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THE EXPERIMENTAL INVESTIGATION ON THE SOUND ABSORPTION COEFFICIENT OF THE SOUND ABSORPTIVE MATERIALS IN SCALE MODEL EXPERIMENT FOR RAILWAY NOISE

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ABSTRACT
On the process of the research concerning the multiple reflection in predicting method of ordinary railway noise, we examined the sound absorption coefficient of the sound absorptive materials for model experiment prior to scale model experiment of ballast and noise barrier with the sound absorptive materials. Therefore it is for the model experiment on the scale of one to twenty, we needed to obtain an absorption coefficient of high frequency range (4−40kHz). We carried out the measurement of the reverberation room method by the nitrogen substitution and the measurement of the oblique incident sound absorption coefficient using the TSP (Time-Stretched Pulse) signals which we newly proposed at 96kHz sampling frequency since the high frequency range is correspondent. Two measurement results were compared and the problem of the measurement was examined.

1 - INTRODUCTION
The ordinary railway noise predicting method applies approximation equations for semi-infinite barriers to calculate the attenuation amount for conditions in which there are elevated construction or other barriers to the path of transmission from the noise source, for example the rolling noise and the motor cooling fan noise, to the sound receiving point [1]. However, in some cases the predicting levels and the actually measured levels do not match. We reported that one of the reasons for this is that there is multiple reflection between the vehicle body and the barrier. That is why we carried out more detailed experiments with a model (1/20 scale) in order to quantitatively systematize the impact of differences in the distance between the car-body and the barrier and the presence or absence of ballast and anti-noise wall sound absorption material [2].
In this report, the sound absorption coefficient was measured with the oblique incident sound absorption coefficient measurement method using TSP (Time-Stretched Pulse) signals and the reverberation room method by the nitrogen substitution. This was a foundational study for ascertaining the sound absorption characteristics of the sound absorption material used to simulate ballast and anti-noise walls in simulation experiments. This paper reports on the consideration of the results of these measurements and measurement problem points.

2 - SOUND ABSORPTION COEFFICIENTS FOR SOUND ABSORPTION MATERIALS FOR SCALE MODEL EXPERIMENTS
In the scale model experiments, it is assumed that the similarity between the model and the actual objects holds for all the physical amounts at the model scale ratio. Therefore, since the frequency

spectrum measured at a point near the main sound sources of typical railways, the rolling noise and the motor fan noise (2 meters from the rail center), is composed of frequencies that peak at 500 Hz − 2 kHz for actual suburban type trains, at a scale of 1/20 in the model, it is necessary to measure the sound absorption coefficient at a maximum frequency of 40 kHz.
The following four types of sound absorption materials were selected for the scale model experiments.

- Urethane foam 5-mm thick (below, " urethane ")
- Cotton cloth (No. 11 canvas) (below, "canvas")
- Crushed rock (3-mm diameter limestone, 30-mm thickness (below, 3-mm ballast)
- Crushed rock (5-mm diameter limestone, 30-mm thickness (below, 5-mm ballast)

Urethane was selected for its high sound absorption coefficient and canvas for its low sound absorption coefficient. Also, 3-mm limestone was selected to simulate ballast by scaling down from the 60-mm maximum grain size in the grain diameter volume addition curve in the railway ballast regulations. 5-mm ballast was selected in order to study the impact of grain diameter on the sound absorption coefficient.
The sound absorption coefficients were measured in the 1/3 octave band frequencies from 4 to 40 kHz (corresponding to 200 Hz to 2 kHz for actual objects).

3 - REVERBERATION ROOM METHOD SOUND ABSORPTION COEFFICIENTS

The test material to be measured was placed inside a reverberation box in which oxygen had been replaced with nitrogen to lower the oxygen concentration to no more than 2 percent and the reverberation time was measured in the 1/3 octave band frequency from 4 kHz to 40 kHz.
In order to compare measurement with nitrogen and with the ordinary atmosphere, the reverberation time was measured in the ordinary atmosphere with just an empty room and urethane without replacing the oxygen with nitrogen. The specifications of the reverberation box used for measurement were as follows:

- Material: Acrylic board (10 mm thick) Surface area for inner surfaces: 1.771715 m^2
- Volume: 0.17898 m^3 Test material surface area: 25cm ×40cm = 0.1 m^2
- Sound source: Wide-band white noise (50 Hz to 100 kHz)

3.1 - Results of measuring sound absorption coefficients by reverberation room method

Figure 1 shows the results of measuring sound absorption coefficients by reverberation room method. From Figure 1, the sound absorption coefficient at 20 kHz (equivalent to 1 kHz for the actual objects) are 0.8 for urethane, 0.6 for canvas, 0.9 for 3-mm ballast, and 0.8 for 5-mm ballast. For urethane and canvas, the sound absorption coefficient increases just about in parallel with the increasing frequency and in the band above 20 kHz, is just about flat. For ballast, the sound absorption coefficient for 3-mm ballast is about 0.1 higher in all frequency regions. The sound absorption coefficient is maximum for both types of ballast at 12.5 kHz, where the sound absorption coefficient is more than 0.9, which is high.

Also, in order to compare the measurement conditions using nitrogen and in the ordinary atmosphere, the reverberation time was measured for urethane using the ordinary atmosphere without replacing oxygen with nitrogen. When using the ordinary atmosphere, the sound absorption coefficient drops extremely in the high frequency regions, with the boundary at 10 kHz. The cause for this is thought to be absorption of sound in the air. Therefore, sound absorption coefficients for high-frequency regions above 10 kHz in the ordinary atmosphere cannot be measured accurately and it is necessary to measure with nitrogen replacement.

4 - OBLIQUE INCIDENT SOUND ABSORPTION COEFFICIENTS

The oblique incident sound absorption measurement method uses the measurement of impulse response for TSP signals used in the fields of indoor acoustics and electro-acoustics. In these experiments, in order to improve the replication of measurements and to secure an adequate signal-to-noise ratio, sound absorption coefficients were measured with impulse response with TSP signals with a sampling frequency of 96 kHz. The measurements in this experiment used TSP signals of about 0.68 second (65536 points) [3], [4], [5]. The distance of the test piece to the microphone and speakers is 1 m. The incident angles

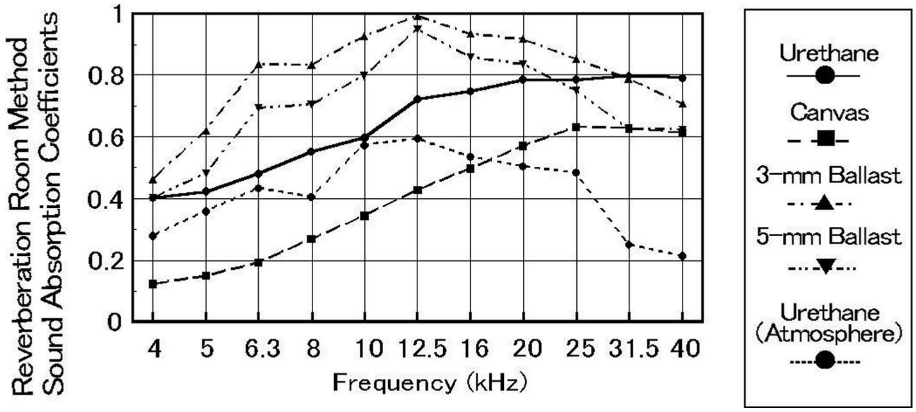


Figure 1: The results of reverberation room method sound absorption coefficient.

were set to 3°, 15°, 30°, and 45° and measurements were made at 60° as well for reference. Under the condition of perpendicular incident radiation, it was decided in this measurement to use an incident angle of 3° for the perpendicular incident radiation. 3 m by 1 m was selected as the surface area for the urethane and the canvas and 2 m by 1 m for both the 3-mm grain size and 5-mm grain size ballast. Also, in order to study the influence of the test piece installation surface area, for urethane and canvas, measurements were also made with installation surface areas of 1 m by 1 m (equivalent to the distance between the sound source and the reflection point).

4.1 - Measurement Results of Oblique Incident Sound Absorption Coefficients

Figure 2 shows the results of the measurement of oblique incident sound absorption coefficient. The values for incident angles of 3°, 15°, 30°, and 45° were arithmetical averaged. From Figure 2, the respective sound absorption coefficients at 20 kHz (equivalent to 1 kHz on the actual object) were 0.8 for urethane, 0.4 for canvas, 0.8 for 3-mm ballast, and 0.8 for 5-mm ballast. Comparing this to the sound absorption coefficients for the reverberation room method in Figure 1, for urethane in the region about 16 kHz, the trend for the sound absorption coefficient to be flat at 0.8 was extraordinarily similar for both methods. Also, the trend for the sound absorption coefficient for canvas to be constant in the region above 20 kHz was the same for both methods, but the values measured with the oblique incident method were about 0.2 lower. For ballast, the pronounced peak at 12.5 kHz seen with the reverberation room method was not seen with the oblique incident method and there were peaks instead at 6.3 kHz for 3-mm ballast and 8 kHz for 5-mm ballast. According to this study, if the trends in the sound absorption coefficients measured with the reverberation room method and the oblique incident method are compared, the sound absorption coefficients for porous materials with uniform surfaces, such as urethane and canvas, show the same trends with both measurement methods even if sometimes the results are higher for one method or the other. However, for granular material, such as ballast, there is thought to be a trend for the peaks to appear in different frequency regions.

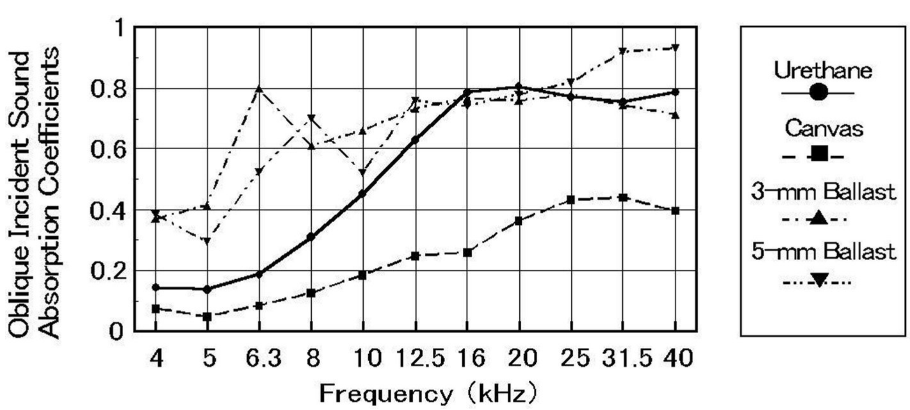
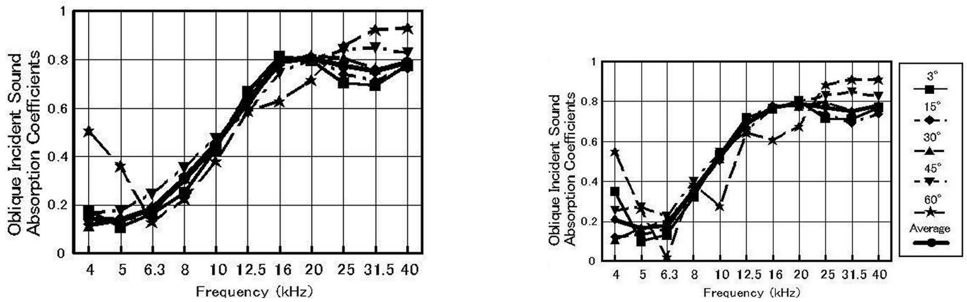


Figure 2: The results of oblique incident sound absorption coefficient.

Figure 3 shows the sound absorption coefficient for urethane for each angle; (a) shows the results for 3 m by 1 m and (b) shows the results for 1 m by 1 m.



(a): 3 m by 1 m. **(b):** 1 m by 1 m.

Figure 3: The results of oblique incident sound absorption coefficient for urethane.

Figure 4 shows the results for 3-mm ballast. The oblique incident sound absorption coefficients are averages for all angles except 60°.

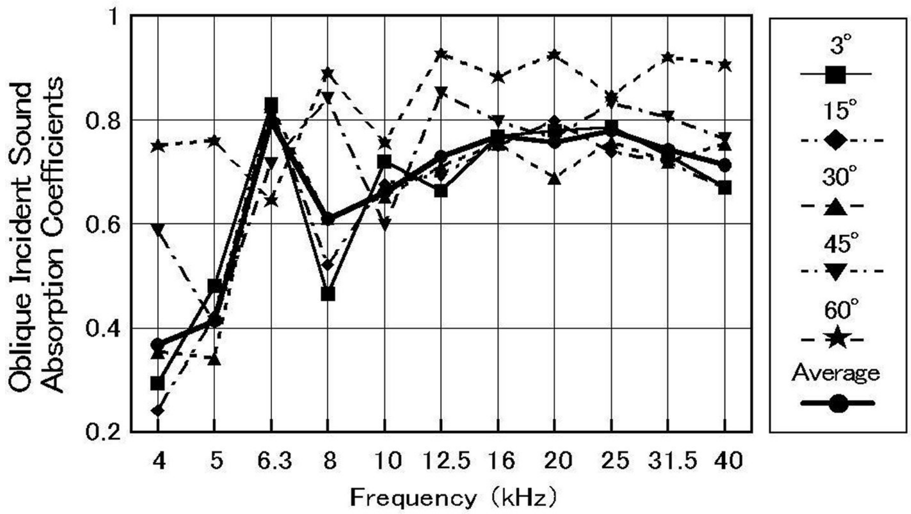


Figure 4: The results of oblique incident sound absorption coefficient for 3-mm ballast.

Comparing Figures 3 (a) and 3 (b), the average values for oblique incident sound absorption coefficients for urethane pretty much match and it is thought that it is good that the test piece surface areas are the squares of the distance between the sound source and the reflection point. Also, when the incident angle is set to 60°, there are regions in which the values measured are different from those for other angles. This trend is particularly noticeable when the test piece surface area is small. Furthermore, from Figure 4, the values for 60° for 3-mm ballast show a different trend from when the angles are smaller. The values for 45° tend to be intermediate between the values for smaller angles and those for 60°. As the cause of this, it may be that under the condition of shallow angles and 60°, since the difference between the distances traveled for direct waves and indirect waves was small, there were problems in the accuracy of waveform separation. Also, it is conceivable that the process in which sound infiltrates the test piece gaps gives a different angle dependence to the sound absorption characteristics for material with a granular surface, such as ballast, and porous material, such as urethane. Therefore, from this study, it is thought that measurement of oblique incident sound absorption coefficients is appropriate for incident angles in the range 0-45°. However, adequate study is required concerning how to handle measurement values for an incident angle of 45° when the test material is granular.

5 - CONCLUSIONS

In these experiments, oblique incident sound absorption coefficients measurement using TSP signals was tried out and studied in comparison with the reverberation room method. This showed that this method is able to measure sound absorption coefficients with almost no problems in actual practice. This measurement method is considerably simpler and safer than measuring replacing the reverberation box with nitrogen. This method makes it possible to reduce the amount of work in selecting sound absorption materials for simulation that have sound absorption coefficient characteristics near those of the actual objects being simulated. In light of these study results, analysis of simulation experiments to ascertain the impact of multiple reflection on railway noise predicting methods is scheduled.

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