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TILTING MOVEMENT OF THE GROUND 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 Suzaka City, Nagano Prefecture.

Two tiltmeters of water-tube type, two tiltmeters of horizontal pendulum type and three extensometers of Benioff type were installed in the underground gallery bored halfway up Kamatayama hill, the eastern suburb of Suzaka City.

From the tiltmetric observations 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.

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. In addition to these, in May, 1967, three extensometers of Benioff type were installed in the same observing room. In this paper some observational results by tiltmeters are merely reported.

2. Observational results by the use of the water-tube tiltmeters

Observations using the water-tube tiltmeters were commenced on the 22nd of July, 1966. This epoch just corresponds to the commence of the third period in the seismic activities of the Matsushiro earthquake swarm. The readings of the ground tilt were taken once a day in the period from July 22nd to August 26th and twice a week thereafter.

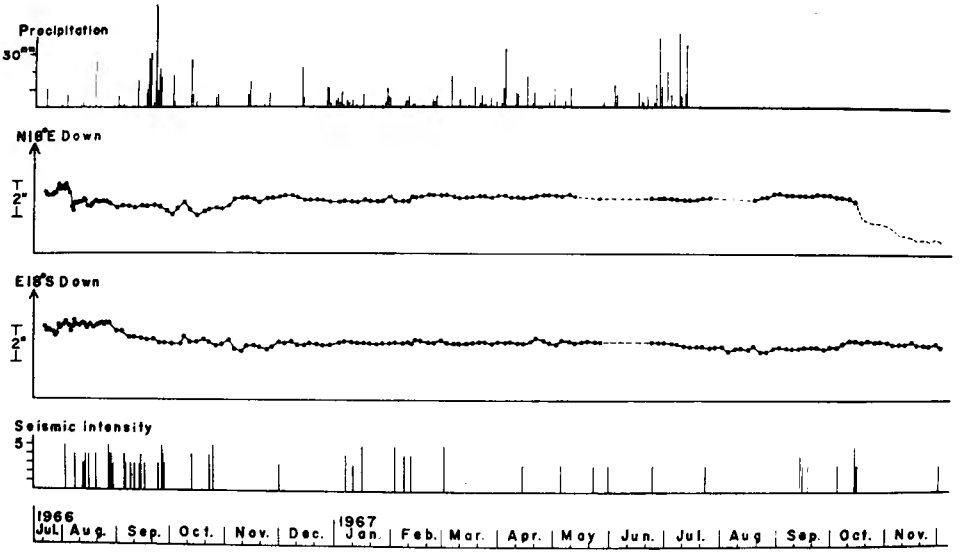

Fig. 1. Reading values of the ground tilt at Suzaka using the water-tube tiltmeters.

Fig. 1 shows the reading values from the commence to the present. 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. 1 are based on the publications [1967] by the Japan Meteorological Agency and some unofficial informations. Precipitation is based on the observations at the Nagano Meteorological Observatory.

Fig. 2 is the vectorial representation of the ground tilt shown by the above-mentioned reading values. In Fig. 2 the direction of a vector shows the down-

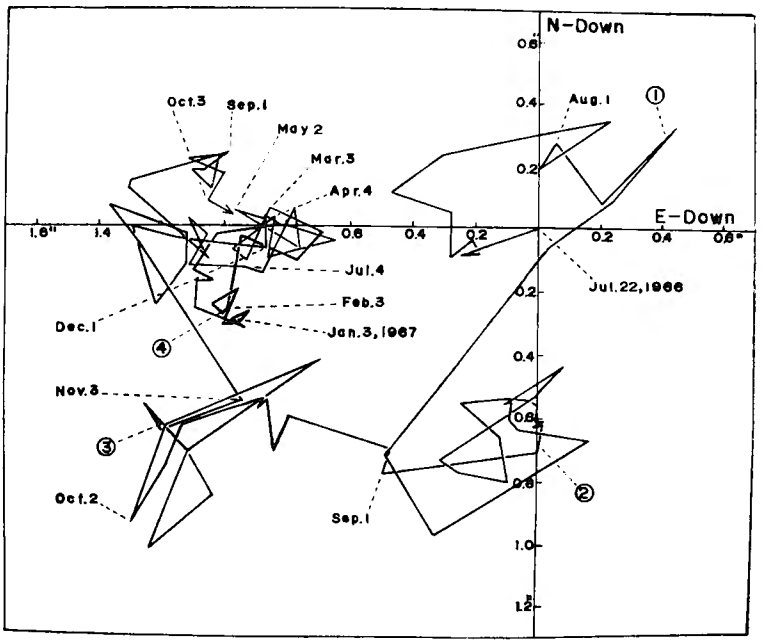

Fig. 2. Vectorial representation of the ground tilt at Suzaka, one vector showing the downward ground tilt in that direction.

ward ground tilt. Since no corrections were applied the vectorial locus is very irregular, 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. 3 shows the location of the epicentres of these earthquakes and the observ-

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	3 km	5.0	22.8 km
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

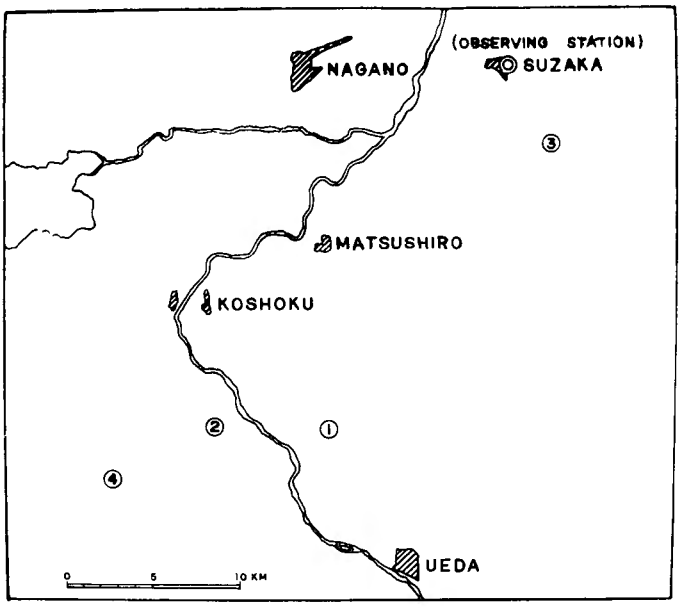

Fig. 3. Location of the epicentres of the earthquakes of a magnitude larger than 5.0 and the observing station.

ing station. Earthquake No. 1 just occurred in the first retarding domain in Fig. 2, 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. It is also pointed out by Hagiwara *et al.* [1966] that the direction of ground tilt has changed after large earthquake activities.

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

3. Observational results by the use of the horizontal pendulum tiltmeters

Observations using the horizontal pendulum tiltmeters were carried out by means of 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

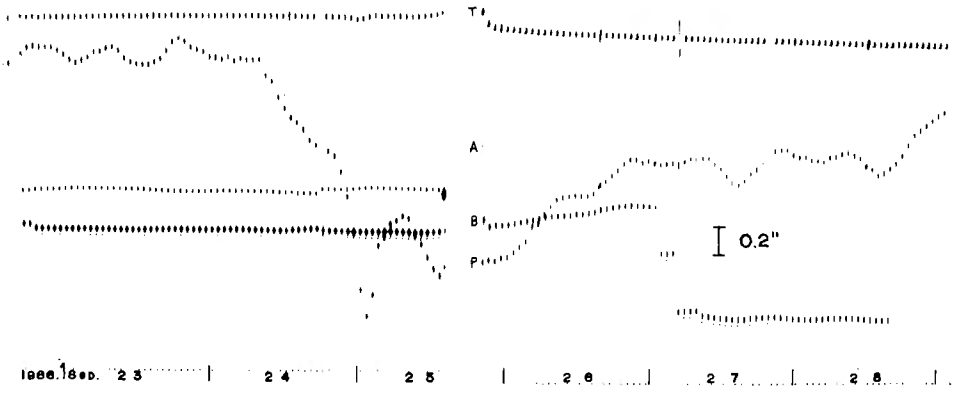

Fig. 4. A tiltgram obtained by means of the horizontal pendulum tiltmeters before and after the occurrence of the earthquake on September 27th, 1966.

observation was not entirely useless because very valuable records were obtained twice in the observation period.

Fig. 4 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-component after 25th, which is much regretted, was caused by some trouble with a light source.

Setting that aside and turning our attention to the change in B-component, it will be clearly observed that around 12 o'clock on the 25th the B-curve began to ascend, it meaning that the ground at Suzaka began to tilt down towards an E18°S direction, around 8 o'clock in 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 leapt down. Thereafter it continued to descend slightly.

Just at the time of the second leap, 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 of Kyoto University, just at the time of the first leap, 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 occurred at 3 minutes past 4 o'clock on September 27th, 1966, the ground at Suzaka began to tilt down towards the direction of E18°S, about 8 hours before the earthquake 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 E18°S–W18°N component in the ground tilt. Concerning the ground tilt in other directions, which is much regretted, we have no information because of lack of the record on A-component.

The only matter is the effect of meteorological disturbances on the ground tilt. As can be easely supposed from the P-curve in the record, on the 25th of September the Typhoon No. 24 has passed on the west side of Suzaka, 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, this question will be solved by the next figure.

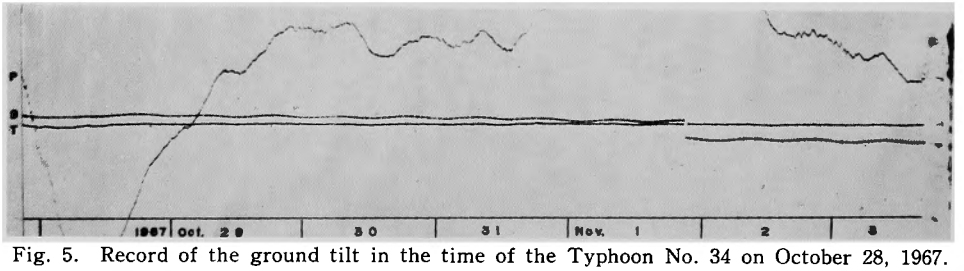

Fig. 5. Record of the ground tilt in the time of the Typhoon No. 34 on October 28, 1967.

Fig. 5 is the record at the time of the Typhoon No. 34 on the 28th of October, 1967. From this record we can not find such an anomalous change in B-component as in that of the former record. From these it may be said that the anomalous ground tilt on September 25th, 1966, was surely caused by the earthquake.

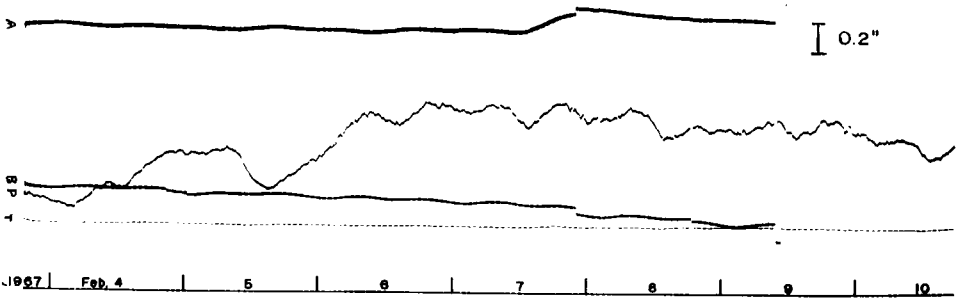

Fig. 6. A tiltgram before and after the occurrence of the earthquake on February 8th, 1967.

Fig. 6 shows another example of the ground tilt related to an earthquake. At 49 minutes past 6 o'clock in the evening of February 8th, 1967, there occurred an earthquake of magnitude 4.2 and intensity 4 in Sakaki 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, it meaning that the ground began to tilt down towards a 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 tilting 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 its process at the time the forerunning fractures of rocks in the focal region commenced. If such a behaviour of the crustal deformation is common to all earthquakes, it will be very useful for earthquake prediction. But, according to past observational results it is not always so. More observational examples are needed before drawing any conclusion about this problem and predicting the occurrence of earthquakes.

Acknowledgement

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