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38. *Seismic Characteristics in Ground of Mountainous Formation. (Observation of the After Shocks of the Kita Mino Earthquake.)*

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1. Introduction

It is well known that earthquake motions depend greatly on the seismic characteristics of ground and damage to buildings and other constructions caused by earthquakes have a considerably close relation to the ground formations on which they are built.[1] Almost all of the past investigations which had been carried out from the present standpoints were made by the phenomena in plain lands.

The Kita Mino earthquake of August 19, 1961 occurred in land of mountaineous formation. A general description of it is presented by other researchers in the present Bulletin.

In order to investigate the relation among the earthquake motions, the seismic characteristics of ground in land of mountaineous formation and damage to various kinds of construction, we made an observation of the after shocks of the present earthquake in the epicentral area during the period from August 26 to August 29.

2. Observation of the after shocks

The observation of the after shocks was made by two seismographs of the inverted pendulum type with a smoked paper recording system. The characteristic curves of the two seismographs are shown in Fig. 2. The positions of the four temporary seismograph stations located on various types of ground are represented in Fig. 3. The standard station is represented by No. 1 in Fig. 3 and the simultaneous observations of

1) K. KANAI, "Semi-empirical Formula for the Seismic Characteristics of the Ground," *Bull. Earthq. Res. Inst.*, **35** (1957), 309, foot-note 1)-4).

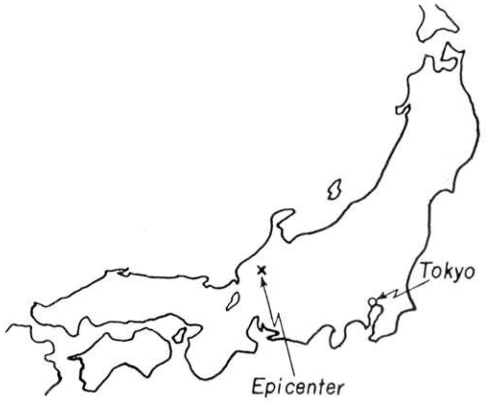

Fig. 1. Epicenter of the Kita Mino earthquake.

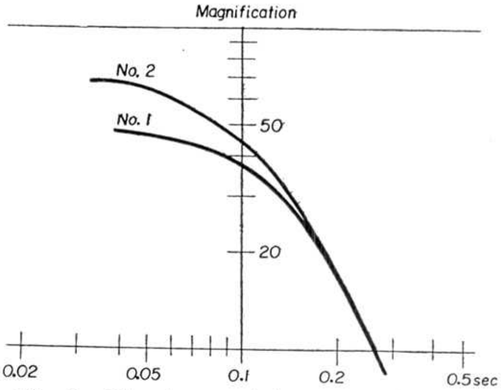

Fig. 2. The characteristic curves of the two seismographs.

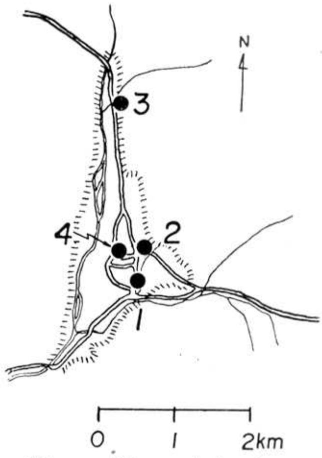

Fig. 3. The positions of the four temporary seismograph stations.

(1): Hakusankan, Shimozaisho, Itoshiro, Shiratori-machi;

(2): Taniya-ryokan, Nakazaisho, Itoshiro, Shiratori-machi;

(3): H. Itoshiro, Kamizaisho, Itoshiro, Shiratori-machi;

(4): J. Uemura, Nakazaisho, Itoshiro, Shiratori-machi;

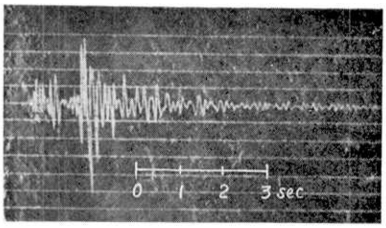

Fig. 4. Representative record of the after-shock observed at the station, No. 4, Aug. 27, 1961. Original×4.5.

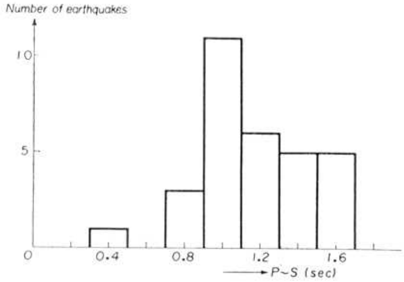

Fig. 5. Relation between the duration of preliminary tremors, so-called P-S time, and number of earthquakes observed at the standard station.

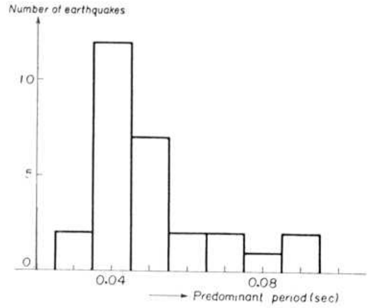

Fig. 6-1. Relation between the predominant periods of the preliminary tremors of after shocks and number of them observed at the standard station.

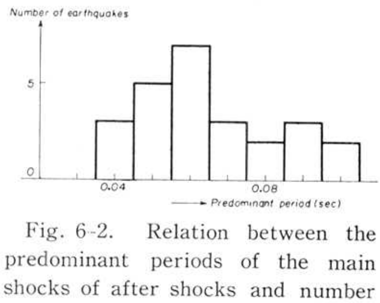

Fig. 6-2. Relation between the predominant periods of the main shocks of after shocks and number of them observed at the standard station.

Table 1. The results of observations of after-shocks of the Kita Mino earthquake.

Date	Time	Station	P-S time (sec)	Predominant period (sec)		Max. displ. (μ)	Max. accel. (gal)
				P	S		
8.25	15.29	1	1.2	0.044	0.052		
	15.37	〃	1.1	0.043	0.064		
	17.21	〃	1.1	0.050	0.059		
	19.06	〃	1.1	0.044	0.074		
8.26	7.22	1	—	0.071	0.039		
	9.43	〃	1.2	0.070	0.15		
	10.19	〃	0.92	0.081	0.093		
	12.00	〃	0.90	0.040	0.056		
	13.47	〃	1.6	0.053	0.073		
	15.59	〃	1.6	0.029	0.042		
	21.22	〃	1.4	0.13	0.12		
	22.34	〃	1.5	0.053	0.12		
	23.41	〃	1.6	0.055	0.062		
8.27	0.13	1	1.0	0.051	0.15		
	4.56	〃	1.5	0.053	0.11		
	13.05	〃	1.6	0.048	0.084	20	37
	〃	4	1.3	0.070	0.14	21	10
	14.21	1	—	0.042	0.088	3.9	3.9
	〃	4	1.2	0.088	0.11	3.5	2.1
	14.22	1	1.4	0.042	0.088	11	10
	〃	4	1.4	0.11	0.11	10	4.2
	14.37	1	1.0	0.042	0.074	6.0	2.5
	〃	4	1.1	0.088	0.13	21	6.5
	16.05	1	1.2	0.090	0.10	36	13
	〃	4	1.1	0.090	0.15	58	15
	19.26	1	0.97	0.042	0.050	—	—
	〃	2	2.3	—	—	—	—
8.28	2.32	1	0.46	0.025	0.048	—	—
	〃	2	0.53	—	—	—	—
	2.52	1	1.3	0.043	0.12	39	12
	〃	2	1.4	0.088	0.13	31	5.9
	11.32	1	1.7	0.050	0.097	29	9.0
	〃	2	1.6	0.070	0.10	12	8.7
	16.17	1	0.88	0.045	0.094	13	85
	〃	2	0.84	0.090	0.14	14	21
	16.22	1	0.84	0.092	0.11	63	15
	〃	2	0.88	0.092	0.16	49	6.9
	20.22	1	1.1	0.062	0.059	26	13
	〃	3	0.97	0.067	0.10	20	17
	21.31	1	1.0	—	0.044	3.5	—
	〃	3	1.1	0.079	0.10	—	—
8.29	0.49	1	1.2	0.046	0.046	6.8	13
	〃	3	1.0	0.10	0.14	15	15
	2.13	1	1.3	—	—	2.4	5.2
	〃	3	1.3	0.084	0.10	8.4	6.8
	9.31	1	1.1	0.044	0.052	4.0	8.5
	〃	3	—	0.084	0.10	6.0	8.4
	9.34	1	0.97	0.041	0.059	—	—
	〃	3	0.97	0.070	0.14	—	—

the after shocks were made between the standard station, No. 1, and each of the other three stations, Nos. 2, 3, 4, successively.

During 5 days, we observed 32 after-shocks and the data concerning them are listed in Table 1. The representative record obtained on the mountaineous formation of the ground is illustrated in Fig. 4.

Fig. 5 shows the relation between the duration of preliminary tremors, so-called P-S time, and the number of earthquakes observed at the standard station. From Fig. 5, it will be concluded that the after shocks observed originated several km away from the temporary seismograph stations because the P-S times of the after shocks ranged from 1 to 1.5 seconds.

The relations between the predominant periods of the preliminary tremors as well as the main shocks and the number of after shocks observed at the standard station are shown in Fig. 6. It will be seen from Fig. 6 that the predominant periods of the preliminary tremors and the main shocks of earthquakes take about 0.4 sec and 0.6 sec, respectively. Consequently, it may be concluded that the predominant periods of about 0.4 sec and 0.6 sec mean the natural periods of the ground, on which the standard station is located, caused by dilatational waves and distortional waves, respectively, because it may be considered that the the ratio of the two predominant periods mentioned above is approximately equal to the ratio of the velocities of the dilatational waves and distortional waves in the ground.

The relations between the maximum displacements as well as the maximum accelerations and the predominant periods of the after shocks observed at the four temporary seismograph stations are shown in Fig. 7.

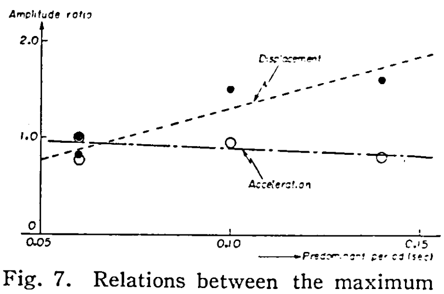

Fig. 7. Relations between the maximum displacements and the maximum accelerations and the predominant periods of the after shocks observed at the four temporary seismograph stations.

At any rate, it is ascertained from Fig. 7 that the larger the predominant period of the mountaineous formation of ground is (the softer or thicker the ground is), the larger the displacement of the earthquake motions is, on the contrary, the sense of acceleration is rather the reverse.

3. Application of an empirical formula for the strong earthquake-motions spectrum.

The acceleration spectrum of earthquake motions on bed rock may be adopted as a schematic view as shown in Fig. 8 which is estimated from the so numerous data of more than fifteen years observations at a 300 meter depth in the Hitachi Mine, Japan.

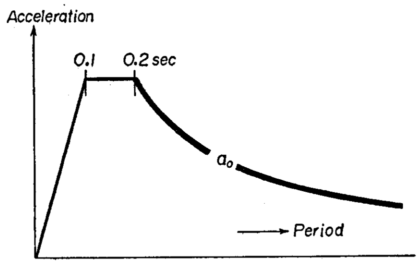

Fig. 8. Schematic view of the acceleration spectrum of earthquake motions on bed rock.

The empirical formula concerning the acceleration spectrum on bed rock represented by a_0 in Fig. 8 and that on ground surface, a, may be written as follows[2):

$$a_0=\frac{10^{0.61\,M-1.73\log R+0.13}}{T}, \tag{1}$$

$$a=a_0\left[1+\frac{1}{\sqrt{\left[\frac{1+\alpha}{1-\alpha}\left\{1-\left(\frac{T}{T_0}\right)^2\right\}\right]^2+\left[\frac{0.3}{\sqrt{T_0}}\left(\frac{T}{T_0}\right)\right]^2}}\right], \tag{2}$$

in which, M=magnitude, R=hypocentral distance, α=impedance ratio of ground to bed rock, T=period of waves, T_0=predominant period of ground. From (1) and (2), the displacement spectra of earthquake motions on bed rock and ground surface can be written as follows:

$$\text{bed rock}; \quad u_0=a_0\left(\frac{T}{2\pi}\right)^2, \tag{3}$$

$$\text{ground surface}; \quad u=a\left(\frac{T}{2\pi}\right)^2. \tag{4}$$

As the first step of the present investigation, we assume $M=7$ and $R=50$ km and adopt $T_0=0.1$ sec which is the average value of the predominant periods of ground in the epicentral area of the Kita Mino earthquake; substituting these values in (1)-(4), we obtained four kinds of spectra, that is; accelerations and displacements on bed rock and ground surface, as shown in Fig. 9.

2) K. KANAI, "An Empirical Formula for the Spectrum of Strong Earthquake Motions," *Bull. Earthq. Res. Inst.*, **39** (1961), 88.

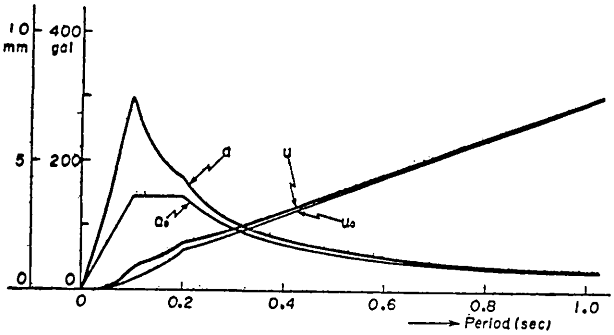

Fig. 9. The calculated acceleration and displacement spectra on bed rock and on ground surface.

Next, the calculated results of behaviour of simplified structures to earthquake motions having the characteristics shown in Fig. 9 will be compared with the effects of the Kita Mino earthquake on various kinds of actural structures.

(i) The case of the deflection of old-Japenese-style wooden houses.

The inclination, θ, of the one mass system of the fraction of critical damping, h, and of the height of the centre of gravity, H, under the condition of resonance with earthquake motions, u, may be expressed as follows:

$$\theta=\frac{u}{2hH} \tag{5}$$

The results of numerical calculations using (5) and Fig. 9 in the cases where $H=500$ cm and $h=0.05$, 0.1 for respective values of u corresponding to the natural periods of the houses, $T_0=0.1$, 0.3, 0.6 and 1 sec, are shown in Table 2. In general, the old-Japanese-style wooden house shall be partially damaged with about 1/30 radian inclination and collapses completely with about 1/15.

Table 2. The calculated values of inclination in wooden houses.

h	T_0			
	0.1	0.3	0.6	1.0
0.05	1/670	1/210	1/110	1/70
0.10	1/1300	1/420	1/220	1/140

The fact in which there was scarcely any damage to wooden dwellings except that caused by earth flows or land slides, at the time of the present earthquake[3] agrees with the result of the present investigation in which all of the values in Table 2 are less than 1/30.

(ii) The case of shearing vibration in solid-like structures.

The displacement of shearing vibrations in solid-like structures, U, caused by earthquake motions of displacement, u, may be written as follows:

$$|U|=\frac{|u|\cos kz}{\sqrt{P^2+Q^2}} \tag{6}$$

where, z=axis, $k=2\pi/VT$, V=velocity of shear waves, T=period of waves, P and Q are terms depending mainly on the natural period and the damping factor of the structure, respectively. Accordingly, the maximum strain in a solid-like structure under the condition of resonance caused by earthquake motions of displacement, u, can be written as follows:

$$\frac{\partial U}{\partial Z}=\frac{2\pi u}{2h'VT_0} \tag{7}$$

in which, h' and T represent the apparent damping coefficient and the natural period of structure, respectively. The results of the numerical calculations using (7) and Fig. 9 in the cases, where V=2 km/sec and h'=0.05, 0.1 for respective values of u corresponded to T_0=0.1, 0.3, 0.6, 1.0 sec, respectively, are shown in Table 3.

The fact that the damage to good and rough construction works of concrete structures caused by the present earthquake was scarce and slight[4], respectively, can be interpreted by the present results in which

Table 3. The calculated values of the strain on rigid constructions.

h'	T_0			
	0.1	0.3	0.6	1.0
0.05	2×10^{-4}	2× 〃	2× 〃	2× 〃
0.10	1×10^{-4}	1× 〃	1× 〃	1× 〃

3) Y. OSAWA, "On the Damage to Buildings during the Kita Mino Earthquake of August 19, 1961," *Bull. Earthq. Res. Inst.*, **39** (1961), 869-872.

4) T. OKUBO, "Damage to Public Works Structures caused by the Kita Mino Earthquake", *The Annual Meeting on Earthq. Engg.*, Japan Soc. Civil Engineers, Oct. 18, 1961.

the values in Table 3 correspond approximately to the strength of weak concrete.

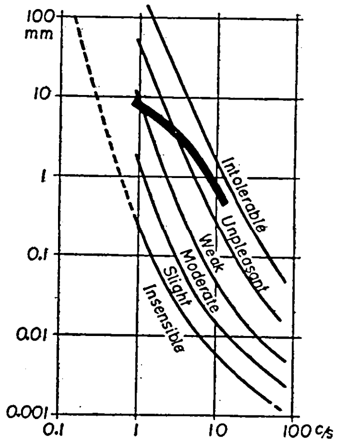

Fig. 10. Relation among the amplitude, the frequency of harmonic vibrations and human susceptibility.

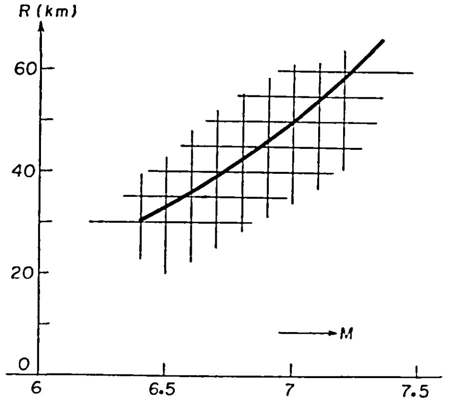

Fig. 11. The values of magnitude (M) and hypoceutral distance (R) on the curve satisfy the actual phenomena caused by Kita Mino earthquake.

(iii) Human senses.

A graph[5] of the relation among the amplitude, the frequency of the harmonic vibrations and human susceptibility is reproduced in Fig. 10. The fat line in Fig. 10 represents the amplitude of the earthquake motion at the ground surface as shown in Fig. 9. The fat line in Fig. 10 tells us that the result obtained by the empirical formula, (4), agrees with the human experience at the time of the Kita Mino earthquake[6] when the consideration that the human susceptibility to shocks is lower than to harmonic motions[7] is taken into account.

(iv) Partial conclusion.

From the present investigations, it can be said that the facts of the effects to the actual structures as well as to humans caused by the Kita Mino earthquake were thoroughly interpreted by the results of the numerical calculations by using the empirical formula concerned with strong earthquake-motion spectrum.

As a further consideration, though it has been outlined in the above discussions utilizing the

5) M. ŌSHIMA, "Vibration and the Human Being", *Rep. Steel Labour Health*, Vol. 2, No. **3-4** (1953), 30, (in Japanese).

6) F. KISHINOUYE and I. ONDA, "On the Kita Mino earthquake", *Bull. Earthq. Res. Inst.*, **39** (1961), 857-868.

7) F. KISHINOUYE, "Human Susceptibility to Shock Vibrations of the Ground", *Bull. Earthq. Res. Inst.*, **33** (1955), 207-210.

results of numerical calculations under the assumptions of $M=7$ and $R-50$ km, the same results will be obtained when the values on the curve in Fig. 11, calculated from (1) are used. In other words, the interpretations carried out in this section agree rather closely with every case using the values of M and R as shown in Fig. 11, furthermore, in the present stage of investigations concerning the magnitude as well as the hypocenter of the Kita Mino earthquake, the values of M and R, ranging in Fig. 11 may be considered as plausible.

4. Conclusion

From the present investigations, it is ascertained that the predominant period of the short period of earthquake motions in ground of mountaineous formation corresponds to the natural period of a thin weathered layer of it.

Furthermore, from the present investigations, it is still further verified that the empirical formula for the spectrum of strong earthquake motions is applicable to destructive earthquakes[8]. In conclusion, the authors are much obliged to Miss S. Yoshizawa who has assisted them in preparing this paper.

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38. 山地地盤の振動性状

(北美濃地震の余震観測)

地震研究所 金井清 / 長田甲斐男

北美濃地震(1961年8月19日14時33分)の余震の2カ所3組における同時比較観測の結果，山地においても，また，卓越周期の長い地盤ほど，最大変位は明かに大きく，逆に，最大加速度はやや小さいことがわかつた．そして，山地における地震動の短周期の卓越振動は，薄い風化層の増巾作用によるものと考えられる．

本地震で，(i)木造家屋には，直接，地震動による被害はなく，(ii)コンクリート構造物のうち古くなつたりして粗雑なものには多少の被害があり，(iii)人体には強く感じた，などの事実は，本地震のマグニチュードと震源距離が第11図の曲線の中に含まれる値であれば，強震動のスペクトラムに関する実験式を使つた計算で一応の説明がついた．言い換えると，前述の実験式は北美濃地震の地震動にもあてはまることになつた．

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8) K. KANAI, "An Empirical Formula for the Spectrum of Strong Earthquake Motions", *Proc. II World Conf. Earthq. Engg.*, (1960), 1541.

I. MURAMATU and T. YABASHI, "The Seismic Intensity at a Certain Dam Site", *ditto*, 1593.