

## Noise-shielding efficiency of barriers with eaves

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### 1. Introduction

Nowadays it is commonly recognized that noise barriers with appropriate acoustical devices on their top should reduce diffraction more efficiently than a simple barrier of the same height [1–3]. They are referred to as “edge-modified” noise barriers. The noise reduction efficiency of the edge-modifying device includes the effects of two factors: one is the effect of its acoustical mechanism such as absorption, interference, resonance and active noise control system, and the other is the effect of the external profile of the device itself (i.e., the increase in the barrier thickness). It is very difficult to measure each effect separately, and only the measurement results of the efficiency of the whole barrier are available when we compare the devices in the stage of environmental impact assessment. In the present paper, the noise-shielding efficiencies of barriers with eaves of various shapes are investigated to discuss the effect of the external profile of edge-modifying devices.

### 2. Geometrical conditions of numerical analyses

A cross-sectional view of the considered two-dimensional sound field is shown in Fig. 1. Numerical analyses using the two-dimensional boundary element method (2D-BEM) are carried out to calculate the diffraction behind noise barriers on the reflective ground. Both a coherent line source and a receiver are aligned on the ground surface for simple discussion without considering the interference due to ground reflection. The horizontal distance between the source and the barrier is denoted as  $x_S$  [m], while the receiver is fixed at a distance of 20 m.

The efficiencies of the noise barriers shown in Fig. 2 are examined. The figure shows cross-sectional profiles; the noise source is assumed to be located on the left-hand side and the receiver is on the opposite side. In this paper, barrier shapes are described by combinations of the following abbreviations. Barrier profiles that are thick (abbreviated to “T”), L-shaped (“L”), J-shaped (“J”), delta (“D”) are considered, with eaves in the direction of the source (“S”), the receiver (“R”), and in both directions (“B”). Barrier thicknesses or eaves depths (defined as  $t$  in Fig. 2) of 0.5 m, 1.0 m and 2.0 m are abbreviated to “05,” “10” and “20,” respectively. The height of all barriers is fixed at 5 m, and their surfaces are rigid.

### 3. Noise reduction by eaves

The relative sound pressure level (SPL), normalized by

unit length power level of the line source, is calculated at 1/15 octave intervals. Results for a thick barrier TS05, an L-shaped barrier LS05, and a simple barrier are shown in Fig. 3. TS05 reduces diffraction more than the simple barrier, and the difference between them increases at high frequencies. The periodic pattern in the frequency characteristics for LS05 is due to the interference shown in Fig. 4. SPL rapidly decreases at frequencies where the path difference between the direct and reflected paths to the eaves edge corresponds to odd-numbered multiples of the half-wavelength. The interference frequencies,  $f_n$ , are shown in Fig. 3. They depend on the source position, as shown in the differences among Fig. 3(a)–(c). The frequency characteristics for TS05 are almost the same as the upper envelope of the LS05 result; it is interpreted that the efficiency of the L-shaped noise barrier can be divided into the thickness effect of TS05 and the additional effect of eaves interference due to the path difference shown in Fig. 4.

Results for LS10 (source-side eaves of 1.0 m depth) and LS20 (2.0 m depth) are shown in Fig. 5. The thickness effect naturally increases depending on the thickness or the eaves depth, and that the interference hypothesis shown in Fig. 4 is reasonable even when the eaves depth increases. Results for LR05 (receiver-side eaves of 0.5 m depth) and LB05 (eaves on both sides, 0.5 m depth each for source and receiver sides) are shown in Fig. 6.  $f'_n$  in the figure denotes the interference frequencies calculated by applying the interference hypothesis to the receiver side. The eaves-interference hypothesis is still reasonable, and the frequency characteristics of LB05 are the superposition of the interference SPL dips for LS05 and LR05.

Let us assume that the source-side straight barrier portions of LS05 and TS05 are perfectly absorbent. They are respectively referred to as “LS05a” and “TS05a,” and the frequency characteristics of the diffracted SPL are shown in Fig. 7. The results of LS05a do not show steep SPL dips due to the eaves interference, because the contribution of the reflection path in Fig. 4 decreases owing to the absorbing surface. However, note that it is difficult for actual building materials to realize perfect absorption at low frequencies, and that the eaves-interference effect may appear for actual noise barriers to some extent in the frequency range.

### 4. Relationship between cross-sectional profile of eaves and efficiency

The noise reduction efficiencies of barriers shown in Fig. 2 are examined. Numerical results by 2D-BEM at 1/15 octave intervals are approximately integrated into 1/3-octave-

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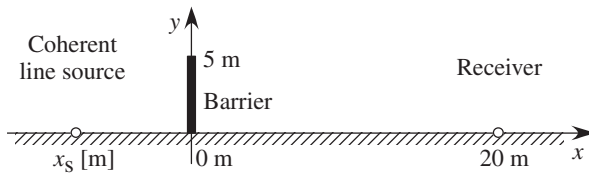


Fig. 1 Geometry of the two-dimensional sound field.

	Source-side	Receiver-side	Both sides
Thick			
L-shaped			
J-shaped			
Delta			
Simple			

Abbrev.	05	10	20
$t$ [m]	0.5	1.0	2.0

ex. LS05: L-shaped,  
Source-side,  
 $t = 0.5$  m

Fig. 2 Cross-sectional shapes and abbreviations of barriers.

band SPLs, and shown as the SPL difference normalized by the results for the simple barrier. Figure 8 shows the results for eaves on the source side. TS05 shows the thickness effect at high frequencies, and LS05 and DS05 show the additional effect due to the eaves interference. Both thickness and interference effects decrease as the source becomes more distant from the barrier. JS05 works less efficiently than the simple barrier at high frequencies, while it shows the eaves-interference effect at low frequencies. A similar tendency is observed when the eaves are set on the receiver side, as shown in Fig. 9. Results for both-side eaves (Fig. 10) are slightly different from the previous two situations. JB05 is efficient at high frequencies compared with LB05 and DB05, while JS05 and JR05 are not efficient. This may be because JB05 forms a so-called “Y-shape” profile causing double diffraction and interference in the cavity between the branches of the Y-shape.

### 5. Thickness effect on the efficiency determination of the edge-modified barriers

It is indicated by the results in the previous sections that barriers with eaves are more efficient than thick barriers with the same thickness, and that the additional efficiency is caused by interference due to the path difference around eaves. In the

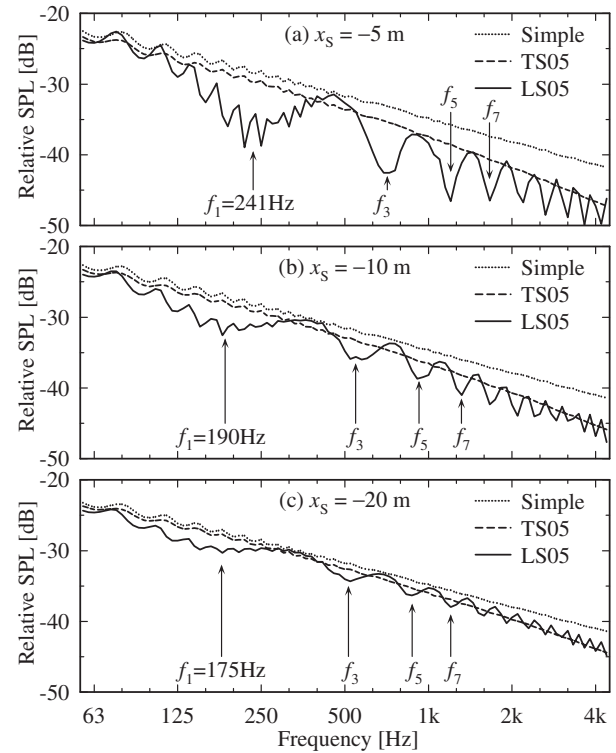


Fig. 3 Efficiency comparison of the thick and L-shaped barriers: the horizontal distance between the source and the barrier is (a) 5 m, (b) 10 m and (c) 20 m.

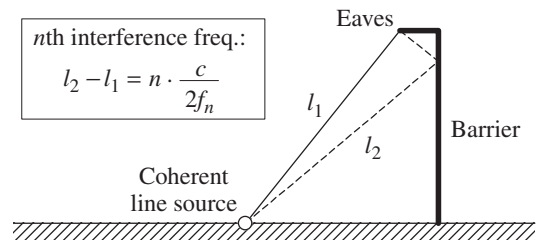
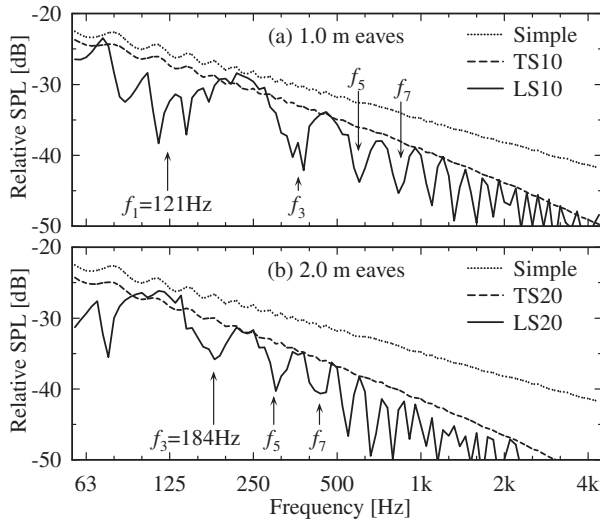


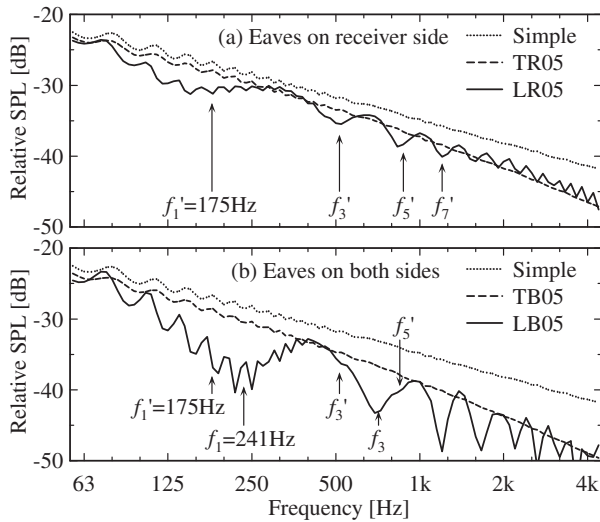
Fig. 4 Eaves interference caused by path difference in L-shaped barriers.

calculations of the barrier efficiencies in this paper, a coherent line source is considered in a two-dimensional sound field. According to Duhamel [4], the steep SPL dips due to interference obtained in the numerical analyses considering a coherent line source do not appear when the source is replaced by an incoherent line source. Noise radiation from a road with a high traffic volume can be approximated as an incoherent line source; therefore, the additional efficiency due to the eaves interference cannot be observed behind actual noise barriers along the road traffic.

On the other hand, in the efficiency determination of an edge-modified noise barrier, the efficiency is generally determined by the measurement of SPL behind the barriers in a common geometrical alignment where a loudspeaker and a microphone are located in the same plane perpendicular to the barrier edge. This alignment is referred to as “normal incidence” in the following. In measurements in the normal incidence alignment, the measured frequency characteristics



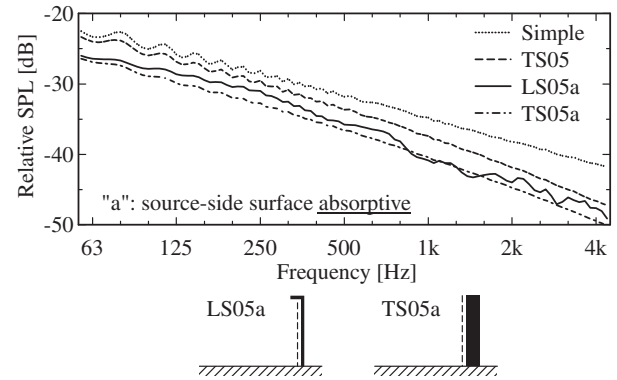
**Fig. 5** Effect of source-side eaves depth for  $x_s = -5$  [m]: (a) 1.0 m depth and (b) 2.0 m depth.



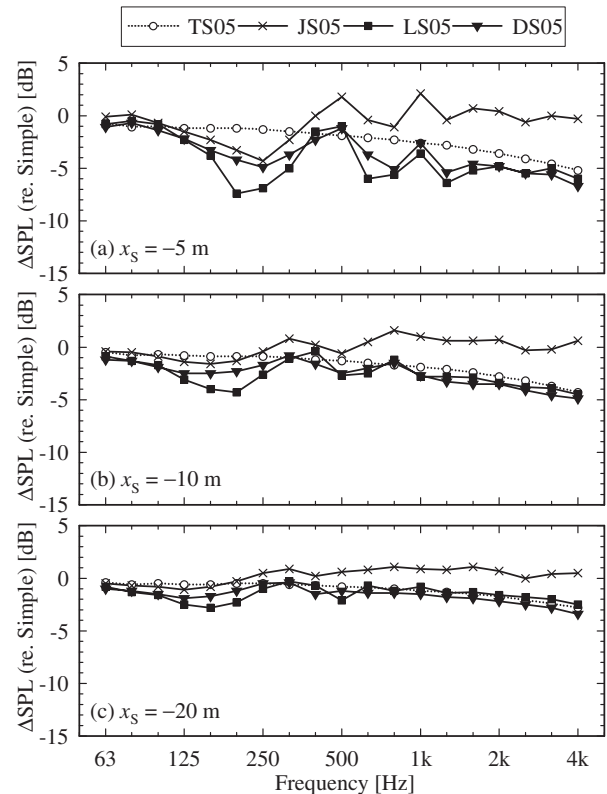
**Fig. 6** Effect of eaves direction for  $x_s = -5$  [m]: (a) 0.5 m eaves on receiver side, and (b) eaves on both sides, 0.5 m each for source and receiver sides.

of SPL contain an interference pattern that is similar to the eaves interference shown in this paper [3,4]. In other words, the efficiency of the edge-modifying device determined in the normal incidence alignment includes the eaves-interference effect due to the external profile of the device. As described above, the interference effect due to eaves or the external profile of devices does not appear as a reduction of actual road traffic noise (i.e., an incoherent line source); therefore, the eaves-interference effect must not be included when determining the efficiency of the edge-modifying device.

In novel procedures to determine the acoustical efficiency of edge-modified noise barriers [2,3], the eaves-interference effect is excluded introducing additional reflective boards, as shown in Fig. 11. This implies that the thickness effect due to the external profile of the device is recognized as the intrinsic efficiency of the device to be determined. Some edge-



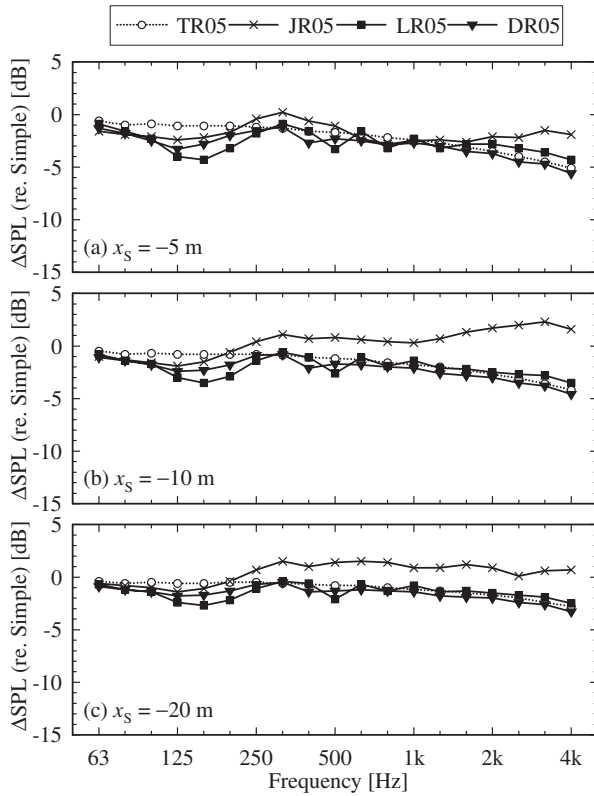
**Fig. 7** Effect of the absorbing straight barrier portion for  $x_s = -5$  [m].



**Fig. 8** Efficiency improvement compared with the simple barrier: 0.5 m eaves on source side.

modifying devices have absorbers in the lower surface of the device, and the absorbing surfaces are hidden by the additional reflective boards. It has been reported, however, that the lower surface of the device slightly affects the efficiency of the whole device [5], and it is expected that the additional reflective boards may not affect the results of the determined device efficiency.

From the viewpoint of the efficiency determination of edge-modifying devices, note that the thickness effect is not small. The thicknesses of some edge-modifying device products (i.e.,  $t$  in Fig. 2) are almost 1.0 m. These devices will have a thickness effect similar to that of TS10 or TB05, approximately 5 dB at 1 kHz for  $x_s = -5$  [m].



**Fig. 9** Efficiency improvement compared with the simple barrier: 0.5 m eaves on receiver side.

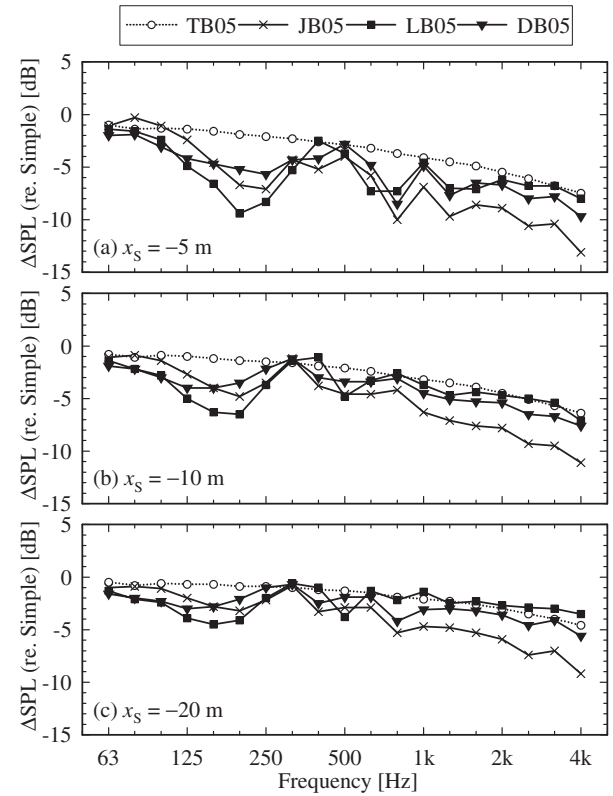
## 6. Conclusions

The noise-shielding efficiency of barriers with eaves was investigated by two-dimensional wave-based numerical analyses considering a coherent line source. It was shown that the effect of the eaves consists of the thickness effect and the eaves-interference effect. The eaves-interference effect may not appear for an incoherent line source; therefore, only the thickness effect should be expected when noise barriers with eaves are applied to reduce road traffic noise.

Although all numerical results in this paper are based on two-dimensional analyses with a coherent line source, a similar investigation has been carried out in a three-dimensional sound field with a point source [6]. It was reported that complicated unit patterns (i.e., time-series patterns of SPL due to single-vehicle passage) are observed behind barriers with eaves particularly at low frequencies, and that the shapes of the unit patterns depend on the frequency. This may be deduced by applying the eaves-interference hypothesis three-dimensionally.

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**Fig. 10** Efficiency improvement compared with the simple barrier: eaves on both sides, 0.5 m each for source and receiver sides.

$$\Delta L_{\text{edge}}(\theta_S, \theta_R, f) = \left\{ \begin{array}{l} \left[ \begin{array}{c} \text{Diagram 1: Barrier with eaves and reflective boards} \end{array} \right] - \left[ \begin{array}{c} \text{Diagram 2: Simple barrier} \end{array} \right] \\ \left[ \begin{array}{c} \text{Diagram 3: Barrier with eaves and reflective boards} \end{array} \right] - \left[ \begin{array}{c} \text{Diagram 4: Simple barrier} \end{array} \right] \\ \left[ \begin{array}{c} \text{Diagram 5: Barrier with eaves and reflective boards} \end{array} \right] - \left[ \begin{array}{c} \text{Diagram 6: Simple barrier} \end{array} \right] \end{array} \right.$$

↑ Additional reflective boards

**Fig. 11** Additional reflective boards introduced to exclude the eaves-interference effect in the efficiency determination of edge-modified noise barriers [2,3].

sound pressure field around a noise barrier," *J. Sound Vib.*, **197**, 547–571 (1996).

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