

## 23. Earthquake Observations in Kawasaki and Turumi Areas and the Seismic Qualities of the Ground.

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### 1. Introduction

It is a well known fact among seismologists that different seismograms of the same earthquake are obtained<sup>1)</sup> when seismometers are distributed in various places with different underground structures. This difference in the underground structure is considered to be closely related to the difference of damage severity when these places are attacked by a great earthquake.

According to investigations made soon after a great earthquake, it has each time been demonstrated that seismic effects on buildings vary greatly with the nature of the ground under them<sup>2)</sup>. It has been found that those on mud-land or watersoaked unconsolidated silt are shaken many times as severely as those on solid rock. In order to explain the relationship that may exist between the characteristic nature of the ground and the damage severity due to earthquake shocks, numerous studies have been made by many authorities since the beginning of modern seismology. It was quite natural that such an investigation should attract the keen attention of seismologists in Japan which has repeatedly suffered so much from great earthquakes within historic times, including among others the great Kwanto Earthquake of 1923 that caused catastrophic destructions in the Tokyo and Yokohama districts and which, according to the Byerly's<sup>3)</sup> compounded scale, ranks as the greatest shock ever experienced by man in modern history.

1) R. TAKAHASHI and K. HIRANO, *Bull. Earthq. Res. Inst.*, **19** (1941), 534.

2) S. SASSA et al., *Bull. Disaster Prevention Res. Inst.*, **2** (1949), 1-33.

T. MINAKAMI, *Bull. Earthq. Res. Inst.*, **24** (1946), 19.

S. MIYAMURA, *Bull. Earthq. Res. Inst.*, **24** (1946), 99.

S. OMOTE and S. MIYAMURA, *Bull. Earthq. Res. Inst.*, **29** (1954), 183.

S. OMOTE, *Bull. Earthq. Res. Inst.*, **27** (1952), 63.

H. KAWASUMI, *Rep. Speci. Comm. Fukui Earthq.*, 1950. Chapter I.

3) P. BYERLY, *Seismology*, (Prentice Hall INC. U.S.A., 1942), 63.

K. Suyehiro<sup>4)</sup> was a pioneer in this field of observation and was succeeded by Ishimoto<sup>5)</sup> who made a thorough study of this subject. Ishimoto distributed seismometers, all of the same type, at ten places in Tokyo and Yokohama and obtained the results summarized in his famous papers cited, by which he found that a predominant period existed at each of the locations. Then, making use of the aftershocks, Minakami<sup>6), 7), 8), 9)</sup> and others made some observations on the earthquake motions at many locations in the shaken area having different underground conditions, and noticed remarkable differences in the nature of the earth vibrations in these locations.

In recent years seismic observations have been carried out in the Tokyo area by Miyamura, Nasu and Kanai and in the Yokohama area by Takahasi and Omote. Among them Miyamura<sup>10)</sup> made especially elaborate observations. In his observations each station was equipped with seven seismometers with different oscillation periods installed side by side in one place for the purpose of making the ground characteristics clear by the different responses of the seismometers to the earthquake motions. He has obtained some remarkable conclusions based on the records of these seismometers that played the role of selective analyzers.

From his observations he detected that records of the ground motion due to the same earthquake exhibited definitely different responses as the conditions of the ground differed from each other. Whereas Kanai<sup>11)</sup> developed a method by which he could determine the period and amplitude of the micro-tremors that happen unceasingly everywhere, and in doing so he found out the ground coefficient related to the earthquake-proof constructions. As this method could be carried out without making any observations of the earthquake motions, it succeeded in minimizing the time of observation.

As will be seen from the historical sketch given above, studies of the connection between ground vibration and seismic destruction have been developed on the basis of observation made on the ground in the

4) K. SUYEHIRO, *Proc. Amer. Soc. Civil Engineers*, **58** (1932), 1-110.

5) M. ISHIMOTO, *Bull. Earthq. Res. Inst.*, **10** (1932), 171; **12** (1934), 234; **13** (1935), 592.

6) T. MINAKAMI, *Bull. Earthq. Res. Inst.*, **22** (1944), 42.

7) T. MINAKAMI, *Rep. Speci. Comm. Fukui Earthq.*, 1950, Tokyo, 77.

8) T. MINAKAMI and S. SAKUMA, *Bull. Earthq. Res. Inst.*, **26** (1949), 61.

9) S. SAKUMA, *Bull. Earthq. Res. Inst.*, **26** (1949), 61.

10) Subsoil Res. Team, E.R.I., *Bull. Earthq. Res. Inst.*, **33** (1950), 471.

11) K. KANAI, T. TANAKA and K. OSADA, *Bull. Earthq. Res. Inst.*, **32** (1954), 199.

Tokyo area. Now, in order to expand these studies we have carried out seismic observations in the Kawasaki and Turumi districts adjacent to Tokyo, under the sponsorship of Kanagawa Prefecture.

## 2. Geology of the place

The topography and geologic structure of the region in which our observations were conducted are shown in Fig. 1. The map was originally prepared by the Fukada Geological Institute<sup>12)</sup>, by whose courtesy it is reproduced here. From this figure we may see the following characteristic features of the place:

i) Alluvial formations are distributed in three areas, one is a narrow zone along the shore line, and the others the basins of the Tama and the Turumi rivers.

ii) Thickness of the alluvium. The soft unconsolidated sediments of the alluvial formations lying thickly in the eastern part of the area become thinner as they approach the west and at last thin out at the hilly regions. In the case of the Tokyo District there has developed wide alluvial layer having an almost constant thickness.

iii) The element composition of the alluviums is considered to be the accumulation conveyed either by the Tama or the Turumi River. The element materials of these alluviums seem to differ not only from each other, but also from that of Tokyo in their grain size, porosities, permeabilities and other characteristics in the soil mechanics.

iv) Fairly large areas of the Kawasaki and Turumi Plain are composed of recently reclaimed lands. Such young, man-made lands on which factory towns are built present various problems as to the response to earthquake shocks.

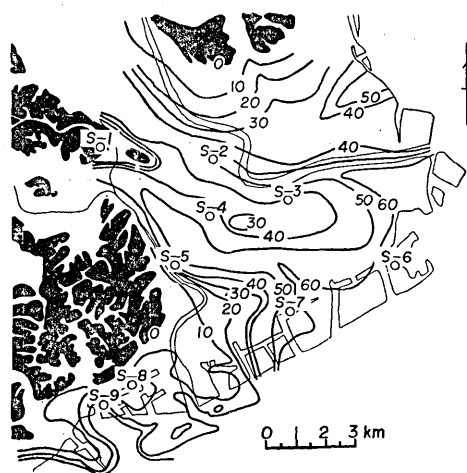


Fig. 1. Topography of the investigated area. The contour lines indicate the thickness of alluvium at every ten meters.

12) FUKADA GEOLOGICAL INSTITUTE, Rep. Spec. Comm. for the Investigation of the Subsoil Conditions in Kawasaki and Turumi Areas, Kanagawa Pref., (1956), 5 (in Japanese).

### 3. Observation stations

The observation of earthquake motions has been carried out at nine places selected in the region as best exhibiting the characteristic nature of the ground. As is well known, the ground vibrations due to earthquake shocks are especially complicated in places where the ground is covered by thick unconsolidated sediments. In order to thoroughly understand the nature of the vibration characteristics of each observation station, it was found convenient to take one of the stations situated on solid ground as the standard. The vibration characteristics of the other observation stations could be compared with those of this standard station. We took as this standard station the Keio High School around which the Kwanto loam of the diluvium formation is exposed without being covered by unconsolidated sediment layers.

Two stations were placed on each of the alluvial plains due to the River Tama and the River Turumi; three others were situated on the artificial land along the seashore, and the last station was installed on the natural land near the shore for comparison's sake.

Observation stations will be listed in the following table:

Table I. Location of observation stations.

Observation station	Location
A. Standard station.	
S-1: Keio High School	Hiyosi-tyo Kohoku-ku, Yokohama
B. Basin of the River Tama.	
S-2: The Toshiba Works at Komukai	Komukai-Toshiba-tyo, Kawasaki
S-3: The Ajinomoto Works at Kawasaki	Suzuki-tyo, Kawasaki
C. Basin of the River Turumi.	
S-4: The Central Market at Kawasaki	Minami-Saiwai-tyo, Kawasaki
S-5: The Morinaga Works at Turumi	Simo-Sueyosi-tyo Turumi-ku, Yokohama
D. Reclaimed area.	
S-6: The Kawasaki Harbour Office	Tidori-tyo, Kawasaki
S-7: The N.K.K. Works at Kawasaki	Minami-Watarida, Kawasaki
S-8: The Kyodo Pier	Ebisu-tyo Kanagawa-ku, Yokohama
E. Fairly firm ground.	
S-9: The Kirin Beer Works at Turumi	Namamugi Turumi-ku, Yokohama

Though the last named station S-9 is situated on a very thin layer of unconsolidated sediment, it is surrounded by man-made land underlain by thick sedimentary formation as will be seen in Fig. 1. We selected two observation stations, S-8 and S-9, very close together as shown in Fig. 2 in order to get a typical example of the difference that may appear on the respective seismograms when two stations are located very near to each other and yet with a great difference between their ground conditions.

The geographic distribution of these temporary stations will be seen in the map shown in Fig. 2.

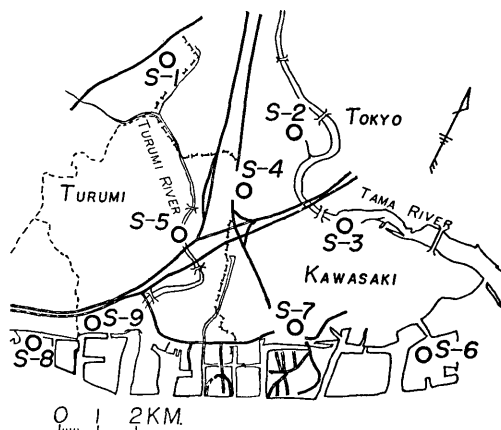


Fig. 2. Geographical distribution of the observation stations.

#### 4. Observation

As only five seismometers were available for the observation, we divided these nine observation stations into two groups, each consisting of five stations. The names of the stations in each group and the length of the period of the observations are shown in Table II.

Table II. Observation period of the stations.

Observation period	Observation stations
(I) 1955, Aug. 5~1955, Nov. 30	S-1, S-3, S-5, S-6, S-7
(II) 1955, Dec. 1~1956, Mar. 30	S-1, S-2, S-4, S-8, S-9

#### 5. Seismometers used

Seismometers used for observing the earthquake motions were of the Ishimoto tromometer type<sup>13)</sup> having a period of one second, with a magnification of about 200 times, and critically damped.

Each observation station was equipped with this type of seismometer with the horizontal component installed so as to register the

13) M. ISHIMOTO, *Bull. Earthq. Res. Inst.*, **14** (1939), 248.

north-south movement of the ground. The instrumental constants of the respective seismometers by which the observations were carried out will be seen in Table III.

Table III. Instrumental constants.

$T$ : Natural period (in seconds),		$h$ : Damping constant			
$\rho$ : Term of solid friction (mm),		$V$ : Geometrical magnification			
Station	Date	$T$	$h$	$\rho$	$V$
S-1	1955, Aug. 5	0.98	0.55	0.26	218
S-1	Dec. 27	1.00	0.62	0.33	218
S-3	Aug. 4	0.82	0.53	0.24	200
S-5	Aug. 7	1.00	0.56	0.24	146
S-5	Sept. 29	1.00	0.55	0.74	197
S-6	Aug. 7	0.80	0.57	0.14	210
S-7	Aug. 6	0.98	0.58	0.19	197
S-2	Nov. 29	0.85	0.65	0.95	195
S-2	1956, Jan. 21	0.90	0.58	0.97	195
S-2	Jan. 25	0.90	0.57	0.19	195
S-4	1955, Dec. 14	1.00	0.60	0.92	190
S-8	Dec. 6	1.02	0.60	0.19	195
S-9	Dec. 6	0.83	0.62	0.19	210

## 6. Analysis of the seismograms

As many as sixty earthquakes or so were recorded at each of these stations. These earthquakes are shown in Table IV. Of these sixty, twelve shocks marked with double circles in the table were chosen as typical ones and detailed analyses were conducted with the seismograms obtained at the respective stations. Six shocks marked with a single circle were analyzed in a simpler way.

Of these 12 shocks, two were distant shocks originated at a distance of more than 150 km; 4 were those of moderate distance whose epicentral distance ranged between 100 km and 150 km; and two others were very near shocks seated within 100 km.

### 6.1. Reading records

In order to make out the periods and amplitudes of the waves recorded on the seismograms, let us begin with the method by which the seismic records were read off. In reading the records we adopted

Table IV. Observed earthquakes.

Earthquake No.	Date	Time	Epicenter	Depth	P-S time	Intensity	Remarks
		<sup>h</sup> <sup>m</sup>	<sup>deg. N</sup> <sup>deg. E</sup>	<sup>km</sup>	<sup>sec.</sup>		
1	1955, Aug. 12	13 09	36.4 141.1	30	17	I	◎
2	Aug. 13	14 51			9		
3	Aug. 14	02 48	33.6 134.4	0~10	62		◎
4	Aug. 25	23 06			12		◎
5	Aug. 29	04 07			9		
6	Sept. 3	10 25	35.6 140.3	70	9		
7	Sept. 3	17 51	35.6 140.3	70~80	9	II	
8	Sept. 11	21 16	34.0 140.8	100	36		
9	Sept. 13	15 28	35.9 140.3	80	9		
10	Sept. 20	07 33	35.7 140.8	80	14	I	◎
11	Sept. 25	21 30	35.9 138.9	10	10	I	◎
12	Sept. 30	04 58	40.1 141.3	90~100	32		
13	Sept. 30	23 16			8		
14	Oct. 5	19 57			14		
15	Oct. 6	14 46	35.6 140.5	50	9	II	
16	Oct. 11	08 03	39.0 141.1	100	40		
17	Oct. 16	18 58			17		◎
18	Oct. 19	11 04	35.4 140.6	20	9	I	○
19	Oct. 20	01 57			33		
20	Oct. 20	22 10	35.2 140.4	40	9	II	○
21	Oct. 21	00 01			6		
22	Oct. 21	01 46			9		
23	Nov. 2	20 52			56		
24	Nov. 3	04 58	36.5 142.0	20	16		
25	Nov. 4	20 33			8		◎
26	Nov. 12	07 51			14		
27	Nov. 14	21 37	34.6 136.6	50	38		
28	Nov. 23	07 11			16		
29	Dec. 2	07 58			10		
30	Dec. 3	23 28	33.8 135.1	20	59		
31	Dec. 7	23 57			107		
32	Dec. 8	01 05	36.2 140.8	20	14	I	
33	Dec. 8	03 28			8		
34	Dec. 8	09 13			15		
35	Dec. 11	03 22			15		○
36	Dec. 12	18 29	36.6 141.0	80	20	II	◎
37	Dec. 12	21 56			8		
38	Dec. 15	17 34	36.2 140.1	50	10	I	◎

Table IV.—(Continued)

Earthquake No.	Date	Time		Epicenter		Depth km	P-S time sec.	Intensity	Remarks
		h	m	deg. N	deg. E				
39	1955, Dec. 17	23	11	37.7	141.2	70	26		
40	Dec. 18	12	18				29		
41	Dec. 18	14	33	36.2	140.0	40	14	II	⊙
42	Dec. 18	15	28	33.7	135.1	70	53		⊙
43	Dec. 19	00	11				13		
44	Dec. 19	07	48				17		⊙
45	Dec. 19	22	00				4		
46	Dec. 20	02	43				13		
47	Dec. 21	02	46				9		
48	Dec. 21	05	04				6		○
49	Dec. 22	17	33				64		
50	1956, Mar. 10	18	33	33.8	138.8	40	32		○
51	Mar. 11	04	10				21		
52	Mar. 11	05	58				16		
53	Mar. 13	06	57				10		
54	Mar. 13	18	26	36.2	142.3	50	27		○
55	Mar. 14	00	54				30		
56	Mar. 17	20	42	39.9	141.1	90	31		
57	Mar. 18	22	56				18		

the rectangular coordinate system whose abscissa coincided with the time line of the seismogram and read off the coordinates of all the crests and troughs of the recorded waves successively.

The recorded waves had a fairly large curvature (Fig. 3a, b) because the final lever of the seismometer was only ten cm. in length. For this reason the period of a wave will not be represented by the difference of the two successive time ordinates. The correction  $\delta t_i$  to be added to the time ordinate  $t_i$  will easily be calculated by the following equation:

$$\delta t_i = \frac{1}{2l} (2a_i D - a_i^2)$$

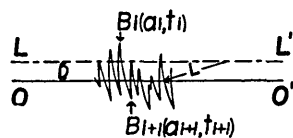


Fig. 4.

where  $a_i$  is the amplitude ordinate,  $OO'$  is the zero line on which the pen of the seismometer moved and  $LL'$  the line along which the rotation axis of the final lever, namely, the third lever is supposed to have moved.  $D$  is the distance



between the lines. The length of  $D$  is adjusted until it diminishes to zero, provided the instrument is very finely adjusted. Usually it occurs very frequently that  $D$  has a small but definite value.  $L$  is the length of the last lever between the pen-point and the rotation axis (Fig. 4). The corrected time ordinate  $T_i$  will be given by

$$T_i = t_i + \delta t_i$$

In like manner the corrected ordinate of the amplitude is given by

$$A_i = a_i + \delta a_i$$

$$\delta a_i = (D - a_i)Da_i/2l$$

where  $\delta a_i$  is the correction for the amplitude ordinate  $a_i$ . From  $T_i$  and  $A_i$  we know that the true amplitude  $A$  and the period  $T$  (whose amplitude is  $A$ ) are given by the equations

$$A = A_{i+1} - A_i$$

$$T = 2(T_{i+1} - T_i)$$

We calculated the amplitude and period with respect to all the waves recorded on the seismograms in the way defined by the above equations.

## 6.2. Frequency histogram

The waves may be divided into several classes according to the length of the period in such a way that one class, for example, would consist of waves whose period is between 0.1 sec. and 0.2 sec. Frequencies of the period of these respective class intervals were calculated at every station, and the resulting frequency histograms are shown in Fig. 5-a, b. The predominant periods obtained from these histograms are shown in Table V. The following are the points we noticed from these figures.

(1) Frequency curves obtained at station S-1 show a very simple form having a single high peak. A similar

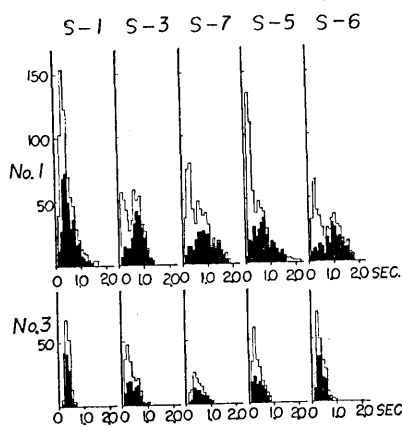


Fig. 5-a. Frequency histograms of period whose class interval is 0.1 sec.

White column:

Histograms due to all waves.

Black column:

Histogram due to larger waves.

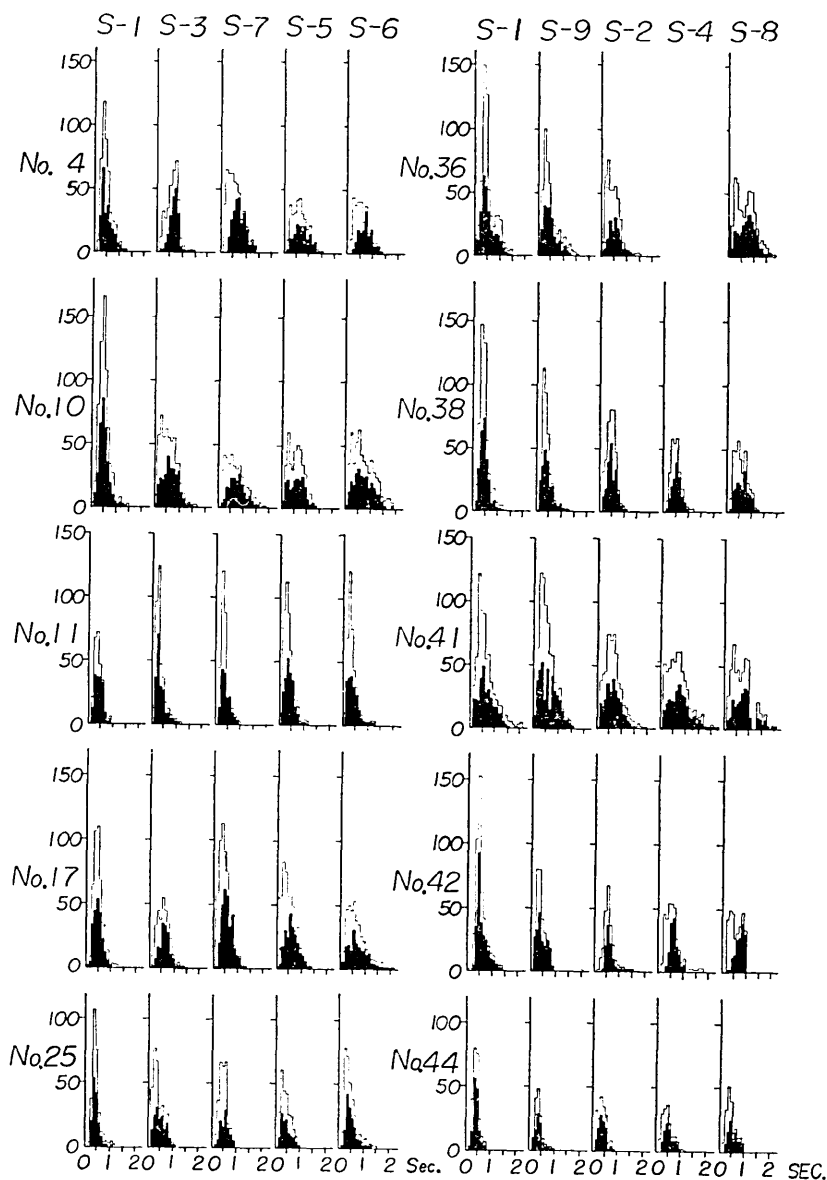


Fig. 5-b.

curve is seen in the case of station S-9.

(2) The form of frequency curves of the other stations are fairly complex and the peaks are not so high.

(3) In some cases two or more maxima are seen in a histogram.

Table V. Predominant periods  $T(N)$  due to all the waves. (in seconds)

Earthquake No.	S-1	S-3	S-7	S-5	S-6
1	0.35	0.65	0.25	0.35	0.15
3	0.35	0.25	0.35	0.25	0.25
4	0.35	0.75	0.25	0.65	0.25
10	0.45	0.25	0.55	0.45	0.55
11	0.35	0.25	0.25	0.25	0.25
17	0.45	0.55	0.35	0.25	0.55
25	0.35	0.25	0.45	0.25	0.25
Mean	—	0.42	0.35	0.35	0.33
	S-1	S-9	S-2	S-4	S-8
36	0.35	0.25	0.25	—	0.25
38	0.35	0.25	0.50	0.45	0.45
41	0.35	0.25	0.45	0.70	0.35
42	0.45	0.30	0.55	0.45	0.35
44	0.35	0.35	0.35	0.45	0.35
Mean	0.38	0.28	0.42	0.51	0.35

(4) As will be seen in Table V, short periods such as 0.3 or 0.4 sec. predominate at S-1 and S-9.

(5) S-5, S-6, S-7 and S-8 have much longer predominant periods.

(6) We see that very short periods, 0.2 and 0.3 sec., are seen to predominate very frequently irrespective of the difference between observation stations.

It occurred to us at once that these short predominant periods are seen in earthquakes having fairly small amplitudes. These waves of short period may be related to the underground structure near the surface.

### 6.3. Frequency of the period with respect to waves with a larger amplitude

It is supposed that waves with a large amplitude have a great bearing on damage to buildings; the effect of waves of small amplitude is considered to be negligible. From such a point of view it is believed convenient to study only the waves that have a larger amplitude and to ignore the waves of smaller amplitude.

All the amplitudes of waves read off from a sheet of seismogram are denoted by  $A_m$  and are arranged in the order of magnitude as  $A_1, A_2, \dots, A_n$  where  $n$  is the total number of waves. This sequence of ampli-

tude may be divided into two groups, one containing  $A_1, \dots, A_{n/2}$  and the other  $A_{n/2+1}, \dots, A_n$ . Now, we will refer to the waves belonging to the first group as "the larger waves", and consider only these larger waves in this paragraph. The frequency of these larger waves is shown by the black columns in Fig. 5 and the predominant periods deduced are shown in Table VI. Comparing this with Table V, which gives the predominant periods of all waves, we notice at once the following:—

Table VI. Predominant periods  $T(N/2)$  due to the larger waves.  
(in seconds)

Earthquake No.	S-1	S-3	S-7	S-5	S-6
1	0.45	0.85	0.85	0.75	0.95
3	0.35	0.35	0.35	0.25	0.35
4	0.35	0.75	0.75	0.65	0.75
10	0.45	0.55	0.85	0.75	0.55
11	0.35	0.25	0.25	0.35	0.25
17	0.45	0.65	0.45	0.55	0.55
25	0.35	0.35	0.55	0.25	0.35
Mean	—	0.54	0.58	0.51	0.54
	S-1	S-9	S-2	S-4	S-8
36	0.35	0.35	0.55	—	0.85
38	0.45	0.35	0.45	0.55	0.75
41	0.55	0.35	0.65	0.75	0.85
42	0.45	0.35	0.55	0.65	0.85
44	0.35	0.35	0.35	0.45	0.45
Mean	0.41	0.35	0.51	0.60	0.75

(1) That the predominant periods obtained at S-1 and S-9 are either 0.3 or 0.4sec., and the values do not differ much from the period obtained from all the waves.

(2) That with respect to the other stations it is clearly seen that longer periods predominate in the case of these larger waves.

(3) That the predominant periods of the Earthq. Nos. 3 and 11 of larger waves, however, are almost equal to the predominant periods in Table V. We notice that these earthquakes are shocks having very small amplitudes.

#### 6.4. Predominant period determined from the histograms of the summed-up amplitudes

We summed up all the amplitudes of waves that fall in one of the

class intervals in the form

$$A_i = \sum_p a_{ip}$$

where  $A_i$  is the summed-up amplitudes of the  $i$ 'th class and  $a_p$  is the element amplitude in the same class.

By these procedures we obtained the histograms of  $A_i$  which may give the predominant period due to the summation of the amplitudes. These predominant periods are shown in Table VII. The figures in this table are in good accord with the figures given in Table VI.

Table VII. Predominant periods  $T(A)$  due to the summed-up amplitudes. (in seconds)

Earthquake No.	S-1	S-3	S-7	S-5	S-6
1	0.45	0.85	0.75	0.65	1.05
3	0.35	0.25	0.40	0.25	0.35
4	0.45	0.75	0.65	0.60	0.75
10	0.45	0.55	0.85	1.35	0.55
11	0.35	0.25	0.30	0.35	0.25
17	0.45	0.55	0.45	0.55	0.55
25	0.35	0.35	0.35	0.35	0.35
Mean	—	0.51	0.54	0.59	0.55
	S-1	S-9	S-2	S-4	S-8
36	0.35	0.55	0.55	—	0.85
38	0.45	0.25	0.45	0.55	0.75
41	0.35	0.65	0.65	0.45	0.45
42	0.45	0.35	0.55	0.65	0.85
44	0.35	0.35	0.35	0.45	0.45
Mean	0.40	0.43	0.51	0.52	0.67

### 6.5. Weighted frequency of the period

Frequency histograms shown in Fig. 5 contain some contradiction. It is quite natural that the frequency of shorter periods is apt to be exaggerated in proportion to that of longer ones, as a greater number of shorter periods can fall in one class interval, all intervals having a uniform duration of time. In order to get rid of this inaccuracy, we multiplied the figure representing the length of the period itself as a weight by the frequency. By doing so we obtained the histograms of weighted frequencies. As to the practical procedures, it is very easy

to make weighted frequency histograms from Fig. 5. The predominant periods from the histograms are tabulated in Table VIII. They seem to differ from those of the all waves in Table V, but they show a good accord with the periods in Tables VI and VII.

Table VIII. Predominant periods  $T(W)$  due to the weighted frequency. (in seconds)

Earthquake No.	S-1	S-3	S-7	S-5	S-6
1	0.45	0.65	0.95	0.75	1.05
3	0.35	0.65	0.55	0.25	0.25
4	0.45	0.75	0.65	0.65	0.75
10	0.45	0.75	0.85	1.35	1.05
11	0.35	0.25	0.25	0.35	0.25
17	0.45	0.55	0.55	0.55	0.55
25	0.35	0.35	0.35	0.45	0.35
Mean	—	0.56	0.59	0.62	0.61
	S-1	S-9	S-2	S-4	S-8
36	0.45	0.35	0.75	—	0.95
38	0.45	0.35	0.55	0.55	0.75
41	0.55	0.75	0.65	0.75	0.95
42	0.45	0.35	0.55	0.65	0.85
44	0.45	0.35	0.45	0.45	0.45
Mean	0.43	0.43	0.59	0.60	0.79

#### 6.6. Predominant periods obtained by the autocorrelation method

Heretofore the subject has been developed on the basis of the period and amplitude read off by the method described in § 6.1. These methods of analysis, however, are somewhat troublesome. Recently Aki<sup>(14)</sup> has designed and constructed a new instrument which can conveniently be used for the calculation of the autocorrelation coefficient. By his courtesy we were allowed to use his relay computer to find out the predominant period from the respective seismograms. The analysis by means of the correlograms was carried out with 18 earthquakes marked with circles in Table IV. It was somewhat regrettable that the computer was so constructed that the correlation coefficient was to be obtained with the ten units of time, so that it was difficult to detect the period shorter than 0.3 sec. so long as the seismograms recorded with the paper speed of 2 mm/sec. were used.

14) K. AKI, *Jour. Seis. Soc. Japan*, II, 8 (1955), 56; 99.

Notwithstanding these inconveniencies it was very effective in saving the time of analysis to find out the predominant period by means of this relay computer. Some examples of the correlograms are reproduced in Fig. 6 and the predominant periods determined by this means are shown in Table IX. These periods look very much like those of Table VI, provided that we disregard the periods shorter than 0.3 sec.

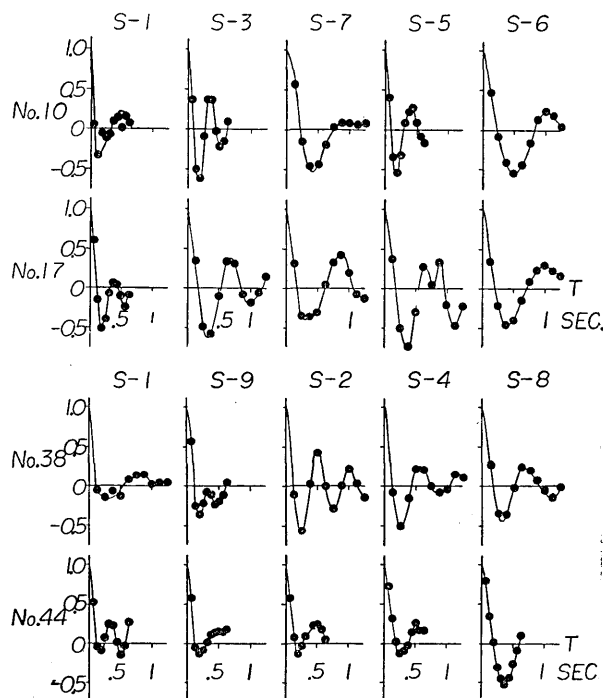


Fig. 6. Examples of correlograms.

#### 6.7. Comparison of the predominant periods found out by different methods

For the purpose of making the discussion simple, let us introduce the following notations:

$T(N)$ : The predominant period due to all the waves of which the total number is  $N$ .

$T(N/2)$ : The predominant period defined from the histograms of the larger waves.

$T(A)$ : The predominant period obtained from the histograms of the summed-up amplitudes.

Table IX. Predominant periods  $T(C)$  due to the autocorrelation method. (in seconds)

Earthquake No.	S-1	S-3	S-7	S-5	S-6
1	1.12	0.75	0.81	0.75	1.12
3	0.31	0.62	0.38	0.56	0.62
4	0.31	0.62	0.88	0.75	1.12
10	0.88	0.68	0.88	0.88	1.00
11	0.31	0.62	0.62	0.62	0.56
17	0.38	0.62	0.88	0.62	1.00
18	0.62	0.75	—	0.75	1.00
20	0.83	0.75	—	0.88	1.12
25	0.31	0.75	0.44	0.62	0.50
Mean	—	0.68	0.70	0.71	0.90
	S-1	S-9	S-2	S-4	S-8
35	0.75	0.75	0.62	—	0.88
36	0.88	0.62	0.62	—	0.88
38	0.88	0.62	0.50	0.56	0.62
41	0.75	0.88	0.50	0.50	0.88
42	0.75	1.00	0.50	0.62	0.75
44	0.31	0.62	0.50	0.50	0.62
48	0.31	0.31	—	0.62	0.56
50	0.50	0.56	0.50	—	0.75
54	1.00	0.62	0.62	—	1.00
Mean	0.62	0.66	0.54	0.56	0.77

$T(W)$ : The predominant period due to the weighted frequency.

$T(C)$ : The predominant period due to the autocorrelation method.

In order to study the mutual relations that may exist among these predominant periods obtained by different methods, in Table X are shown  $T(N)-T(N/2)$ ,  $T(A)-T(N/2)$  and  $T(W)-T(N/2)$ . From this we notice at once that the predominant periods  $T(A)$  and  $T(W)$  are in surprisingly good accord with the  $T(N/2)$  period, while fairly large differences are seen to exist among  $T(N/2)$ ,  $T(A)$ ,  $T(W)$  and  $T(N)$ . It seems that shorter periods are emphasized too much when we take the predominant period due to the histograms based on all the waves read out from the seismograms by the method described in § 6.1.

For the purpose of making clear the true characteristics of the ground, it was necessary to get rid of the effect of these shorter periods obtained from the  $T(N)$ , and to introduce a predominant period



Table X. Comparison of predominant periods by means of different methods. (in seconds)

Earthquake No.	Station	$T(N) - T(N/2)$	$T(N/2) - T(A)$	$T(N/2) - T(W)$	$T(W) - T(A)$
1	S-1	-0.1	0	0	0
	S-3	-0.2	0	0.2	-0.2
	S-7	-0.6	0.1	-0.1	0.2
	S-5	-0.4	0.1	0	0.1
	S-6	-0.8	-0.1	-0.1	0
3	S-1	0	0	0	0
	S-3	-0.1	0.1	-0.3	0.4
	S-7	0	-0.05	-0.2	0.15
	S-5	0	0	0	0
	S-6	-0.1	0	0.1	-0.1
4	S-1	0	-0.1	-0.1	0
	S-3	0	0	0	0
	S-7	-0.5	0.1	0.1	0
	S-5	0	0.05	0	0.05
	S-6	-0.5	0	0	0
10	S-1	0	0	0	0
	S-3	-0.3	0	-0.2	0.2
	S-7	-0.3	0	0	0
	S-5	-0.3	0	0	0
	S-6	0	0	-0.5	0.5
11	S-1	0	0	0	0
	S-3	0	0	0	0
	S-7	0	0.05	0	-0.05
	S-5	-0.1	0	0	0
	S-6	0	0	0	0
17	S-1	0	0	0	0
	S-3	-0.1	0.1	0.1	0
	S-7	-0.1	0	-0.1	0.1
	S-5	-0.3	0	0	0
	S-6	0	0	0	0
25	S-1	0	0	0	0
	S-3	-0.1	0	0	0
	S-7	-0.1	-0.2	-0.2	0
	S-5	0	-0.1	-0.2	0.1
	S-6	0	0	0	0
36	S-1	0	0	-0.1	0.1
	S-9	-0.1	-0.2	0	-0.2
	S-2	-0.3	0	-0.2	0.2
	S-4	—	—	—	—
	S-8	-0.6	0	-0.1	0.1
38	S-1	-0.1	0	0	0
	S-9	-0.1	0.1	0	0.1
	S-2	0.05	0	-0.1	0.1
	S-4	-0.1	0	0	0
	S-8	-0.3	0	0	0
41	S-1	-0.2	0.2	0	0.2
	S-9	-0.1	-0.3	-0.4	0.1
	S-2	-0.2	0	0	0
	S-4	-0.05	0.3	0	0.3
	S-8	-0.5	0.4	-0.1	0.5
42	S-1	0	0	0	0
	S-9	-0.05	0	0	0
	S-2	0	0	0	0
	S-4	-0.2	0	0	0
	S-8	-0.5	0	0	0
44	S-1	0	0	-0.1	0.1
	S-9	0	0	0	0
	S-2	0	0	-0.1	0.1
	S-4	0	0	0	0
	S-8	-0.1	0	0	0

due to  $T(N/2)$ . However, it was fairly troublesome to labour out  $T(N/2)$ . Judging from Table X, it will be certain that so far as the rough study of the character of the ground is concerned, in place of  $T(N/2)$ , the  $T(W)$  period will serve the purpose well.

## 7. The order of the sites as to their seismic quality

If it be taken that the length of predominant periods depends only on the nature of the ground, the latter may contrariwise be classified by the former. But, as will be seen in Table IV, in some cases, two or three kinds of predominant periods are obtained from several different earthquakes, so that the matter is not too simple. Though such is the case, it will be noticed clearly from the histograms of the frequency of period in Fig. 5, that there is an eminent single peak at  $S-1$  and  $S-9$ , where the seismic characteristics of the subsoils are considered fairly good, while with respect to the stations as  $S-5$ ,  $S-6$ ,  $S-7$  and  $S-8$  which are considered to have no good seismic characteristics the frequency histograms are irregular in shape and there are a few peaks to be seen. Consequently, the seismic characteristics of the subsoil may be inferred from the shape of the frequency histograms.

In the following we will take a step forward in describing the seismic quality of the respective stations by the ratios representing the values of the stations divided by that of the standard station. Now, we will nominate this ratio as "the characteristics ratio" of the respective factors proper to each station.

### 7.1. The sharpness factor of the frequency histogram

We now put the sharpness factor  $s$  in the form

$$s = C/N$$

where  $C$  is the width of the peak  $N$  at half its height. In a histogram the smaller the factor is the sharper the peak is. The sharpness factor  $s$  has been determined with respect to the  $N$  histogram (due to the white columns in Fig. 5) and the  $N/2$  histogram (due to the black columns of the same figure) respectively. The sharpness factor  $s_k$  of each of the stations was compared with the factor  $s_1$  of  $S-1$ , and the characteristic ratio of the sharpness factor  $S_k$ , ( $S_k = s_k/s_1$ , where  $k=2, 3, \dots, 9$ ) was calculated which are given in the 1st and 2nd lines in Table XI-a.

Table XI.

a. Characteristic ratios.

	S-1	S-9	S-2	S-3	S-4	S-7	S-5	S-6	S-8
$S(N/2)$	1	1.94	3.03	3.52	3.63	5.23	5.12	4.27	4.09
$S(N)$	1	1.75	2.79	2.62	3.10	3.48	3.94	4.89	5.53
$F(N/2)$	1	1.02	1.16	1.40	1.32	1.64	1.75	1.73	1.42
$F(N)$	1	1.06	1.16	1.37	1.13	1.56	1.62	1.65	1.49
$T(N/2)$	1	0.85	1.24	1.32	1.46	1.41	1.49	1.53	1.83
$T(A)$	1	1.08	1.28	1.28	1.30	1.35	1.48	1.38	1.68
$T(W)$	1	1.00	1.37	1.30	1.40	1.37	1.44	1.42	1.84

b. Orders of the seismic quality of the ground.

	S-1	S-9	S-2	S-3	S-4	S-7	S-5	S-6	S-8
$S(N/2)$	1	2	3	4	5	9	8	7	6
$S(N)$	1	2	4	3	5	6	7	8	9
$F(N/2)$	1	2	3	5	4	7	9	8	6
$F(N)$	1	2	4	5	3	7	8	9	6
$T(N/2)$	2	1	3	4	6	5	7	8	9
$T(A)$	1	2	4	3	5	6	8	7	9
$T(W)$	2	1	4	3	6	5	8	7	9

## 7.2. The flatness factor of the frequency histogram

It is not rare that frequency histograms have more than one peak and are seen flatter in shape. Consequently, in order to show some characteristics of the shape of the histogram, we presented the flatness factor  $f$  in the form

$$f = \sqrt{(\sum d_i^2)/p} \quad (i=1, 2, \dots, p)$$

where  $d_i = N_i - N/p$ ,  $N$  is the total number of waves in the frequency histogram and  $N_i$  is the number of waves in each class interval of period.

The flatness factors of the respective stations were compared with that of S-1, as in the case of the sharpness factor. In this case, however, the value of the flatness factor  $f_k$  is larger with firm ground and smaller with soft ground, so that in the calculation of the characteristic ratio  $F_k$  the reciprocals of the flatness factor were used as given in the form

$$F_k = f_1/f_k \quad (k=2, 3, \dots, 9)$$

The characteristic ratio  $F$  is listed in the 3rd and 4th lines of Table XI-a.

### 7.3. Predominant periods of the stations compared with that of the standard station

On the basis of the materials illustrated in Tables VI, VII and VIII, we computed the mean values of the predominant periods at each observation station as shown in the following table:

Table XII. Mean values of the predominant periods due to  $T(N/2)$ ,  $T(A)$  and  $T(W)$ . (in seconds)

	S-1	S-9	S-2	S-3	S-4	S-7	S-5	S-6	S-8
$T(N/2)$	0.41	0.35	0.51	0.54	0.60	0.58	0.51	0.54	0.75
$T(A)$	0.40	0.43	0.51	0.51	0.52	0.54	0.59	0.55	0.67
$T(W)$	0.43	0.43	0.59	0.56	0.60	0.59	0.62	0.61	0.79

In preparing this Table, such predominant periods as  $T(N)$  and  $T(C)$  were excluded, as the former was too much disturbed by shorter periods due to the very thin uppermost surface layer of the ground, and the latter failed to detect shorter periods. These average predominant periods of the respective stations were divided by that of S-1, the characteristic ratios of the predominant periods being listed in the 5th~7th lines of Table XI.

### 7.4. Averaged order of respective stations

The figures in the same columns in Table XI-a have been arranged in order from small to large and numbered in Table XI-b with respect to each item. Looking carefully at Table XI-b we find that these nine observation stations are to be classified into three groups.

The first group will include stations S-1 and S-9 whose numbers of order are 1 and 2, to the 2nd group will belong S-2, S-3 and S-4, and to the 3rd S-5, S-6, S-7 and S-8, whose numbers of order are 6, 7, 8 and 9. It will be natural to deduce from this that these three groups also indicate the characteristic natures of the ground against seismic vibrations, corresponding to the numbers of their order, from small to large.

Consequently, we graded the characteristic natures of the ground of the nine stations as follows:

- (1) Places considered to have the best seismic quality;  
S-1 and S-9.

- (2) Places considered to have medium seismic quality;  
S-2, S-3 and S-4.
- (3) Places considered to have the worst seismic quality;  
S-5, S-6, S-7 and S-8.

It will be said that such a grouping of the observation stations is very useful in classifying the seismic qualities of the ground.

## 8. Comparison of amplitude

### 8.1. On the maximum amplitude

In discussing the amplitudes of seismic waves, first of all, we made a study of the maximum amplitudes recorded at the respective stations. Observed maximum amplitudes differed so much in their periods that, for correction, they had to be multiplied by the dynamic magnification of the respective periods. The ratios between the corrected maximum amplitude at S-1 and those of the other stations were thus calculated. Averaging the maximum amplitude ratios of all the earthquakes, definite values of the ratio of the respective stations were determined. The values are compared with the thickness of the alluvium at each station in Fig. 7. From this figure we notice the following points;

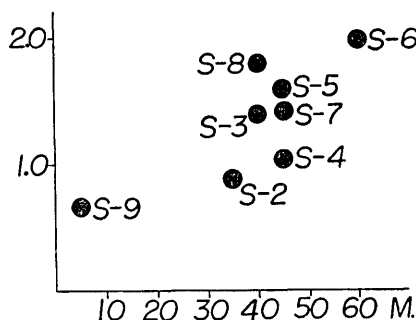


Fig. 7. Maximum amplitude related to the thickness of alluviums.

(1) As the thickness of the alluvium exceeds some thirty meters the ratio increases remarkably<sup>15)</sup>.

(2) The values of the ratio, however, do not exceed 2 even in the station considered to stand on very soft ground.

(3) The ratios of the stations considered to stand on ground of middle quality are seen to be about 0.9.

(4) On the whole we are inclined to think that station S-1 records somewhat too large a maximum amplitude in relation to its firm ground<sup>16)</sup>.

The last point may be explained by the fact that the maximum amplitude of the standard station S-1 might have been enlarged because of the high cliff of some 30m at the brink of which S-1 was situated. As these earthquakes were observed by the same type of seismograph in the

15) S. OMOTE, *Bull. Earthq. Res. Inst.*, **27** (1944), 63.

16) S. MIYAMURA, *Bull. Earthq. Res. Inst.*, **33** (1950), 523.

basement of our Institute at Hongo, Tokyo, it is hoped that these will be compared with the records here analyzed in the forthcoming paper.

## 8.2. The comparison of the amplitude in each class interval

The sums of the amplitudes of all the waves that fall into the respective class intervals of periods were divided by the values corresponding to that of the standard station, and these ratios are plotted against the periods in Fig. 8, from which we know that the ratios due

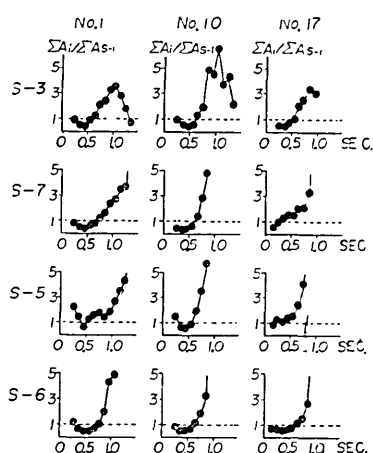


Fig. 8-a.

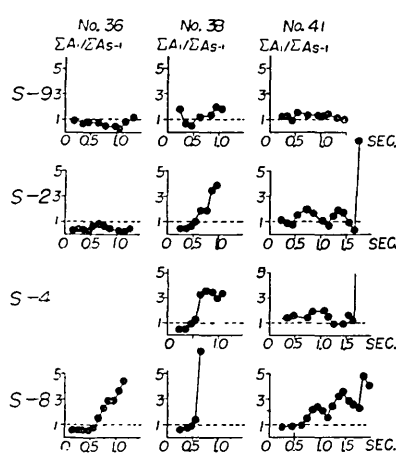


Fig. 8-b.

Period characteristics of amplitude ratio.

(amplitude of respective station)/(amplitude of the standard station).

to S-9 are always smaller than unity throughout the class intervals, while with respect to the other stations, they are somewhat larger than unity in the periods longer than 0.5 sec.

## 9. The predominant period and the structure of the ground

As we have already seen in §7, the characteristic ratio of each station was determined with each item. The average of these ratios with respect to each station is shown in Table XIII. In the same table the

Table XIII. Groupings of the observation stations.

Observation station	S-1	S-9	S-2	S-3	S-4	S-7	S-5	S-6	S-8
Group	I		II			III			
Averaged order	1.3	1.7	3.6	3.9	4.9	6.4	7.9	7.7	7.7
Averaged characteristic ratio	1.00	1.24	1.72	1.83	1.91	2.29	2.37	2.38	2.55
Thickness of alluvium (m)	0	5	35	40	45	45	45	60	40

thickness of the alluviums at each station is also described in the bottom line, and is related to the characteristic ratios of the respective stations. The figures in the first line of this table are closely related to the seismic qualities of the ground. The nearer the numerical value of the station is to unity, the nearer the seismic quality of the ground of the station is to that of the standard station. Generally speaking this table shows that stations with a so-called good seismic quality of the ground are underlaid by thin unconsolidated sediment layers.

### 9.1. The recorded amplitude of the earthquake and the predominant period

Looking at Table V in detail, it is interesting to notice that predominant periods of some 0.25~0.35 sec. are obtained at every observation station with respect to some earthquakes, say, Nos. 3, 11, 25, 36 and 44. These earthquakes do not differ from the others either in the situation of the epicenters or in the epicentral distances, but have smaller amplitudes at all the stations.

In Fig. 9 are illustrated the frequencies of the predominant periods obtained at the respective stations. 9-A is the frequency distribution due to  $T(N)$ , and 9-B, 9-C are those of  $T(N/2)$ .

It is remarkable to see that the periods of 0.25~0.35 seconds are observed to predominate at every station in Fig. 9-A, while the disturbances due to such shorter periods are greatly diminished in Fig. 9-B, for the reason already described in § 6.3. Now in Fig. 9-C, frequencies of the predominant periods of four selected earthquakes that have shaken the station with waves of large amplitude are illustrated. As we see from this figure, a fairly constant predominant period is seen to occur at each station for all four of the earthquakes.

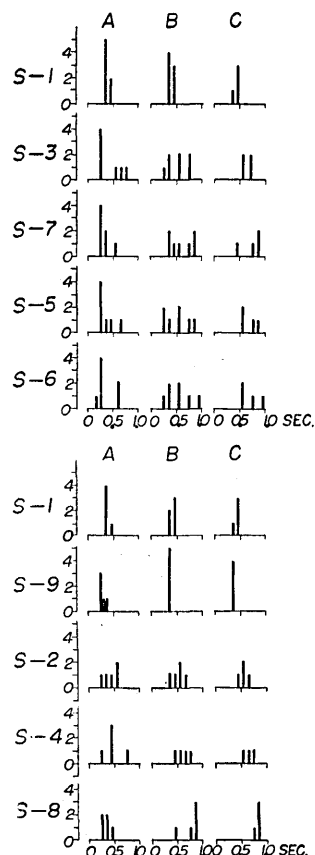


Fig. 9. Frequency of predominant period at each station.

A: frequency distribution due to  $T(N)$ .

B: frequency distribution due to  $T(N/2)$ .

C:  $T(N/2)$  of the selected four earthquakes.

## 9.2. The thickness of alluvium and the predominant period

Fortunately, columnar structures of the core borings carried out at most of the observation stations were available, so that we could compute the period of stationary waves that may exist in the subsurface layer, having a node at the lower boundary of a layer and a loop at the surface of the ground.

In this connection, we need to determine what value to take as to the velocity of the  $S$  wave. Scarcely any seismic prospectings have been made in this region, but there is one made by S. Hayashi<sup>17)</sup> of the Transportation Technical Research Institute a few years ago in an area very near our observation station S-6. The result is as follows:

Layer	Depth	Velocity of the $P$ wave
The 1st layer	0- 2 m	180- 560 m/s
The 2nd layer	2-80 m	1100-1640 m/s
The 3rd layer	lower than 80 m	1800-2140 m/s

In general, the vertical velocity observed from the well shot data is often slower than the horizontal velocity observed in the ordinary refraction shootings<sup>18)</sup>. Further, it may be assumed that the velocity of the  $S$  wave<sup>19),20)</sup> is remarkably slower than that of the  $P$  wave in such a soft silty ground as in this region.

As to the velocity of the  $S$  wave, several values have been proposed by investigators<sup>21),22)</sup>. Now, referring to such values as mentioned above and especially referring to the velocities of waves of large amplitudes observed by us in seismic prospectings in down-town Tokyo<sup>23)</sup>, it seems reasonable to assume the velocity of the  $S$  wave propagated through soft unconsolidated sediments to be as follows:

The nature of the layer	Velocity of the $S$ wave
sand	60 m/s
reclaimed soil	100
sandy clay	100-200
clay	250
pebble with sand	300-400
pebble	600
Tertiary formation	1000 or more

17) S. HAYASHI, *personal communications*.

18) M. B. DOBRIN, P. L. LAMAENCE and R. L. SENGBUSH, *Geophys.*, **19** (1954), 695.

19) Y. SATO, *Bull. Earthq. Res. Inst.*, **29** (1951), 223.

20) K. KANAI, *Bull. Earthq. Res. Inst.*, **31** (1953), 224.

21) N. NASU, T. HAGIWARA and S. OMOTE, *Bull. Earthq. Res. Inst.*, **14** (1936), 560.

22) J. E. WHITE and S. N. HEARPS, *Geophys.* **21** (1955), 715.

23) S. OMOTE, *Bull. Earthq. Res. Inst.*, **33** (1955), 492.



Supposing a period  $T_i$  of the stationary wave occurring in layers whose thickness and velocity are  $H_i$  and  $V_i$  respectively, is expressed by

$$T_i = 4 \sum_{i=1}^n (H_i / V_i), \quad i = 1, 2, \dots, n.$$

we computed the periods of waves that exist in the layers under the observation stations, as shown in Fig. 10. For comparison's sake, the

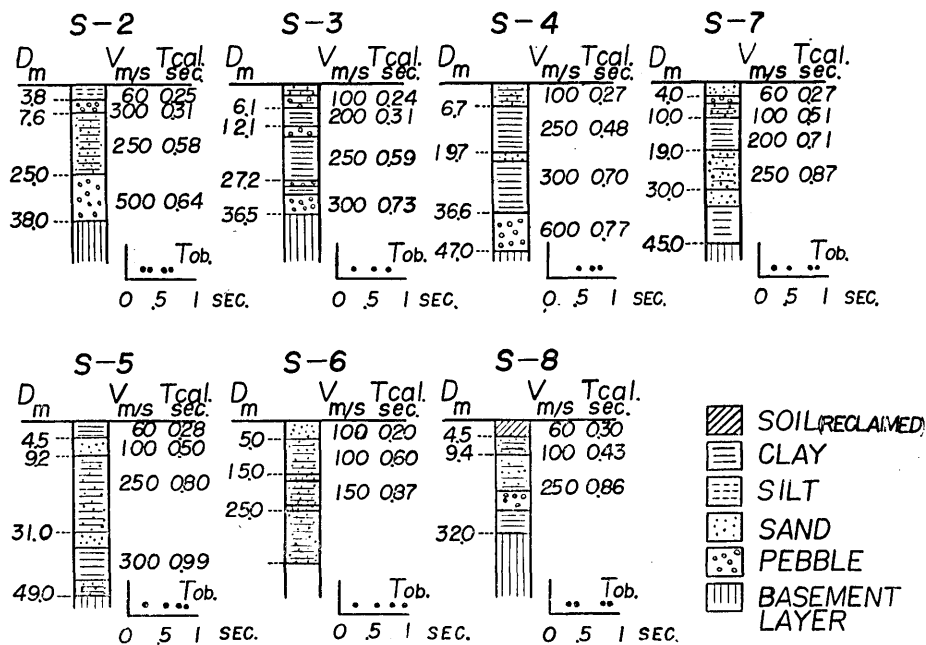


Fig. 10. Subsurface geology of the observation station and the period of waves computed.

observed values of the predominant period are also illustrated in the same figure. Although the assumed velocities are pretty questionable, it is worth while to remark that the computed periods are in very good accord with the observed periods at the respective stations.

### 9.3. Periods theoretically expected from the known underground structure

Not a few theoretical studies<sup>(24), (25)</sup> have been carried out as to the possibility of the free oscillations of the surface layer. Recently,

24) K. SEZAWA, *Bull. Earthq. Res. Inst.*, 8 (1930), 1.

25) K. SEZAWA and K. KANAI, *Bull. Earthq. Res. Inst.*, 13 (1935), 251.

Kanai<sup>26),27)</sup> derived some new formulae by which he was able to calculate the amplitudes of the desired periods, provided the necessary values of

the constants of underground layers were known. Making use of his formulae we calculated the amplitudes of every period that was expected to exist at the respective stations, whose underground structures are known from the section of the borings. These results are illustrated in Fig. 11. From the figure it seems difficult to prove theoretically that waves with the periods assumed in § 9.2. exist as stationary waves in the surface layers. Notwithstanding the above results it is not to be overlooked that the periods assumed in § 9.2. agree well with the periods actually observed in the earthquake motions.

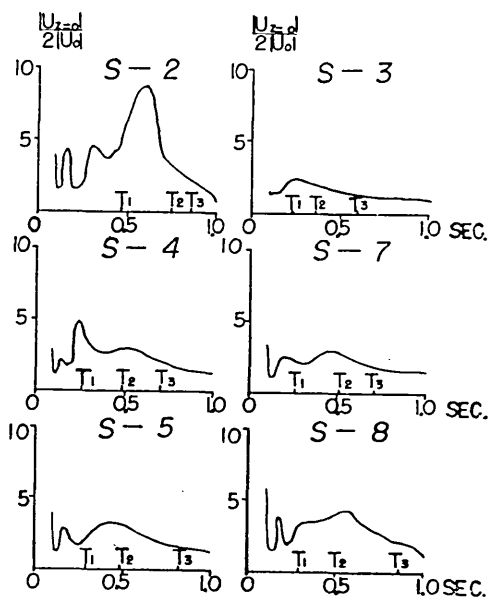


Fig. 11. Calculated spectra of amplitude.

#### 9.4. The relation between the predominant period and the amplitude

It has been noticed in the preceding paragraphs that shorter periods predominate at every station when the amplitude of the seismic waves are small, and that these shorter periods are deeply related only to the uppermost layer of the ground. We have also found that longer predominant periods are obtained in the case of larger earthquakes. In this paragraph we will investigate somewhat minutely the relations that may exist between the periods and the amplitudes. In the first place we will choose an observation station, say S-7, as an example. Take  $\Sigma A$  as the summation of amplitudes of all the waves of one of the recorded earthquakes. Now, in Fig. 12 is illustrated the relation between  $\Sigma A$  and  $T(N/2)$  with respect to each earthquake. As we see from this figure  $T(N/2)$  becomes larger as  $\Sigma A$  increases, and it may be

26) K. KANAI, *Bull. Earthq. Res. Inst.*, **30** (1952), 39; **31** (1953), 219.

27) K. KANAI and S. YOSHIKAWA, *Bull. Earthq. Res. Inst.*, **31** (1952), 275; **34** (1956), 167.

said further that as the  $\Sigma A$  exceeds a certain value,  $T$  approaches some asymptotic value.

$\Sigma A$  of the abscissa is a measure relating to the seismic energy that had shaken the station. So that we may conclude that the stationary oscillation is generated only in the uppermost layer when the energy of the seismic waves shaking the ground is not large enough, while the stationary vibrations that penetrate to the deeper layers can stand when the seismic energy stimulating the ground of the observation station is large enough. With respect to the other stations a like result is obtained as will be seen in Fig. 13.

It is very interesting to find that this asymptotic value of the predominant period coincides with the calculated period of standing waves that have a node at the lower boundary of the alluvial layer.

### 10. Conclusion

From the investigations described above a number of important results will be obtained concerning the seismic characteristics of the ground in the Kawasaki and Turumi regions. The results will be summarized as follows:

- (1) Seismic qualities of the grounds.
- (i) The areas considered to have the best seismic qualities:  $S-1$  and  $S-9$ .
- (ii) The areas considered to have medium seismic qualities:  $S-2$ ,  $S-3$  and  $S-4$ .
- (iii) The areas considered to have the worst seismic qualities:  $S-5$ ,  $S-6$ ,  $S-7$  and  $S-8$ .

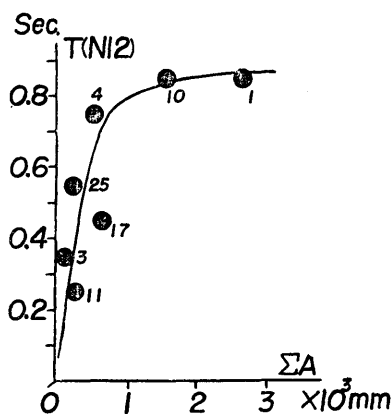


Fig. 12. Summation of amplitudes of all waves of an earthquake and the predominant period of that earthquake. (Station  $S-7$ ). Figures attached to each dot represent the earthquake number in Table IV.

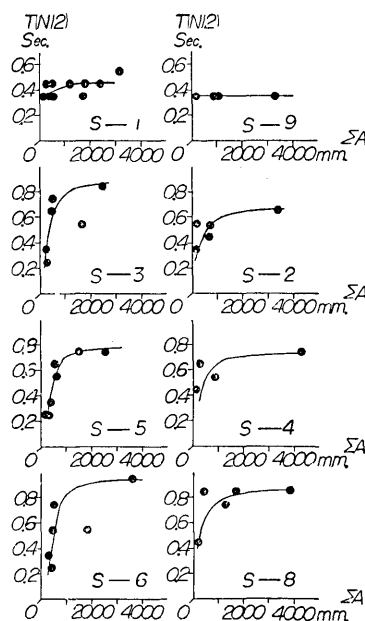


Fig. 13. Summation of amplitudes of all the waves of an earthquake and the predominant period of that earthquake. Stations  $S-1$ ,  $2$ ,  $3$ ,  $4$ ,  $5$ ,  $6$ ,  $8$ ,  $9$ .

The observation stations that belong to the group (i) are located on the ground that has no unconsolidated sedimentary layer or only a few meters of it. Those belonging to the group (ii) are *S*-2, *S*-3 and *S*-4. The first two stand on the fan of the River Tama and the last one is in the region between the two rivers, the Tama and the Turumi. The stations of the third group are *S*-5, *S*-6, *S*-7 and *S*-8. *S*-5 is situated on the soft sediments of the River Turumi, while the other three are on the man-made land along the coastal region.

According to the columnar section of the subsoil geology reproduced in Fig. 10, it will be noticed that the alluvial layer in the fan of the River Tama such as *S*-2 and *S*-3 contains stone or gravel layers in it, while no such stone or gravel layers are seen to exist in the alluvial layer due to the deposit of the River Turumi, as will be seen in the columnar section, say, of *S*-5. It will be safe to say that the alluvial plain of the River Tama is a so-called "gravel plain" and that of the River Turumi is a "mud plain". It has become clear from our study, we hope, that the stations of the alluvial plain of the River Tama have a preferable nature against earthquake shocks, than the station situated on the alluvial plain of the River Turumi. This fact shows a good accord with what was observed in the damage distribution of the Tokaido Earthquake of 1944 and of the Nankaido Earthquake of 1946, which were investigated by Miyamura<sup>28), 29)</sup>

Stations distributed on the reclaimed ground along the coastal region are underlain by thick unconsolidated sediments, and all these stations belong to the 3rd group, namely, the weakest ground against seismic vibrations.

(2) Predominant periods related to the subsurface structures.

The predominant periods computed coincide with the observed periods at the respective stations, notwithstanding some uncertainties in the assumption of the speed of the *S* wave.

(3) The predominant period and the observed amplitude.

Longer periods are seen to predominate when the amplitudes of the seismic waves that shake the station are large enough, and they will approach some asymptotic value. It is interesting to find that this asymptotic value coincides with the calculated period of the standing waves that have a node at the lower boundary of the alluvium.

28) S. MIYAMURA, "Notes on the Geography of Earthquake Damage Distribution" *Proc. Seventh Pacific Science Congress* 2 (1953), 653-661.

29) S. MIYAMURA, *Bull. Earthq. Res. Inst.*, 24 (1946), 99.

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## 23. 川崎鶴見地域 9 ケ所で行った地震観測とその場所の地盤特性

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昭和 30 年 8 月から翌年 3 月迄川崎鶴見地域に於て 9 ケ所の地点を選んで地震観測を行った。この観測に当つて、日吉の慶応高等学校を基準点として観測点を 5 ケ所宛 2 組のグループに分け各観測点に周期 1 秒倍率 250 倍の石本式水平動微動計 1 台宛を設置し、地動の南北成分を記録させた。観測点の配置、観測期間等は次の通りである。

観測点 記号	設置場所	地名	観測期間	摘要
S-1	慶応義塾大学高等学校	横浜市港北区日吉町	1955 VIII~1956 III	基準点、洪積台地
S-3	味の素 K.K. 川崎工場	川崎市鈴木町 296	1955 VIII~1955 XI	多摩川流域
S-5	森永製菓・鶴見工場	横浜市鶴見区下末吉町	"	鶴見川流域
S-6	川崎市港湾事務所	川崎市千鳥町	"	海岸埋立地
S-7	日本鋼管川崎製鉄所	川崎市南渡田	"	海岸埋立地
S-2	東京芝浦電気小向工場	川崎市小向東芝町	1955 VIII~1955 XI	多摩川流域
S-4	川崎市中央市場	川崎市南幸町 3	"	多摩鶴見中間域
S-8	横浜共同埠頭	横浜市神奈川区恵比須町	"	海岸埋立地
S-9	麒麟麦酒横浜工場	横浜市鶴見区生麦	"	沖積層極浅

地震動記録解析による地盤特性：これらの期間中に観測された 60 以上の地震の中から 12 の地震をえらび出して解析を行った。その解析においては各観測点において得られている記象について主要動から後の全ての波の振幅と周期とがよみ取られた。まず周期について 0.1 秒の class interval ごとに周期の頻度を数えて卓越周期  $T(N)$  を求めた。次に各観測点毎に振幅の大きい波を全波数の半数だけとりそれについて卓越周期  $T(N/2)$  を求めた。更に各 class interval 毎の波の振幅を加えたものの頻度図から振幅卓越周期  $T(A)$ 、等しい時間の間に等しい数の波がはいよう補正した荷重周期頻度より卓越周期  $T(W)$ 、安芸の相関係数器卓越周期  $T(C)$  等を求めそれぞれの相異を調べた。これらの卓越周期の値及びこれらの卓越周期を求めるのに用いられた頻度図の山の高さ及び形状を数量的に表現するため尖鋭度、平坦度等を定義し、各観測点のそれらの値と基準点の値との比をもとめ観測点の地盤の性質に関係する特性比とよぶこととした。9 ケ所の観測点についてこれらの特性比の小さいものから順に順番をつけて仔細に考察した結果これら 9 ケ所の観測点は次の 3 つの群にはつきり分けられることが気付かれた。

- 第 1 群 S-1, S-9 洪積台地又はこれに近い地下構造のところ。地震に対する地盤特性は良好であると 考えられる。建設省告示による 第 2 種地盤と 考えられる。
- 第 2 群 S-2, S-3 荒れ川である多摩川扇状地にある観測点。地盤特性は第 1 群に次いで良好であると 考えられる。第 3 種地盤と 考えられる。
- 第 3 群 S-5, S-6 S-7, S-8 鶴見川の沈泥質沖積地又は海岸に沿う厚い沖積層の上にある埋立地にある観測点。いはゆる軟弱な地盤で第 4 種地盤に相当すると 考えられる。

以上のようにして観測点の地盤の地震に対する特性を数量的にあらわすことができた。この同じ地域で金井は微動の観測を行つたが、地震動観測結果を解析して求めた地盤特性と微動観測結果を解析して求めた地盤特性とはよく調和した結論を与えることがしられた。

卓越周期と地下構造：これらの解析で特に気付かれたことは同じ 1 つの観測点であつても、地震が異なることにより異つた卓越周期が得られるということである。この点について特にくわしくしらべた結果第 12 及 13 図に見られるように振幅の小さい地震では短い周期が得られ振幅が大きい地震程卓越周期も 段々大きくなりある程度以上の振幅の地震では 殆ど一定の卓越周期となるということが各観測点について実証せられた。これらの観測点の多くは試錐によりその地下構造が知られていたので地層の不連続面の所を節とし地表を腹とするような定常振動を仮定してそのような定常波の周期を計算した。その際地層の中を通る波の速度をどのように仮定するかが最も問題であるが、他の場所での多くの測定値を参照して § 9.2 に仮定したような値をとると考えれば計算により得られる周期は実際に得られた卓越周期と極めてよく一致していることが見られた。このことから振幅の小さい地震の場合には地表面に近い浅い層の中に定常振動が誘起されるために短い周期が卓越するけれども、振幅が大きい地震の場合にはもつと深い層までが振動に加わることになるので長い周期が卓越するようになるのであらうと考えられた。

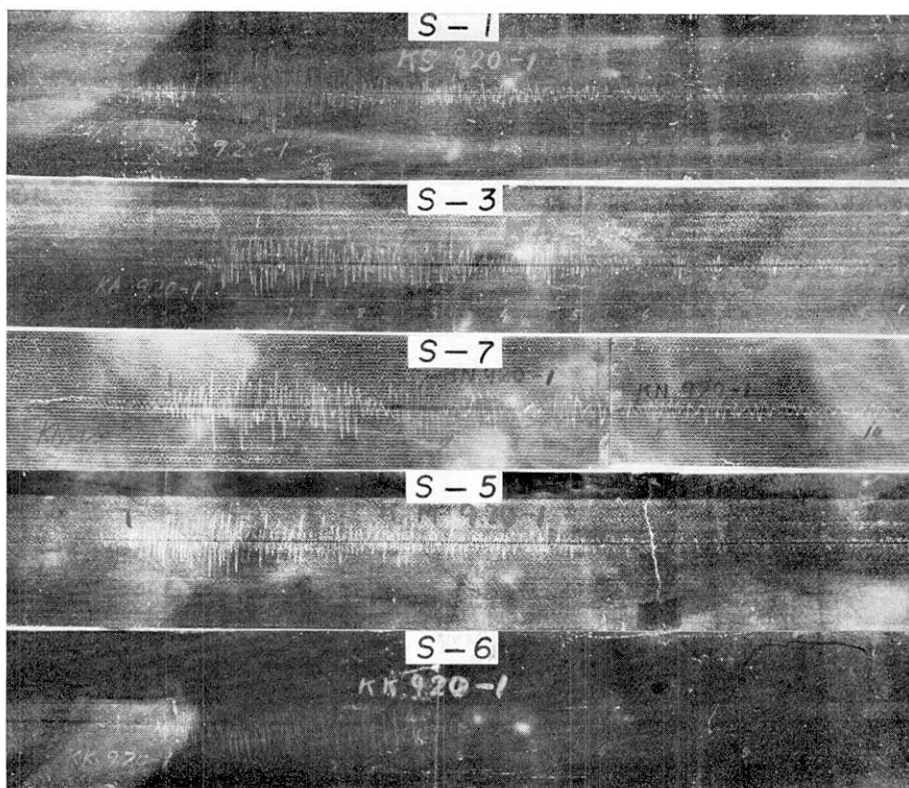
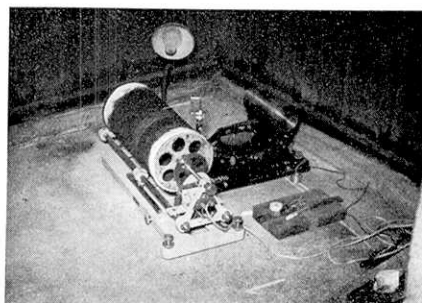
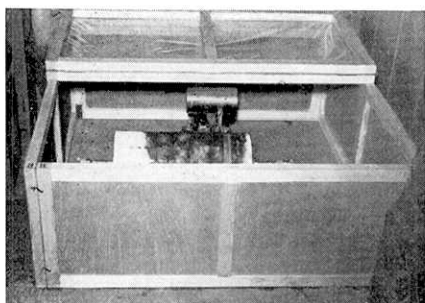


Fig. 3-a. The seismometers at stations S-3 and S-5, and examples of the seismograms obtained. (Earthq. No. 10) (1/2 the actual)

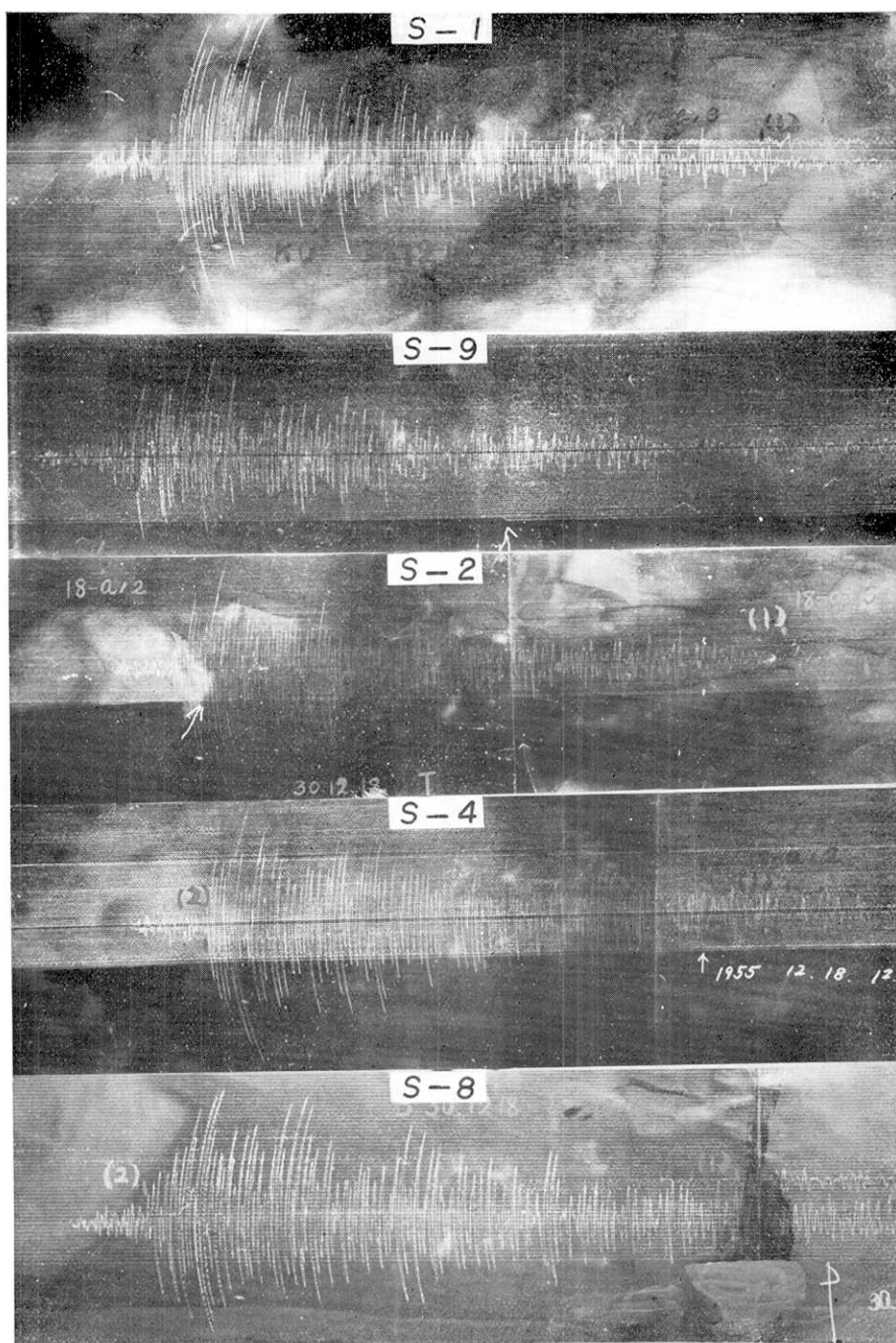


Fig. 3-b. Examples of the seismograms obtained. (Earthq. No. 41) (1/2 the actual)