9. *Observations of the Earthquake-motion at the Different Depths of the Earth.* I.

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1. Introduction.

The problem concerned with the earthquake-motions underground has already been paid attention to by many authors.[1] These researches, being based on observations made in comparatively shallow places in the ground, show mainly the nature of superficial layer of the earth.

In order to throw light on the important question of the nature of seismic waves, we have begun the observation of earthquake-motion by means of setting seismographs on ground surface as well as under-

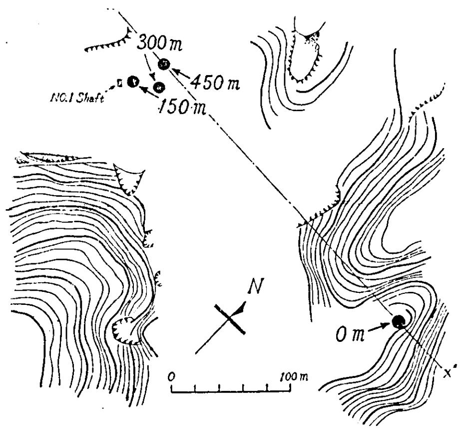


Fig. 1a. Geographical positions of seismograph stations at Hitachi mine.

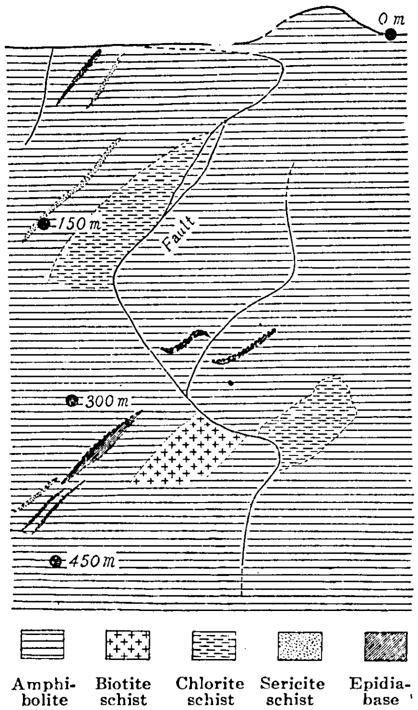


Fig. 1b. Geological formations about seismograph stations at Hitachi mine.

1) F. OMORI, *Publ. Earthq. Inv. Com.*, **10** and **11** (1902),
N. NASU, *Bull. Earthq. Res. Inst.*, **9** (1931), 454,
U. INOUE, *Bull. Earthq. Res. Inst.*, **12** (1934), 712,
T. SAITA and M. SUZUKI, *Bull. Earthq. Res. Inst.*, **12** (1934), 517.

ground, at Hitachi mine in Ibaragi prefecture. Fig. 1 shows the geographical positions of seismograph stations together with the geological formations of that area.

In the first period during eleven months from Dec. 1, 1948 to Oct. 31, 1949, we made observation of earthquakes every day without intermission by means of seismographs set on the ground surface as well as at 450 meter underground, and observed 45 earthquakes. In this period, as the recording papers were changed once a week, that is to say 1 mm length in recording papers corresponded to 3 sec., we would not investigate the wave form. Therefore we shall deal with the seismogramms observed in this period statistically.

In the second period during the one month from April 7 to May 6, 1950, we carried out an observation of the earthquakes every day without intermission by means of setting the seismographs on the ground surface as well as 150, 300, 450 meter underground, and observed 14 earthquakes. In this period, the recording papers were changed once a day, that is to say, 1 mm length in recording papers corresponded to 0.5 sec., therefore we shall be able to investigate the problem concerning the wave forms of seismogramms considerably.

2. Statistical studies of the earthquake-motions at the different depths of the earth.

In the first period, two horizontal seismographs (E-W component) were used of which the instrumental constants are shown in Table I.

Table I. Instrumental constants.

Position	T (sec)	Geometr. magnif.	Damp. ratio
0 meter	1.0	150	13 : 1
450 〃	1.0	150	13 : 1

In order to investigate the characteristics of the amplitude of earthquake-motions statistically, we picked out 10 among 25 earthquakes which had been recorded in the period of about six months from Dec. 1, 1948 to June 3, 1949. The results of the present research are shown in Table II.

Columns 7 and 8 in Table II show that the ratio of the displacement of initial motion in P phase and S phase at 0 meter to those at 450 meter take values within the range of 1～2, but we can scarcely find out the relation

Table II. The results of observation.

No.	Date (1949)	Displacements of initial wave						Epic.	Depth of Hypoc. (km)	Intens. at Mito
		P (μ)		*S* (μ)		0 m/450 m				
		0 m	450 m	0 m	450 m	*P*	*S*			
1	II 11	—	—	2.3	2.0	—	1.2	140.0E 36.1N	Very shallow	II
2	IV 3	0.7	0.7	5.4	4.0	1.0	1.3	139.9 36.4	shallow	II
3	V 4	—	—	1.0	0.9	—	1.1	139.9 36.1	50	II
4	〃 6	—	—	2.3	1.4	—	1.8	141.8 37.5	60	II
5	〃 12	4.1	3.4	—	—	1.2	—	140.8 36.5	shallow	III
6	〃 16	—	—	5.0	4.0	—	1.3	140.6 36.3	〃	I
7	〃 22	—	—	1.4	0.8	—	1.8	142.0 38.4	〃	II
8	〃 25	1.4	0.7	14.8	8.1	2.0	1.8	141.9 37.3	〃	II
9	VI 2	4.0	2.7	28.4	16.9	1.5	1.7	141.2 36.7	30	II
10	〃 2	4.0	2.7	24.3	12.8	1.5	1.9	141.3 36.4	20	II

between the ratio mentioned above and epicentral distance, magnitude of earthquake, depth of hipocentre. And then, we tried to point out the relation between the ratio mentioned above and the epicentre of them. The relation just mentioned are shown in Fig. 2.

It will be seen from Fig. 2 that the displacement of initial motion at 0 meter and at 450 meter are with in the ratios 1∼1.5 when hypocentres are on the land, while on the other hand, the ratios mentioned above are 1.5∼2.0 when the hypocentres are in the sea. This fact tells us that the angles of incidence of *P* waves and *S* waves of earthquakes whose hypocentre were in the sea are smaller than those whose hypocentre were on the land,[2] that is to say, at least in the area of the present observing station, the characteristics of the path of seismic waves would differ according as the hypocentres were

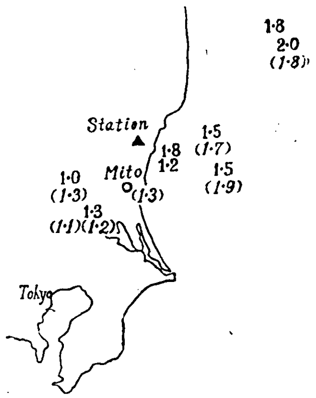


Fig. 2. The ratio of the displacement of initial motion in *S* phase (bracket) and *P* phase at 0 meter to the ones at 450 meter.

2) T. MATUZAWA, *Zishin* (*Earthquakes*), **4** (1932), 7.

on the land or in the sea. Now, we will make the reason of it clear in another occasion as the number of earthquakes observed are yet insufficient.

Next, we shall compare the number of earthquakes observed at Hitachi mine by means of microseismograph (magnification = 150, period = 1 sec.) with those observed at Mito meteorological station, situated about 30 km to the south of Hitachi mine, by means of Wiechert seismograph (magnification = 80, period = 4 sec.). All of the felt-earthquakes at Mito station has been recorded at Hitachi station, but there are many earthquakes un-recorded at Hitachi station among the no-feeling-earthquakes recorded at Mito station. And then, we tried to point out the relation between the earthquakes recorded as well as those not recorded at Hitachi station among no-feeling-earthquakes recorded at Mito station and epicentre of them. The relation just mentioned are shown in Fig. 3. In Fig. 3, marks × and ● represent the recorded and un-recorded earthquakes respectively. The figures beside the marks in Fig. 3 indicate the depth of hypocentre. No figure beside ● and × represent that the depth of hypocentres were unknown and shallow respectively. Fig. 3 shows that the hypocentre whose motions at Hitachi mine were relatively large are shallow in general. It seems to be difficult to explain the fact described in Fig. 3 only through the difference of geological formation near the earth's surface in Hitachi (rock) and Mito (alluvium) on which seismographs operated.

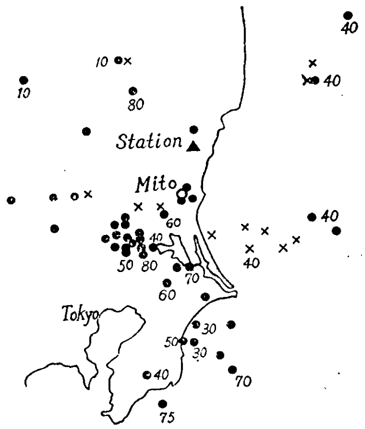


Fig. 3. Marks × and ● represent epicentre of earthquake recorded at Mito together with Hitachi and that recorded at Mito only respectively. The number beside the marks indicate the depth of hypocentre.

3. Distribution of horizontal displacements of earthquake-motions at different depths.

The instrumental constants of the horizontal seismographs (E-W component) used for the present investigations are as follows:

Table III. Instrumental constants.

Position	T (sec)	Geometr. magnif.	Damp. ratio
0 meter	0.92	150	13 : 1
150 〃	0.84	210	〃
300 〃	0.83	200	〃
450 〃	0.94	150	〃

The seismograms of 5 earthquakes, whose records are relatively large and clear among the 15 earthquakes observed during the period of a month from April 7 to May 6, 1950, are shown in Figs. 4~8. Figs. 4, 5, 6 and Figs. 7, 8 are the records of the early parts of the main shocks and of the parts considered satisfactorily to be surface waves respectively.

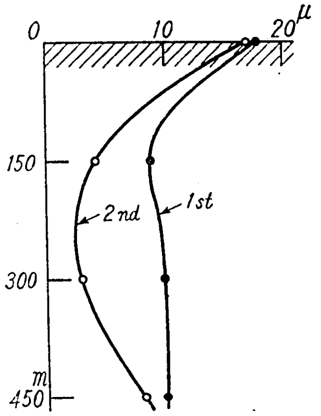


Fig. 9. The distributions of horizontal displacements at different depths of cases corresponding to Fig. 4.

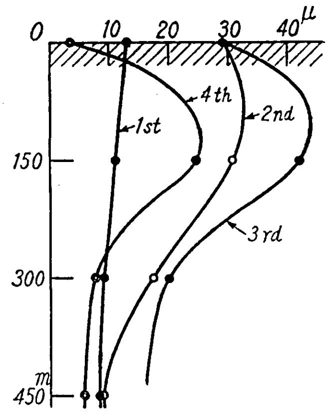


Fig. 10. The distributions of horizontal displacements at different depths of cases corresponding to Fig. 5.

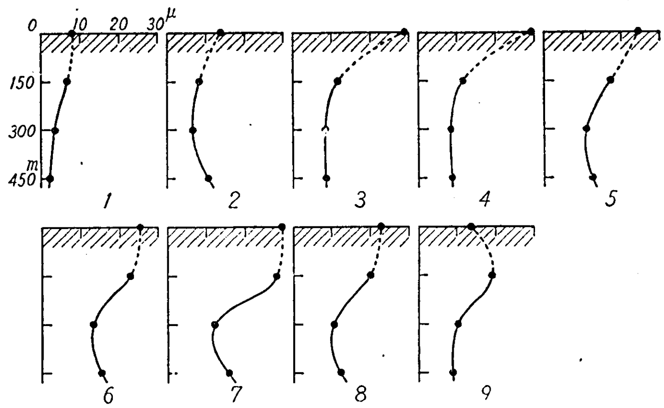


Fig. 11. The distributions of horizontal displacements at different depths of cases corresponding to Fig. 6.

The distribution of displacement at different depths which has been taken out following the order of waves of the records are shown in Figs. 9 ~13. From Figs. 9~13 we found that there are maximum or minimum displacement of waves in a certain depth, excepting the initial parts of the main shocks.

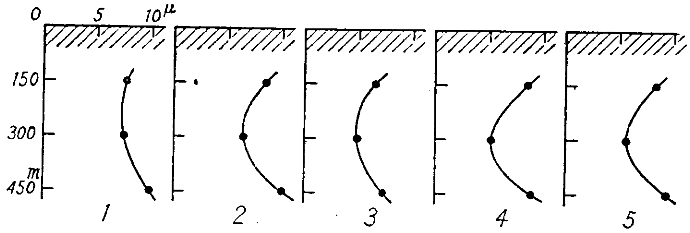


Fig. 12. The distributions of horizontal displacements at different depths of cases corresponding to Fig. 7.

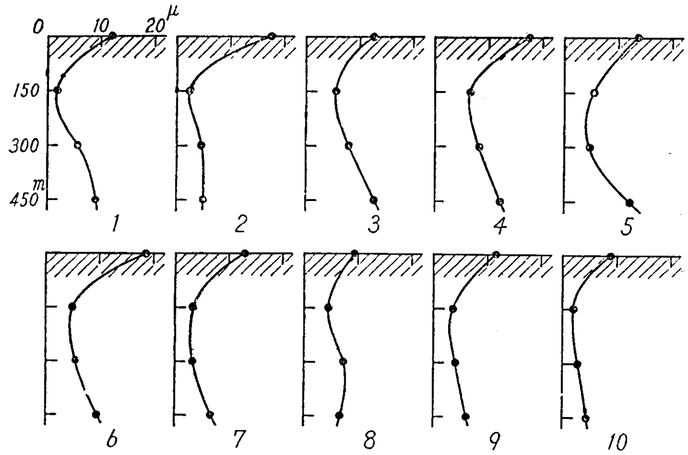
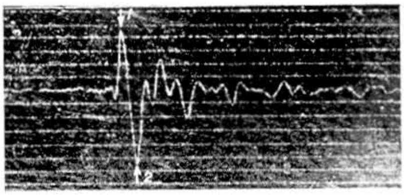


Fig. 13. The distributions of horizontal displacements at different depths of cases corresponding to Fig. 8.

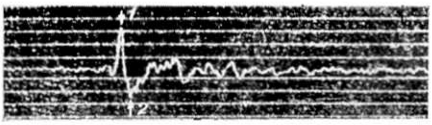
It is a well-known feature of surface waves that since the amplitudes of usual Rayleigh-waves decrease exponentially from the free surface, and those of Love-waves having no horizontal nodal plane in the stratum are distributed sinusoidally, with the maximum at the free surface, then these two kinds of surface waves cannot take the maximum or the minimum amplitude at a certain depth. However, from the results of the recent investigations[3] concerned with the dispersive surface waves transmitted along the surface of a stratified body, we knew that generally the M_2-waves having no horizontal nodal plane in the stratum take a maximum amplitude of horizontal component of displacement at a certain depth.

Thus, from the above consideration, it is possible to assume that the waves having a peculiar feature in distribution of displacement are the M_2-waves.

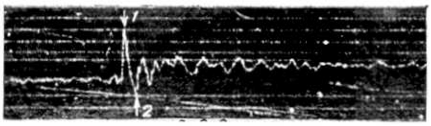
3) K. KANAI, "On the M_2-waves (Sezawa-waves)", *Bull. Earthq. Res. Inst.*, **29** (1951), 45.



0 m



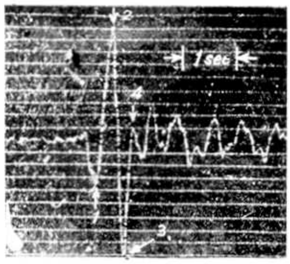
150 m



300 m

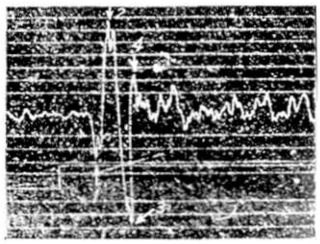
450 m

Fig. 4. Records of the early parts of the main shocks of the earthquake, 36.5° N; 140.8° E, D=very shallow, $\Delta \fallingdotseq$ 21 km, 1950 IV 20. Original × 3.5.



0 m

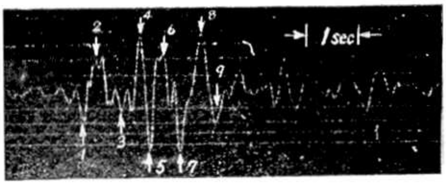
150 m



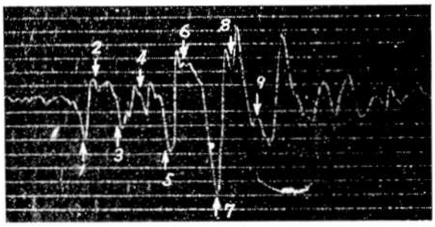
300 m

450 m

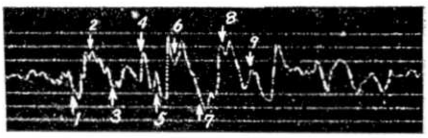
Fig. 5. Records of the early parts of the main shocks of the earthquake, 36.2° N; 140.1° E, D=50 km, $\Delta \fallingdotseq$ 63km, 1950 V 11, Original × 3.5.



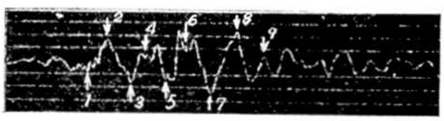
0 m



150 m



300 m



450 m

Fig. 6. Records of the early parts of the main shocks of the earthquake, 36.2° N; 141.2° E, $D=40$ km, $\Delta \fallingdotseq 70$ km, 1950 IV 14. Original × 3.5.

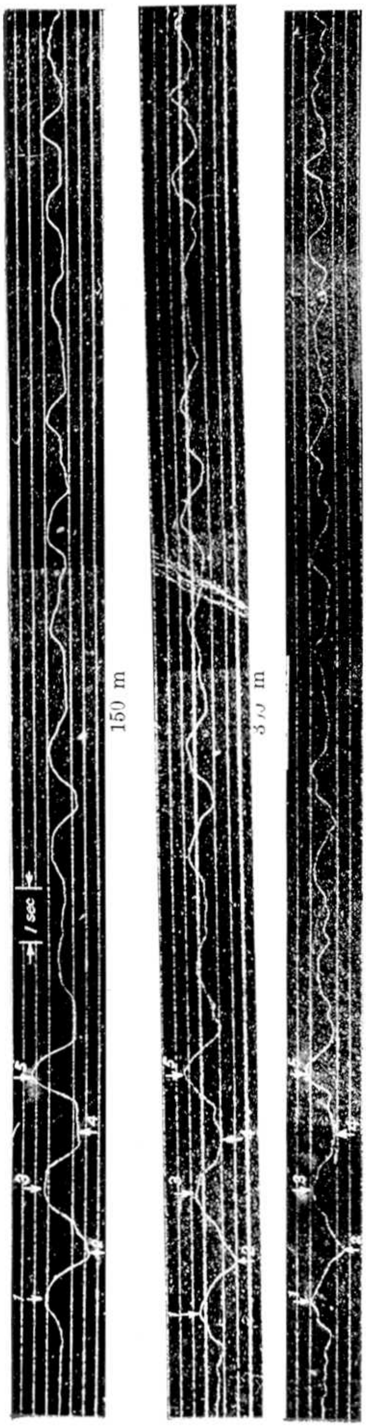


Fig. 7. Records of the parts considered satisfactorily to be surface waves of the earthquake, 33.8° N; 135.8° E, $D=40$ km, $\Delta \fallingdotseq 530$ km, 1950 IV 26. Original × 3.5.

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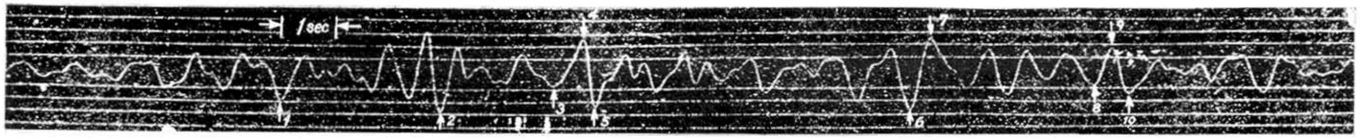
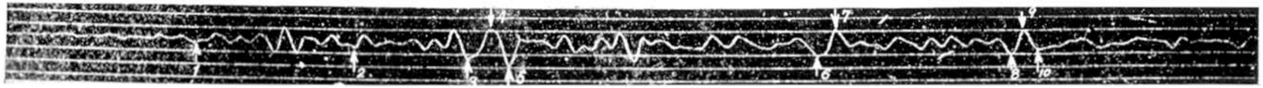
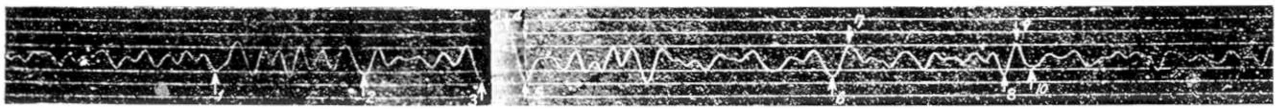


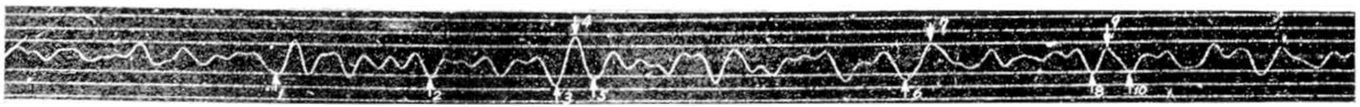
0 m



150 m



300 m



450 m

Fig. 8. Records of the parts considered satisfactorily to be surface waves of the earthquake, 37.6° N ; 142.5° E, D=very shallow, $\Delta \fallingdotseq 200$ km, 1950 V 18. Original × 3.5.

4. Concluding remarks.

From the results of the observation of earthquake-motions at different depths of Hitachi mine, we found some noteworthy facts.

One of the results of observations tells us that the angles of incidence of P waves and S waves of earthquakes whose hypocentres were under the sea are smaller than those whose hypocentres were on the land, whatever the epicentral distance, magnitude of earthquakes and depth of hypocentres may be.

It should be borne in mind that the distribution of horizontal component of seismic waves as to the depth in the earth is not so simple as considered formerly, and the component takes the maximum or the minimum amplitude of waves at a certain depth in the earth in general. From the results of the recent investigations, it is quite possible to assume that the wave having a maximum horizontal amplitude at a certain depth will be the M_2-waves.

In conclusion, we wish to express our sincerest thanks to Professor S. Nishio and the Motoyama-office of Hitachi mine with whose kind aid the present series of investigation were brought forth successfully. We also wish to express our thanks to Messrs. T. Suzuki, K. Osada and Miss S. Yoshizawa for the valuable assistance they offered in these investigations.

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9. 地下における地震動の観測結果 第1報

地震研究所 金井清 田中貞二

茨城縣日立鑛山の地表面並びに地下 150, 300, 450 m の 4 個所で地震動の觀測を行つているが，記象を整理した結果，現在までにわかつた事項について第1報とする。

先づ，P 波，S 波の第1動について 0 m と地下 450 m との比をとると，震央距離，地震の大さ，震源の深さに無關係に，震源が海にある場合の方が陸にある場合よりも，この比が大きく，從つて，地震波の入射角は震源が海にある場合には，陸にある場合よりも小さい性質のあることがわかつた。

日立鑛山における地震動は約 30 km 南方にあたる水戸市における地震動に比べて非常に小さく，この原因は地盤の差違だけでは説明が困難のようである。

次に，主要動の水平成分の地表面よりの深さについての分布をしらべたところ，ごく最初の部分を除くと，この分布は從來考えられていたような單純なものではなく，或深さのところに水平成分の極大や極小がある場合が多いことが見出された。

最近の研究によると，M_2 波の水平成分は，多くの場合，表面層の或深さのところに極大ができるから，この M_2 波の性質を考慮に入れると觀測結果に現われた地震動の水平成分の地下分布に一應の説明をつけることができる。