Study on measurement and habitability evaluation for floor impact vibration on prefabricated housing floor

T. Matsuda¹, T. Shimizu¹

¹ Central Research Laboratory, Daiwa House Industry Co., Ltd., 6-6-2, Sakyo, Nara City 631-0801, Japan

toru.matsuda@daiwahouse.jp

Abstract. This paper reports an experimental study of a method used to select impact and measurement points based on the distribution properties of a floor to determine the habitability resistance performance in the case of floor vibration. The results confirm that it is possible to fully represent the vibration resistance of an entire floor area based on five impact points and measurement points distributed diagonally on the floor surface, excluding measurement points within 455 mm of the impact points.

1. Introduction

The diversification of housing environments and life styles that have occurred in recent years have been accompanied by the a wide range of demands for living environments. There has also been a rise in the level of housing performance related to residential floors, including sound-proofing, vibration-proofing, safety, walking sensation, and insulation performance required by clients and end users. Of these, blocking sound from the upper and lower stories is considered to be particularly important. Lightweight steel construction floors of detached houses and collective housing are often designed to enhance vibration control support. However, in some cases, as a result of excessive focus on improving sound-proof performance, the floor of a home blocks sound from the upper and lower floors, but cannot ensure vibration proofing, resulting in floor vibration problems and dissatisfaction with the functions of the floor. Present habitability evaluation standards for vibration of floors include the international standard ISO2631-2:2003 [1] and the Japanese standard AJIES-V0001-2004 [2] issued by the Architectural Institute of Japan. The concept of evaluation methods under these standards are indicated as the absolute performance of the floor under vibration; these standards do not stipulate the impact sources, impact force properties applied to the floor, impact points, and measuring points. The result is that the evaluations include scattering of properties of impact force applied to the floor, impact points, and measuring points in addition to a floor’s vibration habitability resistance performance (i.e., difficulty in vibrating the floor). The vibration field also requires the concept of evaluating a floor’s vibration resistance performance itself, for example, the “floor impact sound insulation performance” from the field of architectural acoustics. A previous paper [3] reports on a study of an evaluation method using rubber balls with impact force properties of JIS A 1418-2:2000 [4] (ISO140-7:1998[5]) (below, “rubber balls”), which are a standard impact source of heavy floor impact sound insulation, as a method of regulating impact force. However, in order to obtain a floor habitability resistance performance, in addition to setting the impact source and impact force properties applied to the floor, it is also essential to clarify the impact points and measurement points of the floor that is being evaluated. Therefore, it is very useful, if possible, to determine the...
measuring method and the evaluation method specifying the impact point and the measurement point that can represent the vibration distribution of the entire floor. The “floor impact sound insulation performance,” is an evaluation method that includes impact force properties, impact points, and measurement points, stipulated in JIS A 1418-2:2000 [6] (ISO140-7:1998 [7]). Another evaluation method has been specified in JIS A 1419-2:2000 [8] (ISO717-2:2013 [9]).

In this study, we conducted experiments on the method for selecting the impact point and measurement point from the vibration distribution characteristics of the floor. In addition, we examined the measurement method in order to evaluate the comfort of the entire floor rather than the evaluation of the occupancy of the representative points of the floor. The contents of this report are accepted in a previous report [10], and the reanalysis of the measurement method is reported here.

2. Vibration distribution of floor

2-1. Experimental methods

The experiment was conducted using five light-weight steel construction floors of prefabricated houses shown in Table 1. A rubber ball was used to cause impact vibration of the floor, and the vibration acceleration was measured. The experiment was conducted for the four patterns shown in a) and b) below. Figures 1 to 2 show examples of plane figures, impact points, and measuring points.

(a) The rubber ball was dropped from 100 cm at five impact points shown in Figure 1, and the vibration acceleration was measured at intervals of 455 mm over the entire floor for each impact point.

(b) The rubber ball was dropped from 100 cm at the five impact points shown in Figure 2, and at the measuring points, the vibration acceleration at five points distributed diagonally within the floor plane was measured for each impact point.

2-2. Experimental results and discussion

Figures 3 and 4 show vibration distributions in the floor using formula (1). Figures 3 and 4 show Floor A with the smallest floor area and Floor E with the largest floor area when impacted at five points distributed diagonally by experiment methods a) and b). The figures (i) show the following legends (A) and (C) and, the figures (ii) show the following legends (B) and (C). Furthermore, in the Figures 3 and 4, the ranges of 1σ and 2σ obtained from the measurement range of (A) are shown.

| Specimen | Structure | Structure of floor (mm) | Slab dimensions (mm) |
|----------|-----------|-------------------------|---------------------|
| Floor A  | Lightweight Steel Structure | Rubber vibration insulator: 19 (Hardness: 81) + Deck plate: 1.2+ Precast concrete slab: 80 + Asphalt mat: 12 + Wooden floor: 15 | 2730 × 3640 |
| Floor B  | Lightweight Steel Structure | Rubber vibration insulator: 19 (Hardness: 69) + Deck plate: 1.2 + Precast concrete slab: 80 + Asphalt mat: 12 + Wooden floor: 15 | 2730 × 3640 |
| Floor C  | Lightweight Steel Structure | Rubber vibration insulator: 6.5 + Steel joist: 75 × 45 + Particle board: 25 + Plaster board: 9.5 + Particle board: 9 + Wooden floor: 12 | 3640 × 3640 |
| Floor D  | Lightweight Steel Structure | Rubber vibration insulator: 8 + Steel joist: 75 × 45 + Particle board: 20 + Asphalt mat: 6 + Particle board: 15 + Wooden floor: 13 | 3640 × 4550 |
| Floor E  | Lightweight Steel Structure | Autoclaved lightweight aerated concrete: 100 + Particle board: 15 + Wooden floor: 12 | 3640 × 8190 |
\[ L_{Wm,max}(O.A) = 20 \log_{10} \left( \frac{a}{a_0} \right) \quad \text{(dB)} \quad (1) \]

where \( a \) denotes the vibration acceleration corrected 1–80 Hz by the vibration sensation as stipulated by ISO2631-2 [1] (m/s²), and \( a_0 \) denotes the standard acceleration (10⁻⁵ m/s²).

Legend:
(A): Entire floor measured on a grid at intervals of 455 mm for each impact point
(B): Entire floor measured on a grid at intervals of 455 mm for each impact point, excluding points within 455 mm of the impact points
(C): Five points distributed diagonally on the floor plane measured for each impact point
(D): Five points distributed diagonally on the floor plane measured for each impact point, excluding points within 455 mm of the impact points

In the vibration distribution shown in the figure (i) of Figures 3 and 4, the acceleration response measured at five points distributed on the diagonal of (C) in the range measured on the grid at the entire floor of (A) at 455 mm intervals is generally within the range. However, there is an acceleration response far outside the measurement range of (A) for each impact point. In addition, there is also an acceleration...
response outside the range of 2σ. The reason for this is considered to be that when the measurement point is in the vicinity of the impact point, there is a possibility that linearity cannot be maintained or it may be caused by local vibrations. Therefore, it is considered inappropriate to evaluate the vibration distribution of the entire floor by an evaluation that includes those measured values.

The vibration distributions of the (B) and (D) excluding measurement points within 455 mm from the impact point are shown in the figure (ii) of Figures 3 and 4. (A) and (C) on the figure (i) are different, most of the measuring points are within the range of 2σ. Because of these reasons, by excluding the measuring points within 455 mm from the impact point, it is thought that it can be selected. Subsequently, the difference between (A) and (C) and that between (B) and (D) are shown in Figure 5 in order to check the influence of measurement points within 455 mm from the impact point. Similarly, the difference

![Figure 3](image-url)  
**Figure 3** Distribution of floor vibration in the case of impact at five points. (Floor A)

![Figure 4](image-url)  
**Figure 4** Distribution of floor vibration in the case of impact at five points. (Floor E)

![Figure 5](image-url)  
**Figure 5** (A)–(C) and (B)–(D) targeting arithmetic mean and equivalent (Leq) and median (L50).
between (A) and (C) and that between (B) and (D) are shown in Figure 5 in order to check the influence of measurement points within 455 mm from the impact point. In the figure, the arithmetic mean, equivalent (Leq), and median (L50) are calculated and compared for each floor. In (A)–(C) including measurement points within 455 mm from the impact point, there is a difference of about 5 dB in Floor E in the case of the arithmetic mean value and median (L50). The differences in most of the cases other than Floor E are within 3 dB. However, with the equivalent (Leq), there is a difference of more than 5 dB in all floors, and the maximum difference is approximately 9 dB. Next, in the cases of (B)–(D), excluding measuring points within 455 mm from the impact point, no significant change is seen compared with (A)–(C) at the median (L50). However, the arithmetic mean and equivalent (Leq) are within 2 dB on most floors, which is obviously small.

For these reasons, excluding measurement points within 455 mm from the impact point is not affected by the singular point; it is considered to be appropriate as a measurement point that can represent the vibration distribution of the entire floor.

Judging from the above results, to represent the vibration distribution of an entire floor, it is unnecessary to measure many points on a grid; rather by measuring five points distributed diagonally in the floor plane excluding measuring points within 455 mm of impact points in show the Figure 6, these five points can be representative points that can clarify the vibration distribution of the entire floor.

3. Conclusion

This is a report on an experimental study of a method for selecting impact points and measuring points to calculate evaluation values based on distribution properties of an entire floor in order to calculate the habitability resistance performance to vibration of a floor (floor impact vibration habitability resistance performance). In this study, we confirmed that it is possible to fully represent the habitability vibration resistance of an entire floor area based on five impact points and measuring points distributed diagonally on the floor surface and excluding measuring points within 455 mm from the impact point.

In the previous report [10], using the vibration acceleration maximum value measured by the relationship between the impact point and the measurement point described above, we examined the calculation method of the evaluation to evaluate the habitability resistance performance of the entire floor rather than the habitability evaluation at the representative point of the floor.

Furthermore, in order to confirm the adequacy of the evaluation, the relationship between the sensation scale and the evaluation quantity is also examined from the vibration sensation evaluation
experiment. Future prospects of the study include further exploring the vibration control method from the viewpoint of living comfort of an end user.

Reference

[1] ISO 2631-2 (2003): Mechanical vibration and shock -- Evaluation of human exposure to whole-body vibration -- Part 2: Vibration in buildings (1 Hz to 80 Hz)
[2] AJIES-V0001 (2004): Guidelines for the evaluation of habitability to building vibration [in Japanese]
[3] R. Tomita, K. Inoue: Effect of Vibration Sense by Frequency Characteristics of Impact Vibration for Residential Floor, Journal of Environmental Engineering (Transactions of AIJ) Vol. 79 (2014) No. 705 p. 927-935 [in Japanese] http://doi.org/10.3130/aije.79.927
[4] JIS A 1418-2: 2000: Acoustics - Measurement of floor impact sound insulation of buildings – Part2: Method using standard heavy impact sources [in Japanese]
[5] ISO 140-7: 1998: Acoustics -- Measurement of sound insulation in buildings and of building elements -- Part 7: Field measurements of impact sound insulation of floors
[6] JIS A 1418-2, Acoustics — Measurement of floor impact sound insulation of buildings — Part 2: Method using standard heavy impact sources (2000) [in Japanese].
[7] ISO 140-7, Acoustics — Measurement of sound insulation in buildings and of building elements — Part 7: Field measurements of impact sound insulation of floors (1998).
[8] JIS A 1419-2, Acoustics — Rating of sound insulation in building and of building elements — Part 2: Floor impact sound insulation (2000) [in Japanese].
[9] ISO 717-2, Acoustics — Rating of sound insulation in buildings and of building elements — Part 2: Impact sound insulation (2013).
[10] T. Matsuda, T. Shimizu: Study on correspondence between evaluation of vibration sensation, average method, and measurement density of acceleration levels for impact vibration in prefabricated housing floor. Journal of Building Engineering 10(2017) 124-139.