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47. *On the Predominant Period of Earthquake Motions.*

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1. Introduction.

In the previous investigation it was ascertained that the similarity in the shapes of the acceleration-period and frequency-period curves of any earthquake motions, including destructive ones, and the frequency-period curve of microtremors at each spot is close.

It was also ascertained that the vibration characteristics of earthquake motions, including destructive ones, can be explained by the multiple reflection theory of elastic waves in the surface layer.[1]

Roughly speaking, from the results of the observational studies of earthquakes as well as microtremors, it is known that there are two kinds of grounds. That is to say, one type of ground has a predominant period of earthquake motions and another has more than two predominant periods.

The ground of the former type is considered to consist of a single layer, the semi-empirical formula for the seismic characteristics of ground having already been studied.[2]

The ground of the latter type is considered to consist of plural layers. From the previous theoretical studies on the vibration problem of the latter type of ground[3] it has been made clear that, in general, the spectrum of the earthquake motions of the plural layered ground is very irregular and the maximum value of the peak is not so large as in the case of the single layer, since the reflected as well as the refracted seismic waves at the various boundaries interfere complexly with one another.

In the present paper, the relation between the predominant periods

1) K. KANAI, "On the Spectrum of Strong Earthquake Motions", *Bull. Earthq. Res. Inst.*, **40** (1962), 71-90.

2) K. KANAI, "Semi-empirical Formula for the Seismic Characteristics of the Ground", ditto, **35** (1957), 309-325.

3) K. KANAI, "The Requisite Conditions for the Predominant Vibration of Ground", ditto, **35** (1957), 457-471.

of earthquake motions and the magnitude of earthquakes will be mainly investigated.

2. Single layer of ground.

The relation between the predominant period of earthquake motions and the magnitude of earthquake, M, at Kanda, Marunouchi, Aoyama and Hongô in Tokyo[4] and Sukegawa and Motoyama in Hitachi Mine area[5] is shown in Fig. 1. And in Table 1 the data of the earthquakes adopted here is listed.

It will be seen in Fig. 1 that when the magnitude of earthquake is larger than a certain value at any place the predominant period of earthquake motions takes an approximately constant value which is proper to each place, and when the magnitude of earthquake is lesser in

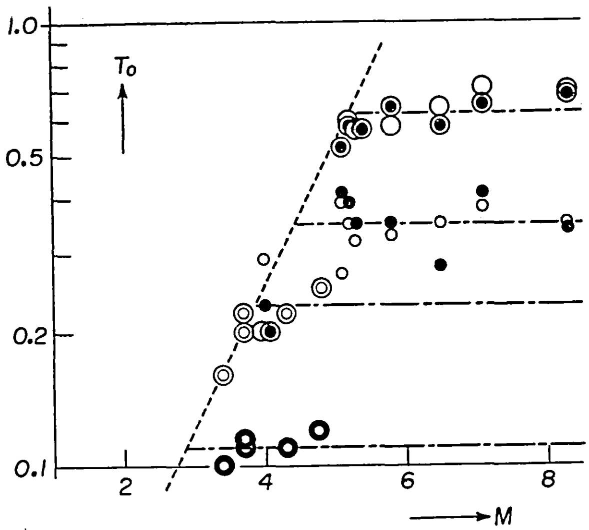

Fig. 1. The relation between the predominant period of earthquake motions and the magnitude of earthquake, M.

4) M. ISHIMOTO, "Etude préliminaire sur l'accélération des séismes", *Bull. Earthq. Res. Inst.*, **9** (1931), 159: **10** (1932), 171: **12** (1934), 234: **13** (1935), 592: **14** (1936), 240: **15** (1937), 536.

5) K. KANAI, K. OSADA and S. YOSHIZAWA, "Observational Study of Earthquake Motion in Depth of the Ground. IV", ditto, **31** (1953), 227.

Table 1. Data of the earthquakes.

Date	Epicenter		Epicentral distance (km)	Magnitude	Intensity	
	Latitude (°N)	Longitude (°E)				
Mar. 3, 1933	39.1	144.4	568	8.3	Japan M.A. scale	III
June 19, 1933	38.1	142.4	377	7.1		II
July 6, 1933	35.6	140.0	24	4.0		II
Oct. 9, 1933	35.5	139.0	73	5.1		II
Apr. 7, 1934	37.3	141.6	227	6.5		II
May 31, 1934	36.3	140.5	95	5.8		II
June 3, 1934	35.9	140.4	61	5.2		III
Sept. 1, 1934	36.2	140.0	58	5.3		II
					Period (sec)	Amplitude (micron)
Nov. 18, 1952	36.1	140.6	89	3.7	0.22	16
Nov. 19, 1952	36.1	140.3	82	3.7	0.20	15
Dec. 11, 1952	37.2	141.5	102	4.3	0.22	40
Dec. 16, 1952	36.1	139.9	100	3.4	0.10	6
Feb. 3, 1953	35.5	140.3	145	4.8	0.27	70

value the period mentioned above becomes smaller with the decrease of the magnitude.

Next, we shall try to explain the fact mentioned above analytically.

The usual meaning of the term "earthquake motions" is the wave motions at ground surface transmitted from the earthquake origin through the earth's crust. If $B(T)$ and $G(T)$ represent respectively the vibrational characteristics of the seismic waves in bed rock and of the ground at an observation station, the spectrum of the earthquake motions at the station may be written as follows:

$$u=f[B(T),\, G(T)]\,. \tag{1}$$

It has already been found that there exists a systematic relation between the maximum values of spectra at the depth of the earth and the periods corresponding to the above-mentioned values. The following empirical formula for this has been obtained from the statistical treatment of the results of spectral analysis of a large number of seismograms.[6] That is,

6) K. KANAI and S. YOSHIZAWA, "The Amplitude and the Period of Earthquake Motions. II", *Bull. Earthq. Res. Inst.*, **36** (1958), 275-293.

$$A_{m.s}=53T_m^{2.56}\,, \tag{2}$$

in which $A_{m.s}$ and T_m represent respectively the maximum value of displacement spectrum at the 100 km hypocentral distance in micron and the corresponding period in sec. On the other hand, the vibration characteristics of ground may be written as follows:[7]

$$G(T)=1+\frac{1}{\sqrt{\left[\frac{1+\alpha}{1-\alpha}\left\{1-\left(\frac{T}{T_0}\right)^2\right\}\right]^2+\left\{\frac{0.3}{\sqrt{T_0}}\left(\frac{T}{T_0}\right)\right\}^2}}\,, \tag{3}$$

in which T, T_0 and α represent respectively the period of seismic waves, the natural period of ground and the impedance ratio of the ground to the bed rock.

Roughly speaking, it is somewhat natural to assume that, when T_m is larger than T_0, the period corresponding to the maximum acceleration at the ground surface approximately coincides with T_0 which is proper to each place, on the other hand, when T_m is smaller than T_0 the period mentioned above nearly agrees with T_m which depends on the magnitude of earthquake.

As a first approximation and with the foregoing considerations in mind, the lower limit of the magnitude of earthquake, in which the predominant period takes a proper value to each place, may be written as follows:

$$M=\log_{10}\left[\{53T_m^{2.56}\}\times\left\{1+\frac{\sqrt{T_0}}{0.3}\right\}\times\{2800\}\right] \tag{4}$$

and

$$T_m=T_0\,, \tag{5}$$

in which the first, second and third terms of the right-hand side of (4) represent respectively the maximum amplitude in a bed rock, the resonance amplification of the ground and the magnification constant of the Wood-Anderson seismograph. The result calculated by (4) and (5) is shown as the dotted line in Fig. 1. The results written in Fig. 1 tell us that the problem of the predominant period of actual earthquake motions may, to a considerable extent, be explained by the assumptions adopted here.

At any rate, from the present investigation, it was ascertained that

7) K. KANAI, "An Empirical Formula for the Spectrum of Strong Earthquake Motions", *Bull. Earthq. Res. Inst.*, **39** (1961) 85-95.

the predominant period of earthquake motions takes an approximately constant value at each place when the magnitude of an earthquake is larger than about 3–6, and the value nearly coincides with not only the natural period of a ground but also the maximum frequent period of microtremors at the respective place.

3. Plural layers of ground.

It is natural to consider that the type of ground which has more than two obvious predominant periods of earthquake motions consists of plural layers.

To be precise, every earthquake motion at a place of the above-mentioned type of ground has different values of the predominant periods,

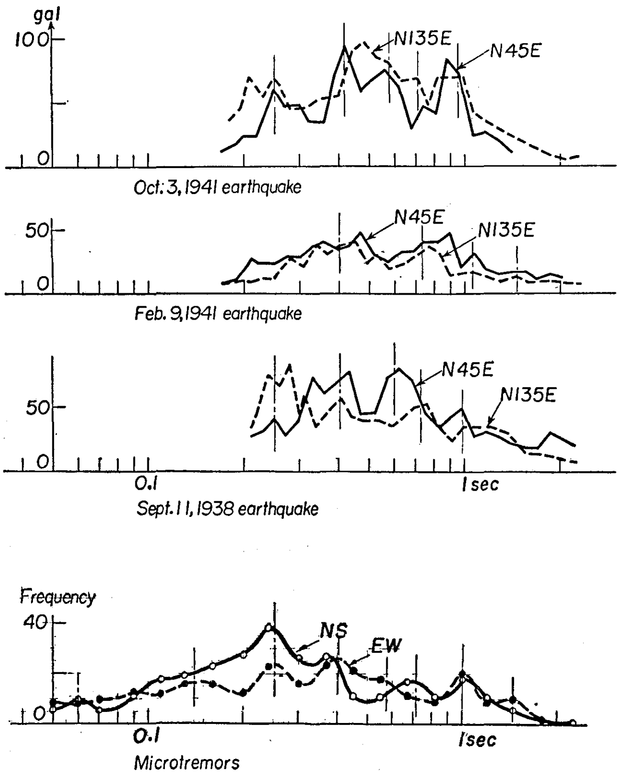

Fig. 2. The relation between the acceleration spectra of three earthquakes observed at Ferndale, California, U. S. A. and the period distribution curve of microtremors at the same place. The vertical strips of chain line represent the maximum frequent periods of microtremors.

because the reflected as well as the refracted seismic waves at the various boundaries interfere complexly with one another.

Nevertheless, in general, the predominant periods of an earthquake motion are more or less connected with the values of the maximum frequent periods of microtemors at the respective places. Furthermore, statistically speaking, it can be said that the predominant periods of earthquake motions may be presumed by the maximum frequent periods of microtremors at the respective places. As an example, the relation between the acceleration spectra of three earthquakes observed at Ferndale, California, U. S. A. and the period distribution curve of microtremors at the same place is shown in Fig. 2. In Fig. 2 the vertical strips of chain line represent the maximum frequent periods of microtremors.

4. Conclusion.

From the present investigations, it was ascertained that the predominant period of earthquake motions at a ground which is considered to consist of a single layer takes on an approximately constant value at each place when the magnitude of an earthquake is larger than about 3-6 and the problem of the predominant periods of earthquake motions at a ground of plural layers is considerably complicated.

In conclusion, the author wishes to express his thanks to Miss S. Yoshizawa who assisted him in preparing this paper.

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47. 地震動の卓越周期について

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地震動の卓越周期は，工学的に問題になる M が6ぐらいより大きい地震については，各土地で固有の値となり，その値は，各土地の常時微動の頻度曲線の山になる周期と一致し，その地盤の固有周期にほぼ等しい．

地震動の卓越周期が2つ以上あらわれる土地では，それらの周期は，地震ごとに変る場合が多いが，常時微動の頻度曲線にあらわれる数多くの山になる周期のうちのいずれかに一致するものである．このような場合の，工学的に考慮すべき地震動の卓越する周期としては，あるひろがりを考えねばならないが，その周期範囲は，各土地固有のものであり，常時微動の頻度曲線からでも推定できるものである．