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# Analysis of Heavy-weight Floor Impact Noise and Vibration of Concrete Slabs in a Residential Building

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## ABSTRACT

Heavy-weight floor impact noise is a structure-borne noise which is mainly caused by vibration of concrete slabs in residential buildings. The majority of previous studies in South Korea have focused on investigating performance of resilient materials on the reduction of the floor impact noise. However, since the heavy-weight floor impact noise is caused by vibration of slabs, the characteristics of slab vibration are needed to be studied in order to fundamentally reduce floor impact noise. In the present study, as a part of such studies, correlation between floor impact noise and vibration of concrete slabs was investigated by performing tests on floor slabs in an actual multi-story residential building. On the basis of the results, a numerical analysis model for predicting heavy-weight floor impact noises was proposed.

## 1. Introduction

In Korea, many people live in multi-story apartment buildings. Floor impact noise frequently causes disputes between the residences, which rise as an important issue in the society. Generally, the structure of such apartment buildings is wall-slab system, where walls replace columns and a room is enclosed by the walls and slab. The main problem of floor impact noise is heavy-weight floor impact sound which is mainly caused by children's jumping or walking.
According to Canada NRC research report (2010), heavy-weight floor impact sound is mainly influenced by structure system type, thickness of slab, mass density and

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boundary condition. The parameters are the properties of the structure, which indicates that heavy-weight floor impact sound is caused by the slab vibration. Thus, it is difficult to reduce the noise level only by using resilient floor finishing materials.

Thus, studies on structural and acoustic properties of a system together are required to find exact causes of the heavy-weight floor impact noise and to predict the level of the noise. Chung (2008) studied correlation between slab vibration modes and floor impact sound level. Mun (2014) proposed a prediction method of concrete slab acceleration and floor impact noise by using frequency response function. (Chung et al. 2008 and Mun et al. 2014)

In this study, a test for floor impact sound and vibration in a multi-story residential building was performed. In multiple stories with an identical floor plan, variations of the sound pressure level according to story level were investigated. Further, numerical analysis was performed to predict the sound pressure level. The results were compared with the test results.

## 2. Test Program

### *2.1. Experiment Site*

The experiment site was a 27-story residential building under construction, which is located at Chunan-si, Korea. Six story floors-from 8th story to 13th story-were selected for the test. The main structural system of this building is bearing wall- slab system and the thickness of the floor slab is 210 mm without any floor finishing materials. The six story floors have an identical floor plan (the floor area = $84\mathrm{m}^2$) as shown in **Figure 1**.

### *2.2. Measurement Plan*

At each story, the floor impact sound pressure and slab vibration were measured at the same time. An impact ball was used as a standard heavy impact source, which is certificated in ISO 140. The measurement of floor impact sound pressure level followed KS F 2810-2 code (Korean Industrial Standard). The location of five impact points and four receiving points are shown in **Figure 2**. In addition, modal test was performed using the same impact and receiving points. The purpose of the modal test is to get acceleration and sound pressure frequency response function (FRF) which represents the structural and acoustic properties of each story floor.

### *2.3. Assessment Plan*

The assessment of floor impact sound pressure level followed KS F 2863 code. When an impact load was applied at the *k*-th impact point ($L_{Fmax,k}$), the average sound pressure level of the receiving points was evaluated by an energy average method.

$$\mathrm{L_{Fmax,k}}=10\log_{10}\left(\frac{1}{\mathrm{m}}\sum_{\mathrm{j=1}}^{\mathrm{m}} 10^{\mathrm{L_{Fmax,j}/10}}\right) \quad (1)$$

Then, the average level of impact points ($L_{i,fmax}$) at each frequency was evaluated by the linear average method.

$$\mathrm{L_{i,fmax}}=\frac{1}{\mathrm{n}}\sum_{\mathrm{k=1}}^{\mathrm{n}} \mathrm{L_{Fmax,k}} \quad (2)$$

The final value ($L_{i,fmax,AW}$) , which is called as Single Number Quantity (SNQ), was evaluated by the inverse-A curve provided by KS F 2863 code, which is a single representative value of impact sound pressure level.

Current KS specified 1/3 or 1/1 octave center frequency analysis method to evaluate floor impact sound pressure level. However, this method does not precisely represent the frequencies at which peak level occurs and the acoustic property. Thus, acceleration FRF and acoustic FRF analysis was additionally performed to evaluate the test results.

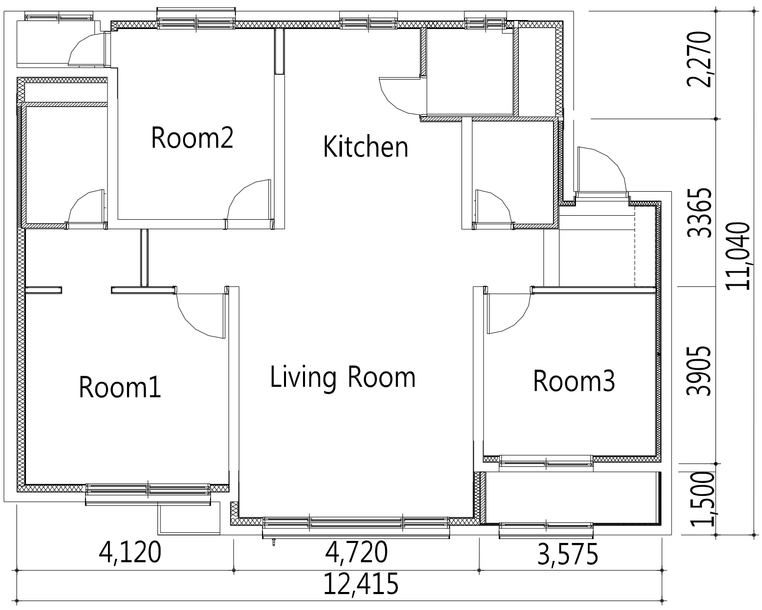


**Figure 1** Floor plan for acoustic experiment (unit: mm)

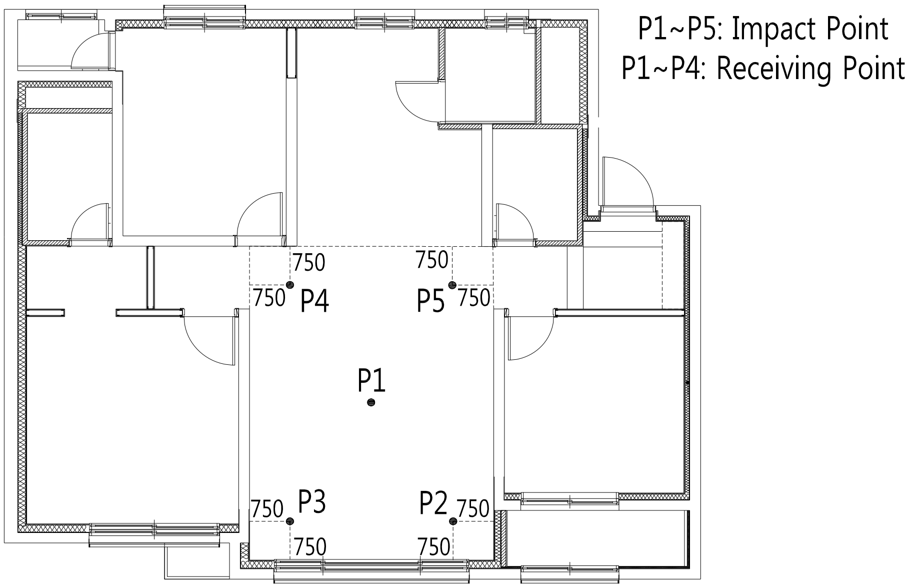


**Figure 2** Locations of impact points and receiving points

# 3. Test Results

## *3.1. Floor Impact Sound Pressure*

The results of floor impact sound level and SNQ are shown in **Figure 3** and **Table 1**. In the six story floors, the difference in the floor impact sound level at 1/3 octave center frequency was about 2-3dB and the difference in the SNQ level was maximum 2dB. **Figure 4** shows the acoustic FRF (i.e. sound pressure level per unit impact force) in the 11th story. The main peak responses occurred in low frequencies of 16 Hz, 26 Hz, 35 Hz, 38 Hz, 65 Hz, and so on. The results were compared with the acoustic modes. The result showed that except for the cases of 26 Hz and 38 Hz, the majority of the peak acoustic response correlated with the acoustic modes which make stationary waves (i.e. waves in a medium in which each point on the axis of the wave has an associated constant amplitude) in a closed space.

## *3.2. Floor Impact Vibration*

The variation of acceleration responses according to different stories is shown in **Figure 5**. In the six story floors, the first natural frequencies ranged from 26 Hz to 32 Hz, and the frequencies at the lower levels were greater except for the 11th story. Because all stories have an identical floor plan, it indicates that material properties such as concrete strength, mass density or construction tolerance such as thickness of slab can be influence factors.

The acceleration FRF and acoustic FRF corresponding to the center impact point (P1) were compared in **Figure 6**. The result showed that the first, second and third vibration modes directly influenced the amplification of the sound pressure level.

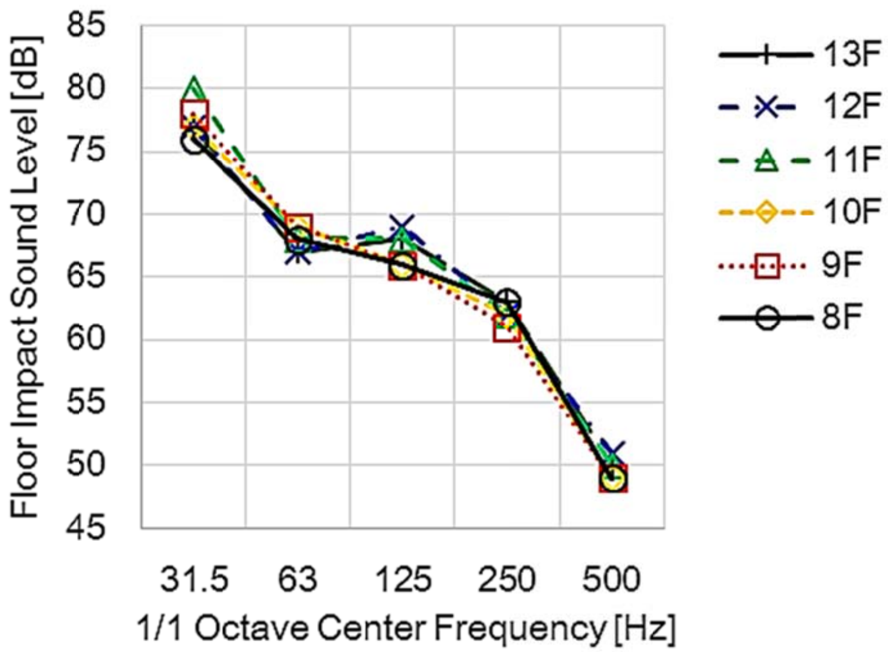


**Figure 3** Floor impact sound level ($L_{i,Fmax}$) at 1/1 octave center frequencies

**Table 1** Floor impact sound level ($L_{i,Fmax}$) and SNQ ($L_{i,Fmax,AW}$)

| Frequency (Hz) | Maximum Level (dB) | Minimum Level (dB) | Average Level (dB) | Maximum Difference (dB) |
|---|---|---|---|---|
| 31.5 | 80 | 76 | 78 | 4 |
| 63 | 69 | 67 | 68 | 2 |
| 125 | 69 | 66 | 67 | 3 |
| 250 | 63 | 61 | 62 | 2 |
| 500 | 54 | 49 | 50 | 2 |
| SNQ | 53 | 51 | 52 | 2 |

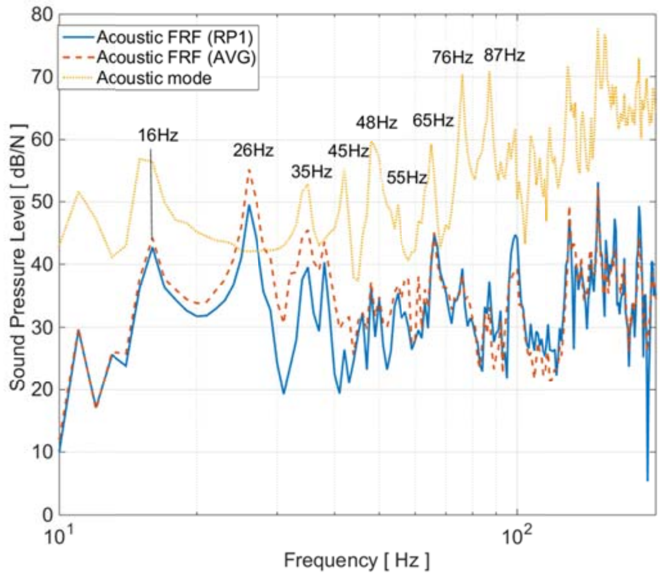


**Figure 4** Acoustic frequency response function

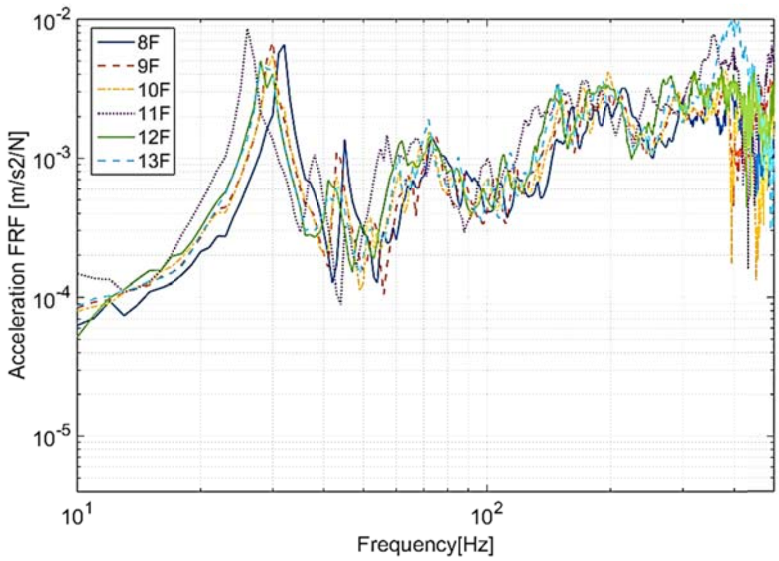


**Figure 5** Acceleration frequency response function of slab vibration

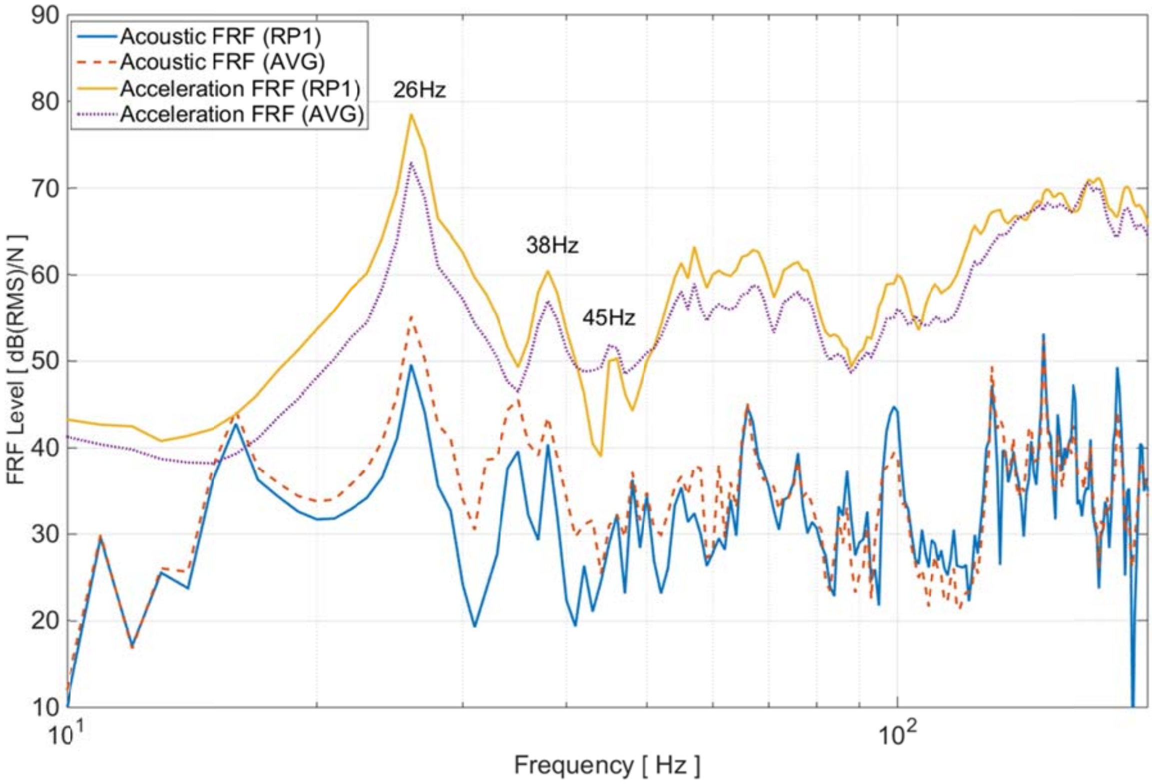


**Figure 6** Comparisons of acceleration and acoustic FRF at P1

## 4. Numerical Analysis

### *4.1. FE Modeling Process*

For finite element analysis, modeling of structural and acoustic response was performed. **Figure 7** shows the structural and acoustic models. In the numerical analysis, first, acceleration response of a floor slab was calculated by using modal superposition and the surface normal velocity was calculated from the acceleration response. Then, sound pressure level in the acoustic field was calculated from the velocity considering the boundary condition.

For structural and acoustic properties, the modal damping ratio and acoustic panel impedance of the slabs was assumed to be 3-4 % and 80000 kg/$m^2$/s, respectively. The mass density and elastic modulus of the concrete were assumed to be 2400 kg/$m^2$ and 23 GPa.

### *4.2. Results*

In Figure 8, the acceleration responses by numerical analysis are compared with the test results. **Figure 9** compares the acoustic responses. In **Figure 8**, the acceleration responses predicted by numerical analysis agreed with the test results particularly at low frequencies less than 100 Hz. The acceleration responses correlated with the acoustic responses. This result indicates that the structural response should be accurately predicted to predict the heavy-weight impact sound pressure level.

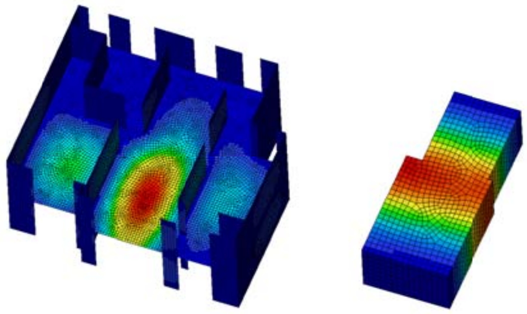

**Figure 7** Structural and Acoustic FE models

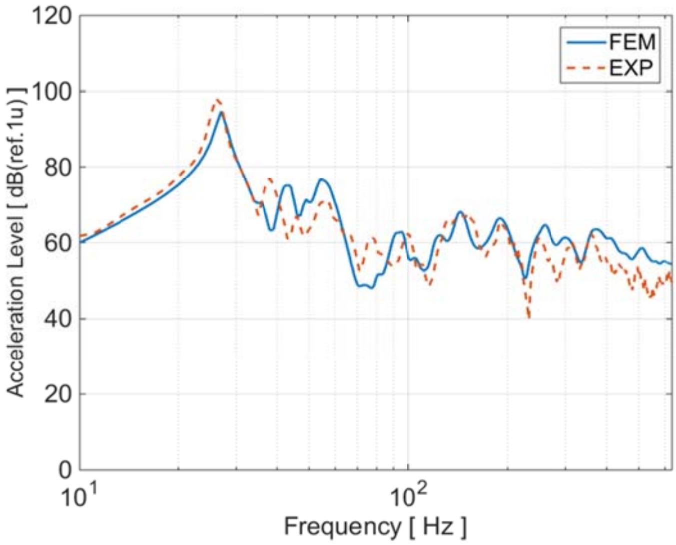


**Figure 8** Numerical analysis and experimental results on acceleration response

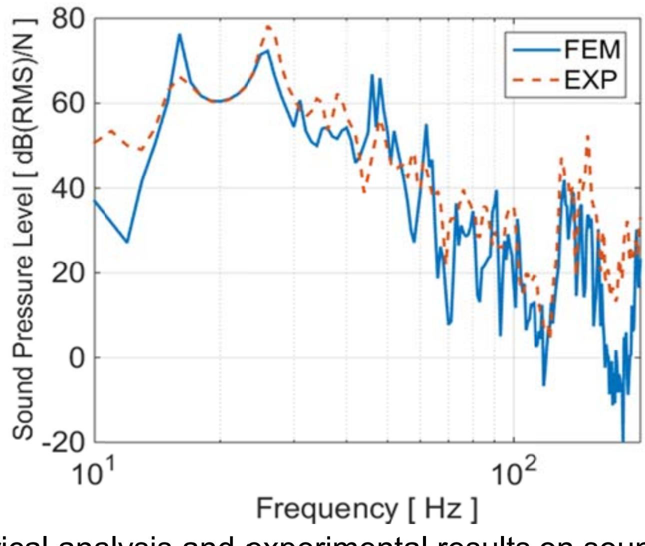


**Figure 9** Numerical analysis and experimental results on sound pressure level

## 5. Conclusions

In this study, heavy-weight floor impact noise and vibration at six story floors in a building were measured and the correlation between the structural and acoustic responses was analyzed. The major findings are summarized as follows.

1. Although the floors had an identical floor plan, the floor impact noise and vibration were different at the slabs. This result indicates that the actual concrete strength, mass density and thickness of the slabs significantly affected the floor impact noise and vibration.
2. The sound pressure level was more influenced by the acoustic modes than the vibration modes. However, the main vibration modes at low frequencies directly affected the peak acoustic response.
3. The proposed numerical analysis method successfully predicted the impact sound level at low frequencies below 100 Hz. The result showed that to accurately predict the impact sound level, first, the acceleration response of the slabs should be accurately predicted.

**ACKNOWLEGMENTS**

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