MADRID
inter.noise 2019
June 16 - 19
NOISE CONTROL FOR A BETTER ENVIRONMENT

Noise Prediction Considering Differences of Sound Characteristics of Noise Barrier

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ABSTRACT

In noise prediction for railway viaducts using numerical analysis, walls such as noise barriers made of adequately thick concrete are often treated as rigid walls. A sound-insulating panel such as a polycarbonate sheet of 8mm thick is sometimes used as additional noise barriers, but its sound insulation performance is generally lower than that of concrete noise barrier. Therefore, it is desirable to consider the realistic sound insulation performance to enhance the accuracy of noise prediction. In this study, the sound insulation performance of the panel is regarded as a damping component and its characteristics is given by associating the complex sound speed with the transmission loss of the panel. The variation of noise levels outside a railway viaduct in increasing the height of the noise barrier is calculated by a finite element method and indicate good agreement with the past findings.

Keywords: Noise barrier, Transmission loss, Finite element method
I-INCE Classification of Subject Number: 76

1. INTRODUCTION

On railway viaducts, additonal sound-insulationg panels have been installed on top of the existing concrete noise barriers to improve the noise reduction performance. Sound insulation performance of sound-insulationg panels such as transparent plastic panels of 8 mm thick is different from that of concrete noise barriers. However, the noise prediction has been conducted by assuming that the additional panels are rigid walls. Therefore, it is desirable to consider the sound insulation performance of sound-insulating panels in order to improve the accuracy and to avoid the overestimation of noise predition with additional plastic panels are installed.

In this study, the authors performed an acoustic analysis with a finite element method (FEM), provided that the transmission loss (TL) of transparent plastic panels could be represented by the complex sound speed in the medium as a damping effect.

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2. Representation of the transmission loss of a sound-insulating panel

2.1 Sound wave in a medium with damping effect

Since the FEM discretizes the entire region to be considered, it is possible to treat sound propagation in a medium. In order to consider the attenuation of the sound wave in a homogeneous isotropic medium, the complex effective density of the air ρ_e and the complex sound speed c_e are introduced.

The wave equation in a medium with damping effect can be expressed as follows:

$$\nabla^2\varphi_p + {k_e}^2\varphi_p = 0 \tag{1}$$

where the subscript p means that the quantity is in a medium with damping effect, and k_e is the complex wave number defined as,

$$\begin{aligned} k_e &= \frac{\omega}{c_e} \\ &= k' - jk'' \quad (k' \text{ and } k'' \text{ are real numbers}). \end{aligned} \tag{2}$$

Provided that a plane wave is travelling in a medium with damping effect, the sound pressure P at distance d from the point of the sound pressure P_0 is represented as follows:

$$P = P_0 e^{-\gamma d} \quad , \tag{3}$$

where

$$\gamma = \alpha + i\beta \tag{4}$$

and γ is the propagation constant, α is the damping coefficient, and β is the phase constant.

2.2 Transmission loss of a sound-insulating panel and damping effect to sound

In this study, it is assumed that a plane wave travels in a medium and that sound decays in a medium is caused in accordance with the transmission loss TL' (dB) of the sound-insulating panel, which can be regarded as a damping effect. If the sound pressure immediately in front of the surface of entering and transmitted side are expressed as $P_{in}$and P_{out}, respectively, then TL' is defined as

$$TL' = 10\log_{10}\left|\frac{P_{out}}{P_{in}}\right|^2 \tag{5}$$

$$= 10\log_{10}\left|\frac{\varphi_{out}}{\varphi_{in}}\right|^2 \tag{6}$$

where the typical expression of the plane wave in Equation (1) could be:

$$\varphi = e^{-i\frac{2\pi f}{c_e}x} \quad . \tag{7}$$

Therefore, if it is considered that the sound wave decays by TL' (dB) in progressing through a sound-insulating panel of Δx (m) in thickness, the following relationship can be assumed:

$$TL' = 10\log_{10}\left|e^{-i\frac{2\pi f}{c_e}\Delta x}\right|^2 \tag{8}$$

where the relationship between the propagation constant and the wave number is as follows:

$$
\begin{aligned}
\gamma &= ik_e \\
&= i\frac{\omega}{c_e} \\
&= i\frac{\omega}{c' + ic''} \\
&= \frac{\omega}{c''^2 + c'^2}(c'' + ic')
\end{aligned}
\tag{9}
$$

here $c_e = c' + ic''$ (c' and c'' are real numbers).

Therefore, if damping effect is represented by the decay related to the distance in Equation (9), c' must be zero in Equation (9), which can be derived from $\beta = 0$ in Equation (4). Consequently, from Equation (8) and (9), the following relationship can be obtained:

$$
c'' = \frac{20 \cdot 2\pi f \log_{10}(e)}{TL'/\Delta x} \quad . \tag{10}
$$

Note that c'' depends upon the frequency as indicated in Equation (10).

2.3 Sound insulation as damping effect in a medium

This section indicates that the relationship between the imaginary part of the complex sound speed and the transmission loss of a sound-insulating panel shown in Equation (10) can be obtained as the sound pressure levels at both side of the medium.

It is considered as a validation model that a plane wave travels through three media along the x-axis, as shown in Figure 1. Media 1 and 2 and media 2 and 3 are deemed to have contact surfaces perpendicular to the axis at, respectively, $x = x_1$ and $x = x_2$, and media 1 and 3 are regarded as having semi-infinite lengths. The sound waves in the media are respectively represented as follows.

The sound pressure of an incident wave in medium 1 is regarded as follows:

$$
p_i^{(1)} = p_{I0}^{(1)} e^{ik_1 x - i\omega t} \tag{11}
$$

and the sound pressure of the reflected wave in medium 1 is regarded as follows:

$$
p_r^{(1)} = p_{R0}^{(1)} e^{-ik_1 x - i\omega t}\,, \tag{12}
$$

then the sound pressure $p^{(1)}$ in medium 1 can be expressed by the superposition of an incident wave and a reflected wave as,

$$
p^{(1)} = \left(p_{I0}^{(1)} e^{ik_1 x} + p_{R0}^{(1)} e^{-ik_1 x}\right) e^{-i\omega t}. \tag{13}
$$

Similarly, the sound pressure $p^{(2)}$ in medium 2 can be expressed as the superposition of an incident wave and a reflected wave in the medium 2:

$$
p^{(2)} = \left(p_{I0}^{(2)} e^{ik_2 x} + p_{R0}^{(2)} e^{-ik_2 x}\right) e^{-i\omega t}. \tag{14}
$$

The sound pressure $p^{(3)}$ in medium 3 is as follows only from a transmitted wave:

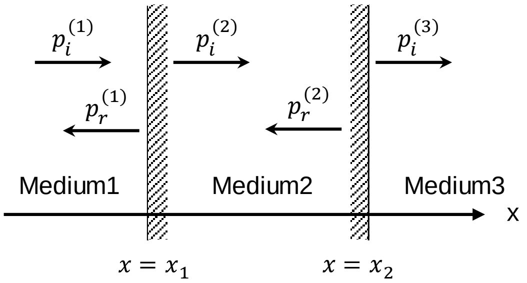


Figure 1 Model of a plane wave propagation through three different media

$$p^{(3)} = p_{I0}^{(3)} e^{ik_3 x - i\omega t} \quad . \tag{15}$$

Note that $p_{I0}^{(j)}$ and $p_{R0}^{(j)}$ in Equations (11) through (15) respectively indicate the amplitudes of the incident wave and reflected wave in medium j. The wave number k_j in each medium is as follows, using the sound speed c_j in each medium:

$$k_j = \frac{\omega}{c_j} \quad . \tag{16}$$

The Details of the validation are shown as follows:

- The thickness $\Delta x (= x_2 - x_1)$ of medium 2 was 1 m and the damping effect in medium 2 in Equation (10) was 10 dB/m.
- The sound speed in media 1 and 3 was 343.7 m/s and the density was 1.205 kg/m^3, and the characteristic impedance of medium 2 was set to the same value as in media 1 and 3.
- The sound source in medium 1 was $p_{I0}^{(1)}$=1 Pa.

Figure 2 shows the sound pressure (real part (Re), imaginary part (Im) and absolute values (Abs)) and relative sound pressure level (SPL) at 400Hz. As a result, the difference in sound pressure level between before and after medium 2 was −10 dB, from which it was confirmed that the applied damping effect of 10 dB/m was correctly obtained.

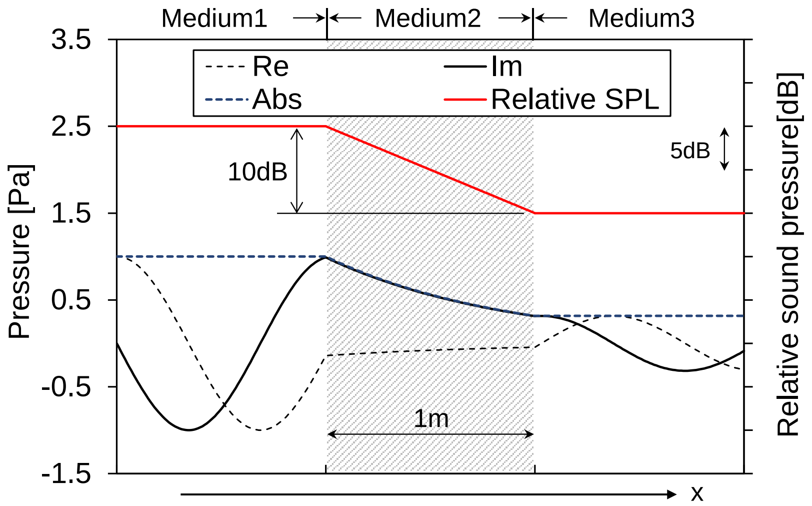


Figure 2 Verification of the internal damping effect of 10dB/m in medium 2

3. Noise prediction for railway viaduct considering the transmission loss of additional plastic panel

3.1 Outline of FEM analysis on railway viaduct with infinite element

For the noise barriers of a railway viaduct, FEM analyses were performed to evaluate the effects of increasing the height of noise barrier by means of transparent plastic panels. This study used FEM introducing infinite elements in order to solve exterior problems without being affected by a pseudo-reflection generated on the domain boundary. In the analysis, the space around the viaduct, including the car bodies and noise barriers, where the propagated sounds became complicated was treated as a finite element domain, while the space outside the viaduct was treated as an infinite element domain.

The complex effective density and complex sound speed were decided according to the sound insulation performance of the transparent plastic panels installed on top of the existing noise barrier.

3.2 Analytical model

Figure 3 shows an overview of the analytical model. The details of the model were as follows:

- An area of 14 m in diameter including the noise source, vehicles and noise barriers was set as a finite element domain

- An area at a distance between 12.5 and 30 m from the center of the track outside the viaduct and at a height ±12 m from the rail level (R.L.) was set as an infinite element domain.

- The finite element domain was deemed to be 0.024 m in depth with an average 0.02 m distance between the adjacent nodal points in consideration of the analysis scale, where the number of nodal points was approximately 1.1 million.

The noise generated from the lower part of the cars (under car noise) and that from the current collection system (pantograph noise), which contribute greatly to the sound generated by high-speed trains, were used as the noise sources [1]. The location of the noise sources consisted of the left and right rails at the height of the R.L. (rail level, the location closer to the noise barrier is called the close side, and the other, far from the barrier, is called the far side) for the under car noise, and one location corresponding to the overhead contact line for the pantograph noise. The noise source at each point was set to a the car

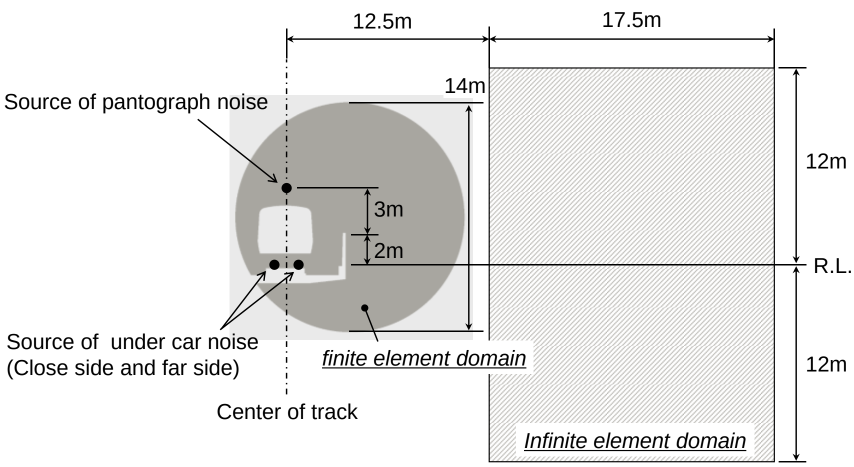


Figure 3 Overview of finite element domain and infinite element domain (Positional relations are same in Figure5, 6 and 7)

bodies and structures such as viaducts were fully reflecting surfaces. The two-dimensional sound pressure level distribution based on the coherent line noise source of infinite length could be obtained from the analytical conditions established in this study.

3.3 Analytical conditions

In this analysis, the distribution of noise levels were compared and noise reduction level was calculated in increasing the height of the noise barrier. Table 1 shows the analytical conditions. Condition 1 was assumed that the noise barrier was 2 m high above the R.L. Conditions 2 was additional installation of a polycarbonate panel based on the assumption that noise reduction measures was taken for Condition 1; the height of the existing noise barrier was increased 1m with a transparent polycarbonate panel using an 8 mm thick (hereafter simply referred to as a polycarbonate panel). The sound transmission loss of the sound-insulating panel is shown in Figure 4.

The acoustic characteristics shown in Figure 4 were need to establish the complex sound speed information of the elements corresponding to the raised parts in accordance with Formula (10). Assuming the characteristic impedance of the sound-insulating panel is equal to the values used in Figure 2, sound reflection between the media cannot occur. On the other hand, it is anticipated that when a polycarbonate panel is installed on an existing noise barrier as in Conditions 2, sound should be reflected on the surface of the polycarbonate panel on a real viaduct. Therefore, the real value of the complex effective density was decided based on Equation (10). The real part of the complex effective density was decided so that the absolute value of the characteristic impedance of the polycarbonate panel would be equal to that of air.

The center frequencies of 1/3 octave bands between 250 and 1250Hz were assumed for the evaluation. The analysis was conducted, for each noise source, at the center frequencies of the 1/15 octave bands including the upper and lower limiting frequencies in response to the evaluation frequencies.

Table 1 Analytical condition

Analytical condition	Details of noise barrier
Condition 1	2 m high above the R.L.
Condition 2	Increased 1m with a polycarbonate panel in addition to Condition 1

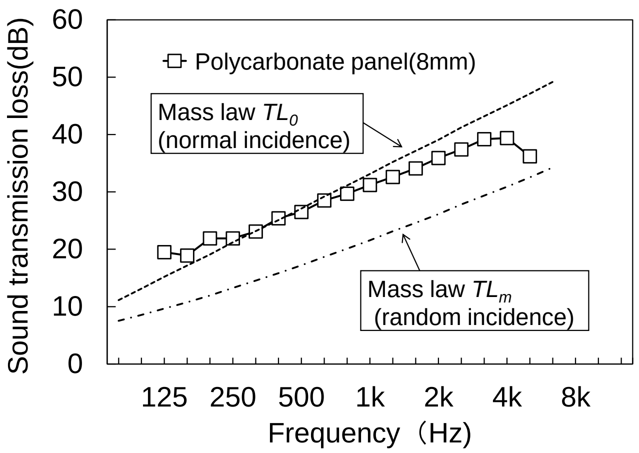


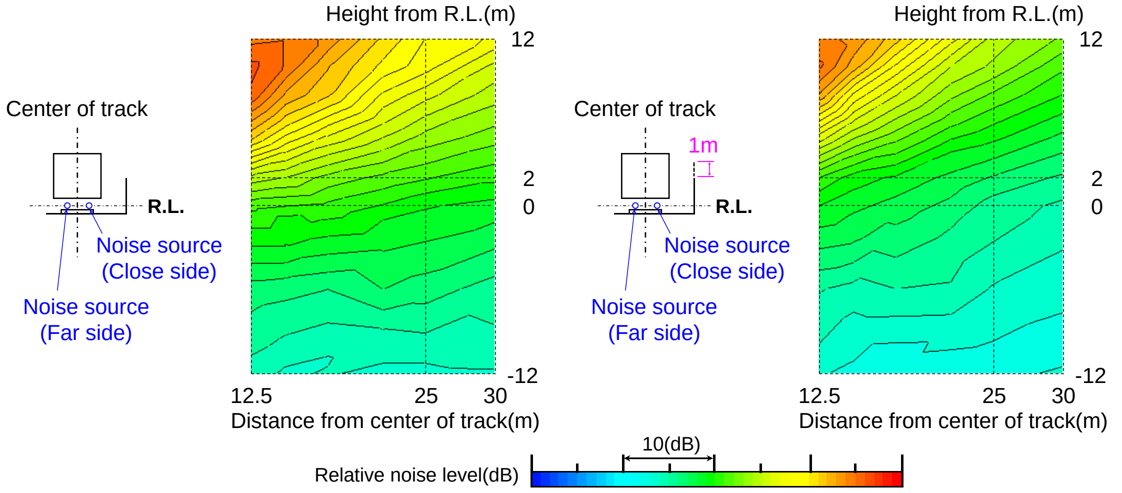
Figure 4 Sound transmission loss of a polycarbonate panel in Condition 2

3.4 Results of the analysis

Figures 5 and 6 show the results of the analyses under each condition for the under car noise and the pantograph noise respectively. Figure 7 shows the noise level reduction in Condition 2 for each noise source. The results are overall (O.A.) values at the frequencies for evaluation, and the numerical values in the charts indicate relative noise levels in infinite element domain. For the under car noise, noise levels shown in Figures were obtained by combining the analytical results for noise sources at close side and at far side.

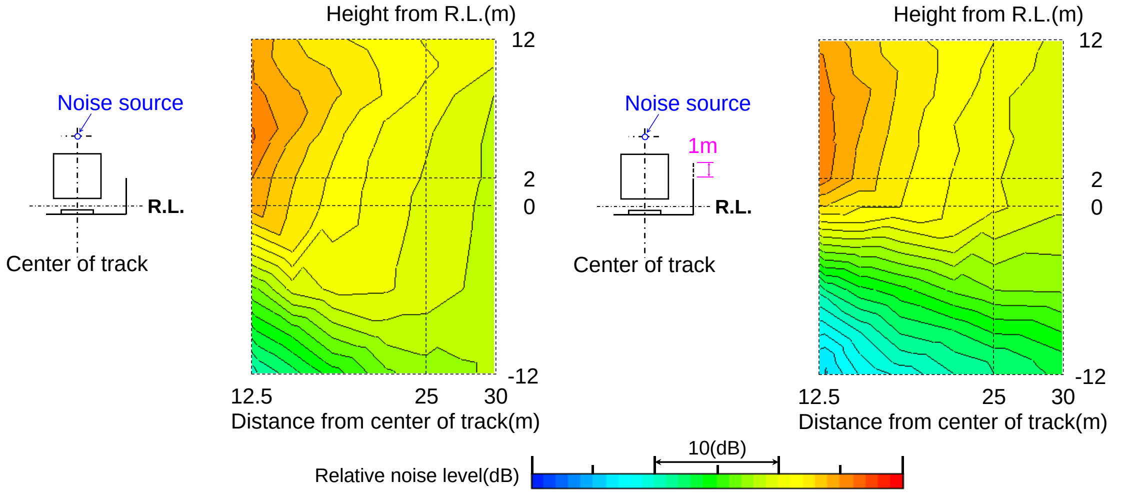
It can be confirmed that the noise levels that radiated outside the viaduct under Conditions 2 were generally lower than that in Condition 1. This is considered to be because the increase in the height of noise barriers not only suppressed the radiation of direct sounds from the noise sources and the reflected sound from the sides of the car bodies outside the viaduct, but also caused an increase in the distance to the upper end of the noise barrier and consequently enhanced the damping effect due to acoustic diffraction.

As for the results of the analyses in the case of the pantograph noise, it is confirmed that increasing the height of the noise barrier and thereby increasing



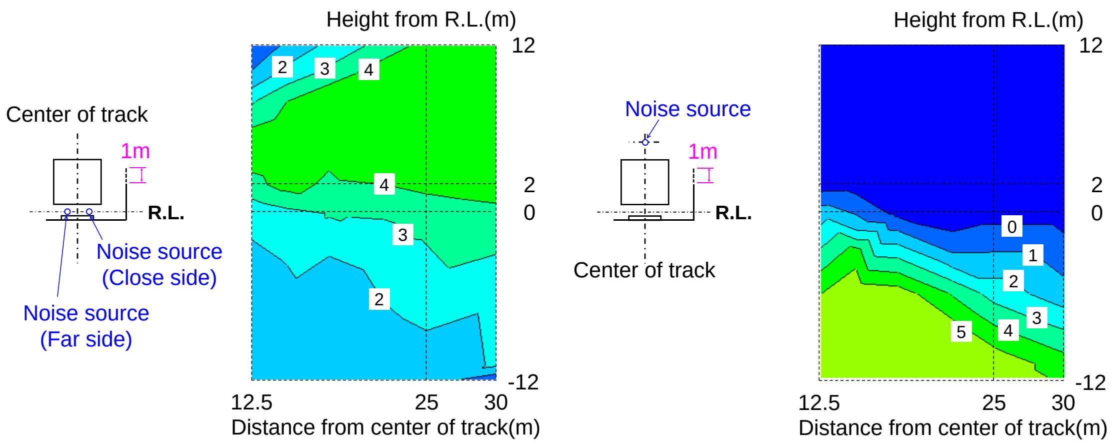
(a) Condition 1 *(b) Condition 2*

Figure 5 Noise level distribution outside of the viaduct for under car noise



(a) Condition 1 *(b) Condition 2*

Figure 6 Noise level distribution outside of the viaduct for pantograph noise



(a) Under car noise *(b) Pantograph noise*

Figure 7 Noise level reduction outside of the viaduct in raising height

the area that shields noise source outside the viaduct, reduces the noise level outside the viaduct at the lower area of the noise barrier. The noise level was reduced significantly, especially in the area behind the raised part with respect to the noise source. These calculated results are good agreements with the past results carried out with scaled model experiments [2].

4. Conclusion and future plans

Considering the sound insulation performance of a sound-insulating panel such as a polycarbonate sheet of 8mm thick is generally lower than that of concrete noise barrier, it is appropriate for noise prediction to reflect the sound insulation performance of the panel.

In this study, the sound insulation performance of the panel was regarded as a damping component by associated the complex sound speed with the transmission loss of the panel and was obtained as the sound pressure level between entering and transmitted sides of the medium. The variation of noise levels outside a railway viaduct was calculated with FEM supposing that a polycarbonate panel with the height of 1m is installed on the top of the existing concrete noise barrier for the under car noise and the pantograph noise. As the results, it is confirmed that the noise levels outside a viaduct were reduced because the additional panel increase the shadow region by noise barriers and improved sound attenuation due to diffraction for the under car noise. These results were in good agreement with the past findings.

5. REFERENCES

1. T. Kurita, Y. Wakabayashi, H. Yamada, M. Horiuchi, *"Reduction of wayside noise from Shinkansen High-Speed Trains"*, Journal of Mechanical Systems for Transportation and Losistics, 4(1), 1-12 (2011)

2. K. Nagakura, T. Kitagawa, *"Study on Effective Shapes of Sound Barriers for Shinkansen"*, RTRI Report (in Japanese), 16(12), 17-22 (2002)