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THE CONTRIBUTION OF THE INDIVIDUAL SOUND SOURCE GENERATED FROM SHINKANSEN VEHICLES

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Abstract

For the prediction of the wayside noise level it is important to comprehend contribution of individual sound source in detail at a measurement point. First, the power level of individual sound source generated from Shinkansen vehicles were estimated by a field test using an acoustic mirror. Next, an acoustic experiment with 1/25 scale models was conducted to investigate the insertion loss of sound barriers for each sound source position. On the basis of the results of the field test and the acoustic experiment, the contributions of the individual sound source to the wayside noise level were estimated when the Shinkansen vehicles run on a viaduct with sound barriers.

1. INTRODUCTION

Shinkansen noise mainly consists of various noise sources, such as the rolling noise, concrete bridge structure noise, aerodynamic noise and so on. It is important for a good prediction of the wayside noise level to comprehend contribution of individual sound source in detail at a measuring point. In this paper, we first measure a noise source distribution of Shinkansen vehicles in a field test using an acoustic mirror and estimate the sound power of the individual sound source generated from the Shinkansen vehicles. Next we investigate the insertion loss of sound barriers for the individual sound source by an acoustic experiment with 1/25 scale models. Finally, we estimate the contributions of the individual sound source to the wayside noise level (at a distance of 25m from the adjacent track) when the Shinkansen vehicles run on a viaduct with sound barriers.

2. FIELD TEST WITH AN ACOUSTIC MIRROR

2.1 Measurement Techniques

Measurement of the noise source distribution of Shinkansen vehicles was conducted using an acoustic mirror. At the test site, the ground was almost flat and there were no sound barriers.

The acoustic mirror consists of a reflector of elliptic shape whose diameter and focal distance are 1.8 m and 5 m, respectively, and nine microphones arranged in the vertical direction near the focus, the positions of which are Δz=0, $\pm 30, \pm 60, \pm 90, \pm 120$ mm (Δz means the vertical offset of the height from the focus). The directivity pattern, $L(z)$, of each microphone is shown in Figure 1. Here, z is the distance between the sound source and the far focus of the reflector. $L(z)$ has a maximum value at z=-10Δz, which means that the measurement area spreads in the range $-1.2 < z < 1.2$ (m). The measurements were performed at four positions of the mirror in height in order to obtain the noise source distribution on the whole train set (see Figure 2). Typical train speed was 340 km/h and the measured values were averaged during the travel distance of about 2.01 m by every 0.47 m step.

2.2 Result of Field Test

Figure 3 shows sound source maps obtained by the field test. Since, above 500 Hz or over, the spatial resolution of the apparatus is sufficient high, at higher frequencies in particular, they provide us with some qualitative information about noise sources of the Shinkansen vehicles at each frequency band. Here it should be noted that the sound source maps at the frequency bands cannot be compared with each other quantitatively because the characteristics of the acoustic mirror depend on the frequency. The features of Figure 3 are mentioned in [1].

2.3 Estimation of the Power Levels of the Sound Sources

On the basis of the result of the field test the noise sources of the Shinkansen vehicles are divided into the domains shown in Figure 4. In order to estimate the sound power level quantitatively on the basis of the data measured with the acoustic mirror, the following assumptions are introduced [1].

(1) The distribution of the sound source is homogeneous in the domain.
(2) Each sound source is incoherent.
(3) The influence of the sound from outside of the domain can be neglected.

The sound power level generated from the domain, *PWL*, is expressed as follows[1].

$$PWL = L_{meas} - 10\log\left[\frac{1}{2\pi R^2}\frac{1}{S_{area}}\iint_{S_{source}} 10^{L(r)/10}\, dS\right] \cdots\cdots (1)$$

where L_{meas} is the power-mean value of the measured sound pressure level with the acoustic mirror over the domain, R is the distance between the acoustic mirror and the sound source domain, $L(r)$ is the directivity pattern of the acoustic mirror and S_{area} is the area of the sound source domain.

3. INSERTION LOSS OF SOUND BARRIER ESTIMATED BY ACOUSTIC EXPERIMENT

3.1 Outline of Experiment

In order to estimate the sound pressure level generated from the Shinkansen vehicles running on an ordinary viaduct at a distance of 25 m from the adjacent track, the insertion loss of sound barriers should be considered. In general, the insertion loss could be estimated from the Fresnel's number by using an empirical formula, such as Maekawa's empirical formula, which is based on an experiment using a semi-infinite thin barrier and a point monopole source [2]. However, Maekawa's empirical formula could cause an error in the case of the railway noise because the vehicle body affects the insertion loss of the sound barrier due to multiple reflections of the sound wave between the vehicle surface and the barrier. Furthermore, the influence of the vehicle body depends on the height of the sound source. Therefore, an acoustic experiment with 1/25 scale models was conducted to investigate the relation between the insertion loss of sound barriers and the height of the sound sources.

The test set-up is shown in Figure 5. 1/25 scale models of a viaduct, Shinkansen vehicle, and straight type sound barriers of 2 m height were arranged in an anechoic room. Two types of omni-directional sound source, that is, a line source and point source, were prepared. The sources were located at various heights to simulate the noise sources distributed on a vehicle body. The sound pressure level was measured at lattice points in a plane perpendicular to the track, which are distributed in a range from 12 m below the rail level (R.L.) to 6 m above in height and from 12.5 m to 50 m in the horizontal distance from the center of the track (see Figure 5). Table 1 shows the positions of the sound sources of the Shinkansen in the experiment. The experiment was carried out independently on each position of the sound source. Furthermore, in order to estimate the power levels of the sound sources, the experiment was also conducted under the condition without sound barriers, in which the sound pressure level was measured at the points located at the same height of the sound sources and at the horizontal distance of 12.5 m from the center of the track. The measured data were analyzed with FFT analyzer. The analyzed frequency ranged from 6,300 Hz to 100,000 Hz band in a model scale (from 250 Hz to 4,000 Hz band in a real scale).

3.2 Analysis Method

The insertion loss of the sound barriers was estimated for each sound source position and for each frequency band. The procedure of the estimation is as follows:

(1)The measured data were analysed by FFT, and summed up to 1/1 octave band frequency spectrum.

(2)The frequency in the experiment was multiplied by 1/25.

(3)The power level of each sound source, PWL_{source}, was estimated by equation (2), using the data of the experiment without sound barriers, $L_{no\_barrier}$.

$$\left.\begin{aligned} PWL_{source} &= L_{no\_barrier} + 10\log \pi r_0 \quad \text{(for a line source)} \\ PWL_{source} &= L_{no\_barrier} + 10\log 2\pi r_0^{\,2} \text{(for a point source)} \end{aligned}\right\} \cdots\cdots (2)$$

Here, r_0 is the distance between the sound source and the measuring point.

(4)The insertion loss of the sound barrier, ΔL, was estimated by equation (3) for each measuring point, by using the measured sound pressure level with sound barriers, $L_{barrier}$.

$$\left.\begin{aligned} \Delta L &= PWL_{source} - 10\log \pi r - L_{barrier} \quad \text{(for a line source)} \\ \Delta L &= PWL_{source} - 10\log 2\pi r^2 - L_{barrier} \text{(for a point source)} \end{aligned}\right\} \cdots\cdots (3)$$

Here, r is the distance between the sound source and the measuring point.

3.3 Result of the Acoustic Experiment

Figure 6 shows the insertion loss of the sound barriers against Fresnel's number. In Figure 6, the calculated value by Maekawa's empirical formula is shown together. For a line source, the insertion loss based on Maekawa's empirical formula, ΔL_l, is expressed as follows.

$$\Delta L_l = -10\log\left[\frac{\int_{-\infty}^{\infty} 10^{-\Delta L_{\mathrm{p}}(x)/10} / (x^2 + r^2)dx}{\int_{-\infty}^{\infty} 1/(x^2 + r^2)dx}\right] \cdots\cdots (4)$$

where the x-axis coincide with the line source, the origin of which is in front of the measuring point; r is the distance from the line source to the measuring point; and $\Delta L_{\mathrm{p}}(x)$ is the insertion loss based on Maekawa's empirical formula at the position x.

In the case of the line source located at 0 m from R.L, the insertion loss of the sound barriers is smaller than that based on Maekawa's empirical formula because the multiple reflections between the vehicle surface and barriers occur. As the position of the sound source becomes higher, the influence of multiple reflections decreases.
As the results of the experiment, equation (5) approximately estimate the insertion loss of the barriers in the real situation, ΔL_{real}, for a point 8 m below R.L. and 25 m away from the adjacent track, which is referred to 'P$_{25}$'.

$$\left.\begin{aligned} \Delta L_{real} &= \Delta L_{maekawa} - 3\text{dB} \quad (\text{for sound source near bogies}) \\ \Delta L_{real} &= \Delta L_{maekawa} \quad (\text{for the other sound sources; see Table 1}) \end{aligned}\right\} \cdots\cdots\cdots (5)$$

4. ESTIMATION OF CONTRIBUTION OF INDIVISUAL SOUND SOURCE

4.1 Result of the Estimation

For each sound source shown in Figure 4, the sound pressure level at the wayside of a viaduct with sound barriers, $L(P)$, is calculated by equation (6).

$$L(P) = PWL - 10\log 2\pi r^2 - \Delta L_{real} \quad \cdots\cdots\cdots (6)$$

where PWL is calculated by equation (1), ΔL_{real} is the insertion loss of sound barriers obtained by equation (5) and r is the distance between the sound source and the measuring point P.

Figure 7 shows the 1/1 octave band frequency spectra of the contributions of individual sound source estimated by equation (6). The measuring point is located at P$_{25}$. The sound power levels used are those at speed 340 km/h. It should be noted that the values shown in Figure 7 are those per one sound source domain. Figure 7(a) shows the results for the sound sources located at the lower parts of the vehicle. Here the front bogie of the leading car and other bogies were distinguished because there was remarkable difference between the two. Figure 7(a) suggests as followings;

- The front bogie is the most dominant sound source among the sources located at the lower part of the vehicle at almost all frequencies.
- The contribution of the lower part of leading car, which is due to a shear flow at the snowplough, almost equals to that of the front bogie at 2,000Hz band.

Figure 7(b) shows the results for the sound sources located at the upper parts of the vehicle. Here the noise from the lower part of leading car, including that from the front bogie, influence the measured data for upper part of the vehicle at frequencies of 250-500 Hz band, so that the results of the door for driver's cab and the upper parts of leading car at those frequencies are omitted. Figure 7(b) suggests that the pantographs are the most dominant sound source among the sources located at the upper part of the vehicle at all frequencies, at high frequencies in particular.

Furthermore, we categorized the sound sources into three components according to their locations, that is, the lower part noise, aerodynamic noise from the upper part and pantograph noise (see Table 1), and estimated their contributions to the wayside noise level ($L_{p\mathrm{A,Smax}}$) by calculating time histories of A-weighted sound pressure level with time-weighting S for individual point sources and summing them up for each category. Figure 8 shows the 1/1 octave band frequency spectra of $L_{p\mathrm{A,Smax}}$ for three components at P$_{25}$, which suggests that the upper part noise is the most dominant and the pantograph noise is the next.

4.2 Comparison of the Calculation with the Result of Field Test

In order to validate the estimation mentioned above, we compared the estimated frequency spectra of the sound pressure level with the measured ones ($L_{pA,Smax}$) on another field test which was carried out for a viaduct with sound barriers. The height of the viaduct and sound barriers were almost the same as those of the calculations. It is assumed that the concrete bridge structure noise at the site could be neglected[3]. Figure 9 shows the comparison of the calculation with the field test data. Both results have the same tendencies at frequencies above 1 kHz. However, at frequencies below 500 Hz, the result of the estimation is 5 or 6dB larger than measured one. This is because the spatial resolution of acoustic mirror is not so good at the lower frequencies, so that the power level of each domain might be overestimated.

5. CONCLUSIONS

The contribution of the individual sound source generated from Shinkansen vehicles running on a viaduct was estimated on the basis of the results of the field test with the acoustic mirror and the insertion loss of sound barriers by the acoustic experiment with 1/25 models. From the result of the estimation, the upper part noise is the most dominant and the pantograph noise is the next at a point 25 m away from the adjacent track and 8 m below from R.L. Then we compared the frequency spectra with the measured ones. At frequencies below 500Hz the estimation is 5 or 6dB larger than the field test. This is because the spatial resolution of acoustic mirror is not so good at the lower frequencies, so that the power level of each domain might be overestimated. In future work, we will investigate the estimation of the power level of the sound sources at the lower frequency.

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[1] K.Nagakura: "Localization of Aerodynamic Noise Sources of Shinkansen Trains", Proceedings of the 8th International Workshop on Railway Noise (2004).

[2] Z.Maekawa: "Environmental sound propagation", Proceedings of the 8th International Congress on Acoustics (1974).

[3] K.Nagakura: "The Method of Analyzing Shinkansen Noise", Quarterly Report of RTRI, Vol.37, No.4 (1996).

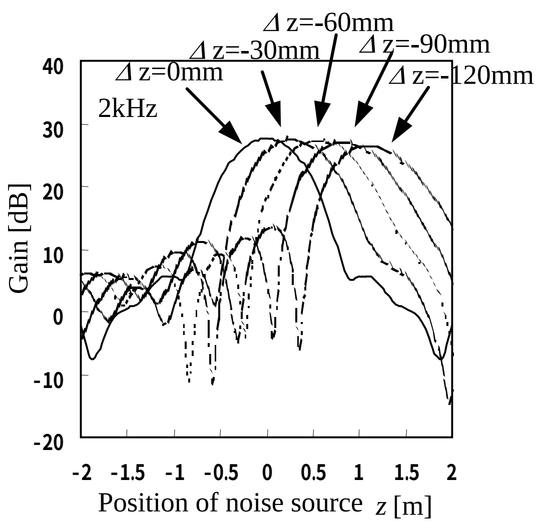


Figure 1. Directivity patterns of the acoustic mirror (1/3 octave band with center frequency=2kHz)

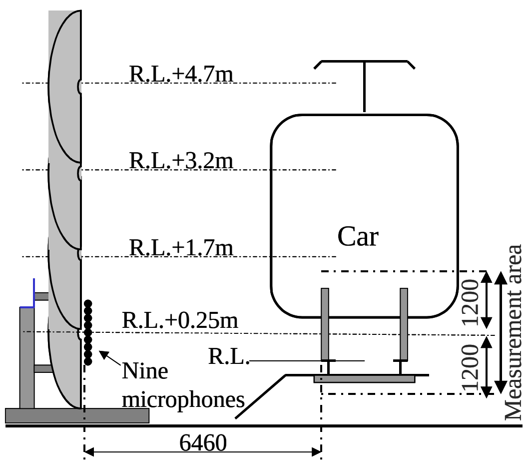


Figure 2. Test set-up of the field test

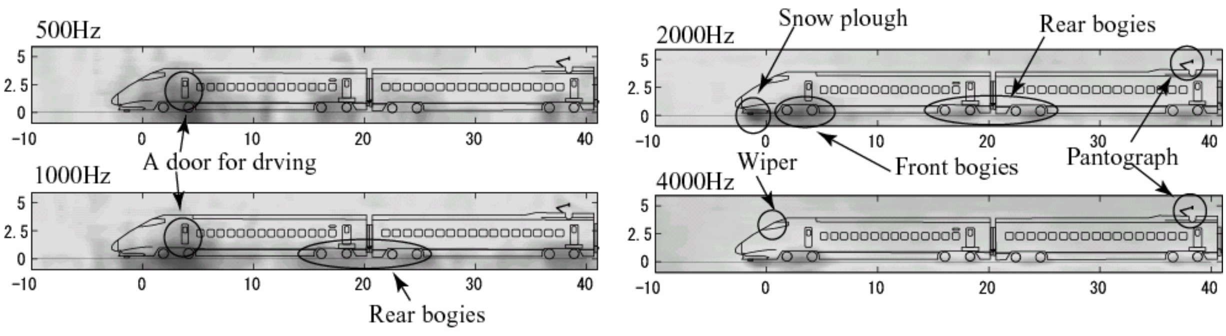


Figure 3. Noise source distribution obtained by measurement with acoustic mirror

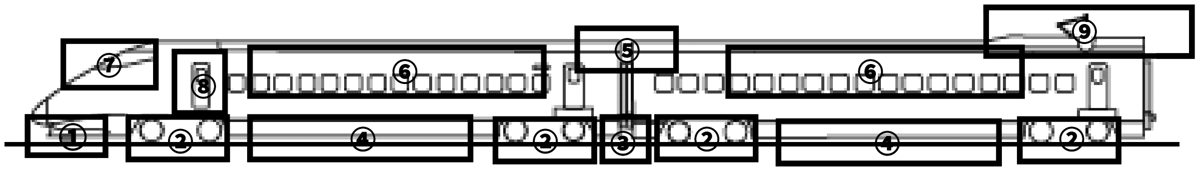


Figure 4. Domains of sound sources generated from the vehicle

Table 1. The sound sources positions

Categories	Real vehicle	Model vehicle
Lower part	①Lower parts of leading car	R.L.＋1.25m
	②Bogies	R.L.＋0m
	③Gap between cars(lower parts)	R.L.＋1.25m
	④Center of cars (lower parts)	R.L.＋1.25m
Upper part	⑤Gap between cars(upper parts)	R.L.＋3.75m
	⑥Center of cars(upper parts)	R.L.＋2.5m
	⑦Upper parts of leading car	R.L.＋2.5m
	⑧A door for driver's cab	R.L.＋2.5m
Pantograph	⑨Pantograph	R.L.＋5m

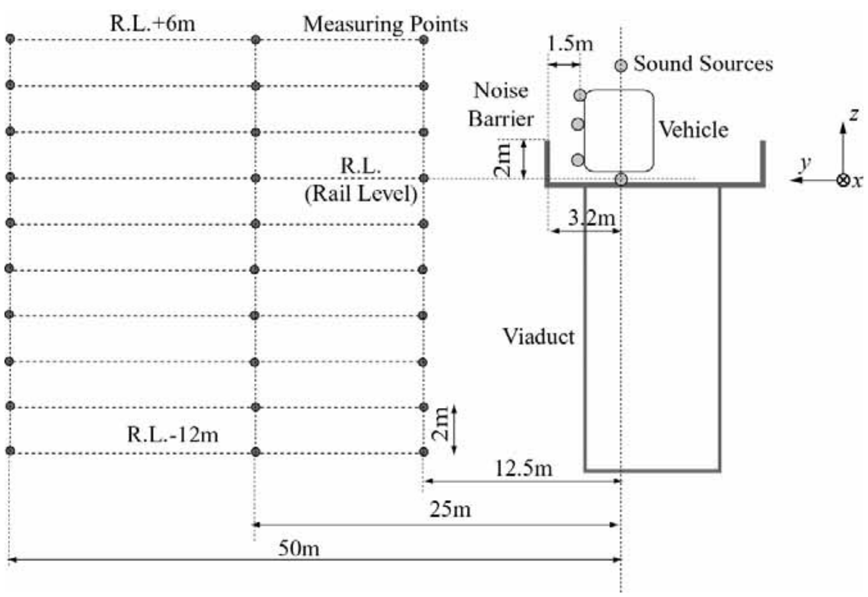
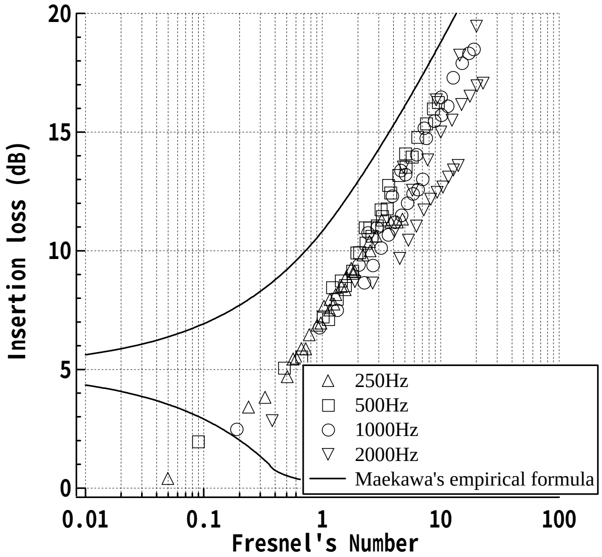
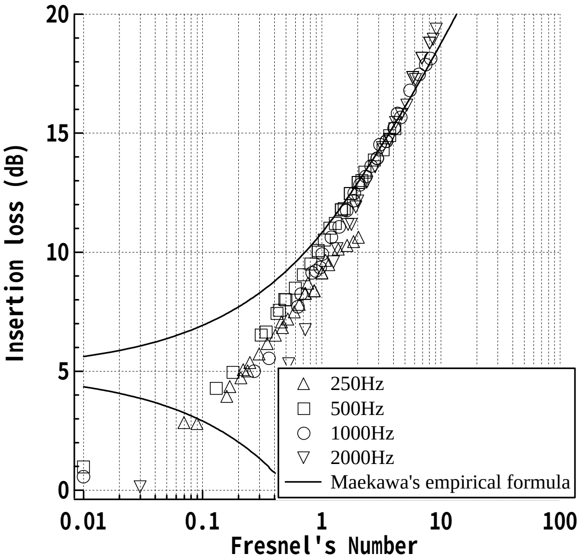


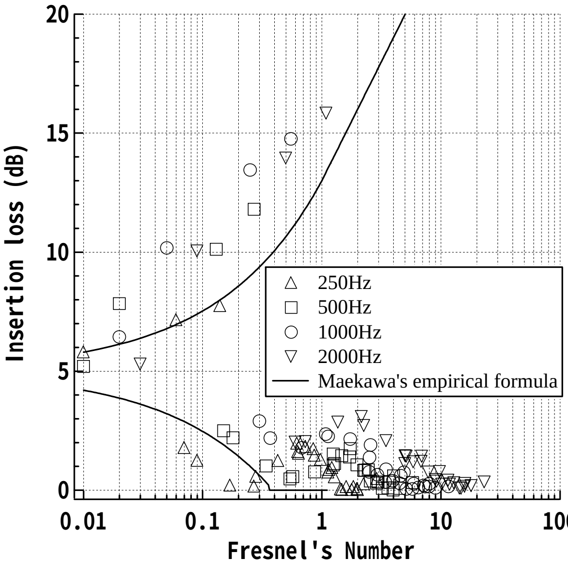
Figure 5. Test set-up of the acoustic experiment



(1) Line source at the height of R.L.+0m

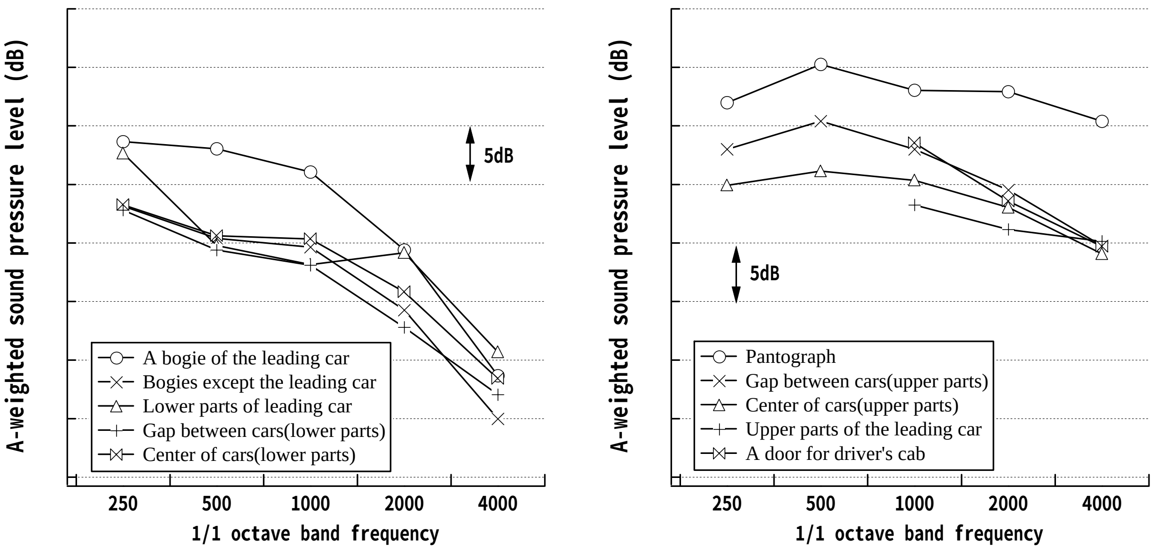


(2) Line source at the height of R.L.+1.25m



(3) Point source at the height of R.L.+5m

Figure 6. The insertion loss by sound barriers in the acoustic experiment



(1) Lower parts (2)Upper parts

Figure 7. The contribution of each sound source at P_{25} (train speed:340km/h)

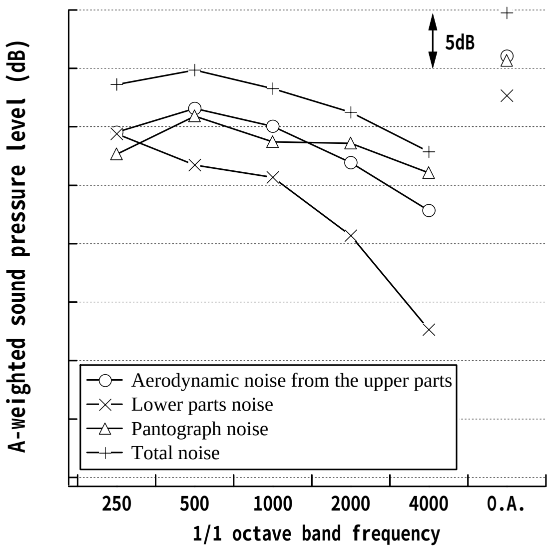


Figure 8. The contribution of individual sound sources from Shinkansen vehicles

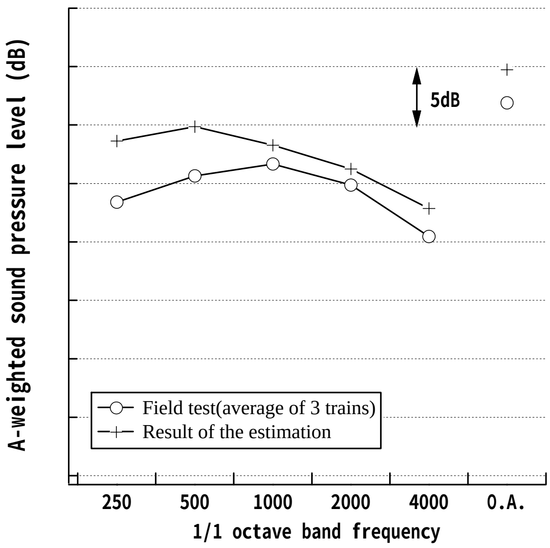


Figure 9. The comparison of field test with estimation