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Sound insulation evaluation of modular housing

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ABSTRACT

This study is that six modular houses of floor impact sound measured and evaluated in Korea. The floor slab of the modular house has been the standard of 150 mm. The reason is that the thickness of the slab is 150 mm at the beam-column structure under Korean law. As a result of the floor impact sound of 6 modular houses, the light-weight impact sound is (31 ~ 39) dB and heavy-weight impact sound is (48 ~ 55) dB. The floor structure is the same as the conventional reinforced concrete structure. There are not many flooring structures of modular house. This paper analyzes the floor impact sound of modular houses in Korea. Based on the measurement results, this study will be applied to the floor impact sound reduction methods of modular houses.

Keywords: Modular construction, Insulation, Floor impact sound

1. INTRODUCTION

In order to overcome the disadvantages of the RC method such as the error of construction in the field, the increase of construction waste, and the shortage of the field workforce, the industrialized housing construction method in which the main structural members such as walls and roofs are prefabricated and assembled in the field is suggested as an alternative [1].

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Modular houses have standardized frames, walls, windows, and doors produced at factories and assembled and finished at the site, which not only shortens the construction period but also lowers construction costs through mass production.

In Korea, recently, the criteria and procedures for recognition of modular housing performance have been streamlined to promote the introduction of modular housing [2].

However, since the performance evaluation standard of the present modular housing standard is the performance evaluation standard based on the PC (Precast Concrete) and the standard of the apartment house performance recognition standard in the housing law, there is a part that does not reflect the characteristic of the modular house, It is necessary to improve the system considering characteristics of modular houses such as performance evaluation of joints between members and members [3].

In this study, the evaluation method considering the characteristics of the industrialization method is first proposed as the performance evaluation method for the boundary walls.

2. CONSIDERATION OF MODULAR HOUSING RECOGNITION SYSTEM

2.1 Modular Housing

Modular housing is a construction method based on factory fabrication by which 50 to 80% of the construction process is completed in factories including a variety of structures, facilities, and building finishes, thereby constructing structures using minimal fabrication at sites. Modular construction minimizes construction time on sites. Thus, it can be reduced the total construction cost including labor and indirect costs as well as construction wastes significantly. Moreover, modular construction has the advantage of facilitating remodeling due to easy partial maintenance and repair and ensuring uniform performance of construction parts and materials. Since 1992, modular housing have been adopted in South Korea and been evaluated as relatively viable methods in terms of schedule shortening, quality improvements, and performance certificate. Modular housing has been actively adopted since 2009 and most methods used in modular construction in Korea have been column-beam steel frame as below figure 1. The early markets were school facilities and military units. Now and then, it has expanded into public housing and office buildings [4].

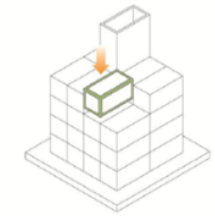
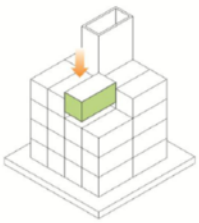
Figure 1. Modular housing in Korea

2.2 Type of construction method of modular housing

Modular housing refers to the construction method of producing unit boxes in factories which contain structural materials, interior materials, various facilities, etc. and constructing buildings on the site with the minimum assembly process [5]. It can save labor cost and achieve good residence performance because the houses are manufactured in factories and field work can be minimized. Moreover, construction waste can be reduced through the minimization of on-site construction work. Unit modular architecture is simple to assemble and disassemble like Lego blocks and affords easy partial maintenance and replacement and repair of aged parts. Therefore, extension remodeling after change of building use is convenient [6].

Another advantage is that it is a method based on industrialized architecture that can achieve equal performance of the materials. Modular housing can be classified by structure and structural system as shown in Table 1 below.

Table 1. Type of construction method of modular housing

Rahmen (Lamination)	Stud panel (Lamination)	Infill
		
Columns and Beam Structural Systems	Stud Structural System	Insert the unit in the structure

2.3 Modular housing certification system

Modular housing means a house constructed by industrialization methods such as a prefabricated construction according to performance standards and production standards set by the ministry of Land, Infrastructure and Transport in Korea., all or part of the main structural parts.

The certification system for modular housing was introduced for the first time in December 1992, and the performance and production standards of modular housing were partially revised in April 2012. The main framework is divided into performance standards and production standards. Performance standards are divided into single-family houses and multi-family homes in table 2 below.

Table 2. Performance Standards

House	Apartment house
Structure safety Ventilation airtight Thermal environment Durability	Structure safety Ventilation airtight Thermal environment Durability Fireproof Evacuation safety Fall prevention Sound environment

2.4 Standard of floor impact sound insulation performance

The criteria for the recognition of apartment housing performance in industrialized housing can be classified into seven categories: structural safety performance, fire resistance and fire performance, ventilation performance and airtight performance, thermal environmental performance, sound environmental performance, durability performance, evacuation safety performance and fall prevention performance is.

In this study, only the performance of floor impact sound is evaluated.

The floor impact sound standard includes the lightweight and the heavyweight impact sound as Table 1. The lightweight impact sound is required to be less than 58dB and the heavyweight impact sound to secure the performance less than 50dB. The modular housing has a problem to reduce the load of floor plate and to secure the floor impact sound insulation performance. The problem should be solved in order the modular housing to be applied to the domestic apartments.

Currently, Korea uses Bang machine to evaluate weight impact sound, which is weight standard cursing sound source. However, as Rubber Ball specified by ISO standard [7] is included in Korean standard[8], a performance standard for rubber ball will be prepared. It's expected that minimum standard is 50dB for Bang machine and 47dB for Rubber Ball .

Table 3. Light & Heavyweight Floor Impact Sound insulation Performance Grade Standard

Grade	Lightweight impact sound [Reversed A-weighted normalized floor impact sound pressure level($L'_{n,AW}$)]	Heavyweight impact sound [Reversed A-weighted floor impact sound pressure level($L'_{i,Fmax,AW}$)]
1	$L'_{n,AW} \leq$ 43dB	$L'_{i,Fmax,AW} \leq$ 40 dB
2	43 dB $< L'_{n,AW} \leq$ 48 dB	40 dB $< L'_{i,Fmax,AW} \leq$ 43 dB
3	48 dB $< L'_{n,AW} \leq$ 53 dB	43 dB $< L'_{i,Fmax,AW} \leq$ 47 dB
4	53 dB $< L'_{n,AW} \leq$ 58 dB	47 dB $< L'_{i,Fmax,AW} \leq$ 50 dB

3. PERFORMANCE EVALUATION OF FLOOR IMPACT SOUND OF MODULAR HOUSING

3.1 Summary of modular housing in Korea

Table 4 gives an overview of modular housing in Korea. The study measured floor impact sound of six modular houses. The floor impact sound isolation performance of the modular house was confirmed.

The modular houses in Korea are under development, and they are mainly composed of basic sample houses and dormitories with less than 5 floors.

The infill type structure to insert the box module into the reinforced concrete structure was able to solve the structural problem, so the dormitory of 12 floors was constructed.

Table 4. Summary of the modular housing in Korea

	Manufacturer	Type of Structure	Purpose	Story
1	P	Beam-column, Steel	Sample house	2
2	P	Beam-column, Steel	Public dormitory	4
3	P	Beam-column, Steel	Public dormitory	5
4	Y	Beam-column, Steel	Public dormitory	4
5	K	Beam-column, Steel	Sample house	2
6	S	Infill, RC+Steel	Dormitory	12

3.2 Results of floor impact sound on the modular housing

3.2.1. Floor impact sound of beam-column structure

The floor construction of the modular sample bed consisted of the floor finishing 8 mm + mortar 50 mm + XPS 60 mm + concrete slab 210 mm.

The slab thickness was increased by 60 mm and the resilient material was increased by 30 mm compared with other modular houses.

As shown in Fig. 2, it was confirmed that the slab thickness and the thickness of the cushioning material were increased and the heavy-weight impact sound performance was improved.

However, due to the thickness of the slab, there are some parts that are difficult to apply in field.

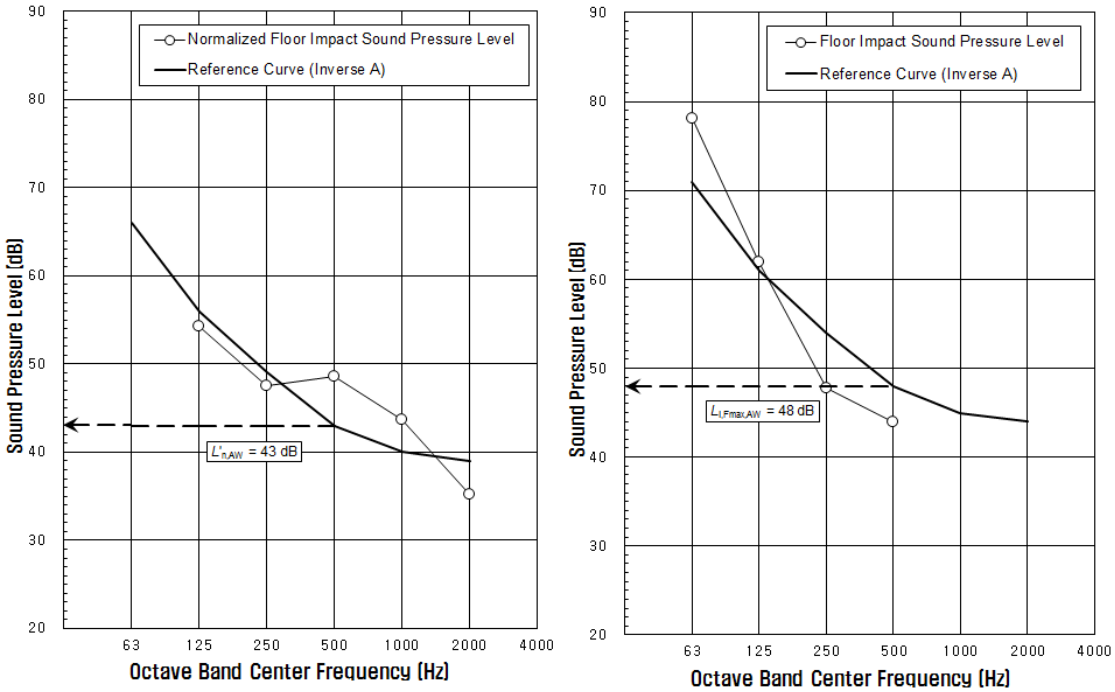


Figure 2. Floor impact sound of P's sample house

The floor construction of the dormitory of Company P is the floor finishing 8 mm + mortar 50 mm + XPS 140 mm + slab 150 mm.

As shown in Fig. 3, the light-weight impact sound was measured at 39 dB and the heavy-weight impact sound at 48 dB.

This is the result of constructing the sample house of the P company by increasing the thickness of the resilient material by 80 mm instead of lowering the bottom slab thickness by 60 mm at the floor finishing 8 mm + mortar 50 mm + XPS 60 mm + slab 210 mm.

Comparing Fig. 2 and Fig. 3, it can be seen that it is more effective to increase the thickness of the resilient material than to increase the slab thickness. This can be a good example of solving the problem of modular housing.

In order to secure the performance of heavy impact sound, it may be desirable to use a resilient material with high density and high dynamic elastic modulus.

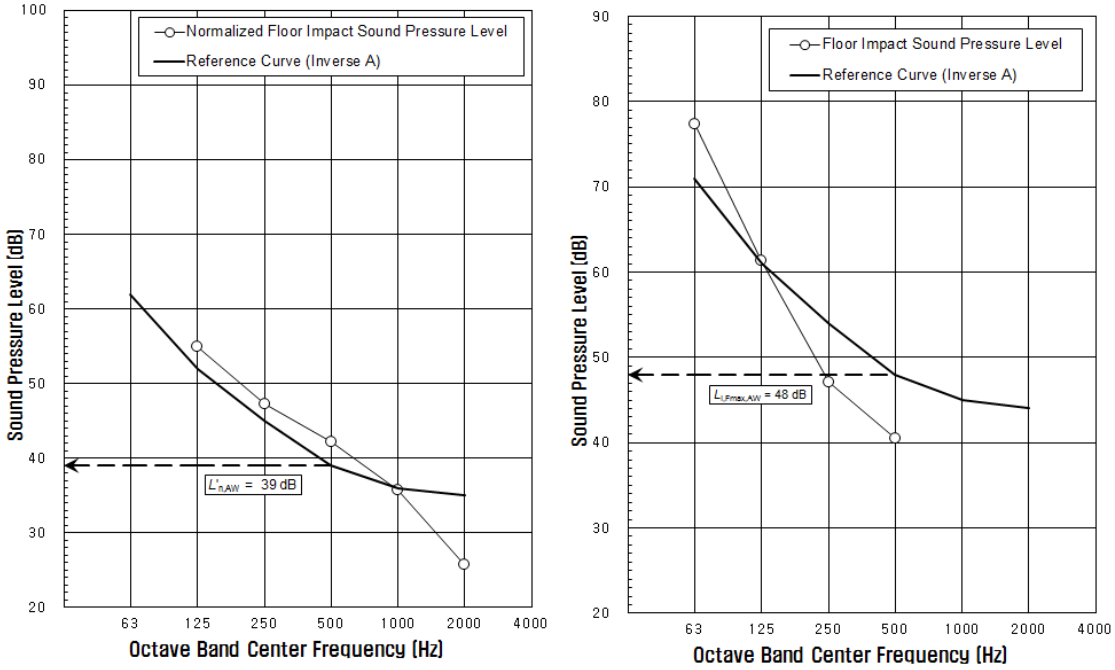


Figure 3. Floor impact sound of P's dormitory

Y's modular housing is a public dormitory house, with floor construction consisting of the floor finishing 8 mm + mortar 70 mm + EPS 30 mm + slab 150 mm.

Figure 4 shows the characteristics and performance results of floor impact sound at the modular houses of Y company.

Light-weight impact sound is 35 dB and heavy-weight impact sound is 51 dB. The result is out of the grade of the heavy-weight impact sound in Korea.

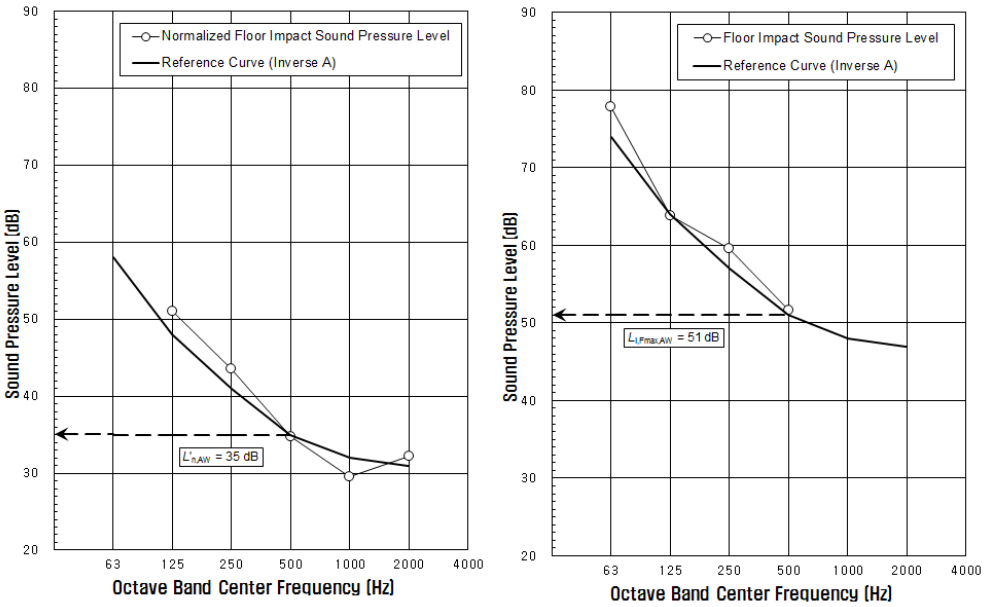


Figure 4. Floor impact sound of Y's dormitory

The floor impact sound results of the K's modular sample houses are shown in Figure 5 and 6. The floor composition of this house is the floor finishing 8 mm + mortar 50 mm + EPS 20 mm + EVA 30 mm + EPS 20 mm + slab 150 mm.

In this sample house, the floor impact sound of one unit and the floor impact sound characteristic of the combined type of two units were measured.

First, the characteristics of the modular housing composed of the 1 unit are shown in Figure 5.

The light-weight impact sound is good at 31 dB, but the heavy-weight impact sound is 55 dB. In particular, the peak frequency at 63 Hz is considered to have a great influence on the overall performance.

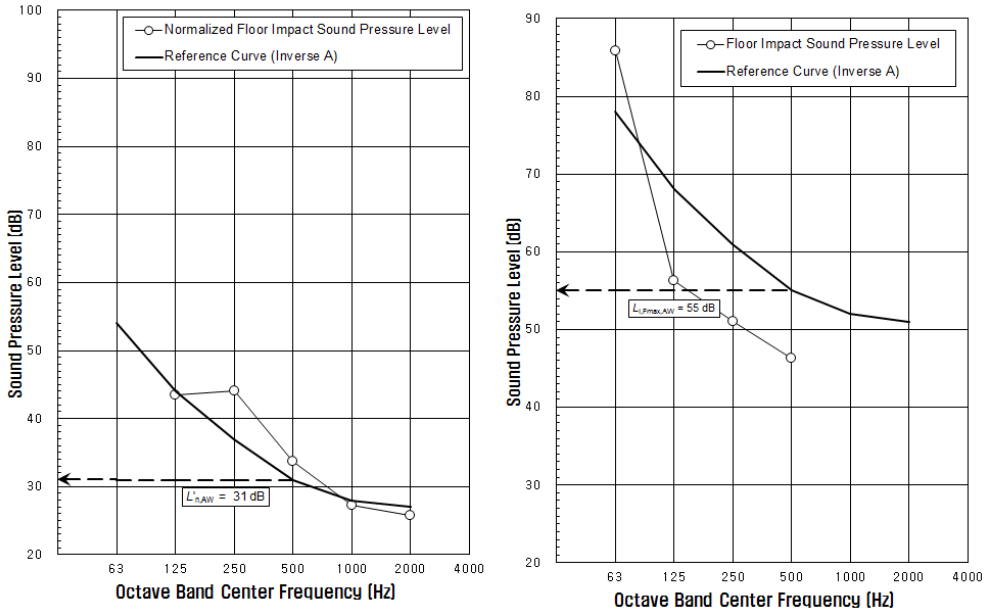


Figure 5. Floor impact sound of 1unit sample house

The result of Figure 6 is the result of floor impact sound of 2 units. The above two units are combined to one room.

As shown in Figure 6, it was slightly higher than the light-weight impact sound, but it was reduced by 3 dB in the heavy-weight impact sound. In the case of the combined floor type, the combined structure of the composite type module with the steel structure can be interpreted as a result of reducing the impact force of the heavy-weight impact source to the structural members.

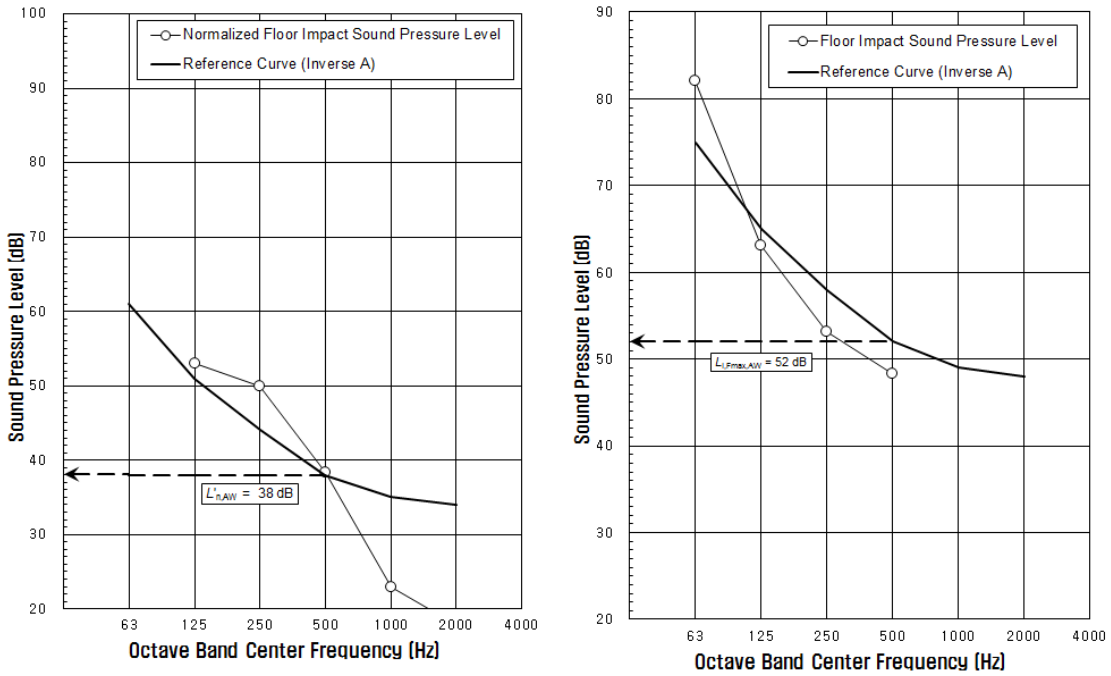


Figure 6. Floor impact sound of 2units sample house

3.2.1. Floor impact sound of infill structure

Unlike other modular houses, the modular housing is an infill type rather than a stacked type. It is a method of inserting a factory-made module into a reinforced concrete structure

Infill type modular housing of floor construction is the floor finishing 8 mm + mortar 50 mm + EPS 30 mm + rectangular steel pipe 160 mm + slab 180 mm.

The floor impact sound measurement result is shown in Figure 7.

In this structure, the structure and the module are structurally separated, and the thickness from the floor surface of the upper floor, which is the sound source room, to the ceiling of the lower floor module, which is the sound receiving room, is 630 mm.

The result of the floor impact sound isolation performance was good that the structure layer was separated and the modular housing with different upper and lower floor space was wide.

In the future, this method is a good example for reference to floor impact sound reduction technology.

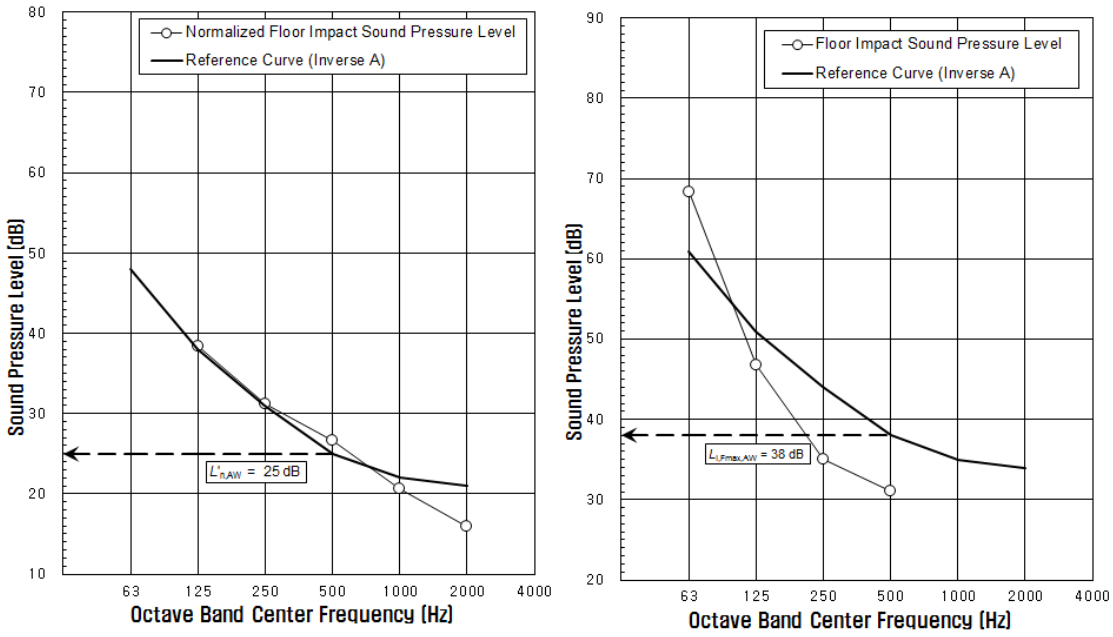


Figure 7. Floor impact sound of Infill structure

4. CONCLUSION

Since the regulations for the approval of industrialized housing were originally set for the recognition of PC industrialized housing in the 1990s, there is a limit to evaluate the industrialized housing that has been developed with various structures at present.

This study investigates modular houses in Korea and measures the floor impact sound performance.

Results of the study will use the modular houses as basic data to improve the floor impact sound of the modular houses. The results are summarized as follows.

(1) The floor slab of the modular house adopts the standard of 150 mm. The reason for this is that under Korean law, the thickness of the slab is specified to be 150 mm for a beam-column structure. As the thickness of the slab increases, the weight of the module increases, so 150 mm is mainly used.

(2) As a result of the floor impact sound performance of 6 modular houses, the light-weight impact sound is (31 ~ 39) dB. And heavy-weight impact sound is (48 ~ 55) dB. A light-weight impact sound is not a legal problem, but a technique capable of securing reduction performance is required for a heavy-weight impact sound.

(3) The modular housing is different from the existing reinforced concrete structure, but the floor structure is the same as the conventional reinforced concrete structure. Also, there are not many different flooring structures or specialized flooring structures because the corresponding method is not activated.

(4) It is expected that the characteristics of the floor impact sound will be changed when the floor is higher. Therefore, it is necessary to reduce the floor impact sound to ensure pleasant indoor sound environment.

In the future study, the floor impact sound characteristic evaluation for the Cheonan Dojung modular housing is further carried out to secure the performance and characteristics of the floor impact sound. Based on this, we compare the characteristics

of the RC type (wall type) in Korea and confirm how the floor impact sound characteristics are different according to the differences of the main structural parts.

In addition, we intend to evaluate the POE of the sound environment for the residents of the modular housing in Korea.

5. ACKNOWLEDGMENT

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