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Determination of impact factor for steel railway bridges considering simultaneous effects of vehicle speed and axle distance to span length ratio

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ABSTRACT

In common bridge analysis method, traffic load is considered as a static load increased by an impact factor. Impact factor is just a function of span length or the first vibration frequency of the bridge according to the present codes. In this paper the effects of various parameters including velocity, train axle distance, the number of axles and span lengths on dynamic responses of railway steel bridges and also impact factor values are studied.

In this regard dynamic responses and impact factors for four bridges with 10, 15, 20 and 25 m span lengths under trains with 100–400 km/h velocity and axle distance between 13 to 24 m have been calculated. Dynamic analysis results show that in most cases the calculated impact factor values are higher than that recommended by the relevant codes and so the offered rations for impact factor are underestimated.

It has also been shown that the train velocity affects the impact factor, so that the value of impact factor rises incredibly with the train velocity. Another effective element for impact factor is the ratio of train axle distance to bridge span length so that the impact factor value varies for the ratio below and above unity. The train number of axles just affects the impact factor under resonance conditions. In this paper some relations are offered for the impact factor considering parameters: velocity, train axle distance and the bridge span length.

1. Introduction

Bridges' response to dynamic loads is one of the most important factors in safety and durability of bridges. Since dynamic loads are imposed on the bridge structure in various forms, the study of these loads, their specifications and their effects on bridges, improves the methods of design and increases the safety and efficiency. One of important points in bridge dynamics is the way traffic loads affect various bridge elements' responses.

Normally when a low-speed load is exerted on a structure, it is assumed that the acceleration on the mass of all elements and parts is equal to zero and there is sufficient time so that the equilibrium between external loads and internal elastic forces happens. In this case, static analysis is adequate for these structures. However, some loads create dynamic reactions in structure because of their rapid exertion, and common static analysis methods no longer acquire design requirements.

Today high speed railway lines are developed in many countries. This fact has brought about some structural problems which relate to the design of bridges along the railways.

Researchers face a new debate which is the effects of moving loads caused by the train movement on the bridges. Bridges Responses to moving loads have been considered as one of the design requirements since the early stages of railway transportation. In studies carried out by Timoshenko, Fryba and others, the main emphasis has been on the dynamic response of a simple beam to a single moving load. Based on these studies, a variety of standards such as Euro code and AREMA for railway bridge design, considered the dynamic effect of a moving load by introduction of the impact factor, which indicates the difference between dynamic and static responses of bridges to the moving load [1].

Recently some, studies have been carried out for verification of impact factor relations introduced in design codes, and comparison with empirical and numerical results. Some of the studies reveal the insufficiency of these relations.

Yang et al. [2] studied Impact Factor for vehicles moving over simple and continuous beams and showed impact factors for different bridge responses (moment, support reactions and deflections) are not the same and suggested different formulas for the Impact Factor.

Zhang [3] conducted research to determine the impact factor for concrete–steel composite bridges. He analyzed 120 various bridges considering different parameters including span length, the number of main beams and the number of traffic lines in

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ABAQUS environment. To stimulate traffic load, some concentrated moving loads were implemented. As the vehicle mass was not very relative to bridge mass, the vehicle bridge interaction was disregarded. According to this research the Impact Factor for composite bridges based on AASHTO formula is over-estimated for moment and deflection and is under-estimated for support reaction.

Fryba [4] studied the resonance condition caused by the train movement on bridges and introduced two parameters as the main causes of resonance vibration: the first is the exerting of consecutive loads due to train axles and the other is the high speed of modern trains. In this research, simple equations for impact factor are proposed. He also showed that the magnitude of vibration amplitude in a resonance condition is in direct relation with bridge span length and squared value of velocity and adversely relates to damping, train length and bridge stiffness.

Cheng [5] studied railway bridge vibration, considering the rail's conditions and showed that the rail's conditions do not have a noticeable effect on bridge vibrations. He also studied dynamic magnification coefficients for the different conditions of rails.

Lin [6] studied the resonance condition in the dynamic response of railway bridges to train movement and showed that the bridge vibration frequencies must be different from train frequency.

Lou [7] evaluated railway bridge and train responses with the finite element model, and studied the effect of rail smoothness on the reduction of bridge dynamic response. In this research, train, rail and bridge were modeled as an integrated model, to study the bridge and train interactions. Equations of motion are directly derived from the Hamilton principle. The resulting equations are solved by direct integration. The results have shown that the rail conditions have serious effects on vertical displacement and acceleration of the train but not on train body rotation and vertical displacement and acceleration of the bridge. Therefore, the rail condition is only important for passengers' comfort.

Goicolea [1], considering the resonance phenomenon in bridges as a result of consecutive moving loads exerted by train passage, emphasized the inadequacy of the European design manual's methods. According to his research, dynamic response of bridges designed based on European Rail Research Institute (ERRI) recommended specifications are more than expected values in some velocities and specific axle distances.

Yang et al. [8] studied the dynamic response of bridge girders with elastic bearings to moving train loads. The results indicate that the insertion of elastic bearings at the supports of the beam for the purpose of isolating the earthquake forces may adversely amplify the dynamic response of the beam to moving train loads.

2. Impact factor in various codes

In common methods for bridge design, in order to account for dynamic effects of vehicle load, traffic load is assumed as a static load increased by implementing the impact factor. The impact factor (I) is defined based on maximum value of dynamic and static responses:

$$I = \frac{D_{dyn} - D_{st}}{D_{st}} \Rightarrow \frac{D_{dyn}}{D_{st}} = 1 + I. \quad (1)$$

As the impact factor based on deflection is greater than those based on other responses like acceleration [2] in this paper dynamic and static deflection at the midpoint of bridges considered the calculation of impact factor.

In most current design, code span length (L) has been recognized as the only effective parameter on dynamic reaction for bridge design. For instance AASHTO manual suggests Eq. (2) for impact factor [9]:

$$I = \frac{15/24}{L + 38/1} < 30\%. \quad (2)$$

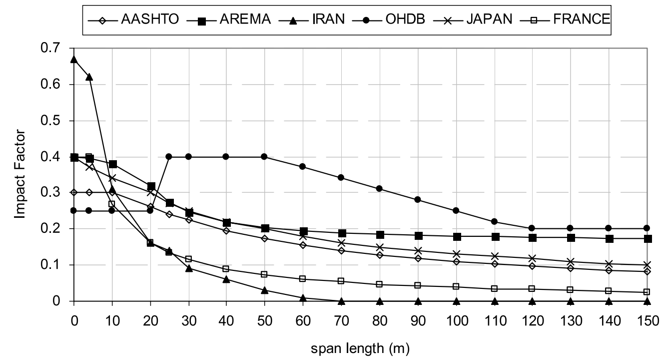

Fig. 1. Impact factor based on various codes.

American railway bridges manual (AREMA) has proposed Eq. (6) for impact coefficient in steel railway bridges [10].

$$I = \begin{cases} 40 - \dfrac{3L^2}{148.6} & L \le 24 \\ 16 + \dfrac{182.9}{L - 9.1} & L \ge 24. \end{cases} \quad (3)$$

Iranian code for loading on bridges suggests relation 4 for impact factor based on bridge span length [11].

$$I = \begin{cases} \dfrac{1.44}{\sqrt{L} - 0.2} + 0.82 : & \text{Good maintenance} \\ \dfrac{2.16}{\sqrt{L} - 0.2} + 0.73 : & \text{Other situations.} \end{cases} \quad (4)$$

In some bridge design codes, such as the OHBD (Canada) and Australian manual, impact factor is measured based on the first vibration frequency of the bridge. For instance, OHBD specified impact factor equal to 0.2, 0.4 and 0.25 for bridges with a first natural frequency less than 1 Hz, between 2.5 and 4.5 Hz and greater than 6 Hz, respectively. For points between 1–2.5 Hz and 4.5–6 Hz the value of impact factor varies linearly. The impact factor relations in Fig. 1 are drawn based on bridge span length according to different codes [11].

Comparison of impact factor values calculated from various codes shows that in span ranges of 25 to 50 m OHDB suggests higher values for (I) among others, while for smaller spans, AREMA and Japan manuals are more conservative.

3. Dynamic responses of bridge under moving concentrated loads

The simplest method to consider the dynamic responses of bridges under moving vehicles is to see the bridge as a simple beam and conduct dynamic analysis of concentrated loads traveling at a constant speed. This method, while precise, is simple and takes a short time to perform many analyses, providing the possibility to consider various parameters' effects, which is necessary in this research. To study the theory of train movement over the bridge with a simple span, a beam with span length "L" and constant cross section is considered (Fig. 2). The train is also assumed as a set of concentrated loads with equal distances which move with a constant velocity (V) on the beam. The distance and load are considered (d) and (P).

The equation of motion and the process of solving the equation are mentioned in detail by Yang [12] which is rewritten in the following paragraphs.

Eq. (5) is the dynamic equation of motion relation of this beam under moving concentrated loads.