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Road Traffic Noise Prediction Model "ASJ RTN-Model 2018" Proposed by The Acoustical Society of Japan – Part 3: Calculation model of sound propagation

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ABSTRACT

As the third part of "ASJ RTN-Model 2018", calculation model of sound propagation is presented. This model is basically developed as a practical calculation model based on Geometrical Acoustics. The calculation equations in this model are defined on the basis of experimental or numerical analysis data. The overall values of the A-weighted sound pressure level of noise propagating from a vehicle are directly calculated by considering the frequency characteristics of vehicle noise. This calculation model consists of shielding effects by several type barriers, excess attenuation due to ground surface, atmospheric absorption effect, sound reflection and meteorological effect. Based on newly obtained knowledge, several improvements were made on the calculation method to develop the model.

Keywords: Road Traffic Noise, Prediction Model, ASJ RTN-Model 2018, Sound Propagation

1. INTRODUCTION

The calculation method of sound propagation in the road traffic noise prediction model "ASJ RTN-Model 2018" is an engineering one for calculating "the unit pattern", a time history of A-weighted sound pressure level L_A for a driving vehicle. This method is based on sound propagation in hemi-free space and various attenuations such as diffraction effect and ground effect are corrected, and the L_A as the summation of all frequency components is directly obtained. The calculation method of sound propagation has been updated every five years by modifying the previous model based on newly obtained knowledge since "ASJ Model 1998" [1] had been published at 1999.

In this version of the model, several components of calculation method of sound propagation are modified from and newly added to the previous version [2]. As for the diffraction effect, values of the parameters to calculate sound diffraction of vehicle noise were improved or newly added under consideration of sound source characteristics of recent road traffic noise. The calculation method for diffraction effects at a wedge with an opening angle as seen in a building and an embankment was newly added, and the effects for thick barrier or overhung barrier were modified based on the results of the wave-based numerical analysis. As for the ground effect, treatment of porous asphalt pavement was newly added based on measurement results.

2. BASIC EQUATIONS OF SOUND PROPAGATION

Considering attenuation due to various factors in the sound propagation from an point source set on a center of driving lane, the A-weighted sound pressure level $L_{A,i}$ [dB] for vehicle noise propagating from the i th source S_i to the prediction point P is calculated as follows:

$$L_{A,i} = L_{WA,i} - 8 - 20\lg r_i + \Delta L_{cor,i} \tag{1}$$

where $L_{WA,i}$ is the A-weighted sound power level of the source S_i [dB] and r_i is the distance from S_i to P [m]. $\Delta L_{cor,i}$ denotes the correction related to various attenuation factors in the sound propagation

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from S_i to P [dB] and is given by

$$\Delta L_{\mathrm{cor},i} = \Delta L_{\mathrm{dif},i} + \Delta L_{\mathrm{grnd},i} + \Delta L_{\mathrm{air},i} \tag{2}$$

where $\Delta L_{\mathrm{dif},i}$ is the correction term for diffraction [dB], $\Delta L_{\mathrm{grnd},i}$ is the correction term for the ground effect [dB] and $\Delta L_{\mathrm{air},i}$ is the correction term for atmospheric absorption [dB].

3. Correction for Diffraction ΔL_{dif}

Correction terms for various types of diffraction are listed in Table 1. The correction for diffraction due to acoustical obstacles, ΔL_{dif}, is calculated using fundamental correction term $\Delta L_{\mathrm{d,k}}$ or $\Delta L_{\mathrm{d,r}}$ [dB] as a function of the diffraction path difference δ [m]. In this version of the ASJ RTN-Model, two fundamental correction terms, $\Delta L_{\mathrm{d,k}}$ and $\Delta L_{\mathrm{d,r}}$, are introduced. $\Delta L_{\mathrm{d,k}}$ is applied for diffraction around a knife wedge such as a barrier, and it was determined from Maekawa's chart for diffraction [3,4] and the frequency characteristics of the recent road traffic noise. $\Delta L_{\mathrm{d,r}}$ is another fundamental correction term for diffraction around wedge with an opening angle which is applied to a building or an embankment road, and is newly added based on the results by numerical analysis [5]. Note that the symbol ΔL_{dif} is a generic term used to represent the correction terms in Table 1. When the shielding effect of acoustical obstacles exceeds approximately 30 dB, it may not be so large as to be indicated by the calculated values because of the influence of actual wind conditions.

3.1 Fundamental correction term for diffraction, $\Delta L_{\mathrm{d,k}}$ and $\Delta L_{\mathrm{d,r}}$

The fundamental correction terms for diffraction $\Delta L_{\mathrm{d,k}}$ and $\Delta L_{\mathrm{d,r}}$ are calculated as a function of the path difference δ [m] shown in Figure 1 for diffraction considering the point source S, the prediction point P and the diffraction point O:

$$\Delta L_{\mathrm{d,k}} = \begin{cases} -20 - 10\lg(c_{\mathrm{spec}}\delta) & c_{\mathrm{spec}}\delta \ge 1 \\ -5 - 17.0 \cdot \sinh^{-1}\left(c_{\mathrm{spec}}\delta\right)^{0.415} & 0 \le c_{\mathrm{spec}}\delta < 1 \\ \min\left[0, -5 + 17.0 \cdot \sinh^{-1}\left(c_{\mathrm{spec}}\left|\delta\right|\right)^{0.415}\right] & c_{\mathrm{spec}}\delta < 0 \end{cases} \tag{3}$$

$$\Delta L_{\mathrm{d,r}} = \begin{cases} -17.5 - 10\lg(c_{\mathrm{spec}}\delta) & c_{\mathrm{spec}}\delta \ge 1 \\ -2.5 - 17.0 \cdot \sinh^{-1}\left(c_{\mathrm{spec}}\delta\right)^{0.415} & 0 \le c_{\mathrm{spec}}\delta < 1 \\ \min\left[0, -2.5 + 17.0 \cdot \sinh^{-1}\left(c_{\mathrm{spec}}\left|\delta\right|\right)^{0.415}\right] & c_{\mathrm{spec}}\delta < 0 \end{cases} \tag{4}$$

where the path difference δ is defined as a negative value when S is visible from P. The function min[a,b] in the Eqs.(3),(4) gives the smallest value of a and b. The coefficient c_{spec} is defined as shown in Table 2. $\Delta L_{\mathrm{d,k}}$ and $\Delta L_{\mathrm{d,r}}$ are illustrated in Figure 2 as a function of δ.

Table 1 – Symbols of correction terms for various types of diffraction.

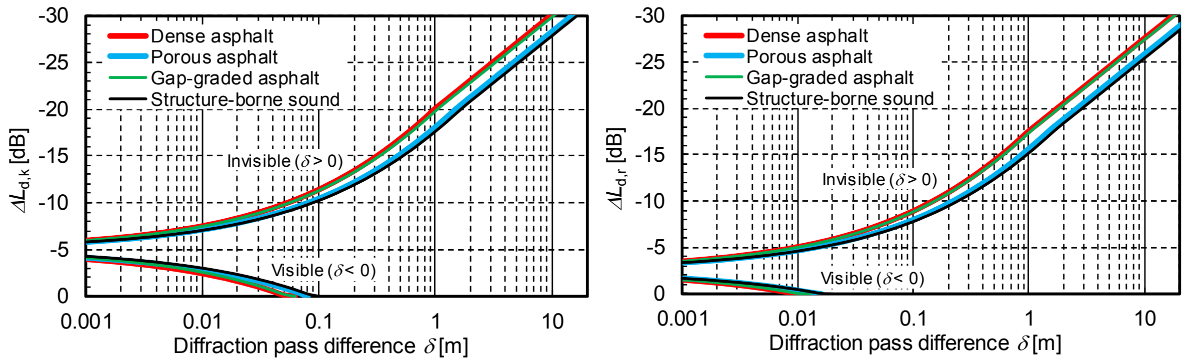
Purpose	Symbol	Summary
Fundamental term		Fundamental term for various types of diffraction
	$\Delta L_{\mathrm{d,k}}$	for a knife wedge
	$\Delta L_{\mathrm{d,r}}$	for a wedge with an opening angle
Simple barrier (Single diffraction)	$\Delta L_{\mathrm{dif,sb}}$	Single diffraction around a simple barrier considering an infinite half-screen
	$C_{\mathrm{dif,abs}}$	Absorption effect of the standard metallic absorptive- type barrier
Embankment	$\Delta L_{\mathrm{dif,rw}}$	Single diffraction at an edge of a shoulder on an embankment road
Double barriers	$\Delta L_{\mathrm{dif,db}}$	Double diffractions due to double barriers
Thick barrier	$\Delta L_{\mathrm{dif,tb}}$	Double diffractions around a thick barrier, including an embankment or a building
Barrier with overhang (Overhung barrier)	$\Delta L_{\mathrm{dif,ob}}$	Diffractions around a barrier with an overhang
	$C_{\mathrm{dif,ob}}$	Overhang effect (Additional correction term by an overhung barrier)
Edge-modified barrier	$\Delta L_{\mathrm{dif,emb}}$	Diffraction around a barrier with acoustic device on the top edge to reduce diffracted sound
	$\Delta L_{\mathrm{dif,hb}}$	Diffraction around a hypothetical simple barrier
	$C_{\mathrm{dif,emb}}$	Additional correction term by edge-modified barrier
Low-height barrier	$\Delta L_{\mathrm{dif,low}}$	Single diffraction around a low-height barrier with a height of 1 m or less in a flat terrain
Transmission through barrier	$\Delta L_{\mathrm{dif,trans}}$	Summation of diffraction over a barrier and transmission through a barrier

(a) For S invisible from P, $\delta = L - R$ (b) For S visible from P, $\delta = -(L - R)$

Figure 1 – Direct path R = SP, diffraction path L = SO + OP and path difference δ.

Table 2 – Coefficient c_{spec} values

Classification of noise		c_{spec}
Noise from running vehicles	Dense asphalt pavement	1.00
	Porous asphalt pavement	0.75
	Gap-graded asphalt pavement	0.96
Structure-borne noise from viaducts (Independent of viaduct type)		0.60



(a). $\Delta L_{d,k}$ for knife wedge (b). $\Delta L_{d,r}$ for wedge with an opening angle

Figure 2 – Fundamental correction term$\Delta L_{d,k}$ and $\Delta L_{d,r}$ as a function of path difference δ.

3.2 Single diffraction

3.2.1 Simple barrier, $\Delta L_{dif,sb}$

The correction term $\Delta L_{dif,sb}$ for diffraction around a simple barrier [dB] is calculated as follows:

$$\Delta L_{dif,sb} = \begin{cases} \Delta L_{d,k} & \text{except for standard metallic absorptive-type barrier} \\ \Delta L_{d,k} + C_{dif,abs} & \text{standard metallic absorptive-type barrier} \end{cases} \quad (5)$$

where $C_{dif,abs}$ is the correction term for the absorption effect of the standard metallic absorptive-type barrier [dB] and is calculated as [6]:

$$C_{dif,abs} = \begin{cases} -0.5\lg(1+20\delta) & \delta > 0 \\ 0 & \delta \le 0 \end{cases} \quad (6)$$

In order to calculate L_{Aeq} at a prediction point around a barrier with a finite length, the "one-path" method considering only the diffraction at the top edge of the barrier can be available. If a line segment SP from S to P crosses a finite barrier in a plan view, ΔL_{dif} is calculated using Eq.(5). If not, the propagation from S to P is calculated for a terrain without a barrier.

3.2.2 Diffraction at wedge with opening angle, $\Delta L_{dif,rw}$

The correction term $\Delta L_{dif,rw}$ for single diffraction around wedge with an opening angle such as an edge of shoulder on an embankment road [dB] is calculated as follows:

$$\Delta L_{dif,rw} = \Delta L_{d,r} \quad (7)$$

3.3 Double diffractions

3.3.1 Double barriers, $\Delta L_{dif,db}$

The correction term $\Delta L_{dif,db}$ for the diffraction around a pair of barriers [dB] with a spacing of 5 m or more, shown in Figure 3, is calculated as follows [7]:

$$\Delta L_{\mathrm{dif,db}} = \begin{cases} \Delta L_{\mathrm{SXP,k}} + \Delta L_{\mathrm{XYP,k}} & \delta_{\mathrm{SXP}} \geq \delta_{\mathrm{SYP}} \\ \Delta L_{\mathrm{SYP,k}} + \Delta L_{\mathrm{SXY,k}} & \delta_{\mathrm{SXP}} < \delta_{\mathrm{SYP}} \end{cases} \tag{8}$$

where $\Delta L_{\mathrm{ABC,k}}$ is $\Delta L_{\mathrm{d,k}}$ for the diffraction path ABC with the path difference δ_{ABC}.

Even if the two barriers are not parallel, $\Delta L_{\mathrm{dif,db}}$ is calculated by Eq.(8) using the coordinates of each diffraction point on the shortest propagation path [8]. As the attenuation due to shielding by double barriers increases, lower frequency components are more dominant as compared with single barrier. Therefore, when $\Delta L_{\mathrm{dif,db}}$ calculated by Eq.(8) becomes approximately -30 dB or less, the calculation error becomes large.

3.3.2 Thick barrier, $\Delta L_{\mathrm{dif,tb}}$

The correction term $\Delta L_{\mathrm{dif,dd}}$ for the double diffraction around an acoustical obstacle such as an embankment or a building [dB], shown in Figure 4, is calculated as follows [5,9]:

$$\Delta L_{\mathrm{dif,tb}} = \begin{cases} \Delta L_{\mathrm{SXP,r}} + \Delta L_{\mathrm{XYP,r}} & \delta_{\mathrm{SXP}} \geq \delta_{\mathrm{SYP}} \\ \Delta L_{\mathrm{SYP,r}} + \Delta L_{\mathrm{SXY,r}} & \delta_{\mathrm{SXP}} < \delta_{\mathrm{SYP}} \end{cases} \tag{9}$$

where $\Delta L_{\mathrm{ABC,r}}$ is $\Delta L_{\mathrm{d,r}}$ for the diffraction path ABC with the path difference δ_{ABC}. Even behind a thick barrier, low frequency components become dominant as compared with a single barrier.

3.3.3 Overhung barrier, $\Delta L_{\mathrm{dif,ob}}$

The shielding effect of the overhung barrier is generally larger than that of a hypothetical thick barrier with the same diffraction point as the overhung barrier. Furthermore, the additional shielding effects depend on the type of the overhung barrier and frequency. In this model, calculation formula of the additional shielding effect was determined based on the results of the numerical analysis in which the shielding effects of overhung barriers in A-weighted overall level for road traffic noise were obtained.

The correction term $\Delta L_{\mathrm{dif,ob}}$ for the diffraction around a overhung barrier [dB], shown in Figure 5, is calculated by the following equations [10]:

$$\Delta L_{\mathrm{dif,ob}} = \Delta L_{\mathrm{dif,tb}} + C_{\mathrm{dif,ob}} \tag{10}$$

$$C_{\mathrm{dif,ob}} = A\left\{\left(\frac{B}{B - \Delta L_{\mathrm{dif,tb}}}\right)^{C} - 1\right\} \tag{11}$$

where $\Delta L_{\mathrm{dif,tb}}$ is the correction term for the hypothetical thick barrier approximated as obstacle with diffraction points X and Y using Eq.(9). $C_{\mathrm{dif,ob}}$ is the correction term for the overhang effect [dB] determined by the difference between the A-weighted sound pressure level behind the overhung barrier and that behind the thick barrier. The coefficients A, B, and C are listed in Table 3.

3.4 Edge-modified barrier, $\Delta L_{\mathrm{dif,emb}}$

The calculation method of the correction term $\Delta L_{\mathrm{dif,emb}}$ for the diffraction around an edge-modified barrier [dB] follows the method of "ASJ RTN-Model 2013", and $\Delta L_{\mathrm{dif,emb}}$ is given as the summation of shielding effect for hypothetical simple barrier and device-dependent efficiency of edge-modified barrier, as follows:

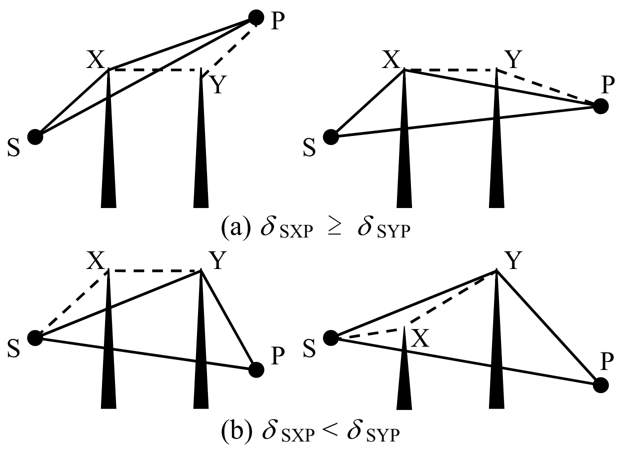


Figure 3 – Calculation of diffraction around double barriers.

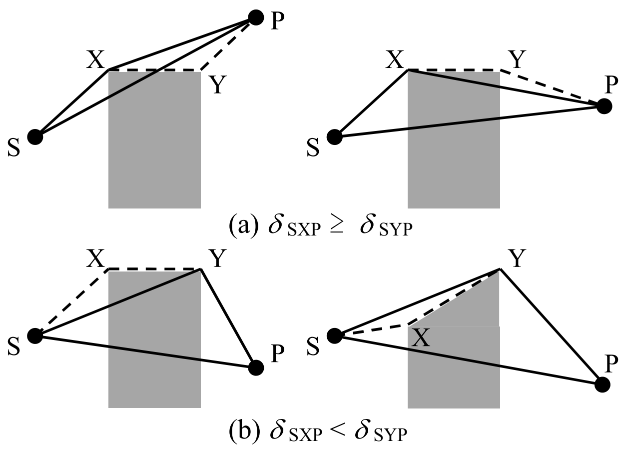


Figure 4 – Calculation of diffraction around thick barrier.

$$\Delta L_{\mathrm{dif,emb}} = \Delta L_{\mathrm{dif,hb}} + C_{\mathrm{dif,emb}} \qquad (12)$$

where $\Delta L_{\mathrm{dif,hb}}$ is the correction term $\Delta L_{\mathrm{dif,sb}}$ for single diffraction by the hypothetical simple barrier [dB] shown in Figure 6, and $C_{\mathrm{dif,emb}}$ is the device-dependent efficiency of edge-modified barrier [dB]. The edge of hypothetical barrier corresponds to the intersection of the two straight lines SO and PO in Figure 6, which are the line through the point source and the source-side edge of the edge-modified barrier, and the line through the prediction point and the receiver-side edge, respectively.

3.5 Low-height barrier, $\Delta L_{\mathrm{dif,low}}$

The calculation method of the correction term $\Delta L_{\mathrm{dif,low}}$ for the diffraction around a barrier with a height of 1 m or less [dB] follows the method of "ASJ RTN-Model 2013", and $\Delta L_{\mathrm{dif,low}}$ is given as the insertion loss of the barrier:

$$\Delta L_{\mathrm{dif,low}} = \Delta L_{\mathrm{d,k,1}} - \Delta L_{\mathrm{d,k,0}} \qquad (13)$$

where $\Delta L_{\mathrm{d,k,1}}$ and $\Delta L_{\mathrm{d,k,0}}$ are $\Delta L_{\mathrm{d,k}}$ for O_1 (an edge of the barrier) and O_0 (an intersection of the barrier and the ground) shown in Figure 7, respectively.

3.6 Transmission through barrier, $\Delta L_{\mathrm{dif,trans}}$

The correction term $\Delta L_{\mathrm{dif,trans}}$ for the transmission [dB] is obtained as a function of the diffracted sound, the sound energy through the hypothetic opening corresponding to the width of the barrier, and the sound transmission loss of the barrier considering the A-weighted spectra of road traffic noise.

4. Correction for Ground Effect, ΔL_{grnd}

4.1 Fundamental correction term for ground effect, ΔL_{g}

The sound wave propagating above a ground with a finite impedance is attenuated due to the interference of the direct wave and the reflected one on ground surfaces. The ground effect by the interference is calculated using the fundamental correction term ΔL_{g} [dB] determined as the difference between the A-weighted sound pressure level propagating above the ground with a finite impedance and that above the rigid surface, as follows [11]:

Table 3 – Coefficient values of $C_{\mathrm{dif,ob}}$

Type of overhung barrier	Coefficient values *A*	*B*	*C*
T-type	3.0	10	1.0
Y-type	3.5	10	2.0
L-type	1.5	10	1.5
Semi-Y-type	1.5	10	1.5

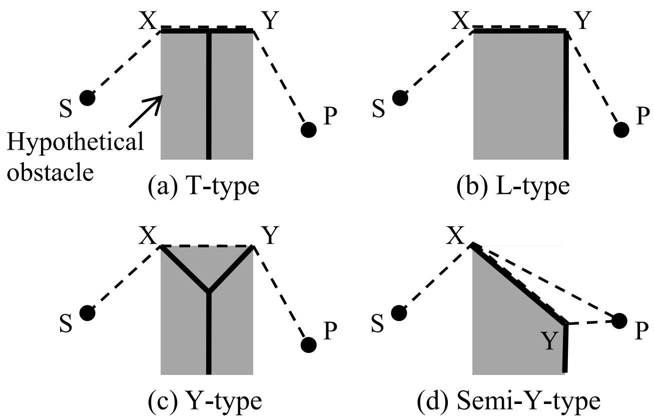


Figure 5 – Calculation of diffraction around overhung barrier.

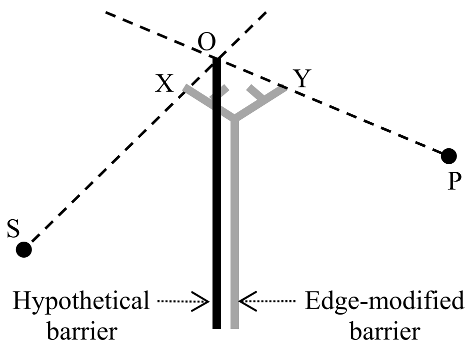


Figure 6 – Calculation of diffraction around edge-modified barrier.

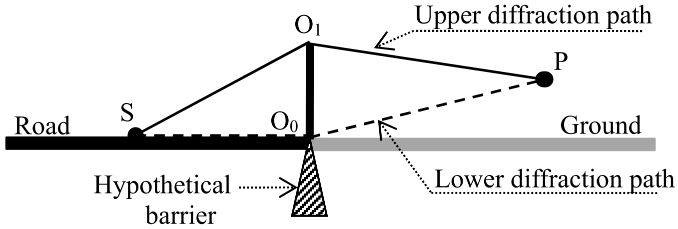


Figure 7 – Calculation of diffraction around a low-height barrier.

$$\Delta L_{\mathrm{g}} = \begin{cases} -K \lg \dfrac{r}{r_{\mathrm{c}}} & r \geq r_{\mathrm{c}} \\ 0 & r \geq r_{\mathrm{c}} \end{cases} \tag{14}$$

where ΔL_{g} is the fundamental correction term for ground effect under consideration of spectral characteristic of road traffic noise, K is a coefficient for the excess attenuation, r and r_{c} are the propagation distance [m] and the critical distance [m], respectively. K and r_{c} depend on the type of ground surface. Equations for K and r_{c} for loose soil, grassland, and compacted ground were provided as a function of the height of propagation path in previous version of the ASJ RTN-Model. In this version, equations for K and r_{c} for propagation above porous asphalt pavement is newly added [12].

4.2 Calculation method of ground effect for several road types, ΔL_{grnd}

The correction term ΔL_{grnd} for excess attenuation by ground effect from a vehicle S to a receiver P is calculated as the summation of fundamental correction terms $\Delta L_{\mathrm{g},i}$ from S to P as shown in Figure 8:

$$\Delta L_{\mathrm{grnd}} = \sum_{i=1}^{n} \Delta L_{\mathrm{g},i} \tag{15}$$

where $\Delta L_{\mathrm{g},i}$ is fundamental correction term ΔL_{g} [dB] for ground effect due to the i th ground surface. ΔL_{g} =0 [dB] for road surfaces paved with dense asphalt or gap-graded asphalt pavement. When the attenuation by ground effect exceeds approximately 30 dB, it may not be so large as to be indicated by the calculated values because of the influence of actual wind conditions.

5. Correction for Air Absorption, ΔL_{air}

The correction due to air absorption ΔL_{air} is specified on the basis of the standard atmospheric condition of 20°C temperature and of 60 % relative humidity and it is given as follows:

$$\Delta L_{\mathrm{air}} = -6.84\left(\frac{r}{1000}\right) + 2.01\left(\frac{r}{1000}\right)^{2} - 0.345\left(\frac{r}{1000}\right)^{3} \tag{16}$$

where, r is the distance [m] between a source point S and a prediction point P.

6. Calculation Methods of Sound Reflection

For the calculation methods of sound reflection, two kinds of calculation methods are prepared in this model. One is specular reflection method applied to flat surface with sufficiently large size and the other is scattered reflection method employed to uneven surface.

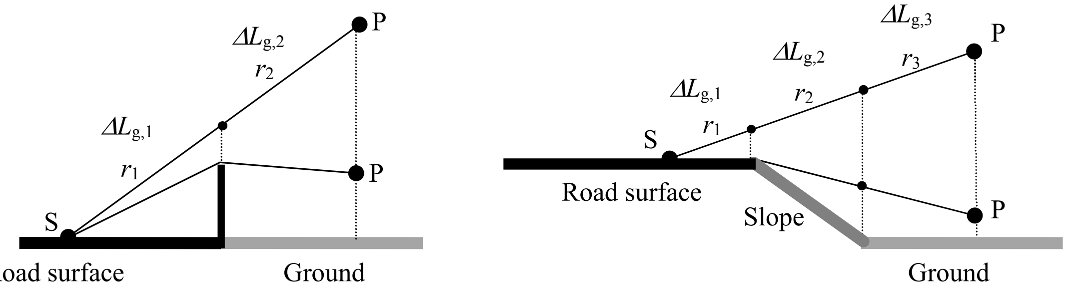
6.1 Specular reflection method

6.1.1 Basic equation

This method is applied to flat surface with sufficiently large size in comparison with the wavelength. The reflection in this situation is equivalently considered as the diffraction from a mirror-image source S' of a real source S to receiver P around a hypothetical absorbing barrier, which is set complementarily to the original reflecting surface, as shown in Figure 9. The specular reflection is calculated as

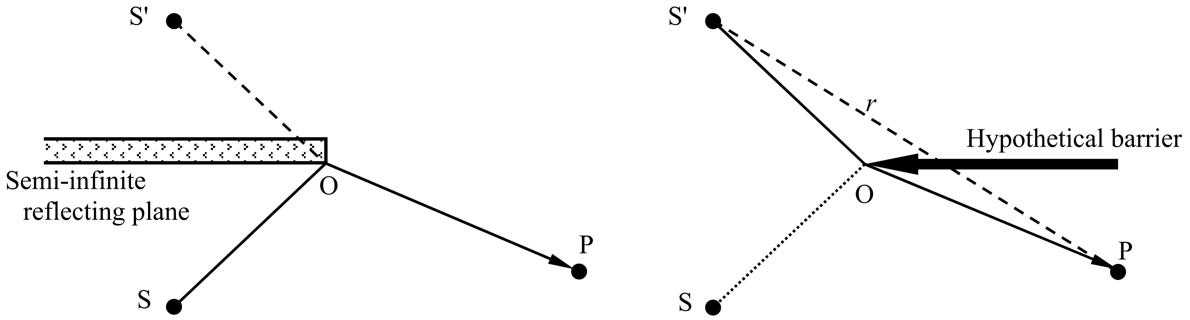
$$L_{\mathrm{A,refl}} = L_{W\mathrm{A}} - 8 - 20\lg r + \Delta L_{\mathrm{refl}} + \Delta L_{\mathrm{abs}} \tag{17}$$

where $L_{\mathrm{A,refl}}$ is the A-weighted sound pressure level of the reflected sound [dB], r is the path length from S' to P [m], ΔL_{refl} is the correction term for reflection and ΔL_{abs} is the correction term for the



(a) Flat (with barrier) (b) Bank

Figure 8 – Calculation of ground effects for various terrains.



(a) Reflection from a semi-infinite flat plane (b) Propagation from a mirror-image source

Figure 9 – Calculation of sound reflection on a semi-infinite flat plane by the specular reflection method.

absorbing characteristics of the reflecting surface [dB].

6.1.2 Fundamental correction term for reflection, ΔL_r

The correction term ΔL_{refl} is calculated using fundamental correction term ΔL_r as a function of the diffraction path difference δ [m] between the path S'OP and the path S'P. ΔL_r is described as

$$\Delta L_r = \begin{cases} -20 - 10\lg(c_{spec}\delta) & c_{spec}\delta \geq 1 \\ -3 - 19.3 \cdot \sinh^{-1}((c_{spec}\delta)^{0.33}) & 0 \leq c_{spec}\delta < 1 \end{cases} \tag{18}$$

The values in Table 2 are applied to the coefficient c_{spec}.

6.1.3 Correction term for reflection on a semi-infinite plane, ΔL_{refl}

The correction term ΔL_{refl} for reflection from a semi-infinite plane in Figure 9(a) is calculated considering the hypothetical barrier in Figure 9(b) as follows:

$$\Delta L_{refl} = \begin{cases} \Delta L_r & \text{for S}' \text{ invisible from P} \\ 10\lg\left(1 - 10^{\frac{\Delta L_r}{10}}\right) & \text{for S}' \text{ visible from P} \end{cases} \tag{19}$$

6.1.4 Correction term for reflection on a finite-width plane, $\Delta L_{refl,slit}$ (slit method)

As shown in Figure 10(a), we consider the flat reflective plane O_1–O_2 with a finite width and an infinite length (i.e., a strip). The sound reflected on the plane is equivalently considered as the contribution from the mirror-image source S' to the prediction point P through slit opening O_1–O_2 with the same width as the strip (see Figure 10(b)).The energy of sound passing through the slit opening is calculated as the difference between the energies of sounds diffracted around the two hypothetical barriers shown in Figure 10(c). The correction term $\Delta L_{refl,slit}$ is calculated as

$$\Delta L_{refl,slit} = 10\lg\left|10^{\frac{\Delta L_{refl,1}}{10}} - 10^{\frac{\Delta L_{refl,2}}{10}}\right| \tag{20}$$

where $\Delta L_{refl,n}$ (n = 1,2) is defined as ΔL_{refl} for diffraction point O_n using Eq.(19).

6.2 Scattered reflection method

For a reflection on the uneven surface such as a bottom of a viaduct road with girders and structural elements, a method of calculating scattered reflection assuming the Lambert's cosine law is employed [13].

6.3 Correction for surface absorption, ΔL_{abs}

The correction term for the sound absorption ΔL_{abs} is calculated as follows:

$$\Delta L_{abs} = 10\lg(1 - \alpha_{A,RTN}) \tag{21}$$

where, $\alpha_{A,RTN}$ is an absorption coefficient which is calculated under consideration of spectral characteristic of road traffic noise.

7. Meteorological effect

Quantitative evaluation of meteorological effects on sound propagation is not easy because the meteorological effect is a complicated phenomenon caused by wind and temperature profiles above ground. Therefore, we investigated the influences of the meteorological conditions on the diffraction and the ground effects by numerical analysis, and determined the limit of these correction values based on the numerical results [14].

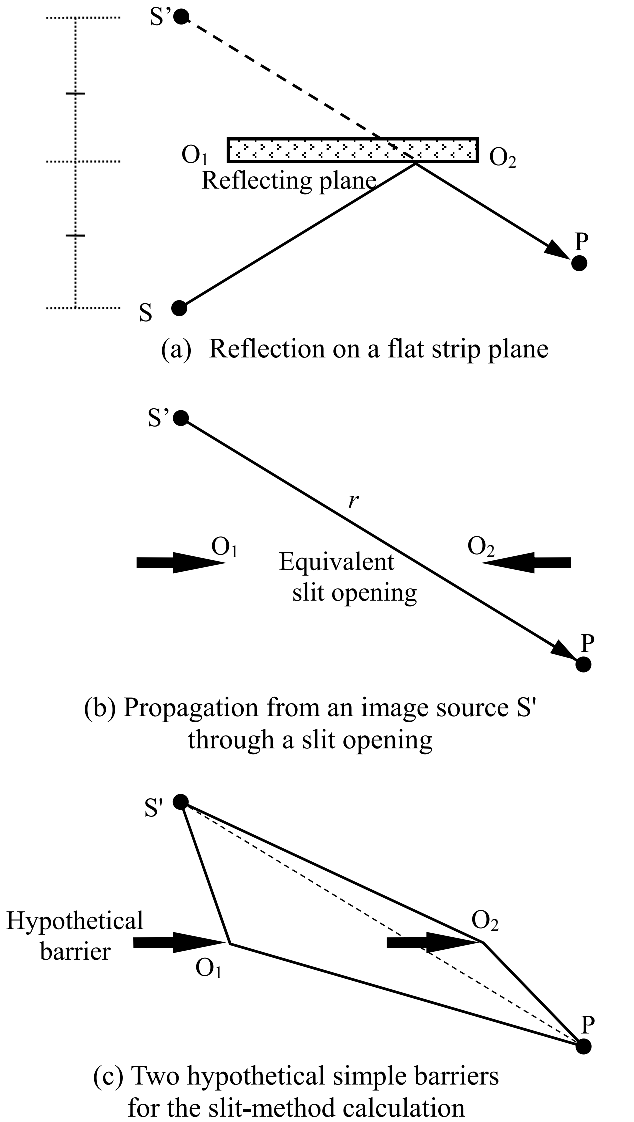


Figure 10 – Calculation of reflection by the slit method.

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