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Effect of the suspended ceiling with low-frequency resonant panel absorber on heavyweight floor impact sound in the building☆

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ABSTRACT

This study investigated the effect of the suspended ceiling panel with low-frequency resonant panel absorber on heavyweight floor impact sound. The resonant panel absorber was designed with a perforated top panel, an air gap with or without glass wool, and a bottom panel to ensure a high absorption coefficient in the low-frequency range around 100 Hz. Absorption coefficient measurements were carried out first in the reverberation chamber for resonant panel absorbers varying with the hole diameter of the top panel, the thickness of the glass wool and the air gap between the top and bottom board. As a result, the glass wool had the greatest influence on the absorption coefficient, and the highest absorption coefficient of the resonant panel absorber was about 0.6 in the band of 100 Hz. Floor impact sounds after installing the suspended ceiling with the best resonant panel absorber were also measured in test building using heavyweight floor impact sound sources (bang machine and rubber ball) and compared with result for normal suspended ceiling with gypsum board. Heavyweight floor impact sound by the resonant panel absorber was decreased by 2 dB and 4 dB in single number quantity ($L_{i,Fmax,Aw}$) for bang machine and rubber ball, respectively. In particular, the resonant panel absorber reduced by 6 dB in 125 Hz octave band with the largest absorption coefficient.

1. Introduction

In Korea, floor impact sound such as children's jumping and running sounds, which has dominant sound energy in the low-frequency has been perceived as most irritating noise in apartment building [1,2] and causes social problems such as murder and arson case. Several surveys [3,4] in European country also reported that the sound insulation in the lightweight as well as heavyweight building is an important factor for comfortable living environment. This floor impact noise problems in Korea is due to fact that there are too many apartment buildings over 60% of all housing types, which has relatively thin slab with 120–150 mm thickness. Another reason is that people inside home do not wear shoes and cause easily footstep noise with their bare feet. Accordingly, Korean government forced to have legal minimum slab thickness (210 mm) and floating floor for apartment building with RC (Reinforced Concrete) structure since 2005. Several studies on the floating floor with resilient materials to reduce floor impact sound have been carried out [5–12]. However, the floating floor with the resilient material resonates low-frequency sound below about 100 Hz especially for heavyweight floor impact sound in box-frame reinforced concrete structure [5,9]. In addition, the several studies [13–23] have been conducted for acoustical treatments on suspended ceiling panel with air gap under structural slab, which is usually used in Korea as well as the other countries. Previous studies [16,18,21] on the suspended ceiling found that air gap between slab and ceiling panel resonates low-frequency sound below 150 Hz, which is due to air-spring effect. The degree of sound resonance in low-frequency ranges varied with air gap thickness [16,18]. It was also reported that the suspended ceilings have limitation on sound insulation because of the bending resonance frequency [13,14]. Several empirical studies [15,19,22,23] investigated the influences of suspended ceiling panel type and size, hanger and stiffness on floor impact sound or sound insulation. Kim et al. [22] found that the perforated ceiling panel with holes of 12 mm diameter and absorption sheet (5 mm) reduces 2 dB in SNQ (Single Number Quantity, $L_{i,Fmax,Aw}$) [24] for heavyweight floor impact sounds. Hui and Ng [19] suggested that combining the nodal line stiffener, nodal point isolator and low radiation efficiency at bending resonance can achieve higher noise and vibration isolation improvement. Results from Jeon et al. [15] and Kim et al. [16] demonstrate that steel hanger with vibration absorber don't have large influence on heavyweight floor

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impact sound insulation. The effects on floor impact sound insulation of wooden-frame construction were also found due to variations of the ceiling structure, which caused different surface density, kind of ceiling board, sound-absorbing material, and the independent ceiling or the direct ceiling [20]. However, there is still no empirical study on resonator absorber ceiling to reduce the specific low frequency floor impact sound resonating within air space between slab and suspended ceiling.

Resonant panel absorber like Helmholtz resonators has been thoroughly studied, and especially, the resonator panel with array of Helmholtz resonators was studied for characteristics of resonance frequency and reduction of broad band noise [25–27]. In addition, several theoretical models to predict the low-frequency resonance of the array of Helmholtz resonator was also suggested [28,29]. In order to enhance the low frequency absorption, several designs of perforated panel with Helmholtz resonator array were suggested by theoretical method [30,31]. However, there is little empirical data on low frequency absorption by random incidence for resonator panel or perforated panel with Helmholtz resonator array.

This study investigated the effect of the suspended ceiling with low-frequency resonant panel absorber on heavyweight floor impact sound. Several resonant panel absorbers were designed to absorb the low-frequency sound around 100 Hz and tested in the reverberation chamber. Heavyweight floor impact sound measurements for the best resonant panel absorber were also conducted in a test building.

2. Design of resonant panel absorber

Resonant panel absorbers to absorb low-frequency sound around 100 Hz were designed. Fig. 1 shows the schematic diagram of resonant panel absorber using two panels. Resonant panel absorbers has perforated top panel and air cavity, and can be seen as a series of Helmholtz resonators placed in parallel. As shown in Fig. 1, design factors of the resonant panel absorber were the hole diameter (d) of the top panel, the thickness (l) of top panel and the air gap (L) and the volumes of cavity (V) between the top and bottom board. Sizes of the design factors were determined for the target resonance frequency of 100 Hz using following equations. In the equation-1 and 2, f_0 and c denotes resonance frequency and speed of air, respectively. Cross-section area is denoted as s, and P indicates aperture ratios of hole, which is calculated using dividing area of board by total hole area. δ is equal to 0.8 d.

$$f_0 = \frac{c}{2\pi}\sqrt{\frac{s}{V(l+\delta)}} \tag{1}$$

$$f_0 = \frac{c}{2\pi}\sqrt{\frac{P}{L(l+\delta)}} \tag{2}$$

As shown Fig. 1, in this study, a unit of the resonant panel absorber consists of a perforated top panel, an air gap with and without porous material (glass wool), rectangular timber and a bottom panel. Area of a unit of the resonant panel absorber was 1.62 m^2 (900 mm × 1800 mm). Top and bottom panel were made using 9.5 mm gypsum board (about 530 kg/m^3 density), and glass wool with 24 kg/m^3 density was used.

Table 1
Test specimen of resonant panel absorber for absorption coefficient measurement and the predicted and measured resonance frequency band (1/3 octave band, f_c).

Type	Air gap thickness (mm)	Hole diameter (mm)	Glass wool thickness (mm)	Resonance frequency band [f_c, Hz]	
				Predicted	Measured
A	25	50	–	160	200
B	50	50	–	100	160
C	25	50	25	–	125
D	50	50	25	–	125
E	50	25	–	63	125
F	50	10	–	32	100
G	50	50	50	–	100
H	50	25	50	–	100
I	50	10	50	–	100
J	50	10	25	–	100

Although more thickness of top panel results in lower resonance frequency, 9.5 mm gypsum board as top panel was used considering total weight of suspended ceiling and its convenient construction. Top and bottom panels were connected with rectangular timbers on four edges of a panel unit. The experimental factors of the resonant panel absorber in this study were the hole diameter of the top panel, the air gap thickness between the top and bottom panel and the thickness of the glass wool. Several resonant panel absorbers varied with experimental factors above were made for the absorption coefficient measurement as shown Table 1.

3. Absorption coefficient measurement

3.1. Method

Absorption coefficient measurements were carried out for 10 specimens (Ã J) of resonant panel absorber in Table 1. This measurement intended to find the effect of experimental factors (air gap thickness, hole diameter and glass wool) on frequency characteristics of absorption including resonance frequency. As shown Fig. 2, measurements were conducted in reverberation chamber with volume of 209 m^3 according to ISO 354 [32]. Test specimen was made by arraying six resonant panel absorbers (2ea × 3ea) and installed on the floor. Area of test specimen was 9.7 m^2 (2.7 × 3.6 m^2). Six microphones and two omni-directional speakers were used. Interrupted noise method was utilized to measure reverberation time using pink-noise, and measurement was repeated once for one specimen.

3.2. Results

Fig. 3 shows absorption coefficient of resonant panel absorber with respect to air gap thickness. In Fig. 3, the results were shown for two groups with or without glass wool. For resonant panel absorber without glass wool, frequency showing peak of absorption coefficient (resonance frequency) was moved from 200 Hz to 160 Hz when air gap

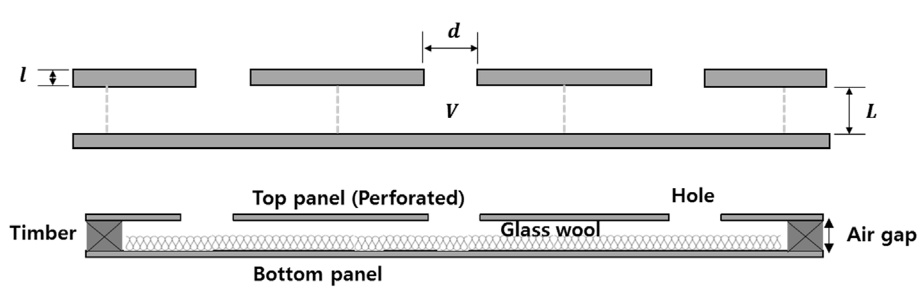

Fig. 1. Schematic diagram of resonant panel absorber using two panels (top) and structure of a unit of resonant panel absorber (bottom).