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Prediction of vehicle-induced local responses and application to a skewed girder bridge

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ABSTRACT

This paper proposes an innovative and flexible simulation method that predicts the dynamic responses of bridges induced by passing vehicles. The decoupled equations of motion of the vehicle–bridge system are derived from Lagrange equations and include the effect of road surface roughness, while the interaction forces between the two systems are calculated step by step, using Newmark's method. This algorithm does not require a special finite element (FE) code and can be implemented with standard FE software and general numerical software such as ABAQUS and MATLAB, respectively. In order to illustrate the practicability of the method, an extensive case study is then presented in which some aspects of the dynamic behaviour of a skewed bridge monitored under vehicle-induced loads are investigated. After adjustment of the boundary conditions and the spectral roughness coefficient, good agreement is obtained between the bridge vibrations predicted by the numerical model and the field measurements. The validated model is further used to analyse the distinctive dynamic effects caused by the skewness. For that purpose, a reference non-skewed bridge model is prepared according to the same design as the original skewed bridge. The obtuse corner of the skewed bridge located near the loading path is found to be a critical region where the slab-negative moments, the girder stress near the sole plate and the bearing force are significantly greater than those in the reference bridge.

1. Introduction

The problem of bridge vibrations induced by moving vehicles has been a topic of interest for more than half a century. The main difficulty is that the interaction forces at the contact points between the two systems cannot be obtained by simple methods. Early research has derived analytical expressions of the vibration of simple beams under a lumped moving mass. Extensive references can be found in the pioneering book by Fryba [1]. Some recent works have proposed a numerical procedure wherein the vehicle is modelled with rigid bodies connected by springs and dashpots, while the bridge is modelled using the finite element (FE) method [2–8]. Global structural matrices are usually derived for the whole vehicle–bridge coupled system. The vehicle–bridge interaction problem is then solved by means of a modal projection on a selected number of modes of vibration of the bridge. A special FE code is, however, often required, which is not widely practical.

This study introduces a new and versatile simulation method that precisely predicts the structural responses of bridges to dynamic vehicular loads without the need for a special FE code. Here, the vehicle–bridge decoupled equations of motion are implemented with the commercial FE method software ABAQUS and the general numerical software MATLAB according to an algorithm based on Newmark's method. A case study is then presented in order to demonstrate the usability of this procedure. The method is applied to simulate the vehicle-induced vibrations of a full-scale steel I-girder skewed bridge that has been monitored. The boundary conditions and the road surface roughness are adjusted by comparing the computed responses with the measurements obtained during field tests of the bridge. Finally, the paper shows in concrete terms how the validated numerical model can be further used to investigate the particular behaviours caused by the skewness of the bridge and to identify critical structural members.

2. Vehicle–bridge system modelling

A versatile numerical procedure is developed in order to simulate the dynamic interaction between the bridge and the vehicle, incorporating the effect of road surface roughness. The method is implemented with standard commercial software and is therefore easily applicable to various types of bridge.

2.1. The coupled vehicle–bridge equations

The vehicle is represented as three rigid bodies connected by linear springs and dashpots, as illustrated in Fig. 1(a)–(c). The

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