I-159 FATIGUE EVALUATION OF HIGHWAY BRIDGES UNDER VEHICLE LOAD

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INTRODUCTION

Important factors which affect the fatigue damage are-(a) relative number of different type of trucks and their characteristics,(b) volume of truck traffic and information on the headway distribution and (c) influence line. First step in the evaluation of fatigue damage is to obtain the stress history. Stress history generated by the passage of a single truck is usually simple with only one cycle of stress change, but it becomes intricate when more than one trucks together move across the bridge. In that case it involves multiple cycle of stress changes with different stress range. Stress range is identified by rainflow counting method. Once the stress ranges and their number of cycles are identified, the total fatigue damage is given by the linear sum of the fatigue damages due to different stress ranges multiplied by their number of cycles.

A close look at the whole fatigue process reveals that if the truck traffic were very scarce such that most of the trucks cross the bridge alone, the stress range spectra, which contains information on different stress ranges and their occurrence frequencies is simply the filtered truck load spectra, where the bridge acts as a filter. For fatigue purpose, the stress range spectra can be represented in terms of the reduced number of cycles, N_{r1}, of some standard loading such as L-20 or HS-20, by taking the weighted average of different stress ranges. N_{r1} cycles of the standard loading give fatigue damage equivalent to the average fatigue damage of truck population. As the truck traffic becomes denser, probability of having more than one trucks together on the bridge increases and consequently N_{r1} also changes by a factor which we call the multiple presence fatigue factor (MPFF), γ_M. Accordingly, the evaluation of total fatigue damage can be divided into two steps. First, N_{r1} is evaluated with no multiple presence. This is easily done by obtaining the filtered load spectra. Second, γ_M is evaluated for the given traffic volume. Then, the multiplication of N_{r1} and γ_M yields reduced no. of cycles of standard loading for the actual truck traffic. Both the above steps have been formulated analytically and explained below.

FILTERED LOAD SPECTRA

Truck traffic is decomposed into certain number of standard truck types. An equivalent point load, P_D, is defined, such that one cycle of stress range produced by the passage of point load P_D gives fatigue damage equivalent to the average fatigue damage of truck population. P_D is given as,

$$P_D = \left[\sum_{i=1}^{n} C_i \beta_i \alpha_i^m \int_{w_{min,i}}^{w_{max,i}} x^m f_{W_i}(x)\, dx \right]^{1/m} \tag{1}$$

where, C_i is the relative number of truck type i, n is the total number of truck types, m is the slope of S-N curve (usually m=3-4), $f_{W_i}(w)$ is the probability density of gross weight w of truck type i, α_i is the configuration factor of truck type i, defined such that when w is multiplied by α it gives an equivalent point load whose passage across the bridge gives rise to a cycle of same stress range, β_i is the factor to account for the effect of multiple axles which cause secondary stress cycles due to the passage of a single truck and is given as the sum of the mth power of the ratios of all the stress ranges to the primary stress range. One cycle of stress range due to P_D can easily be converted to obtain the reduced number of cycles, N_{r1}, of some standard loading, with no multiple presence.

MULTIPLE PRESENCE FATIGUE FACTOR

Trucks, as they cross the bridge, can be divided into groups of one, two or more trucks such that a group of trucks are simultaneously on the bridge and their effects on the stress level superimpose. The truck arrival is modeled as a renewal point process to evaluate the group probabilities, p_i.

Maximum size of the truck group which needs to be considered is determined by the bridge length and the group probability itself.

When a group of trucks move across the bridge, depending upon the intradistances between trucks, it generates different patterns of stress history, which will have either one or two cyclic changes in stress level and in the case of two cycles the stress range may be different. For different patterns of stress history, mean fatigue damage is evaluated making use of the conditional joint probability distribution (CJPD) of intradistances. CJPD is obtained from the headway model. The sum of mean fatigue damages due to different patterns of stress history yields the mean fatigue damage due to the truck group. A group fatigue factor, δ_i, is defined which is given as the mean fatigue damage due to truck group divided by the number of trucks and the mean fatigue damage due to a single truck. Then it follows that

$$\gamma_M = \sum_i i p_i \delta_i \qquad (2)$$

Analytical expressions for p_i and δ_i have been developed (for detailed discussion see Reference 2). Here only the numerical results are presented in Tables 1 and 2 respectively. Case 1,2 and 3 respectively correspond to λL equal to 0.75,1.5 and 3.0, or in other words, for span=100 meter and truck speed=100 km/hr they correspond to truck volumes of 250,500 and 1000 trucks/hr. MPFF has been evaluated using Eq. 2 and plotted in Fig. 1. It has been obtained when the headway distance follows 3rd orderErlang distribution, the stress level is measured in terms of bending moment at the center of a simple beam, the trucks are modeled as point load with equal magnitude and only the static response of a single lane bridge is considered. λ is 3 times the inverse of mean headway distance and L is the span length. In Fig. 1, we observe that for very small traffic volume γ_M is equal to 1.0, as to be expected. As traffic volume increases γ_M goes below 1.0. This is because for small traffic volume, most of the trucks cross the bridge either alone or in a group of two trucks, see Table 1, and group fatigue factor for group of two trucks, see Table 2, have been found to be less than 1.0. But as traffic volume increases further, group of three and more trucks with δ_i more than 1.0 also become significant and hence γ_M goes above 1.0. Moreover, the form of the relation is parabolic and not linear as stipulated by some researchers(1).

Table 1. Group Probability

p_i	CASE 1	CASE 2	CASE 3
p_1	0.919* (0.919)	0.653 (0.653)	0.004 (0.004)
p_2	0.039 (0.040)	0.167 (0.167)	0.168 (0.167)
p_3	0.0 (0.0)	0.004 (0.004)	0.124 (0.162)
p_4	0.0 (0.0)	0.0 (0.0)	0.055 (0.038)

*Simulation results in the bracket.

Tab.2 Gp. Fatigue Factor

δ_i	CASE 1	CASE 2	CASE 3
δ_2	0.73	0.74	0.80
δ_3	1.15	1.19	1.40
δ_4	1.59	1.66	2.13

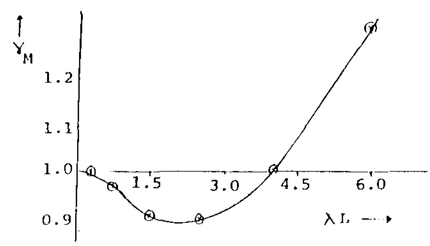

Fig. 1 MPFF vs. λL

DISCUSSION AND CONCLUSION

A simple way to obtain the information on filtered load spectra is presented in the form of Eq. 1.

3rd order Erlang distribution has been found to better represent the truck headway on the bridges and hence we have used this in our model.

Annual average daily truck traffic (AADT) on most of the highways seldom exceeds 500 trucks per hour. For this range of AADT our formulation shows that, see Fig. 1, MPFF will be in the range of 0.9-1.0. It leads to the conclusion that for normal traffic, the effect of multiple presence is not significant and the total fatigue damage can be practically evaluated as the sum of fatigue damages due to individual trucks, which is easily obtained through Eq. 1.

Our study shows that there is no real need to do the simulation, which is rather expensive, for fatigue eavluation. Our simple model is able to reproduce all the trends shown by the simulation results of Miki et al(1).

REFERENCES

(1) Miki,C. et al.: Computer simulation studies on the Fatigue Load and Fatigue Design of Highway bridges, proc. of JSCE Str.Eng./Earthquake Eng., Vol.2, No.1 April 1985.

(2) Fujino,Y., Bhartia,B.K. and Ito,M.: Fatigue Damage to Highway Bridges under Renewal Point Process Loading, Submitted to Proc. of JSCE, for possible publication.