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Field measurements of aerodynamic pressures in high-speed railway tunnels

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ABSTRACT

When a train travels through a tunnel at high speed, obvious pressure transients are generated because of the restricted airspace within the tunnel, which have an impact on the comfort of passengers and the structural safety of the train and the tunnel. In this paper, by performing a series of field measurements for high-speed railway tunnels in China, the aerodynamic pressures at different test points in the tunnels were obtained; the formation mechanism of pressure, the distribution of amplitude and the attenuation of pressure were analyzed. The results show that after the train travelled out of the tunnel, the pressure continued to fluctuate according to a fixed cycle and the pressure amplitude decreased exponentially as the number of cycles increased. The attenuation coefficient of the pressure had nothing to do with the train speed, but was associated with the tunnel length, the position of test points and the holes of the tunnel hoods.

1. Introduction

As a train travels through a tunnel at a high speed, similar to a loose-fitting piston moving quickly in a tube, a series of complex aerodynamic pressures are generated inside the tunnel due to the compression and expansion of the air, which causes some adverse effects such as passenger discomfort, noise surrounding the tunnel, resistance to train movement and possible structural damage to the train body and the tunnel facilities (Ko et al., 2012).

According to previous studies, there are many factors that affect the aerodynamic pressure inside the tunnel, such as the train type, train speed, blockage ratio, tunnel geometry and so on. The pressure rise generated by the compression wave that is produced by the entry of a train into the tunnel is proportional to the square of the train speed and proportional to the blockage ratio (Howe, 1999; Raghunathan et al., 2002). That is, the train speed and the blockage ratio are the two main factors influencing the amplitude of the pressure waves. A good shape of train nose (Kikuchi et al., 2011; Choi and Kim, 2014) and the tunnel hood (Liu et al., 2010; Murray and Howe, 2010; Uystepruyst et al., 2013) have little effect on the maximum amplitude of the pressure waves, but can increase the pressure rise time, and then reduce the pressure gradient. If there is some complex structure inside the tunnel, such as an airshaft (Yoon et al., 2001; Baron et al., 2001; Miyachi et al., 2014) or increased lining (Liu et al., 2015, 2016), the pressure waves will be dispersed or reflected in the process of transmission, which complicates the aerodynamic pressures in the tunnel even further. When the train pulls out of the tunnel, similar to the entry scenario, pressure waves will also be caused in the tunnel exit (Iida et al., 2001). The pressure fluctuation in the tunnel will not disappear immediately, but continue for several minutes after the train leaves (Ricco et al., 2007). Due to the friction with the tunnel wall and the reflection at the tunnel portal, the pressure wave is progressively attenuated during its propagation; many scholars (William-Louis and Tournier, 2005; Mashimo et al., 1997) have described this attenuation using the classical theoretical relation, in which some key parameters, such as the attenuation coefficient and reflection factor, are usually obtained by experiments.

Although extensive research on the aerodynamic pressures in tunnels has been conducted, existing studies rarely contain field measurement data, especially measurements made when the speed of the train is up to 300 km/h. Moreover, as tunnel damage occurs frequently on the high-speed railway in China, some researchers (Ma et al., 2011; Liu, 2010) have begun to pay attention to the impact of the aerodynamic pressure induced by trains on the cracks in the tunnel lining and consider this pressure as a reciprocating fatigue load, making it necessary to study the aerodynamic pressures even when the train has pulled out of the tunnel. In this paper, the processes of change in aerodynamic pressure in tunnels in China both when the train is travelling inside the tunnel and when it has pulled out of the tunnel were measured, and the characteristics of the pressure, such as its amplitude, fluctuation cycle, and attenuation rule, were studied. This can provide the basis for properly assessing the aerodynamic pressure in tunnels in China and for investigating the impacts of this pressure on trains and tunnels.

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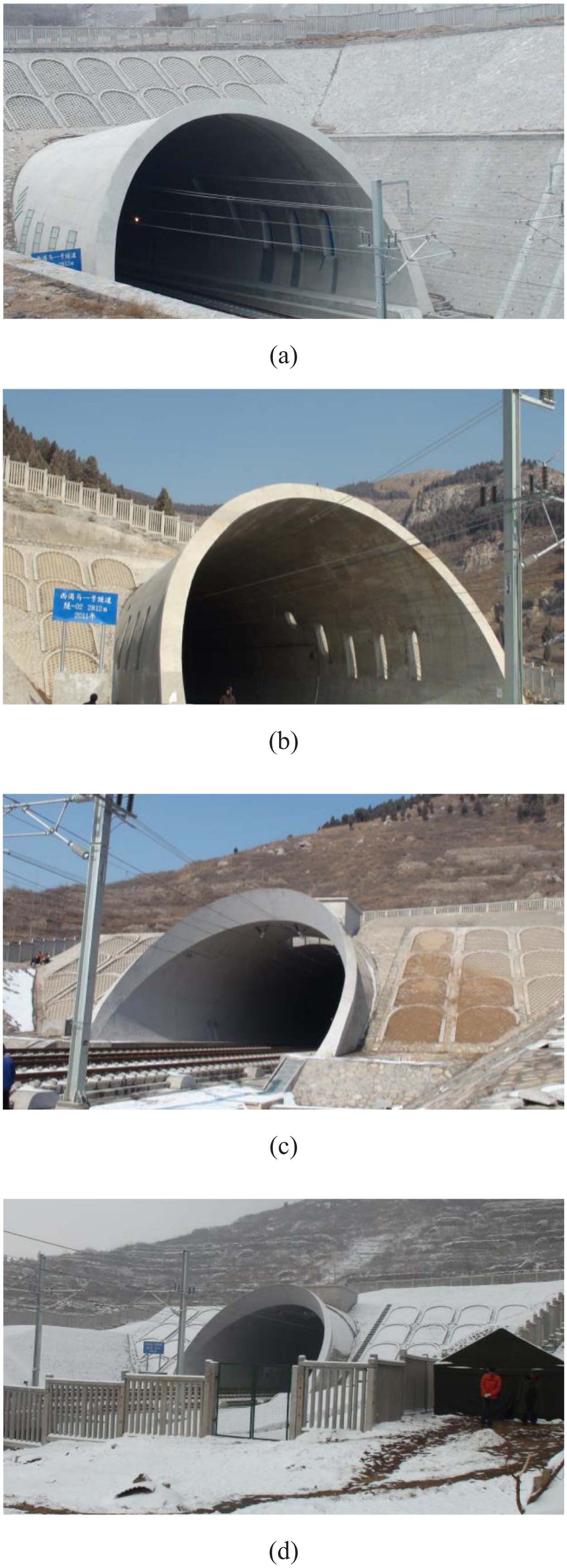

Fig. 1. Characteristics of tunnel portals: (a) north portal of Xikema 1, (b) south portal of Xikema 1 (c) north portal of Xikema 2, (d) south portal of Xikema 2.

2. Measurement configurations

2.1. Measurement targets

The Xikema 1 Tunnel and Xikema 2 Tunnel, selected for our measurements, are located on a passenger-dedicated line between Dezhou City and Zaozhuang City in China. The lengths of the tunnels are 2.8 km and 1 km respectively, and the cross-sectional areas are 100 m^2. The railway in each tunnel is double-track, and the distance between tracks is 5 m. To relieve the aerodynamic effect when high-speed trains pass through, hoods have been built at the entrances and exits of the tunnels. Details of the tunnels are shown in Fig. 1 and Table 1.

This passenger-dedicated line was officially opened in 2011, and the highest operating speed is 350 km/h. Two common electric multiple units (EMUs), the CRH2C EMU and the CRH380AL EMU, were selected for measurement. The details of the test trains are shown in Table 2.

2.2. Test system

The test system mainly consists of dynamic pressure sensors, shielded signal wires, multichannel amplifiers, A/D converters and GPS devices. Based on the ‘Technical Regulations for Dynamic Acceptance for High-speed Railways Construction’, the sampling and filter frequencies were chosen to be 1000 Hz and 250 Hz, respectively. In order not to affect the flow around the test point, a piezoresistive pressure sensor, 8510B-1 of ENDEVCO, Inc., was utilized, as shown in Fig. 2. A multi-channel IMC recording system was used for data acquisition and storage.

The test speed of the trains ranged from 220 km/h to 350 km/h, and at least three repetitions were undertaken for each speed. Based on the relevant instructions in the *Guide to the Expression of Uncertainty in Measurement*, the measurement uncertainty mainly came from the repeatability of measurement, the pressure sensor, and the data acquisition equipment. The relative measurement uncertainty in our tests was 1.83%, which guarantees reliability. In order to observe the successive reflections of the pressure waves between both ends of the tunnel, continuous measurements were carried out for 5 additional minutes after the train had passed.

2.3. Arrangement of test points

The pressure sensors were installed on the tunnel wall at a height of 1.5 m, and were deployed along the tunnel to investigate the propagation and the variation of the pressure waves. The longitudinal layouts of the sensors are shown in Fig. 3. To compare the pressure of different test points in the same cross-section of the tunnel, additional sensors were installed on some sections of the Xikema 1 Tunnel. Considering the difficulty of installing the sensors and the potential danger to the pantograph-catenary system, the sensors could not be positioned in a higher position, as shown in Fig. 4.

3. Test results and analysis

3.1. Time-history and formation mechanism of pressure

Fig. 5 shows the time-history of the pressure change in the tunnel when the CRH2C travelled through Xikema 2 at the speed of 300 km/h. It was calculated that it took the EMU 14.4 s from entering the tunnel to pulling out completely. When the EMU ran inside the tunnel, the pressures at the test points presented fluctuations, which had different amplitudes for the different longitudinal positions. When the EMU pulled out of the tunnel (after 14.4 s), the pressure did not stop fluctuating immediately, but presented a regular change of alternating positive and negative. As time continued, the amplitudes of the pressure decreased gradually and eventually disappeared. The total duration of the pressure change was over 2 min.