

## Study on Conventional Railway Line Noise in High Spaces



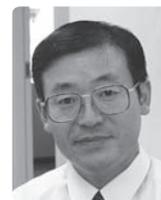
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In this study, we carried out noise measurement in different environments including high spaces because conventional railway line noise characteristics in high spaces had not been well identified up to now. Based on those measurement results, we derived a compensation formula that indicates directional characteristics of noise transferred from the lower part of the car body to high spaces of embankment sections and flat sections. In that formula, the parameter was angle of elevation  $\theta$  according to the difference between prediction and actual measurement in the Railway Technology Research Institute (RTRI) formula. We checked validity of that compensation formula by applying it to noise prediction of other trains. The check results demonstrated that the formula could predict sound level in wayside high spaces with an approx. 2 dB margin of error.

● **Keywords:** Conventional train noise, High spaces, Prediction of conventional train noise, Directional characteristics

### 1 Introduction

In urban areas, buildings are often constructed adjacent to conventional railway lines, and sometimes train noise poses a problem to upper floors of those. Furthermore, environmental assessment for recent new railway construction and large-scale improvement work such as construction of continual two-level crossings requires vertical noise prediction in addition to that for horizontal noise. Need for noise prediction for upper floors of wayside buildings is increasing in this way, but noise characteristics in high spaces along conventional line are still not identified well. In light of that situation, we carried out noise measurement in different environments including high spaces along conventional lines to identify noise characteristics. We further studied application of the existing noise prediction formula (RTRI's formula in "Study on Prediction Model of Conventional Railway Line Noise" (January 2005)) to high spaces.

### 2 Identifying Conventional Railway Line Noise in High Spaces

#### 2.1 Measurement Point

In order to identify differences of noise characteristics between structure types, we chose the following three measurement points.

- (1) Flat section
- (2) Embankment-elevated section
- (3) Concrete viaduct section (with noise barrier)

#### 2.2 Measurement Overview

Fig. 1 shows profiles of the measured areas. Using a high-place work car, we made measurements in a horizontal range of 6.25 m to 31.25 m and in a vertical range of 1.2 m to 25 m, both from the center of the track. In the embankment-elevated section, we measured at the point 10 m from the center of the track because the embankment interfered with measurement at the 6.25 m point.

Sound level meters and cables were suspended on a rope from the high-place work car, and another sound level meter was set near the track. In the concrete viaduct section, we added sound level meters at the top of the noise barrier and just under the viaduct.

#### 2.3 Measurement Results

Fig. 2 shows relative values of sound level in average case at each measurement point, with the maximum sound level near the track as 0.

##### (1) Flat section

Train noise spread in the entire space with the area along the tracks as the center; however, we found relatively strong directional characteristics diagonally from the noise source. At the point 1.2 m above the ground, there was tendency whereby attenuation by distance was greater in the horizontal direction than upward.

##### (2) Embankment-elevated section

As shown in the flat section, train noise spread in the entire space with the area along the tracks as the center, and we observed relatively strong directional characteristics diagonally upward from the noise source too. At the points lower than the noise source (1.2 m and 5.0 m height), noise overall tended to be less than at the points higher than the noise source.

##### (3) Concrete viaduct section (with noise barrier)

Train noise spread diagonally upward from the top of the noise barrier as the center. This could be because noise was discharged from at the top of the noise barrier after multireflection between car body and noise barrier. As observed in the embankment-elevated section, noise was less at the points lower than the noise source (1.2 m and 5.0 m height) than at the points higher than that. That could be regarded as an effect of diffraction by the noise barrier.

Those measurement results revealed that noise was louder at points higher than at the point 1.2 m above ground, the usual noise evaluation point. In noise assessment in the vertical direction, we have to take into account those noise characteristics.

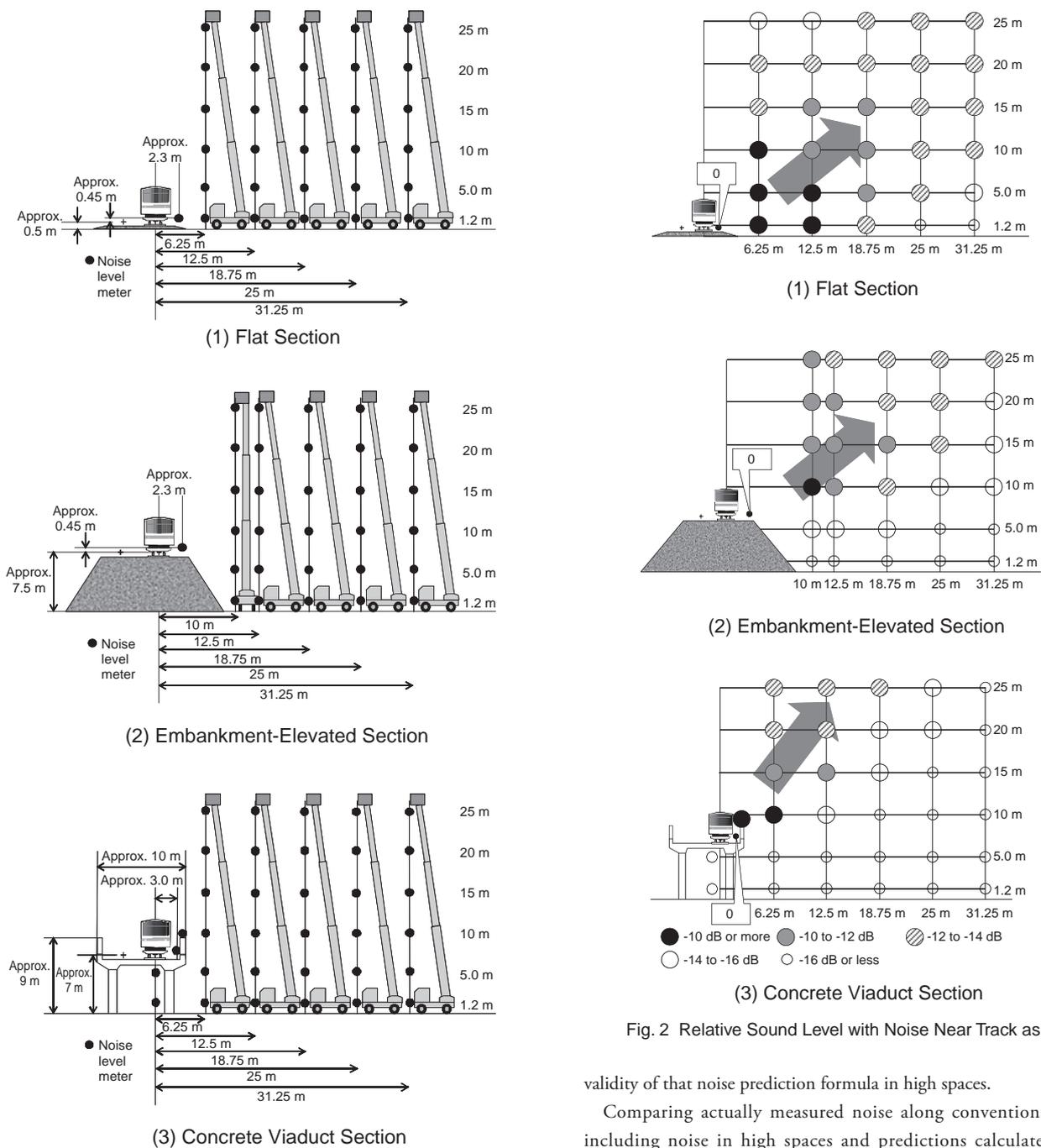


Fig. 1 Profiles of Noise Measurement

**3 Proposal of Noise Prediction Formula for Conventional Railway Line Noise Applicable Also to High Spaces**

**3.1 Development Overview**

To comply with Ministry of the Environment Guideline “Noise Control Guideline for New Construction and Large-Scale Improvement of Conventional Line” (1995), a conventional line noise prediction model has been developed based mainly on noise data measured at around 1.2 m above ground, and that model is applied to noise prediction at that height. Since the present noise prediction formula does not take into account directional characteristics of the noise source on the vertical face and effects of noise reflection between noise barrier and car body, we have to verify

Fig. 2 Relative Sound Level with Noise Near Track as 0

validity of that noise prediction formula in high spaces.

Comparing actually measured noise along conventional lines including noise in high spaces and predictions calculated with existing noise prediction formula (RTRI’s formula in “Study on Prediction Model of Conventional Railway Line Noise” (January 2005)), we found that predicted values exceeded actual values by 2 to 5 dB at measurement points higher than the track, regardless of structure type. Accordingly, noise control work in high spaces that is planned at design stage might be excessive. Thus, there should be demand for a prediction model that could contribute to streamlined design and construction. In the light of the situation, we decided to develop a conventional line noise prediction formula applicable also to high spaces so we could improve noise prediction accuracy at points higher than the track.

**3.2 Examination Overview**

Existing noise prediction formula (RTRI’s formula) is a measure to obtain energy-based noise values (equivalent continuous A-weighted

sound pressure level  $L_{Aeq}$  or sound exposure level  $L_{AE}$ ). Since difference between main noise source power level  $L_W$  that is set in that formula and actual measurement value causes discrepancy between prediction and actual measurement, we predicted noise source power based on actual measurement data. Predicted values of sound exposure level  $L_{AE}$  at each measurement point was worked out from the power level  $L_W$  that was calculated with sound exposure level  $L_{AE}$  at the point near the track.

Power level  $L_W$  was calculated with train speed  $v$  (m/s) and shortest distance from the train's track to the measurement point  $r$  (m) by formula (1) (cited from Reference 1).

$$\begin{aligned} L_{AE} &= L_W - 10 \log(4 \times v \times r) \\ &= L_W - 6 - 10 \log(v) - 10 \log(r) \\ \therefore L_W &= L_{AE} + 6 + 10 \log(v) + 10 \log(r) \dots (1) \end{aligned}$$

Next, we compared spatial distribution characteristics of actual measurement values and predicted values of sound exposure level  $L_{AE}$  to see spatial distribution of level difference between those. We then developed a prediction formula to calculate correction value  $\Delta$  for arbitrary measurement points in high spaces. Correction value  $\Delta$  that we defined was the difference between predicted value of sound exposure level  $L_{AE}$  obtained by RTRP's prediction formula and the actual measurement value of that. This time, we will report on the examination results of the embankment-elevated section and flat section.

### 3.3 Examination Results

#### 3.3.1 Embankment-Elevated Section

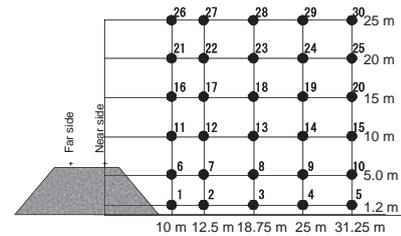
We analyzed noise level with 15-car trains of rolling stock series A and 15-car trains of rolling stock series B. At passing of each train, we worked out noise power level  $L_W$  by formula (1) based on sound exposure level  $L_{AE}$  at the point near the track, and we further calculated level difference between the predicted value of sound exposure level on that power level  $L_W$  and actual sound exposure level. That difference is correction value  $\Delta$ . Table 1 lists differences between predicted values and actual values of sound exposure level of series A trains and series B trains.

Average values in the table are arithmetic mean value of level differences per train type, and deviation  $\sigma$  is standard deviation of those. The table shows that variation (deviation) between trains was small for each car series, with 95% confidence interval of variation ( $\sigma \times 1.96$ ) of 1.5 dB as the maximum. It also shows that there was almost no difference between rolling stock series A and B. In other words, looking at sound exposure level, transmission characteristics of train running noise can be considered stable regardless rolling stock series. So, we classified correction values  $\Delta$  into those of trains on the near side and of trains on the far side, and we plotted with angle of elevation  $\theta$ . The results are shown in Table 3.

Here, angle of elevation  $\theta$  is the angle between the segment from the center of the measured track to the measurement point and the rail level line (horizontal line). From the rail level as the benchmark ( $\theta = 0$ ), higher than that is positive and lower than that is negative. Fig. 3 shows approximation curves of correction

Table 1 Difference Between Predicted Value and Actual Value of Sound Exposure Level

		Embankment section								
Point	r(m)	H(m)	Series A 15-car train				Series B 15-car train			
			Near side		Far side		Near side		Far side	
			Average	Deviation $\sigma$	Average	Deviation $\sigma$	Average	Deviation $\sigma$	Average	Deviation $\sigma$
1	-10.00	1.2	-11.8	0.46	-14.5	0.47	-12.0	0.55	-13.9	0.19
2	-12.50	1.2	-9.7	0.45	-13.0	0.41	-10.0	0.56	-12.3	0.26
3	-18.75	1.2	-8.4	0.38	-11.4	0.45	-8.6	0.56	-10.7	0.23
4	-25.00	1.2	-7.2	0.32	-10.2	0.39	-7.4	0.63	-9.4	0.24
5	-31.25	1.2	-5.6	0.29	-8.7	0.28	-5.8	0.61	-7.9	0.22
6	-10.00	5	-6.6	0.27	-9.6	0.27	-6.8	0.58	-9.0	0.30
7	-12.50	5	-5.7	0.27	-8.9	0.25	-6.1	0.62	-8.4	0.28
8	-18.75	5	-4.0	0.35	-6.9	0.20	-4.5	0.64	-6.4	0.23
9	-25.00	5	-4.2	0.38	-6.8	0.19	-4.5	0.65	-6.2	0.23
10	-31.25	5	-3.9	0.34	-5.9	0.18	-4.2	0.59	-5.4	0.15
11	-10.00	10	-1.4	0.34	0.0	0.11	-1.8	0.62	0.5	0.30
12	-12.50	10	-1.7	0.31	-1.0	0.00	-2.1	0.62	-0.5	0.27
13	-18.75	10	-2.1	0.33	-2.1	0.07	-2.5	0.59	-1.6	0.22
14	-25.00	10	-2.1	0.40	-2.4	0.05	-2.3	0.66	-1.9	0.12
15	-31.25	10	-2.7	0.44	-3.1	0.04	-3.0	0.71	-2.5	0.14
16	-10.00	15	-1.4	0.42	-0.4	0.14	-1.7	0.62	0.2	0.44
17	-12.50	15	-0.1	0.42	0.5	0.16	-0.5	0.63	1.2	0.44
18	-18.75	15	-0.3	0.45	-0.2	0.16	-0.7	0.63	0.4	0.38
19	-25.00	15	-0.6	0.48	-0.9	0.10	-1.1	0.64	-0.4	0.27
20	-31.25	15	-0.9	0.50	-1.3	0.11	-1.2	0.74	-0.8	0.22
21	-10.00	20	-1.1	0.47	-0.4	0.11	-1.4	0.65	0.3	0.39
22	-12.50	20	-0.7	0.45	0.0	0.13	-1.1	0.63	0.7	0.44
23	-18.75	20	0.0	0.46	0.0	0.20	-0.3	0.70	0.6	0.47
24	-25.00	20	0.1	0.54	0.2	0.18	-0.2	0.63	0.8	0.40
25	-31.25	20	0.1	0.55	-0.1	0.20	-0.2	0.70	0.4	0.32
26	-10.00	25	-0.2	0.45	0.5	0.19	-0.5	0.67	1.0	0.37
27	-12.50	25	-1.4	0.49	-0.9	0.23	-1.7	0.67	-0.4	0.37
28	-18.75	25	0.8	0.47	0.6	0.23	0.4	0.62	1.2	0.47
29	-25.00	25	0.6	0.51	0.6	0.22	0.3	0.64	1.2	0.49
30	-31.25	25	0.9	0.56	1.0	0.27	0.6	0.77	1.4	0.46



values  $\Delta$ , excluding those at measurement points screened by embankment slope ( $\theta < 0^\circ$ ). Fig. 3 illustrates directional characteristics where train noise reached its maximum at  $39^\circ$  diagonally upward on the near side and at  $36^\circ$  on the far side. As the difference between approximation formulae for trains on the near and far sides is relatively small within the range of angle of elevation  $0^\circ \leq \theta \leq 65^\circ$ , we developed an average approximation formula that integrates formulae per track line. Those formulae are shown in (2) below.

Average difference between values calculated by average approximation formula (formula (2)) and actual measurement values at each measurement point within the range of angle of elevation  $0^\circ \leq \theta \leq 65^\circ$  was  $-1.1$  to  $+1.3$  dB ( $\sigma = 0.49 - 0.68$  dB) for trains on the near side and  $-0.5$  to  $+1.4$  dB ( $\sigma = 0.27 - 0.51$  dB) for trains on the far side.

$$\left. \begin{aligned} \text{Average: } \Delta &= -0.00303 \theta^2 + 0.223 \theta - 3.77 \\ \text{Near side: } \Delta &= -0.00253 \theta^2 + 0.196 \theta - 3.88 \\ \text{Far side: } \Delta &= -0.00352 \theta^2 + 0.250 \theta - 3.66 \end{aligned} \right\} \dots (2)$$

To verify validity of the approximation formula of correction value  $\Delta$  developed on data of 15-car series A trains and 15-car series B trains, we cross-checked values calculated by that formula with actual measurement data of 10-car series A trains, 11-car series B trains and 6-car series C trains. Table 2 lists differences between predicted values and actual values at each measurement point. Predicted values largely agreed with actual values within the prediction application

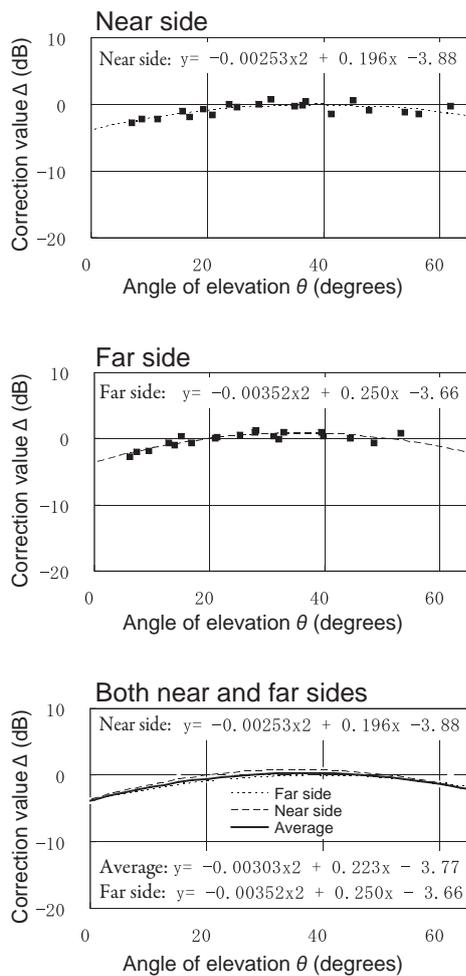


Fig. 3 Relation Between Correction Value  $\Delta$  and Angle of Elevation  $\theta$  in Embankment Section

range (angle of elevation  $0^\circ \leq \theta \leq 65^\circ$ , measurement points 11–30), with differences of -1.6 to +1.2 dB for 10-car series A train on the near side and -2.0 to -0.3 dB for that train on the far side. Similarly, differences for 11-car series B train were -1.5 to +1.2 dB on the near side and -2.0 to +0.3 dB on the far side, and those for 6-car series C train were -1.6 to +1.2 dB.

As explained above, we demonstrated that we can predict sound level in wayside high spaces by approx. 2 dB error of margin regardless of train car series and number of cars by adding the compensation formula developed in (2) to the existing conventional line noise prediction formula.

### 3.3.2 Flat Section

As done for the embankment-elevated section, we calculated level differences between predicted values by RTRI's formula and actual measurement values in a flat section.

We analyzed noise level with 6-car trains of car series D that ran at the same speed on the near and far sides, excluding three trains on each side. Table 3 lists differences in predicted sound exposure level values and actual values. On the both near and far sides, level variation by train was small, demonstrating that transmission characteristics of noise from the lower part of car body are stable. Table 4 shows average level differences—spatial

Table 2 Difference Between Predicted Value and Actual Value of Sound Exposure Level

### Verification Result in Embankment-Elevated Section

Point	r(m)	H(m)	Series A 10-car train		Series B 11-car train		Series C 6-car train	
			Near side	Far side	Near side	Far side	Near side	Far side
1	-10.00	1.2	0.7	4.5	0.6	5.1	0.9	—
2	-12.50	1.2	0.2	4.0	0.1	4.4	0.7	—
3	-18.75	1.2	0.8	3.9	0.7	4.1	1.3	—
4	-25.00	1.2	0.4	3.1	0.6	3.5	1.2	—
5	-31.25	1.2	-0.6	1.9	-0.5	2.3	0.2	—
6	-10.00	5.0	1.0	4.0	1.1	4.1	1.6	—
7	-12.50	5.0	0.5	3.6	0.7	3.5	1.1	—
8	-18.75	5.0	-0.6	2.0	-0.6	1.8	0.0	—
9	-25.00	5.0	-0.3	1.9	-0.4	1.9	0.4	—
10	-31.25	5.0	-0.5	1.2	-0.6	1.1	0.1	—
11	-10.00	10.0	0.6	-2.0	0.5	-2.0	0.7	—
12	-12.50	10.0	0.5	-1.4	0.4	-1.2	0.9	—
13	-18.75	10.0	0.2	-0.9	0.1	-0.6	0.7	—
14	-25.00	10.0	-0.3	-0.9	-0.4	-0.6	0.2	—
15	-31.25	10.0	0.0	-0.5	-0.1	-0.1	0.5	—
16	-10.00	15.0	1.3	-0.4	1.2	-0.1	1.2	—
17	-12.50	15.0	0.2	-1.6	0.0	-1.2	0.3	—
18	-18.75	15.0	-0.1	-1.5	-0.3	-1.1	0.3	—
19	-25.00	15.0	-0.3	-1.3	-0.4	-0.9	0.5	—
20	-31.25	15.0	-0.6	-1.3	-0.6	-0.8	0.4	—
21	-10.00	20.0	0.1	-0.7	0.2	-0.2	-0.2	—
22	-12.50	20.0	0.2	-1.0	0.3	-0.5	0.1	—
23	-18.75	20.0	-0.2	-1.0	-0.2	-0.6	-0.1	—
24	-25.00	20.0	-0.5	-1.5	-0.6	-1.1	-0.2	—
25	-31.25	20.0	-0.7	-1.6	-0.8	-1.1	-0.3	—
26	-10.00	25.0	-1.6	-2.0	-1.5	-1.4	-1.6	—
27	-12.50	25.0	0.2	-0.3	0.2	0.3	0.1	—
28	-18.75	25.0	-1.0	-1.5	-0.9	-1.1	-1.2	—
29	-25.00	25.0	-0.7	-1.6	-0.7	-1.2	-0.8	—
30	-31.25	25.0	-1.2	-2.1	-1.2	-1.6	-1.1	—

distribution of average correction value  $\Delta$ —on each track. Here, data at measurement points of 1.2 m height above ground (points 1–5) is excluded because probably those could be greatly affected by ground surface absorption. Fig. 4 illustrates directional characteristics where train noise reached its maximum at  $38^\circ$  diagonally upward on the near side and at  $37^\circ$  on the far side.

The difference between approximation formulae for trains on the near and far sides is very small within the range of angle of elevation  $0^\circ \leq \theta \leq 80^\circ$ . We thus integrated approximation curves per track line into one.

Approximation formulae per track line and average approximation formula are shown in (3) below. Average difference between calculated values by average approximation formula (formula (3)) and actual measurement values at each measurement point excluding measurement points of 1.2 m height above ground was -2.2 to +2.0 dB ( $\sigma = 0.34 - 0.62$  dB) for trains on the near side and -1.5 to +0.39 dB ( $\sigma = 0.52 - 0.79$  dB) for trains on the far side.

In order to verify validity of average approximation formula of

$$\left. \begin{aligned} \text{Average: } \Delta &= -0.00197 \theta^2 + 0.146 \theta - 2.07 \\ \text{Near side: } \Delta &= -0.00204 \theta^2 + 0.154 \theta - 2.01 \\ \text{Far side: } \Delta &= -0.00189 \theta^2 + 0.140 \theta - 2.12 \end{aligned} \right\} \dots (3)$$

correction value  $\Delta$  (formula (3)), we cross-checked calculated values by that formula with actual measurement data of 6-car series D trains, three trains running at the same speed on each side. Check results clarified that predicted values largely agreed with actual values within the prediction application range (angle of elevation  $0^\circ \leq \theta \leq 80^\circ$ , measurement points 6–30), with differences of -0.4 to +2.1 dB on the near side and -0.4 to +0.9 dB on the far side.

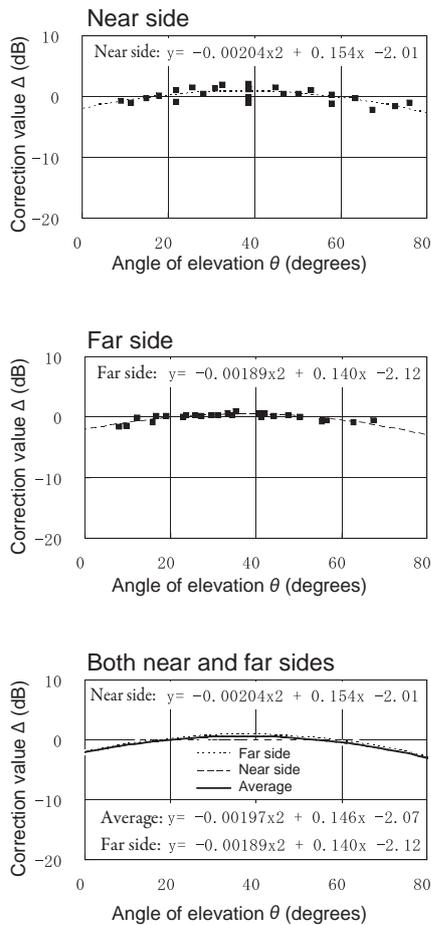


Fig. 4 Relation Between Correction Value  $\Delta$  and Angle of Elevation  $\theta$  in Flat Section

As explained above, we derived a compensation formula that indicates directional characteristics of noise from the lower part of car body in high spaces in a flat section using angle of elevation  $\theta$  as the parameter. That is the same as was done for embankment section. We verified validity of the derived compensation formula by applying that to noise prediction for other trains. Verification results demonstrated that we could predict sound level in wayside high spaces with approx. 2 dB error of margin.

## 4 Other Issues to Examine

Now we will point out not-yet-mentioned issues that have to be overcome to expand the scope of application of the noise prediction model and to improve prediction accuracy.

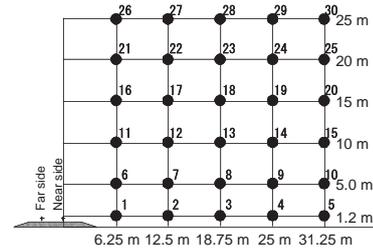
(1) Flat section and embankment section

In this article, we developed approximation formulae of correction value  $\Delta$  for flat sections and embankment sections. In the future, we are planning to integrate those approximation curves in one curve to derive a compensation formula applicable to either flat sections or embankment sections.

(2) Effect of multireflection of noise between car body and noise barrier

Table 3 Difference Between Predicted Value and Actual Value of Sound Exposure Level

Point	r(m)	H(m)	Series D 6-car train			
			Near side		Far side	
			Average	Deviation $\sigma$	Average	Deviation $\sigma$
1	-6.25	1.2	-2.3	0.15	-2.1	0.45
2	-12.50	1.2	-1.8	0.26	-2.1	0.39
3	-18.75	1.2	-3.5	0.46	-4.0	0.49
4	-25.00	1.2	-4.8	0.45	-5.5	0.43
5	-31.25	1.2	-3.9	0.54	-5.2	0.46
6	-6.25	5.0	-1.1	0.34	0.3	0.52
7	-12.50	5.0	-1.0	0.41	0.2	0.79
8	-18.75	5.0	-0.3	0.47	-0.2	0.56
9	-25.00	5.0	-1.0	0.58	-1.4	0.59
10	-31.25	5.0	-0.7	0.56	-1.5	0.60
11	-6.25	10.0	-1.2	0.37	0.2	0.53
12	-12.50	10.0	-0.1	0.39	0.4	0.57
13	-18.75	10.0	0.5	0.48	0.3	0.62
14	-25.00	10.0	1.0	0.56	0.2	0.63
15	-31.25	10.0	0.2	0.57	-0.8	0.65
16	-6.25	15.0	-2.2	0.39	-0.7	0.57
17	-12.50	15.0	0.5	0.45	0.6	0.62
18	-18.75	15.0	1.2	0.48	0.6	0.63
19	-25.00	15.0	1.3	0.45	0.1	0.62
20	-31.25	15.0	1.5	0.48	0.0	0.69
21	-6.25	20.0	-1.6	0.53	-0.9	0.65
22	-12.50	20.0	0.3	0.53	0.0	0.69
23	-18.75	20.0	0.5	0.53	0.0	0.72
24	-25.00	20.0	1.3	0.56	0.4	0.76
25	-31.25	20.0	1.9	0.59	0.4	0.76
26	-6.25	25.0	-1.1	0.56	-0.6	0.74
27	-12.50	25.0	-0.3	0.60	-0.6	0.69
28	-18.75	25.0	1.0	0.56	0.4	0.63
29	-25.00	25.0	1.5	0.57	0.7	0.65
30	-31.25	25.0	2.0	0.62	0.9	0.78



For viaducts with noise barriers, we have to clarify the effect of multireflection of noise between car body and noise barrier. So, we are planning to establish a prediction model for cases with or without noise barriers.

## 5 Conclusion

We are planning to submit the developed noise prediction formula to academic evaluation, with an aim of using that in environmental assessment. For viaducts with noise barriers, we will continue development of a predicted formula, as was done for flat and embankment sections. And we will further study noise control work in high spaces.

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