Engineering Structures 33 (2011) 3546–3558

Contents lists available at SciVerse ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

Random vibration of a train traversing a bridge subjected to traveling seismic waves

Zhichao Zhang [a,b], Yahui Zhang [a,*], Jiahao Lin [a], Yan Zhao [a], W.P. Howson [c], F.W. Williams [c]

[a] State Key Laboratory of Structural Analysis for Industrial Equipment, Faculty of Vehicle Engineering and Mechanics, Dalian University of Technology, Dalian 116023, PR China
[b] Locomotive & Car Research Institute, China Academy of Railway Sciences, Beijing 100000, PR China
[c] Cardiff School of Engineering, Cardiff University, Cardiff CF24 3AA, Wales, UK

ARTICLE INFO

Article history:
Received 18 October 2010
Received in revised form
14 July 2011
Accepted 15 July 2011
Available online 16 August 2011

Keywords:
Train–bridge system
Pseudo-excitation method
Earthquake
Wave passage effect
Non-stationary random vibration
Track irregularity

ABSTRACT

Non-stationary random vibration of 3D time-dependent train–bridge systems subjected to multi-point earthquake excitations, including wave passage effect, is investigated using the pseudo-excitation method (PEM). The motion equation of such a system is established by coupling the train and bridge through wheel–rail contact relationships and accounting for the phase-lags between pier excitations. The horizontal and vertical earthquake excitations are both assumed to be uniformly modulated, fully coherent random excitations with different phases, while the excitation due to track irregularities is assumed to be a 3D, fully coherent random excitation with velocity-dependent time lags. PEM is first proven to be applicable to such time-dependent systems, and is then used to transform the random excitations into a series of deterministic pseudo excitations. By solving for the corresponding deterministic pseudo responses, various non-stationary random responses, including the time-dependent power spectral density functions (PSD) and standard deviations (SD), can be obtained easily. A case study is then presented in which the China-Star high-speed train traverses a seven-span continuous bridge that is being excited by an earthquake. The results show the effectiveness and accuracy of the proposed method by comparison with a Monte Carlo simulation. Additionally, the influences of seismic apparent wave velocity and train speed on the system random responses are discussed.

1. Introduction

The development of high-speed trains has led to more frequent use of bridges or elevated railways. Hence the probability that earthquakes occur while trains are crossing bridges has increased considerably. The importance of this was highlighted during the Niigata Earthquake on 23 October 2004, when a Shinkansen high-speed train derailed while crossing an elevated bridge at 200 km/h. Since then, the dynamic analysis of train–bridge systems subjected to seismic excitations has received much more attention [1–10]. Matsumoto et al. [1] developed a vehicle/structure dynamic interaction analysis program, known as DIASTARS, to study the running safety of railway vehicles subjected to earthquake motion. Yang and Wu [2] investigated the dynamic reliability of trains, initially static or traveling on bridges under different seismic conditions using a 3D train–track–bridge model.

This pioneering research has laid a good foundation for further work. However, the dynamic interaction problem of train–bridge systems under earthquakes has not been solved satisfactorily up until now because of its complexity. It is well known that for long-span bridges subjected to earthquakes, it is very important to account for the phase-lags between ground joints, i.e., the so-called wave passage effect. Doing so gives seismic responses, which may be quite different from those obtained by assuming uniform ground motion. Similarly, it is necessary to consider the wave passage effect in the seismic response analysis of coupled train–bridge systems. However, very little research has been done in this direction.

Yau and Fryba [3,4] analyzed the propagation effect of seismic waves on the vibration of a suspension bridge subjected to the actions of moving loads and vertical support motions, but the dynamic responses and running safety of the train were not analyzed. Xia et al. [5] studied the influence of seismic wave velocity on the responses of vehicle–bridge systems and the running safety of the train with the bridge quasi-static effect neglected.

It is known that both earthquakes and track irregularities are random. The random vibration analysis of such problems has usually been performed by means of time-history methods [1–10].

* Corresponding address: State Key Laboratory of Structural Analysis for Industrial Equipment, Department of Engineering Mechanics, Dalian University of Technology, Dalian 116023, PR China. Tel.: +86 411 84706337; fax: +86 411 84708393.
E-mail address: zhangyh@dlut.edu.cn (Y. Zhang).

0141-0296/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.engstruct.2011.07.018