IMPROVEMENT OF THE PREDICTION MODEL OF SHINKANSEN NOISE

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ABSTRACT
In order to improve the prediction model of Shinkansen noise, which we reported at inter-noise 1997, structure-borne sound radiated from elevated structures and multiple reflections of rail-wheel noise between train bodies and noise barriers were investigated. The acoustic power, the directivity, and the source position of structure-borne sound were determined from the sound intensity data obtained by field measurement. The effect of multiple reflections on sound pressure levels was examined by scale model experiment and the results showed that the effect differed according to barrier heights and source locations. These results were newly introduced into the prediction model.

1.INTRODUCTION

Central Japan Railway Company has been studying a method to predict wayside noise, so as to achieve compatibility between higher operation speed and maintenance of sound environments along the route of Tokaido Shinkansen. This method, which is based on the intensity level of sound measured in the vicinity of a passing Shinkansen train, enables us to calculate level profile of noise radiated from a train body [1]. Then it is necessary to develop a method to calculate sound from elevated structure in order to predict wayside noise at the areas close to that structure precisely. In the prediction model, it is supposed that the increase of sound pressure level due to multiple-reflections of rail-wheel noise between train bodies and noise barrier equals to 2 dB though following factors should be considered; barrier height, a source and receiver positions. To calculate the level profile of rail-wheel noise exactly, we should grasp the amount of increase level relative to those factors. In this paper, we report the procedure to apply these two calculation models to the prediction method and the comparison between calculated and measured profiles.

2.PREDICTION OF SOUND FROM ELEVATED STRUCTURE

2.1. Measurement of sound from elevated structure

In order to grasp the characteristics of sound from elevated structure, sound intensity levels were measured under a Shinkansen elevated structure. Arrangement of measuring points is shown in Fig.2.1. Six intensity probes were ordered horizontally at intervals of 1.8m at a distance of 1m below the under surface of the structure. Two sound level meters were set on the ground, one under the center of two tracks P_1, and the other under the merge of west bound side line of the structure P_2. To record the position of trains and calculate their traveling speed, we installed sensors of infrared light at the rail level height. Each of two tracks on the structure has welded rail joints at intervals of 50m, and the closest joint from the section including these measuring points is, 9m for east bound and 25m for west bound.

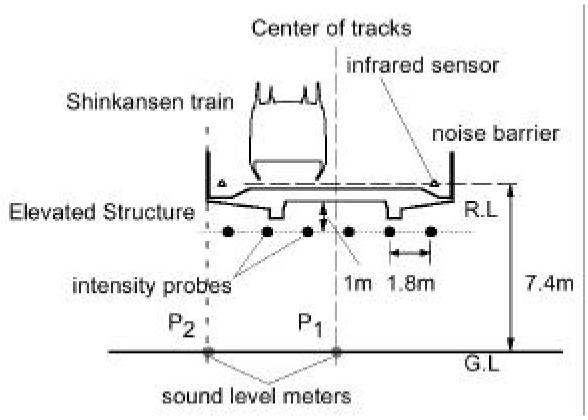


Fig.2.1 Set up of the field measurement.

2.2 Estimation of sound power level for sound from elevated structure

Figure 2.2 shows the distributions of Aweighted sound intensity level, L_I^{meas}, and A-weighted sound pressure level, L_{pA}^{meas}, for "series 700" Shinkansen trains. These values L_I^{meas}, L_{pA}^{meas} were averaged over each passing time. From this figure, we notice that some data of L_I^{meas} under the opposite side of the track, at which train travels, is negative. We estimate that the values L_I^{meas} at these measuring points become negative, because the sound radiated from the structure, L_I^+ is combined with the sound reflected from the ground, L_I^-. In this situation, the measured values, L_I^{meas}, is always lower than the true ones, L_I^+, and this leads to underestimate power level of sound radiated from the elevated structure, L_W. To avoid this underestimation, we estimate the sound reflected from the ground, L_I^-, using following formula (1);

$$L_{pA}^{meas} = 10 * \log_{10}(10^{L_I^+/10} + 10^{L_I^-/10}), \qquad L_I^{meas} = 10 * \log_{10}(10^{L_I^+/10} - 10^{L_I^-/10}) \qquad (1)$$

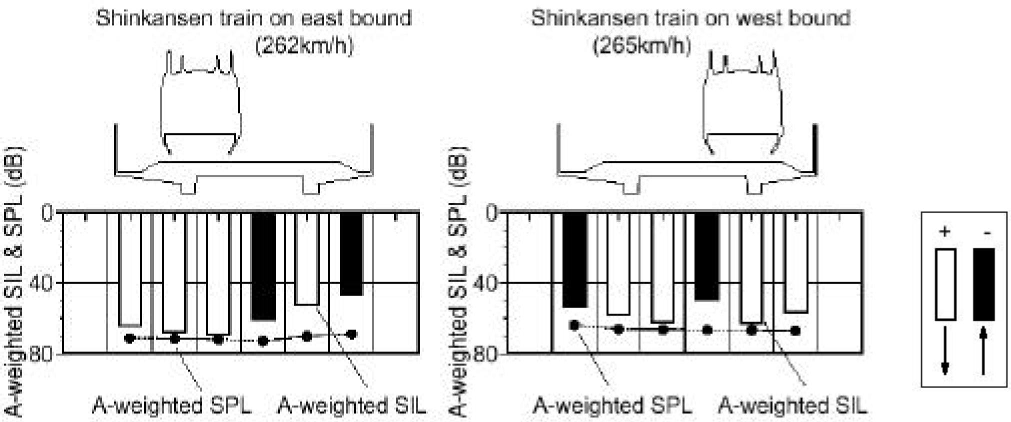


Fig.2.2 Distributions of A-weighted SIL L_I^{meas} and A-weighted SPL L_{pA}^{meas} (Series 700).

We use the data, which the gap between L_{pA}^{meas} and L_I^{meas} is smallest, for the calculation. Moreover, we assume that the levels of L_I^- are same at all measuring points, and calculated the intensity levels of sound radiated from the structure L_I^+ using L_I^{meas} and L_I^-. Finally sound power level, L_W, was calculated from averaged value of six data L_I^+, and the effective area of the structure where radiated the sound, (i.e. train length x structure width). Table 2.1 shows sound power levels L_W for series 700 Shinkansen trains at the speed range from 260 to 270 km/h. The values L_W for the east bound track are larger than those of the west bound track by 5 ~ 8dB. It is the difference of the distance from the closest welded joint to the measuring section that cause the difference of the values L_W between two tracks differs.

Table 2.1 Sound power levels of sound from elevated structure at V= 260 ~ 270km/h.

Train types	Series 700	
Running tracks	East bound	West bound
Sound power level	106 ~ 109dB	100 ~ 101dB

2.3 Calculation model of sound radiated from elevated structure

Table 2.2 shows the averaged gap of the maximum level, $L_{pA,Smax}$, between two positions, that is P_1 and P_2 on the ground. This shows that the level difference of two $L_{pA,Smax}$ is around 4 dB for east bound trains, and 1dB for west bound trains. This result indicates that the sound source corresponding to each track on which the train travels will be placed on different position.

Table 2.2 Level difference of $L_{pA,Smax}$ between P_1 and P_2. (P_2-P_1)

track side(Number of data)	East Bound (N=17)	West Bound (N=25)
AVE [SD]	-3.7 dB [1.35 dB]	-1.0 dB [1.15 dB]

We suppose the following model for sound from elevated structure based on those previous results.

- Apply a model of multiple point sources. These point sources are laid on the under surface just below the track on which train passes by, at intervals of adjacent bogies.
- L_{WP} is applied as the sound power level for each point source. The value of L_{WP} is determined by dividing the value L_W of Table 2.2 by 32, that is the number of bogies.
- Assume that the point source has directivity of $\cos^2\theta$ based on the data of Table 2.2, where θ is the angle with the direction which is perpendicular to the under surface of the elevated structure.
- Consider image sources corresponding to the sound reflected from the ground.
- Sound power W_P of each point source is directly proportional to a cubic of the passing speed V. ($L_{WP} = 10 * \log_{10}(W_P)$, $W_P \propto V^3$)

Figure 2.3 shows the comparison of profiles of A-weighted SPL between measured and predicted using this source model. Table 2.3 shows the averaged gap of $L_{pA,Smax}$ between measured and predicted for 12 trains. The increase of level caused by adding the sound reflected from the ground was assumed as 6 dB. For every measuring points, predicted profiles agree with the measured ones well, and averaged gap of $L_{pA,Smax}$ is within 1 dB.

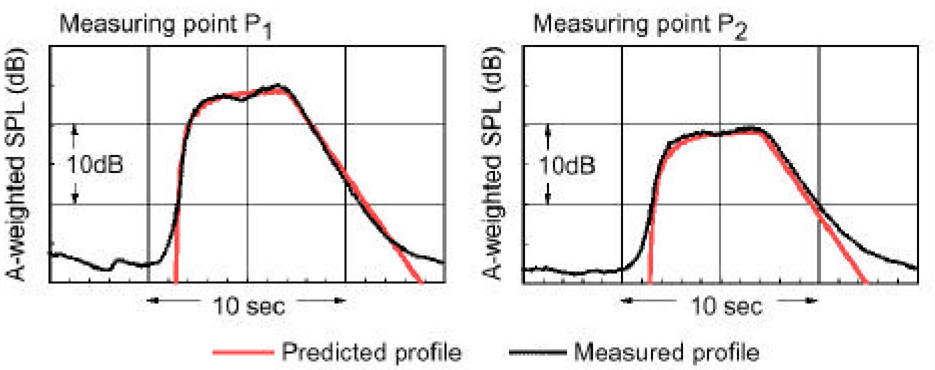


Fig. 2.3 Comparisons of level profiles of sound from the structure between predicted and measured. (Series 700 travels on east bound track at the train speed of 257.6km/h)

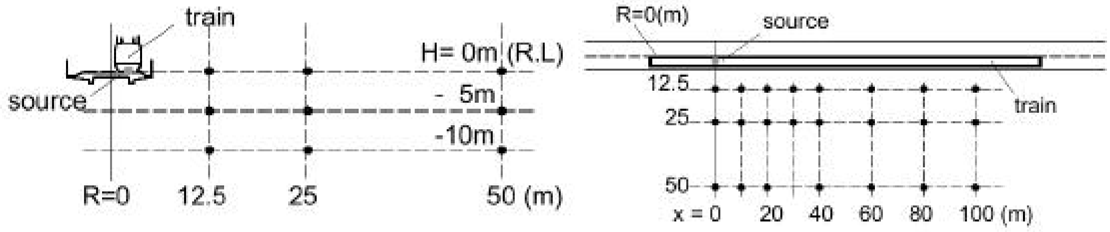
Table 2.3 The averaged gap of $L_{pA,Smax}$ between predicted and measured.

Measuring points	Point P_1	Point P_2
AVE [SD]	0.5 dB [0.85 dB]	0.6 dB [1.12 dB]

3.CALCULATION OF NOISE INCREASE CAUSED BY MULTIPLE-REFLECTIONS

3.1. Scale model experiments

To identify the amount of increase level caused by multiple-reflections of rail-wheel noise between a train body and a noise barrier, we carried out 1/25 scale model experiments for both hard and absorptive barriers. Both an elevated structure (length of 200m in full scale) and a Shinkansen train of series 700 (length of 150m in full scale) were used in the experiments. A noise barrier, its height of 2m or 3m from formation level in full scale, was attached to the edge of the elevated structure. To imitate absorbing material, felt cloth of 3-mm thick, which has high absorption coefficient at the frequency range in scale model, was put on the barrier. Fig 3.1 shows the positions of a sound source and measuring points.



(a) Cross section (b) Plane section

Fig.3.1 Arrangement of a noise source and measuring points in scale model experiments.

3.2. Results of the scale model experiments

Figure 3.2 shows time history of pulse for both hard and absorptive barriers that have 2m or 3m height. This figure shows that the contribution of the diffracted sounds due to multiple-reflections becomes larger when the barrier becomes higher. For the barrier of 3m height, a bogie cover shields the diffracted sound reach to a measuring position directly, and then this direct-diffracted sound becomes extremely smaller than the direct-diffracted one for that of 2m height. This indicates that such complicated propagation of rail-wheel sound should be considered to predict the amount of increase level caused by multiple-reflected sound exactly. Figure 3.3 shows unit pattern levels for both hard and absorptive barriers in 2m or 3m high. Solid line represents the unit pattern level for each hard barrier calculated using Maekawa's chart excluding the contribution of multiple-reflected sounds. From this figure, we notice that the gap of SPL between hard and absorptive barriers dL_{abs} is represented by the sum of the gap of SPL between with and without multiple-reflections dL_{multi} (i.e. that of SPL between measured and calculated values for hard barrier) and that of shielding effect between hard and absorptive barriers dL_{screen} (i.e. that of SPL between calculated value for hard barrier and measured value for absorptive one).

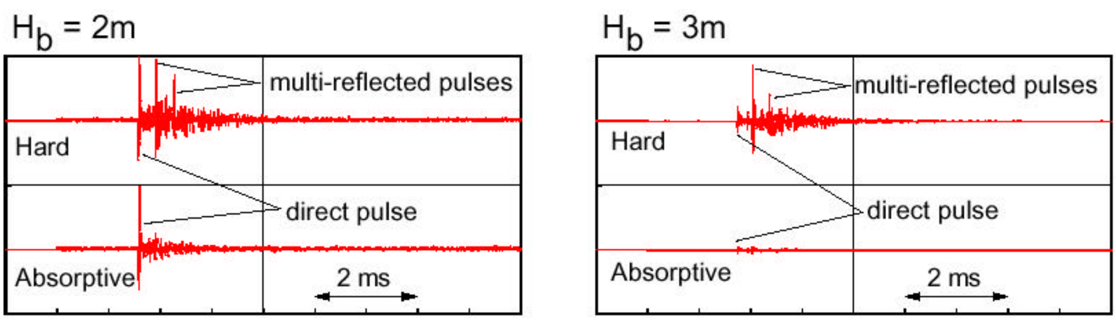


Fig.3.2 Time history of pulse for both hard and absorptive barriers (H=0m,R=25m,x=0m).

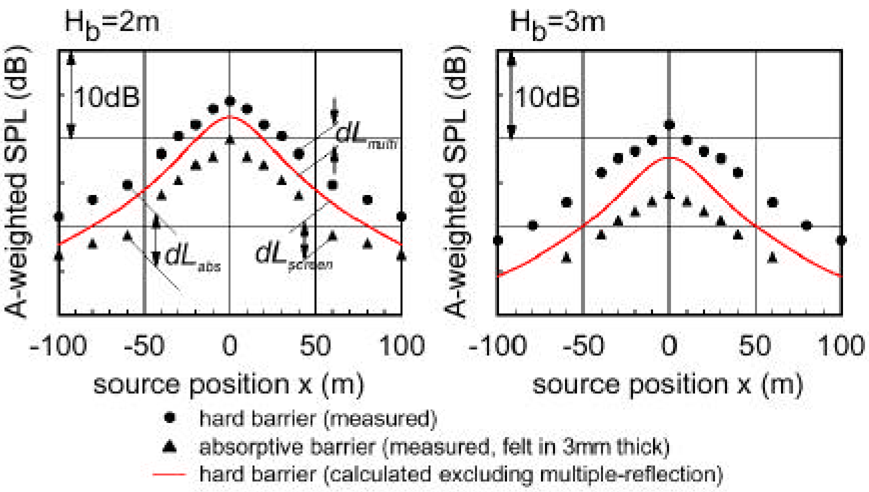


Fig.3.3 Unit pattern levels of noise from a bogie part (H=0m, R=25m).

3.3. <u>Modification procedure of the increase of level due to multiple-reflections</u>

We decide that the profile of rail-wheel noise, including the contribution of multiple-reflections, is predicted by adding the values dL_{multi} to that of rail-wheel noise which calculated using Maekawa's chart. The values dL_{multi}, however, do not always equal to the increase level due to multiple-reflections. Figure 3.4 shows the charts of the correction value dL_{multi} according to source positions for each barrier height.

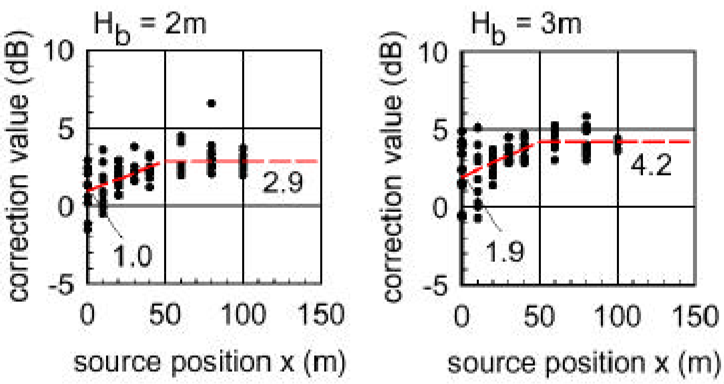


Fig.3.4 Charts of correction value dL_{mult} due to multiple-reflected sounds.

4.MODIFICATION OF PREDICTION MODEL

The profiles of A-weighted SPL were measured at four places along the elevated structure of Tokaido Shinkansen. Fig 4.1 shows examples of measured profiles and calculated ones, using the modified prediction method, at distances of R = 6.25m, 12.5m, and 25m away from center of tracks, for series 700 Shinkansen train. Fig 4.2 shows the comparison between predicted and measured maximum levels $L_{pA,Smax}$. Each predicted profile in Fig. 4.1 is the averaged profile of five calculated using different data of sound intensity for series 700 train. The profile of the sound from the elevated structure is calculated using sound power levels L_W of west bound track, shown in Table 2.1. The total noise profile is the combination of these two profiles. At the position of R=6.25m, accuracy of the modified prediction method improves by around 2 dB, adding the sound from the elevated structure, however the predicted maximum levels $L_{pA,Smax}$ still have errors of 2 to 4 dB at all the points except with R=25m. Since the correction value for multiple-reflections is almost same for both before and after modification of the model, for barrier in 2m high, improvement can not be verified by modifying the influence of multiple-reflections.

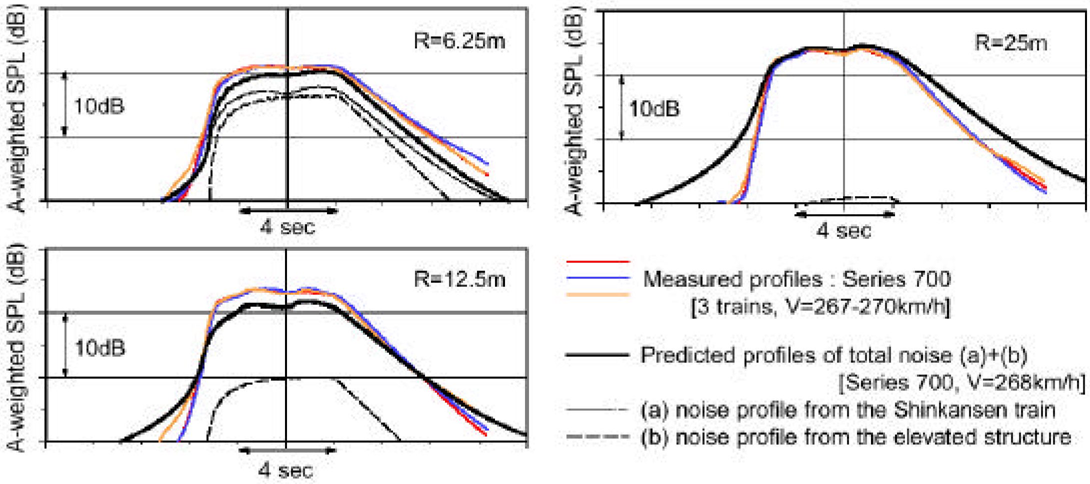


Fig.4.1 Comparisons of noise profiles between with and without sound from the elevated structure. (Height of elevated structure H=6.9m, barrier height H_b=2.0m)

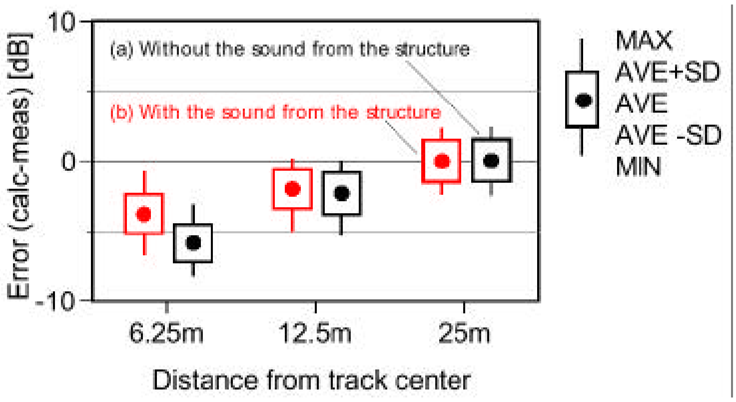


Fig.4.2 Comparison of accuracy of prediction model between with and without sound from the structure. (Height of elevated structures H=6.5 ~ 8.5m, barrier height H_b=2.0 ~ 2.3m)

5. CONCLUSION

We have modified prediction method of wayside noise by adding the model of the sound radiated from the elevated structure of Shinkansen railway and improving the calculation of the noise levels which include multiple-reflections of rail-wheel noise between a train body and a noise barrier. The source model of the sound from the elevated structure was determined on basis of the field measurements. The effect of multiple-reflections on sound pressure levels was examined by scale model experiments and modified the model, previously assumed as 2dB increase, to calculate the effect of multiple-reflections according to barrier heights and source locations. The profiles calculated using the modified prediction model were compared with measured ones at the points close to the elevated structure. The accuracy of this prediction method is improved by around 2 dB, by adding the sound from the elevated structure, however the improvement by modifying the effect due to multiple-reflections could not be verified.

6. REFERENCES

[1] "Source identification and prediction of Shinkansen noise by sound intensity", Mizumasa Kawahara, Hidetoshi Hotta, Masaaki Hiroe and Jiro Kaku, Proceeding of inter-noise '97, p.151 ~ 154, 1997.
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