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Evaluation of Heavy-weight Floor Impact Sound using Tapping Machine

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Abstract

With the recent strengthening of floor impact sound requirements for apartment buildings in Korea, measurement demand has increased, making testing efficiency an important issue. Current assessments require separate measurements using a tapping machine as the light-weight impact source and a rubber ball as the heavy-weight impact source, increasing measurement time, labor, and cost. This study examined whether a single tapping-machine measurement could be used to evaluate heavy-weight floor impact sound characteristics. The analysis used data from 50 floor systems installed in 59 m² and 84 m² apartment units. Single-number quantities and one-third-octave-band results obtained using the two impact sources were compared. When the current A-weighted heavy-weight impact sound evaluation method was applied, the coefficient of determination was R^2= 0.5481. Without A-weighting of the tapping-machine results, it increased to R^2= 0.8072. The frequency-band coefficients were R^2= 0.8001 at 63 Hz and R^2= 0.9151 at 100 Hz. Although the tapping machine cannot directly replace the rubber ball, non-A-weighted tapping-machine results combined with low-frequency correction may support preliminary screening and prediction of heavy-weight floor impact sound performance.

Keywords: *floor impact sound, tapping machine, rubber ball, low frequency band, rating method*

1. Introduction

Floor impact sound is generated when an impact applied to an upper floor excites the building structure and the resulting vibration is radiated as noise into the space below. It is one of the major acoustic performance issues in apartment buildings. In Korea, floor impact sound has increasingly developed beyond an everyday nuisance into serious disputes between neighbors. For example, in connection with an apartment arson incident in Seoul in April 2025, it was reported that the suspect had previously experienced conflict over floor noise at a former residence, highlighting how floor noise can escalate into a significant social issue.

Floor impact sound assessment is divided into light-weight impact sound evaluation, representing impacts such as the dropping of hard objects, and heavy-weight impact sound evaluation, representing impacts such as children jumping. The standardized tapping machine is an internationally used light-weight impact source. Its five hammers are repeatedly dropped from a fixed height, providing stable and highly repeatable excitation. Heavy-weight floor impact sound is generally measured using a rubber ball impact source. The rubber ball strongly excites the low-frequency range and therefore produces characteristics similar to actual heavy residential impacts. However, because it is operated by free fall, the measured results may vary depending on the drop position, drop angle, orientation of the joint line, and contact condition. In addition, operating both impact sources during the same survey increases measurement time and labor requirements.

A simplified measurement procedure using a single impact source could be useful for screening evaluations, product development, and comparative diagnosis during research and development. Therefore, this study investigates whether the low-frequency response of the tapping machine can be used to evaluate heavy-weight floor impact sound characteristics and analyzes the reasons for the limited explanatory relationship between the two impact sources when the current heavy-weight impact sound evaluation method is applied.

2. Measurement and analysis

2.1 Test sources and measurement principle

Standardized floor impact sources can be broadly classified into light-weight and heavy-weight impact

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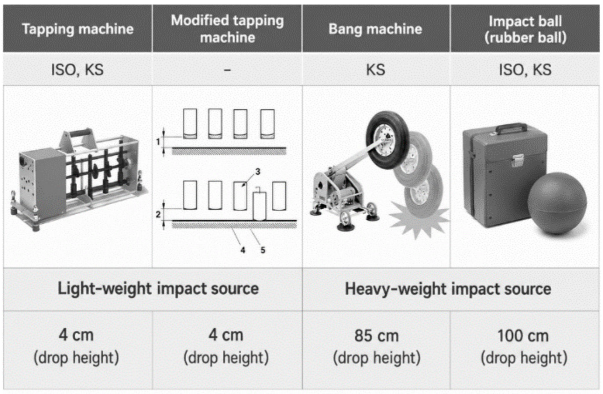
sources, as summarized in Table 1. The tapping machine is commonly used as the standard light-weight impact source, and a modified tapping machine has also been proposed to extend the range of impact characteristics. Heavy-weight impact sources include the bang machine and the rubber ball (impact ball). The comparison presented in Table 1 is intended to describe the general classification and operating characteristics of standardized impact sources.

Table 1. Types of standard impact sources



Tapping machine	Modified tapping machine	Bang machine	Impact ball (rubber ball)
ISO, KS	–	KS	ISO, KS
Light-weight impact source		Heavy-weight impact source	
4 cm (drop height)	4 cm (drop height)	85 cm (drop height)	100 cm (drop height)

Recently, the rubber ball has also been adopted in Korea as the standard impact source for evaluating heavy-weight floor impact sound. Therefore, this study focused only on the two standardized impact sources: the tapping machine and the rubber ball.

The tapping machine generates repeated impacts by dropping five cylindrical hammers from a nominal height of 4 cm at regular intervals. This mechanically controlled operation provides stable and highly reproducible excitation. In contrast, the rubber ball is freely dropped from a height of 100 cm, generating a larger impact force with strong low-frequency components. Although the rubber ball better reproduces heavy impacts occurring in actual residential environments, its free-fall operation may introduce variations in the measurement results depending on the drop position, drop angle, ball orientation, and contact condition with the floor. Figure 1 shows the sound pressure level as a function of the rubber-ball drop height, indicating that the impact sound level tends to decrease as the drop height is reduced.

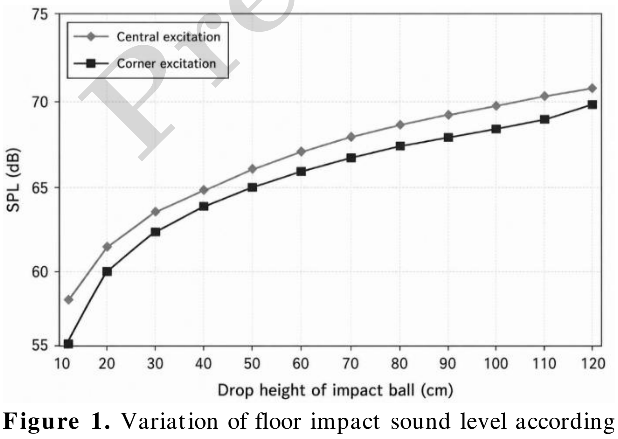


Figure 1. Variation of floor impact sound level according to rubber ball drop height

Field measurements were conducted in accordance with ISO 16283-2. As illustrated in Figure 2, the two impact sources were operated in the source room, and the resulting sound pressure levels were measured at the microphone positions in the receiving room below. The tapping-machine results were conventionally evaluated over the frequency range of 100–3150 Hz using the weighted standardized impact sound pressure level, $L'_{nT,w}$, whereas the rubber-ball results were evaluated over 50–630 Hz using the A-weighted maximum impact sound pressure level, $L'_{iA,Fmax}$ For the comparative analysis, one-third-octave-band levels measured using the tapping machine and rubber ball were obtained and examined over the heavy-weight impact sound evaluation range of 50–630 Hz. This analysis was conducted to determine whether the low-frequency response generated by the tapping machine could be used to predict or screen heavy-weight floor impact sound characteristics.

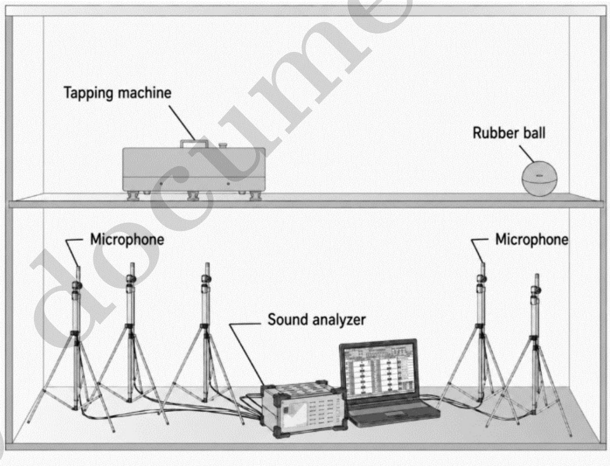


Figure 2. Measurement overview

Table 2. Comparison of Evaluation Methods

Source	Rating method	Frequency range (Hz)	A-weighting	Display format
Tapping	Light-weight	100-3150	X	L'_{nT,w_Tap}
Tapping	Heavy-weight	50-630	O	$L'_{iA,Fmax\_Tap}$
Tapping	Heavy-weight	50-630	X	$L'_{i,Fmax\_Tap}$
Ball	Heavy-weight	50-630	O	$L'_{iA,Fmax\_Ball}$

2.2 Database and statistical analysis

The analysis was based on measurement results from 50 floating-floor systems installed in representative Korean apartment units with floor areas of 59 m² and 84 m². For each floor system, measurement results were obtained using both the tapping machine and the rubber ball. The analysis focused on the low-frequency range most relevant to heavy-weight floor impact sound, with 50, 63, 80, and 100 Hz selected as the principal frequency bands.

First, the single-number quantities (SNQs) obtained from the two impact sources were compared. Next, the relationships between the level in each one-third-octave band and the corresponding SNQ were analyzed. Finally, to isolate the effect of frequency weighting, the heavy-weight impact sound quantity derived from the tapping machine measurements was recalculated without A-weighting. The strength of the linear relationships between variables was expressed using the coefficient of determination, R^2.

3. Results

3.1 Frequency Characteristics Governing the Single-Number Quantity for Each Impact Source

To identify the frequency bands that most strongly influenced the single-number quantities (SNQs) obtained using the tapping machine and rubber ball, the linear relationships between each one-third-octave-band level and the corresponding SNQ were analyzed.
The coefficient of determination between the rubber ball heavy-weight impact sound SNQ and the 63 Hz band level was $R^2 = 0.8547$. This indicates that approximately 85.5% of the variation in the rubber ball SNQ can be explained by its linear relationship with the 63 Hz band level. The next highest explanatory powers were observed at 100, 80, 50, and 160 Hz. This indicates that the rubber ball result is governed mainly by the low-frequency response below 125 Hz. Because the 100 Hz band also showed substantial explanatory power, both 63 and 100 Hz should be considered in a simplified heavy-weight impact sound evaluation.
For the tapping machine, the conventional light-weight impact sound SNQ showed the strongest relationship with the 200 Hz band, with $R^2 = 0.8849$. The principal bands were ranked approximately as 200, 160, 125, 250, 100, and 315 Hz. This indicates that the conventional tapping machine result reflects the mid-frequency response of the floor system more strongly than its low-frequency response.

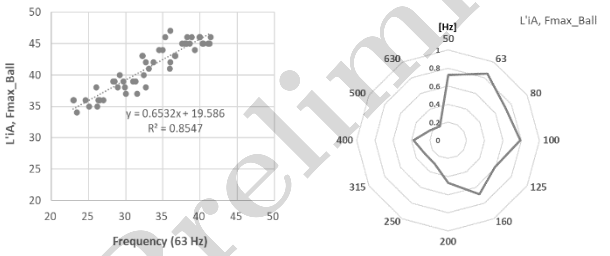


Figure 3. Frequency Dependence Analysis of the Rubber Ball in One-Third-Octave Bands

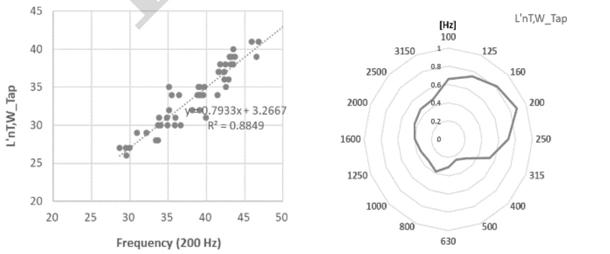
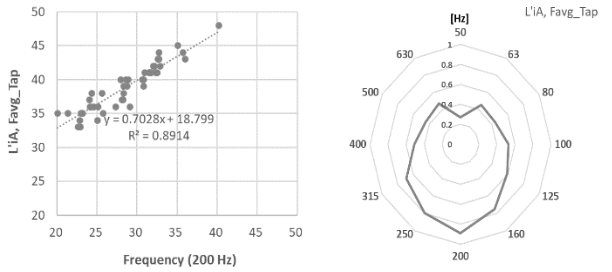


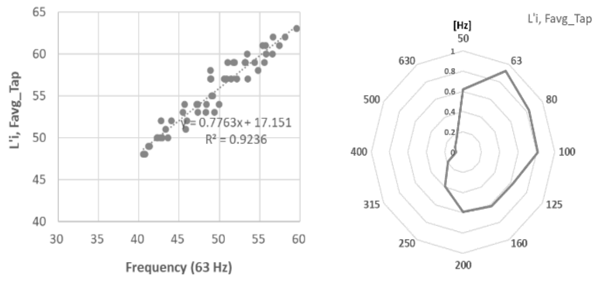
Figure 4. Frequency Dependence Analysis of the Tapping Machine in One-Third-Octave Bands

3.2 Analysis of Heavy-Weight Impact Sound Using a Light-Weight Impact Source

The tapping spectrum was restricted to the heavy-weight evaluation range of 50–630 Hz and processed using the current A-weighting procedure. Even under this condition, the tapping SNQ was most strongly influenced by the 200 Hz band, with $R^2 = 0.8914$. This trend differed from the rubber ball result, in which the low-frequency range around 63 Hz was dominant. The A-weighting corrections used in the heavy-weight impact sound evaluation method are −30.3 dB at 50 Hz, −26.2 dB at 63 Hz, and −19.1 dB at 100 Hz, substantially reducing the contribution of the low-frequency components associated with heavy-weight impact sound. Therefore, direct application of the current heavy-weight impact sound evaluation method to tapping machine data does not adequately preserve the low-frequency information. When the tapping machine results were recalculated without A-weighting, the relative contribution of the low-frequency bands, including 63 Hz, increased, resulting in frequency dependence more similar to that of the rubber ball evaluation than when A-weighting was applied. This indicates that the tapping machine response contains information related to heavy-weight impact sound performance, but that the current A-weighting procedure weakens this relationship.



(a) After A-Weighting to the Tapping Results



(b) Before A-Weighting to the Tapping Results

Figure 5. Comparison of Heavy-Weight Floor Impact Sound Evaluation Results Between the Tapping and Ball (Before and After A-Weighting)

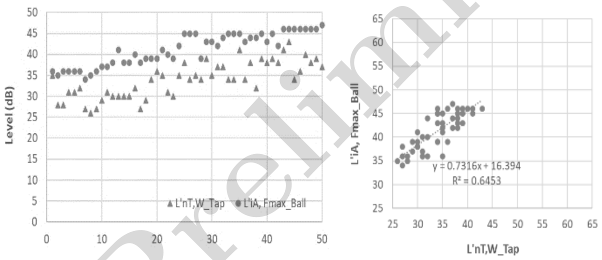
3.3 Comparison of Single-Number Quantities

The conventional light-weight impact sound SNQ obtained using the tapping was first compared with the heavy-weight impact sound SNQ obtained using the ball. The coefficient of determination was $R^2 = 0.6453$. However, because the two quantities are based on different frequency ranges and evaluation procedures, this relationship should not be interpreted as direct equivalence.

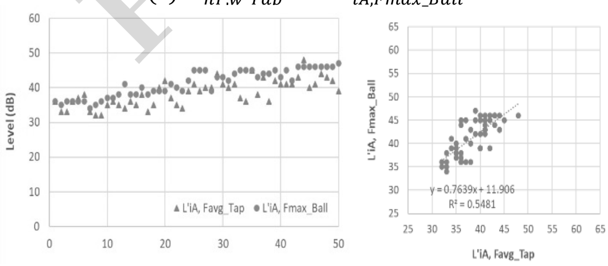
When both the tapping and ball results were evaluated over the heavy-weight range of 50–630 Hz using A-weighting, the coefficient of determination decreased to $R^2 = 0.5481$. This reduction occurred because A-weighting further suppressed the low-frequency components of the tapping machine spectrum, causing the response around 200 Hz to dominate the resulting SNQ.

In contrast, when A-weighting was not applied to the tapping machine results while the current A-weighted procedure was retained for the rubber ball results, the coefficient of determination increased to $R^2 = 0.8072$. This confirms that preserving the low-frequency response of the tapping machine improves its linear relationship with the rubber ball result.

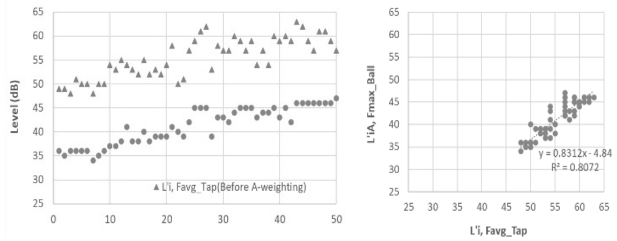
Overall, the relationship between the two impact sources was influenced more strongly by the application of A-weighting than by the nominal frequency range. Therefore, a separate non-A-weighted or low-frequency-based SNQ is required if tapping measurements are to be used for heavy-weight impact sound evaluation.



(a) L'_{nT,w_Tap} and $L'_{iA,Fmax\_Ball}$



(b) $L'_{iA,Fmax\_Ball}$ and $L'_{iA,Fmax\_Tap}$



(c) $L'_{iA,Fmax\_Ball}$ and $L'_{i,Fmax\_Tap}$

Figure 6. Comparison of Single Number Quantities

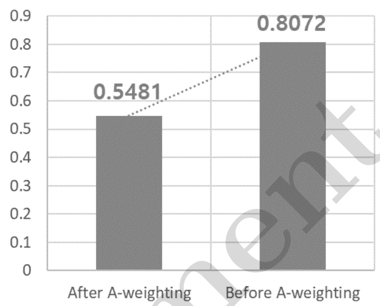


Figure 7. Comparison of Linear Relationships Before and After A-weighting

3.4 Comparison of Heavy-Weight Impact Sound Results

The A-weighted heavy-weight impact sound results obtained using the rubber ball were compared with the non-A-weighted low-frequency results obtained using the tapping machine on a frequency-band basis. Although the two impact sources differed in absolute level and impact-force characteristics, similar performance trends among the floor systems were observed in the principal low-frequency bands. The coefficients of determination were $R^2 = 0.6740$ at 50 Hz, $R^2 = 0.8001$ at 63 Hz, $R^2 = 0.8873$ at 80 Hz, and $R^2 = 0.9151$ at 100 Hz. The relatively high explanatory power observed in these low-frequency bands, which are relevant to heavy-weight impact sound evaluation, suggests that they may serve as important variables in a tapping-machine-based prediction model for heavy-weight floor impact sound. Therefore, by applying a correction model based on the low-frequency measurement results obtained using the tapping machine, it may be possible to predict the relative variation in heavy-weight floor impact sound performance measured with the rubber ball.

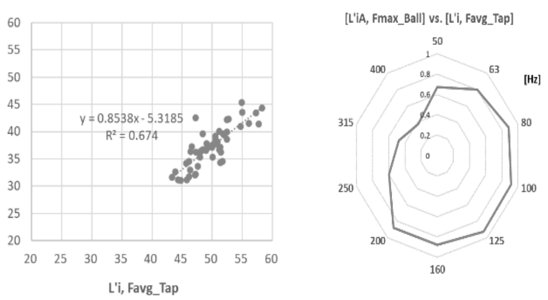


Figure 8. Comparison of Heavy-Weight Impact Sound Results

4. Discussion

4.1 Limitations Due to the Physical Differences Between the Impact Sources

The tapping machine and rubber ball differ in impact-force magnitude, contact duration, and frequency spectrum. The tapping machine generates short, repetitive impacts with relatively strong mid-frequency components, whereas the rubber ball produces a larger impact force with a longer contact duration and stronger low-frequency excitation.

Therefore, even if a high coefficient of determination is observed between the two measurements, the two sources cannot be regarded as producing physically equivalent responses in the floor system. The results of this study should be interpreted as indicating the predictability of relative performance differences among floor systems rather than the physical equivalence of the impact sources.

4.2 Limitations of the A-Weighted Evaluation Method

The current heavy-weight impact sound evaluation method applies A-weighting based on the strong low-frequency excitation produced by the rubber ball. However, when the same procedure is applied to the tapping machine, which has relatively weaker low-frequency excitation, the information in the 50–100 Hz range is excessively reduced, and the response near 200 Hz becomes dominant.

The improvement in explanatory power observed when A-weighting was not applied indicates that the low-frequency information from the tapping machine should be preserved. Therefore, it is more appropriate to develop a separate low-frequency screening quantity or predictive quantity tailored to the excitation characteristics of the tapping machine.

4.3 Applicability and Practical Use

Because the tapping machine generates mechanically controlled and repeatable impacts, its excitation conditions can be managed more consistently than those of a freely dropped rubber ball. It may therefore reduce measurement time and operational variability in product development, resilient-layer evaluation, and screening tests involving repeated comparisons of multiple specimens.

However, the present results are not sufficient to support direct replacement of the rubber ball in regulatory heavy-weight impact sound assessments. Rubber ball measurements should be retained until the prediction error, applicable range of floor systems, and risk of misclassification associated with tapping-machine-based models have been sufficiently verified.

4.4 Future Research

Future studies should verify the general applicability of the prediction model using independent datasets covering different slab thicknesses, room volumes, resilient-layer properties, and floor-finishing conditions. The following topics should also be examined:

- Development of a low-frequency correction model for tapping-machine measurements
- Comparison of the repeatability, reproducibility, and measurement uncertainty of the tapping machine and rubber ball
- Evaluation of the applicability of a modified tapping machine with enhanced low-frequency excitation
- Verification of the relationship between the proposed evaluation quantity and subjective responses to actual residential impacts

5. Conclusions

This study investigated whether the low-frequency response of a tapping machine could be used to evaluate heavy-weight floor impact sound measured with a rubber ball.

Under the current A-weighted evaluation method, the coefficient of determination between the two impact sources was only $R^2 = 0.5481$, indicating that direct replacement of the rubber ball measurement is not feasible. When A-weighting was not applied to the tapping machine results, the coefficient increased to $R^2 = 0.8072$. The frequency-band coefficients of determination were $R^2 = 0.8001$ at 63 Hz and $R^2 = 0.9151$ at 100 Hz.

Therefore, the tapping machine should not currently be regarded as a direct substitute for the rubber ball in regulatory testing. However, when combined with a non-A-weighted and low-frequency-based correction model, it may serve as a supplementary impact source for research, comparative evaluation, and preliminary screening. Further validation using a wider range of floor systems is required.

6. Acknowledgments

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