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Investigation for insertion loss of noise barrier for sound source moving at high speed

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1. Introduction

Noise barriers are used as one method against noise with the objective of securing the living environment for residents along roads and railways. In traffic agency noise predicting, a method is used in which sound sources that actually move are treated as though static and the sound at sound receiving points is found. However, when the sound source is inherently moving, it is known that the frequency modulation and orientation change due to the Doppler effect. It is thought that when the velocity of motion is higher, these changes can not be ignored. This paper reports the results of studying noise barrier insertion losses when the Doppler effect is taken into effect when the sound source moves at high speed.

2. Assumed conditions

2.1. Sound source

The sound source is assumed to be a respiratory sphere with a simple oscillation on its non-oriented surface in a free space. This sound source is moved in a straight line at constant velocity in parallel with the noise barrier. Frequency of the sound source: 15,000 Hz sine wave (wavelength 23.1 mm) (at 25°C). Sound source sound power: 90.0 dB (0.5 m). Sound source movement velocity conditions: 300, 500, 700 km/h (constant velocity).

2.2. Sound source and sound receiving point layout and frequency modulation

Figure 1 shows how the sound source and sound receiving point are laid out. The sound source and sound receiving point are set in a free space and the noise barrier is set as a rigid body knife edge semi-infinite length wall. When a sound source of frequency ν moves at υ_{S}, the frequency of the sound observed at the static sound receiving point in the θ_{S} direction is expressed as ν_i. (c: sound vlocity)

$$\nu_i = \nu \frac{c}{c - \upsilon_{\mathrm{S}} \cos\theta_{\mathrm{S}}} \tag{1}$$

Figure 2 shows the sound frequency modulation observed at the sound receiving point when a sound source having each velocity passes each position when the angle θ_{S} is substituted for the sound source position.

3. Study with Maekawa chart

In the evaluation of the amount of diffraction attenuation for the noise barrier when predicting railway noise, a method is used that uses the Maekawa chart [1] regression equation [2]. On the Maekawa chart, since the noise barrier insertion loss is found from the Fresnel number N $(= 2\delta/\lambda)$, this amount depends on the frequency of the sound source. With the sound source and sound receiving point in the layout of Fig. 1, it is assumed that the sound source is static at each position on the line of movement. When the Doppler effect is take into account, the sound power level at the sound receiving point can be obtained and compared by obtaining the diffraction attenuation amount for the frequency corresponding to the position and velocity in Fig. 2. The results are shown in Fig. 3. The insertion loss for the noise barrier is shown in Fig. 4. From Fig. 3, the peak of the sound power level at the sound receiving point when the frequency modulation due to the Doppler effect is taken into account moves to after the center of the sound receiving point is passed by and that distance toward the rear tends to increase as the speed increases. Also, from Fig. 4, the peak for the noise barrier insertion loss is before the center of the sound receiving point and that distance forward tends to increase as the speed increases. The reason for this is that although the sound source is static, since the noise barrier insertion loss depends on the frequency at each sound source position, the frequency becomes lower with a position before the sound receiving point as the boundary and the insertion loss decreases and the sound power increases. On the other hand, the distance between the sound source and the sound receiving point increases after passage by the sound receiving point center, so the distance attenuation increases and the sound power level decreases. It is thought that this is how the insertion loss peak position moves due to the relationship between the frequency modulation and the distance.

4. Simulation using boundary element method

In the numeric forecasting of railway noise etc., a method [3] that obtains the solution to a three-dimensional sound field by using integration to convert the basic solution found with the boundary element method in a two-dimensional space and applications of that method [4,5] have been reported. This time, this method was applied to the study of the insertion loss for an noise barrier for a moving sound source and the

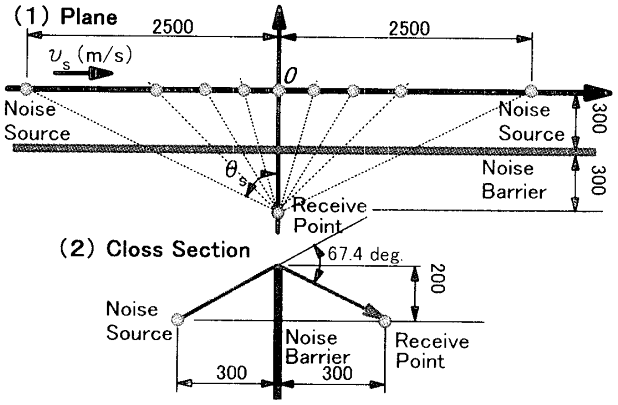

Fig. 1 Sound source and sound receiving point layout diagram.

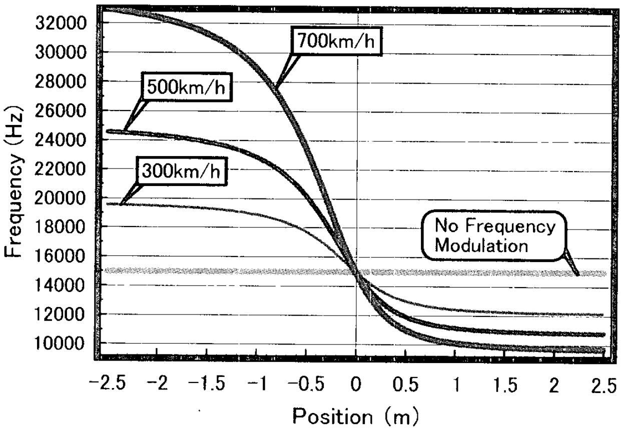

Fig. 2 Frequency modulation at sound receiving point.

influence of the change in frequency modulation and orientation due to the Doppler effect on the noise barrier insertion loss was studied.

4.1. Two-dimensional boundary element method

The noise barrier is a 3-meter high rigid wall whose thickness can be ignored. It is assumed that there is no reflection from the ground surface. The temperature is 25°C and the sound velocity is 346.75 m/s. The frequency interval for the cross-section direction in order to obtain the two-dimensional solution was set fine taking into account integration conversion near 0 Hz and 5 Hz.

4.2. Integration conversion to three dimensions

Analysis time: -0.1 to 0.1 second

Range for wave count $\bar{k}_z$: -1.15 to 1.15 ($\bar{k}_z$)

Interval:

- Within normal range $(-0.9 < \bar{k}_z < 0.9)$ $\bar{k}_z$ divided into 12,000 points at equal intervals (actual interval 1.8/12,000)
- In the region around singularity points $(0.9 < |\bar{k}_z| < 1.15)$, divided into 3,000 points at equal intervals with $\bar{k}_{xy} = \sqrt{1 - \bar{k}_z}$; at $\bar{k}_z$, non-uniform intervals

Sampling frequency: 96,000 Hz

4.3. Calculation results

Figure 5 shows the solution obtained with the three-dimensional boundary element method when the sound source

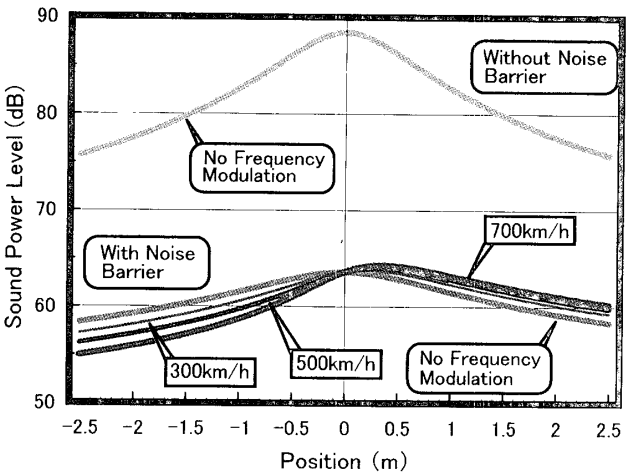

Fig. 3 Sound power change when the sound source is static.

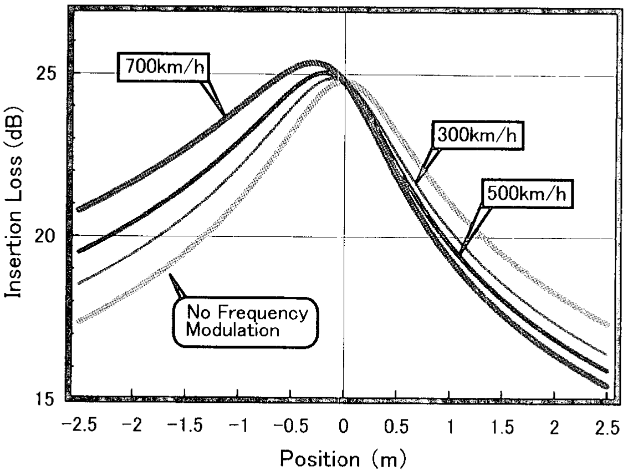

Fig. 4 Insertion loss under the condition of sound source being static.

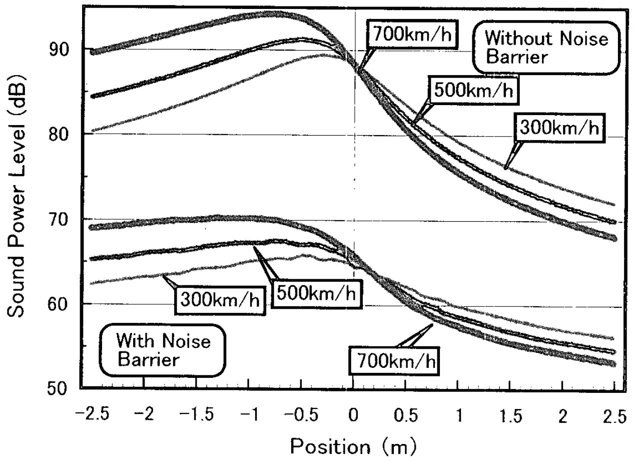

Fig. 5 Results of simulation of change in sound power using 3D-BEM.

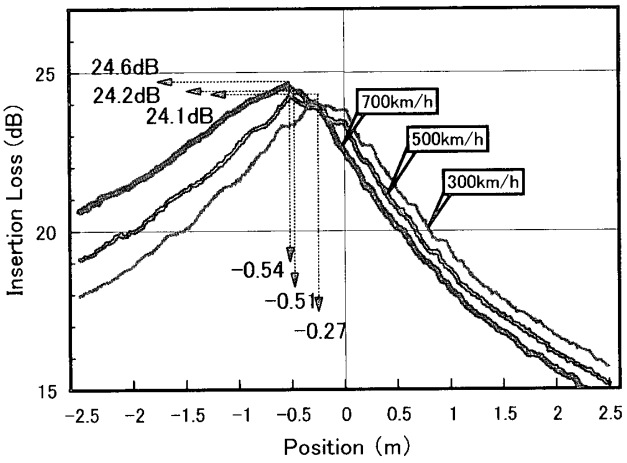

Fig. 6 Results of simulation of insertion loss change using 3D-BEM.

moves at constant speed. Figure 6 shows the insertion loss for the noise barrier. From Fig. 5, as the velocity increases, the maximum value of the sound power level increases and its position tends to move forward from the center of the sound receiving point. This trend is the opposite of the trend for the maximum value position to move rearward from the center of the sound receiving point in Fig. 3 when the frequency modulation was taken into account. It is thought that the reason for this is that as reported by Doi [6] and Tsuru [7], that when the sound source moves at high speed, the Doppler effect causes the sound power to rise and at the same time for the sound field to have an orientation characteristic toward the direction of advance.

From Fig. 6, the maximum value of the insertion loss when the velocity is 700 km/h is 24.6 dB at 0.54 meter before the center of the sound receiving point. Compared to the case in which the frequency modulation is taken into account with the Maekawa chart in the previous chapter, this is 0.25 meter forward and the insertion loss is 0.8 dB less. It is thought that the reason for this is that the same as for the study of the Doppler effect with the Maekawa chart, the maximum sound power observed at the sound receiving point depends on whether or not there is an noise barrier. Also, the change in the insertion loss is not smooth at any velocity, but rather has small ups and downs. This is caused by the ups and downs that can also be seen in the change in the sound power level accompanying the diffraction attenuation of the noise barrier in Fig. 5. This is thought to be the influence of interference between the direct sound from the moving sound source to the sound receiving point and sound reflected from the noise barrier toward the sound source.

5. Conclusions

The following is a summary of the results of studying the insertion loss for a noise barrier taking into account the Doppler effect when the sound source moves at high speed using the Maekawa chart regression equation and using the three-dimensional boundary element method.

1) When the sound insulation amount for the noise barrier is calculated with the sound source in the static state using the Maekawa chart regression equation, by taking into account the frequency modulation caused by the Doppler effect, the peak of the insertion loss for the noise barrier is observed about 0.3 meters forward at a velocity of 700 km/h and its level is about 0.6 dB higher, so when the sound source moves at high speed, it is necessary to consider the Doppler effect.

2) From the results of calculation using the three-dimensional boundary element method, when the sound source moves at high speed, the frequency modulation and sound source orientation change due to the Doppler effect, with the result that the position of the maximum value of the insertion loss for the noise barrier moves and the insertion loss is decreased.

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