Absorption characteristics of sound barrier made of foam concrete

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Abstract

Based on the basic theory of acoustical sound barrier, environmental acoustics boundary element theory and the spectrum characteristics of the traffic noise, the distribution of insertion loss of sound barrier was analyzed at different height and its acoustic points.Test results show that: the insertion loss of sound-absorbing barrier made of foam concrete is zero near the sound source side and in the far side of the sound source its insertion loss distribution into interference, attenuation and stability of the three phases. The sound barrier height and acoustic points'height only affect the close acoustic field distribution, and its insertion loss between each height is no more than 0.2dB in the far side of the stable phase.

Keywords

Sound barrier; traffic engineering ; boundary element; foam concrete; insertion loss.

1. Introduction

At present, there are many studies about acoustic performances and properties of foam concrete at home and abroad. Based on the impact of dry density and compressive strength on its mixture ratio, Li Yingquan concluded the mixture ratio of A02 - A05 foam concrete[1]. Based on the theory of boundary element and the Identification of high-speed-train sound source, Zhou Xin establishes high-speed railway noise barrier acoustic noise reduction effect model with considering orbit and body characteristics[2]. Research has shown that the sound barrier insertion loss and decreased with the increase of the speed of the train, it increases as the frequency increases. Duhamel and Duhring optimize branch branch shaped top structure is the best noise reduction effect of sound barrier[3,4]. The top of the sound barrier structure with coupled boundary element method and genetic algorithm. Research has shown that: the noise reduction effect of T-shaped wall of sound barrier is better than of straight-wall sound barriers, but not the best structure at the top; sound barrier insertion loss of the optimal top structure is higher than of the general structure.

In this paper, combined with the theory of sound absorption type of acoustic sound barrier and the environment acoustic boundary element model, contrary to the spectrum characteristics of traffic noise, the impact of sound barrier insertion loss distribution is studied on the different sound barrier height, the acoustic point height.

2. Acoustic theory of acoustic sound barrier

Acoustic waves incident to absorptive sound barrier surface will produce reflection and transmission in the process of transmission. When the sound barrier size is much larger than the wavelength sound waves, acoustic wave incident on acoustic sound barrier surface would produce the sound wave reflection phenomenon, and attenuate acoustic energy, its reflected sound energy depends on acoustic absorption coefficient of the sound barrier[5]. Sound waves occur multiple reflection (Fig.1), reduce the diffraction of sound energy from the top, and achieve the noise reduction effect between parallel acoustic barrier.

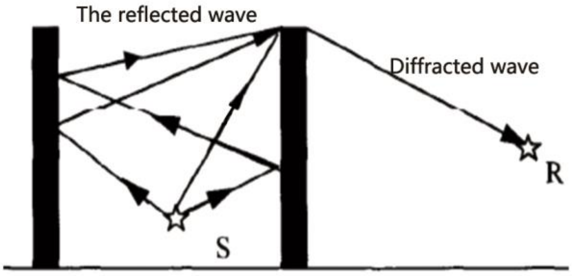

Fig. 1 Sound waves reflected path

3. Environmental acoustics theoretical model

3.1 Boundary element model

Boundary element model of the sound barrier often uses the two-dimensional boundary element model. In order to simplify the boundary element model of sound barriers, this paper carries on the two assumptions[6,7]: ① sound barrier placed plane is infinite long and uniform; ②second, sound barriers surrounding medium is uniform. Based on the above two assumptions, roads, noise which can be seen as an infinitely long term source of direction along the road and acoustic barrier are mutually parallel, that is in the same plane, so the noise three-dimensional acoustic field distribution can be converted into two-dimensional acoustic field distributions(Fig. 2). (r,r0)is a sound source point, p(r,r0)is any point of sound pressure in sound field, s is sound barrier boundary curve, Smis a point on the boundary sound barrier, p(rm,r0)is any point of sound pressure on the boundary sound barrier, β(rm,r0)is the surface normal acoustic admittance on the boundary sound barrier.

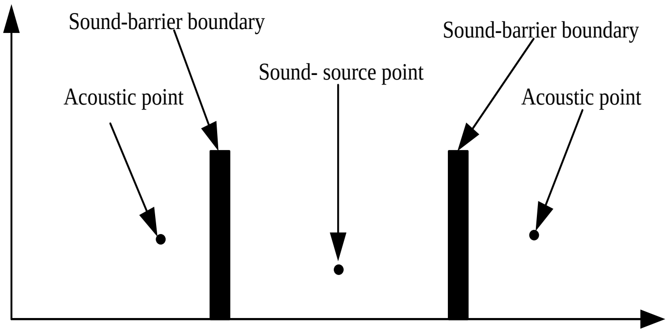

Fig. 2 Dimensional boundary element model of the sound barrier

In the sound field area, sound pressure p(x,y,z,t)is partial differential equations on location and time, which apply to the Helmholtz Equation, defined as:

$$p(x,y,z,t) = p(x,y,z)\cdot e^{jwt} \tag{1}$$

$$\Delta p(x,y,z) + k^2 p(x,y,z) = 0 \tag{2}$$

where $\Delta = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}$, $k = \omega / c$.

Sound barrier in the sound field can be regarded as a scatterer, acoustic field can be composed of the incident sound field and scattering sound field superposition. So p is defined as the sound pressure of an arbitrary point in acoustic field.

$$p = p_i + p_m \tag{3}$$

where pi is silent barrier acoustic field of sound pressure, pm is the scattering sound pressure of sound barriers.

Combining reflects the relation between sound source and acoustic field Helmholtz equation for silent barrier on the sound pressure in the acoustic field calculation, the Helmholtz equation is solved by the Green function method, Green function is acoustic pressure produced of the arbitrary point by any point source in the free field.

$$G(r,r_0)=-\frac{i}{4}\left[J_0(kr)+iY_0(kr)\right] \tag{4}$$

As scattering, the scattering sound pressure of sound barrier meets Sommerfeld radiation condition at infinity and boundary conditions of sound-barrier local reactions, defined as:

$$\begin{cases}\lim\limits_{r\to\infty} r^{\varepsilon}\left(\dfrac{\partial p}{\partial r}-ikp\right)=0\\ \dfrac{\partial p}{\partial n}=ik\beta(r_m)p_m\end{cases} \tag{5}$$

Combined with Green second boundary integral theorem can be translated.

$$\alpha(r)p(r,r_0)=G(r,r_0)-\int_s\left(u^*\frac{\partial p(r_m,r_0)}{\partial n(r_m)}-p(r_m,r_0)\frac{\partial u^*}{\partial n(r_m)}\right)\mathrm{d}s \tag{6}$$

where n(rm)is over the surface (rm) of the sound barrier in the normal direction, G(r,r0) is pressure at the r point in silent barrier.

α(r)is Coefficient of sound field in the position, when it is not on sound barriers surface, α(r)=1, when it is on sound barriers surface but located in the corner, α(r)=0.5, when it is located in the corner on sound barriers surface, α(r)=θ/2π.

Combined with a weight function as the Green function and the formula (6):

$$\alpha(r)p(r,r_0)=G(r,r_0)-\int_s\left[ik\beta(r_m)G(r_m,r)-\frac{\partial G(r_m,r)}{\partial n(r_m)}\right]p(r_m,r_0)\mathrm{d}s \tag{7}$$

If not considering continuous reflection between sound waves in multiple scatterer, G(rm, r) of formula (7) can be simplified into the Green function of free field. Formula (7) also applies to the problem of three-dimensional acoustic field distribution of noise source, the main difference is calculate the number of points. The sound source of two-dimensional model is infinitely long coherent sound source, and the actual traffic noise source is infinitely long non-coherent sound source, therefore, the analysis of three-dimension model is superimposing the sound field distribution of point light source which is scattered from non-coherent sound source, and effectively solve sound field distribution of three-dimensional model.

3.2 Solution of the boundary element model

3.2.1 Boundary discretization

Sound barrier boundary is divided into a series of boundary elements. Each unit of internal sound pressure can be approximately equal. Therefore, formula (7) can be turned into.

$$\alpha(r)p(r,r_0)=G_\beta(r_0,r)-\sum_{i=1}^{n}\int_{s_i}\left[ik\beta(r_m)G_\beta(r_m,r)-\frac{\partial G_\beta(r_m,r)}{\partial n(r_m)}\right]p(r_n,r_0)\mathrm{d}s \tag{8}$$

3.2.2 Acoustic admittance

Acoustic admittance and acoustic impedance are two parameters which reflect the sound absorption performance of materials. Acoustic admittance is the motion of particle vibration velocity and the ratio of acoustic pressure plural and inverse acoustic impedance with relations. In order to estimate acoustic impedance and acoustic admittance, single parameter experience model of Delany - Bazley can be used.

$$\eta=\rho c\left[1+0.057X^{-0.754}-i0.087X^{-0.732}\right] \tag{9}$$

Where ρ is air density, c is the speed of sound in air,ρc is the characteristic impedance of the air.

3.2.3 Sound pressure in the acoustic field

Combining with formula (9) and the sound pressure value on sound barrier boundary can be obtained about the n-dimension linear equations.

$$\alpha\left(r_j\right)p\left(r_j,r_0\right)=G_\beta\left(r_0,r_j\right)-\sum_{i=1}^{n}\int_{s_i}\left[ik\beta(r_m)G_\beta\left(r_m,r_j\right)-\frac{\partial G_\beta\left(r_m,r_j\right)}{\partial n\left(r_m\right)}\right]p\left(r_j,r_0\right)\mathrm{ds} \tag{10}$$

$$j=1,2,\ldots,n$$

Formula (10) are deduced with the method of matrix decoupling arithmetic of each point on the boundary of sound pressure values, the combination of each point on the boundary of sound pressure value and silent barriers of acoustic pressure could solve the arbitrary point of sound pressure value in acoustic field.

$$p\left(r,r_0\right)=G_\beta\left(r_0,r\right)-\sum_{i=1}^{n}\int_{s_i}\left[ik\beta(r_m)G_\beta\left(r_m,r\right)-\frac{\partial G_\beta\left(r_m,r\right)}{\partial n\left(r_m\right)}\right]p\left(r_n,r_0\right)\mathrm{ds} \tag{11}$$

Insertion loss of sound barrier was the sound pressure level difference before and after sound barrier inserted into, sound-barrier insertion loss of any point in the acoustic is defined as:

$$IL=20\lg\left|\frac{p\left(r,r_0\right)}{G_\beta\left(r_0,r\right)}\right| \tag{12}$$

4. Application of boundary element model

Based on the creation and solving of boundary element model of sound-absorbing sound barriers, its matrix is decoupled by MATLAB programming language. Then solving the scattering sound pressure of each point on the boundary and the incident sound pressure are superimposed. Traffic noise frequency as one of the most important parameters of acoustic sound barrier properties is considered. Combined with the road traffic noise spectrum and selecting center frequency of 250 Hz ~ 2000 Hz 1/3 octave to calculate, calculation of each frequency band sound field is finally modified with A weight stack and superimposed.

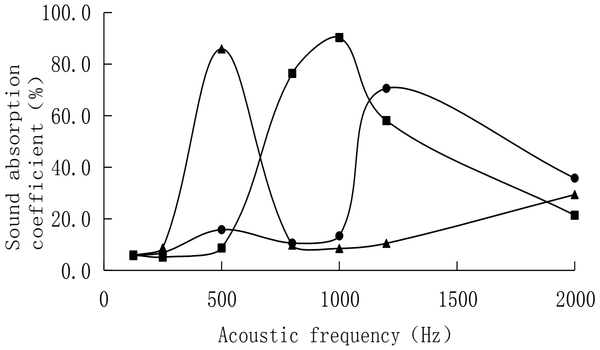

Fig.3 Sound absorption properties of foam concrete

This highway calculation model selects that the road model is bi-directional four-lane road and the sound barriers sound-absorbing material is 600Km/ m3 dry density and 5 cm thickness of foam concrete. The sound absorption properties of foam concrete are shown in Fig.3.

Sound source located at the center of the road. Sound barrier height isH. The acoustic point height is h. On the basis of highway engineering technical standards, due to the road green belts and the sidewalks, the horizontal distance from the sound source to sound barrier is about 8m. In this paper, around the sound source as the focal point of the horizontal distance from the 80m point of sound-barrier insertion loss is analyzed in the different sound barrier height, different positions.

4.1 The height of the sound barrier

The height design of sound barrier is the most important part of environmental acoustic sound barrier, the rationality of the design height could directly affect on sound reduction effect of the sound barrier, the form and the cost of sound barrier. Around the sound source as the focal point of the horizontal distance from the 80m point of sound-barrier insertion loss distribution would be analyzed when sound barrier height is 2m, 3m, 4m, 5m and the acoustic point height is 1m.

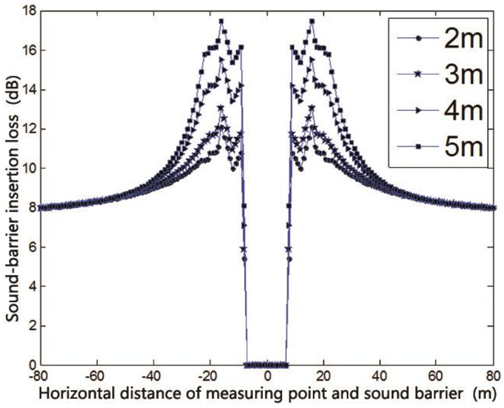

Fig. 4 High impact on the sound barrier insertion loss

Sound barrier height on the influence of sound barrier insertion loss as shown in Fig. 4, between two parallel acoustic barrier which is named near the sound source side, the sound barrier insertion loss is zero, this is because the free field after inserting acoustic sound barrier, most of the sound energy is absorbed by the absorption material or consumption, the reflected sound energy is small and almost negligible, the reflection waves with the next batch of incident sound waves can not form the interference phenomenon. Within a certain range of the sound barrier outside which is named far side of the sound source, the sound-barrier insertion loss exists maximum and minimum. Due to the existence of sound barriers scatterer, incident waves and the scattering waves are intervened. Incident waves and the scattering waves are vibrating strengthening about 12 m from the sound source location, which leads to the minimum points of sound-barrier insertion loss. Incident waves and the scattering waves are vibrating weakening about 12m from the sound source location, which leads to the maximum points of sound-barrier insertion loss. Because of the attenuation of sound energy inversely proportional to the third power of acoustic propagation distance. The sound energy attenuates slowly with the increase of horizontal distance. So the sound-barrier insertion loss gradually stabilized with the increase of horizontal distance on the far side of the sound source.

With the increase of sound barrier height, the insertion loss of sound barrier had no effect on the source side, and is more complex on the far side. On the far side of the sound source interference phase (about 10m ~ 20m), the sound barrier insertion loss increases with the increase of sound barrier height, and its value exists logarithmic function relation with the height. Their correlation and significant are analyzed by SPSS software, and the analysis shows that they have significant correlation and the correlation coefficient is 0.926.On the far side of the sound source attenuation phase (about 20m ~ 50m), the amplitude and rate of sound-barrier insertion loss attenuation increases with the increase of sound barrier height. On the far side of the sound source and stable phase, the insert loss of sound barrier tends to be stable gradually stable with the increase of sound barrier horizontal distance, and the sound-barrier height of insertion loss is less than other height of 0.2 dB, this is because the height of the sound barrier can only affect on the acoustic field distribution near the sound barrier, and acoustic wave propagation distance difference will gradually decreasing with the horizontal distance, thus the height of sound barrier insertion loss is decreased.

4.2 Height of the acoustic point

The height of the acoustic point is one of the analysis of the sound field distribution of sound barrier of the parameters. With the increase of acoustic point height, it is changed from acoustic shadow area to sound bright area and the acoustic wave propagation distance is changed. Around the sound source as the focal point of the horizontal distance from the 80m point of sound-barrier insertion loss distribution would be analyzed when acoustic point height is 1m, 2m, 3m, 4m, 5m and the sound barrier height is 3m.

The acoustic point height on the influence of the sound barrier insertion loss is shown in Fig. 5. With the increase of the acoustic point height, sound-barrier insertion loss does not have any change near the source. On the far side of the sound source interference phase, the sound-barrier insertion loss gradually reduces, this is because with the increase of the acoustic point height, the acoustic point is changed from acoustic shadow area to sound bright area, which leads to reduce the sound barrier insertion loss.

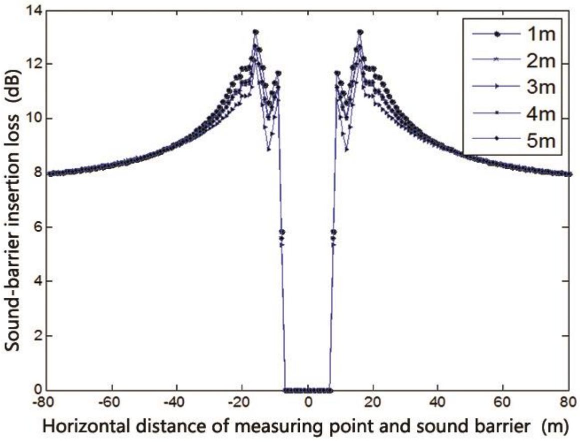

Fig. 5 acoustic point hight impact on the sound barrier insertion loss

When acoustic point height is 3m (the acoustic point height consistent with sound barrier height), the sound barrier insertion loss intensity change is bigger, this is because the acoustic point is at the junction of acoustic shadow area and sound bright area and the distance of sound waves to spread to acoustic point is shortest, the acoustic point receives many the incident sound waves and scattering waves, their interference phenomenon is more obvious than interference phenomenon of other acoustic point height. On the far side of the sound source attenuation phases, the attenuation amplitude and rate of sound barrier insertion loss decreases with the increase of height. On the far side of the sound source and stable phases, the acoustic point height of insertion loss less than other height of 0.1 dB.

5. Conclusion

(1)Foam concrete sound-absorption sound barrier of insertion loss is changing with the horizontal distance of acoustic point: sound barrier insertion loss is zero near the sound source and sound barrier insertion loss can be divided into interference, attenuation and the stability of three stages on the far side of the sound source.

(2)With the increase of sound barrier height, the insertion loss of sound barrier had no effect on the source side. The sound-barrier height of insertion loss is less than other height of 0.2 dB on the far side of the sound source and stable phase. But the sound barrier insertion loss exists logarithmic function relation with the height.

(3)With the increase of the acoustic point height, sound-barrier insertion loss does not have any change near the source, the sound-barrier insertion loss gradually reduces on the far side of the sound source interference phase. When the acoustic point height is consistent with sound barrier height, the sound barrier insertion loss intensity change is bigger. The acoustic point height of insertion would loss less than other height of 0.1 dB on the far side of the sound source and stable phases.

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