Effective Length of Absorptive Cylinder Installed on the Edge of a Barrier

Mizuki INOUE※1 *and Kyoji FUJIWARA*※2

※1 Yotsumoto Acoustic Design Inc.
※2 Faculty of Design, Kyushu University

Abstract

It is common to build a barrier to reduce traffic noise. To improve the efficiency of the barrier with keeping its height low, an absorptive structure is often installed on its top edge. This paper presents a study on an effective length of absorptive cylinder, which has equivalent effect with infinite length.

1. Introduction

Barriers are commonly used to reduce traffic noise. The sound shielding efficiency is improved by increasing the height of the barrier. However, high barriers present various problems, such as their large structural load. Therefore, various new methods have been developed. One of those, it is the installation of an absorptive cylinder on the barrier edge, as shown in Fig.1[1].

In the study of a 3 m height barrier constructed along an actual expressway, a noise reduction of 2 to 3 dB was obtained at the receiving point, where the diffraction angle was relatively large, when a cylinder of about 50 cm diameter was added on its top edge. However, the relationship between the finite cylinder length and its effectiveness is not fully established. It is the purpose of this study to determine the effective length of absorptive cylinder for road traffic noise.

2. Effect for the Incident Angle

Road traffic noise can be considered as an incoherent line source, and it is composed of element point sources with random phases. The sound shielding efficiency of the barrier for road traffic road is often estimated by integrating the results of each point source. However, the incident angle of the acoustic wave on the absorbing material varies with the position of each element point source, as shown in Fig.2. That is, when sound wave skims the surface of the cylinder, the perimeter of absorbing material takes various values, or when sound wave intersects the cylinder, cross section area also takes various values. Therefore, the effect of the absorptive cylinder depends on the incident angle. Thus, the dependence on the incident angle of the effect was examined by analyzing the three-dimensional (3-D) sound field and with a 3-D scale model experiment.

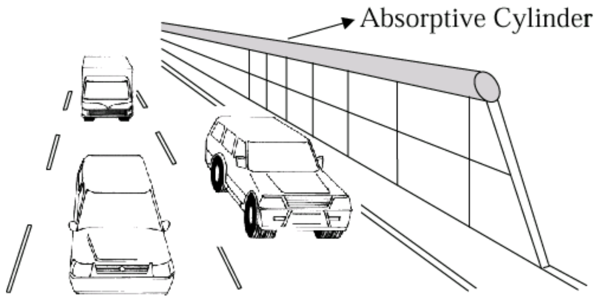

Figure 1: Absorptive cylinder installed on the barrier edge.

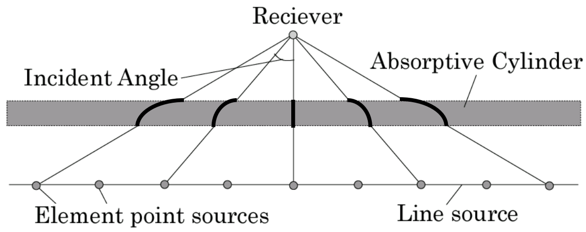

Figure 2: The incident angle and the effect depend on each point source.

2.1. Analysis

An integral transformation method was used for analyzing the 3-D sound field. The solution of the 3-D sound field could be derived from the solution of two-dimensional (2-D) problems by using a Fourier transform method on the wave number axis. Using this method, it is possible to obtain the solution in terms of a spherical sound wave field : $p(x, y, z, K)$ without solving the 3-D sound field problem directly, though solutions at all frequencies (including imaginary frequencies) in 2-D sound field : $q(x, y, k[K, \alpha])$ are necessary. This method was demonstrated by D. Duhamel [2][3], who calculated the effect of barrier attenuation on a finite impedance ground. In this work, we deduced the new integral transform expression given in Eq.(1) for an analysis which could also consider the internal acoustic field of

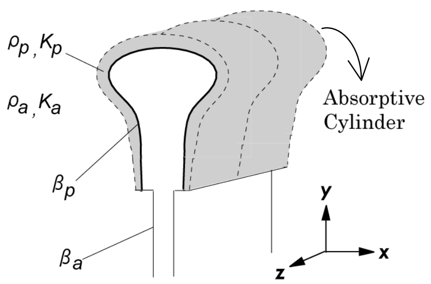

Figure3 : Variables in Eq(1).

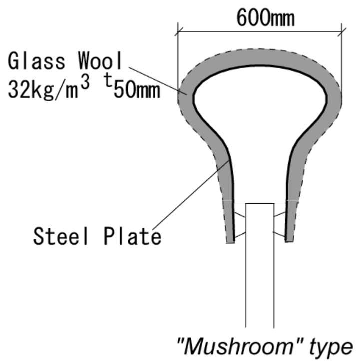

Figure4 : Absorptive cylinder in common use at present.

an absorptive cylinder (we used a coupled solution method using the boundary element method [4]).

In Eq.(1), K denotes the wave number of the 3-D sound field and α is the variable of the integral on the wave number. β is the admittance on the boundary surface, ρ is the density of the medium, and "a " / "p " are indexes corresponding to the exterior / interior sound field for the absorbing material, respectively as shown in Fig.3.

$$p(x, y, z, K_a, K_p, \beta_a, \beta_p, \rho_a, \rho_p)$$
$$= \frac{1}{\pi}\int_0^{+\infty} q\left(x, y, \sqrt{K_a^2-\alpha^2}, \sqrt{K_p^2-\alpha^2}, \frac{\beta_a}{\sqrt{1-\alpha^2/K_a^2}}, \frac{\beta_p}{\sqrt{1-\alpha^2/K_p^2}}, \frac{\rho_a}{\sqrt{1-\alpha^2/K_a^2}}, \frac{\rho_p}{\sqrt{1-\alpha^2/K_p^2}}\right)\cos(\alpha z)\, d\alpha \quad (1)$$

2.2. Results

The effect produced by an absorptive cylinder was calculated considering the structure and physical property of absorbing material used in actual cylinders. A commonly used model called "Mushroom" is shown in Fig.4, in which glass wool is used as absorbing material. Sources and receiving points are shown in Fig.5 and Fig.6. The results of the calculations are shown in Fig.7, at frequencies of 250Hz, 500Hz, 1000Hz, and only for 5 receiver points corresponding to 10~50 degree diffraction angles respectively because of space limitations. The results are normalized with respect to the value at zero-degree (0°) incident angle.

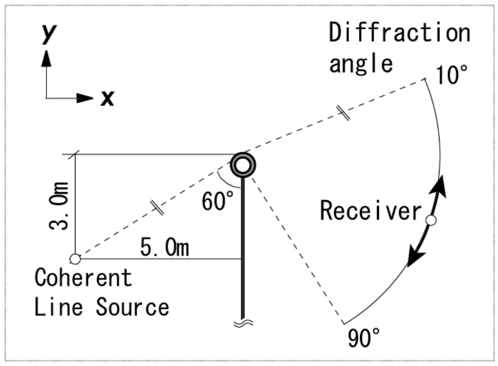

Figure5 : Geometry of barrier, source and receivers for analyzing the sound field in 2-D before integral transform.

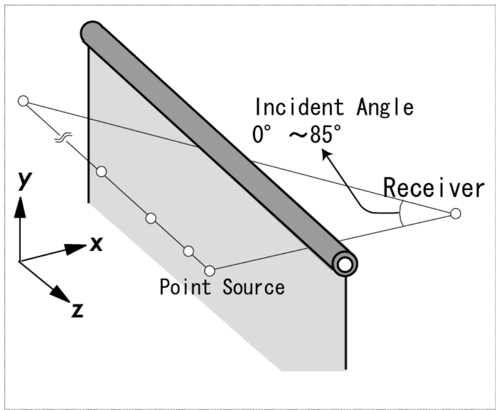

Figure6 : Transformation from 2-D problems to 3-D.

The effectiveness of the absorptive cylinder increases with incident angle and diffraction angle. At low frequency it increases rapidly at large incidence angles, but as the frequency increases, it occurs also at lower incidence angles and it varies almost linearly at high frequency. Similar results are also obtained in a scale model experiment [5].

3. Effective Length of Absorptive Cylinder

3.1. Condition for calculation

Now, we can determine the effective length of absorptive cylinder considering the effect as the function of incident angle. We consider a barrier, an incoherent line source, and receiving points placed as shown in Fig.8. The lower receiving point, which is located at 18m below barrier top, is supposed large diffraction angle such as an elevated road. And the upper, located at 3m below barrier top, is supposed not large diffraction angle such as non-elevated road. Furthermore, level distance of the barrier and the receiving point takes 5m-pitch-distance from 5 m to 30 m. Therefore, we can obtaine various angles of diffraction. The insertion loss of a barrier with a finite length of absorptive cylinder

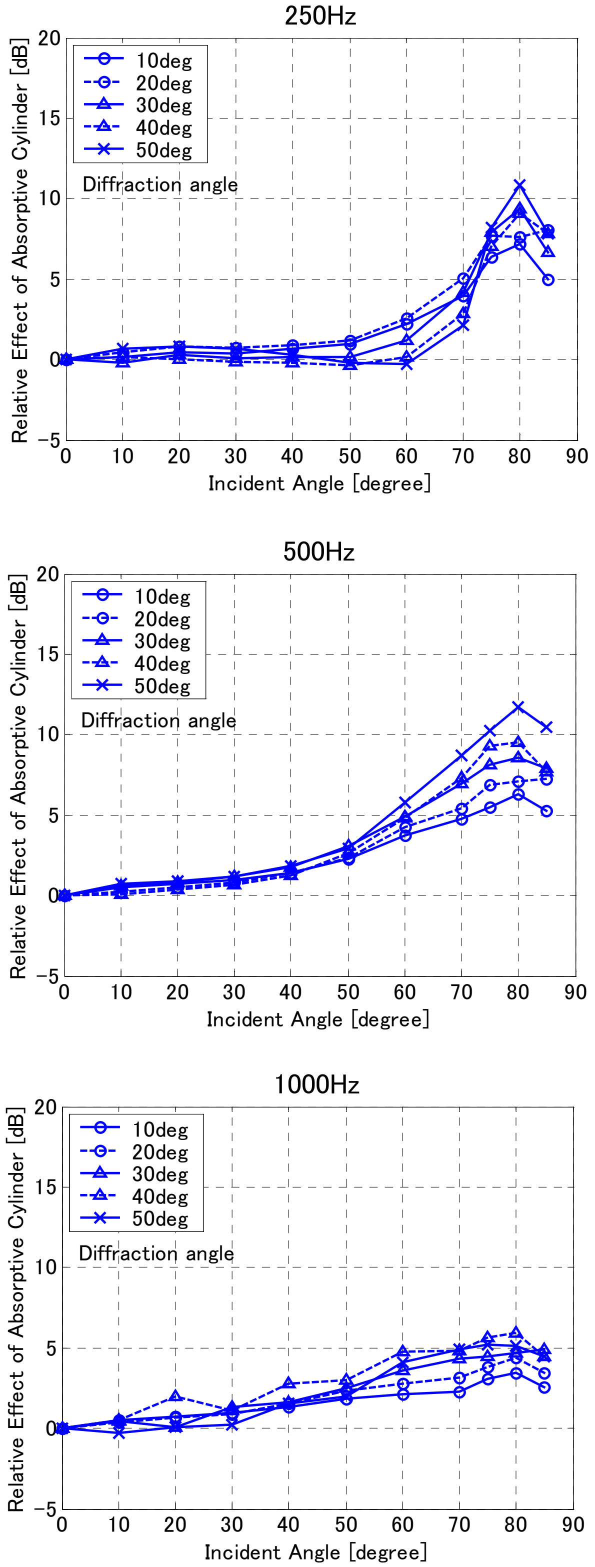

Figure 7: Influence of the incident angle of the effect of the absorptive cylinder for three different frequencies.

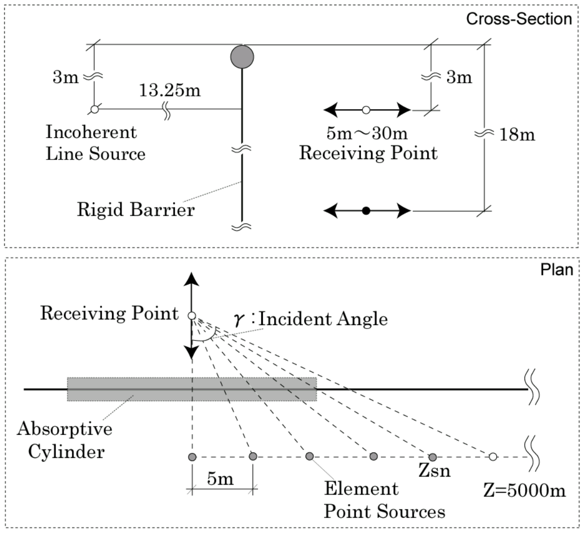

Figure 8: Geometry of barrier, source and receivers for various diffraction angles.

edge for the incoherent line source is calculated as,

$$IL = -10\log_{10}\frac{\int_0^{z_{sn}(\gamma)} |\phi_{WC}(z)|^2\, dz + \int_{z_{sn}(\gamma)}^{z(\gamma)} |\phi_{HB}(z)|^2\, dz}{\int_0^{z(\gamma)} |\phi_{free}(z)|^2\, dz} \qquad (2)$$

where ϕ_{HB} is the velocity potential at the receiving point in the field diffracted by a half-plane only and is calculated by the first approximation solution of Macdonald[6]. ϕ_{WC} is the velocity potential, calculated from ϕ_{HB} plus the effect of the absorptive cylinder as the function of incident angle and diffraction angle. ϕ_{free} is the velocity potential at the receiving point in the free field. The velocity potential was calculated at 1/3 octave center frequencies between 50 and 5000Hz, considering the atmospheric absorption as an excess attenuation [7]. Further, the insertion loss was also calculated for A-weighted road traffic noise [8]. The effect of an absorptive cylinder of finite length is defined as the sound pressure level difference between the cases where the absorptive cylinder is installed or not.

3.2. Results

Results are shown in Fig.9 where the length at horizontal axis denotes a half length of cylinder installed. The results show that the effect increases with length, and converges to certain values. The length, for which the effect is less than 0.5dB below the value obtained for an infinite length, is defined as the "Effective length". The solid line in Fig.10 gives an effective length, it is about 80m, when the horizontal distance from the barrier to the receiving point is 5m for upper receiving point. Similarly, the effective length is about 130m when the horizontal distance from the barrier is 10m. When the receiving point is far from the barrier, a longer length is necessary. The same result is obtained for lower

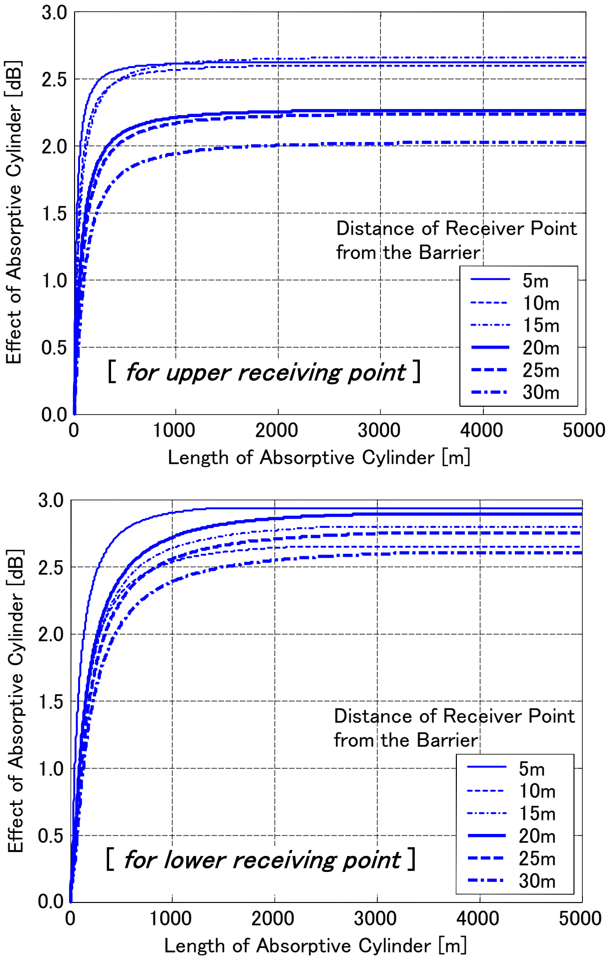

Figure 9: Effect of absorptive cylinder for incoherent line source.

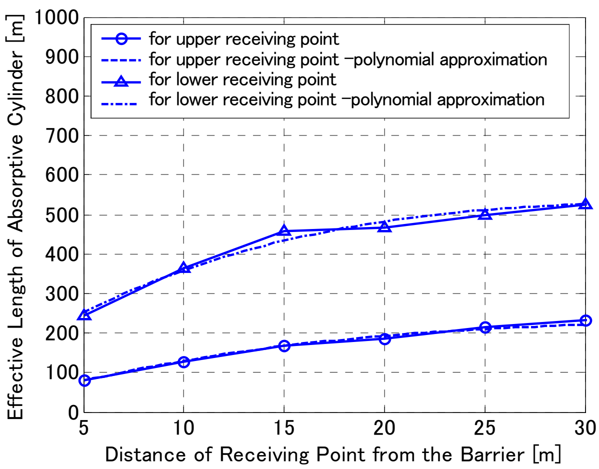

Figure 10: Effective length of absorptive cylinder.

receiving point, but longer lengths are necessary. Because the effect of the cylinder is more important, thus a long length is necessary to obtain an effect equivalent to that of an infinite length.

The effective length (L [m]) could be expressed as a function of the distance (x [m]) between the receiver point and the barrier as shown in the following equation and represented by the dotted line in Fig.10.

$$L = 0.0034x^3 - 0.3778x^2 + 15.254x + 11.797 \quad \text{for upper receiving point} \tag{3}$$

$$L = 0.0078x^3 - 0.8623x^2 + 32.738x + 109.78 \quad \text{for lower receiving point} \tag{4}$$

The effective length increases with the distance of the receiving point from the barrier, but converges to some value.

4. Conclusions

It is shown that the effect of an absorptive cylinder for element point sources depends on the incident angle and that the effect increases with this incident angle.

The effective length of absorptive cylinder for road traffic noise reduction was calculated considering the influence of the incident angle on the effect. The results show that the effective length depends on the position of the receiver point and it could be expressed as a function of the distance between the receiver point and the barrier.

5. References

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