# Heavy/soft impact sound criteria and regulation in Korea

Jeong Ho JEONG

Fire Insurers Laboratories of Korea, Republic of Korea

## ABSTRACT

Most of housings in Korea constructed with reinforced concrete structured high rise apartment. Floor and walls were shared with neighbors and floor impact sound generated on upper floor transmitted into lower unit. Heavy/soft impact sound is become one of social problem. In 2006, heavy/soft impact sound certification system with 4 graded rating systems mandated. 50 dB in $L_{i,Fmax,AW}$; regulated in KS F 2683-2, is minimum requirement. To establish the rating system, auditory experiments on heavy/soft impact sound and field measurements were conducted. In this paper, auditory experiment results and Korean floor impact sound isolation performance certification system will be introduced.

Keywords: Rubber ball impact Sound, Subjective evaluation, Criteria

I-INCE Classification of Subjects Number(s): 69.1

## 1. INTRODUCTION

Most of housings in Korea constructed with reinforced concrete structured high rise apartment. Floor and walls were shared with neighbors and floor impact sound generated on upper floor transmitted into lower unit. Floor impact noise is regarded as the most irritating noise among all noises in multi-story residential buildings. Due to complaints and demands from residential groups, heavy/soft impact sound certification system with 4 graded rating systems mandated. 50 dB in $L_{i,Fmax,AW}$; regulated in KS F 2683-2, is minimum requirement. To establish the rating system, auditory experiments on heavy/soft impact sound and field measurements were conducted. In this paper, auditory experiment results and Korean floor impact sound isolation performance certification system will be introduced.

## 2. AUDOTORY EXPERIMENT IN LABORATORY

Auditory experiments were undertaken in a laboratory, which was built to have an acoustical environment similar to a real residence (a living room of an apartment), to find out the upper and lower limits of the floor impact sound pressure levels based on activity disturbances caused by residential noises. The room had a reverberation time of 0.5 s and a low background noise level.

Subjects determined their upper and lower limits as described in Table 1. As shown in Table 1, the lower limit of tolerance was established as the disturbing noise level for activities that do not require much concentration, such as reading books or newspapers in a living room, whereas the upper limit was established as an unbearable noise level.

Table 1- Situations to establish subjective upper/lower limits

| Upper limit | Lower limit |
| --- | --- |
| the point unable to do any work by the noises in living room | the point to lose concentration when reading papers or magazines at living room |

The rubber ball impact and jumping sound sources were manipulated for auditory experiments by varying the recorded actual noise levels by 2dB steps. Thus, the subjects could choose their annoyance levels. Forty subjects in their 20's, with normal hearing, participated as subjects in the auditory experiments. The subjects sat on a couch in the test chamber, and evaluated floor impact noise. In the laboratory, eight speakers were installed on the ceiling, floor, and walls, and a Lake DSP 8-channel sound presentation system controlled and presented each noise source from the place where it originated.

In the experiments, each noise sources were gradually presented to the subjects from low to high levels in the originating location of the noise source. First, the subjects determined their lower and upper limit for the sound level of each presented sound source. Subjects were asked to label the level of the lower and upper limit with numbers between 40 and 80. Then, the staircase method (Dixon and Mood (1), Levitt (2)) was used for re-evaluating the subjective upper and lower limits, with reversals of three or four times. The upper and lower limits of the floor impact noise were shown in Table 2. The standard deviation of upper and lower limit values, obtained from 40 subjects, is about 3dB. When the value was 5dB lower than the lower limit, more than 85 % of the subjects are satisfied with the level without any annoyance.

Table 2 - Subjective upper/lower limits of rubber ball impact and jumping sound in $L_{i,Fmax,AW}$

| Impact sources | Upper/lower limit | Result [dB] |
|---|---|---|
| Rubber Ball | upper | 66 |
| | lower | 51 |
| Jumping | upper | 64 |
| | lower | 54 |

## 3. AUDOTORY EXPERIMENT IN ON-SITE CONDITION

Auditory experiments on the annoyance of the rubber ball impact and jumping noises generated in real situations were conducted. The purpose of the on-site experiment was to compare its result with previous upper and lower limits and to rate the floor impact sound pressure level according to the annoyance felt by the subjects in real situations. Auditory experiments were conducted with 98 subjects in a living room of a multi-story residential building. The subject group consisted of undergraduate and postgraduate students in their 20s. Rubber ball impact sound pressure levels were manipulated by dropping standard noise sources from different heights.

Subjects responded on three questionnaire sheets on the floor below. Three questionnaire forms originally developed in 1997 by the Architectural Institute of Japan and Jeon et al. (3) modified and used for the evaluation of the floor impact noise. As shown in Table 3, these forms evaluated the sound sources for Noisiness, Disturbance and Amenity. In addition, after careful consideration of the borders of the groups, the upper and lower limits were set up as follows: upper limit - Evaluation Point 7, where noise bothers people greatly, and lower limit - Evaluation Point 4, where the noise started to bother people.

Table 3 - Nine category scales for evaluating annoyance levels of floor impact noise

| Annoyance Group & Subjective magnitude | | Noisiness | Disturbance | Amenity |
|---|---|---|---|---|
| Not Annoying | 1 | Hardly perceivable | At ease | Excellent |
| | 2 | Far-off noise | Not affected | Very fine |
| | 3 | Unconcerned | Undisturbed | Good |
| Annoying | 4 | Slightly heard | Detectable | Controllable |
| | 5 | Heard | Noticeable | Endurable |
| | 6 | Clearly heard | Discernable | Yielding |
| Very Annoying | 7 | Noisy | Obviously | Unbearable |
| | 8 | Very noisy | Undoubtedly | Intolerable |
| | 9 | Extremely noisy | Seriously | Let's move OUT! |

The relationship between subjective response and floor impact noise level (inverse A-weighted impact sound pressure level), which corresponds to the evaluation scales, appears as a linear equation.

The rubber ball impact and jumping noise levels ($L_{i,Fmax,AW}$) according to subjective response drawn from the equation, are shown in Table 4~6. The average value of evaluation point 7, rubber ball and jumping, are 69 dB and 70 dB, and Evaluation Point 4 are 54 dB and 58 dB respectively.

In Table 8, the results of the auditory experiments in a chamber and on-site indicated that the upper and lower limit values from the experiments were similar, in spite of the differences in testing methods. The meaning of the upper level is the limit of the noise level, which for any type of activity performed might be recognized as a tolerable limit, not an allowable limit. The lower level might be recognized as an allowable limit, which can be as a regulating limit and a starting point for annoyance.

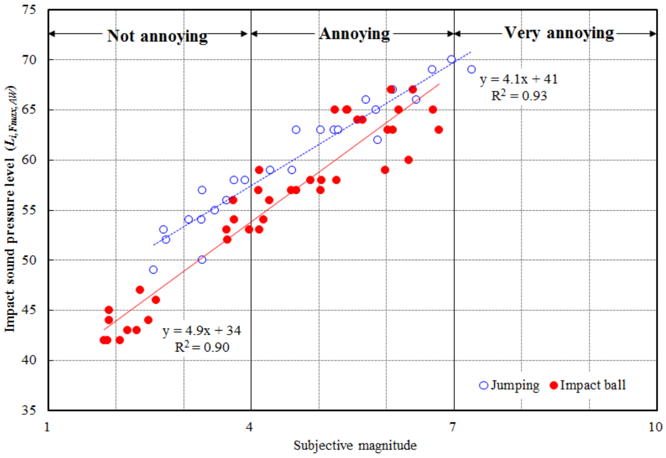


Figure 1 - Relationship between floor impact sound and subjective magnitude

Table 4 - Impact sound pressure levels($L_{\mathrm{i,Fmax,AW}}$) with noisiness

| Subjective magnitude | Noisiness | Rubber ball | Jumping |
|---|---|---|---|
| 1 | Hardly perceivable | 39 | 45 |
| 2 | Far-off noise | 43 | 48 |
| 3 | Unconcerned | 47 | 52 |
| 4 | Slightly heard | 51 | 55 |
| 5 | Heard | 55 | 59 |
| 6 | Clearly heard | 60 | 62 |
| 7 | Noisy | 64 | 66 |
| 8 | Very noisy | 68 | 69 |
| 9 | Extremely noisy | 72 | 73 |

Table 5 - Impact sound pressure levels($L_{\mathrm{i,Fmax,AW}}$) with disturbance

| Subjective magnitude | Disturbance | Rubber ball | Jumping |
|---|---|---|---|
| 1 | At ease | 41 | 47 |
| 2 | Not affected | 46 | 51 |
| 3 | Undisturbed | 51 | 55 |
| 4 | Detectable | 56 | 59 |
| 5 | Noticeable | 61 | 64 |
| 6 | Discernable | 67 | 68 |
| 7 | Obviously | 72 | 72 |
| 8 | Undoubtedly | 77 | 76 |
| 9 | Seriously | 82 | 81 |

Table 6 - Impact sound pressure levels($L_{\mathrm{i,Fmax,AW}}$) with amenity

| Subjective magnitude | Disturbance | Rubber ball | Jumping |
|---|---|---|---|
| 1 | Excellent | 39 | 44 |
| 2 | Very fine | 44 | 49 |
| 3 | Good | 49 | 54 |
| 4 | Controllable | 55 | 58 |
| 5 | Endurable | 60 | 63 |
| 6 | Yielding | 66 | 67 |
| 7 | Unbearable | 71 | 72 |
| 8 | Intolerable | 76 | 77 |
| 9 | Let's move OUT! | 82 | 81 |

Table 7 - Subjective limit of floor impact noise

| | $L_{i,Fmax,AW}$ [dB] | | $L_{Aeq}$ [dB] | | $L_{Amax}$ [dB(A)] | |
|---|---|---|---|---|---|---|
| | upper | lower | upper | lower | upper | lower |
| Rubber Ball | 69 | 54 | 66.7 | 53.5 | 76.8 | 66.9 |
| Jumping | 70 | 58 | 66.1 | 55.0 | 87.5 | 75.8 |

Table 8 - Proposed requirements for floor impact noise insulation

| | Rubber Ball | | Jumping | |
|---|---|---|---|---|
| | upper | lower | upper | lower |
| Chamber | 66 | 51 | 64 | 54 |
| On site | 69 | 54 | 70 | 58 |

The way to deal with classes of acoustical comfort is to provide a well-defined level difference (Subjective magnitude 1, 3 and 5) using two steps of the subjective magnitude in three scales as specified in Table 4 ~ 6. This method has the benefit of selecting distinguished expressions and allowing reasonable deviations in subjective scales for measuring floor impact noise.

The just noticeable difference (JND, minimum perceived noise level) of impact ball noise were investigated to evaluate the appropriate level difference when the floor impact sound was classified. The auditory experiments were conducted using a pair comparison method of 10 postgraduate students in their late twenties. The sound pressure level of the standard stimulus was increased by 1 dB increments, starting from 2 dB up to 5 dB. The subjects listened through headsets and judged the higher level of the floor impact sound within a test chamber. The duration of the sound source was 0.8 s with an inter-stimulus interval of 1 s. The stimuli were randomly presented to the subjects. It was found that the JNDs, which is the sound pressure level of 75 % of people can distinguish the level difference, of the rubber ball impact and jumping noise were about 2dB. As shown in Figure 2, more than 86 % of the respondents could recognize this 3 dB difference. While just about everyone could distinguish a 5 dB level difference, it seemed that a level difference for the floor impact noise evaluation system could be 5 dB.

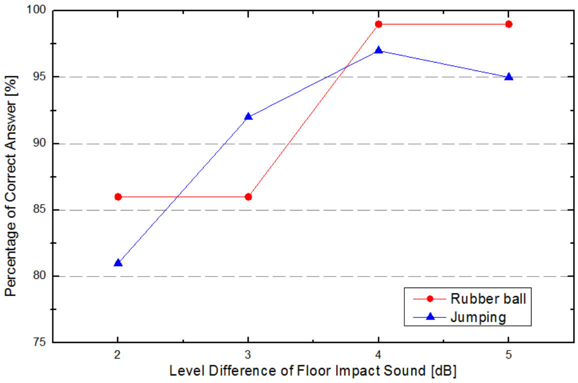


Figure 2- JND of impact ball noise

The difference limen of the floor impact noise was found to be about 5 dB between subjects, between subjective magnitudes on an average in three different evaluation scale steps, a 5 dB level difference between classes seem to be reasonable for the level difference between the evaluation classes. Rindel (4) investigated the legal requirements of sound insulation of dwellings in European countries and proposed that the sound classification system be divided into 5 dB increments.

The meaning of annoyance limit must be recognized as an allowable limit. This can be a guideline and also a starting point for annoyance. Table 9 shows the proposed classes for floor impact sound levels by subjective evaluations.

Table 9- Classes of floor impact sound from the results of subjective evaluations

| | | Class 1 | Class 2 | Class 3 |
|---|---|---|---|---|
| Rubber ball | $L_{i,Fmax,AW}$ | 44 | 49 | < 54 |

## 4. Satisfactory Percentage of Floor Impact Noise

In order to classify acoustical quality and sound insulation between dwellings, Rindel and Rasmussen (4, 5, 6) introduced a percentage of resident's satisfaction on residential noise and their research shows the distribution of the satisfactory percentage of residents against noise level increase. As noise level increases 1 dB, satisfactory percentage was decreased 4 %. The noise levels at the 50 % of satisfaction were proposed as an allowable limit of dwellings. The 50 % satisfaction level means the minimum requirement for houses on a short time basis. While considering the long time basis, the allowable limit should be higher percentage of residents (7, 4).

Results from the on-site experiments were analyzed by Rindel's method. From the nine category scale, 1-4 was assigned as "Good" and satisfactory percentage was calculated by the Probit analysis (4. 8). The expected three categories scale values of four rubber ball impact, jumping and walking noises from the Probit analysis of were plotted in the Figure 3- 5. In addition, the slopes of regression lines in the range of 20 % - 80 % were plotted.

Table 10 shows the results of the Probit analysis of satisfactory percentage. As shown in Table 10, 50 % satisfaction levels for the rubber ball, jumping and walking are 57 dB, 56 dB and 51 dB, respectively. The 50 % satisfaction level of the rubber ball was similar to those of the jumping noise. The average slope of the regressions for rubber ball, jumping and walking are 6 %, 4 % and 6 % per dB, respectively. These results show that the slope of regression line of the rubber ball is similar to the average slope of the jumping and walking.

The rating classes can be established by the satisfactory percentage of residents. When establish the rating classes by 20 % satisfaction, the level difference between classes in jumping, walking and rubber ball noise was 3 dB – 4 dB. Considering subjective responses on the floor impact noises, impact ball is the most similar of the three standard impact sources to actual human impact.

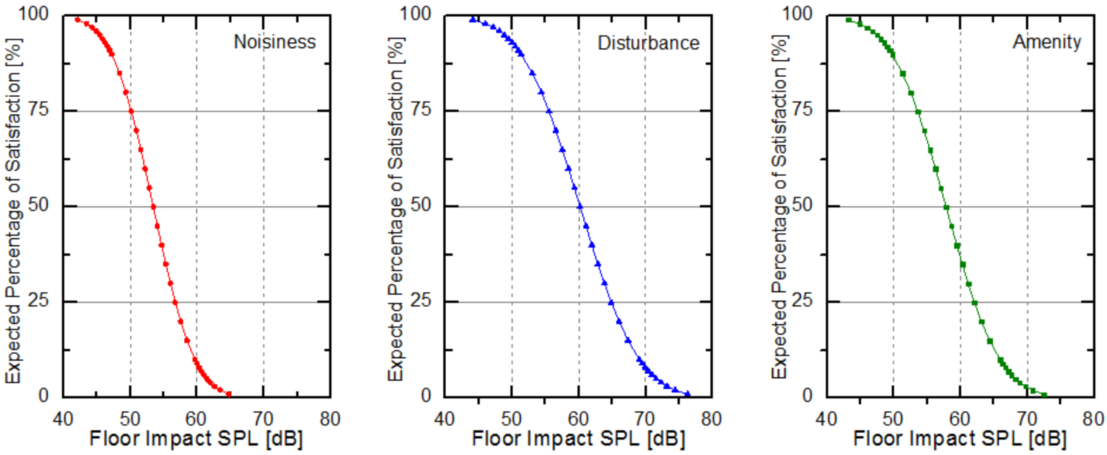


Figure 3- The satisfactory percentage the rubber ball noise

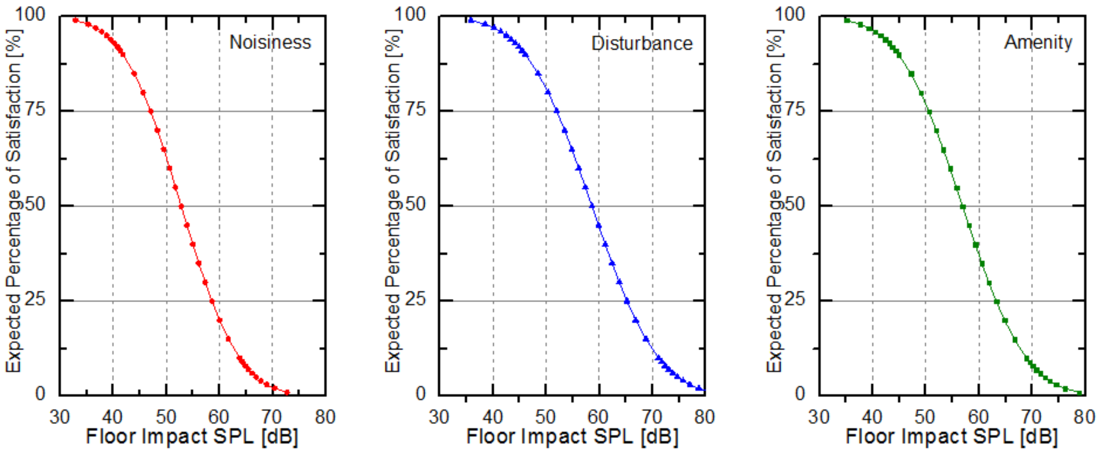


Figure 4 - The satisfactory percentage jumping noise

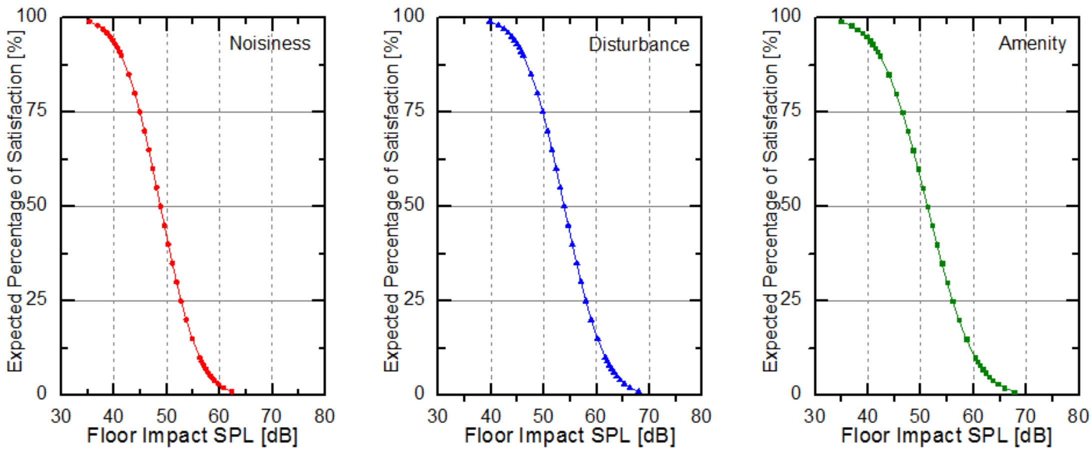


Figure 5 - The satisfactory percentage walking noise

Table 10- Classes of floor impact sound from the results of subjective evaluations

| Evaluation scale | | Ball | Jumping | Walking |
|---|---|---|---|---|
| Noisiness | [dB] | 54 | 53 | 49 |
| | [%/dB] | 7.4 | 4.4 | 5.8 |
| Disturbance | [dB] | 60 | 57 | 54 |
| | [%/dB] | 4.8 | 3.6 | 5.9 |
| Amenity | [dB] | 58 | 58 | 51 |
| | [%/dB] | 5.5 | 3.7 | 5.1 |
| Average | [dB] | 57 | 56 | 51 |
| | [%/dB] | 6 | 4 | 6 |

## 5. Conclusions

In order to construct classes of heavy/soft impact noises, two auditory experiments in the test chamber and the apartment, auditory experiment for the JND of the floor impact noises and floor impact noise measurements were conducted in this chapter. The results from the two auditory experiments showed that the 50 % of respondents satisfying allowable limit of the rubber ball was 51 dB – 57 dB. The JND experiment indicated that the level difference between evaluation classes was 5dB. The average value of the rubber ball was 54 dB. The results of auditory experiments and measurements on the floor impact noise showed that the impact ball accurately simulates actual human impact noises subjectively and physically Table 10 shows the proposed classification for floor impact noise evaluation developed from the results of subjective evaluations and measurements of floor impact noises.

| Class | Rubber Ball | Subjective meaning (Korean) |
|---|---|---|
| Class 1 | 45 | Excellent (Maeumanjok) |
| Class 2 | 50 | Comfortable (Manjok) |
| Class 3 | 55 | Allowable (Manjok hangye) |

As a result, the lower limit of the rubber ball noise were 55 dB in $L_{i,Fmax}$. Three classes of rubber ball impact noises with the 5 dB level difference between classes were proposed.

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