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A modified numerical VBI element for vehicles with constant velocity including road irregularities

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ABSTRACT

There has been a growing interest to model and analyze Vehicle–Bridge Interaction (VBI) of intricate vehicles on bridges. The objective of such an analysis is to realistically investigate the dynamic effects of moving vehicles particularly in case of high-speed trains, where the vehicle acceleration is a design criterion and should be calculated appropriately. One method of analysis is to eliminate the wheel degrees of freedom (DOF) that are in direct contact with the bridge surface resulting in a VBI element, which is a modified beam element acted upon directly by wheel(s) of a running vehicle. The contact force is the mutual force between the wheel and the bridge. The available formulation in the literature is used to formulate the contact forces, which are related to those in the beam element DOFs by the Hermitian interpolation functions. Considering suitable interpolation functions between the beam element displacement vector and those for contact points and also a new formulation for the contact points, a new formulation is proposed for the structural properties of the VBI element, resulting in a new element capable of capturing bridge and vehicle responses more realistically. A study is conducted on the model variables and their effects on the bridge dynamic amplification factor and also bridge and vehicle accelerations, in order to compare the new VBI method with the existing one. The studied parameters include vehicle and bridge damping, frequency parameter, system mass parameter, and a new parameter called vehicle mass parameter. Results generally demonstrate noticeable differences particularly for high speed vehicles. In addition, it is observed that the effect of shear deformations in a simply-supported bridge might not be negligible and should be considered for moving vehicle analysis. For double girder open-deck steel railway bridges, the difference in midspan deflection of models including or excluding shear deformation can vary from 18% to 8% for 4.0 m and 30.0 m spans, respectively, for a sample vehicle.

1. Introduction

Application of high-speed trains has been growing all over the world particularly in Japan, China, France, Germany, and Spain. Currently however, there is only one high-speed route in North America which is the Acela Express in Boston. In Canada, the implementation of new routes is under discussion in order to connect Edmonton to Calgary, as well as a route from Windsor to Québec city. The riding comfort is a key factor in the design of the high-speed railways; hence, it is required to model a vehicle capable of obtaining the maximum acceleration of the car body as the design criterion for riding comfort. Having an elaborate vehicle model necessitates the application of sophisticated methods of analysis for the Vehicle–Bridge Interaction (VBI). This was the subject of much research over the past decade, noting that methods based on numerical analysis have been used by the majority of researchers.

The main objective of this paper is to present a modified two-dimensional VBI element for a constant velocity vehicle. A VBI element is a bridge element acted upon directly by the vehicle wheel. The bridge may have other elements that have no imposed wheel, which are treated as regular beam elements. In the current study, the analysis type used for the VBI problem is the time history analysis with suitable time increments. The calculation of the unknowns at the end of the time increment is often done by an iterative algorithm verifying convergence [1–4]. The convergence criterion is questionable and also for the analysis of a series of vehicles may be considerably time-consuming. However, Yang and Wu [5] presented a method which requires no iteration in the time increments yet may be considered adequately accurate. They proposed a new element which utilizes the concept of dynamic condensation method. They condensed the contact point DOFs, which resulted in a new VBI element with contact mass, damping, and stiffness matrices.

The overall bridge structural matrices are updated in each time increment using VBI elements and regular beam elements. The

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