often not accurately known. In such cases, gross estimates of MGT (million gross tons) can be utilized, if available. The program has a library of historical trains for each of the decades from 1900 to 1990. These historical trains are made up of locomotives and freight cars commonly available during each of the decades. Some of the older trains, although light and short in comparison to today's traffic, had fairly heavy steam locomotives with higher impacts associated with them. The fatigue damage caused by such trains for some long members can be more severe than caused by modern diesel locomotive trains.

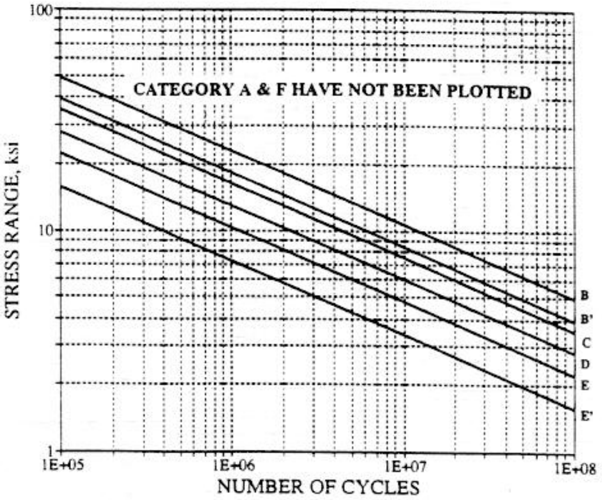


Exhibit 1. Stress Range vs. Number of Cycles to Failure.

THE COMPUTER PROGRAM

The flow chart of the algorithm is shown in Exhibit 2. The program is available for use on personal computers. The program prompts the user to provide the information needed for the analysis, and the output contains the remaining useful life of the member being analyzed. Complete details of the program, how to prepare the inputs and interpret output results are described in the User's Manual. In addition to the interactive version of the program, a menu driven version is also available.

AN ANALYSIS EXAMPLE

The model was used to analyze the fatigue implications of using heavier axle loads for

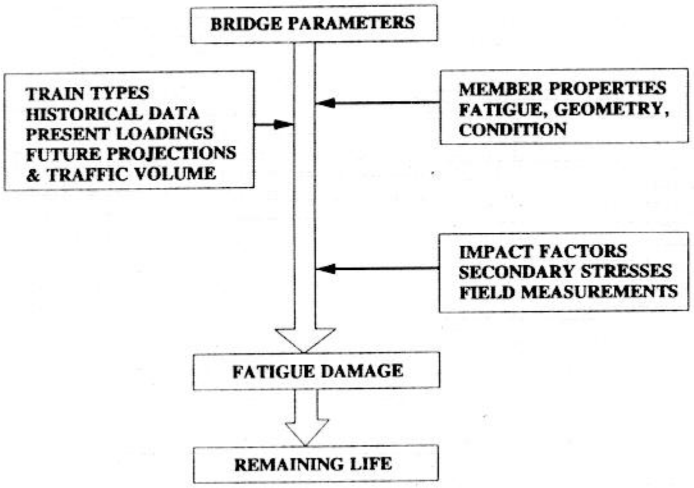
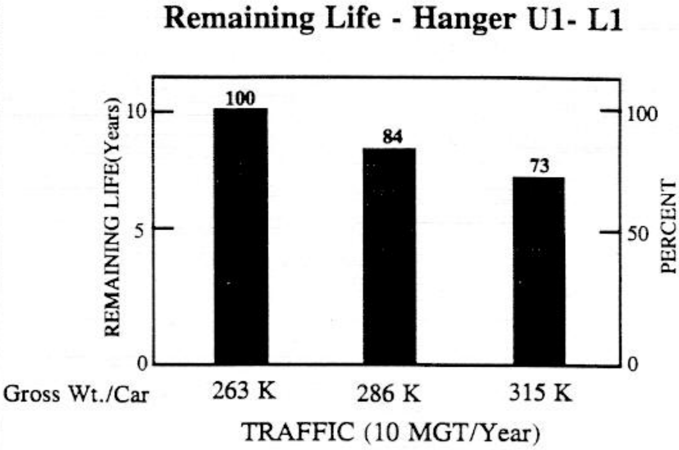


Exhibit 2. Flow Chart of Algorithm for Remaining Fatigue Life of Steel Railway Bridges.

transporting 10 MGT/year of coal traffic. Three train types were considered:

1. Four, 6-axle locomotives followed by a hundred 263 (gross load) coal cars. Net coal tonnage is approximately 71.7% of gross tonnage in this case. 717 trains is equivalent to 10 MGT.
2. Five, 6-axle locomotives followed by a hundred 286 (gross load) coal cars, net coal tonnage being approximately 73.1% of gross tonnage. 656 trains is equivalent to 10 MGT.
3. Six, 6-axle locomotives followed by a hundred 315 (gross load) coal cars, net tonnage being 73% of gross tonnage. 590 trains is equivalent to 10 MGT.

Analysis for the diagonal of a 164'-6" long, pinned-truss built in 1909 having single track and an open deck was conducted using the model. It was assumed that 80% of the fatigue life of the structure had been used up in the past. The comparison of the remaining fatigue life for the three types of traffic is shown in Exhibit 3.



286K cars → 16% Reduction in life for same MGT/Year
315K cars → 27% Reduction in life for same MGT/Year

Exhibit 3. Comparison of Three Traffic Scenarios.

Note: Contact V. Sharma at (312) 808-5843 with questions or comments abut this document.