

Influence of visual sensation on sense of horizontal vibration

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ABSTRACT: Experiments have been carried out to determine the sense of horizontal vibration where subjects can see the view from a window. The visual situation has the greatest influence on vibration perception, and this is closely connected with vibration amplitude. Vibrations cannot be perceived physically in the low frequency and small acceleration range, but they can be recognized visually as movement of the view. Therefore, many subjects can perceive vibrations when they can see the view. It is therefore necessary to assess the perception threshold in consideration of the influence of visual sensation. The visual sensation does not influence perception in the high frequency range, because the vibration amplitude is imperceptible in that range. It is therefore possible to assess vibrations on the basis of perception threshold scatter by physical feeling in the body.

1 INTRODUCTION

Existing vibration evaluation standards, including the AIJ Guidelines (Architectural Institute of Japan 2004), use perception thresholds based on bodily sensation. In real life, however, people sometimes realize there is a vibration by seeing the movement of furniture or the landscape outside a window or hearing the sound of wind or squeaking noise generated by the building, as can be seen from questionnaire surveys relating to existing high-rise apartment buildings and base-isolated buildings. (Ishikawa, Uekusa, Ichiriki & Noda 1993, Nakamura, Kanda, Shioya & Nagaya 1995)

Although the relevant international standard (ISO2631-2 2003) refers to visual effects such as one of the parameters to be considered in its annex, it does not quantify their effects, and therefore does not provide concrete evaluation criteria. To bring habitability assessment more in line with reality by taking into account the effects of circumstantial factors, it is necessary to elucidate the influence of visual sensation, audible sensation and other circumstantial factors on the sense of horizontal vibration.

Of these circumstantial factors, we focused on visual sensation in this study. In actual living environments, there are various objects that could give you a visual clue about vibration, including interior lighting fixtures or furniture, a water surface and the landscape outside a window. (Ishikawa, Uekusa, Ichiriki & Noda 1993, Nakamura, Kanda, Shioya & Nagaya 1995) This paper discusses experiments conducted to elucidate subjects' sense of horizontal vibration when the view outside the window is visible.

Although the authors had conducted various experiments involving vertical stripes (Ishikawa, Noda, Kumazawa & Okada 1994a) and a model high-rise apartment building (Ishikawa, Noda, Kumazawa & Okada 1994b) before, there was still room for improvement in terms of the investigation of the impact of visual sensation based on more realistic visual objects. In our latest experiments, therefore, we provided the subjects with such visual objects by making the actual view outside a window visible to them. Our aim here is to elucidate the influence of visual sensation on subjects' perception thresholds for horizontal vibration through a comparison of cases in which the outside view was visible (Noda & Ishikawa 1999b) and those in which it was not visible (Noda & Ishikawa 1999a).

2 OUTLINE OF EXPERIMENTS

Prior to experiments, a 3 m² and 3 m high simulated habitable room was built on the shake table. To reproduce an environment that is close to an actual domestic indoor space, the habitable room was furnished with sash windows, wall materials, fittings and other common housing features. To minimize the impact of circumstantial factors other than visual sensation, special care was given to the acoustic environment. The mechanical noise from the vibration source was kept to a minimum through the use of an electrodynamic shaker. The walls were filled with a 10 cm-thick sound absorbing material to reduce the transmission of outside noise by about 15 dB. In addition, music was played at a set volume during all experiments.

Figure 1 shows the overall layout of the experimental site and setup of the habitable room interior for experiment (1), which was conducted by keeping the outside view visible to the subjects. Three subjects were instructed to sit on chairs by facing a 140 cm by 100 cm window mounted on one of the walls at a height of about 100 cm. Outside the habitable room, there was a single-story structure at a distance of about 9.3 m, and the subjects were able to view the structure and background landscape through the window. Figure 2 shows the view outside the window as seen from the middle chair, though there may have been a slight difference depending on the actual location of the chair. To the subjects experiencing a left-to-right horizontal vibration, this view would have appeared to be swaying from left to right. This paper examines the influence of visual sensation on the sense of horizontal vibration by analyzing experimental results obtained under those conditions.

Input vibrations were basically horizontal sinusoidal vibrations applied in a left-to-right direction relative to the subjects. In setting the input vibration range, wind vibration in high-rise and super high-rise buildings, wind vibration in low and mid-rise buildings, traffic vibration and equipment vibrations in which high frequency components dominated were mainly considered. 14 frequency options are set ranging from 0.1 to 40 Hz.

During experiments, input vibrations were measured using strain-gauge accelerometers and an oscillographic recorder, with input reproducibility verified each time. A vibration with a gradually increasing acceleration was applied at a frequency selected from 14 options between 0.1–40 Hz. The subjects were instructed to signal the experimenter when they felt a vibration while looking at the outside view, and the experimenter gathered vibration data recorded before and after the signal while constantly monitoring the interior of the habitable room from outside via a CCD camera. The experimenter also gave instructions on the commencement of a vibration run, etc. from outside via a microphone.

By changing frequency in a random sequence, experiments were conducted over the whole spectrum of frequencies. A total of 45 subjects, all females aged between 19 and 24, took part in the experiments.

In experiment (2) (Noda & Ishikawa 1999a), a control experiment in which the view outside the window was blocked, a steel cover was placed over the window of the habitable room, forcing the subjects to detect vibration relying on bodily sensation alone. Unlike experiment (1), in which the view outside the window was visible, experiment (2) involved a single subject squatting on the floor for each session, although other conditions, such as the vibration input method, were the same. From previous experiments, we had learned that subjects' posture and number of

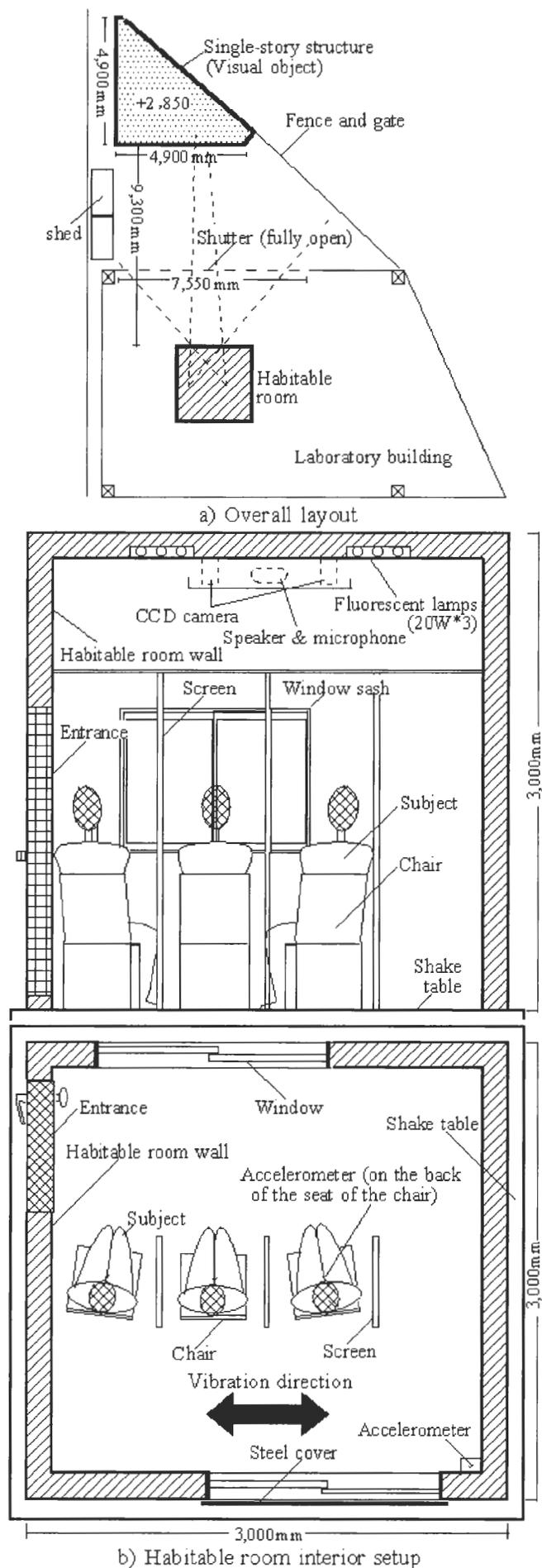


Figure 1. Experimental setup.

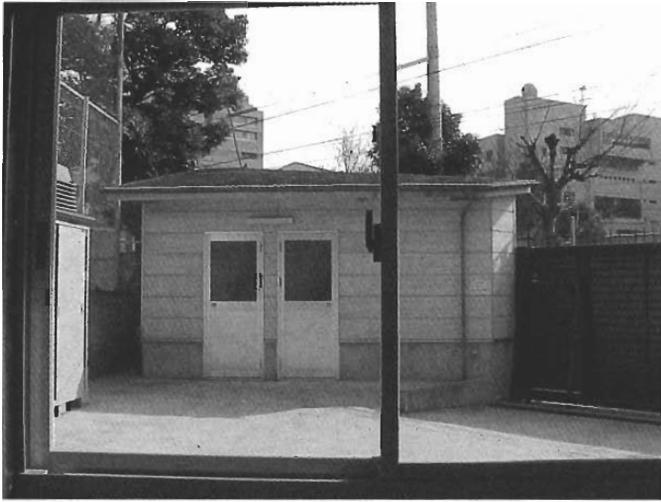


Figure 2. View from habitable room window.

subjects present in each session had a small impact on the results compared to the assessment method, so that experiment (2) was chosen as a control experiment. This experiment involved a total of 35 subjects, all females aged between 19 and 24.

3 INFLUENCE OF VISUAL SENSATION ON PERCEPTION THRESHOLD

From the above observations, it is easy to see that visual sensation exerts a great influence on perception thresholds. In this chapter, we evaluate perception thresholds in terms of signals raised by subjects upon sensing a vibration, and discuss the impact that visual sensation has on perception thresholds.

In experiment (1), in which the view outside the window was visible, acceleration measured at the surface of the seat of the chair was used, while in experiment (2), in which the view outside the window was not visible, acceleration measured at the floor surface was used.

Figure 3 shows the distribution of personal perception thresholds recorded over the whole spectrum of frequencies when the view outside the window was visible. When the view outside the window was not visible (Fig. 4), many subjects did not feel vibration in the low frequency range below 0.16 Hz even at the largest acceleration used in the experiment.

When the view outside the window was visible (Fig. 3), on the other hand, all the subjects felt vibration at all frequencies. This shows that the availability of visual sensation has a great impact in the low frequency range.

When the view outside the window was not visible, the scatter of perception thresholds varied across frequencies, but when the view outside the window was visible, it remained more or less the same up to around 6.3 Hz. When the view outside the window was visible, the scatter of perception thresholds was generally

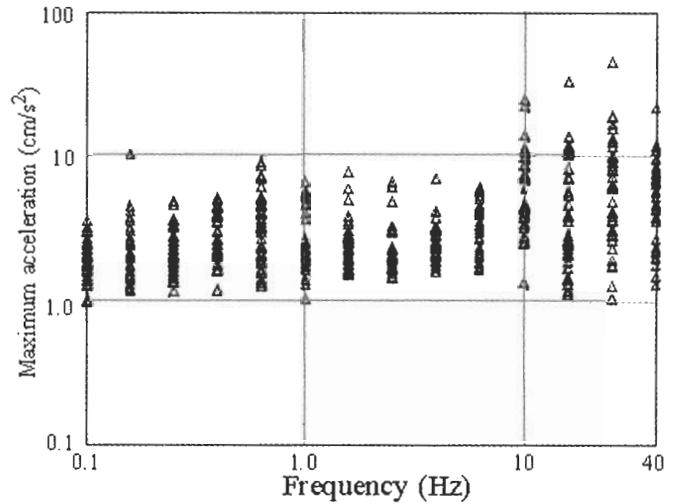


Figure 3. Distribution of perception thresholds when view outside window is visible.

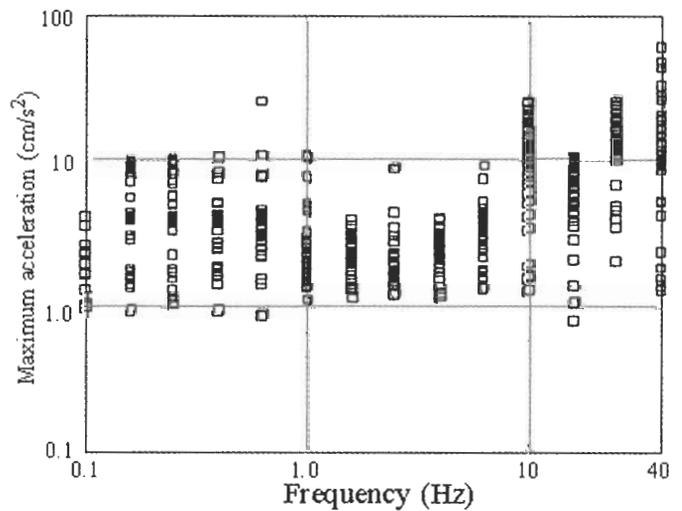


Figure 4. Distribution of perception thresholds when view outside window is not visible.

small, and this tendency was somewhat stronger in the low frequency range, where displacement was large. This can be interpreted that when the view outside the window was visible, displacement as straightforward vibration information provided by vision kept person-to-person variations in perception thresholds small. In the high frequency region, where displacement was small, the scatter of perception thresholds increased as was the case when the view outside the window was not visible because of the difficulty in detecting vibration from a small displacement.

To elucidate the influence of visual sensation on perception thresholds, perception probability curves are calculated and compared for each visual condition. Figures 5 and 6 show regression expression of degree 3 of every 20th percentile perception thresholds for the two cases.

Variations in perception thresholds attributable to differences in visual conditions were observed in the

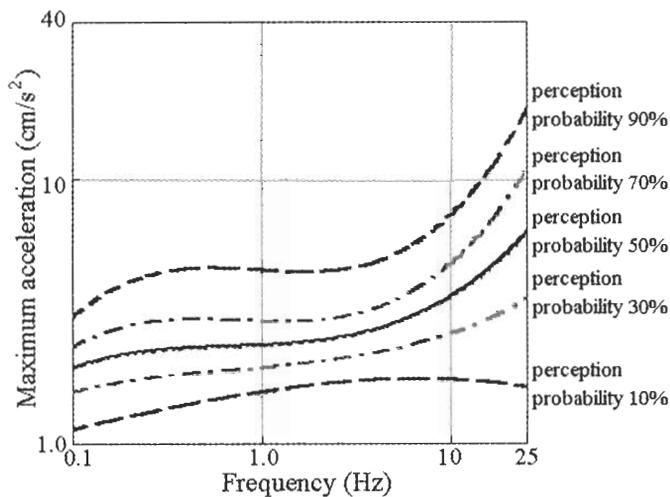


Figure 5. Perception probability curve when view outside window is visible.

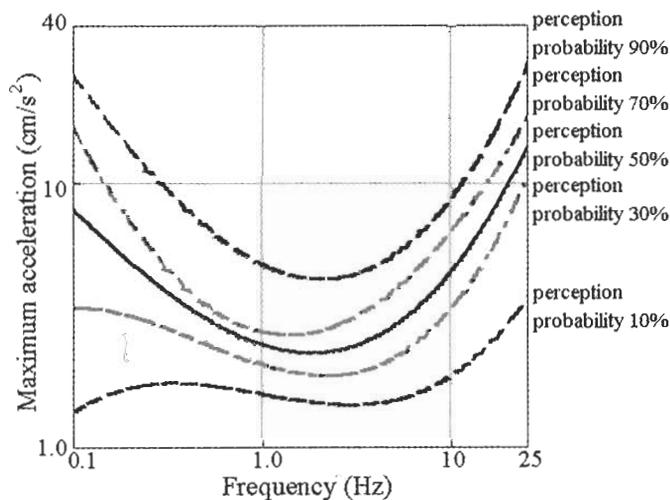


Figure 6. Perception probability curve when view outside window is not visible.

low-frequency region below 0.4 Hz. When the view outside the window was visible, the perception threshold fell as frequency decreased, and the gap between the two curves widened in the low frequency region. This can be interpreted that as the frequency decreases, people have greater difficulty in detecting vibration relying only on bodily sensation, while displacement, the vibration information provided by vision, becomes larger, thus increasing the impact of visual sensation on perception thresholds in the low-frequency region. Namely, subjects detected vibration from the movement of the view outside the window even when their bodies did not feel it.

In the medium to high frequency region above 0.63 Hz, the two sets of perception thresholds were roughly equal. As frequency increased, displacement decreased, making it difficult to detect vibration through visual sensation even if the view outside the window was visible. Namely, visual sensation had a

minimal impact in this region, and perception thresholds were derived mostly from bodily sensation.

Although a discrepancy between perception thresholds appeared again in the high frequency region, this appears to have been due to the interference of the resonance of the chair, which started at around 10 Hz. In experiment (1), in which the view outside the window was visible, the acceleration measured at the surface of the seat of the chair was used in the analysis, but other factors, such as the vibration of the floor and the response of the back of the chair, may also have been involved.

Compared to past experiments conducted by the authors, et al. using vertical stripes as the visual object (Ishikawa, Noda, Kumazawa & Okada 1994a), the impact of visual sensation was small. As has been discussed in a study on perception based only on visual sensation (Tsurumaki, Goto & Inoue 1995), the impacts of near and distant views on perception differ in translational vibration, and people are more sensitive to the near view. Compared to looking at a building standing a fair distance away as was the case in our experiments, looking at a nearby object, such as vertical stripes placed just outside the window, appears to result in a stronger impact of visual sensation because of the ease of gauging the displacement. The impact of visual sensation tended to be stronger in the large displacement region above 1.0 cm in our experiments, but this boundary displacement value is likely to change according to visual conditions.

4 COMPARISON WITH PERCEPTION THRESHOLDS BASED ON BODILY SENSATION IN PAST STUDIES

Figure 7 shows the impact of visual sensation on perception thresholds identified in this study in comparison with perception thresholds measured without showing the outside view to subjects in our past experiments. (Ishikawa & Noda 1998, Ishikawa & Noda et al. 1999, Noda & Ishikawa 1999a) Perception thresholds measured without showing the outside view to subjects are represented by approximation cubic curves plotted from 50th percentile perception thresholds obtained in the experiments after sorting it according to experimental conditions applicable to them so as to show the scatter of perception thresholds based on bodily sensation alone. (Ishikawa & Noda et al. 1999)

As has been discussed in our past study (Ishikawa & Noda et al. 1999), perception thresholds based on bodily sensation exhibit a scatter of the magnitude shown in the figure due to differences in the subjects' state and level of vibration consciousness. When subjects have no prior knowledge of the occurrence of a vibration and are relaxed, perception thresholds tend to be

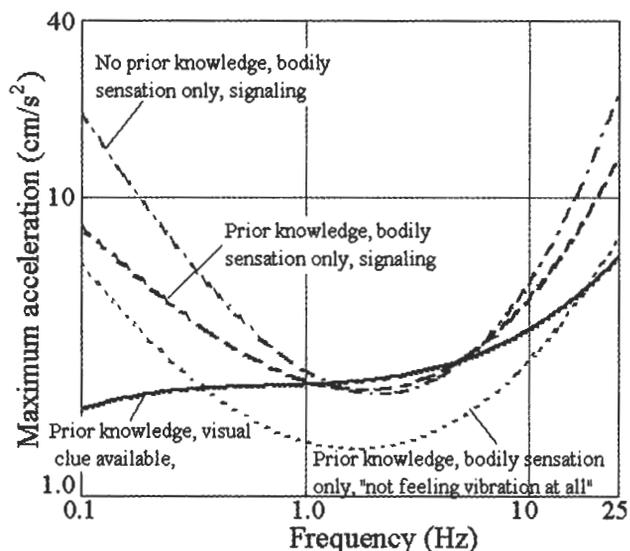


Figure 7. Comparison with perception thresholds based on bodily sensation in past studies.

high. In contrast, when subjects anticipate the occurrence of a vibration and are predisposed to believing “it must be shaking” due to exposure to reply choices in a questionnaire, perception thresholds tend to be low. Various situations in which building occupants are placed in daily lives are likely to encompass all the conditions considered in our experiments, and this gives rise to a need for the thorough incorporation of the resulting scatter of perception thresholds into habitability assessment.

Perception thresholds based on both bodily sensation and visual sensation were lower than those based on bodily sensation alone in the low-frequency region below around 0.25 Hz. Namely, despite the significance of the impact of the subjects’ states and levels of vibration consciousness on perception thresholds based on bodily sensation, there is a region in which the impact of visual sensation even exceeds it. In the low-frequency region, perception thresholds tend to be low as subjects are able to pick up weak vibrations that their bodies do not feel through visual sensation, as displacement is large in that region despite small acceleration. In the low-frequency region, therefore, habitability assessment needs to properly take into account the impact of visual sensation on perception thresholds in consideration of its significance.

In the medium to high frequency range above 0.4 Hz, perception thresholds are mainly determined by bodily sensation, as the impact of visual sensation is small due to small displacement. In this region, the scatter of perception thresholds measured while showing the view outside the window to subjects is in line with that of perception thresholds based on bodily sensation alone. Namely, habitability assessment needs to mainly focus on the scatter of perception thresholds based on bodily sensation despite the fact that visual sensation may exert some influence.

As can be seen from the above, in the lower acceleration region that is within the scope of a habitability assessment, the impact of visual sensation on perception thresholds differs according to the frequency, so that it is necessary to give different weights to bodily sensation and visual sensation depending on the target building. For example, bodily sensation exhibits high sensitivity to vibrations in the frequency range of 2.0–4.0 Hz, common in low-rise buildings such as three-story prefabricated houses (Otsuki, Tamura, Nakata, Naito & Kiriya 1994), and the impact of visual sensation is small compared to other frequency regions. In such a region, therefore, it is appropriate to focus on bodily sensation when conducting a habitability assessment. On the other hand, bodily sensation is relatively insensitive to vibrations in the low-frequency range, common in super high-rise apartments and other buildings, and it is highly likely that visual sensation impacts on the sense of horizontal vibration. In such a region, it is necessary to increase the weight given to visual sensation when conducting a habitability assessment.

5 CONCLUSIONS

In this study, we conducted experiments by making the view outside a window visible to the subjects and analyzed the results in comparison with those of earlier experiments based only on bodily sensation so as to elucidate the impact of visual sensation on the sense of horizontal vibration.

The findings of this paper are listed below.

1. Visual sensation has a significant impact on perception thresholds, and this tendency becomes stronger as the frequency decreases. In the low-frequency region, displacement is large despite small acceleration, and this lowers perception thresholds as the subjects are able to detect vibration their body cannot feel by obtaining sufficient information from vision in the form of a large displacement. In contrast, since displacement decreases as frequency increases, visual sensation has little impact in the high frequency region, so that subjects assess vibration by relying on bodily sensation.
2. The impact of visual sensation on the sense of horizontal vibration is closely related to displacement as the form of vibration information afforded by vision. This impact may therefore be analyzed by dividing the displacement spectrum into three regions. At a certain threshold level, displacement just becomes visually recognizable, though the actual value varies depending on various conditions. If displacement is below this level, people assess vibration by relying only on bodily sensation even if the view outside the window is visible.

If it is above this level, people assess vibration by relying on both bodily sensation and visual sensation in an integrated manner. In a certain displacement region further up the displacement scale, visual sensation intensifies the body's assessment of vibration.

3. Although the perception threshold based on bodily sensation varies depending on the subject's state, level of vibration consciousness, and the like, the impact of these factors is overtaken by that of visual sensation in the low frequency region, and this results in the lowering of the perception threshold. In contrast, the impact of visual sensation is small in the high frequency region, so that habitability can be evaluated by focusing mainly on the scatter of the perception threshold based on bodily sensation despite the fact that visual sensation may still have some impact.

The frequency range in which visual sensation has a significant impact as established in this study is subject to a set of visual conditions, and more universal research will be needed in the future research. Despite such restrictions, this study has shown the necessity of assessing habitability for horizontal vibration after identifying regions in which the impact of visual sensation must be taken into consideration and regions in which it is sufficient to consider bodily sensation.

In an actual living environment, various other factors, such as whether there is a window near an occupant, whether objects prone to shaking are present and if so whether the occupant looks at them, will have to be covered in an evaluation. The authors wish to present a statistical evaluation method for the scatter of perception thresholds that fully takes into account personal and circumstantial variabilities, including the impact of visual sensation as shown above.

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REFERENCES

Architectural Institute of Japan 2004. *Guidelines for the evaluation of habitability to building vibration*. Tokyo: AIJ
 Ishikawa, T. & Noda, C. 1998. Sensory Assessment of Horizontal Vibration over a Wide Frequency Range.

- Journal of Architecture Planning and Environmental Engineering(Transactions of AIJ)* (506): 9–16
 Ishikawa, T., Noda, C., Kumazawa, F. & Okada, T. 1994a. A Study on Serviceability Limit for Wind-Induced Motions in Consideration of Visual Stimulus. *Journal of Structural Engineering* 40B: 1–6
 Ishikawa, T., Noda, C., Kumazawa, F. & Okada, T. 1994b. Effects of Difference in Visual Objects on Sense of Horizontal Vibration. *13th National Symposium on Wind engineering papers*: 107–112
 Ishikawa, T. & Noda, C. et al. 1998. Evaluation of Sense of Horizontal Vibration in a Condition Approached Living Environment – Part 1 Outline of the Experiment and Characteristics of Psychological Evaluation–; – Part 2 Difference in Perception Thresholds Depending on Experimental Conditions –. *Summaries of Technical Papers of Annual Meeting, the A.I.J.(Environmental Engineering I)*: 323–326
 Ishikawa, T. & Noda, C. et al. 1999. Influence of Circumferential Factors on Perception Threshold of Horizontal Vibration- Part I Outlines of the Experiments–; – Part 2 Differences in the Subjects' Consciousness – & – Part 3 Presentation of Guidelines on Perception – *Summaries of Technical Papers of Annual Meeting, the A.I.J. (Environmental Engineering)*: 319–324
 Ishikawa, T., Uekusa, T., Ichiriki, Y. & Noda, C. 1993. A study on vibration sensation considering habitability of high-rise dwelling – Part 1 Outline of the research and the result –. *Summaries of Technical Papers of Annual Meeting, the A.I.J. (Environmental Engineering)*: 95–96
 ISO2631–2 2003. *Mechanical vibration and shock – Evaluation of human exposure to whole-body vibration Part 2: Vibration in buildings (1 Hz to 80 Hz)*
 Nakamura, T., Kanda, J., Shioya, K. & Nagaya, M. 1995. Statistical Study of Perception of Vibration in Base Isolated Buildings during Earthquakes. *Journal of Architecture Planning and Environmental Engineering (Transactions of AIJ)* (472): 185–192
 Noda, C. & Ishikawa, T. 1999a. Influence of the subjects' situation on perception threshold of horizontal vibration. *Journal of Architecture Planning and Environmental Engineering (Transactions of AIJ)* (524): 9–14
 Noda, C. & Ishikawa, T. 1999b. Influence of visual sensation on sense of horizontal vibration. *Journal of Architecture Planning and Environmental Engineering (Transactions of AIJ)* (525): 15–20
 Otsuki, T., Tamura, Y., Nakata, N., Naito, S. & Kiriya, S. 1994. Characteristics of Road Traffic Vibration in Steel Frame Housing. *Summaries of Technical Papers of Annual Meeting, the A.I.J. (Environmental Engineering)*: 1885–1886
 Tsurumaki, H., Goto, T. & Inoue, J. 1995. Research on Effects of Window View on Sense of Vibration for Low-Frequency Vibrations – Part 2 Outline of Vibration-induced Visual Sensation Simulator Experiment and Results –. *Summaries of Technical Papers of Annual Meeting, the A.I.J. (Environmental Engineering)*: 361–362