The effect of the damping materials on heavy-weight floor impact noise in box frame-type structure buildings

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ABSTRACT
Box Frame-type Structures Building floor with a damping layer can be modeled as a sandwich plate. For the efficient reduction of low frequency noise generated by heavy-weight floor impact, thickness of the damping layer needs to be optimized at the design stage. Therefore, modal loss factors were calculated using the Ross-Kerwin-Ungar equation and the optimum thickness of the damping layer was determined at each mode so that several modes in the frequency range of interest can be considered. Furthermore, to investigate the frequency-dependent modal characteristics of complex stiffness of the damping layer, an iteration method is proposed.

Keywords: Heavy weight impact noise, Viscoelastic materials, Box frame-type structures

1. INTRODUCTION
Heavy weight impact noise is the most common irritating noise in reinforced concrete apartment hi-rises in Korea. It is customary not to wear shoes in Korean homes, as this is a common source of low-frequency noise. Energetic children running and jumping are another source. Many tenants who live in high-rise apartment buildings complain about heavy-weight impact sound and noise from the above floor.

Most Korean apartments were built with a concrete structural system reinforced by load-bearing walls. This system does not require columns and beams, and can reduce effectively the vertical distance between floors. In most concrete slab structures, elastic surface layer, floating floor, high-stiffness method and double ceiling methods are used to reduce floor impact sounds [1].

Floating floors, in which resilient isolators are inserted between the structural slab and the upper layer of the floor, are generally used because of their effectiveness in controlling structure-borne and airborne noise [2]. However, according to previous studies, these isolators amplify low-frequency noises (those below 100Hz), which are generally produced by heavyweight impacts. Viscoelastic damping materials are widely used to reduce noise in settings such as vehicles, ships, and machinery; however, there has been no report of their use in apartment building structures for reducing floor impact sounds. In this study, for the efficient reduction of low frequency noise generated by heavy-weight floor impact, thickness of the damping layer needs to be optimized at the design stage. Modal loss factors were calculated using the Ross-Kerwin-Ungar equation and the optimum thickness of the damping layer was determined at each mode so that several modes in the frequency range of interest can be considered in a more systematic way [3].

2. VISCOELASTIC MATERIALS
Damping is the conversion of mechanical energy of a structure into thermal energy. A structure subject to oscillatory deformation contains a combination of kinetic and potential energy. In the case of real structures, there is also an energy dissipation element per cycle of motion. The amount of energy dissipated is a measure of the structure’s damping level.

The addition of damping can be embodied using liquid of viscoelastic such as silicone gasoline and energy is absorbed with superior special characteristics being a solid matter as viscoelastic materials. In the former case, affect that get in other structure urea because increase of damping of only a floor structure is small genuinely.
2.1 Modal loss factor and natural frequency using RKU equation

RKU equation regards as simplicity beam that have sandwich beam that appear to figure 1 do equivalent materials property, get equivalent bending stiffness about boundary conditions and decide modal loss factor and nature frequency.

![Diagram of beam having equivalent materials property of sandwich beam](image)

Figure 1 - Beam having equivalent materials property of sandwich beam

Assumed that there is no glassiest between figure’s binding layers, viscoelasticity layer, and each level that consist of basis layer in RKU equation. Binding layer and basis layer that suppose as viscoelastic damping layer, compressive deformation and tensile strain happen by bending vibration and assumed that bending angle that each layer achieves about vertical direction is same. Also, viscoelastic damping layer inserted between basis layer and binding layer assumed that compressive deformation by bending vibration, tensile strain and shearing strain occur together. Equivalent bending stiffness that is decided in RKU equation is same with equation (1), and displayed meaning of each variable to picture.

\[
B = E_1 \frac{H_1^3}{12} + E_2 \frac{H_2^3}{12} + E_3 \frac{H_3^3}{12} - E_2 \frac{H_2^3}{12} \left( \frac{H_{31} - D}{1 + g} \right) \\
+ E_2 H D^3 + E_2 H_1 \left( H_{21} - D \right)^2 + E_3 H_3 \left( H_{31} - D \right)^2 \\
= \left[ \frac{E_1 H_1}{2} \left( H_{31} - D \right) + E_3 H_3 \left( H_{31} - D \right) \right] \left( \frac{H_{31} - D}{1 + g} \right) 
\]

(1)

\( B \) : equivalent bending stiffness (sandwich beam/plate)
\( E_1, E_3 \) : modulus elasticity (elasticity layer of sandwich beam/plate)
\( E_2 \) : modulus elasticity (viscoelasticity layer of sandwich beam/plate)
\( G_2 \) : complex shearing modulus of viscoelasticity layer
\( P \) : special solution of sandwich beam/plate
Modal loss factor and nature frequency of sandwich beam are decided with that use equivalent bending stiffness.

\[ g = \frac{G_s}{K_s H p} \]

\( P, \rho \) and \( H \) is indicated singular solution, density and thickness.

\[ \eta = \frac{\text{Im}(B)}{\text{Re}(B)} \]  

\[ \omega_s = \rho^2 \sqrt[3]{B} \rho H b \]  

\( P \) regards sandwiches beam as single beam at process that get equivalent bending stiffness, and solution of special equation that apply simple support boundary conditions in single beam's equation.

Therefore, the solution of single beam's equation that is obtained in boundary conditions in addition to simple support, can apply \( P \) to sandwiches beam's bending stiffness and decide modal loss factor and nature frequency about boundary conditions in addition to simple support approximately. RKU equation established to flat to apply in the floor construction to theory for sandwiches beam, and apply method to refer before and applied boundary conditions in addition to simple support approximately.

Apply RKU equation in the floor construction and examined loss factor's change about one mode by viscoelastic damping materials thickness change. Modal loss factor decreases passing the maximum point with figure 2 according to viscoelastic damping materials' thickness increase.

![Figure 2 - Modal loss factor with regard to increase in viscoelastic damping layer thickness](image)

2.2 **Optimal viscoelastic damping materials thickness of apartment floor construction**

If examine about area and aspect ratio, as see to figure 3, viscoelastic damping layer thickness that become optimum modal loss factor increased more than double according to floor area double increase. From length and breadth ratio 1:1 to maximum 1:1.5, according to increase, can know that viscoelastic damping layer thickness decreases 35%.

Therefore, because can know that area is important design variable than length and breadth ratio at viscoelastic damping layer thickness decision, wish to fix length and breadth ratio by 1:1 and consider effect of area. For structural wall boundary condition of apartment floor construction, determined by mean value with calculation of simplicity support and fix support two boundary conditions. Wall or veranda that have window that can't consider as structural wall assumed as freedom support.

Figure 4. indicated optimal viscoelastic damping layer thickness of first mode with regard to area of bedroom.
3. VISCOELASTIC MATERIALS IN BOX FRAME-TYPE STRUCTURE BUILDINGS

3.1 Results of heavy-weight impact and the floor systems

The effect of floor system composition on sound and vibration characteristics was examined in 20 story apartments. As shown in Table 4, the floor systems were composed of 20mm resilient isolator (II-1), 15mm damping material (II-2) and 3mm visco-elastic damping material plus honey-comb structure of 12mm polyethylene (PE) (both II-3 and II-4).

The only difference between Type II-3 and Type II-4 is the position of the damping materials; in Type II-3, the damping material is on the top of the autoclaved lightweight concrete whereas it is below the autoclaved lightweight concrete in Type II-4. Sound and vibration characteristics of heavy-weight impact were analyzed.

Table 3 - Composition of the floor systems

<table>
<thead>
<tr>
<th>Type</th>
<th>Floor System Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>II-1 [115.5 m²]</td>
<td>Concrete slab (150mm) + resilient isolator(20mm) + autoclaved lightweight concrete(40mm) + finishing mortar(50mm)</td>
</tr>
<tr>
<td>II-2 [99.0 m²]</td>
<td>concrete slab (150mm) + damping material(15mm) + autoclaved lightweight concrete (45mm) + finishing mortar (50mm)</td>
</tr>
<tr>
<td>II-3 [112.2 m²]</td>
<td>concrete slab (150mm) + damping material (3mm) + PE honeycomb structure(12mm) + autoclaved lightweight concrete (45mm) + finishing mortar (50mm)</td>
</tr>
<tr>
<td>II-4 [145.2 m²]</td>
<td>concrete slab (150mm) + autoclaved lightweight concrete (45mm) + damping material (3mm) + PE honeycomb structure (12mm) + finishing mortar (50mm)</td>
</tr>
</tbody>
</table>
Table 4 - Experiment II: Results of heavy-weight impact for damping materials

<table>
<thead>
<tr>
<th>Type</th>
<th>Resonant frequency [Hz]</th>
<th>Acceleration [m/s²]</th>
<th>VAL [dB]</th>
<th>( L_{A,\text{max},\text{AW}} ) [dB]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bare Slab Complete Floor</td>
<td>Bare Slab Complete Floor</td>
<td>Bare Slab Complete Floor</td>
<td>Complete Floor</td>
</tr>
<tr>
<td></td>
<td>LR BR LR BR LR BR LR BR LR BR</td>
<td>LR BR LR BR LR BR LR BR LR BR</td>
<td>LR BR LR BR LR BR LR BR LR BR</td>
<td></td>
</tr>
<tr>
<td>II-1</td>
<td>21 39 20 42 0.45 0.56 0.29 0.38 93 95 89 92</td>
<td>51 49</td>
<td></td>
<td></td>
</tr>
<tr>
<td>II-2</td>
<td>27 39 33 46 0.46 0.67 0.1 0.06 93 96 80 76</td>
<td>46 48</td>
<td></td>
<td></td>
</tr>
<tr>
<td>II-3</td>
<td>17 30 32 42 0.34 0.6 0.04 0.07 91 96 71 77</td>
<td>45 45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>II-4</td>
<td>18 31 24 42 0.35 0.53 0.08 0.0 3 91 94 78 69</td>
<td>45 44</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

As shown in Table 4, the vibration acceleration level of Type II-2 was decreased by 13dB in the living room and by 20dB in the bedroom. It was also found that the resonance frequency increases by 6-7 Hz. However, in Type II-1, the vibration level only decreased 4dB in the living room and 3dB in the bedroom, but the resonance frequency did not vary thereafter. The impact sound level of Type II-1 both in living room and bedroom was 6dB lower than Type II-2, II-3 and II-4.

As shown in Figure 3, the sound pressure level of Types II-2-4 (all having damping material) decreases at frequencies below 125Hz where impact energy was concentrated in the Type II-1 isolator.

4. CONCLUSIONS

The thickness of the viscoelastic damping layer that become optimum modal loss factor increased more than double according to floor area increase. From length and width ratio 1:1 to maximum 1:1.5, according to increase, can know that viscoelastic damping layer thickness decreases 35%.

Results of heavy-weight impact and the floor systems, the vibration acceleration level of 3mm visco-elastic damping materials was decreased by 13dB in the living room and by 20dB in the bedroom. It was also found that the resonance frequency increases by 6-7 Hz. However, in resilient isolator, the vibration level only decreased 4dB in the living room and 3dB in the bedroom, but the resonance frequency did not vary thereafter. The impact sound level of resilient isolator both in living room and bedroom was 6dB lower than damping materials. The sound pressure level of all having damping materials decreases at frequencies below 125Hz where impact energy was concentrated in the resilient isolator.

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REFERENCES