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Survey method for field measurement of rubber ball impact sound in reinforced concrete apartment houses in Korea – Based on the Korean measurement method

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Abstract – The rubber ball impact sound has been standardized by ISO 10140 series and ISO 16283-2 for laboratory and field measurements, respectively. The ISO 10052 standard specifies a survey method for the impact sound measurement using a tapping machine and a rubber ball. This study proposed measurement position for the survey method which is highly correlated with result based on the Korean Standards (KS) and the building regulation of South Korea for engineering method. The rubber ball impact sounds were measured in 79 reinforced concrete apartment houses**,** which have a centre point and four perimeter points for both exciting and receiving sounds. The proposed survey method was validated for only a specific type of apartment building layout and construction in the South Korean environment. The excitation and receiving points in the perimeter having the most similar characteristics to the results obtained using the Korean engineering methods were first selected. By combining the selected perimeter point and centre point for both the excitation and receiving sounds, the characteristics of each combination were compared with the results obtained using the Korean engineering method. When one excitation point or receiving point in the perimeter was added to the centre point for the proposed survey method, the difference between the measurement result using the engineering and proposed survey method decreased. The standard deviation of the difference between the SNQs of the proposed survey method and the Korean engineering method for measuring the rubber ball impact sound was smaller than 2 dB.

Keywords: Floor impact sound, Heavy and soft impact sound, Rubber ball, Survey method

1 Introduction

Apartment houses with reinforced concrete structures are widespread in South Korea, and high-rise apartment houses with more than 40 stories have recently been constructed. Owing to the nature of the apartment houses, the floor structures are shared between the upper and lower floors due to which civil complaints about floor impact sounds are continuously raised [1]. Various studies have been conducted to improve the insulation performance of floor impact sound of apartment houses, and it has been reported that the floating floor system can effectively reduce the light-weight impact sound [2–4]. Since 2005, South Korea has enforced the floor impact sound insulation structure certification and has obligated the use of floor impact sound insulation structures certified for performance based on the floating floor system. However, complaints from apartment residents about low-frequency heavy and soft impact sounds, such as the running and jumping sounds of children and the walking sounds of adults, are still being raised. Thus, the insulation structures to reduce low-frequency heavy and soft impact sounds are being developed continuously [5]. Floor impact sounds due to children jumping and walking typically have a frequency below 100 Hz, which coincides with the natural frequency of wooden frames [6] and concrete floor systems [7]. Heavy and soft floor impact sound pressure levels in the low-frequency range show large variations depending on the measurement point within a room [8, 9]. This is due to the non-diffuse sound field associated with different room configurations. New descriptors for the evaluation of the modal floor impact noise have been suggested [10].

Furthermore, the differences in floor impact sound insulation performances of the households of completed apartment houses have known to be large. It has also been reported that the performance of the floor impact sound insulation structures certified officially by the government is different from the insulation performance of the completed apartment households. According to a recent survey conducted by the South Korean government, the distribution

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of the floor impact sound insulation performance of apartment houses constructed with the same floor impact sound insulation structures was widespread [11]. This is due to the lack of quality control at every construction stage of apartment houses. Recently, there has been an increase in interest in the construction quality control during the construction stage of floor structures, including floor impact sound insulation structures and finishing materials [12]. The Korea Land & Housing Company (LH) and many other construction companies in South Korea are strengthening quality control to achieve consistent floor impact sound insulation performance of apartment houses constructed with the same structure. The quality control methods for floor impact sound insulation structures include managing the properties of materials comprising the insulation structures and optimizing each component material after measuring the floor impact sound at each construction stage. In South Korea, the properties of floor impact sound insulation materials used in the field are regularly measured and managed for resilient materials that are the main components of floor impact sound insulation structures (floating floors) [5]. Therefore, to ensure a certain level of floor impact sound insulation performance after the final completion of apartment houses, a method of optimizing the materials comprising the floor structure by measuring the floor impact sound at each construction stage is required.

The floor impact sound measurement methods are classified by the accuracy grade of the precision method, engineering method, and survey method. For the precision method of measuring the heavy and soft impact sounds, ISO 10140 series [13, 14] can be used, and for the engineering method, ISO 16283-2 [15] can be used. However, it is not realistic to use engineering methods for lots of households under the field conditions during construction. Vorländer [16] suggested a simple and fast measurement method with a slightly low accuracy for screening tests and construction quality control in the field, and proposed a survey test method. In addition, Vorländer suggested that a difference of less than 2 dB between the single number quantity (L'_{nw}) of the survey method and the SNQ based on the engineering method is appropriate. The survey method in the building acoustics field has been standardized by ISO 10052 [17], and the introduction of ISO 10052 states that "*The methods may be used for screening tests of the acoustical properties of buildings*". Thus, it is an appropriate method for field use. The survey measurement method is based on the precision and engineering methods, and is specified as a simplified measurement method for the screening test or quality control of building products. Li [18] conducted a research to simplify the insulation performance measurement equipment for light-weight impact sound and to decrease the time required for measurement. The survey method for light-weight impact sounds using a tapping machine has been standardized by ISO 10052. According to the survey method, light-weight impact sounds are generated at two or three points in the upper-floor household and measured in the lower floor space. Next, the person measuring in the lower floor space, where the floor impact sound is transmitted, should measure the sound around the centre for approximately 30 s while holding a sound level meter in hand with the spatial average to maintain the distance of the arm's length. Pontarollo and Di Bella [19] reported that the measurement results obtained using the survey method according to ISO 10052:2004 exhibited a trend similar to those obtained using the engineering method (ISO 140-7). However, no results of studies on the survey method for heavy and soft impact sounds (rubber ball impact sound) have been reported.

This study proposed measurement point for a rubber ball impact sound survey method which is highly correlated with result by Korean engineering method considering Korean building regulation and situation. Based on the measurements in various Korean apartment houses, the proposed survey method was compared with the Korean engineering method according to the KS F 2810-2 [20] and Korean building regulation [5], which is specified for apartment houses in South Korea. The excitation points and receiving points in KS F 2810-2 were different from those used in ISO 16283-2. Table 1 presents a comparison of the corresponding measurement setups. The results of different combinations of sound impact and receiving positions for the proposed survey method setting were compared for the conditions at the centre and perimeter points.

2 Rubber ball impact sound measurement

In South Korea, the floor impact sound insulation performance in the field is typically measured using the Korean engineering method. The measurement of the floor impact sound insulation performance in the field has been standardized according to KS F 2810 part 1 [21] and part 2 [20] for light-weight impact sound using a tapping machine and heavy and soft impact sound measurement methods, respectively. KS F 2810-2 specifies rubber ball as the second standard heavy impact source. According to KS F 2810-2, the impact sound must be generated at 3–5 points on the floor, including the centre point, and the measurements must be spatially averaged at least 4 points, including the centre point of the lower receiving room. In addition, the rubber ball impact sound is measured in the 50 Hz–630 Hz band of the maximum sound pressure level. The floor impact sound measurement method specified in Korean Standards is similar to that specified in Japanese Industrial Standards. South Korea is currently in the process of operating the floor impact sound insulation structure certification system, and the measurement method for the floor impact sound insulation performance is detailed in building regulation [5]. To minimize the discrepancy between testing institutions or testers, Korean building regulation clearly specify the positions of the centre point and four perimeter points with respect to partition walls. All onsite measurements conducted in Korea must observe Korean building regulation. According to the building regulation, the floor impact sound must be generated at the centre point and four perimeter points and measured at height of 1.2 m at the centre point and four perimeter points in the receiving room. When establishing the Korea

Table 1. Comparison of rubber ball measurement conditions required by various standards and Korean building regulation.

	KS F 2810-2	Korean building regulation	ISO 16283-2
Impact positions	3–5 positions including the centre point, positions must be at least 0.5 m from the room boundaries.	More than 4 positions including the centre point.	Four or more positions on the floors.
Receiving positions	At least 4 evenly spaced measurement points separated from each other by > 0.7 m. Additionally, the points should be separated from the ceiling, surrounding walls, and floor by > 0.5 m.	More than 4 receiving positions including the centre point.	Microphone positions shall be distributed within the maximum permitted space throughout each room. No two microphone positions shall lie in the same plane relative to the room boundaries and the positions shall not be in a regular grid.
Minimum distance between microphone		0.75 m from the walls (0.5 m from the walls if the room area < 14 m^2).	0.7 m between microphones. 0.5 m between microphone position and the room boundaries.
Receiving height		1.2 m from the floor.	1.0 m between any microphone position and the partition being excited by the impact source.

Definition of the heavy-weight maximum impact sound pressure level in KS F 2810-2 [20] (Korean Engineering method).

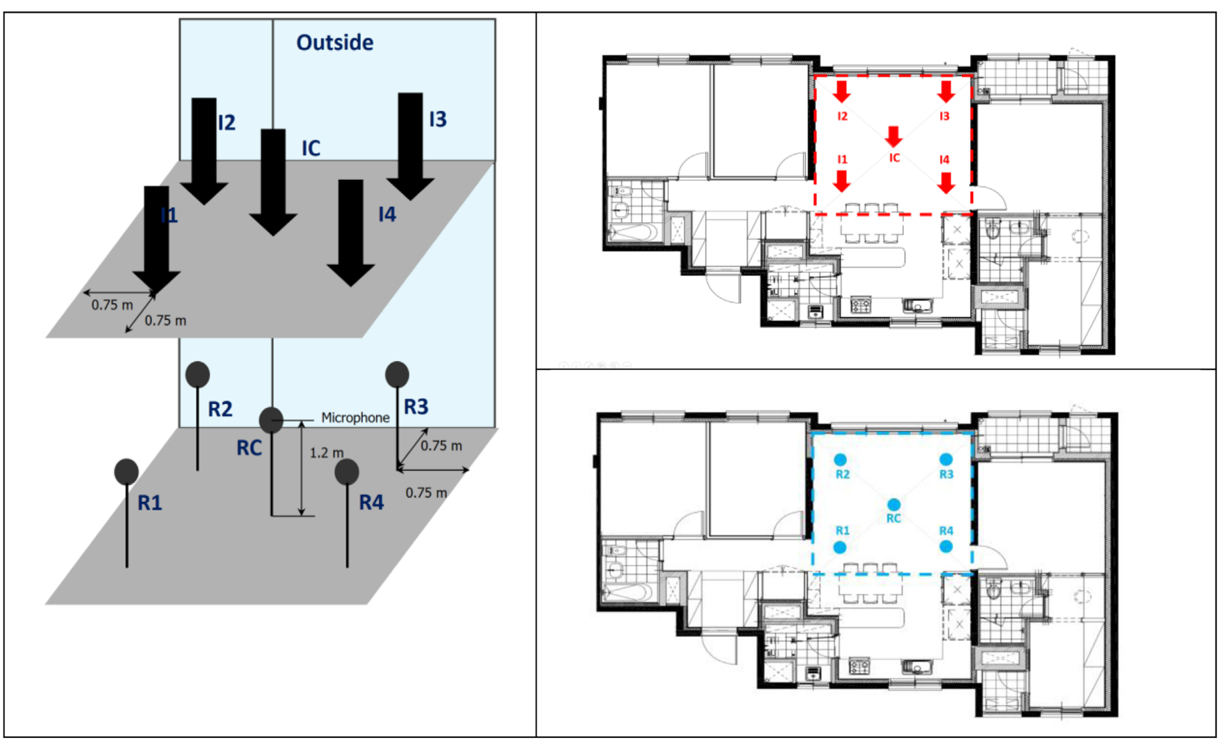


Figure 1. Diagram illustrating the floor impact sound insulation performance measurement settings used in the Korean engineering method based on the KS and Korean building regulation. The impact (red arrows) and receiving points (blue dots) are indicated on the floor plan of a typical Korean apartment building unit (area: 84 m^2). I2 and I3 (R2 and R3) are points in the perimeter area. I1 and I4 (R1 and R4) are points in the virtual perimeter area, which was inside the measurement area marked by the dashed line.

building regulation, Korean experts agreed that the receiving height must be same for the measurements in accordance with the legal building regulation, to minimize the dispute regarding the level difference associated with height differences. Finally, the receiving height was set as 1.2 m, considering the height of a sitting person. The measurement methods specified by the KS and the building regulation of South Korea are illustrated in Figure 1 and compared with

Table 2. Details of the 79 measured units (measurements were conducted in the living room).

Site	Number of units	Area of unit (m^2)	Volume of receiving room (m^3, virtual)	Floor type	Finishing	Construction company
F1	5	84	70.2	F1-A	O	A
	9	84	52.9	F1-B	O	A
	6	84	69.1	F1-C	O	A
	5	84	70.2	F1-D	O	A
	5	59	46.7	F1-E	O	A
F2	3	84	62.6	F2-A	X	A
	3	84	62.6	F2-B	X	A
	3	84	54.2	F2-C	X	A
	6	84	62.6	F2-D	X	A
F3	1	84	56.4	F3-A	O	B
	1	96	77.0	F3-A	O	B
F4	1	84	60.2	F4-A	O	B
	1	110	104.4	F4-A	O	B
F5	4	84	57.6	F5-A	O	B
F6	1	59	44.4	F6-A	O	B
F7	1	84	66.0	F7-A	O	B
	1	96	79.4	F7-A	O	B
F8	2	84	61.0	F8-A	O	B
F9	1	84	64.3	F9-A	O	B
	1	98	85.0	F9-A	O	B
	3	115	108.7	F9-A	O	B
F10	2	84	67.9	F10-A	O	B
F11	1	70	48.2	F11-A	O	B
	1	84	61.2	F11-A	O	B
F12	1	84	61.7	F12-A	O	B
F13	1	84	60.3	F13-A	O	B
	1	99	80.2	F13-A	O	B
F14	1	84	63.3	F14-A	O	B
F15	2	84	66.4	F15-A	O	B
F16	2	84	65.4	F16-A	O	B
F17	3	84	62.4	F17-A	O	B
F18	2	84	67.3	F18-A	O	B
Total	79					

ISO 16283-2 in Table 1. The dashed lines in Figure 1 indicate the rectangular measurement area, which was defined based on the Korean building regulation. This measurement area was selected because most Korean living rooms are connected to the kitchen asymmetrically. Impact and receiving points 2 and 3 are perimeter points on the window side. Impact and receiving points 1 and 4 are virtual perimeter points inside the living room.

The measurement and evaluation results of the rubber ball impact sound obtained using the Korean engineering method standardized according to the KS and Korean building regulation were compared with those obtained using the proposed survey method. The rubber ball impact sound was measured in 78 m^2 to 115 m^2 reinforced concrete apartment houses of 79 households in total. At present, the most widely used apartments in Korea are sized 59 m^2 to 84 m^2, and two or three standard sizes are typically designed to allow the consumers to easily compare the alternatives. In this study, 78 m^2 and 115 m^2 refer to the actual living area, excluding the area of the corridors and stairs. The room height of all apartment units in which the measurements were conducted was 2.4 m, typical for apartments in Korea. Because the apartments in the same or similar blocks of apartment buildings are nominally identical, the findings of this study are limited to similar Korean apartments because the maximum heavy impacts are observed at low frequencies, depending on the room volume and floor size.

The properties of the 79 units are summarized in Table 2. Two types of measurement equipment were used for the field measurements. The B&K PULSE system was used for the measurements of F1 and F2 sites constructed by company A. A Rion SA-02 system was used to perform the measurements for the sites constructed by company B. Robinson and Hopkins [22] showed that for certain transient sounds, different measurement equipment can yield different L_{Fmax} values in low-frequency bands. This aspect likely led to the different results obtained for companies A and B.

In Korea, the floor impact sound insulation performance is mostly required to be measured in the living room of each household, as most floor impact sound and related complaints relate to this area of the apartment. Korean apartment that is constructed with reinforced concrete is built such that the vertically neighbouring units share the same layouts and floor plan. The walls of the living room are

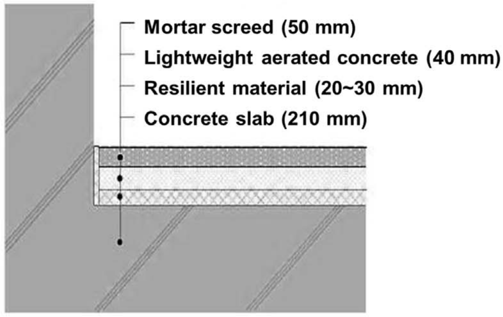


Figure 2. Floor section composition in typical Korean apartment buildings (left) and field measurement setup in accordance with KS and Korean building regulations (right).

mostly load-bearing walls, which are designed to be sectionally consistent throughout units (refer to the floor plan in Fig. 1). The measurement setup for the rubber ball impact sound is shown in Figure 1. The sound was generated at the centre point (IC) and four perimeter points. In the receiving room on the lower floor, the rubber ball impact sound was measured at a height of 1.2 m at the centre point (RC) and four perimeter points. The rubber ball impact sound was measured in the range of 50–630 Hz of maximum sound pressure level in the 1/3 octave band and then converted into the 1/1 octave band level.

For each rubber ball position j, the maximum impact sound pressure level $L'_{F\max,j}$ in the receiving room is determined as

$$L'_{F\max,j} = 10\log\left(\frac{1}{n}\sum_{k=1}^{n}10^{L'_{F\max,j,k}/10}\right),$$

where, $L'_{F\max,j,k}$ is the maximum impact sound pressure level at receiving point (k) when the jth impact point is impacted, and n is the number of receiving positions.

The maximum impact sound pressure level ($L'_{i,F\max}$) of each octave band is determined as the arithmetic average of $L'_{F\max,j}$).

The spectra of each excitation and receiving point were energy-averaged and evaluated using $L'_{\mathrm{iA,Fmax}}$, which is the SNQ defined in ISO 717-2 [23].

Figure 2 also shows the floor section and measurement setup of an apartment house. In every apartment house, certified resilient materials of thickness 20–30 mm were applied on a concrete slab of thickness 210 mm to reduce the floor impact sound. Above the resilient materials, lightweight aerated concrete of thickness 40 mm and mortar screed of thickness 50 mm were applied for heat insulation. All the rubber ball impact sounds were measured in the living room. In 15 households, the sounds were measured prior to flooring and wallpaper finishing work. In 64 households, sounds were measured without furniture after the finishing work. The floor plans shown in Figure 1 were expected to include furniture; however, at the time of the measurements, no furniture was present in the apartment unit. The average SNQ of the rubber ball impact sound measured based on the Korean engineering method in scenarios without and with finishing material installation by company A was 55.6 dB and 52.9 dB, respectively, corresponding to a difference of 2.75 dB. According to the t-test, this difference was statistically significant (Tab. 3).

In addition, the average SNQ of the rubber ball impact sound for different construction companies was compared through the t-test. For company B, all the site measurements were performed after the finishing material was installed. In contrast, for company A, measurements for site F2 were performed before the finishing material was installed. The SNQs for site F1 were compared to those for the site of company B. The average SNQs for companies A and B were 52.9 dB and 48.7 dB, respectively, corresponding to a difference of approximately 4.2 dB, which was statistically significant. The average level difference between companies A and B could be attributed to the use of different measurement equipment [22].

In most Korean apartment buildings, no clear boundary exists between the living room and kitchen. This type of floor plan is designed to provide additional wide space in each unit. Notably, Korean building regulations require the measurement of the floor impact sound isolation performance in the living room of the apartment unit because the questionnaire surveys in Korea have indicated that the floor impact sound is typically generated in the living room. To distinguish the living room from the kitchen space, Korean building regulations consider the virtual cubic space defined based on the basic floor plan.

3 Results: Comparison of the proposed survey method for rubber ball impact sound with the Korean engineering method

The survey method for lightweight impact sound and airborne sound insulation of ISO 10052:2021 specifies that the sound must be generated near the centre of the source room, received near the centre of the receiving room, and then spatially averaged using the manual scanning method. The service equipment sound is required to be measured at two fixed positions by selecting a position close to the corner and an additional point in the reverberant field. This study used a method of generating impact sound at the centre point and one additional point, and receiving sound

Table 3. Results of t-test for the SNQ of rubber ball impact sound between groups.

Group		N	$\overline{X}$	SD	df	t	p
Construction company	A	30	52.8567	1.83128	62	9.733	0.000
	B	34	48.6706	1.60992			
Finishing material	Not installed	15	55.6067	2.00409	43	4.603	0.000
	Installed	30	52.8567	1.83128			

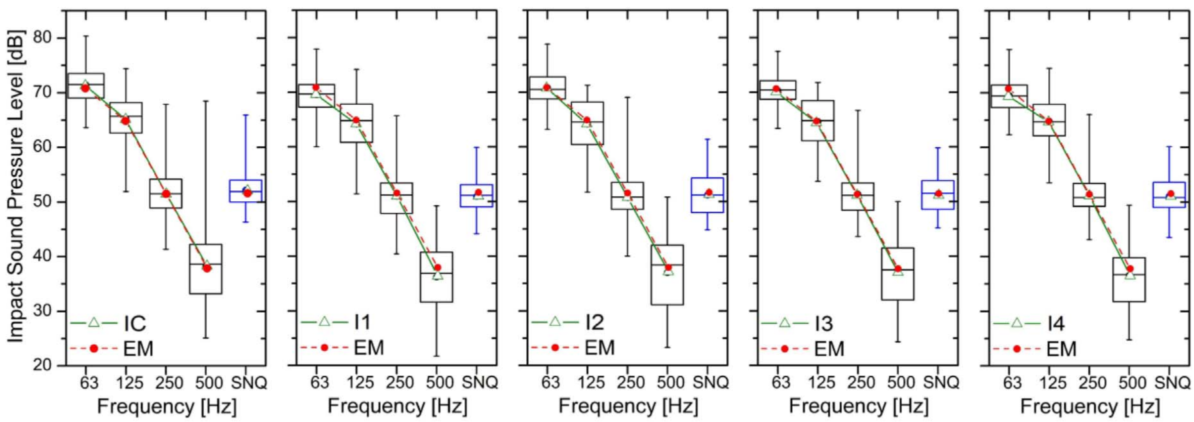


Figure 3. Comparison between the average spectrum at each excitation point (IC and I1 to I4) and average spectrum obtained using the engineering method of 79 apartment houses. The box plot shows the maximum and minimum values, first and third interquartile values, and median values for each excitation point.

at the centre point and one additional point by combining the existing survey method with rubber ball impact sound measurement using fixed microphone positions.

To select a point among the four excitation points in the perimeter area that has the most similar characteristics to the results obtained using the Korean engineering method, the average spectrum in the receiving room at each excitation point (one excitation and five receiving points) of 79 apartment houses was compared with the average spectrum obtained using the Korean engineering method (five excitation and five receiving points). The spectrum under both conditions was spatially averaged over five receiving points. Figure 3 shows the comparison of the average spectra and SNQs at each excitation point with the average spectra and SNQs obtained using the Korean engineering method of 79 apartment houses. The level distribution of each frequency band at each excitation is also shown in Figure 3. The maximum and minimum values in each frequency band are indicated using bars, and the median and first and third quartile values are indicated using boxes. As shown in Figure 3, the spectrum of 63–500 Hz band at the centre excitation point (IC) is highly similar to the spectrum obtained using the Korean engineering method. Table 4 presents the standard deviations for the differences between the rubber ball impact sound level at each excitation point and the average value obtained using the Korean engineering method for 79 apartment houses. As in Table 4, the average spectrum of IC had the smallest level differences from the average spectrum obtained with the Korean engineering method. Among the four perimeter points, the spectra at points I3 and I4 were the most similar to the spectrum obtained using the Korean engineering method, as shown in Figure 3. When the distributions of I3 and I4 points were compared, the level difference and distribution of 63 Hz band at I3 were smaller than those at I4, whereas the distributions of 125 Hz and 250 Hz bands at I3 were larger than those at I4. In Table 4, I3 point shows similar or lower standard deviations than the I4 point, except in the 125 Hz band. Thus, the excitation point I3 showed frequency characteristics similar to the average spectrum among the four perimeter points. The similarity with the averaged spectrum likely changed when different measurement data was gathered from apartment buildings with different sizes and structures.

Table 4. Standard deviations for the differences between the rubber ball impact sound level at each excitation point and the average obtained using the Korean engineering method for 79 apartment houses.

Octave band (Hz)	Impact point				
	IC (dB)	I1 (dB)	I2 (dB)	I3 (dB)	I4 (dB)
32	3.1	2.6	2.6	2.6	2.7
63	0.5	1.3	0.0	0.6	1.4
125	0.3	0.7	0.8	0.3	0.2
250	0.0	0.6	0.8	0.2	0.3
500	0.3	1.7	0.8	0.8	1.3
SNQ	0.6	0.6	0.4	0.3	0.5

Figure 4 shows the comparison of the average spectrum and SNQ at each receiving point with the average spectrum and SNQ obtained using the Korean engineering method of

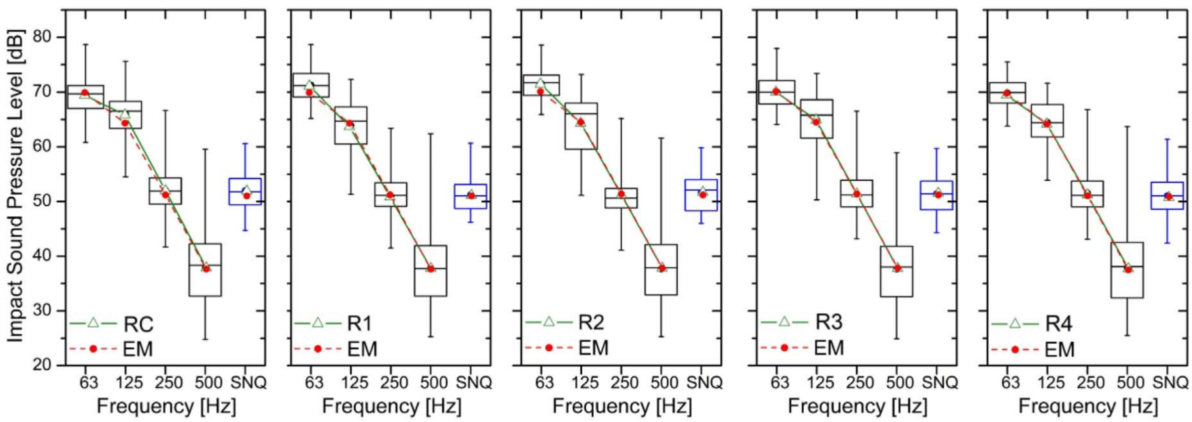


Figure 4. Comparison between the average spectrum at each receiving point (RC and R1 to R4) and average spectrum obtained using the engineering method of 79 apartment houses. The box plot shows the maximum and minimum values, first and third interquartile values, and median values for each receiving point.

79 apartment houses, along with the level distribution of each frequency band at each receiving point. The spectrum under both conditions was averaged over five excitation points. The spectrum at the centre receiving point (RC) differed from the average spectrum in the 250 Hz and lower band obtained using the Korean engineering method. Among the four perimeter receiving points, the difference in the average spectrum obtained using the Korean engineering method in the 63 Hz band at receiving points R1 and R2 was larger than that at the centre point. Among the five receiving points, R3 and R4 showed the most similar characteristics to the spectrum obtained using the Korean engineering method. Table 5 summarizes the standard deviations for the differences between the rubber ball impact sound level at each receiving point and the average value obtained using the Korean engineering method of 79 apartment houses. When the standard deviations for the differences between the spectra at R3 and R4 points and the spectrum obtained using the Korean engineering method were compared, the standard deviation at R3 was lower than at R4, except in the 125 Hz band. In particular, in the case of 63 Hz band, which has the largest impact sound level in the rubber ball impact sound, the standard deviation at R3 receiving point was 0.1 dB; however, it was 1.3 dB at R4 receiving point. A comprehensive examination of the spectrum differences and level distributions at the four receiving points in the perimeter area showed that receiving point R3 had the most similar characteristics to the spectrum obtained using the Korean engineering method.

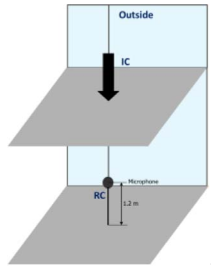
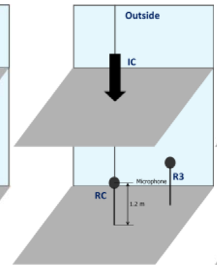
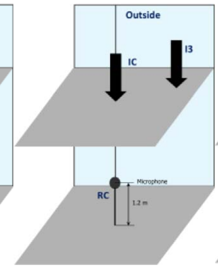
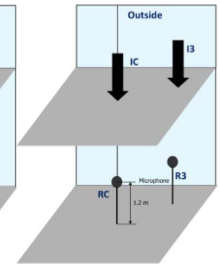
To compare the survey methods for the rubber ball impact sound, we selected the centre excitation and receiving points, and excitation point I3 and receiving point R3, which have similar characteristics to the total average spectrum obtained using the Korean engineering method. Four combinations that can be used as the proposed survey methods with two excitation points and two receiving points, including the centre point, were derived, as shown in Table 6. In addition, the average values obtained using the proposed survey and Korean engineering method are presented in Table 6, along with the average and standard deviation of the absolute differences between the proposed survey and the Korean engineering method. The proposed survey methods overestimated the SNQ from 1.3 dB to 0.5 dB. The SNQ difference between the Korean engineering method and proposed survey methods decreased when the impact and receiving point was added.

Table 5. Standard deviations for the differences between the rubber ball impact sound level at each receiving point and average obtained using the Korean engineering method for 79 apartment houses.

Octave band	Receiving point				
	RC (dB)	R1 (dB)	R2 (dB)	R3 (dB)	R4 (dB)
32 Hz	1.3	1.3	2.6	0.4	0.6
63 Hz	0.5	1.1	1.4	0.1	1.3
125 Hz	1.4	0.6	0.3	0.4	0.1
250 Hz	0.8	0.4	0.3	0.0	0.2
500 Hz	0.1	0.1	0.1	0.1	0.1
SNQ	0.9	0.1	0.5	0.3	0.1

Figure 5 shows the SNQ ($L'_{\mathrm{iA,Fmax}}$) derived from each combination of the proposed survey method settings compared to the SNQ of the measurement result obtained using the Korean engineering method. The first combination (combination 1) of the proposed survey method is a case where the floor impact sound is generated with a rubber ball only at the centre point and is received at the centre point. In a comparison with the SNQ measured and evaluated using the Korean engineering method, the correlation coefficient was 0.830, as shown in Figure 5a. In the first combination, the SNQ value derived using the proposed survey method tended to be slightly larger than the SNQ obtained using the Korean engineering method. The correlation coefficient for the combination of the centre receiving point and an additional receiving point (combination 2) improved to 0.899, as shown in Figure 5b. In the combination of the centre excitation point and an additional excitation point (combination 3), the correlation coefficient was

Table 6. Example combinations of the survey method for rubber ball impact sound.

	Combination 1	Combination 2	Combination 3	Combination 4
Impact point	IC	IC	IC, I3	IC, I3
Receiving point	RC	RC, R3	RC	RC, R3
Set-up				,
Average value ($L'_{\mathrm{iA,Fmax}}$), dB	52.8	52.4	52.3	52.1
Average absolute difference (engineering survey), dB	2.0	1.5	1.5	1.1
Standard deviation of absolute difference (engineering survey), dB	1.5	1.1	1.0	0.7

* The average $L'_{\mathrm{iA,Fmax}}$ for 79 apartment units measured using the Korean engineering method was 51.6 dB.

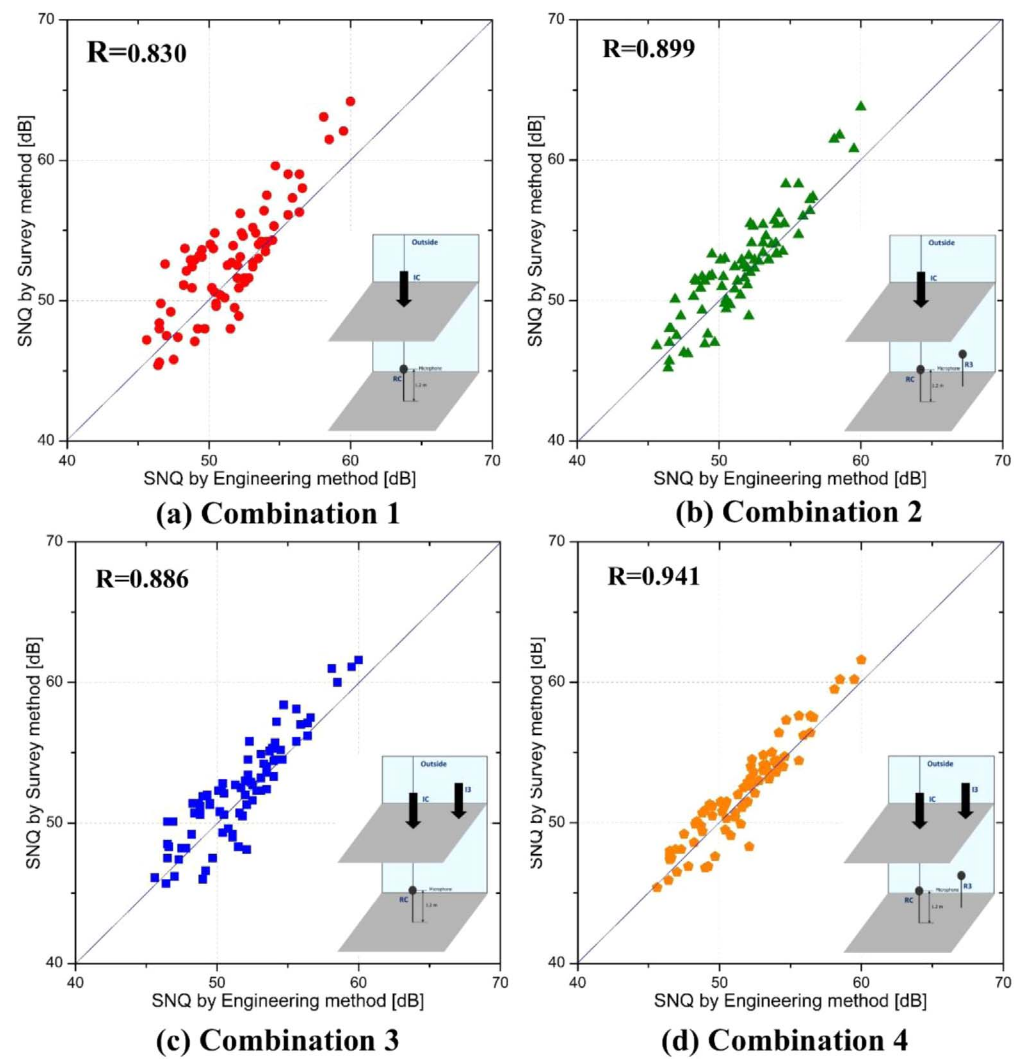


Figure 5. Relationship between the SNQ obtained using the Korean engineering method and four survey method settings for rubber ball impact sounds; R indicates the correlation coefficient between the two methods.

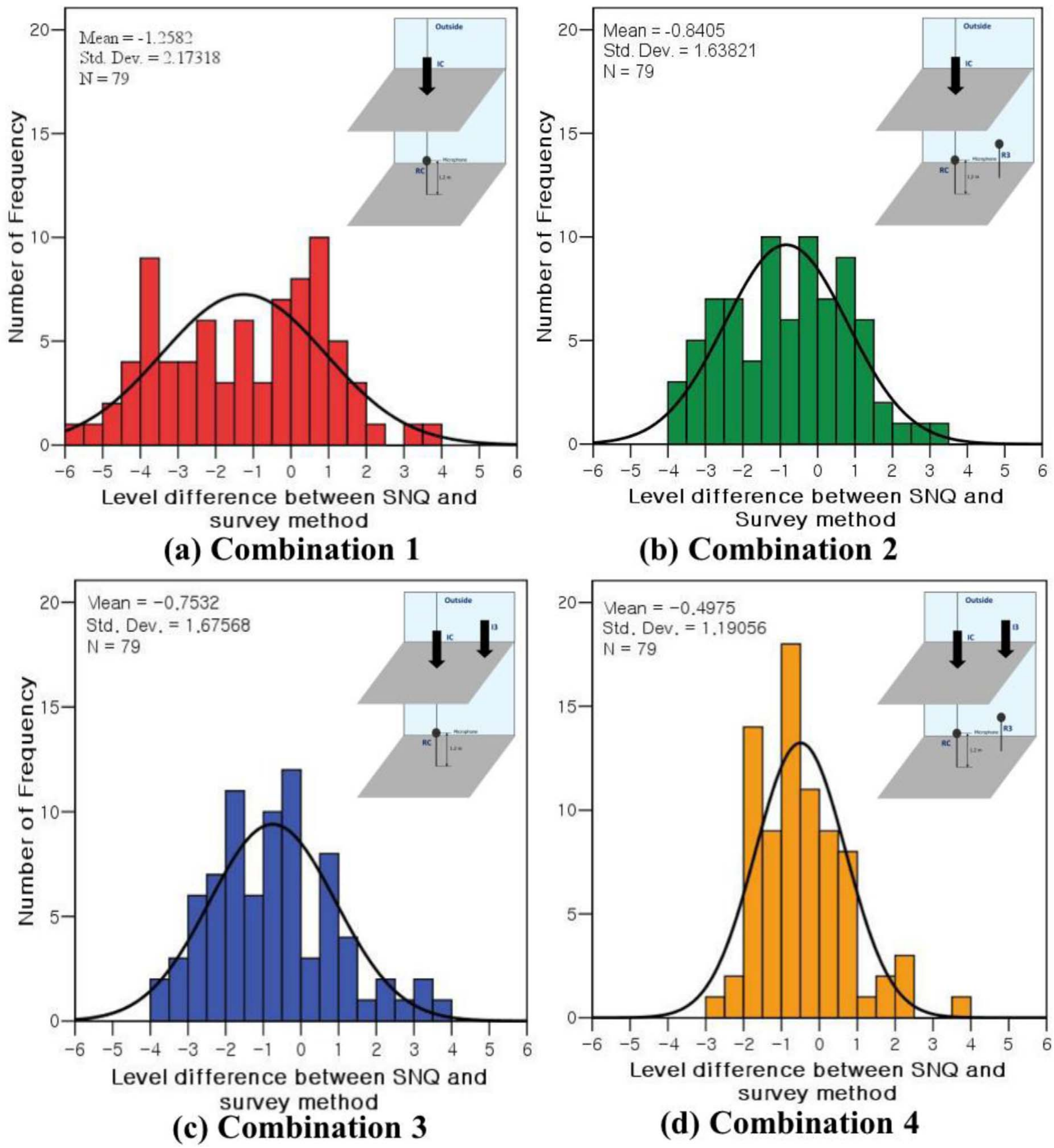


Figure 6. Histogram and estimated normal distributions of the differences between the SNQ derived using the Korean engineering method and four survey method configurations.

calculated as 0.886. When both receiving and excitation points were added (combination 4), the correlation coefficient was the highest at 0.941 among the four cases. When more receiving points were added than the excitation points, the correlation with the Korean engineering method further strengthened. This phenomenon likely occurred because when the number of receiving and excitation points was similar to that in the Korean engineering method, the results were comparable with those of the Korean engineering method. When establishing the survey method, the measurement ease and required time must be considered. This is why, in the ISO 10052 standard, one or two excitation and receiving points and/or a manual scanning method have been standardized for lightweight impact sound. In the case of the rubber ball impact sound, at least two receiving points and one or more impact points were standardized in ISO 10052:2021. In this study, the authors limited the number of excitation and receiving points to two and identified the most effective combination of excitation and receiving points.

Figure 6 shows the histogram and estimated normal distribution curve for the level difference between the SNQs obtained using the Korean engineering method and proposed survey measurement setup. The mean level difference

Table 7. Comparison of ISO 10052 based survey method and proposed survey method bases on the KS and Korean building regulations.

	ISO 10052	Proposed
Source room	• Near the centre of the source room. • A single position is sufficient if the floor and slab are isotropic.	• Centre point of the room • Centre and one perimeter point at the window side • Perimeter point: 0.75 m from the boundary walls or windows
Receiving room	• Two fixed positions including that near the centre position, at different heights. • Distances between the microphones and room boundaries is 0.5 m.	• Centre point of the room. • Centre and one perimeter point at the window side. • Height: 1.2 m. • Perimeter point: 0.75 m from the boundary walls or windows.
SNQ	• A-weighted maximum impact sound pressure level ($L_{iA,Fmax}$) with octave bands (63–500 Hz). • Overall A-weighted maximum impact sound pressure level (measured directly using the sound level meter).	• A-weighted maximum impact sound pressure level ($L_{iA,Fmax}$) with octave bands (63–500 Hz).

for each combination was negative (–), confirming that the SNQ obtained using the proposed survey measurement setup was slightly greater than that obtained using the Korean engineering method. Furthermore, the standard deviation of the level difference distribution of the two methods decreased when the receiving and excitation points were added. In the case of the fourth setup (combination 4) of the proposed survey method, in which the excitation and receiving points were added to the centre point, the difference in distribution was less than 2 dB in the measurement results for 72 out of the 79 households. Both the KS and the building regulation of South Korea specify that receiving points must be set at the same height. Since this reflects only the horizontal spatial average, the level deviation of the measurement results tends to be large. In this study, the level difference between the two methods was large because the proposed survey method setup and Korean engineering method results were compared using the measurement results based on the KS and building regulation of South Korea.

4 Discussion and conclusion

In this study, a survey method for heavy and soft impact sounds was developed, and the spectrum and SNQ was compared with the results of the Korean engineering method standardized according to the KS and building regulation of South Korea.

The proposed survey method for heavy and soft impact sounds was conducted considering the measuring points for light-weight impact sound specified in ISO 10052, and the measuring points specified in the KS and the building regulation of South Korea. The KS and the building regulation of South Korea require that the impact sound must be generated at the centre point and four perimeter points and measured at the centre point and four perimeter points at the same height (1.2 m). To compare the proposed survey method settings for heavy and soft impact sounds using the Korean engineering method, we selected perimeter excitation points and receiving points. The centre excitation point and the centre receiving point in the ISO 10052 standard were also selected. For fast and efficient measurements, four types of proposed survey methods were set and compared by limiting the condition to up to two excitation points and two receiving points. The proposed survey method was designed such that the frequency characteristics most similar to the measured and averaged values obtained using the Korean engineering method (field method) were selected, and small deviations in the major frequency band were investigated.

The SNQ obtained by generating and measuring sound at the centre point was strongly correlated ($R^2 = 0.830$) with that of the measurements obtained using the Korean engineering method. When an excitation point or receiving point was added, the correlation with the SNQ of the Korean engineering method strengthened, and the difference between the SNQs of the KS engineering and proposed survey method decreased. The standard deviation of the difference between the SNQ of the KS engineering and proposed survey methods was less than 2 dB when an excitation point or a receiving point in the perimeter was added. Furthermore, the SNQ of the proposed survey method was slightly higher than that of the Korean engineering method. The centre position and a perimeter position (R3) near the window were selected for the proposed survey method. In general, the perimeter positions (R2 and R3) near the window may be symmetrical in plan but structurally asymmetric because of different side wall profiles. Therefore, the measurements for the perimeter position near the window may vary. Consequently, in this study, a perimeter position near the external wall and window was used for the survey method, where the floor impact sound pressure level vary less across individual apartments than those in the inner positions near the kitchen.

It was confirmed that the proposed survey method for the heavy and soft impact sounds could also be used for screening test or field quality control. However, the result of this study is based on measurements according to the KS and the building regulation of South Korea, and it is necessary to verify the application results and make improvements to apartment houses of various architectures and sound insulation structures. In this study, the proposed survey method for heavy and soft impact sounds were compared based on the measurements made in South Korea. Table 7 indicates the comparison of ISO 10052 based survey method and proposed survey method bases on the KS and Korean building regulations. The results confirmed that the correlations and standard deviations of the proposed survey method for heavy and soft impact sounds are similar to those associated with impact sound insulation with a tapping machine.

To improve the floor impact sound isolation performance in situ, it is necessary to improve the construction quality of the floor impact sound isolation system. The floor system used in Korea is composed of a multi-layered framework with resilient material and a floor heating system. Therefore, the floor impact isolation performance of every unit must be measured using simple measurement methods, and the test results must be comprehensively analysed using the quality control factors in each construction stage. To implement quality management considering the type of structures in each country, it is necessary to establish a measurement method for quality control in field conditions, based on the survey measurement method of ISO 10052:2021. In this study, a survey measurement method was specified for apartment houses in Korea, for which data was measured using a rubber ball impact source. The results of this study can provide guidance for establishing survey measurement methods for quality control in different countries and by different construction companies.

Notably, the proposed survey method has been validated for only a specific type of apartment building layout and construction in the Korea environment. In the future, we will apply the proposed survey method for heavy and soft impact sounds to the construction field and develop a more reliable and useful survey method utilizing the survey method in the research for the performance and construction quality improvement of floor impact sound insulation structures for each construction stage. In addition, as this study is based on the KS and Korean building regulations, its outcomes may differ from those based on ISO 16283-2. As such, further research on survey methods for various measurement outcomes based on ISO 16283-2 is necessary.

Conflict of interest

The authors declare no conflict of interest.

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