42. *Observation of the Deformation of the Earth's Surface at Aburatsubo, Miura Peninsula. Part IV.*

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Contents.

Introduction.

The writers, in the previous paper[1], have reported the outline of the observations of the deformation of the earth's surface at Aburatsubo (35°09′N, 139°37′E), near the southern extremity of the Miura Peninsula, which commenced in 1948. The main instruments used were two components of the water-tube tiltmeter, and three components of the silica-tube extensometer, the construction of which was already described in Part I of this paper. Those instruments were installed in the gallery that was bored horizontally through the sandstone of the hill side near the sea-shore in the Bay of Aburatsubo. As the first step of study, the periodic deformation of the earth's surface caused by the variation of the tidal load was investigated and discussions concerning

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[1] T. HAGIWARA, T. RIKITAKE, J. YAMADA, *Bull. Earthq. Res. Inst.*, **26** (1948), 23.

it have been reported in Part II[2] and III[3] of this paper. The main object of the observation was to obtain continuously the deformation of the earth's crust, but the accumulation of observational data was requisite for this purpose. Hence, the investigation of the secular variation was postponed to the present day.

The deformation of the earth's crust that is occurring gradually in this country in the ordinary time has been revealed by revising the precise leveling, the triangulation, and the measurement of the length of the base line. Among them, the precise leveling proved to be the most effective because of its simplicity in the field work and of its precision in the result. The analysis of the results of the precise levelings that were carried out in various regions in this country made an important contribution to geophysics by clarifying the characters of the deformation of the earth's crust. At present we can say that the precise leveling is an indispensable method for detecting the crustal deformation. The best thing would be to repeat the precise leveling constantly throughout the country but, in practice, it is impossible to do so by economical reason. For this reason, any kind of instrumental observation which would detect the crustal deformation was required. However, the observations made hitherto with the tiltmeter of horizontal pendulum type showed a too large secular change in inclination, amounting to several or several tens degrees in arc during a year. Such large amount of inclination was not seen in the results of the precise leveling except in the case where the levelings were carried out before and after the destructive earthquake. According to the revision of the precise leveling, the peninsulas on the Pacific coast of this country, such as Miura Peninsula, Izu Peninsula, Kii Peninsula, and Muroto Peninsula, were found to be inclining gradually towards south, the respective inclining speed being as follows:

Miura Pen.	Izu Pen.	Kii Pen.	Muroto Pen.
0.05″/year	0.11″/year	0.025″/year	0.051″/year

These speeds of inclination belong to the largest of the crustal deformation occuring in this country in ordinary time. Therefore, we can not believe the result that was obtained by the tiltmeter of horizontal pendulum type. The changes that were recorded by this small instrument are considered to

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2) T. HAGIWARA, T. RIKITAKE, K. KASAHARA, J. YAMADA, *Bull. Earthq. Res. Inst.*, **27** (1948), 35.

3) T. HAGIWARA, T. RIKITAKE, K. KASAHARA, J. YAMADA, *Bull. Earthq. Res. Inst.*, **27** (1948), 39.

indicate the locally limited deformations of the ground surface and not the deformation of the "earth's crust".

The success of the precise leveling must be due to the long distance put between the bench marks. Hence, if we use the water-tube tiltmeter with considerable distance between two water-reservoirs, installed at certain depth under the ground to avoid surface disturbances, such local disturbance as occurred in the case of the tiltmeter of horizontal pendulum type will be eliminated. By the same reason, the silica-tube extensometer that has sufficient length will serve as an instrument to record the crustal deformation.

In the present paper, some discussions will be made whether the secular variations that were observed with the water-tube tiltmeter and the silica-tube extensometer installed at Aburatsubo are reliable enough as an indicator of the deformation of the earth's crust or not.

1. Secular Variation of the Inclination of the Earth's Surface Observed with the Water-tube Tiltmeter.

1-a. The water-tube tiltmeter and its observational result.

The apparatus that measures the changes in inclination of the earth's surface by reading the difference of height of the water surface at both ends of a horizontal water-tube has been devised by A. A. Michelson. The same apparatus was installed in the Earthquake Research Institute about twenty years ago, but it has been out of use. Since the all-silica tiltmeter of horizontal pendulum type was invented, the water-tube tiltmeter has been regarded by the geophysicists of this country to be unuseful. However, as already stated, the experience of observation for ten years showed the tiltmeter of horizontal pendulum type to be unsuitable for observing the secular changes in inclination of the earth's surface and the water-tube tiltmeter came into use again[4].

The construction of the water-tube tiltmeter that was installed at Aburatsubo, as already reported in Part I of this paper, consists of two water-reservoirs connected by a glass-tube with 10 mm diameter. The change in inclination is obtained from the difference between the readings of both ends. The length of the water-tube is respectively 25m for S 22°E* component and 10m for E 9°S** component. As to the reading device, a micrometer with a sharp platinum point was used and the moment at which the point touches the water-surface

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[4] T. HAGIWARA, *Bull. Earthq. Res. Inst.*, **25** (1947), 27.

* For the brevity, we call it N'S'-component.

** For the brevity, we call it E'W'-component.

was detected electrically with a glim-lamp. Remote controlling system was also employed by means of the self-synchronous motors. However, after several months since the beginning of the observation, the platinum point of the micrometer was found to be spoiled remarkably notwithstanding the previous test done in the laboratory. Therefore, the reading device was entirely converted as shown in Fig. 1., in which R is the reservoir made of gun metal (the inside is lacquered), M the micrometer made of stainless steel, and T the water-tube. The contact of the sharp point of the micrometer-spindle to the water surface is discriminated by an ordinary microscope. The observation with this new reading device was commenced from October in 1949. The observation with the old one was abandoned because the reading was considered to be unreliable. The reading of the instrument was done twice a day, namely, at 8h and 16h. To investigate the secular change, the monthly mean was made with respect to the reading of 8h and 16h respectively and they were plotted on the upper part of Fig. 2. In the Figure, the full line and the broken line represent the monthly mean for observation at 8h and 16h respectively. (Since N′S′-component is not affected by the tidal load, both readings of 8h and 16h of that component in the same day are almost equal. So that monthly means for N′S′-component are entirely equal with respect to both observations at 8h and 16h.) For the sake of comparison, the ordinary monthly mean of the sea level[5], the monthly mean of the sea level at 8h on successive days, and the same for 16h, the monthly mean of air temperature in the gallery, and the monthly sum of the precipitation were plotted.

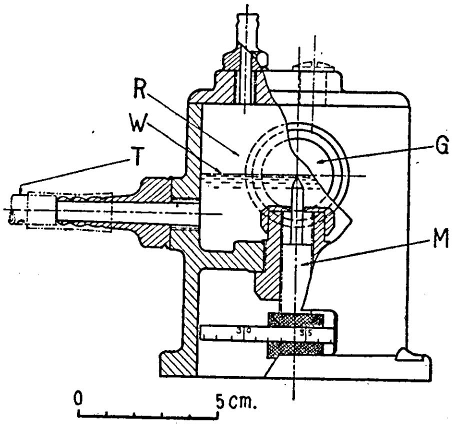

Fig. 1. R: Water reservoir, W: Water surface, G: Glass window, T: Glass-tube, M: Micrometer.

The observation in the present case is not affected by the precipitation as was seen in the tilt observation at Mt. Tsukuba[6] and other places. Underground water does not ooze out into the gallery even in the case of heavy

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[5] Data of the level are due to the mareographic observation at Aburatsubo equipped by the Geographycal Survey Bureau.

[6] T. HAGIWARA, *loc. cit.*.

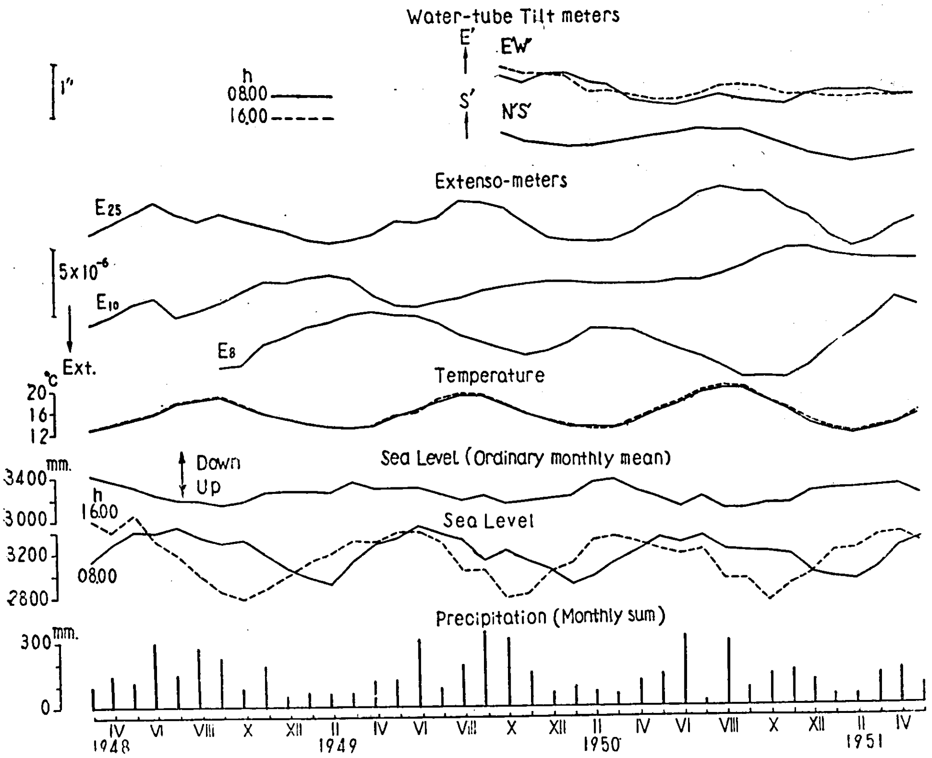

Fig. 2. From upside: E'W' component of tilt, N'S' component of tilt, E_{25}=N22°E component of linear strain (25 m length), E_{10}=E9°S component of linear strain (10 m length), E_8=N25°W component of linear strain (8m length), Air temperature in the gallery, Ordinary monthly mean sea level (measured from the fixed B.M. on the land: Ascending curve means subsidence of sea level), Sea level at 8h and 16h, monthly sum of precipitation.

rain. This seems to be the main reason why the effect of the precipitation does not appear.

1-b. Eliminating the effect of the tidal load.

When we investigate the secular variation of the observational result of the water-tube tiltmeter, it is necessary to eliminate the changes due to the variation in the sea level, because the tilting of the ground is caused by the load of sea water near the observation point. In the present case, the E'W'-component of the tiltmeters is greatly affected by the change in sea level, while it is not so with the N'S'-component-

To determine the amount of change in inclination caused by the change in sea level, we obtained $\delta W.T.$ and $\delta S.L.$; where $\delta W.T.$ is the difference of the inclination measured with the water-tube tiltmeter at 8h and 16h, and $\delta S.L.$ is the difference of the sea level at 8h and 16h of each day. Then, we calculated the monthly means of $\delta W.T.$ and $\delta S.L.$. These monthly means are denoted by $\Delta W.T.$ and $\Delta S.L.$ respectively. Taking $\Delta W.T.$ as ordinate and $\Delta S.L.$ for abscissa, the corresponding points were plotted, as shown in Fig. 3. As will be seen from the Figure, $\Delta W.T.$ and $\Delta S.L.$ are in proportional relation. The proportional coefficient that was decided by the least square method is

for E′W′–component 0.54″/m (E′ downwards when sea level rises),
for N′S′–component 0.04″/m (S′ downwards when sea level rises).

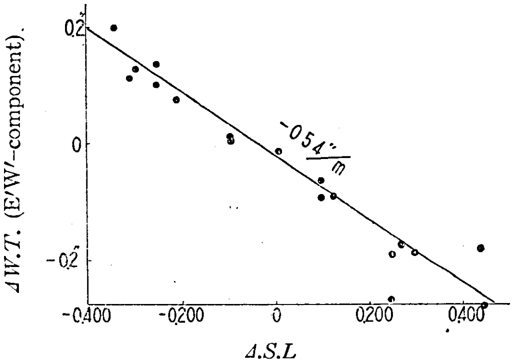

Fig. 3.

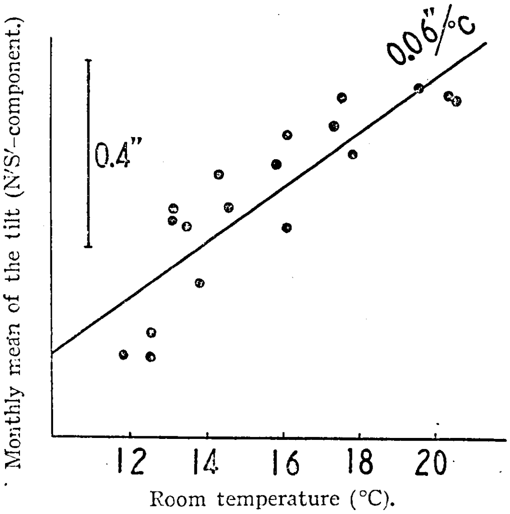

Fig. 4.

Each monthly mean of the measurement was corrected so as to fit the case of a constant sea level by means of this relation.

1–c. Eliminating the effect of the temperature.

The monthly mean of the N′S′–component of the water-tube tiltmeter from which the effect of the change in sea level has already been eliminated by the method just mentioned shows a remarkable annual variation. This variation is entirely parallel to the variation of the air temperature in the gallery. Hence, if we plot the values taking the monthly mean of the tilting as ordinate and the monthly mean of the temperature for abscissa, we obtain a straight line that is shown in Fig. 4. The proportional coefficient between the tilting and the temperature that was determined by the least square method is as follows.

N′S′–component 0.06″/°C (S′ downwards when the temperature increases)
E′W′–component 0

The reason why the N′S′-component alone is affected by the air temperature seems to be traceable to the thermal expansion of the concrete block on which the water reservoir of the water-tube tiltmeter is settled. The height of the two concrete blocks on which the reservoirs are set are entirely equal in the case of E′W′-component, while, there is a difference amounting to 35 cm in the height from the ground surface in the case of N′S′-component. If the thermal coefficient of linear expansion of the concrete were taken to be $1.4\times10^{-5}/°\mathrm{C}$, the value written in ordinary handbooks, the apparent change in inclination due to the expansion of the concrete block corresponds to 0.04″/°C (S′ down when the temperature increases). Both values, the actual and the calculated, are considered to coincide well.

Next, we will examine how the temperature of the concrete follows the air temperature surrounding it. To simplify the mathematical calculation, we consider an endless long cylinder with radius a. When the temperature of the outside of the cylinder varies as $b\cos nt$, the temperature T of the inside of the cylinder is given by

$$T(r)=\frac{\mathrm{ber}\sqrt{\frac{n}{k^2}}r\,\mathrm{ber}\sqrt{\frac{n}{k^2}}a+\mathrm{bei}\sqrt{\frac{n}{k^2}}r\,\mathrm{bei}\sqrt{\frac{n}{k^2}}a}{\left(\mathrm{ber}\sqrt{\frac{n}{k^2}}a\right)^2+\left(\mathrm{bei}\sqrt{\frac{n}{k^2}}a\right)^2}\,b\cos nt$$

$$+\frac{\mathrm{ber}\sqrt{\frac{n}{k^2}}r\,\mathrm{bei}\sqrt{\frac{n}{k^2}}a-\mathrm{bei}\sqrt{\frac{n}{k^2}}r\,\mathrm{ber}\sqrt{\frac{n}{k^2}}a}{\left(\mathrm{ber}\sqrt{\frac{n}{k^2}}a\right)^2+\left(\mathrm{bei}\sqrt{\frac{n}{k^2}}a\right)^2}\,b\sin nt,$$

where r is the distance from the central axis of the cylinder, a the radius of the cylinder, and k^2 the thermometric conductivity.

In the present case, the concrete block is a square column with a side of 20 cm. If we replace it by a cylinder with diameter of approximately 20 cm, the temperature and its phase-lag at the center of the cylinder are calculated by the above formula, as shown in Fig. 5. As seen in the Figure, when the air temperature varies slowly with a period

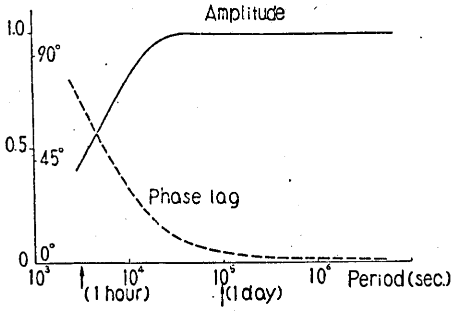

Fig. 5. Ordinate: the ratio and the phase difference of the temperature at the center of cylinder and that at the outside of cylinder.
Abscissa: period of the changes in temperature.

longer than one day, the temperature of the concrete block falls in with the air temperature surrounding it. Hence, we may be able to correct exactly the effect of the expansion of the concrete by using the air temperature in the gallery itself when we deal with the slow changes.

By the above-mentioned reason, each monthly mean of N′S′-component was corrected by subtracting the corresponding monthly mean value of the air temperature in the gallery producted by the coefficient $0.06''/{}^\circ\mathrm{C}$.

1-d. Secular variation of the inclination of the earth's surface.

Each monthly mean in which the effect of the variation in tidal load and of the variation in air temperature were eliminated is shown graphically in Fig. 10.

1-e. Some considerations on the results.

The leveling route is running along the west coast of the Miura Peninsula, branching off from the Tokaido highway to the fixed bench mark at the mareographic station at Aburatsubo equipped by the Geographical Survey Bureau (Fig. 6). The revisions of the leveling on this route were frequently made after the Kanto Great Earthquake, 1923, in order to check the height of the geodetic origin placed in Tokyo. The changes in height of the bench marks

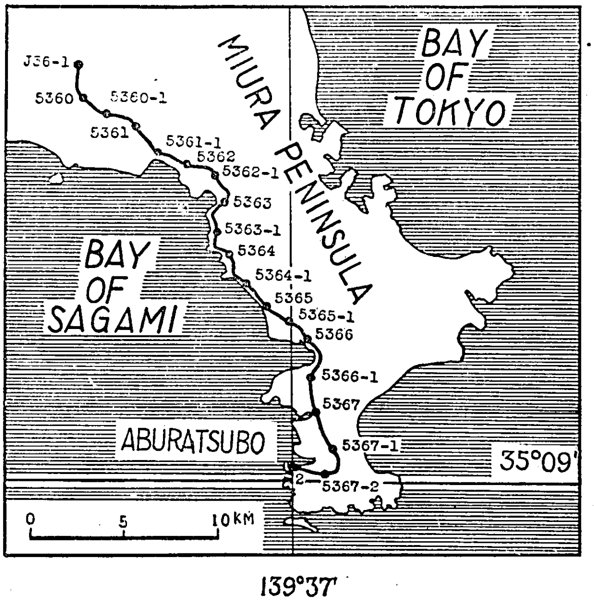

Fig. 6. Leveling route in Miura Peninsula.

in the peninsula that were made clear by the revisions of the precise leveling are shown in Fig. 7, in which the changes in height of the bench marks with respect to B.M. J-36-1 (Fujisawa) were plotted, assuming the change of each bench mark to be zero in 1925. As already pointed out by Y. Harada⁷⁾, the peninsula is inclining constantly as one block, having undulatory motions with smaller wave length on it.

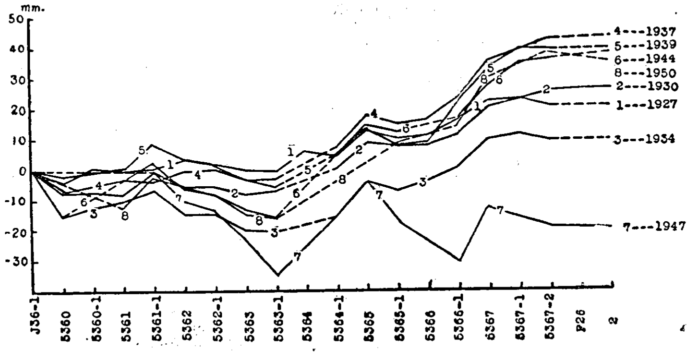

Fig. 7. Changes in height of B.M. in Miura Pen. with respect to B.M. J36-1 (Changes in 1925 were taken to be zero).

Since our observational station is placed in the neighbourhood of the southern extremity of this leveling route, the results of the tilt observation shall be compared with the changes in height of the bench marks such as B.M. 5367, 5367-1, 5367-2 and 2. As will be seen in Fig. 7, the difference in height between 2 and 5367-2, which is on a line of E.W. direction, remains constant always, so that this region seems to make an inclinational motion approximately towards north and south direction. The changes of the difference of height between B.M. J-36-1 and 2 and the changes of the same kind between B.M. 5367 and B.M. 5367-2 were plotted in Fig. 8. The scale drawn in the right-hand side of the Figure is the corresponding value of inclination angle between two bench marks. As will be seen in

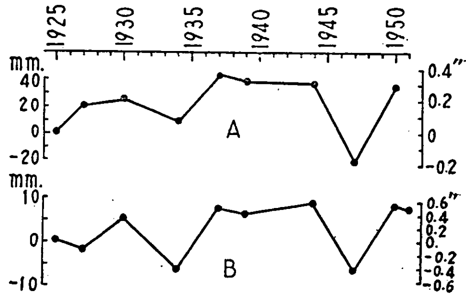

Fig. 8. A: Change in height of B.M. 2 with respect to B.M. J36-1,
B: Change in height of B.M. 5367-2 with respect to B.M. 5367.

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7) Y. HARADA, *Journ. Seism. Soc. Japan* (in Japanese), II Ser., **1** (1948), 52, and **2** (1948), 17.

the Figure, the two curves, the upper and the lower, are very similar to each other except the period just after the Kanto Great Earthquake. Therefore, it can be said that the local movement of the region on which B.M. 5367 and B.M. 5367–2 are placed is related intimately to the movement of the peninsula as one body.

We are to compare the observational results of the water-tube tiltmeter with the changes in inclination between B.M. 5367 and 5367–2 determined by the revision of the precise leveling. The revision of the precise leveling along the route in the peninsula was made only once on Feb., 1950 after our observation of tilt was commenced. Hence, in order to check our observational result, we carried out newly the revision of the precise leveling against B.M. 5367, 5367–1, 5367–2, F–26, and 2 on May, 1951. The result of the leveling is shown in the following Table.

Table I.

B.M.	1950 (Feb.)	1951 (June)	h	h
5367	m	m	mm	mm 0.0
	+74.5438	+74.5432	−0.6	
5367–1				−0.6
	− 6.3382	− 6.3391	−0.9	
5367–2				−1.5
	−53.9948	−53.9942	+0.6	
F–26				−0.9
	−11.9591	−11.9595	−0.4	
2				−1.3
	− 1.6178	− 1.6141	+3.7	
Mareograph				+2.4

As will be seen in the Table, the changes in height of the bench marks are very small in the interval between Feb., 1950 and June, 1951. The observational results of the water-tube tiltmeter show very small inclination in this interval too.

A thorough examination of the observational results, needless to say, can be conducted only after further observation and more numbers of the revision of precise leveling has been made. The writers are planning to revise the precise leveling on that region whenever a large inclination is detected by the water-tube tiltmeter.

2. Secular Variation of the Linear Strain of the Earth's Surface Observed with the Silica-tube Extensometer.

2–a. The silica-tube extensometer and its observational results.

The observation of the silica-tube extensometers in three directions was carried on in parallel with the measurement of the water-tube tiltmeters. The construction of the instruments has been already reported in Part I of this paper. Elements of each component are shown in Table II.

Table II.

Name of component	Length	Direction	Extension corresponding to 1 cm on the record.	Commencement of observation
E_{25}	25m	N22°E	1.3×10^{-6}	III, 1948
E_{10}	10m	N81°W	3.3×10^{-6}	III, 1948
E_8	8m	N25°W	3.5×10^{-6}	IX, 1948

The hourly values were read off from the record of the extensometer, and adding together these values, the daily mean values were obtained. And from these the monthly mean values were obtained. These monthly means are shown graphically in Fig. 2.

2-b. Eliminating the effect of the temperature on the silica-tube.

Since the silica-tube has the thermal expansion coefficient of $0.42\times10^{-6}/°C$, the values of observation were reduced to the state of same temperature (10°C).

2-c. Eliminating the effect of the tidal load.

As reported in Part II and III, the earth's surface extends and contracts owing to the variation of the load of sea water. Hence, this effect shall be eliminated when the secular variations of extension of the earth's surface are investigated. As to the extension of the earth's surface due to the load of M_2-tide has been reported in Part II of this paper. According to it, the extension caused by the rise of sea level was

$$E_{25}: 0.7\times10^{-7}/m, \quad E_{10}: 14.4\times10^{-7}/m, \quad E_8: 9.4\times10^{-7}/m.$$

Assuming these proportional coefficients to be available for the variation of a long period, the effect of sea level were eliminated from the monthly means of the observation.

The monthly means of the variation of extension of the ground in which the correction of the thermal expansion of the silica-tube and the variation of

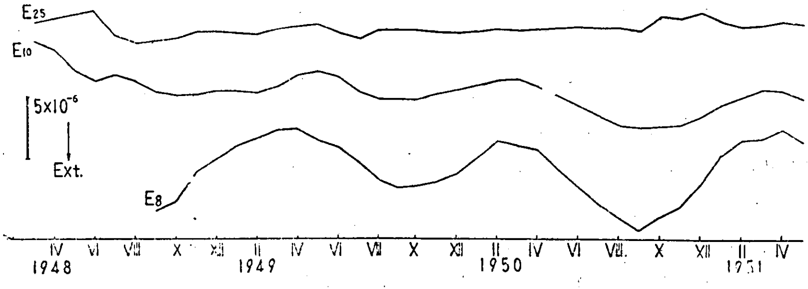

Fig. 9, Monthly mean of linear strains (Thermal expansion of silica-tube and effect of tidal load eliminated).

sea level were made are plotted in Fig. 9.

2-d. Eliminating the annual variation.

The curves shown in Fig. 9 show the remarkable change with annual period. The periodic term was taken out from the two curves, of the strain and of the temperature, by the least square method, assuming the variation to be composed of three terms, that is, the term varying linearly with time, the pure periodic term with the period of one year, and the irregular ones. The result is as follows.

E_{25}	E_{10}	E_8
0	$11.1\times10^{-7}\cos\left(360^\circ\times\frac{n}{12}-240^\circ\right)$	$24.3\times10^{-7}\cos\left(360^\circ\times\frac{n}{12}-240^\circ\right)$

Temperature

$$3.7^\circ\times\cos\left(360^\circ\times\frac{n}{12}-210^\circ\right)$$

in which n is the number of month, taking $n=0$ for January. The phase angle of the periodic term of the strain does not coincide with that of the air temperature in the gallery but differs by 30°. Since the phase of annual variation of the air temperature in the gallery is equal to that of the air temperature outside of the gallery, we can not decide which temperature causes the annual variation of linear strain of the ground.

Although the mechanism in which the air temperature affects the linear strain of the ground is not evident from the present data, we are able to obtain the desired secular variation by subtracting the pure periodic term from the curves shown in Fig. 9.

2-e. Secular variation of the linear strain in the earth's surface.

The final results in which the term of annual variation was eliminated by the method just mentioned are shown Fig. 10.

The shear with respect to x-y axes and x'-y' axes in which x and x' are taken in the north direction and the north-west direction in horizontal plane respectively, the maximum shear, and the surface dilatation (change of area) were also plotted in Fig. 11. These values were calculated from the three components of the linear strain by the formulae shown in (4) and (5) in Part II of this paper.

To examine the observational results of the extensometers, there are no data as in the case of the tilt observation. Only one way to check the order of variation is to compare our results with the measurements of the base lines

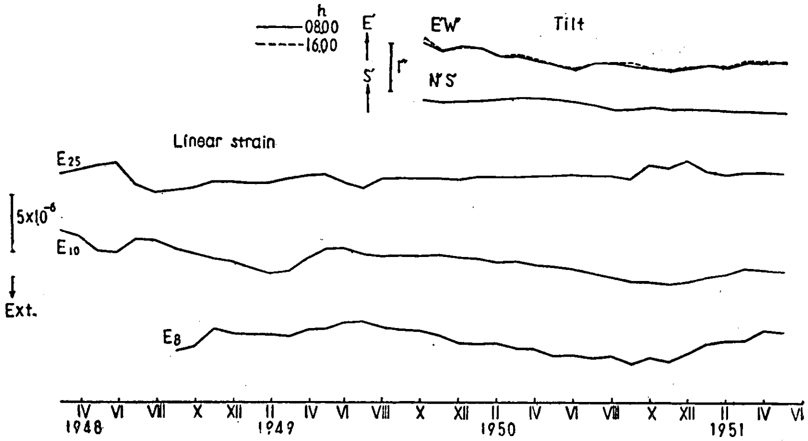

Fig. 10. Corrected monthly mean values of change in inclination and linear strains of the earth's surface.

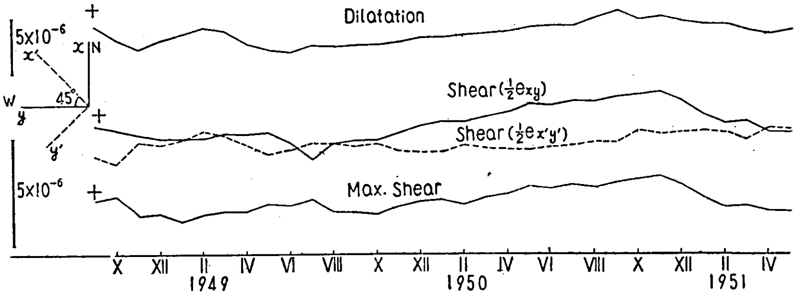

Fig. 11. Dilatation and shears calculated from linear strains of the earth's surface.

at Mitaka, in the west of Tokyo. There are base lines of rhombus shape in the compound of the Tokyo Astronomical Observatory at Mitaka. The length of these base lines have been occasionally measured by experts of the Geographical Servey Bureau since 1916, but unfortunately the revision of the measurement has not yet been carried out since our observation began. However, the results of the measurements in the past shows that the length of the base lines did not remain constant but underwent certain changes, the amount of which is ordinarily in the order of 10^{-6} in a year. This value is of the order of the linear strain observed by our instruments.

In conclusion, the writers wish to express their cordial thanks to Mr. A. Okada who assisted us in the work of the precise leveling.

A part of the expenses of this study was defrayed from the Scientific Research Expenditure of the Department of Education.

42.　油壺における地殼變動の觀測（第4報）

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油壺において行つている地殼變動の觀測の主なものは，水管傾斜計2成分，水晶管土地伸縮計3成分であるが，今回はその觀測結果につき，經年變化を調べてみた。

1.　水管傾斜計により觀測された土地傾斜の永久變化

1-a　この報告の第1報に記載されている水管傾斜計の電氣式讀取裝置は，長い間に白金先端が侵蝕されるので，顯微鏡で直接讀取る方式に改めた。觀測は毎日2回，即ち 8h と 16h に行われている。その各の讀取値につき月平均を求めた。月平均値の變化は第2圖に示してある（實線は 8h 讀取値の月平均，破線は 16h の讀取値の月平均）。

1-b　觀測點附近の海水の荷重變化により傾斜變化が起るので，驗潮儀から知られた海水位の値を使つて，傾斜變化の月平均値を補正し，一定海水位の場合に直した。

1-c　傾斜 N'-S' 成分の年變化は，觀測壕内の溫度の年變化と，非常に良く似た變化をしている。これは水管傾斜計の兩端のコンクリート柱の地表面からの高さに 35cm の差があるため，コンクリート柱の熱膨脹により見かけの傾斜變化が現れるものと解釋された。從つて，壕內溫度の月平均値を用いて，N'-S' 成分の傾斜變化月平均値を補正し，一定溫度の場合に直した。

1-d　以上の補正を施した傾斜變化月平均値は第 10 圖に示してある。

1-e　傾斜の經年變化は，現在の觀測期間においては，非常に小さい。この期間に行われた2回の水準測量結果から附近の水準點の變動を求めてみると同じく變動が非常に小さいことが確められた。將來もし土地傾斜に大きな經年變化が示された場合は，直ちに附近の水準點の改測を行い觀測結果と比較する計畫である。

2.　水晶管伸縮計により觀測された土地伸縮の經年變化

2-a　水晶管伸縮計は，感光紙を使つた連續觀測であるので，記錄紙より毎時の變化を讀取り，先づ日平均値を求め，さらにこれを加えて月平均値を作つた。月平均の生の値は第2圖に示してある。

2-b　水晶管は $0.42\times10^{-7}/^{\circ}\mathrm{C}$ の線膨脹係數を持つているので，伸縮月平均に補正を加えて壕內氣溫が一定の場合の値に直した。

2-c　傾斜變化と同じく，土地伸縮も海水荷重に影響されるので，これに關する補正を行い，伸縮月平均値を一定海水位の場合の値に直した。この補正には，前報告において M_2 潮につき求めた海水位變化と土地伸縮との比例關係が長周期變動にも適用できると假定した。

2-d　以上の補正を施した伸縮變化は第9圖に示す通りであるが，これには著しい年周變化が見られるのである。伸縮變化及び壕內氣溫の年變化から，それぞれ最小自乘法によつて年周期の項を取出して見ると，兩者の位相に相當の差が見られる。現在のところ如何なる機構で氣溫變化が土地伸縮を起しているか分からない。そこで差當つて，三年間の材料の解析によつて定められた伸縮の年周變化の項を差引いて經年變化を求めることとした。

以上の三種の補正を加えた伸縮經年變化は第 10 圖に示す通りである。

2-e　伸縮3成分の經年變化から土地の shear, maximum shear, dilatation 等の經年變化も計算した。Dilatation（面積變化）の經年變化のオーダーは三應ロンバスの測量から求められた値に一致している。