Method for measuring sound scattering coefficients of walls and diffusers by using a non-diffuse sound field with unevenly-distributed sound absorption

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ABSTRACT

Method for measuring sound scattering coefficients of walls has been standardized as ISO 17497-1:2004. This standardized method employs a turntable which carries a test specimen. Due to usage of the turntable there are two limitations listed below: 1) A wall must be cut as circular shape. 2) 3-dimensional diffusers such as bent shells which are suspended from a reverberation chamber cannot be measured. Therefore we are developing a new method for measuring the sound scattering coefficient. This new method has no limitations mentioned above and can measure scattering coefficients of 3-dimensional diffusers, because the method does not employ the turntable. The method utilizes a non-diffuse sound field with unevenly-distributed sound absorption. And a sound scattering coefficient can be calculated by using a difference of reverberation decay curves between a condition with diffusers and a condition without them. Computer simulations and scale model experiments have been conducted for verification of the new method. The results showed that the new method can basically be used for measuring scattering coefficient.

Keywords: Diffuser, Scattering coefficient, Reverberation time, Measurement
I-INCE Classification of Subjects Number(s): 23.6, 25.3

1. INTRODUCTION

The sound scattering coefficient is defined as the ratio of non-specularly reflected energy over total reflected energy. The usefulness of the scattering coefficient is promising in the application to computational sound field simulation based on the geometrical acoustics (1–7). Software developers have found some ways of accounting for non-specularly reflected energy, most commonly involving the assignment of a scattering coefficient to each wall surface. On th other hand, a theoretical framework for quantitatively characterizing sound field diffusion based on scattering coefficient has been development (8), and also is required for theoretical estimation of reverberation time in rectangular rooms (9).

A method for measuring random-incidence scattering coefficients of walls has been standardized as ISO 17497-1:2004 (10). This method is based on work by Vorländer and Mommertz (11–13). Computer simulations and theorem of room acoustics can use the scattering coefficient of various walls by this useful measurement method. However, this standardized method employs a turntable which carries a test specimen. Due to usage of the turntable there are two limitations listed below: 1) A wall must be cut as circular shape. 2) 3-dimensional diffusers such as bent shells which are suspended from a reverberation chamber cannot be measured.

Therefore we developed a basic idea for measuring the sound scattering coefficient (14). The idea utilizes a non-diffuse sound field with unevenly-distributed sound absorption. And a sound scattering coefficient can be calculated by using a difference of reverberation decay curves between a condition with diffusers and a condition without them. This new method has no limitations mentioned above and

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can measure scattering coefficients of 3-dimensional diffusers, because the method does not employ the turntable. Computer simulations and scale model experiments have been conducted for verification of the new method.

2. BASIC IDEA

Non-linear decay occurs in a non-diffuse sound field with unevenly-distributed sound absorption. If diffusers are installed in the sound field, the reverberation decay curve changes (15). Based on this knowledge, as shown in Figure 1, scattering coefficients of the diffusers are estimated by measuring the changes of reverberation decay curves with and without diffusers. Methods for setting absorption walls and diffusers shown in Figure 1 are just examples. Other various settings can be utilized for the new method.

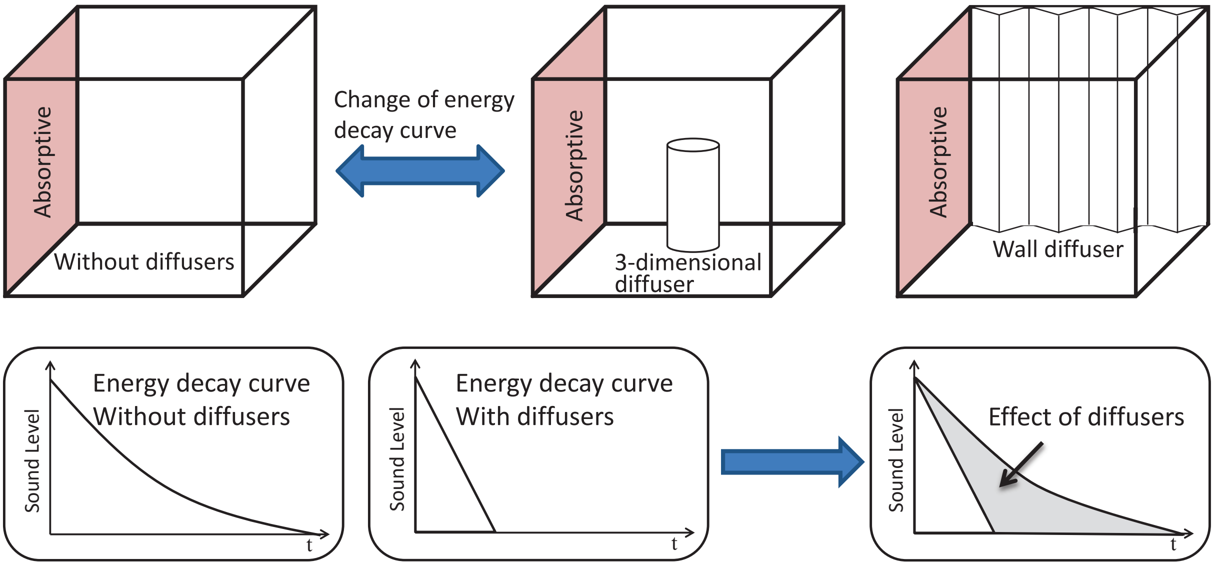

Figure 1 – Basic idea for measuring scattering capability of diffusers

3. INVESTIGATION BY SOUND RAY TRACING METHOD

3.1 Calculation method

The method of computer simulations was the combination of the sound ray tracing method and the Monte Carlo method. First, many sound particles were emitted simultaneously from a point sound source. This corresponds to the emission of a pulse from a sound source, and the number of sound particles corresponds to the sound power of the pulse. One million sound particles were generated in Patterns 1 and 2. Ten million sound particles were generated in Pattern 3. The direction of propagation of the sound particles from the point sound source was determined stochastically with uniform random numbers on the spherical surface. Then the propagation of sound particles was calculated by 0.1 m steps each. The calculation had been performed for 3 s in this simulation.

When sound particles were reflected from the walls, each sound particle was stochastically determined to be absorbed, scattered, or specularly reflected by the Monte Carlo method. Specifically, uniform random numbers between 0 and 1 were generated, and if the number was between 0 to α, sound absorption occurred, while if the number was equal to or more than α, reflection occurred. In the case of reflection, uniform random numbers between 0 and 1 were generated, and if the number was between 0 to β, scatter reflection occurred, while if the number was equal to or more than β, specular reflection occurred. In the case of scatter reflection, the reflection directions were stochastically given as homogeneous diffusion. In the case where sound particles were absorbed, the calculations for the absorbed sound particles were aborted at that time. The total number of sound particles is gradually decreased with time. This describes the energy decay in the space.

3.2 Calculation condition

The changes of reverberation decay curves in various conditions of scattering coefficient are calculated by the above mentioned simulation method. As shown in Figure 2, three patterns of a 10m cubic room were used in this study; Pattern-1: one absorptive wall and one diffusion wall, Pattern-2: one absorptive wall and two diffusion walls, and Pattern-3: two absorptive walls and one diffusion wall. An absorption coefficient, α, of the absorptive walls was set to 1.0(perfect absorption) in all conditions. Scattering coefficients, β_0, of the diffusion walls were changed as 0.0, 0.1, 0.2, 0.4, 0.6, 0.8, 1.0. The sound source was located at a gravity point of the cubic room.

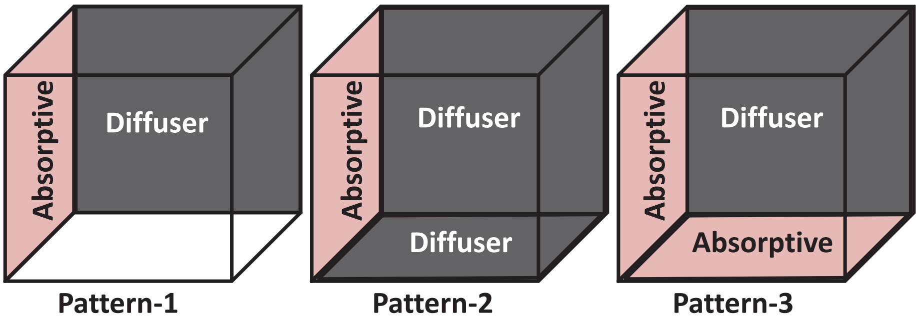

Figure 2 – Patterns of absorption-diffusion treatment of walls

3.3 Estimation of an effect of diffusers

Reverberation energy decay curves with and without diffusers are represented as $E_d(t)$ and $E_0(t)$ respectively. Normalized decay curve $E_n(t)$ is derived as $E_n(t)= E_d(t)/E_0(t)$. The normalized decay curve represents an effect by diffusers. Next a reverberation time T is obtained by linear regression analysis of the normalized decay curve of $10\log_{10}[E_n(t)]$. Then the apparent equivalent absorption area, A', and the apparent average absorption coefficient, α', are calculated as A'=0.163V/T and α'=0.163V/ST, respectively. Here, V is a room volume; S is a total surface area. The A' and α' must relate to the magnitude of the effect of diffusers.

3.4 Results and discussion

Figure 3 shows results of energy decay curves obtained by the computer simulation in each room patterns. And Figure 4 shows results of the normalized decay curve. In both Figures 3 and 4, the slopes of the decay curves become steep as the scattering coefficient become bigger. Sound energy is scattered by a diffusion wall and reflected to absorptive walls. This means that the scattering coefficient works like the absorption coefficient.

As shown in Figure 4, the normalized decay curves in Pattern-2 and Pattern-3 seem almost linear. Therefore, reverberation times are obtained from the normalized decay curves and the apparent average absorption coefficients are derived from the reverberation times. The results of the apparent average absorption coefficients in Patterns 2 and 3 are indicated in Figure 5. In Pattern-3, the apparent average absorption coefficients α' indicate linear relation to given scattering coefficients β_0 of a wall, i.e. $\alpha'=\beta_0/2$. Therefore, the scattering coefficient β of a wall can be estimated by using the relation of $\beta=2\alpha'$ in Pattern-3.

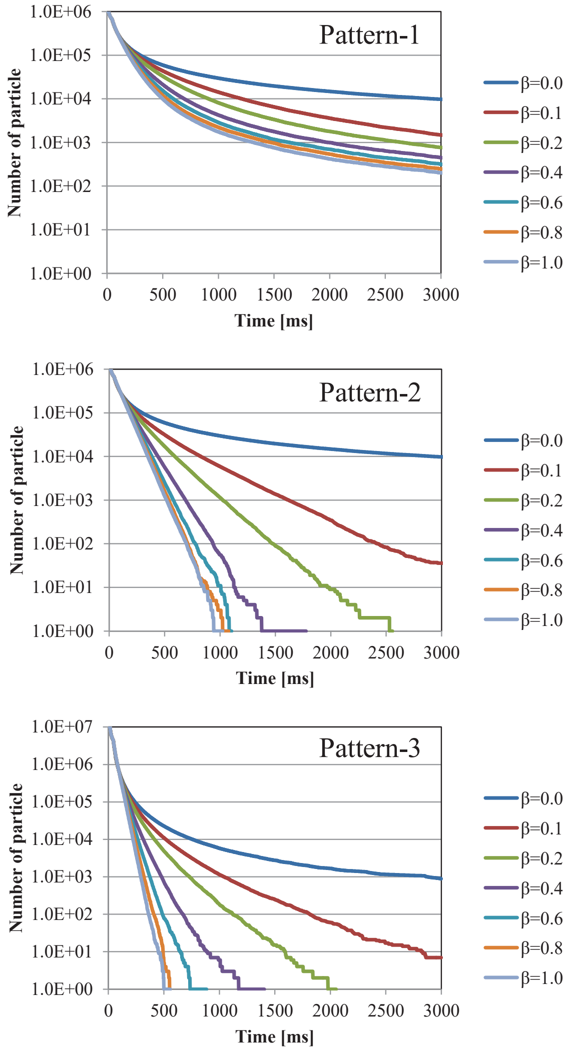

Figure 3 – Energy decay curves for each β

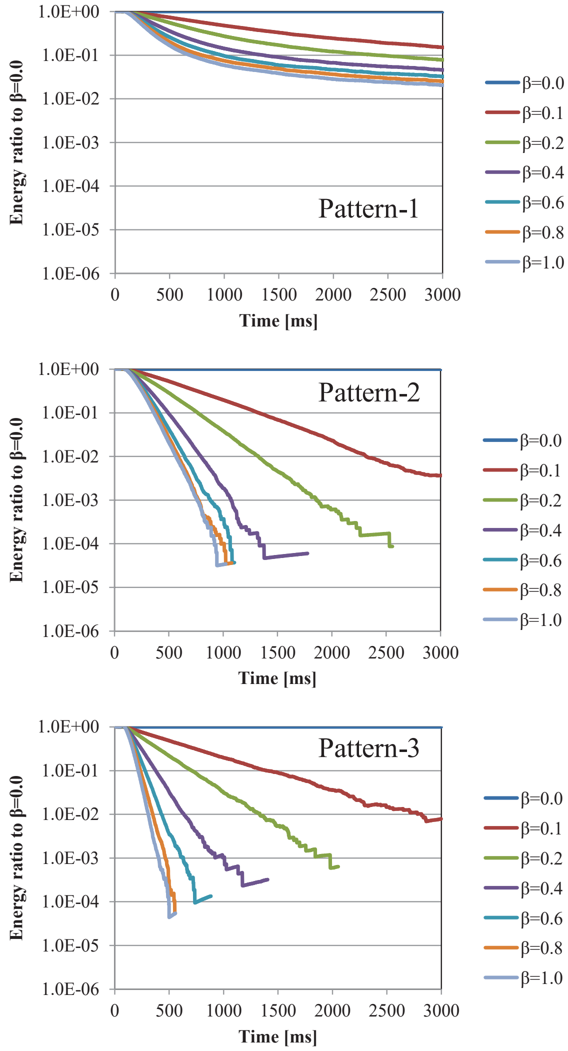

Figure 4 – Normalized decay curves for each β

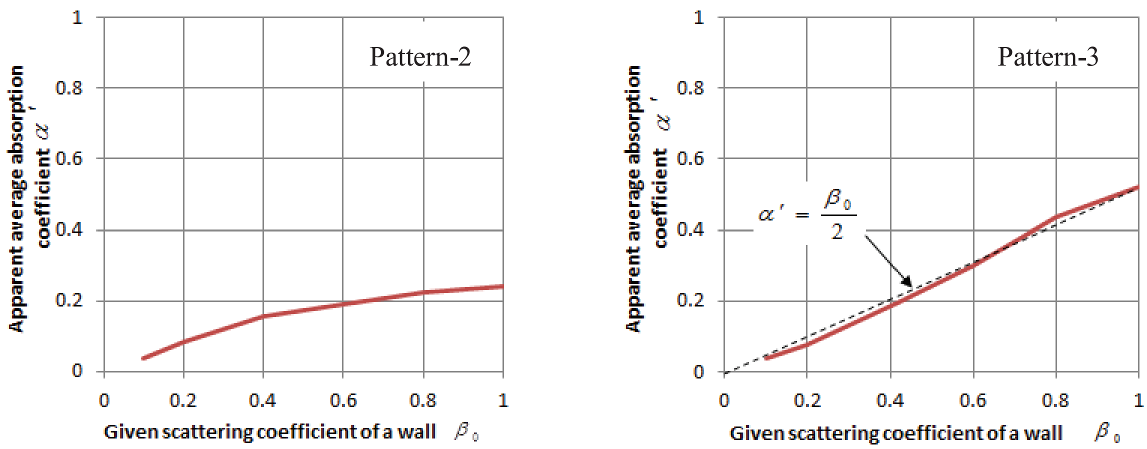

Figure 5 –Apparent average absorption coefficients vs. given scattering coefficient of a wall

4. INVESTIGATION BY 1/10 SCALE MODEL EXPERIMENT

In this chapter, the proposed method for measuring scattering coefficient is investigated by 1/10 scale model experiment.

4.1 Measurement method

Figure 6 shows the block diagram of 1/10 scale model experiment. The Pattern-3 in Figure 2 is used for the experiment. Two walls are absorptive and one wall is diffusive. The scale model is a cube 0.7m on a side (7m in real scale). The model is made of acrylic board with thickness of 15mm. Needle felt is used as a material of absorptive walls. The acrylic board and the needle felt can be considered as almost perfect reflective and absorptive materials respectively in 1/10 scale model experiment.

Five 1/4 inch microphones are located at receiving points from R1 to R5. A small dodecahedron loudspeaker is used as a point sound source which is located at a corner of the room. Time stretched pulse signal is radiated from the loudspeaker for obtaining impulse responses at the receiving points.

Square pyramid shown in Figure 7 is used as a diffuser. Two sizes of the diffuser are used as indicated in Table 1. Diffusers are made of styrene board 5mm thick. Area ratio of total area of the diffusers to area of a wall is set to six steps at 5, 10, 20, 30, 40, 50%. The diffusers are attached on the wall, randomly and uniformly.

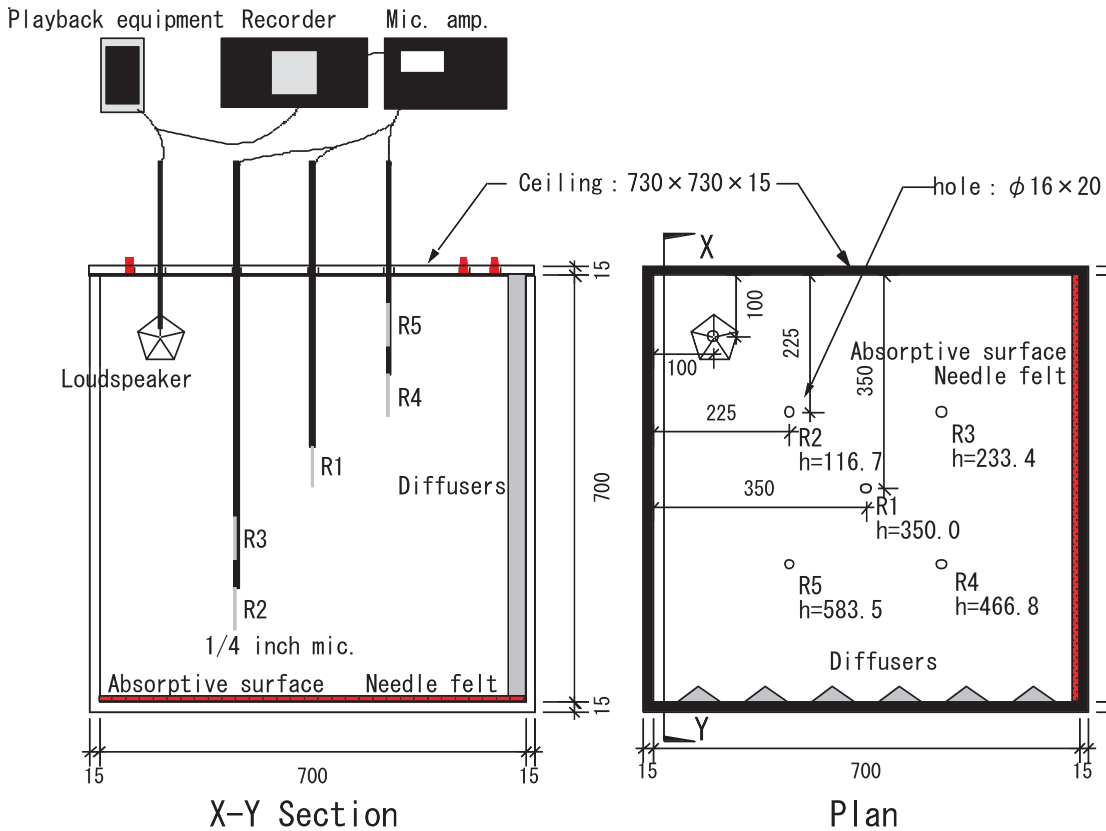

Figure 6 – Block diagram of 1/10 scale model experiment, and arrangement of a sound source and receiving points R1 – R5.

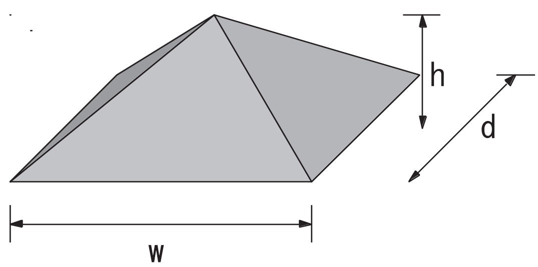

Figure 7 – Configuration of a diffuser used in the experiment

Table 1 – Sizes of two types of diffuser

Diffuser type	Size w*d*h(mm)
Square pyramid (L)	80*80*30
Square pyramid (S)	40*40*15

4.2 Results and discussion

As mentioned in Chapter 3, reverberation time is obtained from the normalized energy decay curve and the apparent average absorption coefficient α' is also calculated from the reverberation time. Scattering coefficient β of the wall is estimated by using the relation of β=2α'.

Frequency characteristics of estimated scattering coefficients in each area ratio of diffusers are indicated in Figure 8. As shown in Figure 8, the scattering coefficient of the wall becomes bigger as an area ratio of the diffusers increases. As for frequency characteristics, the scattering coefficients increase at octave bands above 500Hz in large diffusers, and increase at octave bands above 1000Hz in small diffusers. The sizes of large and small diffuser are 0.8m and 0.4m respectively. Therefore frequencies corresponding to the sizes of large and small diffusers are 425Hz and 850Hz respectively. Thus these measurement results mean that the diffusers can efficiently scatter sound at the frequency bands above 425Hz and 850Hz depending on diffusers' size.

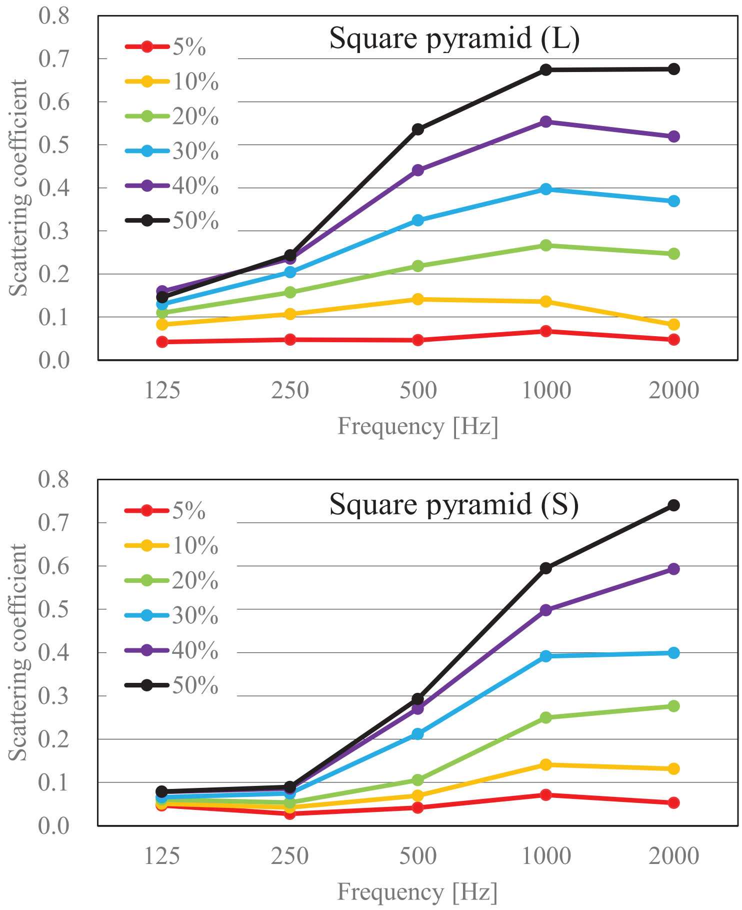

Figure 8– Frequency characteristics of estimated scattering coefficients of large and small diffusers in each aria ratio of diffusers

Next, Figure 9 shows a relation between the estimated scattering coefficient of the wall and the area ratio of diffusers, i.e. amount of diffusers. Note that these results are limited in three octave bands for simplicity. Regardless of the size of diffusers, the scattering coefficients in each octave band increase linearly as the area ratio of diffusers increases. This phenomenon is clear especially in higher frequency bands. When comparing results of large and small diffusers, as mentioned above, it is clear again that the scattering coefficients of large diffusers correspond to those of small diffusers in one octave higher band.

As the above measurement results of the proposed method, the followings are clarified: 1) Scattering coefficient of a wall increase linearly as amount of diffusers increases. 2) If the size of diffusers becomes double, the diffusers can scatter sound in one octave lower band. As observed above, it can be said that the proposed method could detect these well-known phenomena of sound scattering.

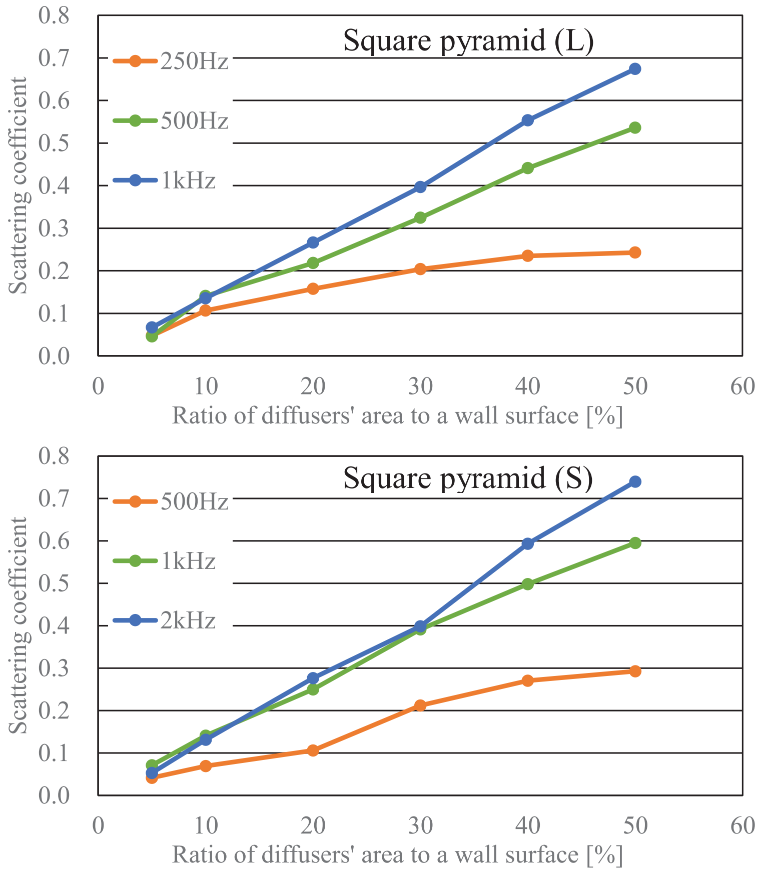

Figure 9– Estimated scattering coefficients vs. area ratio of diffusers to a wall surface

5. MEASUREMENT OF EFFECT OF SPATIAL SCATTERING DIFFUSERS

Spatial scattering diffusers cannot be measured by the method of ISO 17497-1:2004. In this chapter, we investigated whether the proposed method can measure the effect of spatial scattering diffusers such as spherical volume diffusers.

5.1 Measurement method

A 1/10 scale model, a cube 0.7m on a side, used in the previous chapter was employed also in this experiment. The Pattern-3 in which two walls are absorptive and one wall is diffusive is used. Rigid spheres of a diameter of 8 cm (0.8m in real scale) are used as spherical volume diffusers. These spheres are made of polystyrene foam and are hung from ceiling of the scale model. Number of the spheres changed as five steps at 4， 8， 12， 16， 20. The spheres are arranged randomly and uniformly in the space. Arrangement of sound source and receiving points is same as the previous chapter.

Reverberation time T is obtained from normalized energy decay curve and the apparent equivalent absorption area, A’, is calculated as A’=0.163V/T. As for the volume diffusers, value of A’ must relate to the magnitude of effect of diffusers.

5.2 Results and discussion

The apparent equivalent absorption area of the spheres are shown in Figure 10. The apparent equivalent absorption area changes depending on both number of the spheres and frequency bands. The apparent equivalent absorption area becomes bigger as number of the spheres increases. As for frequency characteristics, the apparent equivalent absorption areas increase at octave bands above 500Hz. The diameter of the sphere is 0.8m in real scale. Therefore frequency corresponding to size of the sphere is 425Hz. Thus these measurement results mean that the diffusers can efficiently scatter sound at the frequency bands above 425Hz.

Next, Figure 11 shows a relation between the apparent equivalent absorption area of the spheres and number of the spheres. Note that the result is limited in three octave bands for simplicity. The apparent equivalent absorption area in each octave band increases linearly as the number of the spheres increases. The slopes of increase of the apparent equivalent absorption area in 500Hz and 1000Hz bands are steeper than that in 250Hz band. As mentioned above, this means that efficiency of scattering of spheres with a diameter of 0.8 m is bigger at frequency above 425Hz corresponding to the sizes of the sphere.

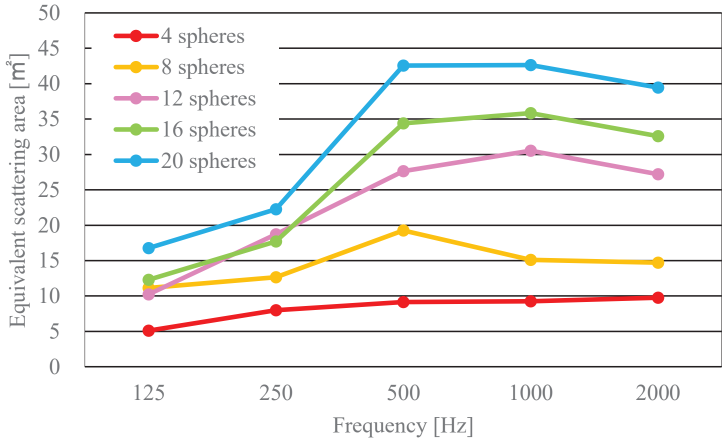

Figure 10– Frequency characteristics of estimated apparent equivalent absorption area

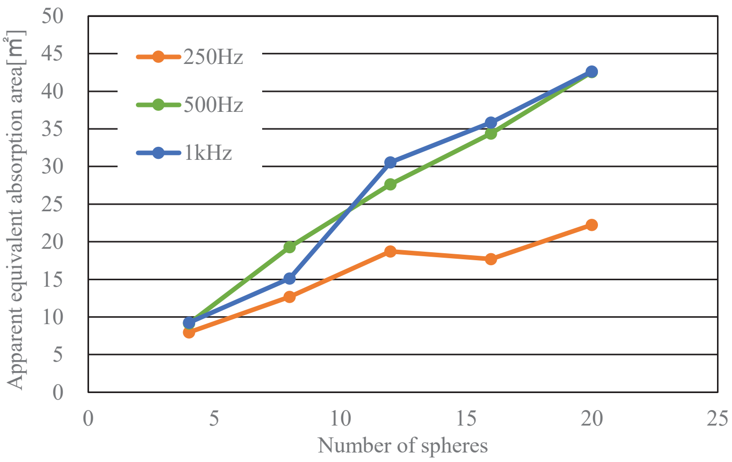

Figure 11– Estimated apparent equivalent absorption area vs. number of spheres

6. CONCLUSIONS

In this study, a new method for measuring sound scattering coefficient was proposed and examined.

The proposed method utilizes a non-diffuse sound field with unevenly-distributed sound absorption. And a sound scattering coefficient can be calculated by using a difference of reverberation decay curves between conditions with and without diffusers. Computer simulations and scale model experiments have been done for verification of the proposed method. The results showed that the method can basically be used for measuring scattering coefficient. Also the method can measure capability of scattering by 3-dimensional diffusers. Finally, it was clarified that this method has a possibility because the proposed method could detect well-known phenomena of sound scattering by this method. However theoretical basis has not been established yet well at this stage. Further studies are necessary for establishing theoretical side of this method.

ACKNOWLEDGEMENTS

This work was supported by the Grant-in-Aid for Scientific Research(C) from Japan Society for the Promotion of Science (No. 1506340).

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