Countermeasures of Noise Reduction for Shinkansen Electric-Current Collecting System and Lower Parts of Cars

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Shinkansen noise can be broadly classified into four categories; noise from the electric-current collecting system, noise from lower parts of cars, aerodynamic noise of the upper parts of cars and noise of concrete bridge structure. It is necessary to study the methods for reducing each of them. This paper discusses the following two points on noise reducing countermeasures; (1) the results of running tests on Series E2-1000 and (2) the result of 2-D numerical simulation and experiment on the scale model for noise reduction from lower parts of cars. For the first item, we checked the performances of the low-noise pantograph and low-noise insulator. At the same time, we examined the noise reducing effect of a pantograph sound insulation plates, single-pantograph running mode, bogie side cowls, sound absorbing structure around the bogie and circumferential bellows. This study has clarified that the low-noise pantograph and low noise insulator allow a reduction of about 0.8 dB below the conventional level at a 25-meter point when running at a speed of 320 km per hour. The study has also made it clear that a reduction of about 3 dB is possible when all the currently conceivable countermeasures have been taken. For the second point, 2-D numerical simulation and scale model experiments in an anechoic room were conducted when the sound absorbing material was provided on the surface of the car body, in order to examine the relationship between the position and amount of the sound absorbing material and its effect of noise reduction. It has been shown that noise from the lower parts of cars can be reduced by about 4 dB when the side surface of the cars is provided with a sound absorbing material.

● Keyword : Noise from lower parts of cars, Electric-current collecting system noise, Series E2-1000 Car, Low-noise pantograph, Low-noise insulation, Model experiment, Isolation of noise source

1 Introduction

To find out how to reduce the noise from the lower parts of cars and electric-current collecting system on the Shinkansen, we conducted the following field test and model experiment:

(1) To estimate the effect of each of the countermeasures taken, the noise level of cars in the Series E2-1000 was measured at a 25-meter point from the center of the structure with sound level meters and with microphone array in the single-pantograph running mode, where these cars were provided with the pantograph sound insulation plates, bogie side cowls, sound absorbing structure around the bogie and circumferential bellows.

(2) We conducted numerical simulation and scale model experiments in an anechoic room to examine the noise reducing effect when sound absorbing material was provided on the car body surface in order to reduce the multiple reflections between the noise barrier and car body.

2 Measuring the wayside noise of the Series E2-1000 cars

2.1 Overview

The Series E2-1000 cars were provided with low-noise pantographs and low-noise insulators in order to reduce the noise of the electric-current collection system. Running tests were conducted to examine the electric-current collecting performance of the low-noise pantograph and low-noise insulator, and the effect of reducing the noise of the electric-current collecting system. For further reduction of the noise from the electric-current collecting system, the pantograph was temporarily provided with a sound insulation plates. To reduce the number of noise sources, a single-pantograph running test was performed to evaluate the effect.

In the meantime, the noise from the electric-current collecting system has been reduced in recent years because of some countermeasures. As a result, the noise from the lower parts of cars of the car shows a relative increase. In these running tests, therefore, we temporarily provided a bogie side cowls and circumferential bellows whose effects had been recognized in a wind tunnel test as countermeasures for the noise form the lower parts of cars. At the same time, the sound absorbing structure was applied around the bogie to estimate of the noise reduction effect.

2.2 Each measure and test schedule

Table 2.1 summarizes the relationship between countermeasures for each section and type of measurements. As shown in this table, the low-noise pantograph and low-noise insulator are mounted, without other countermeasures in Step 1. In Step 2, pantographs installed on cars No. 4 and 6 were provided with sound insulation plates. In Step 3, the sound

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Table 2.1 List of noise reduction countermeasures

	Step1	Step2	Step3	Step4	Step5
Pantograph of car No. 4	No countermeasures	Sound insulation plates	Sound insulation plates with sound absorbing structure	Sound insulation plates with sound absorbing structure	No countermeasures
Between cars No. 4 and 5	No countermeasures	No countermeasures	No countermeasures	No countermeasures	No countermeasures
Between cars No. 5 and 6	No countermeasures	Side cowls / sound absorbing structure around the bogies /circumferential bellows	Side cowls / sound absorbing structure around the bogies /circumferential bellows	Structure with sound absorbing structure on the top of the bogies / circumferential bellows	Structure with sound absorbing structure on the top of the bogies / circumferential bellows
Pantograph of car No. 6	No countermeasures	Sound insulation plate	Sound insulation plates with sound absorbing structure	Pantograph folded, sound insulation plates with sound absorbing structure	Pantograph folded
Between cars No. 6 and 7	No countermeasures	Side cowls / sound absorbing structure around the bogies	Side cowls / sound absorbing structure around the bogies	Structure with sound absorbing structure on the top of the bogies	Structure with sound absorbing structure on the top of the bogies
Between cars No. 7 and 8	No countermeasures	Side cowls / with sound absorbing structure around the bogies /circumferential bellows	Side cowls / with sound absorbing structure around the bogies /circumferential bellows	Structure with sound absorbing structure on the top of the bogies / circumferential bellows	Structure with sound absorbing structure on the top of the bogies / circumferential bellows
Leading portion of car No. 8	No countermeasures	Side cowls	Side cowls	No countermeasures	No countermeasures

* On the leading portion of car No. 8 and trailing portion of car No. 7 on the seaward side, the sound absorbing structure was not provided within the side cowls in order to avoid interference of the speed power generator.

insulation plates were designed into a sound absorbing structure. In Step 4, the single-pantograph running test was conducted, with the sound insulation plates installed in position. In Step 5, the single-pantograph running test was conducted without the sound insulation plates. In the single-pantograph running mode, the pantograph of car No. 6 (on the front side in high-speed running mode) was folded.

In these running tests, such large-scale work as temporary installation or removal of the bogie side cowls and sound absorbing structure around the bogie, or temporary installation of the pantograph sound insulation plates were performed only in Step 1 or Step 2. Due to the construction period, the countermeasures round the bogie were taken not for the entire trainset, but only for the half-composition of a train; namely cars No. 5 to 8. The bogie side cowls were provided in the single-pantograph running mode.

In Step2 and 3, the bogie was provided with side cowls and the sound absorbing structure were used inside the bogie side cowls, and on the front, back and top of the bogie. In Steps 4 and 5, the bogie side cowls and sound absorbing structures on the front and back were removed with the top unremoved. On the other hand, the circumferential bellows were installed between cars No. 5 and 6 and between cars No. 7 and 8 in Steps 2 through 5. The position of temporary installation for noise reduction countermeasures and temporarily installed objects in each car are shown in Fig. 2.1:

2.3 Method of measurements

Measurement was made on the north-bound line between Furukawa and Kurikoma -kogen. In this running test, high-speed running tests were conducted only on the north-bound line. For this measurement, sound level meters and microphone array were installed at a height of 1.2 meters above ground, 25 meters away from the center of the structure. To investigate the distribution of noise sources along the train(1-dimentional distribution), we generally use the microphone array. The train speed was measured by the axle detector mounted on the rail.

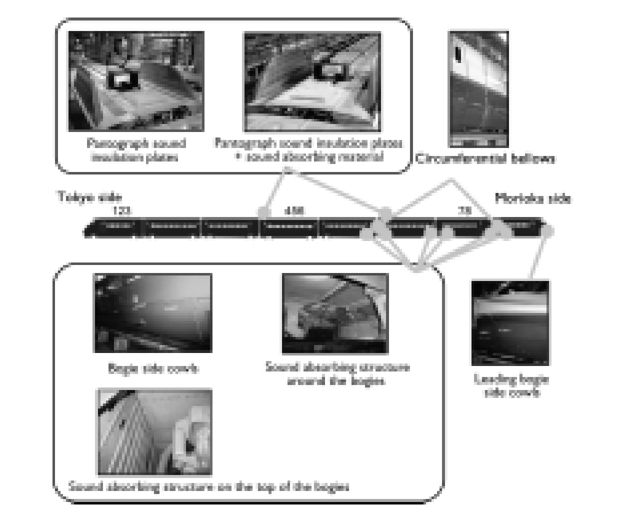

Fig. 2.1 List of the countermeasures of the noise reduction

Fig. 2.2 shows how the microphone array and sound level meters were installed:

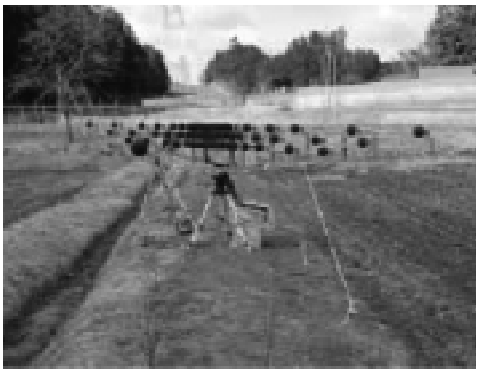

Fig. 2.2 Noise measurement

2.4 Results of measurement

2.4.1 Measured waveform

Fig. 2.3 (a) shows an example of waveforms obtained from the measurement by the sound level meters (time constant: 1s, A-weighted). Fig. 2.3 (b) shows an example of the waveforms obtained from the measurement (time constant: 35 ms, A-weighted) by the microphone array. The two protruding points in Fig. 2.3 (2) indicate the noise level from the pantograph from the electric-current collecting system, the value of which is called “level P”. The maximum level except for “level P” is called “level Q”, and “the levels P” and “Q” are together called "peaks". In the meantime, the minimum value sandwiched between peaks is called the "valley".

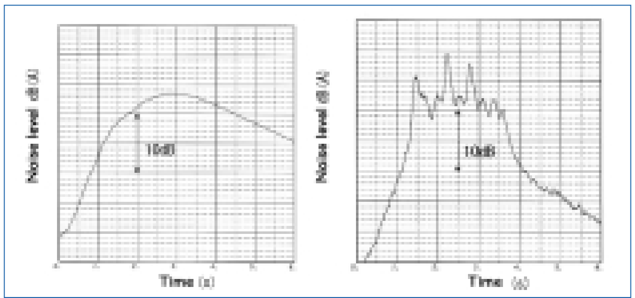

Fig. 2.3 (a) Result of measurement (sound level meter)
(b) Result of measurement (microphone array)

2.4.2 Results of measuring the noise level at 25-meter point

Fig. 2.4 represents the relationship between the noise level at the 25-meter point and train speed plotted in a graphic form. The noise level of Series E2 cars in commercial service was measured in Step 1 of this running test. The data for the high-speed of the Series E2 was obtained at the time of running tests conducted in May 1998. It should be noted that the horizontal axis (speed) in Fig. 2.4 is represented in a logarithmic scale. Each plot also represents the regression line. The regression lines of the Series E2 and Series E2-1000 indicates that the difference of noise levels between the two was about 0.8 dB at the speed of 320 km per hour. This value is considered to indicate the effect of the low-noise pantograph and low-noise insulator.

In addition to the above findings, Fig. 2.4 has provided valuable information. A comparison between Steps 2 and 3 indicates that there is almost no difference in the high-speed range. This suggests that the sound absorbing material of the pantograph sound insulation plates is not effective in the high-speed range. A comparison between Steps 4 and 5 in the single-pantograph running mode and Steps 2 and 3 in the two-pantograph running mode indicate that the noise level is generally lower in the single-pantograph running mode than in the two-pantograph running mode. This signifies a noise reducing effect in the single-pantograph running mode. As shown in Fig. 2.4, however, the noise level at the 25-meter point is reversed in some cases. This is considered to have been attributable to the fact that the noise not inherently present in the two-pantograph running mode is produced by the spark generated as a result of the loss of contact between contact wire and pantograph. Fig. 2.5 shows the waveform where the spark is generated in the single-pantograph running mode.

Fig. 2.5 shows that, in single-pantograph running mode, the electric-current collecting performance must be improved to suppress noise resulting from sparks.

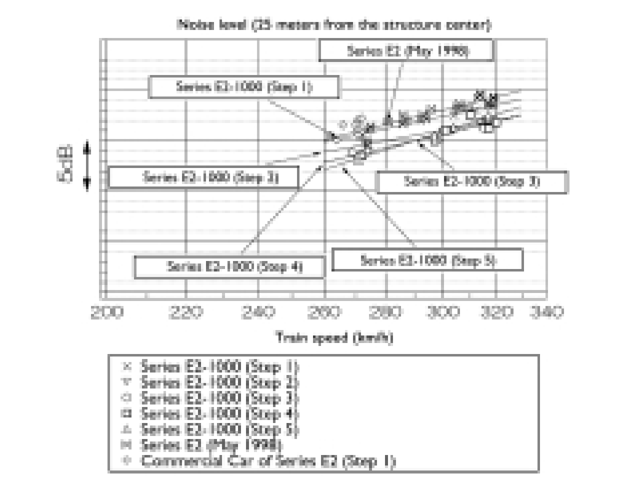

Fig. 2.4 Noise level at a 25-meter point

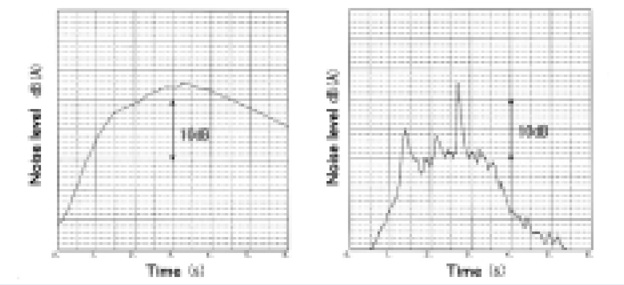

Fig. 2.5 Example of waveform (Spark) in single-pantograph running mode

2.4.3 Results of measurement with the microphone array

To estimate contributions of noise reduction, it is necessary to find out how much the "peak" and "valley" measured by the microphone array has been reduced by the countermeasures. At first we estimated the influence to reduce to level P by the countermeasures for the electric-current collecting system.

Fig. 2.6 shows the result of comparing the level P of car No. 6 with sound insulation plates installed in the two-pantograph running mode and that of Series E2. From Fig. 2.6, it has been revealed that the noise reducing effect of the sound insulation plates of the pantograph upon level P is about 3.5 dB at the speed of 320 km per hour.

It should be noted that reduction of the level P by 3.5 dB does not mean that the noise level at the 25-meter point is reduced 3.5 dB. The noise of Shinkansen is produced from a combination of multiple sound sources. It is necessary to calculate contribution of noise reduction to find out the total noise reduction.

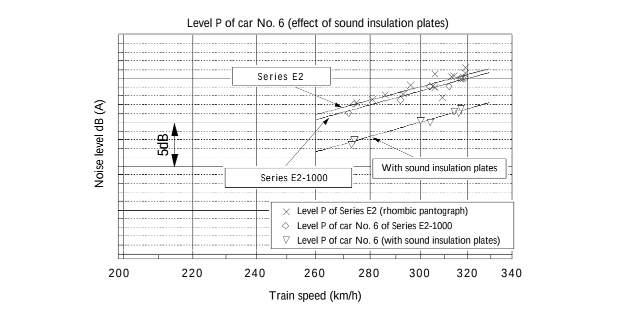

Fig. 2.6 Effect of sound insulation plates (Level P of car No. 6)

Fig.2.7 shows comparison between the level P of the folded pantograph (car No. 6) and that of Series E2, when the sound insulation plates were installed in single-pantograph running mode. As can be seen from Fig. 2.7, the effect of reducing the level P when the sound insulation plates was installed in

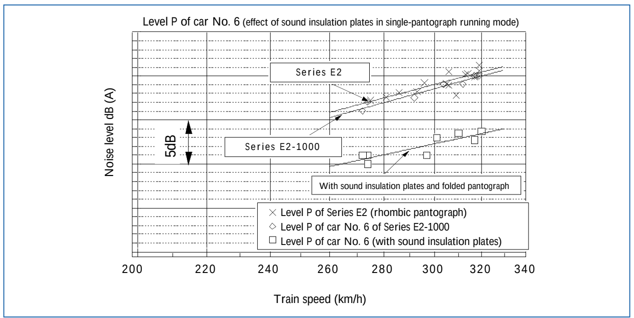

Fig. 2.7 Effect of the sound insulation plates in single-pantograph running mode

single-pantograph running mode can be represented as about 7 dB at 320 km per hour.

The following will discuss the amount of the reduced level Q resulting from the bogie cowls, sound absorbing structure around the bogie and circumferential bellows. Cars No. 4 and 5 were not provided with countermeasures for the lower parts of cars in noise for all the tests, so the speed dependency should be constant. However, level Q in Step 1 tended to be greater than those in Steps 2, 3, 4 and 5. This may be due to the difference of the rolling noise resulting from differences in conditions of the rails and wheels. Accordingly, if level Q in each step from which countermeasures have been taken is simply compared with the value in Step 1, evaluation of the effect of noise reduction will be excessive. So for the cars of the same test number, the positions where countermeasures have been taken are compared with those where such countermeasures have not been taken. Thus, we get the amount of the level Q reduced by the countermeasures for the noise from lower parts of cars.

The bogie side cowls and sound absorbing structure around the bogie are mounted as an integral unit, and cannot be evaluated separately. So comparison was made between (1) the level Q of cars No. 6 and 7 (bogie side cowls and sound absorbing structure around the bogie) in Steps 2 and 3, and (2) the level Q of cars No. 4 and 5 (without any countermeasures, where Step 1 is removed from the scope since the trend of the level is different) in Steps 2 to 5. This comparison has shown that the level Q was reduced about 0.5 dB when the side cowls and sound absorbing structure were provided.

Further, in order to find out the noise reducing effect when circumferential bellows were provided in addition to the cowls on the bogie side and sound absorbing structure around the bogie, we made a comparison between (1) level Q of cars No. 4 and 5 in Steps 2 to 5, and (2) the level Q of cars No. 7 and 8 in Steps 2 and 3 (where circumferential bellows were provided in addition to the bogie side cowls and sound absorbing structure around the bogie). These comparisons have shown that the level Q was reduced about 1 dB.

Based on the above discussion, Table 2.2 summaries the amounts of noise reduction (levels P and Q) measured by microphone array for each of the countermeasures taken. Here it is assumed that the "valley" was lowered by about half the level Q when circumferential bellows were provided in addition to the bogie side cowls and sound absorbing structure around the bogie. In the single-pantograph running mode, the increase in the noise level resulting from spark noise is not taken into account

Table 2.2 Amount reduced by countermeasures taken

(dB) (320km/h)

Sound insulation plates	With sound insulation plates and folded pantograph	Bogie side cowls and sound absorbing structure	Bogie side cowls, sound absorbing structure and circumferential bellows
-3.5	-7	-0.5	-1.0

2.5 Contribution of various countermeasures against noise at 25-meter point

Based on the measurement by the microphone array, we will find out the noise reducing effects of the countermeasures taken, and will calculate the noise level at the 25-meter point, thereby predicting the noise level at the 25-meter point when the entire trainset is provided with all countermeasures. According to the method of finding out the noise level by the sound level meters from the data obtained by measuring with the microphone array, the noise source between cars is assumed as a "peak" of the microphone array, and that of the car middle section as a "valley". The row of these sounds is moved at the train speed, and the response by the sound level meter is calculated (1).

At first, the waveform of the microphone array as a standard is assumed as the waveform obtained in the noise of Series E2 measured in May 1998 (at a train speed of 319 km per hour). Then the amount of reduction obtained in Table 2.2 is subtracted from this waveform, thereby calculating the noise level at the 25-meter point when countermeasures were taken.

- Case 1: Two-pantograph running mode with sound insulation plates

Level Q: -0 dB, valley level: -0 dB

Level P (car No. 6) -3.5 dB, Level P (car No. 4) -3.5 dB

- Case 2: Single-pantograph running mode with sound insulation plates

Level Q2: -0 dB, valley level: -0 dB

Level P (car No. 6) -7 dB, Level P (car No. 4) -3.5 dB

- Case 3: Single-pantograph running mode with sound insulation plates, bogie side cowls and sound absorbing structure around the bogie

Level Q: -0.5 dB, valley level: -0.2 dB

Level P (car No. 6) -7 dB, Level P (car No. 4) -3.5 dB

- Case 4: Single-pantograph running mode with sound insulation plates, bogie side cowls, sound absorbing structure around the truck and circumferential bellows

Level Q: -1 dB, valley level: -0.5 dB

Level P (car No. 6) -7 dB, Level P (car No. 4) -3.5 dB

The response of the sound level meter is calculated for each case. The following summarizes the effect of each of the countermeasures taken, where Case 1 is defined as representing the result of cars in Series E2:

- Case 0 vs. Case 1

Effect of sound insulation plates (including the effects of the low-noise pantograph and low-noise insulator) ... - 1.7 dB

- Case 0 vs. Case 2

Effect of sound insulation plates (including the effects of the low-noise pantograph and low-noise insulator) plus single-pantograph running mode .... - 2.6 dB

- Case 2 vs. Case 3

Effect of sound absorbing structure around the truck and bogie side cowls ... - 0.2 dB

- Case 2 vs. Case 4

Effect of circumferential bellows, sound absorbing structure around the bogie and bogie side cowls ... - 0.4 dB

To give an example of the result of these calculations, Fig. 2.8 shows the waveform obtained by the microphone array and sound level meters in case 4 provided with all the countermeasures.

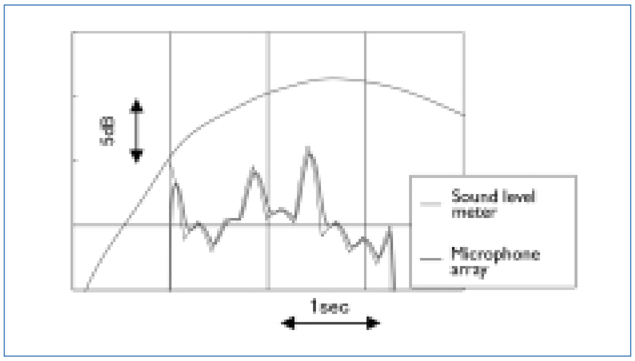

Fig. 2.8 Prediction of noise waveform for Series E2-1000 (waveform for single-pantograph running mode with sound insulation plates, bogie side cowls, sound absorbing structure around the bogie and circumferential bellows

2.6 Summary and subsequent objectives

In the running tests of Series E2-1000, we used the single-pantograph running mode with pantograph sound insulation plates in order to reduce the noise from the electric-current collecting system. Further, to reduce noise from the lower parts of cars of the car, a bogie side cowls and sound absorbing structure around the bogie were installed on cars No. 5 to 8. Circumferential bellows were provided between cars No. 5 and 6 and between cars No. 7 and 8. For noise measurement, microphone array and sound level meter were installed at a point 25 meters away from the structure center. The effects of the countermeasures were compared with those of Series E2. This study has revealed the following information at the train speed of 320 km per hour:

- Overall noise reduction provided by the countermeasures for the noise from the electric-current collecting system

(1) Effect of low-noise pantograph and insulator in Series E2-1000 ... - 0.8 dB

(2) Effect of installing devices given in (1), and pantograph sound insulation plates ... - 1.7 dB

(3) Effect of installing devices (2), and running in the single-pantograph mode ... - 2.6 dB

- Noise reduction provided by the countermeasures for the noise from lower parts of cars reduction under the conditions (1) to (3)

(4) Effect of sound absorbing structure in the bogie (when provided for the entire train composition) .... - 0.2 dB

(5) Effect of providing the above-mentioned (4) and circumferential bellows ... - 0.4 dB

From the above-mentioned information, it can be seen that, for all the test items, noise can be reduced 3 dB (at 320 km per hour) in Series E2.

The subsequent objective is to improve the electric-current collecting performances (follow-up performances) in order to reduce spark noise in the single-pantograph running mode and to further develop a sound absorbing structure around the bogie.

3 A model experiment for the development of countermeasures to reduce the noise from the lower parts of cars

3.1 Overview

For further reduction of the Shinkansen, the surface of the car body was designed in a sound absorbing structure. Numerical simulation and experiments using a scale model in an anechoic room were employed to examine the method for effective reduction of the noise amplified by multiple reflections between the car body and noise barrier and the amount of reduction.

3.2 Numerical simulation

The basic features on the sound absorbing position and noise reducing effects were obtained by numerical simulation in the 2-D sound field, thereby determining the position of the sound absorbing material in the model experiment. The analysis models were broadly classified into two categories; car A (same as Series E2) without a bogie cowls and car B with a bogie cowls. Table 3.1 summarizes the cases for analysis. Fig. 3.1 shows the layout of the sound absorbing material in Table 3.1:

The following describes the conditions for numerical simulation:

- Medium: air: density: ρr = 1.2 kg/m^3; sound velocity: c= 340 m/sec.

- Vibration element: right-hand wheel and side surface of right-hand rail. Vibration speed: ±1.0 m/sec.

- The sound absorbing portion provides an acoustic absorptivity of 1.0.

- Frequency of 100 to 1,000 Hz at a pitch of 10 Hz

Table 3.1 Analysis cases of numerical simulation

CASE	Car shape	Sound absorbing material (67% and 100% for area ratio)		
		①－1	①－3	②
1	A	○	○ 100%	×
2	A	○	○ 67%	×
3	A	○	×	×
9	A	×	×	×
4	B	○	○ 100%	○
5	B	○	○ 67%	○
6	B	○	○ 67%	×
7	B	○	×	×
8	B	×	×	×

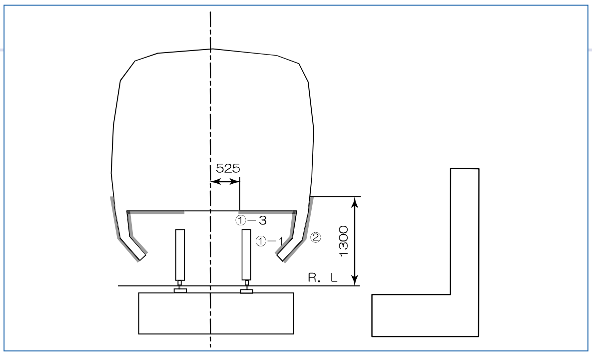

Fig. 3.1 Sound absorbing material layout of numerical simulation

Figs. 3.2 and 3.3 indicate the sound level distribution of numerical simulation. Fig. 3.2 shows the result of calculation at 200 Hz in Case 9 as reference data. Fig. 3.3 shows the result of the calculation in Case 1. Figs. 3.2 and 3.3 show the sound pressure distribution in terms of a circle where the magnitude of sound level is represented as a radius. Further, Figs. 3.4 and 3.5 indicate the amount of noise reduction for each car shape where Case 9 is used as a standard. Fig. 3.4 shows the amount of sound reduction for bogie shape A, and Fig. 3.5 that for bogie shape B for each octave frequency band. This study has revealed the following information:

- A comparison between car shapes A and B shows a remarkable effect of the sound absorption outside the car body (Cases 4 and 5), but the difference resulting from the presence/absence of the side cowls (difference between Cases 6 and 7) is small.

- In the car shape B where a side cowls are installed, there is hardly any difference resulting from the presence/absence of sound absorbing material on the back of the floor (difference between Cases 6 and 7). There is a conspicuous effect resulting from the sound absorbing material outside the car (Cases 4 and 5).

-In some cases, the sound even increased when the sound absorbing material was attached. This is considered to have been caused by the fact that the sound absorption by the inner wall provides a damping effect in the resonance area, resulting in increased sound level.

- No noise reducing effect was observed in the shape A car without a side cowls installed, except at the low frequency of 200 Hz or less. (Fig. 3.4)

- The increase and decrease in the sound level distribution immediately above the noise barrier are approximately proportional to sound pressure distribution at a 25-meter point.

(Figs. 3.2 and 3.3)

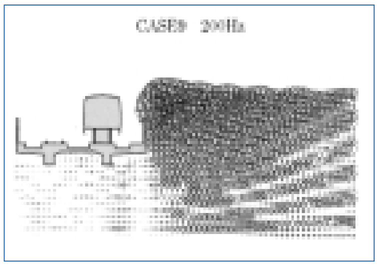

Fig. 3.2 Sound level distribution at 200 Hz in Case 9

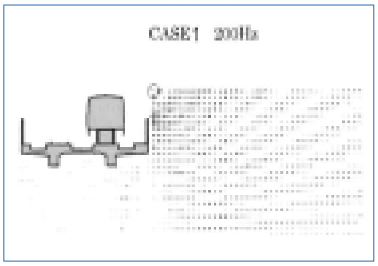

Fig. 3.3 Sound level distribution at 200 Hz in Case 1

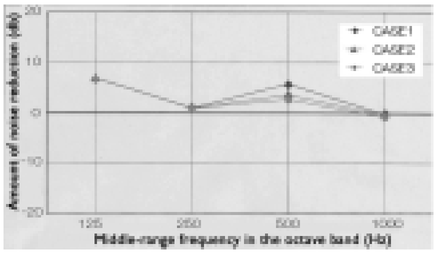

Fig. 3.4 Amount of noise reduction (bogie shape A, Case 9 as a standard)

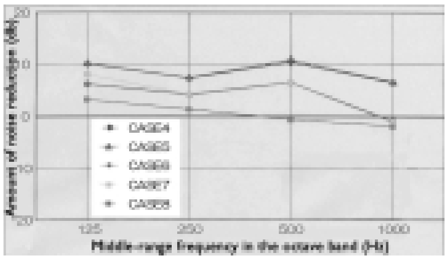

Fig. 3.5 Amount of noise reduction (bogie shape B, Case 9 as a standard)

3.3 Scale model experiment of the car body with sound-absorbing-structure

3.3.1 The model and the position of the absorbing material

The model was manufactured to meet the following specifications:

- Scale: 1/5. Type E2 middle car (1/2 car + 1 car + 1/2 car) and viaduct (Fig. 3.6)

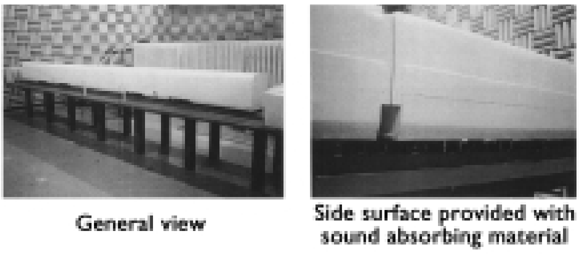

Fig. 3.6 Train and viaduct models

- The position of the sound absorbing material is given in Table 3.2 and Fig. 3.7. It should be noted that the sound absorbing material was made of 4 mm thick felt and 10 mm thick urethane. The acoustic absorptivity of these sound absorbing materials is given in Fig. 3.8.

Table 3.2 Position of sound absorbing material in model experiment

Car side

(1): Around the bogie, on the back of car body	Side cowls	①−1 Inner surface of side cowls
	Around the bogie	①−2 Stopper plate ①−3 Top surface of bogie
	Back of car body	①−4 Around the bogie ①−5 Center of bogie
(2): Outside surface of car body (From indoor floor surface to bottom end)		
(3): Outside surface of car body (From window bottom end to indoor floor surface)		

Viaduct side

(4): Noise barrier
(5): Roadbed surface

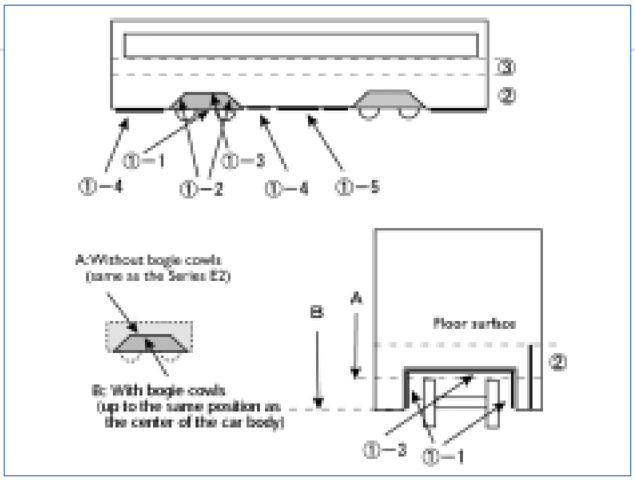

Fig. 3.7 Position of the sound absorbing material for model experiment

3.3.2 Sound source and sound collecting position/method

For the sound source of the wheel, a cone type full-range speaker having a diameter of 16 cm was assumed as a wheel to simulate radiation of sound of wheel sound source from the front and back. It was installed with the magnet side of the speaker facing outside the car. The speaker magnet was regarded as the position around the bearing of the actual car, and the shape models of the axle and motor were built into the bogie model.

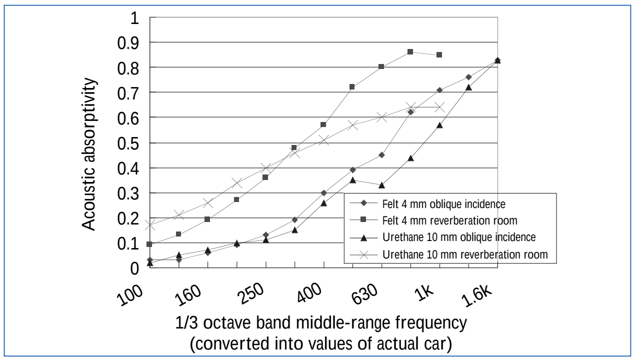

Fig. 3.8 Acoustic absorptivity of sound absorbing material

For the sound source of the rail, a liner sound source with consideration given to the range attenuation was installed in the longitudinal direction. To simulate the radiation of the sound from both sides of the rail, speakers with coned surface designed in an oblong form (120 mm by 60 mm) were classified into 15 groups on each side, 30 groups in total. The degree of the radiated sound was adjusted for each group, thereby reproducing the range attenuation. The source was configured so that signals would be random signals independent for each group. The sounds emitted from each group were uncorrelated. Fig. 3.9 shows the conditions of the speaker at the sound source.

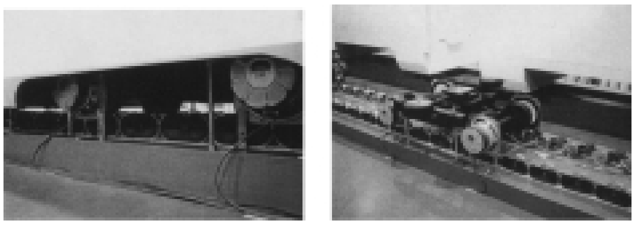

Fig. 3.9 Speakers at sound source

Sound was collected at three points for two cross sections (at the bogie center and car body center) - a total of six points - in the vicinity immediately above the noise barrier at the 25-meter point in terms of the actual car values. The space immediately above the noise barrier was located intermediate between the outer wall of the car and the noise barrier. It was situated 100 mm below the top of the noise barrier in terms of the actual car value. This space was equivalent to the height of the wheels on a perpendicular line.

The method for measure was based on eight channels; a sound level meters at each of six measuring points and microphone array at each of two 25-meter equivalent points. Figs. 3.10 and 3.11 show the installation condition of the sound level meters and their position.

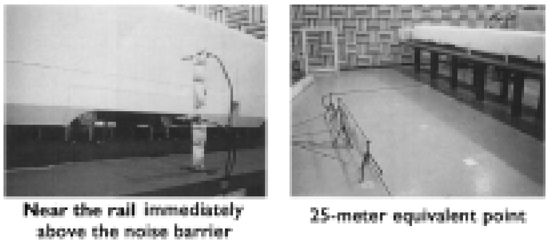

Fig. 3.10 Installation of sound level meter

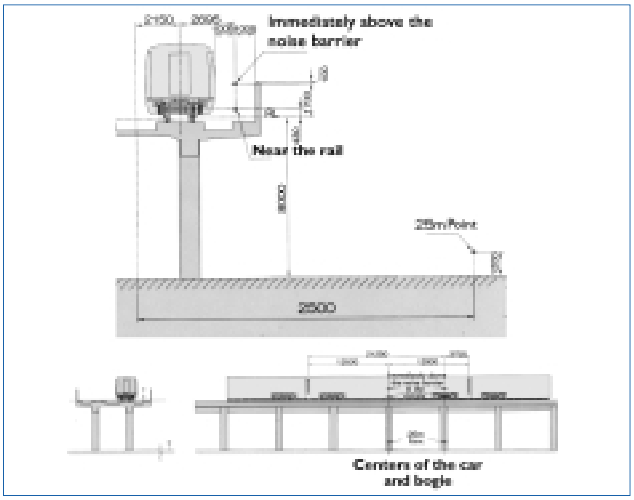

Fig. 3.11 Location of installing sound level meter
(dimensions converted into actual cars)

3.3.3 Conditions for model experiment

Table 3.3 shows the conditions for the model experiment, where:

○ : Felt 100% ◯ : Felt 67%

◎ : Urethane 100% ◎ : Urethane 67%

× : Without sound absorbing material None : Without noise barrier

"100%" and "67%" indicate the sound absorbing area.

The side cowls of (1) - 1 assumes shape B (with cowls) when experiment conditions are represented by "◎" and "○", and shape A (without cowls) when they are represented by " ×".

Except for cases G2 and H1, sound was collected in the direction where the distance between the noise barrier and track was greater (the direction where there was a maintenance passageway). For Case G2 and H1, sound was collected in the reverse direction. For case G0, sound was collected without a noise barrier.

3.4 Results of model experiment

In the model experiment, sound was radiated separately from the wheel and sound source on the rail, and the noise level at eight sound collection points were measured. When the most effective sound absorbing treatment was made, these values were adjusted so that the measurements would be sufficiently large for the back ground noise. So only the relative level between experiment cases is meaningful, whereas the absolute value would be meaningless.

The following principles were used for conversion to the actual car values:

(1) Based on the vibration of the rail for the measurement on the actual car and noise level at a point near the rail, the level of contribution of the sound emitted from the wheel and rail at the point near the rail was calculated.

(2) The noise level in the vicinity of the bogie center in the model experiment is replaced by the degree of contribution calculated in (1). This level difference becomes the converted value. There are two types of sound sources for these converted values; wheel and rail, and each value is provided for each 1/3 octave band.

(3) For the remaining seven sound collection points in the model experiment, the converted values obtained in Step (2) are used for addition and subtraction.

The sound near the rail measured at the time constant of 35 ms at the position without a noise barrier at 260 km per hour for Series E2 was used as the actual car data. However, since the rail vibration was measured only at one point, hypothetical factors were included in the calculation of the sound emitted from the rail.

Table 3.4 summarizes the relative amount of noise reduction (overall value) relative to case G1 in the result obtained by measuring at the 25-meter equivalent point at the center of the bogie, out of the results gained from the model experiment in terms of the values converted for an actual car.

From the result of the model experiment shown in Table 3.4, we can conclude the following:

(1) Based on the result of measurements using microphone array located at a 25-meter point from the center of the bogie, it can be seen that, when sound comes from the wheel and rail, the noise reducing effect is divided broadly into two types, depending on whether the sound absorbing material is provided outside the car body (B1, B2 B3) or not (B4, B5, B6).

(2) A comparison was made between the sound absorbing effect when noise was produced from the wheel alone and that when it was produced from the rail alone. It has been made clear that, in cases B1 to B6, the effect when noise was produced from the wheel alone is greater by 1 dB or more than

Table 3.3 Model experiment cases

Cases	Around the bogie: (1)-1. Inner surface of the bogie side cowls	Around the bogie: (1)-2. Back surface of the car body (stopper plate on the front and back of bogie)	Around the bogie: (1)-3. Back surface of the car body (on the top of the bogie)	Center of the car body: (1)-4. Back surface of the car body (around the bogie)	Center of the car body: (1)-5. Back surface of the car body (center of the car body)	Center of the car body: (2) Outer surface of the car body (below the floor surface)	Center of the car body: (3) Outer surface of the car body (from window bottom to floor surface)	Viaduct: (4) Noise barriers	Viaduct: (5) Roadbed surface
A1	◎	◎	◎	◎	◎	◎	◎	×	×
B1	○	○	○	○	○	○	○	×	×
B2	○	○	○	○	○	○	○	×	×
B3	○	○	○	○	○	○	×	×	×
B4	○	○	○	○	○	×	×	×	×
B5	○	○	○	○	×	×	×	×	×
B6	○	○	○	×	×	×	×	×	×
B4	○	○	○	○	○	×	×	×	×
C1	○	○	×	○	○	×	×	×	×
C2	○	×	○	○	○	×	×	×	×
C3	○	×	×	○	○	×	×	×	×
C4	×	○	○	○	○	×	×	×	×
C5	×	○	×	○	○	×	×	×	×
C6	×	×	○	○	○	×	×	×	×
C7	×	×	×	○	○	×	×	×	×
D1	×	×	×	○	×	×	×	×	×
E1	×	×	×	×	×	○	○	×	×
E2	×	×	×	×	×	○	×	×	×
F1	○	○	○	○	○	○	○	○	○
F2	○	○	○	○	○	○	○	○	×
F3	○	○	○	○	○	○	○	×	○
B2	○	○	○	○	○	○	○	×	×
G0	×	×	×	×	×	×	×	None	×
G1	×	×	×	×	×	×	×	×	×
G2	×	×	×	×	×	×	×	×	×
H1	○	○	○	○	○	○	○	×	×

that when it was produced from the rail alone. That is, the effect of absorbing noise coming from the rail is poorer than that of absorbing noise from the wheel. This is because the sound absorbing effect around the bogie is not effective toward the noise coming from the rail.

(3) We compared the effects between presence and absence of a bogie side cowls (B4 and C4). It has been revealed that, when noise comes from the wheel alone, the effect of 2.3 dB can be obtained. The effect is only 0.1 dB when noise comes from the rail alone. When noise is emitted from both the rail and wheel, the effect is 0.8 dB.

(4) We evaluated the sound absorbing effect on the back surface of the car body (on the top of the bogie) by comparison of B4 with C1, C2 and C3. It has been shown that, when noise comes from both the wheel and the rail, the effect is as much as 0.5 and 0.4 dB.

(5) A comparison between E1 and E2 clarifies the effect relative to the position and area of the sound absorbing material on the lateral surface outside the car body. The effect is increased by expanding the sound

absorbing area from the floor surface to the window bottom. This increase is greater when noise comes from the rail than when it comes from the wheel. This is because the influence of the directional difference or direct sound due to the difference between point source and linear source is greater in the case of a point source.

(6) A comparison between D1 and D2 indicates that it is not effective to extend the sound absorbing material on the back surface of the car body from the space around the bogie to the center of the car body.

(7) The noise reducing effect of a noise barrier is about 10 dB. This corresponds to the conventional empirical result.

(8) In this experiment, we mainly measured the noise level on the side that has a maintenance passageway. When measured on the side without the passageway (G2), the diffraction effect in the high frequency range increased and the level decreased a little. The same trend was observed in the comparison between B1 and H1 where sound absorbing treatment was provided.

(9) The above-mentioned description relates to the results obtained from using a super-directional microphone array. Comparison with the results obtained using the sound level meter indicates that, when the wheel alone was the source of noise, the effect was increased by a maximum of 1 dB. On the other hand, when the rail alone was the source of noise, there was almost no difference. This is thought to be because there was a lot of reverberation when noise was produced by the wheel, but when the noise is produced by the rail, it is mostly direct.

Table 3.4 Amount of noise reduction at a point the equivalent of 25 meters from the center of the bogie

	25m (Sound level meters)			25m (Microphone array)		
Cases	Sound source : rail	Sound source : wheel	Sound source: rail and wheel	Sound source : rail	Sound source : wheel	Sound source: rail and wheel
A1	-6.5	-4.5	-5.3	-4.1	-5.8	-4.6
B1	-6.5	-4.3	-5.2	-4.1	-5.3	-4.5
B2	-5.3	-3.9	-4.5	-4.2	-5.1	-4.5
B3	-4.9	-2.8	-3.6	-3.2	-4.8	-3.7
B4	-4.0	-1.0	-2.1	-0.8	-3.2	-1.5
B5	-3.7	-0.3	-1.5	-0.6	-3.6	-1.4
B6	-3.4	-0.2	-1.4	-0.4	-2.7	-1.1
B4	-4.0	-1.0	-2.1	-0.8	-3.2	-1.5
C1	-3.2	-0.6	-1.6	-0.4	-2.5	-1.0
C2	-3.2	-0.9	-1.8	-0.8	-2.4	-1.2
C3	-2.6	-0.5	-1.3	-0.3	-1.9	-0.8
C4	-0.8	-0.4	-0.6	-0.7	-0.8	-0.7
C5	-0.3	-0.2	-0.2	-0.4	-0.5	-0.5
C6	-0.6	-0.3	-0.4	-0.7	-0.7	-0.7
C7	0.0	-0.6	-0.3	-0.5	0.3	-0.2
D1	0.0	-0.3	-0.1	-0.2	0.0	-0.1
E1	-0.7	-2.0	-1.4	-2.2	-0.4	-1.5
E2	-0.5	-1.0	-0.8	-0.8	-0.2	-0.6
F1	-8.9	-9.9	-9.4	-9.6	-7.3	-8.7
F2	-7.0	-6.0	-6.4	-5.7	-6.2	-5.8
F3	-8.0	-8.5	-8.2	-8.2	-6.6	-7.6
B2	-5.3	-3.9	-4.5	-4.2	-5.1	-4.5
G0	11.5	10.2	10.8	9.7	11.9	10.6
G1	0.0	0.0	0.0	0.0	0.0	0.0
G2	0.5	-0.1	0.2	-0.4	-0.2	-0.3
H1	-6.2	-5.2	-5.6	-4.9	-4.8	-4.9

3.5 Summary and subsequent objective

We used the methods of numerical simulation and model experiments to examine the relationship between the layout of the sound absorbing structure of the car where the outer surface is provided with a sound absorbing property and the effect toward reducing noise. This study has revealed that noise can be reduced only about 1.5 dB by addition of the sound absorbing structure only on the inner surface of the lower part of the car around the bogie and on the back of the car body (on the of the bogie). The study has also made it clear, however, that the noise from lower parts of the car can be reduced more than 4 dB by addition of the sound absorbing structure on the sides.

Thus, the subsequent objective is to develop a concrete method for providing sound absorbing properties on the outside surface of the car body.

4 Conclusion

We have reached the following conclusions through the running tests of Series E2-1000, numerical simulation in the 2-D sound field and acoustic scale model experiment:

(1) The noise level of Series E2-1000 cars was measured at a 25-meter point with a sound level meter and microphone array in the single-pantograph running mode, where these cars were provided with the pantograph sound insulation plates, bogie side cowls, sound absorbing structure around the bogie and circumferential bellows. It has been shown that, for all the specified test items, noise from the lower parts of the car can be reduced to 3 dB below the level of Series E2 cars at the speed of 320 km per hour.

(2) Numerical simulation in the 2-D sound field and model experiment in an anechoic room were conducted to evaluate the noise reducing effect when the surface of the car body was provided with a sound absorbing structure. It has been clarified that noise from the lower parts of the car can be reduced only about 1.5 dB by addition of the sound absorbing structure only on the inner surface of the lower part of the car around the bogie and on the back of the car body. It has also been clarified, however, that the noise from the lower parts of the car can be reduced more than 4 dB by addition of the sound absorbing structure on the sides.

References:

(1) NAGAKURA Kiyoshi, et. al.; "The Method of Analyzing Shinkansen Noise", Quarterly Report of Railway Technical Research Institute, 1996, Vol.37, No4, pp.211.