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Experimental and numerical studies on aerodynamic loads on an overhead bridge due to passage of high-speed train

Na Yang [a,*], Xiu-Kai Zheng [a,b], Jian Zhang [a], S.S. Law [a,c], Qing-shan Yang [a]

[a] Beijing's Key Laboratory of Structural Wind Engineering and Urban Wind Environment, School of Civil Engineering, Beijing Jiaotong University, Beijing 100044, China
[b] The Third Railway Survey and Design Institute Group Corporation, Tianjin 300142, China
[c] Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University, Hunghom, Kowloon, Hong Kong, China

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ABSTRACT

When a high speed train passes an overhead bridge structure, the aerodynamic forces acting on the structure change abruptly. This train-induced aerodynamic loading should be taken into consideration for the design of overhead structures. This paper reports on the field experiment and numerical simulation conducted in the study of the aerodynamic loads on such a structure. Wavelet transformation was conducted on the pressure measurements to analyse the surface pressure fluctuation characteristics and to identify the pressure distribution in different frequency bands. The numerical simulation adopted sliding mesh technology with the two-equation k–ε turbulence model, and commercial CFD software FLUENT was used. The distribution of pressure and the relationship between the pressure and train speed were analyzed. Results showed that when the train passed under the bridge structure, complex unsteady turbulent flow arose between the train and the structure. This flow should be taken into consideration in the structural design of the overhead bridge structure.

1. Introduction

The high-speed train is becoming a popular means of transportation in modern society for a convenient connection between business centres and touristic locations. However a lot of engineering problems emerge with the high speed train and typical problems are the unusual aerodynamic phenomena around adjacent structures during the passage of train.

There is a significant number of studies on the train-induced flow with the train in tunnel. Air inside a tunnel is confined, and a compression wave is created in front of the moving train, while an expansion wave is created behind the train. This phenomenon is called the "pulsation effect" (Gilbert et al., 2012; Sajben, 1997; Howe, 1998; Ogawa and Fujii, 1997). The propagation process of the pulsation effect and the resulting pressure waves has been reported (Novak, 2006; William-Louis and Tournier, 2005). This pulse-like wave, called the micro-pressure wave, is very important when described in terms of noise effect because it may be responsible for the severe booming noise up to 140–150 dB or more (Maeda, 1996). The main factors that influence the strength of pressure waves have been identified as the blockage ratio of the train in the tunnel, which is defined as the ratio of the train cross-section to the tunnel cross-section, the shape of the nose and tail of the train, the speed of the train, the shape of the entrance and exit of the tunnel, the tunnel length and the roughness of the tunnel walls (Baron et al., 2001; Bopp and Hagenah, 2009; Fujii and Ogawa, 1995; Ricco et al., 2007).

Pedestrians may find it uncomfortable or dangerous on platforms with trains passing by in small railway stations at speed up to 140 km/h. Jordan et al. (2008) showed that people can lose their balance at gusts larger than 12 m/s with the gust wind coming from the side, and this is the case with people standing on the platform and facing the track. Sanz-Andres and Santiago-Prowald (2002) and ProRail (2012) made systematic studies on this wind effect on the pedestrians standing on the train station platform.

When the high-speed train is traveling along the track, it generates unsteady transient aerodynamic pressure (Tian, 2007). The train-induced pressure will increase rapidly with an increase in the running speed. The air flow surrounding an adjacent structure can be as severe as that occurring in a wind storm. Therefore, it is necessary to predict the aerodynamic load on structures close to the track to know their limits for the design of these structures.

An overhead bridge in a railway station is a typical structure near the track, and the effect of the train-induced flow on the structure cannot be ignored. Several studies on this flow at the overhead bridge structure have been conducted. Yang et al. (2005) measured the pressure distribution and vibration of Tokaido Shinkansen line steel bridge with passage of train. Analysis showed that vibration was largely caused by the train-induced flow, and the vibration could be

* Corresponding author. Tel.: +86 13641094920; fax: +86 010 51687250.
E-mail address: nyang@bjtu.edu.cn (N. Yang).

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reduced by installing a tuned mass damper. Lei and Liu (1999) studied the pressure distribution on the bridge surface at the passage of train using numerical simulation approach. They found that transient pressure pulses occurred with passage of a train, and the coefficients of the pressure pulses were between −0.135 and 0.095. Hur et al. (2008) studied the wind load distribution of high-speed train stations by numerical simulation approach and wind tunnel experiment. Results showed that the pressure on the upper side of roof was higher than pressure below the lower side. Baker et al. (2012) studied the transient aerodynamic pressures and forces on trackside and overhead structures due to passing trains. Formulas on the aerodynamic loading on trackside structures were then derived from the experimental data which may be useful in future revision of standards. Gerhardt and Kruger (1998) investigated the wind and train-induced air movements in train stations and discussed the means to control the air movement and prevent excessive air infiltration into the train stations.

The aerodynamic characteristics of train-induced pressure and its generation mechanism have been well-researched. However, the pressure distribution of overhead structure in different directions, the relationship between pressure distribution and the train location, the effects of overhead structure height and width dimensions on the pressure distribution require further study. In this paper, field experiment and numerical simulation on the study of aerodynamic loads due to train-induced flow on an overhead bridge structure are reported. The measured pressure data was wavelet transformed, and analyzed to obtain the surface pressure fluctuation characteristics and the pressure distribution in different frequency bands. Sliding mesh technology combined with the two-equation k–ε turbulence model were adopted in the numerical simulation, and the commercial CFD software FLUENT was used. The pressure distribution and the relationship between pressure and dimensions of overhead structures were obtained when the train passed the overhead bridge at high speed.

2. Pressure measurement results

2.1. Field measurement

The field measurement was conducted at the De Zhou East Station. The overhead bridge is shown in Fig. 1 with the windward surface facing the reader. There are five platforms and seven tracks in the train station, two of which are operating lines and five are waiting lines. The overhead bridge locates at the middle of the train station with the overall length, width and height of 81.765 m, 15 m and 8.2 m respectively, as shown in Fig. 2. There are four unequal spans with the maximum span length of 30 m. According to the requirements of design code (TB 10621-2009), the smallest headroom for a railway line is 7 m. The headroom between the track and the overhead bridge of De Zhou East station is 8.2 m. The multi-channel data acquisition system has 96 single-ended input channels and 48 differential input channels. The sampling rate is up to 100 ks/s, which is especially suitable for high-speed acquisition environment. The sampling rate for the field measurement in this study is 20 Hz. System uses high-precision pressure transducer CY2000FAIP for the measurement of wind pressure. CY2000F pressure transducer is made of sensor chip, using aluminum alloy shell and stress isolation technology. The collected pressure data is temperature-compensated and, linear amplified, V/I conversion. The final output signal has the range of 4–20 mA or 1–5 V.

Fig. 1. Photograph of the overhead bridge studied.

There are in total 14 measuring points on the bridge surface with the layout of measuring points and the sensor numbering system shown in Fig. 3. The pressure measurements include 20 different cases, with half of them from long trains and the others are from short trains. A long train consists of up of 16 carriages with a length up to 420 m. A short train is made up of 8 carriages and the length is about 210 m.

2.2. Flow characteristics of train-induced pressure

Fig. 4 shows samples of pressure time history curves obtained at Sensor 1 and 8 for a train travelling at 250 km/h. The curves show that there are significant pressure fluctuations at the passage of the train head or tail. The pressure will attain the positive maximum value at the train head passage, and it drops to the negative maximum pressure quickly. For train tail passage, the pressure will attain the negative maximum pressure first, and then reach the positive maximum pressure quickly. Pressures at different measuring points reach the

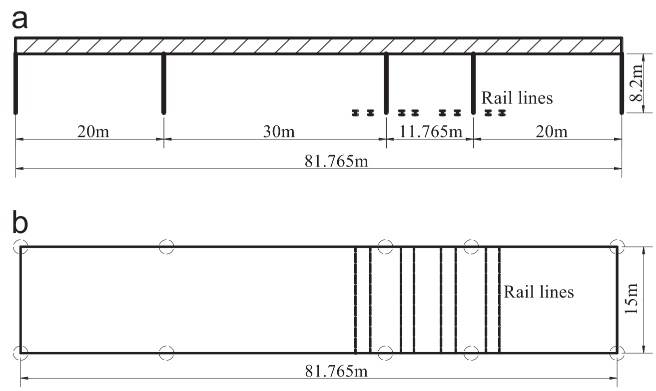

Fig. 2. General arrangement of overhead bridge. (a) Elevations view of overhead bridge. (b) Plan view of overhead bridge.

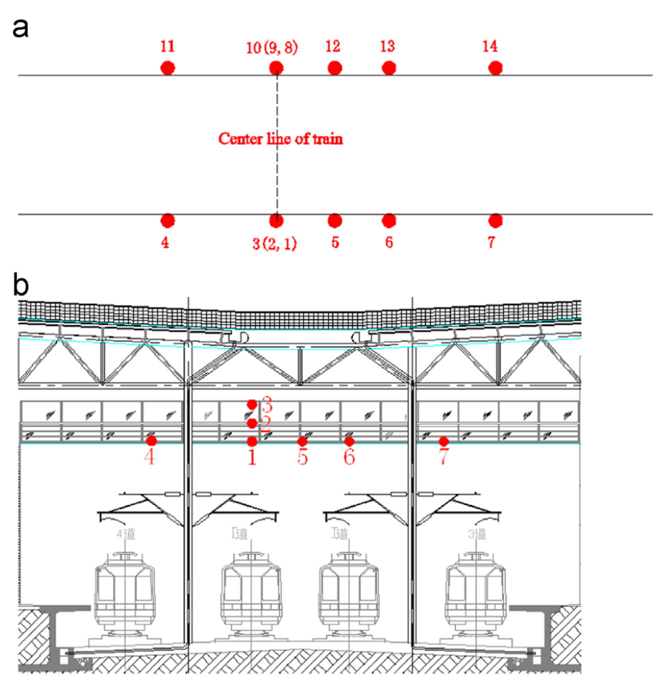

Fig. 3. Layout of field measuring points. (a) Top view of the sensor arrangement. (b) Elevation of the sensor arrangement.