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Human Perception Thresholds of Horizontal Motion

Seuils de la perception humaine du mouvement horizontal

Menschliche Wahrnehmungsschwellen von horizontalen Schwingungen

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SUMMARY

Horizontal responses of tall buildings to wind are generally a narrow-band random process caused by the light damping of structures. It is necessary to evaluate human perception of motion under conditions as similar as possible to those that exist in tall buildings. The human perception thresholds of a narrow-band random process at predominant frequencies of 0.125 Hz to 0.315 Hz are examined and compared with those of sinusoidal motion. Statistical analyses were performed using the experiment data to propose probabilistic criteria for the perception thresholds.

RESUME

La façon dont les bâtiments réagissent au vent est généralement dans des limites étroites, influencées par un léger amortissement des structures. Il est nécessaire d'évaluer la perception humaine sous des conditions aussi semblables que possibles à celles qui existent dans les bâtiments. Les seuils de la perception d'une toute petite action horizontale inattendue, à fréquences prédominantes de 0.125 Hz à 0.315 Hz, sont examinés et comparés avec ceux d'un mouvement sinusoïdal. Les analyses statistiques ont été établies en utilisant les données expérimentales pour proposer des critères probables pour les seuils de la perception.

ZUSAMMENFASSUNG

Horizontale Antworten hoher Gebäude auf Wind sind normalerweise Zufallsereignisse innerhalb eines schmalen Bandes, bedingt durch die leichte Dämpfung des Tragwerks. Es ist notwendig, die menschliche Wahrnehmung der Schwingungen unter Bedingungen zu bewerten, die so ähnlich wie möglich zu denen sind, die sich in hohen Gebäuden finden. Die menschlichen Wahrnehmungsschwellen von engbandigen zufälligen Vorgängen bei vorherrschenden Frequenzen von 0.125 Hz bis 0.315 Hz werden untersucht und denen bei Sinusschwingungen gegenübergestellt. Statische Analysen wurden unter Verwendung der Experimentdaten durchgeführt, um probabilistische Kriterien für die Wahrnehmungsschwellen vorzuschlagen.

1. INTRODUCTION

Horizontal responses of tall buildings to wind are generally a narrow-band random process caused by the light damping of structures. The fundamental natural frequencies of structures are dominant in the time histories of responses. The traces of response are elliptical in shape. It is necessary to evaluate human perception of motion under conditions as similar as possible to those that exist in tall buildings. Although investigations have been conducted on the human perception of horizontal vibration in existing tall buildings[1],[2], the relationship between the perception of random and sinusoidal motion has not been established.

The authors first studied the human perception thresholds of uniaxial, elliptical and circular sinusoidal motions to discuss the effect of the two-dimensional motion[3]. Secondly, we studied the perception thresholds of a narrow-band random process to investigate the effect of random motion.

In this paper, the human perception thresholds of a narrow-band random process at predominant frequencies of 0.125Hz to 0.315Hz are examined and compared with those of sinusoidal motion. Statistical analyses were performed using the experiment data to propose probabilistic criteria for the perception thresholds.

2. TEST METHOD

2.1 Testing Condition

Random motions were synthesized by calculating the response of a single degree of freedom system with light damping (h = 0.01) to the Gaussian white noise with uniformly distributed random phase. Random motions contained combinations of the following parameters: Predominant frequencies - 0.315Hz, 0.25Hz, 0.2Hz, 0.16Hz, 0.125Hz, Body orientations - fore and aft (X direction), side to side. (Y direction). Figure 1 shows the time history of a typical narrow-band random process.

People in the test were placed in a sitting position to the horizontal movements. Human reactions were classified in three ratings as follows : [A] Imperceptible ; [B] Barely perceptible (Level I) ; [C] Distinctly perceptible (Level II). Each subject showed his/her rating of each motion by pushing one of three buttons. A total of 61 people were tested in this experiment.

2.2 Testing Equipment

The equipment used as a vibration generator was the electro-hydraulic servo-controlled 6 degrees of freedom shaking table. A testing room of 3.1m × 4.0m with a 2.6m ceiling was mounted on the shaking table with laminated rubber bearings to cut off higher frequency motions of the shaking table. To avoid the subjects being influenced by noise from the actuator, acoustical insulation was installed in the walls and ceiling

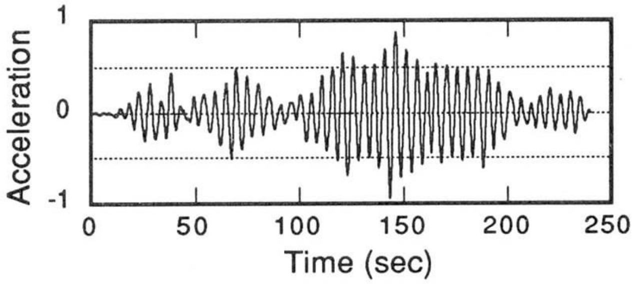

Fig.1 Synthesized Random Process

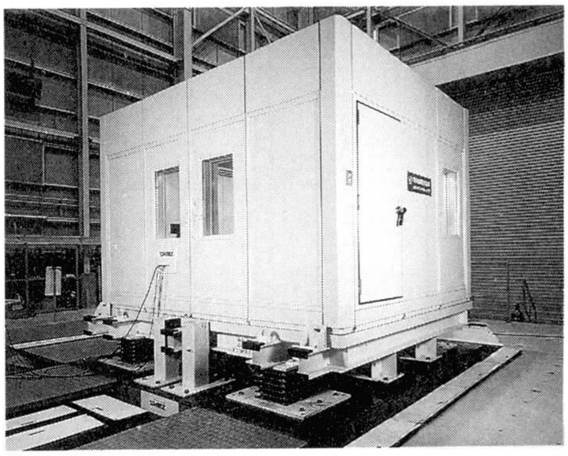

Fig.2 Vibration Simulator

of the testing room. The blinds were pulled down during the measurement so that the subjects could not perceive the motion of the room by sight. Highly sensitive servo-controlled accelerograms were used in three different directions to measure the motion of the vibration simulator.

The exterior of the vibration simulator and body orientation are shown in Figures 2 and 3.

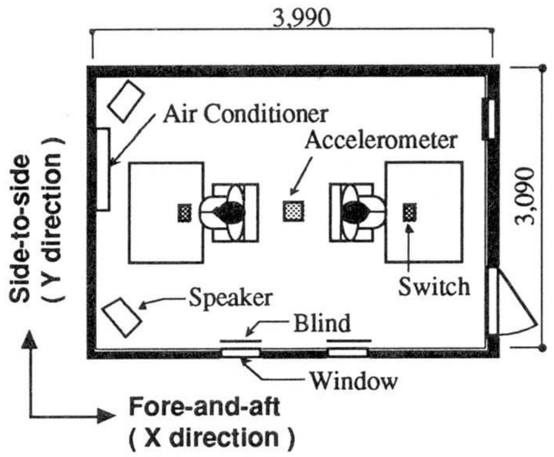

Fig.3 Body Orientation

3. PERCEPTION THRESHOLDS OF RANDOM MOTION

3.1 Detection of Perceived Acceleration Level

The subject showed the rating of each motion by pushing buttons. The perceived accelerations of each subject were read at the switching points of the absolute acceleration envelope in a positive gradient. The perceived accelerations were obtained at several points because the motion was a random process. The mean values of each case were used as his/her perception values.

The relationship between the frequency and the perceived acceleration of all cases was shown in scattered plots and the mean values and standard deviations were calculated by using the data of rating [B] and [C]. The scattergrams of perceived acceleration are shown in Figure 4 . The solid line shows mean values and the dotted line shows standard deviations of each frequency.

The coefficients of variation (COV) are 0.31 to 0.72 in Level I and 0.21 to 0.42 in Level II. It was found from the scattergrams that the dispersion of Level II is smaller than that of Level I and that the perceived accelerations are almost independent of the frequency, especially in Level II in both motion directions.

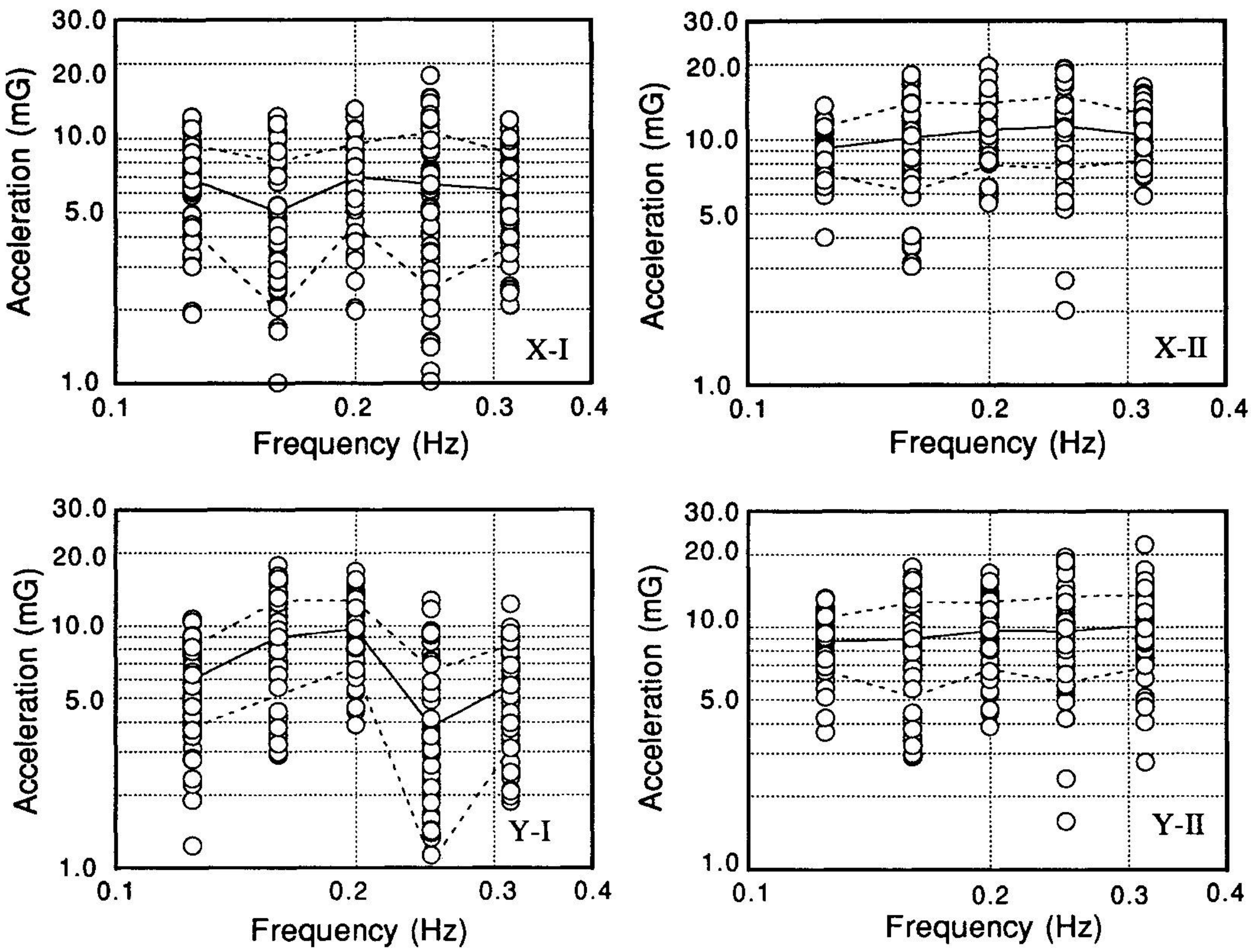

Fig.4 Scattergrams

3.2 Probability Density Function of Perceived Acceleration

Normalized probability density functions of perceived acceleration were calculated by dividing data (X_{ij}) by the mean value of corresponding cases ($X_{j,mean}$). Figure 5 gives the probability density functions of all cases.

The normalized probability density functions were examined by the Chi-square test for the goodness of fit to the normal distribution and the log-normal distribution. It was found that both distributions fit the present data within a 5% significance level, but the log-normal distribution gave a closer approximation. After the Chi-square test and the non-negative of perception level, the log-normal distribution was better than the normal distribution as the probability distribution model of perception threshold.

3.3 Percentile of Perception

The log-normal probability density function is assumed as the model of perception threshold. The log-normal probability density functions of each frequency were first calculated then the probability distribution functions were obtained. The 2, 10, 50 and 90 percentile perception levels were calculated from the distribution functions.

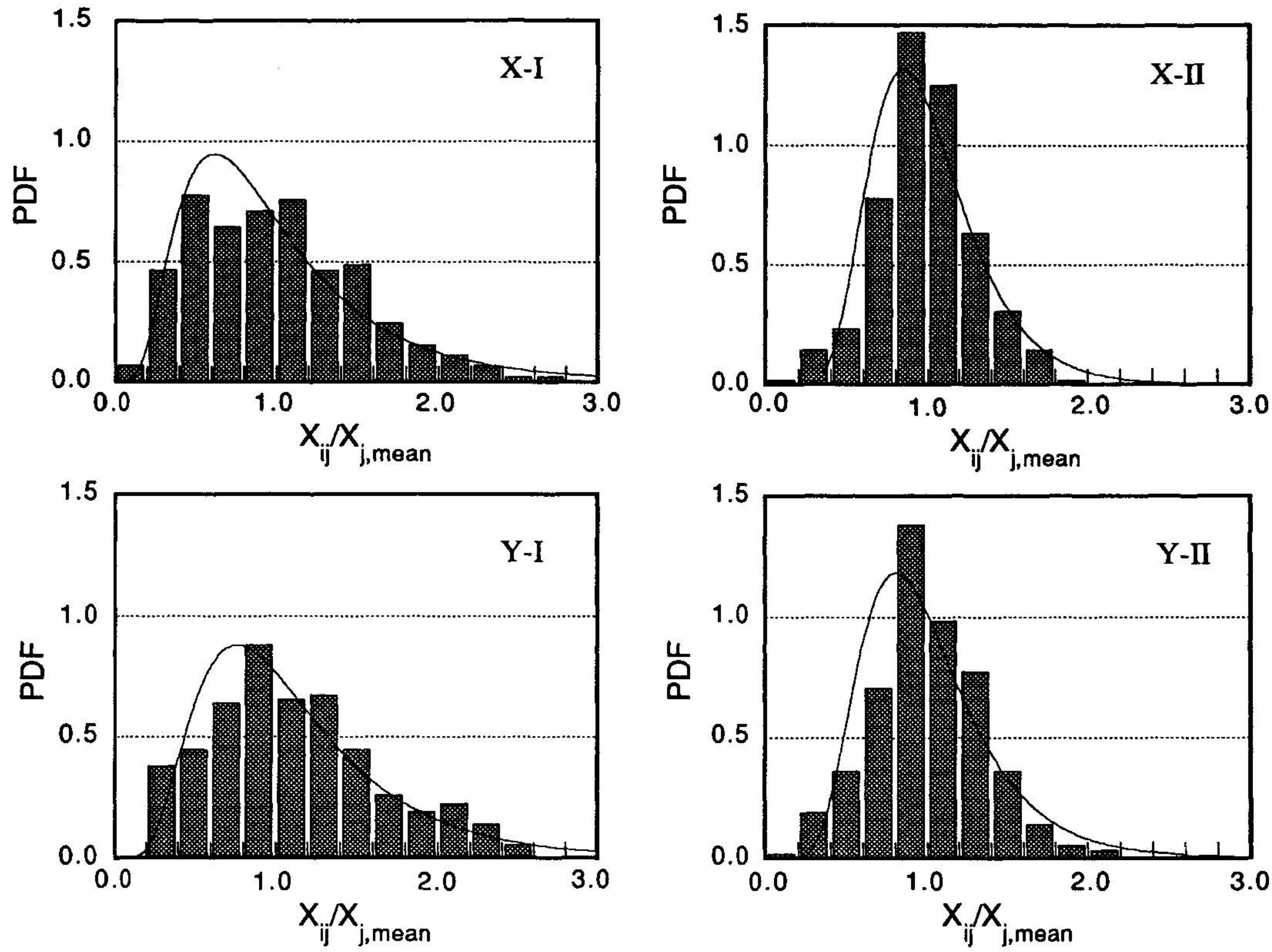

Fig.5 Probability Density Function of Perception

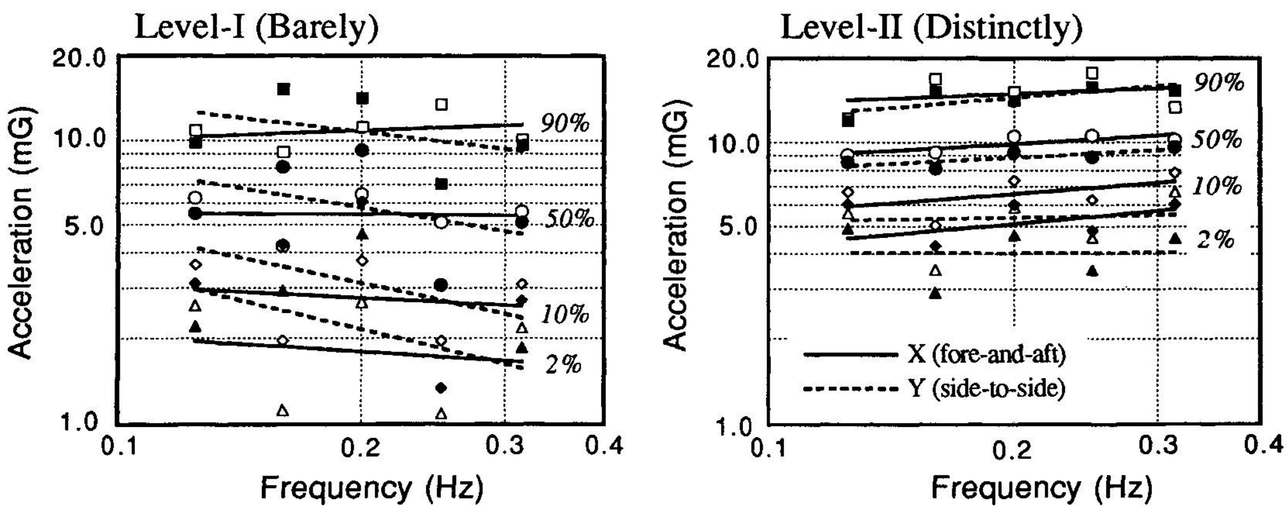

Fig.6 Percentile of Perception to Random Motion

Regression analyses were made on each percentile perception level in the logarithmic scale. Figure 6 shows the regressed percentile of perception of all cases.

The perception dispersion of Level I is rather larger than that of Level II. As the correlation coefficients between perceived acceleration and frequency are very low in

Level I, we examined the result of Level II only.

The side-to-side (Y direction) motions are rather more perceptible than the fore-and-aft (X direction) motions.

The gradient of regression lines are positive and the absolute value of the gradient is very small. The perception levels of random motions are almost constant to the frequency.

The regressed lines of percentiles are parallel to each other. The 50 percentile lines of Level II are nearly equal to 0.01 G.

4. COMPARISON WITH THE SINUSOIDAL MOTION

4.1 Perception of Sinusoidal Motion

The authors studied the perception thresholds of uniaxial, elliptical and circular sinusoidal motions to discuss the effect of the two dimensional motion in the same manner as presented in this paper[3]. We proposed the probabilistic model of perception dispersion. The results of the sinusoidal test are described as follows.

(1) The side-to-side (Y direction) motions are rather more perceptible than the fore-and-aft (X direction) motions in most cases.

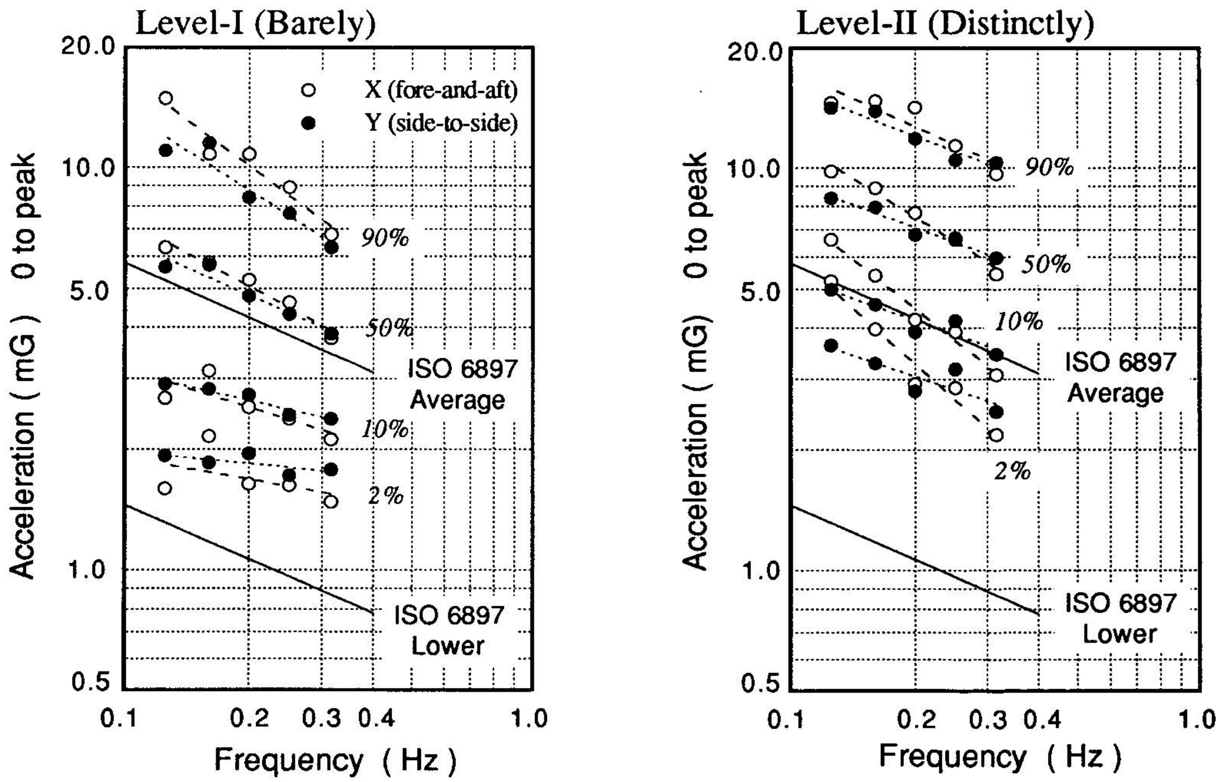

Fig.7 Percentile of Perception to Sinusoidal Motion

(2) The perceived accelerations of the uniaxial motions are almost the same as those for the elliptical and circular motions.

(3) According to the questionnaire studies, half the subjects could not distinguish between uniaxial and elliptical motion.

(4) The log-normal distribution fits the probability distribution model of perception threshold.

(5) The 50 percentile regression lines of Level I agreed approximately with the ISO average threshold line in all cases.

(6) The regression lines of Level II were approximately 20% higher than those of Level I in all cases.

The 2 - 90 percentile of perception thresholds of sinusoidal motion are shown in Figure 7.

4.2 Comparison with Sinusoidal Test

As the perception dispersion of Level I was too large, the 50 percentile lines of the perceived acceleration of random motion of Level II were compared with that of sinusoidal motion. Figure 8 gives the results of the comparison. The average threshold lines of the ISO 6897 are given in the figures for reference.

The 50 percentile thresholds (Level I) of sinusoidal motions agreed approximately with the ISO average threshold line.

The gradient of the regression lines for the sinusoidal motions are negative to the frequency.

On the other hand, the gradient of the regression lines for the perception levels of random motions are positive and almost constant to frequency. This may be due to the subjects' delay of response to vibrations in higher frequencies. The 50 percentile lines of Level II are nearly equal to 0.01G.

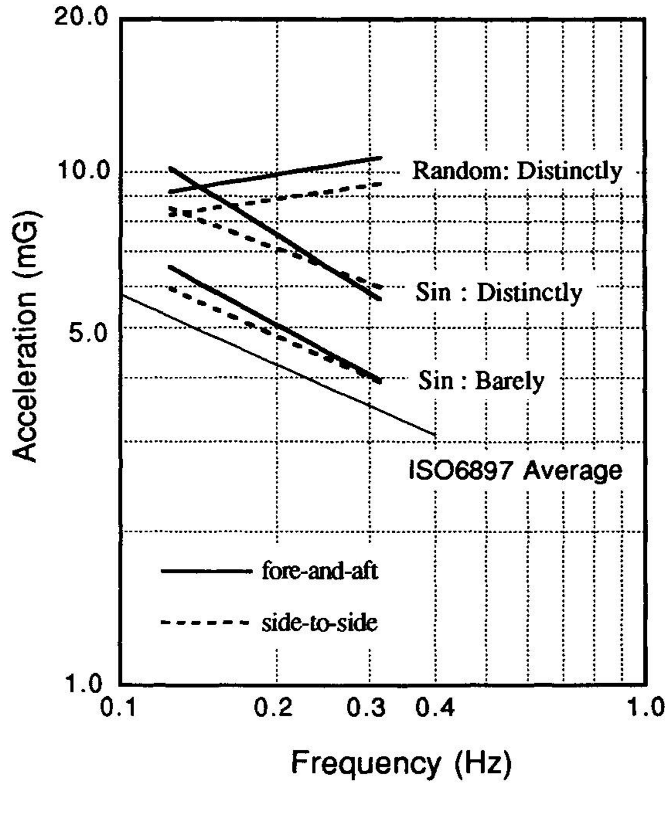

Fig.8 Comparison with Sinusoidal Test

5. SUMMARY AND CONCLUSIONS

The perception thresholds of the narrow-band random motions synthesized as the response of tall buildings to wind were obtained within a highly significant level in the frequency band 0.315 Hz to 0.125 Hz.

(1) The side-to-side (Y direction) motions are rather more perceptible than the fore-and-aft (X direction) motions.

(2) The log-normal distribution fits the probability distribution model of perception threshold.

(3) The perception dispersion of the barely perceptible level (Level I) is rather larger than that of the distinctly perceptible level (Level II).

(4) The perceived acceleration of Level II is almost constant to the frequency.

(5) The 50 percentile lines of Level II are nearly equal to 0.01 G.

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