28. *Experimental Studies on the Mechanism of Generation of Elastic Waves V.*

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1. Introduction

There are many problems in the practical field of seismology which may be idealized as the generation of elastic waves from an origin embedded deep (or not so deep) in a semi-infinite elastic body. Theoretical and experimental works carried out on the origin lying on the surface or embedded quite deep in the body are of much use in these cases. However, the existence of the seismic origin beneath—but not so far apart from—the free surface of the body must have some special effects, which can not be interpreted by the above-stated works only.

Since the well-known work of Nakano[1)], several studies have been made mathematically[2)] from the above-mentioned standpoint, while we have few experiments made either to prove the results of mathematical ones or to find the correspondences between theories and practical fields[3)]. Model experiments on the laboratory scale seemed to be quite useful for the present purpose, and that was the reason why the author undertook laboratory studies, a part of which will be shown in this paper.

2. Systems of experiments

Generation of elastic waves were made in the block of the low velocity material—solution of agar-agar[4)], and observations were carried out on its free surface in vertical component. The whole system of the experiment is shown in Fig. 1. In the inside of the block (90cm long, 30 cm wide, and 30 cm deep) is embedded a cylindrical cavity as

1) H. NAKANO, *Jap. Journ. Astron. Geophysics*, **2** (1925), 233.
2) K. SEZAWA, *Bull. Earthq. Res. Inst.*, **6** (1929), 1, *etc.*
E. R. LAPWOOD, *Phil. Trans. Roy. Soc. London, Ser. A*, **242** (1949), 63.
M. NEWLAND, *Phil. Trans. Roy. Soc. London, Ser. A*, **245** (1952), 213.
3) *f.i.*, *Research Group Explo. Seis. Report*, No. 9 (1954), 14.
4) K. KASAHARA, *Bull. Earthq. Res. Inst.*, **30** (1952), 259.

the origin. The cavity has the dimension of 20 cm in length and 0.6 cm in radius, and is bounded from the surrounding solution of agar-agar by a thin film of rubber. The compliance of the film is high enough

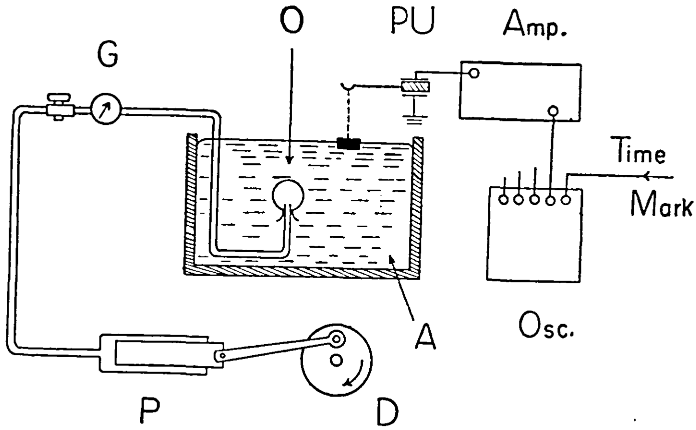

Fig. 1. System of experiments.
A: block of agar--agar, O: origin of disturbances (cylindrical shape),
G: pressure gauge, P: air pump, D: driver
PU: pick-up Amp.: amplifier Osc.: oscillograph

not to obstruct transmission of the inside pressure of the cavity to the surrounding medium. The pressure in the cavity is excited impulsively with an air pump, and its change in time can be measured with a piezo-electric gauge attached to the connecting pipe.

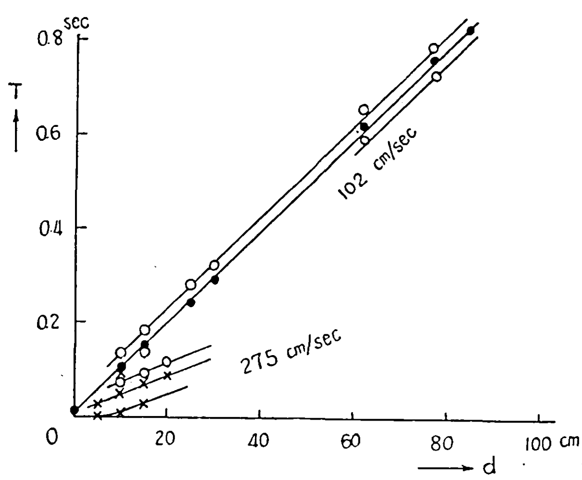

Fig. 2. Travel time curve.

Displacements of the surface are detected by piezo-electric pick-ups connected with thin fibre to marks placed on the surface. Out-puts from pick-ups are amplified by low frequency amplifiers and recorded by a multi-elements oscillograph, with the pressure change and time marks at the same time. Calibrations of electronic systems show that recorded traces of oscillograms can be considered as indicating the velocity of vertical movements of the surface.

3. Results and discussions

We have to know, first of all, the elastic properties of the material under our test, which was so prepared as to have the lowest possible velocities. The travel time curve, Fig. 2, was obtained by applying impulsive pressure to the origin (focal depth: 1 cm). This and other tests[5] indicate the properties of the material being as follows:

velocity of longitudinal wave 275 cm/sec,
velocity of free surface wave 102 cm/sec,
and density of the solution 1.0 g/c.c.

In the course of experiments, observations were made only at points of epicentral distances, 0, 5, 10, 15, 20, 25, and 30 cm. In some cases, disturbances of velocity 102 cm/sec showed remarkable reflection at the side wall of the vessel (Fig. 13), and travel times of these reflected events observed at the said points were used supplementally to draw Fig. 2.

Experiments were made by changing the depth of the origin from 8 to 0 cm. That is, when one set of experiments was finished for a certain focal depth, the surface layer of the block of 2 cm in thickness was taken off before the next step. In this way, effects of changing focal depths could be investigated without changing any of the other conditions.

To the cavity in the block is applied an impulsive pressure of the same duration and of the same maximum value in each experiment (Fig. 13). We know that generations of disturbances are so reproducible that recorded traces can be compared with each other, and Figs. 3 and 4 show representative ones which were obtained by arranging several sheets of oscillograms recorded under the corresponding condition of the origin, respectively. In each case, the epicenter showed a simple impulsive movement followed by slight oscillatory movements, while at points somewhat apart from the epicenter appeared more complicated features, which may be explained as the combination of two series of events: one corresponds to a phase propagating from the origin with the velocity of 275 cm/sec and dissipates rapidly with distance,

5) K. KASAHARA, *loc. cit.*.

while the other appears to be a phase with the velocity of 102 cm/sec and is still remarkable at distant places. The former can be considered as the longitudinal wave from the origin and the latter as the free surface wave of Rayleigh type. The fact that the phase of 102cm/sec shows the linear travel-time curve running from the origin of the coordinates will confirm this interpretation. Figs. 5 and 6 illustrate this result more clearly.

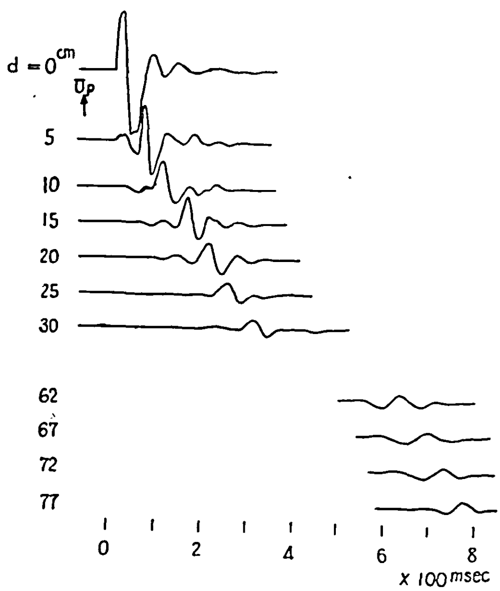

Fig. 3. Traces of disturbances on the surface. Focal depth: 2 cm.

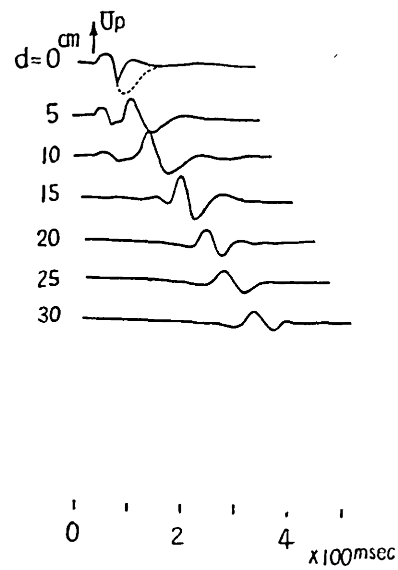

Fig. 4. Traces of disturbances on the surface. Focal depth: 6 cm.

According to the theory of Lapwood, the main shock will show downward initial movement at surface points distant from the origin, when the pressure in the origin increases suddenly (initial P-pulse)[6]. The present result seems to agree with his prediction as well as with the theory of Takeuchi and Kobayashi[7], who carried their study to the phenomena at surface points very close to the epicenter. They showed how the phase of the main shock develops from its primitive form (non-periodic) at the epicenter to its final form (Rayleigh wave) at distant places. From their results, we can easily infer the time derivative of

6) E. R. LAPWOOD, *loc. cit.*

7) H. TAKEUCHI and N. KOBAYASHI, *Annual Meeting of Seis. Soc. Japan*, 1955. (unpublished).

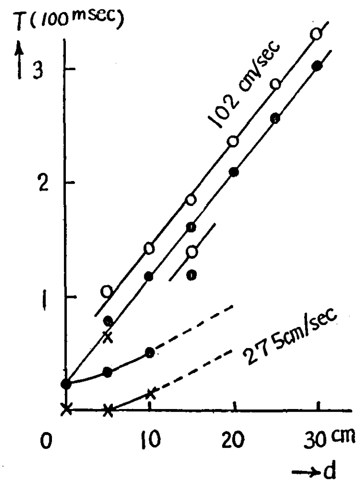

Fig. 5. A part of travel time curves. Focal depth: 2 cm.

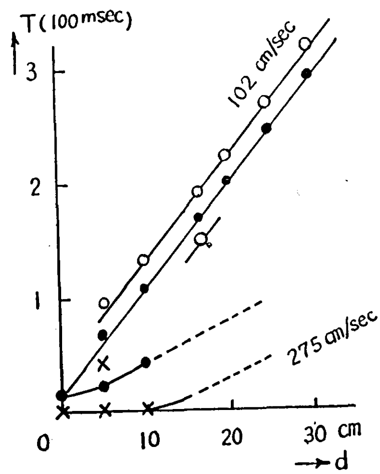

Fig. 6. A part of travel time curves. Focal depth: 6 cm.

movements corresponding to impulsive pressure changes at the line source, which is to be compared with the present experiment.

Nakano has predicted that the event corresponding to free surface waves will be clearly observed only at places where epicentral distances exceed the critical distance, which depends on the depth of the origin[8]. Fig. 7 is offered to illustrate the fact predicted by him. The amplitude of the main disturbance, which forms the surface wave at distant places, shows its maximum value at a critical distance, which becomes larger for deeper origin. Besides this, the fact that the amplitude of this event shows smaller values for deeper origins seems to agree with the theory. We have to notice, however, that remarkable disturbances which show incomplete type of Rayleigh waves exist in the epicentral area of

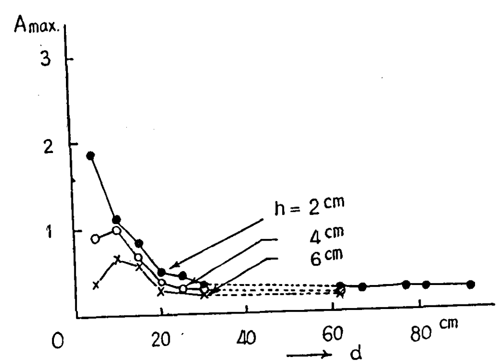

Fig. 7. Amplitudes of main disturbances and epicentral distances.

8) H. NAKANO, *loc. cit.*

shallow origins.

Relations between the amplitude of the initial motion and the depth of the origin are illustrated in Figs. 8 and 9, in which we see amplitudes of initial motions decreasing with increase of the focal depth (h) at the origin ($d=0$) while amplitudes at the point $d=5^{cm}$ show another tendency. Referring to recorded traces (*f.i.* see Fig. 4) we know that the origin area of simultaneous initial disturbances spreads, too, when the focal depth increases.

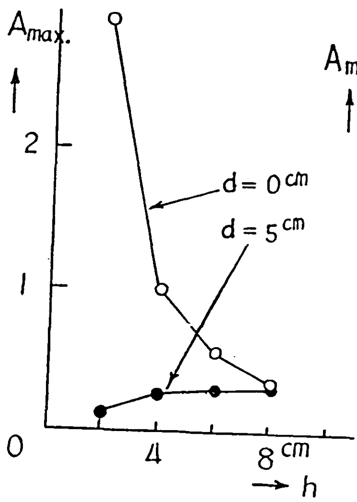

Fig. 8. Amplitudes of initial motions. Short duration of pressure impulses.

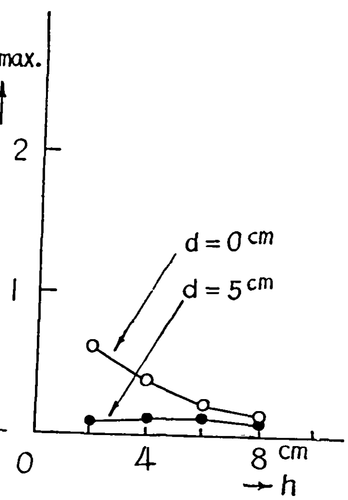

Fig. 9. Amplitudes of initial motions. Longer duration of pressure impulses.

4. Conclusions and acknowledgements

We have made experiments on generation of elastic waves caused by an origin embedded in a semi-infinite elastic body, with a two-dimensional model. Results obtained in this study may be summarized as follows:

1. The initial motion at the epicenter shows an impulsive form, the amplitude of which decreases when the focal depth increases. This tendency appears more clearly when the duration time of pressure impulses becomes shorter.

2. When the shock arrives from the origin, the surface points close to the epicenter commence their motion simultaneously. This area of simultaneous motions spreads when the origin goes deeper in the body.

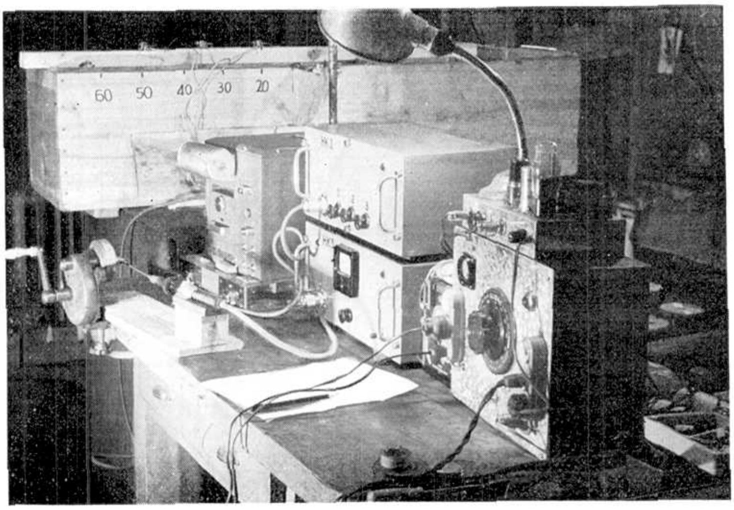

Fig. 10. General view of the laboratory.

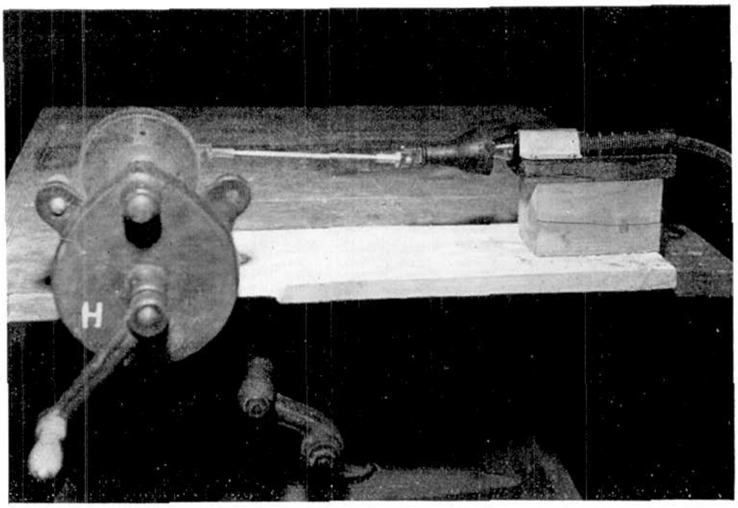

Fig. 11. Air pump and driver.

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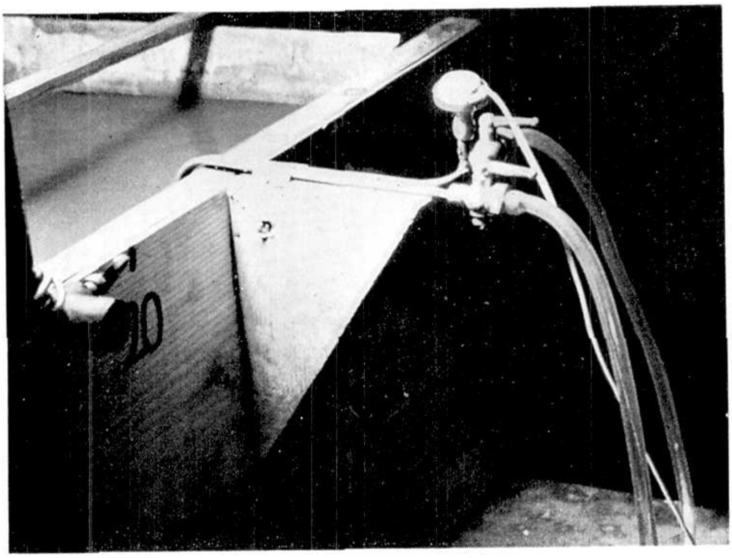

Fig. 12. Pressure gauge.

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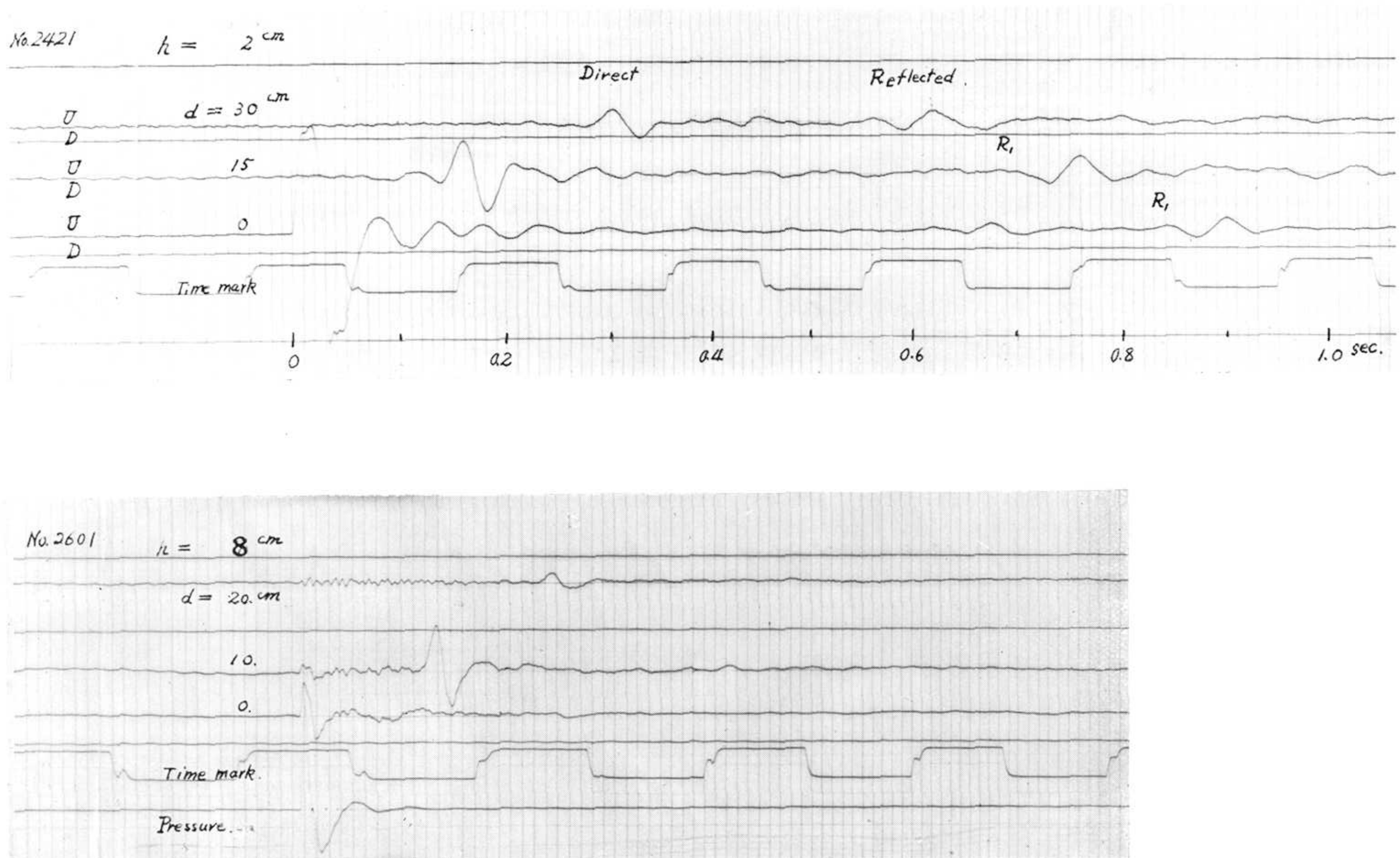

Fig. 13. Examples of oscillograms.

3. The amplitude of main disturbances gets to its maximum value at a critical point on the surface, whose distance from the epicenter depends on the focal depth.

4. The magnitude of main disturbances at the same surface point decreases when the origin goes deeper. This tendency is less remarkable at distant places.

5. The free surface wave shows the linear travel time curve as coming from the epicenter at the origin time of pressure changes.

In the course of this study the author owes very much to encouragement given by Prof. Hagiwara and Dr. Rikitake, both of this institute. He wishes to express his hearty thanks to them as well as to Dr. Takeuchi and Mr. Kobayashi who offered valuable suggestions to him. Mr. Saito and other colleagues kindly helped the author in the laboratory.

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28. 弾性波の発生機構に関する実験 (第5報)

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二次元的模型を用いて，波動源が半無限媒質内部（余り深くない）にある場合の弾性波発生機構を実験した．方法は大体において前報迄のものと類似する．結論されるところは次の諸点である．

1. 波動源に衝撃的圧力変化が起ると，表面上その真上の点は単純な衝撃的運動を行う．その大きさは波動源の深さに伴つて減少する．
2. 衝撃が表面に到着すると，震央部は一斉に運動を開始する．そしてそのひろがりは，波動源が深い程大きくなる．
3. 主要動の振巾はある特定の震央距離において最大となり，この臨界点が波動源の深さに応じて震央を遠ざかることは，理論の結果と比較して興味深い．
4. 同一地点における主要動は波動源が深い場合程少さいが，その傾向は震央を離れた点においては余り明瞭でない．
5. 自由表面波は，あたかも原点時 (origin time) に震央を出発したかのような走時曲線を示している．