26. *Observational Study of Earthquake Motion in the Depth of the Ground. V.* *(The Problem of the Ripple of Earthquake Motion)*

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1. Introduction.

It was found from the records of displacement seismograph shortly after the invention of seismograph towards the end of 19th century that in most cases the waves of short period and small amplitude, the so-called ripples, overlap those of large amplitude and long period[1].

It also became clear from the records of acceleration seismograph that there is a period peculiar to each ground property of which the frequency is predominant[2]. In using an acceleration seismograph waves of comparatively short period such as ripples tend to appear prominently, therefore the predominant period peculiar to each ground property may be due to the property of ripples. Then it is easily assumed that the ripples are the waves generated near the ground surface.

Thus it becomes fundamentally necessary to investigate the property of ripples thoroughly not only for the purpose of clarifying the nature of seismic waves but also for the promotion of engineering seismology.

In this paper, using the results of observation made at the ground surface and 300 m under the ground at Hitachi Mine in Ibaraki Prefecture, the property of the ripples of earthquake motion is investigated.

2. Frequency of the period of earthquake motion.

In Table I the constants of the seismograph used in the observation made at the above-mentioned places are shown.

Although the period frequency of earthquake motion is observed from a number of earthquakes, those which were examined with special

1) F. OMORI, *Pub. Earthq. Inv. Com.*, **10** and **11** (1902).

2) M. ISHIMOTO, *Bull. Earthq. Res. Inst.*, **12** (1934), 234.

Table I.

Position	Horizontal			Vertical		
	Period (sec)	Damp. ratio	Magnif.	Period (sec)	Damp. ratio	Magnif.
0m	EW 0.97 NS 0.87	13:1	EW 220 NS 290	0.10	13:1	2.2 gal/mm
300m	EW 0.91 NS 1.02	13:1	EW 200 NS 240	0.26	13:1	0.3 gal/mm

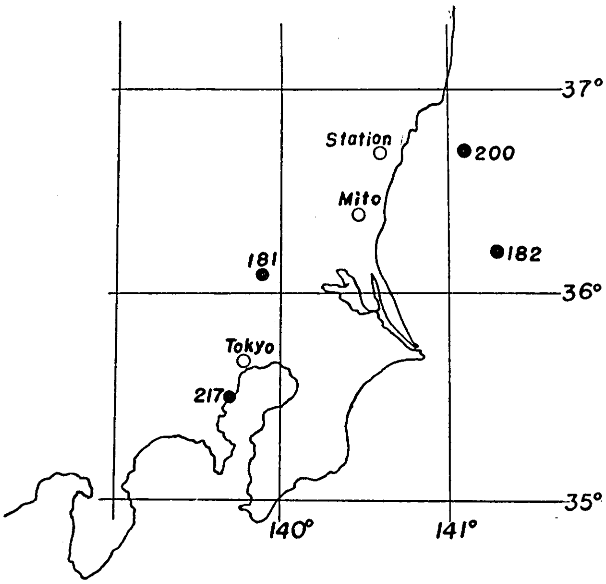


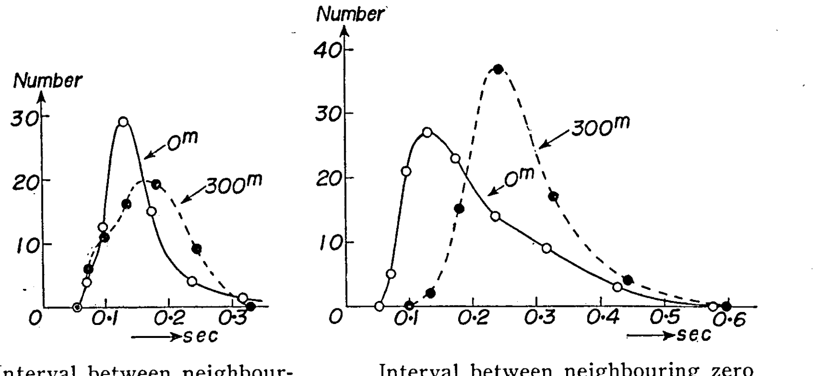
Fig. 1.

preciseness are written in Table II, and the representative seismograms of them are illustrated in Figs. 2 and 3.

From the horizontal seismograms of these earthquakes, the number of waves and their periods i.e. the frequency of period, concerning both the preliminary tremor and the main shock, are found. The period is accepted in two ways. In one way, the interval between neighbouring points at which the wave cross the 0-line is accepted as the period, and in the other way, the interval between neighbouring peaks of the seismogram is accepted. The results are shown in Figs. 4~7.

Table II.

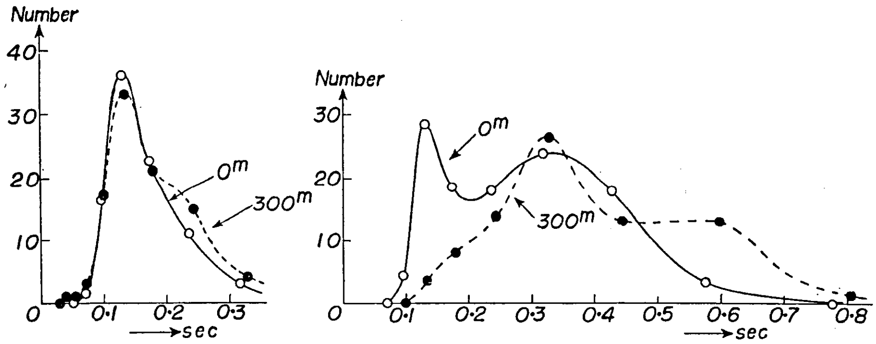
Earthquake Number	Date	Origin		
		φ	λ	Depth (km)
181	1952 II 20	36.1	139.9	55
182	1952 II 26	36.2	141.3	40
200	1952 III 10	36.7	141.1	40
217	1952 IV 8	35.5	139.7	110



Interval between neighbouring peaks is period.

Interval between neighbouring zero amplitudes is period.

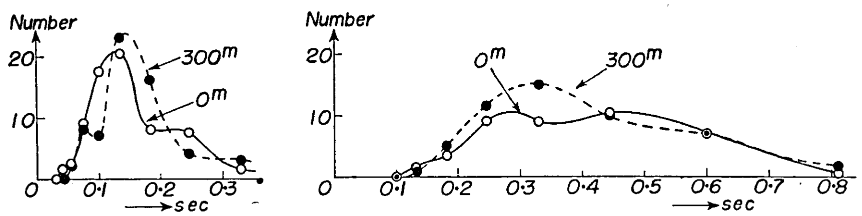
Fig. 4a. The frequency-period relation of the horizontal component of the preliminary tremor of No. 181.



Interval between neighbouring peaks is period.

Interval between neighbouring zero amplitudes is period.

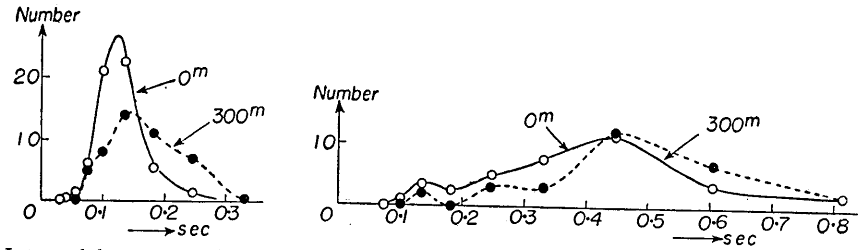
Fig. 4b. The frequency-period relation of the horizontal component of the main shock of No. 181.



Interval between neighbouring peaks is period.

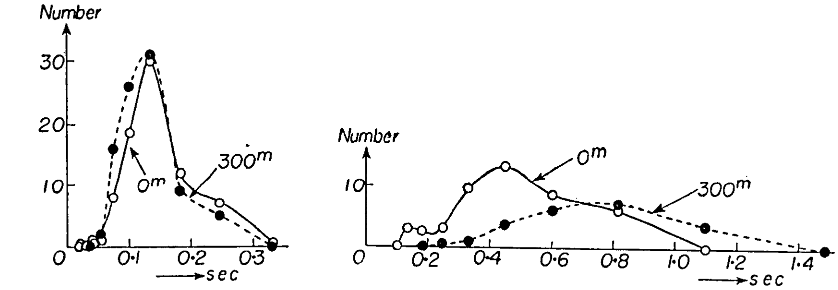
Interval between neighbouring zero amplitudes is period.

Fig. 5. The frequency-period relation of the horizontal component of the preliminary tremor of No. 182.



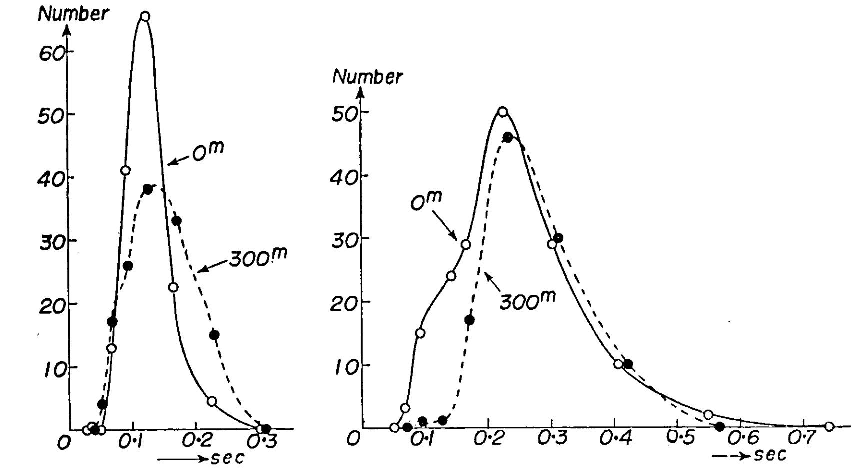
Interval between neighbouring peaks is period. Interval between neighbouring zero amplitudes is period.

Fig. 6a. The frequency-period relation of the horizontal component of the preliminary tremor of No. 200.



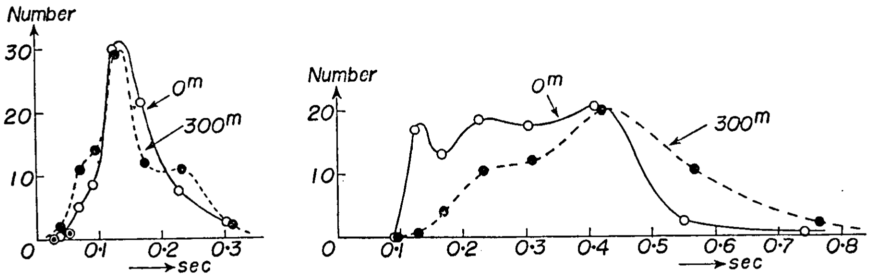
Interval between neighbouring peaks is period. Interval between neighbouring zero amplitudes is period.

Fig. 6b. The frequency-period relation of the horizontal component of the main shock of No. 200.



Interval between neighbouring peaks is period. Interval between neighbouring zero amplitudes is period.

Fig. 7a. The frequency-period relation of the horizontal component of the preliminary tremor of No. 217.



Interval between neighbouring peaks is period.

Interval between neighbouring zero amplitudes is period.

Fig. 7b. The frequency-period relation of the horizontal component of the main shock of No. 217.

From these figures it is easily seen that if the period is considered to be the interval between the neighbouring peaks of seismogram, the frequency distribution at 0 m coincides well with that obtained at 300 m under the ground, and the period corresponding to the maximum of frequency distributions of all earthquakes is definite, its value being about 0.13 sec. In the case when the period is accepted to be the interval between neighbouring points where the 0-line meets the seismogram, the frequency distribution at 0m coincides with that obtained at 300m under the ground in some cases, while in other cases there is quite a difference between them. Moreover each earthquake has its own predominant period. When the period is accepted in this way, the predominant period at 0m often becomes 0.13 sec which is equal to the predominant period value in the case when the period is assumed to be the interval between neighbouring peaks of seismogram. This holds true in the case of P-wave of No. 181.

3. The consideration on the generation of ripples of earthquake motions.

In order to simplify the form of incident seismic wave, it is assumed that it consists of two different kinds of waves, as shown in the following equation.

$$u_0 = A_1 e^{-\frac{(vt-x)^2}{c_1^2}} + A_2 e^{-\frac{(v\overline{t-\tau}-x)^2}{c_2^2}} . \qquad (1)$$

If such a wave as shown in equation (1) propagates in the vertical direction, the vibrations of ground surface will be as expressed in equation (2) due to the multiple reflection of wave in the surface layer.[3]

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

$$u'_H = 4A_1 \sum_{m=0}^{\infty} (-1)^m \frac{(1-\alpha)^m}{(1+\alpha)^{m+1}} e^{-\frac{\beta^2 (v't - \overline{2m+1}H)^2}{c_1^2}}$$

$$+4A_2 \sum_{m=0}^{\infty} (-1)^m \frac{(1-\alpha)^m}{(1+\alpha)^{m+1}} e^{-\frac{\beta^2 (v't - \tau - \overline{2m+1}H)^2}{c_2^2}} \qquad (2)$$

in which $\alpha=\rho' v'/\rho v$, $\beta=v/v'$. Using equation (2) the calculation in two cases, that is, $A_1=-1/2$, $A_2=1$ and $A_1=-2$, $A_2=1$, beside the conditions $\rho=\rho'$, $v=6v'$, $\tau=4H/v'$, $c_1=3H$ and $c_2=30H$, is carried out, and it becomes as shown in Figs. 9 and 10.

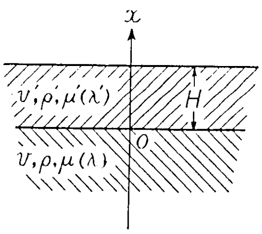


Fig. 8.

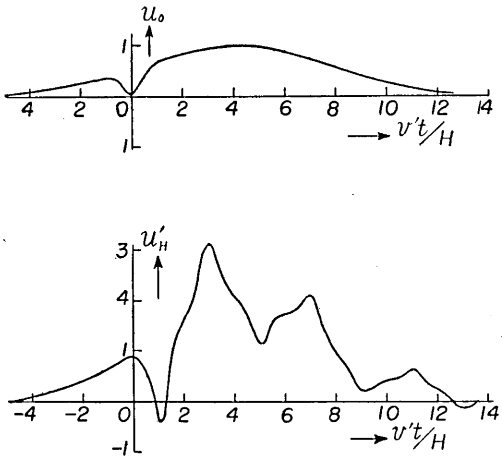


Fig. 9. $A_1=-1/2$, $A_2=1$.

When there are waves of the period equal to or shorter than the natural period of surface layer in incident seismic wave, the natural period of surface layer is apt to appear in the vibration at ground surface. This is clear from Figs. 9 and 10.

It is also seen from Fig. 9 that the wave-form of so-called ripple appears in the vibration at ground surface when the waves of shorter period are of smaller amplitude. P-wave of No. 200 is just an example of this case. In the case when the amplitude of the waves of shorter period is comparatively large, the wave-form of ripple cannot be seen at the ground surface. This will be seen in Fig. 10. P-wave of No. 181 belongs to this case.

From Figs. 9 and 10 it is found that if the interval between neighbouring peaks of seismogram is assumed to be the period, there will be many waves of the period equal to the natural period of surface layer. In other words, the predominant period of the ripples of earthquake motion may be assumed, as the first approximation, to be the natural period of the surface layer. On the other hand, if the interval between neighbouring points where the 0-line meets the seismogram is regarded as the period, many waves of the period equal to the natural period of surface layer can be seen only when the waves of short period which are found among incident seismic waves are of considerably large amplitude. Consequently, in order to find the natural period of the surface layer from seismograms, it may be better to adopt the interval between neighbouring peaks of displacement seismogram as the period.

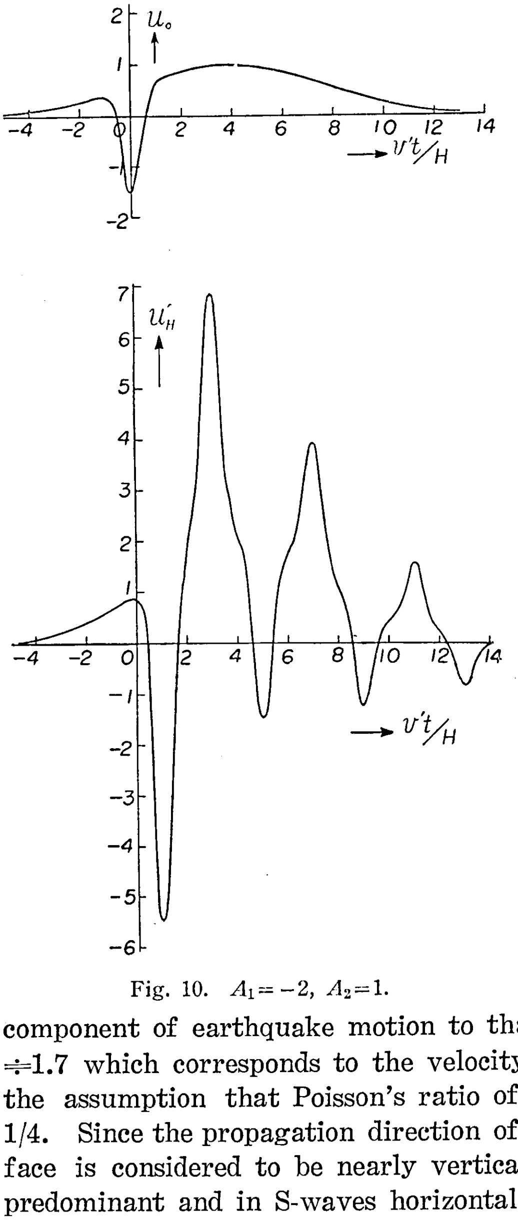


Fig. 10. $A_1=-2$, $A_2=1$.

4. Study of the property of surface layer through the ripples.

Fig. 11 shows the frequency of the period obtained from the vertical seismogram of earthquake motion at the ground surface. The period to which the maximum of the frequency corresponds becomes about 0.07 sec.

The ratio of the predominant period of the horizontal component of earthquake motion to that of the vertical one is $0.13/0.07 \doteqdot 1.7$ which corresponds to the velocity ratio of S-wave to P-wave on the assumption that Poisson's ratio of the material of surface layer is 1/4. Since the propagation direction of the seismic waves near the surface is considered to be nearly vertical[4], in P-waves vertical motion is predominant and in S-waves horizontal motion is so, and the predominant periods of both the horizontal and vertical motions correspond to

4) T. Matuzawa, K. Hasegawa and S. Haeno, *Bull. Earthq. Res. Inst.*, **4** (1928), 85.

T. Suzuki, *Bull. Earthq. Res. Inst.*, **10** (1932), 517.

the natural periods of surface layer concerning P-waves and S-waves respectively. From this it is clear that there are ripples due to S-waves in the preliminary tremor and ripples due to P-waves in the main shock.

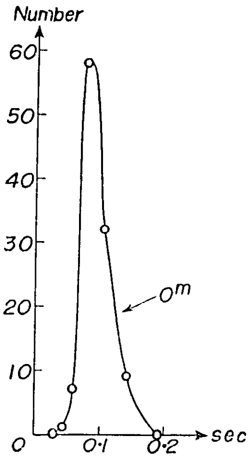


Fig. 11a. The frequency-period relation of the vertical component of the preliminary tremor of No. 182.

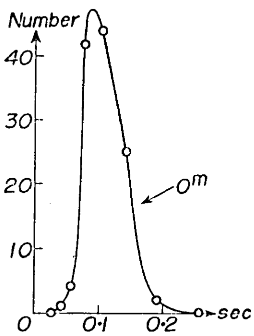


Fig. 11b. The frequency-period relation of the vertical component of the main shock of No. 182.

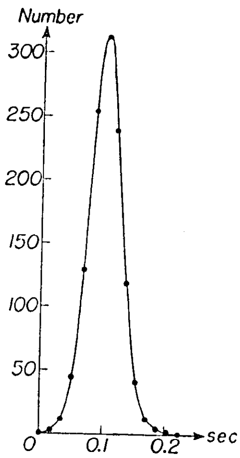


Fig. 12. The frequency-period relation of micro-tremor.

Fig. 12 illustrates the frequency distribution of the period of micro-tremor measured at the ground surface of the observation spot and its maximum value comes to 0.13 sec. From Fig. 12 and Figs. 4~7, it is found that the period to which the maximum of the period frequency of the micro-tremor at a certain place corresponds coincides with the period at the same place to which the maximum of the period frequency corresponds in the case where the interval between neighbouring peaks of seismogram is the period.

This means that the ripples of earthquake motion represent the characteristics of the ground just as the property of micro-tremor does.

In the previous research the relation between the amplitudes at the ground surface and at 300 m under the ground was studied and the result was that the maximum value of the ratio of the amplitude at the ground surface to that of the vibration at 300 m under the ground becomes about 6[5], which is acceptable by assuming that the ratio of the vibration impedance of under ground layer material to that of the

5) K. KANAI, K. OSADA and S. YOSHIZAWA, *Bull. Earthq. Res. Inst.*, **31** (1953), 226, Fig. 6.

surface layer material is 3.

From recent observations it became clear that at the observation spot here concerned there is a soil layer near the ground surface in which the velocity of P-waves is about 500 m/sec. And the previous observation made it clear that there are rocks under the said layer where the mean velocity of P-waves is 1500 m/sec.[6] Consequently, assuming that the ratio of density is approximately 1, the ratio between the vibration impedance of the material of lower medium and that of soil layer becomes 3 and it coincides with the above-mentioned value.

Next, from the velocity of P-waves at the surface layer, 500 m/sec, and the predominant period obtained from the seismogram of vertical component, 0.07 sec, the thickness of the soil layer is found to be 10 m. This is a plausible value in consideration of the conditions of the observation spot.

5. Conclusion.

From the seismograms obtained at the ground surface and 300 m under the ground at Hitachi Mine in Ibaraki Prefecture, the property of the so-called ripples of earthquake motion is studied. Considering the results of both this and the previous study, the following fact is found.

When waves with period equal to or shorter than the natural period of the surface layer are found among the incident seismic waves, the wave form of ripple will originate due the multiple reflection of seismic waves in the surface layer.

Therefore it can be said that the predominant period of the ripple of earthquake motion corresponds to the natural period of surface layer.

Then, in studying the property of surface layer by finding the predominant period from seismogram, it may be appropriate to regard the interval between neighbouring peaks of displacement seismogram as the period.

Finally, it is found that P-waves have a natural period different from that of S-waves, and the period to which the maximum of the period frequency of micro-tremor corresponds is coincident with the natural period of surface layer in case of S-waves, which is of important meaning from the engineering point of view.

In conclusion, we wish to express our hearty thanks to the members

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6) K. KANAI, *Bull. Earthq. Res. Inst.*, **29** (1951), 506, Fig. 4.

of Motoyama Office, Hitachi Mine. We also wish to express our thanks to Messrs. T. Tanaka and T. Suzuki who took part in the observation.

26. 地下深所における地震動の観測結果 第5報 (地震動の漣の問題)

地震研究所 金井 清 / 長田甲斐男 / 吉沢静代

茨城県日立鉱山の地表面及び地下 300 m における地震記録から，いわゆる地震動の漣の性質をしらべたところ，次の事柄がはつきりした．

地震波の中に地表層の固有周期と同程度の周期の波又はそれよりも短い周期の波が混つていると，地震波が地表層の中で重複反射することによつて，いわゆる漣と称される波形が発生する．そして，漣を発生するもとになる波の振幅が小さいときは，漣は振幅が大きく周期の長い波の上に重なつてあらわれることになる．

従つて，地震動の漣の卓越周期を求めると，これは地表層の固有周期に近い値をとることになる．

それで，地震記象から卓越周期を求めて，表面層の性質をしらべようとする場合には，地震動の変位の山から山の間を周期とすることが適当ということになる．

なお，表面層の固有周期は P-波の場合と S-波の場合とで値がちがうわけであるが，常時微動の周期の頻度の最大になる周期は，工学方面で大切な,S 波による表面層の固有周期にあたることが確められた．

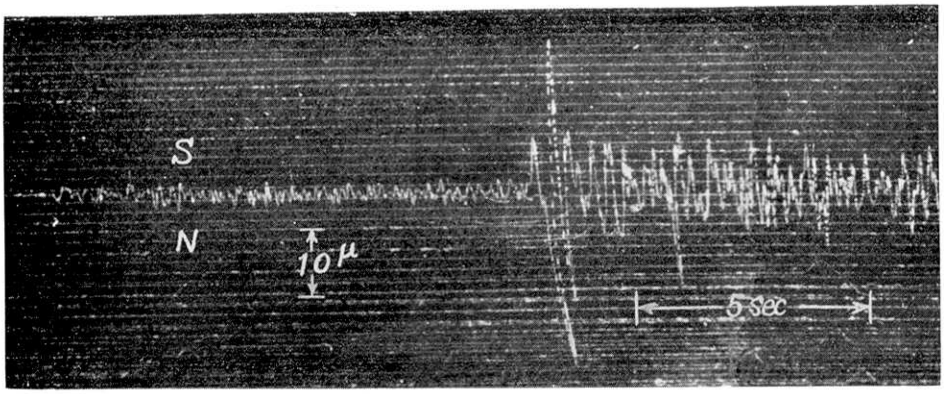

Fig. 2a. Seismogram of No. 181 at the ground surface.

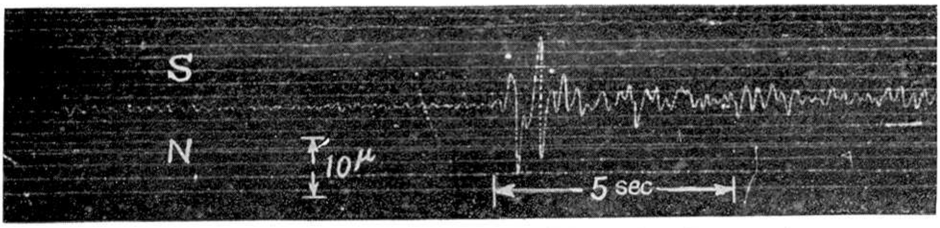

Fig. 2b. Seismogram of No. 181 at 300 m under the ground.

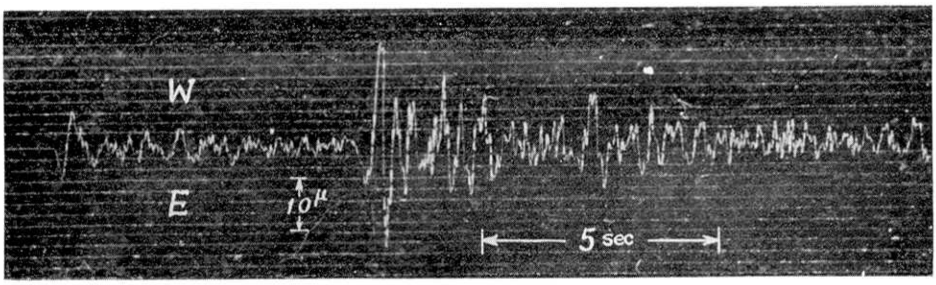

Fig. 3a. Seismogram of No. 200 at the ground surface.

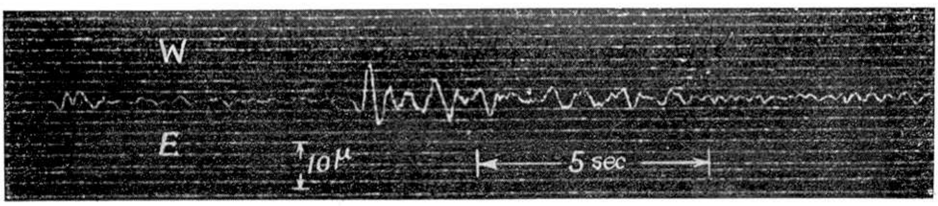

Fig. 3b. Seismogram of No. 200 at 300 m under the ground.