Tunnelling and Underground Space Technology 52 (2016) 62–70

Contents lists available at ScienceDirect

Tunnelling and Underground Space Technology

journal homepage: www.elsevier.com/locate/tust

Effect of increased linings on micro-pressure waves in a high-speed railway tunnel

Feng Liu, Song Yao *, Jie Zhang, Yi-ben Zhang

Key Laboratory of Traffic Safety on Track of Ministry of Education, Central South University, Changsha 410075, PR China

ARTICLE INFO

Article history:
Received 23 December 2014
Received in revised form 16 November 2015
Accepted 25 November 2015
Available online 14 December 2015

Keywords:
High-speed railway tunnel
MPW
Increased lining technology
Full-scale measurement
Numerical simulation
Moving-model experiment

ABSTRACT

A micro-pressure wave (MPW) is generated when a train enters a tunnel at high speed, which causes a strong impact on the environment around the tunnel. The increased lining used to repair damage in high-speed railway tunnels changes cross-sections and has a strong influence on the MPW at the tunnel exit. In this paper, the methods of full-scale measurement, numerical simulation and moving-model experiments are used to study the MPW generated in a tunnel whose lining is increased. The rules governing the effect of increased linings on MPWs are obtained, which can be used as a reference for the Tunnel Damage Regulation Project in China.

1. Introduction

Tunnel damage is a worldwide problem (Wang et al., 2001) that not only threatens traffic safety in tunnels but also shortens the maintenance cycle and service life of the tunnels. Increased lining technology is a common method to repair tunnel damage in ordinary-speed railways. It adds concrete with a certain thickness to the surface of the original lining, which can prevent the development of crack damage (Pei et al., 2013). In recent years, increased lining technology has been widely applied in high-speed railways in China because of the serious tunnel damage. However, the impact of increased lining on the aerodynamic effect in a high-speed railway is more obvious than that in an ordinary-speed railway. It is necessary to study how the increased lining impacts the aerodynamic effect.

An important part of the aerodynamic effect in a high-speed railway tunnel (Raghunathan et al., 2002) is that the MPW is formed as a consequence of the steepening of the nose entry wave and results in the generation of a sonic boom at the exit of the tunnel, which can be sufficiently strong to disturb local inhabitants by, for example, rattling the windows of their houses (Baron et al., 2006; Vardy, 2008). According to previous studies, many factors affect the MPW significantly: the nose of the train (Bellenoue and Kageyama, 2002; Kikuchi et al., 2011; Ku et al., 2010), the hood at the tunnel portal (Liu et al., 2010; Murray and Howe, 2010; Uystepruyst et al., 2013; Xiang and Xue, 2010), shafts (Miyachi et al., 2014; Ricco et al., 2007; Yoon et al., 2001), cross passages (N'Kaoua et al., 2006), track form (N'Kaoua et al., 2006), and so on. However, the effect of increased lining on the MPW has been little studied.

Traditional methods of studying the aerodynamic phenomenon of high-speed trains are full-scale measurement (Iida et al., 2001; Ko et al., 2012; Sakuma et al., 2010), numerical simulation (Choi and Kim, 2014; Muñoz-Paniagua et al., 2014; Uystepruyst et al., 2011) and model experiments (Gilbert et al., 2013; Liu et al., 2010; Miyachi et al., 2014; Zhou et al., 2014). This paper studies the MPW of tunnels with increased linings using all three methods. The results can be used as a reference for the Tunnel Damage Regulation Project in China.

2. Methodology

2.1. Full-scale measurement

The Pingtu Tunnel, selected for our study, is located on a passenger-dedicated line between Chenzhou City and Lechang City in China. The length of the tunnel is 1921 m, and the cross-sectional area is 100 m^2. Although it is a double-track railway, we only study the direction of travel from Chenzhou to Lechang. The entrance and exit of the tunnel have a windowed hood and a hat oblique hood, respectively. A new lining is located 475 m away from the tunnel entrance, for which the length and the thickness

* Corresponding author.
E-mail addresses: lf198187@163.com (F. Liu), 670259022@qq.com (S. Yao), jie_csu@csu.edu.cn (J. Zhang), zhangyiben1228@126.com (Y.-b. Zhang).

http://dx.doi.org/10.1016/j.tust.2015.11.020
0886-7798/

are 90 m and 0.3 m, respectively. There exists a gradual transition of 1 m in length between the new lining and the original one.

To analyse the influence of the new lining on the transient pressure, pressure sensors (model 8515C-15, Endevco) were installed in the side walls of different sections around the new lining. To study the amplitudes of the MPW, low-frequency microphones (model 4193, B&K) were installed 20 m and 50 m from the tunnel exit. A multi-channel IMC recording system and a PULSE (3560C) analyser were used for data acquisition and storage. The tunnel structure and the arrangement of test points are shown in Fig. 1.

This passenger-dedicated line was officially operated in 2009, and the highest operating speed is 350 km/h. Two common electric multiple units (EMUs), the CRH2C double-connection EMU and the CRH380A EMU, were selected for measurement (Fig. 2 and Table 1). The test speed of the EMUs ranged from 250 km/h to 350 km/h, and three repetitions were undertaken for each speed. Measurement uncertainty mainly came from the repeatability of measurement, the pressure sensor or the microphone and the data acquisition equipment. The measurement uncertainties for pressure and for the MPW in our full-scale measurement were under 1.8% and 1.2%, respectively, which guarantees reliability.

2.2. Numerical simulation

It is not practical or economic to rely only on full-scale measurement. In this paper, the influence of the new lining on the MPW is further analysed by means of numerical simulation and a moving-model experiment.

2.2.1. Numerical domain and boundary conditions

To understand the aerodynamic phenomenon of the tunnel entry problem, a three-dimensional, viscous, compressible, unsteady, turbulent model was applied (Liu et al., 2010).

The numerical domain is shown in Fig. 3(a). The external domain is simulated as two rectangular bodies. A sliding mesh technique (Chu et al., 2014) is used to simulate the relative motion between the train and its surroundings. The no-slip solid-wall boundary condition was used for the tunnel walls, the train body and the ground. The far-field boundary condition was used for the external domain and the tunnel extremity. At the beginning of the computation, the train was placed 50 m from the tunnel entrance to ensure the stability of numerical simulation.

2.2.2. Geometrical model and mesh

The calculation model for the tunnel was obtained by simplifying the real geometrical structure of the Pingtu Tunnel. The windowed hood at the entrance and hat oblique hood at the exit were retained, but the curvature radius and the track gradient were ignored in the model. Similarly, the EMU calculation model was obtained by simplifying the geometrical structure of the CRH380A (Fig. 2(c)). This simplification means ignoring some small but complex structures, such as pantographs, lights and door handles. In

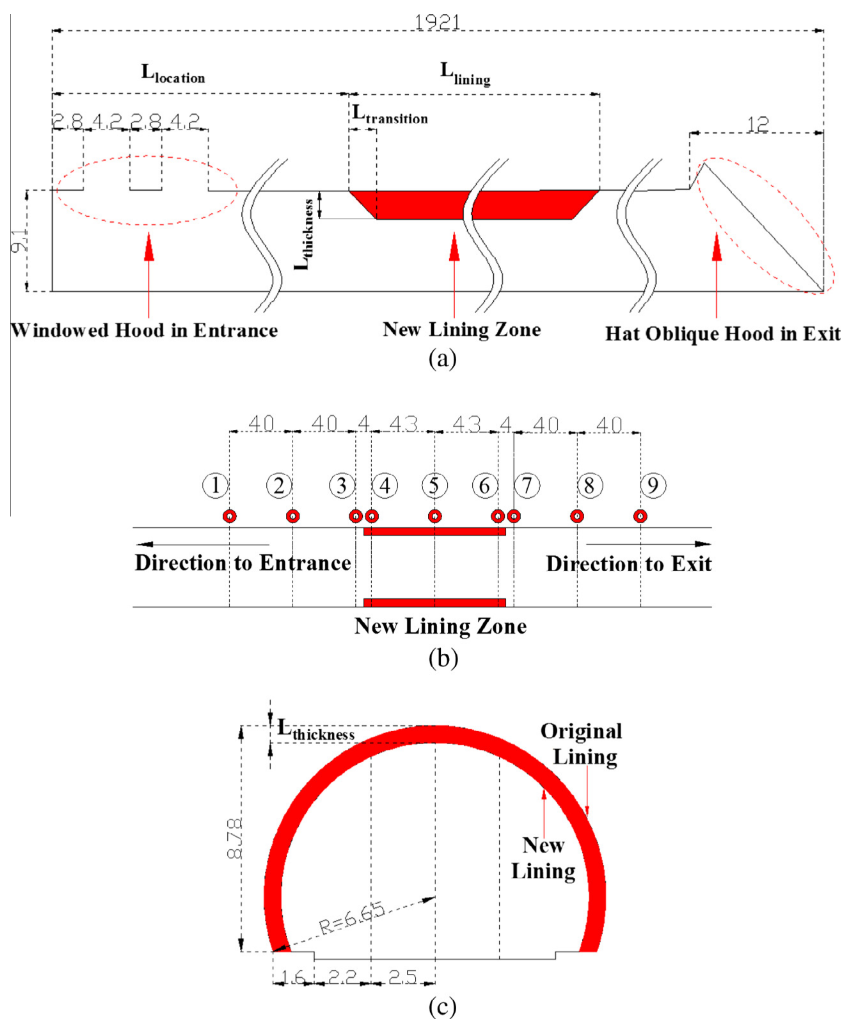

Fig. 1. (a) Profiles of the tunnel, (b) arrangement of the test points near the new lining and (c) cross-section of the tunnel.