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NEW TYPES OF HIGHLY SENSITIVE STRAINMETERS
—H-70 TYPE EXTENSOMETER AND R-70 TYPE ROTATIONMETER—

By

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Abstract

New types of highly sensitive extensometers of the H-70 type and a highly sensitive rotationmeter of the R-70 type have been devised, and their constructions and characteristics are explained.

Both instruments are able to be utilized in the routine observations of the earth tidal strain, crustal deformation and the seismic oscillations.

Records of the earth tide and the crustal oscillations in earthquakes which have been observed with these instruments are presented.

1. Introduction

Sensitivities of strainmeters which are used for the observations of the earth tidal strains, micro changes of the crustal strains and so on should be higher than 10^{-8}/mm. Recently, a technique using a laser interferometer has been made in progress. For example, an instrument whose sensitivity (Savino *et al.* [1966]) is 1×10^{-13}/mm, and anothers whose lengths are 1020 m (Vali *et al.* [1968]) and 55 m (King *et al.* [1969]) have been devised. Some people have said a mechanical gauge is normally 20 to 30 m long, "and strains measured in small ground sample are not representative of regional conditions". The present author thinks that their idea is ideal in an ideal case, and he hopes a laser interferometer gives excellent result in future. It is good for an observation of a dynamical crustal change that a laser beam has no inertia. But the laser interferometer still has many unsolved problems. Our requirements of strainmeters are not only high sensitivities and high stabilities during long observation priods, and also is that the instrument is able to be made economically. This is because a large of inexpensive instruments are able to cover over the large areas with their observations.

Since the author devised highly sensitive types of extensometers (Ozawa [1960]) and that of rotationmeter (Ozawa [1966]), he has been performing observations of the crustal strains by use of these instruments. Now, we have improved these instruments and have devised new types of strainmeters.

2. Principles

(A) Extensometer

Extensometer is an instrument for the observation of a linear strain of the crust. In Fig. 1, the principle of our extensometer is shown diagramatically. $\overline{AB}$ is a standard scale which is fixed at A on a point D in bed rock. When a segment $\overline{CD}$ in the bed rock is strained to $\overline{C'D}$, we find a relative displacement $\overline{BB'}$ between the free end B' of the standard scale and the initial position of the free end B. A vertical pole $\overline{CH}$ is stood with plate springs on the point C. The pole CH is made an inclination of $\angle C'BC=\alpha$, when the segment $\overline{CD}$ on the bed rock is contracted into $\overline{C'D}$. This inclination of the angle α is

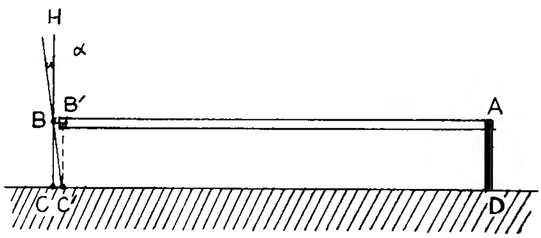

Fig. 1. The principle of the new type extensometer.

amplified into a deflection of an optical beam with a horizontal pendulum of Zöllner suspension type.

Let L, a, l, T, D, m, g and e be the length of $\overline{AB}$, the distance of $\overline{BC}$, the equivalent length of the horizontal pendulum, the period of the pendulum, the length of the optical lever from the horizontal pendulum to the photographic recorder, the displacement of the light spot reflected from the mirror of the pendulum on the recording paper, the gravitational acceleration, and the linear strain of the bed rock, respectively. The sensitivity S of this extensometer is written as

$$S=\frac{e}{m}=\frac{2\pi^2 la}{LDgT^2}=\frac{V}{T^2},\qquad e=\frac{\overline{CC'}}{\overline{CD}}, \tag{1}$$

where V is a constant of the instrument.

Now, let be $L=20$ m, $D=4$ m, $l=5$ cm, $a=3$ cm and $T=10$ sec, we have as a following sensitivity

$$S = 3.8 \times 10^{-10}/\text{mm}.$$

Since this amplifier of the extensometer is a tiltmeter, it has few effect of the ground inclination. The ratio R between tilt amplification and that of linear strain is given as

$$R = \frac{a}{L} = 1.5 \times 10^{-3}.$$

Therefore, the effect of the ground tilt is negligible in this instrument whose sizes of L and a are shown as above.

(*B*) *Rotationmeter*

Let u, v and w be x, y and z components of a displacement at a rectangular coordinate system. Rotationmeter is used to observe one of the components $\partial u/\partial y$, $\partial u/\partial z$, $\partial v/\partial x$, $\partial v/\partial z$, $\partial w/\partial x$ and $\partial w/\partial y$. This instrument has a pair of cantilevers, $\overline{AC}$ and $\overline{BD}$ shown in Fig. 2. The ends A and B are rigidly fixed

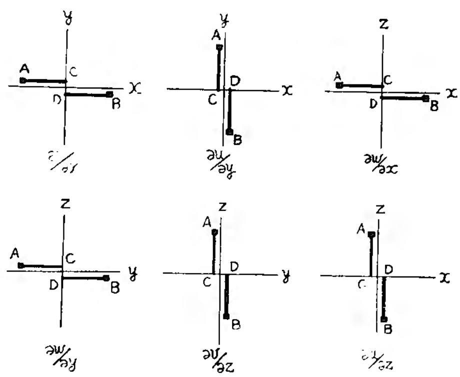

Fig. 2. The principle of the rotationmeters.

on the bed rock. C and D are the free ends. Assume a deformation of the bed rock to be the Cauchy's strain, then changes of the distances between the pairs of cantilevers are equal to $\partial u/\partial y$, $\partial u/\partial z$, and so on. These distances are amplified, and are recorded by the same method with the amplifier of the relative displacement at the extensometer mentioned above.

Let the total length of the pair levers be 10 m and the sizes of the parts of the amplifier system be same with those of the extensometer as $D=4$ m, $l=5$ cm, $a=3$ cm and $T=10$ sec, then the sensitivity of this rotationmeter will be

$$7.6 \times 10^{-10}/\text{mm}.$$

The effect of the ground tilt by using the pendulum of the amplifier is as little as that with the extensometer. The effect of the ground tilt caused by placing the cantilevers horizontally is also negligible because the deflection constants of the cantilevers are large and their periods of the deflectional vibrations are short.

3. Construction of the instruments

(A) *Extensometer*

This instrument consists of a standard scale, an amplifier of the relative displacement BB' and photographic recorder. The standerd scale is made of super-invar pipe whose length is 20 to 100 m or of super-invar rod whose length is several meters to about 20 m. The scale is placed horizontally and is suspended with thin wires at many points. Its end A is fixed rigidly on the bed rock and the other end B is connected to the amplifier. The construction of the amplifier is shown in Fig. 3. An iron plate E is fixed with spring-plates

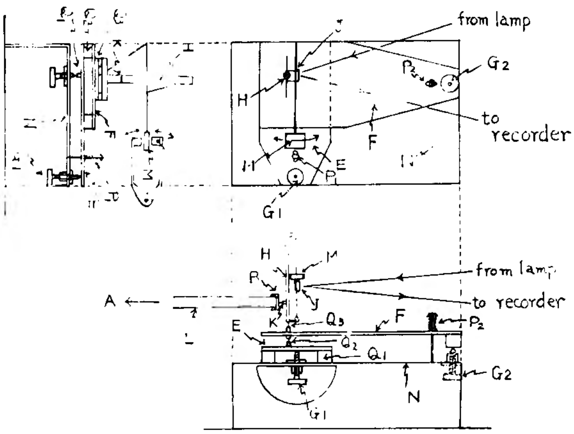

Fig. 3. The construction of the amplifier of H-70 type extensometer.

Q_1 on the channel-like plate N, and the inclination of the plate E is adjusted with a micro screw G_1. An iron plate F is fixed with spring plates Q_2 on the plate E and its inclination is adjusted with a micro screw G_2. The supporting pole H of the horizontal pendulum M is fixed with spring-plates Q_3 on the plate F. The height of the pole H is about 20 cm, and the pendulum M is suspended from the upper and lower ends of the pole. The weight of the pendulum is made of pure copper that it may also serve as an electro-magnetic damper. A concave reflecting mirror is fixed on the rotational axis of the pendulum, and its rotation is amplified with an optical lever on the photographic recorder.

We can easily adjust the period of the pendulum on the range from a few to 30 seconds by use of the screw G_1. The deflection of the pendulum is adjusted with the screw G_2. The screw G_2 is used also a calibration of the sensitivity of the instrument. One revolution of the screw is divided into 100 divisions, and the revolution of one division is equivalent to the displacement of a half micron of the fulcrum of the pole H. For example, we can calibrate directly a strain of more than 1×10^{-8} on an extensometer whose length is 25 m. For routine observations, the sensitivity is calibrated by measurement of the period of the pendulum. Another method of calibration is that the part of the fixed end A is put through a solenoid coil in order to put the scale in a strong magnetic field. The number of roll of the coil is several thousands turns and its length is about ten centimeters. For example, one of the scale is contracted 1.7 microns per one meter by a magnetic field of 200 oersteds and another is contracted 4.2 microns by a field of 880 oersteds. Those contractions are recovered gradually by the heat generated in the coil provided the current in the coil flows for a long time.

(*B*) *Rotationmeter*

It now proceeds to explains the components of the rotationmeter placed on the horizontal plane. The construction of the pair of cantilevers of R-65 type is shown in Fig. 4. Each lever is constructed like a raft or a ladder with six

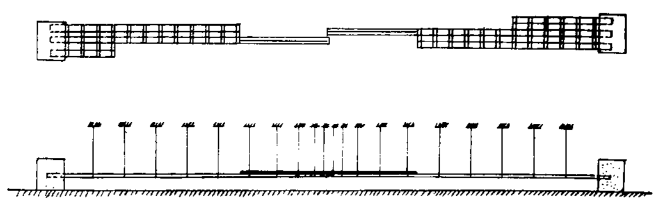

Fig. 4. The construction of the cantilevers of the rotationmeter of R-65 type.

sheets of super-invar plates which are 2 m long, 6 cm wide and 2 mm thick. Each plates of the both ends C and D are reinforced with a super-invar rod whose diameter is 1 cm like a back-bone or a leaf-blade to make hard for the bending in the vertical plane. These levers are designed to make their moment of inertias of the areas large. However, it is hard to make their deflections smaller than one percent of the change of the distance between both levers. The fixed ends of these levers are fastened with a number of bolts which are plunged deeply into the bed-rock, and the ends are fastened directly with concrete on the rock.

The levers are placed horizontally and are suspended with wires longer than 60 cm at intervals of less than 1.5 m. In particular, the vicinities of the free ends are suspended at short intervals. The levers of the R-70 type rotationmeter are constructed with angles (L-shaped beam) and the band-plate made of super-invar. Both sides of the angle are 2.0 cm wide and their thickness is 2 mm. The band-plate is 20 cm wide and is 0.5 mm thick. The fixed ends are pressed with thick iron plates, and are fastened with a number of bolts in the bed rocks.

In R-65 type rotationmeter, the amplifier part is fixed on the free ends; for example, the pendulum part is placed on C and the distance adjuster is placed on D. At R-70 type rotationmeter, the amplifier is placed on the bed-rock by these free ends as shown in Fig. 5. Two horizontal pendulums H_1 and H_2 are set on the two storied plate, E_1, F_1 and E_2, F_2 fixed on the channel-shaped plate N, respectively. The plates E_1 and E_2 contribute to the adjustments of the periods of the pendulums, and the plates F_1 and F_2 contribute to those of the deviations of H_1 and H_2, respectively. Both pendulums are directed parallel to the cantilevers and are on a line. The reflecting mirrors M_1 and M_2 of the pendulums are faced orthogonally in relation to each other as shown in Fig. 5. A light beam from a light source is reflected at first on the mirror M_2,

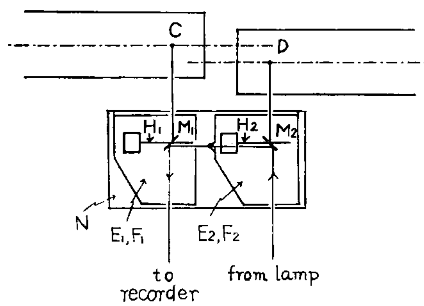

Fig. 5. The construction of the amplifier of R-70 type rotationmeter.

and then is reflected to the mirror M_1. This twice reflected beam goes into the photographic recorder.

The displacements of the cantilevers $\overline{AC}$ and $\overline{BD}$ from each initial positions are transformed and are amplified into the deviations of the pendulums H_1 and H_2, respectively. The difference between these displacements of $\overline{AC}$ and $\overline{BC}$ is obtained and is amplified by the light-beam twice reflecting on M_2 and M_1.

The accordance of their periods of the both pendulums is the most important problem in this instrument. When the difference between the periods of the pendulums is large, and the damping constants of their oscillations are smaller, the resultant dynamic amplification of this instrument is made more complex. However, the resultant dynamic amplification for a uniform strain of the bed-rock is a simple sum of the amplifications of the both pendulums. We can also neglect the lack of accordance of their periods so long as their damping constants are larger than about 0.2. Generally, the complexity is little because this instrument is used for the observations of changes with periods much longer than the periods of the pendulums.

(*C*) *Dynamical sensitivity*

In these strainmeters, their scale or levers are devised to be so rigid that their dynamical characteristics may be neglected. Therefore, we may consider the dynamic characteristics of the pendulums only. These instruments are usually used to observe oscillations whose periods are longer than three times of the natural periods of these instruments and are used at damping constants above 0.2. Therefore, the dynamical sensitivities are nearly flat, and their phase lags are negligible.

4. Observations

(*A*) *Extensometer*

The horizontal components of extensometers of these types H-59 *A*~*E* have been placed at Osakayama Observatory (34°59.6′N, 135°51.9′E), Kishu Mine (33°51.7′N, 135°53.4′E) and Suhara Observatory (34°02.6′N, 135°11.7′E). The vertical components of extensometers of these types V-59 *B*, *D* have been placed at Osakayama Observatory and Suhara Observatory. And also the horizontal component of the extensometer of H-59 *E* type has been placed and will be soon in operation by P. Melchior at Walferdange in Luxembourg.

Photos. 1 (a), (b), (c) and (d) show the observed curves of the earth tidal strains at Osakayama in the directions of the east, the north, the N38°E and the vertical which were observed with H-59 *B*, H-59 *C*, H-59 *D* and V-59 *B* types extensometers, respectively.

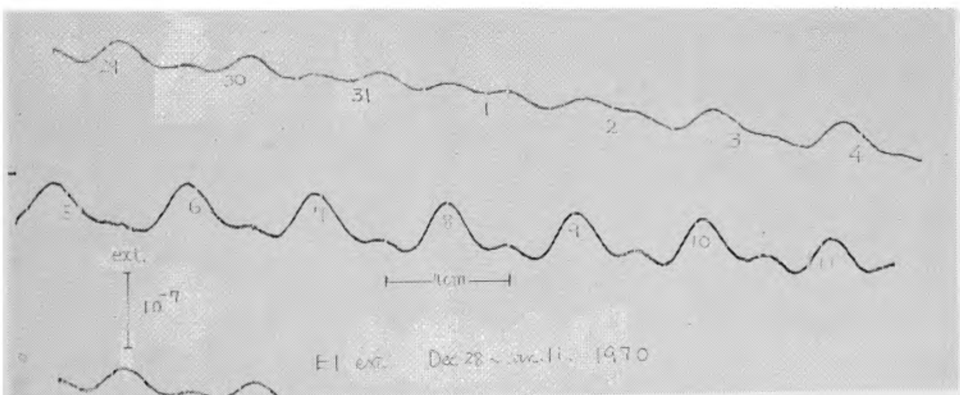

Photo. 1(a). The tide curve in the crustal strain observed with H-59-*B* type extensometer in the direction of the east at Osakayama.

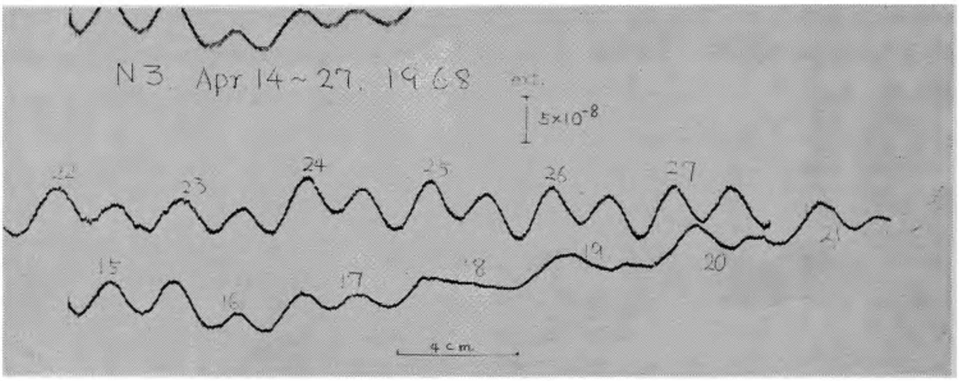

Photo. 1(b). The tide curve in the crustal strain observed with H-59-*B* type extensometer in the direction of the north at Osakayama.

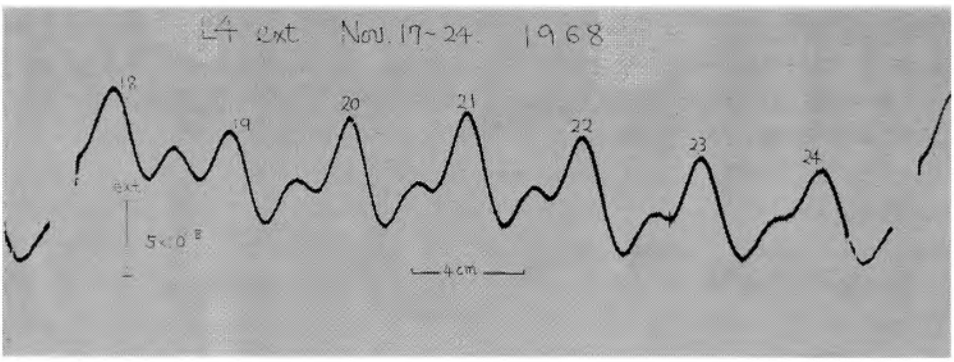

Photo. 1(c). The tide curve in the crustal strain observed with H-59-*D* type extensometer in the direction of the S38°W at Osakayama.

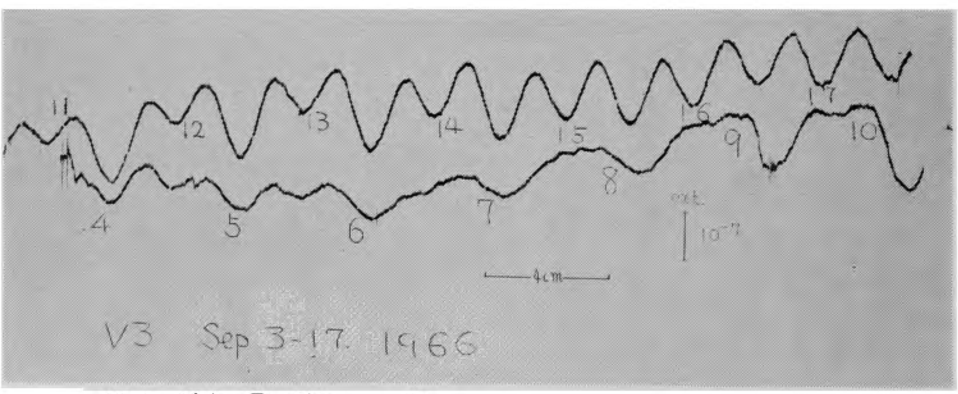

Photo. 1(d). The tide curve in the crustal strain observed with V-59-*B* type extensometer in the vertical direction at Osakayama.

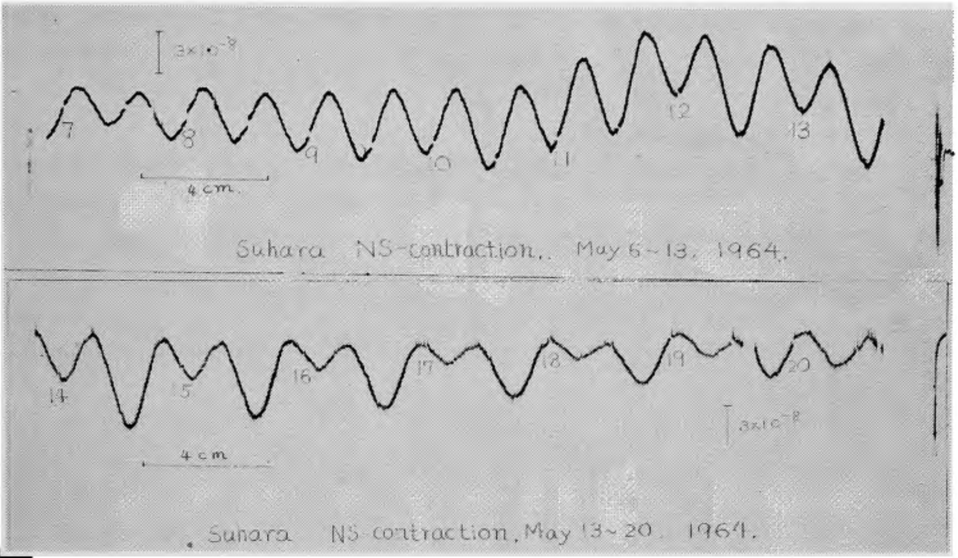

Photo. 2. The tide curve in the crustal strain observed with H-59-*A* type extensometer in the direction of the north at Suhara.

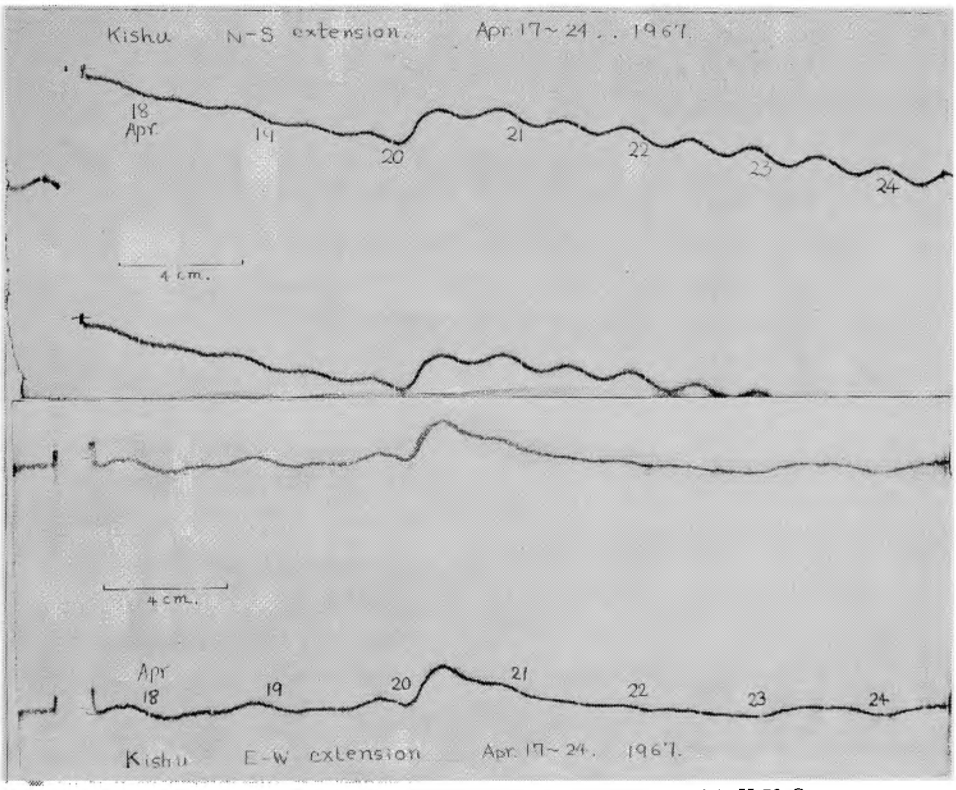

Photo. 3. The tide curve in the crustal strain observed with H-59-*C* type extensometer in the directions of the east and the north at Kishu.

Photo. 2 (a) shows the records of the tidal strain at Suhara where is on the coast.

Photo. 3 shows the records of the tidal strains in the directions of the east and the north observed with H-59 C type extensometers at Kishu.

These instruments have sometimes recorded anomalous changes which start

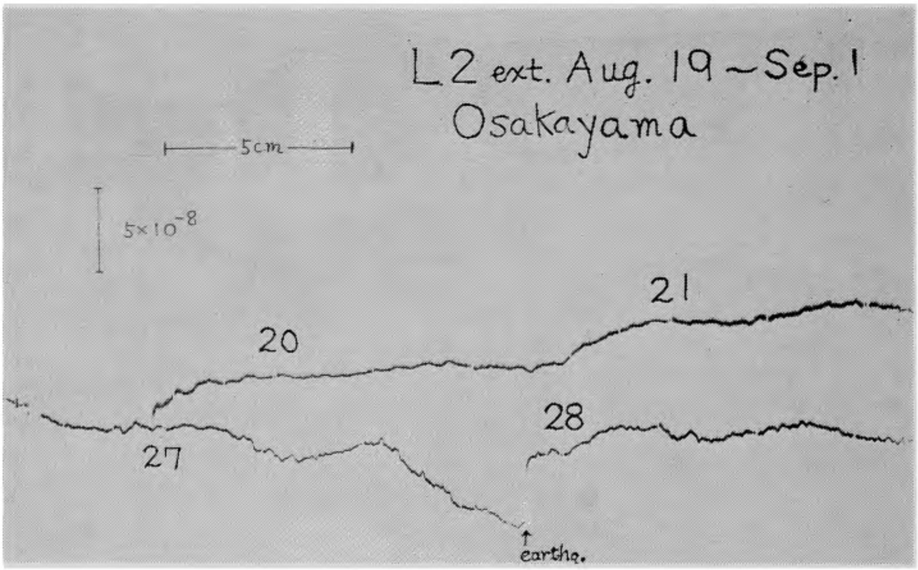

Photo. 4. The anomalous change in the crustal strain before and after the earthquake of Kamiwachi-cho.

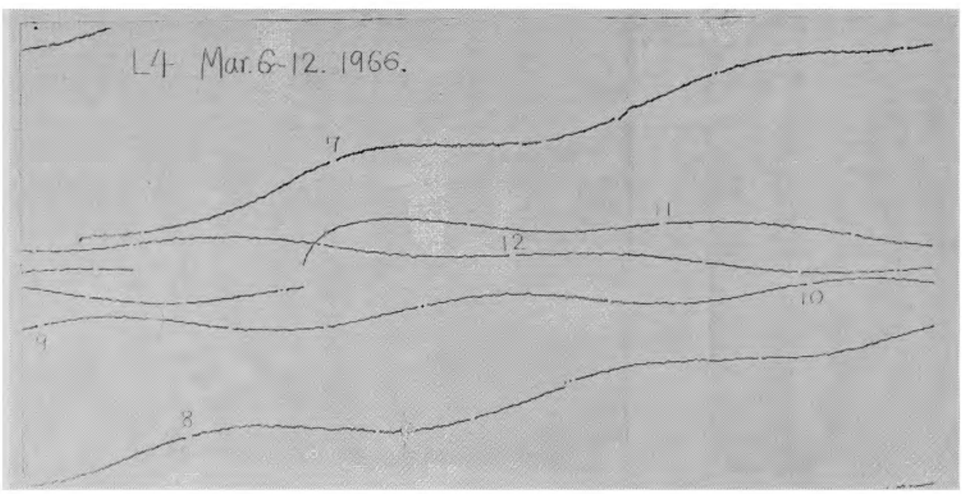

Photo. 5. The abrupt change and the afterworking of the crustal strain observed at Osakayama observed with H-59-D type extensometer in and after the earthquake in the suburb of Kyoto City.

ten odd hours before earthquakes. They have also recorded the abrupt changes during earthquakes.

Photo. 4 shows these anomalous changes observed Osakayama in the times of the earthquakes at Kyoto City.

Photo. 5 shows the abrupt change and the afterworking (creep) in the time of the earthquake in the suburb of Kyoto City. It seems that the afterworking occurred within the earthquake focus.

Sometimes these extensometers are used as strain seismographs, which have dampers of the nearly critical value and have high speed recorders. Photo. 6 shows the records observed at Osakayama of oscillational-strains in the times

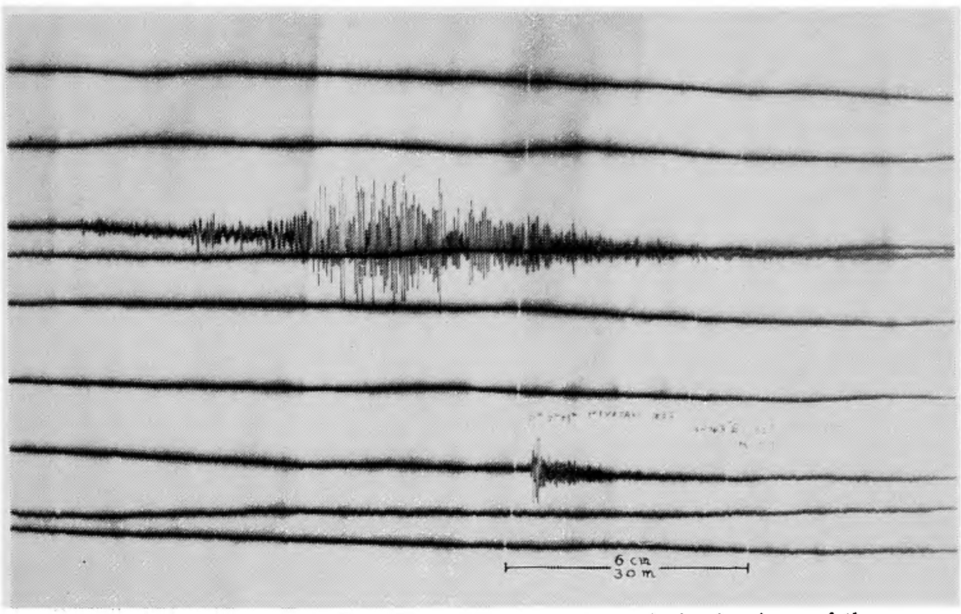

Photo. 6. The seismic oscillations in the crustal strain in the times of the earthquakes of Greece (upper) and off Miyazaki Prefecture (lower).

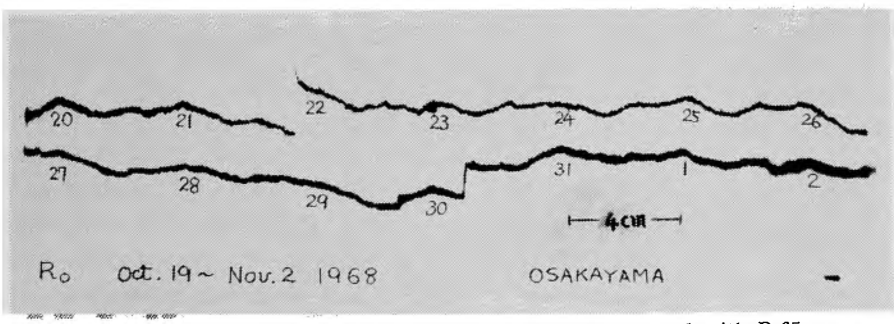

Photo. 7. The tide curve in the crustal strain observed with R-65 type rotationmeter at Osakayama.

of the earthquakes in Greece and off Miyazaki Prefecture, respectively.

These instruments have been operated usually at sensitivities of the order of 10^{-9}/mm in routine observations.

(*B*) *Rotationmeter*

The R-65 type rotationmeter has been placed at Osakayama and has been used at a sensitivity of 1×10^{-8}/mm in routine observation.

Photo. 7 shows the record of the ∂N52°W/∂N38°E component at Osakayama observed with this rotationmeter. We can see the earth tidal changes and the continuous microwaves caused by water-pumping. This record shows some instrumental noise due to the weakness of the cantilevers and its supporters, but these defects will be removed from the instrument of the R-70 type.

Acknowledgements

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