Prediction Model of Wayside Noise Level of Shinkansen

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Abstract
This paper introduces a prediction model of the wayside noise level of Shinkansen. The noise indices used in the model are the A-weighted sound exposure level of a train set pass $L_{AE}$, equivalent continuous A-weighted sound pressure level $L_{Aeq,T}$ and maximum A-weighted sound pressure level (slow) of a train set pass $L_{pA,Smax}$. In this model, Shinkansen noise sources are divided into four components, namely, the noise from the lower parts of cars, concrete bridge structure noise, aerodynamic noise from the upper parts of cars and pantograph noise. Each noise component is regarded as a row of discrete point sources, the positions and power levels of which are decided according to the noise component, train velocity, car type, track and structure so that the wayside noise level of Shinkansen can be predicted under various conditions. The average and standard deviation of the difference between the measured value $L_{meas}$ and the predicted value $L_{calc}$ are 0.7 dB and 1.5 dB, respectively. This result shows that the prediction model is valid enough. The variance of $L_{meas} - L_{calc}$ is mainly due to the variance of the power level of rolling noise and concrete bridge structure noise, which strongly depend on the conditions of the rail and wheel surface.

1. Introduction

The environmental quality standards for Shinkansen superexpress railway noise prescribes that the maximum A-weighted sound pressure level (slow) of a train set pass $L_{pA,Smax}$ at the wayside of the track shall be 70 dB(A) or less in the area for mainly residential used and 75 dB(A) or less in other areas, including commercial and industrial areas, where normal living conditions should be preserved. When Shinkansen commenced operation, all Shinkansen cars are of the same type (Series 0) running at the maximum velocity of about 200km/h. Currently, there are several types of cars running at various maximum velocities, from 220 to 300 km/h, and the noise level depends on the car type. Therefore, it is required to predict the noise levels of Shinkansen under different conditions of construction, car type, velocity and other factors. No prediction models have been published so far for Shinkansen noise, although detailed studies for analysis and control of the Shinkansen noise have progressed [1,2]. In Europe, several prediction models have been developed by either the national railway companies, local research institutes, or the national Ministries of Environment or Traffic. Reviews of these European prediction models are presented by Leeuwen [3]. However, these models cannot be applied to the Shinkansen noise because the noise source characteristics of European railways differ from those of Shinkansen. Under the circumstances, the Railway Technical Research Institute proposed a prediction model of wayside noise level of Shinkansen to the requirement of Environment Agency.

2. Survey of Prediction Model

2.1. Flow chart of prediction model

This model predicts the A-weighted sound exposure level of a train set pass $L_{AE}$, equivalent continuous A-weighted sound pressure level $L_{Aeq,T}$ and maximum A-weighted sound pressure level (slow) of a train set pass $L_{pA,Smax}$. Figure 1 shows a flow chart of the prediction model. First, the conditions of construction, car type, velocity, track and measuring point are introduced, according to which a noise source model is defined. In the prediction model, the noise sources of Shinkansen are regarded as rows of discrete point sources, the position and power levels of which are decided according to the noise component, train velocity, car type, track and structure. The decision of the noise source model is the most important part in the prediction model, which will be explained in detail in chapter 3. Next, the time history of the instantaneous A-weighted

Figure 1: Flow chart of prediction model
sound pressure level of one point source moving on the track (which we call a “unit pattern”) is calculated. Once the unit pattern is obtained, $L_{AE}$ is obtained by integrating the unit pattern and summing them for all point sources contained in a train set. $L_{Aeq,T}$ can be calculated if the number of train passes during the time length $T$ is known. $L_{pA,Smax}$ is calculated as a definition or obtained directly from $L_{AE}$ by using a conversion equation. The process of the calculation can be referred in [4].

2.2. Extent of application

This prediction model can be applied under the conditions shown in Table 1. The extent of velocity has a lower limit because the contributions of noise components such as noise from air conditioners and inverters, which are not considered in the model, cannot be neglected at the velocity below 150 km/h. The restriction for a measuring point can be removed if the effects of the attenuation due to air absorption and ground absorption are considered in the model.

<table>
<thead>
<tr>
<th>Type of car</th>
<th>All Shinkansen cars in operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity</td>
<td>150km/h-maximum velocity in operation</td>
</tr>
<tr>
<td>Track</td>
<td>Ballast track, slab track and vibration-reducing track</td>
</tr>
<tr>
<td>Construction</td>
<td>Concrete bridge structure and embankment</td>
</tr>
<tr>
<td>Sound barrier</td>
<td>Straight type with or without absorbing materials</td>
</tr>
<tr>
<td>Measuring point</td>
<td>At the point at a horizontal distance of 12.5 to 50 m from the track and at a height lower than the upper end of the sound barrier</td>
</tr>
</tbody>
</table>

3. Noise Source Definition

3.1. Classification of noise sources

In the prediction model, Shinkansen noise sources are divided into four components, (1) the noise generated by the lower parts of cars, which consists of the rolling noise, aerodynamic noise, and gear noise, (2) concrete bridge structure noise, (3) aerodynamic noise generated by the upper parts of cars and (4) pantograph noise, which consists of the aerodynamic noise and spark noise. Each noise source is regarded as a row of discrete non-directive point sources (monopole sources). The noises (1) to (3) are radiated to a half space and the noise (4) is radiated to a full space.

3.2. Position of sources

The positions of the noise sources are shown in Figure 2. The coordinates of the noise sources differ in detail according to the type of cars.

3.3. Sound radiation characteristics

Figure 3 shows the time history of the A-weighted sound pressure level (fast) of Shinkansen cars measured at the point 25 m away from the track. The calculated time histories of discrete monopole sources and dipole sources whose axes are parallel to sleepers are also shown in the same Figure. It is found that the radiation characteristics of the Shinkansen noise are similar to those of monopole rather than those of dipole. Thus, all sources are assumed to be monopole sources in the prediction model.

3.4. Power level of noise source

3.4.1. Dependency of power level on velocity

The dependency of the power level on velocity is
defined by the factor “n”, where the power level is proportional to the \( n \)th power of velocity. Here the factor “n” for each noise component is decided on the basis of experimental data of field tests and wind tunnel experiments show that the aerodynamic noise generated from trains increases in proportion to the 6th power of velocity in most cases. Thus, the values of factor “n” are decided as shown in Table 2.

### Table 2: Values of factor “n”

<table>
<thead>
<tr>
<th>Noise source component</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noise generated by the lower parts of cars</td>
<td>3</td>
</tr>
<tr>
<td>Concrete bridge structure noise</td>
<td>3</td>
</tr>
<tr>
<td>Aerodynamic noise generated by the upper parts of cars</td>
<td>6</td>
</tr>
<tr>
<td>Pantograph noise</td>
<td>6</td>
</tr>
</tbody>
</table>

#### 3.4.2. Decision of power level

Once the factor “n” is decided in section 3.4.1, the power level of the noise source \( L_{wi}(u) \) can be given by the equations (1) to (4), where the subscripts \( i = 1, 2, 3 \) and 4 correspond to (1) the noise generated by the lower parts of cars, (2) concrete bridge structure noise, (3) aerodynamic noise generated by the upper parts of cars and (4) pantograph noise, respectively.

\[
L_{wi}(u) = L_{wi}(200) + 30\log(u/200) - \Delta L_i
\]

\[
L_{zi}(u) = L_{zi}(200) + 30\log(u/200) - \Delta L_z
\]

\[
L_{ai}(u) = L_{ai}(200) + 60\log(u/200)
\]

\[
L_{pi}(u) = L_{pi}(200) + 60\log(u/200)
\]

In the above equations, \( L_{wi}(200) \) denotes the power level at 200 km/h and \( u \) is the train velocity (km/h). \( \Delta L_i \) is the correction factor for the noise generated by the lower parts of cars, which is 0 dB for slab tracks and 5 dB for ballast tracks. \( \Delta L_z \) is the correction factor for the concrete bridge structure noise, which is 5 dB for slab tracks with a rubber isolator, 8 dB for ballast tracks with a ballast mat, and 10 dB for tracks with sleepers covered with a resilient material. The values of \( L_{wi}(200) \), which are shown in [4], depend on the type of cars and are estimated on the basis of the measured data [1,2].

### 4. Case Study

#### 4.1. Condition of case study

In order to confirm the validity of the prediction model, the measured values \( L_{meas} \), were compared with the predicted values \( L_{calc} \). A case study was carried out by using data of a total of 2,595 train passes running at 22 sections which contain eight ballast track sections, 10 slab track sections and four vibration-reducing track sections.
sections. The construction of all sections is a concrete bridge structure with a sound barrier, which is the standard construction of Shinkansen. All types of cars are included in the data. The measuring point is 12.5 to 50 m away from the track and 1.2 m above the ground. $L_{pA,\text{max}}$ is used as a noise index.

4.2. Results

The result of case study for all data is shown in Figure 7. The average and standard deviation of the difference between $L_{\text{meas}}$ and $L_{\text{calc}}$ are 0.7 dB and 1.5 dB, respectively. This result shows that the prediction model is valid enough.

In order to clarify the cause of the variance, the standard deviation of the difference between $L_{\text{meas}}$ and $L_{\text{calc}}$ was calculated when one of the conditions was fixed, such as the section, type of cars and distance from the track to the measuring point. The results are shown in Table 3. If the section is fixed, the standard deviation of the difference between $L_{\text{meas}}$ and $L_{\text{calc}}$ is lowered to 1.1 dB, which suggests that the difference of the section causes the variance. This is because the power levels of rolling noise and concrete bridge structure noise strongly depend on the conditions of the rail and wheel surface which vary according to the section. If the type of cars is fixed, the standard deviation of the difference between $L_{\text{meas}}$ and $L_{\text{calc}}$ is lowered to 1.3 dB, thus the type of cars could have some effect on the variance. The distance from the track to the measuring point is considered to have very little effect on the variance.

Next, the data were divided into three categories according to the velocity, namely, from 150 km/h to 200 km/h, from 200 km/h to 250 km/h and above 250 km/h and case studies were carried out separately. Furthermore another case study was carried out using the data below 150 km/h, which are out of application of the model. The results are shown in Table 4. The prediction model is valid above 150 km/h although its precision becomes worse as the velocity decreases. Below 150 km/h, $L_{\text{meas}}$ is greater than $L_{\text{calc}}$ by 5 dB, which is due to the effects of the noise from gears, air conditioners, inverters, etc.

Table 4: Standard deviation of $(L_{\text{meas}} - L_{\text{calc}})$ for different velocity categories

<table>
<thead>
<tr>
<th>Velocity</th>
<th>Number of data</th>
<th>Average of $(L_{\text{meas}}-L_{\text{calc}})$</th>
<th>Standard deviation of $(L_{\text{meas}}-L_{\text{calc}})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Below 150km/h</td>
<td>116</td>
<td>5.61 dB</td>
<td>2.39 dB</td>
</tr>
<tr>
<td>150-200km/h</td>
<td>158</td>
<td>1.00 dB</td>
<td>2.06 dB</td>
</tr>
<tr>
<td>200-250km</td>
<td>1809</td>
<td>0.63 dB</td>
<td>1.44 dB</td>
</tr>
<tr>
<td>Above 250km/h</td>
<td>628</td>
<td>0.76 dB</td>
<td>1.30 dB</td>
</tr>
</tbody>
</table>

5. Conclusions

This paper prescribes the prediction model of the wayside noise level of Shinkansen ($L_{\text{AE},\text{L}_{\text{AQ},\text{F},\text{pA,\text{max}}}}$). In this model, Shinkansen noise sources are divided into four components and regarded as rows of discrete point sources, the positions and power levels of which are decided according to the noise component, train velocity, car type, track and structure. Thus, the wayside noise level of Shinkansen can be predicted under various conditions. As the result of a case study, the average and standard deviation of the difference between the measured value $L_{\text{meas}}$ and the predicted value $L_{\text{calc}}$ are 0.7 dB and 1.5 dB, respectively. The variance of the difference between $L_{\text{meas}}$ and $L_{\text{calc}}$ is mainly due to the variance of the power levels of rolling noise and concrete bridge structure noise which strongly depend on the conditions of the rail and wheel surface.

6. References


