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HUMAN SENSORY EVALUATION OF VIBRATIONS INSIDE TALL BUILDINGS

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Long-period vibrations felt by residents or workers in tall buildings due to wind or earthquake are a frequent problem. Considering the fact that vibration by wind or earthquake is dynamic, we investigated a wide range of random vibration, including long-period vibration. We focused on sensory evaluation and investigated the relationship between perception or psychological quantity (magnitude of anxiety or discomfort) and random vibration. In this study, we performed experiments using actual vibrations in detached houses for original waveforms. The results show the possibility of estimation using the predominant frequency in a fast Fourier transform analysis and maximum acceleration for perception and psychological evaluation. Random vibration is hardly perceived compared with sinusoidal vibration, and anxiety or discomfort is hardly felt. We determined a range in which subjects perceive random vibration but do not feel anxiety or discomfort.

Keywords: Environmental vibration, Random vibration, Horizontal vibration, Psychological evaluation, Probability of perception.

1 INTRODUCTION

Long-period vibration felt by residents or workers caused by wind or earthquake in tall buildings is a frequent problem. Vibrations due to wind or earthquake are dynamic in nature because vibration includes many frequency components, and its frequency and amplitude continuously vary. Random vibration has been pointed out to be different from that of sinusoidal vibration.

We perform experiments focused on perception and psychological evaluation of a wide range of random vibrations, including long-period vibration, to investigate the relationship between random vibration and perception or psychological evaluation.

2 OUTLINE OF A SHAKING-TABLE EXPERIMENT

We performed experiments using actual vibrations in detached houses for original waveforms. We performed four experiments and used 16 types of actual vibrations (patterns A–E and □–□) [1, 2] for the original waveforms. We used patterns A–E in experiment1, patterns A, B, D, and E in experiment2, patterns □–□ in experiment3, and patterns □–□ in experiment4. Input vibration was introduced by increasing or decreasing the time interval to vary the frequency. We used a shaking table, which enabled accurate reproduction of the target waveform, to introduce the input vibration.

Table 1. Vibration conditions.

Predominant frequency (Hz)		Maximum acceleration (cm/sec²)						
		0.63	1.6	4	10	25	63	160
	0.4 Hz	●	●	●	●	○	○	
	1.0 Hz	●	●	●	○	○	○	○
	2.5 Hz	●	●	●	○	○	○	○
	4.0 Hz	●	●	●	○	○	○	
	10 Hz	●	●	●	●	○	○	
	25 Hz	●	●	●	●	●	○	

※We performed a questionnaire survey only in the vibration condition when ○ is entered in this table.
We performed inquiry about the perception in the vibration condition when ● or ○ is entered in this table.
※Experiment1: 0.4-25 Hz, 0.63-4.0 cm/s²; 4.0-25 Hz, 10 cm/s²; 10-25 Hz, 25cm/s²; and 25 Hz, 63 cm/s².
※Experiment2: 1.0-25 Hz, 1.6-160 cm/s²
※Experiment3: 1.0-25 Hz, 1.6-160 cm/s²
※Experiment4: 0.4-25 Hz 1.6-63 cm/s²

Table 1 lists the vibration conditions in the experiments. Sinusoidal vibration with the same frequency and acceleration as those listed in Table 1 was also introduced in the experiments. The subjects were 18–45-year-old women. Eight subjects participated in the experiment each day, and one experiment was conducted for 40 subjects. The total number of subjects involved in the experiments was 161 (one subject was changed during the experiment only in experiment4). In experiment1, we did not perform a questionnaire survey to the subjects in the experiments. Eight subjects sat on the floor in a room by folding their legs. They replied to a questionnaire after subjected to a single sinusoidal vibration as a standard. We instructed the subjects to grab a button to register their reactions upon perception of the vibration. By introducing the vibration, denoted as ○ in Table 1, we instructed the subjects to answer the questionnaire about the felt vibration. The replies of the subjects are shown in Figure 1. We focused on the feelings of anxiety and discomfort to investigate the characteristics of the psychological evaluation of a random vibration. We denoted "felt no discomfort" as "Evaluation1"

Q1	Prevenient vibration	Felt no discomfort — Felt large discomfort

■Questionnaire

Q1	Later vibration					
Q2		Magnitude ( ) / 100				
Q3		Felt no anxiety	Felt a little anxiety	Felt anxiety	Felt considerable anxiety	Felt large anxiety
Q4		Felt no vibration	Felt a little vibration	Felt vibration	Felt large vibration	Felt unbearable vibration

Figure 1. Questionnaire answer forms.

and "felt a large discomfort" as "Evaluation5." "Evaluation1" is indicated by a broken line. "Evaluation5" is also indicated by broken lines, which suggested large discomfort. Three evaluations, which lie between "Evaluation1" and "Evaluation5," are denoted as "Evaluation2," "Evaluation3," and "Evaluation4," indicating lesser discomfort than "Evaluation5."

3 EXAMINATION OF PERCEPTION OF RANDOM VIBRATION

Evaluation of environmental vibration is based on the perception of sinusoidal vibration. On this basis, we examine the perception of random vibrations.

We consider the regression curve of the experimental results of 16 waveform patterns as perception of random vibrations (Figure 2). The regression curve for the sinusoidal vibration is also shown in Figure 2.

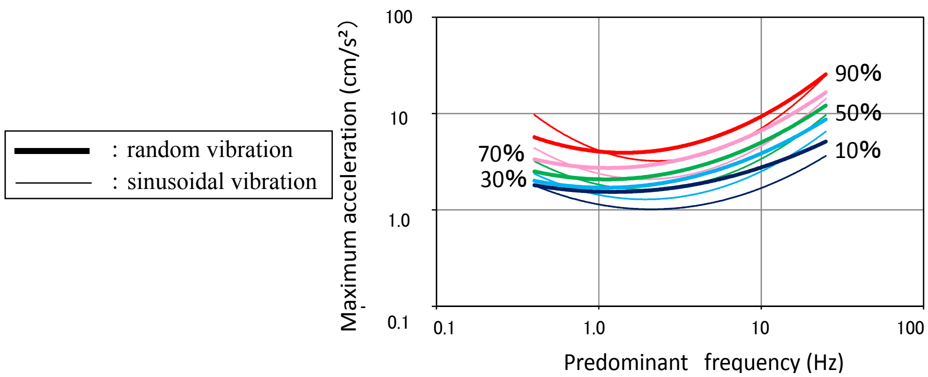

Figure 2. Evaluation curve of the perception of random vibration from the experimental results of 16 waveform patterns.

The figure shows the stable characteristics of the perception curve in random vibration, which shows similar forms and lines at equal intervals in terms of acceleration. We find out that estimation can be possible using the predominant frequency in a fast Fourier transform (FFT) analysis and the maximum acceleration to perceive random vibration. However, we must consider the influence of dispersion of the waveform patterns when we perform 10% or 90% perception probability to estimate the vibrations.

Comparing the position of the acceleration of random vibrations with that of sinusoidal vibrations, the curves of the sinusoidal vibration are smaller than those of the random vibration, which shows that the random vibration is hardly perceived compared with the sinusoidal vibration. On the other hand, the curve profiles between the random and sinusoidal vibrations are slightly different, and therefore, the difference between the random and sinusoidal vibrations varies with the frequency. The difference shows a tendency that it is bigger in the 1.5–2.5-Hz range, which is sensitively detected in the sinusoidal vibration.

4 EXAMINATION OF PSYCHOLOGICAL QUANTITY IN RANDOM VIBRATION

From the results of the perception of random vibrations, we examined the method of evaluating psychological quantity (magnitude of anxiety or discomfort) and the characteristics of psychological quantity in random vibration.

We examined the influence of waveform pattern from the dispersion of the evaluation curves. Figure 3 shows the comparison of 15 types of waveform patterns in the 10%, 50%, and 90% answer probability curves in the “felt no anxiety” level.

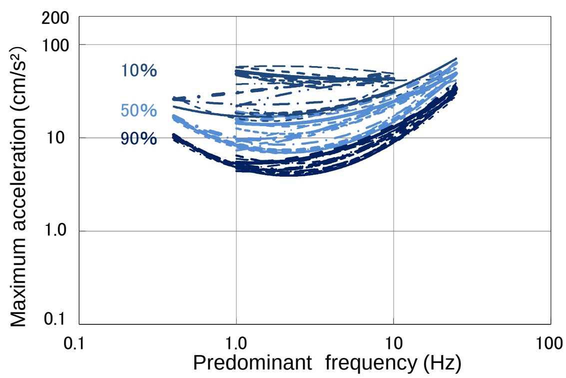

Figure 3. Comparison of the15 patterns of answer probability curves for the “felt no anxiety” level.

The dispersion of the evaluation curves is comparatively small in the “felt no anxiety” level, which reflects a small psychological quantity. The influence of waveform patterns on the evaluation curves is similar in the 10% and 50% answer probability curves in the “felt no anxiety” level. The range of dispersion of the evaluation curves in each 10% or 50% answer probability is approximately 40% as expressed by the answer probability, which is determined by comparing the range of the 20% answer probability curves. The influence of the larger than “felt anxiety” and larger than “felt considerable anxiety” levels is similar in the 10% and 50% answer probability curves to that in the “felt no anxiety” level. We must consider the influence of waveform patterns on the dispersion of the evaluation curves when we perform psychological evaluation to assess the reaction to vibrations.

To compare the anxiety evaluation curve of the random vibration with that of the sinusoidal vibration, we show the plots of the evaluation curve of the sinusoidal vibration and the regression curve data calculated from the results of the 15 waveform patterns shown in Figure 4.

In the range of smaller psychological quantity, the effect of predominant frequency in the random vibration is smaller than that in the sinusoidal vibration. However, the difference between the random and sinusoidal vibrations is small. The curves in the sinusoidal vibration occur under smaller acceleration than those in the random vibration according to the results of the perception. This result shows that anxiety is less hardly felt in the random vibration than in the sinusoidal vibration. In the range of smaller psychological quantity, the range of the difference between random and sinusoidal

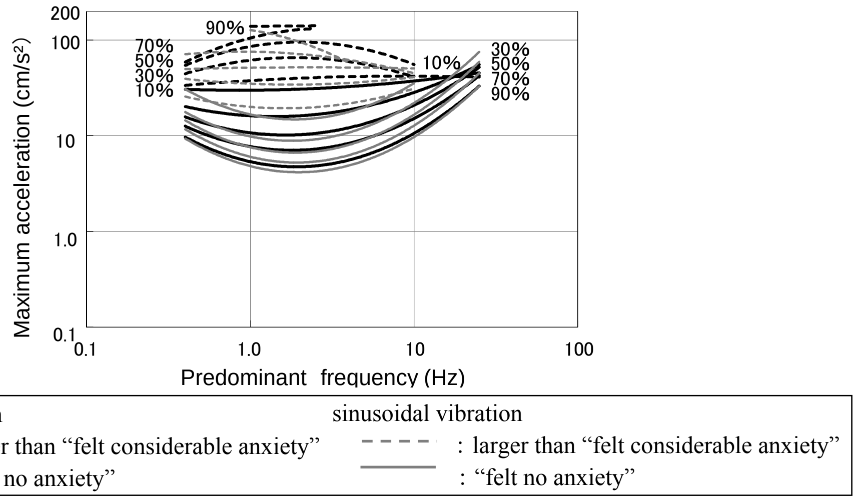

Figure 4. Comparison of the anxiety levels between random and sinusoidal vibrations.

vibrations is expressed as approximately 20%, which is determined by comparing the range of the evaluation curve per 20% in the figure. This value is smaller than that in the case of perception. In contrast, even after considering the fact that the dispersion of the curves is large in the sinusoidal vibration, in the range of large psychological quantity, the range of the difference between the random and sinusoidal vibrations is approximately 20%–40%, which is similar to that in the perception case. Similar trends are observed for the feelings of discomfort.

5 COMPARISON OF PERCEPTION AND PSYCHOLOGICAL QUANTITY

To compare the psychological quantity and perception, the evaluation curves for anxiety or discomfort and the perception probability curve are shown in Figure 5.

The comparison of the evaluation curve of anxiety and discomfort shows a similar curve form. The figure shows that the trends of the feelings of anxiety and discomfort are similar under maximum acceleration and predominant frequency.

The comparison of the evaluation curve for the psychological evaluation and the perception shows that the evaluation curve of the psychological evaluation in the range of smaller psychological quantity and the perception are similar. On the other hand, the evaluation curve of the psychological evaluation in the range of bigger psychological quantity and the perception are different. In the range of bigger psychological quantity, the effect of predominant frequency becomes smaller in the psychological evaluation. We also evaluated the estimation possibility using the predominant frequency in the FFT analysis as well as the maximum acceleration for psychological evaluation from the above-verified result on the comparison of 15 patterns or the comparison between the random and sinusoidal vibrations. This evaluation was based on the fact that the evaluation curves of the psychological evaluation in the range of smaller psychological quantity and that of the perception are similar, and the characteristics of the curve in the

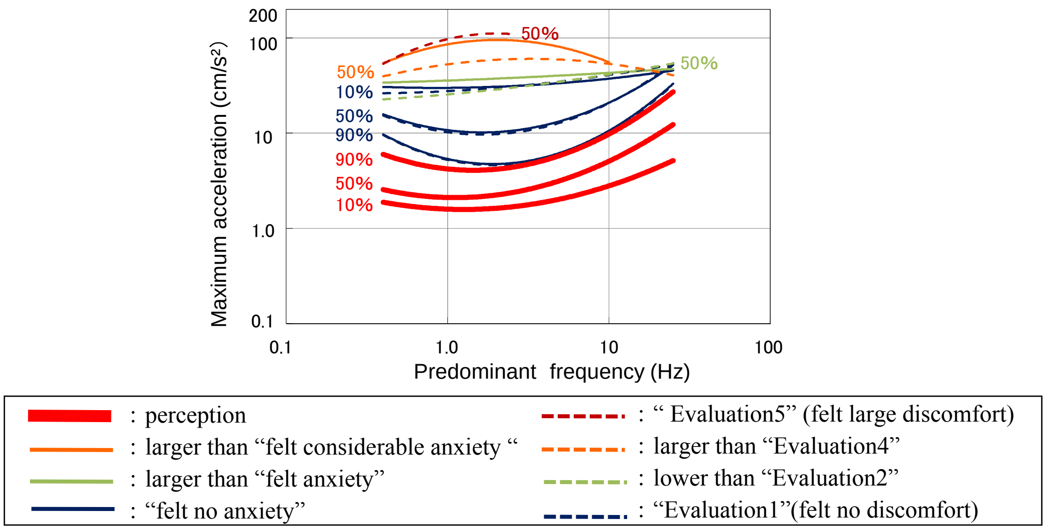

Figure 5. Comparison of perception, anxiety, and discomfort feelings for random vibrations.

psychological evaluation gradually change from a smaller to a bigger psychological quantity. The comparison of the evaluation curves of the psychological evaluation and that of perception shows that the maximum acceleration ranges of these evaluation curves are different. A range exists where the subjects perceived random vibration but did not feel anxiety or discomfort. The characteristics of these curves change in the range of bigger psychological quantity, and the range is widest at approximately 2.5 Hz, where anxiety or discomfort was easily felt or perceived. On the other hand, the range is relatively narrow in high frequencies.

6 CONCLUSION

We have verified our evaluation method of the dispersion of curves and the characteristics of perception or psychological evaluation by performing the evaluation using the predominant frequency in the FFT analysis. As a result, we were able to determine the possibility of estimating perception and psychological evaluation. Perception and feeling of anxiety or discomfort are less hardly felt in random vibration than in sinusoidal vibration. We show that the effect of the predominant frequency becomes smaller in the range of bigger psychological quantity and note the range in which the subjects perceived random vibration but did not feel anxiety or discomfort.

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