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# Vibrational characteristics of floating floor slab in residential buildings

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## ABSTRACT

In this paper vibrational features of floating floor slab is presented. Vibration magnitude of concrete slab at certain low frequency component is amplified when standard heavy-weight impact is applied. Amplified vibration causes amplification of impact noise. Measured data and theoretical model were analyzed to explain this phenomenon of floating floor. According to theoretical model, stiffness ratio between mortar plate, resilient material and concrete slab is a main factor determining floating floor vibration. Based on this study, advanced numerical modeling for predicting floor vibration can be developed.

## 1. INTRODUCTION

Most of apartment floors adopt floating floor system consists of concrete slab, resilient material, and mortar plate. This floor system effectively reduce noise and vibration of high frequency components. But, according to several studies, amplification of noise and vibration occur at relatively low frequency range. This means floating floor can make worse condition when heavy-weight impact mostly composed of low frequency components is applied. In this study, vibrational features of floating floor were analyzed from measurements and theoretical models.

## 2. MEASUREMENTS

### *2.1 Measurement plan*

Fig. 1 shows measurements made on two floor systems to verify the effect of resilient material to the concrete slab vibration.

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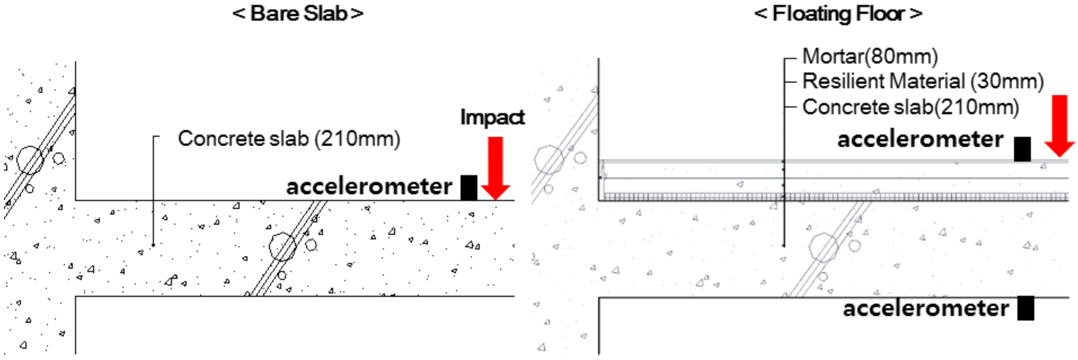



Fig. 1 Vibration measurement of two floor systems

An accelerometer was installed at the center of the bare slab. Two accelerometers were installed on floating floor system to measure mortar plate and concrete slab vibration .Vibrational features of floating floor can be found from a comparison between bare slab vibration and floating floor vibration.

*2.2 Measurement results*

Fig. 2 shows the responses of slab vibration excited by a rubber ball (standard impact source) in frequency domain.

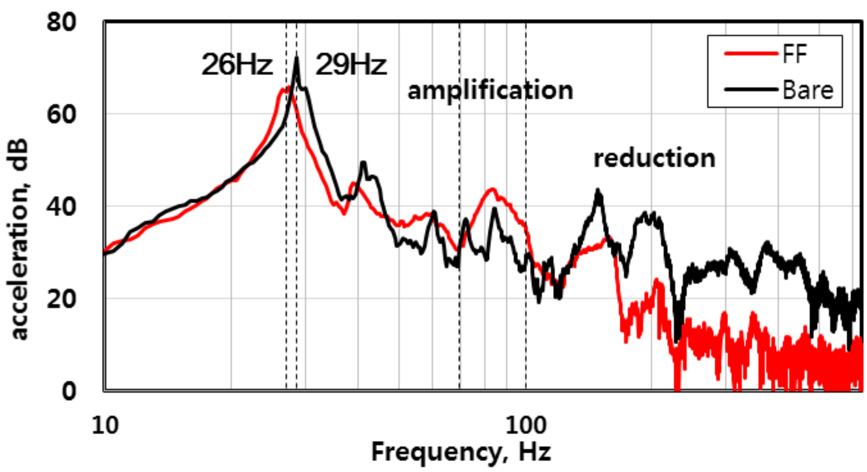



Fig. 2 Slab acceleration of bare slab and floating floor

From the results, three differences between bare slab and floating floor can be found.

*(1) Change of natural frequency*

Mun (2013) has shown natural frequency reduction of 1st mode caused by resilient material. Same phenomenon occurred in the test. Natural frequency of 1st mode decreased from 29Hz to 26Hz due to change of floor system. Also, another peak about 80Hz of floating floor can be observed due to the floating floor system.

*(2) Amplification of vibration*

Acceleration amplification occurred around 60-100Hz. This is an opposite phenomenon considering the purpose of floating floor. Amplified acceleration directly cause amplification of sound pressure.

*(3) Reduction of vibration*

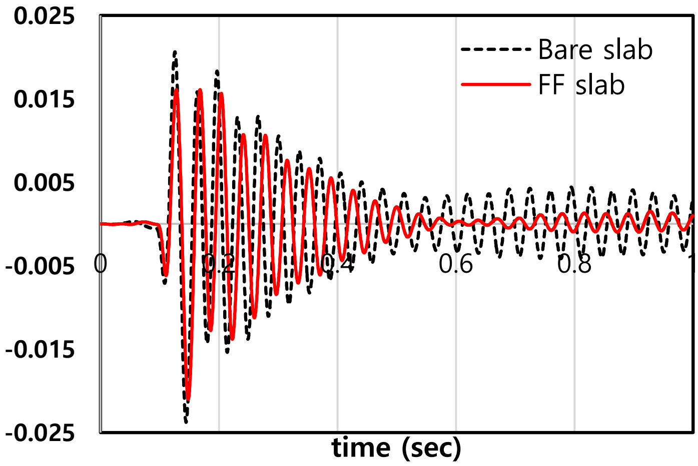
In higher frequency range above 100Hz, substantial decrease of slab acceleration is observed. This means floating floor system effectively decrease the sound pressure in high frequency range.

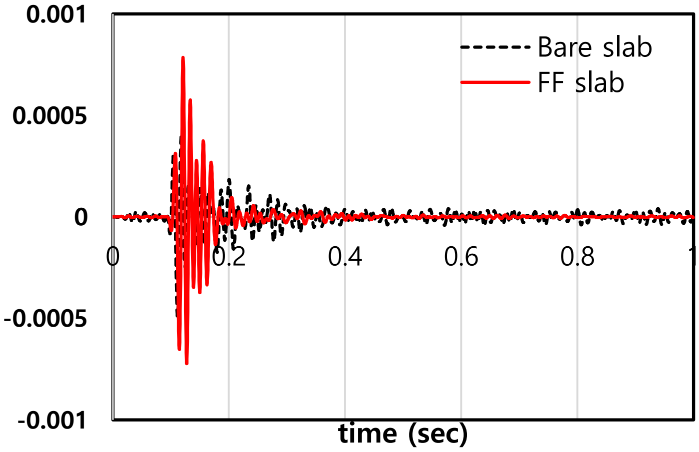
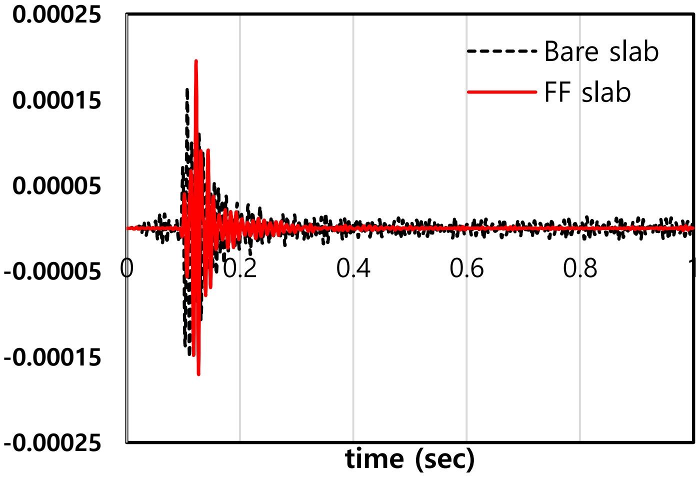
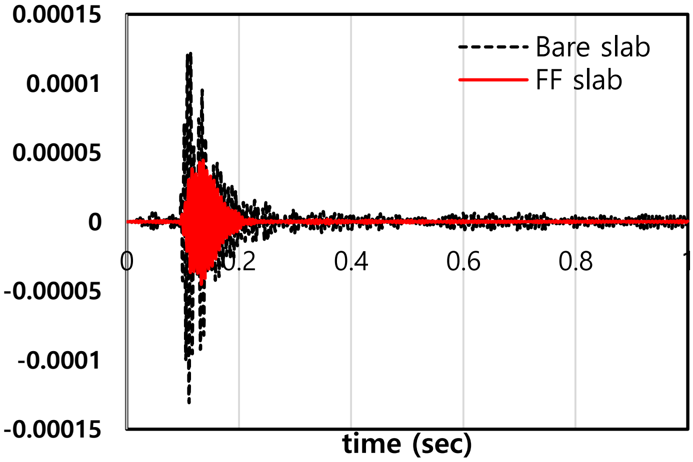
*2.3 Analysis*

Vibrational features observed in frequency domain also can be found in time domain. By using bandpass filter, time domain acceleration data containing all frequency components can be divided into several data composed of certain frequencies of interest. Finally, velocity and displacement data can be obtained from numerical integration of filtered data.

Table 1. Shows the slab displacement of certain frequency range. Overall magnitude is keep decreasing as frequency range increases corresponding to the slab response in frequency domain of Fig. 2.

Table. 1 Filtered slab displacement of bare slab and floating floor

| **Measured data (displacement – time relation)** | **Frequency range (Hz)** | **Max displ _bare (mm)** | **Max displ _ff (mm)** | **ratio** |
|---|---|---|---|---|
|   | 10-60 | 0.024 | 0.021 | 0.88 |

| | | | | |
|---|---|---|---|---|
|  | 60-100 | 4.88 x $10^{-4}$ | 7.86 x $10^{-4}$ | 1.61 |
|  | 100-150 | 1.64 x $10^{-4}$ | 1.95 x $10^{-4}$ | 1.19 |
|  | 150-200 | 1.31 x $10^{-4}$ | 0.45 x $10^{-4}$ | 0.34 |
| **Error increase** | 200 | - | - | - |

In frequency range of 10-60Hz, magnitude of displacements before 0.5 seconds are almost same. After that, the difference increases but it is not a critical factor affecting floor impact noise. In frequency of 60-100Hz, vibration amplification of floating floor is observed. Maximum displacement of floating floor is equal to 161% of maximum displacement of bare slab. Maybe this is caused by interaction between resilient material and concrete slab because the vibration of mortar plate affect concrete slab vibration through resilient material. Also, in frequency range of 100-150Hz, same phenomenon occur but amplification ratio is less than that of 60-100Hz range. In higher frequencies, vibration reduction of floating floor is observed which can reduce the floor impact sound of that frequency range. When frequency range is higher than 200Hz, the magnitude of displacement is very small, which rarely affects overall vibration and hard to get exact value due to relatively large noises (errors)

## 3. THEORETICAL MODEL

Simple theoretical models were suggested to establish the cause of measured results of bare slab and floating floor. Fig. 3 shows the basic concept of these models.

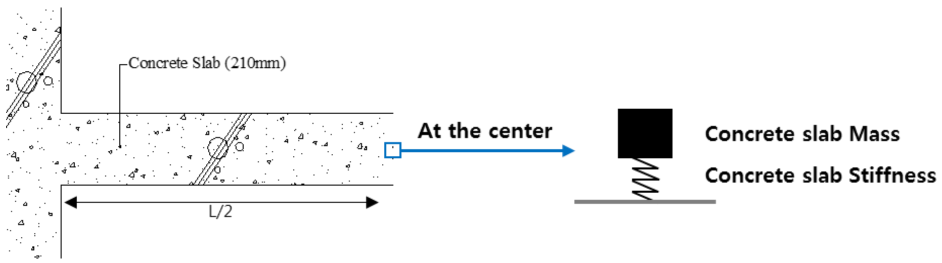



Fig. 3 Simplified model of slab vibration

### *3.1 Modeling*

Floor systems are basically multi degree of freedom (MDOF) system. But as shown in Fig. 3, vibration of a certain point can be expressed as sum of single degree of freedom (SDOF) system. From this simplified SDOF model, measured data were analyzed theoretically.

Displacement of MDOF system can be expressed as Eq. (1).

$$u(x,t) = \phi(x)z(t) \tag{1}$$

At the slab center, Eq. (1) becomes,

$$u(\frac{L}{2},t) = \phi(\frac{L}{2})z(t) = \phi_1(\frac{L}{2})z_1(t) + \phi_2(\frac{L}{2})z_2(t) + \phi_3(\frac{L}{2})z_3(t) + \dots \tag{2}$$

Where L is span of concrete slab. Each term of Eq. (2) can be regarded as a SDOF system with different natural frequency.

*(1) Bare slab*

Bare slab system can be simplified as sum of SDOF system. Where natural frequency of each mode is Eq. (3). Each natural frequency is determined by the ratio of stiffness and mass.

$$Wi = \sqrt{\frac{k_i}{m_i}} \tag{3}$$

*(2) Floating floor*

Modeling of Floating floor is more complicated than bare slab modeling because the model should contain properties of resilient material and mortar plate. Table. 2 Shows assumptions made in floating floor modeling.

Table. 2 Assumptions in floating floor modeling

| Assumptions | Reasons |
|---|---|
| Mass of resilient material is neglected | Mass of resilient material is very small comparing to the mass of concrete slab or mortar plate. |
| Resilient material can be modeled as a spring. | |
| Stiffness of resilient material spring is zero when spring is in tensile stress state. | Resilient material is only resting on the concrete slab. |

Fig. 4 shows the modeling of floating floor based on these assumptions.

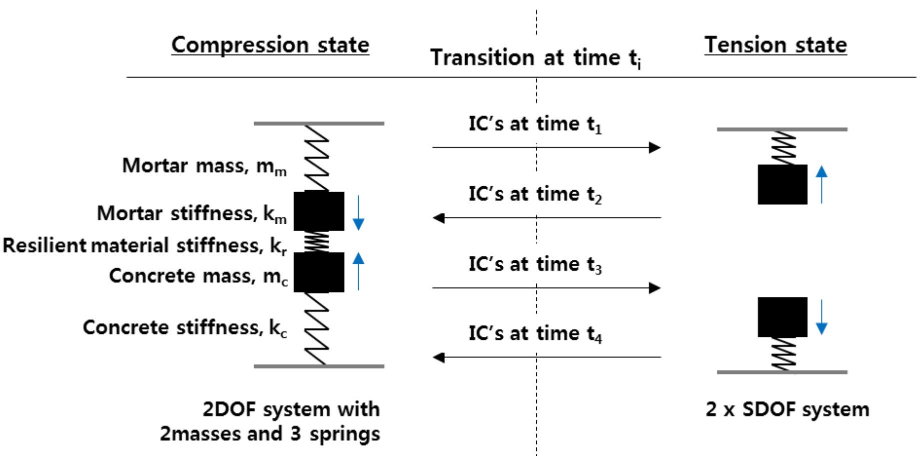



Fig. 4 Simplified model for floating floor vibration

When load is applied to the mortar, resilient material is in compression state. The system can be modeled as 2DOF system with 2 masses and 3 springs. After that, resilient material spring is in tension state due to differential vibration of mortar plate and concrete slab. The stiffness of resilient material is zero in this state. Therefore, floating floor system can be modeled as 2 independent SDOF system. Inverse transition occur by the same reason. And these transitions are repeated. Eq. (4) shows natural frequencies of the 2DOF system where $w_c$: natural frequency of concrete slab, $w_m$: natural frequency of mortar plate. Natural frequency is determined by ratio between mass and stiffness or stiffness values.

$$w_c^2, w_m^2 = \frac{1}{2}\{\frac{(k_c+k_r)\mathrm{m}_m+(k_r+k_m)\mathrm{m}_c}{m_c m_m}\} \mp [\{\frac{(k_c+k_r)\mathrm{m}_m+(k_r+k_m)\mathrm{m}_c}{m_c m_m}\}^2 - 4\{\frac{(k_c+k_r)(k_r+k_m)-k_r^2}{m_c m_m}\}]^{1/2} \quad (4)$$

### *3.2 Theoretical model analysis*

Based on the floor system models in 3.1, two phenomena of floating floor system – amplification and reduction of vibration in different frequency range – can be explained.

Floating floor slab vibration is affected by 2 factors listed below.

*(1) Amplification of vibration*

When same force is applied to bare slab and floating floor, displacement relation is obtained from theoretical model. Eq. (5) and (6) shows the relation.

$$x_{bare\_slab} = (1+\frac{k_m}{k_r}+\frac{k_m}{k_c})x_{ff\_slab} \quad (5)$$

$$x_{ff\_mortar} = (\frac{k_c+k_r}{k_r})x_{ff\_slab} \quad (6)$$

Where, $k_m$ : mortar plate stiffness, $k_r$ : resilient material stiffness, $k_c$ : concrete slab stiffness, $x_{bare\_slab}$ : bare slab displacement at the center ,$x_{ff\_slab}$ : floating floor slab displacement at the center and $x_{ff\_mortar}$ : floating floor mortar plate displacement at the center. The displacement of Eq. (5) and (6) means initial condition of concrete slab of each floor system. Displacement is determined by ratio of stiffness. And stiffness ratio can be obtained from initial displacement of measured data at certain frequency range. Table. 3 shows the stiffness ratio obtained from measured data. At low frequency range, flexural movement of slab and mortar plate are expected ($k_c$, $k_m$ < $k_r$). On the other hand, at high frequency range, axial vibration of resilient material is expected ($k_c$, $k_m$ > $k_r$).

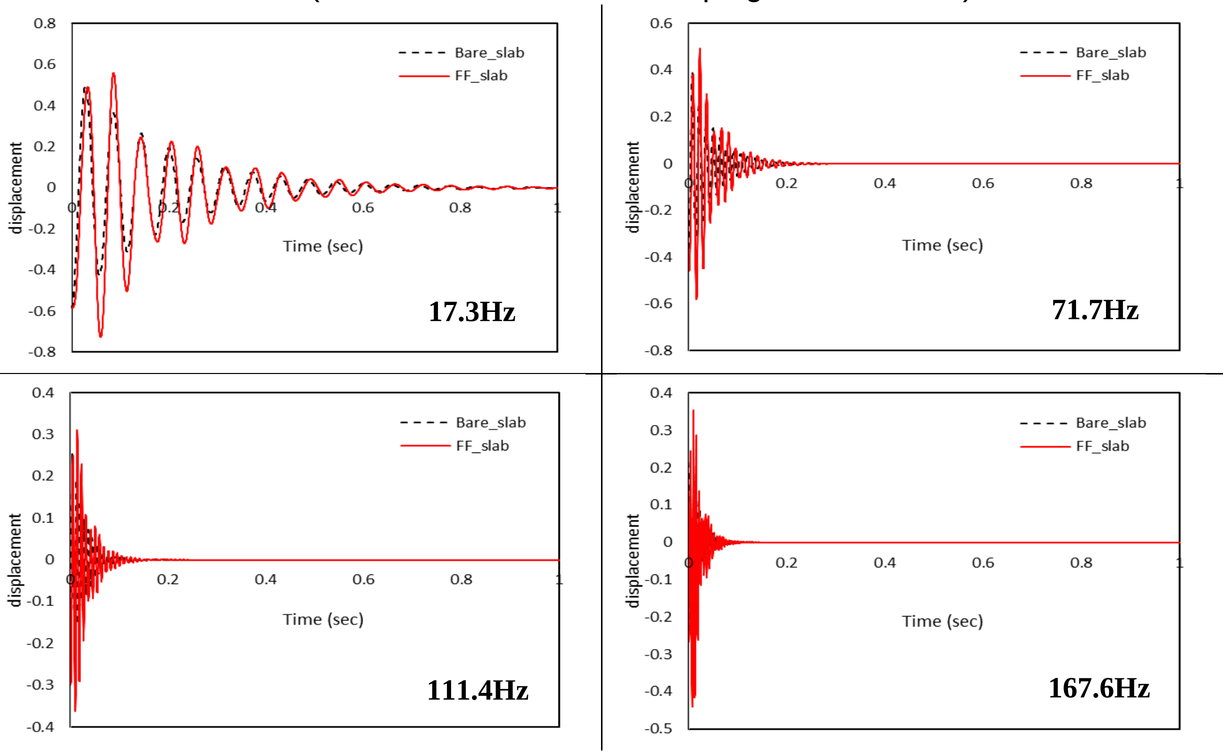
Table. 3 Stiffness ratio from measured data

| Frequency (Hz) | Initial displacement (mm) | | | $k_c/k_r$ | $k_m/k_r$ |
|---|---|---|---|---|---|
| | Bare slab | Floating floor mortar plate | Floating floor slab | | |
| 10-60 | $-7.12 \times 10^{-3}$ | $-4.43 \times 10^{-3}$ | $-6.21 \times 10^{-3}$ | 0.71 | 0.48 |

| | | | | | |
|---|---|---|---|---|---|
| 60-100 | $-8.34\times10^{-5}$ | $-8.70\times10^{-5}$ | $-6.74\times10^{-5}$ | 1.19 | 0.67 |
| 100-150 | $-1.56\times10^{-5}$ | $-2.36\times10^{-5}$ | $-1.00\times10^{-5}$ | 2.36 | 1.10 |
| 150-200 | $-5.61\times10^{-6}$ | $-4.37\times10^{-6}$ | $-1.60\times10^{-6}$ | 2.75 | 2.57 |

Fig. 5 shows the results of bare slab and floating floor slab vibration applying stiffness ratio from Table. 3. Same displacement of bare slab and floating floor slab is assumed to check the amplification of displacement.

Fig.5 Displacement of bare slab and floating floor slab from theoretical model (Same initial condition, damping ratio, $\xi$ = 5%)




At low frequency, slight amplification occur. Amplification is increasing as frequency increases while absolute magnitude is decreasing due to the stiffness ratio increase. As mentioned before, same initial displacement and zero initial velocity was assumed in the theoretical model. Although this assumption make difference between measured data and theoretical results, still the amplification can be described from theoretical model. Amplification would be larger if initial velocity of floating floor slab are applied in the model as in the real case.

*(2) Reduction of vibration*

In measured data, vibration reduction is observed as frequency increases (Table. 3).

This phenomenon is due to the initial condition (displacement) change. As frequency increases, $k_c$ and $k_m$ increase comparing to $k_r$. It results in reduction of initial displacement, $x_{ff\_slab}$, which can be simply explained from Eq. (5) and Eq. (6). Even though amplification of floating floor slab occurs, larger reduction of initial condition cause vibration reduction. Consequently, both amplification and reduction occur at the same time in every frequency range. But in low frequency range, amplification affects more. In high frequency range, reduction due to initial condition is dominant.

## 5. CONCLUSION

In floating floor system, slab vibration amplification in lower frequency range (60-100Hz) and reduction in high frequency range (over 100Hz) is observed. Simplified theoretical model of floating floor contained compression spring with no tension stiffness to describe actual floor system. According to the theoretical model, slab vibration of floating floor is affected by 2 factors. And both factors are determined by stiffness ratio between, $k_c$, $k_r$, and $k_m$ which changes along with frequency change.

## REFERENCES

Mun, D.H. and Park, H.G. (2013), "A study on heavy-weight impact noise amplification in a floating floor structure", Proceedings of KSMI congress, Kang-won.

Mun, D.H., Park, H.G. and Hwang, J.S. (2014), "Prediction of Concrete Slab Acceleration and Floor Impact Noise Using Frequency Response Function", Korean Soc. Noise & Vib. Eng., **24**(6), 483-492.