Measurement and Analysis of Railway Noise in Japan

S. Ono
Technical Development and Research Department, East Japan Railway Company

Environmental Standard

Shinkansen is the first railway running faster than 200km/h in the world. When it was opened in 1964, its wayside noise caused a strong social demand for environmental preservation.

As for other lines, or conventional lines, new lines and upgraded lines are subject to wayside noise standards.

Table 1 Shinkansen and conventional lines

* as of March 2000. Some conventional lines operate faster, but exceptional

Classification	Gauge	Max. Speed *	Traffic
Shinkansen	1.435mm	300km/h	Passenger
conventional lines	1.067mm	130km/h	Passenger & Freight

- ***Shinkansen***

The Environmental Agency laid down the environmental standard of Shinkansen noise in 1975.

Table 2 Shinkansen Noise Standard

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

Note: 1. To be measured 1.2m 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.

To cover all the types of Shinkansen trains, measuring 20 data was considered adequate. 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 not observed. Residents' sensitivity toward Shinkansen noise was considered to depend on the residents' adaptation to the Shinkansen noise, as well as the existing wayside environment before Shinkansen was built.

Questionnaire surveys were carried out to the wayside residents. The proportion of those who appealed some influence from Shinkansen noise was 30% when the noise was 70-75dB(A). The compliance levels are the lower and upper boundaries of the noise.

The classification of areas is decided by the local government based on the land use plan. Not only urban areas but also agricultural areas are designated if they are to be inhabited.

The environmental standard does not have legal force. As an implementation of that standard, the government required the railway operators to achieve so-called "Temporary 75dB(A) Countermeasure." 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 75dB(A) from the beginning of its operation in all areas except uninhabited areas.

Table 3 Temporary 75dB(A) Countermeasure

Area	Noise	Deadline
Phase 1	75dB(A)	31.03.1994
Phase 2		31.03.1997
Phase 3		31.03.2003

- ***Conventional Lines***

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 new lines and upgraded lines 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. Since conventional lines have a variety of vehicles, train length, and speed, equivalent noise level (Leq) was considered as an adequate index. The survey upon residents' response showed that the proportion of those who appealed "noisy" was 30 % when train noise was 50-60dB(A).

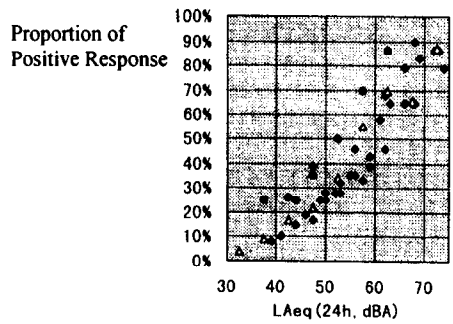

Figure 1 Residents' Response to Conventional Line Noise
◆ *Environmental Agency 1975-84*
● *Environmental Agency 1992-93*
△ *Tokyo Prefecture*

In deciding the compliance levels, feasible noise was surveyed. Using existing measures such as noise barriers, the maximum noise level was 75dB(A), and the maximum train number of new lines was 250 in 7:00-22:00. In such case Leq becomes 60 dB(A).

Table 4 Guideline for New or Upgraded Conventional Line Noise

Case	Noise (Leq)
New Lines	60dB(A) (7:00－22:00) 55dB(A) (22:00－7:00)
Overall Upgrade	Not to worsen present noise level

Noise Measurement and Evaluation

- ***Shinkansen***

Ordinary sound level meters are used. Resent equipment gives the maximum noise level (Lmax) very easily. Using digital interface devices, evaluation values are calculated very quickly.

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

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

- ***Conventional Lines***

Calculating Leq is more complicated than Lmax. JR East does not use built-in functions to calculate Leq, because of the fear to gather background noise. Instead we have dedicated computer software to calculate Leq, sampling the noise level (slow) every one second.

The noise measurement of Shinkansen takes only a half of the day in busiest lines. Leq measurement in conventional lines takes the whole day. In the future, we should be able to estimate Leq for the whole day based on the knowledge of the relation between noise, car type, and speed.

Noise Analysis

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 200km/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 added with an analogue filter, whose weighing parameter is decided in view of the resolution and the level of side lobes. Different combination of the microphones is used for different 1/3 octave band.

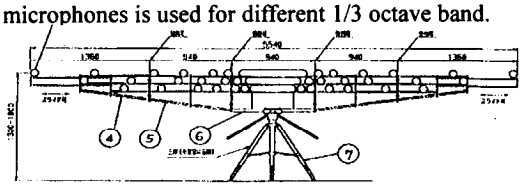

Figure 2 Super-directional Microphones

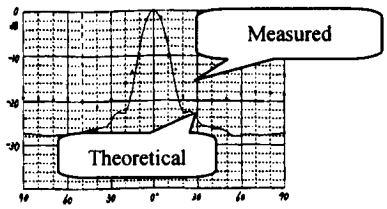

Figure 3 Directivity of Super-directional Microphones

The advantage of 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 does not depend on the wave length. This enables the evaluation in dB(A), for the overall value is meaningful.

Shinkansen noise is hard to detect not only because only pass-by noise can be measured but also because the noise barriers, usually 2 meters high from the rail top, 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.

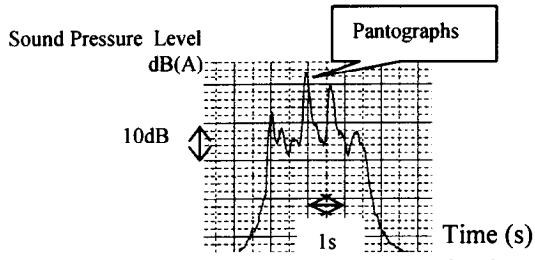

Figure 4 Sound Pressure Level Measured with Super-Directional Microphones

2. Rolling Noise
   Ordinary microphones are installed by the rails to measure rolling noise. To estimate its contribution at reception, the noise of low-speed train (less than 200km/h), in which the rolling noise is considered dominant, 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.

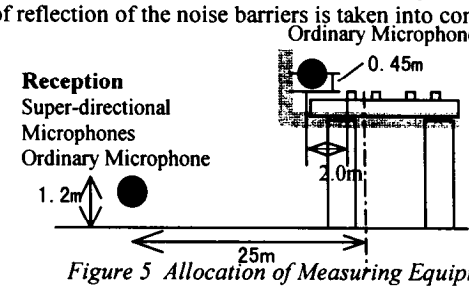

Figure 5 Allocation of Measuring Equipment

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 100Hz) 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.

Noise Forecast

- ***Shinkansen***

The effect of noise barriers is estimated using Maekawa's Table for point sources or Yamashita and Koyasu's for line sources.

The sound power level of each noise source is given so that the forecast noise is consistent with the result of noise analysis which is mentioned above.

- ***Conventional Lines***

In Japan, new lines and overall upgrade are almost confined to urban transit. Hence, noise forecast is important for electric cars running at 100km/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 noise exists in Shinkansen.

Locating the noise sources along the rails, the effect of noise barriers are estimated.

Concluding Remarks

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

Literatures

[1] Central Anti-Pollution Committee, Basis of the Environmental Standard for Shinkansen Noise (1975)
[2] The Environmental Agency, Guideline for New or Upgraded Conventional Line Noise (1997).
[3] Nagakura, K., The methods of Analyzing Shinkansen Noise, RTRI Report, 1996.2, 29-34.