Floor Impact Sound Reduction Structures for Multi-Family Housing Renovation

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Abstract

The residential remodeling market in South Korea is experiencing a compound annual growth rate of 5.4%, yet antiquated multi-family dwellings often feature slender concrete slabs (120–180 mm) that restrict the thickness and loading of retrofit systems. This study develops a wet-type floating floor system by jointly optimizing impact sound insulation and the long-term dimensional stability of resilient layers. Structural stability was evaluated via residual deformation (KS F 2873) and time-dependent deflection monitored using an 18 kg steel load plate (approximately 1.96 kPa), where displacement stabilized within 144 hours with deflection below 0.2 mm. To suppress low-frequency resonance-induced amplification around 50 Hz, a design target for dynamic stiffness (KS F 2868) not exceeding 5 MN/m³ was adopted while maintaining residual deformation within 3 mm. The proposed multi-layered system—consisting of embossed ethylene vinyl acetate (22–25 mm), a sound-absorbing interlayer (12–15 mm), and a 3 mm polypropylene board for load distribution—was validated through field tests on a 150 mm thin slab. The optimized configuration achieved standardized impact sound levels of 38 dB for light impact and 47 dB for heavy impact, successfully meeting the performance targets of Grade 2 and Grade 4, respectively. These results validate that the developed system provides superior acoustic comfort and structural durability, offering a robust engineering solution for environmental noise mitigation in renovated dwellings. Future investigations will explore point-support mechanisms and long-term creep tests exceeding one year to further enhance low-frequency damping performance.

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1. Introduction

South Korea has a rapidly aging multi-family housing stock. The national renovation market was estimated to grow from approximately KRW 17.1 trillion in 2020 to KRW 28.5 trillion in 2030, corresponding to a compound annual growth rate of 5.4% [1]. Unlike new construction, renovation must retain the existing structural frame. Many apartments completed before modern floor-impact-sound regulations have concrete slabs only 120–180 mm thick, whereas contemporary wall-type housing commonly uses slabs of at least 210 mm. The retrofit floor is also constrained by story height, permissible added dead load, wet construction, and the need to accommodate heating pipes.

A resilient layer that is too stiff provides limited vibration isolation, while an excessively compliant layer may amplify low-frequency response near the mass–spring resonance and may undergo unacceptable permanent deformation or creep. The engineering problem is therefore multi-objective: low dynamic stiffness is required for acoustic isolation, but sufficient dimensional stability is required to support the mortar layer, finishes, furniture, and construction loads. This study aimed to develop a practical wet-type floating floor for thin-slab renovation by integrating (i) material-property screening, (ii) short-term load stability assessment, (iii) laboratory mock-up evaluation, and (iv) full-scale validation on 150 and 210 mm slabs.

2. Review of Previous Studies

A floating floor is typically modeled as a mass-spring-damper system resting on an inertial structural base. The concrete slab and finishing mortar layers provide the mass, while the continuous resilient underlayment represents the spring and damper. The dynamic stiffness of the resilient layer is determined by Young's modulus (E) and the initial thickness (L_0) :

$$s' = \frac{E}{L_0}$$

Young's modulus (E) is expressed as:

$$E = \frac{L_0}{\Delta L} \cdot \frac{F}{A}$$

where (F) is the dynamic force perpendicular to the specimen, (A) is the specimen area, and (ΔL) is the length variation. Thus, the dynamic stiffness can be calculated as:

$$s' = \frac{F/A}{\Delta L}$$

Using the resonant frequency (f_{res}), the dynamic stiffness is related to the mass per unit area (m) of the load plate:

$$S' = (2\pi f_{res})^2 \cdot m$$

$$f_{res} = \frac{1}{2\pi}\sqrt{\frac{S'}{m}}$$

For a single-degree-of-freedom floating floor system, the natural resonance frequency (f_0) is estimated as :

$$f_0 = 160\sqrt{\frac{S'}{m}}$$

where S' is the apparent dynamic stiffness per unit area (MN/m^3) and m' is the mass per unit area of the floating slab (kg/m^2). The theoretical performance improvement (ΔL) in impact sound isolation occurs at frequencies above $\sqrt{2} \cdot f_0$ However, at or near the natural frequency of the system, vibration amplification can occur. If this resonance matches the structural modal frequencies of the thin concrete slab, the floor system can amplify low-frequency noise.

Dynamic stiffness per unit area is widely used to characterize resilient layers beneath floating floors. Previous Korean studies reported that lower dynamic stiffness generally improves light-impact isolation, but the relationship with heavy-impact Single-number quantity is weak when products with different materials, thicknesses, surface geometries, and loss factors are pooled [2]–[4]. Under controlled product conditions, frequency-specific correlations become clearer, indicating that dynamic stiffness should be interpreted together with the mass of the upper layer and the resonance frequency rather than as a stand-alone predictor.

Analytical work on concrete slab–resilient layer–mortar systems has also shown that changes in resilient-layer stiffness shift the coupled natural frequencies and can move the amplification region within the 50–80 Hz range [5]. These findings are particularly relevant to renovation because a thin existing slab has lower bending impedance and stronger modal sensitivity than a new 210 mm slab. However, most previous studies focused either on acoustic performance or material properties. Fewer studies have jointly considered acoustic performance, residual deformation, short-term settlement under wet-floor loads, and installation thickness for thin-slab dwellings. The present work addresses this gap using a staged screening-to-validation process.

3. Research methodology

3.1 Material screening and design criteria

Forty-nine resilient-layer combinations were produced using embossed or flat ethylene vinyl acetate (EVA), fibrous sound-absorbing layers, and 3 mm polypropylene (PP) boards of different densities. EVA thickness was mainly 22–30 mm, while the absorber thickness ranged from 7 to 18 mm. The PP board was introduced to distribute construction loads, protect the fibrous layer, and improve handling during wet construction. Dynamic stiffness was measured according to KS F 2868 after conditioning under a 200 kg/m² load for 48 h. Residual deformation was evaluated according to KS F 2873. Based on resonance considerations and dimensional-stability requirements, the screening targets were dynamic stiffness not greater than 5 MN/m³ and residual deformation not greater than 3 mm.

3.2 Load stability and acoustic measurements

Time-dependent settlement was assessed with an 18 kg steel plate measuring 300 × 300 × 30 mm. The resulting pressure was approximately 1.96 kPa, exceeding the estimated 1.10–1.49 kPa dead load of typical combinations of lightweight aerated concrete and finishing mortar. Deflection was recorded at 24 h intervals for up to 240 h. Acoustic screening was then performed on five mock-up constructions with a 50 mm mortar layer. Full-scale tests were conducted in apartment-type test rooms using two 150 mm slab configurations and three 210 mm slab configurations. Light impact was generated by a tapping machine and heavy impact by a rubber impact ball. Measurements and ratings followed KS F ISO 16283-2 and KS F ISO 717-2.

4. Results

4.1 Material properties and load stability

The second modal frequency of the resilient floor system was estimated using the measured dynamic stiffness. Dynamic stiffness was determined in accordance with KS F 2868 after the specimens had been subjected to a static load of 200 kg/m² for 48 h, and the measurements were completed within 1 h after unloading.

The results were used to examine the influence of the constituent materials on the dynamic stiffness of composite layers consisting of ethylene-vinyl acetate (EVA) and a sound-absorbing material. In general, an increase in the thickness of the sound-absorbing layer or a reduction in its density is expected to decrease the dynamic stiffness. However, the present results indicated that, when the sound-absorbing material was combined with EVA, increasing the absorber thickness did not necessarily result in a proportional reduction in dynamic stiffness. This finding suggests that the dynamic response of the multilayer system is governed not only by the individual material properties but also by the interaction between the layers, including their relative thicknesses, geometry, and interfacial conditions.

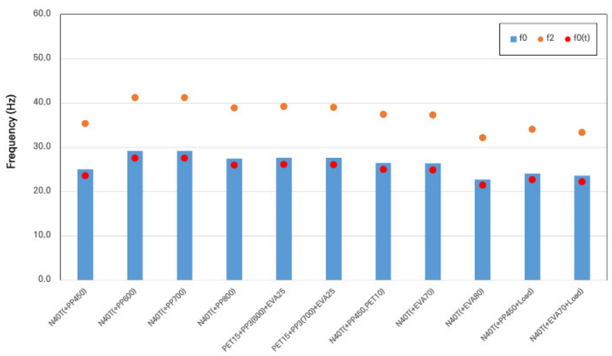

Figure 2. Dynamic Stiffness by Specimen

Based on the measured results and the predicted modal characteristics, a dynamic stiffness of less than approximately 5 MN/m³ was adopted as the design target to reduce the likelihood of resonance-induced amplification in the vicinity of the critical low-frequency region around 50 Hz. Within the range of specimens investigated, configurations incorporating a sound-absorbing layer of approximately 10 mm or less and an EVA layer of at least 25 mm generally exhibited favorable characteristics for achieving this target. However, this tendency should be interpreted within the range of the present experimental dataset.
The residual-deformation results further demonstrated a trade-off between acoustic performance and structural stability. As the dynamic stiffness increased, the resilient system became stiffer and generally exhibited a smaller residual deformation, typically less than 3 mm. Nevertheless, an excessively high dynamic stiffness may reduce the effectiveness of impact-sound isolation. Therefore, the resilient layer should be designed to maintain a dynamic stiffness of approximately 5 MN/m³ or less while simultaneously satisfying the residual-deformation criterion of 3 mm or less.
The density of the polypropylene (PP) board also had a notable influence on the composite system. An increase in PP density generally increased the dynamic stiffness, whereas the residual deformation remained stable below 3 mm. Thus, increasing the PP-board density can improve load-distribution capability and dimensional stability, but may also reduce acoustic isolation by increasing the overall stiffness of the floor system. The PP density should therefore be selected by balancing the requirements for structural stability and low-frequency impact-sound reduction.
The screening tests confirmed a clear trade-off between stiffness and recovery. Increasing PP density generally increased dynamic stiffness, whereas the conditioned residual deformation of the PP-containing specimens remained mostly below 3 mm. Increasing the absorber thickness could lower stiffness, but excessive fibrous thickness increased the risk of residual deformation. EVA thickness had a smaller effect on residual deformation over the investigated range, although specimen flatness and local damage to embossed cells affected repeatability. Figure 3 summarizes representative conditioned results and shows that only a limited subset simultaneously approached both design targets.

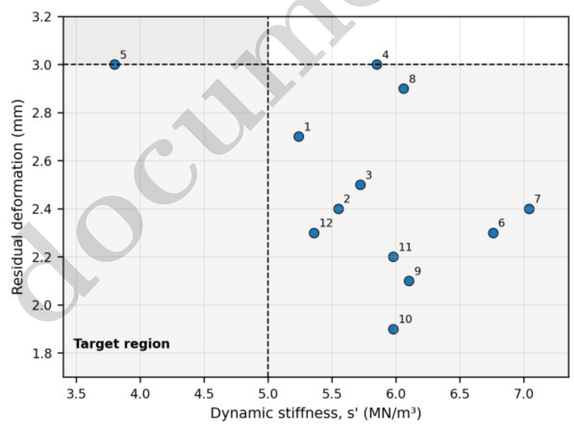

Figure 3. Correlation between Dynamic Stiffness and Residual Deformation by Specimen

Under the 1.96 kPa steel-plate load, the measured displacement stabilized within 144 h. The final deflection remained below approximately 0.2 mm, and the incremental change after stabilization was within 0.1 mm. Specimens with a relatively thick absorber and thinner EVA showed most of their settlement during the first 48 h and then approached a stable value. The test therefore supported the short-term serviceability of the selected layered system, although moisture exposure during wet construction and long-term creep remain important uncertainties.

4.2 Mock-up and full-scale acoustic performance

The five mock-up systems produced heavy-impact ratings between 45 and 47 dB. The best mock-up consisted of 25 mm EVA, a 3 mm PP board, and a 12 mm absorber, reaching 45 dB. The small range among mock-ups indicates that increasing total resilient-layer thickness alone did not guarantee better performance. In particular, configurations with additional EVA showed persistent low-frequency sensitivity, supporting the need to tune stiffness and upper-layer mass rather than simply maximize thickness.

On the 150 mm slab, changing from 25 mm EVA plus a 12 mm absorber to 22 mm EVA plus a 15 mm absorber improved the light-impact rating from 41 to 38 dB and the heavy-impact rating from 50 to 47 dB. This optimized 80 mm build-up achieved the target Grades 2 and 4, respectively, while retaining a practical wet-floor configuration. Applying the same resilient layer on a 210 mm slab improved the ratings further to 33 dB for light impact and 43 dB for heavy impact. Increasing the mortar thickness from 40 to 70 mm on the 210 mm slab did not change the Single-number quantity, suggesting that the slab and resilient-layer interaction dominated within this range. A thicker double-EVA system reached 33 dB and 45 dB, but offered no advantage over the thinner optimized configuration for light impact and was inferior for heavy impact.

The frequency-domain comparison clarifies the rating improvement. Configuration 150-B reduced the 63 Hz band by 4.6 dB and produced substantial reductions above 125 Hz, although the 50 Hz level increased by 2.8 dB. Thus, the lower single-number heavy-impact rating was obtained despite a remaining 50 Hz limitation. This confirms that future optimization should target the fundamental slab–floating-floor interaction rather than only the mid- and high-frequency isolation provided by the resilient layer.

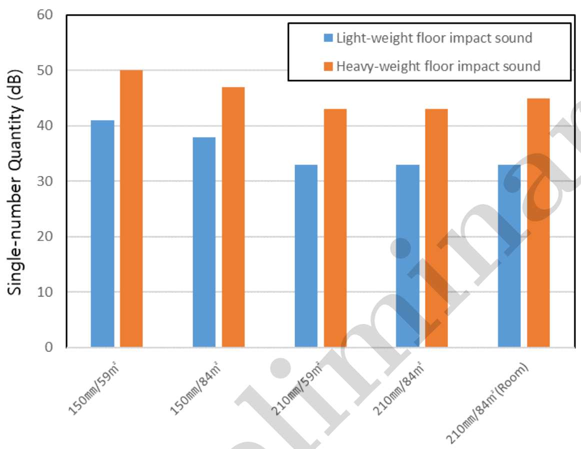

Figure 4. Single-number quantity by Thickness of slabs

5. Conclusions and discussion

A wet-type floating floor suitable for multi-family housing renovation was developed through combined material, stability, mock-up, and full-scale testing. The principal conclusions are as follows. First, the acoustic and structural requirements cannot be optimized independently: very compliant absorbers reduce dynamic stiffness but can compromise residual deformation, while denser PP boards improve load distribution but tend to increase stiffness. Second, an 18 kg plate producing 1.96 kPa caused less than 0.2 mm deflection, with stabilization within 144 h, demonstrating adequate short-term dimensional stability under a load greater than typical wet-floor dead loads. Third, the optimized 150 mm-slab system—22 mm embossed EVA, 15 mm sound-absorbing layer, 3 mm PP board, and 40 mm finishing mortar—achieved 38 dB for light impact and 47 dB for heavy impact.

The 50–80 Hz range remained the critical design region. The results show that performance is governed by the coupled impedance of the slab, resilient layer, and upper mortar rather than by dynamic stiffness alone. For field application, quality control should therefore include material thickness and density, dynamic stiffness, residual deformation, pre-conditioning of curled EVA sheets, continuity of the PP layer, perimeter isolation, and moisture protection of the absorber. The present settlement test was short relative to the service life of a dwelling and was performed under controlled laboratory temperature and humidity. Future work should include creep tests exceeding one year, cyclic and moisture-conditioned loading, uncertainty analysis across rooms, and point-support or locally stiffened mechanisms capable of distributing impact force while preserving low-frequency damping

6. Acknowledgments

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