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Study on the aerodynamic load characteristic of noise reduction barrier on high-speed railway

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ABSTRACT

Noise reduction barrier is a new type of noise barrier, as one of the effective ways to improve the barrier structural safety and reliability, its aerodynamic load characteristic is the key to reflect the overall force of barrier. In this paper, the aerodynamic load characteristics of noise reduction barrier are studied experimentally from three aspects: EMU speeds, distances between train and noise barrier, and EMU types. As the results show, for the bridge section, the positive strain amplitude is about twice the negative strain amplitude at different train speeds. The closer the train is to the barrier, the more sensitive the aerodynamic load is to the speed. The effects of EMU types on the aerodynamic load of the noise barrier are less affected by the train speeds. For the subgrade section, with the increasing of EMU speeds, the increase of positive strain amplitude is much smaller than that of negative strain amplitude. The aerodynamic load characteristic of noise reduction barrier at different distances between train and barrier are highly correlated with the barrier heights. The varies of aerodynamic load on noise barrier with EMU speeds have little relationship with the distances between EMU and barrier.

1. Introduction

In the past few years, the construction of high-speed railway over the world is heating up. At present, the "Fuxing Train" with 350 km/h in China has been put into use, and the EMU experiments with 400 km/h are in progress (Dai et al., 2007). In general, the overall noise sources from train vehicles include both airborne and ground borne noise, the generation and propagation of ground vibrations are of importance (Kouroussis et al., 2015), however, with the rapid development of high speed railway, the noise pollution caused by the aerodynamic force of high-speed train is becoming more and more serious. Studies have shown that nearly 49% of major cities in China are slightly affected by noise pollution, and about 17% of the major cities are under moderate noise pollution (Naderzadeh and Monazzam, 2011).

Noise barrier is an important measure to reduce noise which can effectively reduce noise interference. However, the aerodynamic effects of EMU speed improvements on noise barrier are more and more obvious (Lichtneger and Ruck, 2015; Carassale and Brunenghi, 2013; Quinn et al., 2001; Zheng and Wang, 2009; Zhou et al., 2013; Zhao et al., 2015; Li and Tian, 2012), which makes the noise barrier produce intense structural response, then threatens the railway safety. Due to the damage of noise barrier structure on high-speed railway, railway safety accidents have been reported frequently. In 2003, a full line of metal plug-in noise barrier on Cologne-Frankfurt railway in Germany were destroyed because of resonance under the effects of fluctuating pressure caused by high-speed train, and the reconstruction and maintenance cost tens of millions of Euros (Wang, 2001). Therefore, in order to ensure that the noise barrier can work effectively when the train is running at high speeds, it requires not only good performance of noise absorption and reduction, but also the fine dynamic performance of barrier structure.

Noise reduction barrier, a new kind of noise barrier, as an effective way to improve safety and reliability of noise barrier, is attracting the attention of researchers.

A new type of noise reduction barrier structure was designed by Sato et al. (2012): it is made up of a noise insulation plate and a frame, and the top of noise insulation plate is combined with the frame by a rotating shaft, the other three sides are combined with the frame by magnet. Usually, the noise insulation plate and the frame linked closely, however, the noise insulation plate will open when the pressure on it is greater than 1.5 kPa. Also, they tested the deloading characteristic of this noise barrier in the laboratory, then found that the deloading capacity of the noise reduction barrier can reach 50%.Watanabe et al. (Watanabe et al., 1996; Homma et al., 2005) also proposed a new kind of noise reduction barrier, which can be controlled by electromagnetic force to swing. When

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the pressure is greater than the electromagnetic force, the noise barrier can roll through a rotating shaft to prevent over deformation, so as to prolong the service life of noise barrier under the effects of fluctuating pressure caused by high-speed train and natural wind pressure.

Some research institutions in China together designed an inverted V-shaped metal noise reduction barrier by numerical simulation and wind tunnel test (Li, 2014; Liu, 2016), as shown in Fig. 1, and its aerodynamic load characteristic is the key to decide the application of this product. So, studying on the aerodynamic load characteristic of noise barrier has an important significance. However, compared with field test, numerical investigation on aerodynamic load characteristic of noise reduction barrier simplifies some real conditions, also wind tunnel experiment can only test aerodynamic load characteristic of noise reduction barrier under steady state conditions, while noise barrier is impacted by fluctuating pressure when EMU passes. Therefore, it is necessary to carry out the field test to study on the aerodynamic load characteristic of noise reduction barrier on high-speed railway.

In this paper, the aerodynamic load characteristics of noise reduction barrier in bridge section and subgrade section are studied experimentally from three aspects: EMU speeds, distances between train and noise barrier, and EMU types. The research results will provide a reference for further improving the structural strength of the noise barrier, optimizing the structure of the noise barrier, and promoting the application of the noise reduction barrier.

2. Experiment setup

2.1. Experimental subjects and purpose

Datong-Xi'an high-speed railway, total length of 859 km, starts from Datong and through Shuozhou, Taiyuan, Linfen, et al. 9 cities to Xi'an. The test site was in the specified test interval (Yuanping west station to Yangqu west station) on Datong-Xi'an high-speed railway.

Experiment subject is the inverted V-shaped noise reduction barrier, and the heights of noise barrier have two kinds: 2.15 m and 3.95 m. The photographs of noise barrier are shown in Fig. 2, The noise barrier with 2.15 m was installed in the bridge section, while the one with 3.95 m was installed in the subgrade section. Positions and lengths of test sections and noise barrier are shown in Table 1.

The purpose of this experiment is to get the aerodynamic load characteristics of noise reduction barrier in bridge section and subgrade section from three aspects: EMU speeds, distances between train and noise barrier, and EMU types (as shown in Fig. 3 and Table 2), respectively.

2.2. Experimental devices

For the purpose of this experiment, the experimental equipments required for field test is shown in Tables 3–5. Among others, strain gauges are used to measure the strain on the H-steel column.

The main experimental equipments and test platform are shown in Fig. 4. The test system consists of CL5016 type of data collecting& analyzing instrument (made by IMC Company of German) and computer, and FAMOS (also made by IMC Company) is used as the testing and post-processing software.

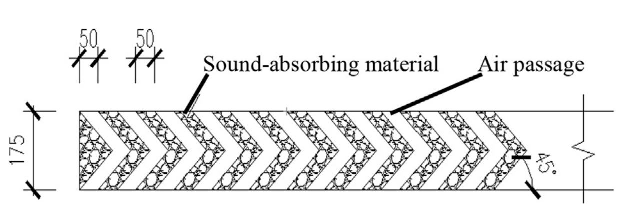

Fig. 1. V-shaped metal noise reduction barrier (Units: mm).

2.3. Experimental contents

According to the actual test conditions and test technology, and for the purpose of minimizing the effects of special unit board and electromagnetic interference on the experimental results, the positions of measuring points are located as shown in Table 6.

The experimental arrangement of measuring points is given as follows: strain gauges are installed respectively on the three unit plates and on the bottom of column, which are used to test strains at different places. The overall layout of the measuring points and column image are shown in Fig. 5.

It should be noted that this paper focuses on the aerodynamic load characteristics of noise reduction barrier, so the most important position of measuring point is in the bottom of column, where the strain value can reflect the magnitude of the aerodynamic load acting on the entire noise barrier.

This experiment involves two test sections: the bridge section and the subgrade section, and the speed distribution of high-speed train CRH380A and CRH380AM are between 175 km/h and 385 km/h. CRH380A and CRH380AM passed the bridge section 38 times respectively, and the actual speed distribution is between 175 km/h and 325 km/h; CRH380A and CRH380AM passed the subgrade section 40 times, and the actual speed distribution is between 190 km/h and 385 km/h.

During the experiment, the test principle is followed as: (1) the measuring points in the same measuring section should use the method of synchronous measurement; (2) each measurement data should be measured when the same train passed through the measurement point; (3) the measurement results should be averaged over multiple measurement data.

2.4. Calibration of the test system

Although the relation between train speed and strain is not accessible, while the relation between pressure on the surface of the noise barrier and train speed is quite easy to find, so the test system is calibrated based on the conclusion that the peak of fluctuating pressure on surface of the noise barrier is proportional to the square of train speed (Liu, 2016). The fitting curve is drawn according to the measured pressures at the bridge section, as shown in Fig. 6.

It can be seen that the correlation coefficient of the measured pressures and the fitting curve $p = 0.00454v^2$ is 0.97796, the maximum relative error between the measured pressure and fitted value is 4.60%, which is less than 5%. Therefore, the measured peak of fluctuating pressure is proportional to the square of train speed indeed, and the test system meets the requirement of the field test.

3. Results and discussions

3.1. Aerodynamic load characteristic of noise reduction barrier (bridge section)

Since this experiment involves two kinds of noise reduction barrier, and they are installed in the bridge section (2.15 m) and subgrade section (3.95 m) respectively. So we will discuss the aerodynamic load characteristics of noise reduction barrier in two test sections. First, the aerodynamic load characteristic in bridge section is analyzed from three aspects: EMU speeds, distances between train and noise barrier, and EMU types.

3.1.1. EMU speeds

The strain value at the bottom of H-type steel column can reflect the magnitude of the aerodynamic load acting on the entire noise barrier. Speed characteristic of noise barrier is that performance index (strain/pressure/displacement, strain is chosen in this paper) varies with EMU speeds. Fig. 7 gives the strain curves at the bottom of H-type steel column