Alleviation of the coincidence effect in double-layered plasterboards composing multiple drywall systems

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Abstract  Double or multiple drywall systems using plasterboards have various advantages and are being widely used, although they have such intrinsic acoustic defects due to mass-air-mass resonance at low frequencies and the coincidence effect at high frequencies. Regarding the latter problem, there is a possibility to prevent the sound insulation deterioration by layering two or more board materials of different physical characteristics and by devising the way of gluing them. In this paper, the results of the experimental investigations on these points are introduced.

1. INTRODUCTION

Double drywalls composed of plasterboards have excellent performances such as lightweight, easy installation, fire resistance and high sound insulation and they are often used for separating walls in apartment houses, hotels and office buildings. Recently, the requirement for sound insulation of building walls has become stricter according to the change in the standard of living. In addition, drywall construction is often applied to
recording studios and cinema-complex buildings, in which an extremely high sound insulation is required.

The essential factors determining the sound insulation performance of a double wall are the mass law determining the general performance, the sound insulation deterioration caused by mass-air-mass resonance at low frequencies and that by the coincidence effect at high frequencies [1], [7], [10]. To improve the sound insulation performance of this type of walls, various studies such as those of a means of layering board materials [3], [7], the effect of inserting porous sound-absorbing materials into a cavity between two double-layered boards [1], [2], [3], [4], [6], [7], [8], [10], [11], and stud construction to prevent the vibration coupling between two double-layered boards [4], [5], [6], [7], [9], [10] have been carried out. By referring to the results of these investigations, the authors have been carrying out experimental studies to develop drywalls composed of plasterboards with a high sound insulation performance. As a result of these studies, the way of preventing the sound insulation defect due to the coincidence effect by layering two plasterboards of different physical characteristics is introduced in this paper.

### 2. MEASUREMENT METHOD OF SOUND REDUCTION INDEX

The sound reduction index measurements were conducted in a combination of a reverberation room and a hemi-anechoic room shown in Fig. 1 in the Institute of Industrial Science, University of Tokyo [13]. The reverberation room (source room) has a volume of 220.4 m³ and hemi-anechoic room (receiving room) has a volume of 210.6 m³ of which walls and ceiling are finished with glass wool of 300 mm thickness. The area of the test opening was 2.7 m (W) × 1.8 m (H) in this study and the sound intensity measurement surface, 2.7 m (W) × 1.8 m (H) × 0.6 m (D), was set in the receiving room. The measurement was performed by the scanning intensity method referring to ISO 15186-1 [14] and the sound reduction index ($R$) was calculated using

$$R = L_{p1} - 6 - L_{ln} + 10 \log \left( \frac{S_m}{S} \right)$$

where $L_{p1}$ is the average sound pressure level in the source room, $L_{ln}$ is the average sound intensity level over the measurement surface in
the receiving room, $S_m$ is the total area of the measurement surface and $S$ is the area of the test specimen under test. In this measurement, the sound reduction indices in each one-third-octave band were measured.

### 3. MEASUREMENT RESULTS OF SINGLE BOARD SPECIMENS

As the first step, in order to examine the basic sound insulation characteristics of single-layer plasterboards, sound reduction indices of the seven different plasterboards shown in Table 1 were measured. Each board specimen was fixed to the metal stud frame (thickness: 0.6mm, width: 65mm) with screws vertically spaced at 300mm.

The critical coincidence frequency of each plasterboard was calculated using

$$
f_c = \frac{c^2}{2\pi h} \sqrt{\frac{12 \rho (1-\sigma^2)}{E}} \tag{2}
$$

where $c$ is the velocity of sound [m/s]; $h$ is the thickness of the board [m]; $\rho$ is the density of the board [kg/m$^3$]; $\sigma$ is the Poisson’s ratio of the board and $E$ is the Young’s modulus of the board [N/m$^2$].

The measurement results are shown in Fig. 2. The broken line shown in each figure indicates the sound reduction index calculated from the mass law for field incidence condition (incidence angle:0 to 78 degree) expressed by

$$
R \equiv 20 \lg (f \cdot m) - 48 \tag{3}
$$

where $f$ is the frequency [Hz], $m$ is the surface density of the board [kg/m$^2$] and $\rho_0$ is the density of the air [kg/m$^3$].

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Board</th>
<th>Thickness [m]*10$^{-3}$</th>
<th>Density [kg/m$^3$]*10$^3$</th>
<th>Surface density [kg/m$^2$]</th>
<th>Young’s modulus [N/m$^2$]*10$^9$</th>
<th>Coincidence freq. [Hz]</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>6TGR</td>
<td>6.0</td>
<td>1</td>
<td>6</td>
<td>4.6</td>
<td>4953</td>
</tr>
<tr>
<td>B</td>
<td>9.5TB</td>
<td>9.5</td>
<td>0.67</td>
<td>6.4</td>
<td>2.1</td>
<td>3789</td>
</tr>
<tr>
<td>C</td>
<td>9.5TSH</td>
<td>9.5</td>
<td>1.21</td>
<td>11.5</td>
<td>6</td>
<td>3013</td>
</tr>
<tr>
<td>D</td>
<td>12.5TB</td>
<td>12.5</td>
<td>0.67</td>
<td>8.4</td>
<td>2.1</td>
<td>2880</td>
</tr>
<tr>
<td>E</td>
<td>12.5TBZ</td>
<td>12.5</td>
<td>0.77</td>
<td>9.6</td>
<td>2.6</td>
<td>2775</td>
</tr>
<tr>
<td>F</td>
<td>15TBZ</td>
<td>15</td>
<td>0.75</td>
<td>11.3</td>
<td>2.8</td>
<td>2199</td>
</tr>
<tr>
<td>G</td>
<td>21TBZ</td>
<td>21</td>
<td>0.76</td>
<td>16</td>
<td>2.3</td>
<td>1745</td>
</tr>
</tbody>
</table>

Table 1: Board specimens used in the test
Fig. 2: Measurement results of sound reduction indices of the single layer plasterboards.
In each figure, it can be seen that the measurement results are in good agreement with the mass law in the low and middle frequency ranges except for the frequency range where the coincidence effect appears. It is also observed in all the measurement results that the dip of the sound reduction index caused by the coincidence effect appears at almost the same frequency calculated using Eq. (2).

4. MEASUREMENT RESULTS OF DOUBLE-LAYERED BOARDS

4.1 Effects of Gluing

At first, the method of gluing two leaves of boards and the effect of the adhesive agents were examined using Specimen H (a combination of the same plasterboard 12.5TB) shown in Table 2. As the adhesive agents, poly-vinyl acetate resin (PVAc) adhesive and special resin adhesive with high damping effect were used. The first layer board was fixed to the metal stud frame as mentioned previously. The second layer was put on the first layer by the two ways: (1) spot-gluing at an interval of 300 mm in both the longitudinal and vertical directions over the entire surface of the board, and (2) daubing all over the board. The two leaves of the plasterboards were fixed with staples as shown in Fig. 3.

The measurement results are shown in Fig. 4. In the cases of spot-gluing condition using PVAc adhesive, the coincidence frequency is almost the same as that of the single-layer condition (12.5TB shown in Fig. 2 (d)). In the case were the two boards were put together by overall gluing with PVAc adhesive the dip due to the

![Fig. 3 The method of gluing two leaves of boards](image)

![Fig. 4 Measurement results of R of the double-layered boards](image)
The coincidence effect is seen around 1440 Hz which corresponds to the critical coincidence frequency of the same plasterboard of two times thickness. On the other hand, in the case of spot-gluing condition using the special resin adhesive, the dip was slightly reduced. Furthermore, in the case of overall gluing condition with the special resin adhesive, the dip due to the coincidence effect almost disappeared.

### 4.2 Measurement Results of Double-layered Specimens

Next, in addition to Specimen H, other five types of double-layered specimens were assembled by combining two types of board from the seven plasterboards as shown in Table 2. Specimens H to J are combinations of a 12.5-mm-thick standard plasterboard (first layer) and another plasterboard (second layer); Specimen H is a combination of the same plasterboard. Specimens K to M are combinations of a 9.5-mm-thick high-density plasterboard (second layer) and another plasterboard (first layer). The first layer was fixed to the metal stud frame as mentioned previously, on which the second layer was put by spot-gluing with PVA_c (poly-vinyl acetate resin) adhesive at an interval of 300 mm in both the length and width directions over the entire surface of the board, as shown in Fig. 3, and the two leaves of plasterboard were fixed with staples.

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Board combination</th>
<th>fc ratio between face and base boards [octave]</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>12.5TB</td>
<td>0</td>
</tr>
<tr>
<td>I</td>
<td>9.5TB</td>
<td>0.4</td>
</tr>
<tr>
<td>J</td>
<td>6TGR</td>
<td>0.78</td>
</tr>
<tr>
<td>K</td>
<td>9.5TSH</td>
<td>0.12</td>
</tr>
<tr>
<td>L</td>
<td>9.5TSH</td>
<td>0.45</td>
</tr>
<tr>
<td>M</td>
<td>21TBZ</td>
<td>0.79</td>
</tr>
</tbody>
</table>

Table 2 | Double-layered board specimens used in the test

The sound reduction indices of these specimens were measured in the same manner as that in the previous case by the sound intensity method. The measurement results are shown in Fig. 5. From these results, we have the following findings.

1. For Specimens H (12.5TB+12.5TB), I (9.5TB+12.5TB) and K (9.5TSH+12.5TBZ), the deterioration of $R$ due to the coincidence effect is observed at approximately 3150 Hz, the same as that observed for the single-layer specimens (9.5TB, 9.5TSH, 12.5TB and 12.5TBZ). This indicates that the deterioration of $R$ due to the coincidence effect cannot be prevented when the first and second layers have close or identical critical coincidence frequencies under the condition of spot-fixing mentioned above.

2. On the contrary, for Specimens J (6TGR+12.5TB), L (9.5TSH+15TBZ) and M (9.5TSH+21TBZ), the deterioration is much improved. In particular, for Specimens J and M, the coincidence effect is scarcely observed. As shown in Table 2, the ratio of the
critical coincidence frequencies of the two boards is large in the cases of these combinations.

5. CONCLUSIONS

As a basic study to develop light-weight double drywall system with a high sound insulation performance, the means to prevent the sound insulation deterioration due to the coincidence effect have been investigated by focussing on the combination of two plasterboards and the way of fixing them and the following results have been obtained.

1. When comparing the two kinds of adhesive agent, PVAc adhesive and the special resin adhesive agents with high damping effect, the latter is better than the former both in the case of spot-gluing and overall-gluing.

2. In the cases of spot-gluing with PVAc adhesive which is commonly used, the tendency that the dip of sound reduction index due to the coincidence effect of each board material remains.

3. In the cases where two plasterboards with different density (thickness) are combined, the dip of sound reduction index due to the coincidence effect is reduced when making the ratio of the critical coincidence frequencies of the two board large.

REFERENCES


