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Evaluation of Habitability under Building Floor Vibration

Evaluation des vibrations d'un bâtiment habitable

Bewertung der Bewohnbarkeit bei Deckenschwingungen

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SUMMARY

AIJ guidelines (Architectural Institute of Japan) are applied to test the vibrations which occur on floors in buildings. The test is done to maintain the habitability of the building. By comparing the past research, six test curves for continuous vibrations and impact vibrations were prescribed to secure the efficiency of a floor subject to vibrations. The test curves were verified by the field data obtained from a floor motion test. Further, AIJ guidelines prescribe both an analytical method for the test of the vibration efficiency of the floor and the response test method made through experiments.

RESUME

Les directives AIJ (Société des Architectes du Japon) règlent les essais de vibrations à réaliser dans des bâtiments. L'essai doit permettre de s'assurer que le bâtiment est habitable. Sur la base de recherches antérieures, six courbes pour des vibrations continues et des vibrations sous l'effet de chocs sont appliquées pour contrôler l'efficacité d'un étage exposé à des vibrations. Les courbes ont été vérifiées avec les données obtenues à partir de l'essai d'un étage en mouvement. De plus les directives AIJ demandent à la fois une méthode analytique pour l'essai d'efficacité de l'étage et la réponse d'essais expérimentaux.

ZUSAMMENFASSUNG

Vom Japanischen Architektur-Institut (AIJ) wurden Richtlinien aufgestellt, um die Schwingungen von Geschossdecken zu bewerten und die Bewohnbarkeit von Gebäuden zu gewährleisten. Aufgrund bestehender Vergleichsdaten wurden für dauernd und intermittierend auftretende Schwingungen sechs Bewertungskurven aufgestellt, mit denen die Schwingungsanfälligkeit von Geschossdecken beurteilt werden kann. Diese Kurven wurden anhand von Testdaten schwingender Decken verifiziert. Für den Nachweis des Schwingungswiderstandes sehen die AIJ-Richtlinien eine analytische Methode und Versuche vor.

1. PARAMETER OF APPLICATION OF AIJ RECOMMENDATIONS

The guidelines of AIJ are applied to the evaluation of the vertical vibration which occurs in a building for the purpose of maintaining a high level of habitability. The evaluated floors are structural floors which will be used as residential spaces, office areas, and for other similar purposes. Floating floors and double decks are not taken into consideration for the evaluation made through the application of the guidelines of AIJ. The vibration to be evaluated is a vibration acting on a building in a vertical direction to the floor's surface. Under donsideration of the actual state of the floor vibration, the natural frequency of the floor is set within an area of 3 ~ 30HZ. The evaluation of the vibration is carried out through the verification of the frequency, amplitude, and damping ratio, all of which can be obtained from the response wave of the floor with the evaluation curves. Furthermore, the floor response wave can be gained from the condition of excitation which is assumed to be the origin of the tremor that is felt under normal conditions of floor use.

2. GUIDELINES FOR THE EVALUATION OF HABITABILITY

The AIJ guidelines for the habitability for floor vibrations evaluation are shown in Fig. 1. The evaluation curves are composed of six curves on the basis of the threshold value for the sensibility which is found in the curve of V-1.5. The standard for the evaluation of habitability is classified into the following three types in accordance with the differences of the vibration behavior.
Classification 1: Habitability evaluation for the floor which is subject to a continuous vibration or a vibration which is repeated intermittenly. : V-5 or less.
Classification 2: Habitability evaluation for the floor with low damping which is subject to an impact vibration. (Damping ratio is 3% or less): V-10 or less.

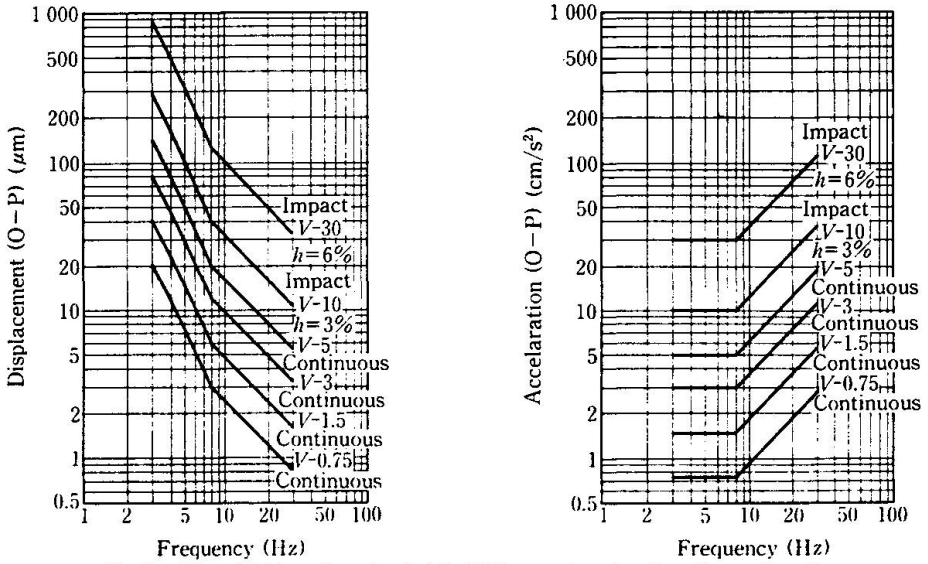

Fig.1 AIJ guidelines for the habitability evaluation for floor vibration.

Table 1:Classification of the habitability building floor vibration

Classification Bldg.Rm. \ Rank		Classifi.1 Rank I	Rank II	Rank III	Classifi.2 Rank III	Classifi.3 Rank III
Resi-dential	Living.rm. & bed.rm.	v-0.75	v-1.5	v-3	v-5	v-10
Office	Conference.rm. Guest.rm.	v-1.5	v-3	v-5	v-10	v-30
	Office.rm.	v-3	v-5	v-5 Approx.	v-10 Approx.	v-30 Approx.

Note: The "Rank" represents the habitability grade, with Rank II being a general average. Rank I is such level that habitability index is recommended to be smaller than this, and Rank III not to be larger than this.

Classification 3: Habitability evaluation for the floor which possesses high damping and is subject to an impact vibration. (Damping ratio is approximately 3-6%): V-30 or less.

Table 1 shows the classification for the habitability evaluation against vibrations and that for the efficiency evaluation of the building according to the manner in which it is used. The displacement amplitude of d, which corresponds to an arbitrary frequency of f in the evaluation curves shown in Fig. 1, can be obtained through the use of the following equation.

$$d = e^{\frac{c-a \cdot \log_e(f)}{b}}$$

where f: Frequency (HZ), d: Displacement amplitude (μ m)
The value for a, b, and c shall be taken from the coefficients indicated in Table-2. The relationship between the frequency and the acceleration (α) is obtained from the equation of $\alpha = d \times (2\pi f)^2$

Table 2: The coefficients value for evaluation curves

Frequency / Evaluation curve	$3 \leqq f \leqq 8$ Hz			$8 \leqq f \leqq 30$ Hz		
	a	b	c	a	b	c
V-30	2	1	8.94	1.265	1.316	8.92
V-10	2	1	7.84	1.265	1.316	7.47
V- 5	2	1	7.14	1.265	1.316	6.56
V- 3	2	1	6.64	1.265	1.316	5.88
V- 1.5	2	1	5.94	1.265	1.316	4.97
V-0.75	2	1	5.25	1.265	1.316	4.06

3. BACKGROUND FOR THE ESTABLISHMENT OF VIBRATION EVALUATION CRITERIA

In 1959, the "standard value for the building structural design to prevent vibration-induced damage (plan)" was deliberated on by AIJ. (Fig.-3). This standard value was established for the influence of vibrations caused by the facilities and equipment present in a building. The standard value is indicated by the B-curve, which was drawn through referring to the research which was carried out by Meister on the various vibrations which a human being can perceive. Moreover, as representative evaluation criteria for floor vibrations, there are such standards and guidelines as exist below.

3.1 GSA VIBRATION EVALUATION CRITERION Note 1

For this evaluation, the following equation which uses the frequency and displacement amplitude damping ratio based on the study made by Wiss & Parmelee as a parameter. Both of them are well known for the research on transient vibrations.

$$R = 5.08 \left(f \, Ao / h^{0.217}\right)^{0.205}$$

where R: Vibration sensibility rank, f: Frequency (HZ), Ao: Displacement amplitude (in), h: Damping ratio

3.2 CSA VIBRATION EVALUATION CRITERION Note 2

This evaluation criterion was established for the continuous vibration and the impact vibration on the basis of the standard made through the study by Allen & Rainer.
The evaluation of the impact vibration is made through the use of the preliminary amplitude, frequency and the damping ratio, all of which are caused by the pounding of feet on the floor surface. The vibration, which possesses the evaluation value of 3, 10 and 30 times the standard value for the continuous vibration, is evaluated as the impact vibration with the damping ratio of 3%, 6%, and 12%.

3.3 ISO 2631/2 GUIDELINE FOR THE EVALUATION OF HUMAN EXPOSURE TO WHOLE BODY VIBRATION

This guideline is applied to the evaluation of the reaction of the human body to vibrations which can be perceived within a frequency area of 1-80HZ. The evaluation coefficient is determined in accordance with the manner in which the floor is used.

3.4 MODIFIED MEISTER CURVE

The Meister curve is also called the Lenzen curve. Lenzen reformed the Meister curve due to the fact that a curve which is almost 10 times that of the Meister curve corresponds quite well to the curve which is used for the evaluation of the vibration caused by the foot steps of a single person. From the results of the aforementioned studies, it is found that the continuous vibration is generally more perceptible than the impact vibration. Although the vibration level on office floors is usually quite high when compared to residential spaces, the vibrations which occur on office floors are allowable. Since the measurements for the amplitude which was found in each of the studies were different, the amplitude was converted into a displacement amplitude (a peak value) for comparison.
It is quite difficult to make a simple comparison of the results obtained from each of the studies, due to the fact that there were differences in the continuing time for the vibrations, the testing method, the evaluation of the results and the purpose for which the floors are used. However, through the investigation of the correlation between each study's result, from the viewpoint of the evaluation of habitability regarding vibrations, the AIJ grade for the evaluation has been established. Fig. 4, in which the data regarding various floor vibrations recorded in Japan is plotted, shows an example of the habitability evaluation for floor vibrations made according to the AIJ guidelines. It is recognized that most of the data is plotted in the area under the V-5 curve and that each floor functions as a sound floor.

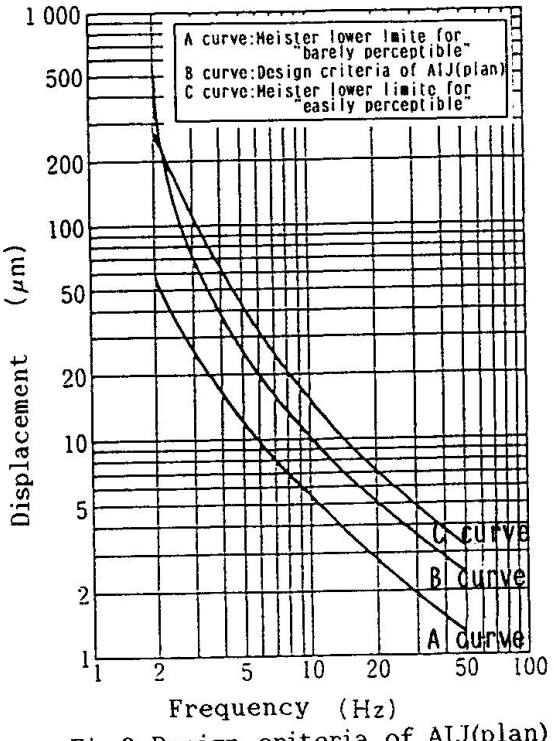

Fig.3 Design criteria of AIJ(plan)

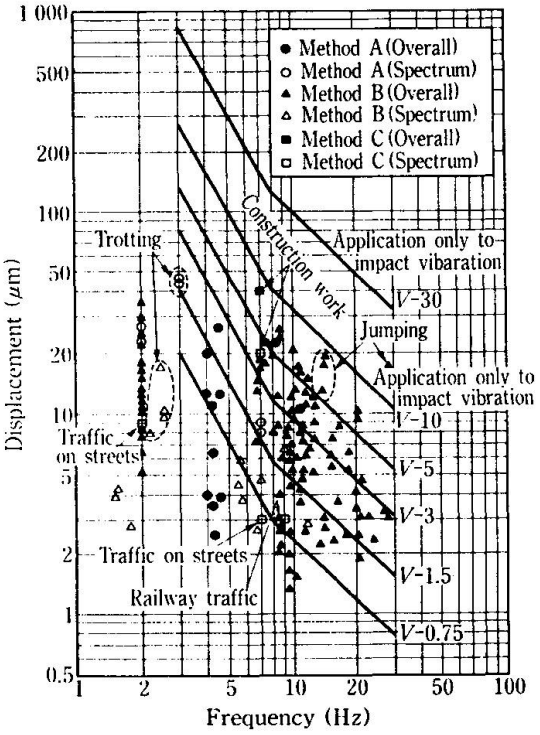

Fig.4: AIJ guidelines for the habitability evaluation for floor vibration.

4. METHOD FOR THE RESPONSE EVALUATION

The evaluation of the efficiency for the floor vibration is carried out through the use of the response wave to the excitation source which is sufficient to expose the objective floors. The AIJ guidelines prescribe the following three response evaluation methods.

a) A method based on the assumed excitation source (Response evaluation method A)
The analytical result of the response caused by the excitation external force which is assumed depending upon how the floor is to be used at the planning stage , is utilized in this method.

b) A method based on a vibration test (Response evaluation method B)
The floor response wave recorded in a vibration test is used. The vibration test in this case is carried out under consideration of an excitation source (the impact induced by one person walking and the impact induced by the footsteps of two people) which was assumed depending on the manner in which the floor is to be used when the building frame is completed.

c) A method based on an actual excitation source (Response evaluation method c)
The floor response wave recorded by the motion of an actual vibration source is used. This actual vibration source is considered to exert a vibrational influence on the floors from both the outside and the inside of the building, after the utilization of the floor begins.

Fig.-5 shows one of the examples of the load imposed upon the floor by a person walking, as well as the walker's response wave. The walk-induced external force acts on the floor repeatedly with the impact generated by the walker's foot steps, and the variation of the load caused by the movement of the walker's body. The period required for a single step is 0.5 sec. In the Fourier spectrum, it is seen that the walking step with 2HZ and the natural frequency of the floor are predominant. However, in order to evaluate the floor efficiency regarding the habitability through the use of a time history wave, the natural frequency of the floor and amplitude A are obtained and are plotted in the evaluation standard. Amplitude A can be obtained from the maximum amplitude 2A in the area where the natural frequency becomes predominant. This method seems to conform to the actual state for the floor vibration.

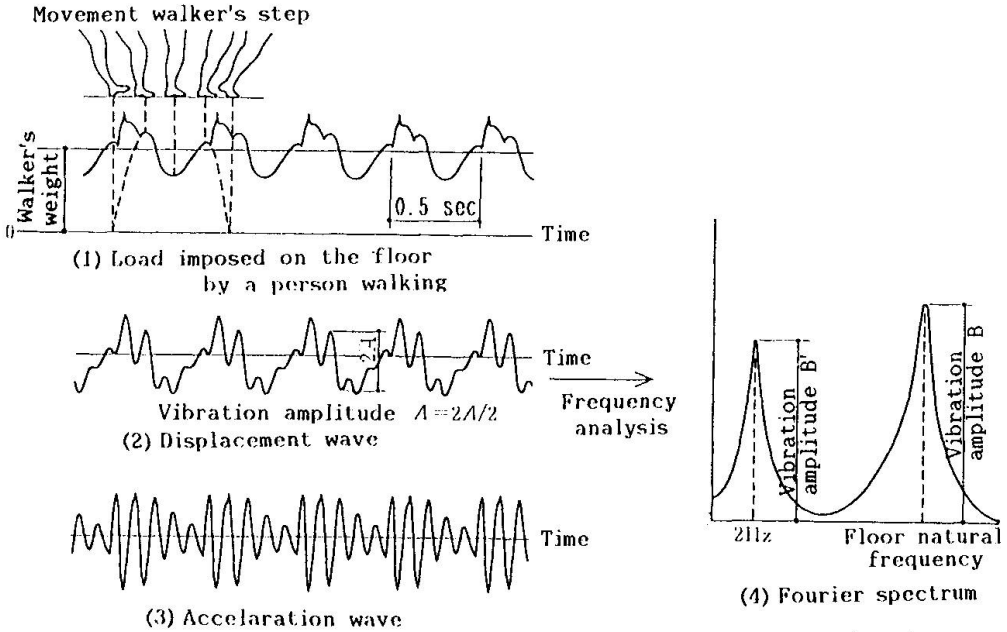

Fig.5: An example of the load imposed on the floor by a person walking and the walker response wave

5. SUBJECT FOR THE FUTURE

The guidelines of the AIJ aim to both clarify the vibration efficiency regarding habitability in a structural plan, and to offer data which is required for the judgment of the evaluation of the vibrational environment in existing facilities. At the same time, the guidelines intend to collect data which has been obtained through actual measurements of vibrations acting on floors of existing buildings in a standardized manner. When data can be accumulated through the application of the standardized method, which will be indicated in the guidelines, in the future, the confirmation and the review of the guidelines may be carried out. Consequently, the maintenance of the environment for the habitability against vibrations in buildings will be assured of attaining a high level.

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Note 1) GSA: General Services Administration Washington U.S.A.
Note 2) CSA: Canadian Standard Association