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Vehicle axle load identification on bridge deck with irregular road surface profile

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ABSTRACT

The vehicular axle load on top of a bridge deck is estimated in this paper including the effect of the road surface roughness which is modeled as a Gaussian random process represented by the Karhunen–Loève expansion. The bridge is modeled as a simply supported planar Euler–Bernoulli beam and the vehicle is modeled by a four degrees-of-freedom mass–spring system. A stochastic force identification algorithm is proposed in which the statistics of the moving interaction forces can be accurately identified from a set of samples of the random responses of the bridge deck. Numerical simulations are conducted in which the Gaussian assumption for the road surface roughness, the response statistics calculation and the stochastic force identification technique for the proposed bridge–vehicle interaction model are verified. Both the effect of the number of samples used and the effect of different road surface profiles on the accuracy of the proposed stochastic force identification algorithm are investigated. Results show that the Gaussian assumption for the road surface roughness is correct and the proposed algorithm is accurate and effective.

1. Introduction

Vehicular axle load information is very important in bridge design and bridge condition assessment. In the bridge–vehicle interaction problem, both the locations and the amplitudes of the vehicular axle loads change with time. Previous research [1] showed that the dynamic wheel load may increase road surface damage by a factor of 2–4 over that due to static wheel loads. The traditional way to obtain the vehicular axle load by weighing the vehicle on site is inefficient and subject to bias. The weight-in-motion system developed in the 1960s could only obtain the equivalent static load. The moving force identification technique is often adopted to obtain the interaction forces between the bridge and the vehicle. This technique, as an indirect measurement method, can be mainly classified into two categories: (a) based on a continuous bridge model and modal superposition technique to decouple the equation of motion with the subsequent solution obtained using an optimization scheme [2,3]; and (b) based on a discrete bridge model with the finite element method to decouple the equation of motion, such as the state space approach [4], the finite element approach with orthogonal function approximations [5] the finite element approach with updated static component technique [6,7], and the wavelet-based method [8], etc. The finite element method has the advantage of dealing with complex boundary conditions over other existing methods.

All existing moving force identification techniques are deterministic in which the road surface roughness is considered as deterministic samples of the irregular profile according to its power spectral density function defined in the ISO standard [9]. This treatment of the road surface roughness will result in the fact that different samples of measured data will give rise to different identified forces due to the randomness in the responses. To overcome the drawback of the deterministic identification method, a full description of the road surface roughness as a random process is introduced into the equation of motion of the bridge–vehicle system. Furthermore, a stochastic force identification algorithm is proposed to identify the statistics of the interaction forces from samples of the random responses of the bridge deck.

Stochastic vibration of a beam structure under moving loads has been investigated by Zibdeh [10]. However, the moving force model in Zibdeh's formulations may not effectively reflect the behavior of the moving vehicles. Spring-mass systems were adopted by other researchers in the stochastic analysis of the bridge–vehicle interaction problem [11,12]. Although the assumption on the road surface roughness as a random process has already been introduced into the dynamic response calculation [13] which is also known as the forward problem in the bridge–vehicle interaction problem, yet little research work based on such model can be found on the moving force identification, which is regarded as one kind of inverse problem. Wu and Law [14] proposed a new moving load identification method based on the Karhunen–Loève Expansion (KLE) in which both the system parameters and excitation forces were assumed as Gaussian random processes. The method provided a theoretical background for the stochastic vehicular axle load identification of a bridge–vehicle system.

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