14. *Experiments on Artificial Earthquakes.*

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1. Since the elegant study made by Professor T. Shida, the observations of the initial motions of an earthquake became very significant among observations of many phenomena accompanied by an earthquake to inform us the mechanism of the earthquake. Afterwards, the studies of this problem were much improved by many investigators from both the theoretical and observational sides. Among the investigations the study made on the problem by Professor K. Sezawa[1] and the study based on observed data made recently by Professor M. Ishimoto[2] are specially mentioning. By these investiagtions the mechanisms of many earthquakes were quite cleared up.

Now, the experimental observations of the shakings of the ground caused by artificial sources, for example, the explosion of the dynamite and the fall of a weight on the surface of the ground, were fully made by Professor J. Milne[3]. He stated about the initial motions of these artificial earthquakes as follows.

Near to an origin the first motion is outwards. At a distance from an origin the first motion may be inwards. As to whether it will be inwards or outwards is probably partly dependent on the intensity of the initial disturbance and on the distance of the observing station from the origin.

It seems to us that at a distance from an origin the first outwards motion might be extinguished by the absorption of the soil on the way to the recording station and the second inwards motion which is usually greater than the first motion might be observed as the initial motion.

Afterwards, Professor F. Omori and Professor A. Imamura[4] observed the shocks caused by dynamite explosions in the military exercise ground at Akabane, near Tôkyô. They found that the direction of the initial displacement of an earth particle at the surface in these earthquakes

1) K. SEZAWA, *Bull. Earthq. Res. Inst.*, **2** (1927), 13~28.
2) M. ISHIMOTO, *Bull. Earthq. Res. Inst.*, **10** (1932), 449~471.
3) J. MILNE, *Trans. Seis. Soc. of Japan*, **8** (1885), 1~82.
4) F. OMORI and A. IMAMURA. *Pub. E. I. C.*, **21** (1905), 67.

were outwards from or inwards to the origin according to the origins of explosions were at or some depths below the surface of the ground respectively.

2. The authors are now carrying out the experiments on artificial earthquakes in the yard of the branch station of the Earthquake Research Institute at Komaba, Tôkyô. We are mainly studying the initial motions of the shocks caused by the explosions of the explosives enclosed in pipes both ends open or closed at one end, and by the fall of a heavy weight on the surface of the ground or into the pits digged at several depths in the ground.

This note is the preliminary report of the latter.

For example, the arrangements of an experiment are shown in Fig. 1. The recording instruments are horizontal pendulums, the each heavy bob is a cylinder weighing about 300 gr. and the each magnification is about twelve times.

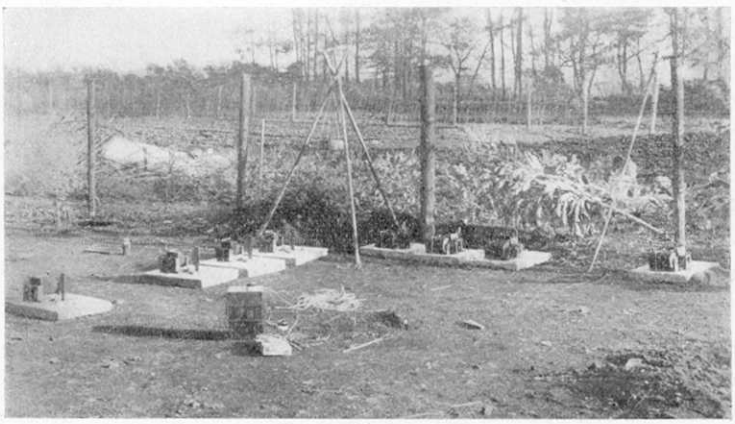


Fig. 1.

The each pendulum has a proper period of about 0·11 sec. and has no damper.

The weight is a iron cylinder weighing about 15 kg. and the diameter is about 19 cm. The amount of the fall of the weight is always about 70 cm.

The pits were digged at 30 cm., 50 cm., 75 cm. and 100 cm. in the ground as narrow as possible to be sufficient for the fall of the weight.

The recording apparatus were mounted at 50 cm., 100 cm., 150 cm., 200 cm. and 250 cm. apart from the origin.

Some of the records obtained by these experiments are shown in Figs. 2 and 3, and the results of observations of the initial motions are

plotted in Fig. 4. In the figure the absissa represents the epicentral distance and the ordinate represents the amount of the initial displacement as recorded. It will be seen in the figure, the initial motions were "push" when the weight had fallen to the surface of the ground. Moreover, in this case, the amounts of initial displacements diminished proportionally to the inverse square of the distance from an origin. When the weight had fallen into a pit sufficiently deep, the initial motions near to the origin were "pull" and at a distance from an origin they were "push". By the way, the periods of waves in these earthquakes mostly are about 0·025 sec.

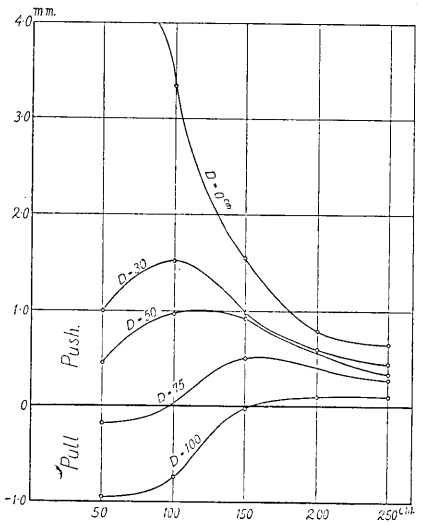


Fig. 4. The relation between the amount of initial motion and the epicentral distance.
D is the depth of the pit.

3. It seems to us that there are two possible explanations for the phenomena above stated.

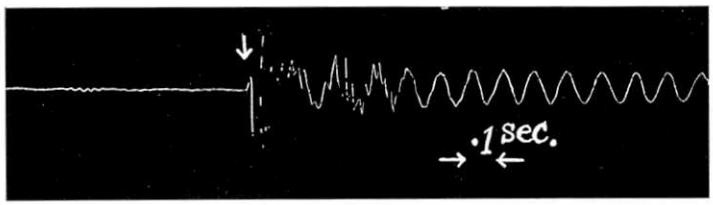
a. The first one is as follows. Near to the origin the ground depressed and at a distance from the origin it bulges out by the impact of the fall of a weight, so that the initial motion is inwards or outwards according to the distance of the observing station from the origin.

b. The second and more probable explanation is as follows. The impact of the fall of a weight may be taken as a doublet force without moment. The dilatational wave spreads out downwards and the condensational wave spreads out upwards from the portion of the ground impacted by the fall of the weight. The nodal plain lies horizontally under the base of the weight. If the velocity of propagation of elastic waves in the ground instead of being constant throughout the medium increases according to the depth, the nodal plain is bent up to the surface of the ground at some distance from the origin, so that the initial motion is "pull" or "push" according to the distance is near to or apart from the origin.

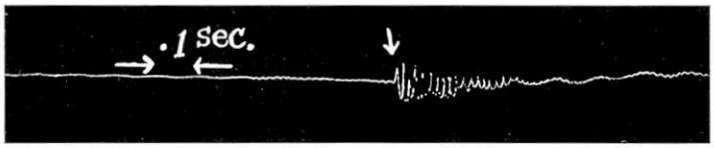
The epicentral distance where the nodal surface bent up to the surface of the ground may be given by the following equation:

$$\Delta = \int_0^H \frac{v\,dh}{\sqrt{\left(\frac{v_0}{\alpha}\right)^2 - v^2}},$$

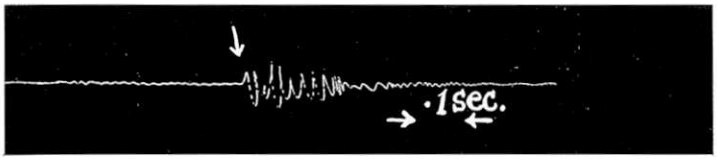
where v is the velocity of the elastic wave at any point, v_0 is that at



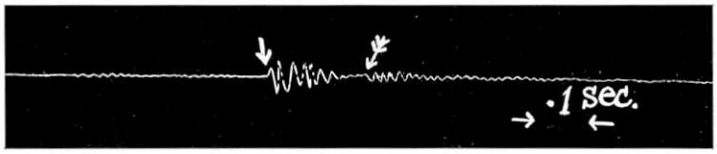
Δ = 50 cm. (Push) (*Full size the actual*)



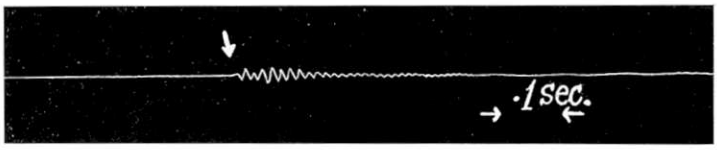
Δ = 100 cm. (Push) (*Full size the actual*)



Δ = 150 cm. (Push) (*Full size the actual*)

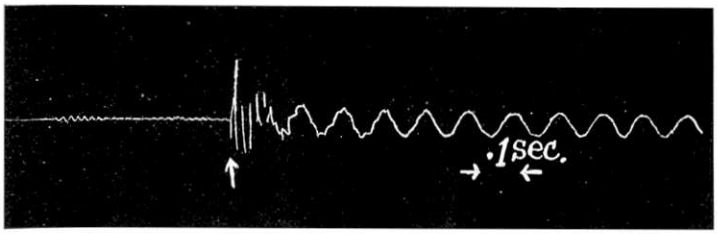


Δ = 200 cm. (Push) (*Full size the actual*)

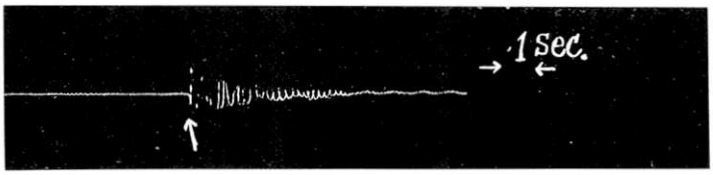


Δ = 250 cm. (Push) (*Full size the actual*)

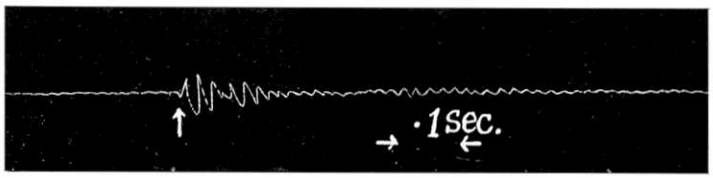
Fig. 2. The shakings of the ground caused by a fall of a weight into a pit of 30 cm in depth.



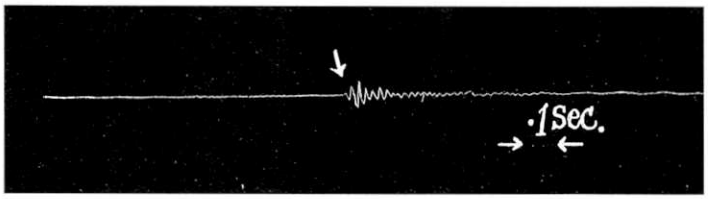
Δ=50 cm. (Pull) (*Full size the actual*)



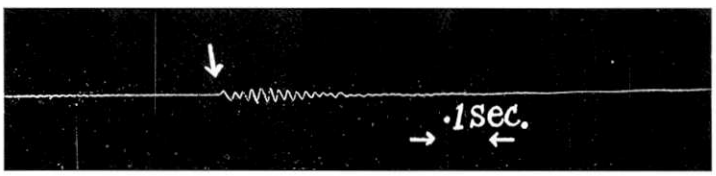
Δ=100 cm. (Pull) (*Full size the actual*)



Δ=150 cm. (Pull) (*Full size the actual*)



Δ=200 cm. (Push) (*Full size the actual*)



Δ=250 cm. (Push) (*Full size the actual*)

Fig. 3. The shakings of the ground caused by a fall of a weight into a pit of 100 cm in depth.

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the surface of the ground, α is the emergency angle of the nodal surface and H is the depth of the pit.

Now, we assume that the wave velocity increases linearly as the depth increases.

$$v = v_0 + ch.$$

Then,

$$\Delta = \int_{v_0}^{V} \frac{v\,dv}{\sqrt{\left(\frac{v_0}{\alpha}\right)^2 - v^2}} = \frac{v_0}{c}\sqrt{\frac{1}{\alpha^2} - 1},$$

where V is the wave velocity at the depth of the pit.

Next,
$$H = \frac{v_0}{c}\left(\frac{1}{\alpha} - 1\right).$$

Eliminating α from these two equations, we obtain

$$c = \frac{2Hv_0}{\Delta^2 - H^2}.$$

Generally, we will obtain different value for the constant c for each experiment changing the depth of the pit, and we can reduce the elastic condition in the earth. In the case of our experiment, when the depth of the pit is 75 cm. the value of $c = 6{\cdot}05\ v_0$, and when the depth of the pit is 100 cm. the value of $c = 1{\cdot}6\ v_0$. This fact suggests that near the surface of the ground the wave velocity diminishes suddenly as the depth decreases.

4. The experiments above stated may serve as examples to depression earthquakes or volcanic earthquakes accompanied by the eruptions of a volcano. In the latter case, the reaction of the eruption may be equivalent to the impact of the fall of a weight into a pit.

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著者等は火藥の破裂，重錘の落下等に依る人工地震の際の初動の研究をしてゐるが，此處には重錘を地上並に地中の穴の中に落した際に生ずる地動の初動の觀測結果を報告してある．此れは陷落地震及び噴火に伴ふ地震の研究並に地下の構造を知る上に幾分役立つものと思ふ．
