DISASTER PREVENTION RESEARCH INSTITUTE

BULLETIN No. 23 JULY, 1958

ON THE OBSERVATION OF THE CRUSTAL DEFORMATION AND METEOROLOGICAL EFFECT ON IT AT IDE OBSERVATORY AND ON THE CRUSTAL DEFORMATION DUE TO FULL WATER AND ACCUMULATING SAND IN THE SABO-DAM

BY

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On the Observation of the Crustal Deformation and Meteorological Effect on it at Ide Observatory and On the Crustal Deformation due to Full Water and Accumulating Sand in the Sabo-dam

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Michio TAKEDA

On the Observation of the Crustal Deformation and Meteorological Effect on it at Ide Observatory

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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. This report is to describe the result of observation and the effect of rainfall on the result of the observation.

1. Introduction

Ide Observatory is located at Ide-cho, Tsuzuki-gun, Kyoto Pref.. In order to observe the crustal deformation, extensometers and tiltmeters are provided here. This observatory was utilized the adit of an abandoned copper mine. The plane

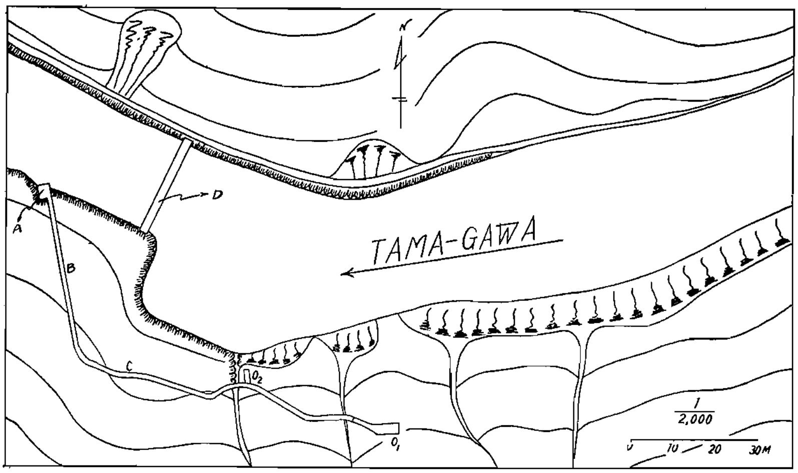


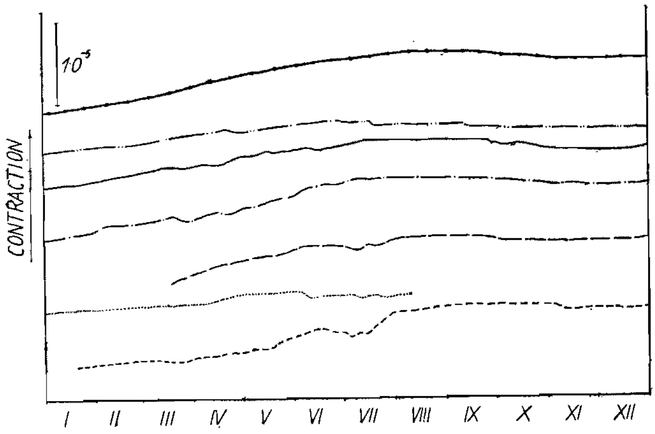
Fig. 1. Illustration of the observatory
A : recording room B : adit C position set up the tele-metrical extensometer D : Sabo-dam O_1 : the 1st observation room O_2 the 2nd observation room

figure of the observatory is illustrated in Fig. 1. Please see about the detail of observatory, instruments and disposition of those at observatory in another

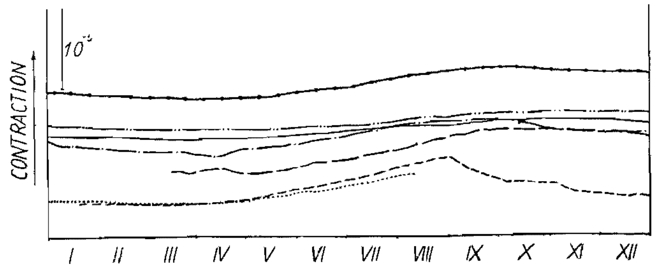
Table 1. List of instruments of Ide Observatory

Mark	Azimuth	Sensitivity	Place
1. Super-inver-bar Extensometer			
		$(10^{-8}/mm)$	
1	Vertical	5.54	O_1
2	Horizontal N88°E	4.92	O_1
3	Horizontal N2°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 magnicfication Extensometer			
I	Vertical	0.329	O_1
II	Horizontal N88°E	0.492	O_1
III	Horizantal 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)			
Ep	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			
		$(10^{-2''}/mm)$	
T.M. A	N45°E	2.0	O_1
T.M. B	S45°E	2.0	O_1
T.M′. A′	N45°W	3.0	O_2
T.M′. 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
$T.M._P$ 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



Component-1



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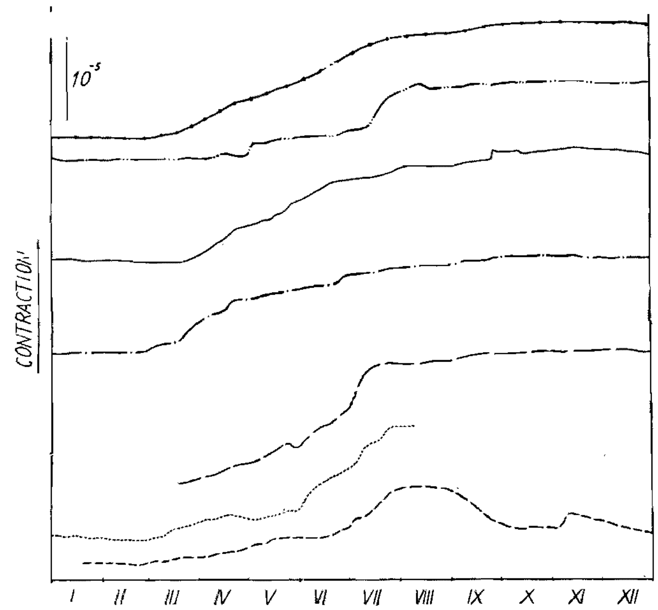
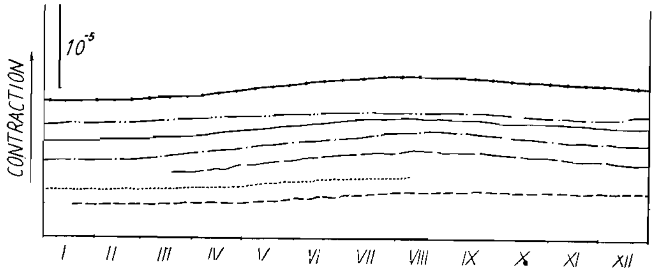
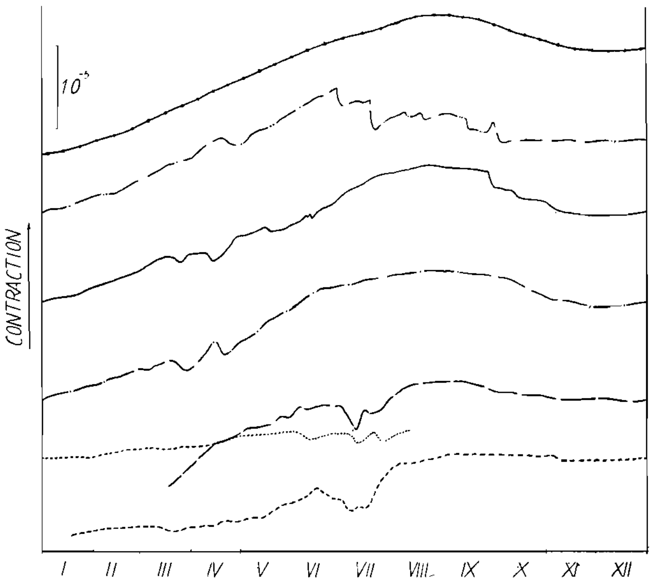


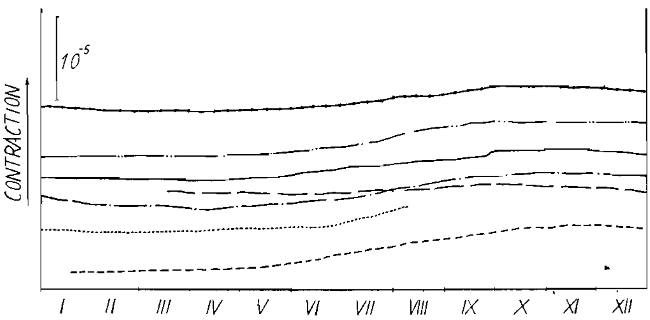
Component-3



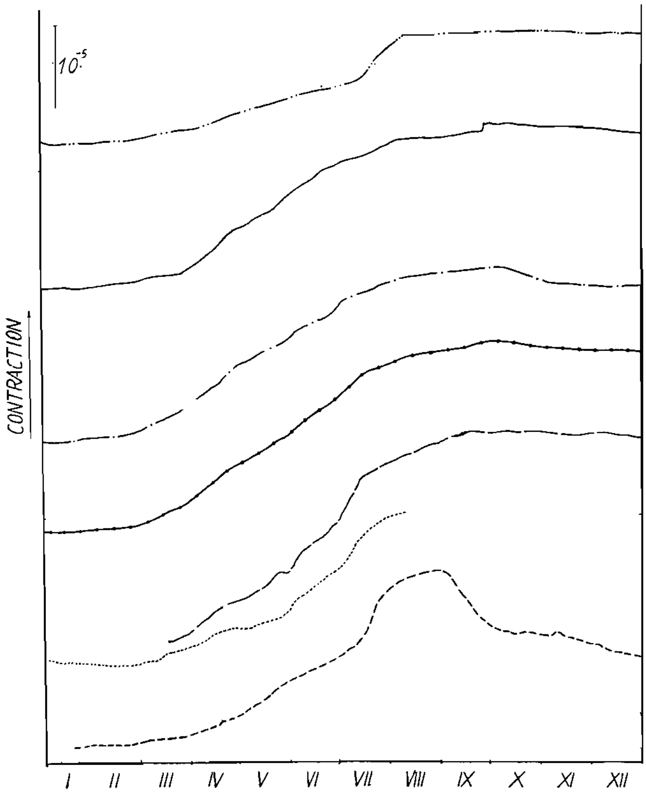
Component-4



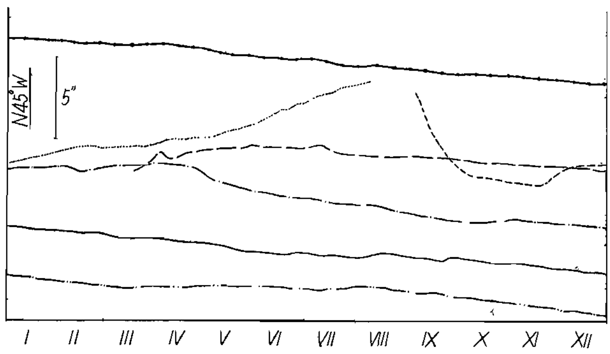
Component-5



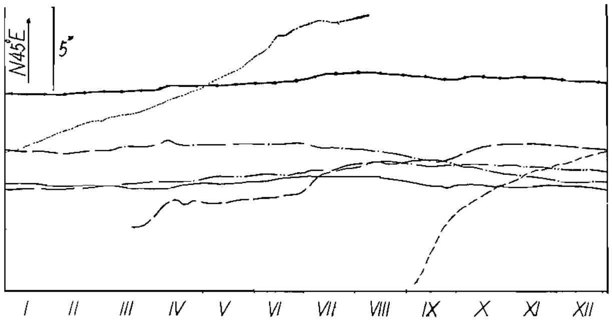
Component-6



Volume dilatation



Tiltmeter (A-component)



Tiltmeter (B-component)

Fig. 2 variation of linear strain, volume dilatation and these annual variation

- - - - - - - - - - - -	1952
....	1953
— — — — — — — —	1954
——·——·——·——	1955
————————	1956
··——··——··——··	1957
—+—+—+—+—+—+—	annual variation

report "On the observation instruments and tele-metrical device of extensometers and tiltmeters at Ide Observatory". The instruments' azimuth, sensitivity and location are shown in Table 1.

All these instruments have not been set up since this observatory was founded but some improvements were made on them or some new instruments were set up gradually according to the advance of the observation. The observation was once obliged to suspend by the Minamiyamashiro flood disaster from 14th Aug. 1953 to 17th Mar. 1954. With the exception for these period the results of obsevation have always been automatically recorded.

2. The results of the observation and the annual variation

The main result of the observation obtained by these instruments are shown in Fig. 2. As the both variations by using 6 components extensometer and tiltmeter at the 1st ovservation room O_1 after April 1954 show the similar variation, the mean of variations for 3 years, assuming as an annual variation marked with —+—+—+— is shown in figure. The volume dilatation is obtained from a formula $e=\varepsilon_1+\varepsilon_2+\varepsilon_3$ which is calculated from the variation of strain value ε_1, ε_2, ε_3, obtained by the exensometers of the 3 rectangular co-ordinate axis "1", "2", "3"

3. The effect of rainfall on the crustal deformation

Many irregular variations are found in Fig. 2. These variations are appearently caused by rainfall, which is supposed to be acted a important part on the strain of the ground. The variation from 12 May 1956 to 8 June 1956, for example, tells us that the effects of rainfall are differed on each component

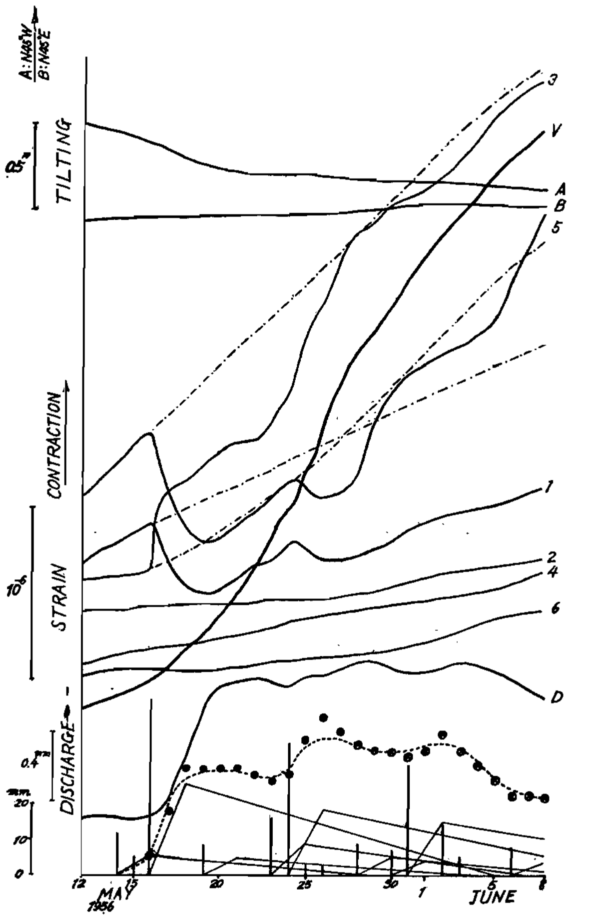


Fig. 3. The variation of linear strain, volume dilatation, tilting and discharge of water in the mine at Ide Observatory and the precipitation at Tanabe-cho, from 12 May to 8 June 1956, and the effective curve of the rainfall.

as shown in Fig. 3. The irregular variation is revealed largely on only 3 components "1", "3", "5" of extensometers and approximately not on the other components "2", "4", "6" and on the tiltmeter. Therefore the observed value should be done with under the consideration of these effects, when we deal with the observation of the crustal deformation. Thus we must examine how does the effect of rainfall work on the strain. Many ways have ever been tried on this matter, but perfect way has not ever been succeded yet.

The variation of the strain is assumed to be very complicated as it differs even by the direction of it on the very same place. As mentioned above, there is no other way but for long term observes and obtains from those results of observation experimentally. The writer therefore decided to obtain the relation between the rainfall and the variation of the strain on the components of "1", "3", "5" by following method.

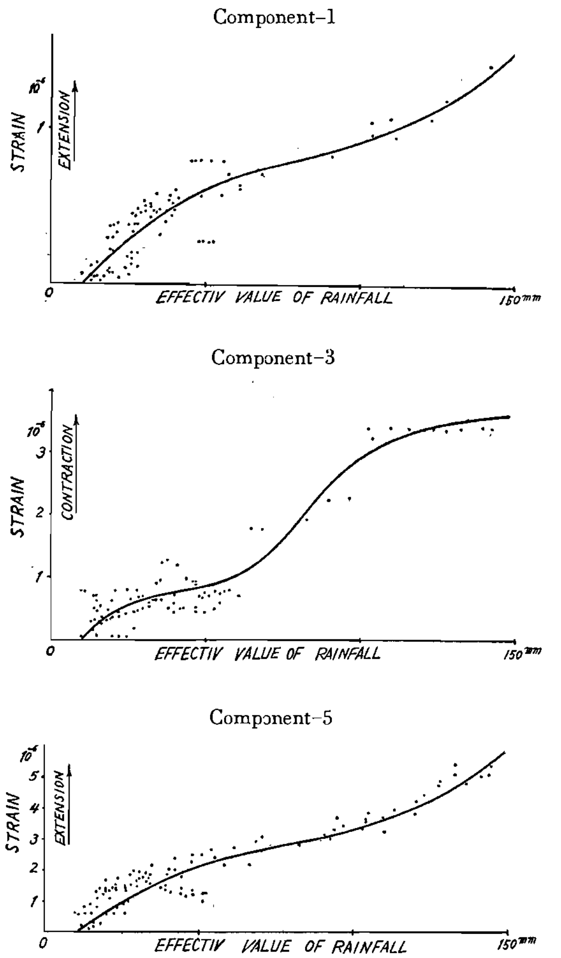


Fig. 4. The relation between the strain and precipitation.

The result of the observation obtained up to this time, of course it differs by the condition, the amount of rainfall shows that it is effected, as a whole, by the amount of rainfall more than 15mm and mount up at its peak two days later after rainfall commenced and it lasts 2 or 3 weeks.

Assuming the effect of rainfall lasts 15 days by 6~20mm and that of 20 days by more than 20mm equally in any rainfall from the results of observation by using extensometers and discharge meter, the writer made a triangle with the hight proportioning to the amount of rainfall after 2 days when rained and with its base taking period of rainfall effect, ⊗ mark in the figure, assuming the sumed value of all rainfall of each day as the effective value, as shown in Fig. 3. As the result obtained by this manner is the zigzag line, after smoothing by overlapping means-method, it becomes the dotted curve line as shown in figure. We call this line the effective curve of the rainfall. Then we obtained the relation between this curve and the variation of the strain on each rainy day. Taking the hight of effective curve as the absissa and the difference between the curve of observation and the annual variation curve of the time (difference between ——line and —·— line) as the ordinate, picking up about 20 rainfalls out of many rains in the past, the curve, which is anomalously irregular, is obtained as shown in Fig. 4. In this way the relation was obtained but we must obtain more practical one which is seemed to be the regular variation, for the place

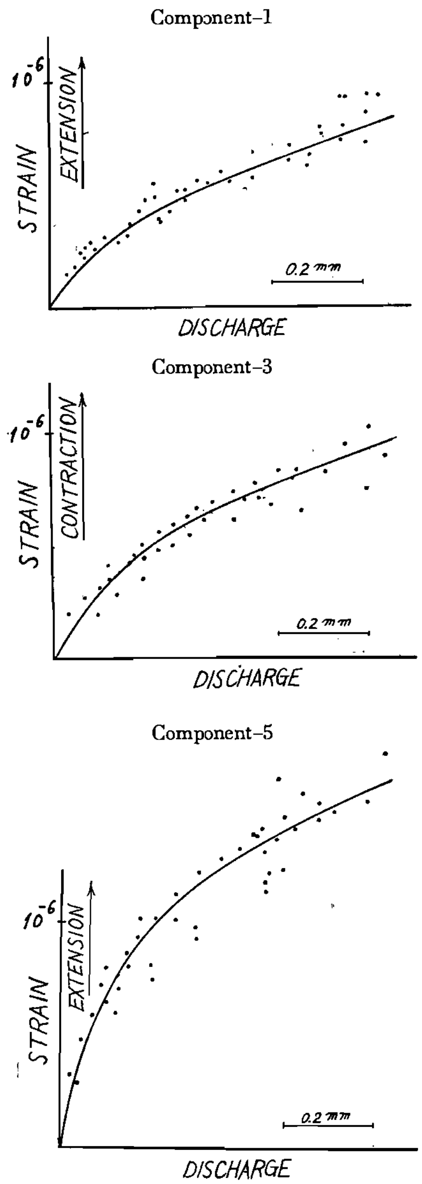


Fig. 5. The relation between the strain and the dischange of water in the mine.

of this effective curve. Therefore we adopped following method, as the variation affected by the rainfall is supposed to be mostly depend upon the amount of the infiltrated water into the adit, we tried to obtain the relation between the quantity of water in the adit and the variation of the strain. The value obtained by the discharge meter which was set for this purpose, was D. As a whole, the variation on the discharge meter will appear after $10 \sim 12$ hours of the rainfall. Assuming the variation on the discharge meter is the one after 12 hours of the rainfall, the relation of both will be obtained, taking the variation of the discharge meter at that time as abscissa and the variation of strain as the ordinate same as before, as shown in Fig. 5. This shows that pretty regular points are arranged as compared with Fig. 4. Therefore if these relative curve are utilized, we can get eliminate of the effect of rainfall on the observed value of the crustal deformation. This method, however, is simpl way but not complete and perfect one. We must study more on this problem.

When we compare the curve of "1" and "3" in Fig. 4 and Fig. 5, "1" is extended and "3" is compressed, but both of these curve shows the similar curve especially in Fig. 5 both curve are coincided each other in the part of low level of the water discharge meter. This fact proves that volume dilatation ($e=\varepsilon_1+\varepsilon_2+\varepsilon_3$) is not affected by the rainfall. Indeed Fig. 3 "V" and Fig. 2 "V" shown that nothing is effected by the rainfall. By the reason as mentioned above, on discussing about the crustal deformation, we must consider not only the linear strain but volume dilatation.

4. Conclusion

The writer has just described the result of observation and the effect of rainfall obtained at Ide Observatory. We have finally found out that strain given by the rainfall differs to the direction of the strain and rainfall does not effect on the volume dilatation. These points will be considered hereafter, when we study the crustal deformation.

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

References

1) Ozawa, I.: On the Observataons of Strain of the Ground Surface Using by Invar-

wire and Invar-bar Extensometer, ane Effect of the Rain-fall to the Charge of the Ground Surface. Bulletin of the Disaster Prevention Research Institute Kyoto University No. 3, 1950, p. 69.

2) Takada, M, : On the Observation Instruments and Tele-metrical Devices of Extensometers and Tiltmeters at Ide Observatory. (Bull. Disaster Prev. Res. Inst. published in the near future)

On the Crustal deformation due to Full Water and Accumulating Sand in the Sabo-dam

by

Michio TAKADA

Abstract

We have been observing crustal deformation by extensometers and tiltmeters in the Ide Observatory of Disaster Prevention Research Institute of Kyoto University. As water filled the Sabo-dam near our observatory, some remarkable variations of ground-strrain and ground-tilt were noted in the extensometric and tiltmetric observation. The mode of strain of the ground near the observatory due to this semi-artificial load is considered.

1. Introduction

Ide Observatory at Ide-cho Tsuzuki-gun, Kyoto-Pref., as shown in Fig. 1,

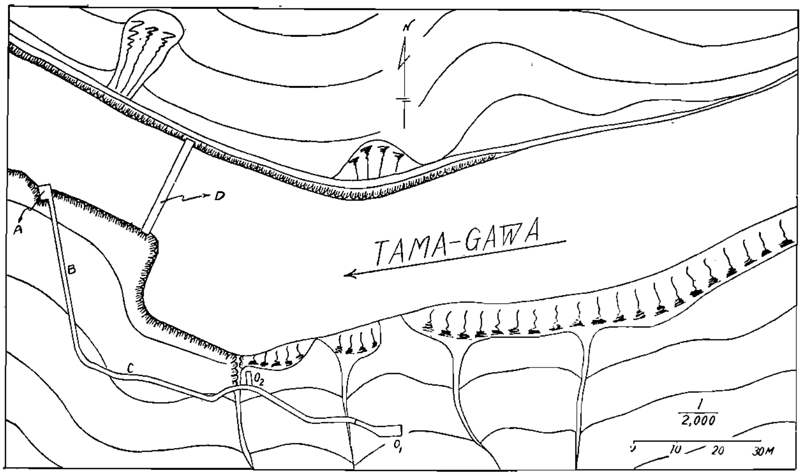


Fig. 1. Illustration of the observatory
A recording room B : adit C : position set up the tele-metrical extensometer D Sabo-dam O_1 : the 1st observation room O_2 : the 2nd observation room

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. Wise 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}″/mm)	
T.M. A	N45°E	2.0	O_1
T.M. B	S45°E	2.0	O_1
T.M.′ A′	N45°W	3.0	O_2
T.M.′ B′	N45°E	3.0	O_2
7. Photocell type Tiltmeter (Tele-metrical Eiltmeter)			
$T.M._P$ A'_p	N45°W	4.0	O_2
$T.M._P$ 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

is a reformed adit of an abandoned copper mine. In the 1st observation room situated at the most secluded place of the adit. 6 components of extensometers, 3 components of high magnification extensometers, horizontal pendulum type tiltmeter and the discharge meter are set up as shown in Fig. 2. The constants of these instruments are indicated in Table 1. In front of the observatory, the Tama River runs without mach water except it rains. The river brings down sand, especially the quantity of washed-out sand has increased after Minamiyamashiro flood disaster. The Sabo-dam was constructed, as one of flood disaster preventive measures, near our observatory. The water is pouring out through a weeping hole at the bottom of the dam, where the sand is not much accumlated usually but when the stream swells, the water and sand staies with the dam. We had rainfall amounting precipitation 180mm for 3 days from 26 Sept. 1956, the water began to overflow the dam at about 9 a. m. on 27 Sept. when the extensometers and tiltmeters caught a specific variation on them. This is presumed that the foundation of the ground strained by the load of pooled water and accumulated sand. The writer tried to compare the result of observation with the result obtained theoretically. We will describe in detail of the above.

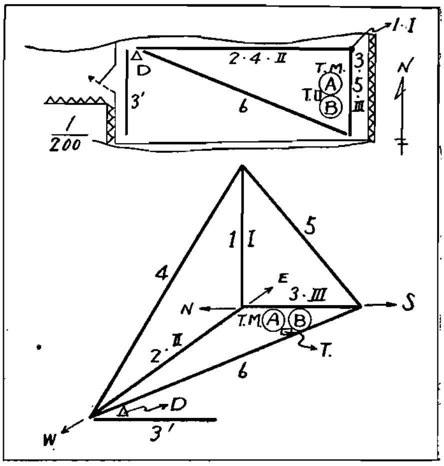


Fig. 2. Disposition of instruments interior the 1st observation room

1,2,3,4, 5, 6, 3' super-invar-bar-extensometer

I, II, III high magnification extensometer

T. M. tiltmeter

T. thermometer

D. discharge meter

2. Result of the Observation

Fig. 3 and 4 show the result of observation by the extensometers, tiltmeter and the discharge meter at this observatory and the precipitation measured after 5 Sept. 1956 at Kyoto-prefectural laboratory of gardening and seedlings which is located at Tanabe-cho, Tsuruki-gun, Kyoto-Pref. about 3km from our observatory. Both of them show the monotonous variation until 26 Sept. when the specific variation was manifest. Photo. 1 shows the records obtained by instruments before and after the full water. On the variatirn of the extensometer component "1" had been extending at the rate of 8.5×10^{-9}/day until

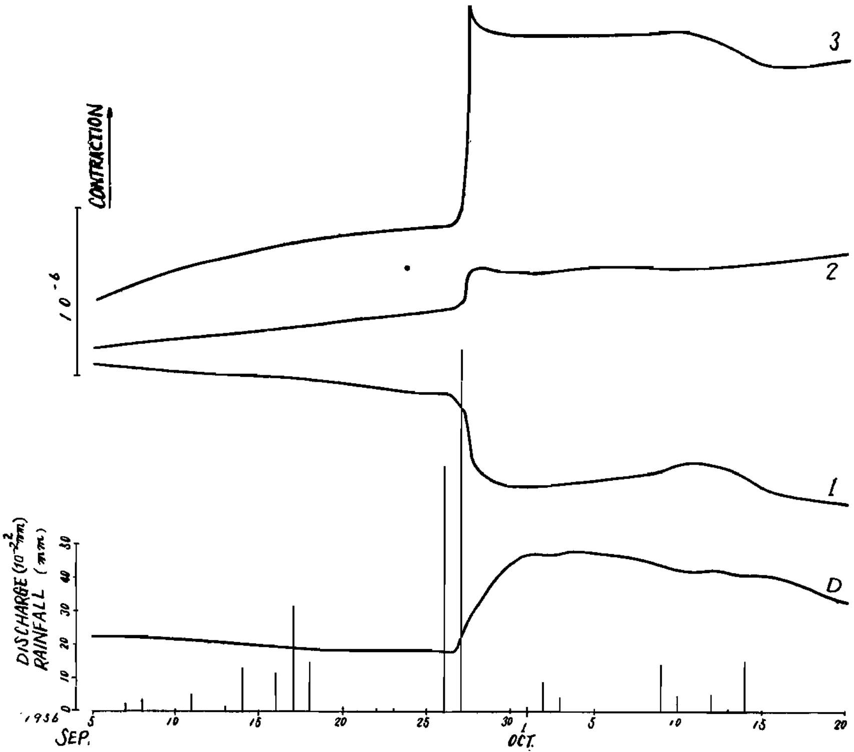


Fig. 3. The variation of strain, volume dilatation and discharge of water in the mine at Ide Observatory and the precipitation at Tanabe-cho about 3km from Ide Observatory, from 5 Sept. to 20 Oct. 1956.

teh time of rainfall on 26 Sept. but it was extended 7.2×10^{-7} suddenly, component "2" and "3" had been compressing at the rate of 11.5×10^{-9}/day and 15.0×10^{-9}/day, but they were compressed 2.4×10^{-7} and 12.6×10^{-7} respectively. On the variation of tiltmeter, it had been inclining at the rate of 0.0175"/day towards south, but it was inclined 0.335" towards the direction of the dam suddenly. Also it increased on the discharge meters. These variations on the instruments obviously caused by the load of the water and the sand but we can say that some part of the variation are caused by the rainfall itself. In order to see how much variation was due to the load of the water and the sand, the annual variation and the variation caused by the rainfall must be eliminated. The elimination of the annual variation was mentioned in another report already. The variation of strain observed by extensometers, eliminated of annual variation

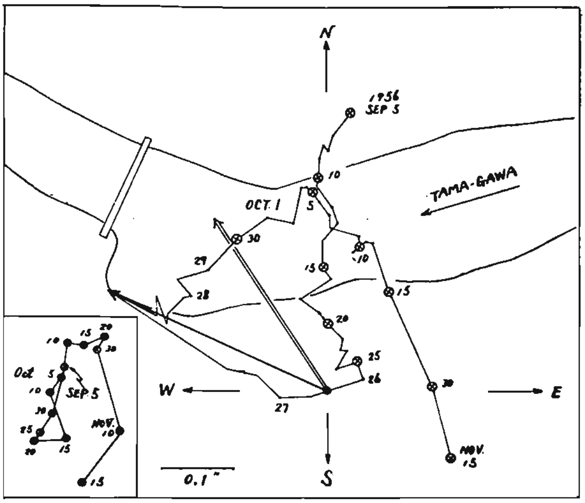
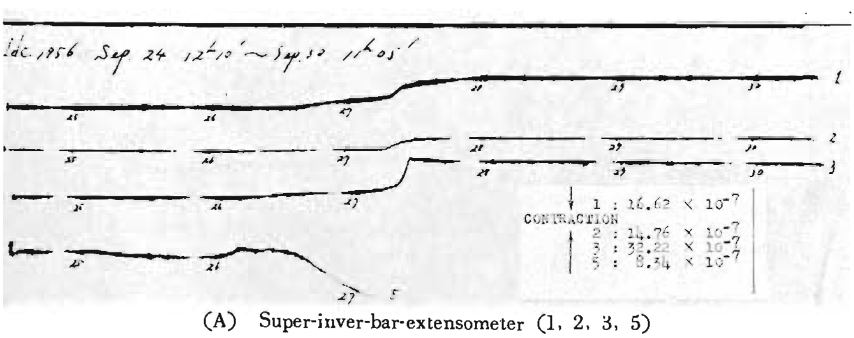


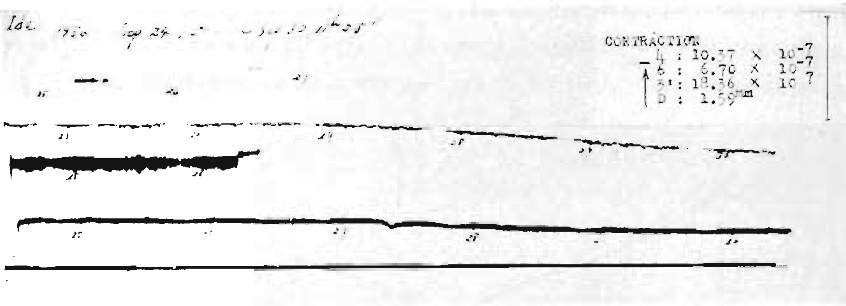
Fig. 4. The tilting motion of ground at Ide Observatory from 5 Sept. to 15 Nov. 1956 and annual variation. Double arrow shows the theoretical tilting.

is indicated in Fig. 5. The annual variation of tilt for these period is illustrated in vector diagram in Fig. 4 left bottom. The effect of annual variation on variation for short period of 25 or 30 days seems to be so small that we left it uneliminated. Secondly on the elimination of variation caused by the rainfall, the variation affected by the rainfall can be obtained from the variation of discharge of water in the adit considering the relation between the discharge

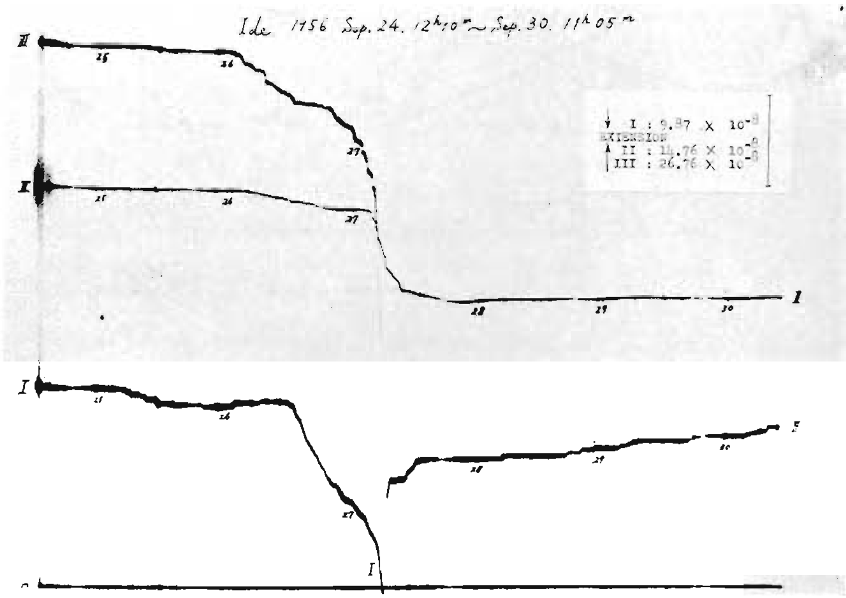
Photo. 1. Records obtained with many types extensometers and tiltmeters and discharge meter before and after the full water in the Sabo-dum.



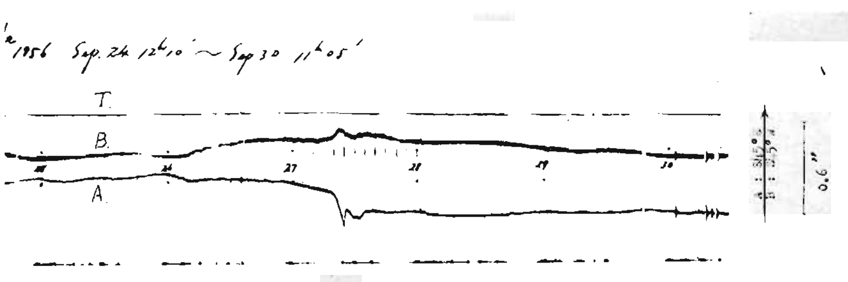
(A) Super-inver-bar-extensometer (1, 2, 3, 5)



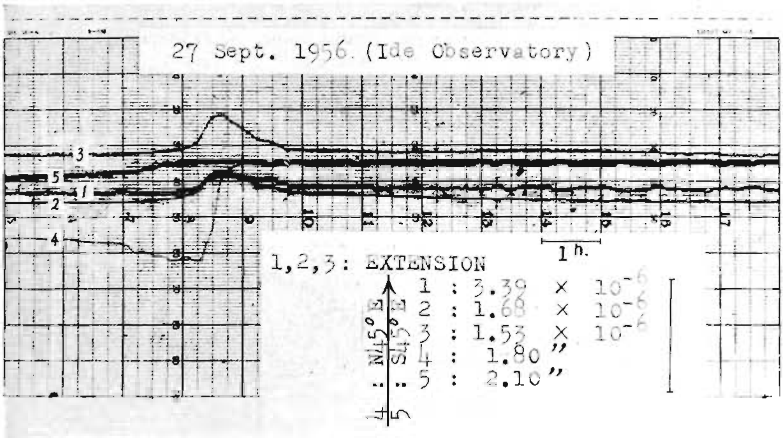
(B) Super-invar-bar-extensometer (4, 6, 3′) and discharge meter (D)



(C) High magnification extensometer (I, II, III)



(D) Tiltmeter (T. M. A, B)



(E) Tele-metrical instruments

1. (E_I) 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)

of the water and the strain, that is to say the relation of Fig. 6.

The variation curve of the strain which was caused by the rainfall for these periods is shown dotted line curve in Fig. 5. Therefore the difference

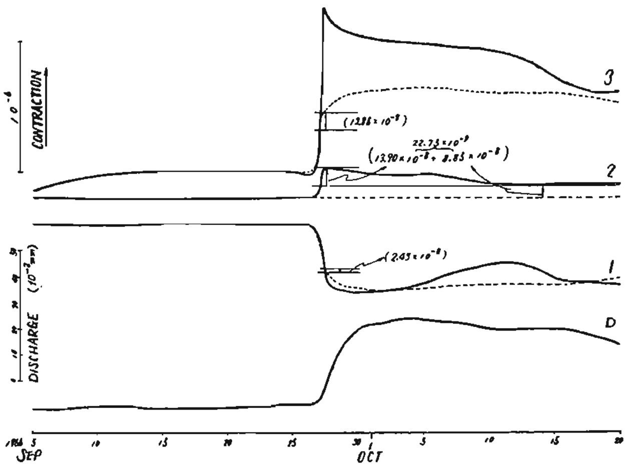


Fig. 5. The variation of strain and discharge of water in the mine, eliminated of annual variaction.

between—line and···line in Fig. 5 and the arrow in Fig. 4 are able to define the strain caused by the load of the water and sand. That is to say, it extended 4.1×10^{-8} to the direction of extensometer, component "1" (vertical) and com-

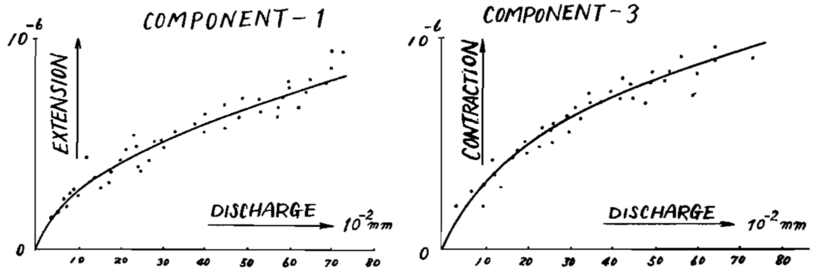


Fig. 6. The relation between the strain and the discharge of water in the mine.

pressed 22.8×10^{-8} to the direction of "2" (horizontal. E2°N. parralell to the river) and compressed 81.0×10^{-8} to the direction of "3" (horizontal. N2°W. almost perpendecular to the river) and inclined $33.5\times10^{-2}{}''$ to the direction of N64.6°W.

3. Study and examination of strain theoretically caused by the load of water and sand.

In the research of the earth tide, reports by many scholars have described how the load of sea water affects on the crust, most of them taking the crust as isotropic semi-infinite elastic solid and inquiring the crust deformation caused by the surface load on the stage of elastic theory by use of Bossinesq's problem. We have also studied how the load of water and sand effect on the crust on the same stage. In case the river water increases, the vertical force is presumed to be the main force affecting on the river-bed, but as there are more or less ups and downs on the river-bed, the horizontal forces must be be also in action. Let P_1 be the increase of vertical force when the water increased as high as Δh, P_2 and P_3 be the increase of x-component and the increase of y-component of horizontal force. If the feature of river-bed is $z=h(x, y)$, P_1, P_2 and P_3 are given as follows.

$$P_1=\frac{\rho\cdot g\cdot\Delta h}{\sqrt{1+\left(\frac{\partial h}{\partial x}\right)^2+\left(\frac{\partial h}{\partial x}\right)^2}}$$

$$\left.\begin{aligned} P_2 &= \frac{-\rho\cdot g\cdot \Delta h \dfrac{\partial h}{\partial x}}{\sqrt{1+\left(\dfrac{\partial h}{\partial x}\right)^2+\left(\dfrac{\partial h}{\partial x}\right)^2}} \\ P_3 &= \frac{-\rho\cdot g\cdot \Delta h \dfrac{\partial h}{\partial y}}{\sqrt{1+\left(\dfrac{\partial h}{\partial x}\right)^2+\left(\dfrac{\partial h}{\partial y}\right)^2}} \end{aligned}\right\} \qquad (3.1)$$

Where ρ is the density of the river water and g the gravity acceleration. Secondly in case a force acts on a point of surface of isotropic semi-infinite elastic solid, we look about the displacement on another point. Let the origin be the point where the force acts. Let x, y and z be Cartisian rectangular co-ordinates, the axis of z being directe downwards and let u, v and w be x, y and z component of displacement respectively and that putting the suffixes of 1, 2 and 3 on them to show displacements caused by P_1, P_2 and P_3 are given in following equations.

$$\left.\begin{aligned} &\left\{\begin{aligned} u_1 &= \frac{P_1}{4\pi\mu}\frac{zx}{R^3}-\frac{P_1}{4\pi(\lambda+\mu)}\frac{x}{R(R+z)} \\ v_1 &= \frac{P_1}{4\pi\mu}\frac{yz}{R^3}-\frac{\mathrm{P}_1}{4\pi(\lambda+\mu)}\frac{}{R(R+z)} \\ w_1 &= \frac{P_1}{4\pi\mu}\frac{z^2}{R^3}+\frac{P_1}{4\pi\mu}\frac{\lambda+2\mu}{\lambda+\mu}\frac{1}{R} \end{aligned}\right. \\ &\left\{\begin{aligned} u_2 &= \frac{P_2}{4\pi\mu}\left(\frac{1}{R}+\frac{x^2}{R^2}\right)+\frac{P_2}{4\pi(\lambda+\mu)}\left\{\frac{1}{R+z}-\frac{x^2}{R(R+z)^2}\right. \\ v_2 &= \frac{P_2}{4\pi\mu}\frac{xy}{R^3}-\frac{P_2}{4\pi(\lambda+\mu)}\frac{xy}{R(R+z)^2} \\ w_2 &= \frac{P_2}{4\pi\mu}\frac{zx}{R^3}+\frac{P_2}{4\pi(\lambda+\mu)}\frac{x}{R(R+z)} \end{aligned}\right. \\ &\left\{\begin{aligned} u_3 &= \frac{P_3}{4\pi\mu}\frac{xy}{R^3}-\frac{P_3}{4\pi(\lambda+\mu)}\frac{xy}{R(R+z)^2} \\ v_3 &= \frac{P_3}{4\pi\mu}\left(\frac{1}{R}+\frac{y^2}{R^3}\right)+\frac{P_3}{4\pi(\lambda+\mu)}\left\{\frac{1}{R+z}-\frac{y^2}{R(R+z)^2}\right\} \\ w_3 &= \frac{P_3}{4\pi\mu}\frac{yz}{R^3}+\frac{P_3}{4\pi(\lambda+\mu)}\frac{y}{R(R+z)} \end{aligned}\right. \end{aligned}\right\} \qquad (3.2)$$

Where $R^2=x^2+y^2+z^2$, λ and μ are Lamé's constants. The extension and the tilt of x direction and the extension of z direction are given by following equations from above mentioned equations on the surface $z=0$.

$$
\left\{
\begin{aligned}
&\left(\frac{\partial u_1}{\partial x}\right)_0=\frac{P_1}{4\pi(\lambda+\mu)}\frac{x^2-y^2}{r^4}\\
&\left(\frac{\partial w_1}{\partial x}\right)_0=-\frac{P_1}{4\pi\mu}\frac{\lambda+2\mu}{\lambda+\mu}\frac{x}{r^3}\\
&\left(\frac{\partial w_1}{\partial z}\right)_0=0
\end{aligned}
\right.
$$

$$
\left\{
\begin{aligned}
&\left(\frac{\partial u_2}{\partial x}\right)_0=\frac{P_2}{4\pi\mu}\frac{x(r^2-3x^2)}{r^5}-\frac{P_2}{4\pi(\lambda+\mu)}\frac{3xy^2}{r^5}\\
&\left(\frac{\partial w_2}{\partial x}\right)_0=-\frac{P_2}{4\pi(\lambda+\mu)}\frac{x^2-y^2}{r^4}\\
&\left(\frac{\partial w_2}{\partial z}\right)_0=\frac{P_2}{4\pi\mu}\frac{\lambda}{\lambda+\mu}\frac{x}{r^3}
\end{aligned}
\right. \tag{3. 3}
$$

$$
\left\{
\begin{aligned}
&\left(\frac{\partial u_3}{\partial x}\right)_0=\frac{P_3}{4\pi\mu}\frac{\lambda}{\lambda+\mu}\frac{y(r^2+3x^2)}{r^5}\\
&\left(\frac{\partial w_3}{\partial x}\right)_0=-\frac{P_3}{4\pi(\lambda+\mu)}\frac{2xy}{r^4}\\
&\left(\frac{\partial w_3}{\partial z}\right)_0=\frac{P_3}{4\pi\mu}\frac{\lambda}{\lambda+\mu}\frac{y}{r^3}
\end{aligned}
\right.
$$

where $r^2=x^2+y^2$.

As the strain on the point, when P_1, P_2 and P_3 act, is thus obtained, if we integrate the natural feature of the river-bed actually, the strain on the observation point can be obtained. As this integral is, in fact, pretty complicated, we adopt the graphical method. As an example, extension of x direction, in case P_1 acts, can be obtained as below. At first the strain $\left(\frac{\partial u_1}{\partial x}\right)_0$ caused by the load of a section encircled by $r=r_n\sim r_{n+1}$, $\phi=\phi_m\sim\phi_{m+1}$ is given in following equations by use of polar co-ordinate where the origin is the observation point.

$$
\begin{aligned}
\left(\frac{\partial u_1}{\partial x}\right)_0&=\iint\frac{P_1}{4\pi(\lambda+\mu)}\frac{x^2-y^2}{r^4}dx\cdot dy=\frac{P_1}{4\pi(\lambda+\mu)}\iint\frac{x^2-y^2}{r^4}dxdy\\
&=\frac{P_1}{4\pi(\lambda+\mu)}\int_{r_n}^{r_{n+1}}\frac{dr}{r}\int_{\phi_m}^{\phi_{m+1}}(\cos^2\phi-\sin^2\phi)d\phi\\
&=\frac{P_1}{4\pi(\lambda+\mu)}\left(\log\frac{r_{n+1}}{r_n}\right)\frac{1}{2}(\sin2\phi_{m+1}-\sin2\phi_m)
\end{aligned}
$$

Therefore suming up the all strains caused by all load of the sections encircled by all $r_n \sim r_{n+1}$, $\phi_m \sim \phi_{m+1}$, the strain can be obtained. In this case, on all m and n, if we divide these sections the value of $\log \frac{r_{n+1}}{r_n}$, $\frac{1}{2}(\sin 2\phi_{m+1} - 2\phi_m)$ keeps the same value that is to say to $k = \left(\log \frac{r_{n+1}}{r_n}\right) \frac{1}{2}(\sin 2\phi_{m+1} - \sin 2\phi_m)$ become the constant value, the strain on the observation point is given by

$$\left(\frac{\partial u_1}{\partial x}\right)_0 = \frac{K}{4\pi(\lambda+\mu)} \sum_{S_2} P_1.$$

$\sum_{S_2}$ means to sum up all values of P_1 on every section. If we follow the dividing as in Table 2, each strain is obtained by following equations.

Table 2. List of integration sections

	k_1	k_2
S_1		$\sin\phi_{m+1} - \sin\phi_m$
C_1		$-(\cos\phi_{m+1} - \cos\phi_m)$
S_2	$\log \frac{r_{n+1}}{r_n}$	$\frac{1}{2}(\sin 2\phi_{m+1} - \sin 2\phi_m)$
C_2		$-\frac{1}{2}(\cos 2\phi_{m+1} - \cos 2\phi_m)$
S_3		$\frac{1}{3}(\sin 3\phi_{m+1} - \sin 3\phi_m)$
S_3		$-\frac{1}{3}(\cos\phi_{m+1} - \cos\phi_m)$

$$\left.\begin{aligned}
&\left\{\begin{aligned}
&\left(\frac{\partial u_1}{\partial x}\right)_0 = \frac{K}{4\pi(\lambda+\mu)} \sum_{S_2} P_1 \\
&\left(\frac{\partial w_1}{\partial x}\right)_0 = \frac{K}{4\pi\mu} \frac{\lambda+2\mu}{\lambda+\mu} \sum_{S_1} P_1 \\
&\left(\frac{\partial w_1}{\partial z}\right)_0 = 0
\end{aligned}\right. \\
&\left\{\begin{aligned}
&\left(\frac{\partial u_2}{\partial x}\right)_0 = \frac{K}{16\pi\mu} \frac{5\lambda+8\mu}{\lambda+\mu} \sum_{S_1} P_2 + \frac{K}{16\pi\mu} \frac{3\lambda}{\lambda+\mu} \sum_{S_3} P_2 \\
&\left(\frac{\partial w_2}{\partial x}\right)_0 = -\frac{K}{4\pi(\lambda+\mu)} \sum_{S_2} P_2 \\
&\left(\frac{\partial w_2}{\partial z}\right)_0 = -\frac{K}{4\pi\mu} \frac{\lambda}{\lambda+\mu} \sum_{S_1} P_2
\end{aligned}\right.
\end{aligned}\right\} \qquad (3.4)$$

$$\left\{\begin{aligned} \left(\frac{\partial u_3}{\partial x}\right)_0 &= -\frac{K}{16\pi\mu}\frac{\lambda}{\lambda+\mu}\sum_{C_1}P_3+\frac{K}{16\pi\mu}\frac{3\lambda}{\lambda+\mu}\sum_{C_3}P_3 \\ \left(\frac{\partial w_3}{\partial x}\right)_0 &= -\frac{K}{4\pi(\lambda+\mu)}\sum_{C_2}P_3 \\ \left(\frac{\partial w_3}{\partial z}\right)_0 &= -\frac{K}{16\pi\mu}\frac{\lambda}{\lambda+\mu}\sum_{C_1}P_3 \end{aligned}\right.$$

where $K=k_1\times k_2.$

Therefore the extension and the tilt of x direction and the extension of z direction, in case P_1, P_2 and P_3 act, are obtained as follows

$$\left.\begin{aligned} \left(\frac{\partial u}{\partial x}\right)_0 &= \left(\frac{\partial u_1}{\partial x}\right)_0+\left(\frac{\partial u_2}{\partial x}\right)_0+\left(\frac{\partial u_3}{\partial x}\right)_0 \\ \left(\frac{\partial w}{\partial x}\right)_0 &= \left(\frac{\partial w_1}{\partial x}\right)_0+\left(\frac{\partial w_2}{\partial x}\right)_0+\left(\frac{\partial w_3}{\partial x}\right)_0 \\ \left(\frac{\partial w}{\partial z}\right)_0 &= \left(\frac{\partial w_1}{\partial z}\right)_0+\left(\frac{\partial w_2}{\partial z}\right)_0+\left(\frac{\partial w_3}{\partial z}\right)_0 \end{aligned}\right\} \quad (3.5)$$

To obtain the strain applying this formula, making up the divided sections as shown in Table 2 on the tracing paper and putting this on the diagram of distribution of P_1 (distribution of the depth of water and accumulated sand) as shown in Fig. 7, also putting the oringin on the observation point, we count the number of sections which are included in each distribution and integrate

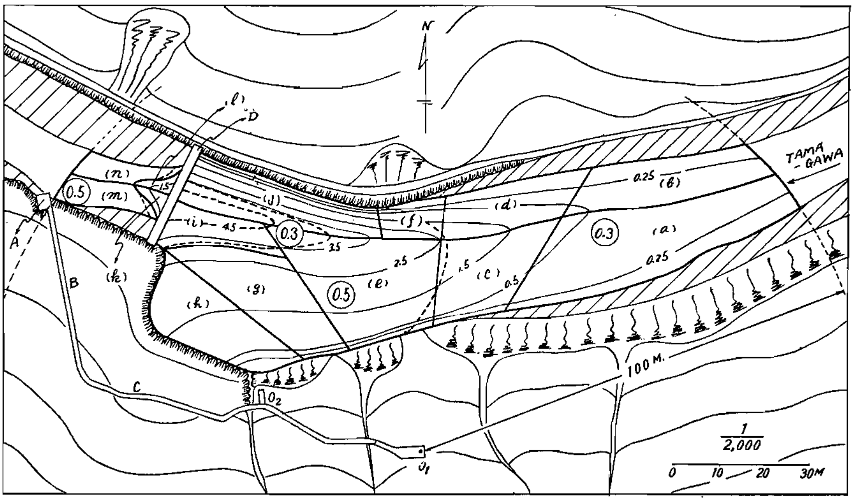


Fig. 7. The diagram of distribution of the depth of water and accumulated sand when the Sabo-dam. was filled up with the water on 27 Sept. 1956. (Unit : m)

it. Thus we can obtain the extension and the tilt of x direction and the extension of z direction. But the extension and the tilt of y direction also can be seen to have an axis of the section diagram, used above and to rotate properly. In this case K is also a constant value which was defined by dividing sections as mentioned above, but if we define the dividing sections that K is the constant value beforehand, it is convenient to calculate the value. So we divided the sections that k_1 and k_2 become 0.05 that is to say $K=0.0025$. In obtaining the horizontal forces of P_2 and P_3, we decided to divide them into 14 small sections $(a)\sim(n)$ which seemed that the value of $\frac{\partial h}{\partial x}, \frac{\partial h}{\partial y}$ keep the same value, and to take the load within 100 m from the observation point. In this way, we obtained the strain dividing it into 2 ways that is to say strains caused by the water and the sand. Secondly, on making such a distribution diagram, as we have been surveying the river-bed twice a year in Apr. & Oct. periodically putting the rainy season in between in order to obtain the relation between accumulated sand and the strain, we made it on the basis of the survey conducted in the middle of Aug. 1956, the measurement of water level when the water filled, on 27 Sept. and the resurvey on river-bed in the middle of Oct., and that value of $\frac{\partial h}{\partial x}, \frac{\partial h}{\partial y}$ obtained by the survey in Aug. on the sand and in Oct. on the water and we made the distribution of accumulated said from the difference between those above 2 surveys. The distribution of water depth was made from the deta of Oct. survey and the measurement of water level when the dam was filled with water. It is natural that these diagrams are different from the fact, especially the diagram of heaped sand distribution when the dam was filled with water seems to show some difference, but in fact as it is very difficult to measure the quantity of the sand when the dam is filled with water we used such method for the sake of convenience. The error accompanied utirizing this convenient method seems small when this is compared with the accuracy which we are going to obtain from now on. On the other hand, as the density of water we adopted the measurement value 1.01 of the density of river water when the dam was filled with the water and as the density of sand we adopted 1.875, assuming that the density of sand is 75% of mean density 2.5 of pebble at river-bed nearby dam. On a basis of such assumptions and these values, we obtained the values of $\sum_{S_1} P_1$, $\sum_{S_2} P_1$..... ect, which are needed on the calculation and these values are shown in Table 3. In this table, we divided them into two parts, as the value caused by the water and the value caused by the sand and the marks 2 and 3 stood for the

Table 3. The values of $\sum_{S_1} P_1$, $\sum_{S_1} P_2$ ························etc.

		By the load of water		By the load of sand	
(×10⁵)		2	3	2	3
$\sum_{S_1}$	P_1	− 135.907	+ 270.393	− 48.174	+ 78.146
	P_2	− 4.565	− 8.700	− 3.421	− 2.675
$\sum_{S_2}$	P_1	− 110.837	+ 110.837	− 36.446	+ 36.446
	P_2	− 4.948	+ 5.341	− 1.568	+ 0.918
$\sum_{S_3}$	P_2	+ 7.360	+ 7.886	+ 0.896	+ 2.337
$\sum_{C_1}$	P_3	− 8.700	− 4.565	− 2.675	− 3.421
$\sum_{C_2}$	P_3	+ 10.427	− 6.672	+ 3.525	− 0.996
$\sum_{C_3}$	P_3	− 7.886	− 7.360	− 2.337	− 0.896

case x axis is taken to the direction of extensometer "2" and the case x axis is taken to the direction of "3" Therefore if the value of λ and μ of the rock are given, each strain can be obtained by use of these values. Under an assumption that $\lambda=\mu$ (this is natural assumption.) denoting the extension of extensometer "1" (vertical) direction, "2" (E2°N. horizontal direction. parralell to the river) direction, "3" (N2°W. horizontal direction perpendecular to the river) direction and tilt of "2" and "3" directions as $\bar{1}$, $\bar{2}$, $\bar{3}$, $\widehat{EW}$ and $\widehat{NS}$ and putting the suffixes of w on the strain caused by the water and s on the strain caused by the sand, strains are shown in following equations.

$$\left.\begin{array}{ll}\bar{1}_w=\dfrac{1.31}{\lambda}\times10^2 & \bar{1}_s=\dfrac{1.12}{\lambda}\times10^2\\ \bar{2}_w=-\dfrac{13.90}{\lambda}\times10^2 & \bar{2}_s=-\dfrac{8.85}{\lambda}\times10^2\\ \bar{3}_w=\dfrac{8.39}{\lambda}\times10^2 & \bar{3}_s=\dfrac{5.50}{\lambda}\times10^2\\ \widehat{EW}_w=-\dfrac{8.16}{\lambda}\times10^{8''} & \widehat{EW}_s=-\dfrac{5.44}{\lambda}\times10^{8''}\\ \widehat{NS}_w=\dfrac{16.32}{\lambda}\times10^{8''} & \widehat{NS}_s=\dfrac{8.88}{\lambda}\times10^{8''}\end{array}\right\}\quad(3.6)$$

As described above, it is concluded as follows by the load of the water and the sand when the dam was filled up with the water.

(i) It extended $\frac{2.43}{\lambda}\times 10^2$ to the direction of component "1" (vertical).

(ii) It compressed $\frac{22.75}{\lambda}\times 10^2$ to the direction of component "2" (E2°N, horizontal. parralell to the river).

(iii) It extended $\frac{13.89}{\lambda}\times 10^2$ to the direction of component "3" (N2°W, horizontal. perpendecular to the river).

(iv) It tilted $\frac{13.60}{\lambda}\times 10^{8''}$ to the direction of W2°S and $\frac{25.20}{\lambda}\times 10^{8''}$ to the direction of N2°W, that is it tilted $\frac{28.95}{\lambda}\times 10^{8''}$ to the direction of N32.5°W.

4. Study and examination on the observed values and the values obtained by theoretical method.

We tried to obtain each strain by use of Boussinesq's solution under various assumptions, and we could compare and examine the observed values with the values obtained by theoretical method, if the values of λ and μ on the rock are given. Both values of λ and μ can be obtained, if the velocity of elastic wave is known by seismic prospecting and by some other suitable method, but we tried to obtain the value of λ under an assumption that $\lambda=\mu$ and taking the advantage that the component "2" is not affected by the rainfall. In the Fig. 5 and Photo. 1 we can fined out that the strain increased suddenly at about 9 a.m. on 27 Sept. and it compressed as much as 22.8×10^{-8} for the period of a short time and resumed as far as 9.2×10^{-8} gradually until 12 Oct. then after that the strain increased again. This is meant that the strain increased by the load of water and sand in accordance with an increase of water then it resumed to decrease of water but the strain caused by thel oad of sand remained then afterwards another variation has come into being as the following

$$22.8\times 10^{-8}=\bar{2}_w+\bar{2}_s$$

$$9.2\times 10^{-8}=\bar{2}_s$$

That is to say

$$\frac{13.90}{\lambda}\times 10^2=13.7\times 10^{-8} \qquad (4.1)$$

$$\frac{8.85}{\lambda}\times 10^2=9.2\times 10^{-8} \qquad (4.2)$$

λ is obtained as $\lambda=1.022\times 10^{10}$ from the equation (4.1) and as $\lambda=0.973\times 10^{10}$

Table 4. The values of strain and tilting of which observed and obtained by theoretical method.

Instrument		Calculated value			Observed value
	Component	Variation of which caused by the load of water	Variation of which caused by the load of sand	Variation of which caused by the load of water and sand	Variation of which caused by the load of water and sand
Extensometer	1 (Vertical)	Extension 1.31×10^{-8}	Extension 1.12×10^{-8}	Extension 2.43×10^{-8}	Extension 4.1×10^{-8}
	2 (N88°E. Horizontal. parallel with river)	Contraction 13.90×10^{-8}	Contraction 8.85×10^{-8}	Contraction 22.75×10^{-8}	Contraction 28.8×10^{-8}
	3 (N2°W. Horizontal, parpendiculer to river)	Extension 8.39×10^{-8}	Extension 5.50×10^{-8}	Extension 13.89×10^{-8}	Contraction 81.0×10^{-8}
Tiltmeter	A (N2°W)	0.1632"	0.0888"	0.2520"	0.150"
	B (N88°E)	0.0816"	0.0544"	0.1360"	0.295"
				Direction of N32.5°W 0.2895"	Direction of N64.6°W 0.335"

from the equation (4.2). The mean of these 2 values is $\lambda=0.998\times10^{10}\fallingdotseq1.0\times10^{10}$. Each strain and tilting obtained from (3.6) applying this mean value in it and each strain and tilting observed practically are shown in Table 4. In comparision of these values, it is natural that the value observed by using extensometer "2" agrees with the value calculated theoretically as we define the value of λ to do so, but the values observed by using extensometer "1" and the tiltmeter seem to agree with the values calculated theoretically. On the contrary both values show the great difference on the direction of component "3" This is because extensometer "3" is set at the right angle to the river and also to the direction of a steep slope of the mountain. It is presumed, therefore, that the observed value show the differance with the value obtained by using Boussinesq's equation, and the rock is considered as isotropic body but it is unisotropic body in fact and values of λ, μ are not supposed to be constant value in every place on the rock. As we can find out by the dotted line of 3 in Fig. 5, this component "3" has a tendency to compress indicating a compression curve with convex upwards when it rains. On the other hand it had been compressing along the compression curve as described above at first but it has been changed discontinuously to extend about 9 A. M. on 27 Sept., as you see in Fig. 5 and photo. 1. This means that a certain kinds of extensible variation is superposed on the specific variation of strain to the direction of "3" affected by the rainfall. We can deduce that is extended by the load of water and sand in accordance with an increase of river water. This variation of strain is beyond comparision with the value obtained by theoretical method, but both of them show the extension and they seem to agree on this point of extending phenomena. Secondly on the value of λ, it is presumed to be too small judging from the structure of the rock in the vicinity, however the difference of this kind is agreeable to be admitted, as it is located at 30 m depth from the ground surface and also the rock is affected by weather.

5. Conclusion

We have been studying the results obtained by both ways, observation and theoretical method as described. We wish to study periodically the relation between the quantity of water and sand and strain, but to our regret we have not minute deta concerning the measurement on river water level and quantity of accumulated sand. Therefore we only studied and described the report for this time in case the water filled the dam. We think that we must research more and more on this subject, but anyway we could obtain the satisfactory result.

At the conclusion of this report the writer sincerely wishes to express his cordial thanks to Prof. Kenzo Sassa for his kind guidance and instruction all the time throughout this study.

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Bulletin No. 23　　Published July, 1958

昭和 33 年 7 月 10 日　印 刷
昭和 33 年 7 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