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DISASTER PREVENTION RESEARCH INSTITUTE

BULLETIN No. 27 JANUARY, 1959

ON THE OBSERVING INSTRUMENTS AND TELE-METRICAL DEVICES OF EXTENSOMETERS AND TILTMETERS AT IDE OBSERVATORY AND ON THE CRUSTAL STRAIN ACCOMPANIED BY A GREAT EARTHQUAKE

BY

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Abstract

By using the extensometers and tiltmeters, the observation for crustal deformation is being carried on at the Ide Observatory of Disaster Prevention Research Institute of Kyoto University. The following is the outline of this observatory and its instruments, especially of tele-metrical devices which have been set up recently.

1. The outline of Ide Observatory

The observatory is situated at 135°49.5′E and 34°47.9′N, Ide-cho, Tsuzukigun, Kyoto Pref. as shown in Fig. 1. The present adit is reformed one of an abandoned copper mine which was excavated some 80 years ago. The neighbouring formation belongs to Palaeozoic system and this surrounding rock is chiefly mica-schist that is called Ryoke metamorphics. The natural feature of surroundings of this observatory is shown in Fig. 2. The size of the adit is 1.3 m in width and 1.8 m in hight and about 120 m in whole length, and the 1st observing room with the size of about 4.5m high and 2.2 m wide is situated at the most sequestered part of the adit. The temperature variation in the observing room which is at 30 m depth from the ground surface is limitted between 14.9°C and 15.4°C all through

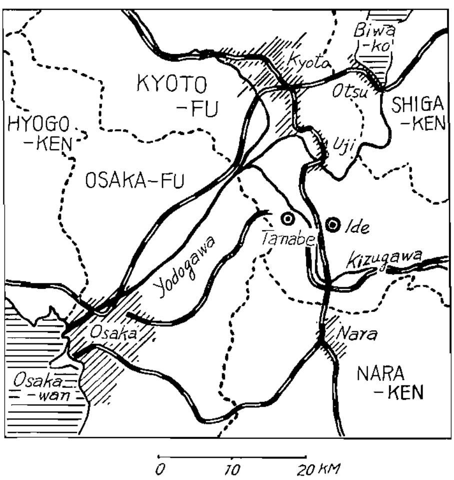


Fig. 1 Position of the observatory.

the year, because of not much effected by the open-air temperature.

The 2nd observing room constructed at the place of old pit mouth, is located at about 90 m from the new pit mouth and 5 m depth from the ground surface, the variation of temperature in this room fluctuated between 15.0°C and 15.9°C. The recording room with the size of 3 m wide and 4 m long stands nearby the pit mouth.

In the 1st observing room, 7 components of extensometers, 3 components of high magnification extensometers, the tiltmeters, the discharge meter and the self-registering thermometer had set up. All variations appeared on these instruments are recorded on the bromides automatically in this room.

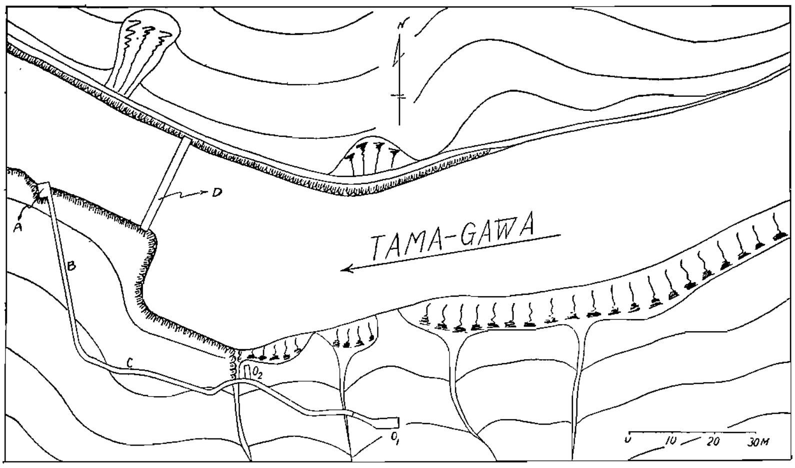


Fig. 2 Illustration of the observatory.
A : recording room, B : adit, C : position set up the tele-metrical extensometer, D : Sabo-dam, O_1 : the 1st observing room, O_2 : the 2nd observing room.

In the 2nd observing room, had set up the tiltmeter. The variation appeared on this instrument is not only recorded on the bromide in this room but also transmitted to the recording room by the tele-metrical device and recorded here.

At the position in the adit about 60 m from the pit mouth, set up another extensometer. The variation on this instrument is not only recorded photograph but tramsmitted also to the recording room by the similar way as tiltmeter in the 2nd observing room and recorded there. At the same position of this extensometer the quantity of water, accumulated in the adit, is also shown on the photographic recording automatically.

At the time of establishment, the 2nd observing room was a pit mouth as described above. The length of the adit was nearly 50 m as so. Due to the Minamiyamashiro disaster on August 15, 1954, however, the observatory suffered from flood by Tama-gawa, which is running nearby. Therefore we were forced to suspend our observation for about 6 months. Farthermore the upper stream of the same inflicted also prethy damaged. Under this cercumstances, whenever it rains a great deal of sand is brought down. Kyoto prefectural government therefore constructed the Sabo-dam of 10 m high, as the preventive measures. In this consequence oure observatory was destined to sink into the pooled water. We took it seriously that our past result being brought naught, we decided to excavate new adit, enclosing old pit mouth, abut 90 m long extending from the down stream of the Sabo-dam to the old adit by the help of prefectural government. On the way of this excavating operation we had faced rock-falling incident, the detail of which was reported already in our previous report. Thus the observatory now in existense, were formed with great effort.

2. Observing instruments

In this paragraph, will be described the outline of each instrument provided in this observatory. The extensometers provided here are called "super-invar-bar extensometer" which has the structure as shown in Fig. 3. This device is to measure the variation of span between 2 concrete blocks which are fixed to a natural rockbase. When one end of the super-invar-bar 1 cm in diameter is fixed to a block, the variation of the strain on the rock is revealed by the relative move between the one end of bar and the other block. Therefore if the rotatable roller is fixed on the block and one end of this bar is put on it, the relative move is revealed on the rotating degree of the roller. When the mirror is attached on that roller and let the lamp light reflect at it, the movement of reflected light is magnified by the rotation of mirror attached to the roller. Then let that light hit on the rotating bromide through the lens, the movement of image is recorded automatically. The position of these components is shown in Fig. 4. Two components of these, "2", "3" are set up horizontally, one component, "1" is set up vertically

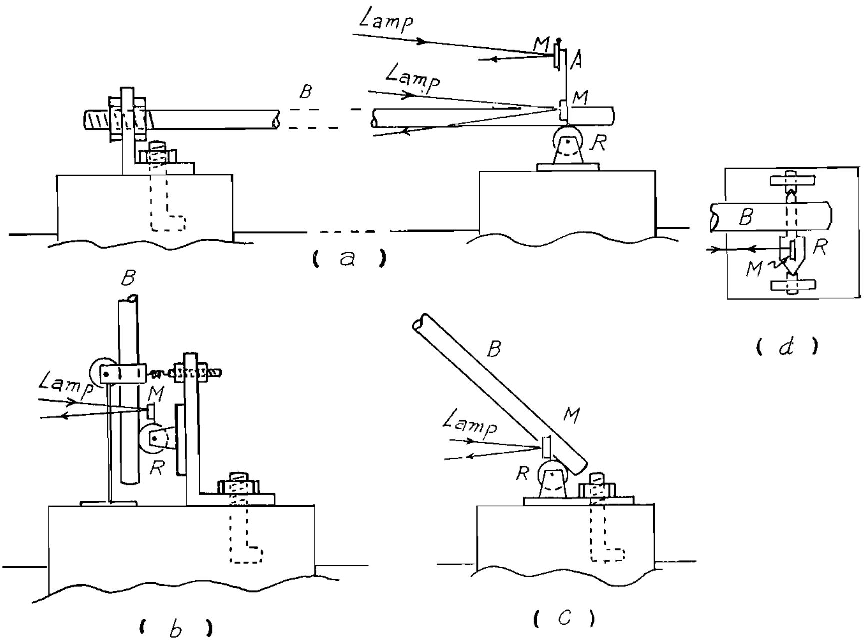


Fig. 3 Illustrations of super-inver-bar extensometers and high magnification extensometer.
A : arm, B : super-invar-bar, M : mirror, R : roller.
(*a*) horizontal component of super-invar-bar extensometer and high magnification extensometer. (2.3,6.3′, II,III)
(*b*) vertical component. (1)
(*c*) sloping component. (4,5)
(*d*) part of roller.

and these three components, "1", "2", "3" are faced to 3 rectangular co-ordinate axis. The other components, "4", "5", "6" are arranged obliquely intersecting each other with 2 components out of three mentioned above. The residual one "3′" is placed in parallel position to the component "3", in order to compare with it.

Three components of the high magnification extensometer "1", "II", "111", are provided for measuring 3 rectangular co-ordinate axis of "1", "2", "3". This extensometer, is the one the magnification of which is made much better than the former by the way that lets the optical lever move with the arm fixed to the roller as shown in Fig. 3(a).

The tiltmeter, used for observing the tilting motion of the ground, is called "tiltmeter with horizontal pendulum of Zöllner suspension type".

The main part of this instrument is the horizontal pendulum as shown in Fig. 5. In case that this pendulum is set on the rockbase, it is suspended towards the direction of the tilt of the rockbase and stops still. If the variation of tilt takes place towards the rectangular direction to this pendulum, the pendulum changes its pointing direction to the same direction of the tilt of the rockbase and stops there. That is to say, the variation of tilting motion of rockbase is revealed on the rotating degree of the pendulum. Therefore, if the mirror is attached on the pendulum, same as extensometer described above, the photographic record is obtained automatically· Two kinds of these tiltmeters are installed in this observatory. Two components of "A", "B" are set adjusting the setting place, so as to face rectangularly each other and the tilting motion of the ground is obtained on these components by vector method.

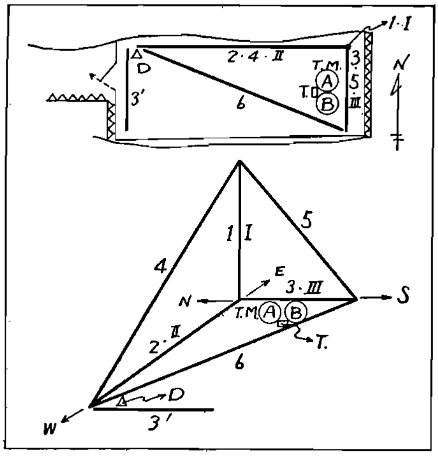


Fig. 4 Disposition of instruments interior the 1st observing room.
1·2·3·4·5·6·3′ · super-invar-bar extensometer,
I · II · III high magnification extensometer.
T. M. : tilmeter,
T. thermometer.
D. dscharge meter.

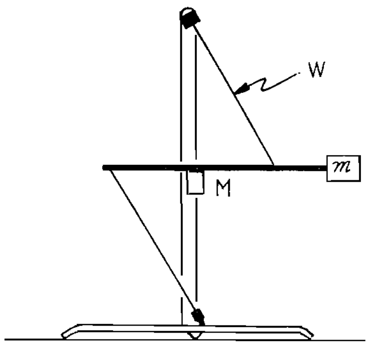


Fig. 5 Illustration of tiltmeter (horizontal pendulum). It is constructed mainly on super-invar. M: mirror, W: super-invar wire (50μ in diameter), m: mass.

In order to measure the quantity of mine water which is infiltrated into the adit, accumulated water is led to the discharge meter of weir box type with which the water level is recorded. The illustration of this device is indicated in Fig. 6.

The self-registering thermometer is provided for measuring the variation of temperature of the adit interior. This is the bimetal type as shown in Fig. 7. It has 2 sheets of bimetal which are bent reverse directions each other by the variation of temperature. On both ends of these bimetals, the

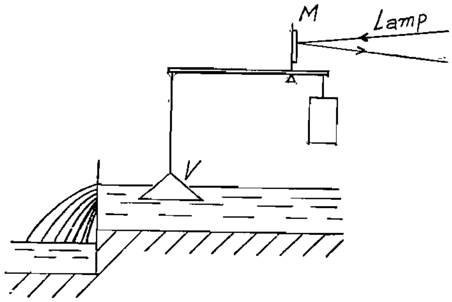


Fig. 6 Illustration of discharge meter.
M : mirror, V : bouy.

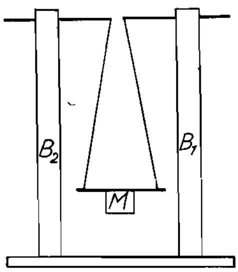


Fig. 7 Illustration of self-registering thermometer.
M : mirror, $B_1 \cdot B_2$: bimetal.

mirror is hung. The rotating degree of the mirror shows the variation of temperature.

In the 2nd observing room, by the use of the tiltmeter with horizontal pendulum of Zöllner suspension type, the photographic record is obtained automatically and the tele-metrical record is obtained in the recording room by use of photocell type tiltmeter. (Dr. T. Hagiwara has ever used photocell type instrument on the tele-metrical observation.)

In the position of C, at the center of the adit, we have been keeping photographic observation by use of super-invar-bar extensometer, as described above, and also tele-metrical observation by same way as the tiltmeter in the 2nd observing room. The following 3 kinds of tele-metrical devices of extensometer are used at this place, changing inductance type extensometer, wire resistance strain meter and photocell type extensometer. At this place we also set up the discharge meter and observed the variation of quantity of mine water.

Among every instruments mentioned above, the super-invar-bar extensometer and horizontal pendulm type tiltmeter have been using long and already known the function of them, but it seems to explain the function of tele-metrical devices.

The values of every instrumental constants on each instrument are shown in Table 1.

Table 1 List of instruments of Ide Observatory.

Mark	Azimuth	Sensitivity	Place
1. Super-invar-bar extensometer			
		(10^{-8}/mm)	
1	Vertical	5.54	O_1
2	Horizontal N88°E	4.92	O_1
3	Horizontal N 2°W	10.74	O_1
4	Dip 50° N88°E	3.46	O_1
5	Dip 66° N2°W	2.78	O_1
6	Horizontal N77°W	2.30	O_1
3′	Horizontal N2°W	6.12	O_1
2′	Horizontal N82°W	2.80	C
2. High magnification extensometer			
I	Vertical	0.329	O_1
II	Horizontal N88°E	0.492	O_1
III	Horizontal N2°W	0.892	O_1
3. Changing inductance type extensometer (Tele-metrical Extensometer)			
E_1	Horizontal N82°W	7.5	C
4. Photocell type extensometer (Tele-metrical extensometer)			
E_p	Horizontal N82°W	3.7	C

Mark		Azimuth	Sensitivity	place
5. Wire resistance strain meter (Tele-metrical extensometer)				
			(10^{-8}/mm)	
E_U		Horizontal N82°W	3.4	C
$E_{F'}$		Horizontal N82°W	5.5	C
6. Horizontal pendulum type tiltmeter				
			($10^{-2\prime\prime}$/mm)	
T.M.	A	N45°E	2.0	O_1
	B	S45°E	2.0	O_1
T.M.′	A′	N45°W	3.0	O_2
	B′	N45°E	3.0	O_2
7. Photocell type tiltmeter (Tele-metrical tiltmeter)				
T.M.$_P$	A'_p	N45°W	4.0	O_2
	B'_p	N45°E	4.7	O_2
8. Discharge meter				
			(water level mm/mm)	
D			5.3×10^{-2}	O_1
D′			1.7×10^{-2}	C
9. Thermometer				
T			0.034(°C/mm)	O_1

3. Tele-metrical devices of extensometers and tiltmeters

The super-invar-bar extensometer and horizontal pendulum type tiltmeter and so forth are used for the observation of the crustal deformation. As all these kinds of instruments are required keen sensitivity and high magnification, most of them use the magnifying devices by the optical lever and photographic automatical recording method. In this method there are not only various advantage but many disadvantages. The greatest disadvantage of all is that we cannot make tele-metrical observation. We have therefore planed to manufacture newly devised extensometer and tiltmeter to relieve the defect of this disadvantage to tele-observation. With a view to realizing above purpose the following conditions are required.

1) To be the same or higher in degree of both sensitivity and accuracy than those of optical instruments as ever-used,

2) To be stable for longterm observation,

3) To be not affected against the variation of moisture and temperature,

4) To be simple in handling and serviceable with less hitch,

5) To be easy and cheap in manufacturing.

To meet to owe satisfaction on above terms, we manufactured for trial the changing inductance type extensometer. We set it up at Ide Observatory and have been observing with it since the end of 1955 to date, comparing with wire resistance strain meter (SHINKOH type PS7-L) and with super-invar-bar extensometer. Thus we have commenced since May 1956 to make comparative observation with photocell type extensometer and tiltmeter and with above stated extensometer and tiltmeter with horizontal pendulum of Zöllner suspension type.

The results of observation will be explained hereunder.

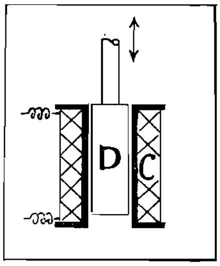


Fig. 8 Illustraction of the changing inductance coil.
C: coil, D: iron core.

3.1. Principles of the devices.

A) Changing inductance type extensometer.

When an A.C. is sent through the coil (C), if the iron core (D) is moved as shown in Fig. 8, the inductance of coil will be varied. So if A.C. voltage is kept in definite, the electric current applied to coil will be changed according to the variation of coil inductance. Therefore the movement of iron core can be obtain if we study the relation between the movement of iron core and the variation of the current beforehand.

B) Wire resistance strain meter.

It is a matter of common knowledge that electric resistance is varied by the extension and contraction of metal wire. By utilizing this theory, sticking gauge, which is made of special metal wire or foil, on the strain-measuring object, strain is measured by the variation of electric resistance and galvanometer is deflected according to the deformation of gauges, if we connect these 4 gauges stuck on the measuring object to be 4 sides of Wheatstone bridge (4 gauges method) as shown in Fig. 9. Therefore if the relation between deformation of gauge and variation of current is to be found, the strain will be obtained by the variation of the current.

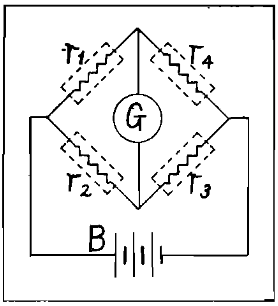


Fig. 9 Arrangement of gauges. (4 gauges $r_1 \cdot r_2 \cdot r_3 \cdot r_4$: F-gauge, B : battery.

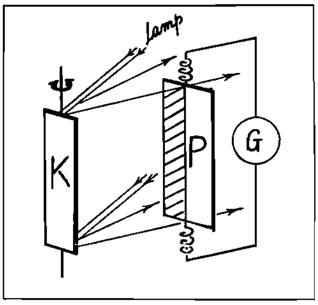


Fig. 10 Shematic view of photocell type instruments. K : mirror, P : photocell, G : galvanometer.

C) Photocell type extensometer and tiltmeter.

When the photocell is exposed to the light, photo current which is generated thereon is varied in proportion to intensity of light or the dimension of exposed area. As shown in Fig. 10 when the light projected from the light source reflects on the mirror and the photocell is exposed in the reflected light, the generated current on the photocell will be varied, if the mirror rotates and the dimension of exposed area on cell varies. Therefore if the relation between the variation of the dimension of exposed area and the variation of the generated current on the photocell is found, we shall be able to find the variation of exposed area of photocell, that is, rotating angle of the mirror by the deflection of galvanometer.

3.2. Measuring circuit and observation.

On the basis of above described principles, we made newly devised extensometer and tiltmeter which can be used for tele-metrical observation. The circuit actually used for observation is shown in Fig. 11. Following is to explain about it in due order.

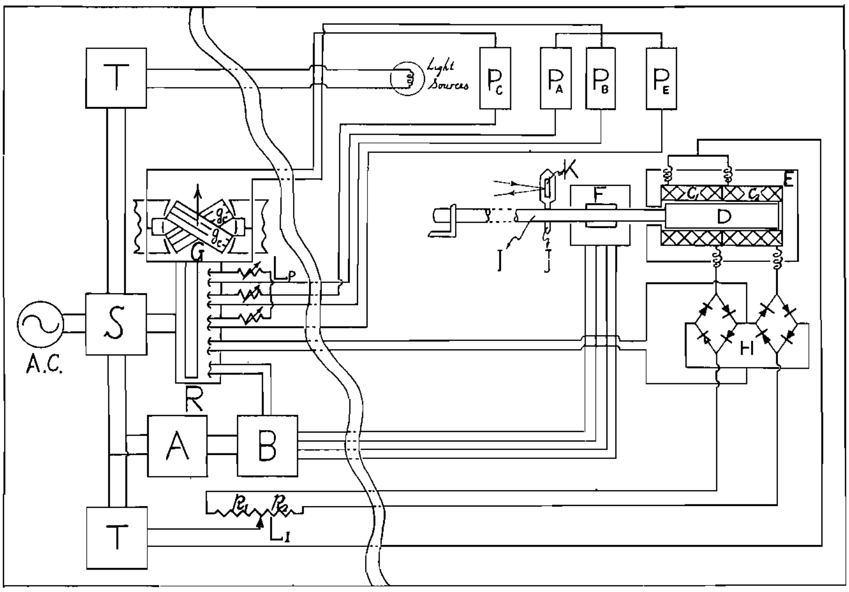


Fig. 11 Electric circuit of tele-metrical devices.
S : stabilizer, T : transformer, $C_1 \cdot C_2$: coil, E : field core, D : moving iron core, H : copper oxide rectifier, R : relay, G : galvanometer, g_c . moving coil of galvanometer, $L_I.L_p$: variable resistance, A : eliminator, B : indicator, F · measuring gauge., J : roller, K : mirror, I : super-invar-bar, $P_A.P_B.P_C$: measuring photocell Pc : compensating photocell.

A) Changing inductance type extensometer.

Setting up a pure iron core on the unfixed end of super-invar-bar (roller side) of super-invar-bar extensometer, fixing magnetizing coil on the concrete block which is fixed to the rockbase, to which the roller is attached and installing iron core into that coil, inductance of coil and current will change as iron core moves inside the coil according to the extension and contraction of the rockbase. Therefore if we induce these changes to the galvanometer at the suitable place and observe the variation of current, we can find the extension and contraction of crust. However it is not easy task in fact to find out the variation of current because of slight changes compared with magnetizing current which is sent through the coil. The 2 coils with same form, size and electromagnetic character are arranged on the straight line, wrapped by the core of heaped silicon sheet steels and inserted into the both bridgesides neighboring each other. If we measure the difference of currents which pass through the above 2 coils, the magnetizing currents are offset and we can extract only the varied current without influence of variation of temperature and voltage. We should here adapt a rectifier, as we use the D.C. galvanometer for measuring current. In order to be free from the influence by the variation of temperature on the rectifier, we set in 2 rectifiers symmetry against the bridge. We used copper sub-oxide rectifier as it forms linear curve even in weak current range. And the general lighting circuit 100 V, 60 $\sim$ is used for as the electric source, and we inserted ferro resonance type voltage stabilizer to keep a unity of voltage and slide wire typy voltage regulator (If it is once adjusted we shall keep it unchanged.) for the purpose of adjusting the magnetizing voltage on the coil. To make it further adjustement on zero point, variable resistance was used so that we can change the magnetizing current on respective coils. This observing room is situated in a old adit, the annual variation of temperature in the room is within 0.5°C approximately however moisture is so high on the contrary. So we fixed coils by pitch and enclosed rectifiers in the vacuum-bottle.

The recorder is a doting type recorder built in cross coil type galvanometer and 6 contractor's relay. It can record different colour dots of 6 elements every 15 seconds. The future photo. 1 (A) is the record indicated by this recorder.

B) Wire resistance strain meter.

If we install 2 ring type plate springs stuck with 2 foil gauges (SHINKOH F-gauge), as shown in Fig. 12 on the unfixed end of super-invar-bar of super-invar-bar extensometer and fix them on the concret block to which roller is attached, those plate springs will deform according to the extension and contraction of the rockbase, and the gauges on one side and another will deform each other to the reveres sense. Therefore as illustrated in previous Fig. 9, if these 2 gauges on one ring are connected on confronted sides of bridge, sensitivity will increase and we will be free from the influence on gauges caused by the variation of temperature. And also if these gauges are connected to SHINKOH type PS7-L indicator, the variation of strain will appear as variation of current, then will be recorded in dots by means of previous mentioned recorder. As for type PS7-L indicator we generally use the dry battery as a power supply, but it is not suitable for long term observation, so we used PS7-E eliminator to be able to observe by A.C. electric source and we inserted ferro resonance type stabilizer to get rid of variation of voltage. And then we used it to let the gauges sink into the insulating oil to get rid of influence of gauge by moisture. Thus we had adopted 4 gauges method at the beginning but we have been observing since May 1956 with U_T-gauge (SINKOH, unbonded strain gauge) in which 4 gauges are compacted in one set as shown in Fig. 13.

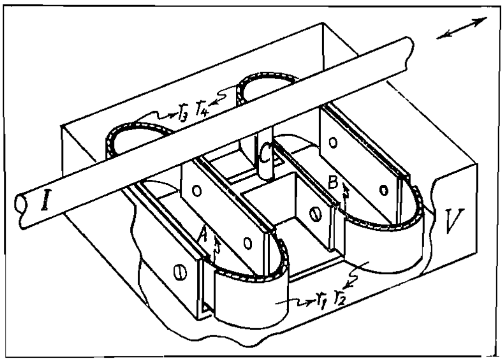


Fig. 12 Sketch of measuring gauges. (4 gauges method).
A• B• : moving plate spring, C : moving arm, $r_1 \cdot r_2 \cdot r_3 \cdot r_4$ F-gauge, I . super-invar-bar, V : oil vessel.

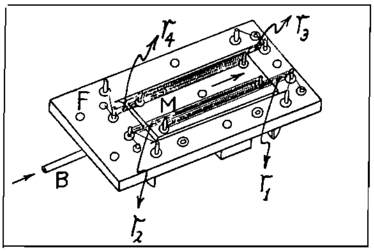


Fig. 13 Sketch of U_T-gauge.
$r_1 \cdot r_2 \cdot r_3 \cdot r_4$: resistance wire, B : moving arm, M: moving element, F : fixed part.

C) Photocell type extensometer and tiltmeter.

Let the light hit on the mirron of the extnsometer or tiltmeter and let the reflected light flux from the mirron hit on the half part of photocell. Then, the exposed area of the photocell changes in accordance with the rotation of mirror, attached to the roller of extensometer, caused by the extension and the contraction of crust, or that of the pendulum caused by the tilt of crust The vartation of ground-strain and ground-tilt appears as variation of photo current, then is recorded by galvanometer.

Having the photocell, however, being exposed from the beginning as stated above, so the pointer of galvanometer deflects to one side. In order to get this pointer back to the vicinity of zero point, we connect measuring photocell on the one of the coil of moving cross coil type galvanometer, and on the other one compensating photocell which is always exposed to the unified light, and let them given counter torque and then if we adjust the photo current of compensating photocell to make the torques of both coils equal, the pointer will be able to get back toward zero point.

Thus equiped as above, it can be refrain to a certain degree from the influence, which effects on photocell, by the variation of brightness of light source and temperature caused by the variation of voltage. It seemed to be the best way to keep the brightness of light source in uniformity, we decided to connect with above stabilizer. And further we covered the photocell with moisture-proof case, made of transparent plastic resin in order to get rid of influence of photocell caused by moisture. And as for the compensating photocell, we put variable resistance in each circuits, to be able to adjust and 3 elements (2 elements on tiltmeter and 1 element on extensometer) can utilize them in common.

3.3. Efficiency of meters.

A) Changing inductance type extensometer.

In using this instrument at the beginning, we investigated how it is affected by the variation of magnetizing voltage and how much voltage the magnetizing coil needs. We also investigated how the pointer of galvanometer changes by putting iron core on a certain position in the coil and taking resistance ratio R_1/R_2 of zero point adjuster, variable resistance L for arbitrary value, and changing the magnetizing voltage from 0 V to 50 V. The result of that experiment is illustrated as in Fig. 14. As you will see in this figure, you can understand that if we properly definite the value of R_1/R_2, placing iron core on a certain position, it keeps stable and hardly to be affected by the influence of variation of magnetizing

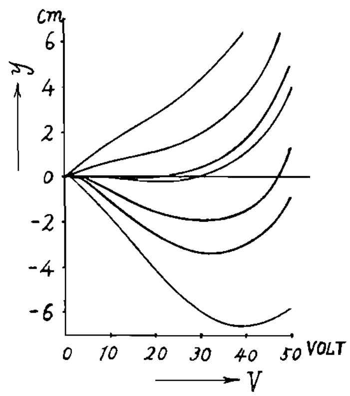


Fig. 14 Stability curve. (Relation between magnetizing voltage of coil and deflection of galvanometer.)

voltage until about 35 V. However on the actual observation, we measure the movement of iron core after R_1/R_2 is adjusted, and we investigated how the magnification rate would change by sending voltages of 20, 25, 30 and 35 V, and we learned that the magnification rate increased according to the raise of voltage.

From the result mentioned above, we understood that the higher the voltage goes up, the more sensitive it becomes, but at the point of stability, voltage is limited below 35 V. In this point of view, we adapted 32 V.

Further, we checked whether the movement of iron core is in propotion to the deflection of galvanometer's pointer or not. That is to say, by giving 32 V on coil, placing iron core at an arbitrary position inside the coil, adjusting R_1/R_2, bringing the pointer on the zero point, and since then moving it to and fro by 1/100 mm (i.e. 2/100 mm), we investigated the details of deflection of the pointer. As shown in Fig. 15 we found that the iron core is placed at any position inside the coil, majority of values was indicated within the oblique line except two or three. This exceptional case that gobeyond the oblique line, was appeared when the iron core was place near to both edges of the coil. This fact showed that the magnification rate is differed by the displacement of the iron core. The steepness toward both edges of this

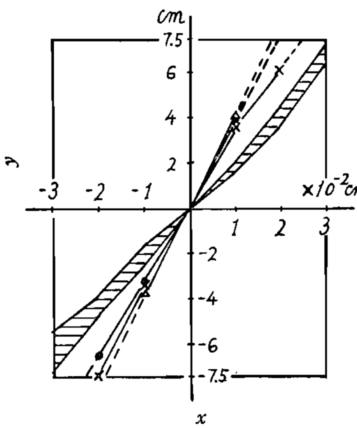


Fig. 15 Relation between movement (x) of iron core and deflection of galvanometer (y).

diagram is casued by constructive nature of this galvanometer. The record obtained by using this recorder is indicated the variation of tangent of rotating angle of galvanometer's coil rather than the variation of rotating angle of it. Because this record is shown by dots pressing down with the pointer of 15 cm in length on the recording paper of 15 cm in breadth. In order to obtain more accurate record based on the aforesaid reason, it must have arrange to use the center part of recording paper. We have now understood that when we use this instrument giving magnetizing voltage of 32 V, adjusting the value of R_1/R_2 and placing the pointer in the vicinity of zero point, then the variation of voltage was less and movement of iron core and deflection of galvanometer will form a linear. However, magnification is differed, as we previously described, by the relative position of the coil and the iron core. The result of such investigation is shown in Fig. 16. By Fig. 16 you will see that magnification is extracted from y, the deflection of galvanometer, making the gap between coil and iron core 1.2 mm, dividing it each 5/100 mm and moving the iron core by every 1/100 mm to both sides from the original location of iron core, as a centre. Thus determined value m is indicated as magnification at the location x. In this case magnetizing voltage was 32 V and we changed the value of R_1/R_2 at the every measurement, to come pointer back to zero point. As you will see in this figure, the magnification rate is increasing, or decreasing when the iron core approches to or off both edges of the coil respectively. However for pretty wide zone of central part, i.e. $x = 0.25 \sim 0.95$ mm, it is to be considered almost similar magnification rate, so we definited the average magnification rate for 2,220 and extracted the sensitivity of instrument. And on setting up this instrument, we placed the core at the center of coil.

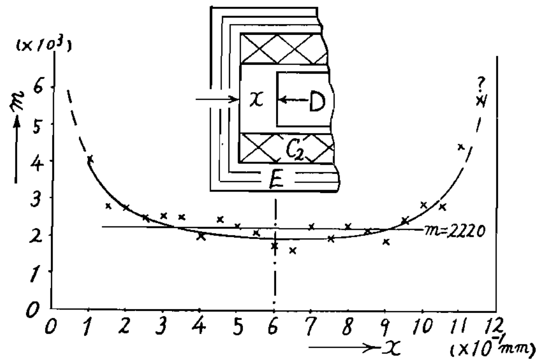


Fig. 16 Magnification curve of changing inductance type extensometer. (Magnetizing voltage of coil=32 V.)
C_2: coil, D: iron core, E: field core, x: gap.

For the reference, we have investigated the annual variation of strain at this observatory for several years past and found out that it is approximately 10^{-5}, so on this extensometer of 6 m in length, we found also the movement of the iron core on tip will be about 6×10^{-2} mm annually and it will appear about $2{,}220 \times 6 \times 10^{-2}$mm $= 133.2$ mm on the recording paper. We do not have worry about the variation of voltage because of the voltage stabilizer

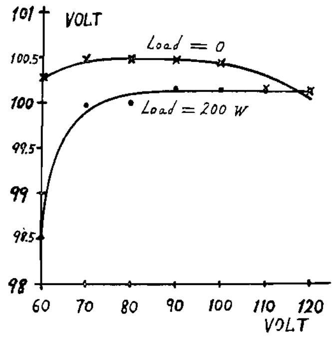


Fig. 17 Characteristic curve of voltage stabilizer.

fixed on this instrument is output power of 100 V ± 0.2 V for the variation of input A.C. voltage from 70 V to 100 V. The efficiency of this stabilizer is shown as Fig. 17.

B) Photocell type extensometer and tiltmeter.

We investigated the relation between exposed area and current on photocell. The results are shown in Fig. 18 (*a*), (*b*), (*c*). (*a*) is illustrated the relation between expored area x and deflection of galvanometer y (i.e. photo

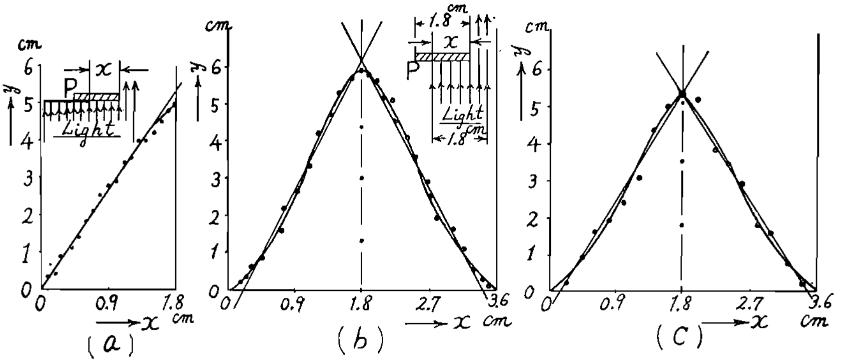


Fig. 18 Relations between exposed area on photocell and deflection of galvanometer (i.e. photo current).

current), when it is exposed to the room-light at the laboratory. (*b*) and (*c*) are the relations between x and y, when the photocell is exposed to the light flux of 1.8 cm in width, at our laboratory and observatory respectivelg. (By using the lens, we let the width of reflected light flux from the mirror make the same width as photocell.) Concerning (*a*), y increases in linear according to x increase, but when exposed area, x is approaching near the dimension of the whole area of photocell, the increasing rate is getting lower. This phenomena is the characteristic of photocell, for the bigger the illumination of photocell's surface and external resistance of photocell, the narrower the range of linear part. On the contrary in case of (*b*), (*c*), they are quite different, while the exposed area is small, and large as exposed the whole dimension of photocell, the increasing rate is also minor, and so large in the medium extent of exposed area, just like the form of Gausse's error curve. It is considered that this is caused by the efficiency of photocell and the difference of light flux's brightness at the parts of edges and center part focused by lens. Then we investigated how the photo current is affected by the variation of lamp's brightness (light source) according to the variation of voltage. The lamp used in this observation is 6 V—25 W bulb. The voltage of electric source is 100 V but it is dropped down to 6V by transformer. The relations between voltage and deflection of galvanometer with the compensating photocell and without it respectively, under changing the voltage of input power from 70 V to 120 V by every 5 V, are shown in Fig. 19 (*a*) and (*b*). In comparing these data, we understood that almost no influence is affected by the variation

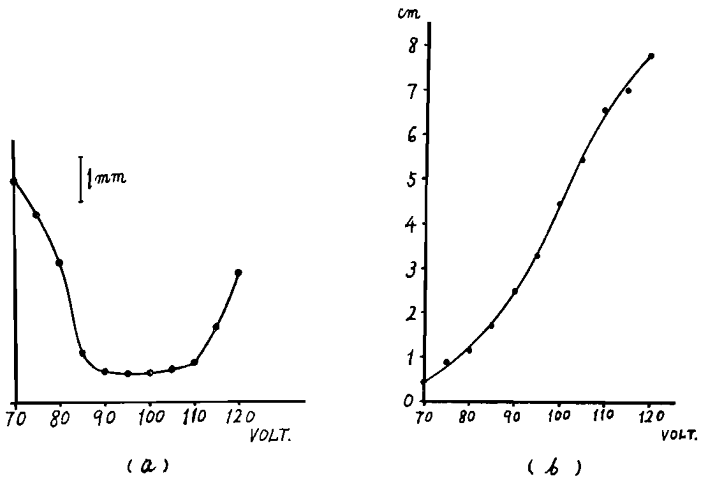


Fig. 19 Relations between voltage of electric source and deflection of galvanometer. (Relations between light intensity of projecting lamp and photo current.)

of voltage with compensating photocell on it. Therefore if we investigate the variation letting the exposed area as much as half dimension of photocell, it can be thought that the relation between exposed area and deflection of galvanometer will form linear curve. Up on this observation, we extracted the sensitivity, seeking the curve same like Fig. 18 (*c*) on each photocell. It seemed to be considered that the photocell had been always exposed to the light it might be fatigued and changed the efficiency of photocell. So we investigated the sensitivity of it at 4 months later. While almost no change, however, was recognized within the permissible error, the lamps for the light source worn out their light intensity. The light intensity of one lamp out of 4 was weakened as much as 10%. In these circumstance, observer must take more care of the lamp to use as the light source.

C) Wire resistance strain meter.

About the wire resistance strain meter, we investigated the relation between the movement of arm on the gauge and deflection of galvanometer. On the F-gauge, we investigated the relation between the movement of arm and deflection of galvanometer with the plate spring stuck with gauges changing its thick 0.05, 0.08, 0.10 and 0.12 mm by turns and found out that the relation between the movement of arm and deflection, when the thin plate is used, hardly form linear. So we decided to use 0.10 mm plate spring. By this experiment it is recognized that it would form linear curve while the movement within 1 mm each front and back from the natural state, that is to say movement of within 2 mm.

On the U_T-gauge we extracted the sensitivity, moving the arm of gauge 0.02 mm, and measuring the deflection of galvanometer, as it is approved that it has about 1% error on strain and current but almost current is in proportion to strain and the variable measuring range of gauge is ± 0.03 mm by the performance test of manufacturing company.

Lastly, values of instrumental constant are shown as follows.

1) Super-invar-bar extensometer

    sensitivity : 2.8×10^{-8}/mm

2) Changing inductance type extensometer

    sensitivity : 7.5×10^{-8}/mm

    (11.3×10^{-8}/1 division of recording paper)

    coil : interion diameter 2.00 cm

    length 6.50 cm

    enamel wire (0.3 mm in diameter), 2500 turns

    iron core : external diameter 1.85 cm

    length 6.38 cm

    pure iron

3) Wire resistance strain meter

    F-gauge sensitivity : 5.5×10^{-8}/mm

    (8.3×10^{-8}/1 division of recording paper)

    U_T-gauge sensitivity : 3.4×10^{-8}/mm

    (5.1×10^{-8}/1 division of recording paper)

4) Photocell type extensometer

    sensitivity : 3.7×10^{-8}/mm

    (5.6×10^{-8}/1 division of recording paper)

5) Tiltmeter with horizontal pendulum of Zöllner suspension type
A-component (N 45°W, period: 21.0 sec)
sensitivity: $3.0\times10^{-2}{}''$/mm
B-component (N 45°E, period: 21.0 sec)
sensitivity: $3.0\times10^{-2}{}''$/mm

6) Photocell type tiltmeter
A-component sensitivity: $4.0\times10^{-2}{}''$/mm
($6.0\times10^{-2}{}''$/1 division of recording paper)
B-component sensitivity: $4.7\times10^{-2}{}''$/mm
($7.0\times10^{-2}{}''$/1 division of recodding paper)

7) Galvanometer
sensitivity: 2.5×10^{-6}amp/mm
(3.6×10^{-6}amp/1 division of recording paper)
period: 2.0 sec resistance: 100Ω

8) Photocell (selenum photocell)
size: 4.0 cm×2.1 cm, exposed area: 3.5 cm×1.8 cm

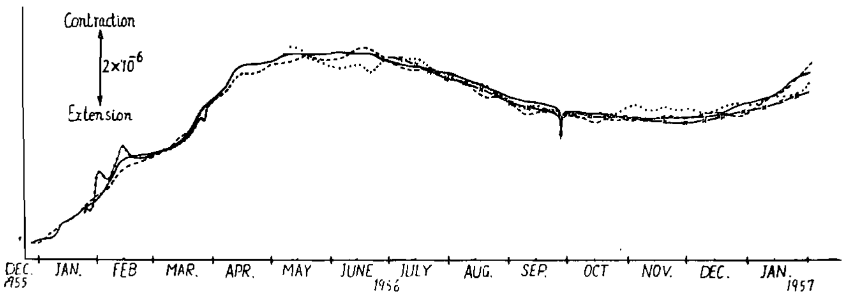
3.4. Result of the observation and the introduction of the observation uith tracing recorder.

In this way we have constructed the tele-metrical devices which can be simply observed at any place and that by gazing at variation directory every moment. But in this long term observation with these instruments, we are not able to tell the accuracy or efficiency of the instruments, we have, therefore to wait the result of further observation. Although these are inferior to the old optical photographic recording we can observe anyhow accurately as 10^{-7} in strain and $10^{-1}{}''$ in tilt. (The sensitivity of the tiltmeter will be raised more if period of pendulum is prolonged.)

Fig. 20 (*a*), (*b*) is shown the result of our observation held at Ide Observatory in which these instruments employed.

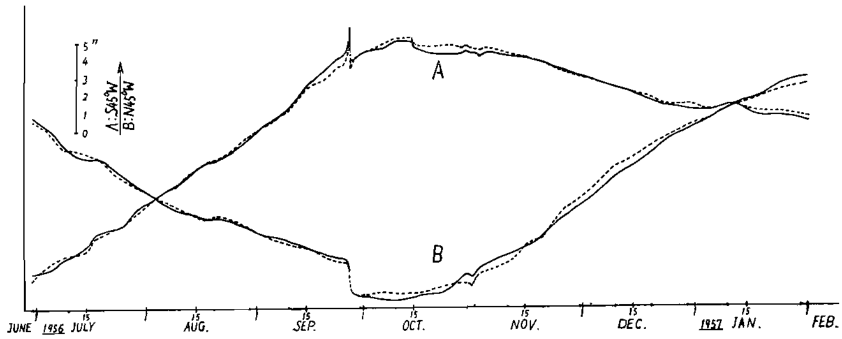
From this observation we can derive almost similar variation by using any instrument. If we are permitted to insist, the variation on wire resistance strain meter is not accorded with at the beginning of the observation. This seems to be that it is influenced by giving them unjust strain, when the gauges are stuck and installed. The variation, however, will be accorded along with the lapse of day when gauges are stabilized.

At the date of 27th of Sept. 1956 the significant irregularity of variation



(*a*) Variation of strain observed with super-invar-bar extensometer, wire resistance strain meter, changing inductance type extensometer and photocell type extensometer, at Ide observatory.

- - - - - : Changing inductance type extensometer
•-•-•-• : Wire resistance strain meter (F-gauge)
• • • • • : Wire resistance strain meter (U_T-gauge)
— × — : Photocell type extensometer
——— : Super-invar-bar extensometer



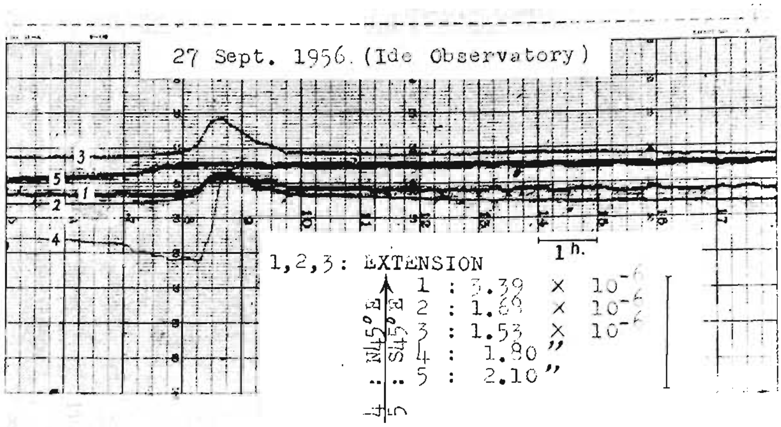
(*b*) Variation of ground-tilt observed with tiltmeter of horizontal pendulum type and photocell type, at Ide observatory.

- - - - - : Photocell type tiltmeter
——— : Horizontal pendulum type tiltmeter
A : A-component, B : B-component.

Fig. 20 Variations ground-strain and ground-tilt observed with the different kinds of extensometers and tiltmeters.

was marked on record. The records in those days are shown in Photo. I (A), (B) and (C). These were caused by the nearby Sabo-dum fall of water by heavy rain.

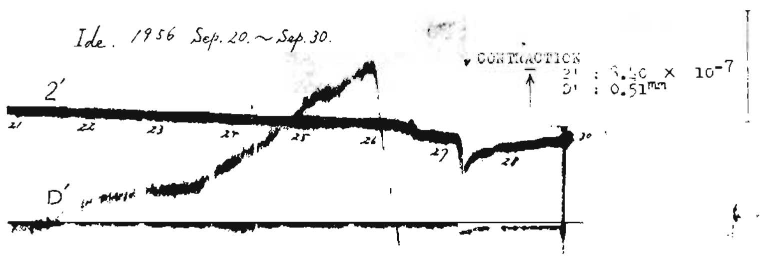
In order to make well the accuracy on the devices to the same extent as photographic recording devices, we manufactured the tracing recorder with



(A) Tele-metrical instruments.

1. (E_1) Changing inductance type extensometer
2. (E_U) : Wire resistance strain meter
3. (E_P) Photocell type extensometer
4. (A'_P) : Photocell type tiltmeter (A'-component)
5. (B'_P) : Photocell type tiltmeter (B'-component)

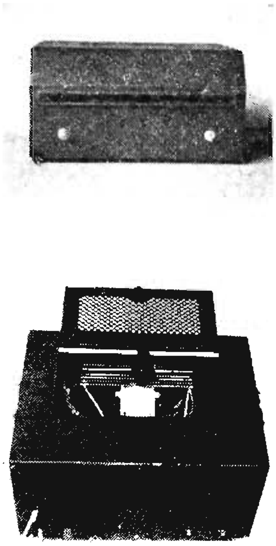
Hitting light runs away the photocell.



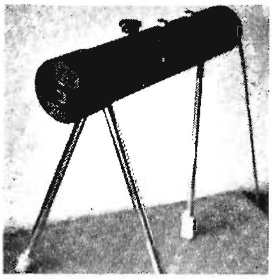
(B) Super-invar-bar extensometer (2') and discharge meter (D'). (Photographic recording).

(C) Horizontal pendurum type tiltmeter (T.M.' A', B'), (Photographic recording).

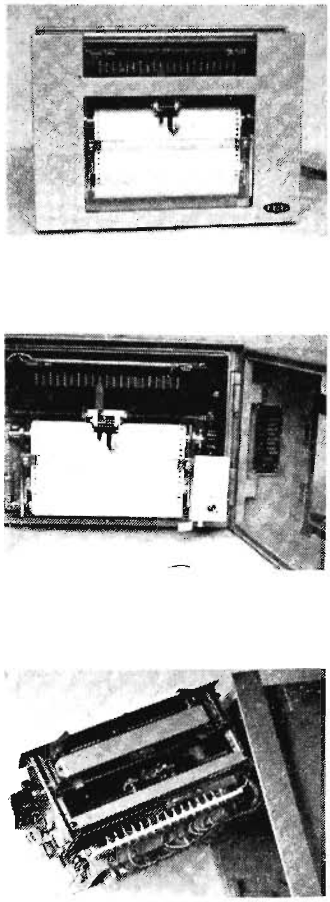
Photo. 1 Records obtained with the different kinds of extensometers and tiltmeters and discharge meter before and after the full water in the Sabo-dum.



(A) Transmitter.



(B) Light source.



(C) Recorder.

Photo. 2 Tracing recorder with photo-transistor.

photo-transistor designed by Prof. K. Sassa as shown in Photo. 2.

We will explain about the detail of this device in another report. The principle of this instrument is as follows. The tracing recorder is composed of the transmitter built in tracing unit incorporating 2 pieces of transistors, linear resistance and scanner, amplifier, chopper and balancing motor, and the recorder built in recording pen, linear resistance and scanner, amplifier, chopper, balancing motor and synchronous motor as shown in Fig. 21. The transmitter is set up in front of observing instrument and the recorder is set up at the great distance from there. Let the reflected light flux L from the mirror on the extensometer or tiltmeter hit on the inner half part of these 2 transistors T_1, T_2 equally, then the same electric current in generated on both transistors. When the mirror on extensometer or tiltmeter rotates, the light flux also moves together. Then the quantity of light, which is hitting on the transistors, also changes the generated current. The difference of the current on both transistors governs the amplifier V_1 driving the balancing motor M_1 with the felt which moves the tracing unit incorporating with the transistors, so that the transistors always follow the light flux of the instrument.

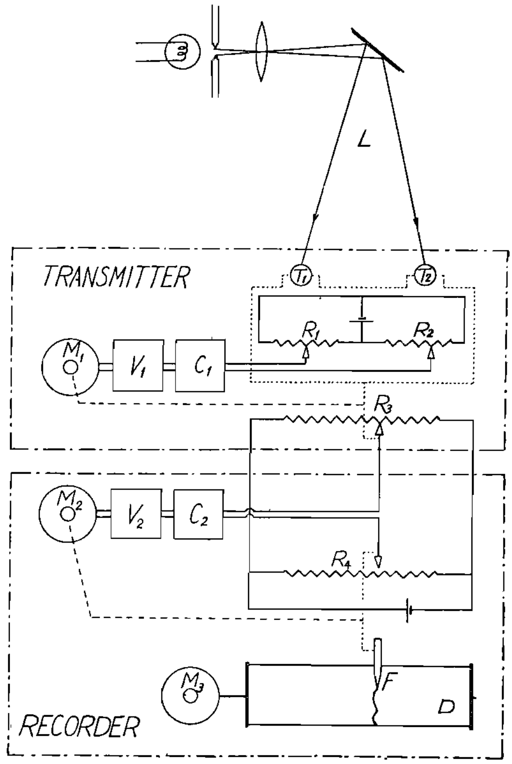


Fig. 21. Illustration of principl of tracing recorder with photo-transistor.
L : light flux, M : mirror, T_1・T_2 : photo-transistor, V_1・V_2 : amplifier, M_1, M_2 balancingmotor, M_3 syncronous motor, C_1・C_2 : chopper, R_1・R_2・R_3・R_4 linear resistance and scanner, F : recording pen, D : recording drum.

On the other hand there is another balancing motor with belt in the recorder to move the pen. Furthermore there is a linear resistance both in the transmitter and in the recorder on which slides a scanner which is firmly connected to the two transistors within the transmitter and to the pen within the recorder. Both resistances are in a bridge connection, in the zero branch of which is situated the balancing motor of the recorder. When the light flux moves, the transistors follow the light flux and adjust the resistance of the transmitter. In this way the bridge balance is adjusted. Then the balancing motor in the recoider runs until the bridge balance is restored and the position of the pen corresponds to the measuring value. The recording paper is driven by a synchronous motor. This tracing recorder is a novel recording instrument producing an immediately visible, continuous record of light pointer movement on recording paper.

However, when the deflecting velocity of the light pointer is too fast, the tracing recorder fails to trace it. In order to be able to continue recording in cases of the deflecting velocity of the light pointer is too fast and the displacement of the light pointer after the stoppage of electric current, the interval of transistors is fixed 15cm. If the movement of light pointer is within 15 cm, the light flux is hitting on either sides of the transistors, so the tracing recorder keeps catching the light pointer.

As we have done manufacturing this instrument lataly, we are not able to explain about the details of this instrument now. But, in order to test the efficiency on this device, we obtained the records of variation of ground-tilt at our laboratory by using this device for about one month. From the result of this observation, we can find out that the result of observation by using this device agrees well with one of observation by using photographic recording device to make comparative observation Photo. 3 is shown the records of the observation obtained by using both devices respectively at our laboratory.

On the other hand, the writer has been observing with the similar

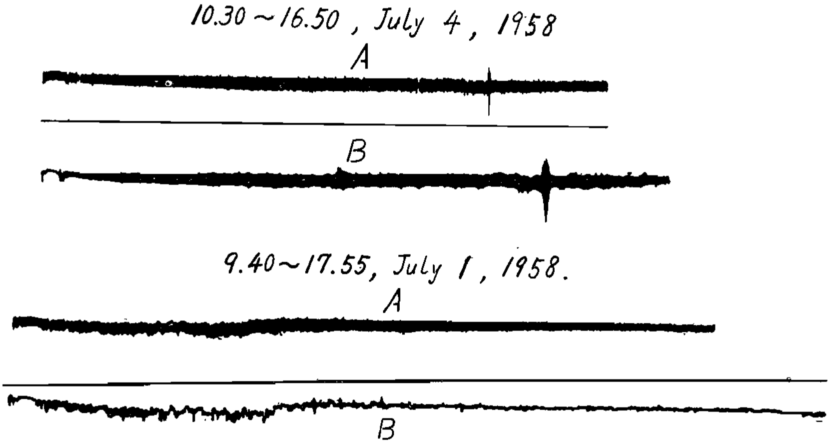


Photo. 3 Comparison of both records obtained with tracing recorder and photographic recorder.

A . Record obtained with photographic recorder.

B : Record obtaioed with tracing recorder.

instrument i.e. "photoelectric tracing recorder" made by DR. B. Lange Co. in Germany as shown in Photo. 4. As the same to former case, we can find out that the result of observation by using this instrument and the result of odservation by photographic recording device resemble very well. Photo. 5 is shown the records of the observation by using both devices at our laboratory.

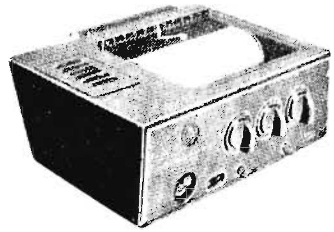


Photo. 4 Photoelectric tracing recorder.

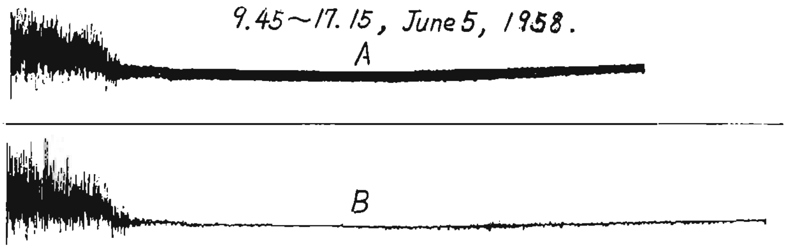


Photo. 5 Comparison of both records obtained with photoelectric tracing recorder and photographic recorder.

A : Record obtained with photographic recorder.

B : Record obtained with photoelectric tracing recorder.

At the conclusion of this paragraph, we will describe the principle and feature of this instrument. The principle of the instrument is shown in Fig. 22. Where L denotes a pencil of light hitting a CdS crystal cell Z. The photo-electric current generated by the cell governs the amplifier V driving the balancing motor M_1 with its spindle S_p which moves the tracing unit incorporating the cell and the capillary pen. The cell is placed in a compensating circuit so that cell and tracer pen follow the light pointer when the light spot moves. The capillary pen writes visibly on paper clamped on the drum T which is driven by a synchronous motor M_2. And the tracing speed of the recording unit amounts

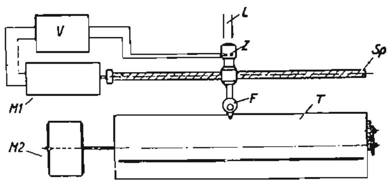


Fig. 22 Illustration of principle of photoelectric tracing recorder.
L : light flux. Z : CdS crystal cell, V : amplifier, M_1 : blancingmotor, M_2 : syncronousmotor, S_p : spindle, F : recording pen, D : recording drum.

approximately to 30mm/sec. Should the deflecting velocity of the light pointer be too fast, the cell driven by the balancing motor spindle follows the light pointer at adjusting velocity until the pen has caught up with the latter. Should the tracing unit arrives at the end of the spindle in the process, its motion is automatically reversed so that it travels again towards the light pointer. Deviations of the plotted curve from the position of the light pointer never exceed 0.5 mm. The type of instrument used by the writer at present is not used for tele-metrical observation. Being under construction of new tele-metrical observation instrument, we are going to use them also for the observation in near future.

4. Conclusion

The writer has described about the instruments for the observation of crustal deformation especially about tele-metrical devices at Ide Observatory. But there are many things to improve further on these instruments. We will do our best to study more and make the best instruments for this purpose. Anyway the first step for the observation of the crustal deformation is seemed to be founded.

At the conclusion of this report the writer sincerely wishes to exprss his hearty thanks to Prof. K. Sassa for his guidance and kind instruction given in the course of this work.

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On the Crustal Strain Accompanied by a Great Earthquake

by

Michio TAKADA

Abstract

In order to study the forecasting of the earthquake, the Disaster Prevention Research Institute of Kyoto University has been observing the crustal deformation with various instruments at several stations. The writer tried to study the crustal deformation before and after the Yoshino Earthquake of July 18, 1952 with the data obtained at Ide Observatory.

1. Introduction

Numerous great earthquakes have ever given a great deal of damages on human lives and properties in this country by the reason why she is called "The Nation of Earthquake." Whenever we think about the damages in the past, we can not help feeling the necessity to research and establish some preventive measures for the elimination of the damage to the minimum on the occasion of accidental earthquakes. Looking over the damages in the past, most of them have been caused by the destruction of all kinds of constructions. If we could prevent the destruction of these, the damages would be extremely eliminated. Among them, buildings are the most related to the damages of our lives and properties. Therefore it is a sine qua non to contrive to designing the aseismatic buildings. For this purpose, first thing to do will be the pervasion of earthquake-proof and fire-proof buildings, in another words, constructing the ferro-concrete buildings. To our regret, however, due to the present economical condition, the pervasion of these buildings are prevailed only on some offices, big stores, amusement facilities and a little part of apartment houses. Still we shall have to depend on the wooden houses for our dwelling for a respectably long period in future. Therefore in order to prevent our houses from earthquake damages, we must give our effort on aseismatic designing buildings not only on newly built houses but on old built houses which may well be said the most effective measnres for preventing the damages. For the purpose of aseismatic designing, we should examine the criterion for earthquake-proof on houses and give some supplemental aid to strengthen on the houses economically when required. On this point of view, the writer already obtained and published the result of the examination of criterion for earthquake-proof on the wooden houses giving some vibration on them.

No matter how such an examination has been undergone, however, we with the human nature are apt to think it silly and trifle with the preventive measures with much expense against uncertain and accidental earthquake, as old saying goes like "Danger past, God forgotten." Therefore if we could foretell the location and time of the earthquake-occurrence and the scale of the earthquake we could promote the pervasion of aseismatic designing buildings and be ready for it and reduce the damage on both our material losses and mental shocks. But, it is indeed very difficult problem for us to forecast of the earthquake now that most of substances under the ground are yet scarcely explored and we can hardly foretell the earthquake-occurence theoretically. Setting the cause of the earthquake aside, the seismic vibration occurs by the occurrence of crustal destruction under the ground reaching the crustal strain to a certain limit. It is certain to be some clue for the forecasting of the earthquake to detect the crustal strain by any means around the vicinity of ground surface, as there must be some deforme on the crust before this destruction.

Thus Kenzo Sassa and Eiichi Nishimura have been observing the ground-strain and ground-tilt by use of extensometers and tiltmeters since some 20 years ago and researching the forerunning of the earthquake, the crustal strain, around the epicentre before the great earthquake. These results of research were already published frequently. The peculiar crustal deformations were detected on the occasions of the Tottori Earthquake of Sept. 10, 1943, the Tonankai Earthquake of Dec. 7, 1944, the Nanki Earthquake of Apr. 26, 1945 and the Daishojioki Earthquake of Mar. 7, 1952. The writer also has begun to observe the crustal deformation before the earthquake-occurrence since 1951 with the extensometers and tiltmeters at Ide Observatory which was reformed the adit of an abandoned copper mine located at Ide-cho, Tsuzuki-gun, Kyoto prefecture (135°49.5′E, 34°47.9′N) under the guidance of Prof. K. Sassa.

After that the earthquake called by name of Yoshino Earthquake was felt at about 1.10 on July 18, 1952 in the whole districts of Kinki, Chugoku, Shikoku, Chubu and parts of Kanto, Tohoku and Kyushu districts. Its epicentre was at southern part of Nara prefecture, 135.80° E, 34.10°N as shown in Fig. 1 and its focal depth and seismic magnitude were 70 km and 7 in Pasadena Scale respectively. But the damage was so slight as its epicentre was in mountainous area and its hypocentre was so deep in the ground. In this Observatory, where is located 100 km from hypocentre and 72 km from the epi centre, we could observe the peculiar crustal deformation before and after the earthquake-occurrence.

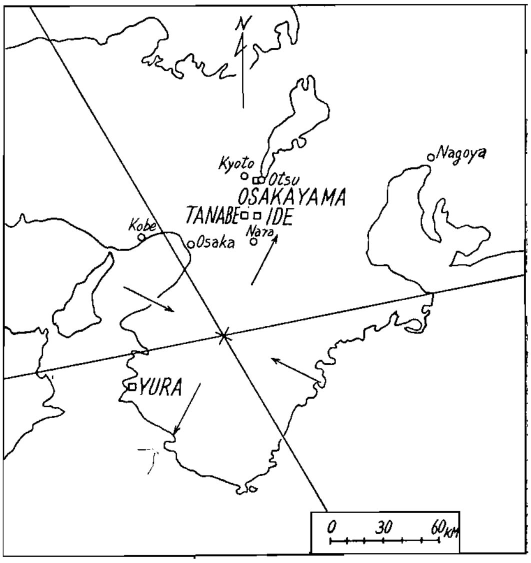


Fig. 1 Positions of the observatories and epicentre of the Yoshino Earthqnake and directions of initial ground motions in its earthquake. (The crossing full lines show the nodal line.)

The writer will report the details of the result of the observation.

2. Result of observation

In this observatory, instruments have been gradually increasing in number year after year and all kinds of instruments as shown in Table 1 arranged at present. But in those days of the Yoshino Earthquake, we had only 6 components of super-invar-bar extensometers. The result of observation with these instruments, the volume dilatation calculated from the observation with 3 components of "1", "2", "3" which are set up rectangular co-ordinate axis and the precipitation measured at Tanabe about 4 km away from this observatory are shown as in Fig. 2. Not only the variation caused by the earthquake but annual variation and the variation caused by the rainfall shoud be included in this variation. In order to find out the variation caused by the earthquake, we must eliminate the variation caused by rainfall and an annual variation. The writer will omit the method of this elimination as be already fully described in another report.

Table 1 List of instruments of Ide Observatory.

Mark	Azimuth	Sensitivity	Place
1. Super-invar-bar extensometer			
		(10^{-8}/mm)	
1	Vertical	5.54	O_1
2	Horizontal N88°E	4.92	O_1
3	Horizontal N 2°W	10.74	O_1
4	Dip 50° N88°E	3.46	O_1
5	Dip 66° N2°W	2.78	O_1
6	Horizontal N77°W	2.30	O_1
3′	Horizontal N2°W	6.12	O_1
2′	Horizontal N82°W	2.80	C
2. High magnification extensometer			
I	Vertical	0.329	O_1
II	Horizontal N88°E	0.492	O_1
III	Horizontal N2°W	0.892	O_1
3. Changing inductance type extensometer (Tele-metrical Extensometer)			
E_1	Horizontal N82°W	7.5	C
4. Photocell type extensometer (Tele-metrical extensometer)			
E_p	Horizontal N82°W	3.7	C

Mark		Azimuth	Sensitivity	place
5. Wire resistance strain meter (Tele-metrical extensometer)				
			(10^{-8}/mm)	
E_U		Horizontal N82°W	3.4	C
E_F		Horizontal N82°W	5.5	C
6. Horizontal pendulum type tiltmeter				
			($10^{-2\prime\prime}$/mm)	
T.M.	A	N45°E	2.0	O_1
	B	S45°E	2.0	O_1
T.M.′	A′	N45°W	3.0	O_2
	B′	N45°E	3.0	O_2
7. Photocell type tiltmeter (Tele-metrical tiltmeter)				
T.M.$_P$	A'_p	N45°W	4.0	O_2
	B'_p	N45°E	4.7	O_2
8. Discharge meter				
		(water level mm/mm)		
D		5.3×10^{-2}		O_1
D′		1.7×10^{-2}		C
9. Thermometer				
T		0.034(°C/mm)		O_1

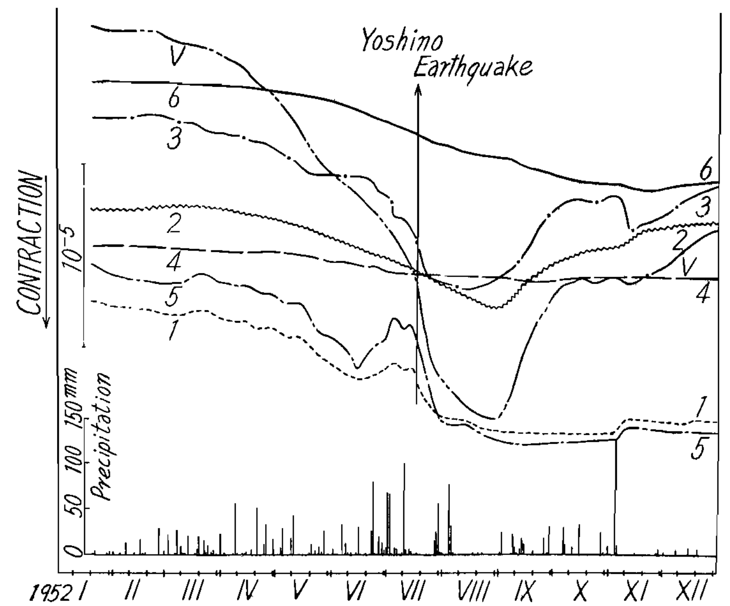


Fig. 2 Variations of linear strains observed at Ide Observatory and volume dilatation calculated from those variations and daily precipitation observed at Tanabe.

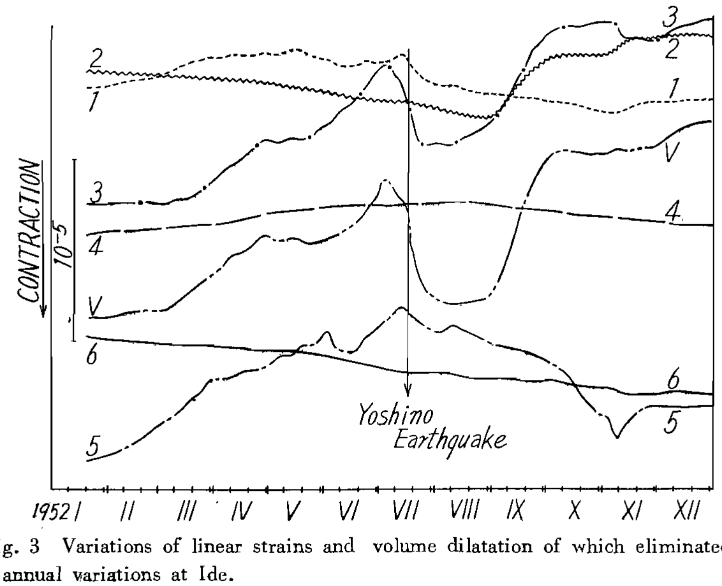


Fig. 3 Variations of linear strains and volume dilatation of which eliminated annual variations at Ide.

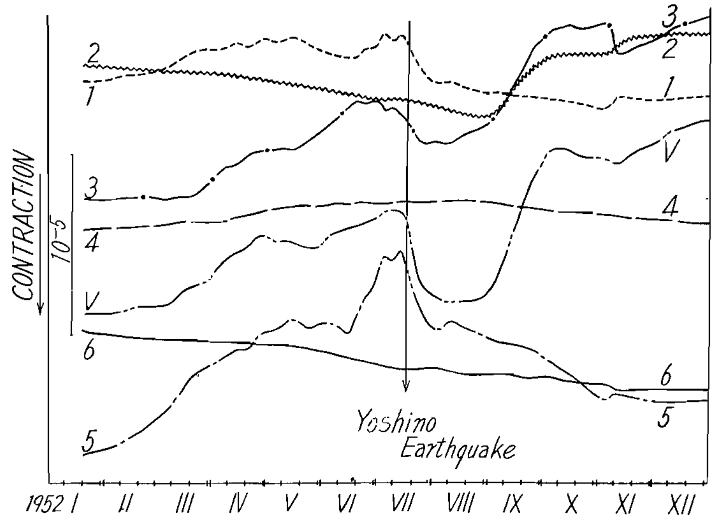


Fig. 4 Variations of linear strains and volume dilatation of which eliminated annual variations and variations caused by rainfall at Ide.

First of all the result of the elimination of annual variation from the variation obtained by the observation is shown in Fig. 3. And then the result of the elimination of the variation caused by the rainfall from the variation on components "1", "3", "5" which were influenced greatly by rainfall is shown in Fig. 4. On this eliminating adjustment, we used the effective curve obtained from the precipitation as we had not yet set up the discharge meter of water in the adit. Therefore the variation of Fig. 4 can be esteemed the crustal deformation related to the earthquake at this observatory before and after the Yoshino Earthquake. As this figure apparently shows us, we find the peculiar variation several months before the earthpuake-occurrence. The writer already found and published the peculiar variation several weeks before the occurrence of rock-falling in a part of adit of this observatory. Anyway though they are differed in scale, whether earthquake or rock-falling are the same phenomena of rock-breaking. Accordingly, there must be stored the strain energy which is necessary for the break of rock in the neighbourhood of that rock and it is considered that the deformation which is epuivalent to the energy comes into being on the crust.

3. Study and examination on the result of observation

Being the directions of extensometers "2", "3", "1" the axis of x, y, z

of Cartisian rectangular co-ordinate, as three components of these extensometers are set up rectangular direction on another, and postulating the components of displacement of a particle at $P(x, y, z)$ as u, v, w, the linear strains ε_x, ε_y, ε_z, the shearing strains ψ_{yz}, ψ_{zx}, ψ_{xy} and the rotating strains ω_x, ω_y, ω_z are given by following formulas.

$$\varepsilon_x=\frac{\partial u}{\partial x},\quad \varepsilon_y=\frac{\partial v}{\partial y},\quad \varepsilon_z=\frac{\partial w}{\partial z},$$

$$\psi_{yz}=\frac{\partial v}{\partial z}+\frac{\partial w}{\partial y},\quad \psi_{zx}=\frac{\partial w}{\partial x}+\frac{\partial u}{\partial z},\quad \psi_{xy}=\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x};$$

$$\omega_x=\frac{1}{2}\left(\frac{\partial w}{\partial y}-\frac{\partial v}{\partial z}\right),\quad \omega_y=\frac{1}{2}\left(\frac{\partial u}{\partial z}-\frac{\partial w}{\partial x}\right),\quad \omega_z=\frac{1}{2}\left(\frac{\partial v}{\partial x}-\frac{\partial u}{\partial y}\right).$$

(Instead of the suffixes of x, y, z, each component's number 2, 3, 1 of extensometers shall be converted hereafter.)

The variations of linear strins ε_1, ε_2, ε_3 are already illustrated with the mark "1", "2", "3" in Fig. 4 at Ide Observatory. And the variation of linear strains before and after the Yoshino Earthquake observed at Osakayama Observatory about 20 km awy from Ide Observatory is shown in Fig. 5. In comparing both variations observed at Ide and Osakayama Observatories, among the extensometers the components which are set up to the similar direction are as follow. The components "3" (N2°W) of the former and N2°W of the later, "2" (N88°E) of the former and N86°E and N76°W of the later. The variations of the later, are illustrated as they are observed with the instruments without eliminating the annual variations which are not known because of this short history, though the one obtained at Ide are adjusted on the annual variations and the effects caused by rainfall. Therefore it is rather unnatural to compare these variations, but the variations due to meteorological effects being very small at Osakayama where the observing

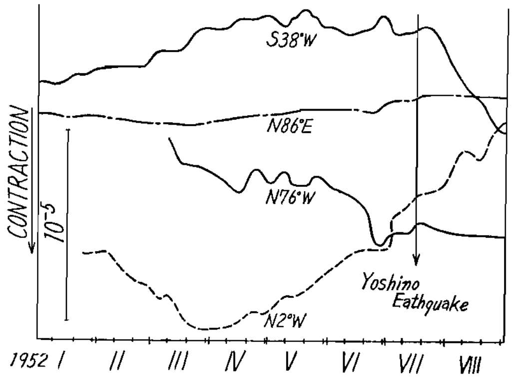


Fig. 5 Variations of linear strains observed at Osakayama Observatory. The variation of component S38°W is eliminated annual variation. (by I. Ozawa.)

room is very deep under the ground, with the exception of component N86°E at Osakayama, the variations of component "3" at Ide and N2°W at Osakayama similarly extended from around March and, on the contrary, the variations of "2" and N76°W contracted. And the variation of component S38°W at Osakayama shown in Fig. 5 is eliminated the annual variation, same one as at Ide. The variations on this component and the component "3" at Ide which is set up to the rather similar direction of the former began to extend from around March and contracted from the beginning of July before the earthquake-occurrence. Next on obtaining the ground-tilt it is presumed and obtained by rotating strains, as the tiltmeter was not set up in those days. On the variation of ground-tilt caused by the occurrence of rock-falling, the writer had ever tried to compare with the result of observation with tiltmeter and the result obtained roughly by rotating strains under such assumption that the origin of rectangular co-ordinate axis, i. e. the point of intersection of both components "1", "2", "3" is kept immovable and found they were almost resembled each other as shown in Fig. 6. Therefore, under the assump-

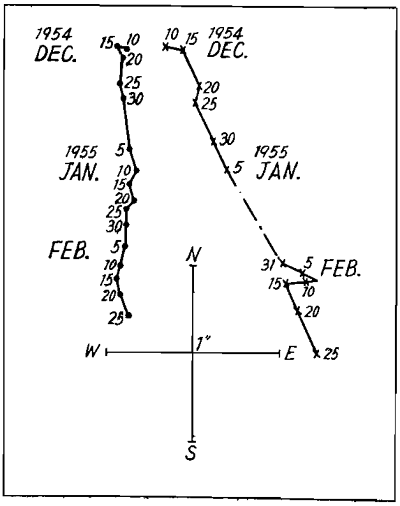


Fig. 6 Comparison of both variations of ground-tilt observed with tiltmeter and presumed from variation of linear strains.

×: ground-tilt observed with tiltmeter,
●: ground-tilt calculated from linear strains.

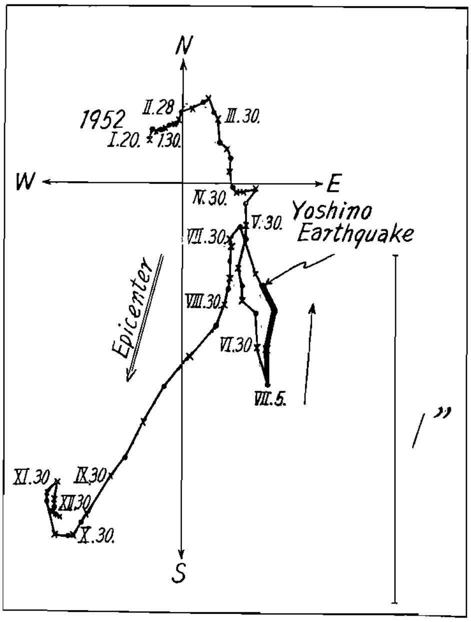


Fig. 7 Variation of ground-tilt at Ide (presumed from variations of linear strains).

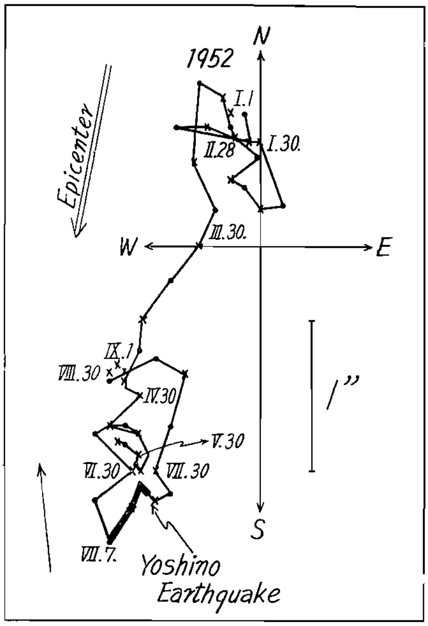


Fig. 8 Variation of ground-tilt observed at Osakayama Observatory (by I. Ozawa).

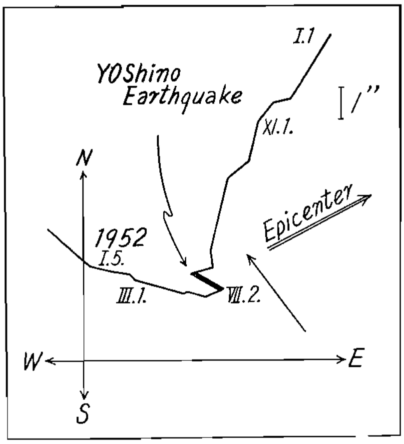
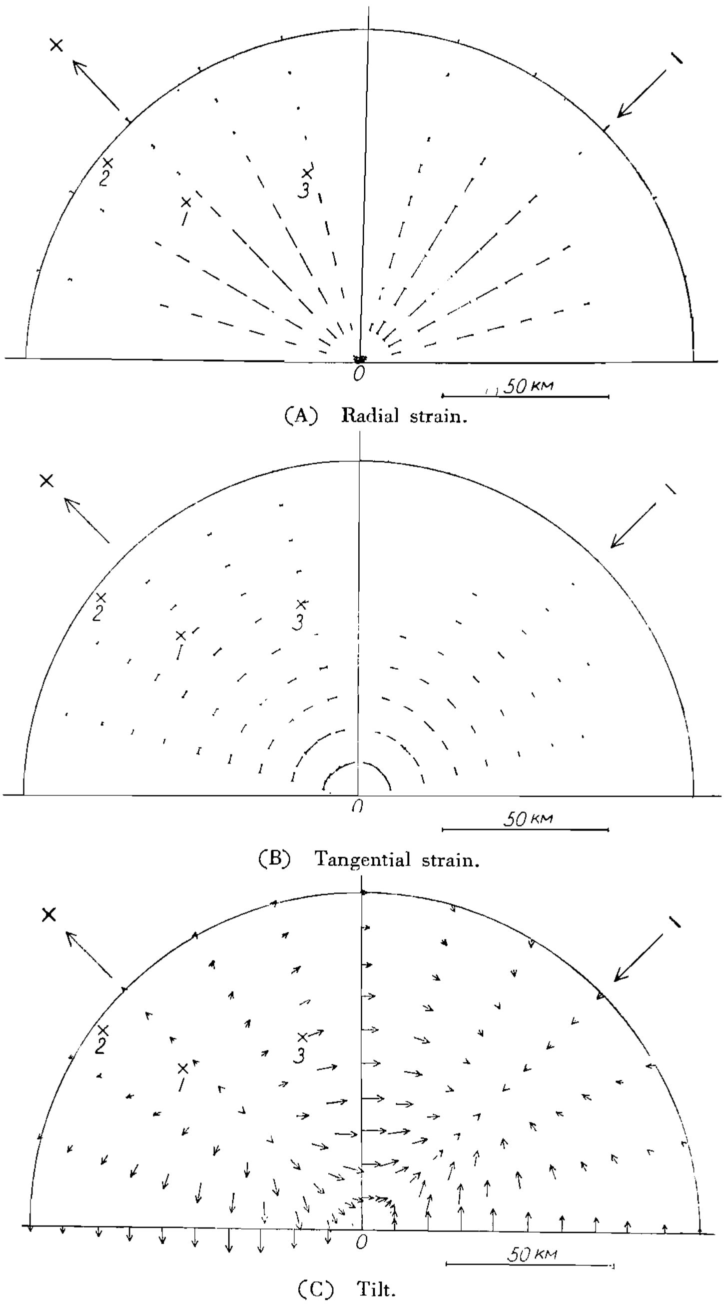


Fig. 9 Variation of ground-tilt observed at Yura Observatory (by K. Hosoyama).

tion as mentioned above, the vector diagram of tilting motion of ground in Fig. 7 obtained roughly by rotating strains is presumed almost similar with the actual variation of ground-tilt at Ide. Now in looking over this variation together with the variations of ground-tilt, illustrated in Fig. 8 and Fig. 9, observed by I. Ozawa at Osakayama Observatory and K. Hosoyama at Yura Observatory, every one of them continued their downward tilting in the direction of the epicentre until the beginning of July and turned their tilting direction to N at Ide and Osakayama and to N-W at Yura on almost same day without much difference of the date (Ide on 5 July, Osakayama 7 July and Yura 2 July). In 1935 F. J. W. Whipple calculated elastico-dynamically the value of deformation on the surface of elastic body that will be deformed by the nucleus of seismic force which is equivalent to the crack-model studied by the late T. Shida. By these ways, the distribution of the strains on the ground surface on the occasion of the Yoshino Earthquake is obtained as shown in Fig. 10. On the other hand, the distribution of initial motion of P-wave on the occasion of the Yoshino Earthquake is shown in Fig. 1 as already drawn, and as three observatories, Ide, Osakayama and Yura, are included into the push zone and also the epicentre distances are 72 km,



(A) Radial strain.

(B) Tangential strain.

(C) Tilt.

Fig. 10 Distributions of surface strains calculated theoretically on the occasion of the Yoshino Earthquake.
+←— : Push zone, ——→ : Pull zone, O : Epicentre,
—— : Extension, ⊢—⊣ : Contraction, ←— : Tilting direction.
1 . Ide Observatory, 2 : Osakayama Observatory, 3 : Yura Observatory.

98 km and 60 km respectively (and the forcal distances are also 100 km, 120.5 km and 92 km), thc calculated tilting directions accompanied by thc earthquake at these observatories should be the directions indicated by arrow marks in Fig. 7, 8 and 9. In these variations observed at these three observatories, the tilting directions are noticed to be changed to the direction theoretically calculated from the beginning of July about 10 days before the earthquake-occurrence. The results of a few observation as mentioned above may be not sufficient to deduce the crustal deformation before and after the earthquake-occurrence, but the ground seems to continue its downward tilting in the direction of the epicentre for a pretty long term before the earthquake-occurrence and also turn its tilting direction towards the direction of which movement will be accompanied by the earthquake and at the time of the earthquake and right after it, it seems to tilt greatly to that direction.

In comparing with the distribution of strain and the result of observation, though we have only two data observed at Ide and Osakayama, each component of extensometer shows the specific variation before the earthquake-occurrence, but these are not so regular variations as the ground-tilt. Especially on checking the variation observed at Ide only, it was extended to the radial direction of "3" until the beginning of July but it began to contract several days before the earthquake-occurrence. On the contrary, it was contracted to the tangential direction of "2" until the beginning of July and though it was slight change, but anyhow extended after then. On the other hand from the distribution of strain calculated about the model of the earthquake, it should extend to the direction of "3" and contract to the direction of "2". They have been changing the same way as the strain distribution until about 2 weeks before the earthquake-occurrence, but began to move opposite after then. On this point the variation of ground-strain was greatly different from the variation of ground-tilt.

Secondary, the shearing strains were obtained as shown in Fig. 11.

It is assumed that the earth's crust is homogeneous and isotropic elastic body, the principal stresses σ_1, σ_2 and σ_3 and principal shear stresses τ_{12}, τ_{23} and τ_{31} are formed as follows;

$$\sigma_1=\frac{E}{1+\nu}\left\{\varepsilon_1+\frac{\nu}{1-2\nu}e\right\},\quad \sigma_2=\frac{E}{1+\nu}\left\{\varepsilon_2+\frac{\nu}{1-2\nu}e\right\},\quad \sigma_3=\frac{E}{1+\nu}\left\{\varepsilon_3+\frac{\nu}{1-2\nu}e\right\},$$

$$\tau_{12}=G\cdot\psi_{12},\quad \tau_{23}=G\cdot\psi_{23},\quad \tau_{31}=G\cdot\psi_{31},$$

where $e=\varepsilon_1+\varepsilon_2+\varepsilon_3$ and also stand for the volume dilatation, and E, G and

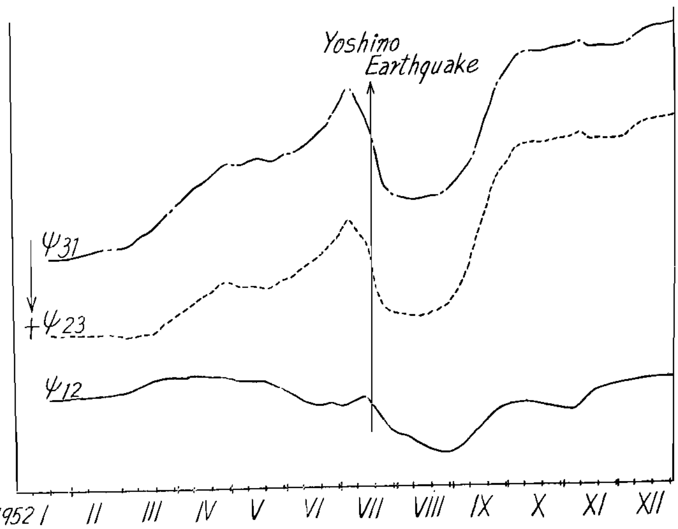


Fig. 11 Variations of shearing strains at Ide.

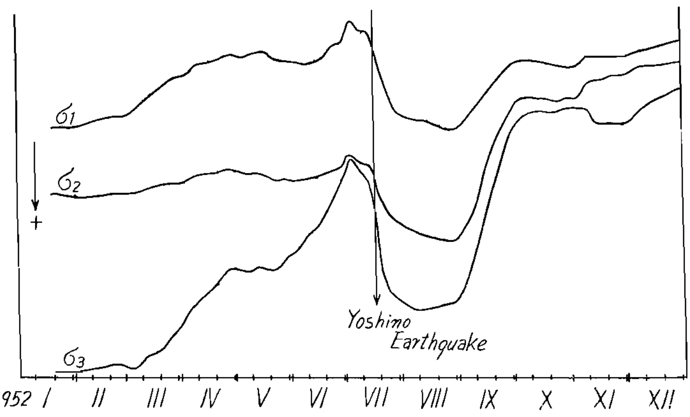


Fig. 12 Variation of principal stresses at Ide.

ν are Young's modulus, modulus of rigidity and Porsson's ratio respectively.

In the special case in which $\nu=\frac{1}{4}$, the variation of principal stresses is obtained from the variation of linear strains as shown in Fig. 12 and the graph of the variation of principal shear stresses also does same in Fig. 11. Anyhow the great specific variation is observed before the occurrence of earthquake.

Finally let us presume the energy of this earthquake from the result of observation. Keeping the eyes on that the variation became great suddenly from around March 1952 and it stopped at the beginning of July and then the reverse change was observed, it is assumed that the main energy of this earthquake has direct relation to the amount of strain observed during the period from 1 March to 7 July, however, it does not seem to store up the whole energy of the earthquake for like these short period. The variations of strains during this period became $\varepsilon_1=+1.2\times10^{-6}$, $\varepsilon_2=-1.5\times10^{-6}$ and $\varepsilon_3=+7.3\times10^{-6}$ (+ : extension). The strain energy E stored up within a unit volume of rock is formed as follows ;

$$E=G\left[\frac{1-\nu}{1-2\nu}(\varepsilon_1+\varepsilon_2+\varepsilon_3)^2-2(\varepsilon_2\varepsilon_3+\varepsilon_3\varepsilon_1+\varepsilon_1\varepsilon_2)\right].$$

In the case in which Lame's constant $\lambda=\mu$, so that $\nu=\frac{1}{4}$, using $\lambda(=\mu)=10^{10}$ (This value was obtained by the observation of strain caused by the full water in the Sabo-dum near this observatory.), it becomes $G=10^{10}$ and $E=0.836$. (Hereafter, all the numerical quantities will be expressed in C.G.S. system.)

On the other hand, the variations of strains at Ide and Osakayama were great as described above from around March 1952 until the beginning of July. Therefore it is to be supposed that the two have some relation with each other. In order to compare these variation quantities of strain, calculating the variation quantity of strain on the azimuth of N38°E at Ide which is the same azimuth of extensometer at Osakayama, it is obtained as 5.0×10^{-6} from the result of observation on the components "2", "3", "6" which are set up to different azimuth one another. I. Ozawa had ever tried to obtain the value of $\lambda(=\mu)$ of the rock near the Osakayama Observatory which was obtained by the strain caused by the earth tide. And its value was about 10^{10}. It is much the same as the value the writer obtained at Ide. Therefore the relation between strain and epicentral distance is obtained as follow from each variation of strain of N38°E direction at Ide and Osakayama as 5.0×10^{-6}, 3.1×10^{-6} and epicentral distances of both observatories as 100 km and 120.5 km respectively.

$$\frac{5.0\times10^{-6}}{3.1\times10^{-6}}=\left(\frac{120.5}{100}\right)^n,$$

$$n=2.55.$$

The directions of N38°E at these observatories are nearly the directions towards epicentre both. From the result above mentioned, the variation of horizontal strain in the direction of the epicentre is in inverse proportion to the epicentre distance r to the 2.5th. For the purpose of simplification of calculation, we will proceed our discussion under the following assumption, namely the material within the sphere of radius r_0 of the focus (Let us call this sphere the "earthquake nucleus".) will be strained until the stored strain energy within a unit volume of rock reaches the maximum energy x to be stored up within it. At the time of earthquake-occurrence, the stored energy is sent out from the earthquake nucleus by some kind of mechanism or other and the strain energy stored up within a unit volume of rock without the earthquake nucleus is in inverse proportion to the epicentre distance r to the 5th.

Under the assumption as mentioned above, the strain energy Er_0 that is to be stored within the earthquake nucleus is given by

$$Er_0=\frac{4}{3}\pi r_0{}^3 x\ ,$$

where x may be taken to be $3\times10^3\sim2\times10^4$. And at $r>r_0$ without the earthquake nucleus, the strain energy within a unit volume of rock forms the following formula.

$$E=\frac{k}{r^5}\ .$$

If we put $E=0.836$ and $r=100\,\mathrm{km}$ at Ide Observatory in this formula,

$$k=0.836\times10^{35}$$

is obtained. If we take $x=3\times10^3\sim10^4$, the radius r_0 of the earthquake nucleus

$r_0=1.94\times10^6\sim1.53\times10^6$ $(=19.4\,\mathrm{km}\sim15.3\,\mathrm{km})$ are obtained. And the strain energy Er_0 stored within the earthquake nucleus

$$Er_0=8.8\times10^{22}\sim14.3\times10^{22}$$

are obtained. On the other hand, the strain energy E_∞ that is to be stored in the body outside the earthquake nucleus are obtained as follows;

$$E_\infty=\int Ed\,V=4\pi k\int_\infty^{r_0}\frac{dr}{r^3}=2\pi k r_0{}^{-2}=14.0\times10^{22}\sim22.5\times10^{22}.$$

It is to be supposed that the earth's material is strained due to some force applied to the earthquake nucleus and the distribution of the strain above mentioned comes into being in the crust. Thus the amount of energy given by some force within the earthquake nucleus would be the same as that of energy given by the same force in the body outside the earthquake nucleus. But, in comparison of both values Er_0 and E_∞, the value of E_∞ is far larger than the value of Er_0.

Generally, if the case is one in which the force is applied to a certain part of the elastic body, the energy E_0 stored is

$$E_0 = E_s + E_w,$$

where E_s is the energy that is dissipated for the work in neutralizing the strain stored in the body and E_w is the energy that is dissipated as elastic waves energy, in the release of the force.

On the other hand, as shown in Fig. 4 the variations of linear strains become great suddenly from around Mar. and show the monotonous variation until the beginning of July about 10 days before the earthquake-occurrence. But the reverse change was observed from the beginning of July and this variation stopped towards the middle of Aug. and then afterwards another variation began. We suppose that the variations of linear strains from the beginning of July until the middle of Aug. show the strains resumed due to the earthquake-occurrence, in other words, the release of the force.

Then, as above-mentioned, the amounts of strain energy E_∞ stored before the earthquake-occurrence in the body outside the earthquake nucleus are

$$E_\infty = 14.0\times10^{22} \sim 22.5\times10^{22},$$

and taking $\varepsilon_1 = -2.0\times10^{-6}$, $\varepsilon_2 = -1.0\times10^{-6}$ and $\varepsilon_3 = -4.5\times10^{-6}$ as the amount of strain resumed after the earthquake-occurrence, the strain energy E_∞' resumed in the body outside the earthquake nucleus will be $8.9\times10^{22} \sim 14.3\times10^{22}$.

Looking the both values, E_∞ and E_∞', we can find out that 63.6 % of the amount of strain energy stored in the body outside the earthquake nucleus before the earthquake-occurrence is equal to the amount of strain energy resumed after the earthquake-occurrence. This is meant that 63.6 % of the amount of strain energy stored in the earthquake nucleus is dissipated for the work in neutralizing the strain energy stored in the body outside the earthquake nucleus due to the earthquake-occurrence and the remainder, 36.4 % of the amount of strain energy stored in the earthquake nucleus is dissipated as elastic wave energy then.

Therefore the energy E of the earthquake, that is the energy of the elastic wave are obtained as follows;

$$E = E_w = Er_0 \times \frac{E_\infty - E_\infty'}{E_\infty} = 0.364\times Er_0 = 3.2\times10^{22} \sim 5.2\times10^{22}.$$

On the other hand, according to the 1956 formula of B. Gutenberg and C. Richter, the energy E of an earthquake is related to its magnitude M as follows;

$$\log E = 1.5M + 11.8.$$

If we put $M=7$ into this formula, which is the magnitude of this Yoshino Earthquake,

$$E = 2.0 \times 10^{22}$$

is obtained which value is smaller than any of the values $3.2 \times 10^{22} \sim 5.2 \times 10^{22}$ estimated by the present writer. But both values may be said to be in concordance with each other considering the nature of the problem of this kind.

In 1954, T. Utsu and A. Seki published an interesting article in which they studied the relation between the aftershock area A and the magnitude M of the main-shock. They obtained a formula as follows,

$$\log A = M + 6.$$

The aftershock area A is the horizontal area in which aftershocks of a large earthquake take place.

If we put the magnitude $M=7$ of the Yoshino Earthquake into this formula,

$$A = 10^{13}$$

is obtained. If the aftershock area A is the earthquake nucleus projected on the earth's surface, which assumption appears to be a reasonable one,

$$A = 10^{13} = \pi r_0^2$$

or

$$r_0 = 1.8 \times 10^6 \ (=18\,\mathrm{km}).$$

This value agrees almost with the values $r_0 = 19.4\,\mathrm{km} \sim 15.3\,\mathrm{km}$ estimated by the writer.

4. Conclusion

As the writer tried to study the problem under several assumptions mentioned above, the peculiar change of the crustal strain before the great earthquake does not appear lawlessly, but it may be said to have close relation with the earthquake as the phenomena forerunning earthquake.

Acknowledgments

In conclusion of this report, the writer wishes to express his cordial thanks to Prof. K. Sassa for his kind guidance and instruction all the time through out this study and also thanks to Dr. I. Ozawa for this lending of the observation data at Osakayama Observatory and his advice.

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Bulletin No. 27 Published January, 1959

昭和 34 年 1 月 15 日 印 刷
昭和 34 年 1 月 20 日 発 行

編輯兼発行者 京都大学防災研究所
印刷者 山 代 多 三 郎
京都市上京区寺之内通小川西入
印刷所 山代印刷株式会社