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Aerodynamic characteristics of a trailing rail vehicles on viaduct based on still wind tunnel experiments

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ABSTRACT

The aerodynamic behavior of rail vehicles subject to crosswind has become one of the hot topics to the Chinese railway community, due to the rapid expansion of the high-speed railway networks in the last decade. To investigate the aerodynamic interference between vehicle and viaduct, models of a typical simply supported 32 m pre-stressed concrete box beam viaduct and CRH2 train with scale of 1:25 were tested in wind tunnel experiments. By using simultaneous pressure scanning technique, various tests combining different cases of vehicles on double tracks on the viaduct were carried out. Pressure measurements were performed on the trailing rail vehicle to avoid the three-dimensional effects of train nose. The influences of wind barrier height and porosity on the aerodynamic characteristics of the train were also addressed. The experimental results indicate that the wind pressure distribution on the trailing vehicle is almost uniform along its axial direction, while the aerodynamic influence of vehicles on different tracks (upstream and downstream tracks) is different. Moreover, the porosity and height of the wind barriers are found to require optimization for different configurations.

1. Introduction

The running safety of railway vehicles subject to crosswind, which is the worst operating condition (Kwon et al., 2011; Kozmar et al., 2012), has drawn extensive attentions in the international railway community. Both soft and hard measures are utilized to improve the traffic safety (Imai et al., 2002; Liu, 2010). The former refers to operation regulation and control, and the later includes shape optimizing, installing wind barriers, etc., which requires intensive study of the aerodynamic characteristics of the trains. However, the aerodynamic characteristics of the rail vehicles subject to crosswind depend on not only the shapes of vehicles but also the infrastructures and wind barriers (Cheli et al., 2010a ; Suzuki et al., 2003).

Due to the high number of bridges in high-speed rail lines (e.g., bridges account for over 80% of the total length in the Beijing–Shanghai high-speed railway line in China), understanding the wind-vehicle-bridge interaction becomes important to ensure the running safety. When a train is running on a bridge with the presence of crosswind, there will be significant aerodynamic interactions between them (Li et al., 2012). On the one hand, the existence of the train on the bridge changes the section shape of the bridge and, subsequently, the aerodynamic forces on the bridge. On the other hand, the train may be submerged in the separated flow induced by the bridge deck, which may cause the aerodynamic forces to be quite different from that of a train on the ground.

In recent years, many researchers have investigated this problem using theoretical analysis (Diana and Cheli, 1989; Xia et al., 2008; Yang and Lin, 2005), computational fluid dynamics (Yang et al., 2013; Cheli et al., 2010b; Zhou et al., 2010), and full-scale and/or wind tunnel testing (Baker et al., 2009; Bocciolone et al., 2008; Willemsen, 1997). Many valuable research results have been obtained. For example, wind barriers can create a region with relatively low wind speed for the vehicles to reduce the wind effects on them (Kwon et al., 2011). Moreover, the effects of wind barrier are not only closely associated with its parameters, for example, height and porosity, but also with the surrounding environment (Jiang and Liang, 2006; Kozmar et al., 2012; Xiang et al., 2012). However, the interaction mechanism in the wind-vehicle-bridge system has not been thoroughly understood yet due to its complexity.

In this paper, the new boundary layer wind tunnel at the National Engineering Laboratory for High Speed Railway Construction located

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in Central South University was employed to test the aerodynamic forces of a CRH2 high-speed train on a pre-stressed concrete simply supported box beam viaduct. The models (both train and viaduct) are of 1:25 scale ratio in the present experiments. Simultaneous pressure-scanning technique was utilized to measure the pressure distribution on the vehicle in various vehicle-bridge configurations to investigate the effects of bridge on the aerodynamic forces of the train. Moreover, the influence of wind barriers with different heights and porosities were also examined

2. Wind tunnel tests

2.1. Wind tunnel description

As an important part of the National Engineering Laboratory for High Speed Railway Construction located in the railway campus of Central South University, the high-speed railway wind tunnel (Fig. 1) has been in operation since June 2012. It is a closed-circuit atmospheric boundary layer wind tunnel with two test sections, that is, the high- and low-speed sections. The high-speed test section is 15 m long, 3 m wide, and 3 m high. Its wind speed ranges from 5 to 94 m/s, and the corresponding turbulence intensity (*Ti*) is less than 0.5%. The low-speed test section is 18 m long, 12 m wide, and 3.5 m high. Its wind speed ranges from 2 to 20 m/s, with *Ti* of 2%. The elevation of the low-speed section is 1.75 m lower than that of the high-speed section, which allows the model rail extending outside of the low-speed section through the reserved doors in its side walls. This can be used for the future moving train model tests.

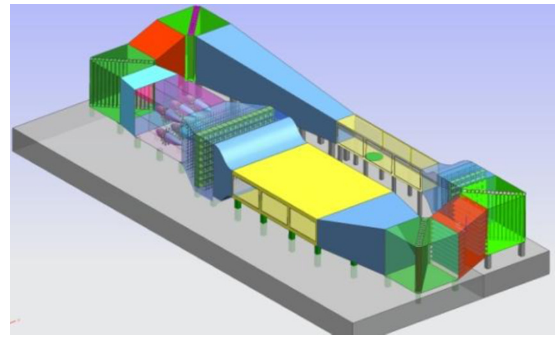

Fig. 1. Schematic diagram of the wind tunnel.

2.2. Test models

The aerodynamic forces of CRH2 passenger train on a pre-stressed concrete simply supported box beam viaduct are presently investigated. The CRH2 train is currently used in most high-speed railway lines in China. The size of the leading vehicle of a full-scale CRH2 train is 25.7 m long, 3.38 m wide, and 3.5 m high, and the trailing vehicle (second vehicle) is 24.5 m long with the same cross-section as the first vehicle. A typical simply supported 32 m span concrete box beam viaduct is chosen as the bridge prototype. Fig. 2 shows the photo of the experimental setup.

In the present wind tunnel experiments, the scale ratio was chosen to be 1:25 for all tested models. For the train model, the dimension of the first vehicle model is 1028 mm long, 140 mm high, and 135.2 mm wide. The length (*L*), height (*H*), and width (*W*) of the second model vehicle are 1000 mm, 140 mm, and 135.2 mm, respectively, as shown in Fig. 3. The maximum blockage ratio caused by the installation of models is 4.2%, thus its effects are neglected in following discussions.

Fig. 2. The train and bridge models.

The experimental models are geometrically similar to their prototypes. Details of the tracks, bogies, and wheels, etc., were considered, but the windows of the train were not reproduced. The models of the vehicle and main beams were made using high-quality wood, while the bridge piers and other components were made from rolled steel. This is because the models require adequate strength and stiffness to avoid deformation and vibration during the experiments to ensure the precision of pressure measurements. Sketches of the tested train model including its dimensions are shown in Fig. 3.

In the wind tunnel experiments, a five span bridge model was used, with each span (*Ls*) of 1280 mm and the height of bridge pier is 400 mm. There are two tracks on the bridge model, with a track center interval (*S*) of 200 mm in model scale, corresponding to a 5 m track interval in full scale.

2.3. Test conditions

As shown in Fig. 4, a total of 28 cases were tested. Generally, three kinds of arrangements were presently investigated: (i) single train on the upstream track (cases 1–5), with the train model shifting every *Ls*/4 along the track for each case, (ii) single train on the downstream track (cases 6–10), and (iii) two trains on both tracks (cases 11–28), which were tested to investigate the interference from adjacent trains. Readers may refer to Fig. 4 and Table 1 for the detailed arrangement of each tested cases.

To study the influence of the height and porosity of wind barriers on the aerodynamic forces on vehicles, wind barriers models with the height of 8 cm, 10 cm, and 12 cm (corresponding to 2.0 m, 2.5 m, and 3.0 m in full scale), with the ratio of 0.57, 0.71, and 0.86 relative to the height of train model, were presently tested. For each height, five different porosities, that is 0, 10, 20, 30, and 40%, were considered. Uniformly distributed square holes were used to get the porosities. It is worth mentioning that the effects of wind barrier were only presented in the present paper for the cases with two trains completely overlapping with each other, that is cases 22 and 28.

All tests were conducted in a uniform oncoming flow in the low-speed test section. The free stream oncoming velocity $U = 10$ m/s, corresponding to a Reynolds number of 0.93×10^5, based on *U* and *H* (the height of train model). The oncoming flow velocity was monitored using a Pitot tube at the centerline of the test section, about 3 m upstream the tested model.

A DTC net electronic type pressure scanning system (Pressure Systems, Inc., USA) was employed to measure the wind pressure. A total of 170 pressure taps were arranged on the surface of the trailing vehicle. Pressure distributions at 10 sections along the vehicle were presently measured, with 17 taps at each section. The arrangement of the pressure taps are shown in Fig. 3(b & c). For each measurement, the sampling duration lasts 30 s with the sampling frequency of 330 Hz.