Evaluation of the Long-Term Deflection Performance of Resilient Materials in Floor Floating Systems

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***Abstract*—About 60 percent of Koreans are living in a public house like multi-unit dwelling. Interlayer noise in living apartment houses rises a social problem in a densely populated country. Many countries established a law to reduce noise pollution induced by floor impact sound. This paper presents the test results of eight resilient materials in floating floor system subjected to long-term load. The main parameters of test specimens were types of materials, density of material, magnitude of load, and duration of load. Test results indicated that the duration of load strongly steadily increased deflection. In addition, long-term deflection of resilient materials was affected by types of materials, density and bottom plate shapes.**

***Index Terms*—multi-unit dwelling, interlayer noise, floating floor system, resilient material, long-term deflection**

I. Introduction

More than 60% of the people are living in public housing in the Republic of Korea and interlayer noise is becoming a social problem. Apartment buildings have increased rapidly since the 1980s due to changes in consciousness of people seeking ease and convenience of housing. However, there are a large number of residents may experience problems due to the nature of Apartment Buildings that are representative of those that inhabited the interlayer noise. More recently, Improved living standards and the requirements for the living environment is diverse, sophisticated there is a growing complaints about noise layers. According to the Ministry of Environment 'noise-related complaints condition', interlayer noise complaints jumped 15,455 cases from 2012 to 2013 and increased about 16,470 cases in 2014 [1].

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The government is making various efforts to suppress interlayer noise problems. Citizens can obtain information about the noise through a website called 'National Information Noise System' and this web site is offering a solution that can be reasonably estimated due to the disputes at an early stage by establishing 'Interlayer Noise Neighborhood Center' [2]. In addition, it established the "Apartment buildings rules on inter noise standards' and presented the extent of inter-noise specified, a reference for each of the sound layers. Play sound and direct impact noise such as walking sound is weekly based on the "one minutes the equivalent noise '43 dB at night 38 dB, the' best noise" a reference to the weekly 57 dB, was defined by the night 52 dB and such as radios, musical instruments air noise has passed regulations so as not to exceed the "five minutes the equivalent noise' as a reference day 45 dB, 40 dB at night [3].

In addition, it announced the 'Floor Impact inter-block structure standards' in 2014 for noise prevention. The block structure has heavy weight floor impact noise below 50 dB, lightweight floor impact noise that can be less than 58 dB impact sound. Classifying the structure of the building in three, and prescribing the minimum thickness of the concrete slab for that structure, the resilient material, the mortar to reduce the damage caused by the interlayer noise [4].

In recent years, a trend using the bottom cushioning is increased. It said buffer material is a material that is provided on the bottom structure in order to absorb the floor impact sound and vibration. The method of increasing the thickness of the slab is effective in noise suppression, but this method has the disadvantage like low inter-floor height and high cost of construction [5]. So it is evaluated as less efficient. Therefore, the methods of using resilient materials that have small thickness and light-weight as compared to the concrete slab frequently

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used to prevent the transmission of vibration and shock energy. Various kinds of resilient materials are produced like EPS (Ethylene Polystyrene), PE (Polystyrene) and EVA (Ethylene Vinyl Acetate). Almost resilient materials have role of insulation to meet the thermal transmittance in inter-floor. In order to control the quality of the various resilient material products, there are some rules that regulate performance of resilient materials. Korea Standard defines density (KS M ISO 845) [6], dynamic stiffness and loss factor (KS F 2868) [7], unrecovered strain (KS F 2873) [8], absorbed amount (KS M ISO 4898) [9], dimensional stability after heating (KS M ISO 4898), thermal conductivity (KS L 9016) [10], [11].

Currently, most of regulations of KS are based on the short-term loading. For example, unrecovered strain (KS F 2873) based on the only 11minutes experiment that is conducted by applying 3 different load cases. However, the floor resilient material to be used in the actual building receives continuous long-term load that is applied after the building is built. Therefore, the proposed criteria subject to short term loading such a KS may does not reflect the long-term characteristics of the resilient material. The resilient materials is not a homogeneous material and produce performance difference in various loading condition and processing methods in factories. Especially, deflection of resilient materials lead to crack and deflection of whole floor concrete slab that causes significantly reduce sound insulation performance of floor.

In this study, we evaluated the deflection performance of total 8 resilient materials under the long-term load. Most of the existing studies have been conducted on short-term performance of resilient materials rather than long-term performance evaluation. Also, it was the long-term performance of non-state of loading. Therefore, this study aims to evaluate deflection of resilient materials that receive continuous long-term load. By evaluating the tendency of deflection with respect to the initial characteristics of resilient materials, proposing a basis for establishing resilient materials performance criteria associated with interlayer noise in multi-unit dwelling.

II. Experimental Program

A. Specimens

Eight most widely used resilient material were selected in for the experiment. Table I shows information of 8 resilient materials. Six types of EPS, one type of each PS and EVA were selected for testing with varying bottom shape and densities. The selected resilient materials include plat, corrugated, embossed type of bottom shapes, and their density ranges from 12.1 to 59.3 kg/m³. The thickness of the resilient material was defined as the most widely used in the domestic 30mm specimen size was 150 X 150 mm designed to be evenly distributed load [11].

TABLE I. Specimens Information

Specimens (material-density-shape)	Load (N)	Material	Density (kg/m^3)	Thickness (mm)	Bottom shape
RM1 (EPS-13-P)	40	Ethylene Polystyrene	13.20	28.94	Plat
RM2 (EPS-12-C)	40	Ethylene Polystyrene	12.08	29.80	Corrugated
RM3 (PE-24-P)	40	Polystyrene	23.96	30.98	Plat
RM4 (EPS-25-P)	40	Ethylene Polystyrene	24.70	29.33	Plat
RM5 (EPS-25-C)	40	Ethylene Polystyrene	25.53	31.85	Corrugated
RM6 (EPS-15-C)	40	Ethylene Polystyrene	15.40	30.89	Corrugated
RM7 (EPS-24-P)	40	Ethylene Polystyrene	24.12	29.3	Plat
RM8 (EVA-59-E)	40	Ethylene Vinyl Acetate	59.26	30.15	embossed
RM1 (EPS-13-P)	80	Ethylene Polystyrene	13.20	29.12	Plat
RM2 (EPS-12-C)	80	Ethylene Polystyrene	12.08	30.02	Corrugated
RM3 (PE-24-P)	80	Polystyrene	23.96	30.84	Plat
RM4 (EPS-25-P)	80	Ethylene Polystyrene	24.70	29.45	Plat
RM5 (EPS-25-C)	80	Ethylene Polystyrene	25.53	31.15	Corrugated
RM6 (EPS-15-C)	80	Ethylene Polystyrene	15.40	30.63	Corrugated
RM7 (EPS-24-P)	80	Ethylene Polystyrene	24.12	29.56	Plat
RM8 (EVA-59-E)	80	Ethylene Vinyl Acetate	59.26	30.14	Embossed

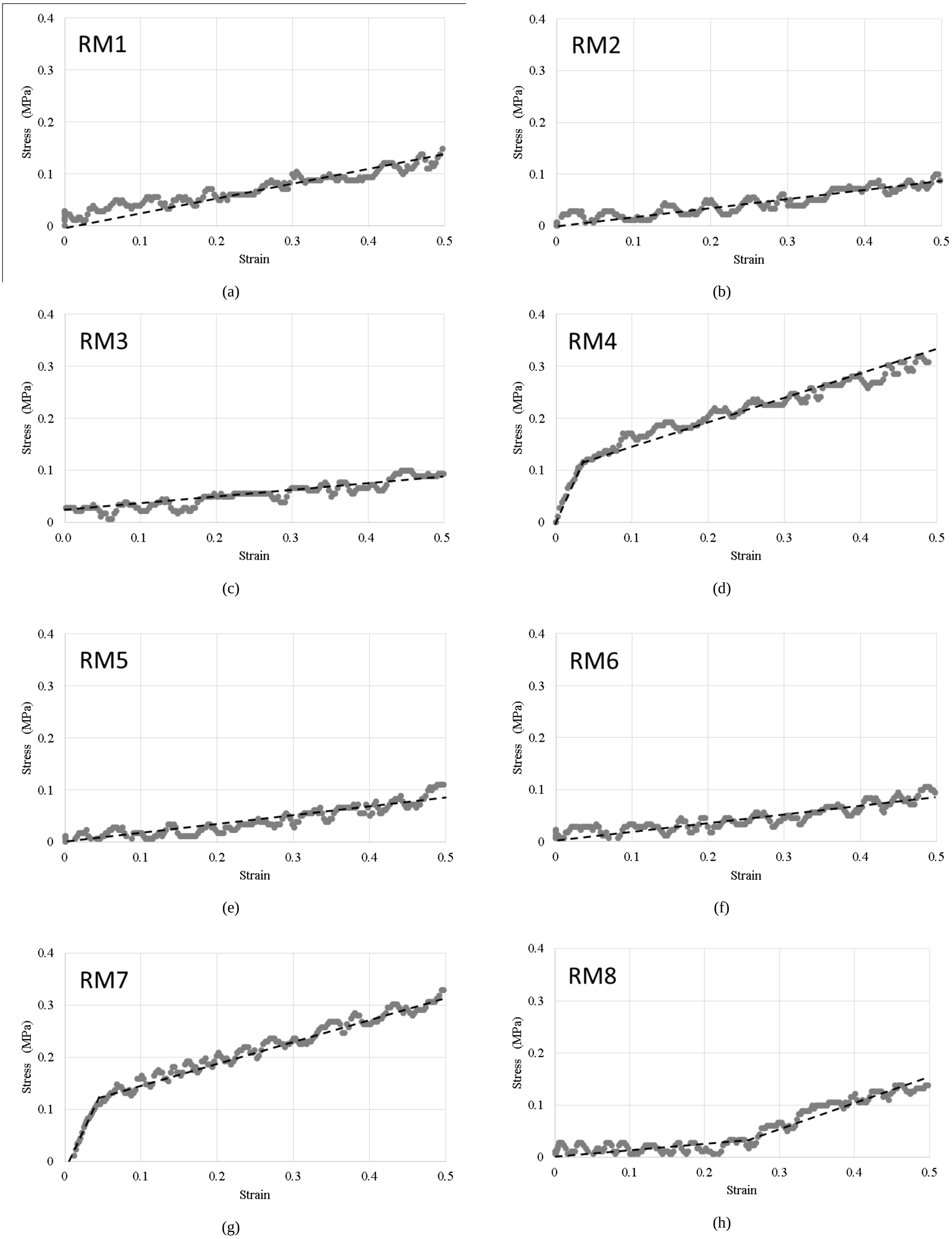

Figure 1. Stress-strain relationship by testing universal testing machine (UTM)

Load conditions were selected as 40N and 80N. 40N load plate was used when only lightweight foamed concrete and finishing mortar are constructed on top of the resilient material, and 80N load plate was used when lightweight foamed concrete, finishing mortar and finish layers are constructed on top of the resilient material that means finish layer was added to the 40N load plate case.

B. *Stress-Strain Relationship*

The stress - strain curves and the elastic modulus were measured using a Universal Testing Machine (UTM) with a displacement control to evaluate the long-term deflection. The experiment was performed as displacement control and the materials were unloaded at the strain to reach the 50% of the original thickness. It was placed a light steel plate on top of the resilient material to minimize the resilient material initial immediate deflection and LVDT was installed on the panel to measure the amount of deformation.

The stress - strain curves of eight types of resilient material were as the following Fig. 1. Stress-strain relationship was largely these two tendencies. RM1-, RM2-, RM3-, RM5-, RM6- experimental group appears likely to increase linearly and RM4-, RM7-, RM8- experimental group increases linearly but interval tended to be divided into two distinct stages. For the specimens RM4- and RM7-, an elastic modulus show reduced tendency up to a strain of 0.05. For the specimens RM8, an elastic modulus show increased tendency up to a strain of about 0.27. The initial stiffness of RM4- and RM7- is strong but since any transformation point, the stiffness becomes weak. It is determined that the influence on factors such as the particle characteristics, the production process of the resilient material. In the specimen RM8-, deflection occurred in the embossing because the initial stiffness of embossing is weak. After the embossed portion is fully sagged, stiffness and elastic modulus were increased because specimens behaved like flat resilient material.

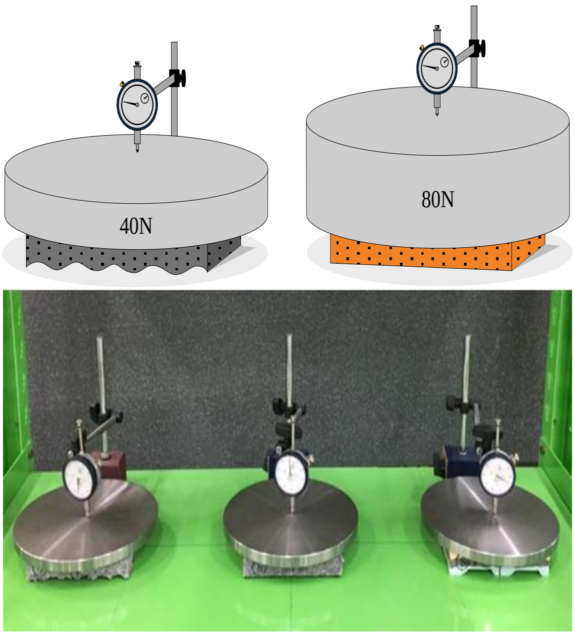

Figure 2. Laboratory settings

C. *Test Method*

Experiment settings are shown in the following Fig. 2. All specimens were placed on the metal shelves, designed durable with sufficient rigidity to ensure the surface flat and level without introducing eccentric load to the specimens. Load plates was made circular shape 40N, 80N, respectively. Load plates were placed on top of each specimens. Note that dial gauges installed in each of the specimens were to monitoring the deflection of the resilient materials with time. Dial gauges were installed center of load plate and showed the nearest hundredth numbers. The experiment was conducted for 50days. The readings were checked once every day for the initial week, once every week for 1 month and at least once every 10day thereafter.

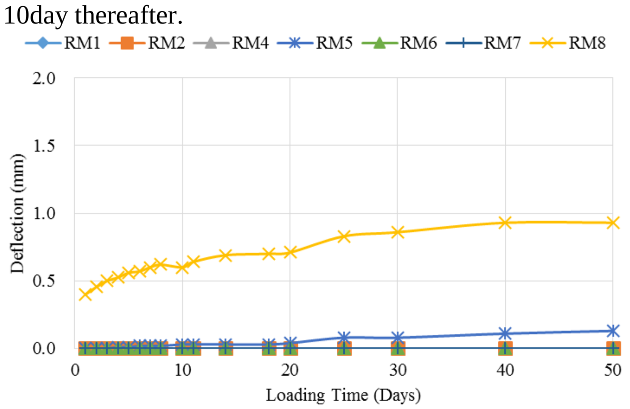

Figure 3. Long-term deflection under 40N load case.

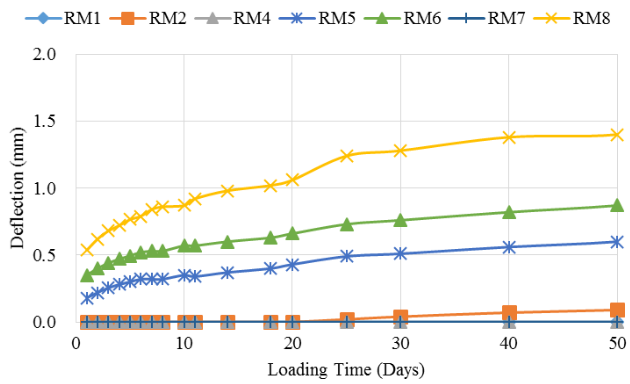

Figure 4. Long-term deflection under 80N load case

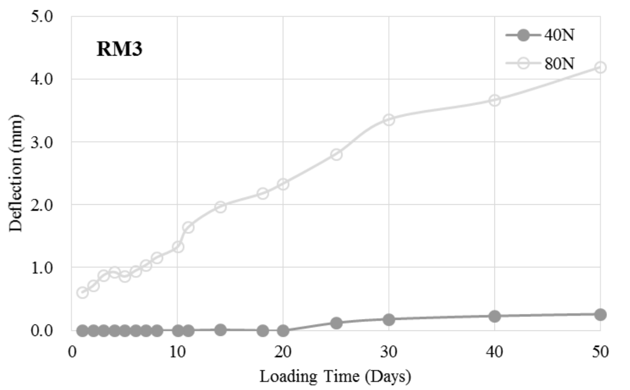

Figure 5. Long-term deflection of RM3-.

III. Test Result and Discussion

A. *General Deflection Behavior*

Long-term deflection test of eight kinds of resilient materials were conducted for 50 days. Deflection is measured 1day, 3day, 7day and 10day intervals. Measurement intervals were short at early time of experiment and getting wider with time for 50days. Fig. 3, Fig. 4 and Fig. 5 show the deflection of resilient materials the weight of each load 40N and 80N. Because Deflection of RM3-80 specimen was so higher than other specimens, graph of RM3-80 specimen is separately represented.

As shown, deflection of resilient materials was gradually increased with time [12], [13]. Some specimens did not deflect the whole period and some specimens did not deflect in early time but had deflection at a specific time. RM1-, RM4-, RM7- specimens did not transform under 40N, 80N both load cases. RM2-, RM6- specimens did not transform under 40N load case but did transform under 80N load case. RM3-, RM5-, RM8- specimens did transform under all load cases. Especially, deflection in RM8-80 sharply increased and modified to 13.13% of the initial thickness.

TABLE II. ELASTIC MODULUS AND DEFLECTION

Specimens	Elastic modulus(MPa)	Deflection (mm, %)			
		40N	strain	80N	strain
RM1	0.21	0.00	0.00	0.00	0.00
RM2	0.19	0.00	0.00	0.09	0.30
RM3	0.15	0.26	0.87	3.94	13.13
RM4	3.01 (0-0.04)	0.00	0.00	0.00	0.00
	0.45 (0.04-0.5)				
RM5	0.17	0.13	0.43	0.60	2.00
RM6	0.14	0.00	0.00	0.87	2.80
RM7	1.83 (0-0.07)	0.00	0.00	0.00	0.00
	0.50 (0.07-0.5)				
RM8	0.01 (0-0.26)	0.93	3.10	1.40	4.67
	0.42 (0.26-0.5)				

B. *Elastic Modulus*

Table II shows each resilient material elastic modulus and deflection. The elastic modulus is closely related to deflection of resilient materials. In general, specimens with small elastic modulus were deformed by loading cases but specimens with large elastic modulus did not deform by loading cases.

RM1-, RM4-, RM7- specimens that have elastic modulus larger than 0.2MPa did not transform by loading cases. RM2- specimens have no deflection under 40N loading case but under 80N loading case deflection appeared in specimens. RM3- specimens with relatively low elastic modulus than the other specimens show the most significant deflection. Total deflection was 3.94mm; that is 87% variation in initial thickness. RM6- specimens with elastic modulus, smaller than RM5-, did not have deflection due to experiment setup process error caused by using load plates. Because RM8- specimen have elastic modulus low as compared to other specimens, had higher deflection than other specimens except RM3-specimens. RM8- specimen with much lower elastic modulus than RM3-specimens, had deflection much higher than RM8- specimens. This means that variables of deflection are not only elastic modulus but another factors like materials, shape and density.

Fig. 6 shows relation between elastic modulus and deflection. In summary, resilient materials that have elastic modulus over 0.17MPa did transform under 40N load case and, resilient materials that have elastic modulus over 0.20MPa did transform under 80N load case. Note that this classification of two limited line is result from only 16 specimens experiment. Further study is needed to examine elastic modulus and deflection when the number of resilient materials is bigger than this research.

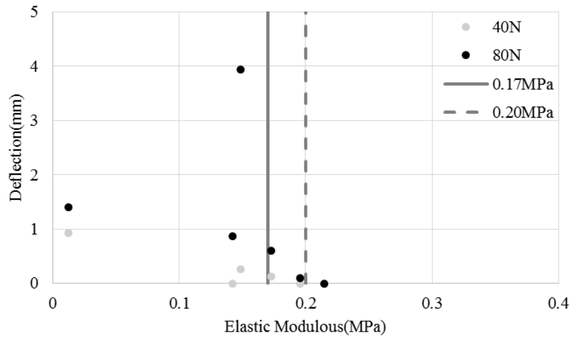

Figure 6. Relation between elastic modulus and deflection

TABLE III. INFLUENCE OF DENSITY

specimens	Density (kg/m^3)	Materials	Bottom shapes	Deflection (mm)	
				40N	80N
1	13.20	EPS	Plat	0.00	0.00
4	24.70	EPS	Plat	0.00	0.00
7	24.12	EPS	Plat	0.00	0.00
2	12.08	EPS	Corrugated	0.00	0.09
5	25.53	EPS	Corrugated	0.13	0.60
6	15.40	EPS	Corrugated	0.00	0.87

C. *Density*

As shown specimen information, density of resilient materials has a range of about 12 to 60 kg/m3 Specimens were selected 2groups that have same density but different materials and bottom shapes. Table III shows influence of density in deflection. RM1- (13.20 kg/m3), RM4- (24.70 kg/m3), RM7- (24.12 kg/m3) specimens have plat bottom shape and were composed of EPS (Ethylene Polystyrene). But RM1-, RM4- and RM7- specimens have no deflection in 40N, 80N load cases, direct analysis of density has been difficult. Also, RM2- (12.08 kg/m3), RM5- (25.53 kg/m3), RM6- (15.40 kg/m3) specimens have corrugated bottom shape and were composed of EPS(Ethylene Polystyrene). Compared to RM2-, RM5-, resilient material RM2- that has half density of RM5- appears lower deflection than RM5-. But compared to RM5-, RM6-, resilient material RM6- that has smaller density than RM5- appears higher deflection than RM6-.

Density influence of deflection in 8 resilient materials under 40N, 80N load cases did not show a constant tendency. Because deflection was very small and the number of specimens was so small.

D. Bottom Shpes

Table IV shows 3groups that were classified according to the bottom shape. Note that under 40N, 5 specimens did not deform. So, using deflection values under 80N load case. Each group had same material and similar density, except bottom shape. RM1-80 (EPS, 13.20 kg/m3), RM2-80 (EPS, 12.08 kg/m3) specimens have same material and similar density but RM2-80 with corrugated bottom shape had higher deflection than RM1-80, which has plat bottom shape. Similarly, when compared to the deflection of RM4-80 (EPS, 24.70 kg/m3) and RM5-80 (ESP, 25.53 kg/m3), deflection in corrugated bottom shaped specimens was higher than plat bottom shaped.

RM3-80 and RM8-80 specimens could not directly compare the effects of the bottom shape because only one specimen in experiment group. The reason for the deflection of RM3-80 came out large is judged that the influence of the material. RM8- specimen that have special bottom shape like embossed shows embossed bottoms shape began to sit down from an initial experiment, and were able to observe that deflection gradually increased until embossed shape to be a flat shape. Deflection value of RM8-80 (1.40mm) is judged only embossed shape deformed and rectangular shape located upper position of embossed shape didn't deform.

Fig. 7 shows three type shape of experiment materials. From left to right, plat, corrugated and embossed shape. 'Plat' means bottom plates are smooth, 'corrugated' means are rough like a valley shape and 'embossed' means something swollen part like a hemispherical shape.

E. Materials

Table V shows the deflection of the materials. To compare the deflection of the materials, RM3- (Plat, 23.96 kg/m3), RM4- (Plat, 24.70 kg/m3), RM7- (Plat, 24.12 kg/m3) which have same plat bottom shape and similar density were compared. Specimens RM4-, RM7- of the EPS series did not occur deflection when the loads were 40N and 80N. In some cases, Specimens RM1-, RM2-, RM5-, RM6- of another EPS (Ethylene Polystyrene) series occurred deflection but the value was very low as compared to specimen RM3- composed of PS (Polystyrene) material.

However, RM3- specimen which composed of PS occurred deflection when the loads were 40N and 80N. Unlike other specimens, RM3- specimen was shown the results that steadily increasing deflection with the course of time. In particular, 80N load tended to increase deflection sharply than other specimens. Stiffness of RM8- specimen composed of EVA (Ethylene Vinyl Acetate) materials was very good but why is this deflection appeared likely due to the characteristics of the embossed bottom shape. Deflection of RM8- occurs at only embossed part and not occur at rectangular part which located upper position. Comparing the EPS and PS, EPS material is expected to deflection appears larger than PS material.

TABLE IV. INFLUENCE OF BOTTOM SHAPES

specimens	Bottom shapes	Materials	Density (kg/m3)	Deflection (mm)
				80N
1	Plat	EPS	13.20	0.00
2	Corrugated	EPS	12.08	0.09
4	Plat	EPS	24.70	0.00
5	Corrugated	EPS	25.53	0.60
3	Plat	PS	23.96	3.94
8	embossed	EVA	59.26	1.4

TABLE V. INFLUENCE OF MATERIALS

specimens	Materials	Bottom shapes	Density (kg/m3)	Deflection (mm)	
				40N	80N
3	PS	Plat	23.96	0.26	3.94
4	EPS	Plat	24.70	0.00	0.00
7	EPS	Plat	24.12	0.00	0.00
8	EVA	Embossed	59.26	0.93	1.40

Plat Corrugated Embossed

Figure 7. Bottom shapes of resilient material.

F. Comparisom with Literature

Lee *at al.*, who tested 8 resilient materials with same characteristics materials under 250N, 500N load cases for 500days conducted long-term deflection and dynamic elastic modulus of resilient materials used in apartment buildings. Fig. 8 and Fig. 9 show deflection of resilient materials under 250N, 500N load cases for 500days. Because deflection of RM3- too higher than others specimens, deflection of RM3- were separately represented in Fig. 10. Except RM4-, RM7- specimens, the other specimens occur deflection. If a severe deflection of resilient material occurs, it may be cause of cracks or damage to the finishing mortar and aerated concrete which has been placed on the resilient material. Especially, RM3- specimen occur the highest deflection over 22mm that means thickness loss was about 74% compared to initial thickness.

Also, when 200 days after the experiment under 250N, 500N load cases, deflection convergence zones that mean deflection does not change greatly with loading time [14]. The reason is judged to sudden increased deflection due to large load conditions and the change of physical properties result from deflection [15].

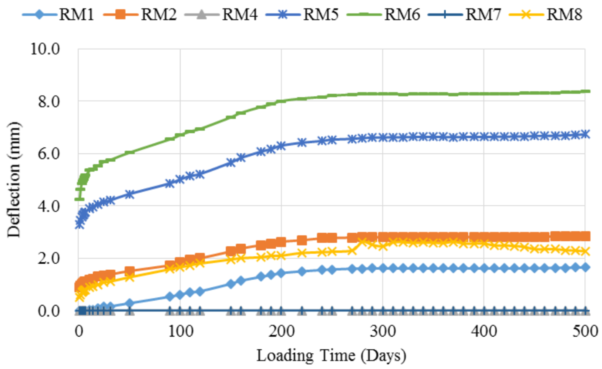

Figure 8. Long-term deflection under 250N load case.

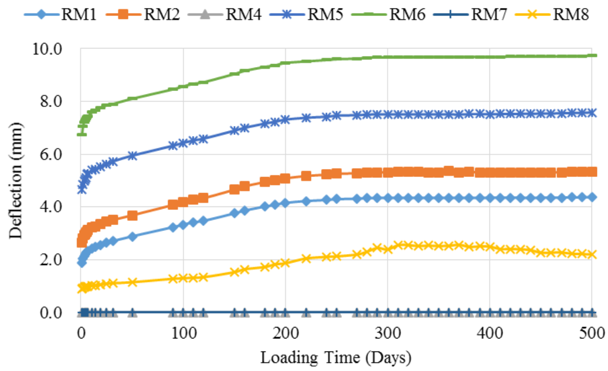

Figure 9. Long-term deflection under 500N load case.

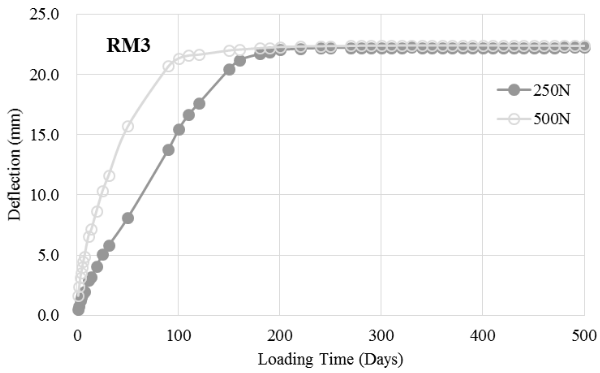

Figure 10. Long-term deflection of RM3-.

As shown Fig. 3 and Fig. 4, deflection convergence zones were not displayed under 40N, 80N load cases for 50days. But judging by the results of previous studies, resilient materials deflection under 40N, 80N load cases expected to increase steadily and deflection convergence zones will be shown at a particular time. When RM1-specimens are described as an example, Fig. 11 shows deflection of RM1- under three load cases. As shown Table II, RM1 specimens under 40N, 80N load cases deflection didn't occurs. But RM1 specimens under 250N, 500N load cases deflection occur. This means that RM1-40, RM1-80 specimens have possibility of deflection that may occur after 50days [16]. This deflection difference of resilient materials is judged by difference of loads which determine tendency of deflection on resilient materials. In the further study, Observing the deflection under 40N, 80N load cases after 50days is necessary for the deflection analysis of the resilient materials [17].

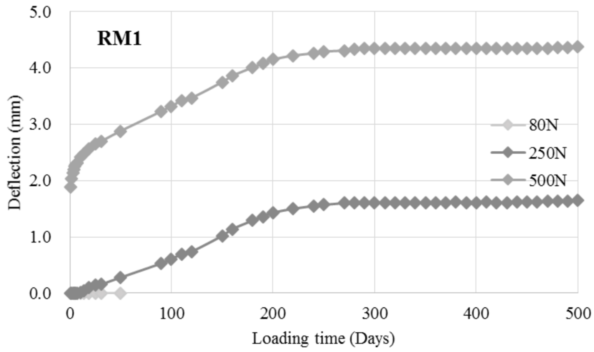

Figure 11. Compare the values of deflection of RM1-.

IV. Conclusion

In this study, the main purpose is to evaluate the performance for deflection in some performance of resilient material after long-term loading. In the experiment, the density of the resilient material, the size of loads, the bottom plate shapes, the elastic modulus were evaluated the effect on long-term performance of resilient material.

- Resilient materials receiving long-term load has steadily increased deflection. Long-term deflection of resilient materials has been affected in combination of types of materials, density and bottom plate shapes.
- The elastic modulus of resilient materials higher than 0.17Mpa, deflection did not occur under 40N load case. Also, the elastic modulus of resilient materials higher than 0.20Mpa, deflection did not occur under 80N load case.

Long-term deflection of resilient materials measured in this study will be able to apply establishment of criteria for interlayer noise suppression. But, this study is the evaluation of deflection obtained by loading for only 50days. So, additional tests and evaluation are required to know long-term performance of resilient materials.

Acknowledgment

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