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Field study on high-speed train induced fluctuating pressure on a bridge noise barrier

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ABSTRACT

The pressure variations induced by a CRH380A EMU on a 2.15 m high bridge noise barrier are investigated in a field measurement. The familiar fluctuating pressure time history curves and the peak-to-peak pressure (ΔP) distributions attributing to the train head on the barrier surfaces are presented. A comparison of the positive head pulse pressure is made between the measurement results and the data calculated by empirical equations in EN 14067-4. Furthermore, the influences of train speed, train running lines, locations of measurement points, train marshalling length and environmental wind speed on ΔP are analysed. The results indicate as the train speed increases, the corresponding time intervals of ΔP decrease gradually, whereas their slopes become increasingly steep. For a CRH380A EMU, the aerodynamic length of the train head is between 7.63 and 7.64 m, which differs from the physical length of a realistic train with 12.00 m. Along the noise barrier from bottom to top, the ΔP values on the inner surface decrease with the increase of height, while these values on the outer surface increase. Taking the wind direction into account, the ΔP values are a little higher when the high-speed trains run against the wind direction.

1. Introduction

In order to use the land economically, reduce the influence of high-speed railways on the environment and avoid the occupation of fertile land, most of high-speed railway infrastructure scenarios in China are built in the form of bridges. Furthermore, noise barriers are always installed on both sides of the high-speed railway bridge to reduce noise pollution for residents living around the lines (Long et al, 2010). When a high-speed train passes close to the noise barriers along the track, it would exacerbate the turbulence intensity of surrounding air and cause unsteady transient aerodynamic pressure on the barriers' surfaces. In turn this forms a transient pressure impact that reaches positive and negative pressure peaks so quickly within tens of milliseconds (Baker, 2010; Tian, 2007; Schetz, 2001). These train-induced fluctuating pressure amplitudes on both sides of the noise barriers increase rapidly with the square of the train speed (Tian, 2007; PEC+S, 2007). And the dilatational and compression effects of fluctuating forces lead to structure fatigue failure at the joints of noise barriers (Zhu and Cheng, 2011; Chen et al., 2011). In 2003, an event related on the noise barriers along the Cologne-Frankfurt high-speed line took place in Germany due to the influence of these fluctuating loads, and it cost approximately 30 million Euros to reconstruct and repair the barriers (PEC+S, 2007). Therefore, to guarantee the operational safety of railway lines, it is significantly important to investigate the fluctuating loads that act on the noise barriers as the high-speed train passes.

Some previous studies have been conducted to research the effects of fluctuating pressure on the noise barriers and buildings surrounding the railway line during the passage of high-speed trains. Most of these are carried out in United Kingdom, Germany, Japan and USA. In United Kingdom, Baker (2010, 2014) studied the changes in the regularity of fluctuating forces suffered by the surrounding buildings when three different shapes of trains passed through the noise barriers, bridges, platform roofing and station platforms. This was performed by using a moving model with the scale of 1/25. The research findings are applied to complement the EU railway standard and the 2013 EN (CEN European Standard, 2013). These standards provide recommended loads based on the fluctuating forces on both sides and at the top of the buildings along the railway line (CEN European Standard, 2013). In Germany, the noise

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barriers dynamic response tests were carried out in the Nuremberg–Ingolstadt high-speed railway line. In this test, the fluctuating pressure, dynamic deformation and natural frequency caused by different train types, train speeds and noise barrier types were obtained. At last, they clearly presented a new formula to calculate the fluctuating wind loads based on the measurements of fluctuating pressure on the high-speed railway noise barriers (PEC+S, 2007). In Japan, Tokunaga et al. (2016) studied the dynamic response evaluation of noise barriers during the passage of high-speed trains based on field tests and numerical simulations. The effects of some factors on the noise barrier response were quantified. At last, two practical design methods for evaluating the dynamic response of noise barriers were proposed. In USA, the Federal Railroad Administration of U.S. Department of Transportation used field measurements to test the effect of fluctuating forces on the stable double-decker container trains when a high-speed train passed. This force was determined from a vehicle dynamics model, and the vehicle response under the action of the fluctuating force was obtained (Lee, 1999; Holmes and Schroeder, 2002). Carassale and Brunenghi (2013) studied the dynamic response of buildings near the track due to the fluctuating pressure, and developed a non-dimensional mathematical model to predict the dynamic response of the trackside structure subject to the fluctuating pressure caused by passing trains.

Additionally, in China some researchers also investigated the aerodynamic pressure loads acting on the noise barriers and surrounding buildings along high-speed train railway lines using tests and simulations (Chen et al., 2011; Zhang et al., 2009). Yang et al. (2015) used the numerical simulations and full scale train tests to study the fluctuating pressure characteristics on an overhead bridge, they observed that the frequency of the fluctuating force was mainly concentrated in the range of 0 Hz–2.5 Hz. Zhou et al. (2014) used a moving model at the ratio of 1/20 to study the fluctuating force acting on the shielding door and the roof of the station platform, and the effect of train speeds, passing position of trains and other parameters of the fluctuating force were obtained. They found that when two trains passing by each other at the speed of 350 km/h in the station, the air compressibility should be considered. Zhang et al. (2009) studied the distribution of fluctuating pressure acting on the sound barrier of a railway bridge with collision walls and box girder flange plates when a high-speed train passed, and the distribution characteristics of fluctuating loads along the height of the noise barrier were obtained. They found that the peak values on the noise barrier and the box girder flange plate are proportional to the square of the train speed.

At present, the literature published are mainly focused on the fluctuating pressure on the noise barrier when the train speed is lower than 350 km/h. However, the spatial distribution of fluctuating pressure and the influence factors of fluctuating force are not yet clear when the train speed is higher than 350 km/h. At the same time, the complete and efficient measurement and evaluation methods on the fluctuating pressure of high-speed railway noise barriers haven't been established in China. In this study, a field experiment is conducted to obtain the distribution law of fluctuating pressure on the noise barriers caused by the passage of high-speed trains at the speed varying from 250 km/h to 380 km/h. The results are used to provide data support for the study on the dynamic response evaluation of high-speed railway noise barriers under fluctuating pressure. At the same time, the results are used to contribute to the data reference for revising and improving the relevant standards for the noise barriers along high-speed railways (Chinese National Railway Standard, 2014). However, due to the limitation of the field tests, it is difficult to obtain sufficient data about the effect of environmental wind on the fluctuating pressure on the noise barriers. In the next work, a further analysis of numerical simulations on the influence of environmental wind directions and wind speeds on the fluctuating pressure should be carried out.

2. Experiment set-up

2.1. Instrumentation

The test section was set up in the middle of a 2.5 km long bridge with noise barriers on both sides along the Beijing-Shanghai high-speed railway. A number of air pressure sensors fixed on the windward side, leeward side, and the top surface of these noise barriers were used to test the fluctuating pressure on the barriers. There were 16 pressure measurement points, of which 12 measurement points were set on the noise barrier close to the tracks (inner surface), and the other points were set on the noise barrier away from the tracks (outer surface). Fig. 1 shows the schematic diagram of the test set-up. The height of the noise barrier was 2.15 m from its top to the rail, and the specific installation section is shown in Fig. 2. The monitoring points in tests are shown in Fig. 3. In this system, LL-250 type pressure sensors produced by the Kulite Company in USA were used to measure the fluctuating forces on noise barriers, and the test range is 15 psi. The thicknesses of these sensors are very thin to minimize the interference on the flow field around barriers. Thus, the results are obtained with high precision.

Some approaches were adopted to reduce the measurement noise, such as the use of pressure sensors and testing equipment with stronger anti-interference performance, the shielded signal lines and the UPS power supply.

A Stalker Speed Sensor (S3) Police Option radar, seeing Fig. 4, with its measurement accuracy of ± 1 mph, was placed near the measurement points on the noise barrier to monitor the train speed as a CRH380A EMU passed it. The width of CRH380A EMU is 3.38 m and the height is 3.70 m. The total length of a 16 car-grounding EMU is 403 m and the length of an 8 car-grounding EMU is 203 m.

According to the CEN European Standard (2013), in the test a sensor (FLUKE 975 was used in this test) is required to be installed along the railway and is used to monitor the temperature and humidity when the train passes the test position. The temperature range of the sensor is -20–50 °C, and the range of relative humidity is 10%–90% RH.

Wind speed and wind direction sensors were also installed in the upstream of the bridge to check the wind speeds and directions, as shown in Fig. 5. The XFY3 type wind speed and direction sensors with the range of 0–100 m/s were adopted in the test. The precision of the sensor is less than or equal to 0.5 m/s when the wind speed is 0–10 m/s. However, when the wind speed reaches 10–100 m/s, the precision is changed as less than or equal to $\pm 5\%$ of the measured value. As to the wind direction of the sensor, its range is 0–360° and the precision is $\pm 3°$.

These data are used to investigate the impact of environmental wind speeds on the fluctuating pressure distributions on the surfaces of noise barriers. The wind speed sensors were fixed at a height of 3 m above the ground and 30 m far from the bridge, and this height was lower than the bridge height that is 10.5 m. Therefore, the wind speeds measured by the wind speed sensors were less than the wind speed at the noise barrier position. In the test, the sampling frequency of wind speed sensor is 4 Hz and the wind speed is the mean wind speed in the 15s interval before the train nose passes. This data processing method can are referred to that in the CEN European Standard (2013).

Due to the limitation of test conditions, the wind data are recorded at the height of 3 m from the ground. In order to obtain the wind speed at the bridge height, a power law is used (Frost, 1948; Wu, 2014). Generally, the wind profile of the atmospheric boundary layer (ABL) (from surface to around 200 m) is logarithmic in nature and is best approximated using the log wind profile equation that accounts for surface roughness and atmospheric stability (Cook, 1985). However, sometimes the surface roughness or stability information is not available, so the wind profile power law relationship is often used as a substitute for the log wind profile. In this section, a power law is used to describe the