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Determination of the critical loading conditions for bridges under crossing trains

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ABSTRACT

A procedure based on experimental and theoretical analyses to identify critical loading conditions on existing metallic railway bridges is presented. This method requires knowledge of the principal modal frequencies, and for this reason, a consolidated and simple procedure to study the bridge dynamics is herein explained. This consists of: preliminary studies; material and dynamic tests; and identification techniques to identify modal parameters and eventual non-linear behaviours. Generally the information collected can be used both to calibrate the bridge model and to obtain the refined frequency response function. In order to avoid high computational effort due to long time-history dynamic analyses by using the bridge model subjected to a series of train crossings, a new frequency domain approach for the identification of critical loading conditions is proposed. Evidence of the influence of the axle spacing and velocity of the vehicle on the dynamic magnification due to the train crossing is shown. The method is based on the construction of an excitation spectrum related to the train axle spacing and the velocity, given the weight of the vehicle. Comparison of the excitation spectrum with the frequency response function allows identification of the load patterns that bring the bridge to resonance conditions and might threaten bridge stability, bearing in mind continual changes in train technology.

1. Introduction

The knowledge of critical loads for existing railway bridges generally involves the simulation of their dynamic behaviour.

With regard to the performance of the bridge under moving vehicles, several studies have shown that the moving loads acting on a bridge are not random in nature, as encountered in highway bridges, but are of regular non-uniform intervals in general. The spacing and velocity can lead to perilous situations, such as unexpected resonance phenomena, ultimately affecting the bridge stability.

In particular, it has been revealed that railroad bridges used for high-speed trains may experience severe vibration due to resonance phenomenon caused by the periodic wheel-load of the train. That is, when the exciting frequency to the train's periodic loading becomes close to the resonance frequency of the bridge, the response of the bridge is significantly amplified. This resonance phenomenon causes not only impact or fatigue related damage to bridge structures but also failure of the ballast-beds due to relaxation and scattering of the ballast. They can consequently compromise the running safety of the trains and the ride comfort of passengers and ultimately increase the bridge maintenance costs [1].

These aspects should be taken into consideration by engineers involved in retrofit or new design of bridges, since improvements in train technology will necessarily create greater demand on bridge performance, and therefore changing train technology will be a factor that is crucial to the assessment of the durability of bridges.

For these reasons investigations on bridge resistance that account for advancements in train technology have lead to the analysis of bridge responses both when subjected to service trains and when subjected to a series of test trains having different speeds and axle spacing. These two parameters – speed and axle spacing – seem to influence the response of the bridge as Fryba emphasizes [2]. In these studies the response of the forced steady-state vibration will obtain its maximum when the time intervals between two successive moving loads are equal to the main period of the bridge in free vibration or to an integer multiple thereof.

In the present paper, first, a consolidated procedure is presented based on the study of the design reports, visual inspection, material testing, dynamic tests and consequent system identification. In particular, an identification technique of non-linear behaviour is presented. The results of these procedural phases are oriented generally to the calibration of a bridge model. It permits static analysis, modal dynamic analysis, step-by-step dynamic analysis (see Fig. 1). In this case, the procedural phase will allow the determination of a reliable frequency response function of the bridge, necessary for the determination of the critical loading conditions as herein proposed.

A frequency domain approach to identify loading patterns that bring the structure to critical condition is presented. This technique allows reduction of the number of dynamic simulations using the

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