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Design and construction factors affecting floor impact sound in multi-residential buildings

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ABSTRACT

The floor impact sound is a structure-borne noise caused by the impact of occupants' walking on the upper floor. The level of the impact sound is influenced by various design factors as well as construction quality. In this study, to evaluate the reduction of the floor impact sound on different design and construction factors, the floor impact sound and the structural vibration characteristic were investigated by the numerical analysis. To validate the accuracy of the prediction, field measurements were carried out in real-scale test-bed housings with a slab thickness of 150 mm. The results showed that heavy-weight floor impact sound is influenced by design and construction factors including slab thickness, wall thickness, room size, concrete quality, etc. This indicates the importance of appropriate building planning and quality control for the multi-residential buildings composed of concrete elements.

Keywords: Floor Impact sound, Design factor, Construction quality
I-INCE Classification of Subject Number: 76

1. INTRODUCTION

The floor impact sound is a noise phenomenon that is caused by the radiation of structural vibration, and by the ununiformed radiated noise distribution in a closed cavity. Especially, since the vibration of the slab is a dominant factor of the floor impact sound [1], vibration characteristic of slab make a deviation of the floor impact sound.

In general, the major factors causing slab vibration are divided into two categories; design factor and construction quality factor. The design factors mean the intended variables such as thickness of slab, position of load-bearing wall and so on. Construction quality factors mean the unintended variables such as property of concrete that occurs on construction. In this study, the influence of these factors on floor impact sound is analysed. In order to analyse the influence on the floor impact sound, Finite Element Method (FEM)-based numerical analysis is used. In addition, the numerical results are verified with the full-scaled mock-up test results.

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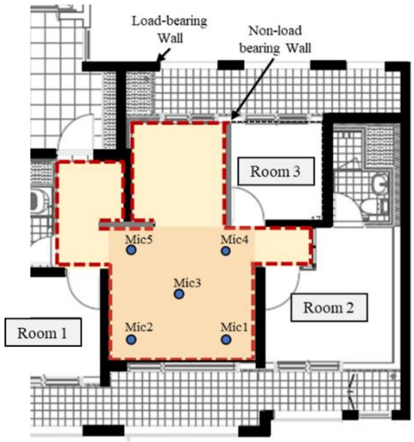
2. ESTIMATION OF FLOOR IMPACT SOUND

2.1 Numerical Model of Full-scale Mock-up

To analyse the influence of design factor and construction quality factor on floor impact sound, floor impact sound was predicted and experiment using full-scaled mock-up structure. This mock-up is consist of two type; 59 m^2 and 84 m^2, that are typical size on Korea, and slab thickness is 150, 180 and 210 mm. In this study, Estimation of floor impact sound is conducted on living room, 59 m^2 and 150 mm, shown in Fig. 1.

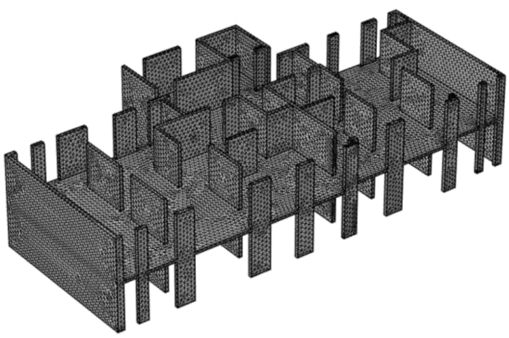


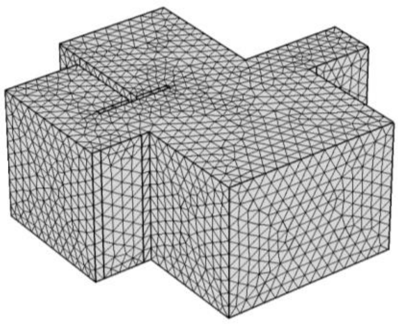
(a) Full-scale Mock-up *(b) Position of Microphones*

***Fig. 1** The Analysis of Floor Impact sound on Full-scale Mock-up*

The floor impact sound is predicted using by a commercially available acoustics analysis software; Comsol Multiphysics 5.3. Fig. 2 shows the numerical model. The numerical model of the mock-up uses 3D elements with the grid size of 50 mm. The fixed boundary conditions on structure model are applied at the base of the mock-up to hold the mock-up in place.

The receiver point was set as in Fig. 1(b) based on ISO standard [2], and excited same point by impact hammer on upper floor. Tapping machine [2] or bang machine [3] were generally used for impact source. However, in this study, impact hammer is used to analyse a normalized acceleration and pressure. The force spectrum of impact hammer allows meaningful measurement for the 1~200 Hz frequency range. On the other hand, bang machine effects a fairly robust excitation for frequency range not exceeding 100 Hz [4].





(a) Structure Model *(b) Acoustic Model*

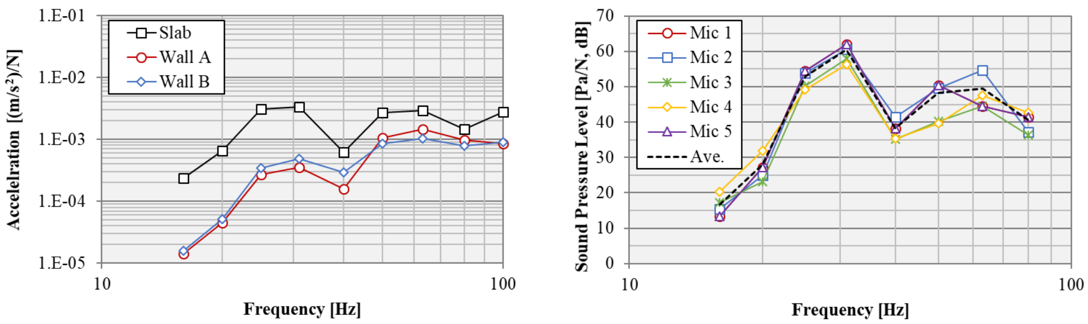
***Fig. 2** Numerical Model: Comsol Multiphysics*

The mechanical properties of the materials used in the numerical model is listed in Table 1. The density and speed of sound in air are set at 1.2 kg/m^3 and 340 m/s, respectively. The absorption coefficient of walls is set at 0.01, while window and door are modelled as non-coupling surfaces in which no interaction takes place between structural vibration and sound radiation.

***Table 1**. Mechanical Property of Concrete*

Material Property	Value
Elastic Modulus	20 G Pa
Density	2600 kg/m^3
Poisson's ratio	0.168
Loss Factor	0.02

The 1/3 octave band acceleration and impact sound predicted results are shown in Fig. 3(a) and (b). The acceleration and noise level are normalized with respect to input force spectrum of an impact hammer [5].



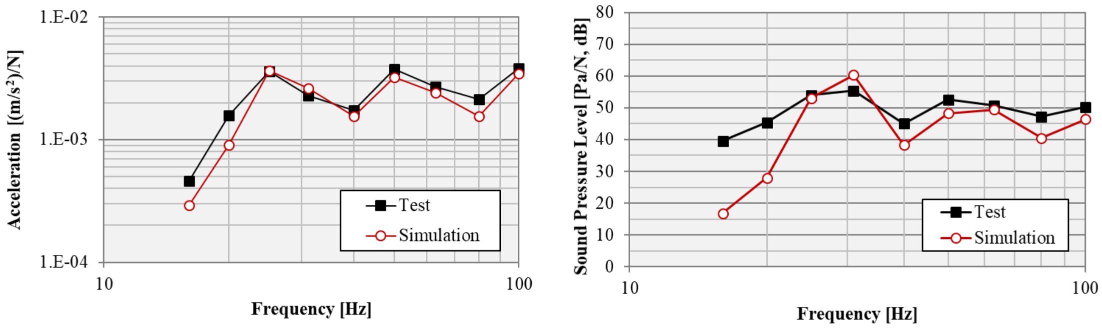
(a) A Normalized Acceleration *(b) A Normalized Pressure*

***Fig. 3** Estimated Results of the Floor Impact sound*

2.2 Correlation between Experiment and Numerical Analysis

Before proceeding with a more in-depth numerical investigation, experimentally measured and numerically simulated vibration and impact sound levels are compared first. An experimentally measure is conducted based on ISO standard. The force of impact generated by an impact hammer with a rubber tip striking the dead center of the floor of the upper chamber marked Mic 3 in Fig. 1(b). The impact sound is measured by five G.R.A.S. 146AE microphones set up in the lower cavity in accordance with ISO 10140 [2]. PCB 352C33 accelerometers attached to either side of the floor measure floor vibration. The data collection uses SIEMNES SCADAS-mobile spectrum analyser.

Using an impact hammer to provide excitation, Fig. 4(a) compares normalized acceleration spectra of the center of the structural slab while Fig. 4(b) compares spectra of sound pressure level of the receiving room averaged over the five microphones. For structural vibration, Fig. 4(a) shows good agreement until 100 Hz band. For impact sound, Fig. 4(b) also shows close agreement throughout the 1/3 octave band until 100 Hz band.



(a) Acceleration *(b) Pressure*

Fig. 4 *Comparison with Numerical Result and Experimental Result*

3. CASE STUDY

3.1 Design factor

Design factors are the thickness of slab, thickness of wall, position of bearing wall, and so on. In general, thickness of slab is the dominant factor on floor impact sound [1]. In this chapter, the floor impact sound is analysed with design factor as shown in Fig. 5. Theoretically, it is known that the noise reduction effect is about 9 dB when the thickness of slab is doubled [6], and it is analysed that it is reduced by about 8 dB in this study.

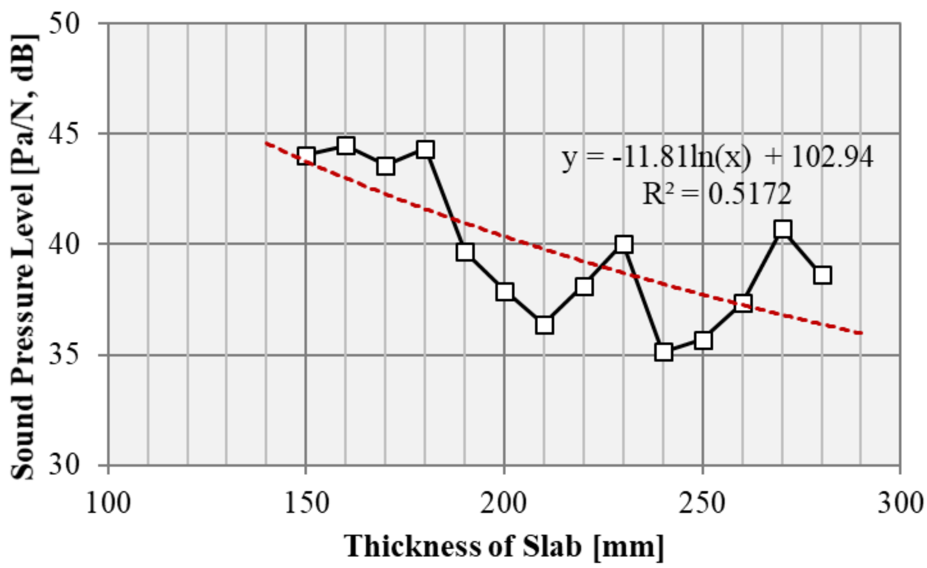
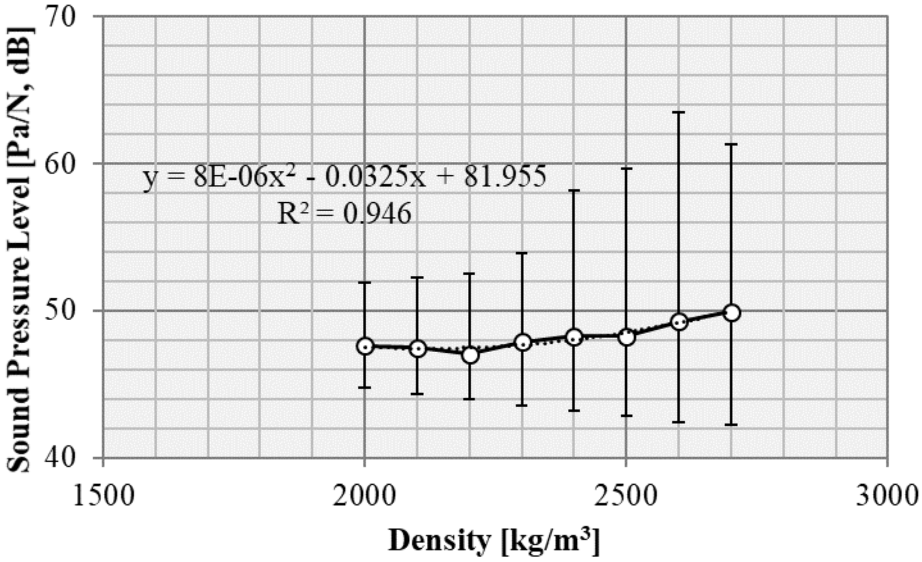


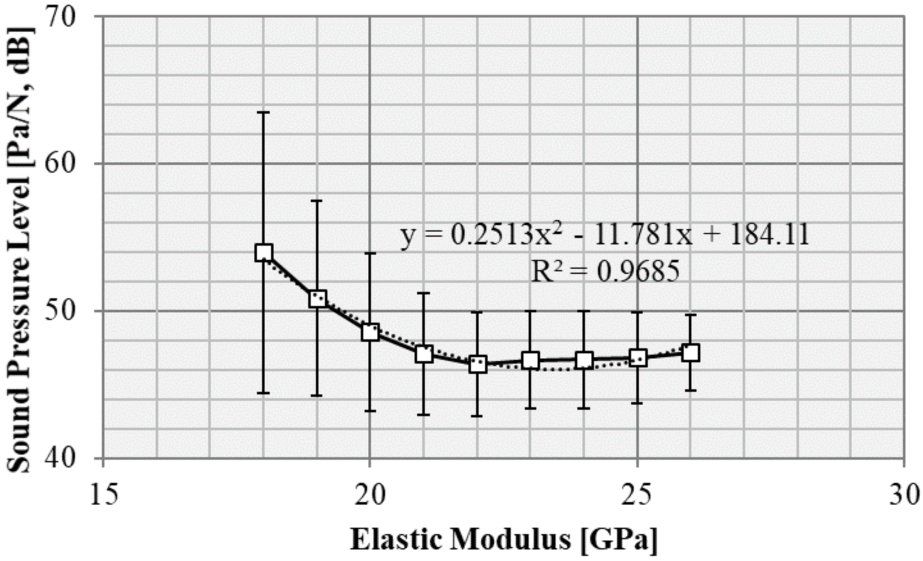
Fig. 5 *Effect of Thickness of Slab on Floor Impact sound*

3.2 Construction quality factor

More than 90% of the building materials is consist of concrete. And the material properties of concrete are affected by construction quality such as water-to-cement ratio. These material properties influence to characteristic of structural vibration, therefore, it causes a variation on floor impact sound. To explore the influence of construction quality factor on floor impact sound, two parameters, density and elastic modulus, are analysed. Fig. 6 shows the predicted the floor impact sound with density and elastic modulus of concrete.



(a) Density of Concrete



(b) Elastic Modulus of Concrete

Fig. 6 *Effect of Construction Quality factor on Floor Impact sound**

(the error bar means variation according to the other parameter)*

Fig. 6 shows the total noise level with variable of the construction factor; density and elastic modulus. An error bar means that variation caused by an elastic modulus or density. As increasing the density of concrete, the floor impact sound increases as shown in Fig. 6(a). While, floor impact sound decrease as increasing the elastic modulus of concrete as shown in Fig. 6(b). The elastic modulus is contribute more than density on floor impact sound. It means that construction quality make a variation of floor impact sound.

Fig. 7 shows the predicted floor impact sound in 1/3 octave band, and present that the contribution of each parameter and the shifting a dominant frequency. This phenomenon is determined by the superposition of the structural mode and the acoustic mode. In future work, the superposition of structural and acoustic mode will be analysed in narrow band.

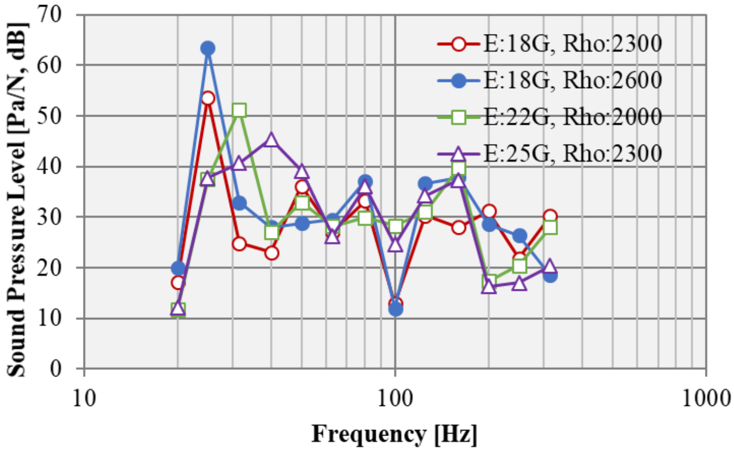


Fig. *7 1/3 Octave Band Floor Impact sound*

4. CONCLUSIONS

In general, the floor impact sound is determined by the slab vibration of the upper floor. In this paper, two main factors in slab vibration were proposed and analysed the effect of these factors on the floor impact sound. The influence of these factors on the floor impact sound is analysed using by numerical analysis. In addition, the reliability of analysis results was analysed comparing with full-scale mock-up test.

The design factor, thickness of slab, is major factor on the floor impact sound and the floor impact sound was reduced when the slab thickness was increased. However, floor impact sound increases when increasing construction factor.

In future work, the floor impact will be analysed with more parameter such as the thickness or position of wall.

5. ACKNOWLEDGEMENTS

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