



Non-linear vehicle-bridge-wind interaction model for running safety assessment of high-speed trains over a high-pier viaduct

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ABSTRACT

In order to properly study the high-speed traffic safety on a high-pier viaduct subject to episodes of lateral turbulent winds, an efficient dynamic interaction train-bridge-wind model has been developed and experimentally validated. This model considers the full wheel and rail profiles, the friction between these two bodies in contact, and the piers P-Delta effect. The model has been used to determine the critical train and wind velocities from which the trains cannot travel safely over the O'Eixo Bridge. The dynamic simulations carried out and the results obtained in the time domain show that traffic safety rates exceed the allowed limits for turbulent winds with mean velocities at the deck higher than 25 m/s.

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1. Introduction

Wind action may cause stability problems on the train travel over the track. When the train crosses a viaduct which has its deck at a considerable height above the ground, valley or river, the expected wind, for a given return period, will be more important. Therefore, the problem that the wind may cause in the train movement will be bigger. The bridge deck height is not the only factor that may worsen the problem caused by the wind on train travel. The laterally flexible railway viaducts, such as the high-pier viaducts with a continuous deck like the one studied in the present work, suspension bridges, and cable-stayed bridges, have natural vibration frequencies which are in the range of wind velocity oscillation frequencies (0–2 Hz). In addition, the fundamental lateral vibration frequency of railway vehicles, both locomotives and passenger cars, is also within the aforementioned range of wind frequencies. For this reason, the dynamic responses of the train and of the laterally flexible bridge may be increased by the action of an expected crosswind.

Another factor that could influence the problem of train stability when lateral wind acts is the viaduct length, since in long viaducts, such as the O'Eixo Bridge (Fig. 1), wind may excite vehicles during a longer time.

The number of works available in the scientific literature in which the problem of dynamic train-bridge-wind interaction is numerically studied, is already considerable. The following references can be cited as examples: [1–3].

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Fig. 1. O'Eixo viaduct.

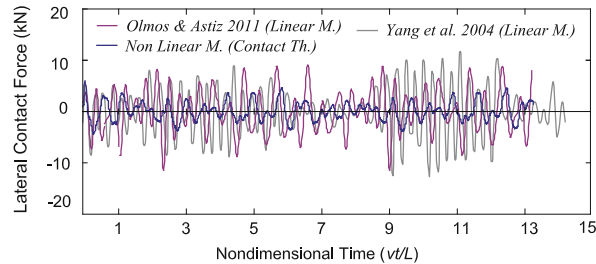


Fig. 2. Left wheel lateral contact force of wheelset 4 in car number 15 of Shinkansen S-300 train. Yang's bridge case.

However, there are still few studies about the train-bridge dynamic interaction, with or without wind, in which the model used considers the non-linearities associated with wheel-rail contact even in simplified form. Some examples are the Refs. [4–9].

In many works regarding train-bridge dynamic interaction [10–14], the contact point of the wheel and the rail is considered fixed in the transversal direction to the train travel. That is to say that there is no transverse relative motion between the wheelset and the track. Therefore, these models do not take into account the non-linearities arising from the contact theory of bodies in motion. With these linear models, the lateral wheelset-track forces are overestimated. Fig. 2 shows the lateral wheel-rail force of the Yang's bridge case [10], simulated by the authors with a linear model and with the non-linear model built for the present study. In Fig. 2 the maximum lateral wheel-rail forces of a wheelset of a train that runs along an irregular track (class 5 F.R.A. [15]) at 360 km/h and over the Yang's bridge are approximately twice when linear interaction models are used.

There are two main reasons that can explain this handicap of such linear models. On the one hand, these models do not take into account the friction in the wheel-rail contact which limits the tangential force between these two bodies. On the other hand, not considering the contact theory of bodies in motion means that damping terms in the composition of the tangential force of the wheel-rail contact are not being taken into account.

The Kalker contact theory of bodies in motion is known [16]; it has been applied to the study of the contact between wheel and rail ([17,18]), and it is frequently used in railway vehicle dynamics simulation models of trains travelling over track ([19]). However, in the case of the dynamic train-bridge interaction problem, consideration of the wheel-rail contact theory introduces an added difficulty. In this case, the mathematical problem is also a non-linear dynamic problem, but with a large number of degrees of freedom due to the bridge finite elements model. The efficiency in the numerical resolution of the problem decreases drastically with the solution methods normally used. The efficiency of the model numerical resolution becomes a problem to be solved.

The present article contains the formulation of the non-linear interaction model proposed, together with the proposed numerical solution method. The model has been validated by comparing results of simpler cases solved numerically in the scientific literature, and by means of experimental measurements of the behaviour of a high-pier viaduct monitored in service.

2. Bridge finite element model

2.1. Bridge model

In order to idealise mechanically the high-pier railway bridge, a finite element model has been established (Figs. 3 and 4). In this model, linear elastic materials have been assumed. In the finite element model the direct stiffness method has been used, that is, the modal superposition method has not been applied (time integration is operated on the full system of equations instead of doing it on the modal decomposed system).

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