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Probabilistic safety assessment of a short span high-speed railway bridge

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ABSTRACT

A probabilistic methodology for the safety assessment of short span railway bridges for high-speed traffic is presented. The purpose is to create a simple, efficient and automatic procedure that allows identifying the critical train speeds over the bridge and assessing the safety of the train–bridge system. The methodology combines simulation techniques with the extreme value theory in order to minimise the required computational time and guarantee accurate results. Stochastic simulation is employed as it allows reflecting the real variability of the parameters that characterise the dynamic response of the train–bridge system. As a case study the safety of a short span filler beam railway bridge crossed by a TGV double train is assessed. The behaviour of short span railway bridges is known to be particularly difficult to predict due to the complexity of the coupled train–track–bridge system, as well as for being particularly sensitive to resonant phenomena. The variability of the bridge, the track and the train was accounted for, as well as the existence of track irregularities. The proposed probabilistic methodology proved to be efficient as it allowed identifying the critical train speeds with a reduced computational cost. Furthermore, for these critical train speeds two different methods were used to estimate the probability of failure. The obtained results showed a good agreement guaranteeing the accuracy of the methodology.

1. Introduction

Transportation systems play a key role in modern societies. Social and economic development depends on the fast and efficient mobility of both people and goods. In this context, the high-speed railway system emerges as a reliable and appealing alternative to road-based means of transportation.

The generalisation of high-speed railway lines over the last decades, the continuous demand for higher operational speed and the introduction of high-speed freight traffic have created numerous engineering challenges. For this reason this area has been the subject of many research works over the last decades. High-speed railway bridges have been identified as sensitive elements of the network. The dynamic amplifications originated by trains moving over the bridge at such high speeds have proved to be the governing factor for bridge design. A comprehensive review of the history and literature on this subject can be found in Fryba [1] and Yang et al. [2].

Short span railway bridges, in particular, have been reported as problematic since the introduction of the first high-speed lines in France due to excessive deck vibrations related to resonance effects [3]. Furthermore, the dynamic response of this type of structure is particularly difficult to predict accurately during the design stage as the dynamic behaviour is influenced not only by the structural dynamic properties but is also strongly dependent of the dynamic properties of both the track and the train.

One of the early methods used to assess the dynamic behaviour of railway bridges and which is still the most commonly method used in the current practice is the moving loads method [4–6]. However, it was noticed that this method may not be sufficiently accurate for cases where the coupled behaviour of the train and the bridge significantly affects the dynamic response. For short and medium span bridges the moving loads method tends to overestimate the maximum accelerations of the bridge deck. To overcome this problem more complex methods that account for the train–bridge interaction were developed [7–11]. Museros et al. [8] compared the dynamic behaviour of 25 simply supported bridges using both the moving loads method and the train–bridge interaction method. This study concluded that the interaction effects lead to a significant reduction (around 25%) of the maximum dynamic response. Goicolea et al. [9] also compared the two methods and analysed scenarios for different bridge spans and damping. These authors were able to draw similar conclusions and verified that differences were higher for structures with structural damping lower than 2%. It should be mentioned though that both works disregard the existence of track irregularities.

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The inclusion of the track in the numerical models is particularly important as it enables obtaining more realistic results. A literature review showed that different track models with varying degrees of complexity and sophistication have already been proposed [12,13]. Another important aspect related to the track are the irregularities which can be an important source of excitation for both the bridge and the train [14,15]. There are two different ways to define the track irregularities: either using values measured experimentally [10,16] or through random generation using power spectral density functions [17,18], which is the approach used in this paper. The second option is possible because numerous measurements have shown that track irregularities represent a stationary and ergodic Gaussian random process that may be adequately described by power spectral density functions (PSD) [17]. Several railway administrations have proposed their own analytical expressions for the PSD functions, based on measured data, for practical application. Thus, each PSD function proposed depends on the maintenance and track quality levels used in each country.

With respect to the train, similar observations were made and several models with different levels of complexity can be found in the literature [19–23]. The degree of sophistication of the model is mostly related to the type of response to be analysed.

The majority of the research papers on the assessment of the dynamic behaviour of railway bridges are deterministic in nature. The analysis is often limited to a specific scenario even when the existence of track irregularities is accounted for. Rocha et al. [24] took into consideration the variability of the structural parameters to assess the safety of a short span railway bridge. Au et al. [19] studied the behaviour of a cable stayed railway bridge for different track irregularities profiles and different track quality scenarios. It was found that the impact factor is not proportional to the magnitude of the roughness. However, it was noted that this impact factor tends to increase for lower track quality. Lu et al. [21] proposed an extension of the pseudo excitation method for the analysis of the behaviour of vehicle–bridge coupled systems. Several examples are shown proving the efficiency of the proposed method against the Monte Carlo method. However, like in the previous reference, the variability is limited to the track irregularities profiles. Cho et al. [25] accounted for the variability of some parameters of both the bridge and the train and performed a reliability analysis of a box-girder railway bridge using an improved Response Surface Method. Nonetheless, the analysis was limited to a single train speed not enabling to conclude how the reliability of the train–bridge system is affected by this parameter.

This paper intends to assess the dynamic behaviour of a short span high-speed railway bridge while accounting for the existence of track irregularities and for the variability of the parameters of the bridge, the track and the train. Attempts are made to guarantee the best possible compromise between accuracy and simplicity of the selected numerical models for each subsystem. Furthermore, in order to reflect the uncertainties that engineers have to face during the design stage, a probabilistic approach based on stochastic simulation is proposed to assess the safety of the train–bridge system. The procedure aims to be simple to use and implement, as well as being efficient and accurate. In order to enhance efficiency and minimise the computational time, simulation techniques are combined with the extreme value theory. The methodology allows identifying the critical aspects of the dynamic response as well as the critical train speeds, thus making it particularly useful for safety assessment analysis.

2. Case study – Canelas Bridge

The selected case study is the same that was used in [24]. Canelas Bridge is located in the Northern line of the Portuguese railway and is composed of six simply supported spans of 12 m each, with a total length of 72 m. The bridge deck is a filler beam consisting of two half concrete slab decks, each supporting a single ballasted track, with nine embedded rolled steel profiles HEB 500. This is a typical deck solution for short span high-speed railway bridges. Under each steel profile a laminated neoprene elastomeric bearing is placed, for a total of 9 bearings for each half deck. A general view of the bridge used as case study is shown in Fig. 1, as well as the typical cross section of the bridge deck.

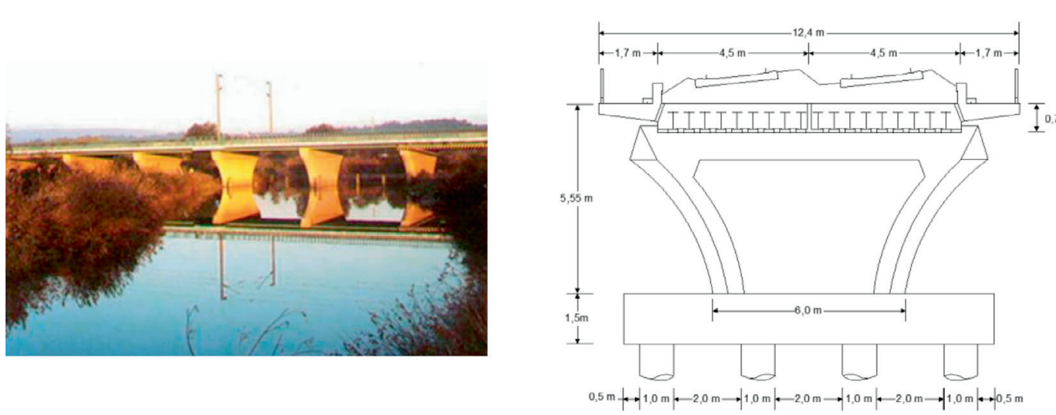
A detailed description of the bridge can be found in [24]. In the following section the numerical model developed for the case study bridge is presented.

The dynamic behaviour of Canelas Bridge will be assessed for the crossing of a TGV double high-speed train, which is an articulated train. The numerical model developed is presented in Section 2.1.2.

2.1. Numerical models

2.1.1. Track-bridge numerical model

The Finite Element Method was used in the numerical modelling. The bridge was discretised with 2D beam elements and the numerical model was defined taking into account the design drawings in order to reflect a real design perspective. A single span was modelled and, as the two half slab decks are independent, only a single track was analysed. Furthermore, in the numerical model the bridge was assumed to be inserted in a straight section of a high-speed railway line. Since the structural system is very simple



(a) General view (b) Typical cross section

Fig. 1. Canelas railway bridge.