ACOUSTIC PERFORMANCE OF NOISE BARRIER DESIGNED FOR HIGH SPEED RAILWAY

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Nosie barrier is an effective facility to solve the high speed railway noise problem. The acoustic performance of noise barrier depends on their profiles and absorption properties. Moreover the noise decreases a lot due to diffraction over the barrier top edge. A type of noise barrier designed for high speed railway is studied. The top of the barrier is installed with acoustic diffusers. A numerical model is established to calculate the insertion loss of the noise barrier. The excitation sources are based on the test results of high speed railway noise. The simulation results of insertion losses demonstrate the presented noise barrier is more effective for high speed railway compared with the traditional rectangular noise barrier of the same height.
Keywords: Noise barrier, High speed railway, Acoustic diffuser, Numerical simulation

1. Introduction

High-speed railway transportation got rapid development in China in recent years. It brought convenience to the people, at the same time, also produced many problems. The high-speed railway noise pollution seriously affected the quality of life of residents living along the route, it is necessary to control the noise problem. Nosie barrier is an effective facility to reduce the noise[1].

There are some ways to improve the performance of noise barrier. The simplest way is increasing the height. But it is not practical to build very high barriers, considering cost and safety. Some alternative methods were proposed without increasing the height of noise barrier. Because the performance of noise barriers largely depends on the profiles, modifying the shape of the barrier is an effective method. Several studies showed that the insertion loss of noise barrier improved a lot by T-shaped and Y-shaped design[2,3]. Acoustic diffuser was also used to improve the insertion loss of noise barrier. Pseudo-stochastic diffusers were invented by Schroeder in 1970s[4,5]. The most popular type is the quadratic residue diffuser (QRD). Monazzam investigated the attenuation of sound by QRD edged single noise barriers using a two-dimensional boundary element model[6].

In this paper, the noise characteristics of high speed railway had been tested first, and then some factors that may influence the acoustic performance of noise barriers were studied. A type of noise barrier with top shape and QRD was designed for high speed railway. The insertion loss of noise barriers is evaluated by numerical model.

2. High speed railway noise test

Since the insertion loss of the noise barrier would be different with the change of the sound source characteristics, the characteristics of the noise source must be taken into account when designing the noise barrier. Compared to ordinary train, high-speed train is significantly different in appearance and speed, so there must be a big difference between high-speed railway noise and ordinary railway noise. Before the high-speed railway noise barrier design, high-speed railway noise characteristics need to be obtained first.

2.1 Measuring points setup

According to the relevant test standards[7], a number of measuring points were set up by the high speed railway to test the noise emitted by the high-speed trains. The measuring points arrangement was shown in Fig 1.Mic1 and Mic3 were 3 meters away from the track line centre, and the height was same as the top of the track; Mic2 and Mic4 were 25 meters away from the track line centre, and the height was above the track 3.5 meters. OP1 and OP2 were photoelectric switches, and the test was controlled by them automatically.

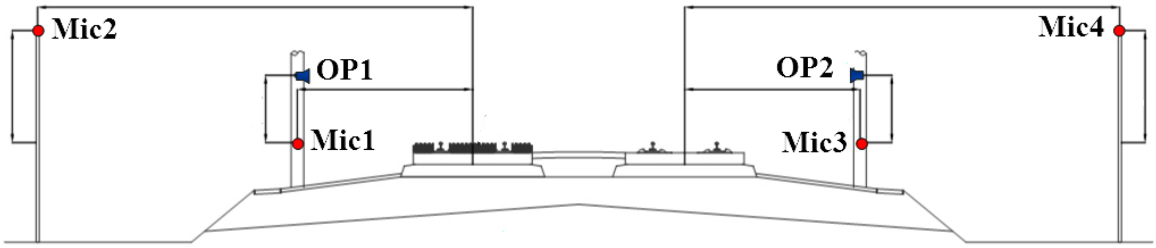

Figure 1. Measuring points' arrangement.

2.2 Test result

Figure 2. shows the A-weighted equivalent sound level (LeqA) values of measuring points Mic1 and Mic3 under different speed. The actual speed is averaged and rounded to nearest tens in convenience of categorization. The speed level included 160km/h, 200km/h, 220km/h, 240km/h, 260km/h, and 300km/h.

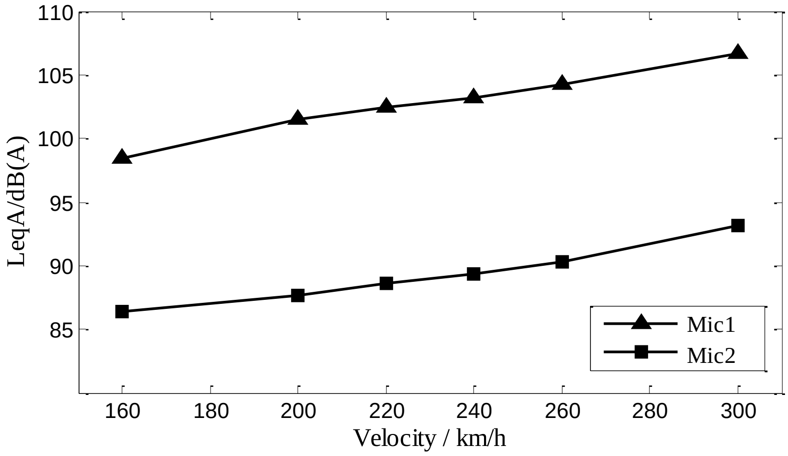

Figure 2. LeqA of different measuring points vs. speed.

It can be seen from Fig. 2, the sound pressure level of Mic1 is much higher than Mic2.When the velocity exceeding 200 km/h, the sound pressure level of Mic1 is higher than 100 dB (A), indicating that the noise in the wheel-rail area plays a leading role. The sound pressure level of Mic2 is between 86.4 and 93.9 dB (A), which is much lower than Mic1. At the same speed level, the difference is 12-14.2 dB (A).With the increase of distance, the radiation noise of high-speed train has a significant attenuation. High-speed railway noise sound pressure level was higher than 85dB (A), which is harmful to the human ear, so setting the noise barrier to control the radiation noise is very necessary.

Figure 3. shows the noise spectrum at Mic1 and Mic2 under speed 300km/h. As can be seen from the figure, high-speed railway noise presented broadband characteristics. The noise at Mic1 is mainly from the wheel-rail area, and the frequency range is concentrated at 400 Hz-2500 Hz, where the peak of the sound pressure level occurs at the 800 Hz and 2000 Hz. The peak reflects the characteristics of radiation noise emitted by wheel-rail and track respectively. The noise at Mic2 has similar spectral characteristics with Mic1, but in the high frequency range above 2500 Hz, the proportion of high frequency noise has a more significant effect on the point, which is due to the contribution of aerodynamic noise becomes larger.

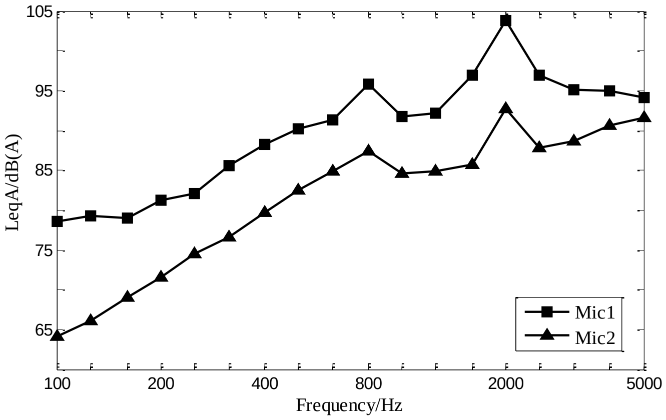

Figure 3. Noise spectrum at Mic1 and Mic2

3. Simulation model

Since the length of high-speed train is much longer than the distance from the sound source to the receiving point, the high-speed railway noise can be regarded as an infinite long-term sound source, and its spectral characteristics do not change in the longitudinal direction. At the same time, in the different plane perpendicular to the running direction of the train, the sound field distribution can be considered the same. Therefore, the insertion loss of the noise barrier is solved by calculating the sound field distribution of one of the sections. In this paper, the Finite Element Method (FEM) was used to solve the sound field distribution in two-dimensional plane. By this method, the number of grids could be greatly reduced, which would save a lot of computing resources and can calculate the sound pressure level of any point in the sound field.

According to the high-speed railway noise distribution characteristics, high-speed railway noise can be divided into the following parts: wheel-rail area noise, mainly including wheel-rail noise and bogie aerodynamic noise; body side noise, mainly including the aerodynamic noise caused by vehicle body side; electric system noise, mainly from the pantograph area, including the aerodynamic noise caused by friction of pantograph and spark arc noise.

High-speed railway noise barrier is mainly effective on the wheel-rail area noise and the lower part of the body noise. The noise of the pantograph area mainly reach the receiver point in the form of direct sound, due to its position is higher than the noise barrier, so the noise barrier has almost no effect on this part of noise. When the frequency is lower than 2000 Hz, wheel-rail noise plays a leading role, so the noise source is simplified to two incoherent line sources S1 and S2 in the wheel-rail area. S1 and S2 is symmetrical along the centre of the track. The distance of S1 and S2 is 1.435m, and the height is 0.3m above the top surface of rail when the frequency is higher than 2000 Hz, the aerodynamic noise caused by the vehicle body side and noise in the pantograph area need to be considered, so S3 and S4 were used to simulate them. S3 simulates the aerodynamic noise on the side of the vehicle body, the distance from the centre line of the track is 1.7m and the height is 2.5m above ground. S4 simulates noise in the pantograph area. It is located at the centreline of the track, and the height is 5m above ground.

The simulation model is shown in Fig. 4. The train is 3.2m wide and 3.8m high. The distance between noise barrier and the centreline of track is 4.175m. The receiver points M1, M2, M3 is 5m distant from barrier, and the height is 1.5m, 2.5m and 3.5m, respectively.

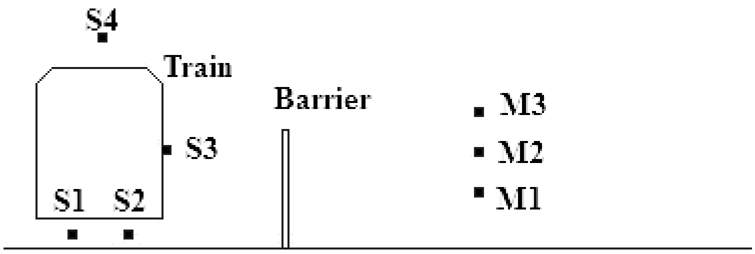

Figure 3. The 2D simulation model

The efficiency of noise barrier is measured by insertion loss (IL). It is the decrease of the sound pressure level achieved by the insertion of the noise barrier. It is defined as the difference of sound pressure level *SPLn* at the receiver before the noise barrier has been installed and sound pressure level *SPLb* after installation.

$$IL = SPL_n - SPL_b \tag{1}$$

4. High speed railway noise barrier design

4.1 Effect of height on IL

Increasing the height is an effective means to improve insertion loss of the noise barrier. At present this is the most commonly used method. But the increase in the height of the noise barrier will be subject to many conditions. Therefore, it is very meaningful to study the relationship between the height and the insertion loss of the noise barrier, and select the most suitable noise barrier height to save the cost.

The heights range from 2.65m to 3.55 m, and the height change step of the noise barrier is 0.1 m. A total of 10 types of noise barriers with different heights were simulated. The thickness of the noise barrier is kept at 0.15m. The frequency range is set to 100-2500 Hz, where the calculated step is set to 20 Hz in the 100-1000 Hz band and the calculated step is set to 50 Hz in the 1000-2500 Hz band. This set on the one hand can reduce the impact of acoustic interference, on the other hand can save computing resources, improve computing efficiency.

Figure 5. shows the average sound pressure level at points M1, M2, and M3 of noise barriers with different height.

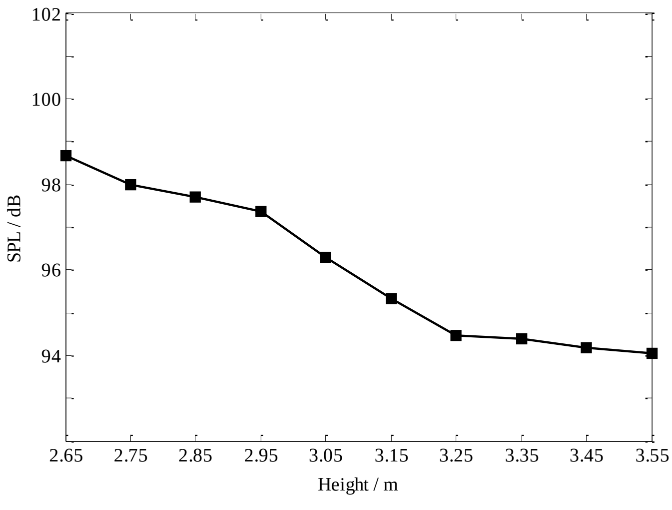

Figure 5. Average sound pressure level of M1, M2 and M3 vs. height

It can be seen from the figure, with the noise barrier height increases, the average SPL showed a downward trend, which means the insertion loss increases, but does not increase linearly. When the height of the noise barrier increases from 2.95 m to 3.25 m, the increase of the insertion loss is 1.1 dB (A), 1.4 dB (A) and 1.2 dB (A) respectively. When the height exceeds 3.25 meters, the insertion loss at the three measuring points is almost constant. There is a "critical point", before the point, the noise reduction effect gain is more obvious with height increasing, but beyond the critical point the noise reduction effect gain is not significantly. For the high-speed railway noise barrier, the height is 3.25m.

4.2 Effect of top shape on IL

In addition to increasing the height, setting the top shape is one of the ways to increase insertion loss. Combined with the high-speed railway noise characteristics, insertion loss of noise barriers with different top shapes were analysed, and the influence of the parameters of the top shape on is studied.

Figure 6. shows four types of top structure commonly used in the highway and ordinary railway noise barrier, including L-shape, Oblique shape, Y-shape and T-shape. Set the four noise barriers with same height 3.25m, and the screen body with same thickness 0.15m.These four top shapes were analysed. The monitoring points and analysis frequency range were same as before.

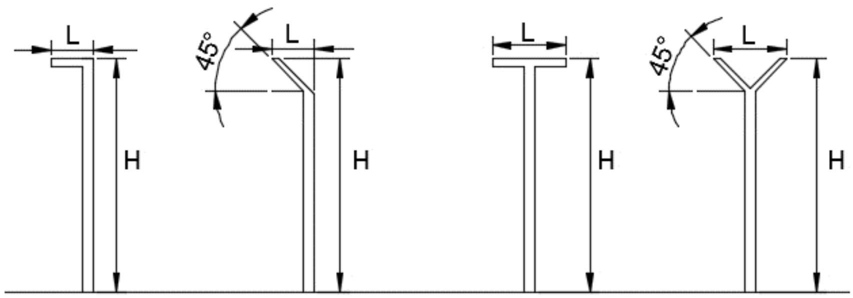

Figure 6. Profiles of the noise barrier with different top shapes

Table 1. shows the sound pressure levels of the four noise barriers at three points and average SPL. It can be seen from the table, the sound pressure level of Y-shaped noise barrier at each point is lowest, indicating the Y-shaped barrier has best noise reduction effect. The average insertion loss of the T-shaped noise barrier is 3.12 dB lower than that of the Y-shaped noise barrier, and the difference of the insertion loss between the L-type and the oblique type is not large, just 0.11 dB.

Table 1. Sound pressure level of noise barrier with different top shape

Top shape	SPL/ dB			
	M1	M2	M3	SPLmean
T-shaped	92.09	92.36	98.67	94.38
Y-shaped	86.58	90.55	96.64	91.26
L-shaped	92.81	93.04	98.54	94.80
Oblique shape	92.40	94.03	98.32	94.91

4.3 The Application of QRD Structure

According to the study of the height and the top shape, it can be seen that the noise reduction effect is mainly on the control of the high frequency noise, the noise reduction effect of the low-frequency noise is not obvious. Therefore, the QRD structure was used to control the low-frequency noise, so that further improve the insertion loss of noise barrier.

The sequence number for the *n*-th well, s_n, is given by:

$$s_n = n^2 \bmod N \tag{2}$$

Where modulo (mod for short) is the least non-negative reminder. N is the prime number, which is also the number of wells per period. The diffuser has best performance at integer multiples of a design frequency, f_r.

The depth of the well is determined by the design frequency, and the design frequency is the first frequency at which the scattering can have uniform energy diffraction lobes. The relationship between the well depth d_n and the design frequency f_r is calculated using the following equation:

$$d_n = \frac{s_n \lambda_r}{2N} \tag{3}$$

The frequency range in which the QRD structure has diffusion effect is determined by following equation:

$$\lambda_{\min} \approx 2w_n \quad \lambda_{\max} \approx \frac{2Nd_{\max}}{S_{n_{\max}}} \tag{4}$$

Considering the high-speed railway noise spectrum characteristics, the design frequency is set to 500Hz. The QRD structure is influenced by the well width and the sequence number *N*, it is necessary to consider the influence of these two parameters together. Four QRD structures were designed, and the width of the well was 0.17 m, 0.14 m, 0.1 m, and 0.09 m, respectively. The number of sequences *N* was 11, 13, 17 and 19. Fig.7 shows four Y-shaped barriers with different QRD structures.

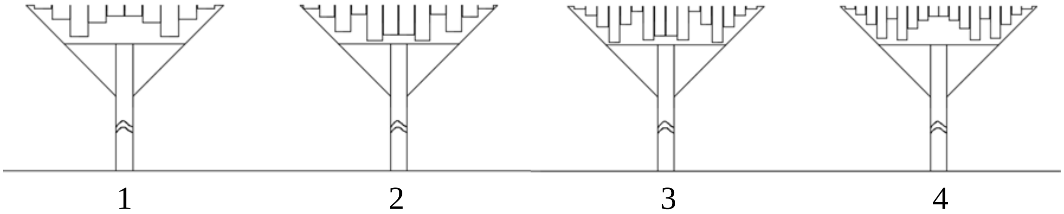

Figure 7. Profiles of the noise barrier with different QRD structures

Table 2. shows the sound pressure level values and their mean values of the four barriers at three monitoring points. It can be seen from the results that the QRD structure with sequence number N = 17, and well width w_n= 0.1 m has the best noise reduction effect.

Table 2. Sound pressure level of noise barrier with different QRD structure

Barrier profile	SPL/dB			
	M1	M2	M3	SPLmean
1	80.83	84.56	92.81	86.07
2	80.08	85.25	92.72	86.02
3	79.73	84.34	92.45	85.51
4	80.25	85.31	92.65	86.07

5. Acoustic performance analysis

Design parameters of high speed railway noise barrier are as follows: height 3.25m, thickness 0.15m, Y-shaped top shape, width 1.8 meters; QRD structure design frequency 500 Hz, well width 0.1 m, the sequence number *N* is 17. In order to analyse the acoustical performance of noise barrier, measuring pointsM1-M5 were set as shown in Fig. 8.

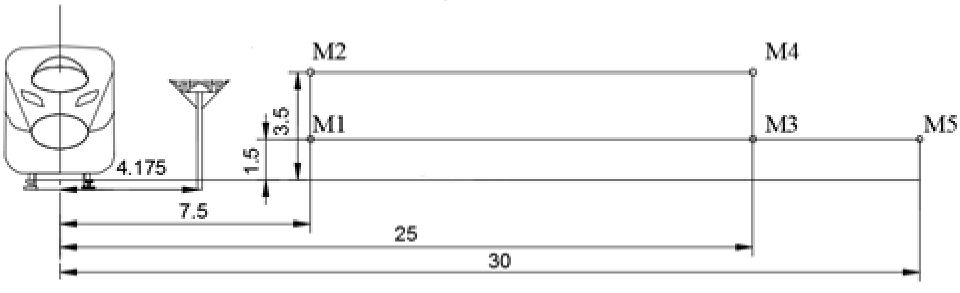

Figure 8. Measuring points distribution (unit: m)

Table 3. shows the insertion loss and the difference between the designed noise barrier and the traditional rectangular noise barrier. As can be seen from the table, the insertion loss of the designed

noise barrier at each point is greater than the traditional rectangular noise barrier. Insertion loss increased by an average of 3.35 dB.

Table 3. Insertion loss at each measuring point

Barriers type	IL/dB				
	M1	M2	M3	M4	M5
Designed barrier	16.59	6.14	12.88	10.10	12.16
rectangular barrier	10.59	4.43	9.49	8.01	8.59
Difference of IL /dB(A)	6.00	1.71	3.39	2.09	3.57

6. CONCLUSIONS

In this paper, a new type of high-speed railway noise barrier is designed, and its acoustic performance is analysed. By the finite element model, various factors were analysed, and the design parameters of the noise barrier are determined. According to the relevant standards, the noise monitoring points were selected to calculate the insertion loss of the new type high speed railway noise barrier at each point, and compared with the traditional rectangular noise barrier. The results show that the insertion loss of the designed high speed railway noise barrier is 3.55 dB (A) higher than that of the existing traditional rectangular noise barrier, and the noise reduction effect is improved obviously.

ACKNOWLEDGEMENTS

This work was supported by the National Key technologies Research &Development program under Grant No. 2016YFC0801702 and National key Basic Research Program of China (973 Program) under Grant No. 2013CB632905.

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