J. Acoust. Soc. Jpn. (E) **21**, 6 (2000)

SYMPOSIUM REPORT

Measurement and analysis of railway noise in Japan

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In this paper the author gives a review about the measurement and analysis method of railway noise in Japan. First, the environmental goals for Japanese railways are introduced. Both Shinkansen and non-Shinkansen line standards have their own basis, and averages of L_{max} and L_{eq} are used respectively. Next, measurement of railway noise to evaluate the fulfillment of environmental standards is introduced. The status quo and future necessity of automatic data processing is described. Third, the author describes technical aspects of noise measurement and evaluation, that is, to locate noise sources and to estimate their contribution in the wayside. Since the observation time is very short, the variety of equipment is limited. It is thus an important technique to compare observed data to estimate the contribution of noise sources. Finally, the author briefly states about the basic ideas of formulating the equations of wayside noise assessment.

Keywords: Railway noise, Shinkansen, Conventional lines, Environmental standard, Noise analysis, Super-directional microphones

PACS number: 43. 50. Yw

1. ENVIRONMENTAL STANDARD

1.1 Shinkansen

When Shinkansen was opened in 1964, its wayside noise caused a strong social demand for environmental preservation.

Questionnaire surveys to the wayside residents showed that the proportion of those who appealed some influence from Shinkansen noise was 30% when the noise was 70–75 dB(A). Based on that result, the Environmental Agency laid down the environmental standard of Shinkansen noise in 1975 as Table 1. The compliance levels correspond to the lower and the upper boundaries of the noise.[1]

Measuring 20 data was considered adequate to cover all the types of Shinkansen trains. Averaging the larger 10 values was based on the understanding that the residents' feeling of noisiness depends on loudest trains because Shinkansen noise was interval.

The frequency of trains was not taken into account because, comparing wayside residents' response along busy lines and non-busy lines, no significant difference was observed. It was justified because of the possible difference in the residents' adaptation to the Shinkansen noise, as well as that of the existing environment before Shinkansen was built.

Local governments designate the area classification based on the land use plan. Not only urban areas but also agricultural areas are designated of they are to be inhabited.

The government standard does not have legal force. As an implementation of that standard, the government required the railway operators to achieve so-called "Temporary 75 dB(A) Countermeasure," as Table 2. Those areas are based on the presence of wayside houses, expanded from densely inhabited areas to less dense areas. On the other hand, the Hokuriku Shinkansen, which opened in 1997, was supposed to achieve 75 dB(A) from the beginning of its operation in all areas except uninhabited areas.

1.2 Conventional Lines

As for conventional lines, new lines and upgraded

Table 1 Shinkansen Noise Standard.

Area		Noise
Type 1	Residential Area	70 dB(A)
Type 2	Industrial and Commercial Area	75 dB(A)

Note:
1. To be measured 1.2 m above the ground
2. Indices are the power averages of the larger 10 peak noise levels, using the time constant SLOW, among 20 successive trains.

Table 2 Temporary 75 dB (A) countermeasure.

Area	Noise	Deadline
Phase 1	75 dB (A)	March 31, 1994
Phase 2		March 31, 1997
Phase 3		March 31, 2003

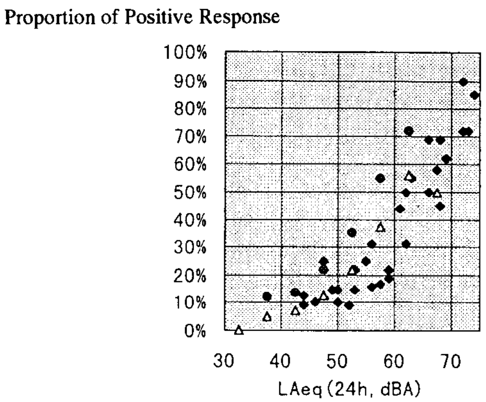

Fig. 1 Residents' response to conventional line noise.
◆ Environmental Agency 1975–84
● Environmental Agency 1992–93
△ Tokyo Prefecture; Source: Literature.[2]

lines are subject to noise standards.

When Shinkansen noise standard was discussed, it was decided that the noise standard of conventional lines would be laid down when adequate noise indices and their influence to wayside residents were clarified through further investigation. So conventional line noise was coped with in the case-by-case principle until 1988, when a new line connecting Honshu and Shikoku and upgraded lines connecting Honshu and Hokkaido caused complaints from wayside residents. This triggered the awareness to prevent conventional line noise before commercial operation. In 1995, "Guideline for New or Upgraded Conventional Line Noise" was laid down.[2] Since conventional lines have a variety of vehicles, train length, and speed, equivalent noise level (L_{eq}) was considered as an adequate index. The survey upon resident's response showed that the proportion of those who appealed "noisy" was 30% when train noise was 50–60 dB(A) as Fig. 1 shows.

Table 3 Guideline for new or upgraded conventional line noise.

Case	Noise (L_{eq})
New lines	60 dB(A) (7:00–22:00) 55 dB(A) (22:00–7:00)
Overall upgrade	Not to worsen present noise level

In deciding the compliance levels for the guideline as Table 3, feasible noise level was surveyed. Using existing measures such as noise barriers, the maximum noise level was 75 dB(A), and the maximum train number of new lines was 250 in 7:00–22:00. In such case L_{eq} becomes 60 dB(A).

2. NOISE MEASUREMENT AND EVALUATION

2.1 Shinkansen

Recent ordinary sound level meters display the maximum noise level (L_{max}). Noise indices are calculated with personal computers very quickly.

As for Shinkansen lines there "Temporary 75 dB(A) Countermeasure" is applied, measuring points are decided by local governments to represent the standard noise level of each 75 dB(A) area. As for Hokuriku Shinkansen, noise is measured at 500 m interval.

Although the environmental standard does not specify the measuring location to the track, noise is usually measured 25 m apart from the track center so that the results can be compared each other.

2.2 Conventional Lines

Calculating L_{eq} is more complicated than L_{max}. Although recent sound meters have built-in functions to calculate L_{eq}, JR East does not use them, because of the risk to gather background noise. Instead we have dedicated computer software to calculate L_{eq}, sampling the noise level (slow) every one second.

Measuring L_{eq} is much more costly than L_{max} when measured manually. The noise measurement of Shinkansen takes only a half of the day in busiest lines. L_{eq} measurement in conventional lines takes the whole day. In the future, we should be able to estimate L_{eq} for the whole day based on the knowledge of the relation between noise, car type, and speed.

3. NOISE ANALYSIS[3)]

To locate noise sources is important to find which noise abatement is effective. Also this technique is used to evaluate the effect of individual noise abatement technique. For this purpose, noise measurement and analysis technique has been developing for Shinkansen in Japan.

Since Shinkansen train goes faster than 200 km/h, aerodynamic noise is one of the major noise sources. So, the following four noise sources should be considered;

…Pantograph Noise (considered mainly aerodynamic)
…Rolling Noise
…Car Body Aerodynamic Noise
…Structure-Borne Noise

As for special microphones to separate those sources, we have;

Linear Array Microphones
Cross Array Microphones
Sound Intensity Microphones

Linear array microphones, or super-directional microphones, are used most often. Nine microphones are located at half of the wave length, hence the array length is four times of the wave length. The signals from the microphones are weighed and summed so that both the resolution and the level of side lobes are desirable. Different combination of the microphones is used for different 1/3 octave band.

The advantage of using this equipment is as follows;

(1) The output is obtained on the spot. No post processing is necessary.
(2) This equipment is installed in safe places and does not threaten the safety of trains and staff.
(3) The directivity (Fig. 2) does not depend on the wave length. This enables the evaluation in dB(A), for the overall value is meaningful.

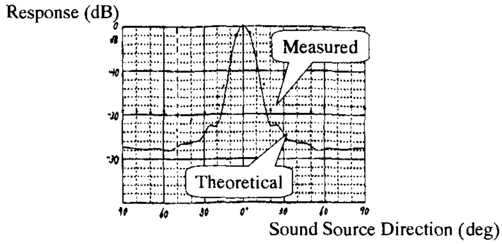

Fig. 2 Directivity of super-directional microphones.

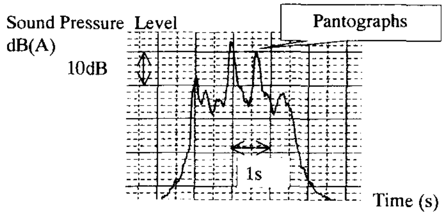

Fig. 3 Sound pressure level measured with super-directional microphones.

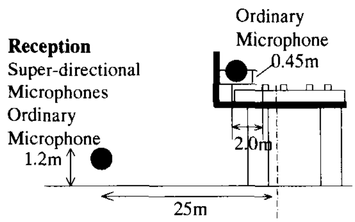

Fig. 4 Allocation of measuring equipment.

Shinkansen noise is hard to detect not only because of very short time to observe but also because of the existence of noise barriers. They are usually 2 meters high from the rail top and abate only rolling noise. You have to discuss which noise is dominant at reception — rolling noise abated by barriers and other noise without obstacles to the reception. The following procedures are taken to identify the contribution of each noise source at reception.

(1) Pantograph Noise

The noise from pantographs is separated using the data measured with super-directional microphones (Fig. 3).

(2) Rolling Noise

To measure rolling noise, ordinary microphones are installed beside the rails (Fig. 4). To estimate its contribution at reception, the noise of low-speed train (less than 200 km/h), dominated by the rolling noise, is used to relate the sound pressure levels by the rails to the wayside. The effect of reflection of the noise barriers is taken into consideration.

(3) Body Aerodynamic Noise

It is estimated by subtracting the rolling noise from the super-directional noise level.

(4) Structure-Borne Noise

It is estimated by adding the low frequency components (around 100 Hz) at reception.

(5) Summing-up of Individual Noise Sources

To calculate the noise level with ordinary microphones from that with the super-directional microphone, the following assumptions about the nature of the noise sources are needed ;

···Directivity

···The length of the noise sources

Super-directional microphones do not give information about these attributes. So, try-and-error procedures are required.

4. NOISE FORECAST

4.1 Shinkansen

In forecasting Shinkansen noise of new lines, track type, noise barrier height, and track height from the ground, are considered. The effect of noise barrier height and track height, or geometrical conditions, is derived from Maekawa's Table for point sources or Yamashita and Koyasu's Table for line sources.

The sound power level of each noise source is given so that the forecast noise equals to the result of noise analysis mentioned above.

The effect of track type (ballast/slab) is reflected as the difference of the power level of rolling noise.

4.2 Conventional Lines[4)]

In Japan, new lines and overall upgraded lines are almost confined to urban transit. Hence, noise forecast is important for electric cars running at 100 km/h or so. Since aerodynamic noise from pantographs and car bodies are small, because of the speed, the cause of noise is mainly rolling noise and traction motor noise. Traction motor noise, aerodynamic noise from the cooling fans fixed to their axles, is very dependent on motor types, train speed, and gear ratio. In forecasting traction motor noise, those factors are taken into account in the calculation for each car type. Note that Shinkansen trains' traction motors have machined cooling system. Hence no motor fan exists in Shinkansen.

Hence, rolling noise and traction noise are given as noise sources. They are both located along the rails. The effect of noise barriers and the estimation of sound power level take similar procedure as in Shinkansen.

5. CONCLUDING REMARKS

The measurement and evaluation method of the railway noise in Japan is thus very historic. It is desirable to update those methods to the recent changes, such as the introduction of L_{eq} and the improvement of data processing.

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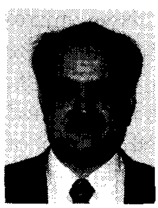

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