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Research paper

A plane model of the interaction of a vehicle with the road infrastructure

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In road transportation, bridges´deck exhibit large deflections when compared with those of the pavements. The interaction of vehicles with these two types of road infrastructures signifies enormous costs for maintaining the whole infrastructure in economic operational conditions. In this paper, an integrated model for simulating the vehicle – infrastructure coupled interaction, is proposed. While the infrastructure model is based upon FEM, the vehicle considers a multibody model. A parametric analysis is carried out to analyse the effect of vehicle and infrastructure operational conditions, as well as vehicle design characteristics, on bridge and flexible pavement dynamic responses.

1. Introduction

The consequences of the interaction of vehicles with the infrastructure are both damaged pavements and deteriorated bridges that originate extra costs to infrastructure users [1–3]. However, for maintaining the infrastructure in good, operable condition, the different operators have to make costly investments, on the order of billions of US dollars [4]. Consequently, research efforts have been focused on identifying the most influential factors causing the failure of the infrastructure, both for the pavements and the bridges, after hundreds of thousands of loading cycles derived from traffic. Nevertheless, these research efforts, especially those involving theoretical research, have been made separately, i.e., only an experimental research was carried out in the nineties involving both the pavement and bridge infrastructures, thorough the Dynamic Interaction of Vehicle and Infrastructure Experiment (DIVINE) [5]. The outputs from such experiment included some general recommendations about the use of road-friendly suspensions, and for the magnitude of axle loads for single and multiple-axle groups. According to that research, for a smooth profile, the effect of truck suspension was insignificant, although the importance of the suspension type became noticeable for uneven pavement decks. In relation with pavements, that study showed that steel or hard suspension generated more damage to the pavement, in comparison with a soft or air suspension. In the case of bridges, early analytical models have reported the effects of pavement roughness and vehicle speed. Fig. 1 describes an example of these results, where it can be noted the effects of both speed and decks roughness on calculated impact factors, according to which, surface condition deeply affects the value of the dynamic loads on the bridge [6].

In spite of the extensive research on vehicle – infrastructure interaction, key issues remain to be clarified: while the effect of the length of vehicleś wheelbase has been firmly accepted through the Bridge Formula [7], the dynamic effect of such vehicle property has not been reported in the literature.

In this paper, a theoretical model integrating the two circumstances under which the vehicle and infrastructure dynamic interaction takes place, is presented. The review of literature includes the research efforts as they have been published, i.e., involving separately the two types of infrastructure: pavements and bridges. Furthermore, and in the context of the present research, the review of literature focusses on the development of models and formulations dealing with specific aspects of the vehicle – infrastructure interaction, especially with regard to the coupled vehicle-infrastructure dynamic response. This paper is based upon Romero et al. [8], containing an expanded review of literature and revised performance measures, leading to different trends, especially in the case of vehicle-pavement interaction.

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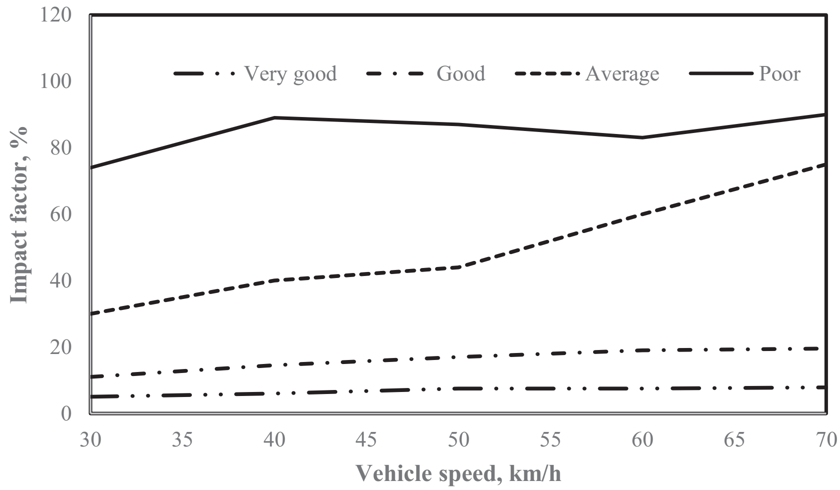

Fig. 1. Effect of road roughness and vehicle speed on impact factor (with data from [6]).

2. Review of literature

2.1. Vehicle – pavement interaction modelling

Ding et al. [9] propose a coupled vehicle – pavement model for analysing the effect of a quarter-of-a-car vehicle on a flexible pavement represented by a beam supported on spring and dashpots. They report a resonance at a speed of 15 m/s as a by-product of the coupling vehicle – beam effect. Xu and Prozzi [10] report vibration frequencies on the order of 20 Hz when the pavement is subject to a vehicle moving load. Bescou and Theodorakopoulos [11] report resonance pavement response, or critical speed, of 195 m/s, for specific values of the elastic foundation stiffness, Poissonś ratio, as well as the plateś thickness and elastic constant. Fang et al. [12] report a FE pavement analysis to study the effect of tire pressure distribution on the pavement response to tire loads, assuming a quasi-statically approach to simulate the dynamic load sequence. The authors simulate the maximum rut depth for the different pavementś layers. In [13], a coupled three-dimensional model is developed for the analysis of the vehicle-pavement interaction, focusing on the magnitude of the tire forces as a function of pavement and vehicle operational conditions, finding significant effects of pavement roughness on the dynamic loads on the pavement. Local effects of vehicle-pavement interaction modelling, including tire pressure and the shape of the contact area, have been studied and reported in [14]. In [15], an uncoupled vehicle-pavement model was developed for simulating the dynamic vehicle forces on the pavement, as a function of different vehicle and pavement parameters, finding that dynamic loads reduce with soft suspensions while these forces increase with pavement roughness. Rebound of the pavement after being traversed by a moving load and the influence of the temperature on the pavement deflection due to an impact load is analysed in [16], reporting a rebound of around 70% of the initial deflection.

2.2. Vehicle – bridge interaction modelling

In relation with the effect of pavement characteristics on the bridge response, González et al [17] study the effects of both the expansion joint condition and bridge deck roughness on the bending and shear load effects, reporting dynamic increments on the order of 20% due to such irregularities. Bridge deck unevenness has been modelled through specialized software [18]. In [19], the importance of bridge deckś roughness is shown through the simulation of the different bridgeś vibration modes, and the elimination of potential perturbation resonances. Bowe and Mullarkey [20] report a simplified vehicle – beam interaction model, representing an unsprung mass travelling on a beam that could represent a bridge or a railway. The authors support the concept of simulating the coupled dynamics of the vehicle – bridge system through the consideration of what they call a convective acceleration term in the equations of motion. They find that this coupling term represents differences on the order of 4 to 1 in infrastructureś deflection. In [21], a close solution for a moving load on a multi-span bridge is presented, assuming a negligible effect derived from the vehicle‘s sprung mass vibration. The proposed model considers an elastic beam supported by linear and spiral springs. Results illustrate upwards deflections before and after the load is applied, finding a close relationship between the analytical and the finite element method results.

3. Model description

From the literature review presented above, it is clear that many aspects of the interaction of vehicles with the infrastructure needed to be studied and clarified. Above all, no single model was found which integrated the two types of infrastructures that interact with the vehicles.

3.1. Formulations

Both infrastructures are modelled as a series of finite elements. For the pavement, a viscoelastic material is considered, as the magnitude of its Modulus of Elasticity depends on both the pavement temperature and the loading time rate. While some rheological models have been proposed for the pavement viscoelastic behaviour [29], the loading time rate and temperature dependency of the elastic modulus of the asphalt pavement, have been considered in this paper from experimental data reported in the literature, as it is described below, in Section 3.1.2.

3.1.1. Pavement and bridge finite elements

The finite elements considered for both infrastructures are described as standard four degrees-of-freedom (dof) beam elements, that represent the surface layer of the pavement and the elements of the bridgeś deck. In the case of the pavement, however, the beam elements rest on vertical two-dof viscoelastic bar elements, in order to simulate an asphaltic base course. Fig. 2 illustrates the finite elements and the associated dof.

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