Flanking floor impact sound insulation in cross laminated timber model building for experiment

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Abstract. The Act for Promotion of Use of Wood in Public Buildings (Law No. 36 of 2010 of Japan) was enforced in 2010. The promotion of the use of wood can contribute to the prevention of global warming etc. A public building in a low layer is supposed to attempt making to timber construction by this act. Moreover it is expected that the building such as apartment houses comes to be made from timber construction. For effective use of the Japanese wood, CLT (Cross Laminated Timber), which had been used in Europe, was standardized by JAS (Japanese Agricultural Standard) as a building material in 2014. Among the objections and the troubles of buildings in Japan, the sound insulation performance is one of the most serious issues, especially floor impact sound insulation. We, however, have little knowledge about sound insulation of CLT building. Therefore we built a 3-story CLT model building for experiment and investigated the floor impact sound insulation and the flanking floor impact sound insulation. This paper presents the results of floor impact sound insulation and the surfaces vibration in a sound-receiving room. The results showed the influences of damping material, ceiling and floating on the floor impact sound insulation, and the floating floor showed possible improvements in the heavy-weight and the light-weight floor impact sound insulation of CLT building. The vibration velocity level of the ceiling was the largest. However, it is necessary to decrease the vibration velocity level of the sound-receiving room’s wall for improvement of the heavy-weight floor impact sound insulation by using damping material.

1. Introduction

The Act for Promotion of Use of Wood in Public Buildings (Law No. 36 of 2010 of Japan) was enforced in 2010. The purpose of this act is proper maintenance of the forest and an improvement of the rate of self-sufficiency of wood. The promotion of the use of wood can contribute to the prevention of global warming etc. A public building in a low layer is supposed to attempt making to timber construction. Moreover it is expected that the building such as apartment houses comes to be made from timber construction. For effective use of the Japanese wood, CLT (Cross laminated Timber), which had been used in Europe, was standardized by JAS (Japanese Agricultural Standard) as a building material in 2014. Among the objections and the troubles of buildings in apartment houses of Japan, the sound insulation performance is one of the most serious issues, especially floor impact...
sound insulation. A timber building usually has inferior performance of floor impact sound insulation than a concrete construction. Zeitler et al. investigated the impact sound insulation of cross laminated timber floors [1]. Author reported the effect of floating floor (dry double system floor) on the floor impact sound insulation in timber building [2]. We, however, have little knowledge about sound insulation of cross laminated timber building. Therefore we built a 3-story cross laminated timber model building for experiment and investigated the floor impact sound insulation and the flanking floor impact sound insulation. This paper presents the results of floor impact sound insulation and the surface vibration in a sound-receiving room.

1.1. Building frame
Figure 1 shows the cross-sectional view of the cross laminated timber model building. One floor of this building measures 3.64 x 3.18 m (10.4 m² in a floor area) and the entire building is three-storied. H steels were set on the concrete earth floor and 1st floor was finished the floating floor. The 2nd and 3rd floor were 5-ply 150 mm thickness CLT panel. All walls were 3-ply 90 mm thickness CLT panel. As for the ceiling height, the 2nd floor was 2.3 m, the 1st floor was 2.7 m. The floor is jointed the wall by bolts and angles, it was structure to be proof against earthquakes.

![Figure 1. Cross-sectional view of the cross laminated timber model building.](image)

1.2. Specifications of floor section
In order to investigate the influences of damping material, ceiling and floating floor on floor impact sound insulation for cross laminated timber building, the floor section specifications of the specimen were determined. Table 1 shows the outline of section specifications of 11 specimens. Specimen No. 1 as reference specimen was only building frame without damping material, ceiling and floor topping. Specimens No. 1, 2 and 3 were No. 0 with damping material. The damping material is polyurethane elastomer foam of 12.5 mm thickness. As for each Young's modulus of static load, damping material A is approximately 8.0 N/mm², damping B is approximately 1.8 N/mm². Specimen No. 1 was No. 0 with damping material A between 2nd wall and 2nd floor, Specimen No. 2 was No. 0 with damping material B between 2nd wall and 2nd floor, and Specimen No. 3 was No. 0 with damping material B between 3rd floor and 2nd wall.

Specimens No. 4 was No. 0 with suspended ceiling. The ceiling was constructed in 9.5 mm thickness gypsum board with substrate light gauge steel. Specimens No. 5, 6 and 7 were No. 0 with floating floor, and specimens No. 8, 9 and 10 were No. 4 with floating floor. Figure 2 shows the cross-
sectional view of floating floors. The floating floor is designed by supporting legs with rubber vibration isolators supported the particle boards etc., and contained air layers. The topping of floating floors was changed with and without 8 mm thick asphalt sheet.

Table 1. Outline of floor section specifications of specimen.

| Damping material | Ceiling | Floor topping |
|------------------|---------|--------------|
| None             | Gypsum board, t=9.5 mm | Floating floor A |
| Damping material A | None | Floating floor C |
| (between 2nd floor wall and 2nd floor) | None | Floating floor A |
| Damping material B | None | Floating floor B |
| (between 2nd floor wall and 2nd floor) | None | Floating floor C |
| Damping material B | None | Floating floor A |
| (between 3rd floor and 2nd floor wall) | None | Floating floor B |

Figure 2. Cross-sectional view of floating floors. (Left: Floating floor A, Center: Floating floor B, Right: Floating floor C)

2. Measurements
The floor impact sound insulations were measured in conformity with JIS A 1418-2 [3] for the heavy-weight floor impact sound insulation and JIS A 1418-1 [4] for the light-weight floor impact sound insulation. The impact sources for measurement of the heavy-weight floor impact sound were a car-tire source (a Bang machine) and a rubber ball source, and of the light-weight floor impact sound was a tapping machine. The impact positions were five positions, and the sound-receiving positions were five positions. The floor impact sound insulations were evaluated with JIS A 1419-2 [5].

The heavy-weight floor impact sound insulation would be closely related to the indoor surface vibration in the sound-receiving room. Therefore the vibration velocity levels were measured. The vibration velocity levels (reference value 0 dB = 5 x 10^-8 m/s) of the ceiling, four walls (north-side, south-side, east-side and west-side) and floors of the sound-receiving room were measured in response to the rubber ball source impacts on the floor of the sound source room. The impact position was centre position which was similar to those used in the measurement of floor impact sound. For each surface, the maximum vibration velocity energy were measured in every third octave band frequency.

3. Results and Discussions

3.1. Floor impact sound insulation
Figure 3 shows the measurement results of the floor impact sound insulation; the 3rd floor was the sound-source room and the 2nd floor was the sound-receiving room. As for specimen No. 0, the
heavy-weight floor impact sound insulation using the car-tire source was \( L_r - 90 \). The heavy-weight floor impact sound insulation using the rubber ball source was \( L_r - 80 \) and the light-weight floor impact sound insulation was \( L_r - 105 \). These floor impact sound insulations were exceedingly low performance for actual buildings. Specimen No. 10 yielded high performance, showing \( L_r - 75 \) in the heavy-weight floor impact sound insulation using car-tire source, \( L_r - 65 \) in the heavy-weight floor impact sound insulation using rubber ball and \( L_r - 70 \) in the light-weight floor impact sound insulation.

Figure 3. Measurement results of the floor impact sound insulation of the cross laminated timber model building. (Sound-source room: 3rd floor, Sound-receiving room: 2nd floor) (Left: Car-tire source, Center: Rubber ball source, Right: Tapping machine).

3.2. Effects of damping material, ceiling and floating floor
To confirm the effects of the damping material, ceiling and floating floor on the floor impact sound insulation, the floor impact sound pressure level differences from specimen No. 0 were calculated. Figure 4 shows the improvements of floor impact sound pressure levels relative to that of specimen No. 0. The positive values indicate that the room has a higher floor impact sound insulation than specimen No. 0.

There were few level differences in the 63 Hz octave band between car-tire source and rubber ball source. In contact, the level differences of the rubber ball were higher than of the car-tire source in the 125 Hz octave band or higher frequency.

There are few changes of the level difference by the damping material (specimen No. 1, 2 and 3) in the 125 Hz octave band or high frequency regardless of the floor impact source. The floor impact sound insulations were increased in the 63 Hz octave band by damping material. In addition, an effect of damping material was the highest in specimen No. 3. The differences were 6.0 dB in the case of the car-tire source, and 6.6 dB in the case of the rubber ball source.

The value of the effect of the ceiling (specimen No. 4) in all octave bands were approximately 5 dB regardless of the floor impact source. From the above results, the ceiling has the effect on heavy-weight and light-weight floor impact sound insulation of cross laminated timber building.

The effect of the floating floor (specimen No. 5, 6, 7, 8, 9 and 10) on the heavy-weight and the light-weight floor impact sound insulation. Furthermore the floor impact sound insulation was high by mass on the topping of the floating floor. It was a performance gain of approximately 3 dB a layer in the asphalt sheet in the floor impact sound insulation.
Figure 4. Improvements of floor impact sound pressure levels from specimen No. 0. (Left: Car tire source, Center: Rubber ball source, Right: Tapping machine).

3.3. Flanking floor impact sound insulation

Figure 5 and 6 show the measurement results of vibration velocity levels when rubber ball source impact on room’s center position. The vibration velocity level measurement results of specimens No. 0, 1, 2 and 3 in Figure 5 shows that the vibration velocity level of the ceiling surface hardly changes even when a damping material was inserted. On the other hand, the wall surface vibration velocity level of specimen No. 3 is small near the 63 Hz octave band. This indicates that the damping material between the floor and the floor reduces vibration propagation to the wall and reduces the radiated sound from the wall surface (the flanking floor impact sound). The vibration velocity level measurement results of the specimen’s No. 0, 8 and 10 in Figure 6 show that the vibration level is reduced in the frequency range lower than the 63 Hz octave band and higher than the 80 Hz octave band by the construction of the floating floor. Furthermore, although the effect of reducing the radiated sound from the ceiling surface is small, the radiated sound from the wall surface is greatly reduced by inserting the asphalt sheet on the floating floor, and the effect of the asphalt sheet on the upper surface material is appearing.

Based on the above results, the floor impact sound insulation performance of cross laminated timber building is often not able to ignore the radiated sound (the flanking floor impact sound) from the wall surface.

Figure 5. Measurement results of vibration velocity levels 1. (Left: Ceiling, Right: West wall).
Figure 6. Measurement results of vibration velocity levels 2. (Left: Ceiling, Right: West wall).

4. Conclusions
This paper presents the results of floor impact sound insulation and the vibration of surfaces of sound-receiving room of the 3-story cross laminated timber building. The results of the floor impact sound insulation suggest the influences of the damping material, ceiling and floating on the floor impact sound insulation of cross laminated timber building. We conclude that the floating floor showed possible improvements in the heavy-weight and the light-weight floor impact sound insulation of cross laminated timber building. In addition, we showed the possibility of reducing the radiated sound from the wall surface (the flanking floor impact sound) by using damping material.

5. References
[1] Zeitler B, Schoenwald S and Sabourin I 2014 Direct impact sound insulation of cross laminate timber floors with and without topping Proc INTER-NOISE 14
[2] Hiramitsu A 2013 Floor impact sound insulation of wooden three-story school building for full-scale fire experiment Proc INTER-NOISE 13
[3] Acoustics - Measurement of floor impact sound insulation of buildings – Part 2: Method using standard heavy impact sources. (2000). Japanese Industrial Standard JIS A 1418-2: 2000, Japanese Industrial Standards Committee.
[4] Acoustics - Measurement of floor impact sound insulation of buildings – Part 1: Method using standard light impact source. (2000). Japanese Industrial Standard JIS A 1418-1: 2000, Japanese Industrial Standards Committee.
[5] Acoustics - Rating of sound insulation in buildings and of building elements – Part 2: Floor impact sound insulation. (2000). Japanese Industrial Standard JIS A 1419-2: 2000, Japanese Industrial Standards Committee.

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