Abstract

As the third part of “ASJ RTN-Model 2003”, calculation model of sound propagation is presented. The model is an up-grade version of the previous model that was proposed in 1999. For the calculation procedures, we adopted a practical model that is essentially based upon Geometrical Acoustics. It contains effects of shielding by barriers or buildings, ground surface, air absorption and meteorological condition. The procedures of application to roads with special case, such as interchange, double deck viaduct, tunnel and road with built-up areas are included. Calculation model of structure borne noise of viaduct is also presented.

1. Introduction

The road traffic noise prediction model “ASJ RTN-Model 2003” employs an engineering method for the calculation of sound propagation. The method is developed for wide application and high accuracy by modifying the previous method called “B-Method” in ASJ RTN-Model 1998. The framework is almost the same as the previous one, but newly obtained knowledge is taken into account. For example, correction term of diffraction for the noise at drainage asphalt concrete pavement is supplied. A treatment of scattered reflection is also included, which is applied to non-flat surface. For the case with complicated boundary condition, an application of numerical analysis based on two-dimensional wave theory is suggested.

2. General procedures

2.1. Basic equation

For a non-directional point source located at an i-th position at a road, A-weighted sound pressure level $L_{A,i}$ at a prediction point is given by the next equation:

$$L_{A,i} = LW_{A,i} - 8 - 20\log_{10} r_i + \Delta L_{\text{cor},i}$$  (1)

where, $L_{W,A,i}$ is the sound power level of a running vehicle, $r_i$ is the direct distance, $\Delta L_{\text{cor},i}$ is a correction term. The correction is given by the next expression:

$$\Delta L_{\text{cor}} = \Delta L_{\text{dif}} + \Delta L_{\text{grnd}} + \Delta L_{\text{air}}$$  (2)

where, $\Delta L_{\text{dif}}$ and $\Delta L_{\text{grnd}}$ are the correction terms of diffraction and ground effect, respectively. The term $\Delta L_{\text{air}}$ is the correction for air absorption.

Note: For predictions at higher floor of buildings located close to a road, correction of sound directivity of the source may be taken into account.

2.2. Correction for diffraction effect

2.2.1. Single diffraction

A road shoulder or a noise-shielding barrier provides sound reduction due to diffraction effect. The correction term is given by the numerical expression shown as follows:
\[ \Delta L_{\text{dif}} = \begin{cases} -a - 10 \log_{10}(\delta) & \delta \geq 1 \\ -5 \pm \frac{-a + 5}{\ln(1 + \sqrt{2})} \cdot \sinh^{-1}(\delta^{0.414}) & b \leq \delta < 1 \\ 0 & \text{else} \end{cases} \] (3).

The symbol \( \delta \) denotes the path length. Plus and minus signs are used for \( \delta > 0 \) and \( \delta < 0 \), respectively. The plus sign in \( \delta \) is given to a receiver in a barrier shadow zone. Constant \( a \) and \( b \) are specified to the types of road surface, i.e., dense asphalt concrete and drainage asphalt concrete, as shown in Table 1. The curve for the correction is shown in Fig. 1.

**Table 1: Constant \( a \) and \( b \) in Eq. (3)**

<table>
<thead>
<tr>
<th>Type of pavement</th>
<th>( a )</th>
<th>( b )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dense asphalt concrete</td>
<td>20</td>
<td>-0.0537</td>
</tr>
<tr>
<td>Drainage asphalt concrete</td>
<td>18</td>
<td>-0.0724</td>
</tr>
</tbody>
</table>

**Figure 1:** Correction chart for single edge diffraction

**Note 1:** Small obstacles such as wire rope and curbstone are to be ignored.

**Note 2:** For low height noise barrier, the correction must be given by the insertion loss.

**Note 3:** Transmission loss of material should be taken into account, if the barrier is made of light material.

**Note 4:** This model also provides calculation method for finite length noise barriers [1].

### 2.2.2. Double diffraction

Embankments and hills may form a double diffraction. For double diffraction as shown in Fig. 2(a), correction \( \Delta L_{\text{dif,dd}} \) is simply expressed by the next formula [2].

\[ \Delta L_{\text{dif,dd}} = \begin{cases} \Delta L_{\text{SXP}} & \text{zone I \& II} \\ \Delta L_{\text{SYP}} + \Delta L_{\text{SXY}} + 5 & \text{zone III} \end{cases} \] (4)

where \( \Delta L_{\text{suffix}} \) is a correction calculated by Eq. (3) and the suffix denotes the sound path.

### 2.2.3. Multi-edge diffraction and others

ASJ RTN-Model 2003 provides calculation method for corrections to wide barriers, double barriers and triple barriers [3].

### 2.2.4. Edge modified barriers

Recent noise barriers are well developed to obtain large noise reduction by modifying the top edge. The barriers may have some acoustical devices on the top. For the configuration as shown in Fig. 2(b), the correction \( \Delta L_{\text{dif,emb}} \) is given as follows:

\[ \Delta L_{\text{dif,emb}} = \Delta L_{\text{dif,eb}} + \Delta L_{c} \] (5)

where, \( \Delta L_{\text{dif,eb}} \) is the correction to the barrier of effective height that is assumed by considering the intersection of two straight lines, one drawn from a source through source side edge, the other drawn from a prediction point through a receiver side edge. The shielding effect is determined by Eq. (3). \( \Delta L_{c} \) is an additional correction that is unique to types of edge modification. It should be obtained by experiments or numerical simulation such as 2D-BEM (Boundary Element Method).

**Figure 2:** (a) Double diffraction by a bank, (b) Edge modified barrier

### 2.3. Correction for ground effect

Ground effect is attenuation over inverse square law when sound propagates over absorptive ground. It depends upon the ground impedance, heights of source and receiver above the ground, the distance between the two. In this engineering method, the correction \( \Delta L_{\text{grnd}} \) is expressed by,

\[ \Delta L_{\text{grnd}} = \sum_{i=1}^{n} \Delta L_{\text{grnd},i} \] (4)

where \( \Delta L_{\text{grnd},i} \) is the correction for the \( i \)-th ground and is given by the next empirical equation:

\[ \Delta L_{\text{grnd},i} = \begin{cases} -K_{i} \log_{10}\left( \frac{r_{i}}{r_{c,i}} \right) & r_{i} \geq r_{c,i} \\ 0 & \text{else} \end{cases} \] (5)
Symbol $K$ is a coefficient that characterizes the attenuation rate per doubling of distance, $r$ is a distance, and $r_c$ is a specific distance where the ground effect starts increasing. $K$ and $r_c$ are obtained by numerical simulation of sound propagation and given by expressions for three types of absorptive ground [4].

2.4. Sound reflection

Two kinds of treatment are included for sound reflection. One is specular reflection applied to flat surface with finite size, the other is scattered reflection employed to non-flat surface. The selection of the treatment depends on the dimension of the roughness and the wavelength.

2.4.1. Slit method

As is shown in Fig.3, the reflected sound from a finite size surface (a stripe of wall) is regarded as a transmitted sound through the slit that has the same size as the reflection wall. The calculation method is derived on the assumption that Babinet’s principle holds in sound energy field. The correction $\Delta \text{dif,slit}$ due to the diffraction of slit opened between the edge $X$ and $Y$ is specified as,

$$\Delta \text{dif,slit} = 10 \log_{10} \left| 10^{L_{S'XP} / 10} - 10^{L_{S'YP} / 10} \right|$$

(6)

where $\Delta \text{suffix}$ is a correction of single diffraction and the suffix denotes the sound path. On calculation the barrier direction must be carefully specified as shown in Fig.4.

2.4.2. Scattered reflection

The assumption of this method is that a wall does not reflect sound specularly, but in a completely diffuse manner, i.e., according to Lambert’s law. For the arrangement in Fig.5, total A-weighted sound pressure level of reflected sounds $L_A$ is given by the next formula:

$$L_A = L_{WA} - 13 + 10 \log_{10} \int_S \frac{\cos \theta_1 \cdot \cos \theta_2}{r_1^2 \cdot r_2^2} \, d\sigma$$

(7)

where, $L_{WA}$ is A-weighted sound power level, $S$ is the total area of reflection surface.

2.5. Correction for air absorption

Correction due to air absorption $\Delta L_{\text{air}}$ is specified on the basis of the standard atmospheric condition (temperature 20°C, humidity 60%) and given by the next expression,

$$\Delta L_{\text{air}} = -6.84 \left( \frac{r}{1000} \right) - 2.011 \left( \frac{r}{1000} \right)^2 - 0.3452 \left( \frac{r}{1000} \right)^3$$

(8)

where $r$ [m] is the distance between a point source and a prediction point. The correction is obtained from ISO 9613-part 1.

2.6. Meteorological effect

Meteorological effect is generally difficult to be included in an engineering model, because it is a complicated phenomenon caused by wind profile and temperature profile above ground. As is the same consideration in ASJ RTN-Model 1998, wind effect is provided as an expected deviation of $L_{\text{eq}}$ due to vector wind. The vector wind is defined as the component of the wind perpendicular to line of a road. The deviation $\Delta L_{\text{m, fine}}$ is expressed by an empirical equation that is obtained by field data, as shown,

$$\Delta L_{\text{m, fine}} = 0.88 \cdot U_{\text{vec}} \cdot \log_{10} (\ell / 15), \quad \ell > 15$$

(9)

where $U_{\text{vec}}$ is vector wind [m/s] and $\ell$ is horizontal distance [m] from the center line of a road. This term is applied to correct the final predicted values of $L_{\text{eq, T}}$.

3. Prediction methods for special road cases

ASJ RTN-Model 2003 provides prediction methods for special road cases. The methods are based on the fundamental calculation procedure described above. Here is some more information needed in the prediction stage.
3.1. Interchange and intersection

The model provides acceleration and deceleration of speed of vehicles as shown in Table 2 to calculate speed profile in computer programming. The service time for paying highway charge is specified for noise exposure time and it is shown in Table 3.

<table>
<thead>
<tr>
<th>Light vehicles</th>
<th>Heavy vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceleration [m s(^{-2})]</td>
<td>1.8</td>
</tr>
<tr>
<td>Deceleration [m s(^{-2})]</td>
<td>-1.0</td>
</tr>
</tbody>
</table>

3.2. Depressed and semi-underground road

The problems in prediction are the treatment of multiple sound reflections between the retained walls. The following methods are provided.

1. Image sources method
2. Hypothetical point source method [5]
3. Two dimensional BEM or FDTD

3.3. Road tunnel

In the model, two hypothetical sources are assumed. One is a point source that represents a direct contribution of sound from a vehicle in tunnel. The other is a surface source that represents residual sound with multiple reflections on the walls inside the tunnel. The model is developed on the basis of sound energy balance inside the tunnel [6].

3.4. Overhead road and double deck viaduct

Noise reflection from the underside of an overhead roadway and a double deck viaduct is provided in the ASJ model. The reflection is treated by slit method or scattered reflection method as described in 2.4, the selection of which depends on the roughness of the surface. In a special case where multiple reflections affect, 2D-BEM or 2D-FDTD is to be used.

4. Structure borne noise of viaduct

Structure of viaducts generates noise when heavy trucks passing on it. The noise is called structure noise of viaduct. The A-weighted sound power level \(L_{W_A, str}\) is given as follows:

\[L_{W_A, str} = d + 30 \log_{10} V, \quad (40 \text{km/h} \leq V)\]  

where \(d\) is a constant and \(V\) is the running speed of heavy truck. The constant \(d\) is specified in Table 4 [7]:

<table>
<thead>
<tr>
<th>Type of viaduct</th>
<th>(d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metal girder with metal slab</td>
<td>40.5</td>
</tr>
<tr>
<td>Metal girder with concrete slab</td>
<td>36.9</td>
</tr>
<tr>
<td>Concrete girder with concrete slab</td>
<td>33.5</td>
</tr>
</tbody>
</table>

In prediction, a non-directional point source is assumed to be located at the underside of viaduct.

5. Effect of individual buildings and built-up area

Building is an obstacle that shields and reflects noise. To calculate the effect of building, both sound reflection and diffraction should be taken into account. However, a built-up area is formed due to high density of buildings, the noise prediction at a specific position becomes almost impossible. The ASJ model provides an empirical method for estimating sectional energy-averaged level \(L_{Aeq}\). A simple correction of shielding effect by buildings is presented [8].

6. References