

Long-Term Structural Behavior of Resilient Materials for Reduction of Floor Impact Sound

J. Y. Lee, J. Kim, H. J. Chang, J. M. Kim

Abstract—People's tendency towards living in apartment houses is increasing in a densely populated country. However, some residents living in apartment houses are bothered by noise coming from the houses above. In order to reduce noise pollution, the communities are increasingly imposing a bylaw, including the limitation of floor impact sound, minimum thickness of floors, and floor soundproofing solutions. This research effort focused on the specific long-time deflection of resilient materials in the floor sound insulation systems of apartment houses. The experimental program consisted of testing nine floor sound insulation specimens subjected to sustained load for 45 days. Two main parameters were considered in the experimental investigation: three types of resilient materials and magnitudes of loads. The test results indicated that the structural behavior of the floor sound insulation systems under long-time load was quite different from that the systems under short-time load. The loading period increased the deflection of floor sound insulation systems and the increasing rate of the long-time deflection of the systems with ethylene vinyl acetate was smaller than that of the systems with low density ethylene polystyrene.

Keywords—Resilient materials, floor sound insulation systems, long-time deflection, sustained load, noise pollution.

I. INTRODUCTION

THE number of high-rise apartment houses has been steadily increasing since the 1980's in a densely populated country. More than 58 percent of Koreans are living in apartment houses in 2012 [1]. High-rise apartment houses have advantages to use effectively relatively small land area, whereas they have also disadvantages in housing environments. One of the big residential environment concerns in living apartment houses is noise pollution induced by floor impact sounds caused by footsteps, falling objects, moving furniture, etc.

In the reinforced concrete apartment buildings, the floor impact sound from the floor above can be easily transferred to the floor below. Due to interior dry walls and thin floors, neighboring occupants can often hear each other's conversations and even snoring at night. The communities set several standards on floor soundproofing to reduce the impact noise of apartment houses. Apartment Housing Performance Grade Indication System currently enforced in Korea classifies sound performance of apartment into several grades according to floor impact sound. The maximum of light-weight impact sound and heavy-weight impact sound is enforced to be lower

than 58 dB and 50dB, respectively [1].

There are two types of floor soundproofing solutions to reduce impact noise, acoustic matting or floating floors; both solutions can reduce impact noise transferring through wooden and concrete floor structures. In case of floating floors, resilient materials are normally placed between concrete or wooden slab and finishing materials. The resilient materials may effectively reduce impact sound through a floor by reducing the vibration caused as an item hits the floor. The level of noise that will transmit through the floor depends on the force of the impact, the vibration transmission characteristics of the floor structure and the floor covering. It is generally accepted that floor impact sound reduction increases with the decrease of dynamic stiffness of resilient material. Jeon et al. [2] evaluated heavy-weight impact sounds in multi-story reinforced concrete residential buildings. The results indicated that the noise from the impact ball is similar to the noise of children running and jumping, and that subjective responses to the noise correlate well with Zwicker's Loudness model and the newly defined floor impact sound level. It was also found that the noise level of the impact ball was slightly higher than that of the bang machine, although the impact ball had a lower impact force. In addition, when the noise from the impact ball was evaluated under both laboratory and *in situ* conditions, the allowable sound level was found to be 54 dB. Kim et al. [3] tested 51 resilient materials in order to investigate the correlation between the dynamic stiffness of resilient materials and their heavyweight impact sound reduction level. Test results indicated that dynamic stiffness, as a physical property of resilient materials, decreased as the thickness of the resilient materials increased. If resilient materials with low dynamic stiffness are layered on top of resilient materials with high dynamic stiffness, the dynamic stiffness of the layered structure is similar to that of the resilient materials with low dynamic stiffness. Im et al. [1], [4] tested several multi-layered damping materials used to improve the effect of floor impact noise insulation. Test results indicated that the dynamic stiffness of multi-layered damping material consisting of expanded polystyrene (EPS), expanded polyethylene (EPE), ethylene vinyl acetate (EVA) and polyester could be estimated by using the material proprieties of components. And it was also found that the dynamic stiffness of whole structure did not change even if the disposition of components changed. Buratti and Moretti [5] investigated the impact sound insulation performances of materials used as floor coverings in buildings to reduce impact noise. Test results indicated that floating floors must be carefully installed to reduce the annoyance due to an impact sound transmission between rooms in residential

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buildings.

Many studies on the effects of types and density of resilient materials, dynamic stiffness, size of windows, wall types and materials, and different numbers of stories have been performed to examine the sound insulation of buildings. On the other hand, few test results are currently available regarding the long-time deflection of floor sound insulation systems. This paper presents the deflection of floating floors with resilient materials for sound insulation.

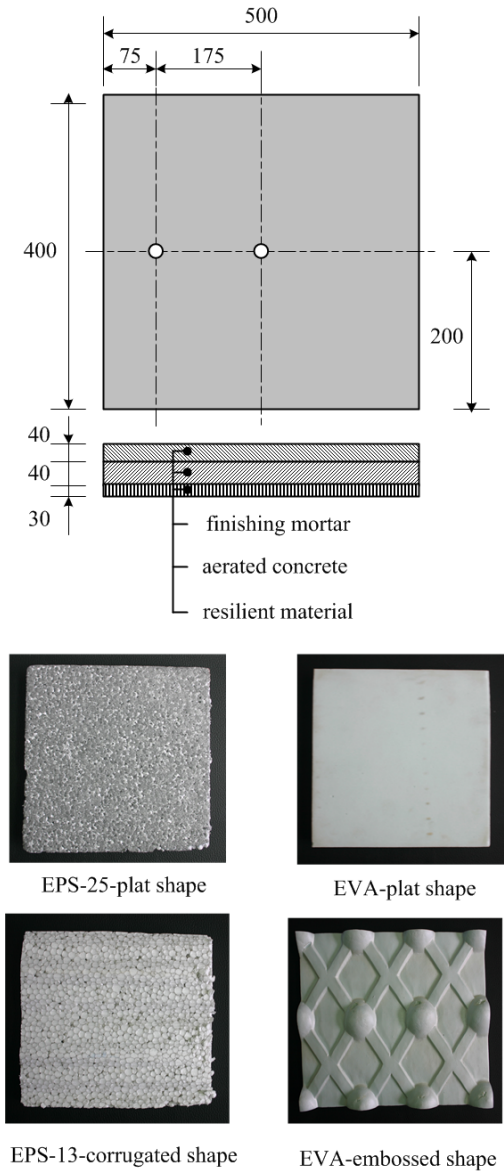


Fig. 1 Dimensions of test specimens and types of materials

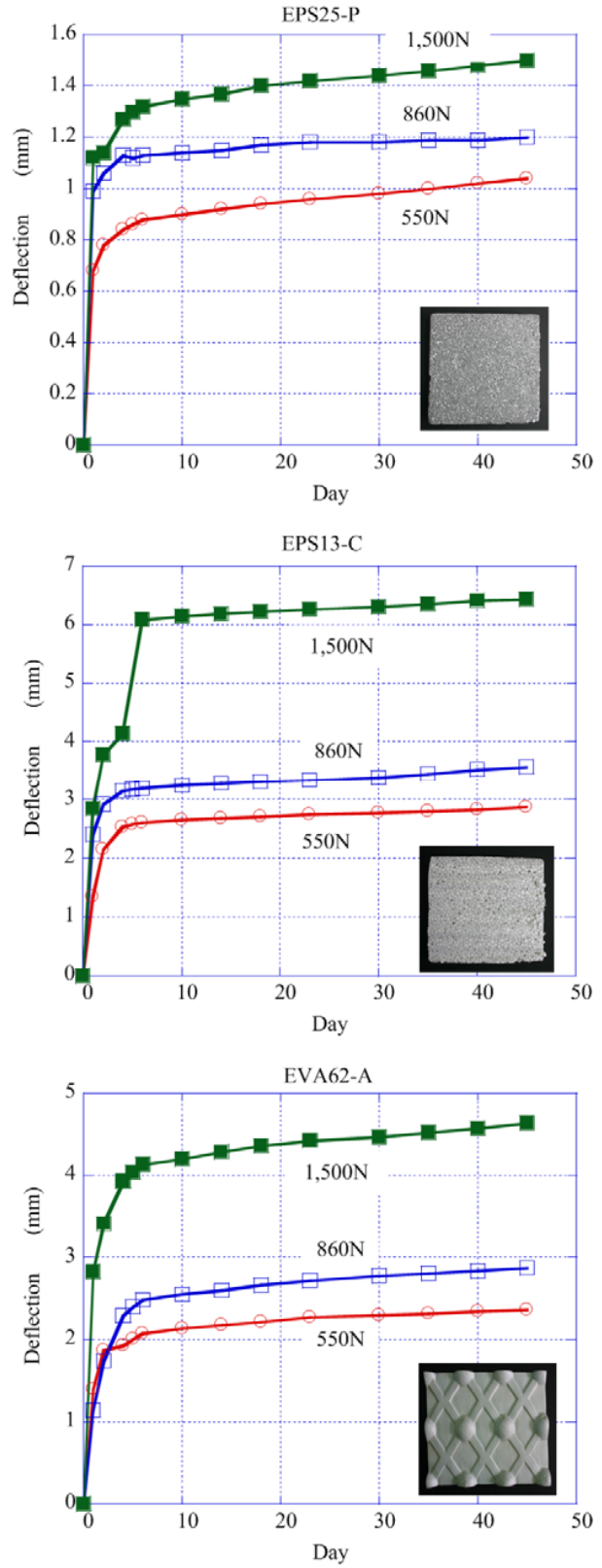


Fig. 2 Deflection vs. loading period curves of tested specimens

II. TEST PROGRAM

Test results [2] in the literature indicated that the density and the slab contact area of materials increased the dynamic stiffness of material. Therefore, soft resilient materials or resilient materials with small slab contact area are commonly used to reduce dynamic stiffness. The resilient materials placing between reinforced concrete slab and finishing mortar should not only reduce floor impact sound vibrated from the floor but also support load from the floor. Thus, even if soft

resilient materials are satisfied with the maximum limitation of light-weight impact sound and heavy-weight impact sound, these materials may not support load from the floor. As a result, there is possibility that cracks develop on the finishing mortar and the floor sags.

In this research, nine floor sound insulation specimens subjected to sustained load were tested in order to investigate the long-time deflection of resilient materials in the floor sound insulation systems of apartment houses.

TABLE I
TEST SPECIMENS

Groups	Specimens	Weight (N)	Density (kgf/m ³)	Bottom surface	Loading period (days)	Deflection (mm)	
						1day	4days
EPS25-P	EPS25-P-55	550	25	Plat	45	0.68	0.84
	EPS25-P-86	860	25	Plat	45	0.99	1.13
	EPS25-P-150	1,500	25	Plat	45	1.12	1.27
EPS13-C	EPS13-C-55	550	13	Corrugate	45	1.35	2.58
	EPS13-C-86	860	13	Corrugate	45	2.40	3.18
	EPS13-C-150	1,500	13	Corrugate	45	2.85	4.50
EVA62-A	EVA62-A-55	550	62	Emboss	45	1.07	2.01
	EVA62-A-86	860	62	Emboss	45	1.14	2.40
	EVA62-A-150	1,500	62	Emboss	45	2.83	4.03

A. Specimens

Floor sound insulation systems of apartment houses generally consist of three materials; resilient material to absorb floor impact sound, aerated concrete, and finishing mortar. The thicknesses of resilient material, aerated concrete, and finishing mortar are usually 20-30mm, 40-50mm, 30-40mm, respectively. In this study, nine floor sound insulation system specimens were prepared. The specimens consist of three materials, as shown in Fig. 1. Resilient material is placed on the reinforced concrete slab to absorb the impact sound transmitted from the floor above. On the resilient material, aerated concrete and finishing mortar are laid (see Fig. 1).

The used resilient materials for reducing floor impact sound were two types of Ethylene Polystyrene (EPS) and one type of Ethylene Vinyl Acetate (EVA). Because the density and the dynamic stiffness of resilient material effects on the floor impact sound, three types of materials were tested. The EPS materials had different types of density (25kgf/m³ and 13kgf/m³) and bottom shapes (plat shape and corrugated shape, see Fig. 1). The density of EVA material was 62 kgf/m³ and the bottom surface of the material was embossed shape. The thicknesses of all resilient materials were 30mm.

Aerated concrete laid between resilient material and finishing mortar was prepared in accordance with KS F 4039 standard. The compressive strength and modulus of elasticity of aerated concrete were approximately 3.5MPa and 220MPa, respectively. Finishing mortar was placed on the aerated concrete. The compressive strength and modulus of elasticity of finishing mortar were approximately 20MPa and 1,600MPa, respectively.

B. Specimens and Test Configuration

A total of nine specimens were tested to measure the

long-time deflection of sound insulation systems of apartment houses. Each specimen consisted of resilient material, aerated concrete, and finishing mortar. The cross sectional dimension of the specimens was 400 x 500mm and the thicknesses of resilient material, aerated concrete, and finishing mortar were 30mm, 40mm, and 40mm, respectively. Aerated concrete and finishing mortar were cast on the resilient material in the horizontal position inside the timber formwork. After molding, the specimens were initially cured by covering them with plastic sheet, which prevented moisture loss for 24 hours. Immediately after the removal of the molds, specimens were cured in accordance with ASTM Standard C 511[6] until the time of test. During this curing period, they were sprayed with water two times a day to maintain moisture on the surfaces at all times.

Two parameters were considered in this investigation: the types of materials (two types of EPS resilient materials and one type of EVA resilient material) and sustained loads (550N, 860N, 1,500N). The properties of specimens are shown in details in Table I.

The sustained load tests were performed by putting cement bricks and concrete blocks on the top of specimen. Reinforced concrete blocks were manufactured to apply sustained load to the specimen. The weight of a cement brick and a concrete block was 18.5N and 860N, respectively. The size of a cement brick and a concrete block was 190 x 90 x 57mm and 1,000 x 300 x 120mm, respectively. Three types of loads (550N, 860N, 1,500N) were applied to the specimens for 45 days. The deflection of specimen was measured using a digital dial gage which was placed vertically on the top of the specimen.

III. TEST RESULTS

The structural behavior of three types of resilient materials in

sound insulation systems subjected to sustained load for 45 days was observed from the experimental tests. All of the specimens showed gradual increment of deflection as loading time passes. None of specimens showed the local failure at the residual material, the cracking of the finishing mortar, and the splitting of the aerated concrete.

A. Group EPS 25-P

Fig. 2 shows the deflection vs. loading period curves obtained from a long-time loading test of sound insulation systems. The observed structural behavior of the specimen was similar to that obtained from the resilient material tests subjected to long-time load by Lee *et al*[1]. The deflection of the specimen under heavy load was greater than that of the specimen under light load. The deflection of Specimen EPS25-P-150 under 1,500N was 1.12mm at the first day after loading, while those of specimen EPS25-P-55 and EPS25-P-86 under 550N and 860N were 0.68mm and 0.99mm, respectively. The deflection of sound insulation systems subjected to long-time load rapidly increased at the first or second day after loading. After the first rapid increase of deflection, the deflection of tested specimens gradually increased with time.

The deflection vs. loading period curve of the test specimen is divided into three stages as follows:

Stage I (immediately after loading): highly deflection increases with little change in loading time. The deflection of the specimens in Group EPS25-P at the first day after loading was almost the same to that of the resilient material under short-time load obtained from UTM test.

Stage II (from loading to a few days after loading): the deflection of specimen rapidly increases as loading period increases.

Stage III (after a few days): the deflection of specimen gradually increases as loading period increases. The slope of deflection vs. loading period curve at Stage III is lower than that at Stage II.

B. Group EPS 13-C

The test results of the specimens in Group EPS13-C subjected to sustained load is plotted in Fig. 2. The deflection – loading period of the specimens in Group EPS13-C also showed the long-time deflection behavior associated with three stages, as observed in the specimens in Group EPS 25-P. However, the deflection of the specimens in Group EPS13-C at the first loading day was greater than that of the specimens in Group EPS25-P. In addition, the increasing rate of deflection at Stage III of the specimens in Group EPS13-C was greater than that of the specimens in Group EPS25-P. This is because the density of the specimens in Group EPS13-C is lower than that of the specimens in Group EPS25-P, and the contact area to the RC slab of specimens in Group EPS13-C is smaller than that of the specimens in Group EPS25-P.

C. Group EVA62-A

The deflection vs. loading period curves of the specimens in Group EVA62-A showed characteristics that are more similar to those of the specimens in Group EPS25-P, but displayed a greater deflection value than that of the specimens with EPS

(density of 25kgf/m³). The deflection of the specimen EVA62-A-86 under 860N at 10 days after loading was 2.57mm, which was 1.43mm higher than that of the specimen EPS25-P-86. The deflection of the specimens in Group EVA62-A was greater than that of the specimens in Group EPS25-P, but smaller than that of the specimens in Group EPS13-C. The increasing rate of deflection at Stage III of the specimens in Group EVA62-A was smaller than that of the specimens in Group EPS13-C. The deflections of specimens at the first and fourth day after loading are listed in Table I.

IV. PREDICTION OF THE DEFLECTION OF FLOOR SOUND INSULATION SYSTEMS

In order to perform the numerical analysis for predicting the deflection of sound insulation systems consisting of three materials (aerated concrete, finishing mortar, and resilient material), Winkler model [7] was used in this study. This analytical model is normally used to investigate the deflection of members supported by continuous constant stiffness foundation. The deflection of a member subjected to concentrated load, P , or uniform load, w , can be from Winkler model.

$$y = \int_0^l \frac{w \cdot dx}{2k} \cdot \beta e^{-\beta x} [\cos(\beta x) + \sin(\beta x)]$$

(uniform load) (1)

$$y = \frac{P \cdot \beta}{2k} \cdot e^{-\beta x} [\cos(\beta x) + \sin(\beta x)]$$

(concentrated load) (2)

where y : deflection of member, w : uniform load, k : spring coefficient, P : concentrated force, β : strength coefficient.

The deflection of floor sound insulation systems to the modulus of elasticity of resilient material with different loading locations and loads is shown in Fig. 3. As shown in Fig. 3, the modulus of elasticity of resilient material strongly effects on the deflection of resilient materials for reduction of floor impact sound. The deflection of resilient material decreased with the increase of the modulus of elasticity. In addition, the deflection of resilient material loaded at the side of the specimen was greater than that of resilient material loaded at the centre of the specimen. When the modulus of elasticity is 0.5MPa, the deflection of resilient material loaded at the centre of the specimen is 0.56mm, while that of resilient material loaded at the side is 1.81mm. The deflection of floor sound insulation system almost proportionally increases to the increase of load.

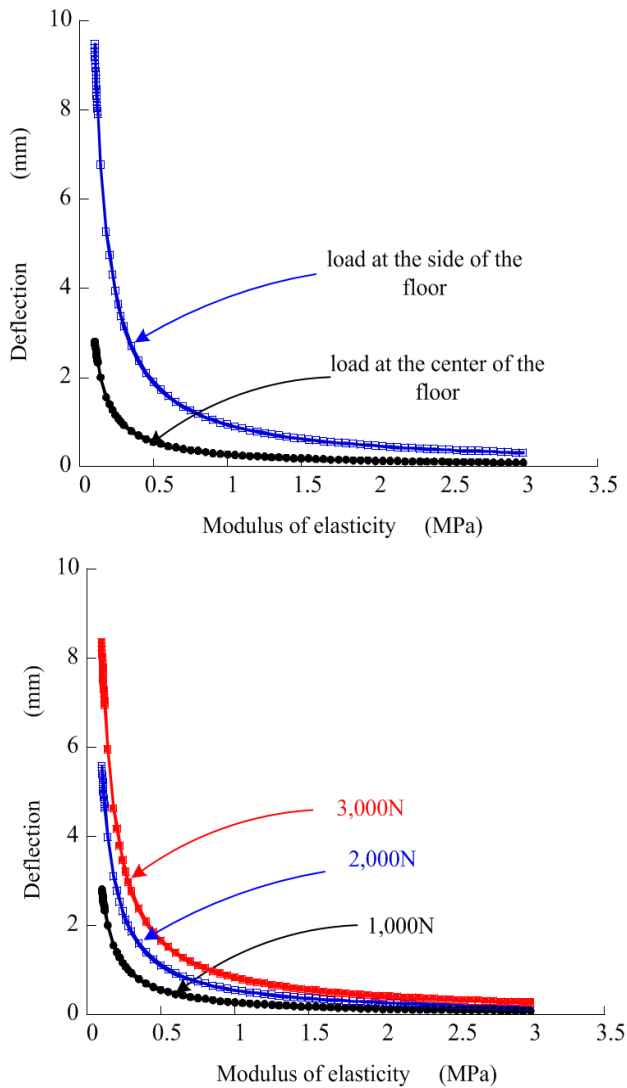


Fig. 3 Deflection vs. modulus of elasticity curves

V. CONCLUSIONS

Based on the experimental and analytical results of nine tests of floor sound insulation systems of apartment house subjected to sustained load for 45 days, the following conclusions are made.

The deflection of resilient materials in the floor sound insulation systems subjected to sustained load was more severe than that of resilient material subjected to short-time load, because the loading period decreased the modulus of elasticity of EPS type and EVA type resilient material. The increasing rate of the long-time deflection of the floor sound insulation systems with EVA was smaller than that of the systems with low density EPS.

The analyzed results of the Winkler model indicated that the modulus of elasticity of resilient materials was most significant influencing factors to induce the deflection of floor sound insulation systems. However, additional study is needed to develop the analytical model that takes into account the effects

of sustained load on the long-time deflection of resilient material in floor sound insulation systems.

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REFERENCES

- [1] J.-Y. Lee, S.-C. Lee, S.-H. Choi, A.-R. Lim, J.-S. Park, and J.-M. Kim, "Structural behavior of resilient materials subjected to short-term load and long-term load," *Inter. J. of Engineering and Technology*, vol.6, No.1, pp.65-69, 2014.
- [2] J.Y. Jeon, J.K.Ryu, J.H.Jeong, and H. Tachibana, "Review of the Impact Ball in Evaluating Floor Impact Sound," *ActaAcustica united with Acustica*, vol. 92, no. 5, pp. 777-786, 2006.
- [3] K.-W. Kim, G.-C. Jeong, K.-S. Yang, and J.-Y. Sohn, "Correlation between dynamic stiffness of resilient materials and heavyweight impact sound reduction level," *Building and Environment*, vol. 44, pp.1589-1600, 2009.
- [4] J.-B. Im, J.-Y. Chung, K.-W. Kim, and G.-C. Jeong, "A Study on Dynamic Stiffness of Multi-layered Damping Materials," *Proceedings of the KSNVE Annual Conference*, Seoul, 2007, CD printing.
- [5] C. Buratti and E. Moretti, "Impact noise reduction: laboratory and field measurements of different materials performances," *Conf. Euronoise 2006*, Tampere, Finland, 2006.
- [6] ASTM, "Standard test method for comparing concretes on the basis of the bond developed with reinforcing steel. C234 - 91a," American Society for Testing and Materials, West Conshohocken, PA, 1991.
- [7] A. C. Ugural and S. K. Fenster, "Advanced strength and applied elasticity," 3rd edition, Prentice Hall PTR, 1995, 570p.

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