Basic Study on a Laboratory Measurement Method of the Normal-Incidence Scattering Coefficient

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Summary

Regarding scattering coefficient that represents the acoustic scattering of wall surfaces, a reverberation room method for measuring the random-incidence value has standardized in ISO17497-1. However measurement methods for the angle-incident values are not yet fully established. In this paper, a laboratory measurement method is introduced for obtaining the normal-incidence scattering coefficient, which can be useful to predict the suppression of flutter echoes. The measurement is done in a rectangular room in 1/4 scale model, where installing highly absorbent materials on all side walls, and a test sample on the floor. In the one-dimensional sound field, the normal-incidence scattering coefficients of the sample can be obtained by monitoring the changes of reverberation times with and without it.

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1. Introduction

Since scattering coefficients that characterize the acoustic diffusivity of wall surfaces have been proposed, it is widely utilized to improve the accuracy of geometric room acoustic simulation. For measuring the values, specimen rotation methods in the free-field and in the reverberation room have been developed by Vorländer [1]. The principle of the method is to extract the specular reflection components by coherent averaging of the impulse responses while rotating a circular sample on a turntable. The reverberation room method has come to standardize in ISO17497-1 [2] on the account of its powerful process for the direct determination of the random-incidence scattering coefficients. We also investigated the effect of border setting and revolution speed of test samples on this method [3].

However measurement methods for the angle-incident values are not yet fully established. Especially, normal-incidence scattering coefficient can be useful to predict the suppression of flutter echoes, accordingly its measurement method is required. Recently, Rindel proposed an in-situ measurement method for the normal-incidence scattering coefficient [4], and this method has tested through numerical simulation and experiment [5]. In this paper, we introduce a laboratory measurement method for obtaining the normal-incidence scattering coefficient, which is done in the one-dimensional sound field of a rectangular room with highly absorbent side walls. The measurement is tested for several types of diffuse surfaces in 1/4 scale model. We will discuss the validation of this measurement method in comparison with numerical results.

2. Measurement principle

The principle of measuring normal-incidence scattering coefficient is derived from that the reverberation time of the room is altered as a diffuse surface is installed. As illustrated in Figure 1, generate an one-dimensional sound field by installing highly absorbent materials on all side walls of a rectangular room, and install a test sample on the rigid floor. The normal-incidence scattering coefficients can be obtained by monitoring the changes of reverberation times with and without it.

(a) Rectangular room. (b) Absorbers on all side walls. (c) Test sample on the floor.

Figure 1. Illustration of laboratory setting.

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In the one-dimensional field, normal incidence is dominated for the sample surface due to alternate reflections between the floor and ceiling. Based on the reverberation theory for one-dimensional field [6], the following equation for scattering coefficient can be derived from the reverberation times with and without the sample.

\[ s_{Ez,1} = \frac{13.8L_z}{c} \left( \frac{1}{T_1} - \frac{1}{T_0} \right) - \left( \alpha_{Ez,1} - \alpha_{Ez,0} \right) \]  

(1)

where \( L_z \) is the dimension of a rectangular room in the \( z \)-direction, \( T_0, T_1 \) are the reverberation times without/with the sample, and \( \alpha_{Ez,0}, \alpha_{Ez,1} \) are the Eyring absorption coefficients of the \( z \)-directional walls without/with the sample as follows

\[ \alpha_{Ez,0} = -\ln(1 - \alpha^n) \]  

(2)

\[ \alpha_{Ez,1} = -\ln\sqrt{(1 - \alpha^n)(1 - s^n)} \]  

(3)

where \( \alpha^n \) is the normal-incidence absorption coefficient of the floor and ceiling, \( \alpha^n, s^n \) are the absorption and scattering coefficients of the sample, with giving

\[ s_{Ez,1} = -\ln\sqrt{1 - s^n} \]  

(4)

From the above equations, the normal-incidence scattering coefficient is obtained by:

\[ s^n = 1 - \frac{1 - \alpha^n}{1 - \alpha^n} \exp \left( \frac{27.6L_z}{c} \left( \frac{1}{T_0} - \frac{1}{T_1} \right) \right) \]  

(5)
values over 1 at all frequencies. Thus an one-dimensional sound field is almost generated in the vertical direction of the room. Although the absorption coefficients of rib structure are around 0.1, the normal-incidence values of the sample, the floor and ceiling are assumed to be 0 in the following when calculating the normal-incidence scattering coefficients by Eq. (5).

As shown in Figure 2(d), two source and five receiving points (10 measurements) are arranged in the room. A time-stretched pulse signal is used for the impulse response measurements, and the decay curves are obtained by the Schroeder backward integration method. Then reverberation times are calculated using the least-square estimation of the slope tangent of decay curves. The values are expressed by the arithmetic mean of reverberation time for 10 measurements in 1/3 and 1/1 octave frequency bands.

4. Results and discussion

4.1. Characteristics of decay curves

Figure 3 illustrates the energy decay curves of the room with/without test sample in 1/1 octave bands. The black line represents the arithmetic mean of the curves measured with different source and receiving positions. Although the differences of energy level occur among the curves, those slopes are relatively similar.

Figure 4 shows the average decay curves with/without test sample in 1/3 and 1/1 octave bands. By installing the sample, the attenuation increases in higher frequency bands. In particular, curvature of the decay curve is seen in the 1/3 octave band of 2 kHz, however the tendency is eased in the 1/1 octave band. In addition, the effect of sample orientation is hardly seen in all frequency bands.

4.2. Determination of reverberation time

The reverberation times with/without test sample are determined in the decay level ranges of 10, 20, 30 dB as $T_{10}$, $T_{20}$, $T_{30}$, on the condition verifying the signal-to-noise ratio. Figure 5 shows the results of various decay ranges in 1/3 octave bands. The reverberation times from the late decay generally tend to be longer in all cases. Furthermore, the values become to converge as the decay level range is greater. It is seen that the reverberation times with test sample are generally less than without it, especially around 2 kHz.

Figure 3. Energy decay curves measured with different source and receiving points in 1/3 octave bands.

Figure 4. Average energy decay curves with/without test sample in 1/3 and 1/1 octave bands.
Figure 5. Reverberation times estimated by different decay level ranges. (a) without sample, and (b), (c) with samples (rect1, rect2).

Figure 6. Normal-incidence scattering coefficients estimated from the reverberation times in different decay level ranges for rect1, rect2. Black lines represent the values obtained by numerical analysis.
4.3. Determination of normal-incidence scattering coefficient

Figure 6 shows the normal-incidence scattering coefficients of the test samples (rect1, rect2) measured with the above method, and also calculated with the directivity correlation method by BEM [8]. The measured results are obtained from the above reverberation times in 1/3 octave bands. Although the measured values are unreliable below 500 Hz, good agreement is generally seen between the measured and calculated values. Reflecting the above results of reverberation time, the measured values from the late decay generally decline in all cases, and tend to converge as the decay level range is greater. The effect of sample orientation seems relatively small, but some difference is observed in the peak values at 2.5 kHz.

Figure 7 illustrates the normal-incidence scattering coefficients of the sample (rect2) in 1/1 octave bands. Differently from the results in 1/3 octave bands, the measured values are not in agreement with the calculated values in all frequency bands. The disagreement is considered to arise from the variation of scattering coefficient in each 1/1 octave band. From the results, it can be stated that 1/3 octave band analysis is practically suitable for the determination of the normal-incidence scattering coefficient by this method.

4.4. Case study with various test samples

The normal-incidence scattering coefficients are measured and calculated for other test samples with different shapes and sizes. In the same way as Figure 6, the results are shown in Figure 8. As is seen for the above sample, the measured values are in good agreement with the calculated ones, especially for the two samples with high diffusivity. Regarding the sample with low diffusivity, the measured values from the late decay are relatively close to the calculated ones. Special attention is necessary to determine the reverberation time from the decay curve with test sample.

5. Conclusions

We introduced a laboratory measurement method for normal-incidence scattering coefficients, and investigated its validation through experiments and numerical analysis. As a result, the followings are demonstrated:

- Identification of reverberation time: The measured value of normal-incidence scattering coefficient somewhat depends on the decay level range to identify reverberation time. For the sample with high diffusivity, the values obtained from early range are relatively in good correspondence with the calculated values by numerical analysis.
- Arrangement of test sample: The sample orientation does not strongly affect the measured values. However, in order to control the effect, it can be considered to regulate the sample area to be square.
- Frequency band width: The measured values in 1/1 octave bands are not adequate, while those in 1/3 octave bands are practically useful for rough evaluation of scattering coefficients with the proposed method.

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Figure 8. Normal-incidence scattering coefficients estimated from various reverberation times for different shapes and sizes of test samples. Black lines represent the values obtained by numerical analysis.

References