Detecting sound transmission path of floor impact noise using acoustic visualization in a multi-story building

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ABSTRACT

This study aims to investigate the sound transmission path of floor impact noise in multi-story buildings through acoustic visualization. Floor impact noise was measured in a multi-story building with the 32-channel spherical microphone array. The floor impact noise was generated by the impact ball in a living room. A microphone array was located at the center of the receiving room. Plane wave decomposition and adaptive beamforming technique, such as Minimum Variance Distortioneless Response (MVDR) spatial spectrum estimate, were used in order to detect the sound transmission path in the room. Directional impulse responses (DIRs) were generated and the sound level was visualized. Through the acoustic visualization, sound transmission path was discussed based on the contribution of room components such as a ceiling, walls and windows on the floor impact noise.

Keywords: Floor impact noise, Acoustic visualization, Microphone array
I-INCE Classification of Subjects Number(s): 51.5

1. INTRODUCTION

In multi-story residential buildings, floor-impact noise, typically an impulsive sound coming from upper floors and generated mainly by individuals walking, running, or jumping, is considered an annoyance. The frequency bands in the vibration from human footsteps are generated by a force applied to the surface of the floor and are concentrated in the low-frequency range below 500 Hz (1, 2). These phenomena occur in buildings with certain structural systems, such as the box-frame type. Because of the various sound transmission paths, called structure-borne flanking paths, that floor-impact noise can follow, solutions to this longstanding problem remain elusive. In general, floor-impact noise is transferred directly through the floor; it can, however, be transferred through walls, so that it could affect not only the floor immediately below, but also households two stories down in taller buildings. In addition, the sound propagates in the receiving room through the building's elements, such as the ceiling and walls; the sound directivity follows various paths because of the effects of the structural and room modes. In a previous study, Jeon (3) revealed that lowered inter-aural cross correlation (IACC), resulting from the varied directivity of floor-impact noise, caused greater levels of annoyance. Therefore, it is necessary to define the sound-transfer path and characteristics of directivity in terms of floor-impact noise in order to develop proper noise-control methods.

In this study, floor-impact sounds and vibration levels were measured at the ceiling and side walls of the receiver room to determine the levels of structure-borne sounds and their contributions to sound-pressure levels. At the same time, sound directivity was investigated using a 32-channel spherical microphone and analyzed through acoustic visualization methods based on plane-wave decomposition and an adaptive beamformer (4). We selected common structure types of box-frame to investigate the effects of the structure mode on the directivity of floor-impact noises.

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2. Measurements in a multi-story building

2.1 Test building

The laboratory conditions following ISO 140 do not fully represent the boundary conditions with regard to impact noise of in situ multi-story building. Therefore, in this study, the measurements of floor impact noise were conducted in a mockup of multi-story building constructed for investigating building environment. The building employed a box-frame type structure similar with a common multi-story building as shown in Fig. 1. The floor's construction includes a 210 mm slab, 110 mm panel heating and finishing 3 mm and the heights of ceiling was 2.4 m.

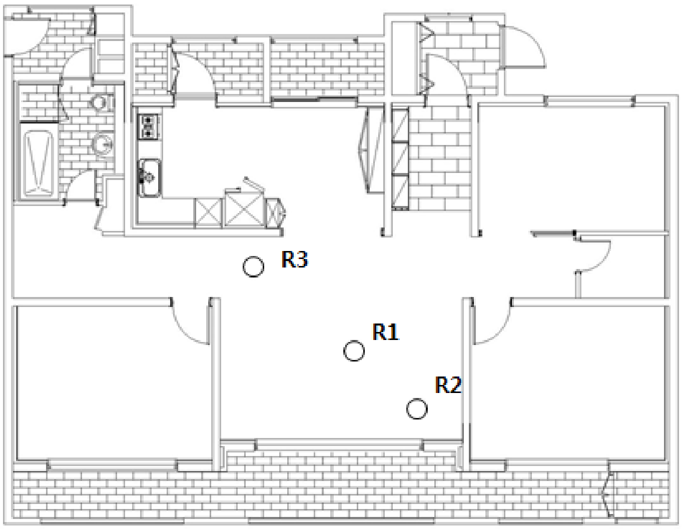

Figure 1 – Floor plan of the test building

2.2 Measurement set-up

An impact ball was used as an impact source generator in order to investigate the sound transmission path. Because previous studies [5] reported that the physical properties of an impact ball more closely resemble those of a human impact source than those of a bang machine, we used only the impact ball. Sound-pressure levels were measured at three positions: R1 (center), R2 (corner), and R3 (corner). Also vibration levels were measured in a receiving room at the center of the ceiling (VL1) and at the center of the side walls (VL2, VL3, and VL4, respectively), as shown in Fig. 2. The ceiling and all side walls were finished with plaster board. The finishing of the ceiling consisted of 9.5 mm thick plaster board. For acoustic visualization, a 32-channel spherical microphone (Eigenmike, mh acoustics) was located at the center of the receiving room at heights of 1.2 m and 0.7 m. The front of the spherical microphone was directed to face the balcony.

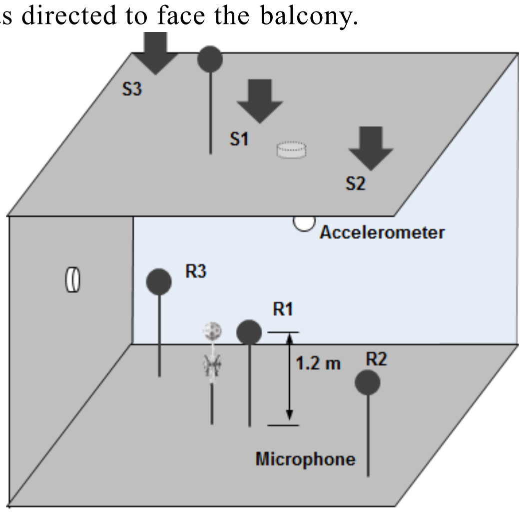

Figure 2 – Source and receiver positions for measurements

2.3 Sound field synthesis

Sound field synthesis, based on the Kirchhoff–Helmholtz integral, computes the sound field on a real or imaginary surface, whereupon the remainder of the sound field can be determined mathematically. This approach enables the plane-wave decomposition and beamforming to be determined. Three techniques, namely adaptive beamforming, minimum variance distortionless response (MVDR), and sound field extrapolation, were used to obtain a dynamic signal for each direction, an approach referred to as directional impulse response.

A spherical microphone array was used in this study to capture the sound field on a rigid real surface. Theoretically, continuous sound-field properties are required on a spherical surface; in contrast, our 32-channel array yielded values at discrete spatial sampling points. A spatial Fourier transform technique was used in the sound-field synthesis to decompose the sound field into spherical harmonics. The spherical harmonics formed the angular portion of a set of solutions of the Laplace equation. The selection of higher order harmonics enabled a higher directional selectivity of the array to be obtained. In conventional beamforming, commonly known as delay and sum beamforming, once the array geometry is fixed and the steering direction is determined, the characteristics of the beam pattern remain fixed. Therefore, readjustment of the beam pattern would require physical changes to the geometries of the microphone array geometries; such readjustment was not possible (5).

To resolve this problem, adaptive beamforming, capable of responding to the frequency bands, was considered by using the MVDR beamformer (6) instead of simple spatial filters. This beamformer generally uses a finite impulse-response filter to constrain the desired signal, using unity gain, while minimizing the filter output energy. This technique was developed to detect the direction of arrival of a desired signal during array processing.

3. Results

3.1 Sound pressure level

Frequency characteristics of heavy-weight impact sounds were calculated in octave bands as shown in Fig. 3a. Average sound pressure level (SPL) has the range of 20 dB to71 dB. The highest SPL was occurred at the band of 32 Hz as the first order structural mode. Likewise in Fig. 3b, the spectrogram of impact noise show higher value below 100 Hz. Also the pattern of spectrogram represents the characteristic of modulation due to the structural mode and room mode effects (7) in the frequency range of 0 to 300 Hz.

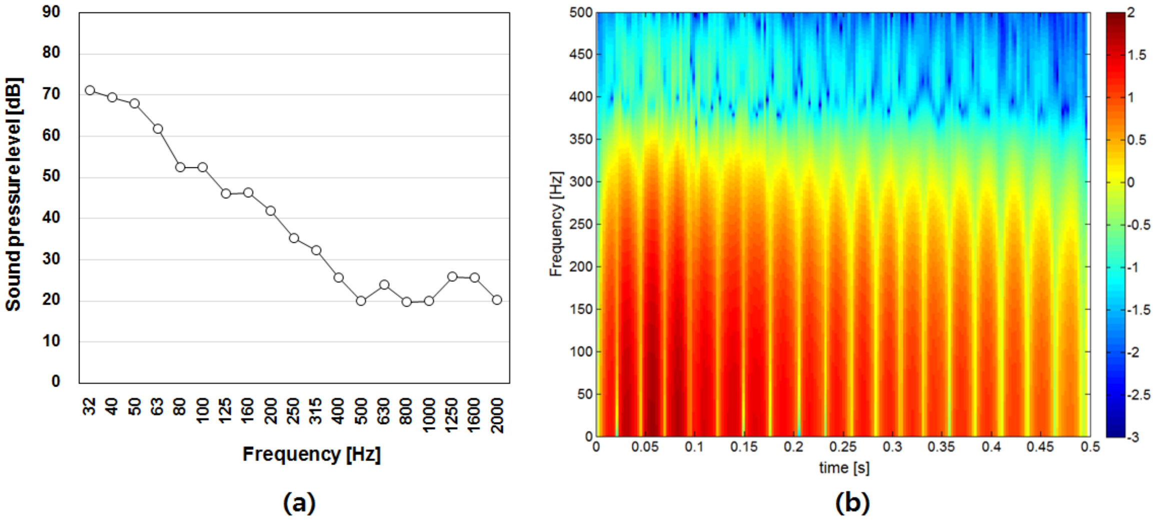

Figure 3 – Frequency response of impact noise generated by impact ball at S1

(a) Averaged SPL in octave band and (b) Spectrogram in 0 to 500 Hz

3.2 Acoustic visualization

Based on the measurement results of the impacts from a heavy weight source, acoustic visualization was conducted based on plane-wave decomposition and the MVDR beamformer. The sound transmission after structural transfer was verified through acoustic visualization, as shown in Fig. 4. The accumulation result during the interval from 0 ms to 150 ms was compared with the square value of the impact noise in the time domain. The directivity of noise could be detected from the ceiling, side walls, and floor. The sound pressure level of these directions had similar value and this means that the directivity of floor impact noise has not only the ceiling direction, but also various directivities at the receiver position.

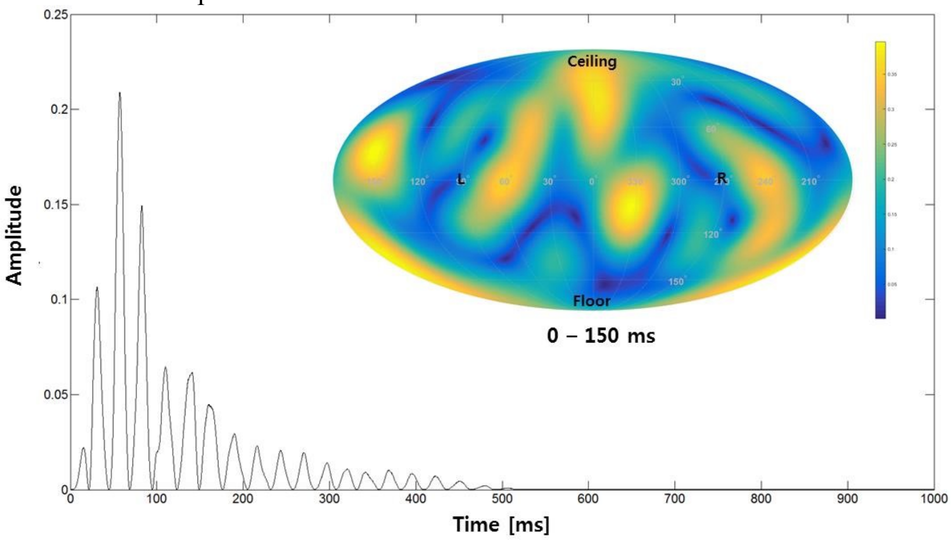

Figure 4 – Response of the noise generated by an impact ball and acoustic visualization result

4. Summary

In the present study, floor impact noise and vibration of each building elements were measured in a multi-story building. In order to investigate the directivity of floor impact noise, acoustic visualization was analyzed using 32-channel spherical microphone. From the results, we revealed that the directivity of floor impact noise was not only from the ceiling but from all directions, including side walls, balcony, and the floor. It seemed that structural and room mode affect floor impact noise especially in low frequency range with modulations. In further study, acoustic visualization according to time can be conducted in order to investigate the effect of room and structural modes in the box-frame and Rahmen structure types additionally. Also transfer path analysis using SPL and vibration level can be conducted to derive the contribution of building elements on floor impact noise.

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