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Effect of modulation on perceived annoyance of floor impact noise

Sinyeob LEE[1]; Dukyoung HWANG[1]; Junhong PARK[1]

[1] Mechanical Engineering, Graduate School of Engineering, Hanyang University

ABSTRACT

Floor impact noise generation depends on the configuration of multistory building structures. In this study the sound radiation mechanisms between the two different structural configuration are compared through experimentation using laboratory setup of the scaled model. The transfer of vibration energy from external impact source is calculated and compared with the measured results. Parameters affecting the radiated sound energy are determined and evaluated. The in and out-of phase vibrations of the building floors resulted in tonal sound radiation at two-closely located frequencies which resulted in modulated floor impact sound. This modulation increased the perceived annoyance of residents. Eventually, a design method to efficiently reduce the floor impact sound is proposed.

Keywords: Floor impact noise, Modulation
I-INCE Classification of Subjects Number(s): 51.3

1. INTRODUCTION

In multi-layered buildings, heavy-weight impact sounds caused by walking, running or jumping are important sources of noise transmission through floors. These sources produce low-frequency noise, and several standard impact sources, such as bang machines and impact balls, have been proposed to evaluate the sound insulation performance of a floor. Generally, noise was evaluated by sound pressure level or loudness. However, these parameters did not fully explain about perceived annoyance for residents. The other factors influences evaluation of the noise. In addition, difference from construction methods to the sound generation mechanism was not fully understood. Because multi-layered residential buildings are being built continuously, noise transmission should be reduced to provide quiet and private residential spaces. The noise generation mechanism of multi-story buildings should be understood in order to propose practical methods of minimizing the floor impact sound transmission. In this study, we analyzed modal characteristics of box-frame structure and evaluate the modulation sound annoyance caused by twin peak.

2. MESUREMENT IN ACTUAL STRUCTURE

2.1 Measurement setup

The modal properties of floors have a significant influence on the radiated sound for heavy-weight sources like an impact ball. To determine the characteristics of floor impact sounds, experiments were performed in a standardized testing room at the Korea Institute of Construction Technology Center. The room has dimensions of $5.1 \times 4.5 \times 2.85$ m, and the floor and side wall thicknesses were 180 mm and 120 mm, respectively. When the upper floor was excited by an impact ball, the resulting vibrations at the upper and lower floors were measured simultaneously using accelerometers (B&K 4507). The sound radiation was measured at the center of the room with a microphone (B&K pressure microphone 4187). The vibration of upper floors was larger since it is directly impacted and the modal cross-terms disappear. The vibration of the lower floor is also significant and contributes to the radiated sound.

[1] parkj@hanyang.ac.kr

2.2 Frequency response

The first natural frequency was measured as 30 Hz. At this resonance, the radiated sound pressure was greatest, and there are two resonance peaks rather than one. These twin peaks are generally observed when impact hammer tests are performed improperly. To further investigate the twin peaks, experimental modal analysis was performed after measuring the vibrations at four evenly spaced locations (1 m apart) on the upper and lower floors using a hammer (B&K Modal Sledge Hammer 8210) excitation at the center of the upper floor.

2.3 Modal test

The mode shapes at each resonance peak were identical for each mode. Their vibrations were out of phase to each other. The two floors moved out-of phase at the lower resonance mode. At the higher resonance mode, the two floors moved in phase. This suggested that the twin resonance peaks were actual physical characteristics of the floor vibration rather than an experimental error from double impacts.

3. MEASUREMENT OF SCALE MODEL

3.1 Measurement setup

The two-layer simple structure were made to understand the change of vibration characteristics. The bakelite was chosen as a material for the specimen for its similarity to the concrete structures. Columns were affixed using epoxy between floors in order to reproduce the actual structural finish. Experiments were performed by impact hammer. And vibration signal was measured at 78 point with accelerometers(ENDEVCO Model 2250A-10). Vibration response and modal characteristic of each point were analyzed after applying load at both ends.

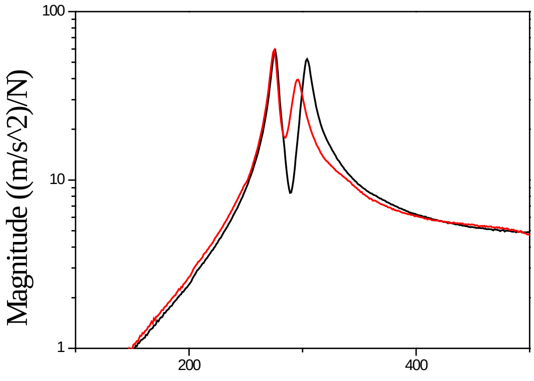
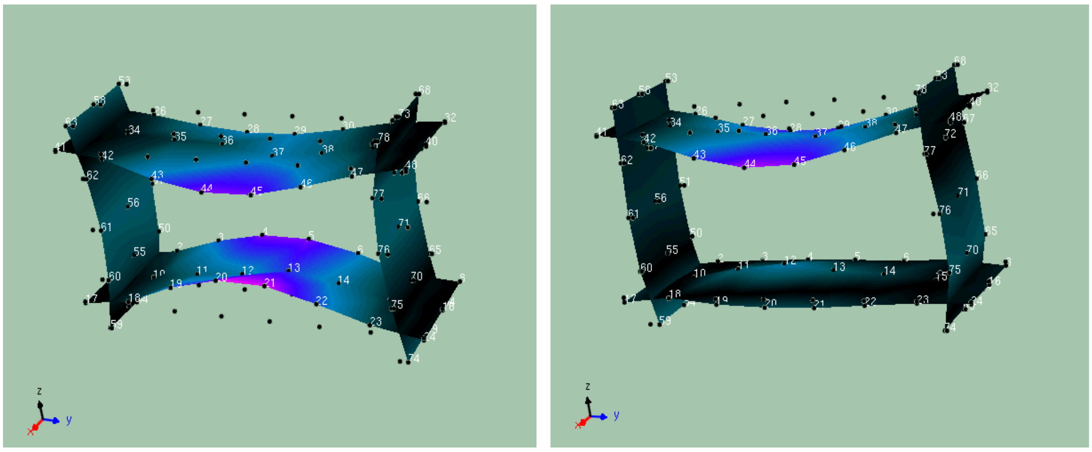


Figure 1. Twin resonance peak clearly shown at first natural frequency region of scale model



(a) (b)

Figure 1. (a) Out-of-phase and (b) in-phase vibration modes of box-frame type construction at each

twin resonance peak

3.2 Compared with actual structure

The first natural frequency was measured as 300Hz. In this region, there are two resonance peaks which are also observed for the actual structure shown in Fig. 2. mode shapes at each resonance peak shows same phenomenon in-phase and out-of-phase modes of floor vibration.

4. EFFECTS OF MODULATION ON THE PERCEIVED ANNOYANCE OF FLOOR IMPACT NOISE

4.1 Impact sound samples for auditory experiments

For the auditory experiments to investigate the effects of the twin modes, sound samples with identical sound levels but different modulation frequencies are required. To simulate the sound generated from the impacted floor, the damped free vibrations from the initial velocity imposed by impact sources were utilized.

4.2 Evaluation of Annoyance using the Paired Comparison Method

Auditory experiments were conducted to evaluate the effect of annoyance with modulated heavy-weight impact sounds by comparison to those sounds having different pressure level without modulation. Generally, people feel the modulated sound at a modulation frequency of 2~20 Hz.

Paired comparison refers to any process of comparing test samples in pairs to judge which samples are preferred. This test method was performed for eight stimuli with changes in ε, A_1 and A_2, and it was repeated for all pairs in the changed order of ω_1 (30, 60 and 90 Hz). The sounds were presented by calibrated headphones (Sennheiser HD600) with a minimal frequency loss from 12 Hz to 20 kHz of less than 3 dB. There were 32 participants between the ages of 20 and 32 who passed the consistency test and then participated in the experiment. Subjects were first asked to imagine the same hearing situation as in the previous experiment. They were asked to choose the more annoying noise from among several sources with the same frequency (ω_1). Consistency tests indicated that 32 out of 35 subjects had a significant ($p < 0.05$) ability to distinguish between various degrees of annoyance.

5. CONCLUSIONS

In this study we analyzed modulated sound effect for multi-layered building. The modulation effect was identified from measurements of actual building and scale model structure vibration. The out-of and in-phase vibrations of upper and lower floors generated two very closely spaced vibration modes from which modulated sounds were generated. The modulation has a significant influence on the heavy-weight floor impact sounds. To identify the influence on the perceived annoyance, auditory experiments utilizing the paired comparison method were performed using various impact sounds having different magnitudes of modulation. By comparing these sounds to impact sounds without modulation at a different sound level, the influence of the modulation on the perceived annoyance was identified. The increasing magnitudes of modulation reduces the maximum sound level that is an index currently used to evaluate the floor impact sound transmission. The annoyance from modulated sounds increased with the increasing modulation.

ACKNOWLEDGEMENTS

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