Experimental study of sound insulation performance in the wood-framed building

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Summary
The sound insulation performance of the wooden constructions is low in comparison with the concrete constructions. Among the objections and the troubles of the apartment houses in Japan, the sound insulation performance is one of the most serious issues. Therefore, we built a wood-framed model building for experiments, and the specifications of the separation floor and wall were investigated for the purpose of high performance of the floor impact sound insulation and the airborne sound insulation of the separation wall. The floating floors were set on some wooden separation floors. About the separation walls, the arrangement of studs and the thickness of air layer were changed. This paper reports the results of the floor impact sound and the airborne sound insulation performance. We provide that the floating floors are effective and suitable for the floor impact sound insulation in wooden construction.

1. Introduction
According to the Building Standards Law, Article 61, the buildings in fire-protection districts with three stories or more, or of more than 100 square meters, should be a fireproof building. Other buildings must be either fireproof or quasi-fireproof constructions. Building Research Institute and Japan 2x4 Home Builders Association have cooperated on research regarding fireproof structures of wood-framed structure and developed a wooden fireproof construction in 2004. Accordingly, application of wood-framed buildings is now possible for four-story apartment houses and special structures in fire-protection districts.

At the same time, the knowledge about the technology used to construct a four-floor wood-framed building was little. Therefore, a full-size four-story building for experiments was built, and examined the structural stability, characteristics of vibration [1] and amount of building settlement, etc. One of the most serious issues for apartment houses in Japan concerns the acoustics environment. The important matters in acoustics environment of apartment houses are a floor impact sound insulation performance and an airborne sound performance of a separation wall. It goes without saying that the acoustics environment of apartment houses made of wood constructions shows worse performance than that of concrete construction. The experiments on the model building’s acoustic environment were also conducted. The model building had six kinds of separation floor and four kinds of separation wall. Each floor and wall had own cross-sectional specifications for the examination of the acoustics environment.

In this paper, we report the results of our experimental study on the acoustics environment of the model building. They are included the results of measurement of the floor impact sound insulation performance, the vibration performances and the airborne sound insulation performance.
2. Wood-framed model building for experiments

2.1 Outline of the building

The wood-framed model building was a four-story fireproof building (four floors and a loft) that was 7,735 mm wide and 4,777.5 mm deep. Its eave height was 12,639 mm. Fig. 1 shows the appearance of the wood-framed model building, and Fig. 2 shows a plane view of the fourth floor. Each of the four floors had almost the same arrangement of living space, and there were two living areas (dwelling units) on each floor. The outer walls and balcony rails varied from floor to floor. Fig. 3 shows a sectional schematic of the model building. As mentioned earlier, it had four floors, each of which had two dwelling units. Accordingly, it had six separation floors (2A, 2B, 3A, 3B, 4A and 4B), each of which had its own section specifications. Moreover, each of the four separation walls (W1, W2, W3 and W4) had its own section specifications.

<table>
<thead>
<tr>
<th>Floor</th>
<th>2A</th>
<th>2B</th>
<th>3A</th>
<th>3B</th>
<th>4A</th>
<th>4B</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
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<td>3rd</td>
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<td>4th</td>
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</tbody>
</table>

Fig. 1 Appearance of the wood-framed model building

Fig. 2 Plane view of the wood-framed model building and chart of measurement points

Fig. 3 Schematic section view of the model building

2.2 Specifications of separation floors

Tab. 1 shows the six section specifications of separation floors. Separation floor 4A had the standard specifications commonly used in separation floors. Separation floor 4B was the same as 4A but with the asphalt sound-insulation sheets inserted, and separation floor 2B was the same as 4A but with dampers built into its joists. Each of the other three separation floors (2A, 3A, and 3B) was the same as 4A but with floating floor in place of the composite finish flooring used in 4A.

Fig. 4 shows a sectional view of the standard separation floor, 4A. The two-ply reinforced gypsum board (thickness: 15 mm + 21 mm) of floor and ceiling is the foundation of the fire-resistant structure, and the walls have the same two-ply reinforced gypsum board. The ceiling is independent, and no sound absorbing material such as glass wool has been inserted in it.
Fig. 5 shows an example of a section of the floating floor. The floating floors were the floor coverings that contained air layers. Supporting legs with rubber vibration isolators supported the particle board, the wooden flooring etc. These floors are superior because the space facilitates the installation of plumbing facilities and the adjustable legs obviate the need for barriers such as steps to cover changes in level. Under the influence of air spring and propagation vibration the heavy-weighted floor impact sound insulation performance is worse than with a bare floor. The floating floors are the most popular floor covering used in Japanese concrete construction apartment houses. However, it is rarely used in wooden construction apartment houses.

Tab. 1 Summary of the six section specifications of separation floors

<table>
<thead>
<tr>
<th>Separation floors</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>4A (Standard)</td>
<td>Fire-resistant specifications + composite flooring (12)</td>
</tr>
<tr>
<td>4B</td>
<td>Fire-resistant specifications + asphalt sound-insulation sheet (8) + composite flooring (12)</td>
</tr>
<tr>
<td>3A</td>
<td>Fire-resistant specifications + floating floor A</td>
</tr>
<tr>
<td>3B</td>
<td>Fire-resistant specifications + floating floor B</td>
</tr>
<tr>
<td>2A</td>
<td>Fire-resistant specifications + floating floor C*</td>
</tr>
<tr>
<td>2B</td>
<td>Fire-resistant specifications + damping material* inserted for sound insulation</td>
</tr>
</tbody>
</table>

Note: The asterisked floating floor C and damping material were trial products. The numbers in parentheses indicate thickness.

2.3 Specifications for separation walls

Tab. 2 shows the four section specifications of separation walls. When seen in cross-section, the four separation walls are: an air space of 140 mm with staggered stud placement (W1), an air space of 140 mm with common stud placement (W2), W2 with an air space of 90 mm (W3) and W3 with resilient metal channels reinforcement.

Tab. 2 Summary of the four section specifications of separation walls

<table>
<thead>
<tr>
<th>Separation Walls</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>W4</td>
<td>Common Studding, Gypsum boards(9.5+9.5) + Air layer(12) + Gypsum boards(21+15) + Air layer(90) + Gypsum boards(21+15)</td>
</tr>
<tr>
<td>W3</td>
<td>Common Studding, Gypsum boards(21+15) + Air layer(90) + Gypsum boards(21+15)</td>
</tr>
<tr>
<td>W2</td>
<td>Common Studding, Gypsum boards(21+15) + Air layer(140) + Gypsum boards(21+15)</td>
</tr>
<tr>
<td>W1</td>
<td>Staggered Studding, Gypsum boards(21+15) + Air layer(140) + Gypsum boards(21+15)</td>
</tr>
</tbody>
</table>

Note: The numbers in parentheses indicate thickness.
3. Measurement of floor impact sound insulation

3.1 Measurement summary

The floor impact sound insulation was measured in conformity with the requirements of JIS A 1418-2 [2] and JIS 1418-1 [3]. As shown in Fig. 2, the five points were designated as impact points and sound-receiving points. Each impact point was impacted by the standard impact sources, and the floor impact sound levels were measured with a multi-channel analyzer. As the three kinds of impact source, we used ‘a car-tire’ and ‘a rubber ball’ as the impact sources specified by JIS A1418-2 and ‘a tapping machine’ specified by JIS A1418-1. The floor impact sound insulation was measured in a sound-receiving room furnished with a sofa, carpet, and curtains, and the reverberation was adjusted. Fig. 6 shows the results of measurement of floor impact sound levels.

![Figure 6: Results of measurement of floor impact sound levels](image)

(Left: Car-tire source; middle: Rubber ball source; right: Tapping machine)

Fig. 6 Results of measurement of floor impact sound levels

3.2 Heavy-weighted floor impact sound insulation

There was little difference in the heavy-weighted floor impact sound level between separation floor 4A and 4B, which incorporated the asphalt sheets (thickness: 8 mm), regardless of whether the impact source was the car-tire or the rubber ball. Although measures of the heavy-weighted floor impact sound insulation basically show both increased rigidity and area density by following the formula used to calculate the driving-point impedance \( Z = 8\sqrt{Bm} \), it is presumably because both the rigidity and the area density of the floor hardly changed. The damper in the separation floor 2B was designed to dampen vibration around the 63 Hz oct. band. It was observed that a difference (about 4 dB) in the heavy-weighted floor impact sound level between separation floor 4A and 2B around this band and found that the damper was effective. In separation floors 2A and 3A, which had floating flooring, the heavy-weighted floor impact sound level was improved by about 10 dB compared with 4A. Separation floor 3B showed little difference in the heavy-weighted floor impact sound level compared with 4A in the case of the car-tire source, but the floating flooring successfully improved the heavy-weighted floor impact sound insulation by about 3 dB in the 63 Hz oct. band in the case of the rubber ball source. Separation floor 3A showed the highest heavy-weighted floor impact sound insulation among the six sound receiving rooms; L-Number was 62.
3.3 Light-weighted floor impact sound insulation

There was little difference in the light-weighted floor impact sound level between separation floors 4A and 2B. This is because the damper in separation floor 2B was designed for the heavy-weighted floor impact sound insulation (only around the 63 Hz oct. band) and because the surface of the floor was composite flooring. Separation floor 4B, which had an asphalt sound-insulation sheet inserted, showed improved the light-weighted floor impact sound insulation compared with 4A in the 250 Hz and 500 Hz oct. bands, proving the effect of the asphalt sound-insulation sheets, which was not observed at the heavy-weighted floor impact sound insulation. Separation floor 2A, 3A, and 3B, all of which had floating floor, were showed improved the light-weighted floor impact sound insulation compared with 4A. As was the case for the heavy-weighted floor impact sound insulation, separation floor 3A gave the highest light floor impact sound insulation among the six sound-receiving rooms; L-Number was 53. Although no sound absorbing material had been inserted in the ceiling of the model building, it would clearly be possible to improve the light-weighted floor impact sound insulation by inserting glass wool in the ceiling.

From the above results, we concluded that the floating floors are effective for the heavy-weighted and light-weighted floor impact sound insulation in wood-framed structures. This is presumably because of the vibration damping by the rubber vibration isolators.

3.4 Discussion of the floor impact sound insulation performance

In Japan, floor impact sound insulation performance is most often valued using the classes set up by the Architectural Institute of Japan. These classes are shown in Tab. 3. Separation floor 3A had a heavy-weighted impact level of Third Class and its light-weighted impact level was Second Class, showing a high performance level.

<table>
<thead>
<tr>
<th>Impact Source</th>
<th>Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Special Grade</td>
</tr>
<tr>
<td>Heavy and Soft Impact Source</td>
<td>L-45</td>
</tr>
<tr>
<td>Light Impact Source</td>
<td>L-40</td>
</tr>
</tbody>
</table>

* Apply to wooden structure, lightweight steel-frame construction, etc.

4. Vibration measurement

It was predicted that the heavy-weighted floor impact sound level would be closely related to the indoor surface vibration in the room below. Therefore, we measured vibration acceleration levels to examine the vibration performance of each surface of the rooms below separation floors with the highest (3A) and lowest (4A) performance in terms of heavy-weighted floor impact sound insulation.

4.1 Measurement summary

The vibration acceleration levels (reference value 0 dB = 10^{-5} m/s^2) of the floors of the room above and the ceilings, walls, and floors of the room below were measured in response to the car-tire source on the floor of the room above. The five impact points were similar to those used in the measurement of floor impact sound level. For each surface we averaged the maximum vibration acceleration energy in every 1/3 oct. band frequency and then summed them to calculate the vibration acceleration level.

4.2 Measured results

Fig. 7 shows the measured vibration acceleration level of each surface. The acceleration vibration levels of the floors (4A, 3A) of the rooms above differed. It is because of the influence of the rubber
vibration isolators of the floating floor in high frequency and the decrease of the rigidity in low
frequency. The four wall surfaces had similar vibration acceleration levels. The ceiling surface level
was the largest, and the floor surface of the room below was the smallest. The relative frequency
responses of the ceilings in response to the floor impact sound were the highest. It is effective to
increase the heavy-weighted floor impact sound insulation performance in controlling vibration of
the ceiling.

Fig. 8 shows the relationship between the vibration acceleration level and the floor impact sound
level. The value for 1/1 oct. band of vibration acceleration was calculated by adding the values for
1/3 oct. band levels as the results of Fig. 7. This result shows that the heavy-weighted floor impact
sound level was closely related to the indoor surface vibration level of the room below.

![Fig. 7 Maximum vibration acceleration levels](image)

**Fig. 7 Maximum vibration acceleration levels**

![Fig. 8 Relationship between vibration acceleration level and floor impact sound](image)

**Fig. 8 Relationship between vibration acceleration level and floor impact sound**

5. Measurement of airborne sound insulation performance of separation walls

5.1 Measurement summary

The airborne sound insulation was measured in conformity with the requirements of JIS A 1417 [4].
The average sound pressure levels of two rooms, sound source room and sound receiving room,
were measured and by showing the difference between the noise levels in two rooms. It needs to be
mentioned that with separation wall W4, the sound source and the sound receiving rooms were also
inversed for a different measurement (W4”).
5.2 Measured results

Fig. 9 shows the results of measurement of the airborne sound insulation performance of separation walls. The performance of the wall with staggered studs (W1) was the highest, showing a rating of D-42. With common studs placement (W2, W3 and W4), there was hardly any difference in performance, even though there were differences in thickness of the air layer or of the wall. From these results, it is able to confirm that staggered placement of studs with separation walls is very effective in regard to improving the airborne sound insulation performance. At the same time, use of resilient metal channels reinforcement in separation wall W4 showed an increase in performance when compared with W3 at a frequency range of 1 kHz oct. band or more, but at lower frequencies, there was hardly any difference. When comparing the results of measuring separation wall W4 and the reversing of the sound source and receiving rooms (W4'), the figures were about the same. It must be mentioned that these results took into account the difference in sound levels caused by flanking transmission sounds coming from balconies or interior hallways.

![Fig. 9 Results of measurement of airborne sound insulation of separation walls](image)

5.3 Discussion of the airborne sound insulation performance of separation walls

The air sound insulation performances of separation walls were based on the classification system of the Architectural Institute of Japan as is the case with the floor impact sound insulation performance in 3.4. This class is shown in Tab. 4. While the highest performance, that separation wall W1, was Third Class, the rest of the party walls were unrated. In view of this, further consideration needs to be given to improving the airborne sound insulation performance.

<table>
<thead>
<tr>
<th>Area</th>
<th>Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Special Grade</td>
</tr>
<tr>
<td>Separation Wall</td>
<td>D-55</td>
</tr>
</tbody>
</table>

Tab. 4 Classes by Architectural Institute of Japan of apartment house 2
6. Conclusions

In this research, we studied the floor impact sound insulation and the airborne sound insulation of the four-floor wood-framed model building and obtained the following points:

1) The floating floors (i.e. the finished flooring material used in the concrete constructions) are effective in improving the heavy-weighted and light-weighted floor impact sound insulation performance of the wood-framed constructions.
2) Increasing the heavy-weighted floor impact sound insulation performance is effective in controlling vibration in the ceiling.
3) For the air sound insulation performance of party walls, there was little influence of wall density, but the staggering of studs was found to be effective.

The following areas need to be considered further.

i) Consideration with other wood-frame structures.
ii) Consideration of other types of floating floors.
iii) Laboratory measurements of the reduction of transmitted impact sound by ISO140-11 [5].

We are planning to continue our considerations of acoustics environment performance as it relates to wood-frame structures.

7. References