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Influence of Top Shape on Noise Reduction Effect of High-Speed Railway Noise Barrier

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Abstract. The top shape of the noise barrier mainly affects the acoustic diffraction, scattering and interference, changes the acoustic transmission path, increases the number and difficulty of diffraction, and thus reduces the field noise. This paper investigates the structural parameters of T-shaped and Y-shaped noise barriers at the top, analyses the noise reduction effect of different structural noise barriers by empirical formula method, and draws a conclusion with universal reference value, which provides a reference for the selection of noise barrier and noise control of high-speed railways in China.

1. Introduction

The rapid development of high-speed railway brings convenience and comfort to people's travel, but its noise also brings a certain impact on the surrounding environment of towns through which the railway line runs [1]. As one of the most important methods of railway noise isolation, noise barrier can effectively shield the propagation of various noise sources on the transmission path and has been widely recognized and applied in the research field of high-speed railway noise reduction [2-3].

Under the condition that the height of the noise barrier is determined, the diffraction of noise can be further suppressed by setting different shaped structures on the top of the noise barrier, and the insertion loss can be increased [4-5]. This method has been developed for many years and has been applied in highway and common railway. However, in the design of high-speed railway noise barrier, there are still few studies on the top structure, which is one of the reasons why China's high-speed railway noise barrier is still mainly vertical. The existing research on the top shape of high-speed railway noise barriers is mainly based on the finite element method [5] or boundary element method [4], which requires the establishment of two-dimensional or three-dimensional computational simulation model of noise barriers, and the analysis process is relatively complex. Therefore, this paper studies the insertion loss of T- and Y-type noise barriers of high-speed trains by empirical formula method. The analysis method in this paper is simple and rapid, which can easily provide reference for the selection and noise control of high-speed railway noise barrier.



2. A-weighted radiated noise frequency characteristics of high-speed train

In order to analyze the spectrum characteristics of radiative noise in high-speed railway operation, the linear sound pressure level (SPL) of radiative noise is selected when a high-speed train passes the bridge section at a speed of 350 km/h in literature [6]. However, in noise control engineering, in order to make the objective physical quantity of sound approximate to human auditory subjective feeling, A-weighted SPL is usually adopted as the weighted method in noise control standard. The A-weighted SPL can be corrected by the linear SPL of the acoustic point:

$$L_{Ai} = L_{Pi} + \Delta i \quad (1)$$

Where, L_{Pi} is the linear weighted SPL and Δi is the A-weighted correction at frequency point f_i . The specific correction of Δi at each frequency point can be seen in Table 1:

Table 1. Correction value of a weighted [7].

f/Hz	$\Delta i/\text{dB}$	f/Hz	$\Delta i/\text{dB}$	f/Hz	$\Delta i/\text{dB}$	f/Hz	$\Delta i/\text{dB}$	f/Hz	$\Delta i/\text{dB}$	f/Hz	$\Delta i/\text{dB}$
20	-50.5	80	-22.5	250	-8.6	800	-0.8	2500	1.3	8000	-1.1
25	-44.7	100	-19.1	315	-6.6	1000	0	3150	1.2	10000	-2.5
31.5	-39.4	125	-16.1	400	-4.8	1250	0.6	4000	1.0	12500	-4.3
40	-34.6	160	-13.4	500	-3.2	1600	1.0	5000	0.5	16000	-6.6
50	-30.2	200	-10.9	630	-1.9	2000	1.2	6300	-0.1	20000	-9.3
63	-26.2										

After modification, the spectrum characteristics of radiated noise during the operation of high-speed trains with A-weighted can be obtained, as shown in Figure 1.

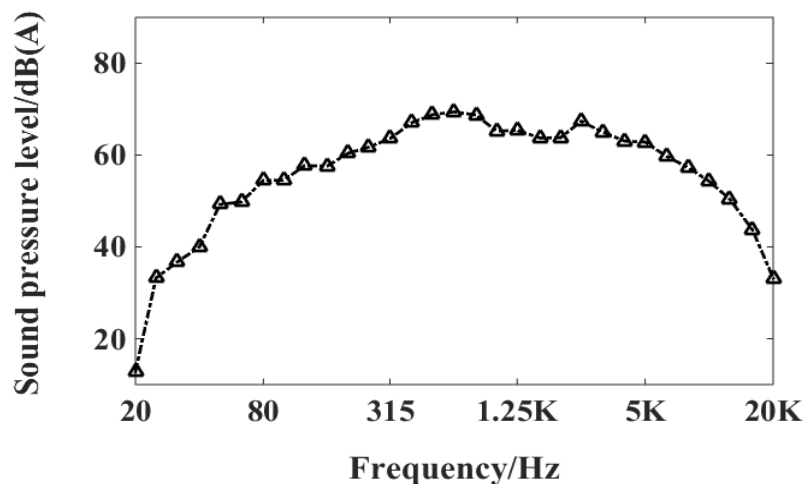


Figure 1. A-weighted spectrum of radiation noise of high-speed train

Figure 1 show that for the A-weighted SPL, the significant frequency band of the bridge section is concentrated in the middle-high frequency band, especially in 800-5000Hz.

3. Calculation method of noise barrier insertion loss (IL)

The noise reduction effect of the noise barrier is usually measured according to the size of the IL. The calculation methods of IL mainly include geometric and wave acoustic method, empirical formula method, finite element or boundary element numerical calculation method, etc. The empirical formula

method is based on the diffraction attenuation of noise at the top of the noise barrier and has the advantages of fast calculation speed, simple operation and relatively high accuracy [8]. The total A-weighted IL value of the noise barrier is:

$$IL = 10 \lg \left[\sum_{i=1}^n 10^{L_{bi}/10} \right] - 10 \lg \left[\sum_{i=1}^n 10^{(L_{bi}-IL_i)/10} \right] \quad (2)$$

Where, L_{bi} is the SPL in the A-weighted band in the absence of a noise barrier at the sound receiving point, IL_i is the IL of the noise barrier at the frequency point f_i :

$$IL_i = \begin{cases} 10 \lg \left[\frac{3\pi\sqrt{1-t^2}}{4 \arctan(\sqrt{1-t}/\sqrt{1+t})} \right], t = \frac{40f_i\delta}{3c} \leq 1 \\ 10 \lg \left[\frac{3\pi\sqrt{t^2-1}}{2 \ln(t + \sqrt{t^2-1})} \right], t = \frac{40f_i\delta}{3c} > 1 \end{cases} \quad (3)$$

Where, f_i is frequency (Hz), c is the sound velocity in the air ($c = 340$ m/s), and δ is the sound path difference. At present, the calculation of railway noise barrier usually adopts a single sound source mode, assuming the sound source position to be a certain height above the rail surface. Su WeiQing [9] pointed out that when the train speed exceeds 300 m/s, it is recommended to set the equivalent sound source height to 3.5m above the rail surface. When the bridge noise barrier IL in document [6] is calculated by using the equivalent sound source height of 3.5m, the total A-weighted IL is 6.1 dB(A), which is close to the test result of 6.5 dB(A) [6], and the error is only 0.4 dB(A).

4. Analysis of the influence of top shape on IL

4.1. Shape and structural parameters of the top of noise barrier

In order to analyze the influence of the top shape on IL, the vertical noise barrier in document [5] was selected as the reference for comparison. The measurement points of noise reduction effect of the noise barrier in document [5] is distributed at a distance of 30 m from the outer rail and 1.5 m above the rail surface, and the distance between the bridge noise barrier and the center line of the outer rail is 3.4 m as shown in Figure 2.

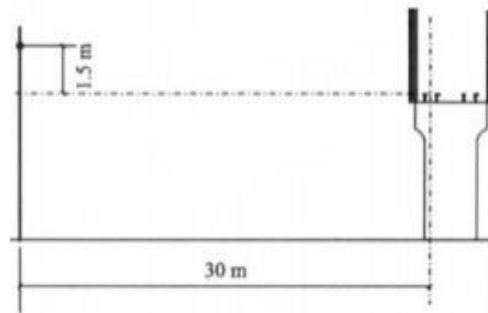


Figure 2. Noise barrier measurement point layout

Sound path difference of the vertical type noise barrier is determined by the method shown in Figure 3.

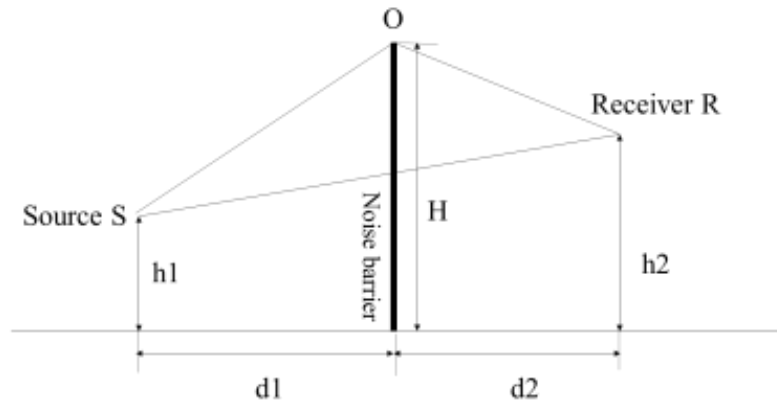


Figure 3. Schematic diagram of sound path difference.

In Figure 3, S is the equivalent sound source point, R is the sound receiving point, O is the highest point of the noise barrier, and the sound path difference is $\delta = SO + OR + SR$, $SO = \sqrt{(H - h_1)^2 + d_1^2}$, $OR = \sqrt{(H - h_2)^2 + d_2^2}$, $SR = \sqrt{(h_2 - h_1)^2 + (d_1 + d_2)^2}$.

The typical noise barrier structures with T-shaped and Y-shaped tops were selected to analyze the influence of the top shape on IL. Figure 4 (a) is Y-shaped noise barrier, the vertical length of the Y-shaped side is L1, and the values of L1 are 0.5 m and 1.0 m, respectively, with an included angle of 90 degrees marked as Y1 and Y2. Figure 4 (b) shows a T-shaped noise barrier with side length L2 of 0.5 m and 1.0 m, respectively, labeled as T1 and T2. In order to ensure that the difference in IL is only caused by the shape of the top, the height of all three kinds of noise barriers is set to 3m.

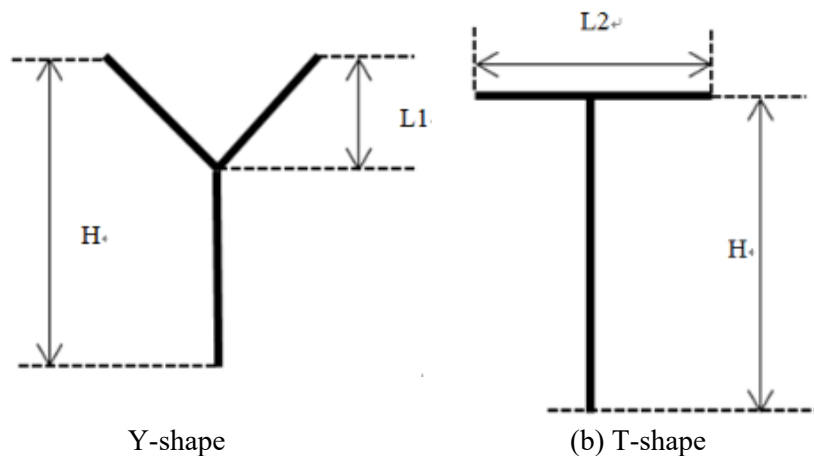


Figure 4. Noise barrier of Y-shape and T-shape

4.2. Analysis of calculation results

For the Y-shaped noise barrier, the actual effective height should be $H + L1$, while the effective height of the T-shaped noise barrier should be $H + 0.5 \cdot L2 \cdot \frac{H - h1}{d1 - 0.5 \cdot L2}$. The A-weighted IL of different structures varies with the third octave band frequency as shown in Figure 5, and the total A-weighted IL are shown in Table 2.

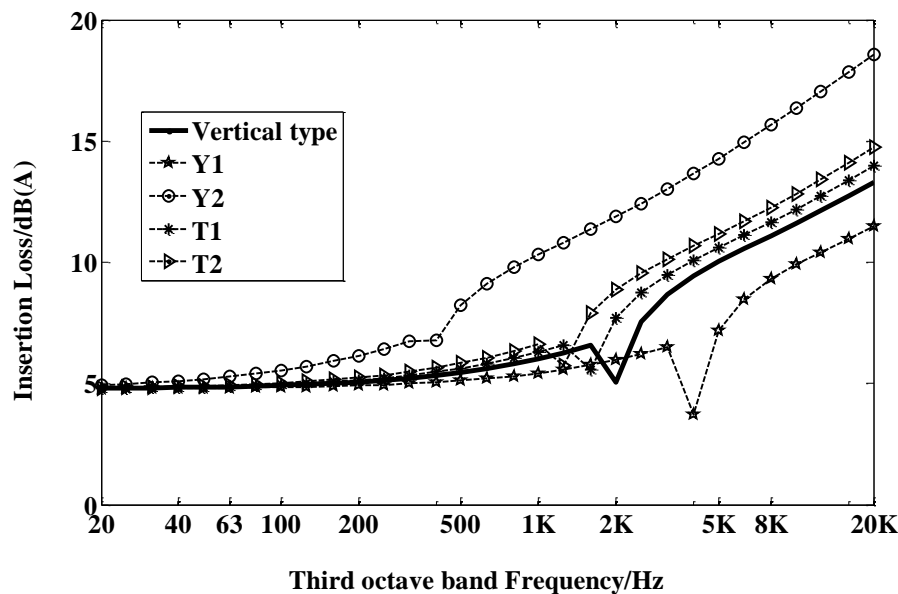


Figure 5. A-weighted IL of different structures

Table 2. Total A weighted IL of different structures (dB (A)).

	Vertical	Y1	Y2	T1	T2
IL	6.14	5.45	9.28	6.46	6.77

Curves in Figure 5 show that the IL of Y2 is the largest of the five kinds of noise barriers and the noise reduction effect is the best. The total A-weighted IL of Y2 is also the largest, which is 3.14 dB(A) higher than the normal vertical type with the same height, and 2.82, 2.51 dB(A) higher than the two T types respectively. The main factor affecting the noise reduction effect of the T-shaped noise barrier is the length of the T-shaped edge. From Table 2, it can be seen that the length of the T-shaped edge has doubled and the total A-weighted IL has only increased by 0.31 dB (A). However, when the vertical length of the Y-shaped noise barrier is doubled, the total A-weighted IL is increased by 3.83 dB (A).

The above analysis shows that although the noise reduction effect of Y-type noise barrier is significantly higher than that of T-type and common vertical type, the value of the vertical length L of Y-type edge has a great influence on the noise reduction effect of noise barrier. If L value is not good, it is likely that the effect of noise reduction is not as good as that of normal vertical type, such as Y1 ($L=0.5\text{m}$) analyzed above.

4.3. Influence of vertical length on Y-shaped noise barrier

Four different Y-shaped noise barriers are selected below. The vertical lengths L of Y-shaped edges are 0.5m, 1.0m, 1.5m and 2.0m, respectively. The calculated IL of A-weighted changes with third octave band frequency as shown in Figure 6, and the total A-weighted IL are shown in Table 3.

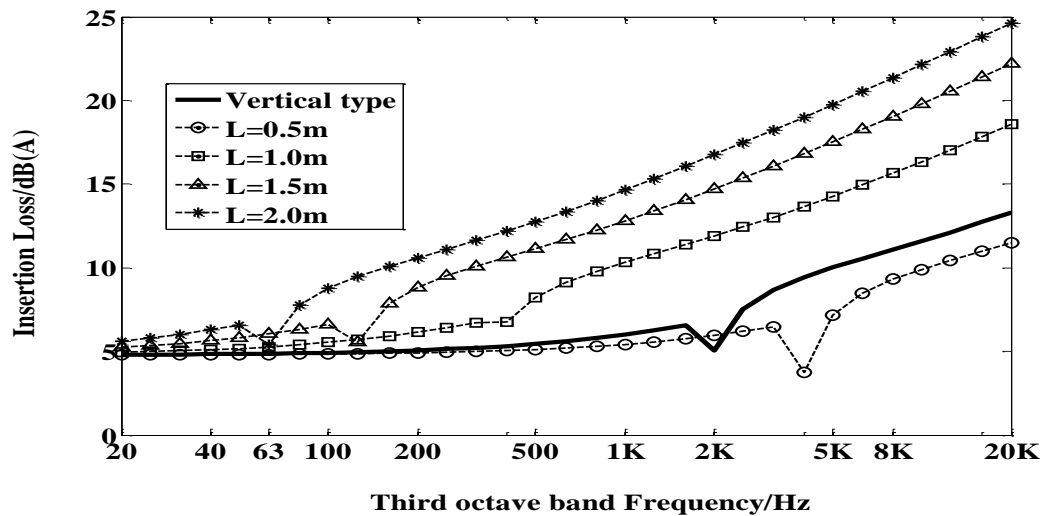


Figure 6. A-weighted IL of structure Y with different L value

Table 3. Total A weighted IL of Y with different L value.

	Vertical	L=0.5 m	L=1.0 m	L=1.5 m	L=2.0 m
IL(dB)	6.14	5.45	9.28	12.02	13.82

The results in Figure 6 and Table 3 show that the IL of the Y-shaped noise barrier increases with the vertical length of the Y-shaped side, especially in the high frequency band. The total A-weighted IL also increases with value of 3.83 dB (A), 2.74 dB (A) and 1.8 dB (A), respectively, indicating that the noise reduction effect increases with the vertical length of Y-shaped side.

5. Conclusion

The IL of T-type and Y-type noise barriers are studied by empirical formula method, and the following conclusions are obtained:

- (1) The noise reduction effect of Y-shaped noise barrier is best when the height of noise barrier is the same.
- (2) The main factor affecting the noise reduction effect of the T-shaped noise barrier is the length of the T-shaped edge.
- (3) For the Y-typed noise barrier, the noise reduction effect increases with the increase of the vertical length.

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