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Noise Control of Shinkansen and Its Reference Significance to China

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Abstract: Japanese society has always been concerned about noise issues in the environmental protection of high-speed railways, and various efforts have been made administratively and technically to address high-speed railway noise issues. Administrative efforts include regulatory measures such as setting environmental standards for high-speed railway noise and noise measurement and assessment; technical efforts include testing and control using appropriate means for various railway noise sources. The environmental noise problem of the Shinkansen has become one of the key factors limiting the ability of the Shinkansen to increase its operating speed. China's high-speed railway construction has been developing rapidly since 2008, and increasing attention is being paid to environmental protection. With the increase in China's high-speed railway construction lines and the gradual increase in high-speed railway speed, China's high-speed railway's new higher-speed technology shall be put into operation in the future. The issue of high-speed railway noise control is also becoming increasingly important to China. China's high-speed railways have applied both active and passive noise reduction technologies, but in view of the research on high-speed railway noise control the concept and design of environmental protection, especially noise control, of the Japanese Shinkansen railway was carried out relatively early, and the research on advanced technology of some Shinkansen noise control measures has certain significance for China's high-speed railway operations.

Keywords: Shinkansen, Environmental Protection, Noise, Speed Increase

1. Introduction

When the Tokaido Shinkansen line opened in 1964, noise and vibration problems were not considered as part of environmental protection, resulting in growing discontent among residents along the Shinkansen and the development of a regional movement of residents in 1965 demanding that the former Japan National Railway Company take strong measures to eliminate the nuisance. [1] Various efforts have been made at the legal, administrative and technical levels to address railway noise and vibration problems in Japan. Therefore, the study of environmental protection regulations and measures for high-speed railways in Japan has implications for the development of high-speed railways and the construction of an environmentally friendly society in China.

Administrative work on noise countermeasures for Shinkansen railways in Japan includes the development of environmental standards for Shinkansen railway noise; the development of noise control guidelines for new or extensively renovated Shinkansen lines; and the development of a railway noise measurement and assessment manual. Technical work includes measures to deal with various sources of railway noise (e.g. aerodynamic noise, rolling noise, structural noise, vehicle equipment noise, etc.), and countermeasures to reduce noise transmission by building sound barrier walls, etc. [2]

2. Japan's Environmental Regulations on Noise of High-speed Railway

In accordance with the provisions of Article 16 of the Basic Environment Law (Law No. 91 of 1993), the environmental conditions relating to Shinkansen Superexpress Railway noise standards are notified as follows. [3]

Table 1. *The environmental conditions relating to Shinkansen Super express Railway noise standards.*

Category of area	Standard value [in dB]
I	70 or less
II	75 or less

Note: Area category I refer to areas used mainly for residential purpose and area category II refers to other areas, including commercial and industrial areas, where the normal living conditions shall be preserved.

2.1. Measurement Method

(1) Measurements shall be carried out by recording the peak noise level of each of the Shinkansen trains passing in both directions, in principle, for 20 successive trains.
(2) Measurements shall be carried out outdoors and in principle at the height of 1.2 meters above the ground. Measurement points shall be selected to represent the Shinkansen railway noise levels in the area concerned, as well as points where the noise is posing a problem.
(3) Any period when there are special weather conditions or when the speed of the trains is considered lower than normal shall be avoided when selecting the measurement time.
(4) The Shinkansen railway noise shall be evaluated by the energy mean value of the higher half of the measured peak noise levels.
(5) The measuring instrument used shall be a noise meter that meets the requirements of Article 88 of the Measuring Law (Law No. 207 of 1951), with A-weighted calibration and slow dynamic response. [4]

2.2. Noise Measurement of Shinkansen in Japan

According to Japan industrial Acoustics standard—Description and measurement of environmental noise, this Standard defines the basic quantities to be used for the description of environmental noise and describes basic assessment procedures. The standard defines the following types of environmental noise: (1) total noise: noise that can be clearly identified in the comprehensive noise; (2) Specific noise: from the perspective of acoustics, the noise can be clearly identified from the comprehensive noise, and the sound source can usually be determined; (3) Background noise: all other noises when focusing on a specific noise; (4) Residual noise: in the comprehensive noise, the residual noise of all specific noise is removed. [5]

The evaluation quantity for Shinkansen railway noise is: maximum noise level $L_{A,Smax}$ - the maximum value of the noise level observed at the time of noise generation, measured in decibels (dB). The maximum value derived after setting the time-weighted characteristic of the noise meter to S (slow), using a noise level of $L_{A,Smax}$. In principle, for each train with a maximum noise level ($L_{A,Smax}$) of 20 trains passing continuously, including both upward and downward trains, the average value of the energy in the upper half is calculated according to the following formula as the evaluation quantity for the measurement point in question (maximum noise level of Average value$\overline{L}_{A,Smax}$), expressed as an integer value.

$$\overline{L}_{A,Smax} = \mathrm{Log}10\left\{\frac{1}{n}\sum_{i=1}^{n} 10^{\frac{LA,S\max,i}{10}}\right\}(\mathrm{dB})$$

In the equation, n: the number of data (n=10 when the data in the top half is 10); $L_{A,Smax,i}$: the value of the ith maximum noise level (dB) in the top half [6].

3. Japanese Government's Supervision of High Speed Railway Noise

The Japanese Ministry of the Environment and local governments regularly measure Shinkansen noise, set up survey points along the lines, conduct tests in accordance with regulations, monitor whether Shinkansen noise meets environmental noise standards, and post announcements on government websites to take appropriate countermeasures. Since 1985, as a measure to achieve environmental standards, the Japanese government and related organizations and companies have been promoting the "75 decibel measure", which reduces noise levels to below 75 decibels in densely populated residential areas along the Shinkansen.

The Ministry of the Environment will request the Ministry of Land, Infrastructure, Transport and Tourism to take additional measures immediately on those sections of the measure that exceed 75 decibels, and to continue to promote the measure in areas that exceed 75 decibels outside the existing measure areas. [7]

4. Noise Reduction Measures for Speed Increase of High-speed Railway in Japan

Japan's Shinkansen high-speed trains usually operate in densely populated areas, and the Ministry of the Environment has set environmental noise standards from the perspective of reducing the burden on the environment along the routes. In order to control the noise of the Shinkansen railway lines, the Environmental Agency established the “Environmental Quality Standards for Shinkansen Super-express Railway Noise” in 1975. To date, the opening of new Shinkansen lines and the speed-up of Shinkansen lines must be promoted in accordance with that environmental standard.

Shinkansen noise has been divided into four components according to source position, (1) pantograph aerodynamic noise, (2) aerodynamic noise generated from the upper part of cars (electric insulator, gaps between cars and uneven car surfaces), (3) the noise generated from the lower part of cars (mainly rolling noise and aerodynamic noise around bogies), and (4) concrete bridge structure noise. Among these, when Shinkansen trains run at high speed above 270 km/h, the aerodynamic noise becomes a major source. [8] The contribution of these sources to noise emissions along the Shinkansen varies with the increase in HSR operating speed.

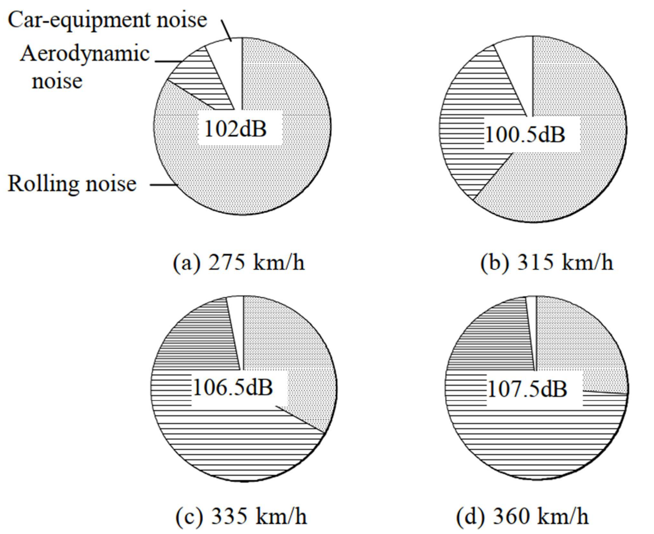

Figure 1. *Contribution of the rolling noise and aerodynamic noise of Shinkansen.*

When the Tokaido Shinkansen Line commenced operation in 1964, the noise value was about 90dB (A). The main component of Shinkansen noise at that time was rolling noise. In response to the urgent need to reduce the wayside noise, sound barriers were constructed along the track. This reduced the noise value to 80-82dB (A).

Since 1964, when the Tokaido Shinkansen opened with Series 0 cars, operating at a speed of 210km/h, noise control was not considered at the time of construction and the main source of noise was wheel-track noise. In 1982, the Shinkansen series 200 cars were put into operation, with a maximum operating speed of 210km/h. Sound barriers of two meters in height were installed along both sides of the line, with the main source of noise being the pantographs and aerodynamic noise from the upper part of the cars. In 1986, the operating speed of the Tokaido line was increased from 210 km/h to 220 km/h and the noise increased to 77 dB (A), with the main noise sources being pantograph noise and aerodynamic noise from the upper part of the cars.

In 1992, the series 300 cars on the Tokaido line was put into service and the operating speed was increased to 270km/h. The first car that was designed for low aerodynamic noise is a Series 300 car. In Series 300 cars, most equipment, such as air conditioners, was moved to the lower part of cars which is screened by a sound barrier, and the upper part was almost smoothened except electric insulators and gaps of cars. As a result, the aerodynamic noise from the upper part of cars was reduced dramatically and the noise level of Series 300 cars at 270km/h run was 75-76dB. At the same time, the number of train sets of Series 0 cars whose noise levels were higher than those of other cars decreased and the noise value was reduced to 75dB in spite of remarkable speed-up. [9]

In 1997, series 500cars of Sanyo Shinkansen line was put into operation, increasing speeds to 285-300km/h and noise to 76dB (A). The series 500 cars adopted a long nose similar to the shape of aircraft nose, in order to reduce air resistance and aerodynamic noise; In 1999, the Tokaido Shinkansen 700 series cars were put into operation at a speed of 285 km/h. The low noise pantograph design and the smoothing of the car surface have reduced the noise to 75 dB (A). [10]

In 2013, series E5 cars were adopted by Tohoku Shinkansen line. Noise reduction technologies for Shinkansen high-speed trains such as new low-noise pantographs, pantograph noise insulation plates, sound-absorbing panels and circumferential diaphragms were used for this new generation Shinkansen trains-series E5 (Figure 2). Series E5, with a maximum speed of 300 km/h, was introduced in March 2011, after which by March 2013 the maximum speed was increased to 320 km/h, the highest Shinkansen speed in operation in Japan. [11]

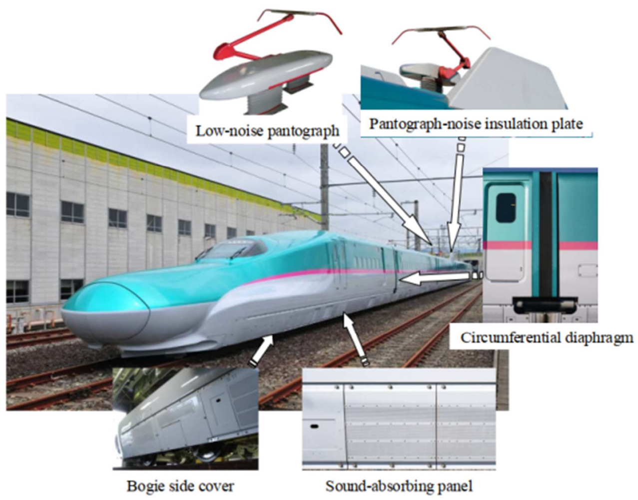

Figure 2. *New technologies used for series E5.*

In accordance with JR East's vision for the future development of noise reduction technology, in May 2019, JR East began a three-year operational test of the new test train E956 (ALFA-X). The noise reduction techniques being developed are full vehicle smoothing and an improved nose shape with a 22 meter long nose to reduce aerodynamic drag; the pantographs are of a low-noise construction and two types of low-noise pantographs have been fitted to the car for testing and the structure of the hinges and shape of the insulating hood have been improved by placing the hinge section inside the insulating hood to reduce aerodynamic noise. [12] JR East plans to put the ALFA-X test model into service on the Tohoku and Hokkaido Shinkansen lines around 2030, and the manufacturers of the test model, Kawasaki Heavy Industries and Hitachi, will continue to promote innovative noise reduction technologies, with the expectation that the maximum speed of the Tohoku and Hokkaido Shinkansen lines will increase to 360 Km/h while meeting environmental standards for noise emissions.

5. Reference Significance to China HSR

At the very beginning of Shinkansen development, Japanese National Railways (JNR) did not pay attention to noise emission. Therefore, Japan HSR followed a process of pollution first and then treatment. The relevant parties of Japan's railway paid a lot of costs. As China's high-speed railway speed continues to improve, the problem of aerodynamic noise is also gradually highlighted, along the noise problem will also be more prominent. Therefore, for the effective control of high-speed train noise, Japan's high-speed railway car noise reduction design concept and its railway noise reduction technology are worthy of reference.

According to the comprehensive test data of Beijing-Shanghai and Zhengzhou-Xuzhou passenger dedicated HSR lines in China, when the test speed of high-speed train is increased from 300km / h to more than 400km / h, the aerodynamic noise on the upper part of the train increases significantly in the contribution value of sound source. [13]

At the level of active noise reduction, China HSR relevant parties has taken measures to optimize the head shape of high-speed trains, improving the aerodynamic noise reduction performance of high-speed trains during open-line operation. The next step should be to carry out research on noise reduction technology in the upper areas of the car body, such as the pantograph, and further optimize the design of the pantograph and other areas to reduce the aerodynamic noise in the operation of high-speed trains. [14] The next step of the noise reduction research should be to carry out research on noise reduction technology in the upper areas of the car body, such as the pantograph, and further optimize the design of the pantograph and other areas to reduce the aerodynamic noise in the operation of high-speed trains. In terms of passive noise reduction, the design of sound barriers in China is relatively single, mainly plug-in metal sound barriers, accounting for more than 90% of the total number of sound barriers along the railway. Compared with developed countries, the research and application of sound barrier in China started late, but the high-speed railway network in China with dense and wide coverage, a large number of high-speed railway sound barriers have been built, with a total length of more than 4000 km. [15] The Japanese railway sound barrier technology can provide a lot of experience for China in terms of manufacturing standards and road landscape design.

6. Conclusion

In the course of the Shinkansen speed increase, all parties concerned in Japan have attached great importance to the noise emission generated by the operation of Shinkansen high-speed trains, and the core issue in the Shinkansen operation speed increase is how to control the noise. Whether the noise level of the Shinkansen railway is below 75dB is one of the key factors limiting the speed of Shinkansen trains. Japan's high-speed railway environmental noise control course to China's high-speed railway construction and high-speed railway existing line speed provides an extremely useful reference point to China's HSR.

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