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Numerical analyses and experimental evaluation of reduction technique for sound transmission through gaps

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ABSTRACT

Unintended gaps that occur around door sets and windows cause sound leakage and decrease sound insulation performance. In the Boundary Element Method (BEM) analysis, sound transmitted through a gap is expressed as the integral of the particle velocity. This means that the transmitted sound field can be expressed based on the particle velocity at the gap only. Hence, it is demonstrated here through numerical analysis that a decrease in sound insulation performance is caused by an increase in sound particle velocities in the vicinity of gaps in a rigid wall. We call this phenomenon the "gap effect". It is also shown that the movement of particles around the gaps can be suppressed by installing a thin sound-absorbing material such as thin or nonwoven fabric, reducing the sound leakage from the gaps. Furthermore, the sound insulation performance obtained by suppressing the particle velocities at the gaps is experimentally verified. The results of this study show that the improvement observed in the sound insulation performance following the installation of sound-absorbing layers into the gaps is quite significant and is suitable for practical use.

1. Introduction

At the perimeter and bottom of a door set, sliding door, or sash window, unintended gaps are easily created owing to the structures of these objects; these gaps cause a decrease in sound insulation performance. To prevent sound leakage through these gaps, airtight materials and rubber-based devices are generally used. However, it is difficult to fully suppress the sound leakage, and the cavities formed by the installation of airtight devices may create another pathway for leaked sound. Additionally, in cases in which airtight materials and devices are used, it is not possible to ensure ventilation through the door set. This is particularly required in toilets and facilities for the elderly that require constant ventilation. Over many decades, various studies have been conducted on sounds transmitted through gaps such as these. Regarding sound transmission through holes, gaps, and slits in walls of a given thickness, Gomperts studied and verified their impact on sound insulation performance using an approximation approach along with experiments, and argued that, by changing the shape, size, and the thickness of the wall, the performance could be varied [1]. He conducted experimental studies on the influences of these parameters on the sound insulation characteristics, and also proposed a prediction method incorporating the effects of air viscosity [2].

However, the approximation method proposed by Gomperts is limited to slight gaps which are shorter than the sound wavelength. Wilson and Soroka proposed a method which removed this limitation and which was experimentally verified [3], and Sauter and Soroka then proposed a method which extended this approach to a rectangular section [4]. Lewis conducted experimental studies on the impact of the characteristics of an entire window set on the sound insulation performance, including the effects of the gaps around the window [5]. Sound insulation prediction formulae have been proposed by Hongisto, using the prediction method given by Gomperts [1]. This prediction method incorporates the influence of the transmitted sound through the gaps around the door sets [6].

The practical prediction formulae proposed in these studies have been verified empirically using door gaps [7]. To reduce the sound leakage from these gaps, Horiuchi et al. conducted numerical analyses and experiments on transmitted sound from noise barrier gaps [8], while Kimura et al. measured and confirmed the effects of sound barrier gaps on sound insulation performance [9]. Similarly, Asakura et al. reported numerical analysis of the

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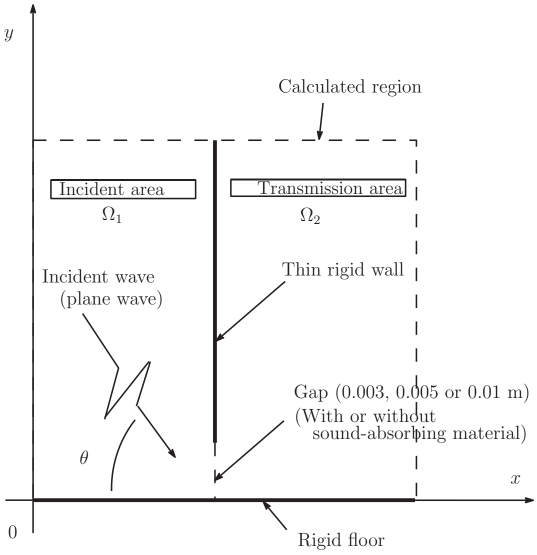

Fig. 1. Gap analysis model and the calculated region.

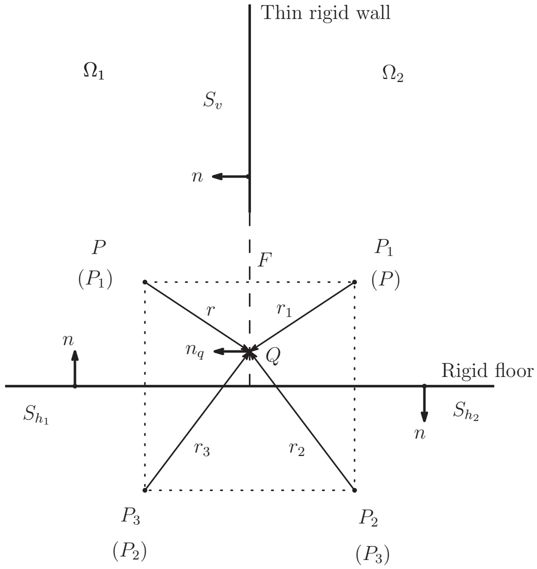

Fig. 2. Numerical analysis model.

transmitted sound from sash-window gaps, and the resultant sound insulation performance due to the gap effects [10,11]. Additionally, Asakura et al. have conducted a numerical analysis using the Finite Difference Time Domain (FDTD) Method and experiments on sound insulation improvement techniques, which involve suppressing the sound transmission through the gaps using sound-absorbing materials [12]. Yamashita et al. reported a study [13] on the effects of treatment of soft boundary surfaces at gap edges using resonator techniques.

As regards the physical characteristics of sound transmission through gaps, the pressure gradient becomes large in areas where a large difference in sound pressure occurs, such as at the edges of a thin rigid plate. This phenomenon is known as the “edge effect”, details of which have been reported by Kawai and Toyoda [14], who also reported that the particle velocity can be effectively reduced by installing sound-absorbing, thin, permeable materials with appropriate flow resistivity in the area where the particle velocity is large.

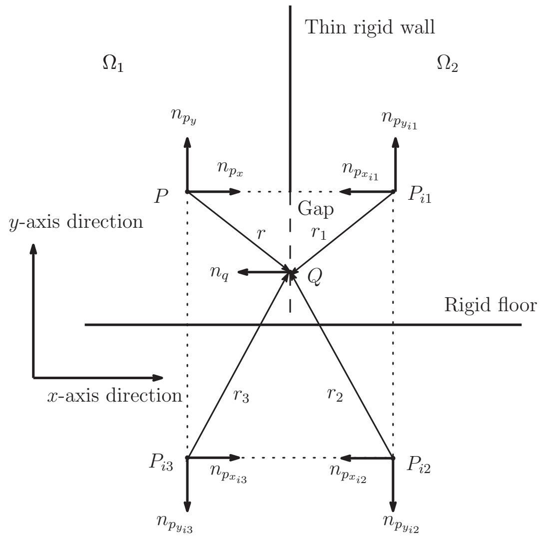

Fig. 3. Numerical analysis model for calculating sound intensity.

Table 1
Surface densities, flow resistivities, and thicknesses of sound-absorbing materials used in this study.

Sound-absorbing material	Gap height (m)	Flow resistivity (N s/m^3)	Surface density (g/m^2)	Thickness (mm)
A-1	0.003	53.9	104	2.6
A-2	0.005			
A-3	0.01			
B-1	0.003	120.2	209	2.5
B-2	0.005			
B-3	0.01			
C-1	0.003	204.2	314	2.5
C-2	0.005			
C-3	0.01			
D-1	0.003	306.4	415	2.6
D-2	0.005			
D-3	0.01			
E-1	0.003	412.5	503	2.7
E-2	0.005			
E-3	0.01			
F-1	0.003	360.2	606	4.3
F-2	0.005			
F-3	0.01			
G-1	0.003	606.8	814	4.8
G-2	0.005			
G-3	0.01			
H-1	0.003	806.5	1001	5.1
H-2	0.005			
H-3	0.01			
I-1	0.003	584.1	1111	8.9
I-2	0.005			
I-3	0.01			
J-1	0.003	919.1	1522	9.7
J-2	0.005			
J-3	0.01			
K-1	0.003	1225.5	1844	9.7
K-2	0.005			
K-3	0.01			
L-1	0.003	1465.4	2024	9.6
L-2	0.005			
L-3	0.01			