VIBRATION AND LOW-FREQUENCY IMPACT SOUND GENERATED BY NORMAL HUMAN WALKING IN LIGHTWEIGHT WOOD-JOISTED FLOOR-CEILING ASSEMBLIES

Lin Hu[1] and Jean-Philippe Migneron[2]
[1]Department of Building Systems, FPInnovations, Quebec, Canada, Lin.Hu@fpinnovations.ca
[2]École d'architecture, Université Laval, Québec, Canada, jean-philippe.migneron.1@ulaval.ca

1. INTRODUCTION

Human walking generates vibrations and impact sound in lightweight wood-joisted floor-ceiling assemblies. Design methods have been developed to successfully control the perceptible vibrations and construction solutions or materials help to reduce high frequency impact sound transmission, but not low-frequency footstep noise. This paper presents two cases of unsatisfactory low-frequency footstep noise transmission in wood-framed floor-ceiling assemblies and discusses about limited remedies available.

1.1. Context of the study

Conventional North American floor systems in wood-framed multi-family buildings are usually built with a multi-layer topping, a wood-joisted floor and a decoupled ceiling. Footsteps made when somebody walks on the floor can excite all assemblies to vibration, which then generates impact sounds. If those assemblies lack of sufficient stiffness or solid supports, then the excessive vibrations make the occupants uncomfortable. Great efforts have been made to develop design methods to control perceptible vibrations; these have proven to be successful. However, a number of complaints over low-frequency footstep impact sound transmission were received. Occupants in condominiums described the "character" of that particular noise using terms such as "thuds", "thumps", "booming", and "drum effects". The sound resembles a pure tone sound at the fundamental natural frequencies of wood floor-ceiling assemblies (about 15-25 Hz). The measured sound pressure levels (SPL) of the impact sound using an ISO tapping machine revealed that peak SPL occurred around those frequencies. It should be noted that there is no agreement among acousticians on a suitable method to quantify low-frequency sound. Finding a remedy proved to be very challenging. The practical solution is to add a topping, but the mass of that subfloor layer is limited by the building load carrying capacity, and the thickness is limited by the room height. Furthermore, installation of a topping in an occupied building brings other constraints.

2 CASE OF LUMBER-JOISTS ASSEMBLY

This first study case concerns annoying low-frequency footstep sound transmission through a lumber joisted floor-ceiling assembly with a concrete topping. As previously reported by Wakefield [1], it shows that the concrete topping of 90 kg/m^2 did not ensure satisfactory low-frequency impact sound insulation. Even with an important attempted to retrofit the problem, occupants were still unsatisfied of thumping noises induced by the footsteps.

3 CASE OF I-JOISTS ASSEMBLY

3.1 Actual floor-ceiling assembly

The actual floor-ceiling assembly studied in the reference condominium consisted of four components: 1) a 19-mm thick hardwood finishing of 18 kg/m^2; 2) a 13-mm thick OSB topping of 8 kg/m^2 on a 6-mm thick foam impact isolation barrier; 3) a base floor system made of 300-mm deep wood I-joists spaced at 400 mm o.c. and a 16-mm thick OSB subfloor; 4) a ceiling decoupled by resilient channels spaced at 400 mm o.c and using two layers of type X gypsum board, 16-mm thick. Batt insulation 140-mm thick filled the ceiling cavity. The floor spans varied from 3.35 m to 4.88 m, depending on the type of room.

3.2 Tested toppings for the subfloor

Due to the limitation of the room height, the thickness of the topping was restricted to around 50 mm. This was another challenge in developing an effective remedy. Based on our experience and on previous studies, the following four topping candidates for testing were proposed : 1) standard 19-mm thick finished hardwood nailed over 19-mm thick plywood sleepers of 152 mm in width, each spaced at 152 mm. This solid assembly was mounted as a floating floor over 19-mm thick textile felt, without any glue or other attachment; 2) 16-mm OSB on 38 mm by 38 mm wood sleepers at 406-mm spacing, with the cavity filled with sand, and floating on 19-mm thick textile felt; 3) 45-mm thick raft composed of three layers of OSB and 2-mm thick insulation layers between the OSB layers, and floating on 19-mm thick textile felt; 4) 45-mm thick LVL over a 2-mm thick insulation layer.

3.3 Measurements

Direct noise levels in the receiving room were measured using a tapping machine located in the room above, according to ASTM E1007 method. In order to observe the transmission of the sound through the floor-ceiling assembly at lower frequencies, the spectrum range was extended between 0.8 Hz and 20 kHz. These measurements were useful in describing the footstep percieved sounds. Then, ASTM E989 method was used to normalize data and determine an approximate value for the impact sound insulation in terms of FIIC.

4 RESULTS WITH TOPPINGS

The measured FIIC of the original floor-ceiling assembly was 41. Table 1 summarizes the impact noise reductions from measured SPL and the increase of FIIC after adding the 1.2 m by 1.2 m topping patches to the original noisy floor-ceiling assembly. Regarding those results, among the four toppings, topping No. 1 and 2 were more effective with respectively impact noise decrease of 12.1 dB(A) and 12.5 dB(A). That represents a direct improvement, which was greatly appreciated by occupants.

Figure 1 shows the spectra of measured sound levels with extended frequency components down to 10 Hz in the receiving room, before and after adding toppings over actual floor of the source room. Results obtained with toppings No. 1 and 2 represent two good solutions to the footstep noise transmission problem, while No. 3 and 4 are less efficient. Topping No.1, with sleepers and felt, gives a transmitted level of 56.4 dB(A), while topping No. 2, with the addition of sand, reduces the average value to 56.0 dB(A). As noticed with the actual floor, impact sound insulation is poor at lower frequencies, i.e. below 200 Hz.

By comparing the effectiveness of topping No. 4 and 1, we found that even if topping No. 4 was heavier, topping No. 1 was much more effective. Considering that topping No. 1 was floating on the 19-mm thick textile felt, but that topping No. 4 was floating on the 2-mm thick insulation layer, we can conclude that the thickness and resilience of the insulation material have a significant effect on the performance of toppings.

Table 1. Changes in SPL and FIIC due to addition of the topping patches.

Topping No.	Added mass	Measured impact SPL	FIIC increase
1	18 kg/m^2	-12.1 dB(A)	+7
2	67 kg/m^2	-12.5 dB(A)	+8
3	23 kg/m^2	-10.4 dB(A)	+4
4	21 kg/m^2	-2.9 dB(A)	+2

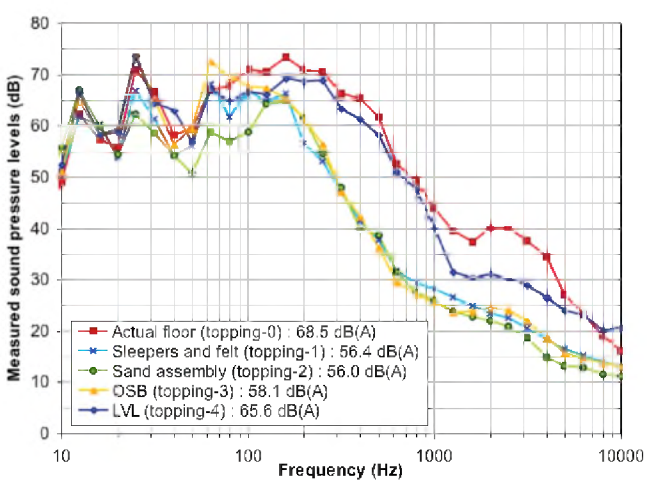

Figure 1. Spectra of impact sound transmission through the wood I-joisted floor-ceiling assembly with and without the additional wood topping patches.

The effect of the topping mass on the impact sound insulation was clearly shown by comparison of third octave spectra measured in the receiving room. Being aware that topping No. 2 was much heavier than topping No. 1 (67 kg/m^2 vs. 18 kg/m^2), we were not surprised to find that topping No. 2 was more effective in terms of reducing the impact sound transmission for components below 100 Hz, except for the component at the fundamental natural frequency of the floor-ceiling assembly. At this time, we do not have any explanation for this exception. However, it is often considered that the SPL measurements are not reliable at low frequencies. A review of the methods to measure SPL in that range is under way.

In a nutshell, the test results demonstrated that the proper combination of mass and sound insulation materials in toppings may provide solutions to the problem of annoying low-frequency impact sound transmission.

5 CONCLUSIONS

Footstep sound transmission through wood floor-ceiling assembly is a complicate problem, and needs a collective research effort. To thoroughly address the issue of poor low-frequency sound insulation with current lightweight wood floor-ceiling assemblies, we developed our research plan to:

1) Get a better understanding of physics involved in footstep low-frequency impact sound transmission through wood-joisted floor-ceiling assemblies;
2) Develop a testing method and standard for quantitative determination, and correlate it to the human perception;
3) Predict the quantitative values using the properties of the floor-ceiling assemblies;
4) Build a database of insulation material properties including density, damping, surface and compression stiffness, porosity, sound absorption coefficient, flow resistance, and price.

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