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Continuous Observations of the Ground Deformations Related to the Matsushiro Earthquakes

By

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Abstract

In order to investigate the relations between ground deformations and seismic activities in Matsushiro and neighbouring regions, continuous observations on the ground tilt and strain were carried out at Matsushiro and Suzaka.

At Matsushiro, three tiltmeters of horizontal pendulum type and two extensometers of bow-string type were installed in the underground gallery bored into Zōzan hill, the western suburb of Matsushiro Town. At Suzaka, two tiltmeters of water tube type and two tiltmeters of horizontal pendulum type were installed in the underground gallery bored halfway up Kamatayama hill, the western suburb of Suzaka City.

As to Matsushiro, it was observed that the velocity of the ground tilt sometimes changed before the occurrence of an earthquake.

As to Suzaka, it proved that the direction of the ground tilt changed markedly every time an earthquake of a magnitude larger than 5.0 occurred, and an anomalous ground tilt appeared before the occurrence of the earthquakes of Sep. 27, 1966, and Feb. 8, 1967.

PART I. Observations at Matsushiro*)

In order to investigate the ground deformation relating to the earthquake swarm which began in August, 1965, continuous observation of the ground tilt and strain was carried out at Matsushiro, as a part of the co-operative observation of the Matsushiro earthquake swarm undertaken by several universities and institutes in Japan.

Three tiltmeters of the horizontal pendulum type and two extensometers of the bow-string type were installed in the underground gallery at Zōzan (36°33.3′ N, 138°11.8′E), where seismometric observations have been conducted by the Earthquake Research Institute. The three tiltmeters were arranged on one concrete base in such a manner that the directions of two were perpendicular to each other, with the other bisecting them, namely E-W, N-S and NE-SW.

The period of the pendulum was about 20 seconds and 1 mm deflection on the recording paper corresponded to the ground tilt of 0.025″. The two extensometers were oriented to N38°E and S52°E and the standard lengths and sensitivities were both 5 m and 1.7×10^{-8} to 1 mm deflection, respectively. Although the observation site was at a distance of about 100 m from the entrance of the gallery, air flowed freely into the gallery and the fluctuations of the air temperature reached a maximum of 3°C, which disturbed observation

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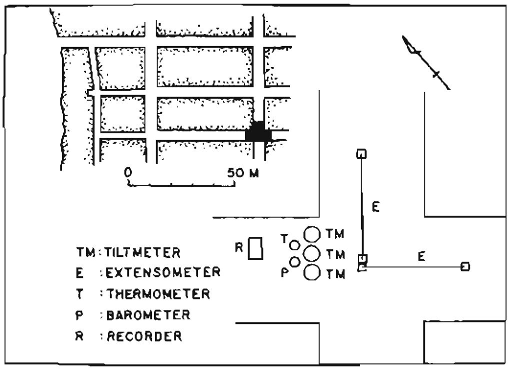

Fig. 1. Plan of the Zōzan gallery and arrangement of instruments.

in some degree. Fig. 1 shows the plan of the Zōzan gallery and arrangement of the instruments.

Observation was continued from Dec. 23, 1965 until Mar. 23, 1966, but it was so often interrupted by large earthquakes, that gaps in data were unavoidable, especially in the case of extensometric observation.

In Fig. 2, changes of the ground tilt, linear strains, room temperature and atmospheric pressure are shown, where the reading interval was 12 hours and abrupt changes in the tiltmetric records appearing at the occurrence of severe earthquakes were smoothly connected, because they were perceived to be instrumental shifts of the neutral position of the pendulum due to violent shocks. Correlation between the ground tilt and strain and temperature is apparently seen in the figure, especially in changes over a short period. As there are many gaps in the data in the extensometric record, we shall consider tiltmetric results only in the

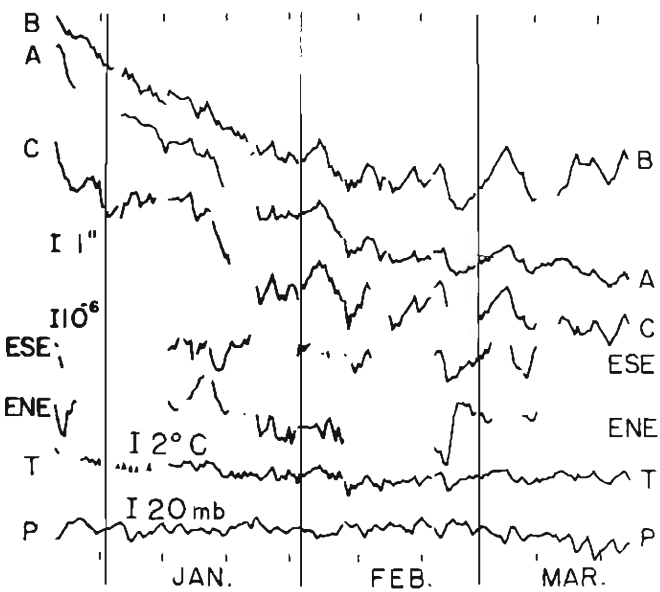

Fig. 2. Secular changes of the ground tilt, strain, room temperature and atmospheric pressure observed at Zōzan.

A : ground tilt (E-W component), B : ground tilt (N-S component),
C : ground tilt (NE-SW component), ESE : ground strain (S52°W component),
ENE : ground tilt (N38°E component), T : room temperature,
P : atmospheric pressure.

following.

Firstly, the amplitudes of the deflections in the tiltmetric records caused by temperature changes were plotted for each instrument to get the correlation between them, the results of which are shown in Fig. 3. If the ground near the concrete base was inclined by thermal expansion, then the tilting vectors synthesized from two arbitrary sets of tiltmeters might coincide with each other. However, the directions of the resultant vectors calculated from the correlation in the figure do not coincide and it is concluded that the thermal influence appearing on the tiltgrams was not attributable to the thermal deformation of the ground but to the bending of the concrete base or to the instrument.

At any rate, for the purpose of reduction of the apparent thermal influence, we have practised subtraction of the term of the temperature change from the original tiltmetric records, by using the correlations represented by dashed lines in the figure which may represent the maximum values, assuming the relations to be linear. The results are shown in Fig. 4.

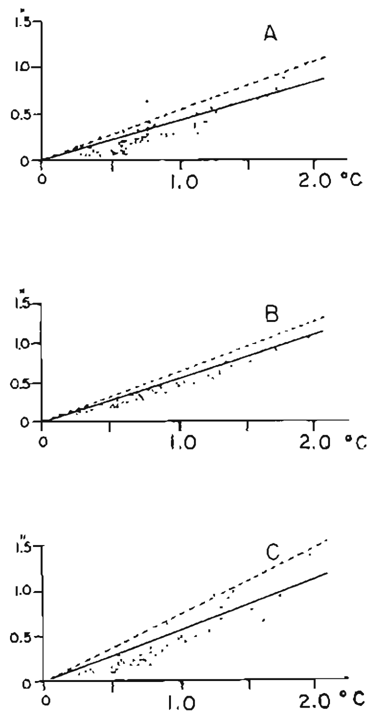

Fig. 3. Relation between the deflection of tiltmetric records and room temperature.

Secondly, as a monotonous drift which may have been caused by the setting up of the instruments is seen in the E-W and N-S components, although it is not so clear in the S45°W component because of the lack of data, we subtracted the drift, assuming it to be approximated as exponential function shown in the

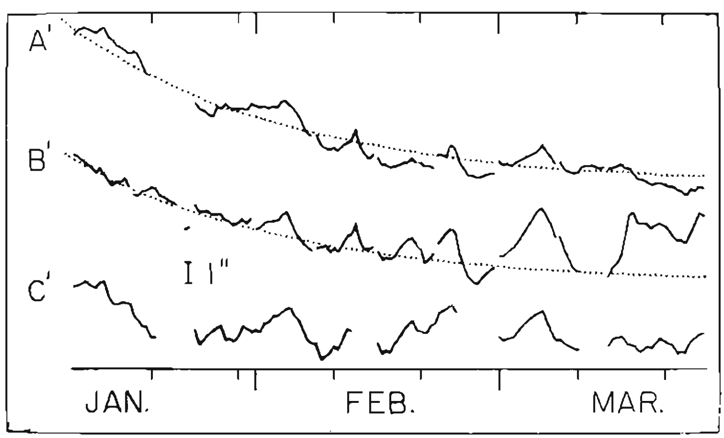

Fig. 4. Secular changes of the ground tilt corrected as to temperature influence.

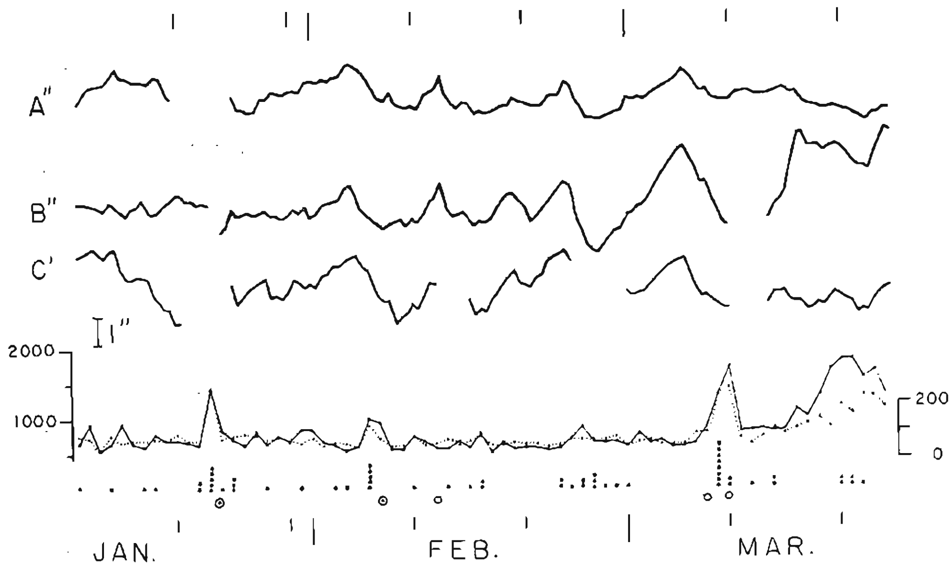

Fig. 5. Secular changes of the ground tilt corrected in regard to temperature influence and monotonous drift, and daily numbers of earthquakes (Reproduced from the Zishin Kazan Gaikyō[1]).

Solid line: Daily numbers of earthquakes.

Dashed line: Daily numbers of felt earthquakes.

●: an earthquake of seismic intensity 3.

○: an earthquake of seismic intensity 4.

⊙: an earthquake of seismic intensity 5.

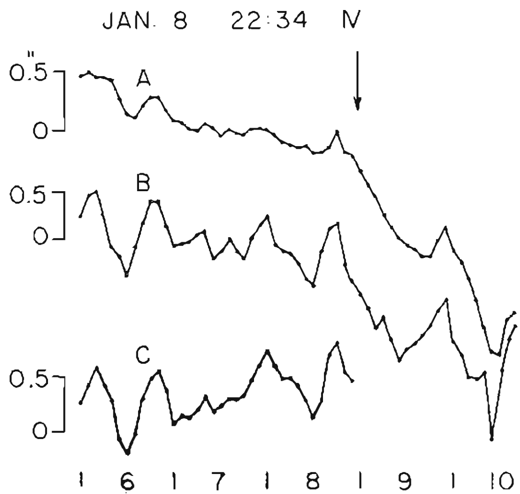

Fig. 6. Ground tilt observed before and after the earthquake on Jan. 8, 22h34m, 1966 (M=4.7[2]).

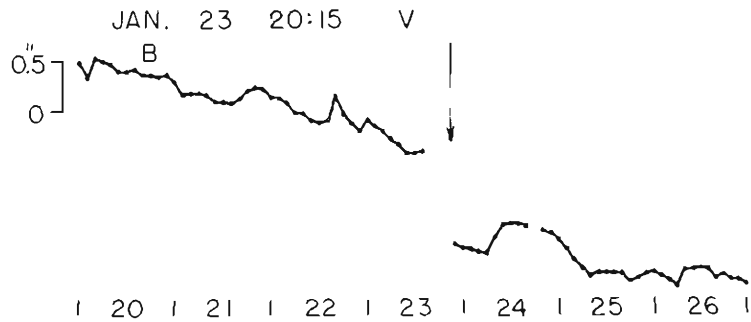

Fig. 7. Ground tilt observed before and after the earthquake on Jan. 23, 20h15m, 1966 (M=4.6[2]).

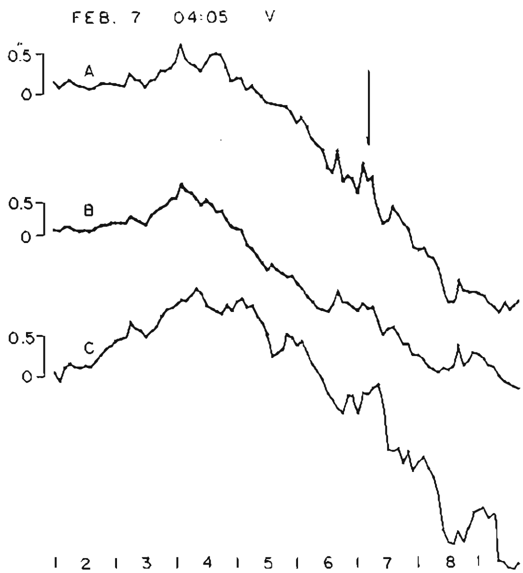

Fig. 8. Ground tilt observed before and after the earthquake on Feb. 7, 04h05m, 1966 (M=4.4[2]).

figure by dashed lines. The results obtained are shown in Fig. 5, together with the daily number of earthquakes and severe ones reported in the Zishin Kazan Gaikyō[1] issued by the JMA.

It is noticeable that the descent of the curves of the tilting corresponds to the increase of seismic activities, namely those in the first and last parts of February, and before and after March 10.

In Figs. 6 to 10, changes of the ground tilt are shown in some detail before and after seven large earthquakes. In each case, disturbances in the temperature change have been reduced by using the correlations represented by solid lines in Fig. 3. However, fluctuation over a period of several hours still remains in these results, which may be attributable to thermal influence. The

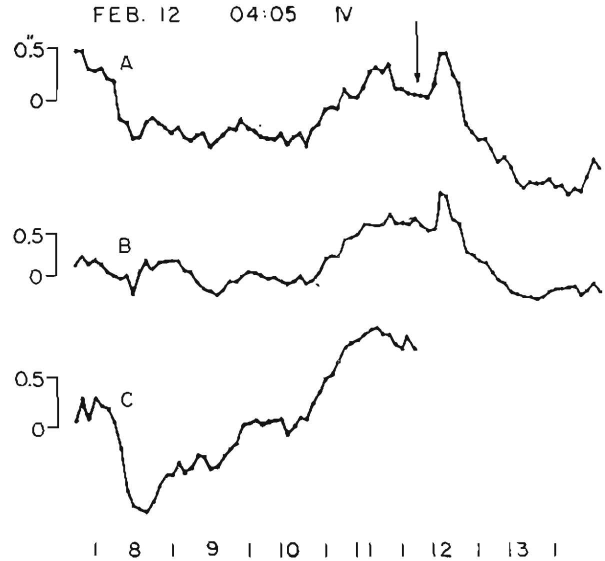

Fig. 9. Ground tilt observed before and after the earthquake on Feb. 12, 04h05m, 1966 (M=4.6 [2]).

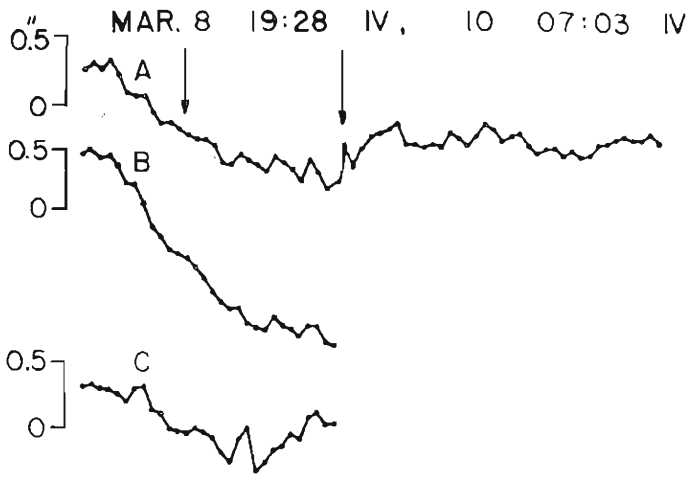

Fig. 10. Ground tilt observed before and after the earthquake on Mar. 8, 19h28m, 1966 (M=4.5 [2]).

reason why we used these different correlations as the thermal influence here is to prevent the overdrawing of the temperature terms, because the relation between tiltgrams and temperature shown in Fig. 4 is not linear and it appears to become larger as the amplitude of the fluctuation of temperature increases.

Fig. 11 shows the epicental distribution of the comparatively large earthquakes

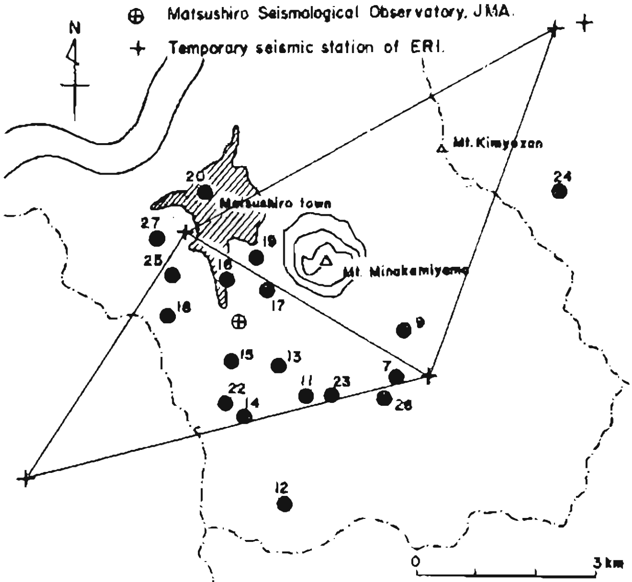

Fig. 11. Epicenters of the Matsushiro earthquakes with Magnitude larger than 4.4 (After Hagiwara, Yamada and Hirai[2]).

which occurred between Dec. 11, 1965 and Mar. 27, 1966, given by T. Hagiwara et al[2]. Zōzan is expressed by the upper cross of the central part on the figure. Numbers 20, 22, 23, 25, 26 and 27 in the figure correspond to the epicenters of the earthquakes that occurred on Jan. 8, 22h34m, Jan. 23, 20h15m, Feb. 7, 04h05m, Feb. 12, 04h05m, Mar. 8, 19h28m and Mar. 10, 07h03m, respectively, and thus the epicenters of the first (Fig. 6), fourth (Fig. 9) and the last (Fig. 10) were located near Zōzan, so that the epicentral distances might be smaller than 1 km.

A velocity change in the tilting movement is apparent at the occurrence of the earthquake on Jan. 8, as seen in Fig. 6, and a similar phenomenon can be seen at the time of the earthquake occurrence on Mar. 10 (Fig. 10), although only the record of the E-W component could be obtained without scale out by the shock in this case. Moreover, such a tendency of the anomalous tiltings of the ground seems to have begun several hours before the occurrence of these earthquakes. It has not been ascertained whether the gradual change in tilting from Feb. 12 to 13 seen in Fig. 9, is a real movement of the ground relating to the earthquake occurrence or a thermal influence. As to other earthquakes, no characteristic changes can be seen, which may be caused by the long distance to the epicenters.

These peculiar tilting movements including those of the secular changes mentioned above, cannot be immediately concluded to be crustal movements relating to the occurrence of earthquakes, since the thermal influence could not be completely reduced and the amounts of the tilting movements are somewhat large, compared with the results observed at Matsushiro Seismological Observatory by T. Hagiwara et al[2].

However, the discrepancy in the amounts of the tilting movement may be interpreted as being due to the difference of the epicentral distances, circumstances of the observation sites and source mechanisms of earthquakes, and furthermore the mode of the tilting motions bears a striking resemblance to that reported by E. Nishimura[3], nevertheless the magnitude and focal depth of earthquakes are considerably different compared with the present case.

Consequently, it is inferred that the two examples of the tilting movements of the ground observed shortly before and after the earthquakes on Jan. 8 (Fig. 6) and Mar. 10 (Fig. 10) are characteristic patterns of the crustal movements related to the occurrence of earthquakes.

The writers would like to express their sincere gratitude to Prof. T. Hagiwara and Mr. S. Saito, of the Earthquake Research Institute of University of Tokyo, for providing so many facilities for this observation. The assistance of Mr. Y. Horiuchi, teacher, and pupils of the Matsushiro Upper Secondary School with this work is also gratefully acknowledged. The assistance from the Science Research Fund of the Ministry of Education was essential to the completion of the work.

PART II. Observations at Suzaka*)

1. Situation of the observing station and the instruments

The observing station is situated in an underground gallery reticulately bored halfway up Kamatayama hill, the eastern suburb of Suzaka City. The gallery was bored by the military for an air-raid shelter at the time of the Second World War. Kamatayama hill is composed of porphyrite of which the degree of weathering is comparatively low. The breadth and height of a cross-section of the gallery are 4 and 3 metres respectively and the total length of the gallery is about 270 metres; the observing room being a part of the gallery divided by partition walls. The interior of the observing room is well dried, the room temperature being kept constantly at about 16°C. The location of the observing room is as follows:

Latitude φ:	36°38.7′N
Longitude λ:	138°19.7′E
Height above sea level H:	450 metres
Depth below the earth's surface D:	40 metres

In July, 1966, two tiltmeters of water-tube type and two tiltmeters of horizontal pendulum type were installed in this observing room. The length of each water-tube tiltmeter was 20 metres. The horizontal pendulum tiltmeters were Zöllner suspension type and made of super-invar alloy. The setting direction of one water-tube and one pendulum tiltmeter was N18°E-S18°W, and that of the other water-tube and pendulum tiltmeter was E18°S-W18°N.

2. Observational results using the water-tube tiltmeters

Observations using the water-tube tiltmeters were commenced on the 22nd of

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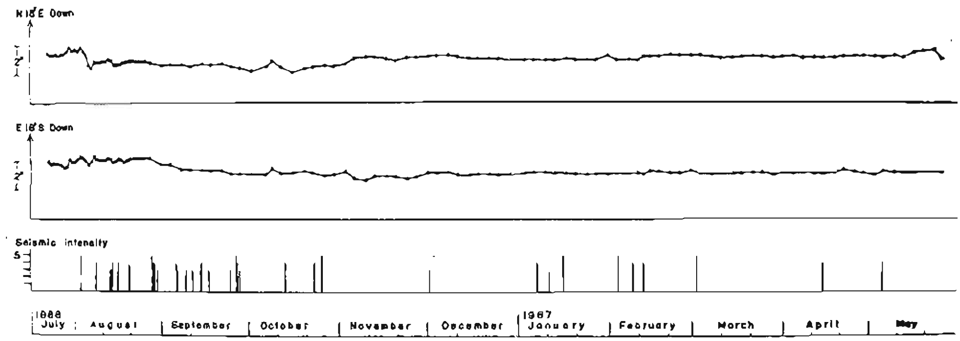

Fig. 12. Reading values of the ground tilt at Suzaka using the water-tube tiltmeters.

July, 1966. Readings were taken once a day in the period from July 22nd to August 26th and twice a week thereafter.

Fig. 12 shows the values of the readings. These reading values are considered to include some effects by meteorological disturbances and some instrumental and observational errors. But in this paper no corrections were applied for these reading values. The seismic intensities in Fig. 12 are based on the publications[4] by the Japan Meteorological Agency and some unofficial information.

Fig. 13 is the vectorial representation of the ground tilt shown by the reading values in Fig. 12. In Fig. 13 the direction of a vector shows the downward ground tilt. Since no corrections were applied the vectorial locus is very ir-

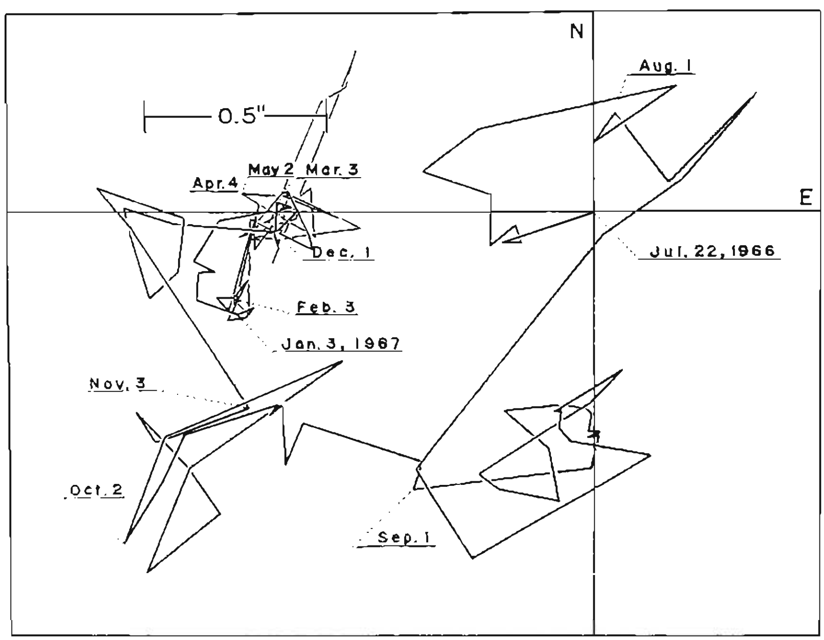

Fig. 13. Vectorial representation of the ground tilt at Suzaka, one vector showing the downward ground tilt in that direction.

regular, at first sight. But if it is examined in detail it will be found that the vectorial locus is retarded in four domains: the first neighbouring the origin (from July 22nd, 1966, to August 5th), the second southward from the origin (from August 6th to September 4th), the third south-westward from the origin (from September 8th to November 3rd), and the fourth westward from the origin (from November 6th to the present).

Table 1 shows the earthquakes of a magnitude larger than 5.0 which occurred in the neighbouring region of Matsushiro during the observation period. Fig. 14 shows the location of the epicentres of these earthquakes and the observing station. Earthquake No. 1 just occurred in the first retarding domain in Fig.

TABLE 1.
Earthquakes of a magnitude larger than 5.0 which occurred in the neighbouring region of Matsushiro in the period from July 22nd, 1966, to May 31st, 1967.

Earthq. No.	Date	Time	Hypocentre			Magnitude	Epicentral distance
			Latitude	Longitude	Depth		
1	1966 Aug. 3	03 h 48m	36°28′N	138°12′E	3km	5.0	22.8km
2	Aug. 28	13 09	36 28	138 08	6	5.2	26.1
3	Oct. 26	03 04	36 36.6	138 20.8	9	5.1	4.8
4	1967 Feb. 3	17 17	36 26.5	138 03.9	10	5.1	32.2

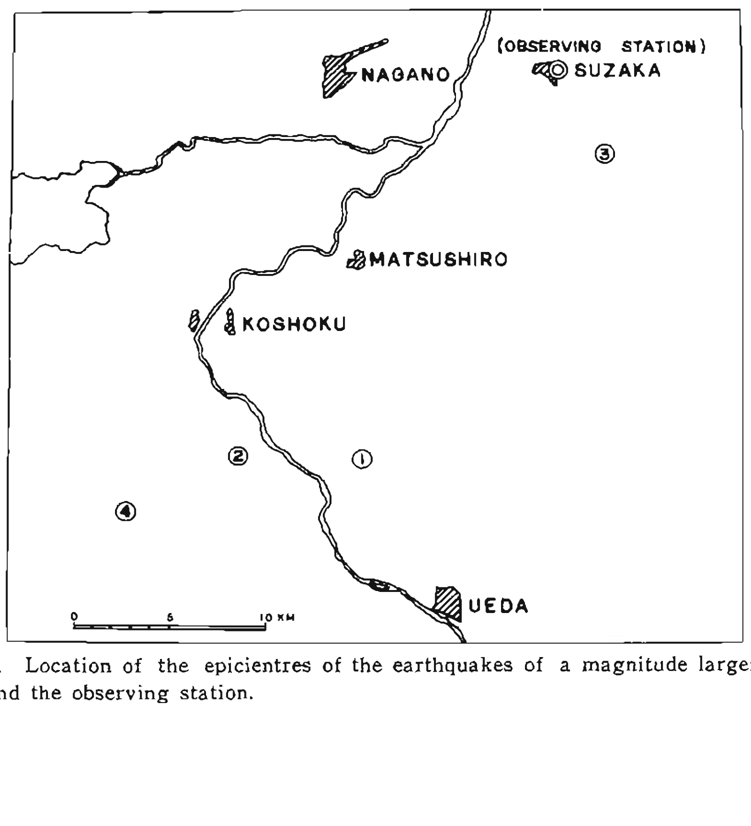

Fig. 14. Location of the epicientres of the earthquakes of a magnitude larger than 5.0 and the observing station.

13, No. 2 in the second domain, No. 3 in the third domain, and No. 4 in the fourth domain, that is to say four earthquakes of a magnitude larger than 5.0 just occurred one by one in each of the four domains without exception. In other words, the tilting movement of the ground at Suzaka markedly changed its direction every time an earthquake of a magnitude larger than 5.0 occurred.

This observational fact shows that the tilting movement of the ground at Suzaka proceeded through four stages in this observation period, though seismic activity in the period appears to be unitary from the point of view of seismic frequency.

3. Observational results using the horizontal pendulum tiltmeters

Observations using the horizontal pendulum tiltmeters were carried out by means of the photographic self-recording method, the recording paper usually being changed once a week. This type of tiltmeter is so sensitive to ground tilt that the record used to be discontinued every time a large earthquake occurred; consequently, for the observation period, it was impossible to draw such a continuous diagram of ground tilt as that of the water-tube tiltmeters. But, this observation was not entirely useless because very valuable records were obtained twice in the observation period.

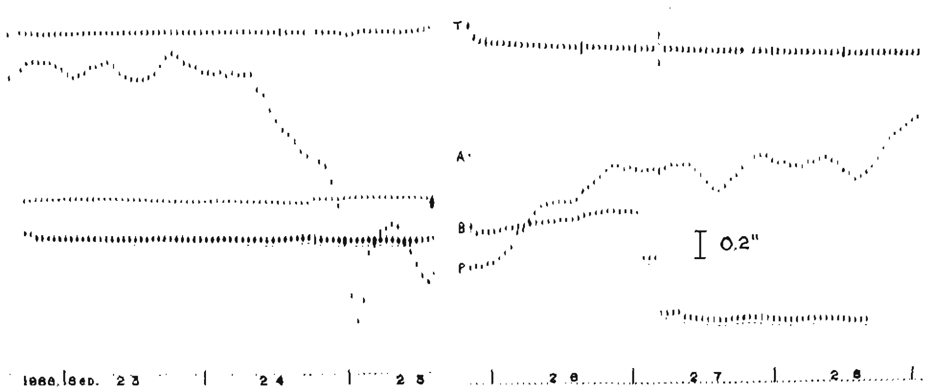

Fig. 15. A tiltgram obtained by means of the horizontal pendulum tiltmeters before and after the occurrence of the earthquake on September 27th, 1966.

Fig. 15 is a connected record of the latter half of that from September 18th to 25th and the first half of that from September 25th to October 2nd, where A, B, P and T denote respectively the N18°E-S18°W component for ground tilt, E18°S-W18°N component for ground tilt, atmospheric pressure, and room temperature. Interruption of the record for 5 hours on September 25th was caused by being detained for the change of recording paper and readjustment of the instruments. Interruption of A after 25th, which is much regretted, was caused by trouble with a light source.

Setting that aside and turning our attention to the change in B, it will be clearly observed that around 12 o'clock on the 25th the B-curve began to ascend, meaning that the ground at Suzaka began to tilt down towards an E18°S direction, around 8 o'clock on the evening of the 26th it reached the highest point, thereafter it slightly descended, though there remains some question that it might have depended on tidal change. At half an hour past midnight and at 4 o'clock on the 27th it suddenly and spectacularly descended. Thereafter it continued to descend a little.

Just at the time of the second sudden descent, strictly speaking at 3 minutes past 4 o'clock on the 27th, there occurred an earthquake of magnitude 4.6 and intensity 5 in Kōshoku City. According to seismometric observations made by the members of the Disaster Prevention Research Institute, Kyoto University, just at the time of the first sudden descent, strictly speaking at 29 minutes past midnight on the 27th, there occurred another earthquake of magnitude 2.5 to 3.0, which might be regarded as a foreshock of the earthquake at 4 o'clock.

Considering these circumstances, it may be said with considerable reliability that, about 40 hours before the earthquake which occurred at 3 minutes past 4 o'clock on September 27th, 1966, the ground at Suzaka began to tilt down in the direction of E18°S, about 8 hours before that it reversed its direction, and about 3.5 hours before that it suddenly recovered by a foreshock, proceeding farther by the main shock. The above is only concerned with the ground tilt in the E18°S-W18°N direction. Concerning the ground tilt in other directions, it is regretted that we have no other information because of the lack of records.

The only matter weighing on our mind is the effect of meteorological disturbances on the ground tilt. As can be easily supposed from the P-curve in the record, on the 25th of September a typhoon passed over or near Japan, bringing considerable precipitation. It is supposed, as a matter of course, that the change of atmospheric pressure and precipitation by this typhoon might have had some effect on the ground tilt at the observing station. But at present we have no exact knowledge about this matter, because our observation is not so long that a statistical conclusion could be derived from it about this matter.

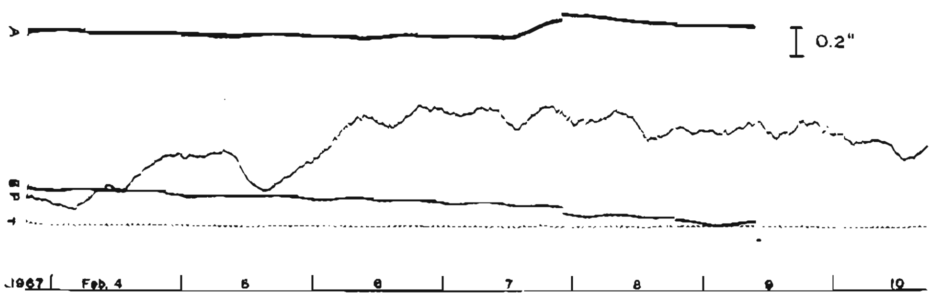

Fig. 16. A tiltgram before and after the occurrence of the earthquake on February 8th, 1967.

Fig. 16 shows another example of the o'clock ground tilt related to the occurrence of an earthquake. At 49 minutes past 6 o'clock on the evening of February 8th, 1967, there occurred an earthquake of magnitude 4.2 and intensity 4 in Sakai Village. Before then, around 10 o'clock at night on the 7th and 2 o'clock on the 8th, there occurred two small earthquakes which were regarded as the foreshocks of the earthquake of magnitude 4.2. Around 1 o'clock in the afternoon of the 7th the A-curve began to ascend, meaning that the ground began to tilt down towards an N18°E direction, but at the time of the first foreshock it reversed its direction.

A phenomenon common to this and the former examples is that the ground tilt reversed the direction of its movement at the time a foreshock occurred. This observational fact seems to indicate that the deformation of the earth's crust reversed the direction of the process at the time the forerunning fractures of rocks at the focal region commenced. If such behaviour of the crustal deformation is common to all earthquakes, it will much useful for earthquake prediction. But according to past observational results it is not always so. More observational examples are needed before drawing any conclusions about this problem and predicting the occurrence of earthquakes.

Acknowledgement

The authors thank the members of the Suzaka Municipal Office and Mr. Eiji Okawa and Mr. Kiichi Miyazaki for their help with the carrying out of this observation. This study was supported by the reserve fund of the Japanese Government.

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