Model Seismology, Part ?

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Model Seismology (Part I)

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Abstract

The propagation of elastic waves produced in a thin plate by an ultrasonic pulse is studied as a two dimensional model of seismic waves. Both vertical and horizontal vibrations are detected at various distances. Each seismogram obtained is consisted of two separate pulses, the first one being identified by a hodographic method to be the primary body wave and the second one to be the surface wave of Rayleigh type. The model experiments in complex structure are also carried out. Travel time of the refracted waves by a step-shaped discontinuity is ascertained to coincide with the consideration of the ray-theory.

1 Introduction

It is desirable that many seismological problems may be studied under the controlled conditions by using small scale models, which enable one to replace the seismic waves with short waves, and the earth with a medium, the properties of which are known. The model study of seismic waves was originated by TERADA and TSUBOI [1], who obtained many interesting results. Recently, many investigators [2–11] have studied the problems by using waves of ultrasonic frequencies travelling through small scale models. The application of ultrasonic pulses makes it possible to avoid the difficulties in procuring suitable model materials and in fabricating desirable configuration.

It may be a natural course in the study of this kind to examine, at first, whether or not the experimental results coincide well with those predicted by the mathematical study of elastic wave propagation, and next to put forwards the study to more complex cases in which the mathematical prediction is difficult because of the complexity of the medium. In this paper, therefore, the propagation of a pulse in homogeneous thin plate, that is, LAMB's two dimensional case [12], was studied at first. We made further experiments on the refracted waves when the medium is consisted of two homogeneous plates divided by a step-shaped boundary, as an example of complex cases, in which theoretical attacks have not been made with good success.

2 Experimental Procedure

The transmitting and receiving equipments are of usual type in the studies of model seismology. A block diagram of the equipments is shown in Fig. 1. An electrical pulse of about 4 micro-seconds duration is applied to the transmitter of a small piezoelectric element. The form of pulse delivered by this transmitter is recorded as shown in Fig. 2. The record is obtained by the operation of contacting the receiver

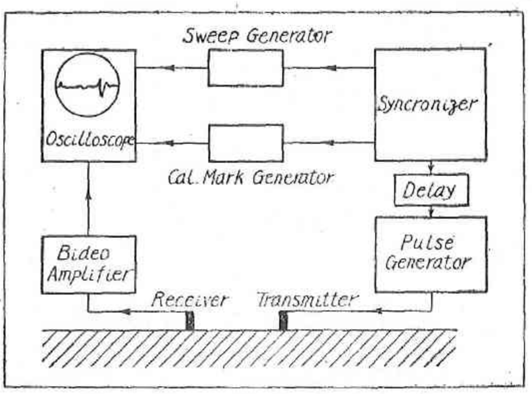


Fig. 1. Block diagram of apparatus.

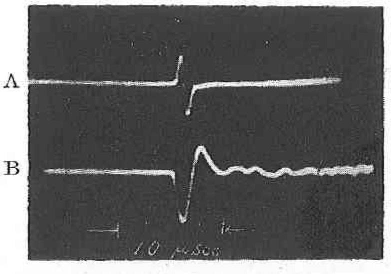


Fig. 2. A : Electrical Pulseal
B : Pulse, obtained by the operation of contacting the receiver directly with transmitter.

directly with the transmitter.

The acoustical energy arriving at various points in the model is detected by a receiver similarly designed to the transmitter. Thus obtained waves are amplified and are displayed on a cathod-ray oscilloscope. The pulse repetition rate is taken to be 200 pulses per second in our case. The pulse amplifier have a good response within the frequency range from several tens Kc/sec to about a few Mc/sec. The transmitting transducer is a cylinder, made of barium titanate, whose thickness is 1 mm and effective diameter 6 mm. The receiving transducer is a rectangular slice, also made of barium titanate whose dimension is $4\times2\times1$ in mm unit.

One of the difficult problems in model seismology is how to produce and detect a pulse of simple form. In this point of view, we provide a crystal transducer with a suitable backer having an acoustical impedance matching with that of the crystal, in order to prevent the complication of pulse form by reverberation. Other difficulties caused by the free oscillation or ringing are avoided by utilizing a frequency far lower than the ringing frequency of the crystal.

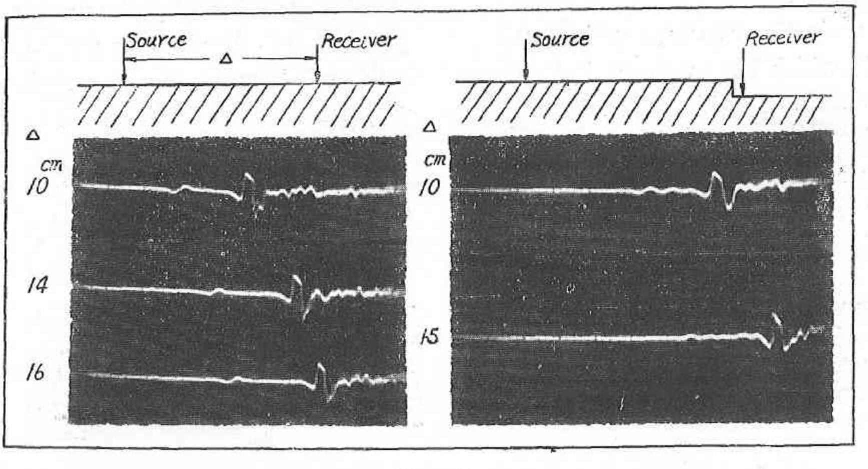
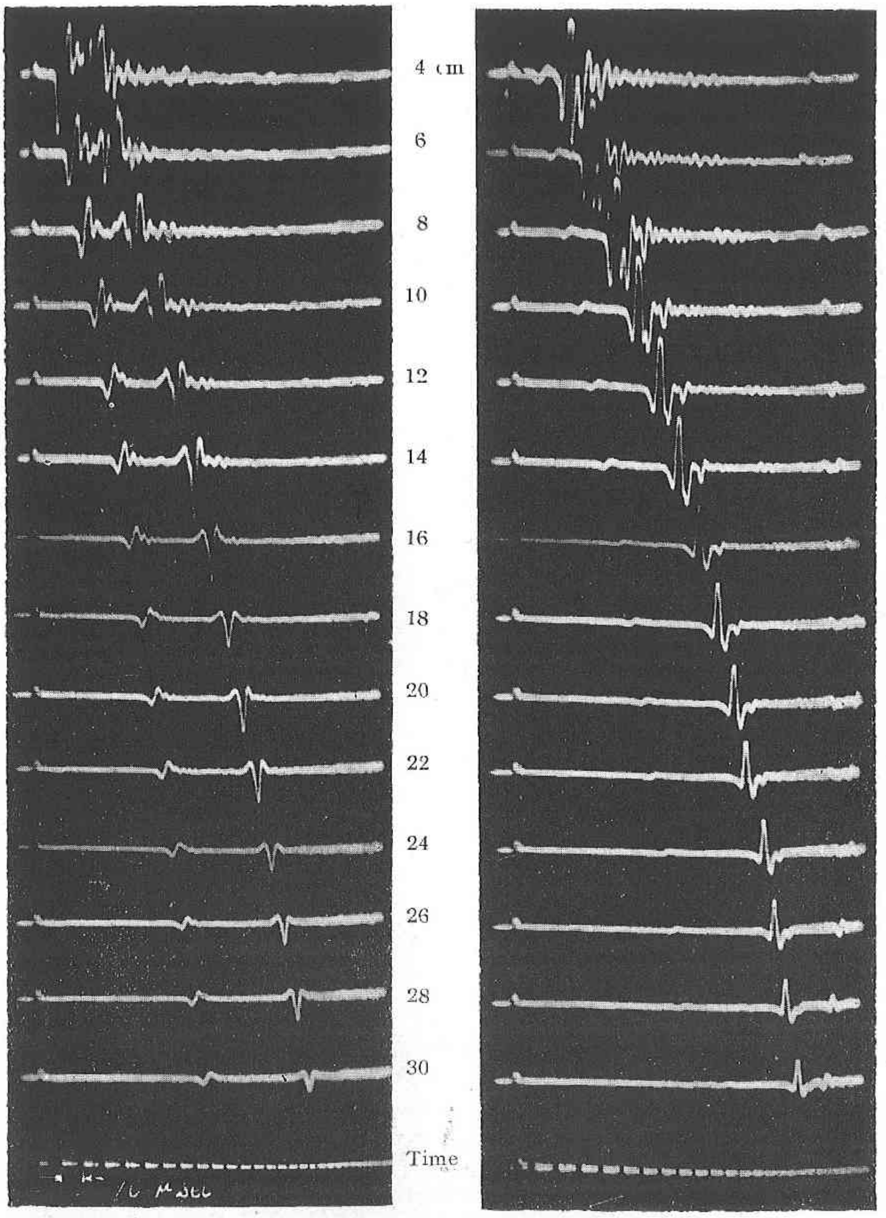


Fig. 3.

The pulse generating source is placed vertically to the edge of the model, the vertical vibrations at a point are measured by the usual method with a fixed transmitter and a moving receiver. The fixed transmitter is located at 15 cm apart from the corner of a plate in order to avoid the mixing of reflected waves by the vertical edge of the plate.

In order to detect the motion of horizontal direction we make small step of



Horizontal Component Vertical Component

Fig. 4. Typical model records for spreads from 4 cm to 30 cm on semi-infinite solid model. (Bakelite plate)

8 mm depth on one corner of the horizontal edge of the model as illustrated in right-hand figure of Fig. 3. The receiver placed vertically to the side plane of the step can detect the horizontal movements at the point. An examination of the effect of the step on the propagation of waves is preliminarily carried out. The motions for the medium with and without the surface step are measured at the same distance from the transmitter. The obtained seismograms with and without the step are also shown in Fig. 3. As obviously seen in the figure, no appreciable change in wave character is found between the two seismograms, which indicate that the effect of the step is practically negligible. Hence we can safely adopt the above stated method for detecting the horizontal movements. In this case, the system of a fixed receiver and a moving transmitter is adopted for the measurements at various distances. The

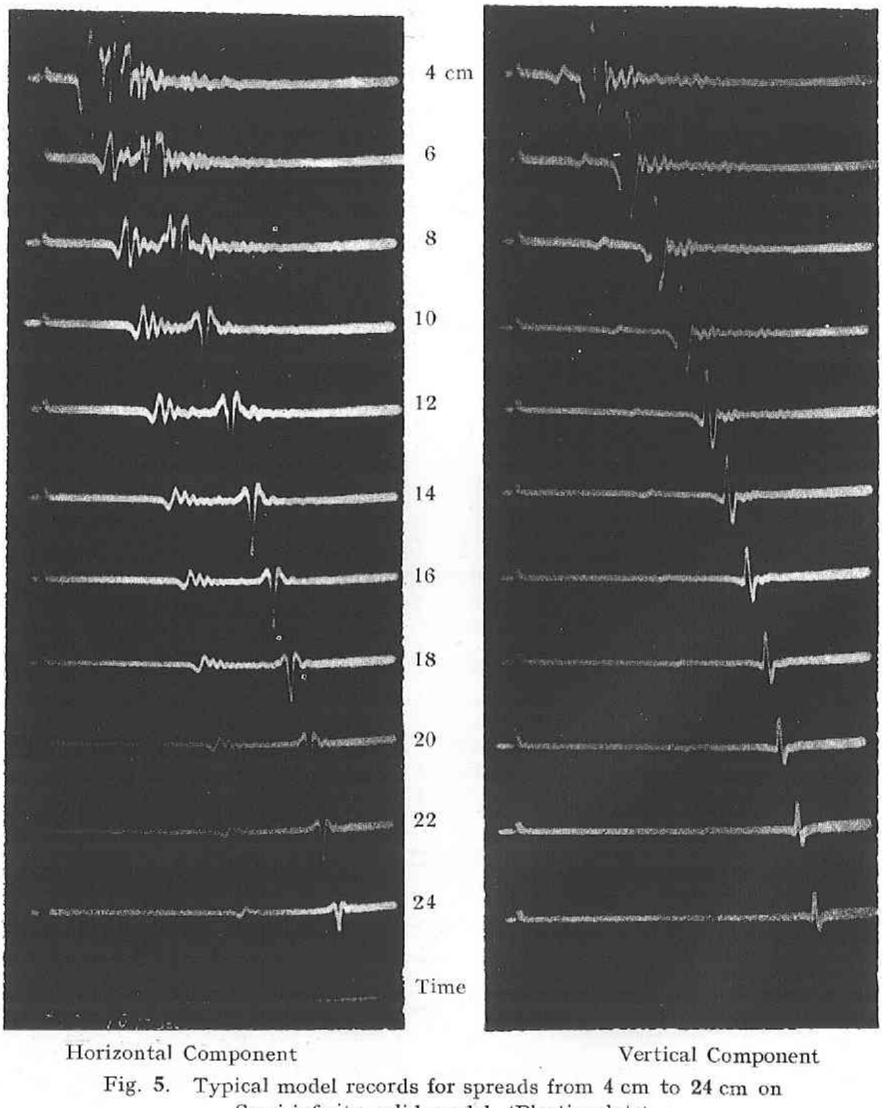


Fig. 5. Typical model records for spreads from 4 cm to 24 cm on Semi-infinite solid model. (Plastic plate)

fixed receiver is placed on the side plane of the step at 15 cm apart from the corner. By above stated method we obtained the seismograms of both horizontal and vertical components.

3 Propagation of a Pulse in a semi-infinite thin Plate

We applied our method on LAMB's case at first. The plastic plate of $70\times90\times0.3$ (cm) in size or the bakelite plate of $30\times60\times0.3$ (cm) served as a model for a semi-infinite solid. The measurements are carried out at each 2 cm interval within the range of distance 30 cm from the transmitter. Figs. 4 and 5 show the seismograms in cases of the plastic and bakelite plates respectively. Time marks at each 10 microseconds are shown at the bottom of the figures in logarithmic scale. The image on oscilloscope in the present experiments is adjusted as to be displayed in logarithmic time scale to make convenience of showing the general scope of a seismogram.

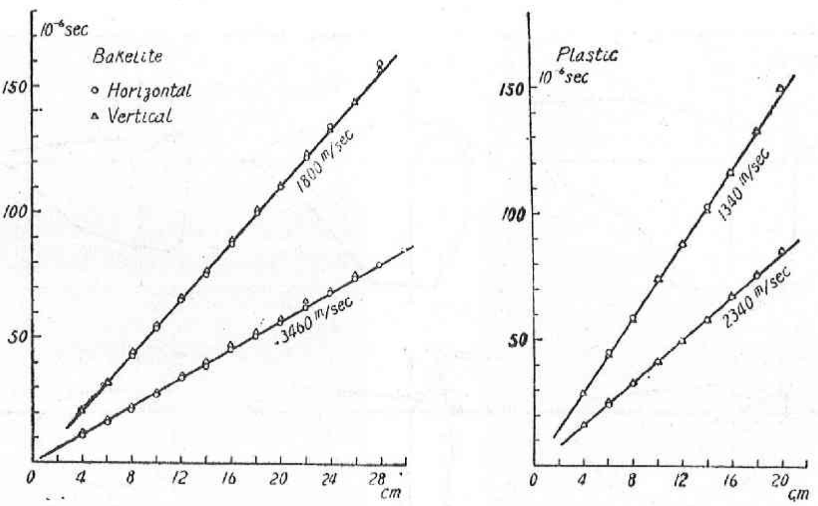


Fig. 6. Travel-time curves for semi-infinite solid model.

As shown in these figures, two predcminant phases are found in every seismogram. These phases do not change suddenly in period and amplitude with increasing distance. For the identification of these phases, travel-times of the initial motion of these phases are taken as shown in Fig. 6. The curve of travel-times of each phase are well expressed by a straight line crossing the ordinate at the origin. Hodographs for the orbit of the pluses, obtained from the seismograms of two components, are shown in Figs. 7 and 8. The arrows in the figures repersent the time interval of 1 micro-second. As the hodographs in Fig. 7 show, the first pulse is always consisted of large horizontal and small veritcal motions. The amplitude ratios of both motions are in the range of 3 : 1 and 4 : 1, the values being in good coincidence with the theoretical result by LAMB. Concerning the second phase, hodographs in Fig. 8 indicate the character of Rayleigh waves shown in LAMB's study.

The S waves, whichar e expected to appear between the two pulses, were not

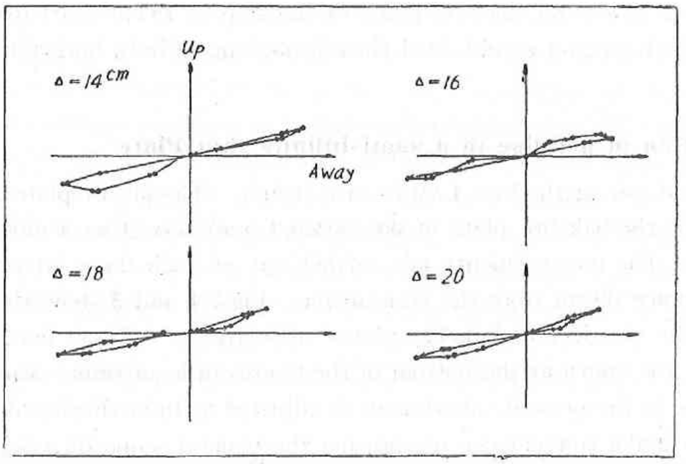


Fig. 7. Hodographs for the first pulse (Traced amplitude).

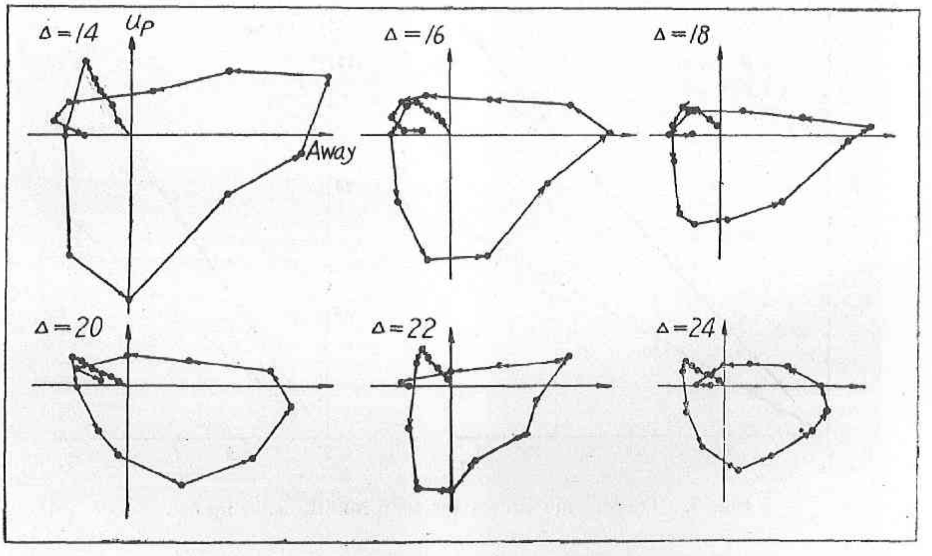


Fig. 8. Hodographs for the second pulse (Traced amplitude).

recorded so distinctly in the present seismograms. The foregoing part of the second pulse might be considered as the S phase. The discussion on S waves will be made in the next paper.

4 Wave Propagation in complex Structure

Some authors [9, 10, 11] made model seismological studies in the medium with a single superficial layer, and the existence of the refracted waves is experimentally estabilshed. We studid on the more complex cases whose theoretical treatment is too complicated to carry out.

The case treated in the present investigation is of a kind of two layer problems. The boundary of the two layers is not a single plane but has a step-shaped form as illustrated in Fig. 9. The horizontal distance between the step and the transmitting source is 15 cm, the thickness of the superficial layer being 2.8 cm and 5.8 cm at shallow and deep part respectively.

The ratio of the wave-length to the dimensions of structure is essential in the wave propagation in two layered medium. The recent study of Press and others [9] on refraction arrivals showed that the velocity or the depth determination from refracted records is unreliable, when the ratio of wave-length to the layer thickness is too large. The wave-length in the present case is estimated to be about 2 cm if we take the period of the transmitting pulse to be twice the width of the first peak. Therefore, the thickness of the superficial layer even in the shallow part is larger than the wavelength, and the unfavourable condition above stated is avoided.

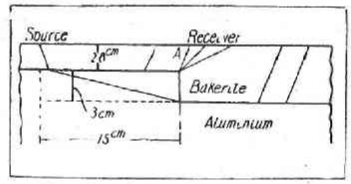


Fig. 9. Step-shaped model.

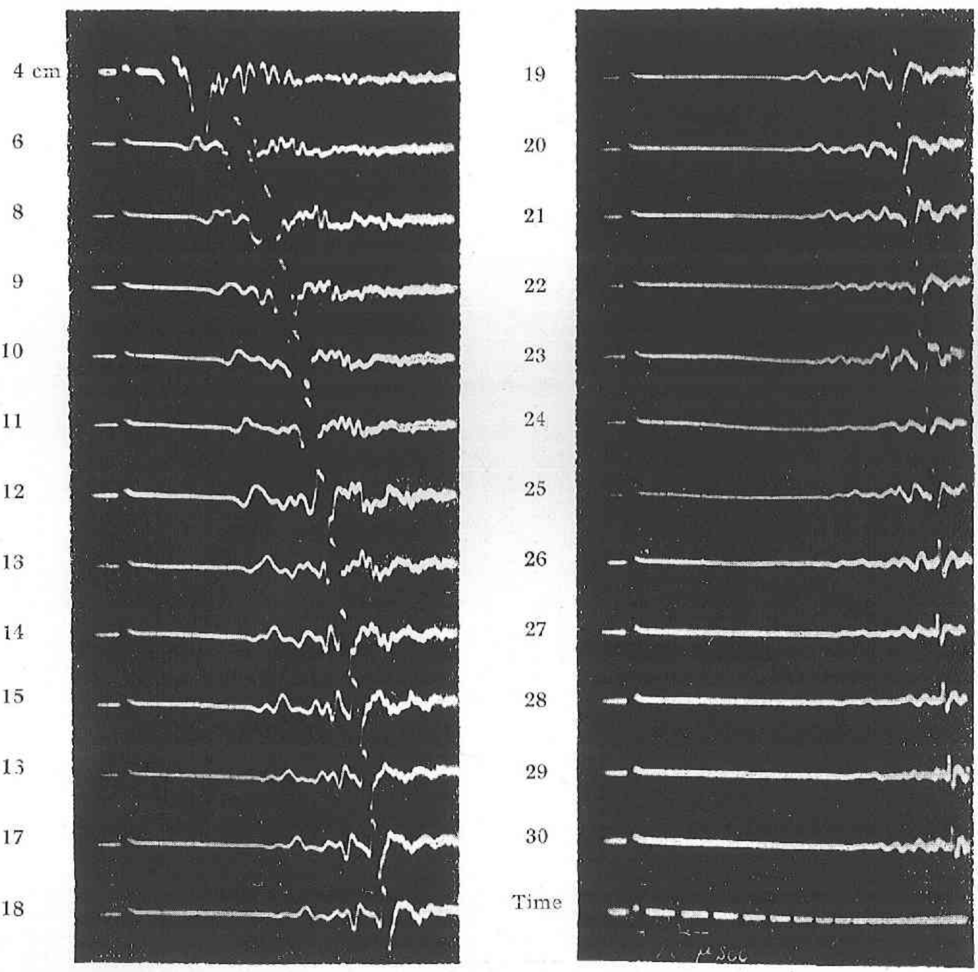


Fig. 10. Seismograms for spreads from 4 cm to 30 cm on the two layers, which are consisted of two homogeneous plates divided by a step-shaped boundary.

The materials used are bakelite and aluminium for the superficial and underlying respectively.

The obtained seismograms are shown in Fig. 10. As shown in these seismograms, the waves in this case are not so simple as those in the former case. The travel times of peaks and valleys in seismograms are plotted in Fig. 11. The travel-time curves of each peak and valley show the following character. The curve in the vicinity of source is the straight line corresponding to the direct waves, and at critical distance, it changes into the line corresponding to the refracted waves, traveled through the underlying medium. The travel times at the distance beyond the point, say A, in Fig. 9, are expressed by a curved line with concave upward curvature. When the distance increases further, the curve becomes a straight line parallel to that of the refracted waves at smaller distance. On the other hand, the travel times of waves corresponding to the second pulse are expressed as a straight line over the whole range of distance, as shown by the point ⊗ in the figure, indicating that the pulse

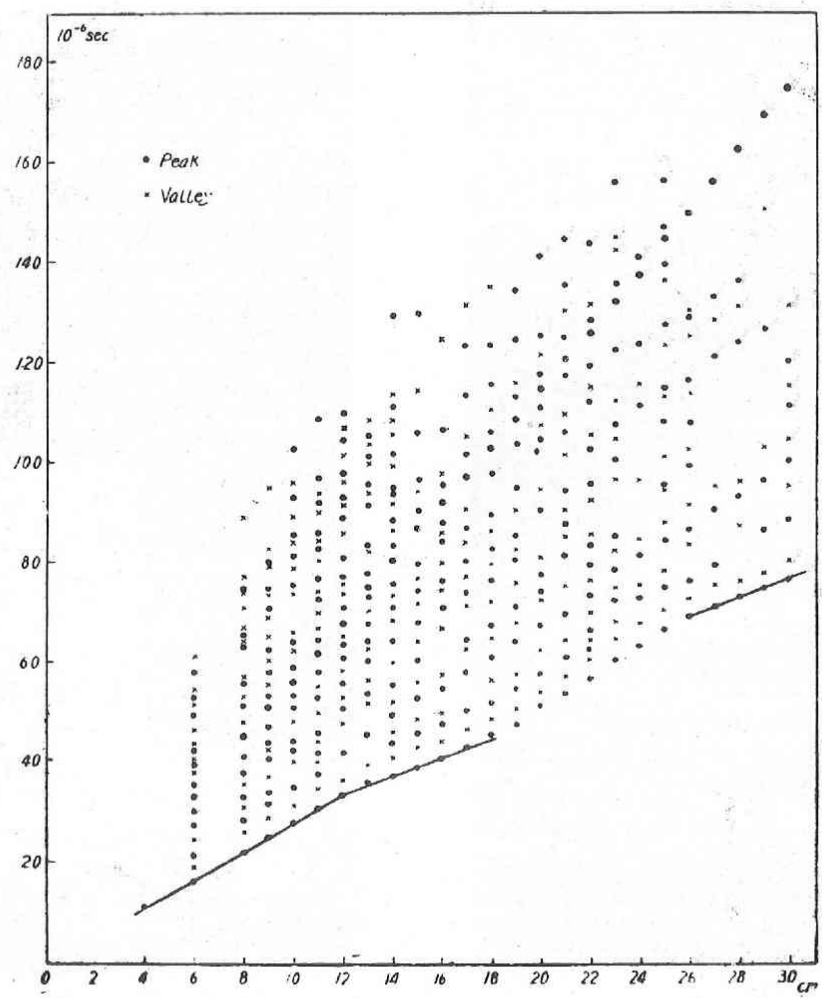


Fig. 11. Travel-times for complex structure.

is identified with Rayleigh wave. Other characters of the propagated waves are that the wave forms are not regular and that the first motion is recorded very weakly in the transitional region. It is of much interest that the above stated circumstances are in good coincidence with the results expected from the ray-theory.

5 Conclusion

As a first step of our study in model seismology we treated the wave propagation in two cases, i.e., LAMB's case and a more complex case. The experiments were designed to detect the motions in both horizontal and vertical components and we described the orbit of the motions of waves by a hodographic expression. The results of the experiments are summarized as follows.

(1) The seismograms obtained are consisted of two separate pulses which are identified with the primary body waves and Rayleigh waves respectively.

(2) The characters of these pulses are quite similar to those in LAMB's theoretical study.

(3) Although the waves are somewhat complicated when the medium is not so simple, the travel times of the waves are well explained by the ray-theory.

In conclusion, the present writers wish to express their hearty thanks to Prof. S. Tanaka, Institute of High Speed Mechanics, Tôhoku University and Mr. T. Anzai, Research Institute for Scientific Measurement, Tôhoku University who kindly constructed the measuring apparatus by which present studies were carried out. The authors also express their thanks to Prof. H. Honda for his kind suggestion and encouragement throughout the course of this investigation.

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