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20. *Observation of Tilting of the Earth's Surface Due to Matsushiro Earthquakes. Part 1.*

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In connection with the earthquake swarm that began in August, 1965, we conducted continuous observation of tilting of the ground at Matsushiro. Two components of the water-tube tiltmeter and two components of the Ishimoto horizontal pendulum tiltmeter were installed in the underground gallery of the Matsushiro Seismological Observatory of Japan Meteorological Agency in the outskirt of the town of Matsushiro.

The water in two reservoirs installed on the concrete blocks with distance of 40 m was connected with a glass water-tube and the changes in level of water surfaces in both the reservoirs were read off with a microscope.* The difference of reading between the micrometers of 1 micron corresponded to the change in the tilt of 0.005″. The horizontal pendulum of the Ishimoto tiltmeter was made of fused silica and the deflection of the pendulum was recorded on a photographic paper by means of an optical lever. The period of pendulum was set at 20 seconds, and deflection of 1 mm on the record corresponded to change in the tilt of 0.05″. The horizontal pendulum tiltmeters were installed on the flat floor in the gallery. These instruments were placed at a distance of 200 m from the entrance of the gallery. Since there are many doors on the way to this place from the entrance, the air temperature there is not affected by the temperature change outside the gallery. Fig. 1 shows the plan of the horizontal gallery. The observation of tilting was commenced at the beginning of October, 1965.

Table I shows comparatively large earthquakes with magnitude larger than 4.4 among the present earthquake swarm and Fig. 2 shows the epicenters of these earthquakes. The numbers in the figure correspond to the numerical order of the earthquakes in the table.

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* Detail of the water-tube tiltmeter, see T. HAGIWARA, "Observation of Changes in the Inclination of the Earth's Surface at Mt. Tsukuba (Third Report)," *Bull. Earthq. Res. Inst.*, **25** (1947), 27.

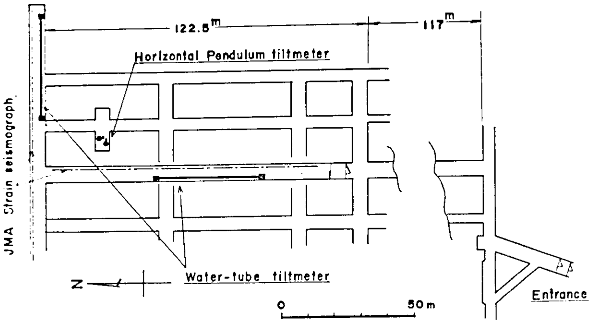

Fig. 1. Plan of the horizontal gallery.

Table 1. List of large earthquakes with magnitude larger than 4.4.

Earthq. No.	Date	Time	Magni-tude	Depth	Epicentral Distance	J.M.A. Intensity Scale	Remark
7	11 04	23 45	4.6	3.7	2.9	IV	松代で IV
9	13	23 14	4.5	2.9	2.8	IV	松代で IV
11	21	03 30	4.7	2.7	1.7	IV	松代で IV
12	21	15 38	4.4	1.1	3.1		
13	22	21 09	4.8	3.7	1.0	IV	松代, 更北, 篠の井で IV
14	22	22 30	4.7	3.2	1.6	IV	松代, 長野, 更北で IV
15	23	02 57	5.0	2.5	0.7	IV	松代, 長野, 更北, 篠の井で IV
16	24	14 13	4.4	3.6	0.8	IV	松代で IV
19	01 03	03 59	4.5	4.0	1.2	IV	松代, 更北で IV
20	08	22 34	4.7	3.7	2.3	IV	松代, 更北で IV
22	23	20 16	4.6	2.9	1.4	V	松代, 更北, 篠の井で V 長野で IV
23	02 07	04 05	4.4	1.5	1.9	V	松代で V 更北, 篠の井で IV
25	02 12	04 05	4.6	2.5	1.4	IV	松代, 更北で IV
26	03 08	19 28	4.5	3.6	2.8	IV	松代, 更埴で IV
27	10	07 03	4.4	1.9	1.9	IV	松代, 更北で IV

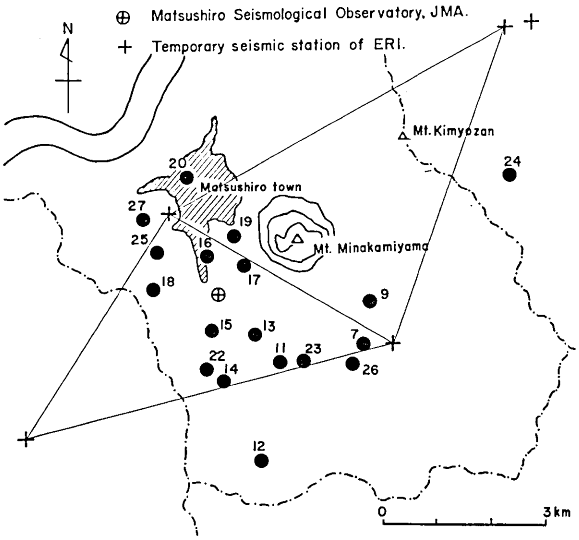

Fig. 2. Epicenters of the Matsushiro earthquakes with magnitude larger than 4.4.

The reading of the water-tube tiltmeters was made once a day as a rule. In the case of the pendulum tiltmeter, hourly values were read off from records and daily means were made. A slight fluctuation in tilting due to the earth tide was perceived on the records but this effect was cancelled by making daily means. The results of observation with the tiltmeters of both types are shown in Fig. 3. At a glance over the figure we may say that both the results, of water-tube and of pendulum, coincide with one another fairly well.

With an earthquake with intensity larger than IV on the JMA intensity scale (which corresponds to intensity VI in the modified Mercalli intensity scale), a slight abrupt change in tilting is observed on the records of the pendulum tiltmeter. Such discontinuity took place in the case of certain large earthquakes but not in the case of others. Comparing these discontinuities of tilting with the large earthquakes listed in Table 1, we find that discontinuities took place in respect of 10 large earthquakes but no changes appeared in other five large earthquakes. Such discontinuity cannot be perceived by the water-tube tiltmeters except at the time of a particular earthquake on November 23 (No. 14 or 15 in the table). Hence we may say that these discontinuities seen on the records of the pendulum tiltmeters were due to the dislocation of neutral position

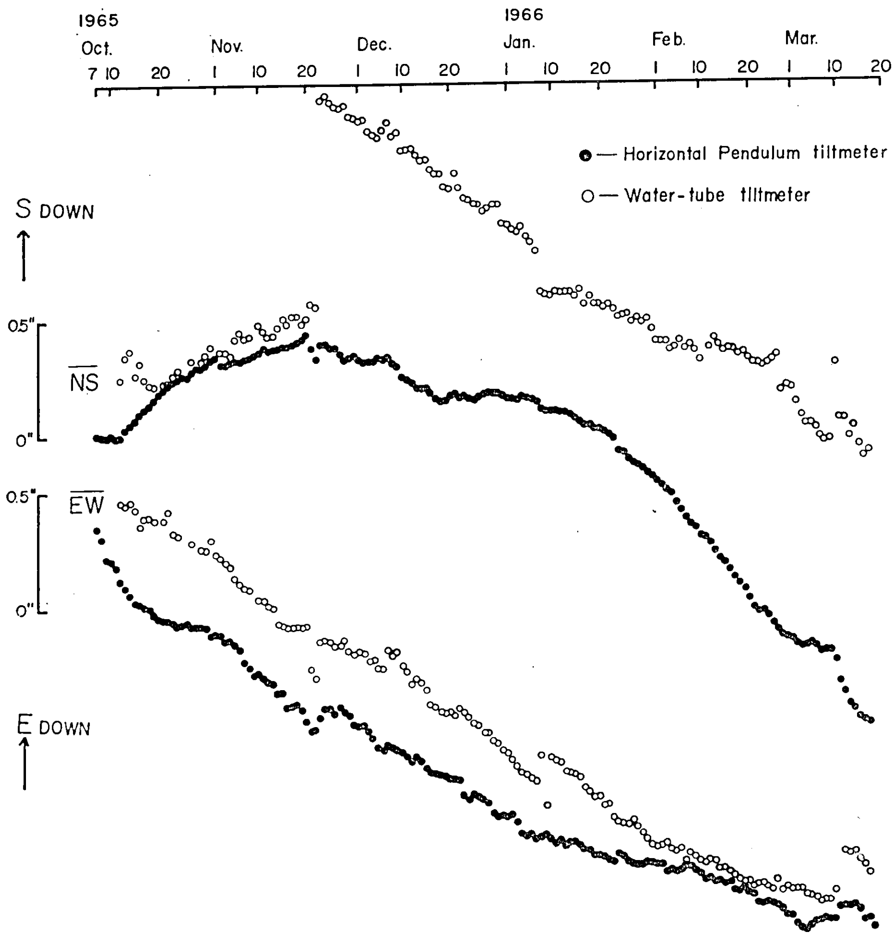

Fig. 3. Secular changes in the tilt observed at Matsushiro.

of the pendulum caused by violent shocks. The reason why an abrupt large change took place in the N-S component of the water-tube tiltmeter at the time of the earthquake of No. 14 or 15 is not clear. However, such changes were not perceived in the other component of this tiltmeter and, moreover, both the components of the pendulum tiltmeters showed no discontinuity of tilting of such a large amount. Therefore, the origin of the abrupt large change in question might not exist in the hypocenter but might be due to small cracks created by violent shocks in rocks near the instrument at the time of earthquake.

Fig. 6 shows the changes in tilting expressed vectorically with respect

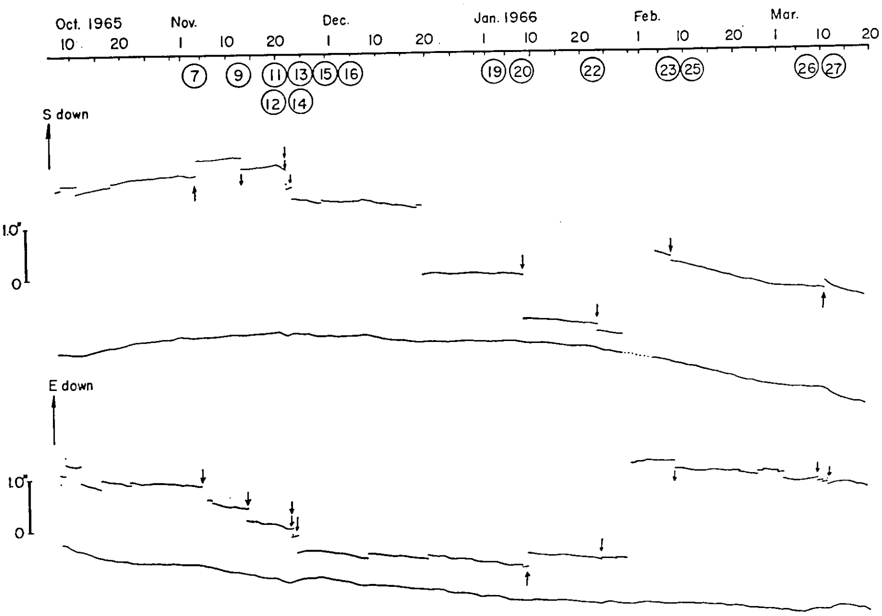

Fig. 4. Discontinuities of tilting recorded by the pendulum tiltmeters. Discontinuities connected smoothly in the lower curves.

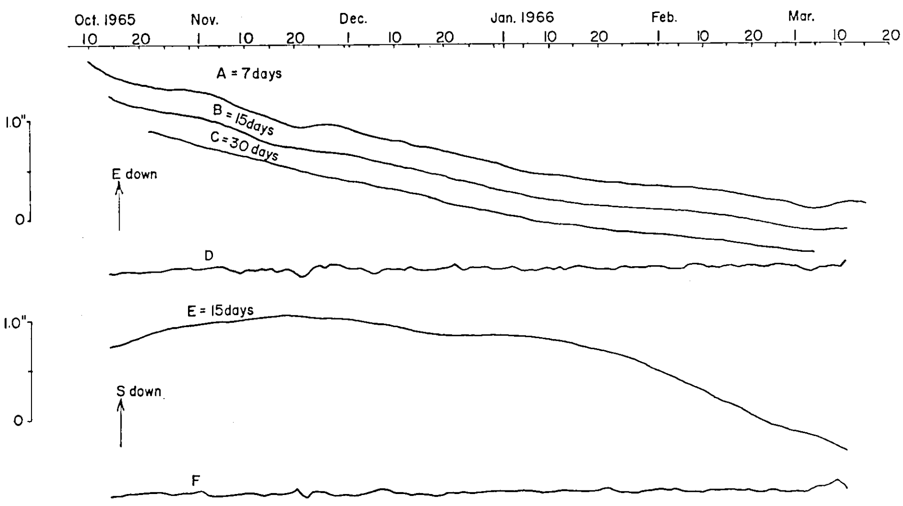

Fig. 5. A, B, C, E: Overlapping means of the changes in the tilt recorded by the pendulum tiltmeters. D, F: Daily means from which the overlapping means of 15 days were subtracted.

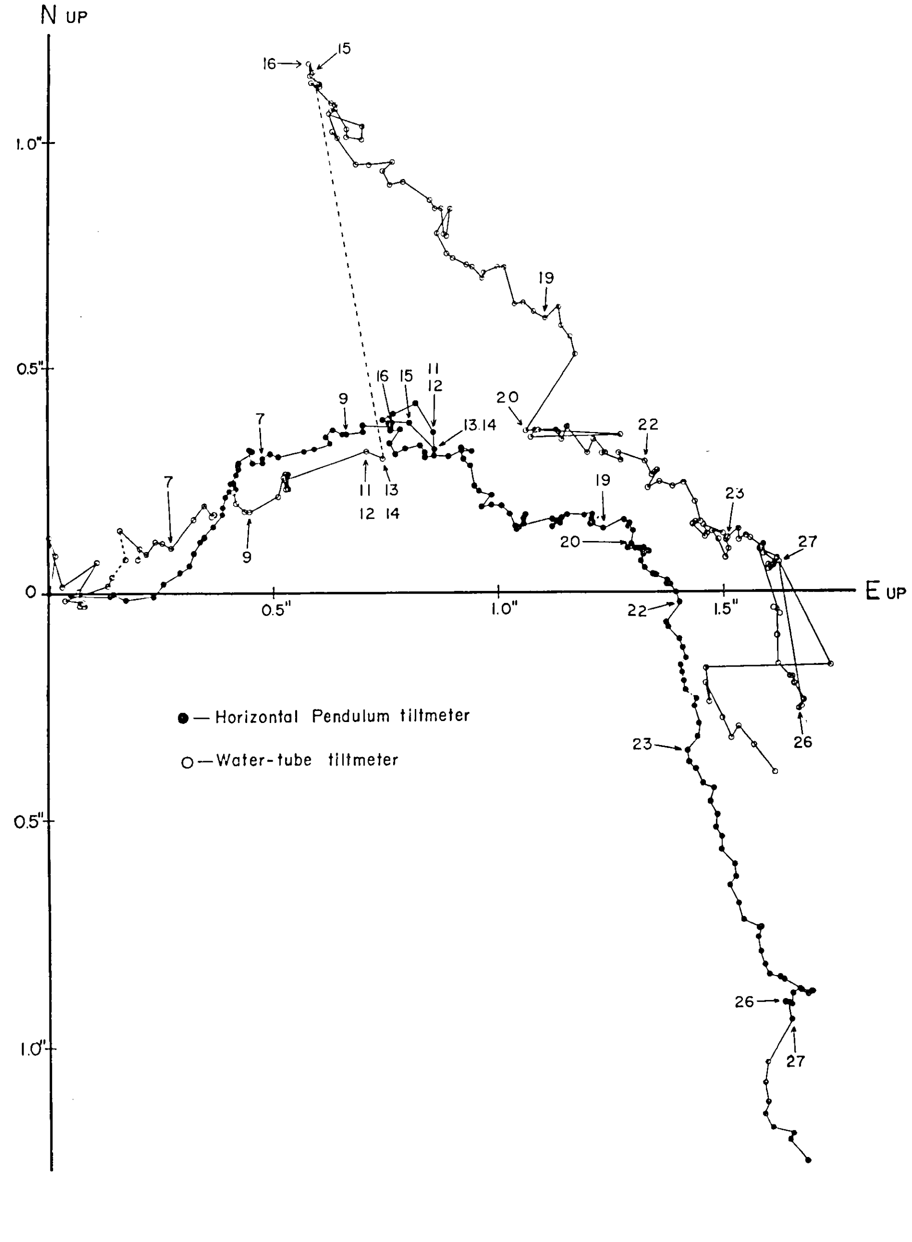

Fig. 6. Vectorical representation of the changes in the tilt.

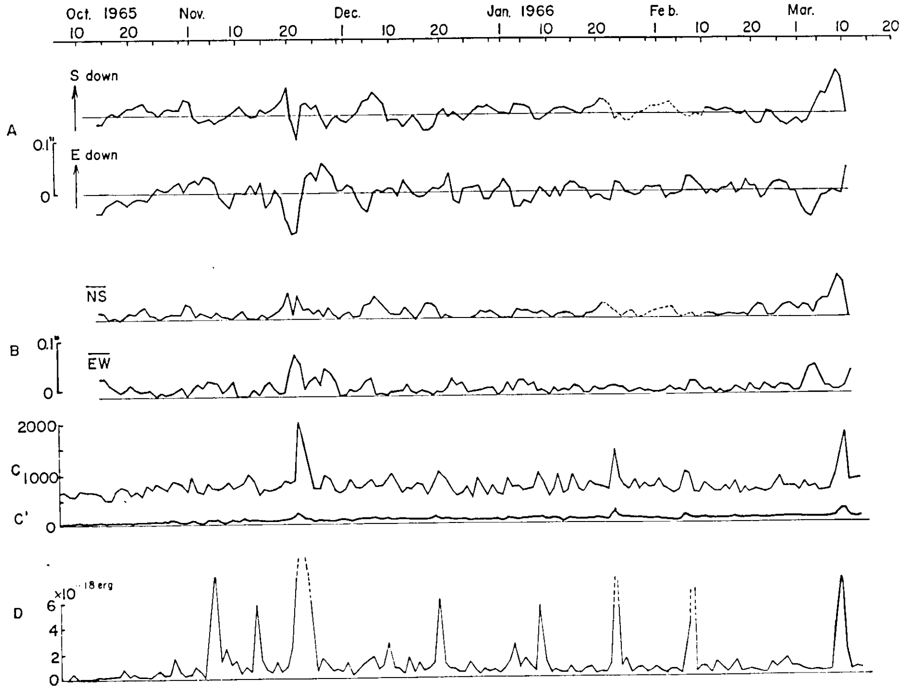

Fig. 7. Relation between the changes in the tilt and the activities of the Matsushiro earthquakes. A: Daily means from which the overlapping means of 15 days were subtracted. B: Turning negative values of changes into positive. C: Daily frequency of recorded earthquakes. C′: Daily frequency of felt earthquakes. D: Daily release of energy.

to daily means of the changes. The discontinuities in tilt recorded by the pendulum tiltmeter which were mentioned in the foregoing were connected smoothly, regarding as instrumental errors. The numbers indicated in the figure correspond to the earthquake numbers in Table 1. The change in tilt was, in general tendency, first towards the southwest and then altered its direction towards the northwest after the outstanding earthquake activity of Dec. 22~23, 1965. The changes in tilt corresponding to individual large earthquakes are not clear but slight changes in direction of tilt seem to have been caused after large excessive earthquake activities.

In order to investigate the relation between the changes in tilt and the earthquake activities in detail we made overlapping means of 7, 15 and 30 days with respect to changes in tilt, these being subtracted from the original values. The overlapping means of 15 days were found to be

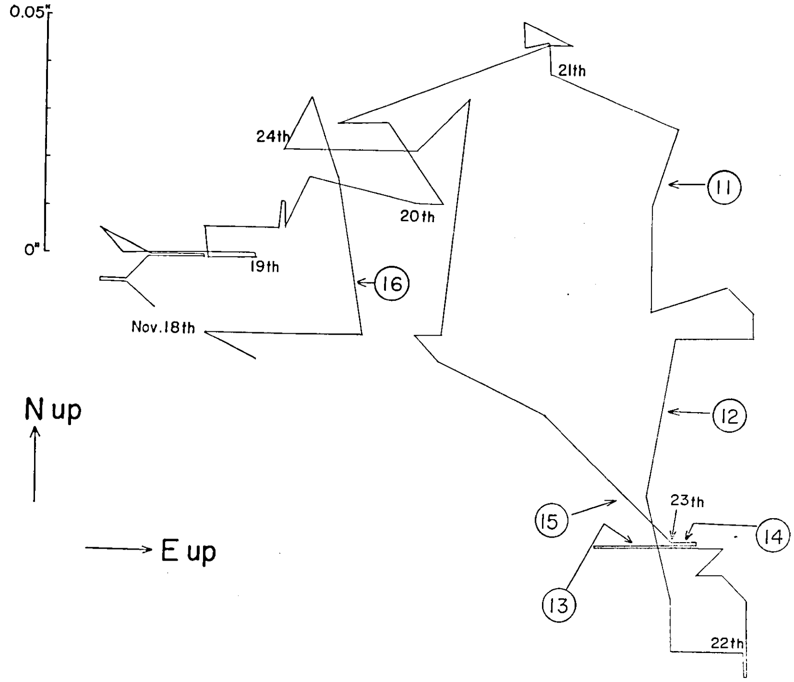

Fig. 8a

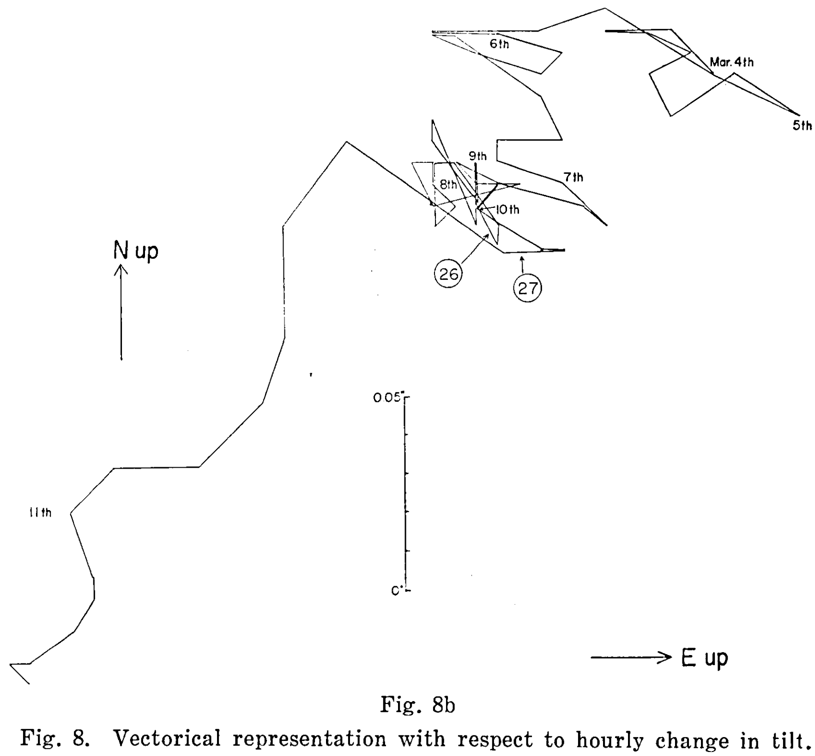

Fig. 8b

Fig. 8. Vectorical representation with respect to hourly change in tilt.
a. Nov. 18-24, 1965, b. Mar. 4-11, 1966.

adequate for this purpose. The changes from which the overlapping means were subtracted give fluctuations in small intervals of time. These changes in tilt were compared with daily frequency of felt and recorded earthquakes and daily release of energy due to earthquakes, as shown in Figs. 5 and 7. The curves B in the figures were obtained in order to make the comparison easier by turning all negative values of changes into positive values, similar to full-wave rectifying of electric current. At a glance over the figures, a clear correspondence between change in tilt and seismic activity is noticeable in the cases of the earthquakes occurring on Nov. 22, 1955 and Mar. 10, 1966. In both cases, the change in tilt appeared a few days before the occurrence of earthquakes of large magnitude. In order to examine these two cases in more detail, we draw a vectorical figure with respect to hourly change in tilt, as shown in Fig. 8. The change in tilt took place in the direction where the epicenter of the earthquake of large magnitude appears to upheave before its occurrence returning to subside after wards.

According to the precise levelling in the area of Matsushiro repeated by members of our institute* such an area in which seismic activities were occurring was upheaving. Our result of tilt observation coincides with the general tendency of such levelling but comparison in detail will be made after further repeat levelling is carried out.

Résumé

1) Concerning the slow changes in tilt, observational results of the water-tube tiltmeters and the pendulum tiltmeters coincided well with one another.
2) In general aspect, the change in tilt altered the direction from the Southwest (Southwest downwards, Northeast upwards) to the Northwest (Northwest downwards, Southeast upwards) on November 23, 1965.
3) Evident correspondence between the change in tilt and seismic activity was noticeable in two cases of seismic activity on Novembr 23, 1965 and March 10, 1966.

   In other cases, the correspondence between the change in tilt and individual earthquakes of large magnitude was not clear.

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* Read at the monthly meeting of the Earthquake Research Institute held on Dec. 21, 1965. I. Murata, S. Izutuya, I. Tsubokawa. "Levelling Survey in Matsushiro-Area (Second Report)".

The daily observation was conducted by Mr. S. Saito and Mr. T. Takahashi of our Institute and we express many thanks for their efforts over long periods. Mr. M. Takehana, director, and members of the Matsushiro Seismological Observatory of Japan Meteorological Agency cooperated in our work for which we express our sincere thanks.

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20. 松代地震における土地傾斜の観測 (第1報)

地震研究所 萩原尊礼 / 山田重平 / 平井正代

1965 年 8 月に始まる松代地震群に際し，土地傾斜の連続観測を行つた．水管傾斜計 2 成分，石本式水平振子傾斜計 2 成分を松代町郊外にある気象庁地震観測所の地下横坑内に設置した．

水管傾斜計は 40 m の距離にある 2 つのコンクリート台の上に置いた水の容器をガラス管で連結し，その水位変化をマイクロメーターで読取るもので，読の差 1 ミクロンに対する傾斜変化は 0.005″ である．石本式傾斜計は熔融水晶で作られ，振子の振れを光テコで拡大して写真感光紙に記録する．振子の周期は 20 秒で，そのときの感度は記録紙上の 1 mm が傾斜変化 0.05″ に相当する．計器を設置してある場所は観測坑の入口から 200 m ほど奥にあり，途中いくつかの扉によつて外気温度の影響を防いでいる．第一図は観測坑の平面図である．1965 年 10 月上旬より観測を開始した．

第 1 表はこのたびの地震群のうち比較的大きな地震，マグニチュード 4.4 以上の表で，第 2 図はその震央図である．震央の番号は第 1 表の地震番号に対応する．

水管傾斜計の読取は 1 日 1 回，振子型傾斜計は記録紙から毎時の値を読取り日平均値を作つた．記録の上では地殻潮汐による傾斜の僅かな変動が認められるが，日平均を作ることによりその影響を除くことができる，両種の傾斜計による観測結果を第 3 図に示す．一見して両者の記録はよく一致しているように思う．

気象庁震度階で IV 以上の地震の場合に，振子型の傾斜計の記録線に小さな段 (不連続的な変化) があらわれている．このような不連続的な変化は大きな地震のときに現われる場合と現われない場合とがある．第1表の地震について，10 個の地震については段が現われているが，5 個の地震については段が現われていない．その様子を第 4 図に示す．このような不連続変化は水管傾斜計の場合，11 月 22 日の地震 (No. 14 または 15) 以外には見られない．それゆえ振子型傾斜計では激しい地震動のために振子の静止の位置に移動が起つたと考えられる．No. 14, 15 の地震でなぜ水管傾斜計の NS 成分にだけ大きな変化が起つたか，その理由は明らかでない．このような変化は他の成分には現われていないし，振子型傾斜計では傾斜の不連続はそれほど大きく現われていない．それゆえ，この突然の大きな変化が震源において起つた変動によるものではなくて，地震による急激な衝撃で計器の附近の岩に小さな割目が生じたためと推定される．

第 6 図は傾斜変化の日平均値の変動を示すベクトル図である．振子型傾斜計の記録については前述の不連続は計器の誤りと考え，つなぎ合せ平滑にしたものについて書いてある．図の地震番号は第 1 表の番号に対応する．傾斜変化の全般の傾向は，はじめ南西に向つていた (南西の方が下がる) が，1965 年 11 月 22, 23 日の大きな地震活動の後北西に向を転じた (北西の方が下がる)．傾斜変化と個々の地震との対応は明らかでないが，大きな地震活動のあとで僅か方向の変化が現われるように思われる．

傾斜変化と地震活動との関係を調べるために 7 日，15 日，30 日の移動平均を作り，これともとの値との差を作つてみた．このたびの目的には 15 日の移動平均が最も適当と思われた．第 5 図はこれらの移動平均およびもとの値と 15 日移動平均との差を示すものである．移動平均を差引いた変化分には短周期変動のみが現われる．この傾斜の変化分を有感地震回数，総地震回数および日別放出エネルギーと比べたものを第 7 図に示した．この図で B は，比較しやすいため，負の部分を反転し，電流の全波整流のような操作を行つたものである．傾斜変化と地震活動が一見して明瞭に対応のつくのは 1965 年 11 月 22 日と 1966 年 3 月 10 日の二つの顕著な活動期の場合である．この二つの場合，大きな規模の地震の起る数日前に傾斜の変化が見られる．その間の消息を一層細かに調べるため，第 8 図に示すように傾斜変化を 2 時間毎にベクトル図に描いてみた．傾斜の変化は大きな規模の地震が起る前にその震央が隆起するような向に起り，地震が終れば沈降し元にもどる．

当研究所の所員等によつて行われた松代周辺の水準測量によると，地震活動の区域は隆起しつつある．この結果は一般的傾向としてはわれわれの観測と合つているが，細部に亘つては今後の測量の報告に待つて比較を行うつもりである．

総　括

以上述べたことを総括すると次のようになる．

1) 傾斜の緩慢な変化に関しては，水管傾斜計と振子型傾斜計の観測結果はよく合つている．
2) 大きく見て，傾斜変化の方向は 1965 年 11 月 23 日を境として南西（南西下り，北東上り）から北西（北西下り，南東上り）に変つた．
3) 傾斜変動と地震活動との関係については 1965 年 11 月 23 日と 1966 年 3 月 10 日の 2 つの活動期の場合明白に対応がつく．他の場合，個々の比較的大規模な地震と傾斜変化との対応については明らかでない．

毎日の観測は当研究所の斎藤貞夫，高橋辰利の両氏によつてなされた．長い間の尽力に対し感謝の意を表したい．なお，この仕事は気象庁地震観測所の竹花所長ほか所員の方々のご協力をいただいた．ここに厚くお礼を申し上げる次第である．