48. *A New Extensometer for Measuring Crustal Deformation.*

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1. In November, 1915, the Imperial Japanese Geodetic Commission specially constructed five base-lines in the ground of the Tokyo Astronomical Observatory at Mitaka, near Tôkyô, for the express purpose of obtaining geophysical data. The base-lines are all 100 m long, forming the four sides and the diagonal of a rhombus. These base-lines were first measured in May of the following year, since when 19 measurements have been made, and every time with a mean error of less than 0·05 mm. The results of these measurements are contained in the reports issued by the Japanese Land Survey.

It is well known that in the case of the great Kwantô earthquake, remarkable crustal deformations took place throughout the Kwantô district. This earthquake also caused remarkable changes in the lengths of the rhombic base-lines at Mitaka. The maximum change was found in the diagonal of the rhombus, which amounted to as much as 3·6 mm. Ch. Tsuboi[1], on calculating the change in the area of the rhombus, found it to be of the same order and sense as the areal change in the same locality as deduced from the results of the post-seismic triangulation survey. As Tsuboi has pointed out, this fact may be regarded as demonstrating that the change of the base-lines is the result of general crustal deformation and not that of mere displacement of the terminal marks of the base-lines through earthquake vibrations.

In recent years, a number of investigators in various places have observed certain peculiar variations in the intensity of the earth current taking place a few hours before the occurrence of an earthquake as well as during it. Such observations are getting so frequent as to give support to belief in the existence of these variations, although their nature is still unknown. They seem to indicate that

1) *Proc. Imp. Acad.*, 6 (1930), 367.

something happens to the earth's crust just before the occurrence of an earthquake. The writer thinks that the most natural explanation of this change in the earth current is the variation in the electric conductivity of the soil, which could easily be caused by the slightest deformation of the soil, from which it would seem possible to observe a deformation of the earth's crust before an earthquake occurs.

In these circumstances, it is very desirable to maintain continuous observations of the length of a base-line in some region that is subject to frequent earthquakes. Professor A. Tanakadate was the first to advocate such observations, which he did as far back as in 1910. His advocation was realized for the first time in 1915 with the construction of the rhombic base-line at Mitaka, and for the second time in 1929, when, with the establishment of a branch station of this Institute at Komaba, a western suburb of Tôkyô, it was arranged that continuous base-line observation as recommended by Tanakadate should constitute one of the duties of this station.

2. In order to reduce to the minimum the effects of atmospheric temperature variation and those arising from any heterogeneity of the soil that may exist near the surface, the whole apparatus was installed in a straight trench about 27m long and of the section shown in Fig. 1 *a*.

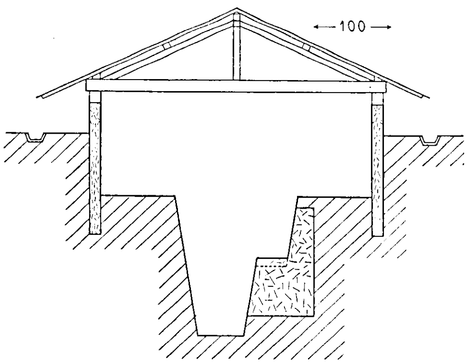

Fig. 1 *a*.

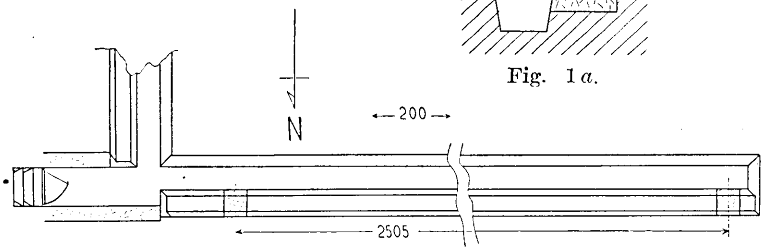

Fig. 1 *b*.

Two such trenches, both of the same construction lie in directions due N-S and due E-W, joined together in the form of the letter L.

They are to contain respectively the NS- and EW-component apparatus of the soil extensometer. The trenches, which are in a natural layer of the so-called Kwantô loam, are not lined with any material, for fear of its interference with crustal deformation or of undesirable deformations likely to be generated by the lining material itself. The apparatus was installed on a shelf on the north wall of the trench. Two concrete blocks, 60 cm thick and of the shape shown in Fig. 1 *a*, were embedded in the wall of the trench in the position shown in Fig. 1 *b*, a distance of 2505 cm separating the two. The shelf on the concrete block is 10 cm higher than the shelf on the trench wall. To reduce to the minimum the effect of any inclination of these concrete blocks, the block was so shaped that the measuring apparatus lies in their centres. The central line of the apparatus is situated 1·6 m beneath the ground surface. The trenches are protected by a wooden roof supported on concrete walls. These concrete walls have breaks in them every 3 meters to allow the soil to perform its deformations unhampered. For the same reason, the roof is only connected loosely to the concrete wall. The trenches are provided with electric lamps, sewer pipes, pulley blocks and various other equipments necessary in the installation of the apparatus.

3. The principle of the observation is essentially that of comparing the distance between the two concrete blocks with an etalon of nearly equal length. The etalon, which is a circular tube of fused silica, floats on water contained in a cast-iron vessel in order to avoid various troubles, such as indeterminate flexure which might result from the finite number of supports. If one end of the silica etalon were rigidly fixed to one of the concrete blocks, the other end of the etalon will describe, relatively to the other concrete block, a differential dilatation of the soil and of the silica etalon, which is recorded by an optical lever device on photographic paper. The apparatus consists therefore of three main parts; (1) that part including the optical lever and the recording device, (2) that part holding the end of the etalon, and (3) the cast-iron conduit containing water and the etalon that floats on it.

The first part of the apparatus is shown in Fig. 2. A is the silica etalon, of which a detailed description will be given later. B is a scale, graduated on platinum film spattered on a plane quartz plate fixed horizontally to the etalon. It is graduated to 0·1 mm and for a length of 10 mm. The etalon has a ring at each end which engages with the hook, C, cut to form from an invar block. D is another invar piece, which is forced to the right-hand side of the figure by a pin, H, and a lever G, which in turn is forced by spring, F. Between C and D, is a very flexible diaphragm, E, made of thin nickeled copper plate, which serves to hold the invar pieces in position and at the same time allow them to move with the etalon end. The water in the conduit is intercepted at this diaphragm. The right end of piece, D, is a highly polished plane perpendicular to the centre-line of the apparatus.

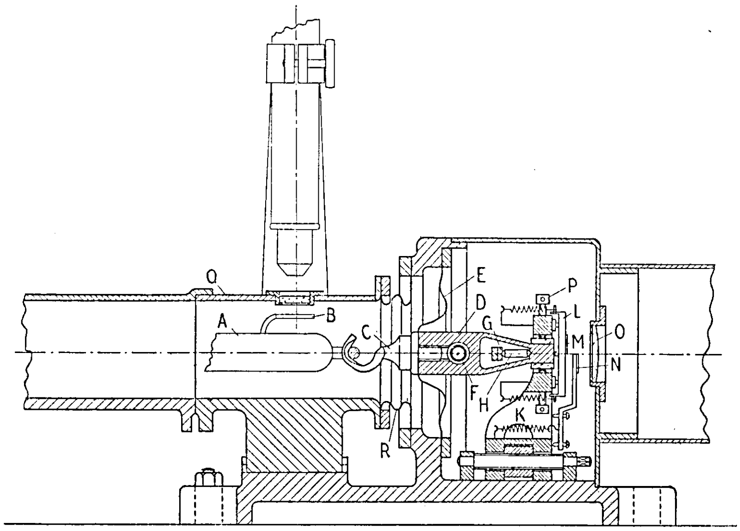

Fig. 2.

The optical lever, L, rests on this polished plane and two small steel pieces attached to the front surface of stand K. These two steel pieces have respectively a slot and a hole to act as a geometric constraint to the optical lever. The three legs of the optical lever have rounded tips, while the arm is 2·00 mm long. A plane mirror is provided on the front surface. Stand K is movable in a longitudinal direction to permit setting of the optical lever in the correct direction. In the upper part of stand K are provided 6 set-screws, P, to prevent any movement of piece, D, that is not longitudinal. The ends of these screws are rounded and just in contact with the agate collar fixed to D. There is also an adjustable plane mirror, N, in front of stand K, which serves to produce the datum-line on the record. Lens, O, which is placed in front of the mirrors, M, N, has a focal length of 100 cm. The magnification coefficient of the optical lever is therefore just 1000. There is nothing new with regard to the recording system. The light source is a small electric lamp having a straight vertical filament. The time-marks are made by opening the circuit of this lamp at 6 h and 18 h by clock work.

By means of a tender expansion-joint, *R*, the conduit tube, *Q*, can move independently of this part of the apparatus, which is fixed firmly to one of the concrete blocks with four anchor-bolts.

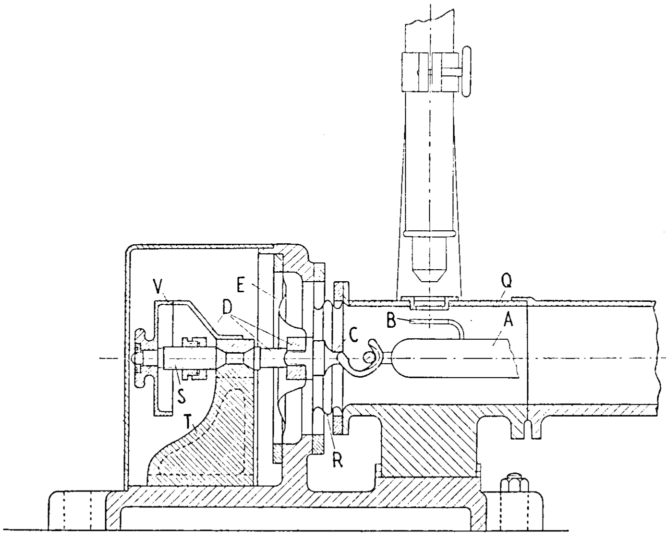

Fig. 3.

The second part of the apparatus is shown in Fig. 3. Externally it is almost similar to the first part just described. *A* is the silica etalon with a scale, *B*, and a ring that engages with invar hook, *C*, as before. *A*, *B*, and *C* are similar in shape and size to the corresponding letters in the first part of the apparatus. The invar piece, *D*, which has the shape shown in the figure, engages with the micrometer screw, *S*. Between *C* and *D* is a thin copper diaphragm just as in the first part. The screw, *S*, is held by the stand, *T*, which is fixed to the base of the apparatus. The screw has at its end a graduated drum *V* with 100 divisions, and since the pitch of the screw is 1 mm, one division of the drum corresponds to 1 μ. This micrometer equipment serves for occasionally adjusting the position of the light spot on the photographic paper, and at the same time for measuring the secular or long period dilatation of the soil.

Just above the scales, *B*, at either end of the silica etalon (Fig. 2 and 3), are provided two microscopes, each fitted with an eye-piece micrometer and firmly fixed to each of the base-plates of the two apparatus. By means of these microscopes it is possible to compare the length between the concrete blocks with that of the silica etalon at any time, the result being the value of the dilatation of the soil entirely free from errors arising from the mechanism for continuous recording.

The third part of the apparatus consists of the cast-iron conduit and the silica etalon. The conduit in turn consists of short iron castings, each 1 m long, of section shown in Fig. 4, and bolted together

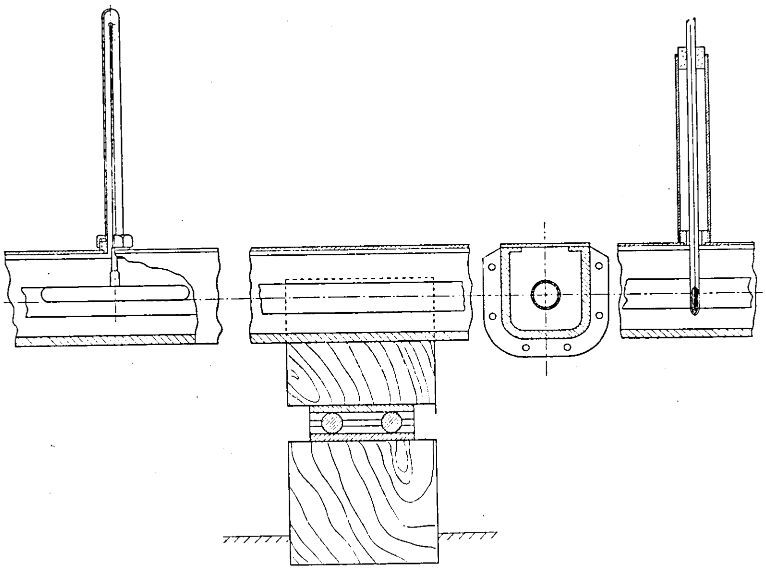

Fig. 4.

at the end flanges. Each casting rests on its centre on a wooden block, which is movable by means of a roller bearing on another wooden block. Since the conduit has at both of its ends tender expansion joints, *R*, the whole can translate, expand, or contract quite independently of the soil and parts of the apparatus.

The silica etalon is a circular tube closed at both ends, 2485 cm long, 16 mm inner and 20 mm outer diameter. Except for a length of 15 cm at each end, where transparent silica is used to increase its strength, it is made of opaque silica. The etalon was made of tubes of 1 m length supplied by the Thermal Syndicate, England. To connect them in a perfectly straight line, Y-stands were laid out in an accurate straight line and leveled by means of a theodolite, the distance between two consecutive Y-stands being 30～50 cm. The silica tubes were placed on these stands and then joined together by an oxy-hydrogen flame while being rotated slowly by hand. The joining work, which required considerable skill, was satisfactorily executed by Mr. U. Nakamura of our Institute. The etalon thus constructed floats on water, showing about 2/5 of its diameter above the water surface. A float water gauge and 3 thermometers to show the quantity and the temperature of the water in the conduit are attached to the conduit in the manner shown in Fig. 4.

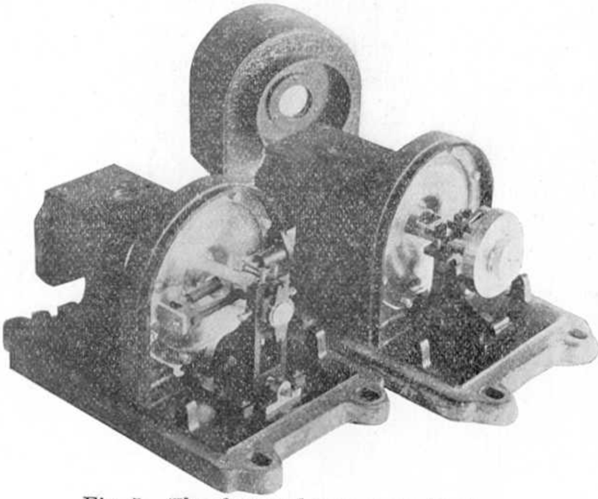

Fig. 5. The first and second parts of the apparatus, microscopes removed

4. The installation of the EW-component of the apparatus was completed in June this year. To our regret, however, installation of the NS-component is not possible at present through lack of funds. Regular observation began on June 23. Fig. 7 is a reproduction of records obtained by the present instrument. Fig. 8 shows the relation between the observed dilatation of the soil and the air temperature recorded by a Richard thermograph installed in the trench. The thick curve in the figure represents the dilatation of the soil, the scale of which is given to the right of the figure, while the

Fig. 6. The silica etalon in course of construction.

thin curve indicates the air temperature. As may be seen from this figure, the observed dilatation is almost similar in form to the air temperature variation, except that the latter advances in phase by some 2·5 h before the former. Further inspection will show that the soil

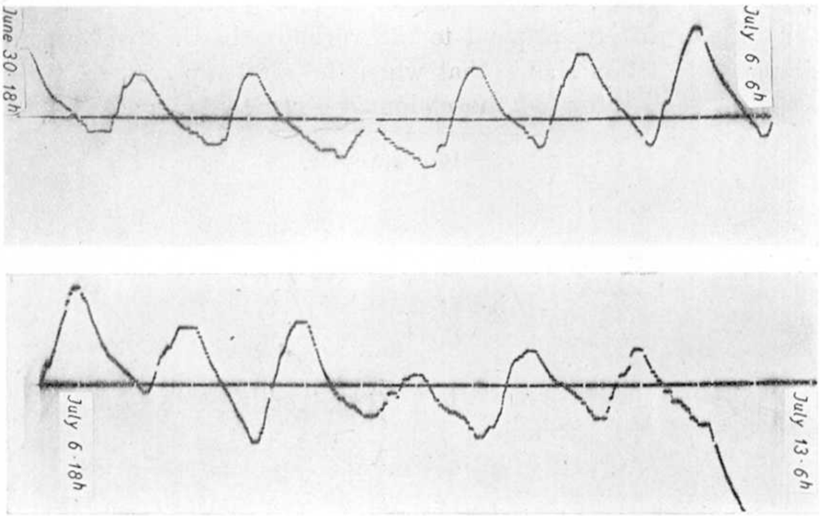

Fig. 7. Reproduction of records obtained by the apparatus.

appears to contract by 6·6 μ for every 1° C rise of air temperature. This gives as the apparent expansion cofficient of the soil a negative value of $-2{\cdot}6\times10^{-7}$.

It is obvious that this apparent expansion is in reality the true expansion of the soil minus the change in length of the silica etalon. To study the dilatation of the soil, it is therefore indispensable to know

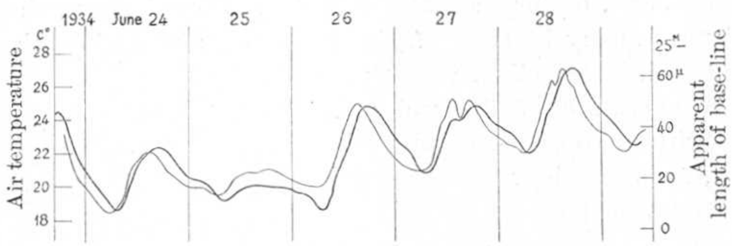

Fig. 8.

the expansion coefficient of the silica etalon as well as the temperature of it, toget.er with changes in length of the etalon that might result from various other causes. We accordingly measured, by means of the interferometric method, the expansion coefficient of the silica tube that was used in making the etalon, and obtained the value of $4{\cdot}75\times10^{-7}$ c.g.s. for the temperature interval 24°6∼99°7 C, which we have adopted as the expansion coefficient of the etalon.

The silica etalon, owing to its being placed in the conduit pipe, does not immediately respond to the variation in the air temperature. A simple calculation shows that when the air tempearature varies as $A\cos\lambda t$, the temperature of the etalon is given by

$$u=A\Phi\cos(\lambda t-\delta),$$

where

$$\Phi=\frac{1}{\sqrt{\mathrm{ber}^2\sqrt{\frac{\lambda}{\beta}}a+\mathrm{bei}^2\sqrt{\frac{\lambda}{\beta}}a}},$$

$$\delta=\arctan\frac{\mathrm{bei}\sqrt{\frac{\lambda}{\beta}}a}{\mathrm{ber}\sqrt{\frac{\lambda}{\beta}}a},$$

and $\beta=k_m/c_m\rho_m$ or the mean diffusivity, if we were to replace the conduit, water, and the etalon with a homogeneous circular cylinder of radius a and of thermal diffusivity equivalent to the real heterogeneous system. Inserting the numerical data, the above expression gives

$$\Phi=0{\cdot}95,\quad \delta=25^\circ 7\quad \text{or}\quad \frac{\delta}{\lambda}=1{\cdot}7\,\text{h}$$

for $\lambda=0{\cdot}7\times10^{-4}$, or for the daily variation. Since however these values are not trustworthy because of the numerous assumptions that had to be made in their deduction, we took records of the temperature of the water in the conduit with a constantan-copper thermo-junction, from which we deduced Φ and δ for the etalon to be

$$\Phi=0{\cdot}85,\qquad \delta/\lambda=3{\cdot}0\,\text{h}.$$

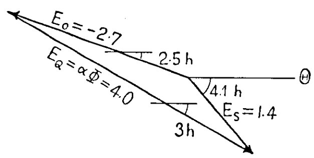

Fig. 9.

Now if we denote the daily variation of air temperature by $\theta=Ae^{i\lambda t}$, the temperature of the etalon would be $\Phi\theta e^{-i\delta}$ or $A\Phi e^{i(\lambda t-\delta)}$, so that its length is expressed by

$$L = L_0(1 + \alpha\Phi\theta e^{-i\delta}).$$

On the other hand the observed dilatation of the soil is

$$\Delta L = D_0 e^{-i\delta_0} = E_0 \theta L_0 e^{-i\delta_0},$$

whence the true dilatation is

$$E_0 \theta L_0 e^{-i\delta_0} + \alpha\Phi\theta L_0 e^{-i\delta} = E_s \theta L_0 e^{-i\delta_s},$$

that is

$$E_0 e^{-i\delta_0} + \alpha\Phi e^{-i\delta} = E_s e^{-i\delta_s}.$$

This relation will be clearly seen from the vector diagram Fig. 9, from which we obtain as the true expansion of the soil

$$E_s = 1{\cdot}4 \times 10^{-7}; \qquad \delta_s = 4{\cdot}1 \text{ h}.$$

5. We shall now examine the question of the extent to which the length of the etalon will vary as the result of variation in air temperature, in atmospheric pressure, and in the level of the water in the conduit pipe.

Variation in the level of the water in the conduit is due partly to vaporization and condensation of the water, and partly to variation in the inclination of the ground on which the station stands. The former effect produces the same variation in the water level at both ends of the conduit, while the latter produces equal and opposite variations at the ends of the conduit. Any variation in water level can be resolved into these symmetric and asymmetric variations.

Now taking the origin at the water surface at the middle of the etalon and y-axis vertically upwards, we will suppose that the change in water level caused a flexure of the etalon such that a line that is marked on the etalon and which originally coincided with water surface, is now expressed by $y = f(x)$, $f(L)$ and $f(-L)$ being therefore the change in water level at the ends of the etalon.

The load at x is then $-g\rho b f(x)$, where g is the acceleration of gravity, ρ the density of water, b the breadth of the etalon at the water surface. Since the etalon is supported at its ends, the bending moment at x due to the load at ξ is given by

$$M(x) = g\rho b f(\xi)\frac{(L+\xi)(L-x)}{2L} \qquad x > \xi,$$

$$= g\rho b f(\xi)\frac{(L-\xi)(L+x)}{2L} \qquad x < \xi, \quad \ldots\ldots\ldots(1)$$

where $2L$ is the length of the etalon.

Then the moment at x due to the total load is

$$g\rho b\int_x^L f(\xi)\frac{(L-\xi)(L+x)}{2L}d\xi+g\rho b\int_{-L}^x f(\xi)\frac{(L+\xi)(L-x)}{2L}d\xi \quad (2)$$

which must be equal to

$$EI\frac{d^2f}{dx^2}, \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

where E is Young's modulus of the silica of the etalon[2] and I the moment of inertia of the sectional area of the etalon. Differentiating expressions (2) and (3) twice with respect to x, and writing $g\rho b/EI=4\beta^4$, we have

$$\frac{d^4f}{dx^4}+4\beta^4f(x)=0. \quad \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

As the symmetric solution of this differential equation we have

$$f_0(x)=A\cosh\beta x\cos\beta x+B\sinh\beta x\sin\beta x,$$

together with the conditions

$$f_0(x)=\varepsilon \quad \text{at} \quad x=L \quad \text{and} \quad x=-L,$$
$$f_0''(x)=0 \quad \text{at} \quad x=L \quad \text{and} \quad x=-L.$$

We then have

$$A=\varepsilon(\cosh\beta L\cos\beta L)/(\cosh^2\beta L\cos^2\beta L+\sinh^2\beta L\sin^2\beta L),$$
$$B=\varepsilon(\sinh\beta L\sin\beta L)/(\cosh^2\beta L\cos^2\beta L+\sinh^2\beta L\sin^2\beta L).$$

Now since $g=980$, $b=1{\cdot}5$, $E=6{\cdot}58\times10^{11}$, $I=0{\cdot}3362$, and $\rho=1{\cdot}0$, all being in c. g. s. units, we have $\beta L=8{\cdot}00$. We have hence approximately

$$\cosh^2\beta L\cos^2\beta L+\sinh^2\beta L\sin^2\beta L\doteqdot\cosh^2\beta L\doteqdot\sinh^2\beta L,$$

so that we obtain

$$f_0(x)=\varepsilon\left[\frac{\cosh\beta x}{\cosh\beta L}\cos\beta x\cos\beta L+\frac{\sinh\beta x}{\sinh\beta L}\sin\beta x\sin\beta L\right],$$

which is again approximately equal to

$$f_0(x)=\varepsilon e^{-\beta(L-x)}\cos\beta(L-x) \qquad x>0,$$
$$=\varepsilon e^{-\beta(L+x)}\cos\beta(L+x) \qquad x<0.$$

The asymmetric solution of differential equation (4) is

$$f_1(x)=C\cosh\beta x\sin\beta x+D\sinh\beta x\cos\beta x,$$

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2) Young's modulus of the silica used in the present apparatus was measured by the writer to be $6{\cdot}58\times10^{11}$ c. g. s.

in which C and D are determined by the conditions

$$f_1(x)=\varepsilon \quad \text{at} \quad x=L, \qquad f_1(x)=-\varepsilon \quad \text{at} \quad x=-L,$$
$$f_1''(x)=0 \quad \text{at} \quad x=\pm L,$$

to be

$$C=\varepsilon(\cosh\beta L\sin\beta L)/(\cosh^2\beta L\sin^2\beta L+\sinh^2\beta L\cos^2\beta L),$$
$$D=\varepsilon(\sinh\beta L\cos\beta L)/(\cosh^2\beta L\sin^2\beta L+\sinh^2\beta L\cos^2\beta L).$$

Since we have again approximately

$$\cosh^2\beta L\sin^2\beta L+\sinh^2\beta L\cos^2\beta L\doteqdot\cosh^2\beta L\doteqdot\sinh^2\beta L,$$

we have

$$f_1(x)=\varepsilon\left[\frac{\cosh\beta x}{\cosh\beta L}\sin\beta x\sin\beta L+\frac{\sinh\beta x}{\sinh\beta L}\cos\beta L\cos\beta x\right]$$
$$\doteqdot\varepsilon e^{-\beta(L-x)}\cos\beta(L-x) \qquad x>0,$$
$$\doteqdot-\varepsilon e^{-\beta(L+x)}\cos\beta(L+x) \qquad x<0.$$

Comparing with the case of symmetric solution we have

$$f_0(x)\doteqdot f_1(x) \quad \text{for} \quad x>0,$$
$$f_0(x)\doteqdot -f_1(x) \quad \text{for} \quad x<0,$$

whence the variation in the effective length of the etalon is given by

$$\int_{-L}^{L}\left[\sqrt{1+\left(\frac{df}{dx}\right)^2}-1\right]dx\doteqdot\int_0^L\left(\frac{df}{dx}\right)^2dx,$$

both for symmetric and asymmetric flexure. We have therefore

$$\Delta L=\varepsilon^2\beta^2\int_0^L e^{-2\beta(L-x)}[1+2\sin\beta(L-x)\cos\beta(L-x)]dx$$
$$=\frac{1}{2}\varepsilon^2\beta\left[\frac{3}{2}-e^{-2\beta L}(1+\sin 2\beta L+\cos 2\beta L)\right]$$
$$\doteqdot\frac{3}{4}\varepsilon^2\beta=4{\cdot}80\varepsilon^2\times10^{-3}. \qquad (\varepsilon \text{ in cm})$$

If therefore we denote by Δh the symmetric variation in the water level we have

$$\Delta L=-0{\cdot}480(\Delta h)^2,$$

where ΔL is measured in μ and Δh in mm. If there were a tilt of the ground of amount $\Delta\theta$ (in seconds of arc), we have $\varepsilon=L\Delta\theta\sin 1''$ and the corresponding ΔL becomes

$$\Delta L=-0{\cdot}0018(\Delta\theta)^2,$$

where ΔL is measured in μ as before.

Now the force acting vertically on the supports at the ends of the etalon is given by

$$W = g\rho b\int_0^L f(x)dx = \frac{g\rho b\varepsilon}{2\beta}[e^{-\beta L}(\sin\beta L - \cos\beta L) + 1]$$

$$\doteqdot \frac{g\rho b\varepsilon}{2\beta} = 1{\cdot}15\,\varepsilon \times 10^5 \text{ dyne} \doteqdot 12\,\varepsilon \text{ gram-weight.}$$

The invar hook that engages with the etalon pulls it by means of the spring F, Fig. 2, with a force of about 100 gram-weight. Therefore referring to Fig. 10 we have

Normal pressure $N = \frac{1}{\sqrt{2}}(H + w)$,

Tangential force $T = \frac{1}{\sqrt{2}}(H - w)$,

Frictional force $F = fN$.

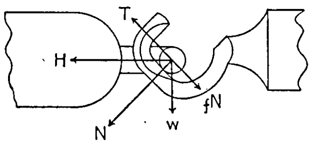

Fig. 10.

Since we can safely assume the frictional coefficient f between the silica and invar steel to be less than 0·3, we have

$$T - F = \frac{1}{\sqrt{2}}(H - w) - \frac{0{\cdot}3}{\sqrt{2}}(H + w) \doteqdot 0.5H - w.$$

We therefore see that $T - F > 0$, that is, the etalon is in correct position in the hook, if $2w < H$, or if ε is less than 4 mm.

We will next examine the effects of variation in atmospheric pressure or in that of the pressure inside the etalon. We will assume for a while that the etalon is perfectly straight. Let the excess of the pressure inside the etalon over that on the outside be ΔP. Then, considering an elementary volume, we have approximately

$$2\Delta P r_0 dx = 2T dx \qquad \text{or} \qquad \Delta P r_0 = T.$$

On the other hand we have $T = Et\frac{dr}{r_0}$, where E is Young's modulus, r_0 the radius when the thickness t of the wall is supposed to be very small. We have therefore

$$\frac{dr}{r_0} = \frac{r_0}{Et}\Delta P.$$

The elongation ΔL_1 of the etalon is then

$$\Delta L_1 = -\sigma L\frac{dr}{r_0} = -\sigma\frac{r_0 L}{Et}\Delta P,$$

where σ is Poisson's ratio. In addition to this force acting on the side-wall of the etalon, force $S\Delta P$ acts at each end tending to elongate the etalon, where S is πr_0^2. The elongation due to this force is

$$\Delta L_2 = \frac{\pi r_0^2 L \Delta P}{E(2\pi r_0 t)} = \frac{r_0}{2Et}\Delta P.$$

The total elongation of the etalon is therefore

$$\Delta L = \Delta L_1 + \Delta L_2 = \frac{r_0 L}{Et}\left(\frac{1}{2} - \sigma\right)\Delta P,$$

or

$$\Delta L = 0{\cdot}0891\,\Delta P, \qquad \text{if} \quad \sigma = 0{\cdot}17,$$

in which ΔL is measured in μ and ΔP in mm of Hg. Should ΔP denote increase of atmospheric pressure, ΔL will take a minus sign.

The pressure of the air in the etalon varies with the temperature according to the law

$$Pv = P_0 v_0 (1 + 0{\cdot}003665\,T).$$

The pressure variation ΔP is consequently given by differentiation:

$$\Delta P = 0{\cdot}003665 P_0 \Delta T = 3{\cdot}71 \times 10^3 \Delta T \text{ dyne/cm}^2,$$

where P_0 has been taken to be 1 atmospheric pressure, or $1{\cdot}013 \times 10^6$ dyne/cm². Using this value of ΔP we obtain

$$\Delta L = 0{\cdot}252\,\Delta T,$$

in which ΔL is in μ as before and ΔT in C°.

We have in the above studied the extension of a straight etalon under pressure variation. In treating next the case in which the etalon is supposed to be slightly curved, we may assume that the wall of the etalon is inextensible. Then since the etalon has a circular cross-section, the effect of pressure variation in such a manner as is observed in Bourdon's tube is negligible.

Now consider an elementary slice of the etalon. The forces acting on the two sectional areas are $\pi r^2 \Delta P$, which are in equilibrium with the pressure acting on the lateral wall. There is no moment to rotate this elementary slice, so that the x-derivative of the bending moment is zero, that is the bending moment is constant. But it is obvious that since the bending moment is zero at both ends of the etalon, it is zero everywhere. The inextensible etalon does not therefore change its shape by pressure variation. This may be seen also from the following calculation. There acts on the lateral wall of the etalon the force

$\pi r^2 \frac{d^2y}{dx^2}\Delta P$ perpendicularly to the centre-line of the etalon, and force $\pi r^2 \Delta P$ at both ends along the central line. The bending moment at x due to these forces is

$$M(x)=\pi r^2\Delta P\Big[(y-y_L)+\int_x^L \frac{d^2y}{d\xi^2}\frac{(L+x)(L-\xi)}{2L}d\xi + \int_{-L}^{x} \frac{d^2y}{d\xi^2}\frac{(L-x)(L+\xi)}{2L}d\xi\Big],$$

which gives

$$\frac{d^2M}{dx^2}=\pi r^2\Delta P\Big[\frac{d^2y}{dx^2}-\frac{d^2y}{dx^2}\Big]=0.$$

But since M is zero at both ends of the etalon, we have $M=0$ everywhere.

Besides these effects due to variations of temperature, pressure, tilt, or vaporization of water, there are many other possible causes that may change the effective length of the etalon, but all such effects are very small. We get therefore as correction terms, including thermal dilatation, the following expression which is to be added to the length of the etalon in order to obtain its true value:

$$\Delta L=12{\cdot}001\,\Delta T-0{\cdot}089\,\Delta P-0{\cdot}0018(\Delta\theta)^2-0{\cdot}480(\Delta h)^2,$$

where L is measured in μ, T is the temperature of the etalon in C°, P the atmospheric pressure measured in mm of Hg, $\Delta\theta$ the tilt of the ground measured in seconds of arc, and Δh the change in water level measured in mm.

At any rate, excepting the temperature variation, all the various factors considered above can safely be ignored in the present research.

6. *Concluding Remarks.* Prof. T. Terada and others[3)] have found that the crustal deformation caused by an earthquake is generally within the order of 10^{-5} when it is continuous, but in excess of it should there form certain discontinuities, such as faults, etc. The above figure suggests the ultimate strength of the crust. A crustal deformation of this amount, should it occur, would cause in the present apparatus a throw of light spot as large as 250 mm. With this apparatus, there-

3) T. TERADA and N. MIYABE, *Proc. Imp. Acad.*, 6 (1930), 49; *Bull. Earthq. Res. Inst.*, 7 (1929), 223; N. MIYABE, *Bull. Earthq. Res. Inst.*, 9 (1931), 1; Ch. TSUBOI, *Jap. Journ. Astr. Geophys.*, 10 (1933), 93.

fore, it would be possible to easily detect crustal deformation, despite the daily fluctuation due to temperature variation.

Although no particular dilatation, excepting the daily variation, has been observed since the installation of this apparatus in June this year, the writer is confident that sooner or later some interesting result will be obtained with it.

In conclusion, the writer wishes to express his sincere thanks to Professors A. Tanakadate, H. Nagaoka, and M. Ishimoto for their kind advices and their interest in this research.

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48. 土地伸縮測定裝置（概要）

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關東地震以來地殼變動に關する測量及び研究が頻りに行はれた結果，土地の伸縮の不斷觀測の必要が切實に感ぜらるゝに到つたのである．此の要求に應じ，昭和6年當研究所の駒場支所の設立さるゝに當つて，土地の伸縮の不斷觀測が計畫されたのであるが，最近に到つて正規觀測が始められた．玆に述べたものは卽ち其の觀測に用ひらるゝ裝置であつて著者の考案に成るものである．

觀測方法の原理は，地中に埋設した2箇の混凝土塊の間隔を，共れと略同長なる石英管製標尺と比較し，共の較差變化を光挺を用ひて擴大自記するに在る．裝置は凡て溫度の變化共他の影響を輕減する爲に第1圖に示す如き塹壕内に設置された．器械の構造は第2圖～第5圖に示した通りである．石英管製標尺は屈曲を防ぐ爲に鐵樋中の水面に浮游せしめてある．第7圖は此の裝置にて得られたる記象である．器械の感度は，若し地震後に普通に見受けらるゝ程度の地殼變動が生じたならば約25粍の偏れを記錄する樣になつてゐる．

本文は尙鐵樋中の水面の變化，氣溫の變化，外氣壓の變化等が觀測値に及ぼす可き影響に就ても論じてある．
