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Floor impact sound insulation of the six-story wood-frame model building

Atsuo HIRAMITSU[1]; Ryuta TOMITA[2]; Susumu HIRAKAWA[3]; Masayoshi SATO[4]

[1] National Institute for Land and Infrastructure Management, Japan

[2] Nihon University, Japan

[3] Building Research Institute, Japan

[4] Japan 2x4 Home Builders Association, Japan

ABSTRACT

In Japan, the Act for Promotion of Use of Wood in Public Buildings was enforced in 2010. As a result, the number of constructions using the timber structure became more popular for the buildings. However, the performance of the floor impact sound insulation in the timber construction buildings is often concerned as worse than the concrete constructions. In this paper, an experiments were carried out on a newly built six-story wood-frame building to investigate the performance of the floor impact sound insulation on five different floors; CLT panel floor, stressed skin panel floor, LVL floor, I-joist floor and chord truss floor. The result showed that the stressed skins panel floor has the highest performance of heavy-weight floor impact sound insulation. The paper also reports the sound insulation of separation wall and the vibration performance in the timber construction building, and proposes an improvement plan for the better floor impact and airborne sound insulation performance in the timber construction buildings.

Keywords: Floor impact sound insulation, Wood-frame construction, Cross Laminated Timber

1. INTRODUCTION

In Japan, the Act for Promotion of Use of Wood in Public Buildings. was enforced in 2010. As a result, the number of constructions using the timber structure became more popular for the buildings. Thus, consideration is being given to the high-rise building by timber construction.

Currently, the knowledge about the performance of the high-rise timber building is limited. It is believed that the sound insulation performance in the high-rise timber building is often concerned as worse than the concrete construction. However, there is no rigorous report has been published yet. For this reason, we built a six-story wood-frame model building for assessing the performances of construction, building deformation, living environment, durability and sound insulation.

In the previous studies, we investigated the floor impact sound insulation performance of a wood-framed model building for experiments which had four-story, and we tried to improve the floor impact sound insulation in reference (1). For the CLT building, we reported the measurement results of floor impact sound insulation and sound insulation of separation wall in Cross Laminated Timber building in references (2, 3 and 4).

In this paper, the experiments were carried out on a newly built six-story wood-frame building to investigate the performance of the floor impact sound insulation on five different separation floors; CLT panel floor, stressed skin panel floor, LVL floor, I-joist floor and chord truss floor. Moreover, this paper also reports the sound insulation of the separation wall and the floor vibration performance in the model building.

[1] hiramitsu-a92ta@mlit.go.jp
[2] tomita.ryuta@nihon-u.ac.jp
[3] sh@kenken.go.jp
[4] m-satou@2x4assoc.or.jp

2. SIX-STORY WOOD-FRAME MODEL BUILDING

Fig. 1 shows an outside view of the six-story wood-frame model building. It is 7,280 mm wide, 5,005 mm deep and 17,309 mm height. Each of the five floors (1st floor to 5th floor) has almost the same arrangement of living space, and there were two living areas (dwelling units, 3,640 mm wide and 2,502.5 mm deep) on each floor except for the 6th floor. The 6th floor has one living area (dwelling units, 3,640 mm wide and 2,502.5 mm deep).

Fig. 2 shows a cross-sectional view of the six-story wood-frame model building. The five different separating floors exist on each floor; 2nd floor: CLT panel floor, 3rd floor: stressed skin panel floor, 4th floor: LVL floor, 5th floor: I-joist floor and 6th floor: chord truss floor is shown.

Figure 1 – Photograph showing the outside view of six-story wood-frame model building

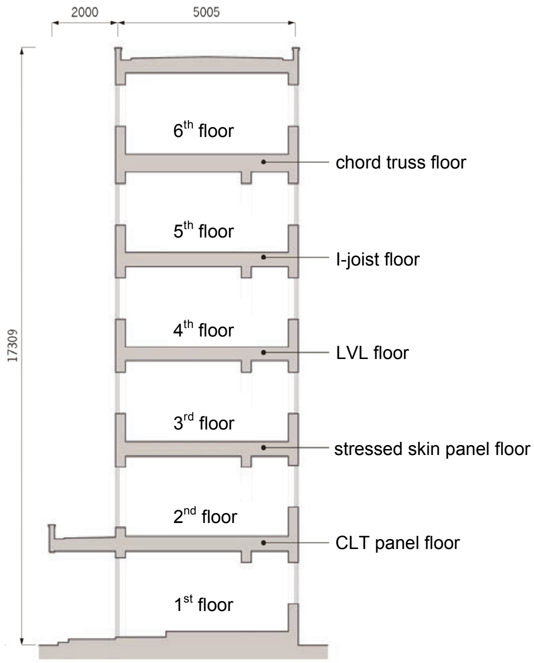

Figure 2 – Cross-sectional view of six-story wood-frame model building

3. MEARSURMENT METHOD

3.1 Floor Impact Sound Insulation

The floor impact sound insulations were measured in conformity with requirements of JIS A 1418-2: 2000 (5) for the heavy-weight floor impact sound insulation and JIS A 1418-1: 2000 (6) 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 source 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: 2000 (7). A-weighted floor impact sound pressure levels by synthesis were also calculated; heavy-weight floor impact sound: 31.5 to 500 Hz octave band, light-weight floor impact sound: 125 to 2000 Hz octave band.

3.2 Airborne Sound Insulation of Separation Wall

The airborne sound insulation of separation wall was measured in conformity with requirements of JIS A 1416: 2000 (8). The sound receiving positions were five positions in each room. The airborne sound insulation of separation wall was evaluated with JIS A 1419-1: 2000 (9).

The measurements of airborne sound insulation of separation wall were performed on the 3rd floor and 5th floor. The separation wall of the 3rd floor is *Midply wall system* which had double 12 mm thick Oriented Strand Board and two-layer 21 mm thick fire-resistant gypsum board finish, and the separation wall of the 5th floor is wood-frame construction and two-layer 21 mm thick fire-resistant gypsum board finish.

3.3 Floor Vibration Performance

The floor vibration performance was measured the vibration acceleration level for the each floor. The excitation method was dropped the rubber ball source from the height of 1 m. The vibration measurement position was the center of the room, and a vibration level meter was used. The analysis method was 10 ms for the time constant, and the maximum value of the vibration acceleration level of the 1/3 octave band from 3.15 to 80 Hz band was obtained.

The results of vertical measurements were plotted in the performance evaluation curve of vertical vibration of "Guidelines for the evaluation of habitability to building vibration (10)". V - ◯ indicates the perceptual probability of ◯%. Starting from the smallest point, the line is made up of V- 10, 30, 50, 70, 90.

4. MEARSURMENT RESOLUTS AND DISCUSSIONS

4.1 Floor Impact Sound Insulation

Fig. 3 shows the measurement results of floor impact sound pressure level.

In the case of heavy-weight floor impact sound insulation using the car-tire source, the 3rd floor (SSP, stress skin panel floor) yielded the highest performance, showing L_r-70 (70.9 dBA). The 4th floor (LVL, LVL floor), the 5th floor (I-joist, I-joist floor) and the 6th floor (CT, chord truss floor) yielded low performances, showing almost L_r-80. The 2nd floor (CLT, CLT panel floor) yielded middle performances, showing L_r-75, and decrease in performance are seen in the 250 Hz and 500 Hz octave bands because it is considered as resonance.

In the case of heavy-weight floor impact sound insulation using the rubber ball source, the performance tended to be similar to that of the car-tire source. However, the 4th floor (LVL, LVL floor) has high performance, showing L_r-70. This is considered to be due to the non-linear response of the LVL floor to impact forces.

In the case of light-weight floor impact sound insulation using the tapping machine, the 4th floor (LVL, LVL floor) yielded the highest performance, showing L_r-75. The 2nd floor (CLT, CLT panel floor) yielded low performances, showing L_r-95, and decrease in performance are seen in the 250 Hz and 500 Hz octave bands and tended to be similar to that of the heavy-weight floor impact sound.

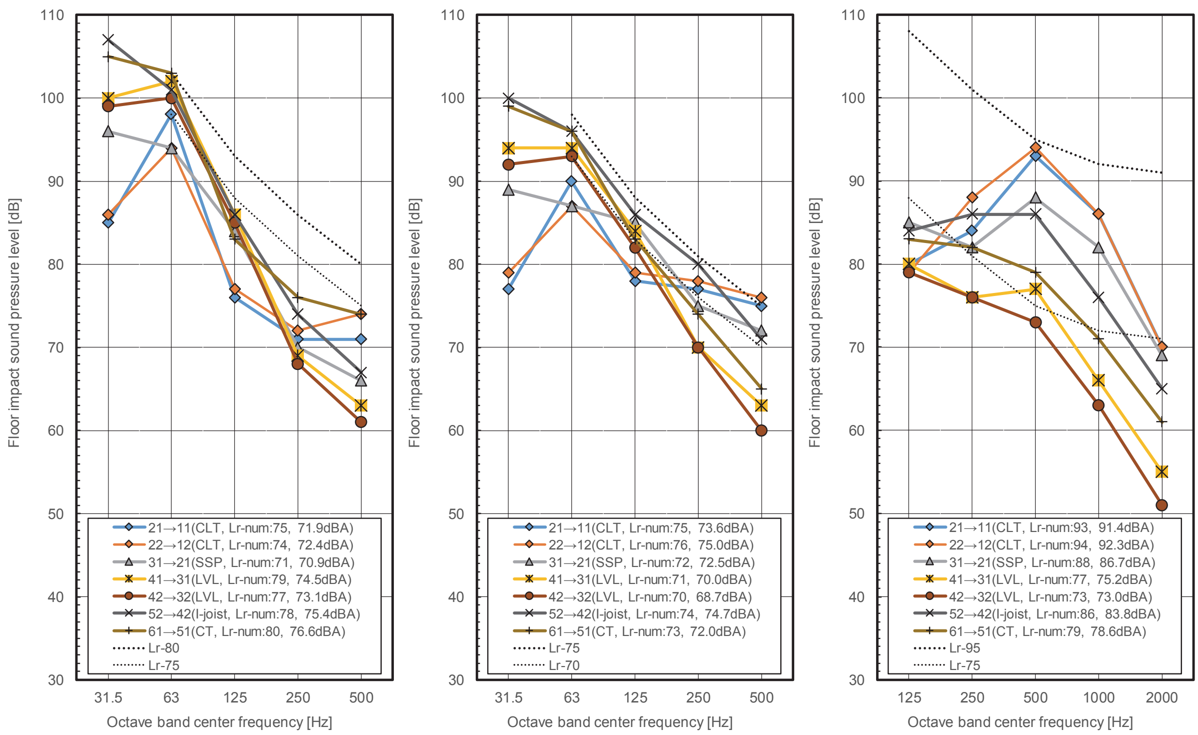

Figure 3 – Measurement results of floor impact sound pressure level
(left: car-tire source, center: rubber ball source, right: tapping machine)

Table 1 shows the applicable grades of the floor impact sound insulation for apartment house specified by the Architectural Institute of Japan (11). Only the car-tire source is used to evaluate the heavy-weight floor impact sound insulation. The comparison between the results from Fig. 3 and Table 1 shows that the heavy-weight floor impact sound insulation and the light-weight floor impact sound insulation were outside the grade range of applicable grade. The countermeasures are considered necessary to improve the floor impact sound insulation.

Table 1 –Architectural Institute of Japan grades of the floor impact sound insulation for apartment house

Impact source	Special Grade	First Grade	Second Grade	Third Grade
Heavy and soft source (only Car-tire source)	L-45	L-50	L-55	L-60, L-65*
Light impact source	L-40	L-45	L-55	L-60

*Apply to wooden construction, lightweight steel construction, etc.

4.2 Airborne Sound Insulation of Separation Wall

Fig. 4 shows the measurement results of airborne sound insulation of the separation wall. The 3rd floor separation wall (*Midply wall system*) yielded level difference D_r-30, and the 5th floor separation wall (wood-frame construction) yielded level difference D_r-35.

Table 2 shows the applicable grades of the airborne sound insulation for apartment house specified by the Architectural Institute of Japan (11). The comparison between the results from Fig. 4 and Table 2 shows that the airborne sound insulation of the separation wall was outside the grade range of applicable grade. The countermeasures are considered necessary to improve the airborne sound insulation of the separation wall.

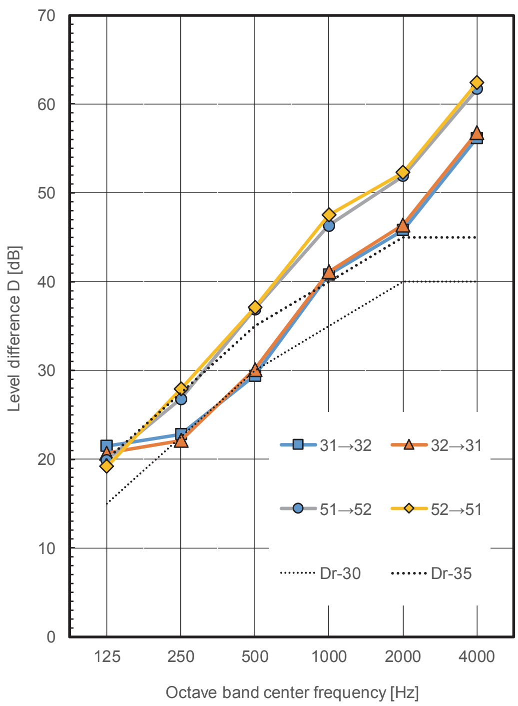

Figure 4 – Measurement results of airborne sound insulation of separation wall, Level difference *D*

Table 2 –Architectural Institute of Japan grades of the airborne sound insulation for apartment house

Part	Special Grade	First Grade	Second Grade	Third Grade
Separation wall Separation floor	D-55	D-50	D-45	D-40

4.3 Floor Vibration Performance

Fig. 5 shows the measurement results of the response acceleration level by the rubber ball source excitation. The 6th floor (R61, chord truss floor) has no separation wall as there is only one room. Hence, the tendency is different from the other floors. This is due to the fundamental frequency is in the 25 Hz 1/3 octave band. While the fundamental frequency of the other floors is in the 40 Hz band or above as the dimensions are much larger 2.5 m × 3.6 m. The 2nd floors (R21 and R22, CLT panel floor) have a small response acceleration, and the floor vibration performance is better than other floors from the viewpoint of vibratory sensation. Overall, the results on the 3rd floor (R31, stressed skin panel floor), 4th (R41, LVL floor) and 5th floor (R51, I-joist floor) do not show much difference. It will be necessary to conduct detailed studies including impedance characteristics.

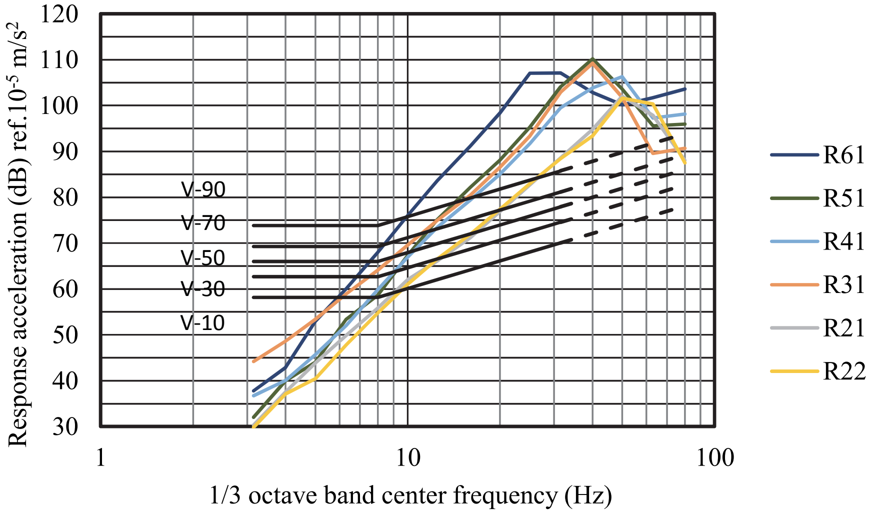

Figure 5 – Measurement results of response acceleration level by the rubber ball excitation

5. CONCLUSIONS

This paper has reported the measurement results of the floor impact sound insulation, the airborne sound insulation of separation wall floor and the vibration performance of six-story wood-frame model building. As the results, the following findings have been obtained.

・ It became clearer that the heavy-weight floor impact sound insulation and the light-weight floor impact sound insulation is poor. Hence, it is necessary to conduct investigations aimed at improving performance such as adopting a dry-type double floor structure (the floating floor) with rubber vibration isolator which has been confirmed in previous reports.

・ The airborne sound insulation can also be considered as poor, also. We propose the methods for the increase in airborne sound insulation; double-layer board finish, addition extra gypsum board wall and insertion of the sound absorption material.

・ From the viewpoint of vibratory sensation, it is necessary to investigate the floor vibration response by excitation and impedance characteristic of the floor.

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