8. *Preliminary Report on the Observation of the Tilting of the Earth's Crust with a Pair of Water Pipes.*

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The instrument used in the present observation is based on the same principle with that used by A. Michelson in 1914 in his observation of the earth tide.[1] It consists essentially of a pair of pipes which are buried horizontally in the ground perpendicular to each other and halfly filled with water. The present observation was planned before the time of construction of the main building of the Earthquake Research Institute, and the pipes and the observing chambers were constructed in parallel with the main building of the Institute.

Observations of the tilt of the ground with this instrument has already been made for nearly one year. The results obtained will now be given in the following, together with some descriptions of the pipes and the observing chambers.

1. The observing chambers are situated at the corners of the site of the main building of the Institute as shown in Fig. 1. The distance

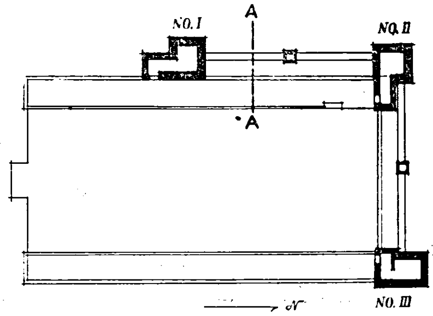

Fig. 1.

between two chambers is 17·5 m. The two end chambers are 2·5 m. × 2 m.

1) A. A. MICHELSON, *Astrophys. Journ.*, 39 (1914), 105.

in dimension, while the central one is 2·5 m. × 2·5 m. In Fig. 2 is given the section of an end chamber as an example to show the construction of the observing chambers. Each wall of the chamber is 80 cm. thick including an air space of the thickness of 15 cm. The floor is 100 cm. thick. The cielings, walls and floors are all of reinforced concrete and are lined with white mortar. Each chamber is provided with an electric fan for ventilation, a switch-board and a double door.

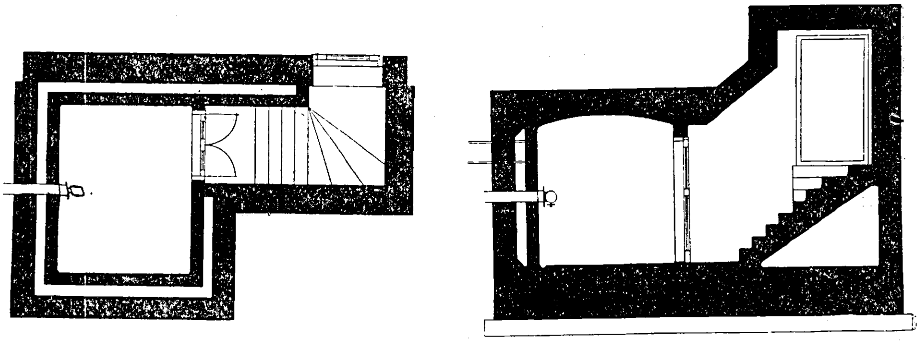

Fig. 2.

The chambers are connected with an under-ditch having a manhole at the middle point. The water pipe is placed in this ditch. Details of the construction of the ditch and the manner of fixing the pipe in it are to be seen in Fig. 3. The pipes are made of iron, 6 inches in diameter, 18 metres in length and are lined with enamel to prevent the water contained in it from staining. Besides these main pipes there are buried two other pipes each 1 inch in diametre to serve as the pass of leading wires connecting the electrical equipments in each observing chamber.

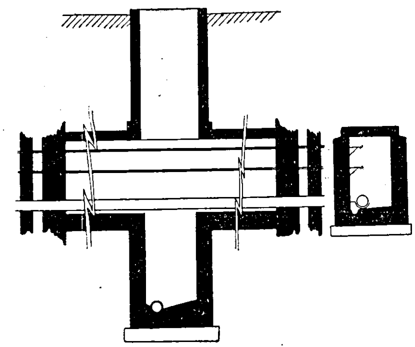

Fig. 3.

The ceiling of each chamber is at the depth of 2·4 m. under the surface of the ground.

Temperature condition of the observing chambers and the ditches are thus held pretty good. A recording thermograph inserted in the ditch showed practically no variations in temperature in a period of a week.

2. Now if the ground tilts to the direction of a pipe, the water in the pipe changes its level relatively to the pipe. The amount of the change of the level is just proportional to the amount of tilt of the ground, if there is no condensation or evaporation of the water or an asymmetrical bending of the pipe. The effect of the condensation or evaporation of the water in the pipe can be eliminated by taking the algebraic difference of the variation of the level of the water at the both ends of a pipe. There are three kinds of the methods of measuring the variation of water level which have already used for this purpose; namely the micrometer method, the optical lever method and the interference method. In the present observation the first method was adopted. The second method is recently used by J. Egedal[2] in his niveauvariometer observation. In his instrument the displacement of a float on the water surface in the pipe was magnified by an optical lever. This method is not free from objections, though it has its own merit in the simplicity of the apparatus. The third method seems to be most accurate and perfect one, but for certain purpose such a highly accurate method is not fitted.

The apparatus used in the micrometer method consists essentially of a micrometer screw with a sharp point under the surface of the water, the level of which is to be measured. The sharp point and its image reflected at the surface of the water are brought into contact by turning the screw. The number of turns of the screw shows the height of the water surface measured from an arbitrary zero. The details of the instrument used in the present observation can be seen in Fig. 4. The

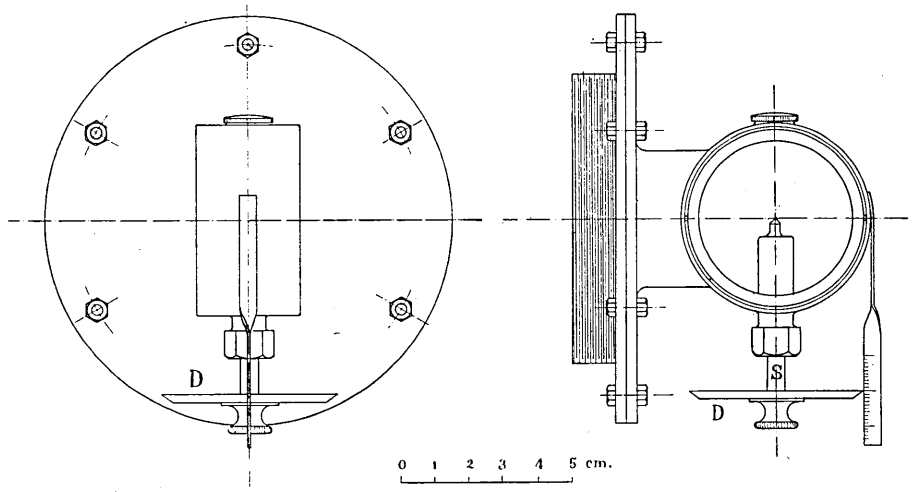

Fig. 4.

2) J. Egedal, "On an Apparatus for Registeration of Variations in the Position of the Earth's Crust etc.", *Report of the 18. Scandinavian Naturalist Congress in Copenhagen, 26–31, Aug., 1929.*

micrometer screw S is made of stainless steel and the pitch of the srew is 0·5 mm. This stainless steel proved to be quite satisfactory in that it did not grow rusty during the period of the observation for a year. The micrometer screw is provided at its lowest end a dial D which is graduated in 250 divisions, so that the smallest division of the dial corresponds to $2\,\mu$. It is easy to set the screw S into contact with its image within the error of 2 divisions of the dial without using a microscope or a magnifying glass, because a slight clearance between the screw and its image becomes visible when they are illuminated from behind.

By the pipe of 18 metres in length, a tilt of the ground of the amount of 1″ produces the elevation of the water surface corresponding to 22·5 dial divisions at one end of the pipe and the depression of the same amount at the other end. Therefore the difference of the variations of the water level at both ends becomes 45 divisions which can be measured within the error of 4 divisions.

In the neck part of the instrument which connect the main part to the flange, a buffer is provided to minimize mechanical disturbances in the water. 1 gram of HgCl was solved in the water contained in the pipe to prevent the water from corruption.

3. Results of Observation.[3] In the first place, we will describe about the daily tilt of the ground. Readings of the values of the water level at both ends of a pipe were taken at every one hour in days and at

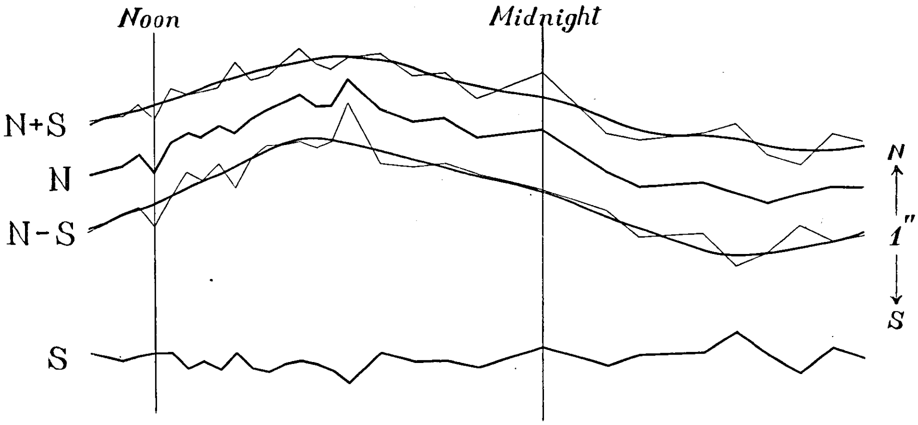

Fig. 5. N-S Component, Feb. 18th. 10h—19th. 10h, 1929.

every two hours at nights. As an typical example of such observations, the results obtained on February 18th. is shown in Fig. 5. These daily variations are quite similar in form with the variation of air temperature.

3) The present observation is limited only to N-S component, as the apparatus for E-W component, which is based on the interference mothod, is yet under preparation.

The amplitude of the daily variation is generally less than or equal to 1″ and the maximum northward tilt occurs at about 18 h. The ground tilts northwards with rising temperature and tilts southwards with lowering temperature. It shows a phase lag of about 4 hours relatively to the air temperature.

The value of the tilt at noon coincides roughly with the mean value of the daily tilt curve. It is therefore enough to take the reading of the level of the water once a day at noon for the purpose of detecting a secular or cumulative tilting of the ground. In Fig. 6 is shown a tilt curve for the period from February to December of the year 1929 obtained by such simplified method of observation. In the same figure a curve showing the atmospheric temperature variation for the same period is also inserted. The annual variation of the inclination of the ground is clearly seen from the figure. In the annual variation, the ground tilts also northwards with the rising temperature. The amplitude of the annual variation amounts to about 15″ and the maximum northward tilt occurs in August.

The period of the observation is not yet long enough to detect the cumulative or secular tilt of the ground.

In the under-cellar observation room of the Institute which is at the southern end of the building of the Institute, a pair of the Ishimoto[4] tiltmeters made of fused quartz is installed. They are in principle horizontal pendulums of Zöllner's suspension type. These tiltmeters show daily tilt of the amount of 8″. Comparison of this record with the record obtained with the water pipe, shows that they are quite similar in form though their amplitudes are much different, but in sense they are quite opposite. When the water pipe tilts northwards, the tiltmeter in the under-cellar tilts southwards and *vice versa*. The cause of this apparently curious phenomenon was sought from various points of views and finally attributed to the thermal bending of the building of the Institute and of the ground adjacent to it. The thermal bending of the building is concidered to be caused by the excess of the expansion of the part of the building above the surface of the ground. When the air temperature rises the part of the building in the air makes expansion, while the part under the ground remains as original. The result of this unequal expansion must be the bending of the building.

If the upper part of the building which is 10 metres high and 30 metres long, is higher in temperature by 2° C than the lower part of

4) M. Ishimoto, *Bull. Earthq. Res. Inst.*, 2 (1927), 1; *Jap. Journ. Astro. Geophys*, 4 (1928), 83.

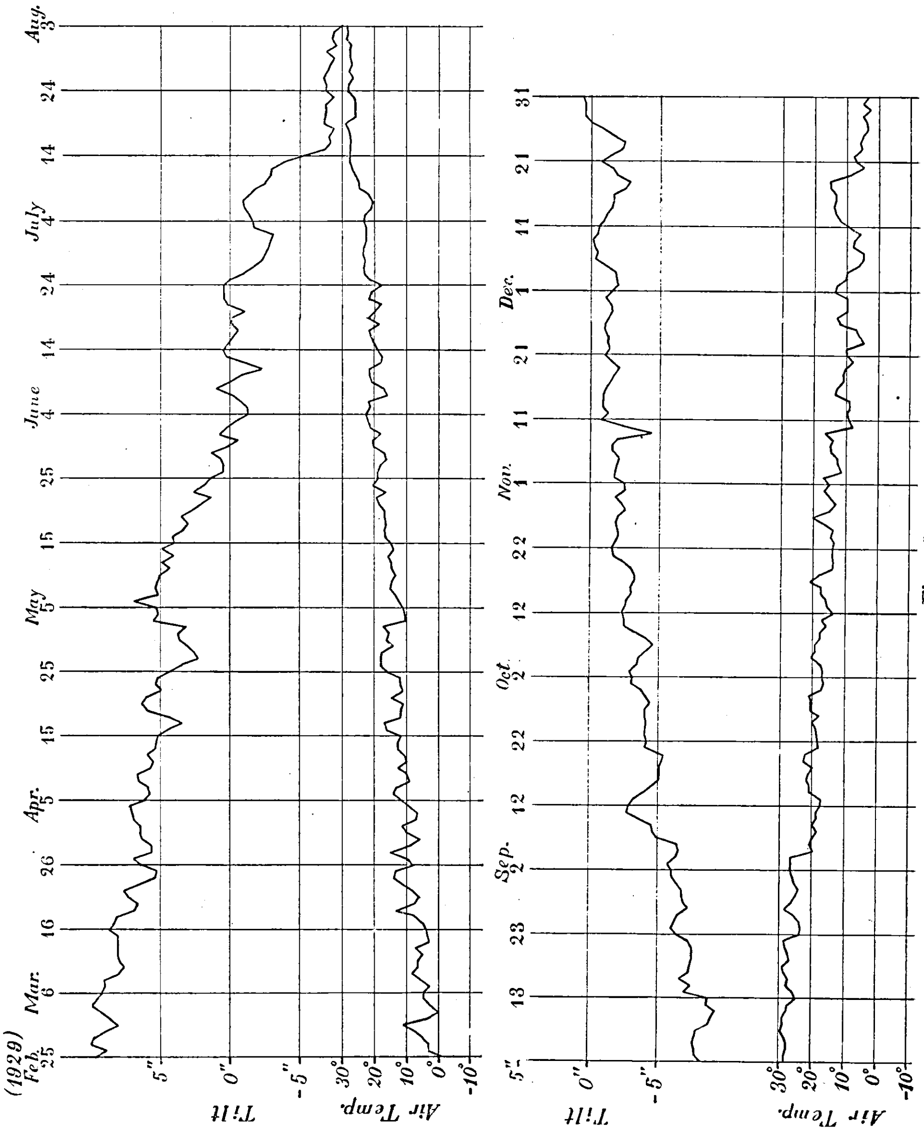
(1929)
Feb. 25
Mar. 6
16
26
Apr. 5
15
25
May 5
15
25
June 4
14
24
July 4
14
24
Aug. 3
Sep. 2
13
23
12
22
Oct. 2
12
22
Nov. 1
11
21
Dec. 1
11
21
31
Tilt
Air Temp.

Fig. 6

the building, then the difference of the length of the building caused by the unequal expansion is

$$dl = 30\text{ m} \times (2\times10^{-5}) = 0{\cdot}6\text{ mm},$$

taking the expansion coefficient of concrete to be the same with that of iron. With this difference of length between the upper and lower parts of the building, we have for the radius of curvature of the bending

$$R = 30\text{ m} \times \frac{10\text{ m}}{dl} = 5 \times 10^5\text{ m},$$

therefore for the distance of 18 m., which is the distance between No. I and No. II chambers, the difference of the tilt will be

$$\theta = \frac{18}{5} \times 10^{-5}\text{ radian} = 7{\cdot}2''.$$

The tilt measured by the pipe is, however, the difference of the level of the water in the pipe divided by the length of the pipe. In the present case of the bending of the building of the Institute, the vertex point of the bending where no thermal tilt is produced coincides roughly with the line A–A in Fig. 1, as is stated in the later pages of this paper. The distance between the line A–A and No. I chamber is about 6 metres. We have therefore as the tilt observed by the pipe

$$\theta = \frac{\frac{1}{2}\left(\frac{2}{3}L - \frac{1}{3}L\right)}{R} = \frac{3}{5\times10^5} = 1{\cdot}2'',$$

which is almost in the same order with the actually observed value.

For the purpose to ascertain more clearly the mode of this thermal bending of the building, two tiltmeters were installed in No. I and No. II chambers respectively in N–S direction. In Fig. 7 are shown the record of tiltmeter installed in No. II chamber and that of the tiltmeter installed in the under-cellar for the same period. The tiltmeter installed in No. I chamber showed daily tilt of only 1″ or less and the tilt was in the same sense with that of the under-cellar. This is very reasonable, because No. I chamber is situated at about the middle point of the building of the Institute and is hence near to the minimum point of the tilt caused by the bending.

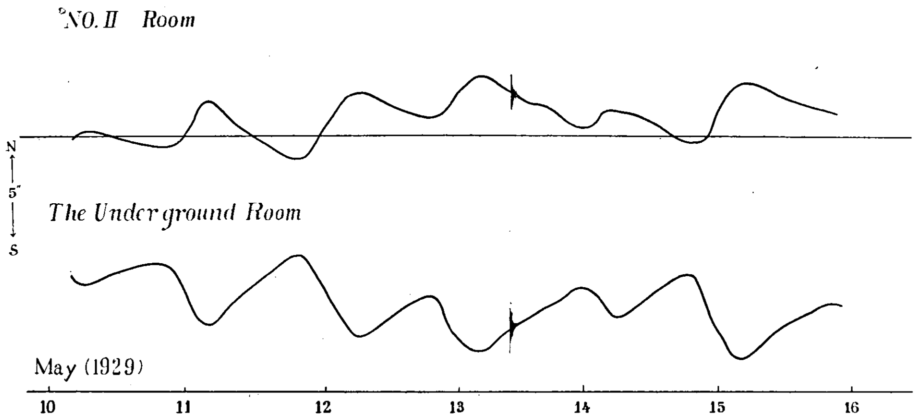

Fig. 7.

Now if the water pipe bends, the rise of the water level at one end of the pipe is not equal in amount to the depression of the level at the other end. The algebraic sum of the amount of the variation of the level at both ends is not constant. In such cases, the algebraic difference of the values of the water level at both ends does not represent the amount of tilt of the ground and we must make some calculations to obtain the true tilts.

Taking the origin of coordinate at the highest point of the bended tube which was initially straight and horizontal, and using the following notations:

ζ the variation of the level of the water in the pipe,

ζ_0 the variation of the level of the water in the pipe at the origin,

R the radius of curvature of the bent pipe,

L the length of the pipe,

x the coordinate taken along the pipe,

we have

$$\zeta = \frac{x^2}{2R} - \zeta_0,$$

and that

$$\int_{-l_1}^{l_2} \zeta \, dx = 0$$ [5],

5) In this case, the effect of condensation or evaporation of the water in the pipe was neglected. In the present observation, the temperature of the chambers and ditches, and of the water in the pipe was practically constant and there is, if any, only an insignificant effect caused from this origin.

where l_1 and l_2 are the coordinates of the ends of the pipe. Then we have for ζ at l_1 and l_2,

$$\zeta_{l_1} = \frac{1}{6R}(2l_1^2 + l_1 l_2 - l_2^2),$$

$$\zeta_{l_2} = \frac{1}{6R}(-l_1^2 + l_1 l_2 + 2l_2^2),$$

from which we obtain

$$l_1 = \frac{L}{2} + \frac{L}{6}(\zeta_{l_1} - \zeta_{l_2})/(\zeta_{l_1} + \zeta_{l_2}),$$

$$l_2 = \frac{L}{2} - \frac{L}{6}(\zeta_{l_1} - \zeta_{l_2})/(\zeta_{l_1} + \zeta_{l_2}).$$

These l_1 and l_2 give almost constant values when there is no true tilting of the ground, and the value of l_1 is a little larger than $L/3$ in our case. Denoting by $\bar{l}_1$ and $\bar{l}_2$ the mean values of l_1 and l_2, we have for a case when there is a true tilt of the ground of the amount of θ,

$$\zeta_1 = \zeta_{\bar{l}_1} - \frac{L\theta}{2},$$

$$\zeta_2 = \zeta_{\bar{l}_2} + \frac{L\theta}{2},$$

where ζ_1 and ζ_2 are the observed values of the variation of the level of the water at both ends of the pipe. From these relations we get for the value of the true tilt

$$\theta = \frac{1}{L}\left\{\lambda(\zeta_1 + \zeta_2) - (\zeta_1 - \zeta_2)\right\},$$

where

$$\lambda = \frac{3}{L}(\bar{l}_1 - \bar{l}_2).$$

By these analysis we could find that in our case the highest point of the bending of the building of the Institute or the point where there is no thermal tilt coincides with the position indicated by the line A–A in Fig. 1. The distances from this A–A line to the tiltmeters installed in the under-cellar, in No. I chamber and in No. II chamber are about 17 m., 6 m. and 12 m. respectively. These distances are approxomately proportional to the amount of tilt of each tiltmeter.

As to the true tilt of the ground, it will be given in near future after the accomplishment of the calculation which is now going on.

In conclusion the author wishes to express his most cordial thanks to Professor Mishio Ishimoto for his valuable critiques and discussions.

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8. 十八米突の鐵管による地表傾斜變化の觀測（豫報）

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此の觀測に用ひた裝置は 1914 年に A. A. Michelson が地殼の潮汐現象の觀測に用ひたものと同じ原理に基づくものである。今、地中に水平に、東西及南北の方向に、鐵管を埋め、其の中に水を半ば容して置く。地表の傾斜に若し變化を生ずれば、管中の水は管に對して其の水位を變へる。卽一端に於ては水位は高くなり他端に於ては水位は低下する。其の水位の變化を精密に測定すれば、傾斜變化を知りうるのである。水位の變化を測定するには色々の方法があるが、現裝置に於ては測微螺子を用ひてゐる。此の方法に依つて約十分の一秒迄の傾斜變化を測定しうるのである。

此の裝置によつて約十ケ月間の觀測を行つた結果、此の器械に現れる變化の主なるものは、氣溫の變化に依つて本研究所の建物が膨脹收縮する爲に生ずる建物の彎曲であつて眞正の地表の傾斜變化は觀測の結果に或る計算を施さねばならぬ事が判明したのである。眞の地表の傾斜變化に就ては計算の完了を待つて發表する豫定である。
