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Effects of wind barrier on the safety of vehicles driven on bridges

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ABSTRACT

The evaluation of the sheltering efficiency of wind barriers is directly related to the safety of vehicles under crosswind. A series of work has been carried out in order to optimize the wind barrier scheme. Firstly, based on a large scale section model of bridge in the wind tunnel, the aerodynamic coefficients of two types of high-sided road vehicles, located on bridge deck, are obtained as different wind barriers installed on the bridge. Then the expressions of the aerodynamic forces on road vehicles are deduced based on the quasi-steady theory after considering the effects of turbulent wind on the yaw angle. Taking the natural wind, vehicle and bridge as an interaction system, a three-dimensional analytic model for the wind–vehicle–bridge coupling vibration system is presented. And the judging criterias for the vehicle safety are proposed according to the dynamic response of the vehicles. Based on the analytical model and the safety criteria, the sheltering efficiency of the wind barriers affecting the safety of vehicles driven on bridge has been finally investigated. The results show that the wind barriers have dramatically improved the driving stability of vehicles. Therefore, it can be recommended to adopt wind barriers according to their sheltering efficiency.

1. Introduction

The effects of crosswind on the ground vehicle have received increasing concerns in terms of traffic safety. And high-sided road vehicles are prone to suffer from wind-induced accidents at exposed locations (e.g. coastal and oversea bridge, viaduct and open road) according to a post-disaster investigation of wind-induced traffic accidents (Baker and Reynolds, 1992). On August 11, 2004, seven high-sided road vehicles were overturned by high wind when they were driven on the Humen suspension bridge in China just before a strong typhoon (Zhu et al., 2012).

To ensure the vehicle safety, it is necessary to assess the risk of vehicle accidents due to strong crosswind, which is a complex and multidisciplinary task involving the stochastic characteristic of wind process, aerodynamic actions of crosswind and the dynamic model of vehicle. Baker (1987) established the analytic model of vehicle under crosswind and investigated the critical wind speed for vehicle safety based on wind tunnel tests. Snæbjornsson et al. (2007) introduced a response hyper-surface in the space of basic variables into the limit state function of vehicle performance and quantified the risk of safety by safety index. Chen and Chen (2011) adopted the response surface method to provide an efficient estimation of accident risks. Chen and Chen (2010) developed a single-vehicle accident assessment model and introduced new critical variables in assessing the accident risks under comprehensive hazardous driving conditions. The above research only focused on the accidents risks of vehicles without considering the effects of wind barriers. Without the aid of wind barrier, it has to frequently close the traffic or bridge in strong wind or typhoon days, which brought out great inconvenience due to the inefficient traffic. It has been recognized that wind barriers, including trees, shrubs and perforated plates, have been widely used in environmental protection (Cornelis and Gabriels, 2005), to protect people and their property from the effects of harsh climate. Recently, wind barriers have been introduced into bridge engineering to reduce the effects of crosswind on the trains (Imai et al., 2002) or road vehicles (Coleman and Baker, 1992). Kwon et al., (2011) investigated the design criteria required for wind barriers to protect vehicles driven on an expressway under a high crosswind. Considering the sudden change of the aerodynamic forces on road vehicles, Charuvisit et al. (2004) analyzed the aerodynamic coefficients of vehicles in the wind tunnel test under the conditions of considering or neglecting the wind barriers as vehicles approach the bridge towers. Kozmar et al. (2012) paid great attention to the mean velocity field and turbulence structure behind the wind barrier on the bridge and concluded that wind barrier greatly reduced the mean velocity of the incoming wind. Further,

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Chu et al. (2013) analyzed the influence of wind barriers on the aerodynamic coefficients of vehicles.

The sheltering efficiency of wind barriers is affected by many factors, such as height, ventilation rate and barrier types. The wind barriers in actual bridges should be adopted according to the safety of vehicle crossing the bridge. The evaluation of the sheltering efficiency of wind barriers, depending on the aerodynamic coefficients of vehicles (Argentini et al., 2011; Charuvisit et al., 2004; Chu et al., 2013) and the flow field above bridge deck (Kozmar et al., 2012), is still far from perfect. In the present study, the aerodynamic coefficients of high-sided vehicles (commercial van and articulated lorry) are firstly obtained by a large scale section model in the wind tunnel. The wind tunnel test is devoted to investigate the influence of bridge scenario with different wind barriers on the aerodynamic coefficients of high-sided road vehicle. Moreover, new expressions of aerodynamic forces acting on road vehicles have been deduced considering the influence of turbulent wind on the yaw angle. Then the aerodynamic force on vehicle is available based on the wind tunnel results and the expressions of the aerodynamic force. Taking the natural wind, road vehicle and bridge as an interaction system, the framework of the wind–vehicle–bridge interaction system is established. Finally, the effects of wind barrier parameters on the dynamic behavior of vehicles are especially investigated.

2. Wind tunnel experiments

The purpose of the wind tunnel test is to provide analytical parameters for the coupling analysis of the wind–vehicle–bridge system. Due to the lack of the aerodynamic coefficients of specific road vehicles, approximate aerodynamic coefficients have been adopted in the previous studies (Cai and Chen, 2004; Guo and Xu, 2006). Considering the effects of wind barriers with various ventilation ratios on the aerodynamic coefficients, it is necessary to investigate the aerodynamic coefficients of vehicles by means of wind tunnel test. The experiments are carried out in the wind tunnel (XNJD-3) at Southwest Jiaotong University. It is a closed circuit facility and comprises of a boundary test section that is 36 m long, 22.5 m wide and 4.5 m high. The wind speed can be adjusted from 0.5 to 16.5 m/s.

2.1. Models of vehicle, bridge and wind barrier

High-sided vehicles are vulnerable to crosswind because of their relatively large side areas. Two types of chinese high-sided vehicle models are examined: a commercial van and an articulated lorry. The geometric scales of the two vehicles are set as 1:20. The details and dimensions of the vehicles are given in Fig. 1. The bridge deck is composed of two parallel concrete flat box girders and carries a dual three-lane carriageway, as shown in Fig. 2. The dimension of the cross section of the deck is 35.5 m in width and 3.0 m in height. The six lanes are identified as Lane 1–6 (from the windward side to the leeward side). The same scale (1:20) is adopted for the bridge deck model. Besides, a pair of pipes and hand rail, and two sets of safety fence are installed on the deck model to reflect the real environment of the deck because of their significant influence on the aerodynamic forces of vehicles. According to the principle of the equivalent ventilation rate, the

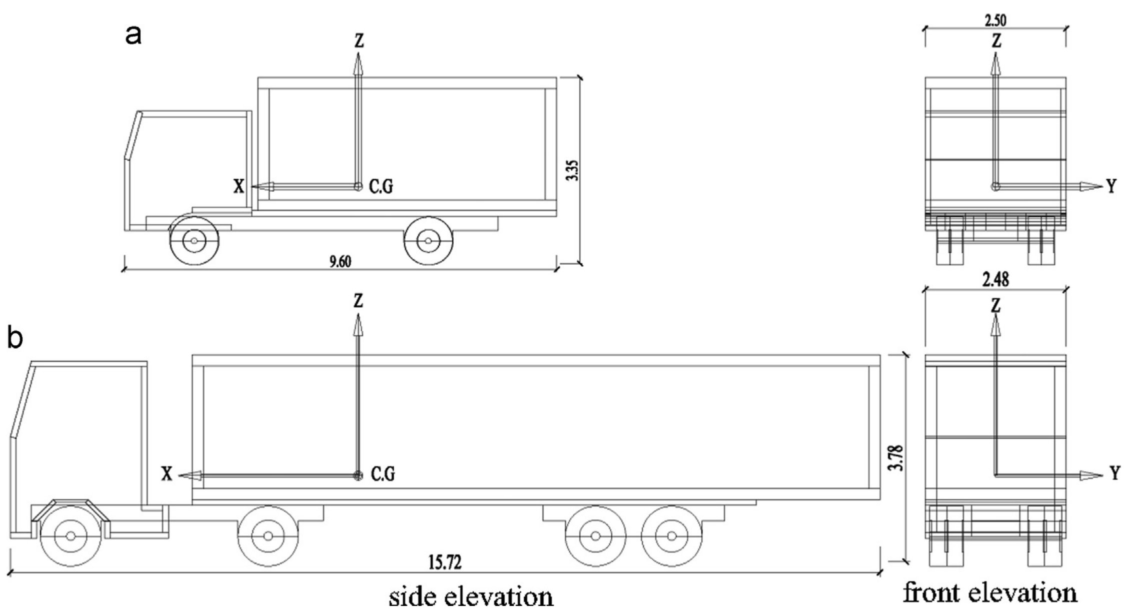

Fig. 1. Vehicle geometrical sizes in full scale (a) commercial van (b) articulated lorry (unit: m).

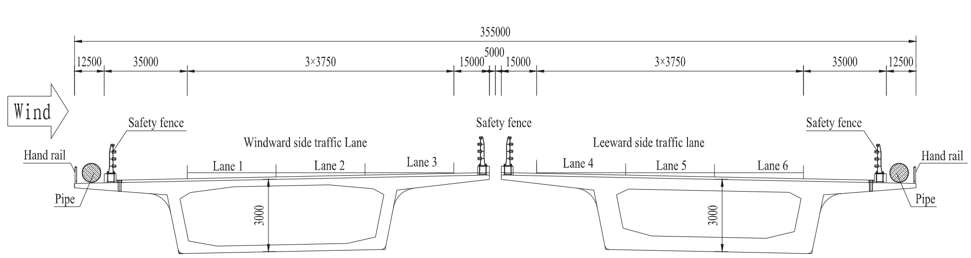

Fig. 2. Cross section of bridge deck (unit: mm).