

Observed Secular Tilting Motion of the Ground which Preceded the Occurrence of Several Destructive Earthquakes

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Abstract

Some details of tilting motion of the ground continuously observed for a long period with the aid of the highly sensitive, fused-silica tiltmeter of horizontal pendulum type at the Kamigamo Geophysical Observatory is described in this paper, with regard especially to the secular ground-tilting in connection with seismic activity in the surrounding area of the Observatory. It was consequently clearly ascertained, after the careful examination and perfect exclusion of various disturbing effects, that the ground commenced a characteristic tilting motion downward to the direction of the epicenter several months before the occurrence of the destructive earthquakes, and showed a recovering motion after the quakes, so far as the present cases of the five destructive earthquakes around the Observatory concern.

1. Introduction

The study of the phenomena forerunning the occurrence of a large destructive earthquake is not only important in the field of practical seismology to mitigate earthquake-damage, but it will also largely serve us for the advancement of our knowledge on the nature of earthquake as well as on the mechanism in its occurrence. Particularly the study of crustal deformation, especially upheaval and subsidence of the ground made clear by the geodetic survey of triangulation and levelling after the occurrence of a large destructive earthquake, is considered to help in bringing the problem to the solution. Along this line of research, the observation on ground-tilting, ground-strain, variation of geomagnetic element, time change of gravity intensity and other phenomena has been carried out by our Institute at 24 different stations in Japan since the early part of 1937. During the period of the twenty years certain interesting

phenomena forerunning some destructive earthquakes have been reported by SASSA and NISHIMURA (1951, 1956), HOSOYAMA (1952), NISHIMURA (1953), NISHIMURA and HOSOYAMA (1953), and some other scholars. In this article, certain characteristics of secular tilting motion of the ground observed at the Kamigamo Geophysical Observatory, which have preceded several destructive earthquakes originating in the surrounding area of the Observatory, are reported after some detailed analysis of and discussion on the large amount of observational data obtained with the highly sensitive tiltmeter during the long period of twenty years.

2. Twenty years of observations at the Kamigamo Geophysical Observatory

The tiltmetric observation at the Kamigamo Geophysical Observatory of Kyoto University was started early in 1910 by T. SHIDA

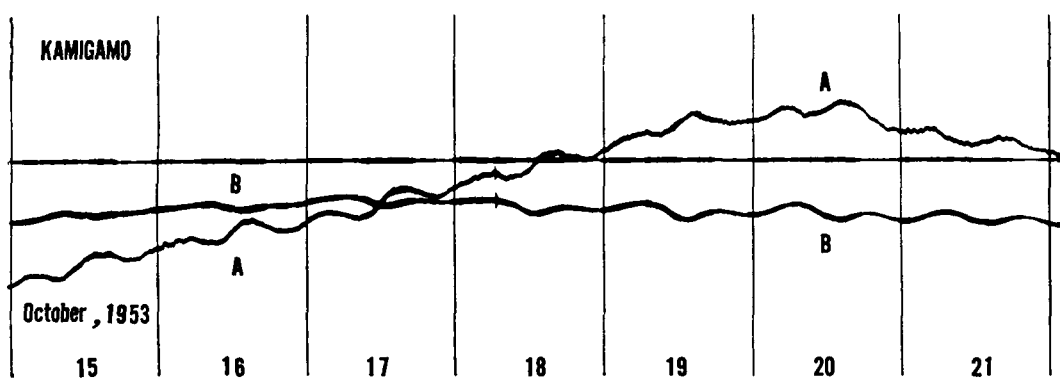


Fig. 1. Tiltgram observed at Kamigamo.

(1912) with the tiltmeter of Rebeur-Paschwitz type of point-suspension and continued for nearly two years, and after some interruptions it was resumed by one of the writers of this article in 1937 with the tiltmeter of horizontal pendulum type of Zöllner-suspension, which has been continued to the present time.

The Observatory is located at $135^{\circ} 46' E$ and $35^{\circ} 04' N$ at the north end of Kyoto City, and stands on a hill of 190 m above sea level and 100 m in relative height, the rock formation being chert mixed with shale and sandstone of Chichibu Paleozoic system. For the tiltmetric observation the fused silica-tiltmeter of the horizontal pendulum type of Zöllner-suspension devised by M. ISHIMOTO (1928) has been used since 1937 to the present time without any interruption. The tiltmeter is set up at the bottom of the concrete dry well built in the basement room of the stone building. The depth of the well is 9 m below the ground surface. The sensitivity of the tiltmeter has been kept nearly at $0''.003/\text{mm}/3\text{m}$ on the photographic recording paper, which is changed once a week, the length of the one day-mark being 70 mm.

As is shown in an example of tiltgram observed at Kamigamo in Figure 1, the meteorological effect which is largely observed in general, is comparatively small at Kamigamo. Besides, the local deformation of the observation room, usually caused by the enormously large rock pressure in case of the deeply seated observation room, and disturbing the study of secular tilting motion of the ground, is little observed in the present case.

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Concerning these disturbing effects, K. HO-SOYAMA (1957) has fully discussed them, giving the large amount of analysed data observed during good many years at many stations in different conditions. From these circumstances the tiltmetric observational data at Kamigamo is considered to be certainly serviceable for the study of secular ground-tilting connected with the crustal deformation in the comparatively large area.

The procedure of the analysis is as follows: the daily value is first determined by dividing the sum of hourly read values during oh to the next oh by 25 for the reason that the earth tidal change is predominantly observed in the present case. Secondly the monthly value is calculated from the average of thus obtained daily values, which is plotted in Figure 2. In the same Figure, the monthly mean of atmospheric temperature and pressure, and the monthly amount of precipitation observed at Kamigamo are plotted together for the convenience of reference with the monthly mean value of ground-tilting.

As clearly seen in Figure 2, the annual variation of ground-tilting observed at Kamigamo was ascertained to be fairly regular and the amplitudes are considered to depend, in a certain degree, on the value of annually mean atmospheric temperature and pressure, and not directly connected with the amount of precipitation. Contrary to the close relation between the amplitude of annual variation of ground-tilting and meteorological elements, the secular ground-tilting obtained from the annually averaged value of the monthly values

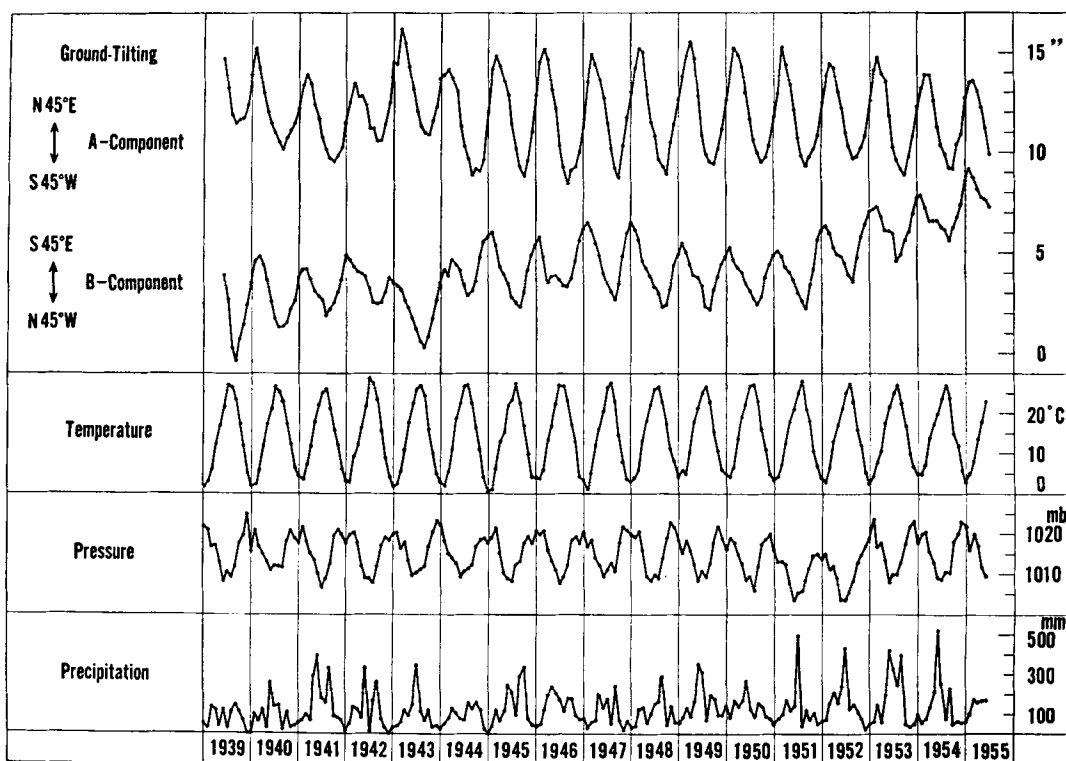


Fig. 2. Annual ground-tilting observed at Kamigamo during the epoch of 1939–1955.

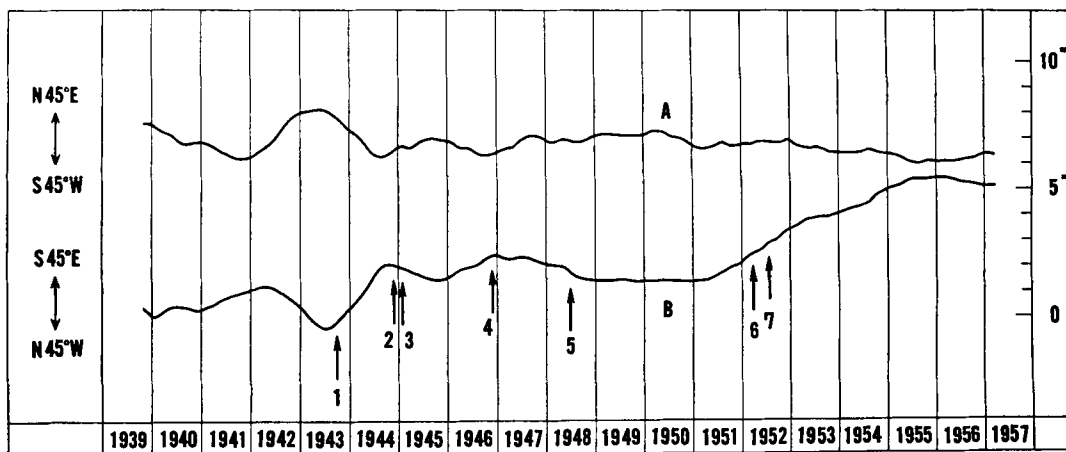


Fig. 3. Secular ground-tilting observed at Kamigamo during the epoch of 1939–1957.

is certainly said to have no connection with any change of meteorological element. And, in the case of Kamigamo, the effect caused by the deformation of the observation room on account of rock pressure is, as already mentioned, favourably small and may safely be neglected in the present argument. Under these circumstances the secular ground-tilting which is considered to be unaffected by any disturbing effect, is graphically represented in Figure 3.

3. Characteristic ground-tilting observed before the occurrence of several destructive earthquakes

During the recent twenty years, seven destructive earthquakes have occurred, whose seismic magnitudes in Pasadena scale were more than 7 and with epicentral distances within about 200 km from Kamigamo. Their respective conditions are tabulated in the following and their positions of epicenter represented in Figure 4.

No.	Name	Date	Magni- tude	Epicentral distance
1	Tottori	Sept. 10, 1943	7 1/2	150 km
2	Tonankai . .	Dec. 7, 1944	8	150
3	Mikawa	Jan. 13, 1945	7.1	120
4	Nankaido . .	Dec. 21, 1946	8.2	230
5	Fukui	June 28, 1948	7 1/4	130
6	Daishoji-Okii	Mar. 7, 1952	7 1/4	160
7	Yoshino	July 18, 1952	7	70

The times of occurrence of these seven earthquakes are indicated by the arrows in Figure 3 together with the curve of secular ground-tilting. In the same Figure, the upward motion of the A- and B-component shows the downward ground-tilting to the direction of N 45° E and S 45° E respectively. From this Figure the following points will be observed with some certainty. Namely, with regard to five earthquakes of No. 1, 2, 4, 5, and 7, the ground at Kamigamo has shown a characteristic tilting-motion nearly one year before the occurrence of respective earthquakes. But, it should be remarked here that these characteristic ground-tiltings, forerunning earthquakes, had actually appeared in the time of less than one year, say several months, before the occurrence of the earthquake. Because the secular ground-tilting at any month represented in Figure 3 is the value calculated from the running mean of the preceding and succeeding six months of any month. Practically speaking, the ground had commenced a peculiar tilting motion continuously downward to the direction of epicenter several months before the earthquake-occurrence, and, in general case, these ground-tiltings reversed their direction after the earthquake-occurrence. This character was clearly observed, especially with respect to the cases of the earthquakes No. 1 (Tottori), No. 2 (Tonankai) and No. 4 (Nankaido), and though somewhat vaguely, in the cases of the earthquakes No. 5 (Fukui) and No. 7 (Yoshino). Concerning the two cases of the earthquakes No. 3 (Mikawa) and No. 6 (Daishoji-Okii), it is reasonably interpreted that such kind of ground-tilting as above mentioned was not observed at Kamigamo for the reason mainly of their rather small seismic magnitude and comparatively large epicentral distance, though other conditions also were of influence. In Figure 4, the

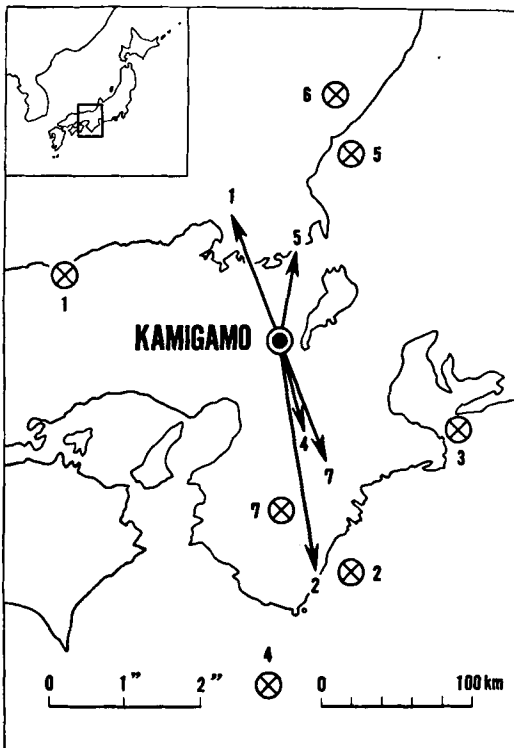


Fig. 4. Characteristic ground-tilting preceding the occurrence of earthquake

characteristic ground-tiltings, which were observed several months before the earthquake-occurrence, are vectorially represented with respect to five earthquakes concerned.

It is difficult to consider that the obtained relation between these characteristic tilting motions of the ground at Kamigamo and the occurrence of earthquakes originating in the surrounding area of Kamigamo is merely accidental. Consequently, it is safely concluded that these characteristic, secular ground-tiltings have, though, in the present stage, it should be treated half qualitatively, an intimate connection with the occurrence of earthquakes, and will be of great value, in the near future,

for the advancement of our knowledge on the nature of earthquakes, and of the practical technique of earthquake-prediction. In addition, the surrounding area of Kamigamo has, seismically speaking, been exceedingly calm in the recent five years (1953—1957), as seen in Figure 3. But, with regard to the aspect of secular ground-tilting at Kamigamo, the reversion, observed especially in the B-component, from the beginning of 1956 should carefully be treated, and it may possibly foretell, in the near future, the occurrence of any destructive earthquake in the surrounding area of Kamigamo.

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