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AN EXPRESSION OF SEISMIC INTENSITY IN TERMS OF FREQUENCY-DEPENDENT PHYSICAL PARAMETERS

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SUMMARY

In aiming at the wider application of seismic intensity in earthquake engineering, a study to disclose its physical background has been examined formulating the experimental equation in terms of frequency-dependent physical parameters by which more correlative relation can be expected with observed seismic intensities over those existing in terms of peak acceleration, peak velocity, or duration of acceleration, etc. As the result, it has been found that component waves in the lower frequency contributes more effectively with increasing seismic intensities.

INTRODUCTION

The desired way of evaluating the seismic severity is doubtless to use the instrument data by strong motion seismographs. Their distribution density is, however, not high enough even in Japan to estimate exactly the severity of seismic input motion in a damaged area. Seismic intensity is known as a convenient substitute for the instrument data because it permits the dense survey after an earthquake. But, its physical meaning has not been well disclosed as yet. On account of this the effective use of seismic intensity is still less popular than expected. This study aims at a better expression of seismic intensity in a systematic manner in order to explore its physical background.

METHOD

Many researchers (for example, Refs. 1,2, and 3) have been discussing the seismic intensity with ground motion factors as peak acceleration or peak velocity, etc. Besides, they have defined many scales for measuring the destructiveness potential of earthquake ground motion, and have compared their scales with those of seismic intensity, i.e., the Modified Mercalli (MM) intensity, the MSK intensity, and the Japan Meteorological Agency (JMA) intensity. For example, Housner (Ref. 4) and Blume (Ref. 5) defined the spectral intensity and the engineering intensity, respectively, based on spectral response velocities. Espinoza and Arroyo (Ref. 6) proposed the instrumental intensity as the sum of the enveloped areas by seismic wave forms. Most of the proposed experimental equations assume the linear combination between seismic intensity (I) and another physical factor (X_I) as follows:

$$I = B \cdot X_I + C \quad (1)$$

where B and C are constant coefficients. But, such past studies have not found out the well correlated relation through which the physical background of seismic intensity is disclosed.

Fig. 1 shows an example of the average Fourier acceleration spectra calculated from the strong motion records at a station in Tokyo for intensities ranging in the JMA scale II to IV (almost equivalent to the MM scale III to VII). As is seen in this figure, the increasing rate of spectral amplitude in long periods becomes larger than that in short periods according as the intensity increases. The frequency-dependent characteristic of spectra, as is in this figure, is normal as far as recorded accelerograms are concerned. We also recognize the similar characteristic in Fig. 2 on the modeled Fourier acceleration spectra derived from the strong motion accelerograms recorded in the Western United States (Trifunac, Ref. 7). The authors, therefore, pay special attention to the frequency dependence of seismic intensity and try to develop a new relation between the intensity (I) and spectral amplitude of ground motions ($X(\omega)_I$) in the form of

$$I = \sum_{\omega} B(\omega)_I \cdot X(\omega)_I + C_I \quad (2),$$

where $B(\omega)_I$ is frequency-dependent coefficient determined at respective intensities. The above relation is a generalized one of the equation of (1) and is advanced in considering that the effective frequency band of ground motions changes with the seismic intensity.

ANALYSIS

The data for this analysis are from 76 earthquakes with magnitudes between 3.4 and 7.9 occurred in and around Japan and consist of horizontal accelerograms. Those are records obtained by SMAC type accelerograph and the specially designed digital type strong motion seismograph (Ref. 8), ranging from 0 to V in the JMA intensity scale. The seismic intensities reported at the respective JMA observatories were adopted as data to be examined. The intensity data is listed in Table 1, together with the relation between the JMA and the MM intensity scales.

As an example of the existing relations by the equation of (1), Fig. 3(a) presents plots of seismic intensity versus peak horizontal acceleration for all the used data. As shown in this figure, the correlation is not sufficient enough to evaluate the seismic intensity neither in higher level over IV in the JMA intensity scale which gives rise to disasters and is then important from the engineering point of view, nor in lower intensity level. It is therefore impossible to rationalize the physical background of seismic intensity using peak acceleration term. Some other physical factors as duration of acceleration, r.m.s. amplitude of acceleration, peak horizontal velocity, r.m.s. amplitude of velocity, and Housner's spectral intensity defined as the sum of response velocity spectra of period from 0.1 to 2.5 sec are examined in regard with the reported JMA intensity and compared in Fig. 4. This figure suggests it impossible to discriminate IV clearly from V , only based on the above relations by equation of (1) in which no frequency dependence is considered of seismic intensity.

To fix the frequency dependence of seismic intensity into an experimental equation, the authors recall the derived Fourier acceleration spectra. The frequency range between 0.125 (8 sec) to 10 (0.1 sec) Hz is divided into 6 bands of [0.125 (8 sec) to 0.2 (5 sec) Hz], [0.2 (5 sec) to 0.5 (2 sec) Hz], [0.5 (2 sec) to 1(1 sec) Hz], [1 (1 sec) to 2 (0.5 sec) Hz], [2 (0.5 sec) to 5 (0.2 sec) Hz], and [5 (0.2 sec) to 10 (0.1 sec) Hz], and the logarithms of maximum spectral amplitude in respective frequency bands are designated as the physical parameters $X(\omega)_I$ in the equation of (2). The data used is classified into 4 sets according to seismic intensities, followed to get the relation between the reported intensity and the logarithmic maximum spectra $X(\omega)_I$ in a concrete form of 4 experimental equations by the multi-regression analysis. The obtained frequency-dependent coefficient $B(\omega)_I$ is listed in Table 2. Fig. 3(b) presents plots of the reported JMA intensities versus the calculated intensities by the derived equations. The calculated intensities agree well with the reported ones for a full range of intensity between II and V. The correlation coefficient is 0.97 between them. As shown in Figs. 3 and 4, the newly obtained experimental equation considering the frequency-dependent physical parameters is most dominant in correlation with the reported intensity.

PHYSICAL BACKGROUND

It is of interest to explore the seismic intensity and its physical background by examining how the spectral amplitude of ground motions $X(\omega)_I$ contributes at respective frequencies. To evaluate the contribution of spectral amplitude to seismic intensity, the standard regression coefficient $\beta(\omega)_I$ defined in the following equation

$$\beta(\omega)_I = B(\omega)_I \cdot \sigma_{X(\omega)} / \sigma_I \qquad (3),$$

is introduced and calculated as shown in Fig. 5. Here $B(\omega)_I$ is the frequency-dependent coefficient in Table 2, and $\sigma_{X(\omega)}$ and σ_I are the standard deviations of spectral amplitude $X(\omega)$ and of seismic intensity, respectively. It is in the relationship that the more increases the value of $\beta(\omega)_I$, the more remarkably the spectral amplitude contributes to the seismic intensity. As the result of this figure, it is found that the shorter period component wave, particularly beneath 0.5 sec, is superior in low intensity level, on the contrary the longer period component wave is more effective in high intensity level over III. This fact means that seismic intensity dependence on physical parameter changes as well governed by peak acceleration or short period component wave when the seismic intensity is low, but in concordance with increasing seismic intensities it gradually shifts to be characterized by peak velocity. In other words, seismic intensity is highly frequency-dependent, and consequently, it is concluded better to express seismic intensity in using the relation by the equation of (2) than the equation of (1).

CONCLUDING REMARKS

If the physical meaning of seismic intensity could be clarified through research in which the intensity could be associated with seismic waves, more systematic way for effective use of the seismic intensity would be developed so as to understand the linked phenomena from an earthquake occurrence mechanism and wave propagation to structural damages. Namely, a lot of existing data stocks on seismic intensity would be more deeply interpreted in reinforcement with seismological approaches.

Out of the above expectation, we tried to explore the physical background of seismic intensity and constructed a group of experimental equations for estimating it. The group of equations could be one of the plausible expressions for understanding the physical background of seismic intensity. If it is the case, the application capability of seismic intensity as a fundamental measure in earthquake engineering is thereby sure to be developed.

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Table 1
Intensity Distribution of Used Data

MM INTENSITY SCALE	JMA IMTENSITY SCALE	NUMBER OF DATA
VIII	V	6
VII VI	IV	8
V	III	7
IV III	II	13
II	I	15
I	0	27
	TOTAL	76

Table 2
Frequency-Dependent Coefficients in Equation of (2)

frequency band in Hz (period range in sec) / Intensity classified	$B(\omega)_i$						C_i
	0.125-0.2 (8-5)	0.2-0.5 (5-2)	0.5-1 (2-1)	1-2 (1-0.5)	2-5 (0.5-0.2)	5-8 (0.2-0.125)	
0 ~ II	-0.298	-0.378	0.707	0	1.394	-0.043	0.079
I ~ III	-0.262	0.302	0	0.388	0.686	0.444	1.090
II ~ IV	-0.202	0.828	0	0.121	0.724	0.079	1.907
III ~ V	0.153	0	0.825	0.191	0.506	-0.408	2.697

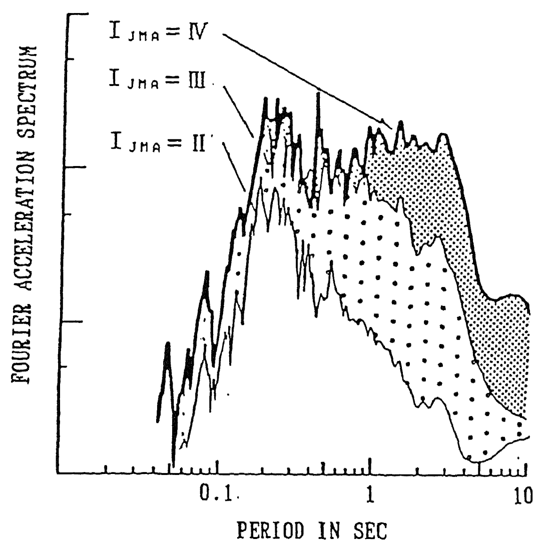

Fig.1 Average Fourier Acceleration Spectra at a Station in Tokyo.

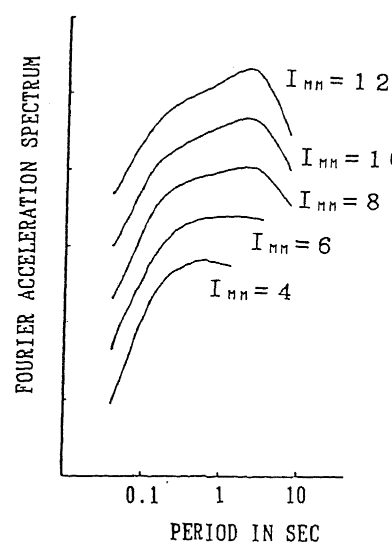

Fig.2 Modeled Fourier Acceleration Spectra in the Western United States[after Trifunac, Ref.7].

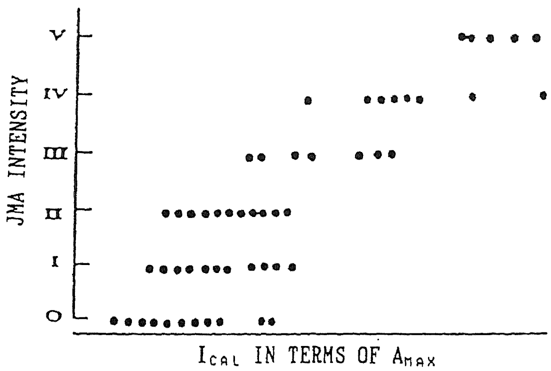

Fig.3(a) Plots of Reported Seismic Intensity vs. Peak Horizontal Acceleration.

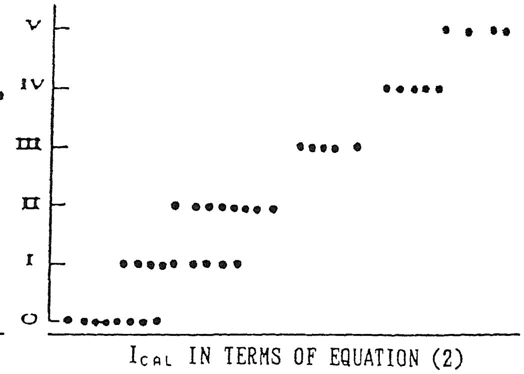

Fig.3(b) Plots of Reported Seismic Intensity vs. Calculated Intensity by Equation of (2).

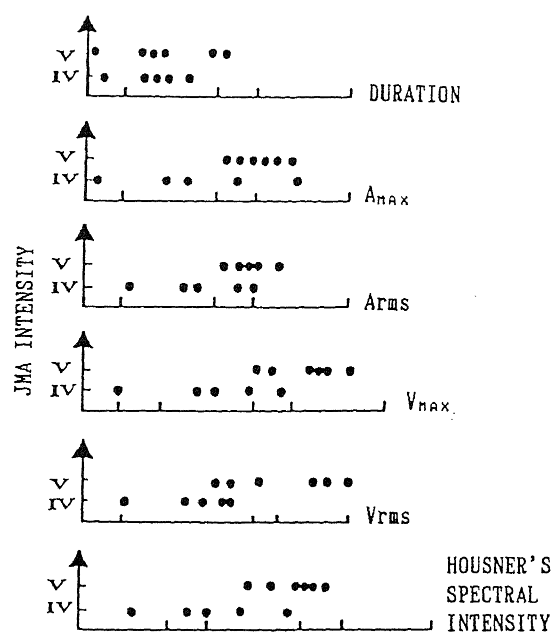

Fig.4 Plots of Reported Seismic Intensity vs. Ground Motion Factors.

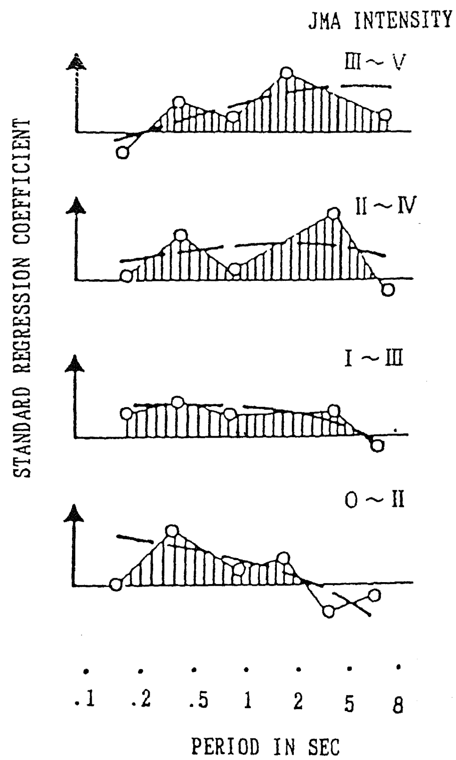

Fig.5 Contribution of Spectral Amplitude to Seismic Intensity.