A Study on Predicting Shinkansen Noise Levels Using the Sound Intensity Method*

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The purpose of this paper is to demonstrate a new method developed to predict track wayside noise levels resulting from the passage of high-speed trains. The method calculates noise levels based on data acquired by the sound intensity method developed by the Central Japan Railway Company. This measurement method allows one to identify each sound source and its characteristics as well as identify how much each source contributes to the overall resulting noise level. Structure borne noise and multiple reflected noise between train car bodies and noise barriers are also studied. As a result of this study, a prediction method was created which can calculate and predict noise levels resulting from such various factors as structure, train type, train speed and noise barrier. Noise levels predicted during this study agreed well with those actually measured under various conditions, thus indicating the prediction method model resulting from the study is a useful tool to verify noise levels occurring at receiver positions. Furthermore, it can also verify in advance how much effect noise barriers or train source noise level reduction devices would have on noise reduction.

Key Words: Acoustic, Measurement, Noise, Railway, Prediction Method, Shinkansen, Sound Intensity Level

1. Introduction

The Central Japan Railway Company, CJRC hereafter, is making an effort to improve the track wayside environment such as noise levels related to train operations, by modifying train aerodynamics and installing noise barriers along track routes. In relation to this, CJRC has been studying methods to identify and position sound sources resulting due to trains traveling at high speeds. The sound intensity method, which creates contour maps of train-generated noise, is one of achievements of our study. This paper introduces a model for calculating a train wayside noise profile for passing high-speed trains by using sound intensity level data measured by the method developed during the study.

2. Sound Intensity Method

In order to clarify the characteristics of sound sources of trains traveling at high speeds, it is necessary to first identify the position which sound sources emanate from.

A sound level meter was used to measure noise levels during train passage. Figure 1 shows an A-weighted sound pressure level obtained from sound level meter readings. In this case, it is difficult to identify any specific sound source because the time constant involved is too slow, so the unit-pattern comes to a single peak. We next employed a system of linear alley positioned microphones to identify sound sources resulting from high-speed train passage. This system is designed to obtain sound coming vertically to microphones in the alley. As shown in Fig. 2, this system allows one to identify sound sources resulting from the passage of trains several hundreds of meters in length. It also allowed us to identify sound sources at the...
train head and tail, pantographs, and coupling areas. However, this method is not able to distinguish sound sources in vertical direction, which means that it can not separate sound sources for bogie parts from that of coupling areas. The alley microphone system can distinguish noise sources occurring for more than a 5-meter passage due to its directional ability, but this is not enough to determine how much noise the source actually generates.

CJRC next developed the sound intensity measurement system shown in Fig. 3 (a). Six sound intensity microphones, positioned vertically at intervals of 1.2 meters from rail level, were set 1 meter from the train body passage area\(^{(1)}\). This system measured the intensity level of sounds generated by a high-speed train passage at 10 msec intervals using a real time analyzer. Contour maps were then drawn based on the acquired data. Figure 3 (b) shows a contour map for a series 700 Shinkansen train operating at a speed of 270 km/h. The dark colored map areas are noise sources. As can be seen, it identifies sound source positions, not only horizontal to travel direction but also vertically, so the sound source level generated by a passing train can be precisely pinpointed.

3. Prediction Method for Train Wayside Noise

Based on the obtained sound position and sound intensity level data, we developed a new prediction method to calculate noise levels occurring at wayside areas during high-speed train passage\(^{(1)}\). Our goal was to create a method that can be used to predict and verify wayside noise occurrence and also to determine what noise reduction measures, such as noise barriers and low noise trains, are effective. To achieve this goal, our method is designed to calculate noise levels resulting from the various conditions shown in Table 1. In our study, we acknowledged that the calculated level did not agree well with the level measured in the wayside area adjacent to the track. We assumed that the difference was caused by structure borne noise and multiple reflected noise between train car bodies and the noise barrier. Considering this, we conducted an additional study to incorporate the effects of such noise factors into the method.

3.1 Train passage sound source model

From the contour map resulting from the sound intensity level data, we decided on using the following four sound sources as the main high-speed train noise factors during calculation. As shown in Fig. 4, these are the (a) bogie part, (b) pantographs and their covers, (c) car coupling areas, and (d) head and tail sections. We assumed a horizontal directivity of \(\cos \theta\) for bogie part sound source (a), other three types of noise sources are non-directional.

In the prediction model, the sound power level of each sound source is determined from Eq. (1), as shown below.
We investigated the relationship between the intensity of sound generated by each sound source and the train speed, when traveling at 200 km/h to 300 km/h, and determined values for “m” as shown in Table 2.

\[ PWL(V) = \text{SIL}_{\max}(V_0) + 10 \times \log_{10}(2pd^2) + 10 \times \log_{10}(V/V_0)^m \]  

(1)

- **PWL**: Sound power level of noise source
- **V₀**: Passing speed when the SIL is measured
- **d**: Distance between microphone and noise source
- **SILₘₐₓ**: Maximum level of SIL for individual source
- **V**: Traveling speed for the prediction
- **m**: Power-law for traveling speed

### 3.2 Sound source model for structure borne noise

Noises generated by structures must be considered when calculating noise levels in areas close to elevated structures. In consideration of this, we propose the following for the prediction model(2) based on some of the field measurements taken.

- Assume multiple point sound sources lay on the under surface just below the track on which the train passes by at adjacent bogies intervals as shown in Fig. 5.
- The value of each point sound source, \( L_{WP} \), is determined as 85.5 dB at a speed of 265 km/h.
- Assume that the point sound source has a directivity of \( \cos^2 \theta \), where \( \theta \) is an angle whose direction is in the vertical to the under surface of the elevated structure.
- Consider image sources corresponding to ground reflected sound.
- Sound power for each point sound source is proportional to passing speed \( V \) to the power of 2.4

### 3.3 Sound propagation calculation

The model calculates train wayside noise level during Shinkansen train passages using the equation previously mentioned and also considers sound propagation by following procedure.

1. The noise level from each sound source is calculated at 10msec intervals, and considering attenuation damping and noise reduction due to noise barriers.
2. Adjust time delay caused during sound propagation and consider time weighing, calculate the noise level of each sound source at the receiver position correspondent to the passing high-speed train.
3. Sum up the noise level of each sound source and calculate total sum noise level for the passing high-speed train.

Maekawa’s chart shown in Fig. 6 is used to calculate the amount of noise reduction attributable to noise barriers during calculations. The model also assumes and incor-

![Fig. 4 Sound sources of passing high-speed train (Series 700)](image)

![Fig. 5 Sound source model for sound from structure](image)

Table 2 Power law for traveling speed (m) of noise level for Series 700

<table>
<thead>
<tr>
<th>Noise source</th>
<th>Exponential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bogie</td>
<td>3.3</td>
</tr>
<tr>
<td>Pantograph and cover</td>
<td>4.6</td>
</tr>
<tr>
<td>Coupling area*</td>
<td></td>
</tr>
<tr>
<td>With cable head/nothing</td>
<td>2.6</td>
</tr>
<tr>
<td>With bus joint</td>
<td>2.3</td>
</tr>
<tr>
<td>The head part of a train</td>
<td>4.9</td>
</tr>
<tr>
<td>The tail part of a train</td>
<td>4.6</td>
</tr>
</tbody>
</table>

* depend on the conditions of roof of coupling area

![Fig. 6 Maekawa's chart](image)

![Fig. 7 Correction value due to multiple-reflected sounds](image)
porates noise increase caused by multiple reflected rail-wheel noise by adding values \( dL_{\text{multi}} \) to that of the rail-wheel noise factor, as shown in Fig. 7. This value corresponds to a moving sound source. Correcting values \( dL_{\text{multi}} \) are decided based on a 1/25 scale model experiment\(^2\).

### 4. Verification of Prediction Method

To verify the accuracy of the prediction method resulting from our study, calculated noise level was compared with data measured during passage of a CJRC Tokaido Shinkansen. Figure 8 shows a comparison of the A-weighted SPL between measured and predicted levels, at a receiver positioned 25 meters away from the center of the closest track. Structure height is 7.8 meter from ground level, G.L., to rail level, R.L., and embankment height is 5.6 meter from G.L. to R.L. Even when conditions such as train speed, structure, or noise barrier were varied, the predicted noise level matches well with the measured one as shown.

Figure 9 shows a comparison of maximum level, \( L_{pA, \text{Smax}} \) for the same places. This indicates that the predicted data also agreed well with data measured at various receiver positions as shown.

### 5. Conclusion

A prediction method that can determine noise levels at train wayside areas during high-speed train passage was developed. This method calculates noise levels based on measured sound intensity levels using the sound intensity measurement method developed by CJRC. The developed method can calculate noise level under various conditions and predicted level agrees well with measured level. Study results show that the prediction method is also precise in terms of the noise levels predicted. This method can be used to not only calculate train wayside noise levels, but also to measure the effect noise barriers and train source noise level reduction devices have in advance, thus enabling us to implement more efficient and effective wayside noise reduction measures.

### References
