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PREDICTION AND EVALUATION METHODS FOR ROAD TRAFFIC NOISE IN BUILT-UP AREAS

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ABSTRACT
Since the Japanese environmental quality standards for noise were revised in 1998, it has become increasingly important to predict and evaluate the road traffic noise in built-up areas in Japan. This paper presents a method of calculating L_{Aeq} averaged in an evaluation section behind buildings facing an arterial road. In this method, the buildings are classified into the first row of buildings directly facing the road and the remaining buildings behind them. Then the values of the sectional energy-averaged L_{Aeq} are simply calculated mainly according to the density of the buildings and the distance from the road to the evaluation section, by summing the sound-energy contributions from the sound paths propagating through the buildings and over them. The validity of the method presented herein has been verified by measured data in field surveys.

1 - INTRODUCTION
In Japan, the environmental quality standards for noise were revised in September 1998 and enforced in April 1999 [1]. This revision includes two main matters crucial to prediction and evaluation of road traffic noise: 1) L_{Aeq} has replaced L_{50}, which had been used as a noise index since 1971; and 2) the "areas facing roads" have been divided into the "areas adjacent to an arterial road" (within 15-20m from the border of the road area) and the remaining areas. Thus, it has become increasingly important to predict and evaluate L_{Aeq} of the road traffic noise behind the buildings facing the road as well as just at the roadside.

There are several documents about methods of predicting road noise in built-up areas in European countries [2,3]. However, the derivation of the formulas proposed in these methods is not clear and the validity of them is not verified in the documents.

In this paper, we introduce a method of predicting and evaluating the road traffic noise in built-up areas. This method has been presented in an appendix of the ASJ Model 1998 [4-6], which is a standard prediction model for road noise used in the environmental impact assessment in Japan [7].

2 - NECESSITY OF SECTIONAL EVALUATION INDEX
It is possible to predict the road traffic noise at a specific point behind the buildings if each building is located sufficiently apart from the others as in rural areas [8, 9]. On the contrary, the prediction at a specific point is almost impossible when the buildings are so densely arranged that the road is not visible from the prediction point (see Fig. 1). This is because: 1) it is difficult to calculate multiple diffraction and multiple reflection between the many buildings; 2) it is not practical to survey the parameters for prediction such as the scale, shape and position of the buildings; and 3) it is also difficult to select the typical prediction point of the evaluation section since the noise level varies considerably between the prediction point and the buildings.

In order to solve these problems, we propose that the sectional energy-averaged equivalent continuous A-weighted sound pressure level ($\overline{L_{Aeq}}$) defined in Eq. (1) is used as an evaluation index of road traffic noise.

$$\overline{L_{Aeq}} = 10\log_{10}\left(\frac{1}{x_2 - x_1}\int_{x_1}^{x_2} 10^{L_{Aeq}(x)/10}dx\right) \tag{1}$$

where x_1 and x_2 are the positions of the beginning and the ending point of a linear evaluation section which is parallel to the road.

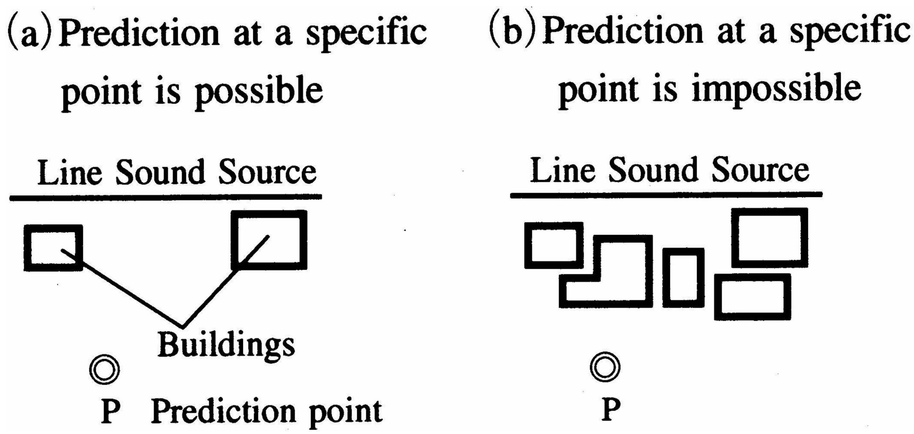

Figure 1: Possibility of road noise prediction at a specific point.

3 - MODELLING OF A BUILT-UP AREA AND PREDICTION METHOD

3.1 - Modelling of a built-up area

Fig. 2 shows a proposed model of a built-up area. In this model, the buildings are classified into the first row of buildings (FRB) directly facing a road and the rear group of buildings (RGB) behind it. Since the density of buildings forming FRB is frequently larger than that of RGB in Japanese cities, this classification is necessary for the better calculation.
Five parameters for calculation are given relating to FRB and RGB:

- the average height of FRB and RGB h;
- the spacing of buildings forming FRB $\alpha = \left(\sum_{i=1}^{n} g_i\right)/l$;
- the average width of FRB w_1;
- the density of buildings forming RGB $\beta = \frac{A}{w_2 l}$ (A: Area of existing buildings); and
- the average width of RGB w_2.

3.2 - Prediction equations in the case of a road at ground level

This section shows the equations for calculating $\overline{L_{Aeq}}$ behind the buildings facing a road at ground level where no noise barriers are erected.

Basic equations

$\overline{L_{Aeq}}$ of the evaluation section behind the buildings is calculated by the following equations, in which the ground is considered to be reflective.

$$\overline{L_{Aeq}} = L_{Aeq}\,(\text{without buildings}) + \overline{\Delta L_{builds}} \tag{2}$$

where L_{Aeq}(without buildings) is an imaginary value at the evaluation section if it were not for the buildings, which is calculated by the B-method of the ASJ Model 1998 [4-6]; $\overline{\Delta L_{builds}}$ is a correction term expressed by a minus value, which represents sectional energy-averaged excess attenuation by the buildings.
$\overline{\Delta L_{builds}}$ is calculated by the next equation, which considers the sound-energy contributions from three paths shown in Fig. 3.

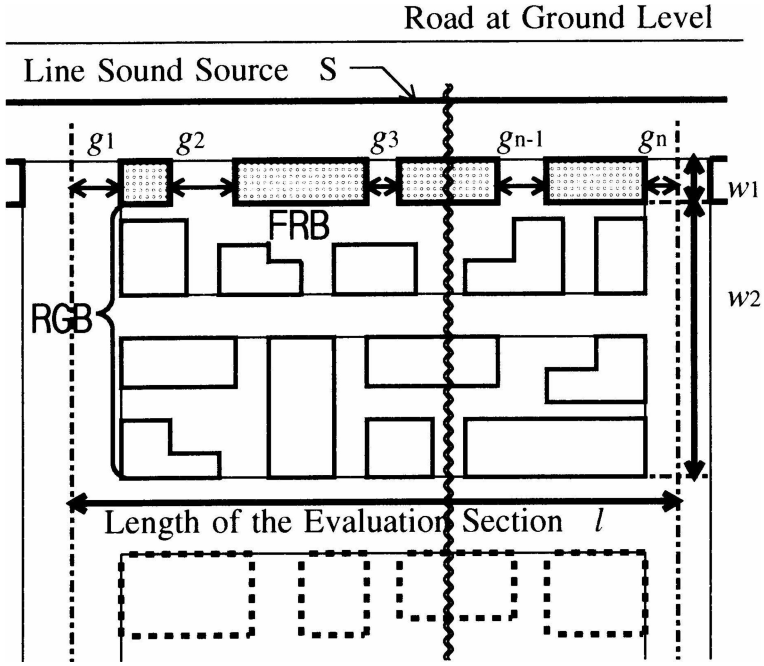

Figure 2: Modelling of a built-up area.

$$\Delta L_{builds} = \log_{10}\left(\frac{C_1 + C_2 + C_3}{C}\right) = \log_{10}\left(\frac{C_1}{C} + \frac{C_2}{C} + \frac{C_3}{C}\right) \tag{3}$$

where

- C is the sound-energy contribution from the line source without the buildings;
- C_1 is the contribution from Path 1 which propagates through both FRB and RGB;
- C_2 is the contribution from Path 2 which propagates over FRB and through RGB;
- C_3 is the contribution from Path 3 which propagates over both FRB and RGB.

Then, C_1/C, C_2/C and C_3/C are given by

$$C_1/C = \alpha\left(1 - 10^{\Delta L_{SXYP,line}/10}\right) 10^{\overline{\Delta L(\beta,d_1)}/10} \tag{4}$$

$$C_2/C = (1-\beta)\left(10^{\Delta L_{SXYP,line}/10} - 10^{\Delta L_{SXZP,line}/10}\right) 10^{\overline{\Delta L(\beta,d_2)}/10} \tag{5}$$

$$C_3/C = 10^{\Delta L_{SXZP,line}/10} \tag{6}$$

where $\Delta L_{SXYP,line}$ and $\Delta L_{SXZP,line}$ are correction terms for the diffraction effect of an infinite- length thick barrier placed parallel to a line source of noise (see Eq. (7)); $\overline{\Delta L(\beta, d_i)}$ is a correction term for sectional energy-averaged excess attenuation by RGB, if it were high enough to neglect the contribution from the path propagating over itself (see Eq. (8)); d_i is the length of Path i (i=1,2) which goes through RGB.

Calculation of sound propagating over buildings

Sound propagating over buildings is calculated by regarding them as one body with no space between them, that is, an infinite-length thick barrier. In the case of a point sound source, a correction term for diffraction by the barrier $\Delta L_{SXYP,point}$ is obtained by the next equation [8] (see Fig. 4).

$$\Delta L_{SXYP,point} = \begin{cases} \Delta L_{SXP} & \text{for } P \text{ is higher than } X \text{ and } Y \\ \Delta L_{SXP} + \Delta L_{XYP} - 5 & \text{for } P \text{ is lower than } X \text{ and } Y, \text{ and } \delta_{SXP} \geq \delta_{SYP} \\ \Delta L_{SXY} + \Delta L_{SYP} - 5 & \text{for } P \text{ is lower than } X \text{ and } Y, \text{ and } \delta_{SXP} < \delta_{SYP} \end{cases} \tag{7}$$

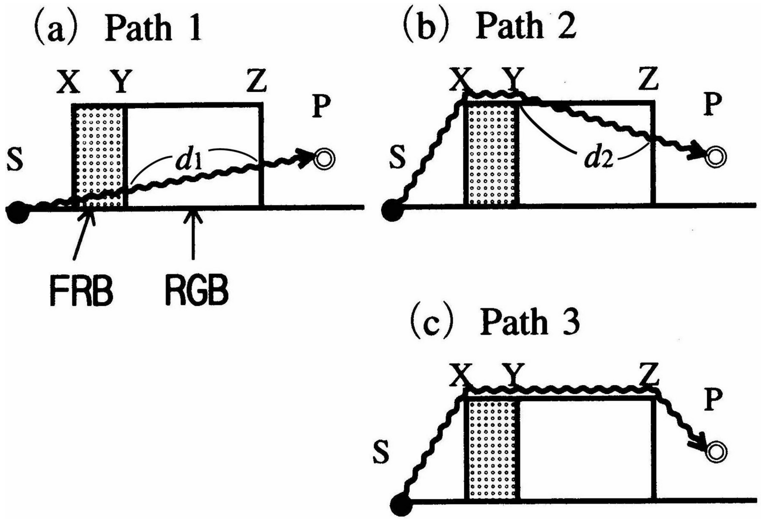

Figure 3: Three sound propagation paths in the built-up area.

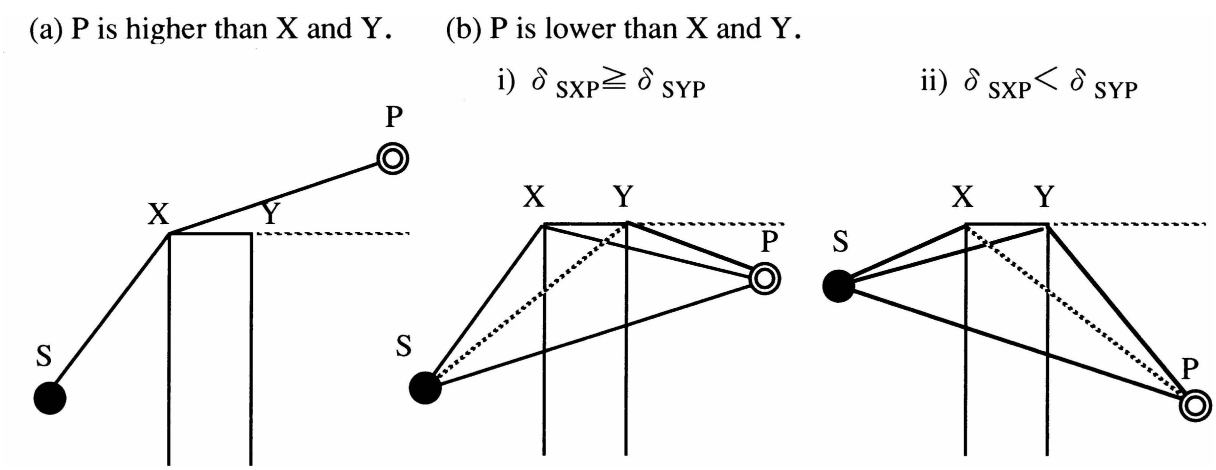

Figure 4: Calculation method for $\Delta L_{SXYP,point}$.

where ΔL_{SXP} is a correction term for diffraction by a semi-finite screen with the edge X, which is equal to ΔL_d defined in the B-method of the ASJ Model 1998 [6]; δ_{SXP} and δ_{SYP} are path length differences [6].
$\Delta L_{SXYP,line}$ is obtained as the difference of energy-integration values of the "unit-pattern" [4] with and without the infinite-length thick barrier, the former of which is calculated by using Eq. (7).

Calculation of sound propagating through buildings

We have obtained a regression equation for $\overline{\Delta L(\beta, d_i)}$ as a result of scale-model experiments (1/40) in an anechoic chamber [10].

$$\overline{\Delta L(\beta, d_i)} = -0.775 \{\beta/(1-\beta)\}^{0.630} \times d_i^{0.859} \quad (8)$$

in which the power spectrum of sound source is considered as that of vehicle noise proposed in the ASJ Model 1998 [5].
If frequency f is added as a variate, Eq. (8) is expressed as

$$\overline{\Delta L(\beta, d_i, f)} = -0.235 \{\beta/(1-\beta)\}^{0.646} \times d_i^{0.833} \times f^{0.201} \quad (9)$$

3.3 - Examples of simplified equation

Eq. (3)-(6) and (8) can be rearranged in simple forms if C_2 and C_3 are negligible, e.g. when the height of an evaluation section is 1.2 $-$ 1.5 m and the horizontal distance between the border of the road area and the evaluation section d_{road} is within about 50 m.

$$\overline{\Delta L_{builds}} \approx 10\log_{10}\alpha - 0.775\left\{\beta/\left(1-\beta\right)\right\}^{0.630} \times \left(d_{road} - w_1\right)^{0.859} \qquad (10)$$

In Japanese residential areas, w_1 is $10 - 15$ m in general. If it is difficult to distinguish between FRB and RGB, ΔL_{builds} can be calculated using the density of buildings in the entire built-up areas β_{all}. In this case, Eq. (10) is changed into the next equation.

$$\overline{\Delta L_{builds}} \approx 10\log_{10}\left(1-\sqrt{\beta_{all}}\right) - 0.775\left\{\beta_{all}/\left(1-\beta_{all}\right)\right\}^{0.630} \times \left(d_{road} - w_1\right)^{0.859} \qquad (11)$$

On the other hand, if the evaluation section is just behind FRB, Eq. (10) is changed into

$$\overline{\Delta L_{builds}} = 10\log_{10}\alpha \qquad (12)$$

4 - COMPARISON WITH MEASURED DATA

Field surveys were conducted in Tokyo to verify the validity of Eq. (10). Fig. 5 shows one of the survey sites, in which P1-P10 stand for noise measuring points, and A1 and A2 stand for evaluation sections.

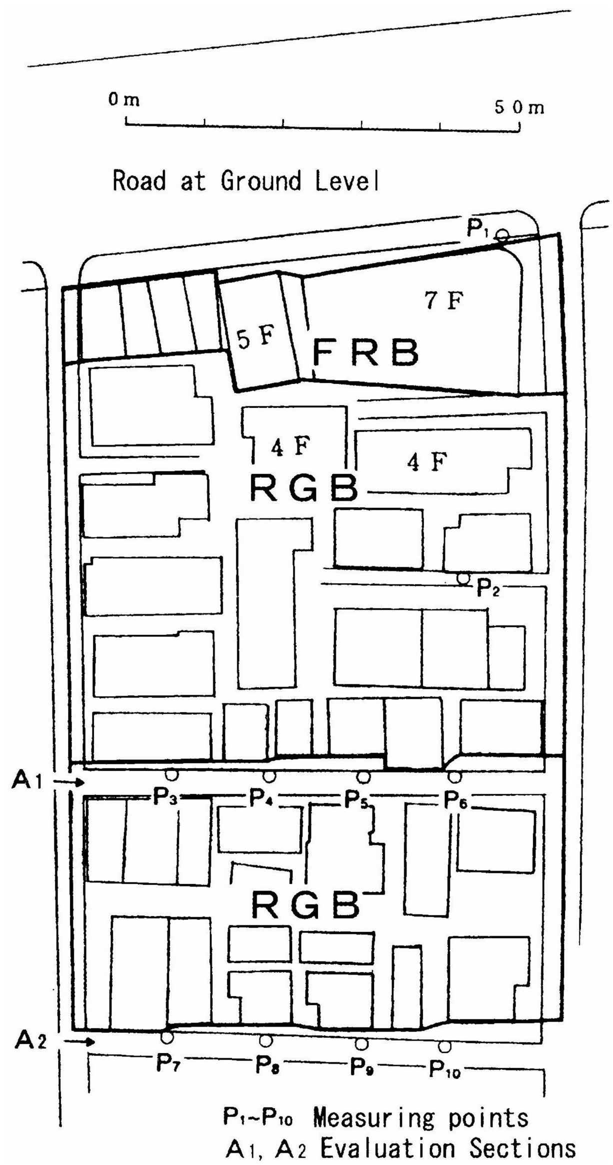

Figure 5: Example of field survey sites (A district).

Fig. 6(a)-(c) shows the calculated results by Eq. (10) and by ISO 9613-2 method [2] together with the measured data. Since measurement was done at midnight, background noise was assumed 40dB in the calculation. The values calculated by Eq. (10) are in good agreement with the measured data. However, the ISO calculation method gives much less excess attenuation by the buildings than measured.

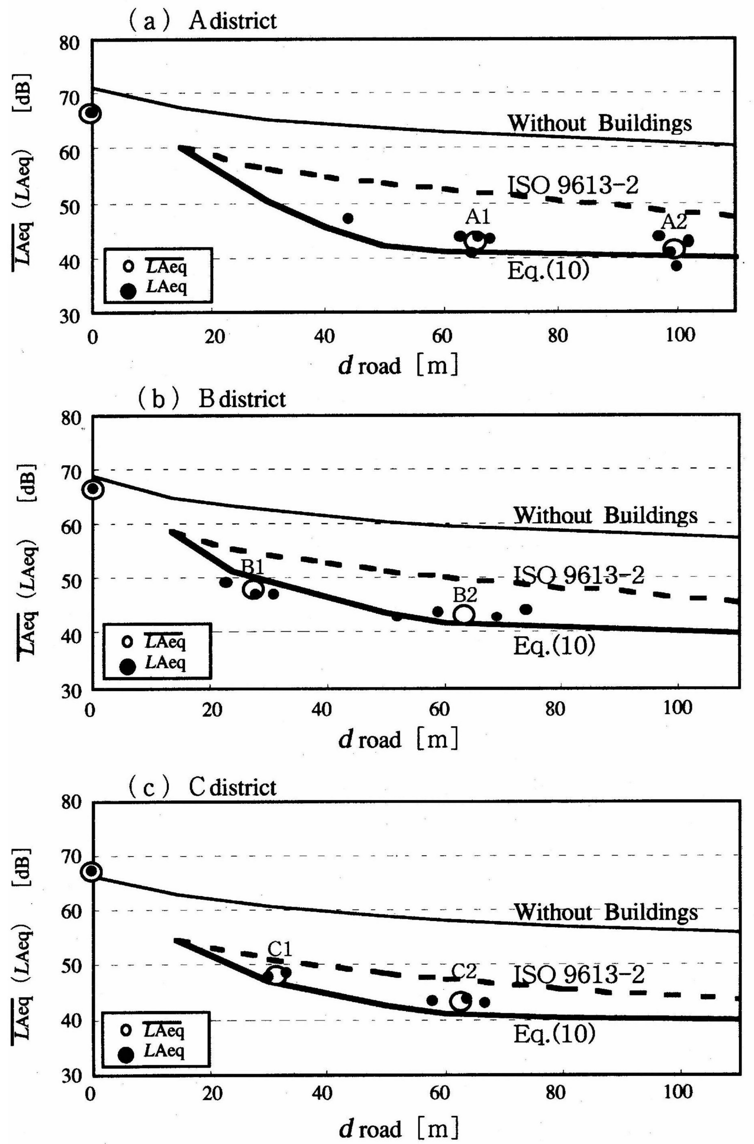

Figure 6: Comparison of calculated and measured values.

5 - DISCUSSION

This paper has described the calculation method for $\overline{L_{Aeq}}$ in built-up areas, facing a road at ground level without noise barriers, where the average heights of FRB and RGB are approximately equal. The use of this method can be extended to the cases of a road on embankment and a viaduct with noise barriers, and to the case where FRB is taller than RGB [10].

This method would also be applicable to the case where the sound source has a different spectrum from that of Japanese vehicles [5], e.g. trains and the other countries' vehicles. In this case, calculations must be done using the center frequencies of 1/3 or 1/1 octave band. Then, ΔL_{SXP}, ΔL_{XYP}, ΔL_{SXY} and ΔL_{SYP} of Eq. (7) can be obtained by the Maekawa's Chart [11], and Eq. (9) is selected to calculate the excess attenuation by RGB.

Future work will be necessary to confirm the accuracy of the prediction method through collection of further measured data in field surveys. It is also required to develop a practical procedure for investigating and setting the prediction parameters such as α and β.

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