16th World Conference on Earthquake, 16WCEE 2017
Santiago Chile, January 9th to 13th 2017
Paper N° 4824
Registration Code: S-J1465523577

CORRESPONDENCE OF THE HABITABILITY EVALUATION CURVE AND ANXIETY UNDER STRONG MOTION

Y. Nakamura(1), T. Takahashi(2), M. Nakae(3)

(1) Associate Professor, Graduate School of Engineering, Chiba University, nakamura.yukiko(a)faculty.chiba-u.jp
(2) Professor, Graduate School of Engineering, Chiba University, takahashi.toru(a)faculty.chiba-u.jp
(3) Former Student, Dept. of Architecture, Chiba University
…

Abstract

One of the present authors previously proposed performance limit curves of human actions and anxiety in a room under strong motion. An evaluation method of human vibration is specified in JIS B 7760-2:2004 Whole-body vibration—Part 2: General requirements for measurement and evaluation method [1] and 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]. Various evaluation criteria of human exposure to vibration have been defined for habitability in the event of building vibration caused by wind and traffic and for safety and working limits in the construction of a high-rise building. Meanwhile, the mitigation of indoor risk, such as the risk of an accident in which furniture overturns in a room under strong motion, has been studied. The present paper examines the relations among performance limit curves of anxiety under strong motion, criteria of human vibration and indoor risk estimated using various indicators.

Keywords: Limit curves of human performance; Indoor risk; Anxiety; Action difficulty; Shaking table test

1. Introduction

The seismic performance of a building has been expressed in terms of the building's structural capacity, such as the building's resistance to collapse in the event of a severe earthquake. The authors have investigated the indoor human response and evacuation limit and have proposed performance limit curves of human action difficulty and level of anxiety in a room under strong motion [3, 4, 5]. A method of evaluating human vibration is specified in JIS B 7760-2:2004 Whole-body vibration—Part 2: General requirements for measurement and evaluation method and 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). Various evaluation criteria of human exposure to vibration have been defined for habitability in the event of building vibration caused by wind and traffic and for safety and working limits in the construction of a high-rise building.

Meanwhile, the mitigation of indoor risk, such as the risk of accidents in which furniture overturns in a room under strong motion, has been studied.

The present paper makes a comparative review of the evaluation criteria and human performance limit curves for anxiety and action difficulty, and examines relations between performance limit curves of anxiety under strong motion and indoor risk estimated using various indicators.

2. Human performance limit curves for anxiety and action difficulty obtained from a shaking table test

In previous research, one of the present authors performed shaking table tests for a new criterion of structural performance and proposed human performance limit curves for the level of anxiety and action difficulty [3]. The floor response in the shaking table tests was under one-dimensional motion. Human subjects were asked to answer a questionnaire about anxiety and action difficulty after each input motion. Figures 1 and 2 show the human performance limit curves for anxiety and action difficulty fitted with linear regression, while Figs 3 and 4 show the human performance limit curves for anxiety and action difficulty fitted with Weibull regression.

The oscillation of a building during an earthquake is a two-dimensional motion. Shaking table tests were therefore also conducted using an x–y slider. In these tests, subjects remained sitting on a chair because of the limited size of the shaking table, and the results of the questionnaire survey thus reveal not action difficulty but action possibility. Human performance limit curves of anxiety and action possibility were obtained for motions in two directions [5]. These curves are shown in Figs 5 and 6 and are fitted with linear regression.

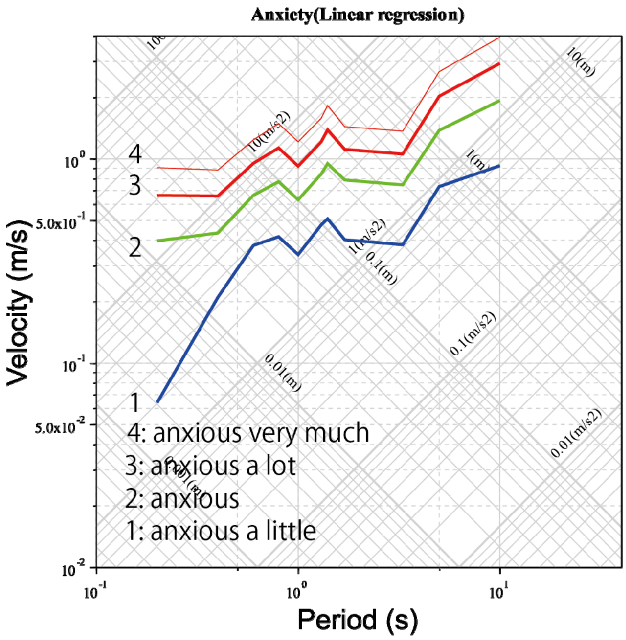


Fig. 1. Human performance limit for anxiety

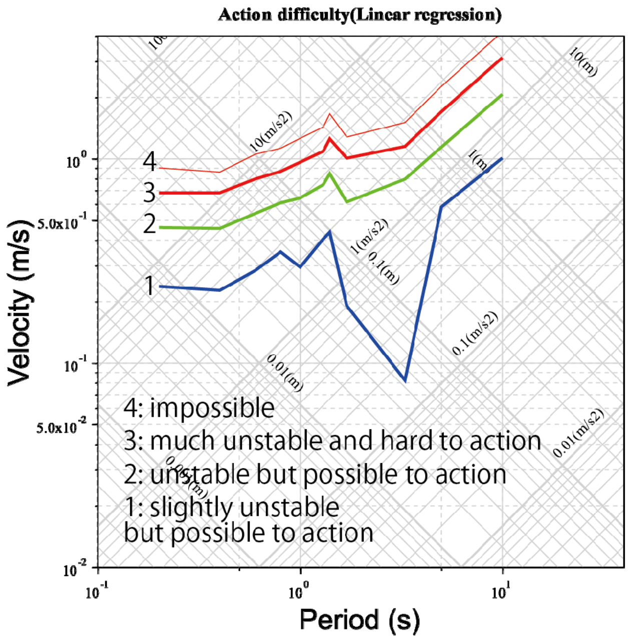


Fig. 2. Human performance limit for action difficulty

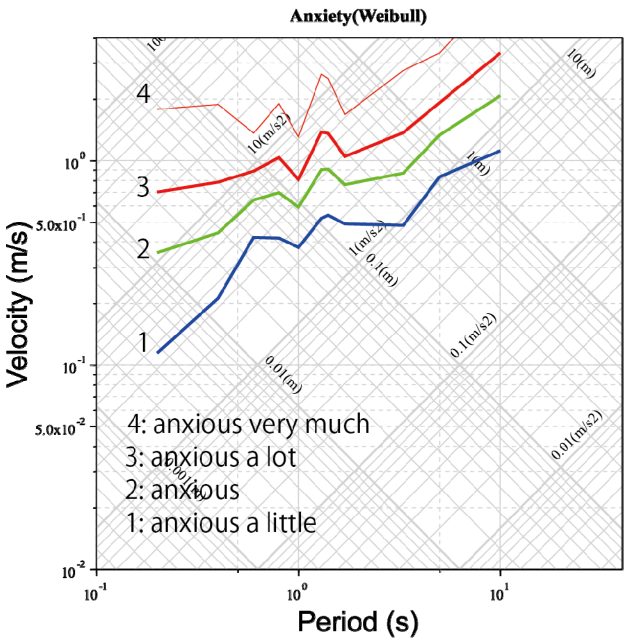


Fig. 3. Human performance limit for anxiety

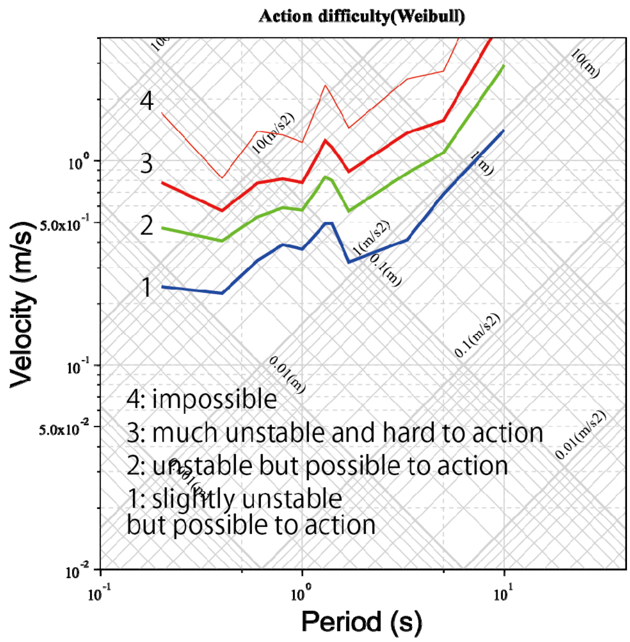


Fig. 4. Human performance limit for action difficulty

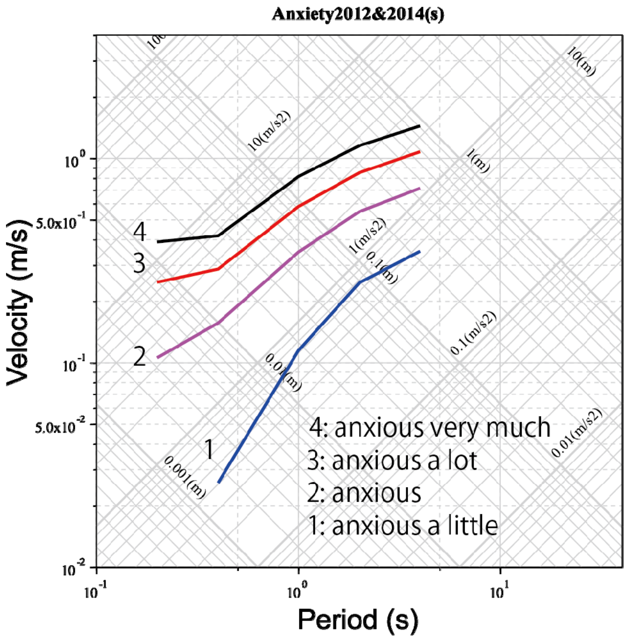


Fig. 5. Human performance limit for anxiety

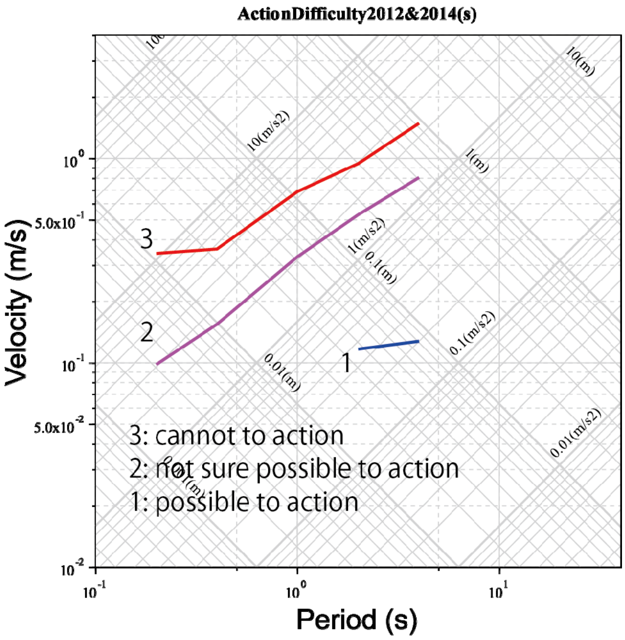


Fig. 6. Human performance limit for action possibility

3. Human perceptual evaluation curve and vibration evaluation indices

3.1 Evaluation of habitability in the event of building vibration

The Architectural Institute of Japan proposed guidelines for the evaluation of habitability in the event of building vibration and published a handbook on design based on environmental vibration performance [6]. The guidelines and handbook gave habitability grades for the vibration of buildings due to wind and traffic. Figure 7 shows the limit curve of vibration perception ratios (i.e., the ratio of people who feel the shaking); the lines show vibration perception ratios of 10%, 30%, 50%, 70% and 90%. The habitability grade for horizontal vibration based on residents' perception is shown in Fig. 8 [7, 8]; lines show very good, good, normal and excusable habitability.

3.2 Seismic intensity scale

The new JMA (Japan Meteorological Agency) seismic intensity scale has been derived from strong ground motions observed since 1996 and comprises 10 grades (i.e., 0, 1, 2, 3, 4, 5 lower, 5 upper, 6 lower, 6 upper, and 7) [9]. The relation between the maximum acceleration and JMA seismic intensity scale can be defined if the earthquake acceleration record is a steady sinusoidal wave. The relation is shown in Fig. 9. Although the JMA seismic intensity scale provides not only an evaluation of habitability, its graph is similar to that of the evaluation of habitability in the event of building vibration; i.e., plots of acceleration against frequency are V-shaped for the JMA seismic intensity scale and habitability grade, with higher acceleration at low and high frequencies. The JMA also gives information on long-period earthquake ground motion. The seismic intensity scale for long-period ground motion is defined using a pseudo velocity response spectrum with a 5% damping factor [10]. Figure 10 shows this scale converted into acceleration.

3.3 Working and safety limits in the construction of a high-rise building

Working limits and postural control for low-frequency vibration were examined for the construction of a high-rise building. The limit curve of welding operation in a high-rise building is shown in Fig. 11 [11]. The limit curve of postural control in a high-rise building is shown in Fig. 12 [11]. The natural period of a high-rise building lies in the area of low frequency. The limit of postural control is therefore strict in this low frequency band.

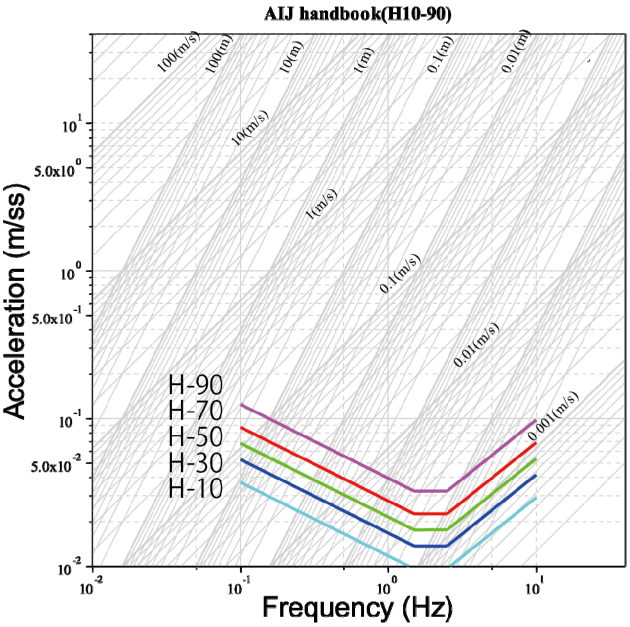


Fig. 7. Limit curve of vibration perception ratios

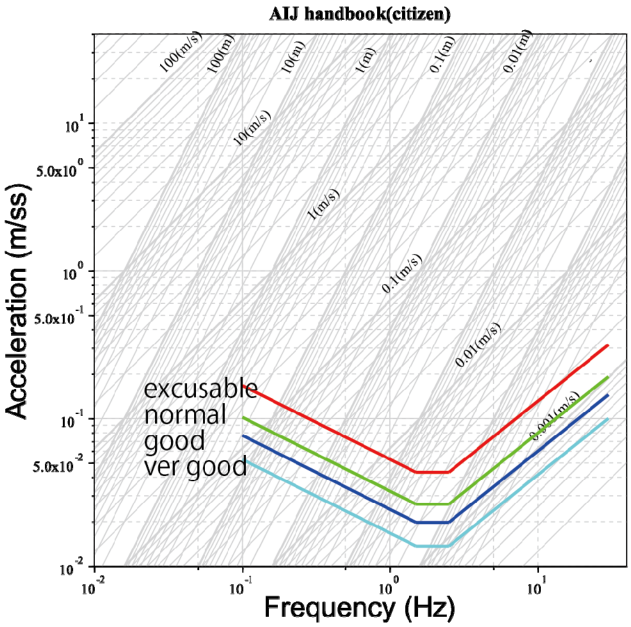


Fig. 8. Habitability grade

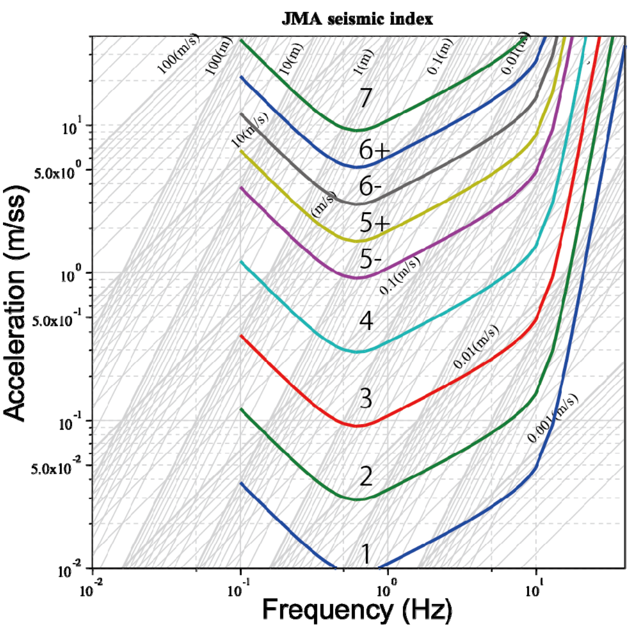


Fig. 9. JMA seismic intensity scale

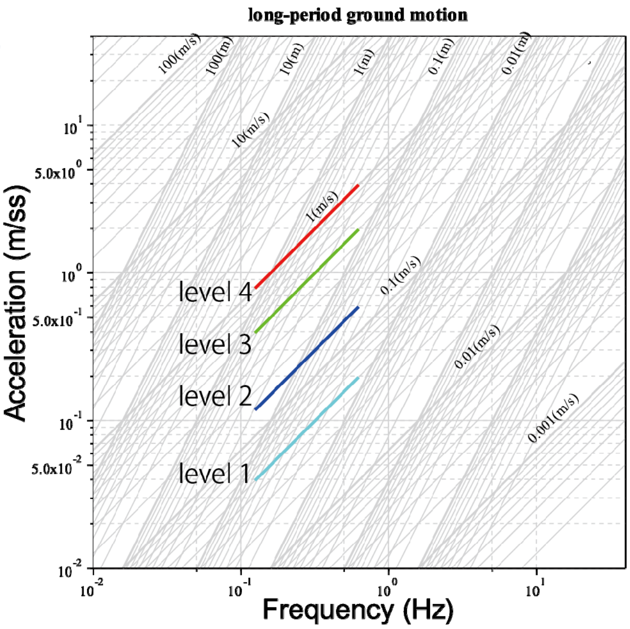


Fig. 10. Long-period earthquake ground motion

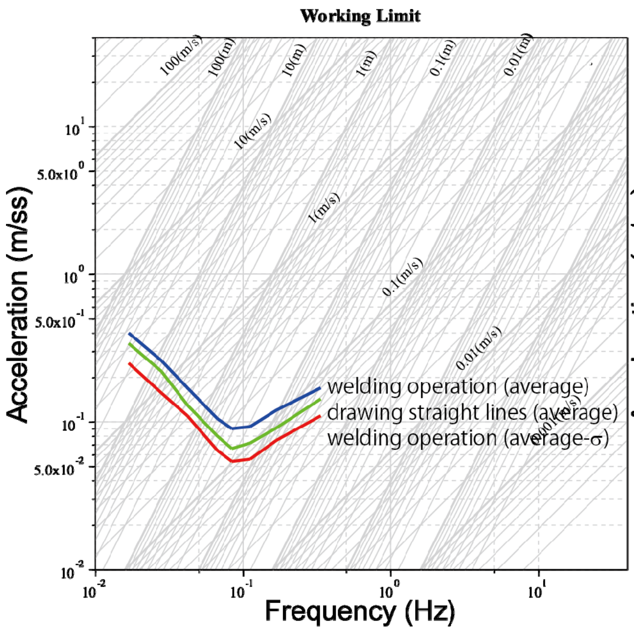


Fig. 11. Limit curve of welding operation

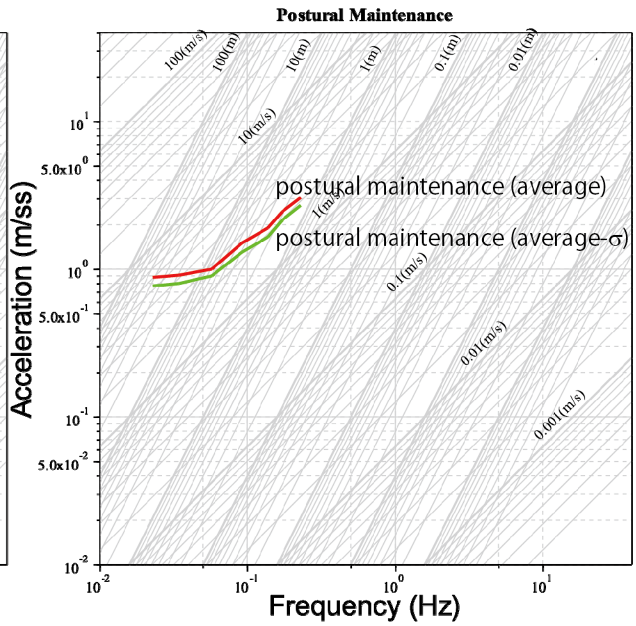


Fig. 12. Postural maintenance limit in a high-rise building

4. Relation between anxiety felt in a building and indoor risk during strong motion

Human anxiety might be affected by the indoor risk. The relation between anxiety and existing indoor risk indicators were therefore comprehensively examined. The furniture-overturning ratio, furniture damage and human damage in the event of strong motion were used as indicators of indoor risk.

Each indoor risk indicator was calculated using the 71st input motions used in previous two-dimensional shaking table tests for anxiety [12, 13]. The JMA seismic intensity scale was also considered, though it is not an indoor risk indicator.

4.1 Overturning ratio of furniture

Kaneko studied a method of estimating the overturning ratio of furniture during an earthquake [14]. The present authors estimated the overturning ratios for the 71st input motions. Figure 13 shows that anxiety increases with the overturning ratio.

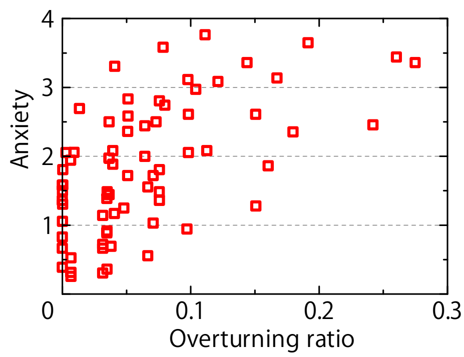
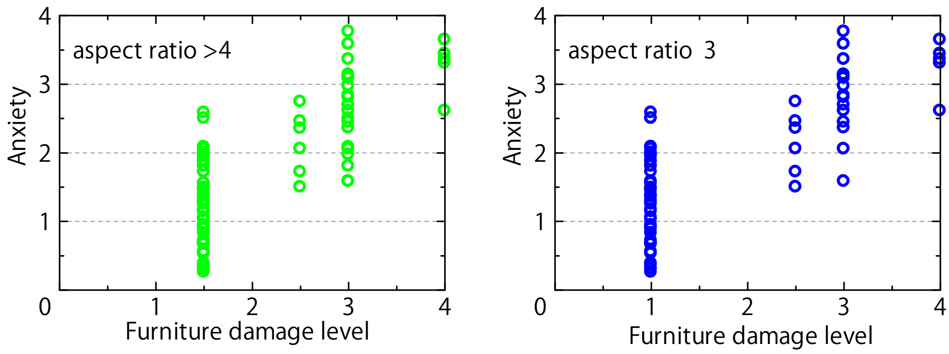


Fig. 13. Relation between anxiety and the furniture-overturning ratio

4.2 Furniture damage level

Shimano et al. studied the estimation of the level of furniture damage in rooms [15]. There are four levels of furniture damage (i.e., D1: no damage, D2: minor damage, D3: damage, and D4: severe damage or overturning). The relation between anxiety and level of furniture damage is shown in Fig. 14. Anxiety increases with the level of furniture damage, as it did with the furniture-overturning ratio.



Aspect (vertical to horizontal) ratio of furniture exceeding four Aspect ratio of furniture of around three

Fig. 14. Relation between anxiety and the furniture damage level

4.3 Human damage in rooms

Shiga et al. studied the estimation of human damage in rooms during an earthquake [16]. Human damage was defined as the percentage of people injured by accidents in which furniture overturned in rooms under strong motion. The relation between anxiety and human damage is shown in Fig. 15. The estimated human damage was zero in more than half of cases of the input motion used in shaking table tests. However, for some input motions of relatively high frequency, such as 2.5 and 5 Hz, there was no estimated human damage but anxiety was high.

4.4 JMA Seismic Intensity Scale

The relation between anxiety and the JMA seismic intensity scale is shown in Fig. 16. A correlation is seen in the figure. The JMA seismic intensity scale of a building was found to correlate strongly with anxiety. The anxiety tends to increase between grades of five lower and five upper on the JMA seismic intensity scale.

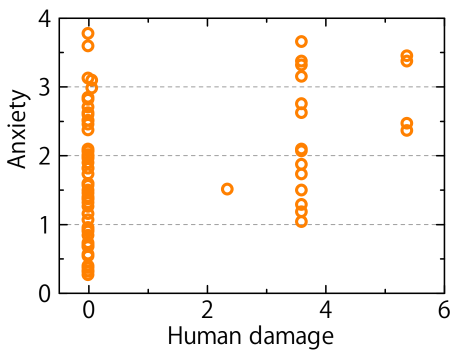


Fig. 15. Relation between anxiety and human damage

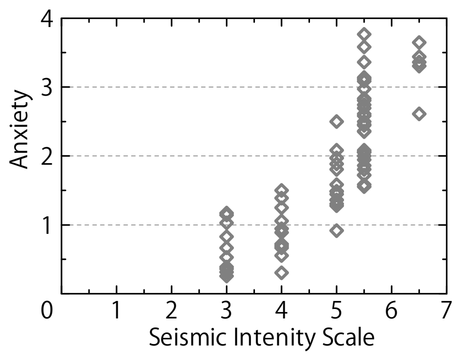


Fig. 16. Relation between anxiety and the JMA seismic intensity scale

5. Conclusions

Habitability evaluation curves, criteria and limit curves for buildings were compiled. Each habitability evaluation curve tended to be stricter in different frequency bands of different purpose of each indicators.

Human performance limits of anxiety and action difficulty during strong motion correlate with indicators of indoor risk. Anxiety is strongly felt in comparison with indoor risk indicators when input motions are of relatively high frequency, such as 2.5 and 5 Hz. The indoor risk, human damage level and anxiety are higher when maximum acceleration exceeds 0.3 ms^{-2} and when maximum velocity exceeds 0.4 m/s. These accelerations and velocities correspond to approximately 5 lower on the JMA seismic intensity scale. The thresholds of human anxiety and indoor risk are considered to be at about this level on the JMA seismic intensity scale.

6. References

[1] Japanese Standards Association :JIS B7760-2, Whole-body vibration Part 2:General requirements for measurement and evaluation method

[2] ISO2631-1:1997 , Mechanical vibration and shock-Evaluation of human exposure to whole-body vibration-Part1:General requirements

[3] Toru Takahashi, Toshiko Suzuki, Taiki, Saito, Tatsuya Azuhata, and Koichi Morita (2010) : Shaking Table Test for Indoor Human Response and Evacuation Limit, 7CUEE

[4] Toru Takahashi, Taiki, Saito, Tatsuya Azuhata, and Kazutoshi OHTOMO (2004) : Shaking Table Test on Indoor Human Response and Evacuation Limit in Strong Ground Motion, Paper No.1320, 13WCEE

[5] Kimura Una, Watanabe Haruhiko and Takahashi Toru (2013) :Quantitative Evaluation of Anxiousness against Two Directional Input Motion using Shaking Table, pp.51-52, Summaries of Technical Papers of Annual Meeting, Architectural Institute of Japan.

[6] Architectural Institute of Japan (2004): Guidelines for the evaluation of habitability to building vibration

[7] Architectural Institute of Japan (2010): Handbook for environmental vibration performance based design

[8] NODA Chizuko and ISHIKAWA Takashige (2010) :Habitability grade of horizontal vibration based on residents' consciousness, pp.131-137, Journal of Environmental Engineering, Architectural Institute of Japan.

[9] Japan Meteorological Agency :Tables explaining the JMA Seismic Intensity Scale, http://www.jma.go.jp/jma/en/Activities/inttable.html

[10] Japan Meteorological Agency :Seismic Intensity Scale for Long-Period Ground Motion, http://www.data.jma.go.jp/svd/eqev/data/choshuki/index.html

[11] Katsutoshi OHDO et al. (2001) : Working Limits and Safety Limits in Regards to Accidental Fall for Wind-Induced Vibration during High-Rise Construction Work, Specific Research Report of the National Institute of Industrial Safety, NIIS-SRR-NO.22.

[12] U. Kimura, H. Watanabe, Y. Nakamura and T. Takahashi (2014) : An Experimental Study on Quantification of Anxiety during Strong Motion : Part 1 A Study of the Questionnaire, pp.919-920, Summaries of Technical Papers of Annual Meeting, Architectural Institute of Japan.

[13] A. Masuzawa, T. Ohno, U. Kimura, Y. Nakamura and T. Takahashi (2015) : An Experimental Study on Quantification of Anxiety during Strong Motion : Part 4 Result of Experiments in 2014, pp.967-968, Summaries of Technical Papers of Annual Meeting, Architectural Institute of Japan.

[14] M. Kaneko (2002) : METHOD TO ESTIMATE OVERTURNING RATIOS OF FURNITURE DURING EARTHQUAKES, pp.61-68, Journal of Structural Engineering, Architectural Institute of Japan.

[15] Shimano Yukihiro et al. (2001) : Suggestion of Damage Level Estimation during Earthquake, pp.97-98, Summaries of Technical Papers of Annual Meeting, Architectural Institute of Japan.

[16] SHIGA Shunsuke, SATO Takeshi and MOTOSAKA Masato (2006) : A STUDY ON THE ESTIMATION OF HUMAN DAMAGE IN ROOMS DURING EARTHQUAKE, pp.477-480, AIJ Journal of Technology and Design.