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Heavy-impact sound insulation performance according to the changes of dry flooring structure in wall structure

Jongwoo Cho [1]*, Hyun-Soo Lee [1], Moonseo Park [1], Hohwan Lim [1], Jagon Kim [1]

[1] *Department of Architecture and Architectural Engineering, Seoul National University, Seoul, Korea*
E-mail address: leone1118@snu.ac.kr

Abstract: The floor heating method generally uses a wet construction method including the installation of resilient material, lightweight foam concrete, heating piping, and finishing mortar. Such a wet construction method not only delays other internal finishing processes during curing period for two mortar pouring process, but also has a disadvantage that it is difficult to replace the floor heating layer when it deteriorated because it is integrated with the frame. Dry floor heating construction method can be a good alternative in that it can solve these defects. Conversely, when it applied to the wall structure that is vulnerable to the interlayer noise compared with the column-beam structure, the question about the heavy-impact sound(HIS) insulation performance is raised. Therefore, conventional dry floor heating method is hard to apply to the wall structure apartments.

Therefore, for the purpose to improve the applicability of dry floor heating method in wall structure apartments, this study investigated the change of floor impact sound, especially HIS insulation performance which is one of the required performance for the floor structure. This study tried to examine whether the change of heavy-impact sound pressure level(SPL) shows a tendency at the significant level according to the shape and mass of the floor structure.

Through filed experiments on wall structure apartment, this study confirmed that the form of the raised floor shows better HIS insulation performance than the fully-supported form. In addition, it was also confirmed that the HIS insulation performance increases with the mass on the upper part. Moreover, this study found the fact that a mass of about 30 kg/m^2 or more should be placed on the upper structure to reduce the heavy-impact SPL according to the bang machine measuring method. Although this study has a limit due to insufficient experiment samples, if the accuracy of this study is increased, it will contribute to the diffusion of dry floor heating by setting the HIS insulation performance target and designing the dry floor heating structure that meets the target.

Key words: Dry floor method, Heavy-impact sound, Sound insulation performance, Wall structure

1. INTRODUCTION

Nowadays, apartments are the most common type of housing in Korea. According to the data from National Housing Census of Korea, the proportion of people living in apartments has increased since 1990's, and now approximately 60% of the population lives in them (Fig. 1).

Conversely, the average lifespan of Korean apartment buildings is relatively short compared with other countries, which causes waste of resources (Fig. 2). One of the reasons of this short lifespan is due to the fact that parts and equipment with short-term lifespan are integrated with the concrete skeleton of apartments. Therefore, for longevity of apartments, the replaceable parts and the skeleton should separate each other.

In Korea, where has a high preference for floor heating, wet construction method is generally used to form the floor heating layer. It includes sequentially the installation of resilient material, lightweight foam concrete, heating piping, and finishing mortar. This method requires the curing period for two mortar pouring process. Such a wet construction method has the disadvantage of not only making it difficult to obtain uniform quality, but also delaying other internal finishing processes during curing period. However, the most important defect of this wet method is to make the floor heating equipment totally bond to the concrete frame. As a result, it is difficult to demolish only the heating layer when the heating pipe is aged and needs to be replaced. A dry floor heating construction method can be a suitable alternative in that it can solve these defects.

Fig. 1. Housing stock by type in Korea [1]

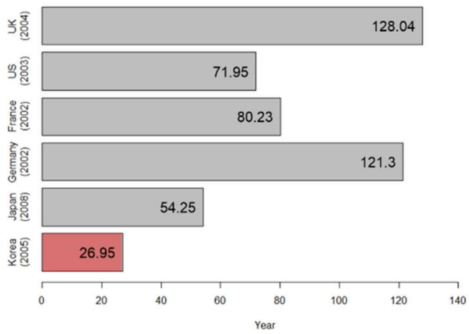


Fig. 2. Average replacement period of houses between countries [2]

In Korea, the interlayer noise is a serious social problem. Although there are many noise sources related to interlayer noise problem, the main cause of conflicts is the floor impact sound, especially heavy-impact sound(HIS) such as the sound of children leaping [3]. In addition to this, Korean apartments built after the 90's have mainly applied wall structure known to be relatively vulnerable to floor impact sound compared with column-beam structure [4]. Therefore, to mitigating the interlayer noise conflicts, only the certified floor structure for the performance about floor impact sound insulation can be built.

However, since it is known that the floor impact sound can be amplified when using the ordinary fully-adhered dry type method, the application of it is avoided in the field of wall structure apartments. As a result, the wet method for the floor finishing work still dominates in Korea.

Therefore, this study aims to contribute to improve the possibility of applying the dry floor heating method for wall structure apartment by studying on the trend of reducing HIS in the flooring structures based on dry method.

2. PRELIMINARY STUDY

To achieve the purpose as mentioned in introduction, this study investigates two types of floor structure constructed by the dry method at first. After that, we define the concept of interlayer noise insulation performance and, investigate literatures on the influence factors of HIS considered to be most closely related to floor impact sound insulation performance. Based on them, this study establishes and implements an experimental design.

A. Dry Floor Structure

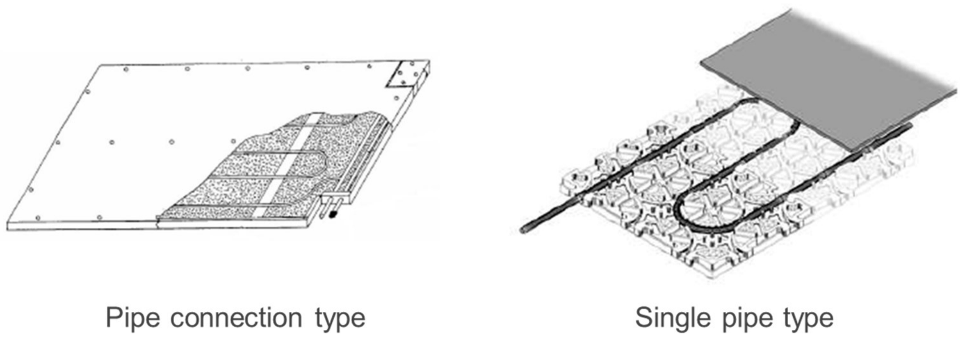
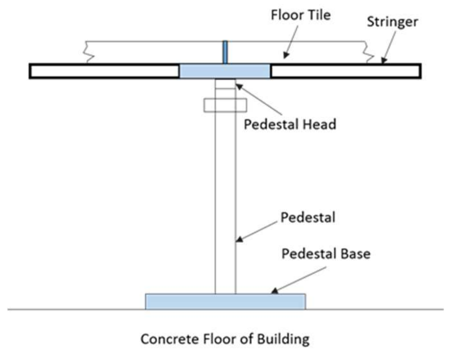


Fig. 3. Two type of Floor panels for hot water heating [5]

As mentioned in Chapter 1, the wet construction method is common to achieve floor heating using hot water. However, in Korea, where demand for hot water heating is high, products that can be implemented as dry method are manufactured. These are called Floor panels for hot water heating. In the Korean Standard(KS) regarding Floor panels for hot water heating [5], they are divided into Pipe connecting type (A type using panels with heat pipe pre-installed and connecting them with joint parts) and Single pipe type (A type using long and single heat pipe without any joints after the installation of pipe support panels) according to the installation method of the heating pipe. Although there is such a classification, both types fundamentally assume a form that fully attached to the floor surface. The detailed shapes of them can be seen in Fig. 3.

Another type of dry floor structure is Raised access floor that is typically used in office or computer room. The Raised access floor is defined as a floor with a combination of unit panels mounted on the floor of the structure and having a function that is easy to accommodate equipment such as electric, communication cable, or air conditioning facilities in its lower part [6]. Due to the burden of increasing construction costs, it is not used well in the residential buildings where the necessity of flexibility is relatively low compared with the office facilities. However, if applied, it can contribute to the longevity through improved flexibility of apartment unit plan.

Kim and Sohn (2006) present the concept of sound-insulated Raised access floor which contains resilient material such as anti-vibration rubber to the bottom of the support [7]. The detailed section of it can be seen in Fig. 4.



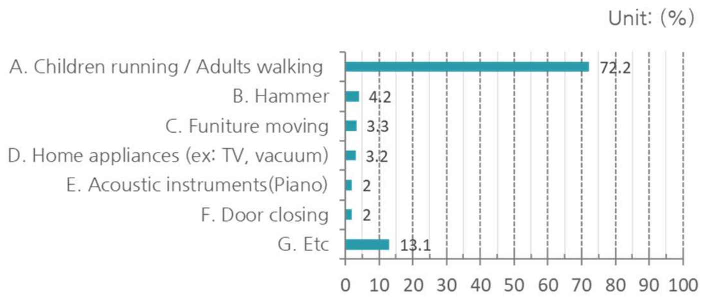


Fig. 4. Model of Raised access floor [8] **Fig. 5.** Cause of complaints related to interlayer noise [3]

B. Concept of Interlayer Noise Insulation Performance

Interlayer noise can be defined as the sound caused by the occupant's activities and damages to other occupants. According to the National Institute of Environmental Research(NIER) Report (2011), interlayer noise can be divided into air-borne sound transmitted through the air such as musical instruments and TV sound, hammer, and structure-borne sound (Or floor impact sound) transmitted through the impact of the structure such as children's beating sound. Of these, the floor impact sound is classified into two types of light-impact sound (which have small impact force and short duration such as small thing falling and heels, LIS) and heavy-impact sound (which have large impact force and long duration such as walking and running impact, HIS) [9].

According to the data of National Noise Information System of Korea, the cause of the conflict due to the interlayer noise can be seen in Fig. 5. Looking closely at this, most of them are floor impact sounds (81.7% = A+B+C+F of Fig. 5), and HIS (72.2% = A of Fig. 5) is dominant among them [3]. For that reason, the Grade criteria for floor impact sound isolation performance of Korea applies different criteria to LIS and HIS, and requires a higher level on HIS. However, in the case of LIS, 89% of the certified floor structures received 1st or 2nd grade, but in the case of HIS, only 19% of them could receive 1st or 2nd grade [9]. Therefore, this study sets the decrement of heavy-impact SPL to a representative index of the performance of interlayer noise insulation, and focuses on this, following experiments is implemented.

C. Influence Factors of Heavy-impact Sound

In the case of the floor structure constructed by the wet method, lots of studies have been conducted focusing on the resilient layer regarding the factors affecting the HIS. There is, however, a controversy in their results.

Seo et al. (2003) argued that in the range of dynamic stiffness of the resilient material commonly used in the conventional wet method, resonance can occur in the low frequency band which affects the heavy-impact SPL value, and it can lead deterioration of the performance [10]. Song et al. (2004) confirmed again that the movement of the natural frequency of the floor structure varying with the resilient material is highly correlated with the heavy-impact SPL [11]. Kim et al. (2008) demonstrated that as the resilient material becomes thicker, the value of dynamic stiffness decreases, and when various resilient materials are laminated, the total value of dynamic stiffness is similar to that of the lowest one. In addition, it was concluded that this value correlated with the decrement of heavy-impact SPL [12].

One the other hand, Oh and Sohn (2010) insists that there is no significant correlation between the value of dynamic stiffness and of reverse A-weighted SPL through the statistical analysis of the experimental data of the certified floor structures [13]. Moreover, no significant heavy-impact SPL insulation performance changes were observed for changes in rubber (resilient material) hardness in the experiment result of Yeon et al. (2012) [14].

Although it is not a conclusion for floor structures constructed by dry method, the LHI Report (2013) explains that using heavy-weight, high-rigidity flooring improves the performance of heavy-impact SPL insulation because the floor becomes hard to vibrate against floor impact sound [15].

Despite these precedent studies have collected data for each frequency band through experiments, they show a common tendency to make final decision with only single-number quantity for rating called reverse A-weighted SPL. Therefore, this study changes the mass and shape of the dry floor structure and measures heavy-impact SPL of each structure. After that, this study tries to estimated heavy-impact SPL reduction by changing these factors through statistical analysis focusing on the SPL results in the low frequency band that are considered to have a large influence on the reverse A-weighted SPL.

3. EXPERIMENTS

A. Experiments Data Collection

In this study, the measurement of the HIS insulation performance was carried out according to KS F 2810-2: 2012 [16]. The measurement site was a living room of two units(A, B) of a wall-structured apartment with a floor slab of 210mm.

HIS was generated by using ‘Type 1’ of standard heavy impact source generally called the Bang machine, which are specified in KS F 2810-2. The impact position was set at five points evenly distributed, including one point near the center point and four points of which 0.75m away from the wall surface of indicated living room. The plan of them and impact positions can be seen in the Fig. 6.

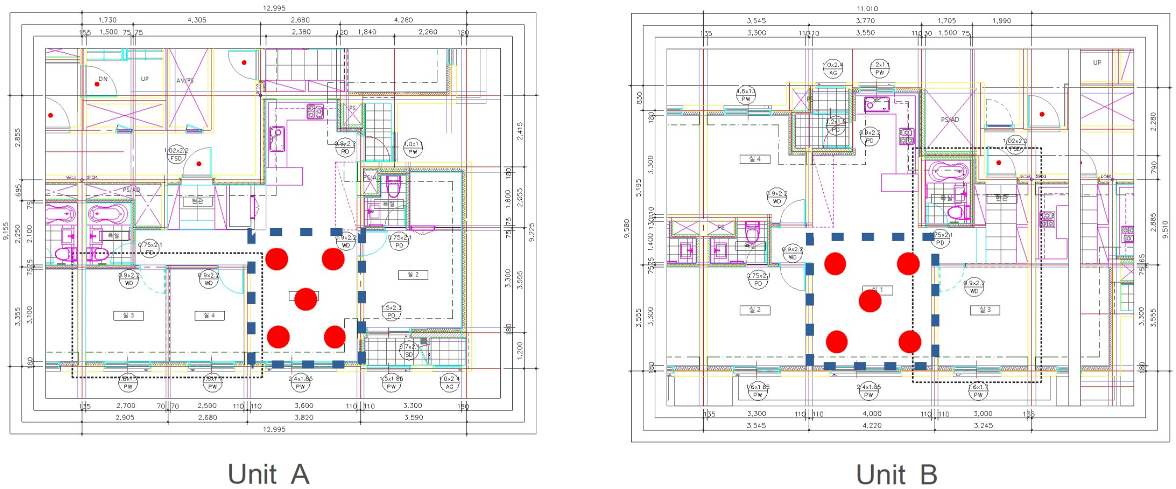


Fig. 6. Plan of measurement units and impact position

The microphones were installed at four evenly distributed measuring points located in 0.75m away from the wall of the receiving room (Directly below of impact room). The height of the microphone was 1.2 m above the floor.

The floor impact SPL was measured with four center frequency(63, 125, 250, 500 Hz) of 1/1 octave band. Moreover, the measurement was implemented in a state in which the influence of background noise was minimized. Nevertheless, if it is determined that there is an influence of background noise, the measured values were calibrated for each frequency band by using the equation (1). When the difference between the SPL value of background noise and measured one is less than 6 dB, the measured value at that time was not used.

$$L = 10\ \log(10^{L_{sb}/10} - 10^{L_b/10})[dB] \quad (1)$$

L_{sb} : *SPL at which the signal and background noise are combined*
L_s : SPL of *background noise*

The floor impact SPL $\overline{L_j}$ which indicates the floor impact sound insulation performance of floor structures, was obtained according to equation (2) for each measurement frequency band.

$$\overline{L_j} = 10\ \log\left(\frac{1}{n}\sum_{j=1}^{n} 10^{\frac{L_j}{10}}\right)[\mathrm{dB}] \quad (2)$$

L_j : SPL at point j
n : Number of measuring point

Lastly, the specification of measuring equipment can be seen in Table 1.

Table 1. Specification of measuring equipment

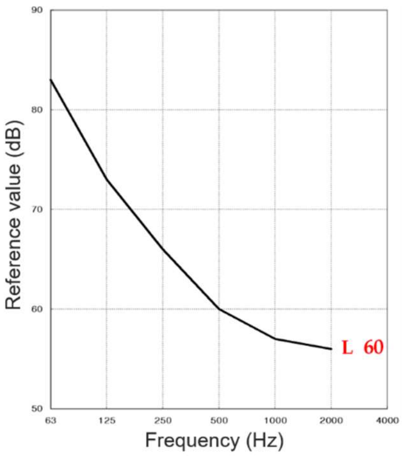
Measuring equipment		Model and manufacturer
Impact source room	Bang machine	FI-02(Japan, RION)
	Rubber ball	-
Receiving room	FFT Analyzer	Pulse 15.0 (Denmark, B&K)
	Microphone set	TYPE 46AE (Denmark, GRAS)
	Sound Level Calibrator	NC-74 (Japan, RION)
	Speaker & Amplifier	OMNI12 & AMPLI12 (France, 01dB)

B. Performance Evaluation

The HIS insulation performance is generally assessed as a single-number quantity for rating in accordance with KS F 2863-2 [17]. The single-number quantity evaluation is a method using reverse A-weighted curve (Fig. 7) as a reference for assessment. The process is as follows.

1) Move the reference curve up or down by 1 dB for the curve connecting the octave band measurement results of 63 to 500 Hz center frequency.
2) The reference curve should be moved as low as possible within a range in which the sum of the measured values above the reference curve in the four octave bands does not exceed 8 dB.
3) At this time, the value of the 500 Hz band of the reference curve becomes a single-number quantity for evaluation.

This study basically expresses the result in this way. However, the result discussion will focus on SPL values in the 63 and 125 Hz bands, which are considered to be most relevant to HIS insulation performance.



Frequency (Hz)	Reference value (dB)
63	83
125	73
250	66
500	60
100	57
2000	56

Fig. 7. Reverse A-weighted curve and the reference values

C. Experiments Design

The research hypothesis to be confirmed in this study are following two. 1) There are significant differences in HIS insulation performance depending on the shape of dry structure. 2) There are significant differences in HIS insulation performance depending on the mass of dry structure. The biggest difference between the two structures investigated in Chapter 2-A is the way of adhesion with concrete slabs. The Floor panels for hot water heating is the form a fully adhered to the slab, the Raised access floor has a partially bonded form. In other words, the former is Fully-Supported(FS), and the latter is Point-Supported(PS). Therefore, in addition to these two, this study selects totally three kinds of structures including Linear-Supported(LS) form as experimental subjects, in order to see if insulation performance varies due to the difference in form of dry floor structure. Moreover, in order to confirm Hypothesis 2), the experiments are planned in which the 12T CRC boards are stacked on top of these structures for the purpose of mass changing. Consequently, section drawings of all experimented structures can be seen in the following fig. 8.

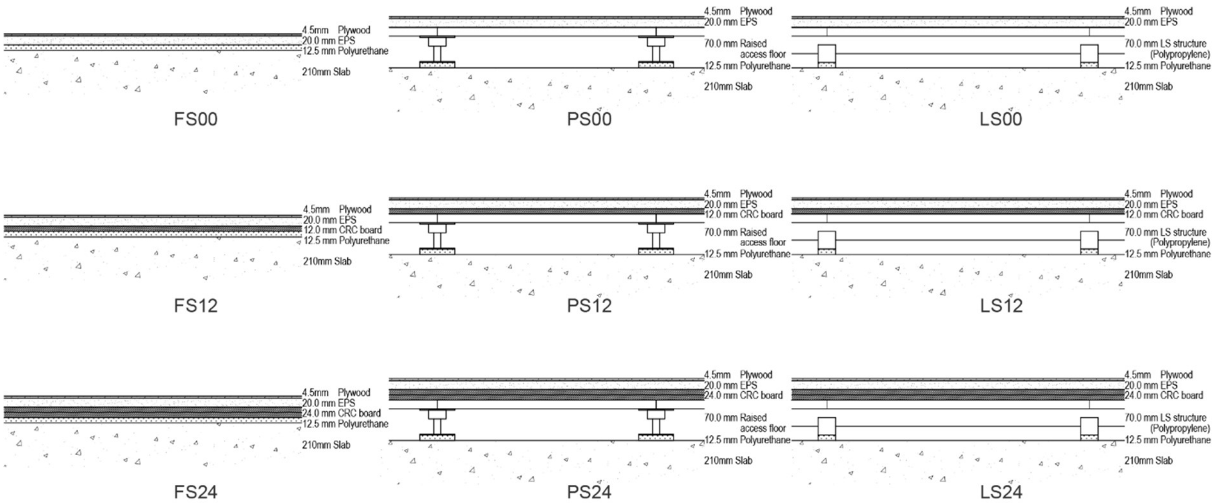


Fig. 8. Section drawings and named code of experimented structures

4. RESULTS DISCUSSION

A. Results

The following Table 2 shows the results of a single-number quantity for rating regarding the two experimented units and nine floor structures on them. Since the results of the bare slab states of the two units are different, the unit in which each structure was installed is denoted with the structure name, and the decrement of the single-number quantity (The bare slab value of the installed unit minus value of structure installed state) is described next to the measurement results.

Table 2. Experiment results (Impact source: Bang machine)

(Unit: dB)

		Forms of structure				
		Unit A	Unit B	FS (Unit A)	PS (Unit B)	LS (Unit A)
Stacked	0kg/m^2 (0T)	50	46	50(0)	48(-2)	52(-2)
mass	16.34kg/m^2 (12T)	-	-	55(-5)	47(-1)	51(-1)
(Thickness)	32.67kg/m^2 (24T)	-	-	54(-4)	45(1)	51(-1)

*Single-number quantity (Decrement)

Since most structures have amplified results contrary to initial expectation, two additional experiments were carried out using two(24T) and four(48T) stacked CRC boards with a thicker resilient material (20 mm) for LS (Unit A). These experimented structures were named as LS A24 and LS A48. The single-number quantity and decrement of these structures were 48 (2) and 44 (6) respectively. The graph showing the above results in 1/1 octave band can be seen in Fig 9.

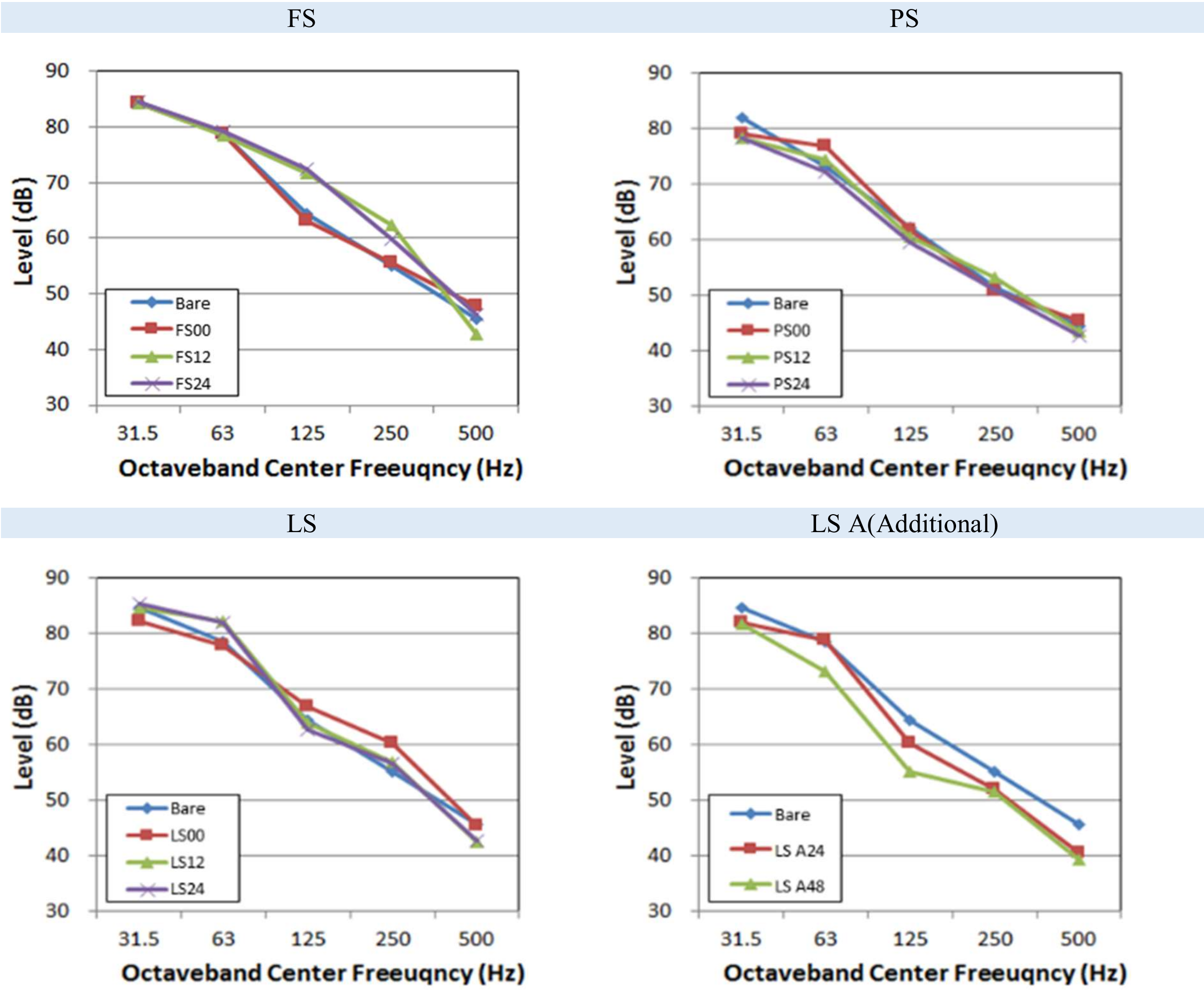


Fig. 9. Overall experiment results by 1/1 octave band frequency

B. Discussion

First, the reason why the results of the bare slab state of two units are different is due to the tower crane installed near the outer wall of unit B and holding the vibration of the building.

Therefore, the analysis of the experiment results was carried out with the decrement of SPL per 1/1 octave band. In addition, in case of FS00, the floor hardness was not secured and the bang machine could not be properly supported when impacting that structure. Accordingly, considering the results were not reliable, they result were excluded from the analysis. Consequently, Analysis of Variance(ANOVA) and Tukey's Honestly Significant Difference(HSD) were conducted based on 40 data sets of 8 structures (Five impact points per structure) excluding the results of FS00.

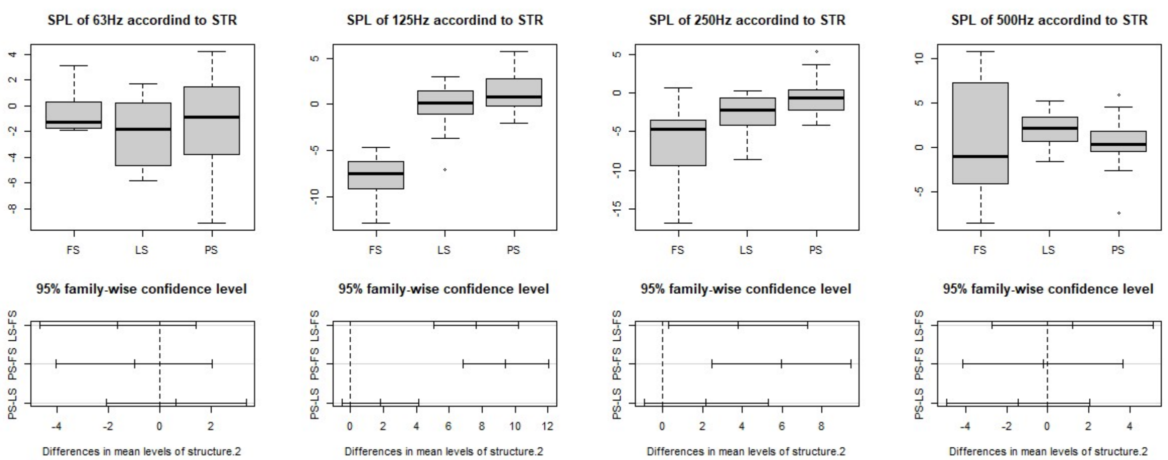


Fig. 10. Boxplot of SPL decrement(Above) and Tukey's HSD result(Bottom) by the shapes of structure

Through the ANOVA, it is confirmed that the difference of the decrement according to the forms of the structure is significant in the 125, 250Hz band (95% confidence level). Because of following Tukey's HSD pair comparison, it is also confirmed that the insulation performance of FS is lower than the other two (Fig. 10).

However, according to the ANOVA carried out only with the results of initial experiments, the difference by changing mass is not significant at the confidence level of 95%. Therefore, the results of ANOVA performed with only LS structure condition data including the result of two additional experiments show that the difference in the decriment according to mass is significant in all four octave bands. In addition, the Tukey's HSD pair comparison also shows that the larger difference in mass, the more significant difference in decrement (Fig.11).

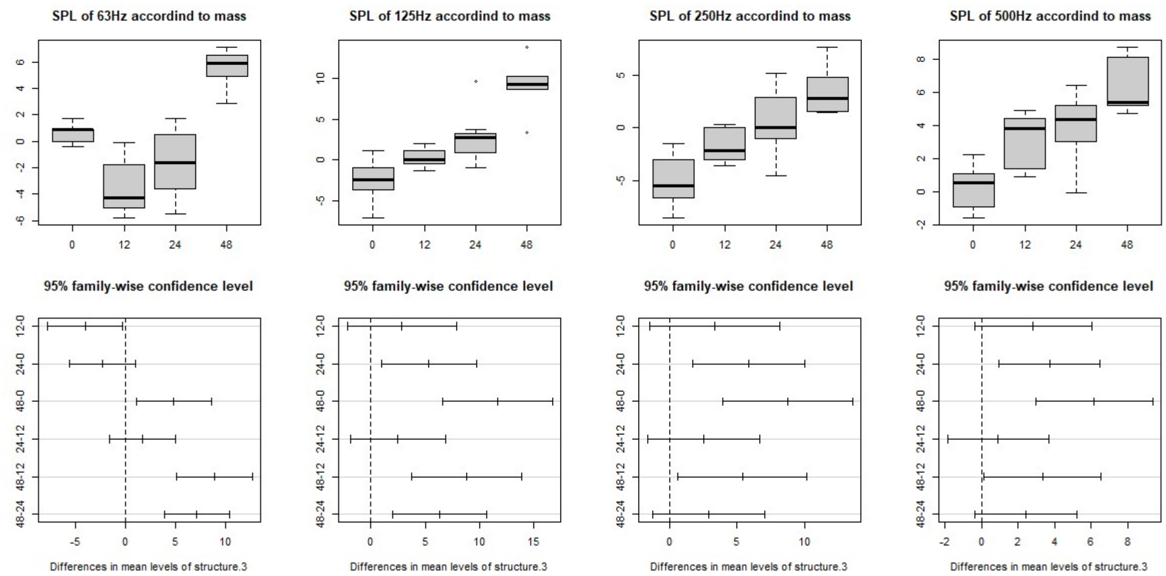


Fig. 11. Boxplot of SPL decrement(Above) and Tukey's HSD result(Bottom) by stacked mass

Lastly, linear modeling and simple regression analysis between mass and decrement of SPL was implemented for each frequency. As a result, the frequency bands in which the mass acts as a significant explanatory variable in the linear model were 63 and 125 Hz band (95% confidence level). The regression equation for the 63Hz band is $Y = -5.46 + 0.1673X$ and the coefficient of determination, R^2 value is 0.7528. The regression equation for the 125Hz band is $Y = -1.06 + 0.15549X$ and the R^2 value is 0.7073. The regression graph for these results can be seen in Fig 12.

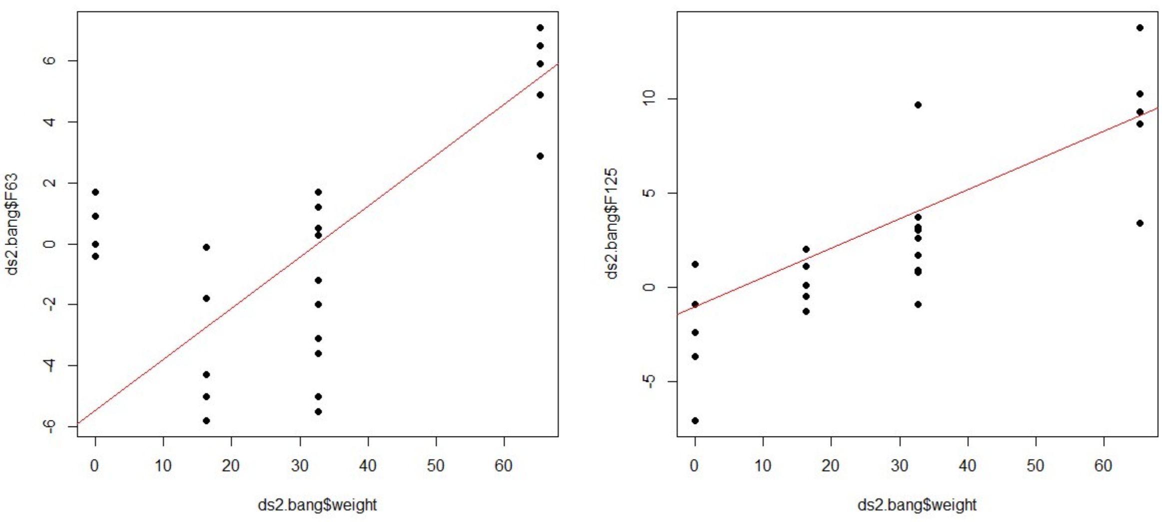


Fig. 12. Regression graph of 63Hz(Left) and 125Hz(Right) (x-axis: mass, y-axis: decrement of SPL)

5. CONCLUSION

For the purpose to improve the applicability of dry floor heating method in wall structure apartments, this study investigated the change of floor impact sound, especially HIS insulation performance which is one of the required performance for the floor structure. This study tried to examine whether the change of heavy-impact SPL shows a tendency at the significant level according to the shape and mass of the floor structure.

Results from the initial design experiments confirm that the form of the raised floor (PS and LS) shows better HIS insulation performance than the fully-supported form. In addition, when combined with additional experiment results, it was also confirmed that the HIS insulation performance increases with the mass on the upper part. Moreover, to reduce the heavy-impact SPL according to the bang machine measuring method, it was confirmed that a mass of about 30 kg/m2 or more should be placed on the upper structure through the estimation of regression analysis.

However, this study needs further study in that it cannot completely control the difference in mass depending on the shape of the structure and that the number of samples is insufficient to use the parametric statistical analysis method. If the accuracy of this study is increased, it will contribute to the diffusion of dry floor heating by setting the HIS insulation performance target and designing the dry floor heating structure that meets the target.

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REFERENCES

1. HOUSTA. <http://housta.khug.or.kr> (AUG. 20, 2017)
2. Korea Institute of Civil Engineering and Building Technology(KICT), 2013. *Study on Mid- and Long-Term Management Strategy According to Life Cycle of Apartment Houses*. Ministry of Land, Infrastructure and Transport Report, Korea
3. National Noise Information System. <http://www.noiseinfo.or.kr> (AUG. 20, 2017)
4. Jo JH 2013. Direction of Regulation Improvement Related Interlayer Noise in Apartment Houses. *Journal of KSNVE*, 23(3): 9-12
5. KS B 8025: 2010. *Floor Panels for Hot Water Heating*
6. KS F 4760: 2016. *Raised Access floor*
7. Kim NH, Sohn JY 2006. A Experimental Study for Developing of the Dry Double Floors Hydronic Ondol System. *Journal of The Korean Housing Association*, 17(3): 1-7
8. Im HC 2012. Evaluation of seismic Performance of Earthquake Resistance Access Floor Systems. , MS thesis, Seoul National University of Science and Technology, Seoul, Korea
9. Hanyang University, 2011. *Investigation on current state of interlayer noise in Apartment Buildings*. National Institute of Environmental Research Report, Korea
10. Seo SH, Song HS, Jeon JY 2003. Noise and Vibration Characteristics by Heavy-weight Floor Impact. *Proceedings of the KSNVE Annual Autumn Conference*, The Korean Society for Noise and Vibration Engineering, pp. 919-922
11. Song HS, Young-Jeong, Jeong JH, Jeon JY 2004. Investigating of a Floor-Impact Isolation Sytem Using Damping Materials in Apartment Buildings. *Proceedings of the KSNVE Annual Autumn Conference*, The Korean Society for Noise and Vibration Engineering, pp. 499-504
12. Kim KW, Jeong GC, Sohn JY 2008. Evaluation of the Dynamic Stiffness and Heavy-weight Floor Impact Sound Reduction by Composition of Resilient Materials. *Transactions of the Korean Society for Noise and Vibration Engineering*, 18(2): 247-254
13. Oh JK, Sohn JY 2010. Correlation Analysis between Dynamic Stiffness and Heavyweight Impact Noise and Application of Impedance Method. *Journal of The Architectural Institute of Korea Planning & Design*, 26(6): 305-312

14. Yeon JO, Kim KW, Choi HJ, Yang KS, Kim KH 2012. Experiment Evaluation for the Heavy-weight Impact Sound of Dry Double-floor System. *Proceedings of the KSNVE Annual Autumn Conference*, The Korean Society for Noise and Vibration Engineering, pp. 280-285

15. Land and Housing Institute 2013. *A Study on the Development Direction of Technology for Reducing Heavy Impact Sound in Apartment Housing*. LHI Report, Korea

16. KS F 2810-2 : 2012. *Field measurements of floor impact sound insulation of buildiings - Part 2: Method using standard heavy impact sources*

17. KS F 2863-2 : 2012. *Rating of floor impact sound insulation for impact source in buildings and of building elements - Part 2 : Floor impact sound insulation against standard heavy impact source*