ON OBSERVATIONS OF LOCAL EARTHQUAKES AND THE CRUSTAL DEFORMATION AT WAKAYAMA

BY

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1. Introduction

As many destructive earthquakes were accompanied by crustal deformation in epicentral region, an observation of the anomalous movement of the ground preceeding earthquakes had come to be regarded as one of the promising ways to foretell an occurrence of the earthquake.

But, because of rare occurrences of the great earthquakes in a few selected areas where the crustal movement has been continuously kept under observation, it is difficult to collect sufficient data on anomalous crustal deformation forerunning earthquakes. Now, if it exists that small local shocks are also correspondingly accompanied by small deformation of the ground close by the epicenters, an observation of these phenomena in any active area of small local shocks, will give us a sufficient amount of data, and consequently some useful clues for elucidation of the accumulation process of energy of earthquakes and mode of its release, and further to prediction of an earthquake occurrence.

For the purpose above stated, observation of local shocks and the crustal movements by high sensitive tiltmeters, extensometers and short period seismographs has been kept up at Oura and Akibasan in Wakayama City.

It is a matter of common knowledge that an observation of crustal deformation with those instruments must be made in a deep adit to avoid effects from meteorological disturbances. But, since both observation rooms in the present case are shallowly seated and near the sea, the ground deformations observed are considerably affected by not only meteorological changes, but also by oceanic tides. Consequently, elimination of these disturbing factors is necessary to obtain a substantial crustal deformation connected with local earthquakes.

2. Observation Stations and Instruments

Oura station is at northern slopes of Mt. Takatsushi; height and depth of the observation room, about 50 m above sea level and 5 m beneath the ground surface, bed rock of the observation room weathered crystalline schist, and observations

Table 1 List of instruments at Oura

Instrument	Type	Azimuth	Sensitivity	Mark	Recorder speed
Tiltmeter	Horizontal pendulum	*E-W*	0.007″ /mm	Ao	180 mm/hour ; Mar. 26 —Aug. 29, 1960
		N-S	0.005″ /mm	Bo	
Extensometer	Benioff	*E-W*	2.8×10^{-9}/mm	Eeo	30 mm/hour ; Aug. 12, 1960 —Sept. 15, 1961
		N-S	5.0×10^{-9}/mm	Eno	
Barometer	Aneroid		0.18 mb /mm	Po	7 mm/hour ; Sept. 15, 1961 —Present
Thermometer	Bimetal		0.01° C /mm		
Seismometer	Variable reluctance	*E-W*	$T_p=0.50$ sec.		30 mm/min. ; Mar. 26 —June 22, 1960
		N-S	$T_g=0.33$ sec.		75 mm/min. ; July 25 —Nov. 25, 1960
		U-D	$V=3000$ with shunt		12 mm/min. ; Nov. 25, 1960 —present

since March. 25, 1960, while the instruments equipped in Oura station are showed in Table 1. (135°09′30″ E., 34°11′16″ N.)

Akibasan observation station was set up at foot of a small hill called Akibasan on July 14, 1960, being about 1 km distant from Oura, in order to fill up and verify the result observed at Oura, the depth of the observation room being about 10 m and the bed rock crystalline schist. (135°10′23″ E., 34°11′48″ N.) As would be discussed later, Akibasan station was considered to be more suitable for observation of crustal movement than Oura from probable reason of its deeper situation compared with that of Oura and the difference of position of the room (namely at the foot of a hill in case of Akibasan, and at a mountain slope in case of Oura). Table 2 shows the instruments at Akibasan station.

Table 2 List of instruments at Akibasan

Instrument	Type	Azimuth	Sensitivity	Mark	Recorder speed
Tiltmeter	Horizontal pendulum	*E-W*	0.004″ /mm	Aa	180 mm/hour ; July 15 —Aug. 12,1960
		W-E	0.007″ /mm	Aa′	
	〃	*N-S*	0.004″ /mm	Ba	30 mm/hour ; Aug. 12, 1960 —Sept. 15, 1961
		S-N	0.007″ /mm	Ba′	
Extensometer	Benioff	*E-W*	3.1×10^{-9}/mm	Eea	
		N-S	2.3×10^{-9}/mm	Ena	
Barometer	Aneroid		0.11 mb /mm	Pa	7 mm/hour ; Sept. 15, 1961 —Present
Thermometer	Bimetal		0.01° C /mm		

3. Some Results on Local Earthquakes

Seismometric observation was carried out to investigate the activity of local shocks at Oura. In the second period from July 25 to Nov. 27, 1960, two electromagnetic seismometers of horizontal component and one of vertical component were installed, while only one vertical seismometer was used in the third period from Nov. 28, 1960 to the present. A frequency spectrum of *P-S* duration times of the local shocks recorded at Oura station showed that the highest frequency lay in a period between 0.9 and 1.0 sec.. Daily variations of occurrences of the local earthquakes are shown in Fig. 1. It seems probable that local shocks are apt to occur in midnight and afternoon.

Fig. 2 shows the relation between the maximum trace amplitudes and the numbers of earthquakes. It is concluded that Ishimoto-Iida's coefficient is about 1.9 in this district.

The number of the local shocks at Oura in one day, which represented approximately the activity of the local shocks in this area, was considerably vicissitudinous

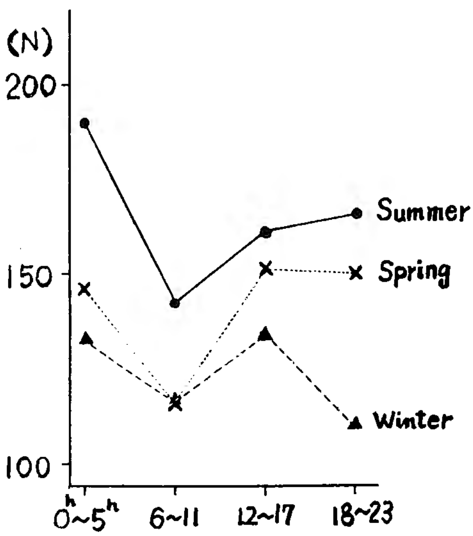

Fig. 1 Frequency distribution of time of local earthquake occurrence
Winter ; Dec., 1960—Feb., 1961
Spring ; Mar.—May, 1961
Summer ; June—Aug., 1961

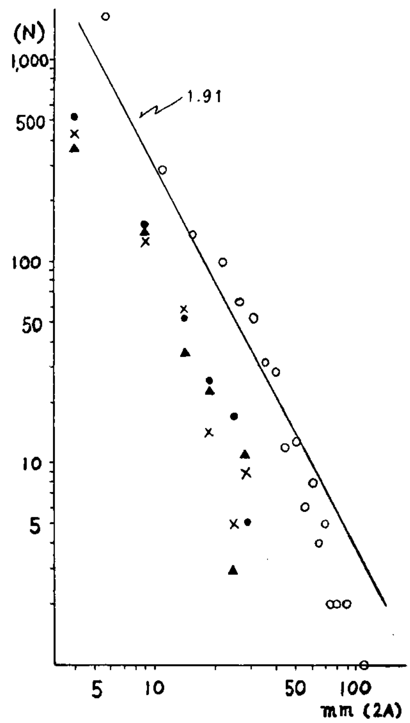

Fig. 2 Frequency distribution of maximum trace amplitude at Oura.
○ ; Sept.—Nov., 1960
▲ ; Dec., 1960—Feb., 1961
× ; Mar.—May, 1961
● , June—Aug., 1961

as shown in Fig. 3, even though some shocks were probably overlooked by the instrumental and observational errors.

These results were obtained from observed local earthquakes, *P-S* duration times or the durations of the shocks shorter than 2 sec..

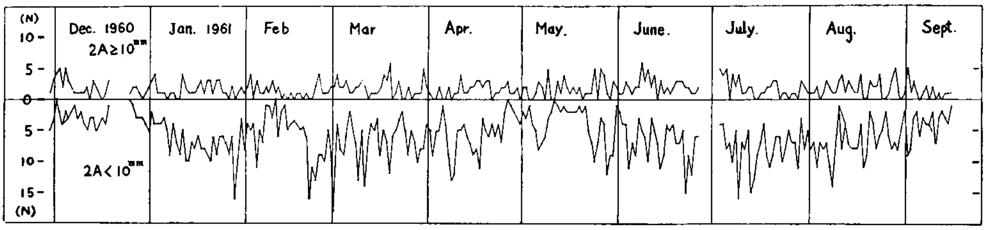

Fig. 3 Changes of the number of local earthquakes in a day at Oura.
A ; Maximum trace amplitude

4. Crustal Deformations at Oura and Akibasan

Since the ground deformations observed at both observation stations were, as shown in Fig. 4, considerably affected by meteorological changes and oceanic tides of the near sea, it is necessary to exclude these disturbances in order to find the proper crustal movement. In order to examine the instrumental error two sets of tilmeters, one set having two components of orthogonal direction, were set in parallel direction at Akibasan station.

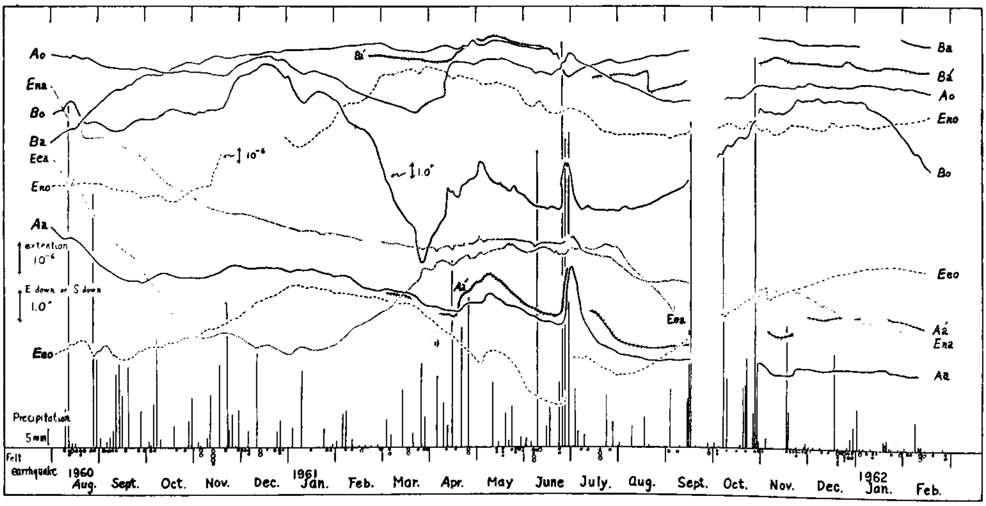

Fig. 4 Tilting motions and variations of linear strains observed at Oura and Akibasan station.
○ ; Remarkable local earthquakes ● ; Felt local earthquakes
Vertical line ; Precipitation

The disturbing factors are briefly discussed in the following.

1) Precipitation

As seen in Fig. 1, both observation stations are affected by precipitation, when its amount exceeds 10 mm. This effect may be somewhat reduced for the secular ground deformation, but it is very difficult to decide the form and amount of the ground deformation caused by rainfall. Therefore, we cannot help omitting the data observed on rainy days in case of the investigation of the minute but anomalous ground deformation of a short period.

2) Atmospheric Temperature

The deformation of the ground is generally affected to a certain extent by change of atmospheric temperature, and especially the observation of crustal deformation at a shallowly seated room is greatly disturbed by it. The atmospheric temperature at Oura hence has been provisionally adopted as effective temperature on the thermal deformation of the ground.

3) Atmospheric Pressure

Observations of the ground tilt and strain at both stations are remarkably disturbed by changes of the atmospheric pressure. There is no phase difference between the pressure change and the ground deformation at first sight. As it is reasonable that the direct pressure change and the pressure gradient are mainly attributable to a ground deformation, we adopt, in discussion of disturbing effect of atmospheric pressure upon the crustal deformation, the direct pressure change and the time gradient of pressure at Oura, it substituting the pressure gradient as a first approximation.

4) Oceanic Tides

Since Oura and Akibasan station are situated at the point of 0.7 and 1.5 km distance from the nearest sea (Wakaura Bay), the earth tidal changes of the ground tilt and strain are chiefly caused by bending action of the loading mass of near sea water upon the ground. According to this fact, we assume that the observed amount of the ground tilt or strain is proportional to the oceanic tidal height of Wakaura Bay. Then the tidal change of the ground deformation observed at Oura and Akibasan can be corrected by the ratio of M_2 component of the ground tilt or strain to the water height of the near sea. In this case, the ratio of the amplitudes and the phase difference of each tidal constituent are presumed equal. We adopted the water height of Wakayama Harbour Tidal Station as that of the near sea. The amplitudes and the phase differences to the tidal height are as follows;

		Ground Tilt or Strain pea 1 cm Change of Tidal Water Height	Phase Difference (Hour)
Oura			
Tilt	*E-W*	0.000294″	0.32
	N-S	0.000107″	1.68
Strain	*E-W*	-1.31×10^{-11}	2.04
	N-S	4.31×10^{-10}	−0.06
Akibasan			
Tilt	*E-W*	−0.000366″	0.43
	N-S	0.000190″	0.10
Strain	*E-W*	-2.39×10^{-11}	−0.34
	N-S	-8.40×10^{-11}	0.40

Where positive sings of the ground tilt and strain mean *E*-down tilt or *S*-down tilt and extension, positive signs of phase difference mean advancement of disturbing factors (water height).

5) Observation Room Temperature

The observation room Temperature sometimes changed irregularly to the degree of about one-tenth at Oura station, which seemed to come from the change of the underground water temperature. The relations between the temperature change and the ground tilt and strain were as follows;

Oura			
Tilt	*E-W*	$6.0''\times10^{-2}$	per 1°C change of room temprature
	N-S	$25.0\ \times10^{-2}$	
Strain	*E-W*	$-3.5\ \times10^{-8}$	
	N-S	$33.0\ \times10^{-8}$	

Using these coefficients, effect of room temperature was eliminated following change of the temperature. At Akibasan station, neither the daily variation nor irregular change of the room temperature was observed and no reduction for the room temperature was required.

6) Ground water Level and Insolation

We omit the consideration on these effects in the present article.

Let us now consider elimination of the disturbing effects of the atmospheric pressure and temperature in treatment of the observed data. If all disturbing factors affect independently upon the ground deformation, we are able to reduce the impedimental deformations of the ground separately. In the first place, effect of the oceanic tides is subtracted from the mean daily ground tilt or strain, by the ratio and the phase stated in 4). Then the disturbing coefficients of the atmospheric pressure and temperature upon the ground deformation are determined from

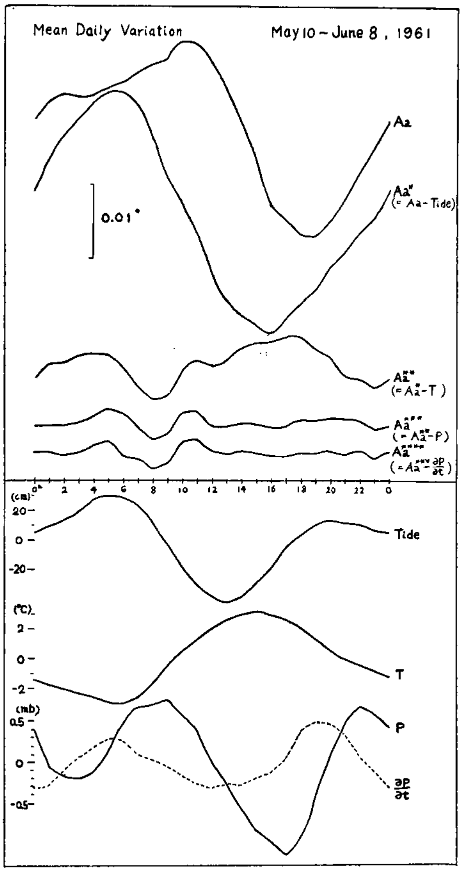

Fig. 5 Elimination of the meteorological and oceanic tidal disturbance about E-W tilt of Akibasan.

Aa ; Original record of E-W tilt of Akibasan

Tide ; water height at Wakayama Harbour

T ; Atmospheric temperature at Oura

P ; Atmospheric pressure at Oura

$\partial p/\partial t$; Time gradient of the atmospheric pressure at Oura (mb/hour)

the residual above obtained by the method of least squares. We adopt the phase of the atmospheric temperature which minimized the mean error. Attempts to calculate these coefficients are made of the period from May 10 to June 8, 1961 for the ground tilt, and from Aug. 9 to Sept. 7, 1961 for the ground strain. This procedure is shown in Fig. 5 on E-W tilt at Akibasan.

From above we obtain coefficients for the disturbing factors which are listed in Table 3, together with those for oceanic tidal effect and room temperature.

On November 14, 1960, three earthquakes were felt in the vicinity of Wakayama City, for which we made a trial to reduce the above-mentioned disturbances from the data. The result was shown in Fig. 6. As seen in the Figure, the disturbances were not subtracted sufficiently. We were not able, in the present stage, to conclude whether there were any peculiar crustal movements connected with these local earthquakes or not, calling, therefore, for a more precise method of ellimination for this purpose.

5. Conclusion

For the purpose of study of a minute deformation, if existing, of the ground connected with the small local shocks, some observations have been carried out in the seismically active area of Wakayama District, where averaged numbers of small or micro-earthquakes in one year exceed several thousands.

The results obtained are summarized in the following;

Table 3 Coefficients of the disturbing factors to the ground tilt and strain
Positive signs of the ground tilt and strain mean *E*-down or *S*-down tilt and extension. Positive signs of phase difference mean advancement of the disturbing factor.
Time gradient of atmospheric pressure is defined as

$$\left.\frac{\partial P}{\partial t}\right|_{t=t_0}=\frac{1}{2}\{P_0(t_0+1)-P_0(t_0-1)\},\ \text{(mb/hour)}$$

Instrument \ Disturbance	Water height change of 1 cm	Atmospheric temperature change of 1°C	Atmospheric pressure change of 1 mb	Time gradient of pressure, mb/hour	Room temperature change of 1°C
Aa	$-0.0366'' \times 10^{-2}$ (+0.43 hour)	$(-0.544'' \pm 0.014)\times 10^{-2}$ (−1 hour)	$(-0.346'' \pm 0.048)\times 10^{-2}$	$0.098'' \pm 0.076)\times 10^{-2}$	
Ba	$0.0190'' \times 10^{-2}$ (+0.10 hour)	$(-0.115'' \pm 0.015)\times 10^{-2}$	$(-0.0781 \pm 0.053)\times 10^{-2}$	$(-0.032'' \pm 0.098)\times 10^{-2}$	
Ena	-0.084×10^{-9} (+0.40 hour)	$(0.95 \pm 0.\ 23)\times 10^{-9}$ (−1 hour)	$(3.28 \pm 0.\ 83)\times 10^{-9}$	$(7.5 \pm 1.4\ )\times 10^{-9}$	
Eea	-0.024×10^{-9} (−0.34 hour)	$(-4.24 \pm 0.\ 34)\times 10^{-9}$ (−1 hour)	$(0.3 \pm 1.2\ )\times 10^{-9}$	$(1.3 \pm 1.5\ )\times 10^{-9}$	
Ao	$-0.0249'' \times 10^{-2}$ (+0.32 hour)	$(-0.008'' \pm 0.010)\times 10^{-2}$	$(-0.426'' \pm 0.035)\times 10^{-2}$	$(0.000'' \pm 0.065)\times 10^{-2}$	$6.0'' \times 10^{-2}$
Bo	$0.0107'' \times 10^{-2}$ (+1.68 hour)	$(0.008'' \pm 0.017)\times 10^{-2}$	$(-1.367'' \pm 0.059)\times 10^{-2}$	$(-0.11 \pm 0.11\ )\times 10^{-2}$	$20.0'' \times 10^{-2}$
Eno	0.436×10^{-9} (−0.06 hour)	$(7.61 \pm 0.\ 43)\times 01^{-9}$	$(-5.5 \pm 1.4\ )\times 10^{-9}$	$(1.4 \pm 2.2\ )\times 10^{-9}$	12.0×10^{-9}
Eeo	-0.0131×10^{-9} (+2.04 hour)	$(0.527 \pm 0.030)\times 10^{-9}$	$(-6.4 \pm 1.1\ )\times 10^{-9}$	$(-2.74 \pm 0.16\ )\times 10^{-9}$	-35×10^{-9}

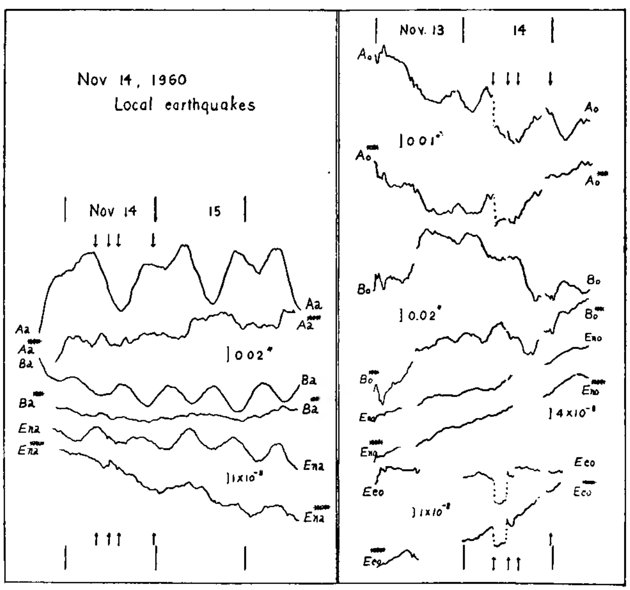

Fig. 6 Tilting motions and variations of linear strains before and after the remarkable local earthquakes on Nov. 14, 1960.

1) Number of occurrence per day of the local shocks recorded at Oura observation station was considerably vicissitudinous, and the coefficient of Ishimoto-Iida's formula was estimated about 1.9. The local shocks had a tendency to occur in midnight and afternoon.

2) A tentative method of elimination of disturbing factors such as oceanic tides and meteorological changes, was introduced. The coefficients of the disturbances upon the ground deformation were determined as shown in Table 3. An improvement of the method was considered necessary for study the relation between the local earthquakes and the minute deformation of the ground. This problem would be treated in more precise way on further accumulated data obtained in Wakayama area in near future.

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