29th International Congress on Sound and Vibration
The annual congress of the International Institute of Acoustics and Vibration (IIAV)
9–13 July 2023
ICSV29

ACOUSTIC PERFORMANCE OF A NOVEL FLOATING FLOOR WITH RUBBER CUSHIONS

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Abstract: The most problematic noise in apartment buildings is structure-borne sound, which is created when an impact causes the floor to vibrate and radiate sound. Until now, several studies focus on developing multiple layers of resilient materials are used to construct floating floors in order to absorb impact and minimize structure-borne noise. This study proposes a novel floating floor with rubber cushions for reducing floor impact noises. Experiments using a mockup of the proposed floating floors subjected to heavy impact loading were conducted on floor configurations with various rubber cushion shapes. Furthermore, a numerical analysis was carried out and verified by experimental data. According to the experimental and analytical results, increasing the height of the rubber cushions and adding a layer of lightweight concrete lowers the heavy-weight floor impact sound and improve acoustic performance for conventional concrete floor systems.
Keywords: Floor impact noise, Floating floor, Vibro-Acoustic Numerical Simulation, Rubber cushion, Structure-borne noise.

1. Introduction

To date, more than half of all dwellings in Korea are apartments. High-rise apartment buildings are commonly constructed in Korea due to the country's high population density (480 inhabitants per square kilometer) and its comparatively small land area (99,373 km^2) [1]. This is an effective strategy for addressing the problems posed by today's dense urban populations.

Apartment residents are annoyed by a range of noises, including floor impact noise, which results in a considerable quantity of complaints. In addition, floor noise is exceedingly challenging to regulate legally due to its varying sensitivities, and no obvious solution has been proposed. Heavy weight impact noises caused by children's activities (running, jumping, etc.), footsteps, and falling and hitting objects are the most common source of indoor noises. Floating floors are recognized as an efficient method for limiting impact sound without affecting the structural design. Therefore, impact sound insulation using floating floors is a significant study topic in noise control engineering and has been investigated extensively.

In this study, a novel floating floor with rubber cushions, which is layered on top of the conventional concrete floor systems of existing apartments, was presented and employed to reduce heavy-weight impact noise. Acoustic experiments and vibro-acoustic numerical analysis based on finite element method were undertaken to find the effects of the shape of rubber cushions and a lightweight concrete layer on the floor impact noises.

2. Experimental program

2.1 Floating floor specimen description

This study presents two types of a novel floating floor with rectangular rubber cushions. The spacing between the rubber cushions was 200 mm. Type 1, as depicted in Fig. 1, consists of a 40 mm thick mortar layer, a 3 mm thick PP sheet, and a layer of sound-absorbing material with a thickness equal to the height of a rubber cushion. Two specimens, Type 1-H28 and Type 1-37.5, with rectangular rubber cushions of 30 x 30 x 28 mm and 30 x 30 x 37.5 mm respectively, were investigated.

Compared to Type 1, Type 2 includes an additional 30 mm layer of lightweight concrete, as shown in Fig. 2. Type 2 was also investigated with two different specimens, Type 2-H28 and Type 2-37.5, using rectangular rubber cushions of the same size as Type 1.

Layers of PP board and sound-absorbing materials, and rubber cushions are modularized into 600x600 mm sheets for transport and installation convenience on the construction sites. The floating floor is then completed with mortar and lightweight concrete layers.

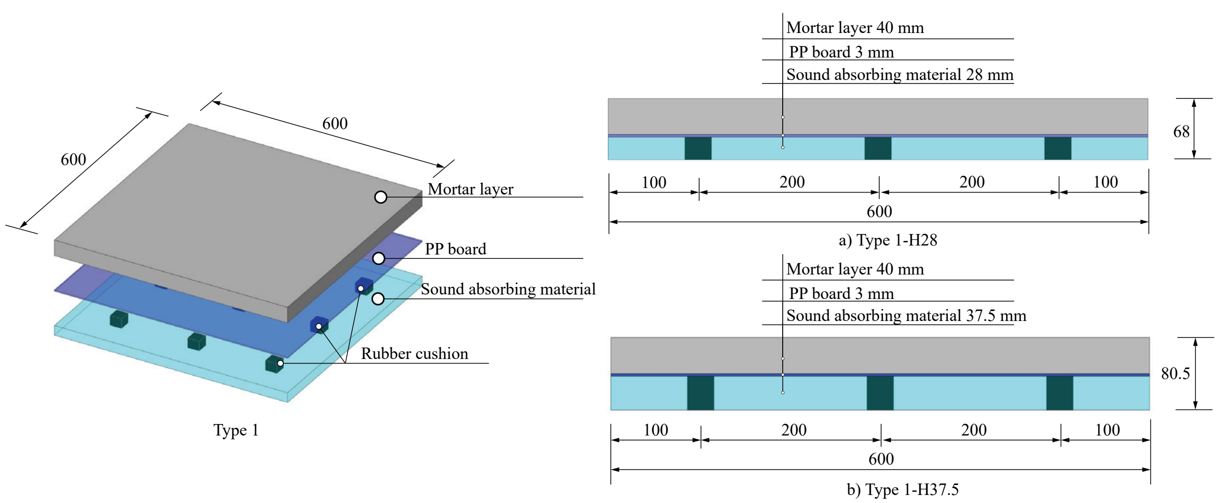


Figure 1: Configuration and cross-section of a module of the tested floating floor Type 1.

2.2 Acoustic experiments

Acoustic research was carried out according to the Korean standard KS F 2810-2 for the heavy-weight impact noise [2]. Fig. 3 depicts a chamber model with horizontal dimensions of 4.63 x 3.9 m and a height of 2.59 m [3]. The thickness of the structural slab made of concrete is 210 millimeters. The thickness of walls W1 and W2 is 200 millimeters and 100 millimeters, respectively. Five measurement points were selected, including one point at the floor's center and four points at 750 mm from each wall [4]. Installation height for microphones was 1200 mm.

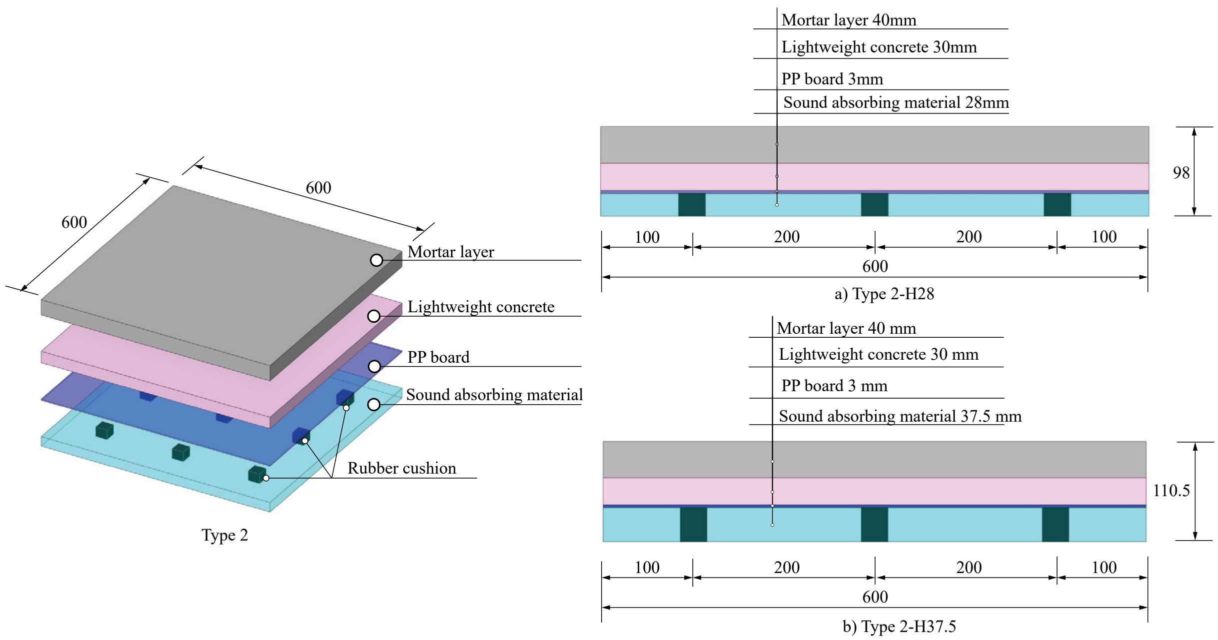


Figure 2: Configuration and cross-section of a module of the tested floating floor Type 2.

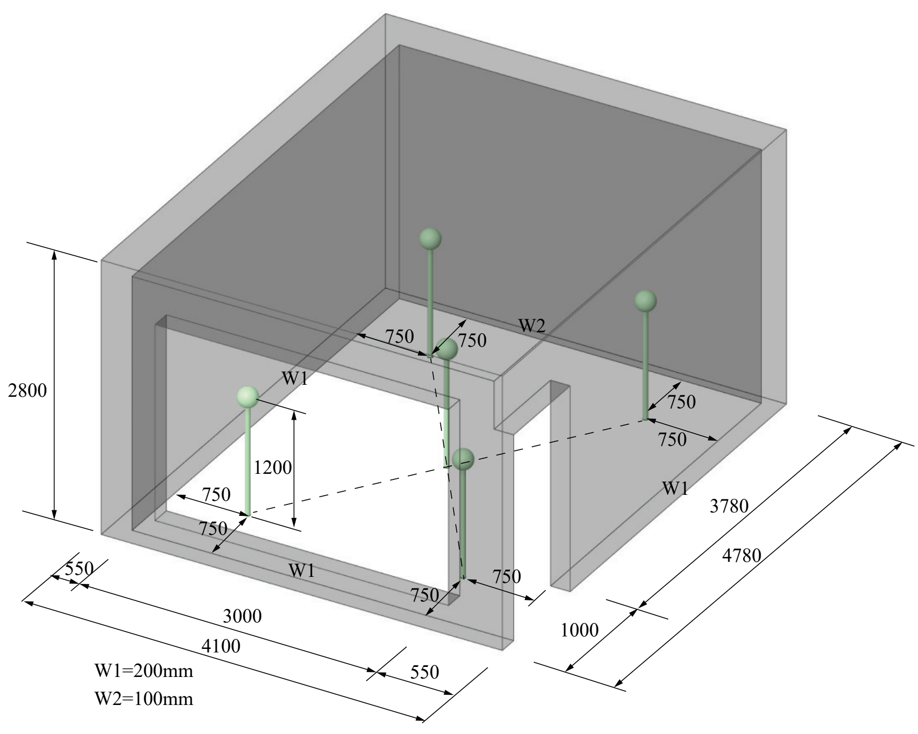


Figure 3: The schematic diagram of the experimental facility used for the impact sound measurement.

The specimens were placed at the center of the concrete slab. A rubber ball hit the center of each specimen to generate the impact force. Fig. 4 shows the experiment set-up. Fig. 5 displays the force spectrum for the impact ball.

(a) The actual image of a mock-up.

(b) The microphones installed in the receiving room under the load-bearing slab.

(c) The standard impact source (rubber impact ball) and an unit of a novel floating floor.

Figure 4: The experiment set-up.

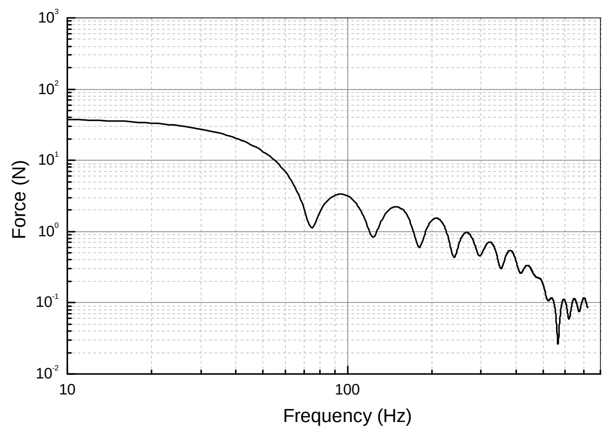


Figure 5: Force spectrum of the impact ball.

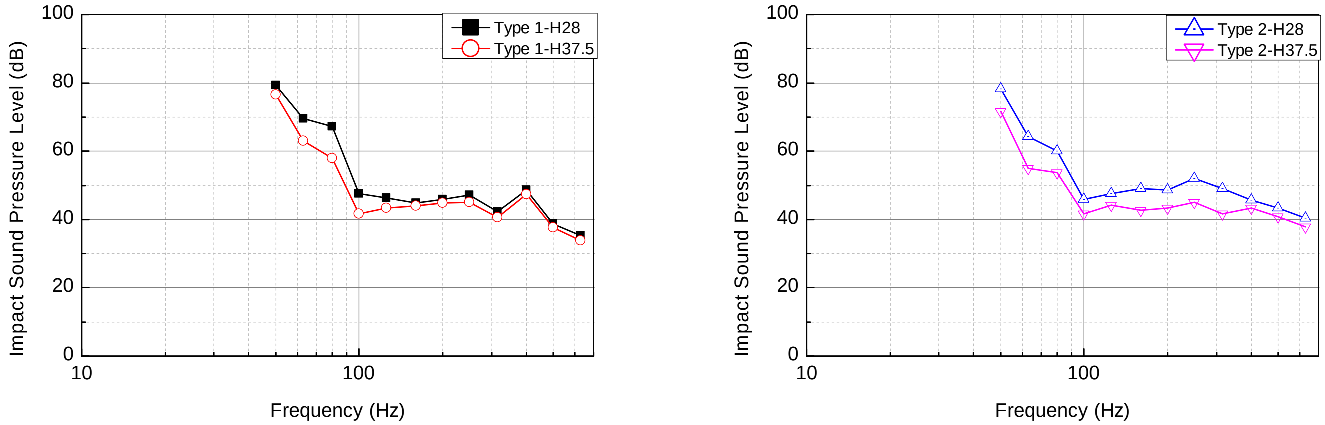
3. Experimental results and discussion

Fig. 6 compares the spectra of the receiving room's sound pressure level measured by the average of the five microphones at the 1/3 octave band in four tests using two types of the novel floating floor. The results indicate that the Type 1-H37.5 specimen has a lower heavy-weight impact sound level than the Type 1-H28 specimen. The Type 2-H37.5 specimen also shows a lower heavy-weight impact sound level than the Type 2-H28 specimen.

Fig. 7 shows that with the same rubber cushion height of 28 mm, the specimen Type 2-H28 has a lower heavy-weight impact sound level in the low-frequency region (below 100 Hz) and a higher heavy-weight impact sound level in the high-frequency region (above 100 Hz) when a lightweight concrete layer was added. Type 2-H37.5, which has the same rubber cushion height as Type 1-37.5 (37.5 mm), has a lower heavy-weight impact sound level in the low-frequency area and the same heavy-weight impact sound level in the high-frequency region due to the addition of a lightweight concrete layer.

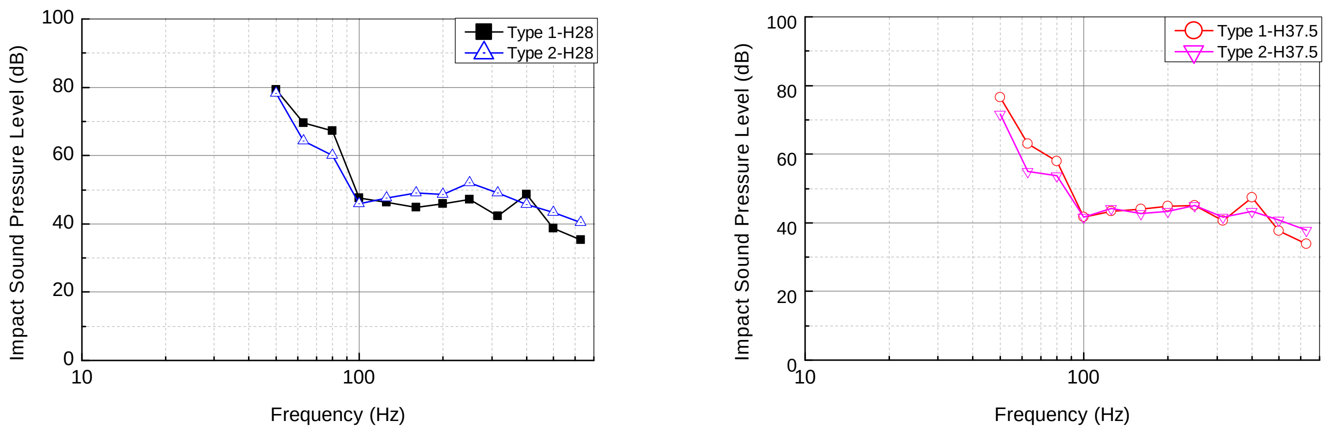
Fig. 8 shows the SNQ-based (Single-number quantity-based) evaluation (A-weighted maximum impact sound level $L_{iA,Fmax}$) for the results of the field measurements. The figure also shows the numerical results from finite element analysis and this will be discussed later. The results indicate that the SQN value for Type 1-H28 is higher 6.49% than that of Type 1-H37.5. The same trend remains true, with the SQN value being higher 11.85% for Type 2-H28 than Type 2-H37.5. Type 1-H28 is observed to have the lowest acoustic performance, whereas Type 2-H37.5 has the highest acoustic performance.

Overall, the experimental findings indicate that raising the height of rubber cushions and adding a layer of lightweight concrete reduces the heavy-weight impact sound of the floor.



(a) Type 1 (b) Type 2

Figure 6: The influence of the height of the rubber cushions on the acoustic performance of the novel floating floor.



(a) H=28 mm (b) H=37.5 mm

Figure 7: The influence of the lightweight concrete layer on the acoustic performance of the novel floating floor

4. Finite element modeling

4.1 Numerical modeling

To investigate the relationship between structural vibration and noise in the receiving room, the commercially available vibro-acoustic analysis software Simcenter 3D version 2021.2 by SIEMENS was used to build a numerical model based on the finite element method with the same specifications as the experimental mock-up from the previous section. The numerical model depicted in Fig. 9 employed 2D elements with a 50 mm grid size for four walls. 3D elements modeled the layers of the 600 x 600 cm

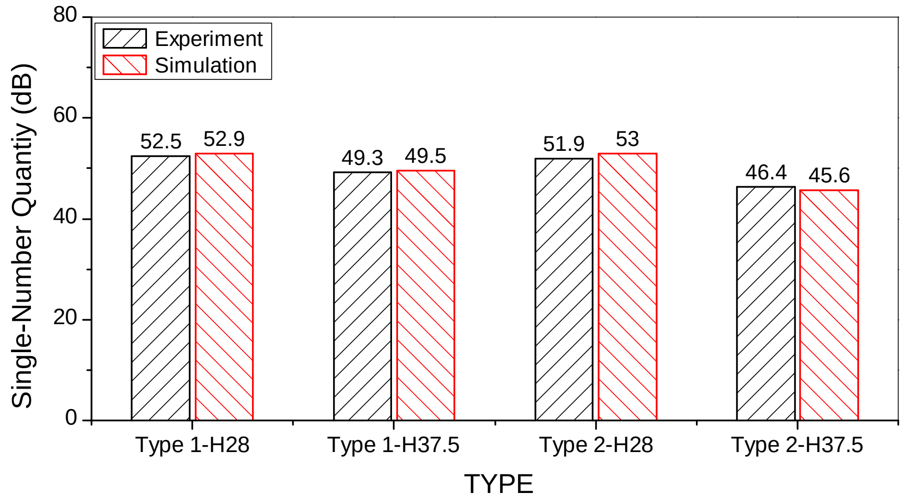


Figure 8: Comparison of experimental and numerical results of single number evaluation.

floating floor module and the concrete slab. The grid size for mortar, lightweight concrete, and sound-absorbing material layers was 25 mm. 100 mm was the mesh size used to model the concrete slab. It is noted that the model did not account for the effect of the thin PP board on the acoustic performance of the floor. The rubber cushions were modeled by 3D elements with a 5 mm grid spacing. Fixed boundary constraints were applied to all nodes at the base to hold the mock-up in place.

Table 1 summarizes the mechanical parameters of the materials employed in the numerical model of the floating floor and the mock-up. The mechanical properties and geometric parameters have been set to match the experimental mock-up from the previous section. The Linear Elastic Isotropic Model was used to model these materials. Air is considered to have a density of 1.2 kg/m^3 and a speed of sound of 340 m/s. The absorption coefficient of walls is set at 0.01, whereas windows and doors are modeled as non-coupling surfaces with no structural vibration and sound radiation interaction [5].

Table 1: Mechanical properties of the novel floating floor.

	Mortar	Rubber	Concrete	Lightweight concrete
Young's Modulus (MPa)	20000	6.35	27000	1200
Density (kg/m^3)	2400	1000	2400	500
Poisson's ratio	0.167	0.4	0.167	0.2

4.2 Verification of the FE model

Excitation was provided by an impact ball with the force spectrum shown in Fig. 5. Fig. 8 provides SNQ-based evaluations for both field measurements and numerical simulations. The numerical models accurately predicted the SNQ values of the tests with a maximum error of 2.12%. Fig. 10 shows the comparison of normalized SPL spectra averaged across five microphones. It shows a high degree of agreement between the experimental and simulation results in the frequency domain except for 100 Hz and 500-630 Hz regions. Overall, this highlights the finite element method's capacity to accurately predict floor vibro-acoustic behavior, allowing for more extensive parametric analysis and replacing time-consuming and costly field measurements.

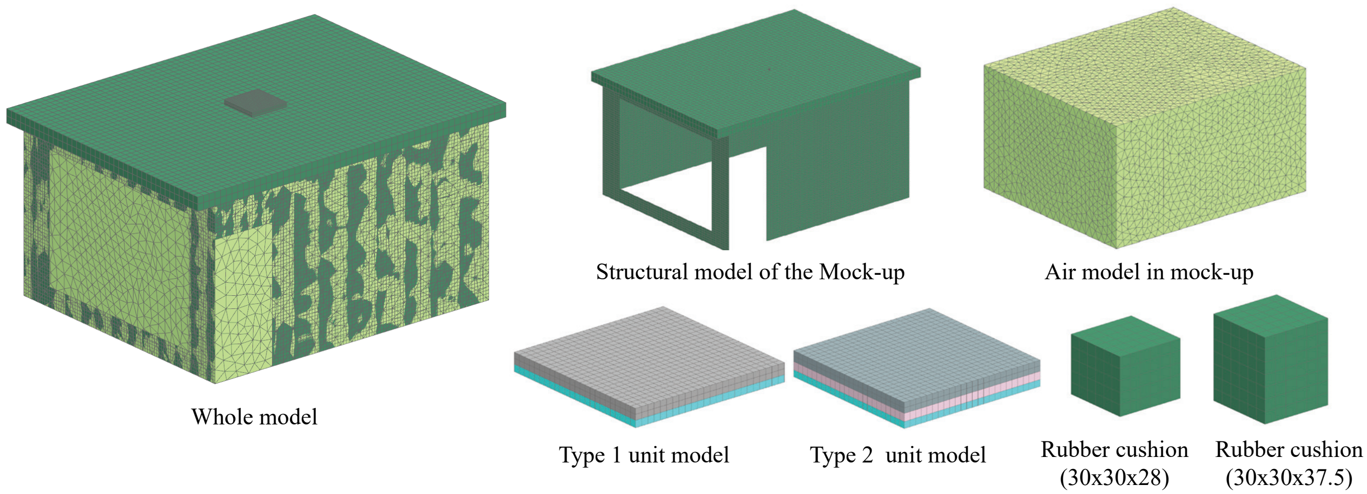
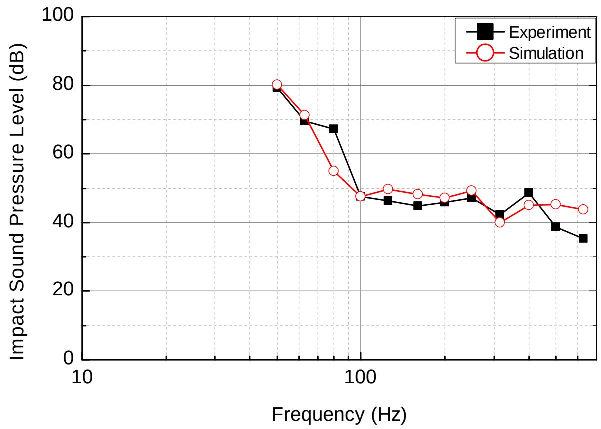
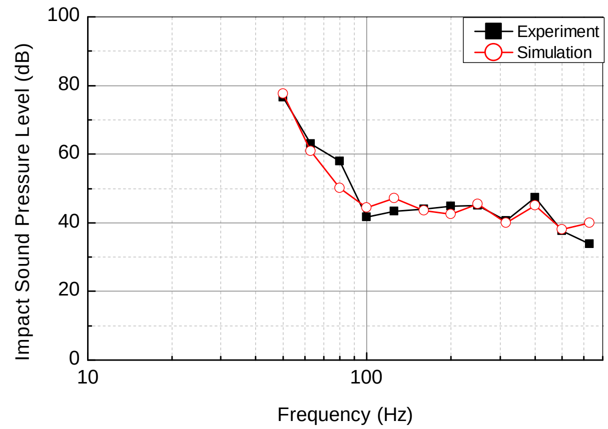


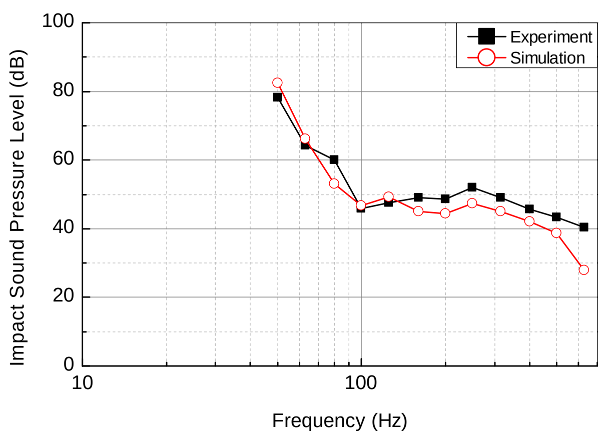
Figure 9: Details of FE models used for numerical investigation.



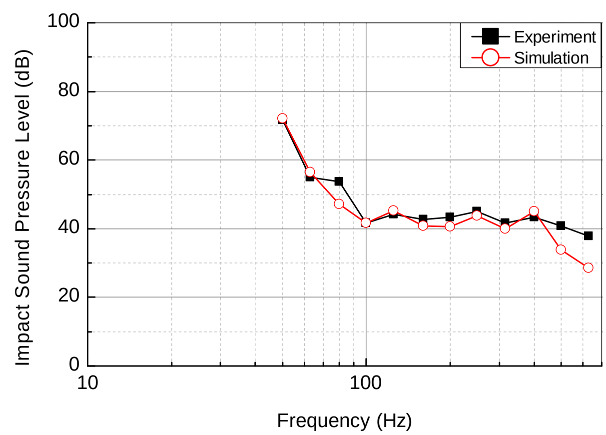
(a) Type 1-H28



(b) Type 1-H37.5



(c) Type 2-H28



(d) Type 2-H37.5

Figure 10: Comparison of experimental and numerical results: 1/3 octave band

5. Conclusions

In this research, acoustic performance of a novel floating floor with rubber cushions was investigated using experimental measurements and numerical analysis approaches. The following primary conclusions can be drawn from the test and simulation results.

- Two types of the novel floating floor with rubber cushions were presented.
- Increasing the height of rubber cushions and adding a layer of lightweight concrete reduces the heavy-weight impact sound of the floor.
- Using a commercial software, a vibro-acoustic analysis was performed to predict the acoustic performance of the novel floating floor. In terms of a frequency range of one-third of an octave and SNQs, the results of experiments have been compared with those of numerical models. The comparison results indicate that the vibro-acoustic analysis results were reasonably accurate.
- Numerical simulations using the proposed method may replace costly and time-consuming field experiments.

This study introduced a novel floating floor with rubber cushions for decreasing heavy-weight floor impact noises. Research on optimizing mortar thickness, lightweight concrete, shape and distance between rubber cushions will be presented in the following studies.

6. Acknowledgments

This research was supported by Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Education(NRF-2020R1A2C2007195)

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