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A correlation between a single number quantity and noise level of real impact sources for floor impact sound

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ABSTRACT

The floor impact sound is one of many uncomfortable noises in apartment houses that can disturb neighboring residents. For floor structure in apartments, resilient materials-applied floating floors have been used and standard impact sources were used for performance evaluation. In particular, bang machines and rubber balls were used to evaluate a low-frequency region. The insulation performance against floor impact sound was analyzed via single number quantity and heavyweight impact sounds were measured at four frequency bandwidths. However, since 63 Hz bandwidth of heavyweight impact sound was characterized by high impact sound level, single number was determined at 63 Hz. Although the single number quantity ($L_{i,Fmax,AW}$, $L'_{n,AW}$) is evaluated by considering a certain frequency range, its performance was mainly determined at a specific frequency. It is important to identify a relationship between performance results determined at a specific frequency and noise that occurred due to real impact source. The present study analyzed a correlation between a single number quantity and noise level (dB (A)) due to real impact source (human activity) in order to review the applicability of the single number quantity that evaluated performance of floor structure. The analysis result showed that a correlation between floor structure performance evaluated via the single number quantity and noise level occurred due to real human activity was not significantly high.

1. Introduction

An apartment is a type of housing in which a large number of households reside in a single building, in contrast to detached houses. Apartments are effective in terms of land usage since many households can be constructed on a small plot of land and constructed vertically. However, since many households are adjacent to each other, noise can be easily delivered to adjacent households. The noise delivered can be floor impact sounds, air delivery sounds between households, and plumbing noises in bathroom. In order to minimize the damage to residents due to noise delivery, a number of nations have proposed building specification standards and performance criteria during construction of apartments [1]. Among the many sources of noise disturbances, floor impact sounds, which occurred between both upper and lower houses in apartments is one of the most common noise disturbances in Korea. In order to reduce the floor impact sound, the Korean government has set the criteria of insulation performance of floor impact sound in buildings from the construction phase of apartments as a law [2]. In Korea and Japan, heavyweight impact source (Bang machine, Rubber ball) and lightweight impact source (Tapping machine) are used to evaluate a floor impact sound. In Europe and the USA, only lightweight impact sources are used to evaluate floor impact sound in consideration of residential characteristics. Heavyweight impact sources are used to evaluate noise in low frequency bandwidth occurred due to children's activities (running, jumping) or adults walking. Among heavyweight impact sources, a rubber ball is a newly suggested impact source by overcoming an excessive impact power of bang machine (Tire) [3]. After a rubber ball was proposed as a new heavyweight impact source, a number of researchers compared the inter-characteristics between rubber ball and other impact sources [4] and a study on subjective loudness was conducted to propose an evaluation method of rubber ball and the result showed that Loudness N10 of Zwicker was the highest correlation [5].

In order to evaluate floor impact sound, it is important to choose an impact source used in the evaluation that simulates the characteristics of real impact source well. W. Shi et al. [6] compared the characteristics of frequency of impact source using human walking, running, and jumping, as well as using sand bags, sand balls, tires, and tapping machines and proposed that a fall of

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sand ball at a specific height was most similar to the characteristic of actual impact sound.

It has been known that the factors that affect the floor impact sound were floor composition, slab thickness, plan type, and physical characteristics of resilient materials [7,8]. In particular, there have been a number of studies on resilient materials that were inserted in a floating floor [9,10] and physical changes in characteristics of resilient materials [11–14]. A study on physical characteristics of resilient materials has been concentrated on dynamic stiffness and compressibility determination. The development of resilient materials that have accurate dynamic stiffness measurement and low dynamic stiffness number is a basic physical goal required to predict floor impact sound insulation performance [15]. In the previous study [16], a correlation between dynamic stiffness of resilient materials and heavyweight impact sounds were analyzed and the result showed that insulation performance of floor impact sound was improved as dynamic stiffness was lower not only in lightweight impact sound but also in heavyweight impact sound. In order to measure accurate dynamic stiffness, a relationship with loading time of loading plate, which was not determined in the ISO standard [17], was studied [18] and the result showed that as a loading time of loading plate was increased, dynamic stiffness was increased and compressibility was also increased continuously. A resilient material used in floating floor was also significant in changes in reduction performance of floor impact sound over time [19].

The floor impact sound can be evaluated via a number of indices using standard impact sources. For example, a single number quantity using reference curves, arithmetic mean value by frequency, and noise level have been used. Among them, a single number quantity using reference curves have been most widely used [20]. T. Okano analyzed a correlation with bang machine and rubber ball used as heavyweight impact source and proposed an estimation equation that can predict a level by frequency [21]. Bang machine or rubber ball is a standard impact source that evaluates insulation performance with regard to low frequency region, which is 50–630 Hz. Reverse A curve is used as a reference curve in Korea as a single number quantity, which specifies that a total sum of values that exceed the reference curve shall be within 8 dB [22]. It is important to know a relationship between methods that calculates a single number quantity based on multiple frequency bands and resident's real response to the noise. A single number quantity can be an insulation performance of floor impact sound in buildings and differences in insulation performance due to evaluation methods shall be related to a level of noise that residents are actually felt.

There was a study on definite correlation between physical index and vibration sense even over 30 Hz by analyzing a correlation between vibration intensity of low frequency and human perception level [23]. In relation to noise, K. Inoue analyzed a correlation between LH grade, which is an evaluation index of heavyweight floor impact sound used in Japan, and response from residents. The above study suggested that there was a fair correlation between insulation sound grade and complaint rate of noise by residents. For example, when a grade was L-55, approximately 30% of residents indicated noise [24].

As such, noise evaluation methods shall represent the reaction of actual residents. To do this, it is necessary to review a variety of evaluation methods. Thus, the present study analyzed a correlation between single number quantity used in Korea and noise occurrence due to real impact source (human activities, drop of objects). Through the correlation analysis, basic data about response to real impact source in the single number quantity are provided and data required for the development of evaluation index in the future are secured.

2. Test methods

In order to analyze a correlation, 30 apartments were chosen and seven activities of noise occurrence inside the apartment were selected. The target apartments can be divided by slab thickness: 10 apartments whose slab thickness was 210 mm, 10 apartments were 180 mm, 4 apartments were 150 mm, and 6 apartments were 135 mm. Most apartment floor structures have anti-shock materials of a certain thickness on the upper surface of slabs as shown in Fig. 1. A floor structure generally consists of foamed concrete, finish mortar, and finish floor material. This kind of structure is called ondol structure, which has been used to reduce floor impact sound and increase insulation performance.

The reason for the division by slab thickness was because heavyweight floor impact sound among floor impact sounds was significantly affected by concrete slab thickness. Furthermore, most apartment floors had resilient materials inserted. Table 1 shows the overview of the target measurement apartments. The floor areas of the chosen apartments had a range of 66.3–120.7 m^2 and most finish materials used were timber.

The insulation performances of impact sound and impact noise due to daily living activities in the selected apartments were measured. The insulation performance of floor impact sound was analyzed with a single number quantity using three standard impact sources (Bang machine, Rubber ball, and Tapping machine). The following activities were chosen as daily living activities: children's activities (running, jumping) and adults walking (normal walking, heel walking). The reason for the selection of children activities was because children activities were main factors to noise occurrence. Furthermore, basketballs and golf balls were dropped freely from 30 cm, 50 cm, and 70 cm heights. The apartments to be measured are divided according to various factors such as the floor slab thickness, the floor structure, and size of the room. Thus, one adult and one child were selected in consideration of average weight and height of adult and children to minimize the deviation of impact applied to the floor in order to minimize the effect of resulting values to be derived under various parameter conditions [25,26].

The reason for a basketball and a golf ball being selected as an impact source was because the impact applied to the floor was more consistent than human activities thereby minimizing input parameters for evaluation of the impact sound level. That is, a basketball can reproduce a characteristic of a low frequency band while a golf ball can reproduce a characteristic of high frequency. The drop height was selected in consideration of radius of activity taken by a child's age. Male and female children were targeted and their weights were within a normal range of body mass index (BMI), which was 23 kg for male children and 28 kg for female children. For the adult walking performance test, male and female subjects were targeted as well and their weights were 78 kg and 55 kg. Adult walking and children running activities were performed while subjects were moving diagonally in the living room in the target apartments to create noise. To measure the activities of children jumping and the dropping of objects were conducted at Point 1 in the center in the living room. Noise due to walking and running was measured into three noises during noise occurrence: maximum noise (Lmax), minimum noise (Lmin), and equivalent noise level (Leq). For background noise (BGN), a distribution of minimum noise level was revealed during the measurement.

Noises due to children and adult activities may be inconsistent regardless of the same person measurement in contrast with standard impact source, which was why basketballs and golf balls that can apply consistent impact were selected additionally to conduct the test. Noises due to daily living activities were measured by selecting 'A-weighting'. Furthermore, impact power and sound exposure levels were measured at the laboratory for impact source