Prediction Model for Railway Noise in Consideration of Sound Reflection on Bridge

Yukie OGATA  Toshiki KITAGAWA  Hidetoshi SAITO
Noise Analysis Laboratory, Environmental Engineering Division

This paper describes a model for predicting wayside noise close to an overpass on Shinkansen railway line. In the development of the model, sound reflection on the bottom surface of bridge should be taken into consideration. The effect of sound reflection was examined in acoustic experiments with scale models. Then, a mirror image source and a correction value due to the reflection on the finite surface were introduced into the prediction model. It was validated by comparing the measured results with the results simulated by the prediction model. It was found by using the prediction model that the mirror image sources corresponding to the noise generated from the lower part of railway cars and the track have a greater influence on the wayside noise.

Keywords: noise, noise prediction technique, overpass

1. Introduction

When a Shinkansen car runs, noise sources around the Shinkansen train are mainly categorized as noise generated from the lower part of the cars and the track (lower part noise), pantograph noise, aerodynamic noise generated from the upper body of the cars (upper part aerodynamic noise), and bridge noise. The noise contribution of each source at a sound receiving point varies according to the railroad structure, car condition, and the position of the receiving point. The noise level and its frequency properties vary according to the reflection, shielding, and diffraction during the propagation of the sound. The same is true in the case of wayside areas near overpasses. In References [1-3], it is indicated that wayside noise near an overpass increases due to the sound reflection on the bottom surface of the overpass.

Wayside noise for Shinkansen lines without the influence of reflection or shielding by non-railway structures has been predicted by using a conventional model [4]. For the area near an overpass, this paper presents a prediction model in which the sound reflected on the bottom surface of the overpass is added to the results of the conventional model. The validity of the noise prediction model is confirmed by comparing the predicted results with the results of an acoustic model experiment or a field measurement of actual railway noise, and the characteristics of the wayside noise in the vicinity of an overpass are described.

2. Evaluation of sound reflection on the bottom of an overpass

The effect of the sound reflection on the bottom of an overpass on the wayside noise was evaluated by using the results of an acoustic model experiment, and a prediction model based upon it was proposed.

2.1 Outline and results of an acoustic scale model experiment

An acoustic scale model experiment was carried out in an anechoic chamber at RTRI [1]. Figure 1 shows the model arrangement, and Table 1 presents the outline of the experiment. The dimensions denoted therein are values converted into actual trains (the same hereinafter). The simulated sound sources were the lower part noise and the upper part noise (i.e., upper part aerodynamic noise + pantograph noise), which were situated over the entire length of the car model at rail height or at R.L. + 5 m height, respectively. The results of the measurement were arranged according to the following procedure:

1. By applying the acoustic similarity law, the obtained frequency was multiplied by 1/25.
2. The noise level of each frequency band corresponding to the actual train was determined by considering the difference between the sound power level measured near each sound source in the experiment and the sound power level of the actual train (300 km/h).
3. By using the results of step 2, the difference between the noise in the presence and that in the absence of an overpass was calculated.
4. The noise contribution of each sound source in the absence of an overpass was determined by the conventional model.
5. By adding the results of step 3 to those from step 4, the noise contribution in the presence of an overpass was calculated.
6. The difference between the results in the presence and absence of an overpass was considered to be the increase in noise level due to the overpass.

Figure 2 shows examples of the experimental results. The increase in noise level is greater in the case of a remote train than in the case of an adjacent train. As stated in Section 2.4, since the contribution of the lower part noise is greater than that of the upper part noise, the distribution of the increase in the total sound is closer to that in the lower part noise, and the shape of the contour lines runs...
along the overpass. In the case of the upper part noise, the increase in noise level near the point of the intersection of the railway track and the overpass is large, and the contour lines reveal an elliptical shape with this intersection at its center.

2.2 Model for predicting sound reflection on the bottom surface of an overpass

2.2.1 Basic concept

The prediction model is based on the conventional model, and a model for estimating reflection-correction at the strip-shaped reflection surface indicated in the ASJ RTN-Model 2013 [5] for the evaluation of the sound reflected on the bottom surface of an overpass (slit method) is applied to this prediction model. The noise sources investigated here were the lower and upper part noises dealt with in the above acoustic scale model experiments. Figure 3 is a schematic of the prediction model. The noise level, \( L_r \) [dB], at receiving point, \( P \), in the case of the presence of an overpass can be obtained from (1). The components of the direct noise are the lower and upper part noises and bridge noise, whereas the components of the mirror image noise (image noise, the same hereinafter) reflected on the overpass bottom surface are the lower and upper part noises.

\[
L_p = 10 \log_{10} \left( \frac{L_o}{10} + 10 \frac{L_m}{10} \right) \tag{1}
\]

where \( L_o \) is the noise level due to sound source, \( S \), and \( L_m \) is the noise level due to the image source, \( S' \). The reflected noise can be considered to be a noise which arrives at the point \( P \) from the image source \( S' \) after passing through the opening (slit) \( O_1-O_2 \) of the same width as that of the reflecting surface. The energy of the sound passing through the slit is obtained as the difference of the sounds diffracted due to two semi-infinite imaginary barriers. The reflected noise, \( L_m \), is obtained by adding the reflected sound correction, \( \Delta L_{r,\text{refl,slit}} \) [dB] (< 0), to the noise level, \( L_r \) [dB] (considering complete opening), originating from the image source, \( S' \) (Eq. (2)). The reflection correction in this prediction model is obtained by (3).

\[
L_m = L_{S'} + \Delta L_{r,\text{refl,slit}} \tag{2}
\]

\[
\Delta L_{r,\text{refl,slit}} = 10 \log_{10} \left( \frac{\Delta L_{r,\text{refl,1}}}{10} + 10 \frac{\Delta L_{r,\text{refl,2}}}{10} \right) \tag{3}
\]

where \( \Delta L_{r,\text{refl,1}} \) and \( \Delta L_{r,\text{refl,2}} \) are reflection corrections, \( \Delta L_{r,\text{refl}} \) [dB], when considering \( O_1 \) or \( O_2 \) as the edges respectively, and are calculated using (4) and (5). When \( S' \) cannot be seen from \( P \), while assuming a hypothetical barrier:

\[
\Delta L_{r,\text{refl}} = \Delta L_r \tag{4}
\]

When \( S' \) can be seen from \( P \) while assuming a hypothetical barrier,

\[
\Delta L_{r,\text{refl}} = 10 \log_{10} \left( 1 - 10 \frac{\Delta L_r}{10} \right) \tag{5}
\]

\( \Delta L_r \) is the diffraction correction at the image source, \( S' \), dif-
fraction point O₁ or O₂, and the receiving point, P.

The directional characteristics, \( D \) [dB], of the lower part noise in the cross section orthogonal to the railway track is given by (6) \[6\] by using the function of angle, \( \phi \) [rad], subtended between the horizontal direction and the direction of the radiation of the sound. The upper part noise is non-directional.

\[
D(\phi) = 10\log_{10}(0.1 + 0.9\cos\phi)
\]  

### 2.2.2 Sound source model

Figure 4 shows an outline of the image source model. Insertion loss due to the image barrier is estimated expect the lower part noise of an adjacent train.

1. **Lower part noise of an adjacent train (Fig.4 (a))**
   
   The sound from the image source is radiated from the upper end of the gap between the car body and the barrier after multiple reflections in the gap. Therefore, the hypothetical image source of the sound reflected on the bottom surface of the overpass is set at the center of upper end of the gap. The insertion loss due to the image barrier is not added in the calculation because they are taken into consideration at the power level.

2. **Lower part noise of a remote train (Fig.4 (b))**
   
   The distance between the barrier and the sound source of the lower part noise for the remote train is longer than that for the adjacent train. Therefore, the effect of multiple reflections between the car body and the barrier is assumed to be less. Thus, the position of the source of the sound reflected on the bottom surface of the overpass is set to the image position of the direct sound source.

3. **Upper part noise (Fig.4 (c))**
   
   The direct sound source of the upper part noise is set to the position of the source of the pantograph noise as the source is set in the conventional model. In the conventional model, the sound from the direct noise radiates throughout the entire space. The sound reflected on the upper surface of the car body is also added. As for the sound reflected on the bottom surface of the overpass, a reflection correction is applied by using the slit method, with the upper surface of the car body considered to be the reflecting surface.

4. **Power level**
   
   The power levels of the image sources reflected on the bottom surface of the overpass or the upper surface of the car body are determined as shown in Fig. 4. These values were determined in consideration of the effect of the energy loss from the multiple reflection, or shielding by the image barrier, based on the results of the acoustic scale model experiment.

### 2.3 Evaluation of the validity of the prediction model

#### 2.3.1 Set Conditions for the prediction

Figure 5 shows the schematic diagrams of the predictions used for comparison with the results of the acoustic scale model experiment. The sound sources are distributed over a distance of \( \pm 50 \) m, i.e., 100 m in total longitudi-
nally, just as in the case of the experiment. The directional characteristic of the sound source is considered to be \( \cos^2 \theta \), where \( \theta \) is the angle subtended between the direction normal to an array of the point sound sources and the radiation direction of the sound. This is the directional characteristic of the sound source apparatus used in the model experiment. The sound receiving points are the same as those in the model experiment of Section 2.1.

2.3.2 Comparison of acoustic model experiment results with predictive calculations

Figure 6 shows the results of the calculations of the increase in noise level due to an overpass, by application of the prediction model in Section 2.2. The increase in noise level is the difference between the noise, \( L_s \), and the noise, \( L_p \). The prediction conditions are the same as those given in Table 2. The results of the predictions show good agreement with those of the acoustic model experiment (Fig. 2).

Since the contribution of the lower part noise is greater than that of the upper part noise in both Fig. 2 and Fig. 6, the distribution of the increase in the total noise is closer to that for lower part noise. The contour lines follow the overpass, and are properly reproduced by using the slit method in which the bottom surface of the overpass is a reflecting surface. This contour line shape indicates that the reflection points on the bottom surface of the overpass extend over a long distance away from the railway structure. Inversely, in the case of the upper part noise, the area of the maximum increase in noise level is located only near the intersection of the railway track and the overpass. The effect due to the overpass is restricted to the vicinity of the intersection of the railway track and the overpass. This is because the direct upper part noise is screened by the barrier, whereas the reflected noise is not affected by the image barrier.

The results of the predictions show that the increase in noise level is greater in the case of a remote train than for an adjacent train. In both the results of the model experiment and the predictions, the difference in the increase of the total noise level between the two positions of the train is a maximum of 4–5 dB in the area 12.5 m or more away from the center, and the difference decreases with distance from the overpass. This is because the correction in \( L_p \) for the diffraction from an image barrier in the case of a remote train is less than that for an adjacent train.

2.4 Characteristics of wayside noise when a railway track and an overpass intersect orthogonally

Figure 7 shows the calculation results of the noise contribution rates at points separated from the center of the adjacent track by 25 m in the case of the presence of an overpass, under the same conditions as are shown in Fig. 6. The evaluation points are the points ①, ② and ③ as shown in Fig. 6. For the same position of the running track of the train, the contribution of each noise was equal at the evaluation points. In the case of the adjacent train, if the lower part noise (direct) is \( L_s \) [dB], the upper part noise (direct) becomes \( L_s - 2.5 \) [dB], and the bridge noise (direct) is \( L_s - 12.5 \) [dB]. Similarly, in the case of the remote train, if the lower part noise (direct) is \( L_s \) [dB], the upper part noise (direct) is \( L_s - 5.9 \) [dB], while the bridge noise (direct) is \( L_s - 10.3 \) [dB]. In the absence of an overpass, the contribution rate of the lower part noise is greater. Moreover, the contribution rate of the lower part noise is greater in the case of a remote train than for an adjacent train.

Next, in case of the presence of an overpass: Figs. 6 and 7 show that the increase in noise level grows as the evaluation point nears the overpass. The greater the increase in noise level is, the greater the contribution of the reflected lower part noise is. Further, the contribution of the reflected noise for the remote train is greater than that for an adjacent train.

From the above, the following points can be understood about the characteristics of wayside noise in the vicinity of an overpass when the railway track and the overpass intersect orthogonally.

1. In the presence of an overpass, there is a region where the noise level increases more than if there were no over-
pass.

2. In the region extending up to about 50 m from the center of the railway track, the increase in noise level is somewhat constant in the longitudinal direction of the overpass, but it decreases with distance from the overpass.

3. In the case of a double track structure with a barrier, the increase in noise level is greater for a remote train than for an adjacent train.

4. When an increase in noise level is 3 dB or more, the contribution rate of the reflected lower part noise is larger than the contribution rate of other noise.

5. The reflection point at the bottom surface of the overpass extends over a long distance. Therefore, if an overpass is built across a railway track, countermeasures taken to reduce the noise reflected on the bottom surface of the overpass may be useful.

3. Experimental evaluation of wayside noise with an actual train

Figure 8 shows the results of predictions and field measurements conducted to investigate the increase in noise level due to an overpass, when the railway track and the overpass cross diagonally. Conditions of the predictions and the field measurements are as mentioned in Table 2. It was found that the predictions appropriately reproduce the distribution of the increase in noise level observed in field measurements on the actual train. The following primary items can be understood from Fig. 8.

1. The increase in noise level in the region enclosed by an obtuse angle (right-hand side of the overpass in the figure) is more than that in the region enclosed by the railway track and the overpass which intersect at an acute angle (left-hand side of the overpass in the figure).

2. The maximum increase in noise level is not seen at a position right under the overpass, but at a position somewhat separated from the overpass. Moreover, over-all trends of the maximum value and its position obtained by the prediction are in good agreement with measurements from actual trains.

4. Conclusions

A model for predicting wayside noise in the presence of an overpass was devised in which the noise is predicted by adding the noise reflected on the bottom surface of an overpass to the noise which would be generated in the absence of an overpass. Source models in which the noise reflected on the bottom surface of an overpass was assumed to be equivalent to the noise generated from the image source and passed through a slit having the same width as the reflecting surface were used in the prediction model. The results obtained with the prediction model showed good agreement with results obtained from both the acoustic scale model experiment and actual measurements from trains. Thus, the validity of the prediction model was confirmed. The predictions demonstrated that, when the increase in noise level due to an overpass in the total noise is larger, the contribution of the lower part noise reflected on the bottom surface of the overpass is greater, and the reflection point is not restricted to the region right above the railway track structure. Therefore, it is important to investigate countermeasures for reducing noise reflected on the bottom surface of overpass, while building such structures.

Table 2 Prediction and measurement conditions

| Item                  | Condition                                                                 |
|-----------------------|---------------------------------------------------------------------------|
| Railway structure     | RC rigid frame viaduct + partial embankment, Viaduct height: 14 m (G.L.-R.L., portion crossing with overpass), Ballast track Noise barrier: R.L. + 1.6 m (partially raised up to R.L. + 2.1 m) |
| Overpass structure    | Angle of intersection of railway viaduct and overpass: 30°, width: 12 m Bridge clearance height: 27.3 m (G.L.-lower edge) |
| Noise measuring point | 22 points (at up to 150 m each from the crossing position in longitudinal direction and up to 150 m from the center of the adjacent track in the direction of sleepers), height above the ground: 1.2 m |
| Noise evaluation      | Maximum value of train pass-by noise with time weighting S |
| Train                 | Length: 400 m (16 cars), 300 km/h, remote track |
References

[1] Masanari NISHIMURA, et al, “Evaluation of the effect of structures over railway track on the wayside noise,” Institution of Noise Control Engineering of Japan, 2012 fall meeting for presenting research papers, collection of papers, pp. 289–292, 2012 (in Japanese).

[2] Yukie OGATA, et al, “Study of prediction model of railway noise in consideration of reflection on bridge,” Institution of Noise Control Engineering of Japan, 2013 fall meeting for presenting research papers, pp. 159–162, 2013 (in Japanese).

[3] Yukie OGATA, et al, “Effect of sound reflection on a surface of bridge on railway noise,” Institution of Noise Control Engineering of Japan, 2014 fall meeting for presenting research papers, pp. 71–74, 2014 (in Japanese).

[4] Kiyoshi NAGAKURA, et al, “Prediction model of wayside noise level of Shinkansen,” International Congress on Acoustics, pp. IV2563–2566, 2004.

[5] The Research Committee on Road Traffic Noise, the Acoustical Society of Japan, “Road traffic noise prediction model ‘ASJ ASJ RTN-Model 2013’,” Acoustic Sci. and Tech., vol. 36, No. 2, pp. 49–108, 2015.

[6] Kiyoshi NAGAKURA, et al, “Prediction model of railway noise at high-rise buildings,” Inter noise, in09_101, 2009.

Authors

Yukie OGATA
Senior Researcher, Noise Analysis Laboratory, Environmental Engineering Division
Research Areas: Railway Noise

Hidetoshi SAITO
Technical Manager, West Japan Railway Company
Research Areas: Railway Environment

Toshiki KITAGAWA, Ph.D.
Senior Chief Researcher, Laboratory Head, Noise Analysis Laboratory, Environmental Engineering Division
Research Areas: Railway Noise