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Excess Attenuation of Road Traffic Noise by Detached Houses in the Residential Area around a Low Embankment Road

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Abstract [451] In the "Environmental Quality Standards for Noise in Japan," the problem of environmental noise in areas facing to roads is evaluated by obtaining the numbers and the rates of the buildings at which noise levels exceed the environmental quality standards. In order to estimate noise distribution in the residential area facing to roads, it is necessary to grasp the excess attenuation by the buildings. The authors proposed in the previous study a simple method to predict the excess attenuation of road traffic noise by detached houses when the road is on the same level with that of the houses. However, there are lots of residential areas where are located around a low embankment road. In such residential areas, the noise would be expected to be higher. The purpose of this paper is to derive a new method to predict the excess attenuation of road traffic noise by detached houses when a road is a low embankment. A one-twentieth scale model experiment is performed. On the basis of the experimental results, to extend the authors' predicting method to be applicable when a road is a low embankment is examined, and then a simple procedure to compensate the noise increase caused by the increase of the height of a road is derived. The results of an additional experiment verify the validity of the proposed method.

1 INTRODUCTION

In order to take a countermeasure to the effect of road traffic noise in the areas facing to arterial roads, the Ministry of Environment in Japan revised the "Environmental Quality Standards for Noise" [1] in 1999 and has been enforcing it. According to the standards, the problem of road traffic noise in areas facing roads is evaluated by obtaining the numbers and the rates of the buildings at which noise levels exceed the standards. The standards allow for the estimation of noise levels, instead of requiring actual measurements, in cases where taking the actual measurements would be difficult. For estimating noise levels, it is necessary to grasp the excess attenuation by the buildings. The Acoustical Society of Japan introduced a method of estimating 'average' noise level behind the buildings, which was originally presented in ASJ Model 1998 [2] and also adopted into ASJ RTN-Model 2003 [4]. In addition to this, the authors proposed in the previous study [3] another simple method to predict the excess attenuation of road traffic noise by detached houses when a road is on the same level with that of the residential area. This method can estimate the noise level at specific individual points in residential area and be applicable to the evaluation of the Environmental Quality Standards for Noise. However, there are lots of residential areas being located around a low embankment road. In such areas, the noise is expected to be higher than that when the road is on the same level with that of the residential area caused by the sound energy traveling over the houses. Therefore, a predicting method of the noise level in such residential areas is necessary. On such point of view, to extend the authors' predicting method applicable when a road is a low embankment is examined in this paper.

2 SCALE MODEL EXPERIMENT

2.1 Outline of the Experiment

To achieve the above purpose, a scale model experiment was performed in succession with the previous study [3]. A one-twentieth scale model of a residential area, 100 m $*$ 80 m (original size), was set in a semi-anechoic chamber, as shown in Figure 1. The sound pressure level (L_p) was measured at receiving points in the residential area as a model vehicle ran along a straight road 100 m in length. The excess attenuation of the road traffic noise by the detached houses was then calculated.

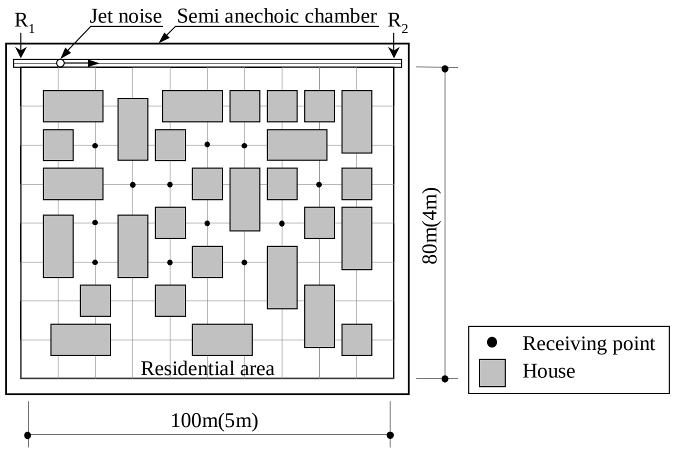

Figure 1: *Outline of the experiment*

2.2 Model Houses

Each detached house was assumed to be a rectangular parallelepiped, 8 m $*$ 8 m or 8 m $*$ 16 m according to the ground plan and with a height of 7 m or 10 m, and was to be placed in the residential area at random. The model houses were prepared in four patterns of arrangements, and the ratios of the areas of the houses to the entire residential area (hereafter referred to as

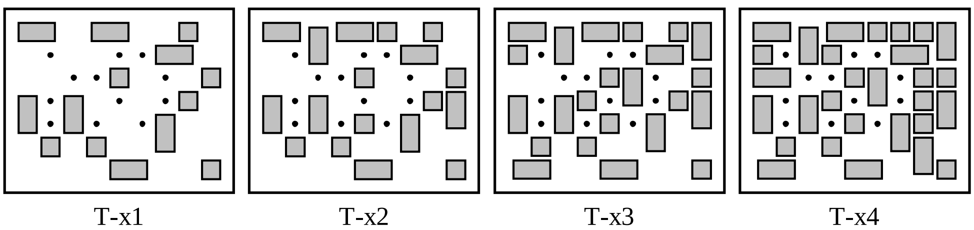

Figure 2: *Arrangement of model houses*

the ‘covering percentages’) were 16.8%, 21.6%, 28.0%, and 34.4%, as shown in Figure 2. Here a symbol ‘T-xy’ shows a pattern of arrangements of the model houses; x=2 and 3 for which x is a number showing the height of the houses (7 m and 10 m respectively) and y= 1, 2, 3, and 4 is a number showing the pattern number of house arrangement. The model houses were made of polystyrene which was reflective of the frequency range of the measurements.

2.3 Model Source and Receiving Points

Jet noise was used as the model sound source. The frequencies of it covered a range of 200 Hz to 1,600 Hz (original scale) for road traffic noise; and thus, it was considered to be an omni-directional point source for those frequencies. Since the road was assumed to be a low embankment, the height of the source (h_s) was 0.5 m, 5.5 m or 8.5 m from the ground. The L_p was continuously measured while the source was moved at a constant speed from R_1 to R_2, as shown in Figure 1. Assuming that the model source had a spectrum of road traffic noise [5], the measured L_p at each receiving point was converted into an A-weighted sound pressure level (L_pA) using a digital filter.

The number of receiving points was twelve, as shown in Figure 1. The perpendicular distances between the receiving points and the straight road (d) were 20 m, 30 m, 40 m, or 50 m, while the height from the ground (h_p) was 1.2 m, 5.2 m, or 8.2 m. Let’s note that the height of all the receiving points here was lower than the height of the houses.

2.4 Excess Attenuation

The sound exposure level (L_AE) was calculated from the unit pattern that was time-changed from the noise level measured at the receiving point, while the source moved from one end (R_1) to the other (R_2) along the straight road. The excess attenuation by the houses (ΔL_AE) was defined by the subtraction of L_{AE_1} from L_{AE_0}, where L_{AE_1} and L_{AE_0} were the values of L_AE measured under the conditions that houses were placed and not placed, respectively. It should be noted that the excess attenuation defined here has a contrary meaning to the usual definition.

3 DERIVATION OF THE PREDICTION FORMULA

3.1 Prediction Formula When a Road is the Same Level with the Area

Here, the predition formula of the excess attenuation of road traffic noise by detached houses when a road is the same level with that of the residential area [3] was shown.

$$\Delta L_\mathrm{AE} = \begin{cases} a \log_{10}\left(\frac{3\phi}{2\pi}(1-b)+b\right) & (\phi \neq 0) \\ a \log_{10} b + u\,\xi + v & (\phi = 0) \end{cases} \tag{1}$$

where

$$\begin{aligned} a &= p + q \log_{10} d \\ &\quad p = 2.03H - 2.63h_\mathrm{p} + 4.64 \\ &\quad q = -1.10H + 1.47h_\mathrm{p} - 1.21 \\ b &= 10^{(sd+t)/a} \\ &\quad s = -0.0023H - 0.009h_\mathrm{p} - 0.123 \\ &\quad t = -0.29H + 0.94h_\mathrm{p} - 3.74 \end{aligned}$$

$$
\begin{aligned}
u &= -20.0 \\
v &= 6.59 \\
\Delta L_{\mathrm{AE}} &: \text{ excess attenuation by detached houses (dB)} \\
\phi &: \text{ open angle (rad)} \\
\xi &: \text{ house-occupied rate (-)} \\
d &: \text{ distance between receiving point and road (m)} \\
H &: \text{ height of houses (m)} \\
h_{\mathrm{p}} &: \text{ height of receiving point (m)}\,.
\end{aligned}
$$

The definition of five parameters, ϕ, ξ, d, H, and h_{p} were illustrated in Figure 3.

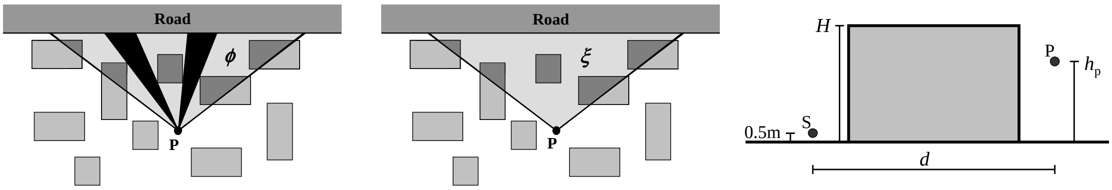

Figure 3: *Noise prediction parameters*

3.2 WHEN A ROAD IS A LOW EMBANKMENT

3.3 Hypothesis for Prediction When a Road is a Low Embankment

When a road is a low embankment, the noise in the residential area is expected to be higher than that when the road is on the same level with that of the residential area caused by the sound energy traveling over the houses. Therefore the expansion of the equation (1) to the case when the height of the source (h_{s}) is variable is examined.

A simple hypothesis, the noise level when the height of the sound source becomes heigher could be compensated by the level difference caused by the change of the source height, was assumed. At first, the excess attenuation of a receiving point with the height of 0.5 m when a road was on the same level with the residential area ($h_{\mathrm{s}} = 0.5\,\mathrm{m}$) was denoted by $\Delta L_{\mathrm{AE,P,0.5}}$ as shown in Figure 4. In the same way, the excess attenuation when only the height of the source was changed to be h_{s} could be expressed by $\Delta L_{\mathrm{AE,P},h_{\mathrm{s}}}$. In the following section, the relation between the difference of excess attenuation obtained from the experiment and the noise prediction parameters was examined in order to derive an expanding method of the equation (1) to the case when the height of the source is higher than 0.5 m. Here the noise parameters were five used in the equation (1) ($\phi, \xi, d, H, h_{\mathrm{p}}$) and the height of the source (h_{s}).

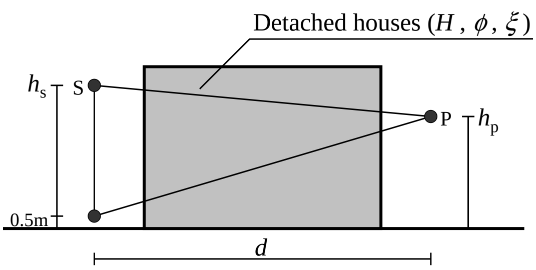

Figure 4: *Heights of sound source, houses, and receiving point*

3.4 Effect of the Change of Source Height on Excess Attenuation

It has been known in the previous study [3] that the amount of excess attenuation was greatly changed whether ϕ was zero or not zero, that is the road was invisible or visible from a receiving point. Considering this, the relation between the average values of the level differences $(\Delta L_{\mathrm{AE,P},h_\mathrm{s}} - \Delta L_{\mathrm{AE,P,0.5}})$ and the change of source height $(h_\mathrm{s} - 0.5)$ were examined individually when ϕ were zero and not zero. Some examples were shown Figure 5. It could be found in this figure that $(\Delta L_{\mathrm{AE,P},h_\mathrm{s}} - \Delta L_{\mathrm{AE,P,0.5}})$ increased linearly as $(h_\mathrm{s} - 0.5)$ increased. Hence, $(\Delta L_{\mathrm{AE,P},h_\mathrm{s}} - \Delta L_{\mathrm{AE,P,0.5}})$ was firstly expressed with the equation $a'(h_\mathrm{s} - 0.5)$, and then regression coefficients a' was calculated.

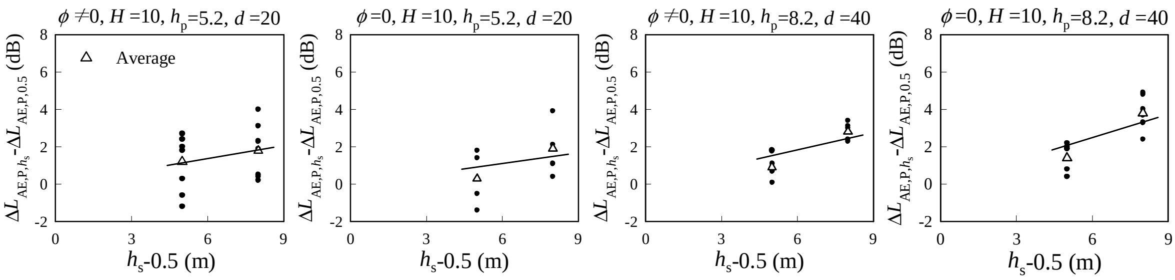

Figure 5: *Relation between* $(\Delta L_{\mathrm{AE,P},h_\mathrm{s}} - \Delta L_{\mathrm{AE,P,0.5}})$ *and* $(h_\mathrm{s} - 0.5)$

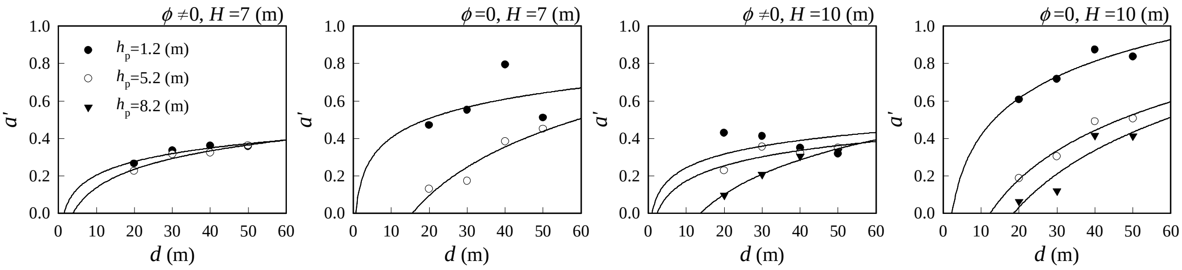

Figure 6: *Relation between* a' *and* d

3.5 Effect of the Distance from a Road

The regression coefficients obtained in the above were classified into two groups when ϕ were zero and not zero, and then the relation between a' and d in each H and h_p was examined for each group. Some examples were shown in Figure 6. It could be found in this figure that a' increased logarithmically as d increased. Hence, a' was expressed with the equation $s' \log_{10} d + t'$, and then regression coefficients s' and t' were calculated.

Moreover, the relation between s', t' and $(H - h_\mathrm{p})$ were examined individually when ϕ were zero and not zero. The relations between them were shown in Figure 7. It could be found in this figure that both s' and t' increased linerally as the change of $(H - h_\mathrm{p})$. Hence, s' and t' were expressed with the equation $k_1(H - h_\mathrm{p}) + w_1$ and $k_2(H - h_\mathrm{p}) + w_2$ respectively, and then regression coefficients k_1, w_1, k_2, and w_1 were calculated.

3.6 Empirical Formula When the Sound Source is High

Thus, an empirical formula to predict excess attenuation of road traffic noise by detached houses when a road was heigher than 0.5 m was obtained as follows:

$$\Delta L_\mathrm{AE} = \Delta L_{\mathrm{AE,0.5}} + a'(h_\mathrm{s} - 0.5) \tag{2}$$

where

$$a' = s' \log_{10} d + t'$$

$$S' = \begin{cases} -0.0352(H - h_\mathrm{p}) + 0.497 & (\phi \neq 0) \\ -0.0562(H - h_\mathrm{p}) + 0.996 & (\phi = 0) \end{cases}$$

$$t' = \begin{cases} 0.0676(H - h_\mathrm{p}) - 0.5074 & (\phi \neq 0) \\ 0.1573(H - h_\mathrm{p}) - 1.3911 & (\phi = 0). \end{cases}$$

Due to the experimental conditions, the formula is valid only when d is within 50 m of the road, ξ is less than 0.4, H is within 10 m, and h_p is less than the height of the houses.

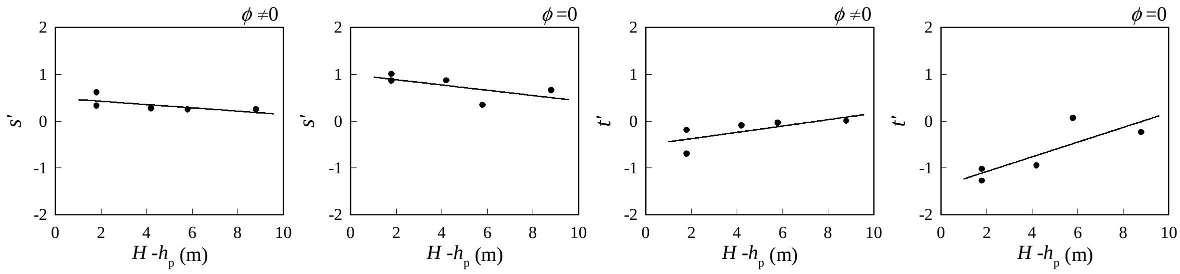

Figure 7: *Relation between* s'*,* t' *and* $(H - h_\mathrm{p})$

A comparison between the experimental and the predicted values by Equation (2) is shown in Figure 8. The differences between them are mostly within ±3 dB and no systematic error can be found. This proves that the prediction formula has sufficient accuracy.

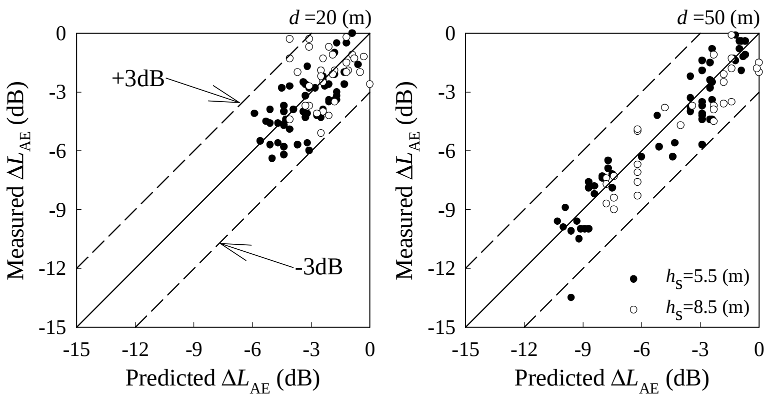

Figure 8: *Comparison between measured values and predicted ones*

4 EXAMINATION OF THE VALIDITY OF THE PREDICTION FORMULA

In order to verify the validity of the proposed method, an additional model experiment was performed. In the experiment, two new arrangements of the houses were employed as shown in Figure 9 and the heights of the source were set to be 3.8 m and 6.7 m. Other experimental conditions were almost the same with those in the former experiment. The comparison between the experimental and the predicted values was shown in Figure 10. The differences between them were roughly within ±3 dB. This verifies that the proposed method has sufficient accuracy.

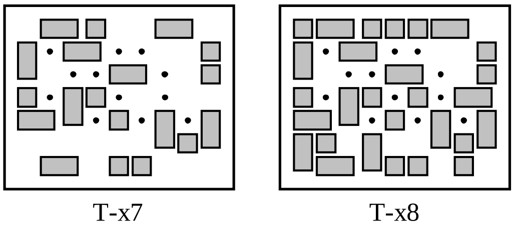

Figure 9: *Arrangement of model houses in an additional experiment*

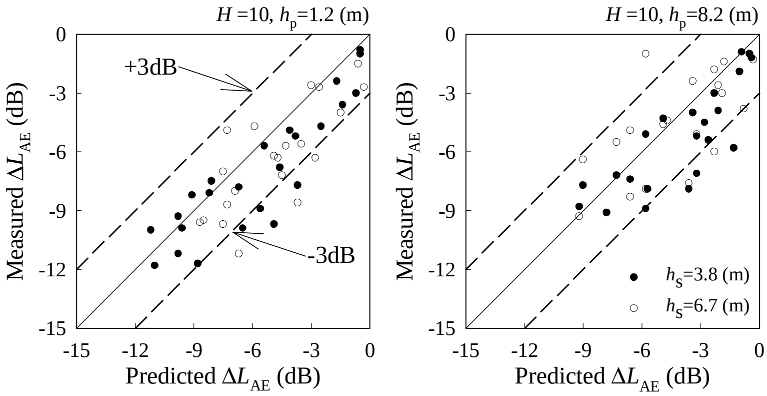

Figure 10: *Comparison between measured values and predicted ones*

5 CONCLUSION

A simple method to predict the excess attenuation of road traffic noise by detached houses when a road is located higher than a residential area was proposed. This was derived by extending the authors' prediction formula when a road was on the same level with that of a residential area. Since it can predict excess attenuation at arbitrary points in the residential area, by using the equation (1) and (2) the "Environmental Standards for Noise" could be evaluated not only when a road was on the same level with that of the residential area but also when a road was located higher than a residential area.

ACKNOWLEDGEMENTS

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