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ROAD TRAFFIC NOISE PREDICTION MODEL 'ASJ MODEL 1998' PROPOSED BY THE ACOUSTICAL SOCIETY OF JAPAN - PART 3: CALCULATION MODEL OF SOUND PROPAGATION

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ABSTRACT
In this paper, one of the significant parts of "ASJ Model 1998", i.e., calculation method for sound propagation is presented. For the factors that affect sound propagation, diffraction, ground effects, meteorological effects, sound reflection are included. The application of the calculation model to roads in various types, such as interchange, semi-underground road, double deck viaduct, road tunnel and road in built-up area is presented. As an additional contribution to road traffic noise, the treatment of structure noise caused by the vibration of viaduct is described.

1 - INTRODUCTION

In developing the calculation model of sound propagation for "ASJ Model 1998" [1], [2], two approaches are basically considered. One is a precise version, denoted by "A-method (precision method)" and it is derived from the wave theory. The other is a simple version, denoted by "B-method (engineering method)" which consists of geometrical acoustics with empirical models. This approach is to separate the propagation factors of road traffic noise prediction into a series of correction terms, each of which has physical significance to road traffic noise engineers. Both methods essentially take sound diffraction and ground effects into consideration, and a vehicle is regarded as a non-directional point source located just on the road surface. The meteorological effects and the treatment of sound reflection from a finite size surface are included. Applications of the calculation model to various roads such as interchange, semi-underground road, double deck viaduct, road tunnel and road in built-up areas are presented. The specific noise that is cased by the vibration of viaduct slob is also described.

2 - OUTLINE OF A-METHOD (PRECISION METHOD)

A-method is based on the theoretical treatment of sound diffraction [3] and that of sound propagation over a finite impedance boundary [4]. The calculation procedure seems rather complicated because complex numbers and special functions are included in the computation. In this method, however, we can deal with cases having an arbitrary noise spectrum and acoustical properties of ground and barrier surfaces.

Basic equation

For a certain position of a source, A-weighted sound pressure level L_{pA} (dB) at a prediction point is calculated by the following equation,

$$L_{pA} = 10 \log_{10} \sum_{i=1}^{n} 10^{L_{pA,i}/10} \tag{1}$$

where $L_{pA,i}$ is the sound pressure level (in A-weighting) at ith frequency. It is expressed by the next equation,

$$L_{pA,i} = L_{WA,i} - 8 - 20 \log_{10} r + 10 \log_{10} \left| \frac{\phi_i}{\phi_{g,i}} \right|^2 \tag{2}$$

where

- $L_{wA,i}$: sound power level (in A-weighting) of a source at ith frequency (dB),
- r: distance between a source and a prediction point (m),
- ϕ_i and $\phi_{g,i}$: complex quantities of sound pressure at ith frequency for the field that includes sound diffraction and reflection and for free field, respectively.

The frequency range to be considered is from 63 Hz to 4 kHz and the center frequencies of 1/1 octave band within this range are used in this calculation.

Equations for diffraction and ground effects

We use the next equation for the complex quantity of sound pressure at a distance of r from a point source in free field:

$$\phi_g = \frac{e^{ikr}}{r} \tag{3}$$

By using this expression, we can express the total sound pressure as the sum of contributions corresponding to sound path at geometry of a source and receiver.

$$\phi = \phi_1 + \phi_2 + \cdots + \phi_n = \sum_{j=1}^{n} \phi_j \tag{4}$$

where

$$\phi_j = Q_j \cdot D_j \cdot \frac{e^{ikr_j}}{r_j} \tag{5}$$

The terms Q and D in Eq. (5) are complex reflection coefficient and diffraction coefficient, respectively.

Diffraction coefficient (D): The theoretical method for the sound diffraction is based on the asymptotic solution that was formulated by Kouyoumjian [3].

Complex reflection coefficient (Q): The complex reflection coefficient Q is determined by Kawai's method [4]. Types of ground are classified by the effective ground flow resistivity σ_e (Pa s/m^2), i.e., 75×10^3, 300×10^3 and 1250×10^3.

3 - OUTLINE OF B-METHOD (ENGINEERING METHOD)

B-method is derived from an experimental basis of sound propagation with a representative spectrum of vehicle noise. A-weighted sound pressure levels are directly obtained from the calculation procedure. This equation is formulated by a simple expression that includes inverse square law and correction terms for diffraction and ground effects. The correction term for diffraction is obtained by Maekawa's chart [5] and representative spectrum of road traffic noise [2]. An empirical model [6] that was obtained from numerical simulation of a theoretical sound propagation gives the term for ground effect.

Basic equation

A-weighted sound pressure level L_{pA} (dB) is given by the next equation:

$$L_{p\mathrm{A}} = L_{W\mathrm{A}} - 8 - 20\,\log_{10} r + \Delta L_d + \Delta L_g \tag{6}$$

where $L_{W\mathrm{A}}$ is A-weighted sound power level, ΔL_d and ΔL_g are the correction terms of diffraction and ground effect, respectively.

<u>The correction term for diffraction effect</u> (ΔL_d)

A road shoulder or a noise-shielding barrier provides diffraction effect. The correction term is given by the numerical expression shown as follows:

$$\Delta L_d = \begin{cases} -20 - 10\,\log_{10}(\delta)\,, & \text{for } \delta \geq 1 \\ -5 \pm \dfrac{-15}{\ln\left(1+\sqrt{2}\right)} \cdot \sinh^{-1}\left(|\delta|^{0.414}\right), & \text{for } -0.0537 \leq \delta < 1 \\ 0, & \text{else} \end{cases} \tag{7}$$

The symbol δ denotes the path length difference that is defined as the difference between a direct path to a prediction point and a diffracted path over the top of a diffraction edge. Plus and minus signs in Eq. (7) are used for $\delta>0$ and $\delta<0$, respectively. The plus sign in δ is given for a receiver in a barrier shadow zone.

<u>The correction term for ground effect</u> (ΔL_g)

Sound that propagates along a ground surface receives attenuation over inverse square law. It depends upon the ground impedance, heights of source and receiver above the ground. In B-method, the correction term is expressed by,

$$\Delta L_\mathrm{g} = \sum_{i=1}^{n} \Delta L_{\mathrm{g},i} \tag{8}$$

where $\Delta L_{g,i}$ is the correction for the ith ground and is given by the next empirical equation:

$$\Delta L_{g,i} = \begin{cases} -K_i \log_{10}\left(\dfrac{r_i}{r_{0,i}}\right), & \text{for } r_i \geq r_{\mathrm{o},i} \\ 0, & \text{else} \end{cases}$$

The symbol K is a coefficient that characterizes the attenuation rate per doubling of distance, r is distance, and r_o is a specific distance where the ground effect starts to increase. K and r_o are given by numerical expressions [6] for three types of absorptive ground.

4 - AIR ABSORPTION AND WIND EFFECTS

Correction terms due to air absorption $\Delta L_{\mathrm{A,air}}(r)$ and wind effects $\Delta L_{\mathrm{m},\ell\mathrm{ine}}$ are included in "ASJ Model 1998". The former is specified on the basis of the standard atmospheric condition (*temperature* 20°C, *humidity* 60 %) and given by the next expression,

$$\Delta L_{\mathrm{A,air}}(r) = -0.3452\,(r/1000)^3 - 2.011\,(r/1000)^2 - 6.840\,(r/1000) \tag{10}$$

The latter is expressed by an empirical model based on field data, as shown,

$$\Delta L_{m,\ell ine} = 0.88 \cdot U_{\mathrm{vec}} \cdot \log_{10}(\ell/15)\,, \quad \text{for} \quad \ell > 15 \tag{11}$$

where U_{vec} is vector wind (m/s) and ℓ is horizontal distance (m) from a road. This term is applied to correct the finial values of $L_{\mathrm{Aeq},T}$.

5 - MULTI-EDGE DIFFRACTION

Embankments, hills, rows of buildings and etc. may sometimes form a geometrical configuration of multi-edge diffraction. For double diffraction as shown in Fig. 1, the correction term $\Delta L_{\mathrm{d,dd}}$ is simply expressed by the next formula [7],

$$\Delta L_{\mathrm{d,dd}} = \begin{cases} \Delta L_{SXP}, & \text{for zone I and II} \\ \Delta L_{SYP} + \Delta L_{SXY} + 5, & \text{for zone III} \end{cases} \tag{12}$$

where ΔL is a correction term due to single diffraction and the suffix of each term denotes the sound path. The second equation of Eq. (12) is expressed in a single diffraction term (ΔL_{SYP}) and an adjustment of the shielding effect due to the width of an acoustical obstacle (ΔL_{SXY}). By applying the same concept, the correction to multi-edge diffraction is obtained in the same way as in Eq. (12).

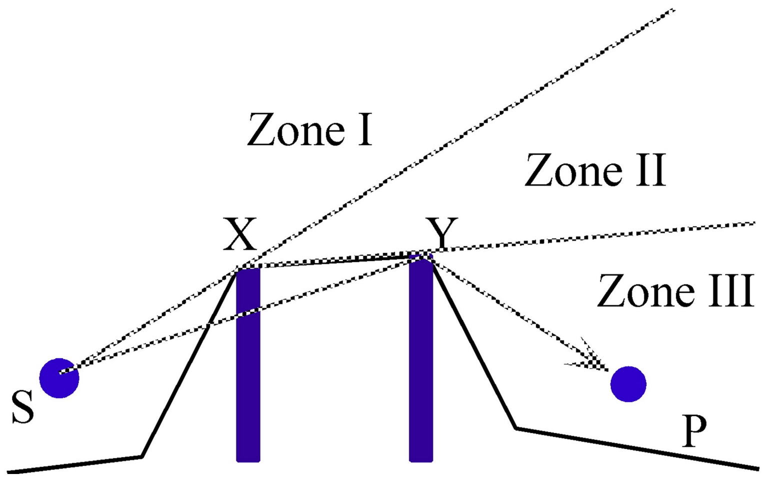

Figure 1: Double diffraction by a bank.

6 - TREATMENT OF REFLECTION FROM FINITE SIZE SURFACE

Noise barriers, retaining walls, buildings and etc. are usually shielding obstacles against noise, but also they sometimes become significant sound reflection objects. In the procedure of noise calculation, the treatment of specular reflection is employed, however, the size of the reflection surface is considered. As is shown in Fig. 2, the reflected wave from a finite size surface (a stripe of wall) is regarded as the transmitted wave through the slit that has the same size as the reflection wall. Since the transmitted sound wave is affected by the diffraction of edge X and Y, the correction due to slit diffraction $\Delta L_{\mathrm{d,slit}}$ is specified as,

$$\Delta L_{\mathrm{d,slit}} = 10\log_{10}\left|10^{\Delta L_{S'XP}/10} - 10^{\Delta L_{S'YP}/10}\right| \tag{13}$$

where ΔL is a correction term due to single diffraction and the suffix denotes the path. On calculation the barrier direction must be specified to downward from the edge position i.e., X and Y, when the distance $\overline{S'XP}$ is greater than $\overline{S'YP}$. If $\overline{S'XP}$ is less than $\overline{S'YP}$, the barrier should be considered as upside down. Equation 13 is derived on the assumption that Babinet principle holds in sound field described by geometrical acoustics.

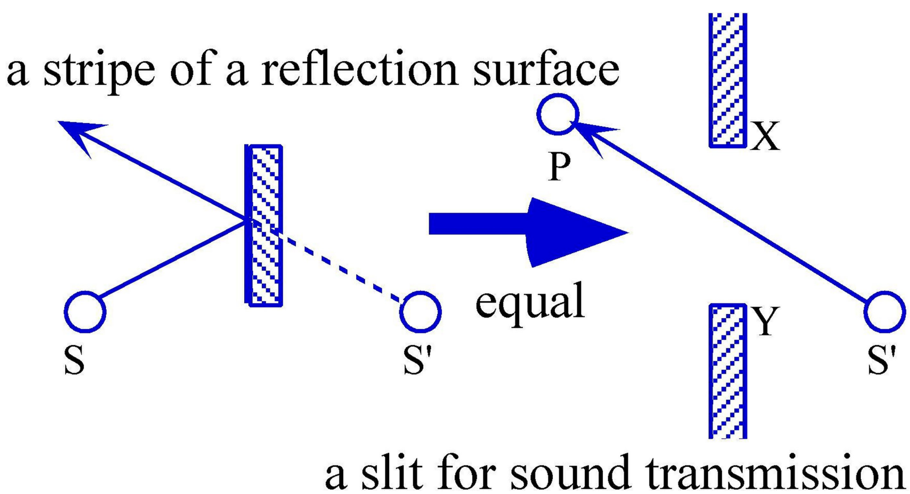

Figure 2: Reflection from a stripe of wall.

7 - APPLICATION TO ROAD IN VARIOUS TYPE

The "ASJ Model 1998" essentially covers the procedures of noise prediction for roads in all types. Here is some more information that is provided in the calculation stages.

7.1 - Interchange

Interchange section includes ramp, toll gate, fork and junction. Consequently, geometrical configuration and traffic flow are really complex. In particular, speed of vehicles is not constant in this section and thereby sound power level is variable with regard to the speed in operation. The "ASJ Model 1998" provides acceleration and deceleration of speed of vehicles as shown in Table 1 and one must calculate speed profile at interchange section in a programming step. There is one more information for service time at a gate if it is a toll road, as shown in Table 2.

	light vehicles	heavy vehicles
at acceleration (m s^{-2})	0.7	0.6
at deceleration (m s^{-2})	-1.0	-0.8

Table 1: Acceleration and deceleration of speed of vehicles.

for receiving a card at an entrance (s)	6
for toll collection by cash at an exit (s)	14
for toll collection by ticket at an entrance (s)	8

Table 2: Service time at tollgate.

7.2 - Depressed road & semi-underground road

For the noise mitigation strategy, depressed road and semi-underground road (the same as depressed road but it has overhang portion supported at the top edge) are coming into use nowadays in the suburbs. The problems in prediction are the treatment of multiple sound reflection between the retained walls. In programming, mirror sources must be specified in the walls and the contributions of these mirrors are calculated as the transmitted sound through the walls. The contribution of ith mirror is expressed by the next formula,

$$L_{p\mathrm{A},i} = L_{W\mathrm{A}} - 8 - 20\,\log_{10} r_i + \Delta L_{\mathrm{d},i} + \Delta L_{\mathrm{d,s\ell it},i} + \Delta L_{\mathrm{g},i} \qquad (14)$$

where $\Delta L_{\mathrm{d,s\ell it},i}$ is the correction due to slit diffraction effect. The slit corresponds to the stripe of the wall. Total sound pressure level is computed by the energy summing of the contributions from real source and mirror sources.

7.3 - Road tunnel

Road tunnel is sometimes regarded as a good abatement measure against road traffic noise, but sometimes it causes serious noise problem when residences are located close to the tunnel mouth. The "ASJ Model 1998" includes the procedure of noise calculation from tunnel mouth and the details will be presented [8] in this conference by one of the present authors. In modeling, 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 in the tunnel. The model is developed on the basis of sound energy balance inside the tunnel. This model is applicable to road traffic noise around tunnel with a noise control of absorptive treatment on the walls.

7.4 - Reflection from overhead road way and double deck viaduct

The "ASJ Model 1998" provides calculation procedure of noise reflection from the underside of an overhead roadway and a double deck viaduct. The influence of reflection causes build-up of noise to the side areas when noise barrier is applied to the lower road. There are three types of viaduct structure, i.e., structures supported on I girder, box girder and flat girder. The treatment of sound reflection depends upon the roughness of the reflection surface, however all situation is treated as specular reflection instead of scattered reflection for simplicity. In calculation three sound paths must be considered; 1) direct path, 2) reflection path from the underside of viaduct, 3) reflection path through the underside of viaduct and then through ground. The expression for reflected sound is the same as Eq. (14).

8 - STRUCTURE NOISE OF VIADUCT

At the passage of vehicles on viaduct, mechanical vibrations of the road structure are generated. The vibrations of the slob and the girder produce noise in audible frequency, and the noise propagates to the side areas. The noise is called structure noise of viaduct and is included in the present model. When a tall barrier is installed on a viaduct, it sometimes becomes predominant component of road traffic noise measured on the ground level. However the intensity depends upon the quality of road structure. The present model includes the calculation procedure, but it is limited to the case for the passage of heavy vehicles at the speed over 60 km/h, and the calculation range is within a horizontal distance of 50 m from the road shoulder below the slob level. Assuming that a moving point source on the underside of the viaduct, A-weighted sound pressure level $L_{pA,\mathrm{str}}$ is simply given by the next basic equation,

$$L_{pA,\mathrm{str}} = L_{WA,\mathrm{str}} - 8 - 20\log_{10} r \tag{15}$$

where $L_{WA,\mathrm{str}}$ is A-weighted sound power level of structure noise. Although, there are still lots of future work for developing the model, the power level of 95.3 (dB) is specified at the present stage for both concrete and metal structure viaducts.

9 - BUILT-UP AREA

Buildings shield the sight of noise sources and hence produce noise attenuation behind them. They also reflect incident noise at the facade and provide build-up of noise in front of them. The calculation procedure of the present model predicts those influences. However, if the density is high and they form a built-up area, the combined influence of scattering, reflection and diffraction affects sound propagation in the area. In this case, the "ASJ Model 1998" provides a method for estimating sectional energy-averaged level $\overline{L_{\mathrm{Aeq},T}}$ and calculated by the next formula,

$$\overline{L_{\mathrm{Aeq},T}} = L_{\mathrm{Aeq},T} + \overline{\Delta L_{\mathrm{builds}}} \tag{16}$$

where $L_{\mathrm{Aeq},T}$ is the predicted value without buildings and $\overline{\Delta L_{\mathrm{builds.}}}$ is the correction term due to buildings. The correction is expressed as a function of the density of buildings located between road and prediction point. The details are given by one of the present authors [9].

10 - CONCLUDING REMARKS

The outline of methods for predicting road traffic noise propagation is presented in this part 3. A-method is available to both research works of noise abatement measures and noise assessment. It is also applicable to the prediction of sound propagation from any type of transportation system. B-method is useful to road traffic noise simulation in a practical stage. Both methods are being revised for practical application to roadways where the sound propagation is more complicated than the present situation.

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