Journal of Traffic and Transportation Engineering(English Edition)
2014,1(4):293-308

Wind-vehicle-bridge coupled vibration analysis based on random traffic flow simulation

Tao Wang[1,*], Wanshui Han[1], Fei Yang[1], Wen Kong[2]

[1] *Key Laboratory for Bridge and Tunnel of Shaanxi Province, Chang' an University, Xi' an, Shaanxi, China*

[2] *Department of Civil and Environmental Engineering, Louisiana State University, Baton Rouge, LA, USA*

Abstract: A wind-vehicle-bridge system can be regarded as an interaction result of wind-bridge interaction, wind-vehicle interaction and vehicle-bridge interaction, which is determined by nature wind, dynamic characteristics of vehicle and bridge structures, interrelationship between bridge and vehicle dynamic properties and so on. Firstly, based on the traffic loading investigation on the expressway bridge within 24 hours a day, all the critical parameters of traffic flow, such as the vehicle type, weight, separation space and speed are all recorded and analyzed to extract its statistical characteristics, which are used to work out random traffic flow simulation program RTF. This RTF program can be embedded with the other general FEM software. Secondly, a dynamic analysis module RTFWVB of the wind-vehicle-bridge coupling vibration under random traffic flow is presented, which can consider arbitrary number of vehicles, multi-lanes and traffic flow direction. Finally, Hangzhou Bay Bridge in China is selected as a numerical example to demonstrate dynamic interaction of the RTFWVB system. The results indicate that the traffic flow direction has just a little influence on bridge dynamic response, that the mean responses are mainly determined by the moving vehicle loads, and that the fluctuating components will increase with the increase of wind speed.

Key words: wind-vehicle-bridge system; traffic investigation; random traffic flow; dynamic responses; traffic flow direction

1 Introduction

The new era of bridge construction has been coming when lots of world famous bridges across bays or gulfs are under construction during the 21st century. When 12 high level national roads in China, 5 longitudinal roads and 7 latitudinal roads, have been constructed one by one, some of cross-sea bridges spanning gulf in China, such as the Bohai Bay Bridge, Huangdao Island Bridge, Hangzhou Bay Bridge, East China Sea Bridge and Zhoushan Island Bridge, have already been placed on the agenda (Xiang 2002). In

* **Corresponding author**: Tao Wang, PhD, Lecturer.
E-mail: 48045664@qq.com.

order to avoid the difficulty in deep water base construction and meet the need of navigation, many long-span bridges will be the best alternative for cross-gulf bridges, including cable-stayed and suspension bridges. Wind becomes a very important factor of bridge engineering. In recent years, besides the aerodynamic stability of bridge deck, the reliability of wind-induced random vibration, vortex-induced vibration and wind-rain-induced cable vibration (Scanlan and Gade 1977; Scanlan 1978; Bucher and Lin 1988; Hikami and Shiraishi 1988; Jain et al. 1996; Ge and Tanaka 2000; Xiang and Ge 2002; Guo 2003; Gu and Du 2005; Guo and Xu 2006; Zhan et al. 2008; Gu et al. 2009) attract more and more attention with respect to the problem of wind-induce driving safety on bridge deck.

If a long span bridge is built in a wind-prone area, when vehicles move on the bridge subjected to cross-wind, the interaction of wind, vehicles and bridge can be out-lined as follows: 1) Coupling vibration between moving vehicles and flexible bridge will occur because of road surface roughness. 2) Static and buffeting responses of the bridge are induced by mean and stochastic components of incoming wind, respectively, which will influence the property of vehicle-bridge vibration. 3) The wind loads acting on moving vehicle will significantly change vibration property of vehicle. 4) Wind loads on a certain segment of the bridge deck vary with the arrival and departure of moving vehicles. 5) Wind loads on vehicles will be affected due to the existence of the bridge deck. 6) Dynamic distribution of vehicle mass varying along the bridge deck change the vibration property of bridge.

A considerable amount of study of wind-vehicle-bridge vibration system is underway or of initial step. The primary researches of wind-vehicle-bridge vibration are always concentrated on rail vehicles. Ge et al. (2001) considered aerodynamic influence between rail-vehicles and bridge in vehicle-bridge analysis but ignored both self-excited forces and the correlation of stochastic wind. Xu et al. (2003) presented a framework for predicting the dynamic response of a long suspension bridge to high speed wind and running trains, in which the trains run inside the bridge deck of a closed cross section and there were no wind forces directly acting on the trains. Li et al. (2005) presented an analytical model considering many special issues in a wind-rail vehicle-bridge system, including fluid-solid interaction between wind and bridge, solid contact between vehicles and bridge, stochastic wind excitation on vehicles and bridge, time dependence of the system due to vehicle movement, and effect of bridge deck on vehicle wind load and vice versa. The main achievements about wind-vehicle-bridge interaction are as follows: Xu and Guo (2003) presented a framework for performing dynamic analysis of coupled road vehicle and cable-stayed bridge systems under turbulent winds and the equations of motion of wind-vehicle-bridge are assembled using a fully computerized approach. Cai and Chen (Cai and Chen 2004; Chen and Cai 2004) developed a three-dimensional analysis of the coupled bridge-vehicle-wind system and presented a framework of vehicle accident analysis model on long-span bridges in windy environments. However, the traffic flow in the current wind-vehicle-bridge analysis is definite, whereas the traffic flow passing the highway bridge is stochastic, thus certain discrepancy exists between the analysis and the actual situation. In this paper, the wind-vehicle-bridge coupled vibration analysis under random traffic flow is developed. Firstly, a random traffic flow simulation program is compiled based on the traffic investigation. Then, a three-dimensional dynamic model of the wind-vehicle-bridge coupling vibration under random traffic flow is presented, which can consider arbitrary number of vehicles, multi-lanes and traffic flow direction. Moreover, the approach is used to work out dynamic analysis module (RTF-WVB) and the module is coded to the self-developed BDANS program (bridge dynamic analysis system). Hangzhou Bay Bridge in China is finally selected as a numerical example to demonstrate dynamic interaction of the RTFWVB system.

2 Traffic investigation and random traffic flow simulation

2.1 Investigation and statistics analysis to traffic load

The accuracy of random traffic flow simulation usu-