Evaluation method of rubber ball impact sound

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Summary
For the measurement of low frequency impact sound in heavy structured residential buildings, rubber ball is used in Korea and Japan. Rubber ball was regulated as standard heavy/soft impact source in ISO 10140-5 and ISO 16283-2. Rubber ball impact sound had similar characteristics with child's jumping and running in concrete apartment buildings. However, single number evaluation method on rubber ball impact sound was not regulated in ISO standard. In this paper, based on results of subjective auditory experiments, single number evaluation method will be proposed.

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1. Introduction

Low frequency noises from the mechanical equipment, home theatre and foot step in residential building have been increasing. In order to evaluate and reduce the low frequency air borne noise, measurement procedure and single number index were discussed in ISO.
One of the major low frequency noises in residential building is foot step noise; dominant frequency bands are from 50 Hz to 250 Hz. As a standard impact source for the measurement of low frequency impact sound, rubber ball was standardized in ISO 10140-5[1] and ISO/FDIS 16283-2[2]. However, single number evaluation method on rubber ball was not standardized.
Some researches on low frequency floor impact sound evaluation method based on auditory responses were conducted. Jeon et al. [3] conducted loudness evaluation experiment with rubber ball impact sound recorded in concrete structure apartment and made comparisons with several single number indices. Ryu et al. [4] conducted annoyance experiments with rubber ball impact sound measured in Japanese wooden houses. Ryu et al proposed arithmetic mean and Zwicker's percentile loudness ad single number indices. Jeon et al. [5, 6] and Jeong et al. [7] reported that physical properties and subjective impression of rubber ball correlates well with of real heavy impact in buildings.
In order to control low frequency impact sound in residential buildings standardized test method and single number evaluation method is needed. In this paper, single number evaluation method based on results of subjective loudness experiments with rubber ball impact sound which were measured in concrete structure building was compared.

2. Evaluation method in KS and JIS

Heavy-weight impact sound source was used from mid-80 in Korea and Japan. At first, car tire and bang machine was the only heavy-weight impact source. Bang machine have too much impact force comparing with adult walking and child's running. Rubber ball had similar impact force and several physical properties with real impact. Rubber ball was standardized in KS [8] and JIS [9] as a standard impact source with bang machine.

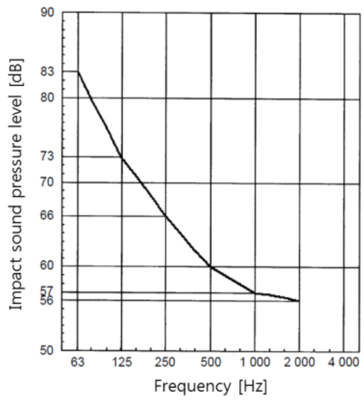

Figure 1

Korea and Japan have their own standard on heavy-weight impact sound evaluation method. KS and JIS use same reference curve shown in Figure 1. As a single number index, $L_{i,Fmax,AW}$ is standardized in KS [10]. In addition, $L_{iA,Fmax}$ and $L_{iFavg,Fmax}$ were regulated in Annex A and B. $L_{i,Fmax,r}$, $L_{i,Fmax,AW}$, $L_{iA,Fmax}$ and $L_{iFavg,Fmax}$ were standardized in JIS [11]. These single number indices were used for evaluation of bang machine impact sound and rubber ball impact sound.

3. Subjective Evaluation of Rubber ball sound

For the objective evaluation of rubber ball sound, the single number evaluation method of rubber ball sound should correlates well with subjective responses. Auditory experiments were conducted to investigate the relationship between single number indices and subjective responses.

Rubber ball impact sound sources were measured and recorded in reinforced concrete structure apartments. Rubber ball sounds were measured in eight apartments with different impact sound isolation system. The measuring condition of the place was just before moving-in after completing construction. The rubber ball sounds were recorded at the center of bedrooms and living room through a dummy head for the auditory experiments.

Auditory experiment on annoyance of rubber ball sound was performed in a testing booth. Electrostatic headphones were used for the binaural hearing experiment. The signals recorded from the reference floor and from seven other treated flats were presented to 30 Korean subjects who were mostly undergraduate and postgraduate students.

Table I. Nine category scales for evaluating annoyance levels of rubber ball sound.

Subjective magnitude		Scale 1 Noisiness	Scale 2 Disturbance	Scale 3 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!

After listening to each signal with duration of 10 seconds, subjects were asked to evaluate their annoyance to each floor impact noise using a three category annoyance scale by selecting average magnitude numbers from 1 to 9 on the computer screen. The three annoyance categories were; 'Noisiness', which specifies noise intelligibility, 'Disturbance' to ordinary activities at home and 'Amenity' as an evaluation of suitability of living. Table 1 shows that the noisiness levels ranged from a subjective magnitude of 1 which specifies the floor impact noise as 'hardly perceivable' to a magnitude 9 which specifies the floor impact noise as 'extremely noisy'. The values for the subjective evaluation were divided into three groups (1-3, 4-6, and 7-9). This helps subjects reduce the difficulty in determining the points of the scale.

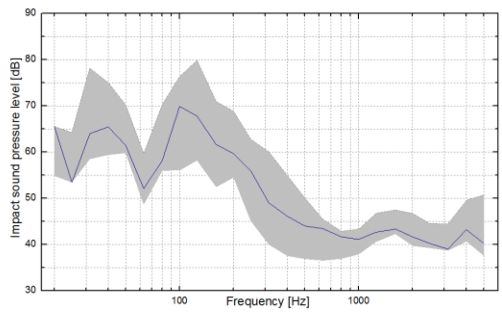

Figure 2. Frequency range of rubber ball sound

In order to select single number evaluation method for rubber ball sound, the relationships between the subject evaluation value and the single number evaluation value such as Arithmetic Mean (arithmetic mean value of octave band sound pressure level), L_{Amax}, Japanese L-index, Inverse-A and Zwicker's loudness were analyzed.

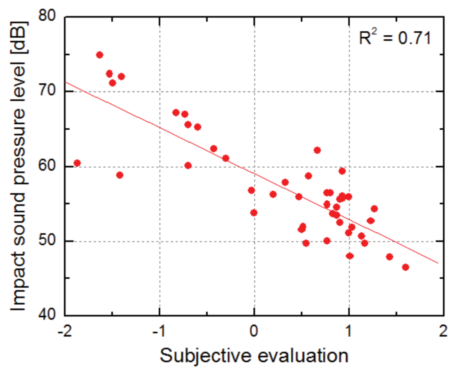

Figure 3. Relationship between subjective evaluation and arithmetic mean value

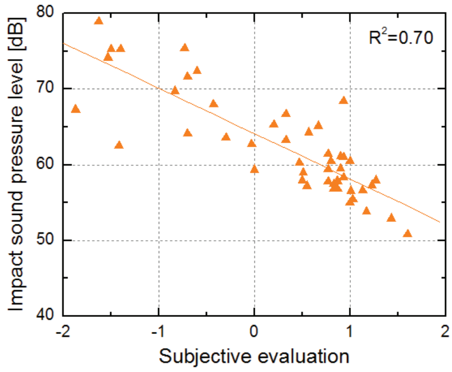

Figure 4. Relationship between subjective evaluation and A-weighted maximum sound pressure level

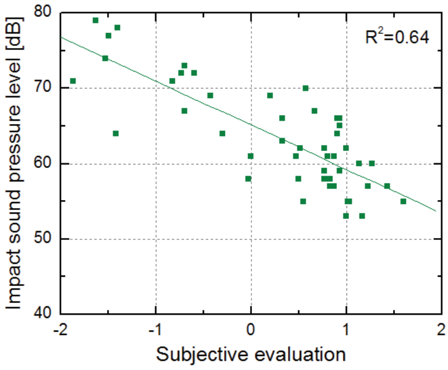

Figure 5. Relationship between subjective evaluation and L-index

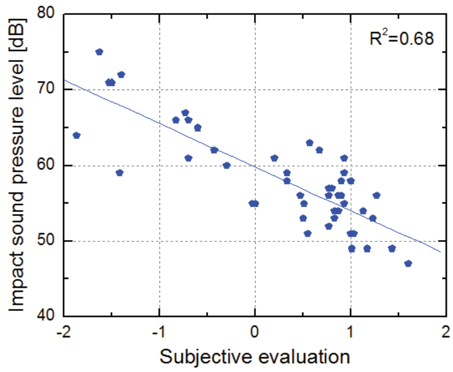

Figure 6. Relationship between subjective evaluation and Inverse A value

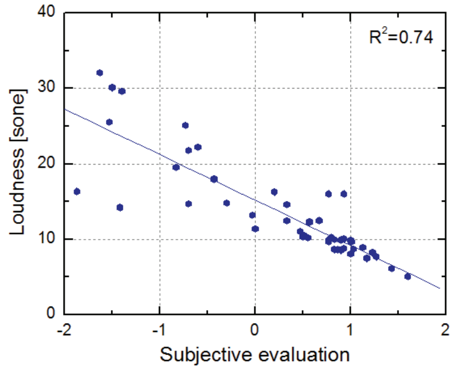

Figure 7. Relationship between subjective evaluation and loudness

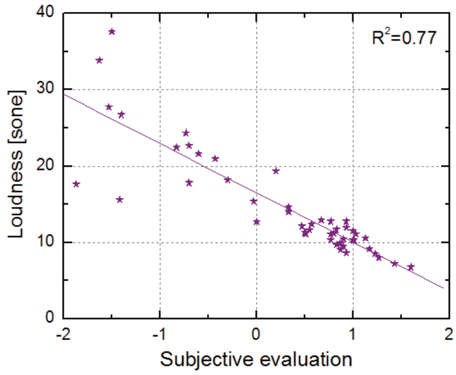

Figure 8. Relationship between subjective evaluation and loudness L10

The relationship between the subjective evaluation and the single number quantities for rubber ball was investigated. Figure 3 ~ 8 show the relationship between the subjective responses and single number quantities

The R^2 value of arithmetic mean of maximum sound pressure level of rubber ball sound was 0.71. The R^2 value of A-weighted maximum sound pressure level (L_{Amax}) with the rubber ball was 0.70. In the case of Japanese L-index, the R^2 value was 0.64. The relationship between subjective response and Inverse-A value ($L_{\mathrm{i,Fmax,AW}}$) was 0.68. L_{Amax} and $L_{\mathrm{i,Fmax,AW}}$ were based on L-curve(see Figure 1). L_{Amax} and arithmetic mean showed better relationship than L-curve based single number indices.

The relationship between Zwicker's loudness and subjective responses was calculated and shown in Figure 7 and 8. The R^2 value of loudness was 0.74. The relationship between Zwicker's L10 loudness and subjective responses was 0.77.

The best evaluation method related to subjective responses on the rubber ball sound was Zwicker's loudness L10.

4. Conclusions

For the evaluation of low frequency impact sound in residential building, the rubber ball was standardized in ISO standards. However, single number evaluation method on rubber ball was not standardized. There are several single number evaluation methods on heavy weight impact sound in KS and JIS; $L_{\mathrm{A,max}}$, arithmetic mean, L-index and $L_{\mathrm{i,Fmax,AW}}$. Loudness and loudness N10 were also known for high correlation with subjective evaluation results on rubber ball sound.

In order to find out single number index, which is correlated well with subjective results, auditory evaluation on rubber ball sound measured in high-rise concrete apartments was conducted. Subjective evaluation results show that L_{Amax} and arithmetic mean value had better relationship than L-curve based single number indices. Zwicker's loudness and loudness N 10 show the best correlation. However, measuring and calculating loudness need special equipment or software especially in field condition.

Previous study [4], which was conducted on Japanese wooden houses, show that L_{Amax} and arithmetic mean value could be used as single number index of rubber ball sound. L_{Amax} and arithmetic mean value showed good correlation performance with subjective results in concrete and wooden houses.

References

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