Investigation of the Structure of the Earth's Crust in Relation to Local Earthquakes (Preliminary)

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Abstract

Preliminary observations of local earthquakes of frequent occurrence in the Wakayama District were made with a vertical seismograph of short period and high magnification. It was confirmed by the reflected seismic wave that there exist some distinct surfaces of discontinuity in the earth's crust in the Wakayama District.

1. Introduction

The earth's crust means the surface layer of the earth having a thickness of several score kilometers. Its structure, property and movement are very much diverse from place to place, and the foci of destructive earthquakes, the magma reservoirs of volcanoes, the origins of hot springs and the causes of other various phenomena such as gravity anomaly, magnetic anomaly, crustal deformation, continental drift, and pole-wandering are all existing in the domain of the earth's crust itself. The detailed investigation of the earth's crust is not only an attractive research subject of geophysics but also an important task directly connected with public welfare in our daily life.

The structure of the earth's crust has been investigated mainly by two methods: gravity anomaly and seismic wave. From the stand-point of isostasy, its compensation depth was calculated and discussed from the data of observed gravity anomaly. It is confirmed from both the theoretical and observational sides that half the depth of compensation according to the Pratt-hypothesis is nearly equivalent to the thickness of the earth's crust according to the Airy- or Heiskanen-hypothesis. Consequently, it could not be determined from the distribution of gravity anomaly alone as to whether the mode of isostatic compensation of the earth's crust is really according to Pratt or Airy, but it necessitates further evidence from the observation of seismic waves.

Since the first investigation of the earth's crust from the observation of near earthquakes was commenced by A. Mohorovičić in 1909, various

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studies have been made by many researchers for determining the crustal structure from the observed data of near earthquakes and the surface waves of distant earthquakes. And recently the studies of the crust by using artificial powder explosions of large dimensions are very much prevalent at many places in the world. Consequently, our information on the crustal structure has been increasing more and more with time, but in proportion to the accumulation of the observed data the complexity and locality of the structure and properties of the earth's crust have been more and more distinctly brought fo light.

On the other hand, the properties and movement of the earth's crust have been investigated by geodetic survey and geophysical observation. That is to say, the precise levelling and triangulation, gravity and geomagnetic survey, the tiltmetric and extensometric observation, and other measurements such as the measurement of earth's electric current and ground radiation, all reveal local variations in the properties and peculiar motion of a small area of the earth's crust, especially for the disturbed domain suffering the occurrence of destructive earthquakes and the large crustal deformation.

From the above stated reason it is considered to be an essential for clarifying the nature of destructive earthquakes to investigate the fine structure of the earth's crust in the disturbed regions. For that purpose the seismometric observation of local earthquakes of frequent occurrence and the after-shocks of a great earthquake were scheduled by our Institute, and in this article a preparatory observation of local earthquakes frequently occurring in the Wakayama District made with a vertical seismograph of short period and high magnification will be reported. It is to be remarked here that a local earthquake means an earthquake of very small magnitude which could not be recorded even with a sensitive seismograph beyond some twenty kilometers' distance from the epicenter. The reasons for selecting local earthquakes of frequent occurrence and the after-shocks of a great earthquake exists in the points that: 1.) frequent occurrence saves the expense of long period observation, 2.) artificial powder explosions are very expensive, and 3.) as the hypocenters of those local earthquakes and after-shocks generally lie just within several kilometers depth, the reflected seismic waves, used in investigating the discontinuous surfaces more than several kilometers' depth in the crust, are preferably utilized in observation at near-by stations without any consideration of refracted seismic waves altered (PS, SP) and unaltered (PP, SS) at the discontinuous interface.

2. Seismograph (R_1)

The instrument used is a vertical seismograph of the variable reluctance type and is shown in Figure 1. The inertia mass (B) of 2.2 kg weight is horizontally supported by two sets of crossed plate springs at the position (E) and by a helical spring (S). The armature (A) made of pure iron is fixed perpendicular to the inertia mass, both forming the L-shaped frame. Consecuently the vertical motion of the inertia mass causes the corresponding horizontal displacement of the armature. The horizontal motion of the armature between the air gap of the two strong permanent NKS-magnets (M) causes a variation in length of the working air gap which induces an electromotive force in the induction coil (C). The induced electromotive force is lead to a highly sensitive galvanometer, and thus the deflection of the galvanometer-mirror follows the vertical motion of the ground. The number of turns, ohmic resistance, and diameter of silk-covered copper wire of C are 4000 turns, 440 ohms and 0.21 mm respectively. These large values of the number of turns and

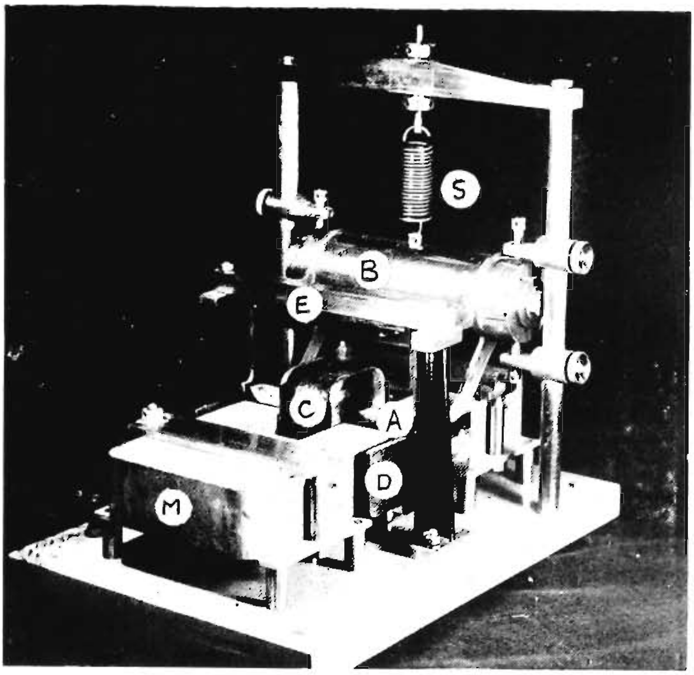

Fig. 1. R_1-Seismograph
S-suspension spring, B-inetia mass, E- bar with crossed platesprings, C-induction coil, A-armature, D-damper, M-U-Shaped permanent magnet.

electric resistance are not always adequate for direct galvanometric registration, but as this seismograph was ordinary planned to observe ground oscillation over very short periods (0.005~0.001 sec.) with a vacuum tube amplifier, the elements of the induction coil were unalteredly used in the present observation. The two copper plates (D) fixed to the armature are playing the role of damper, but as the damper the copper plate may preferably attached parallel to the armature. The free periods of the pendulum and the galvanometer are 0.25 sec. and 0.40 sec. respectively. The number of turns, ohmic resistance and diameter of enamelled copper wire of the galvanometer coil are 40 turns, 20 ohms and 0.05 mm respectively, and the length, ohmic resistance and the torsional rigidity of the two upper and lower suspension strips of the galvanometer coil are 3 cm and 8.5 ohms for one strip, and 0.31 c.g.s/rad./cm. respectively. The current sensitivity of the galvanometer is calibrated as 4.0×10^{-8} amp./mm at the optical distance of 1 meter, and the magnification curve of the seismograph with the galvanometric registration at 1 m-optical distance is as shown in Figure 2.

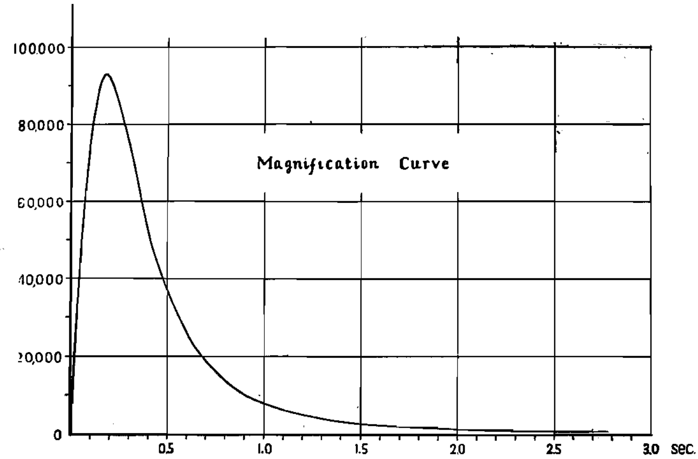

Fig. 2. Magnification curve of R_1-Seismograph, abscissa-period of ground oscillation, ordinate-value of magnification.

3. Seismometric Observation

Test observation with the R_1-seismograph was made at Yura in the Wakayama District on February and November, 1952. Yura (135°07′E, 33°57′N) is situated in the northern part of Wakayama Prefecture and close by the sea. The observation room is located in an adit of 60 m-length and 30 m depth, the ground rock being Mesozoic shale and sandstone. In the Wakayama District a large number of local earthquakes had been occurring year after year with an ebb and flow of some ten or twenty years. In the one year of 1923, 299 local shocks were felt by human beings, one of the highest rates of incidence in the past 50 years. Recently the local shocks have again increased in number, amounting to several shocks a day in observation with the R_1-seismograph. The detailed investigation of local shocks in the Wakayama District was made by A. Imamura [1932] and recently by the Joint Research Committee of the Osaka Meteorological Observatory, the Earthquake Research Institute of Tokyo University and the Geophysical Institute of Kyoto University [1953]. In the following the observed data obtained at Yura and its preliminary interpretation will be described. It should be remarked that, as the equipment used in the present case was only a single vertical seismograph, the focal depth of each shock recorded is undetermined and that the epicentral distance may be provisionally determined from the observed duration time of preliminary tremors. In the paper by Imamura [1932] the focal depth and the distance coefficient k (the hypocentral distance ($\triangle$) in km $= k \times$ the duration time of preliminary tremors ($P \sim S$) in seconds) of eleven shocks observed in 1928 within several kilometers' distance from the observation point were estimated to be 0.6～5.8 km and 2.43～3.82, their mean values being nearly 3.0 km and 3.8. And the values of focal depth and k determined by S. Miyamura of the Earthquake Research Institute of Tokyo University in the Report of the Joint Research Committee [1953] were estimated to be 0.1～21 km and 1.6～7.0 respectively for five local shocks within some twenty kilometers' distance from the observation points observed on November, 1952 in the Wakayama District. In the same Report the somewhat strong but local earthquake of Nov. 25, 1952 of about 10 km-focal depth was discussed by the staff of the Earthquake Department of the Osaka Meteorological Observatory and, according to its travel time-distance curve, the apparent velocities of P- and S-wave for the epicentral distance of 40 km～200 km are estimated to be 5.4 km/sec and 3.1 km/sec respectively, giving 0.25 as the value of Poisson ratio. The general and detailed discussions for the crustal structure of our country were made by T. Matsuzawa [1928, 1929], giving the structure of the uppermost sedimentary layer of several kilometers' thickness, the underlying granitic layer of some 15 km-thickness with the seismic velocity of 5.0 km/sec ($\overline{P}$) and 3.2 km/sec ($\overline{S}$), the intermediate layer of 30 km-thickness with the seismic velocity of 6.2 km/sec (P^*) and 3.7 km/sec (S^*), and the basement layer with the seismic velocity of 7.5km/sec (P_n) and 4.5 km/sec (S_n). And the world-wide data on the investigation for the crustal structure were discussed in detail with a large number of references by J. B. Macelwane in Chapter X of the "Internal Constitution of the Earth" (Second revised edition of volume VII of the Physics of the Earth, edited by B. Gutenberg, 1951).

In the present observation of February, 1952, the following local shocks were observed at Yura only during the day-time recording. The rotation speed of the photographic registration cylinder was nearly 4 mm/sec.

Concerning the under Table, Yuasa is situated at the point (135°11′E,

Table 1

Date	Shock-number	Time of Occurrence	(P~S) Time at Yura	(P~S) Time at Yuasa	Remarks
Feb. 1952					
1	1	16^h 00^m			
〃	2	17 53	0.7_6 sec.		
〃	○ 3	17 53			
〃	4	22 36			
3	5	11 22			
〃	○ 6	12 13	4.6_6		
〃	7	12 48			
〃	8	13 22			
〃	9	15 18			
〃	10	15 21			
〃	○11	17 13	1.1_0		
〃	○12	17 13	1.1_0		
〃	13	18 30		2.1 sec.	
〃	14	19 21			
〃	15	19 33	1.3_2		
〃	○16	19 33	1.3_2		
〃	○17	20 47	4.3_8	3.0	near Wakayama City (135.2°E, 34.2°N)
〃	18	20 59			
〃	19	21 25	9.0_2	8.2	near Akashi-Straits (135.0°E, 34.6°N)
〃	20	22 51			
4	21	00 12			
〃	○22	17 41	3.7_9		
〃	○23	19 11	2.1_6	1.0	
〃	24	21 15			
5	25	11 00			
〃	26	11 24			
〃	27	11 54			
〃	28	12 12			
6	○29	18 10	4.4_5	5.4	near Tanabe-Bay (135.3°E, 33.7°N)
〃	30	18 50			
〃	31	19 04			
〃	32	21 04			
8	33	11 58			
〃	34	13 32			
〃	○35	23 32	3.6_0		
9	36	00 10			

34°02′) and equipped with two horizontal seismographs having a geometrical magnification of 50 and a free period of 4 sec., the mechanical registration being done on a sooted paper. And Yuasa is 10 km distant in the NE-direction from Yura. Among the thirty six shocks observed on February 1–9, 1952, ten clear shocks of the Wakayama District were selected for examination because the observed amplitudes of the other

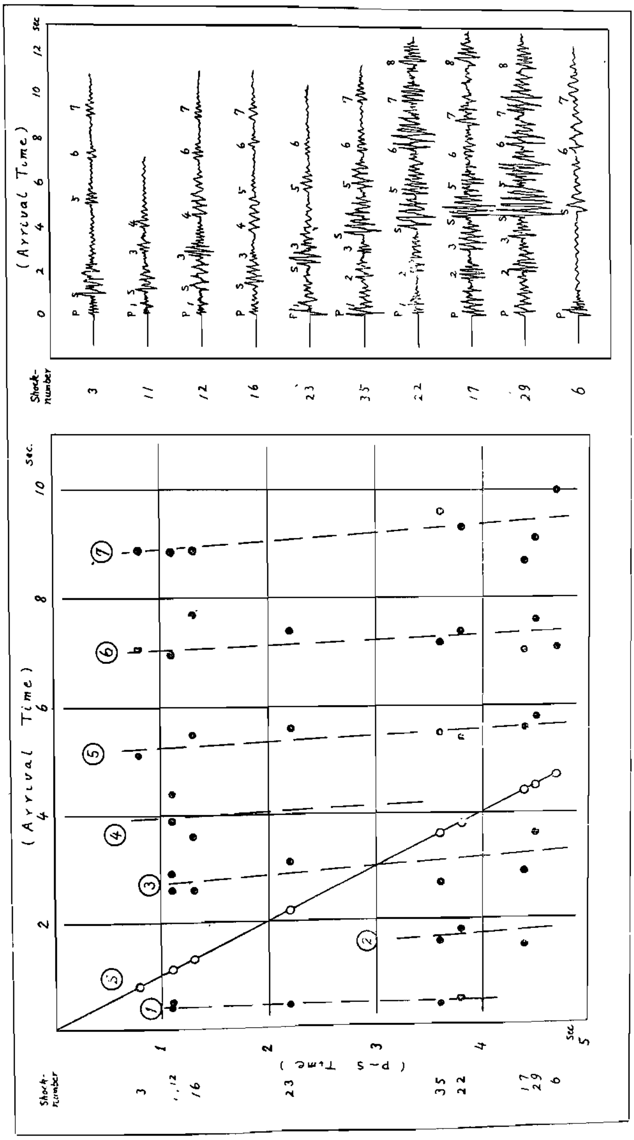

Fig. 3. Arrival times of various phases observed in ten local shocks and their seismograms.

shocks were too small to detect any phase in the train of seismic wave. And in the present account, the data obtained by the November-observation in 1952 was not treated.

Of the ten shocks selected the various phases as well as the direct P- and S-wave were read from the seismograms, and their times measured from the arrival time of P-waves with their enlarged seismograms are shown in Figure 3 in the order of the time duration of (P~S).

As seen in Figure 3, various phases may be tentatively grouped as 1, 2, 3, … etc., considering their arrival time differences from the first arrival of the P-waves and their vertical amplitudes. The significance of these groups of phases could not be interpreted in the present case, but they may possibly be the derived waves reflected at the interfaces between the sedimentary layer, the granitic layer and the intermediate layers, or at the free surface of the ground. It necessitates the accurate evaluation of the focal depth of each shock and the velocity of each layer for the determination of the thickness of each layer. Recently four sets of seismographs of the R_1-type have been constructed at our Institute, and a complete seismometric observation of the local shocks near Yura at four stations several kilometers apart is scheduled for November, 1953. After this observation a more conclusive discussion on the crustal structure in the Wakayama District will be given again in this Bulletin.

In conclusion, the preliminary report was given on the preparatory seismometric observation of small local shocks frequently occurring in the Wakayama District with a vertical seismograph of short period and high magnification at the station of Yura. Many distinct phases, which may be correctly classified and grouped, were recorded in the seismograms obtained. But their interpretation should be postponed until after the subsequent complete observation at the four neighbouring stations.

Acknowledgment

The writers wish to express their heartfelt thanks to Prof. E. Nishimura for his kind guidance and to Prof. K. Sassa for his apt advice throughout this study. The writers are also greatly indebted to Mr. Y. Kishimoto of our Institute, Mr. K. Shinya of Taikyu High School and Mr. M. Ozaki, Chief of the Town of Yura, for their deep understanding and kind help in the present observation. The cost for the observation was partly covered by the Grant in Aid for Scientific Research of the Ministry of Education.

References

Imamura, A., Kodaira, T. and Imamura H., The earthquake swarms of Nagusa and vicivity, Bull. Earthq. Res. Inst., vol. 10, no. 3, 636-648, 1932.

Matsuzawa, T., Hasegawa, K. and Haeno, S., On the forerunners of earthquake motions of certain earthquake, Bull. Earthq. Res. Inst., vol. 4, 85-106, 1928.

Matuzawa, T., Observation of some of recent earthquakes and their time-distance curves.

Part I, Bull. Earthq. Res. Inst., vol. 5, 1-28, 1928

Part II, " , vol. 6, 177-204, 1929

Part III, " , vol. 6, 205-212, 1929

Part IV, " , vol. 6, 213-229, 1929

Matsuzawa, T., Yamada, K. and Suzuki, T., On the forerunners of earthquake-motions, The Second Paper, Bull. Earthq. Res. Inst., vol. 7, 241-260, 1929.

Research Committee for Local Shocks in the Wakayama District, The Report of Research for Local Shocks in the Wakayama District, Research Report of Osaka Meteorological Observatory, no. 6, March, 1953 (in Japanese)