The objective and subjective evaluation of heavy-weight floor impact noise in box frame-type structures

Yoon Joon LEE [1]; Yeong JEONG [2]

[1] Korea University, Korea

[2] Research center for sustainable building design & construction, Korea

ABSTRACT

Low frequency heavy-weight impact sound is the most irritating noise in Korean high-rise load bearing wall system reinforced concrete apartment buildings. In order to control low frequency heavy-weight impact noise, floating floors using damping materials or isolation materials such as glass-wool mat and poly-urethane mat and ceiling, wall insulation material were applied. The effect of damping materials and impact isolators were compared in on-site experiment conducted in a high-rise apartment building. In addition, reinforcement of concrete slab using plate was analyzed, using the FEM on the heavy-weight impact vibration acceleration. It was found that one influential factor in floor impact noise transmission is the thickness of the concrete slab. The objective and subjective evaluation of different sound insulation treatments, and acoustical characteristics of these sounds were clarified by using the factors extracted from the autocorrelation and inter-aural cross-correlation functions.

Keywords: Finite element model, Box frame-type structures, Heavy-weight impact noise, floating floors

1. INTRODUCTION

The floor impact noise in the apartment buildings has recently become a very big issue in Korea, therefore, regulations for limiting the noise level will be enforced to all new apartments approved after July, 2005. Low-frequency, heavy weight impact noise is the most common irritating noise in reinforced concrete apartment hi-rises in Korea. It is customary not to wear shoes in Korean homes, as this is a common source of low-frequency noise. Energetic children running and jumping are another source. Many tenants who live in high-rise apartment buildings complain about heavy-weight impact sound and noise from the above floor.

Most Korean apartments were built with a concrete structural system reinforced by load-bearing walls. This system does not require columns and beams, and can reduce effectively the vertical distance between floors. In most concrete slab structures, elastic surface layer, floating floor, high-stiffness method and double ceiling methods are used to reduce floor impact sounds. Heavy weight impact noise is the most common irritating noise in reinforced concrete apartment hi-rises in Korea. It is customary not to wear shoes in Korean homes, as this is a common source of low-frequency noise [1] [2]. Energetic children running and jumping are another source. Many tenants who live in high-rise apartment buildings complain about heavy-weight impact sound and noise from the above floor [3].

2. FINITE ELEMENT ANALYSIS

The structural finite element model (FEM) was built with ANSYS software using shell 8mode element with 6 degrees of freedom (3 translational and 3 rotational along x, y, z) at each node for the slab of the standard test facility. The material properties had a modulus of elasticity of 2200MPa, a density of 2400kg/m^3, and a Poisson's ratio of 0.167. The model has two boundary conditions according to the shape of the structure between the floor and wall. One condition is an all free condition and the other is an all

[1] yoonjoonlee@korea.ac.kr

[2] jysarang@hanyang.ac.kr

fixed condition in which 6 rotational and traditional degree of freedom was fixed. (see Figure 1)

The natural frequencies and mode shapes calculated by FEM are given in Table 1. Table 2 shows that the nature Natural frequency increased according to change of thickness of each slab, and acceleration value decreased. The frequencies from the first mode by analytical modal analysis corresponded well with the experimental vibration with an error of less than 20% as shown in Table 3.

Therefore, in order to reduce the noise level below 100Hz, the structural shape of the living room should be modified. If we consider the importance of the low frequency characteristics by the heavy-weight impact source, it is effective to increase the fundamental natural frequency of the slab.

The general slab thickness and strength is usually 150mm~210mm and 210kgf/cm^2 in the reinforced concrete structures. The natural frequencies increase 10~15% per 30mm in the thickness.

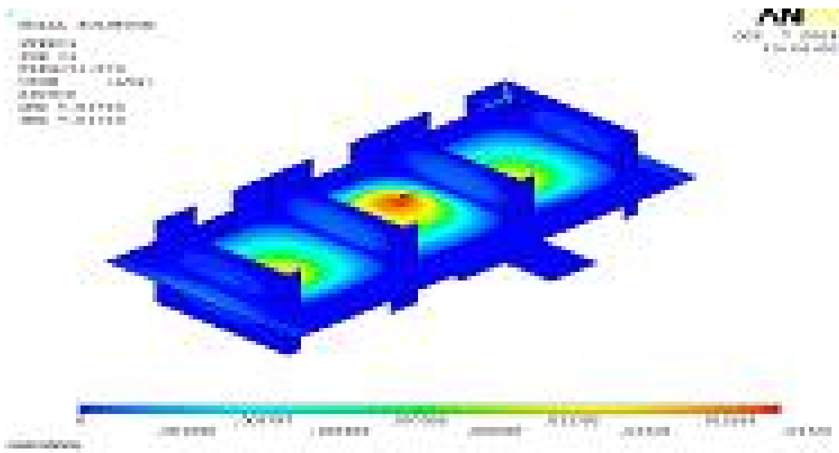

Fig 1- ANSYS modeling

Table 1- Natural frequency by bang machine

Thickness(mm)	Poisson 0.185, dens 2.4E^3, ex 2.6954E^{10}		
	1st	2nd	3rd
150	**32**	**33**	**34**
180	**37**	**38**	**40**
210	**42**	**43**	**46**
240	**46**	**48**	**51**

Table 2- Natural frequency and Acceleration of typical floor thickness with FEM

Thickness (mm)	Natural frequency	Acceleration	Acceleration level
	1st [Hz]	[m/s2]	[dB]
150	**32**	**0.71**	**97**
180	**37**	**0.44**	**94**
210	**42**	**0.37**	**91**
240	**46**	**0.30**	**89**

Table 3- Comparison of natural frequencies between experiment and FEM

Thickness(mm)	Experiment[Hz]	Analysis[Hz]	Error (%)
150	**33**	**32**	**4**
180	**38**	**37**	**3**
210	**35**	**42**	**16**
240	**38**	**46**	**17**

3. VIBRATION CHARACTERISTICS OF FLOOR IMPACT NOISE IN BOX FRAME-TYPE STRUCTURE BUILDINGS

In this chapter study, the radiation characteristics of the floor impact sound in a standard test building, which is constructed for application and evaluation of the reduction structure for floor impact sound, were investigated using a vibro-acoustic analysis.

3.1 Measurements from Standard Test Facility

The standard test building was constructed for shortening the developing period of the reduction structure and standardization of the test facilities. This building reflects the construction situation of a real apartment for practical purposes. It employs a box frame-type structural system. In this study, the field measurement and the computational analysis of the two center rooms, which have 180 mm and 240 mm slab thicknesses.

The field measurements were conducted to verify the vibro-acoustic analysis model. The dynamic characteristics of each slab structure, natural frequency and mode shape, were measured using the modal test. The test based on the fixed excitation method was conducted using an impact hammer (Dytran 5803A) and accelerometers (Endevco 751-10). The Frequency Response Functions (FRF) was acquired from the transducers. Measurements were taken at a total of 120 points at intervals of the 50 cm, 12 points along the horizontal axis and 10 points along the vertical axis.

Table 4 - The single number rating value of the two measured rooms

Slab thickness	Impact SPL [dB]				
	63 Hz	125 Hz	250 Hz	500 Hz	$L_{i, Fmax, AW}$
180 mm	75	67	64	52	**53**
240 mm	65	64	54	50	**47**

To measure the sound transmission characteristics and to verify the acoustic analysis model, SPL distribution was measured in the receiving room. During the standard heavy weight impact source, bang machine (Satsuki Kizai Co.), excited the center point of the slab. On the grid surface of 1.2m height in the receiving room, the impact sound pressure level was measured. The single number rating values ($L_{i,Fmax,AW}$) of each slab are evaluated from the 5 points and SPL distribution contours of each room are shown in Table 4, Figure 2.

The variation of impact SPL in the receiving room had a maximum of 15.5dB at 63 Hz for the 240 mm thick slab and a minimum of 11.3dB at 125Hz for the 180mm thick slab. From the result, distribution shape of impact SPL in each frequency band was almost identical. This showed the effect of the room-mode caused by the rectangular shape of the room. The large SPL at the corner of the wall at low frequency reflected the characteristics of the structure-borne sound, generated by the wall vibration at low frequency bands.

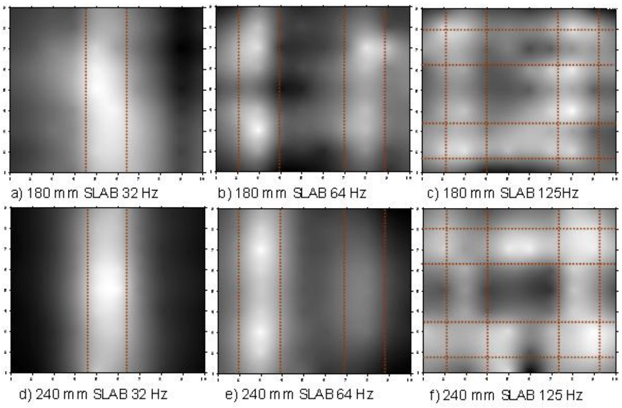

Figure 2 - Distribution contour of impact SPL driven by the center position

4. SUBJECTIVE EVALUATION OF HEAVY-WEIGHT FLOOR IMPACT SOUND

To investigate the relationship between the objective parameters such as sound pressure level and the subjective evaluation of the heavyweight impact noise, subjective tests were conducted. First, binaural measurements of the floor impact noises produced by the impact ball and bang machine were conducted in apartments with different sound insulation treatments. Then, acoustical characteristics of these sounds were clarified by using the factors extracted from the autocorrelation (ACF) and inter aural cross-correlation functions (IACF). The integration interval was 0.5s and the running step was 0.01s. Primary sensations (loudness, pitch, and timbre) and spatial sensations (source location, spatial impression, and source width) of sounds are described by ACF and IACF factors.

Scale values of annoyance were measured by using the paired-comparison method. For each heavy-weight impact source, eight impact sounds with a wider range of ACF and IACF factors were selected. The signals were binaurally presented using headphones in a testing room. The sound levels were kept constant at 45 and 55dB [$L_{i,Fmax,Aw}$] for both sources. Multiple regression analysis using a linear combination was conducted to calculate the effect of each factor on perceived annoyance. The best combination of variables was found as the mean and the variance of sound energy $\Phi(0)$, the variance of τ_e which is defined by the ten-percentile delay of ACF, and the variance of the magnitude of the inter-aural cross-correlation (IACC). Standardized partial regression coefficients of each variable, a_1, a_2, a_3, and a_4 in Eq. (1) were 0.58, 0.46, –0.36, and –0.30 respectively, and these coefficients were statistically significant ($p < 0.05$).

$$SV_{annoyance} \approx a_1\,\Phi(0) + a_2\,VAR\_\Phi(0) + a_3\,VAR\_\tau_e + a_4\,VAR\_IACC + c \quad (1)$$

As shown in Figure 3, using these tentative values and a constant c = 0.91 in Eq. (1), the total correlation coefficient 0.76 was obtained with a significance level $p < 0.01$. This result shows that the temporal and spatial fluctuation as well as A-weighted sound level and its fluctuation of the impact sound had a major effect on annoyance.

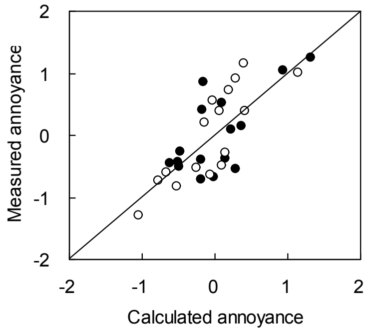

Figure 3 - Relationship between measured and calculated annoyance using linear combination of ACF and IACF factors. ●: Ball; ○: Bang.

5. CONCLUSIONS

In this study, numerical analysis using FEM on the heavy-weight impact vibration acceleration was also carried out. It can be concluded that the influential factor in floor impact sound transmission seems to be the thickness of the concrete slab. However, heavy-weight impact sound can be reduced effectively using damping materials within the concrete slab. In addition, objective and subjective evaluation of different sound insulation treatments, as well as acoustical characteristics of these sounds were clarified by using the factors extracted from the autocorrelation and inter-aural cross-correlation functions.

ACKNOWLEDGEMENTS

This work was supported by grant No. 2014000120008 from the Core Environmental Technology Development Project of the Korea Ministry of Environment.

REFERENCES

1. B. Berglund, P. Hassmen and R.F. S. Job. Sources and Effects of Low-frequency Noise. J Acoust Soc Am. 1995; 99(5):2985-3002.
2. W. Scholl and W. Maysenholder. Impact Sound Insulation of Timber Floor: Interaction between Source, Floor Coverings and Load Bearing Floor. Building Acoustics. 1999;6(1):43-61.
3. L. L. Beranek and I. L. Ver, Noise and vibration control engineerings: Principles and applications, New York, John Wiley & Sons, 1992.