Improvement of sound insulation of doors/windows by absorption treatment inside the peripheral gaps

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ABSTRACT
Slit-shaped gaps included in such building elements as doors and windows are apt to deteriorate sound insulation performance of the wall system. In order to reduce sound transmission through these parts, sound absorption layer is often put inside the gaps. In this study, the effect of such a sound absorption treatment was examined by numerical and experimental studies. In the numerical study, the effect of sound absorption treatment on the gaps existing around doors/windows was examined by applying the FDTD method. To examine the results of the numerical study, a full-scale model experiment was performed using the sound intensity measurement method. A considerably good agreement was found between the results of the numerical study and those of the experimental study. As a result, it has been indicated that the sound insulation defect caused by the sound transmission through the gaps can be much improved by sound absorption treatment inside the gaps.

1 INTRODUCTION
Narrow gaps which exist around the door panel or window sash are apt to deteriorate sound insulation performance of the total wall system. The influence of the acoustical transmission through the gaps or apertures has been theoretically investigated [1-6]. More practical case studies on sound insulation performance of such real building elements with gaps as doors and windows has also been investigated [7-11]. However, prevention of sound transmission through such peripheral gaps has not been reported. In this study, therefore, we examined the effect of sound absorption treatment in narrow gaps with various shapes in cross section. As a case study, in-situ measurement of sound insulation performance of a door panel in an office building was performed under the conditions of with and without absorption treatment.

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2 SOUND TRANSMISSION CHARACTERISTICS OF NARROW GAPS

Figure 1 shows the cross sections of narrow gaps under investigation. Straight and bent gaps which often exist in the peripheral parts of door panel and window were modeled in 2-dimensional shapes. Regarding the straight-types, the width of the gap was changed in two conditions: 2 mm (Type A1) and 6 mm (Type A2). Then, Type A2 was modified into twelve variations by changing the way of setting the sound absorption layer (one side and both side), its thickness (15 mm, 30 mm and 45 mm) and the density of sound absorbing material (glass wool: 32 kg/m$^3$ and 96 kg/m$^3$).

Regarding the bent-types, Type F1b is the basic type with 4 mm width and it was compared with a straight-type (Type F1s) with the same width and the path length. The middle part of the gap was modified into three conditions: 30 mm wide without absorption (Type F2), 70 mm wide without absorption (Type F3) and 70 mm wide filled with 96 kg/m$^3$ glass wool (Type G).

2.1 FDTD Calculation

Sound transmission loss through gaps was calculated using 2-dimensional finite difference time domain (FDTD) method [12, 13]. The propagation of sound wave inside absorption material was also included in the FDTD calculation by assuming the flow resistance of the material. In this calculation, values of flow resistance of 10000 Ns/m$^4$ and 50000 Ns/m$^4$ were set for glass wools of 32 kg/m$^3$ and 96 kg/m$^3$ density, respectively.

Figure 2 shows the 2-dimensional sound field set for the FDTD calculation. The sound field is terminated with perfectly matched layer (PML) [14]. In this calculation, transmission loss $R$ was calculated by

$$ R = L_{J,I} - L_{J,T} $$

where, $L_{J,I}$ is the sound energy level of the incident sound and $L_{J,T}$ is that of the transmitted sound. The transmitted sound energy was calculated by integrating the sound intensity at 13 receiving points on the measurement line shown in Fig. 2. In the FDTD calculation, a discrete spatial grid size of 0.002 m and a time interval of 0.004 ms were chosen.

2.2 Measurement

Figure 3 shows the experimental set up for the measurement of sound transmission loss. A narrow gap of 0.1 m wide and 1,800 mm long was made in the separation wall. The measurement was performed by the scanning intensity method referring to ISO 15186-1 [15]. Sound transmission loss $R$ was calculated by

$$ R = L_p - 6 - \left( L_{in} + 10 \log_{10} \left( \frac{S_m}{S_{gap}} \right) \right) $$

where, $L_p$ is the average sound pressure level in the source room, $L_{in}$ is the average normal sound intensity level on the measurement surface in the reception room, $S_m$ is the total area of the measurement surface in the anechoic room and $S_{gap}$ is the area of the gap opening.
Figure 1: Cross sections of the modeled gaps.

Figure 2: Sound field for 2-dimensional calculation.
2.3 Results

**Straight-types**

Figures 4 (A) and 4 (B) show the calculated and the measured results of sound transmission loss of Type A1 and A2, respectively. In these figures, the arrow (↑) indicates the frequency band in which the lowest sound transmission loss appeared. In comparison between the calculated and the measured results, good agreement is seen. The frequency bands in which sound transmission loss is the lowest are also in fairly good agreement between the calculated and measured results. These sound insulation defects are caused by the open pipe resonance.

Figures 5 and 6 show the calculated and measured results of the straight gaps with and without absorption treatment. Also in these figures, the arrow (↑) indicates the frequency band in which the lowest sound transmission loss appeared. In all configurations, it is seen that the dip frequency decreases as the thickness of the glass wool increases. At high frequencies, $R$ steeply increases with the increase of frequency.
Bent-types

Figures 7 (A) and 7 (B) show the calculated and the measured results of Types F1b, F1s, F2, F3 and G. In the calculation, the results of Type F1b and Type F1s are almost the same and it means that the sound transmission characteristics of bent gaps with uniform width are determined only by the length of the path. By comparing Types F1b, F2 and F3, it is seen...
that the dip frequency decreases in this order. In the frequency bands higher than the dip frequency, it is seen that the wider the space in the bent gap is, the higher the sound transmission loss becomes. In comparison between Type F3 and Type G, the effect of absorption treatment is seen especially in the frequency range around 315 Hz.

![Figure 7: Calculated and measured results of the bent-types.](image)

3 SOUND TRANSMISSION CHARACTERISTICS OF DOORS WITH NARROW GAPS

In the previous section, the sound transmission loss of the gaps with absorption treatment was calculated and the results were examined by laboratory experiment. In this section, as a case study, in-situ measurement was performed in an office building in order to investigate the effect of absorption treatment on narrow gap existing in peripheral parts of a single swing door panel.

3.1 Settings of In-situ Measurement

Figure 8 shows the plan view of the measurement site, the elevation and the cross section of the door panel under test. The door panel is made of MDF (medium density fiber board, 700 kg/m³ density). The dimensions of the door panel are 2115 mm (H) and 770 mm (W) and absorption treatment was applied inside the peripheral gaps on the three sides of the door panel. The width of the gap was distributed from 3 mm to 5 mm. In the cross section B-B’, the thickness of the glass wool arranged along the path of the narrow gap was varied in three steps of 0 (no absorption treatment), 15 and 75 mm as shown in Table 1. In addition, the measurement was performed for the case where all gaps were filled with clay (Case 0).

The sound pressure level difference between the two points in front of and behind the specimen, $D_p$, was calculated by

$$D_p = L_1 - L_2$$

(3)

where, $L_1$ is the sound pressure level measured at the receiving point in the source room and $L_2$ is that at the receiving point outside the source room. The opposite area facing to the specimen was treated with glass wool board in order to prevent multiple reflection.
Figure 8: The plan view of the measurement site, elevation and cross sections of the door with narrow gaps.

Table 1: Variation of the thickness of the glass wool, $\alpha$, arranged along the path of the gap.

<table>
<thead>
<tr>
<th>Case 0</th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>without gap</td>
<td>$\alpha$: 0 mm</td>
<td>$\alpha$: 15 mm</td>
<td>$\alpha$: 75 mm</td>
</tr>
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3.2 Measurement Results

Figure 9 shows the measurement results. To compare them with Case 0, the sound insulation performance in Case 1 is much deteriorated by sound transmission through the peripheral gaps in the frequency range higher than 315 Hz. In the results of Case 2 and 3, it is seen that the sound insulation has been improved by 7 to 15 dB in the frequency range between 2 kHz to 5 kHz. In the frequency range from 315 Hz to 1.25 kHz, $D_p$ was also improved with the increase of the thickness of the glass wool.

Figure 9: Sound insulation of the door measured under four conditions.
4 CONCLUSIONS

Sound transmission characteristics through narrow gaps with typical shapes were investigated by numerical analysis and the results were examined by performing full scale model experiment. As a result, it has been found that the sound transmission can be weakened by inserting sound absorbing material in middle and high frequency bands for both of the straight and bent type gaps. The improvement of the sound insulation of a door by acoustically treating the gaps in the peripheral area was confirmed by an in-situ measurement.

5 REFERENCES


