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Sound absorption characteristics of a panel absorber with an air-back cavity of non-uniform depth

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Abstract

A panel absorber, which is often used for controlling sound fields at low frequencies, is usually composed by a light-weight interior panel and a heavy concrete wall with an air-cavity in-between. In some cases, the panel and the wall are not in parallel because of the irregular shape of the room or some other architectural design considerations, and hence this cavity is not of uniform depth. Therefore, the acoustic properties of panel absorbers with non-uniform cavity depth need to be clarified in order to predict them in the design stage. As a pilot study on predicting sound absorption characteristics of a panel absorber with a back cavity of non-uniform depth, sound absorption characteristics of such a panel absorber are measured in a reverberation chamber. The experimental results are compared with those for the absorbers with uniform cavities. In an attempt to generate a predictive technique for a panel absorber with an air-back cavity of non-uniform depth, an existing predictive theory for a panel absorber with a uniform cavity is used. By applying several systematic approaches, experimental results for the specimen with a non-uniform cavity are compared with empirical results obtained from the existing theory.

Key words: Sound absorption, panel absorber, non-uniform cavity

1. Introduction

In the acoustical design of rooms, controlling noise level and reverberation time at low frequencies is necessary for good sound environment. This is often difficult as porous or fibrous materials are not efficient at low frequencies, and other sound absorbing systems such as a panel absorber or a Helmholtz resonator must be employed. A panel absorber is most widely used for this purpose, because this is usually formed by a light-weight interior panel with a back wall.

Many studies have been carried out on panel absorbers and membrane-type absorbers both experimentally and theoretically. Kimura [1] measured the sound absorption characteristics of various panel absorbers and discussed their sound absorption mechanism. Ford and McCormick [2] theoretically analysed the acoustic properties of a panel absorber made of a thin steel plate. Hiraizumi et al [3] analysed normal incidence sound absorption coefficient of a circular disk backed by an air cavity formed between the disk and a rigid backing. The authors have conducted a systematic study on the theoretical prediction of sound absorptivity of panel absorbers [4-7]. In these studies, various configurations of back cavity are considered and the mechanism of sound absorption of panel absorbers are theoretically investigated.

Although these results are useful for designing a panel absorber and predicting its characteristics, all of these previous studies assume a cavity of uniform depth. In practice, the cavity may not be of uniform depth because of other architectural design considerations. For example, when an interior panel is attached to a concrete exterior wall, there are usually projections of columns or beams. Also, in irregularly shaped rooms, interior panels can have round or irregular shapes in spite of a regular shape of the building body. In such a case, the cavity formed between the interior panel and the exterior wall has a non-uniform depth. However, there is no predicting theory for a panel absorber with non-uniform cavity depth. In addition, there are no measured or empirical data available for reference. Many practitioners employ a rule-of-thumb to estimate the characteristics for acoustical design. Establishing a prediction method as well as a database of sound absorption characteristics of this type is necessary.

In this paper, a pilot study on predicting sound absorption characteristics of a panel absorber with a back cavity of non-uniform depth is presented, where the sound absorption characteristics are measured in a reverberation chamber. The experimental results are compared with those obtained for absorbers with uniform cavity. In an attempt to generate a predictive technique for a panel absorber with an air-back cavity of non-uniform depth, an existing predictive theory for a panel absorber with a uniform cavity [4] is used. By applying several systematic approaches, experimental results for the specimen with a non-uniform cavity are compared with empirical results obtained from the existing theory.

2. Experimental study

2.1 Experimental procedure

Reverberation sound absorption coefficients of a panel absorber with an air-back cavity of non-uniform depth were measured in a reverberation chamber. For comparison, the sound absorption coefficients for panel absorbers with an air-back cavity of uniform depth were also measured for comparison. The specimens used in the experiment are described in detail in Fig. 1 and Table 1. In all the specimens, a plywood panel 3 mm thick was used. The specimen N has a non-uniform depth air-back cavity, of which the depth linearly changes from 0.03 m to 0.15 m: the panel and the rigid back wall are not parallel, and the cross section is in the shape of a trapezium. The specimens U1, U2 and U3 are with uniform-cavity depth of 0.03 m, 0.09 m and 0.15 m, respectively. These depths correspond to those of the specimen N at its lower edge, centre and higher edge, respectively. By comparing the result for N with those for U1, U2 and U3, one can evaluate how the panel absorber with non-uniform cavity behaves.

The measurements were carried out by the conventional method according to the JIS A 1409 standard (equivalent to ISO 354) in a reverberation chamber of 130 m^3 volume and 153 m^2 surface area. At least five receiving points (in some cases up to ten receiving points at low frequencies) were used in the measurements to minimise the effect of poor diffuseness in the reverberation chamber.

Table 1. Description of the specimens used in the experiment.

Specimen	Cavity depth [m]	Panel	Panel dimension [m^2]
N	0.03 (minimum) to 0.15 (maximum)	Plywood panel 3 mm thick (surface density: 1.59 kg/m^2)	1.8 × 3.6
U1	0.03		
U2	0.09		
U3	0.15		

2.2 Results

The measured results of the diffuse incidence absorption coefficient of the panel absorber with a non-uniform cavity (Specimen N) is shown in Fig. 2, and compared with those for the panel absorbers with uniform-depth cavity (Specimens U1-U3). The sound absorption characteristics of U1-U3 show similar tendencies: the characteristics have a peak at 315, 250 and 160 Hz, respectively, according to their cavity depths – the deeper the cavity is, the lower the peak frequency is. This tendency is in agreement with well-known previous studies [1,8], and validates the experimental accuracy.

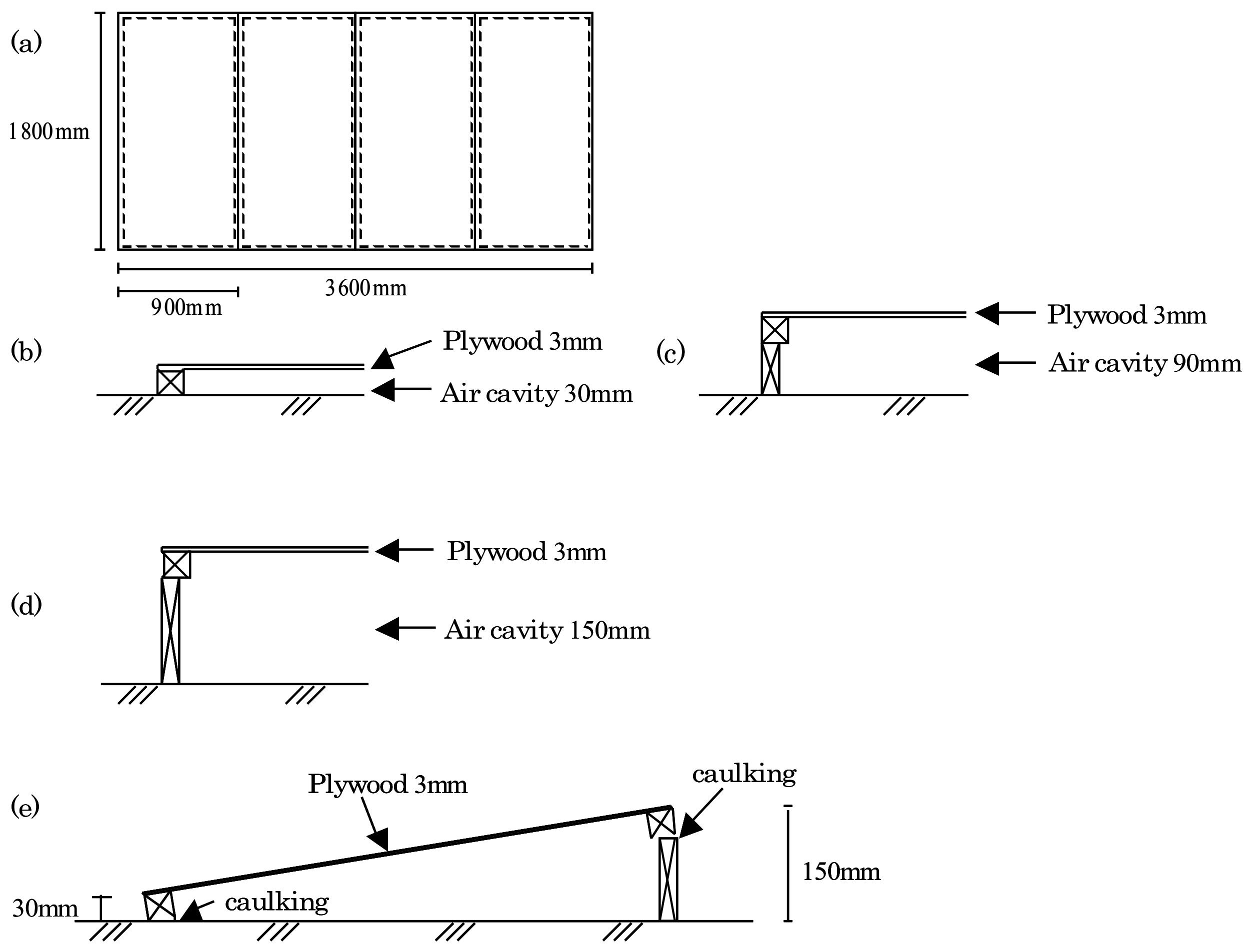

Figure 1. Schematic description of the specimens used in the experiment. (a) top view (U1-U3 and N), and cross-sections of the Specimens U1 (b), U2 (c), U3 (d) and N (e).

The characteristics of the non-uniform depth cavity absorber shows a rather broader peak in a wider frequency range that includes the peak frequencies of U1-U3.The value at the peak is slightly lower than 30 mm uniform case (U1), but almost the same as the others (U2 and U3). This shows that a significant panel absorption results even if the cavity depth is not uniform. Absorption in a broader frequency range than in the uniform case is also shown.

By comparing these results, the following discussions can be achieved:

(1) The average depth of the non-uniform cavity panel absorber (Specimen N) is 90 mm, which is, in this case, in the centre of the panel, where the panel is considered to vibrate most violently. Therefore, the characteristics of Specimen N show a similar tendency to those of 9 cm uniform case (U2). Comparing N and U2, the peak shape is quite similar, but N shows broader peak. The value at the peak is slightly lower in N than in U2.

(2) The depths of the cavity of U1, U2 and U3 correspond to the minimum, average and maximum of the cavity depth of the non-uniform case N. Therefore, the peak frequency of N should be between those of U1 and U3. This implies that the average of the characteristics of U1-U3 can give an approximation to those of N. Comparison between the average of the measured absorption coefficients for U1-U3 and that for N is shown in Fig. 3. The average shows a very good agreement with the characteristics of the non-uniform cavity absorber at frequencies above the absorption peak, though, below the peak frequency the

characteristics show somewhat larger discrepancies. However, the maximum discrepancy is less than 0.1, and this implies a possibility that the average can give a good approximation of the absorptivity of a skewed cavity panel absorber.

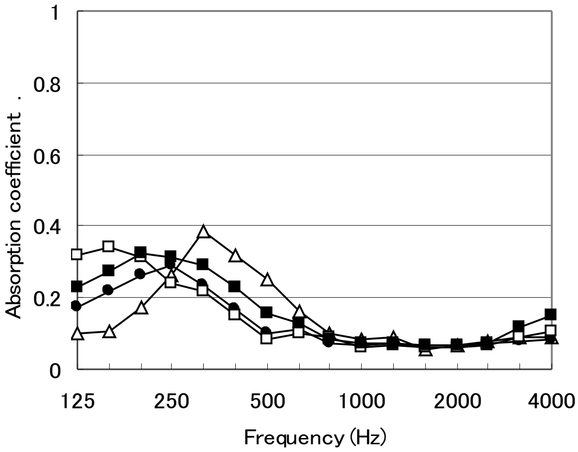

Figure 2. The measured results of random incidence sound absorption coefficients of the panel absorbers. Specimens N (with a non-uniform depth air-cavity) (■) is denoted with in comparison with uniform cavity cases, Specimens U1 (30 mm, △), U2 (90 mm, ●) and U3 (150 mm, □).

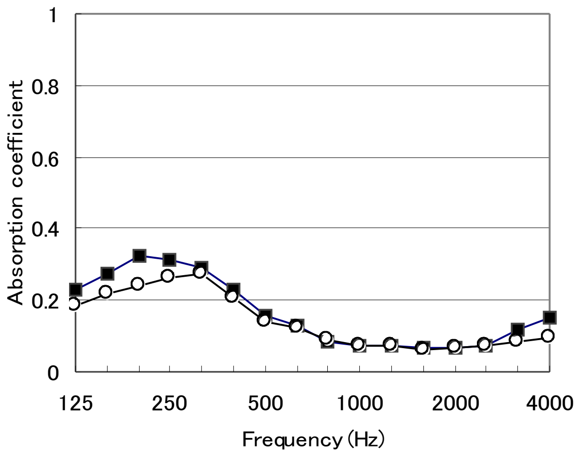

Figure 3. Comparison of the average of the measured results of random incidence sound absorption coefficients of Specimens U1, U2 and U3 (○) with that of Specimen N (with a non-uniform air-cavity) (■).

3. Attempt for prediction of absorption coefficient

Predicting sound absorptivity is essential for acoustical design not only in room acoustics but also in noise control. For a panel absorber, some attempts have been made to predict its acoustic properties theoretically [4-7]. However, they assume only a back cavity of uniform depth and are not applicable for the non-uniform cavity cases. Theoretical considerations on the acoustic properties of a panel absorber with a non-uniform cavity are required for establishing a predicting theory. For this purpose, vibration of a panel coupled with the sound field in a cavity of non-uniform depth needs to be solved. However, the sound field in a non-uniform cavity can only be solved approximately by analytical means [9], but the approximate solution takes very complicated form which is not realistic to introduce to the analysis.

In this section, an attempt to predict the absorptivity of a panel absorber with a cavity of non-uniform depth is presented by using a prediction theory for a panel absorber with a uniform cavity. The theory presented by Sakagami et al [4] is used here. The theory has been previously experimentally validated and shows excellent agreement with measured results for thin panels.

As a preliminary study to discuss the accuracy of the theory, the present measured results for the uniform cavity panel absorbers (Specimens U1-U3) are compared with the values predicted by the theory [4] in Fig. 4.

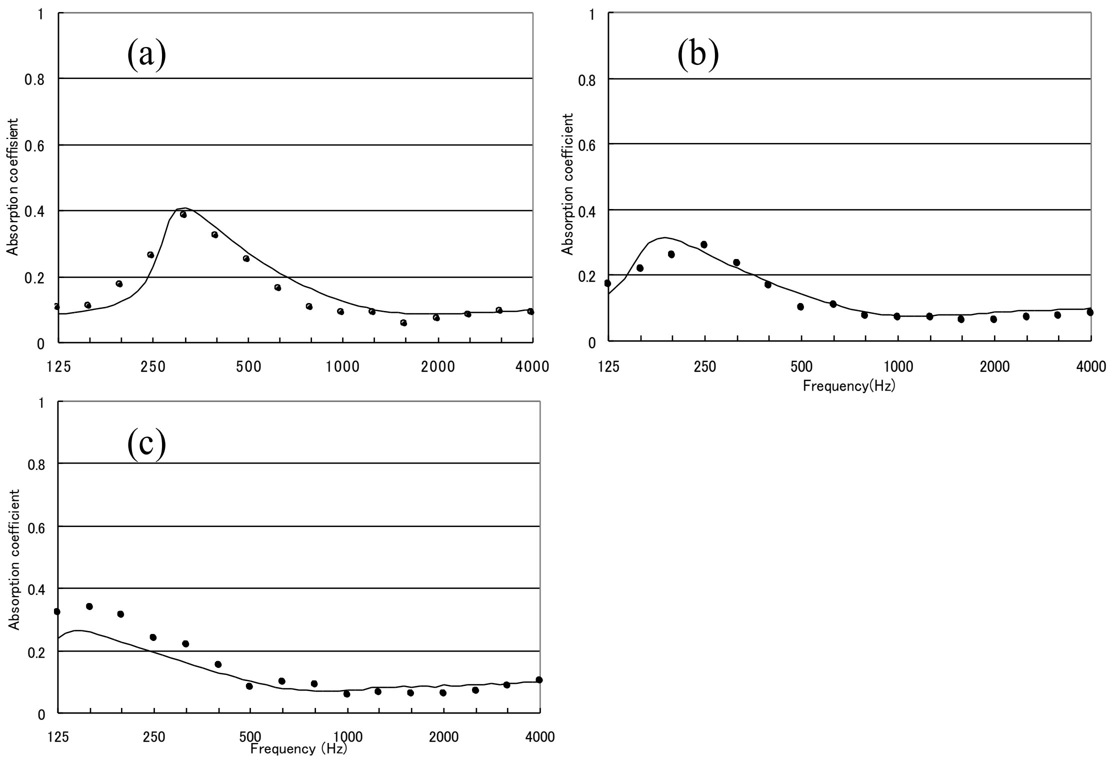

Figure 4. Comparison of the measured (dotted line) and theoretical (solid line) results for the specimens with cavity of uniform thickness, U1 (a), U2 (b) and U3 (c).

The theoretical results are in very good agreement with the experimental results and show similar behaviour. For the peak frequencies, the theoretical results compare well with the experimental ones when the cavity is 30 mm deep. In the case of deeper cavities, the experimental peak occurs at higher frequencies than the theoretical peak. This disagreement is attributed to the fact that the stiffness of the panel including the frame becomes relatively large. However, the theory on the whole can be considered useful as the basis for the prediction of absorption characteristics of panel absorbers, and will be used in this study for ones with cavities of non-uniform depth.

Applying this theory to the present problem, the following approaches can be considered:

(a) Calculation by the theory with the average depth of the cavity, 90 mm. This calculation means that, assuming the panel is vibrating most violently at its centre, the cavity's behaviour is considered to be dominated by its average depth.

(b) Average of the theoretical results for panel absorbers with uniform cavity of 30, 90 and 150 mm deep. This calculation means that, dividing the cavity into three portions, the absorber's characteristics are described by the average of those of each portion.

(c) Average of the theoretical results for panel absorbers with uniform cavity of 60 and 120 mm deep. This is the same idea as (b), but the absorber is divided into two portions in this case.

(d) Average of the theoretical results for panel absorbers with uniform cavity of 50, 90 and 130 mm deep. This is also similar to (b), but taking the average of the depths of each portion as its depth.

(e) Calculation by the theory with the depth of the non-uniform cavity panel absorber at the gravity centre of the cross-section of its cavity, 103.3 mm. The gravity centre corresponds to the gravity centre of the air volume in the cavity.

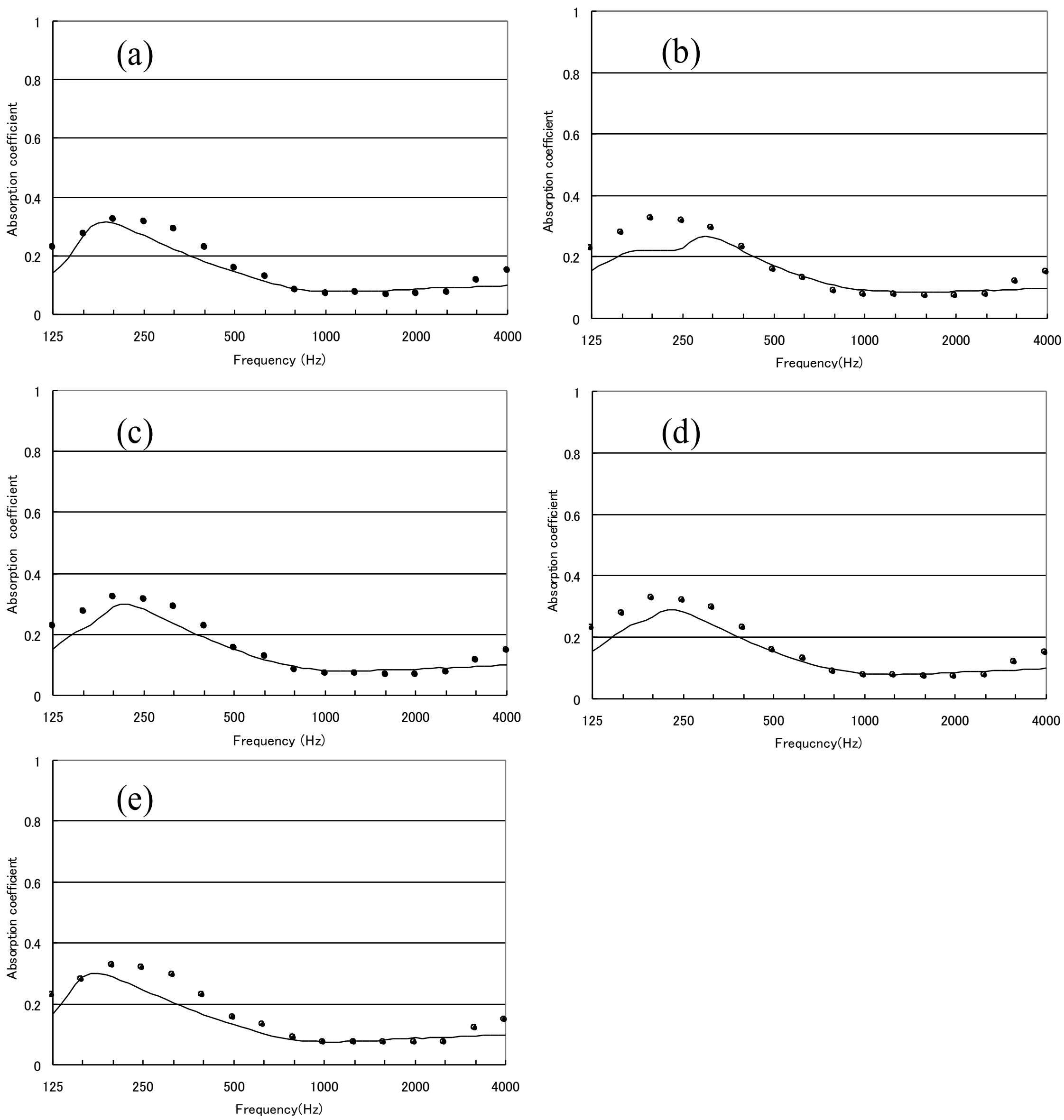

Figure 5. Comparison of the measured result for the specimen with non-uniform cavity, N (dotted line). The solid curves in the panels (a) to (e) show the calculated values predicted by the approaches (a) to (e), respectively.

The results of (a) to (e) are shown in Fig. 5, each comparing with the experimental result for

Specimen N. Comparing these results, although there is not a large difference, the result of (a) seems to show the smallest discrepancy. Approach (a) is the simplest and the most physically reasonable. Also this has been suggested from the discussion on the experimental results in the preceding section. Therefore, the absorption characteristics of a panel absorber with an air-cavity of non-uniform depth can be predicted by the theory for that with uniform depth cavity with the average depth. However, if the cavity depth changes dramatically, or a cavity is filled with an absorbent, another consideration may be necessary.

4. Concluding remarks

In order to gain an insight into the sound absorption characteristics of a panel absorber with an air-cavity of non-uniform depth, an experimental study was carried out. Results show that the absorption characteristics of such an absorber has a broader absorption peak than that with a uniform-depth cavity, and the peak lies between the peak frequencies of uniform-depth cavity absorbers with the minimum and the maximum depth of the non-uniform absorber. The characteristics compare well with those of the panel absorber with a uniform cavity of the depth which corresponds to the average depth of the non-uniform cavity.

As an attempt to predict the absorption characteristics of a panel absorber with a non-uniform depth cavity, some approaches using the theory for uniform-cavity cases are examined. Comparing the theoretical results for a uniform cavity, of which the depth corresponds to the average depth of the non-uniform cavity, with experimental results obtained for the non-uniform cavity, shows that the theoretical technique gives a reasonable prediction.

Further investigation will be needed for the cases in which the cavity depth is dramatically changed or filled with an absorbent.

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