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Outline of "Some Problems of Seismic Prospecting".*

By

Masami Hayakawa**

Contents

1. General Introduction.

Seismic exploration has been applied practically to the determination of geologic structure. Usually, we utilize refraction and the reflection waves. In the refraction case, only the first arrivals have been considered. By observing the first arrivals for a variety of shot detector distances, a time distance curve can be constructed. The first arrivals are the fastest travelling waves, therefore refracting method is concerned only with longitudinal waves. Now, if we can use not only the first arrivals, but also the wave forms, such as amplitude, period, damping ratio, etc., the application of seismic prospecting may increase evidently than to-day.

In this meaning, the writer attempts to apply these geophysical interpretations to seismic prospecting, and has studied on these problems for these 7 years. You will see the outline of his study in the following explanation.

For this purpose we must know at first characters of our usage of seismographs. Then, in chap. 2, the writer describes on characters of the "Haeno Seismograph" which has been utilized in the Geological Survey of Japan, and also describes what kind of waves this seismograph would draw. In chap. 3, the writer describes about mechanisms of dynamite explosions. Next, in chap. 4, he discusses about the wave forms such as, amplitude, period, damping, etc. by applying above described results. And he also discusses on subsurface structures calculated from corresponding wave amplitudes, depths of weathering layers by using corresponding wave periods. Finally, in chap. 5, he discusses about the detectable possibility of underground small structures by means of seismic method

2. On the characters of Haeno seismograph.

As above described, we have utilized Haeno seismograph. This seismograph consists of detectors, amplifiers and oscillographs likewise other electrical seismographs, although there are some variations in detail. Then, the wave forms pictured on a record are not the same as incident waves. It is very necessary to clear this relation between the nature of incident waves and the one of pictured waves for the application of wave forms to seismic prospecting. At first, he explains on the construction and characters of Haeno seismograph, then, about some experiments of each parts of apparatus. Finally, he describes on the theories.

Construction of Haeno seismograph.

As above described, this seismograph

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** Staff of Div. Geophys. Prospec. in Geol. Surv. Japan.

consists of three parts, namely detectors, amplifiers and oscillographs. In addition to them, shooting machine (electrical blasting mechine) and telephones are used. In the case of seismic prospecting on seabottoms, radio apparatus and hydrophones etc. are also added to them.

Detectors respond to the resulting ground motions of elastic waves propagated through the medium of shot points. We have a series of six detectors. By catching resulting ground motions, there will be produced electromotive forces, simultaneously. Foucault currents are applied as a damper. Voltages produced in a detector are proportional inversely to vibrating periods by external forces.

Magnitudes of earth movements measured in seismic prospecting are extremely small. Detectors, together with their associated amplifiers, are usually made sensitively enough so that they can record micro impulses. In this case, sensitivities of an oscillograph are proportional to vibrating periods of currents.

Experiments.

The writer makes experiments on detectors, amplifiers, oscillographs. Now, the writer will explain some details of them as follows. At first, he makes experiments on detector about three problems. One of them is to obtain normalized frequency responses of detectors. The second problem is to examine self periods of detectors,and the last one is to examine damping ratios. And he has obtained their results as shown in Tab. I and Fig. I. (In this case, the given amplitude in detectors is 0.1 mm.)

Next, he makes experiments on amplifiers. In this case, his aim is only to obtain composite filter curves of each amplifiers. Finally, he makes experiments on oscillographs. In this case, as was already described in detector's experiments, there are three problems, namely, sensitivity, self vibration and decrement. And he has obtained their results as drawn in Tab. I, and Fig. I.

Theories.

As was already described above, we could

Table I. Results obtained by experiments.

Characters of Haeno Seismograph

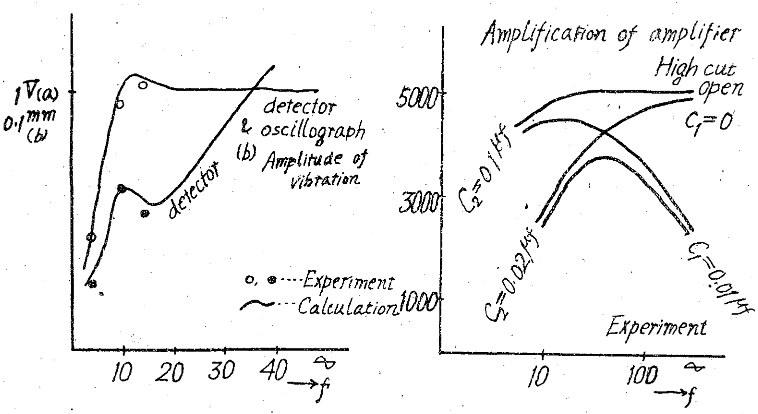
	self period	sensitivity	damping
Detector	10/100 sec.		1/3 critical
Oscillograph	13~14/100 sec.	0.1~0.2 mm/μA	critical

Amplifier	range
a differential	20∞>
b	20~50∞
c integral	>50∞

Comparison of forced vibrating periods with self period

	forced vibrating period	self period of detector forced vibrating period	self period of oscillograph forced vibrating current period
initial movements	3~5/100 sec.	>1	>1
surface wave	8~12/100 sec.	≈1	≈1
sound wave	5~6/100 sec.	>1	>1
sound wave in sea water	2~3/100 sec.	≫1	≫1

Fig. I.



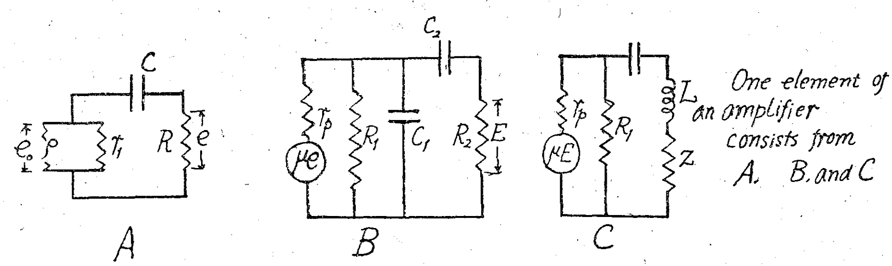
know the characters of Haeno seismograph by some fundamental experiments. And yet, in using this seismograph practically, it is very necessary to study their theories strictly, in order to prove the reliability of experiments. Then, the writer studies their theories. In this case, at first, he studies each parts of apparatus, and then their combinations. Now, he will explain some details of them as follows.

As for detectors and oscillographs, Mr. Haeno has already studied in general, then the writer omits to explain them, and here he will explain only amplifiers.

A schematic arrangement of an amplifier element is shown in a diagram. (Fig. II). As will be seen from Fig. II, this arrangement consists of three parts: A, B and C. according to their necessary ranges by filters. C_1 (high out), and C_2 (low cut) respectively. Finally, in C, the amplified voltage response through the 2nd tube is amplified by current and voltage of the 3rd tube, and this amplified current is transmitted to the oscillograpy through output. At first, the amplification of B part (i. e., the ratio of the amplitude of the response at the output of a tube to the one at the input of the same tube) is calculated. A calculated curve of B part by applying constants of utilized elements (in the case of two tubes with one power tube) is shown in a diagram. (Fig. III)

The processes in A and C are also drawn in another diagram. (Fig. IV). The over all amplification of this amplifier (i. e., the

Fig. II.



In A, a small electrical impulse from detector is transmitted by a cable to the grid of the first tube.

Then in B, the response (voltages) of this small electrical impulse is amplified by the first and second tubes, and at the same time some selected responses are filtrated

Fig. III.

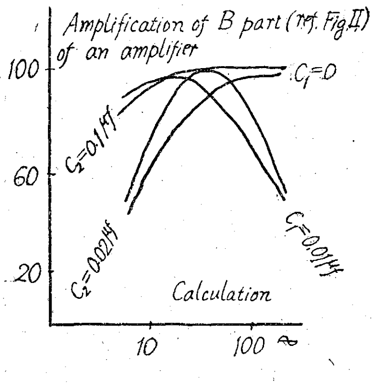
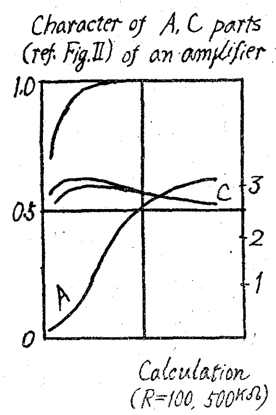


Fig. IV.



ratio of the amplitude of the response at the output of the 3rd tube to the one at the input of the first tube) is calculated from these diagrams. By comparing these results with those of experiments, you will see that these two resemble each other. As for the characteristics of a, b and c parts

Table II. Cases only displacements can be recorded.

(x····displacement of the earth)

self period of detector forced vibrating period	electro-motive force produced in detector E	rôle of amplifier ref. (Table I)	self period of detector forced vibrating period	motion of oscillograph	record obtained
$\gg 1$	$K_1 \frac{dx}{dt}$	b	$\gg 1$	$k_1 \int i\, dt$	$K_1\ k_1\ x$
$\gg 1$	$K_1 \frac{dx}{dt}$	$c = bx \iint E\, dt\, dt$	$\ll 1$	$k_3 \frac{di}{dt}$	$\gamma^1\ K_1\ k_3\ x$
≈ 1	$K_2 \frac{d^2x}{dt^2}$	c	≈ 1	$k_2\ i$	$\beta\ K_2$
$\ll 1$	$K_3 \frac{d^3x}{dt^3}$	c	$\gg 1$	$k_1 \int i\, dt$	$\alpha^1\ K_3\ k_1\ x$

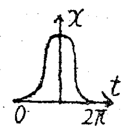
of an amplifier, you will see easily that they correspond to the differential, constant, and integral meanings, respectively.

Finally, the writer wishes to explain synthesized theories. By considering those effects as described in the preceding study, it is recognized how the nature of the pictured waves differ from incident waves. To examine these relations, the writer makes a diagram as will be shown in Tab. II. (This table shows the case in which only displacements can be recorded.) From this table, you will see their relations. For example, in the case of sound waves through seawater, their perfect displacements are pictured, and in the case of first kicks of refraction waves, somewhat displacementlike movements are pictured. As for sufrace waves, velocity or acceleration movements are pictured.

Foregoing descriptions are cases of continued vibrations, and here the writer will explain a transcient motion. He thinks that the first vibration which is transmitted through elastic media from the shot would be a simple shock type wave, when the observation point is near the shot. Then he calculated what type of wave should be pictured, when a simple type wave reached the detector. The figure of a shock type wave is supposed as the equation I. The result from calculation by applying experimental data is drawn in a diagram. (Fig. V). An example of practical record near the shot is shown in Fig. VI. From these two figures, you will see that the result of calculation resembles to one of the experiments.

From foregoing investigations, we know the characteristics of our apparatus (Haeno seismograph). Summarizing the results obtained in this chapter, we can say, at any rate, that according to these acknowledgements, it becomes possible to discuss the wave forms, such as amplitude, period, and damping ratio etc.. The writer wishes to explain some problems of explosions at seismic prospecting before practical

Eqation I.



$t<0 \quad x=0$

$0<pt<2\pi \quad x=\frac{3}{2}-2\cos pt.+\frac{1}{2}\cos 2pt$

$pt>2\pi \quad x=0$

Fig. V.

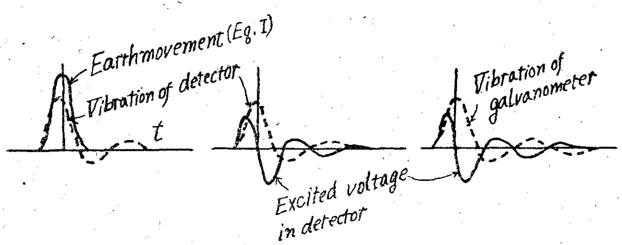
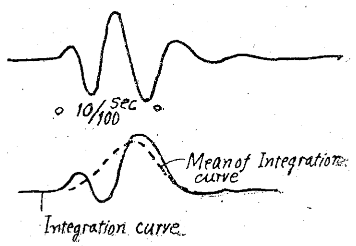


Fig. VI.



applications of these wave forms.

3. Some problems of explosions at seismic prospecting

Needless to say, it is very important to investigate the shooting mechanism at seismic prospecting. It is no exaggeration to say that the good or bad qualities of records depend upon the method of explosion, geology at shot and recording points and the sensitivity of seismographs. Then the writer studies some fundamental problems of explosions at seismic prospecting shooting mechanism, outbreak of transverse wave, and explosion of a cap. You will see the results of these investigations in the following explanations.

Shooting mechanism.

If records are very good, there may be usually many outstanding pulses, namely direct refraction, reflection, sound and surface waves on all records.

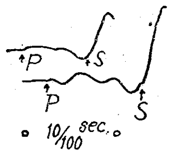
However, these phases can be obtained only by long shot detector distances. As for records obtained by near shots, we must study on wave forms. For example, the writer points out a record, (Fig. VI) in which the shot detector distances is only about 15 meters. As will be seen from this record, the wave form appeared near a shot point is a simple shock type kick. We can say from this fact that the shooting mechanism is very simple and, at the same time, a correct record can be pictured by this seismograph. As a rule, wave forms get out of shapes according as they leave shot points. This phenomenon is attributed to visco-elastic properties of the earth crust.

Outbreak of transverse wave.

The theory of elasticity shows that a homogeneous isotropic medium can transmit two kinds of wave which have different speeds of propagation, depending on elastic constants. These are longitudinal and transverse waves. In natural earthquakes, both longitudinal and transverse waves are usually recorded, and the constitution of the earth has been explained by means of calculations of these propagating waves.

On the other hand, at seismic prospecting we can usually recognize only longitudinal waves on its record. However, sometimes, we can find transverselike waves on records. (Fig. VII). Concerning whether these are transverse waves or not, many discussions are done, i. e., about ratios of amplitudes between initial and second waves (in question), ratios of arriving times between them, etc.. On these inquiry, the writer has decided these transverselike phases as S waves.

Fig. VII.



Now, in what conditions S waves appear? After many investigations, he has obtained some trustworthy results.

(1) The media around the shot point is very hard.

If $\mu \to 0$, the velocity of transverse wave $\sqrt{\frac{\mu}{\varphi}} \to 0$, then, even if there occurs transverse wave at the shot point, it can not pass through media to far distance points.

(2) Shot point is not far from the surface. (Fig. VIII).

Fig. VIII.

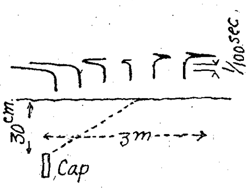
In the case of a deep shot, energies of explosions disperse equally in every direction.

(3) Shape of dynamite is not round.

Explosion of a cap.

As will be seen from the results described above, the mechanism of explosion is ordinarily very simple, but in some cases we have obtained some special type waves as transverse wave. Regarding this fact, the writer will describe on the mechanism of explosion of a cap in the following explanation. Using the arrangement of apparatus as will be seen in Fig. IX, the writer obtains an important result. (Fig. IX) (Directions of initial kicks vary according to shot detector distances) From this, the writer supposes that in the case of explosion of a cap, its shooting mechanism resembles to the one in natural earthquakes. These phenomena give us some hints on the improvement of shooting method. From foregoing investigations, we find mechanisms of shooting at seismic prospecting. Summarizing the facts obtained in this chapter, we can say that there are

Fig. XI.



possibilities of improving shooting methods. There also exist many interesting phenomena in the case of seismic prospecting on seabottoms etc. but they are omitted here. On the other hand, as for the sharpness of wave forms, the writer has obtained a result that wave forms become sharp when rigidities of shot points are large or shot points lie in deep places.

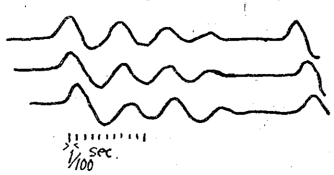
4. On geophysical interpretations of records obtained at seismic prospecting.

Now, we see the characteristics of Haeno seismograph and also mechanisms of explosions, as are already described in preceding two chapters. Here, in this chapter, the writer will describe wave forms, such as amplitude, period, damping, and these applications by using foregoing investigations in the following explanation.

Calculation of depths of surface layers by applying periods obtained from seismic records.

Some stationary vibrations may appear frequently, being superposed on refraction waves fairly later than initial kicks on seismic records. You will see some of them in Fig. X. These waves may be excited by other

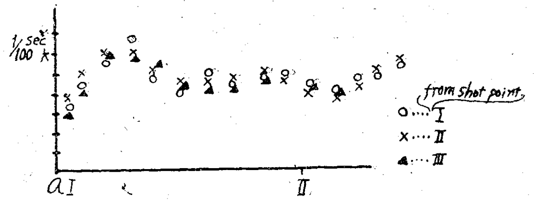
Fig. X.



original waves. And these waves are proper motions in surface layers. To make clear these relations, the writer plotted these periods after reading seismic records as ordinates, and detector distances as abscissae. (Fig. XI).

He has tried this examination at every shot point, simultaneously. Values of periods from every shot point agree each other on an observation point. This fact may show that these stationary waves are produced by

Fig. XI.



the proper motions in surface layers. After calculating these depths of surface layers, he has obtained reasonable results. (Tab. III)

Table III.

V	T	h
0.6 km/sec	0.05 sec.	0.0075 km.
0.8 ,,	0.05 ,,	0.0100 ,,
0.8 ,,	0.10 ,,	0.0200 ,,

these values are calculated from next equation.

$$\lambda = vT \qquad \frac{\lambda}{4} = h = \frac{vT}{4}$$

here,

h····depth of surface layer.
λ····wave length.
v····seismic wave velocity.
T····period.

Precautions must be paid on rigidity $\left(\sqrt{\frac{E}{\rho}}\right)$ distributions on an occasion of calculating the depth, because the velosity is also concerned to rigidity, provided that substances of surface layer vary horizontally.

Application of sound waves to the decision of amplitudes of initial kicks by comparing decrement ratios of sound waves.

Here the writer has studied the application of sound waves. Some records of sound waves are shown in Fig. XII. And, some records in seawater are also shown in Fig. XII. As for soundwaves, there are two applications. One of them is to the decision of shot detector distances, and the other is to the decision of amplitudes of initial kicks by comparing decrement of ratios of sound waves.

Needless to explain the former, so he will explain the latter problem in the following explanation. Until now, only very few applications of amplitude have been done at seismic prospecting, for the qualities of

Fig. XII.

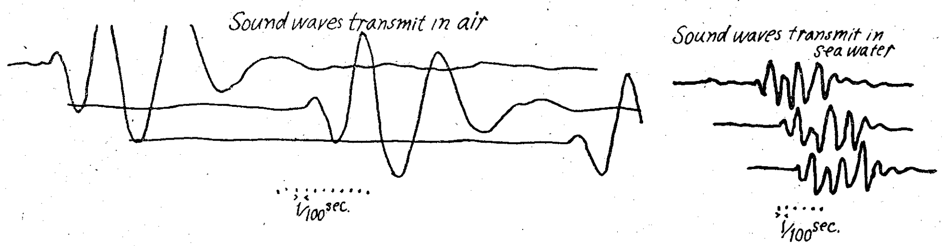


Fig. XIII.

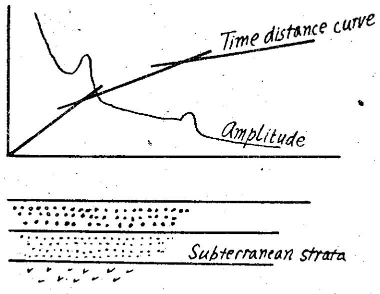
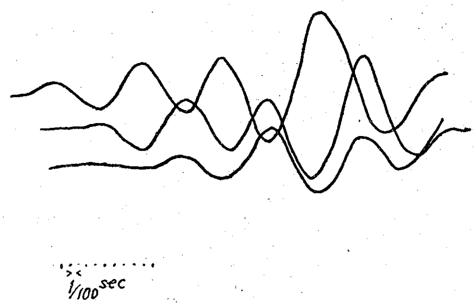


Fig. XIV.



records obtained at seismic prospecting greatly differ from incident waves. The writer makes a decrement diagram of sound wave energy (amplitude) according to shot detector distances. By this diagram, we can calculate total amplifications of seismograph in each record. Applying this amplification, he calculates amplitudes of initial kicks in each record. Some of these results are shown in Fig. XIII. These discontinuities of amplitude may correspond to inflection points of time distance curves. And, at the same time, we may say that it may be possible to know not only velocity distributions but also distributions of other physical properties of substances of subsurfaces, by collecting many data on amplitudes experimentally. He has also succeeded to detect some faults by this same method.

Application of surface waves to the decision of velocities and depths of surface layers.

As for surface waves in natural earthquakes, many investigations have been already performed, but in the case of seismic prospecting, surface waves are not yet applied so much. The writer will describe on this problem in the following explanation.

Some surface wave-like records are shown in Fig. XIV. After investigations, he knew that there might appear not only Rayleigh waves, but also Love type waves. By applying these results, he has obtained velocities and depths of some surface layers. In Love type waves, he applies the phenomenon of dispersion as follows.

In the case of short wave length, the velocity of Love wave approaches to the velocity of transverse wave in the surface layer. (1 st. layer). In the case of long wave length, the velocity of Love wave approaches to the velocity of transverse wave in the subsurface layer. (2 nd layer). Of course, there are indispensable conditions to produce such waves. On the condition to obtain clear phases at seismic prospecting. Finally, the writer describes this broblem. It is the most important affairs to catch clear phases on records at seismic prospecting. For this purpose, the writer has picked up three factors as follows: (except A. V. C. or compander equipments).

(1) On explosion.

(2) On geologies of observation points and transmitting media.

(3) On seismograph. (damping)

As for the first and the last problems, the writer already described in foregoing chapters. For the second problem, he obtained a result that rigidities of observation points and transmitting media must have been large.

On the other hand, he obtained a good record in another condition — the earth of observation point is soft —, small surplus vibrations are absorb d in the earth of observation poin , but in this case there is a weak point that the sharpness of wave forms decreases quickly.

From foregoing investigations, the writer proved the possibility of calculation of depths of surface layers by applying periods of vibrations obtained from seismic records. And he also succeeded in applying sound waves to the decision of amplitudes of initial kicks by comparing decrement ratios of sound waves. Finally, he studied on the application of surface waves to the decision of velocities and depths of surface layers.

5. Detectable possibility of underground small structures by means of seismic method.

In this chapter, the writer will describe on a somewhat different broblem from foregoing studies…detectable possibility of underground small structures. It is said generally that we can not detect underground small structures which is small comparing with wave lengths of dynamite detonations. In spite of this scientific commonsense, the writer met with a few examples, from which he could calculate 2 or 3 meters depth layers by comparing analyzed data of time distance curves with their corresponding boring data. In another case, he obtained transmitting sound waves through seawater 1 or 2 meters depths which reached comparatively far shot detector distances. Dr. Sassa also describs that he could detect a coal layer by analyzing zigzag parts of a time distance curve. By Geophysics, No. 4, Vol. XIV, 1949, seismic wave can pass along wires pending from earth surfaces in the holes.

Of course, there are yet many questions, but it is very necessary to study limits of detections of underground small structures by both experiments and calculations.

Finally, there remain many questionable problems, for example, differences of arrival times at both sides in a time distance curve, etc. But here the writer omits these discussions.

6. Summary and Conclusion.

Some problems on seismic prospecting have been studied in recent 12 years by scholars of the Geophysical Institute of Kyōto University, and some conclusions of them were written in No. 1, Vol. 2 of Geophysical Exploration of Japan by Dr. K. Sassa.

The writer has also studied on the same problems at seismic prospecting in recent 7 years. Of course, as there are slight differences in details, he wishes to write the conclusions of his study in this paper.

In short, key points of his investigations are as follows:

(1) Developments of interpretation of data have obtained from seismic prospecting, by applying not only times of initial arrivals, but also wave forms…amplitudes, periods, phases, etc..

(2) For this purpose, it is necessary to know the qualities of the apparatus utilized in the field, the mechanisms of explosions of dynamites and also the geology of shot and detector points.

He describs some details of these problems in the foregoing chapters and clears many phenomena. Still, there remain many problems to be solved and we must apply these results of investigations to real field works.

In conclusion, the writer desires to express his sincere thanks to Dr. Iida and Dr. Fuchida for their kind guidance in the course of this study. (Feb. 20, 1950).

地震探鑛記錄の吟味

早　川　正　巳

要　旨

地震探鉱解析の際，震波の初動到着時刻による走時曲線の解析のみならず，波の形，周期，振幅，減衰等をも利用して，地下構造を従来より一層明かにする爲，この研究を行つた。はじめに器械の性質について論じ，次に火薬の爆発機構について研究し，最後にこれ等を利用して上述の項目について吟味した。かんたんに結果をのべれば，記録上の波の定常部分から表土層の厚さを求めること，振幅比較により地下構造の推定出来ること，爆発條件により，種々異る波の出ることなど分つた。ここには研究のごくあらましのことしか書いてない。何れ近い中に詳細についてのべる機會があることと思われる。