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PREDICTION OF ROAD TRAFFIC NOISE AROUND TUNNEL MOUTH

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ABSTRACT
Prediction of road traffic noise in the vicinity of a road tunnel mouth has been one of the most difficult problems. The build-up noise in the tunnel radiates towards outside the mouth. A practical calculation model for this noise radiation is developed in this paper which is based upon a sound energy balance inside the tunnel. Two imaginary sources are assumed. One is a point source that represents a direct sound from a vehicle in the tunnel. The other is a surface source that represents residual sound with multiple reflection between the walls of the tunnel. Results of a sound pressure level (L_{Aeq}) measurements at a highway tunnel show good agreement with an accuracy of less than 2 dB between the calculated and the measured. It is shown that this model is also applicable to road traffic noise around tunnel with a noise control of absorptive treatment on the walls.

1 - INTRODUCTION
In the vicinity of a road tunnel mouth residents receive specific noise with high level and long reverberation time, which often causes an impression of "noisy" and accordingly complaint appears. To avoid this problem before the road construction, it is necessary to predict noise level correctly for a road tunnel with a well-established counter measure against tunnel noise. Several prediction models [1], [2], [3] have been proposed by researchers and engineers from this point of view. However, most of them are not necessarily satisfactory to road traffic noise engineers because some of them are available to a limited situation and the rest of them have the poor precision in predictions. In this paper a new model is presented to predict noise around a tunnel mouth, which is applied to the road traffic noise prediction model "ASJ Model 1998" proposed by Acoustical Society of Japan.

2 - PROPAGATION IN TUNNEL
Now consider a schematic presentation of a semicircular cross section tunnel as shown in Fig. 1, where S denotes a point source, h is the radius of the mouth whose center is O, and x is the distance from S to O. Assuming that the sound power of the point source is P, then the power directly radiated from one side of the tunnel mouths is half the power, i.e.,$P/2$ when the absorption coefficient α of the inside walls is equal to 0 (perfectly reflecting wall). On the other hand when α is equal to 1 (perfectly absorbing wall), then the power directly radiated outside through the mouth depends on only the solid angle Ω (see Fig. 1) and the direct power P_{D} is written by the next formula.

$$P = \frac{P}{2\pi}\Omega = \frac{P}{2}\frac{x}{\sqrt{hx}} \tag{1}$$

Consequently, the direct power radiated from tunnel mouth takes the values between $P/2$ and P_{D} according to the value of α ($0 \leq \alpha \leq 1$). Next consider the total power P_{T} that is radiated from a tunnel mouth. It is approximately given by,

$$P = \frac{P}{2}\frac{ax}{\sqrt{h\ (ax)}} \tag{2}$$

where a is a parameter related to the absorption properties of the inside walls (hereafter it is referred to as absorption parameter) and take the values $a = 0$ for $\alpha = 0$, and $a = 1$ for $\alpha = 1$.

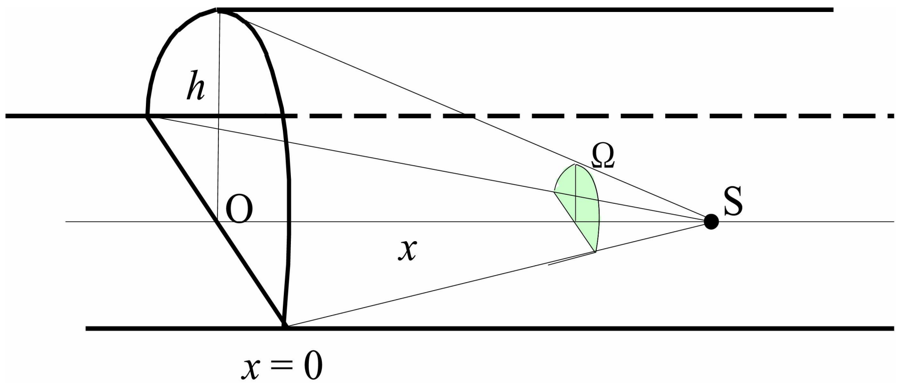

Figure 1: Geometry of a semicircular cross section tunnel.

In the case of a tunnel having a rectangular mouth as shown in Fig. 2, the direct sound power P_{D} is expressed by,

$$P_D = \frac{P}{2\pi}\Omega = \frac{P}{\pi}\tan^{-1}\frac{wh}{\sqrt{x^4 + (w^2 + h^2)\,x^2}} \tag{3}$$

where w is half the width of the tunnel mouth, and h is the height. The total sound power P_{T} is approximated by the next equation.

$$P = \frac{P}{\pi}\tan^{-1}\frac{wh}{\sqrt{(ax)^4 + (w^2 + h^2)\,(ax)^2}} \tag{4}$$

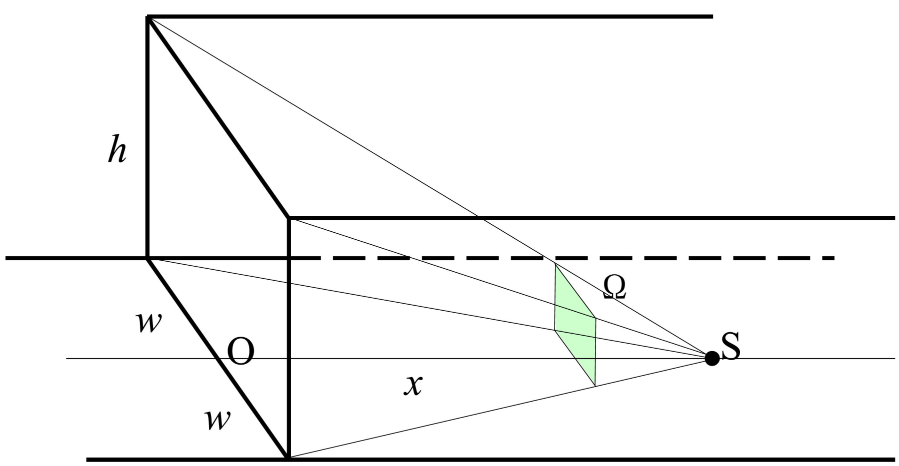

Figure 2: Geometry of a rectangular cross section tunnel.

3 - CALCULATION METHOD [4]

For the help of comprehension of the calculation method, the sound sources assumed and a prediction point are schematically shown in Fig. 3. A-weighted sound pressure level $L_{p\ \mathrm{A}}$ at the prediction point P is given by,

$$L_p = 10\log_{10}\left(10^{L_{\mathrm{TD}}/10} + 10^{L_{\mathrm{TR}}/10}\right) \tag{5}$$

where L_{TD} is a sound pressure level due to the imaginary point source that relates to the direct sound, and L_{TR} is a sound pressure level due to the imaginary surface source that relates to reflected sound.

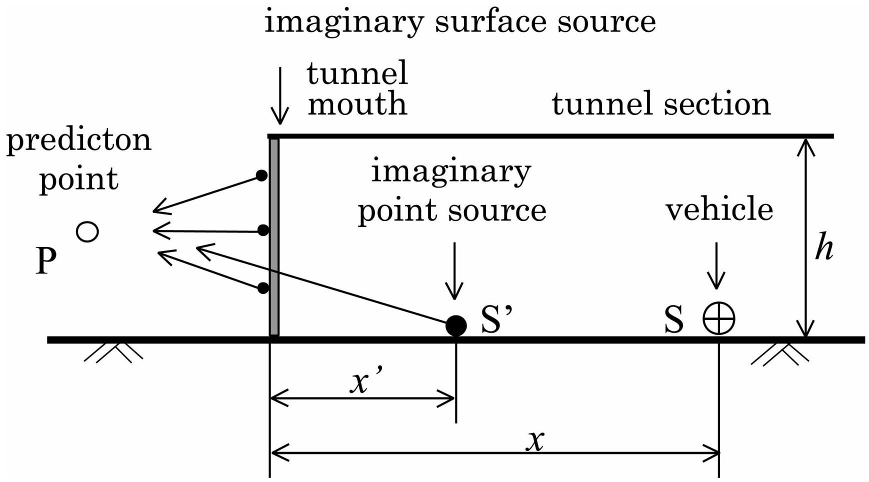

Figure 3: Two imaginary sources and a vehicle in the tunnel.

L_{TD} is given by the next equation based on B-method of ASJ Model 1998 [5],

$$L_{\mathrm{TD}} = L_{W\mathrm{A}} - 8 - 20\mathrm{l\ og}_{10} r + \Delta L_{\mathrm{d}} + \Delta L_{\mathrm{g}} \tag{6}$$

where L_{WA} is the A-weighted sound power level, r is the distance between an imaginary point source and a prediction point, ΔL_{d} is the correction term for diffraction effect and ΔL_{g} is the correction term for ground effect.
The sound power level of imaginary point source is the same as that of the real source. The distance x' from the imaginary point source to tunnel mouth is given by $x'=ax$. When the sound absorption characteristic in the tunnel is different according to the section, a is given by the value weighted on the length of the section and averaged over the total length of the tunnel as is given by,

$$a = (a_1x_1 + a_2x_2 + \cdots + a_nx_n)/x \tag{7}$$

where a_i is the absorption parameter in the ith section, and x_i is the length of the ith section ($x = x_1 + x_2 + \cdots + x_n$).
The location of the imaginary surface source is specified at the mouth of a tunnel. The sound power level L_{WR} of the imaginary surface source is obtained by the subtraction of the direct power from the total power and expressed as follows.

$$L_W = 10\log_{10}\left\{(P - P)/10^{-12}\right\} \tag{8}$$

By dividing the surface source into small elements with equal area and specifying a point source on each element, the sound pressure level L_{TR} at a prediction point is given by the energy summation of contributions from point sources as shown,

$$L = 10\log_{10}\left(\sum_{i=1}^{N} 10^{L_{\mathrm{TR},i}/10}\right) \tag{9}$$

where N is a number of divisions of the surface source, and $L_{\mathrm{TR},i}$ is a contribution from ith point source.

4 - COMPARISON WITH MEASUREMENT VALUE

We measured time history of A-weighted sound pressure level caused by an isolated vehicle passage, which is referred to as unit pattern, and equivalent continuous A-weighted sound pressure level L_{Aeq} around a tunnel mouth. The shape of the tunnel is semicircle in cross-section and the walls inside the tunnel are made of concrete. The open road is bank. Ten measurement points were arranged at outside the tunnel and one was just at the tunnel mouth.

The absorption parameter a is estimated by a curve fitting technique. Figure 4 shows a comparison of unit pattern at the tunnel mouth between a measured data and calculated curves. The curves are obtained by specifying the absorption parameter as 0.03, 0.04 and 0.07. One can see that the inclination of the unit pattern for $a = 0.04$ is the most similar to the measurement value. At the present stage, the absorption parameter $a = 0.04$ is selected for tunnels with concrete wall surfaces, however, we need to collect data for tunnels in various wall types, which is a future work.

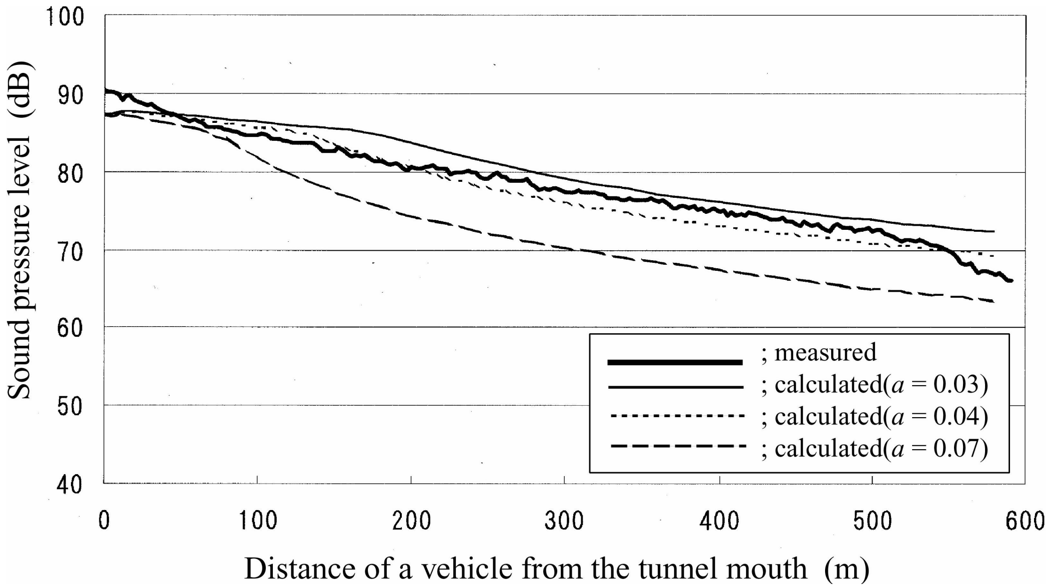

Figure 4: Sound pressure level at tunnel mouth, radiated from a traveling vehicle in the highway tunnel which walls are reflective.

Figure 5 shows the comparison of unit patterns between the measured and the calculated at the receiver positions outside the tunnel, i.e., at the top and the foot of the bank road with a horizontal distance of 38 m from the tunnel mouth. There is a slight difference between the curves of the measured and the calculated, however, a good similarity is obtained for the level pattern that decreases as the distance of a vehicle increases from the mouth in the tunnel.
By following the procedure of the "ASJ Model 1998", values of L_{Aeq} were calculated. The comparison with the measurement value is shown in Fig. 6. The averaged value of difference between the calculation and the measurement is 1.6 dB.

5 - RELATION BETWEEN ABSORPTION PARAMETER AND SOUND ABSORPTION COEFFICIENT

The value of absorption parameter a was obtained by the measurement. However, a physical meaning of a is indefinite. Then, the relation between parameter a and the sound absorption coefficient α was investigated. We compared Eq. (2) with the next equation that is derived from the image source method [3] based on geometrical acoustics strictly,

$$\mathrm{P} = \frac{\mathrm{P}}{2}\left\{1 - \sum_{m=0}^{\infty} \frac{\alpha\,(1-\alpha)^m\,x}{\sqrt{(2m+1)^2\,h^2 + x^2}}\right\} \tag{10}$$

where m is a reflection degree in the inside wall, and the road is assumed to be a complete reflection. We can obtain a value of α corresponding to a from Eq. (2) and Eq. (10), and it is shown in Fig. 7. By assuming the relational equation of $1 - a = (1-\alpha)^t$, and obtained the value of t for matching the data point of Fig. 7, next relation can be obtained.

$$1 - a = (1-\alpha)^{0.48} \approx \sqrt{1-\alpha} \tag{11}$$

6 - CONCLUSION

A simple model has been proposed for the prediction of road traffic noise that is radiated from a tunnel mouth. In developing the model imaginary sources are assumed, which represent the direct sound and

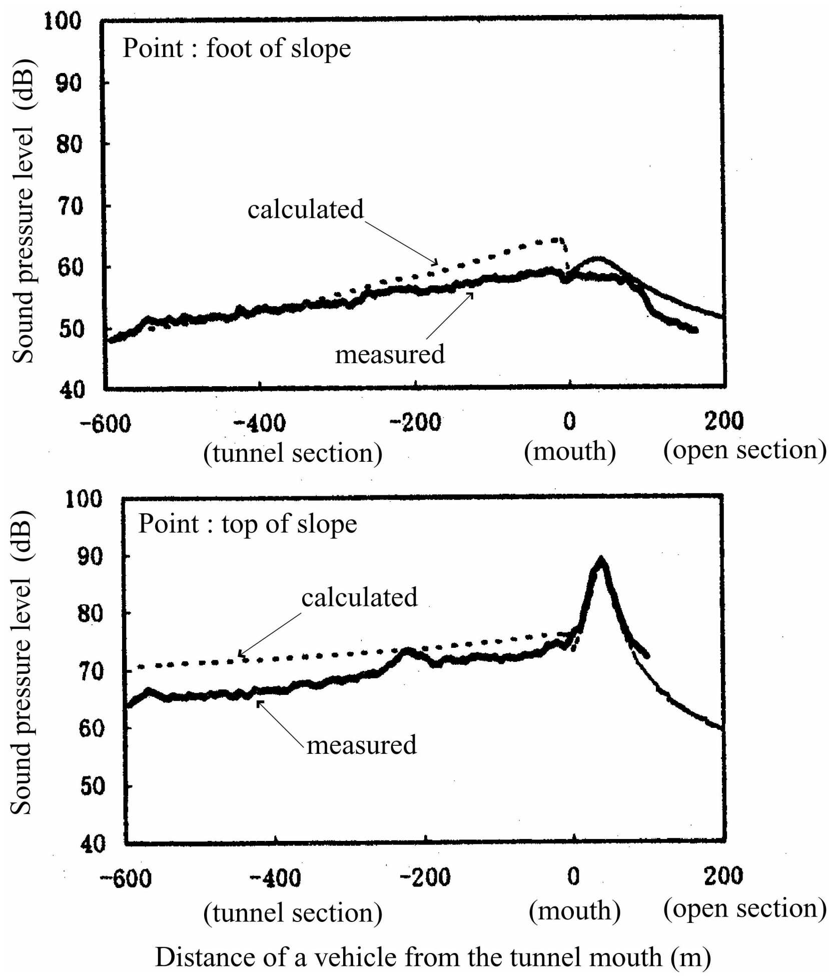

Figure 5: Unit pattern of sound pressure level in the vicinity of tunnel mouth, by a vehicle traveling tunnel and bank road.

the residual reflected sound, while the energy balance of the power is taken into account. An absorption parameter a is introduced to the model, which is related to the absorption property of the tunnel walls. A value of 0.04 is determined as an absorption parameter for concrete wall. A comparison of L_{Aeq} data shows good agreement between the measured and the predicted with an accuracy of less than 2 dB. It is shown that this model is applicable to the control of road traffic noise around road tunnel with an absorption treatment to inside walls.

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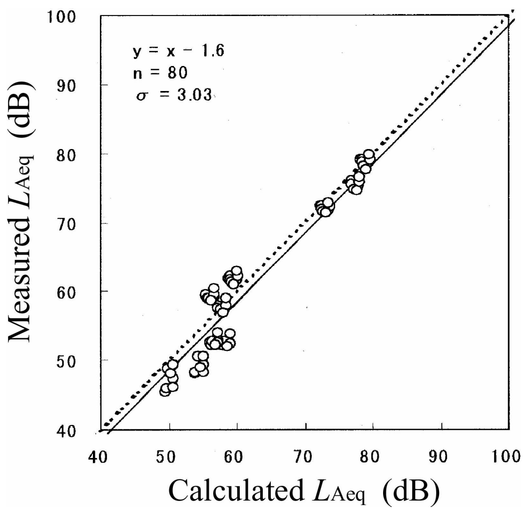

Figure 6: Comparison of the measured L_{Aeq} *and calculated* L_{Aeq}.

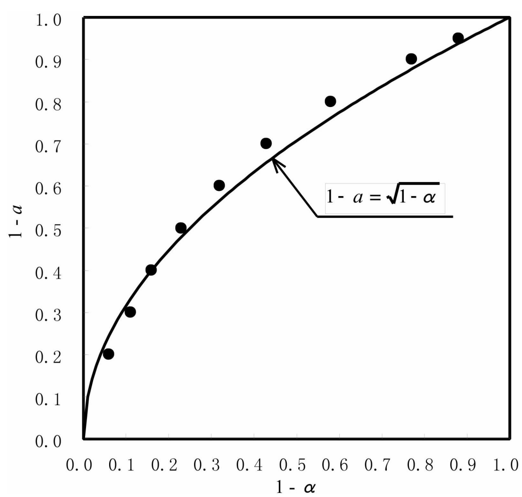

Figure 7: Relation between a and α.