A METHOD FOR EVALUATING AND SETTING THE LOAD POSTING FOR HIGHWAY BRIDGES IN CONSIDERING THEIR RELIABILITY AND REMAINING LIFE

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Abstract - The load posting of old deteriorated bridges in Vietnam's road system to ensure safety for services have experienced a lot of inconsistencies among the related sides such as bridge engineers, management units, transportation inspectors, police, etc. A great deal of load posting is not reasonable, which causes pressing as well as affects the traffic. In addition, there have been some bridge collapses due to the overloading of vehicles. Currently, the Ministry of Transport have determined to control the load operating on highways and are considering to repost the allowance load on the highways in order to make it more suitable and more scientific. This study introduces the fundamental analysis and the load posting for bridge systems in considering the service reliability and the bridge remaining life.

Key words - load posting; bridge operating; deteriorated bridge; reliability; remaining life.

1. Bases for bridge evaluation and load posting

Generally, the loading capacity of bridges is decreased due to their service time under the impact of environmental factors and traffic loading, which can make bridge material deteriorate gradually. This leads to the reduction of the loading capacity of the structure.

In contrast, the traffic load tends to increase over time in accordance with the socio-economic development and transportation needs. If the current bridge load capacity is determined through testing and evaluation periodically, which could not withstand the typical loads, we will have to post the allowance load or to improve and repair bridges to ensure safety and transportation.

Currently, Vietnam has not published procedures for bridge evaluation which is consistent with the design specification 22TCN 272-05 (AASHTO LRFD-1998).

The methodology for bridge evaluation of current guidelines in Eurocode and the AASHTO standard follows the semi-probability. Based on the statistical analysis of structural resistance and load capacity and a careful calibration process, the resistance coefficient and the load factor are takes into account as the characteristics of the random design variables.The evaluation of the live loadbearing capacity isRF (rating factor) by MBE-2011 [1] is as follows:

$$\mathrm{RF} = \frac{\mathrm{C} - \sum \gamma_{\mathrm{DC}}\mathrm{DC} - \sum \gamma_{\mathrm{DW}}\mathrm{DW} \pm \sum \gamma_{\mathrm{P}}\mathrm{P}}{\gamma_{\mathrm{L}}(\mathrm{LL} + \mathrm{IM})} \qquad (1)$$

In which:

RF denotes the Rating Factor. C is the Capacity, $C=\phi_c.\phi_s.\phi.R_n$, equal to the allowable stress f_R or the factored member resistance. R_n represents the nominal member resistance in the LRFD code and is computed from the as-inspected condition. DC, DW, P, LL and IM denote the load effects due to the weight of structural components and attachments, the weight of wearing surface and utilities, other permanent loads, the live load, and the dynamic allowance, respectively. γ_{DC}, γ_{DW}, γ_P and γ_{LL} are the corresponding load factors. φ_c, φ_s and φ are the condition factor, the system factor and the resistance factor, respectively.

Safety posted loading:

$$\mathrm{SPL} = (W/0.7)\,(\mathrm{RF} - 0.3) \qquad (2)$$

W: vehicle load for bridge evaluation,

RF: Rating Factor in service (reliability β=2.5).

When the RF of any vehicle which is less than 0.3, the vehicles should not allow to across the bridge. When the RF of all eligible vehicles of AASHTO less than 0.3, bridge owners should consider closing the bridge.

2. Establishing the relationship between load posting SLP and reliability β

2.1. Closed-form formula

The closed form formula shows the relationship between the rating factor RF, reliability, safety posted load SPL introduced in [1].

Another closed form formula for the case with computed variables R, DC, DW, LL is the standard random variables as follows [4]:

$$RF = \frac{\mathrm{R_n} - \gamma_{\mathrm{DC}}\mathrm{DC_n}}{\gamma_{\mathrm{LL}}\mathrm{LL_n}} < 1 \qquad (3)$$

$$\beta_o = \frac{(\lambda_R\gamma_{Dc} - \lambda_{DC})\xi + (RF\lambda_R\gamma_{LL} - \zeta\lambda_{LL})}{\sqrt{[V_R\lambda_R(RF\gamma_{LL} + \xi\gamma_{DC})]^2 + (V_{DC}\lambda_{DC}\xi)^2 + (\zeta V_{LL}\lambda_{LL})^2}} \qquad (4)$$

In which:

RF is the Rating Factor. R_n represents the nominal member resistance in the LRFD code and is computed from the as-inspected condition. DC, DW, P, LL denote the load effects due to the weight of structural components and attachments, the weight of the wearing surface and utilities, other permanent loads, the live load, respectively. γ_{DC}, γ_{DW}, γ_P and γ_{LL} are the corresponding load factors.

λ_R,λ_{DC}, λ_{LL} are the factor of resistance, the dead load, the live load, respectively; $V_RV_{DC}V_{LL}$ are the variant cofficient of resistance, the dead load, the live load, respectively.

$$\xi = DC_n/LL_n \;;\; \zeta = LL_n'/LL_n \qquad (5)$$

LL_n' the allowing live load effect corresponding to the load posting with reliability targets β_o.

The above equation can be solved via the use of the Excel tool SOLVER to determine the relationship between the allowed working load effects with the reliability β_o.

2.2. Using Monte Carlo Simulation

When the resistance variable R and load Q have a non-standard form of distribution or the standard log, we can use Mone carlo simulation to calculate the reliability corresponding to the nominal value of the different live load (load posting), we can determine the relationship between the posting and the reliability β.

Limit state function: $Y=R-(DC+DW+LL)$ (6)

In which:

R represents the resistance of the structure. DC, DW, LL denote the load effects due to the weight of the structural components and attachments, the weight of the wearing surface and utilities, other permanent loads, the live load, respectively.

R, DC, DW, LL have the statistics average value μ, bias factor, λ: average value divided by the nominal value, the coefficient of variation V, respectively. The statistical parameters can be determined from the statistical analysis of data sets which were built for research or consulting with Nowak [3].

A program written in Matlab called MCR (Monte Carlo Rating) have the ability to calculate and plot the relationship between service live load effects and the reliability index β as the foundation for choosing the posted loading by choosen reliability.

3. Relationship between service load and remaining life

The content of the load posting of old bridges will affect the common internal forces (stresses) appearing in the bridge structure.

Concerning to fatigue limit state described in [1] the fatigue life related to service live load is as follows:

+ Approximately effective stress $(\Delta\sigma)_{eff}$ in detailed studies

+ Number of loop N, involving ADTT traffic flow (vehicles / day).

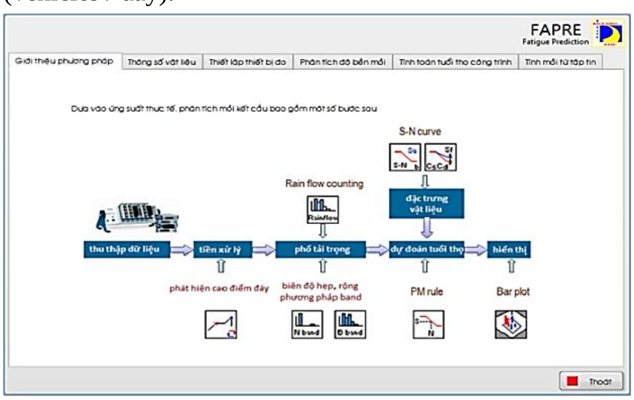

Figure 1. *InterfaceFAPRE-referralprogramsystem*

The effective stress $(\Delta\sigma)_{eff}$ can be determined through simulation or measurement calculated at the bridge site through load testing. We can calculate the cumulative fatigue damage from popular formats (stress) over time by monitoring, load testing by measuring and analyzing system FAPRE which was developed in this study through the diagram shown in Figure 1.

4. Application Case: Pho Nam cable supported bridge. Da Nang City- Vietnam

MCR program has established the correlation of reliability and loading effects expected for the service state for the structural cross beam (the weakest one) for Pho Nam-Da Nang city. The input parameters are as follow:

+ The nominal value of load effects DC, DW,

+ The vector of nominal internal forces value of the load cases which are expected for service state,

$LL=[LL_{H8}, LL_{H10}, LL_{H13}, LL_{H18}, LL_{1xe3T\text{-}VN}, LL_{1xe4T\text{-}VN}]$

+ The value of nominal resistance Rn,

+ The statistics of load and resistance (according to Nowak, 1999) [3]

$bias_{DC}=1.05$;

$bias_{DW}=1$;

$bias_{LL}=1.18$;

$bias_{R}=1.12$;

$cov_{DC}=0.1$;

$cov_{DW}=0.25$;

$cov_{LL}=0.18$;

$cov_{R}=0.1$,

+ Number ofloops N=100.000.

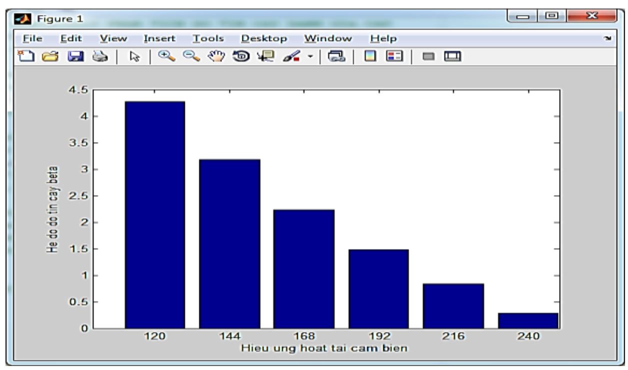

Figure 2. *The relationship between reliability (probability of damage) with moment (KN.m) due to live load in diaphragm*

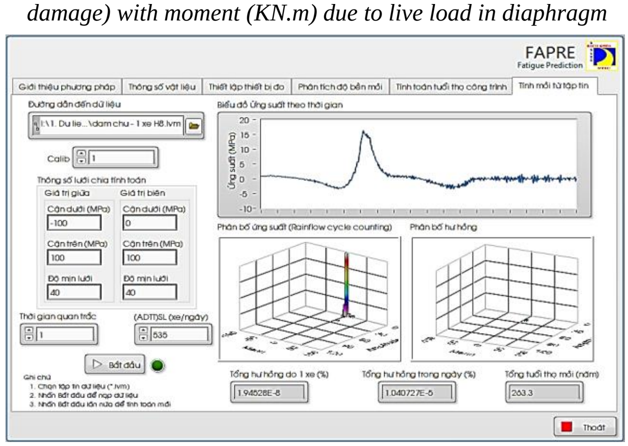

Figure 3. *Calculating the remaining fatigue life in case of the H8 vehicle*

The calculation results of the remaining fatigue life correspond to the expected service's vehicle, the vehicle traffic/day for diaphragm by FAPRE program, in which the stress spectrum by time is due to a crossing vehicle, was analyzed by SAP2000 V.14 software.

***Table 1.** Results of the remaining fatigue life*

Traffic/day	**The remaining fatigue life**		
	H8	**H10**	**H13**
50	88.5	18.6	-3.4
250	6.5	-7.5	-11.9
500	-3.7	-10.7	-12.9

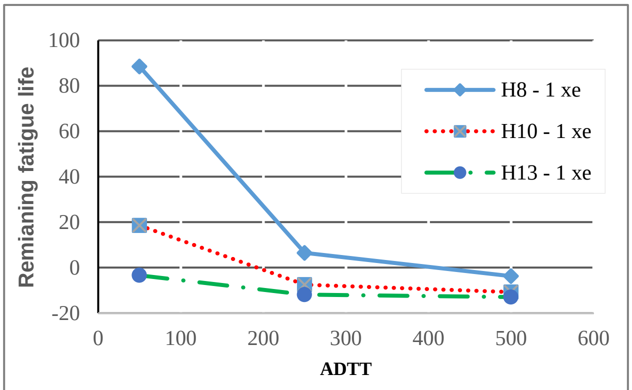

***Figure 4.** Remaining life verus ADDT*

* Load posting recommendations for Pho Nam bridge:

With the analytical reliability results via the strength limit state, the bridge can post for the load H13 (13T) with the reliability β=2.3, which is appropriate. However, if we calculate the limit state of fatigue, only the vehicle H8 (8 tons) can be acceptable to ensure the long life for the diaphragm.

5. Conclusions and recommendations

The evaluation of load posting for bridges in Vietnam often focus on the strength limit state without considering the remaining life and structure reliability. This study sheds a new light on the relationship between the posting value related to the selected reliability as well as the remaining life. The MCR and FAPRE program developed in this study can be well applied for evaluation and analysis in considering the reliability and bridge remaining life.

As for the recommendations for structures that are vulnerable to fatigue, it is necessary to evaluate via the fatigue limit state to establish the relationship between the posting load and the reliability.

The posting load and the remaining fatigue life allow us to select a reasonable way, which satisfies the strength safety and ensure the expected remaining life.

The field inspection data for the measuring spectral distortion of load testing vehicles make the fatigue life calculations more reliable.

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