Subjective evaluation of floor impact sound of wood-frame construction dwellings in different living situation

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ABSTRACT

This paper presents the subjective difference of floor impact sound of wood-frame floors with different floor-ceiling systems. All impact sounds of wood-frame floors were measured in reverberation chamber with standardized rubber ball. The impact sound of concrete floor was also measured. Sheffe's paired comparison method was used to obtain psychological scale values of each impact sound. The listening test confirmed that all wood-frame test floors are quieter than the RC floor, performance of larch plywood floor without resilient channel was lower than standard plywood floor but the performance of larch floor can be improved greatly with resilient channel. Furthermore, there are some cases those psychological scale value can differentiate conditions but the A-weighted maximum level cannot present differences between them.

Keywords: Floor impact sound insulation, I-INCE Classification of Subjects Number(s): 51.5

1. INTRODUCTION

Floor impact sound has been reported as the most irritating noise source in residential buildings [1-2]. For rating of the floor impact sound insulation, a rating curve [3] with octave-band sound pressure levels from 125 to 2,000 Hz (or 1/3 octave-band sound pressure levels of 100–3,150 Hz) has been used and revision is currently discussed in ISO working group.

Several studies have suggested the Zwicker loudness [4-5], the A-weighted maximum level [6], and the arithmetic average of octave-band sound pressure levels [7] as good quantitative indicators of noisiness or annoyance by heavy-weight floor impact sound in concrete or wooden structures. Authors also presented that maximum Zwicker loudness and the A-weighted maximum level can predict their annoyance [8].

The purpose of this study is seeking the possibility to find differences of detailed floor-ceiling systems of wood-frame structure in terms of subjective and objective single number quantities. The physical indices used in this study are Maximum Zwicker loudness presented and $L_{\mathrm{iA,Fmax}}$ as used in previous study[8]. Sheffe's paired comparison method was used to obtain psychological scale values [9].

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2. Auditory experiment to measure subjective ratings for impact sound measured in test chamber

2.1 Stimuli

Heavy-weight floor impact sounds of a bare concrete floor and four of wood-frame system were measured in the reverberation chamber. The concrete floor was measured in the test chamber in General Building Research Corporation of Japan. The floor size was 2.7 m x 3.7 m, room volume of receiving room was 70 m^3, and thickness of the floor, which was rigidly connected to wall system, was 150 mm. The reverberation time of the chamber was controlled from 1 to 2 s. Wood-frame floor-ceiling systems were measured in the reverberation chamber of Building Research institute, Japan. The floor size was 3.0 m x 4.0 m, room volume of receiving room was 208 m^3. The reverberation time of the chamber was controlled from 1 to 2 s. Specification of wood-frame floor-ceiling systems is presented in Table 1. All of wood-frame floors have double layer floor system. Five floors were used in the experiment.

Table 1 – Specification of wood-frame floor-ceiling systems

<table>
<tr><td colspan="2">Floor code</td><td>A02</td><td>B01</td><td>B02</td><td>B03</td></tr>
<tr><td colspan="2">Topping</td><td>Typical wood panel flooring, t=12 mm</td><td>Wood panel flooring, of birch, t=15 mm</td><td colspan="2">Wood panel flooring, of birch, t=15 mm, bonded to base floor material</td></tr>
<tr><td rowspan="3">Top layer</td><td>Base floor material</td><td>Insulation mat t=12 mm</td><td colspan="3">Plywood of larch, t=28mm</td></tr>
<tr><td>Base</td><td colspan="4">Particle board, t=20mm</td></tr>
<tr><td>Base floor material</td><td colspan="4">Plywood, t=15mm</td></tr>
<tr><td rowspan="5">Base layer</td><td>Floor joist</td><td colspan="4">2x10, 235mm@455</td></tr>
<tr><td>Sound absorber</td><td colspan="4">GW24K-100mm</td></tr>
<tr><td>Ceiling joist</td><td colspan="4">2x6, 140mm@455</td></tr>
<tr><td>Ceiling channel</td><td colspan="2">None</td><td>Resilient channel</td><td>improved resilient channel with lower resonance frequency</td></tr>
<tr><td>Ceiling material</td><td colspan="4">Doubled fire-resistant gypsum board, t=15 mm x 2</td></tr>
</table>

The standardized rubber ball [10] were utilized for heavy/soft impact source. Impact source was driven at the center of the upper floor and at the height of 100 cm and 10 cm. Floor impact sounds were recorded monaurally with 2250 B&K sound level meter at the center of floor plan of the lower floor and at the height of 150 cm. Twenty stimuli with combination of five floors, two dropping heights of rubber ball and two impact positions were prepared.

Figure 1 presents relationships between measured and simulated impact sound levels both for Maximum Zwicker loudness presented and $L_{\mathrm{iA,Fmax}}$. Adjustment of sound pressure levels of stimuli was done with $L_{\mathrm{iA,Fmax}}$. As a result of comparison between measured and simulated values, simulated values is 0.6 dB higher than measured value for $L_{\mathrm{iA,Fmax}}$. .

Figure 2 presents relationship between simulated impact sound levels of Maximum Zwicker loudness presented and $L_{\mathrm{iA,Fmax}}$.

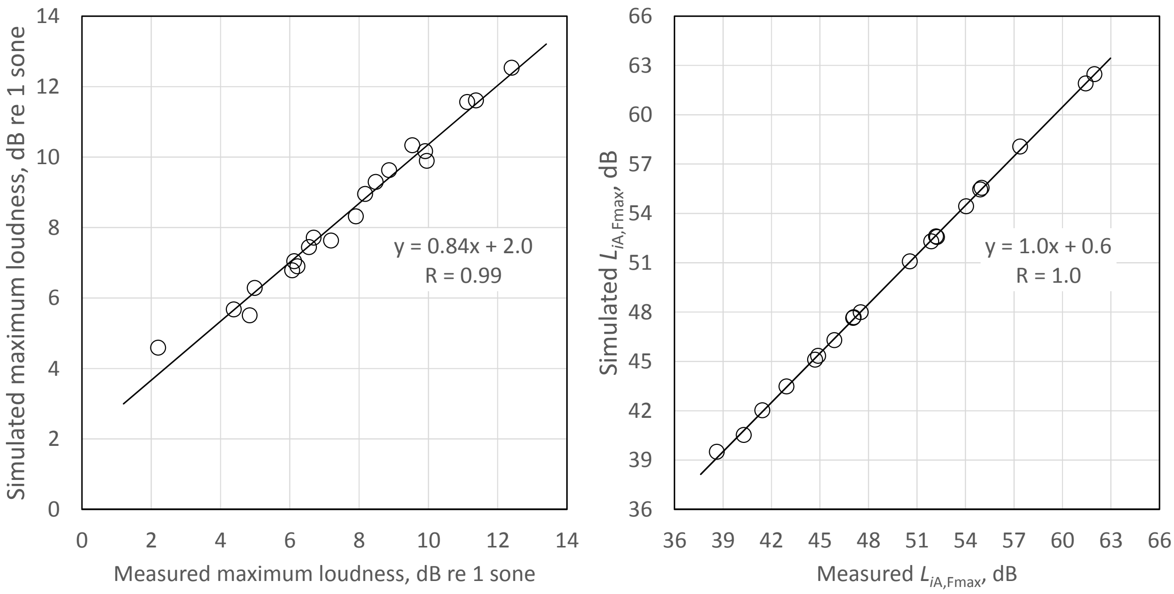

Figure 1 Relationships between measured and simulated impact sound levels (left: maximum loudness, right: $L_{\mathrm{iA,Fmax}}$)

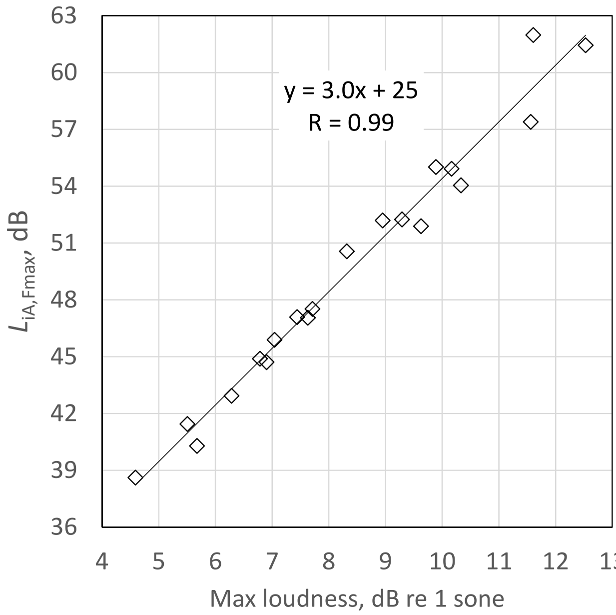

Figure 2 Relationship between simulated impact sound levels of Maximum Zwicker loudness and $L_{\mathrm{iA,Fmax}}$

2.2 Stimuli and Method of subjective evaluation

The experiment was done in a semi-anechoic room. Subjects were asked to be seated and to look at 23” touch panel screen in front of the subject. Twenty of young adults (university students) and twenty of older adults more than 60 years old were participated. All subjects were signed on the informed consent form. Forty of the subjects who didn’t report hearing difficulty in daily life. Subjects were asked to rate the differences for each pair in one of five categories. They did this by touching a number on the touch panel screen with the following descriptions after listening to each pair of sentences:

1) Former is much more annoying than latter.
2) Former is more annoying than latter.
3) No difference is found on both sound
4) Latter is more difficult than former.

5) Latter is much more difficult than former.

The categories were assigned scores of -2, -1, 0, 1, and 2 corresponding to the first to the fifth responses in the list above, respectively. A total of 400 different pairs of impact sound conditions including pairs of same stimulus were presented.

The floor impact sound stimuli were presented from the ceiling loud speaker (GENELEC 8040, ≧ 60 Hz) 0.7 m away from subject's head and the sub-woofer (GENELEC 7071A, < 60 Hz) located 0.5 m away from back of subjects.

2.3 Results and discussions

The results of both younger and older adults were quite the same as Figure 3 presents and both group were analyzed together in this study.

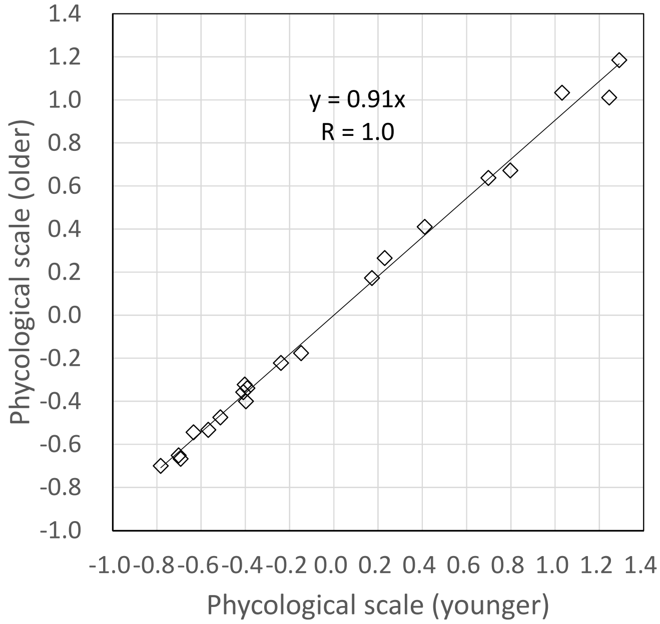

Figure 3 Relationship between psychological scale of younger listeners and that of older listeners. Each plot corresponds to each stimulus.

The result of the ANOVA of the results from the psychological scale of annoyance to floor impact sound showed that there was a significant effect of stimuli as shown in Table 2. Although other factors has statistically significant, the effect of stimuli is quite larger than other factors. The Yardstick was calculated to be 0.0067 ($p<0.05$) and 0.075 ($p<0.01$). If a difference of scores between stimuli would be larger than Yardstick of specific probability, each of them are statistically different in the specific probability.

Table 2 Result of ANOVA

Source	Sum of squares	Degree of freedom	Mean square	*F*	Significance (*p*)
Stimuli	13005.2	19	684.5	2429.7	<0.00001
Stimuli x individuals	962.2	741	1.3	4.6	<0.00001
Combination	325.8	171	1.9	6.8	<0.00001
Order	16.6	1	16.6	59.1	<0.00001
Order x individual	124.6	39	3.2	11.3	<0.00001
Error	4008.6	14229	0.3		
Total	18443	15200			

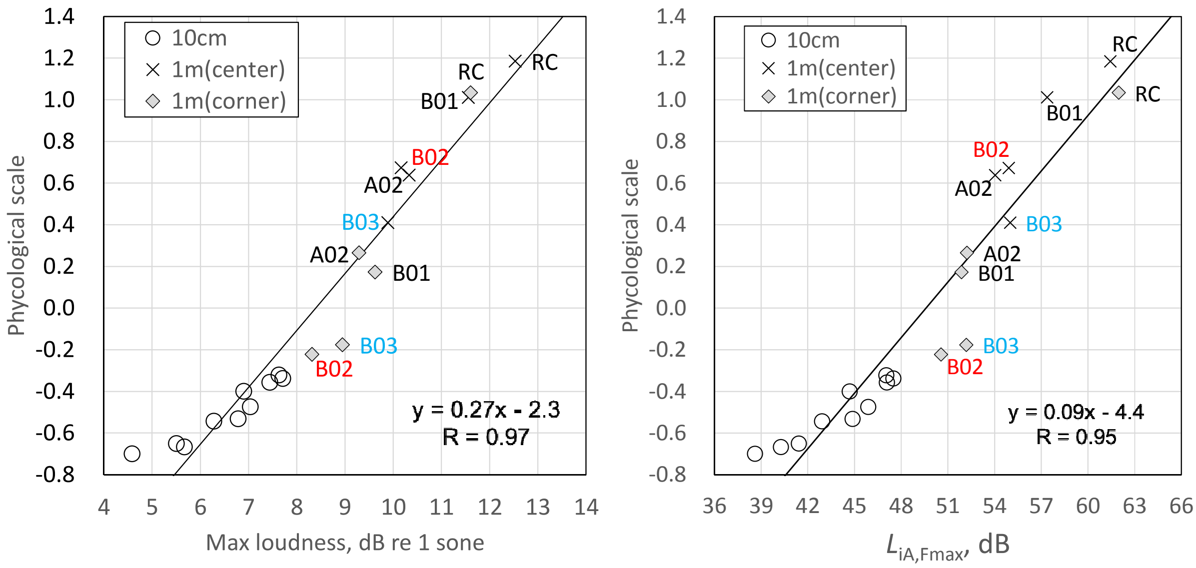

Figure 4 Relationship between physical measure of impact sounds and psychological scale value of impact sound (left: maximum loudness, right: $L_{\mathrm{iA,Fmax}}$)

Figure 4 presents relationship between physical measure of impact sounds and psychological scale value of impact sound. Maximum Zwicker loudness in dB scale presents slightly better relationship than $L_{\mathrm{iA,Fmax}}$. Both relationships are almost liner as author presents.

The variation ranges of impact sound with dropping height of 10 cm are narrower than that with dropping height 1m for both of psychological scale and physical scale.

Following discussion will be about impact sounds with dropping height of 1 m. Impact sounds generated with impact on center position is louder and more annoying than that on corner position. The effect of impact position is smaller for RC floors than wood-frame floors. All of impact sounds measured with wood-frame floor are quieter than those of RC floors.

Let us discuss about the larch floor (B01) and the standard floor (A02). For the corner impact cases, both are quite the same for both psychological and physical numbers. However, for the center impact cases, B01 presents larger numbers than A02.

Let us discuss about the effect of resilient channel on floor impact sound. The difference between B01 and other type “B” floors are resilient channel. For the corner impact cases, B02 and B03 presents more than 0.4 points difference in terms of psychological scare. This difference is quite large compare to Yardstick (0.075 for $p<0.01$). This difference was presented weakly by maximum loudness value but not by $L_{\mathrm{iA,Fmax}}$. This means that resilient channel was subjectively effective to reduce annoyance. The difference between B02 and B03, resonance frequency of channels, was not significant. For the center impact case, B03 was quieter 0.25 in psychological scale than B02. Furthermore, both B02 and B03 are significantly quieter both for psychological and physical scales. This means that resilient channel was subjectively effective to reduce annoyance and the effect can be presented by physical measure. It can be said that resilient channel with lower resonance frequency is quite effective when the impact would be made on close to center position.

3. CONCLUSIONS

This paper presents the challenge to reveal detailed difference of heavy-weight floor impact sound with standardized rubber ball between different floor-ceiling systems.

The listening test confirmed that all wood-frame test floors are quieter than the RC floor, impacting center of floor generate louder impact sound, and level range of higher dropping height is wider than that of lower dropping height.

Performance of larch plywood floor without resilient channel was lower than standard plywood floor. However, the performance of larch floor can be improved greatly with resilient channel.

Comparing $L_{\mathrm{iA,Fmax}}$ and psychological scale value, there are some cases those psychological scale value can differentiate conditions but $L_{\mathrm{iA,Fmax}}$ cannot present differences between them.

ACKNOWLEDGEMENTS

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