40. *On Different Types of Time-variation in the Rate of Vertical Displacement of Bench-marks in Tôkyô and its Vicinity.*

By Naomi MIYABE,

Earthquake Research Institute.

(Read May 17, 1932.—Received June 20 1932.)

1. There are more than 60 bench-marks distributed in Tôkyô and its vicinity. These bench-marks are connected by levelling routes as shown in Fig. 1. The levelling surveys along these routes were carried out 11 or 12 times since the year 1892, except for the route from Hukagawa-Kôen (B. M. 9831) to Hunabasi (B. M. J-3828 (Fig. 1) which was surveyed 5 times, since the bench-marks along this route was installed in 1918. The dates of these levelling surveys with the times elapsed

Table I.

No. of Survey	Dates of Survey	Years elapsed since the former survey was carried out
1	1892·II—IV ***	—
2	1894·I—IV	2·0
3	1895·XII—1896·III	1·9
4	1899·I—IV	3·1
5	1902·III—IV	3·4
6	1909·XII—1910·III	7·9
7	1914·IV—VII	4·2
8	1918·IX—XII	4·3
9	1923·X—1924·II	5·2 *
10	1925·XI—1926·IV	2·0
11	1930·II—III	4·2
12	1931·VII	1·3 **

* The data of the vertical displacements of B. M.'s 9831, 9832, 9833, 9834, 9835, 9836, 9837, 9838, 9839, 9840, 9841, 9842 and 9843 are obtained first in the result of this survey.

** This survey was carried out along the routes.
- i) From the Standard Datum Point to Kasukabe (B. M. 2014) via Senzyu ;
- ii) From Nippori (B. M. 24) to Ômiya (B. M. 482) via Itabasi ;
- iii) From Bakuro-tyô (B. M. J-5) to Kameido (B. M. 3379) ;
- iv) From Sin-hunamatu-tyô (B. M. J-0) to Suna-mati (B. M. 9834).

*** Numerical figures in roman type denote the month.

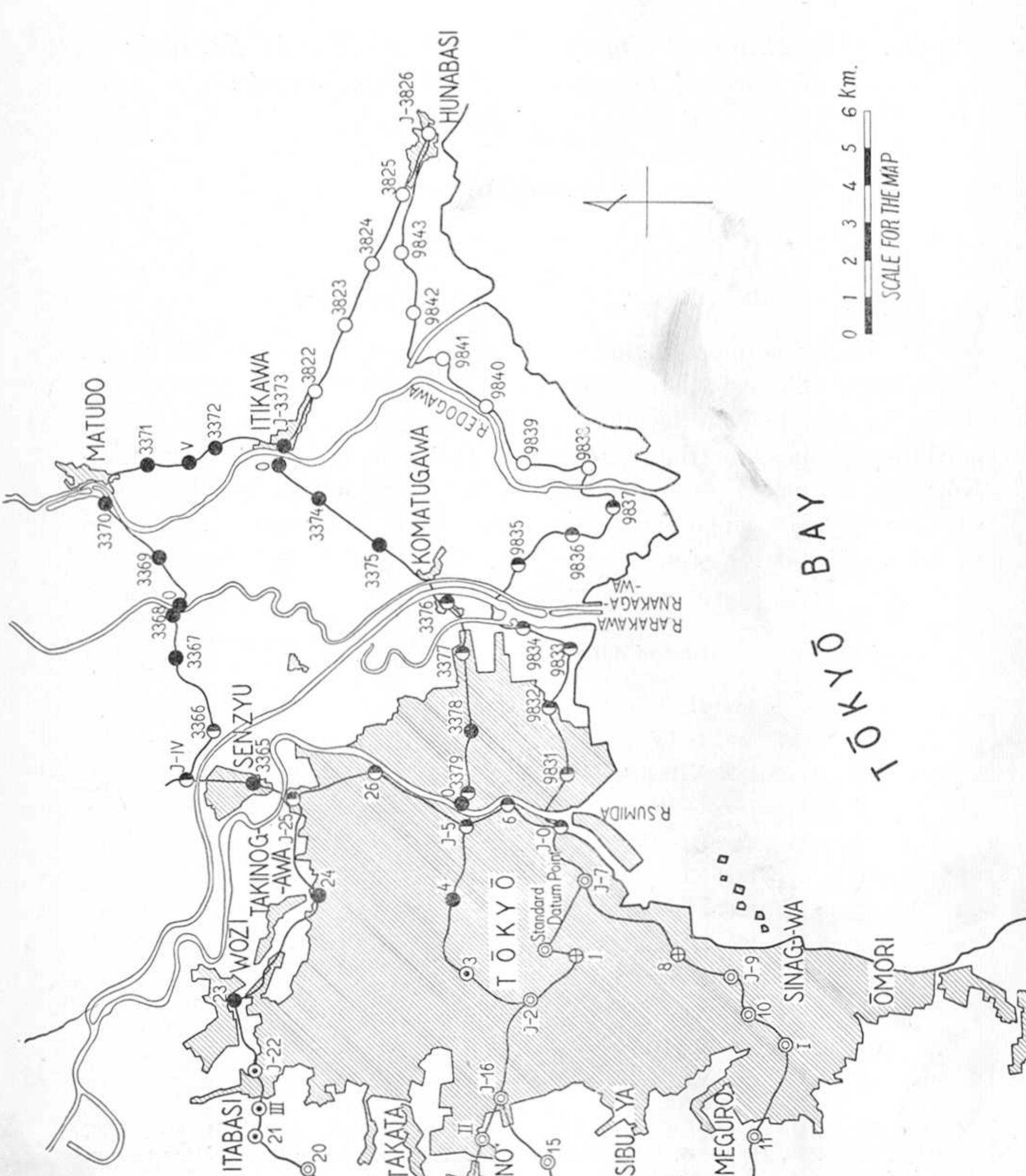

Fig. 1. Distribution of Bench-marks in Tôkyô and its Vicinity.

between successive surveys are shown in Table I.

The present writer intended to investigate the modes of the time variations of the vertical movement of the earth's crust in the vicinity of Tôkyô by utilizing the above data. For this purpose, the time rate of the vertical displacements of each bench-mark for different time intervals were calculated. As the time intervals during which the vertical displacements measured had taken place are not the same for different epochs, the discussions on the time variations of the modes of vertical movements should be based on the time-rates thus obtained.

The data of vertical displacements of the bench-marks employed in the present investigation were taken from Messrs K. Mutô and K. Atumi's paper,[1] the Report on the Results of the Levelling Surveys of 1930[2] and that of 1931.[3]

2. The rate of vertical displacement of each bench-mark is obtained by dividing the vertical displacement ΔH through the corresponding time interval Δt during which the vertical displacement ΔH occurred. Thus, the rates of vertical displacements, $\Delta H/\Delta t$, were calculated and represented numerically in mm./year for each bench-mark with respect to different time intervals and the results are given in Table II. The modes of time variations of vertical displacements of several bench-marks are shown by the curves in Fig. 2.

In Table II or Fig. 2, we notice that there are several different types with regard to the time variations of $\Delta H/\Delta t$. According to the types of curves for $\Delta H/\Delta t$, the bench-marks may conveniently be classified into five different groups. It may also be a remarkable fact that the bench-marks respectively belonging to different groups, above classified, are also distributed in respective groups in different regions. The general characters of modes of time variations of $\Delta H/\Delta t$ for the different groups of bench-marks are pointed out as follows:

i) Type I. As shown in Fig. 2a, the vertical displacements which may be considered as the direct effect of the Kwantô Earthquake of 1923, seem to be generally upward. The rates of the vertical displacements, especially those of depressions, of these bench-marks were discontinuously increased after the Kwantô Earthquake. The bench-marks of which the time variations of $\Delta H/\Delta t$ are of this type are distributed mainly in NE suburb of Tôkyô. Those are B. M. 0 (Yokoami) B. M.

1) K. Mutô and K. Atumi, *Bull. Earthq. Res. Inst.*, **7** (1929), 495.
2) The Report published by the Authorities of the Military Land Survey, (1931).
3) *Bull. Earthq. Res. Inst.*, **9** (1931), 508.

Table II. $\frac{\Delta H}{\Delta t}$ of the Bench-marks in mm./year.

Locality of the Bench-mark	Time Interval / No. of Bench-mark B. M.	1892–1894	1894–1895	1895–1898	1898–1902	1902–1910	1910–1914	1914–1918	1918–1923	1923–1926	1926–1930	1930–1931
Aoi-tyô	1	0·3	-2·0$_5$	0·9	—	1·8	-0·0$_5$	-1·1$_6$	-2 9$_8$	-2·0	-8 8	
Kioi-tyô	J-2	1·6	2·7	-2·0$_6$	-0·6$_7$	—	0·1	0·6$_6$	-2·1$_4$	-0·1$_8$	0·7$_6$	
Huzimi-tyô	3	2·9	0·4$_5$	-4·8$_4$	-0·4	—	-0·9$_8$	0·3	-3·0	-4·0	0·1	
Surugadai	4	1·7	1·1	-3·0	-0·2	—	-0·0$_5$	-0.3$_9$	0·8$_1$	-5·4$_6$	-2·2$_9$	
Bakuro-tyô	J-5	1·1	1·2	-2·4$_7$	-0·3	0·3$_5$	-0·6	—	-2·4$_5$	-7·4$_6$	-5·6$_6$	-2·4
Hama-tyô	6	0·5	-5·3$_8$	-5·2$_8$	-1·0	-2·2	-5·2$_5$	-4·8$_7$	-8·6	-21·3	-20·4	-30·2
Sin-Hunamatu-tyô	J-0	—	-0·3$_9$	-3·4	0·1$_7$	0·1$_8$	-1·3$_5$	-0·5$_5$	-0·6$_9$	-4.2$_6$	-0·9$_8$	-3·0
Tukidi	J-7	0·1	0 0$_6$	-0·8	-1·8$_7$	—	0·7$_9$	-0·3$_4$	-0·1$_8$	-0 8	—	-3·8$_5$
Ta-mati	8	-9·6	11·4	-7·7	-3·0$_7$	-0·4$_7$	-0·9	-0.5$_9$	-0·2$_7$	1·8	-10·1	
Takanawa-kita-mati	J-9	0·3	-2·5	2·6$_9$	-3·2	—	-0·1	0·0$_5$	-1·2$_9$	3·9$_5$	0·4	
Simo-Ôsaki	10	0·8	-0·5$_5$	0·4$_5$	-2·5	-1·4	1·3$_5$	-1·6$_6$	-3·8	3·9	1·9$_8$	
Kirigaya	I	0·5$_5$	0·8$_9$	2·5	-2·1$_7$	-0·4	1·2$_6$	1·0	-3·2	5 2$_8$	2·1$_7$	
Himonya	11	0·8$_5$	1·3	1·4$_7$	-1·7	-0·3$_7$	0·7	0·8$_9$	-5·9$_6$	5·1$_5$	1·8	
Kamiuma	12	0·5$_5$	1·7$_8$	0·4	-2·0$_7$	0·5$_8$	—	1·0	-9.5$_4$	4·8$_4$	2·1	
Daita	13	0.9$_5$	1·1	-1·1	1·5$_7$	0·6	1·7$_9$	0·8$_6$	-10·1$_4$	2·5$_8$	2·3	
Hatagaya	J-14	0·7$_5$	2·4$_4$	-2·0	2·5	—	1·2$_8$	1·0$_7$	-10·0	1·4	1·9	
Hatagaya	15	0·5	2·5$_6$	2·7$_8$	1·3	—	-0·8$_4$	0·1	-8·8$_4$	-0 2$_6$	-1·8	
Asahi-mati	J-16	—	-2·0$_5$	-0·1$_9$	0 1	-0·4	0·4	0·4$_8$	-10·8$_6$	-4·0	-4·2$_5$	
Nakano	J-17	-0·3$_5$	3·6$_6$	-3·1	2·8	-0 9	1·0$_5$	0·8$_4$	-9.2	-3·3$_4$	0·6$_8$	
Kasiwagi	II	0·3	2·9$_4$	-3·0$_9$	1·3	-0·3	0·0$_7$	0·7$_5$	-7·4	-1·6$_9$	1·1$_5$	
Arai	18	-1·5$_5$	5·2$_7$	-3·8	2·9	-1·2$_7$	1·2$_8$	1·0$_7$	-10·6$_9$	-4·0	0·4$_6$	
Otiai	19	-1·7	4·6$_6$	-3·8	0·6	-0·8	0·2	0·8$_4$	-9 2$_4$	-6 0	1·0	
Nagasaki	20	-1·8$_5$	4 0	-3·7	-0·6	-0·5	—	0·5$_9$	-8 3	-7·5$_5$	0·9$_5$	
Simo-Itabasi	21	-0·5$_5$	4·3	-4·6$_5$	-1·8	-1·1$_9$	0·4$_4$	0·1$_4$	-7 7$_6$	-9 4	0·6$_6$	
Simo-Itabasi	III	0·7$_5$	5·0	-5·1$_8$	-1·6	-0·9$_8$	-0·2	0·1$_6$	-6 7$_4$	-9·2$_9$	0·5$_4$	
Simo-Itabasi	J-22	0·0$_5$	3 0	-4·5	-1·5	-1·1$_9$	-0·5$_6$	-0 0$_9$	-5·6$_7$	-9 3	0·0$_5$	-9·5
Wôzi	23	0·7	2·3	-3·9$_7$	-3·0$_7$	-0·5$_8$	—	-0·3$_4$	-1·4	-14·0$_8$	-0·2$_4$	-8·8
Nippori	24	-0·3	3·3	-4·1	-2·9	0·6	—	-0·4	1·5	-13·0$_5$	2·4$_8$	-5·9
Senzyu Minami-gumi	J-25	-0.6	3·8	-7·8	-2·6	-1·2	-4·5	-8·6$_8$	-11·9	-37·1	-23·8	-28·8
Syôden-tyô	26	0·1	1·9	-4.6	-1·6	-0·8	-4·3	-4·4$_5$	-4·4	-25·4$_5$	14·2	-19·6
Senzyu Naka-gumi	3365	-0·4	-4·4	-8·7	-2·4	-0·6	-4·1	-3·8$_8$	-0·8$_4$	-28·3	14·5	-25·4
Senzyu 1-tyôme	J-IV	1·2	3·2	-9·4	-2·3	-0·2	-4·6$_5$	-5·3$_4$	-8·5$_4$	-39·7	-30·0	-37·4

(to be continued.)

Table II. (*continued.*)

Locality of the Bench-mark	No. of Bench-mark. \ Time Interval	1892–1894	1894–1895	1895–1898	1898–1902	1902–1910	1910–1914	1914–1918	1918–1923	1923–1926	1926–1930	1930–1931
Kosuge	B. M. 3366	-0·3	5·2	-10·1	-2·8	-0·2	-4.3	—	$-10{\cdot}4_{5}$	-29·3	-21·2	
Kameari	3367	$-0{\cdot}0_{5}$	4·9	-9·2	-2·6	0·4	-4·3	—	$4{\cdot}0_{6}$	-21·5	-19·0	
Kameari	3368	1·1	0·9	—	-3·1	$-0{\cdot}4_{4}$	-4·9	$-3{\cdot}2_{7}$	$-1{\cdot}7_{8}$	-28·1	-22·6	
Sinzyuku	0	0·6	2·4	-8·2	-4·1	$-0{\cdot}2_{4}$	-6·4	$-4{\cdot}6_{4}$	-0·1	-25·2	-17·8	
Kanamati	3369	0·4	2·7	-6·0	-3·3	$0{\cdot}6_{5}$	-4·3	-3·3	$5{\cdot}7_{5}$	-19·3	-3·3	
Kanamati	3370	0·1	3·9	—	-11·6	-4·1	-7·4	$-3{\cdot}6_{4}$	$9{\cdot}8_{5}$	-12·9	-11·0	
Kanamati	0		-1·4									
Matudo	3371	-0·5	-15·8	5·6	-1·2	—	$-3{\cdot}2_{8}$	-1·0	$10{\cdot}9_{5}$	-8·4	-2·7	
Matudo	V	-0·5	-16·7	6·9	-1·1	0·5	$-2{\cdot}7_{4}$	$-1{\cdot}4_{5}$	11·4	$-8{\cdot}0_{5}$	-3.4_{4}	
Itikawa	3372	-2·2	-15·8	5·8	-1·3	-0·1	-2·8	$-1{\cdot}3_{4}$	11·2	-7·6	$-3{\cdot}9_{8}$	
Itikawa	J-3373	-0·4	-16·3	6·6	-3·0	$0{\cdot}7_{4}$	$-2{\cdot}8_{8}$	-1·4	$11{\cdot}5_{6}$	-8·1	$-2{\cdot}4_{4}$	
Koiwa	0	-4·2	-18·4	-2·7	—	$-0{\cdot}2_{8}$	-2·7	-1·8	11·3	$-11{\cdot}9_{5}$	-4·7	
Simo-Koiwa	3374	-1·4	-7·0	3·0	-1·4	$-0{\cdot}6_{5}$	-2·4	-1·8	7·7	$-12{\cdot}9_{7}$	$-3{\cdot}3_{4}$	
Higas - Komatugawa	3375	-2·2	-4·2	-0·5	-1·5	$-0{\cdot}6_{9}$	$-3{\cdot}1_{4}$	$-2{\cdot}6_{8}$	0·4	-42·9	-39·2	
Nisi-Komatugawa	3376	-2·5	-3·6	-3·1	-2·1	$-2{\cdot}3_{4}$	$-9{\cdot}0_{5}$	—	-34·9	-57·7	-47·2	
Kameido	3377	0·5	-6·7	-4·8	-3·3	-4·6	$-21{\cdot}2_{5}$	-26·2	-47·2	$-88{\cdot}8_{5}$	-58·8	-58·5
Kayaba-tyô	3378	$-3{\cdot}0_{5}$	-9·1	-9·2	-11·3	-5·8	-18·3	-27·1	-22·0	-52·5	-133·5	-134·0
Koidumi-tyô	3379	0·3	-4·7	-6·9	-6·8	$-2{\cdot}2_{4}$	$-6{\cdot}6_{5}$	-17·5	$-29{\cdot}9_{4}$	$-47{\cdot}0_{5}$	-37·8	-48·3
Yokoami	0	1·3	1·0	-4·3	-0·1	-0·2	-2·9	-1.5	$2{\cdot}5_{8}$	$-13{\cdot}1_{5}$	$-11{\cdot}5_{6}$	-10·7
Hukagawa-Kôen	9831								-31·8	$-37{\cdot}1_{5}$	$-43{\cdot}0_{5}$	-81·5
Higasi-Hirai-tyô	9832								-72·9	-93·8	-91·2	-115·5
Suna-mati	9833								-20·1	$-45{\cdot}6_{5}$	-38·0	-39·2
Suna-mati	9834								-53·0	-85·0	-55·9	-54·1
Matue-mati	9895								-10·4	-44·5	-29·6	
Kasai	9836								$0{\cdot}1_{7}$	-23·6	-29·0	
Kasai	9837								0·6	-20·5	-11·8	
Urayasu	9838								$0{\cdot}3_{5}$	-22·3	-10·5	
MinamiGyôtoku	9839								10·7	-6·8	-2·4	
MinamiGyôtoku	9840								9·3	-11.2	-5·2	
Gyôtoku	9841								10·8	-8·7	-2·9	
Katusika	9842								13·4	-6·8	-1·4	
Katusika	9843								13·8	-6·7	-1·1	
Hunabasi	J-3826								16·6	-5·5	-0·9	

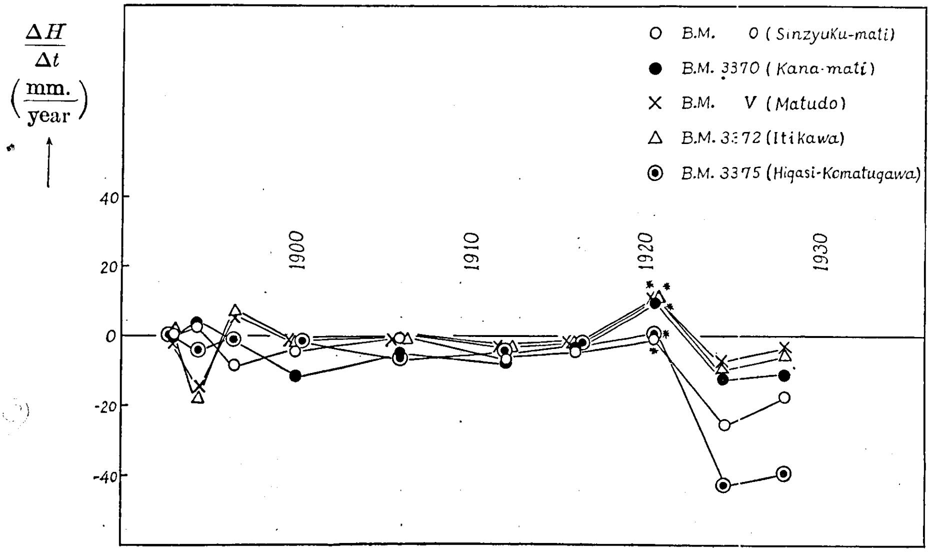

Fig. 2a. The time variation of $\frac{\Delta H}{\Delta t}$: Type I.

Points marked by asterisks represent $\frac{\Delta H}{\Delta t}$, during the corresponding time interval, the Kwantô Earthquake occurred.

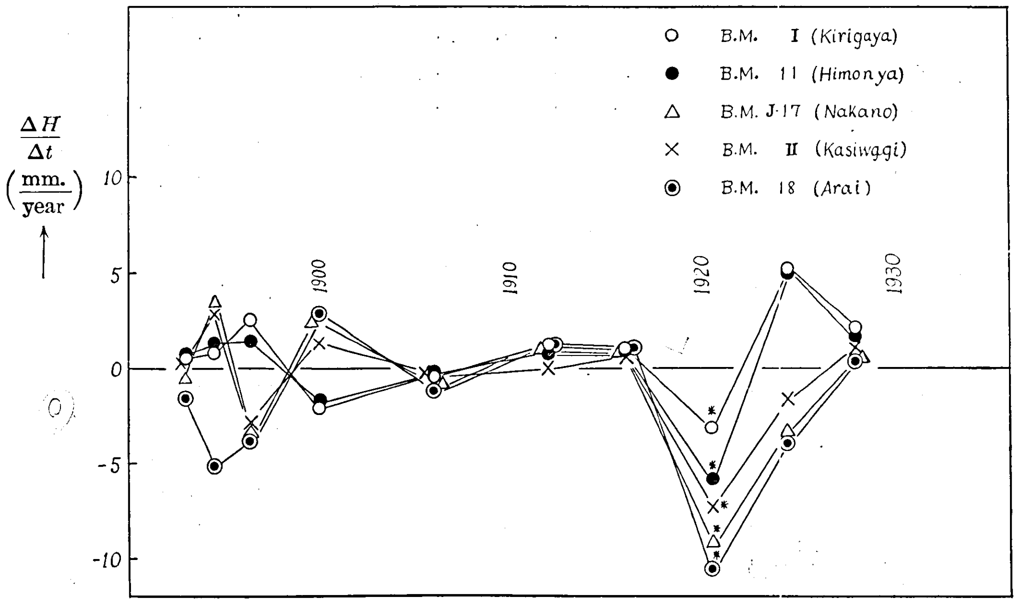

Fig. 2b. The time variation of $\frac{\Delta H}{\Delta t}$: Type II.
The asterisks mean as in the case of Fig. 2a.

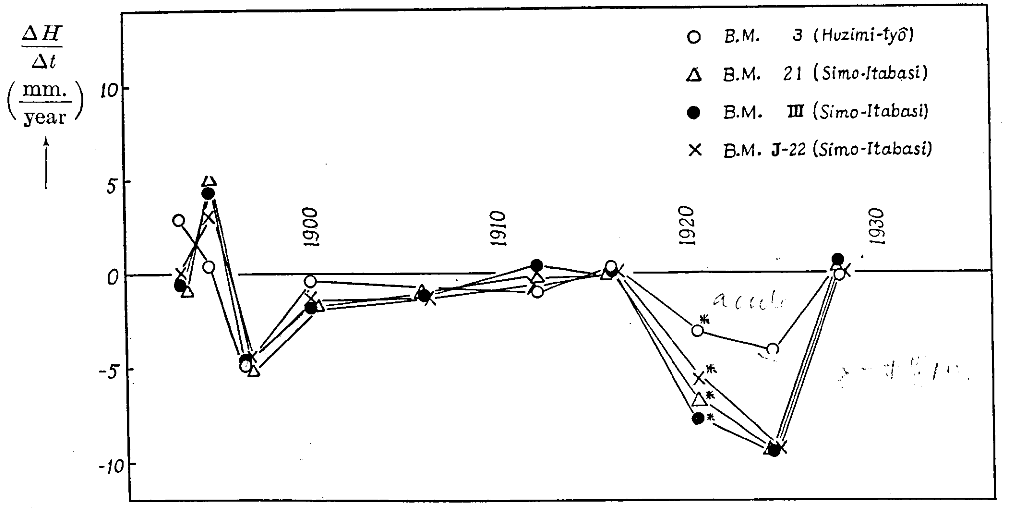

Fig. 2c. The time variation of $\frac{\Delta H}{\Delta t}$: Type III.
The asterisks mean as in the case of Fig. 2a.

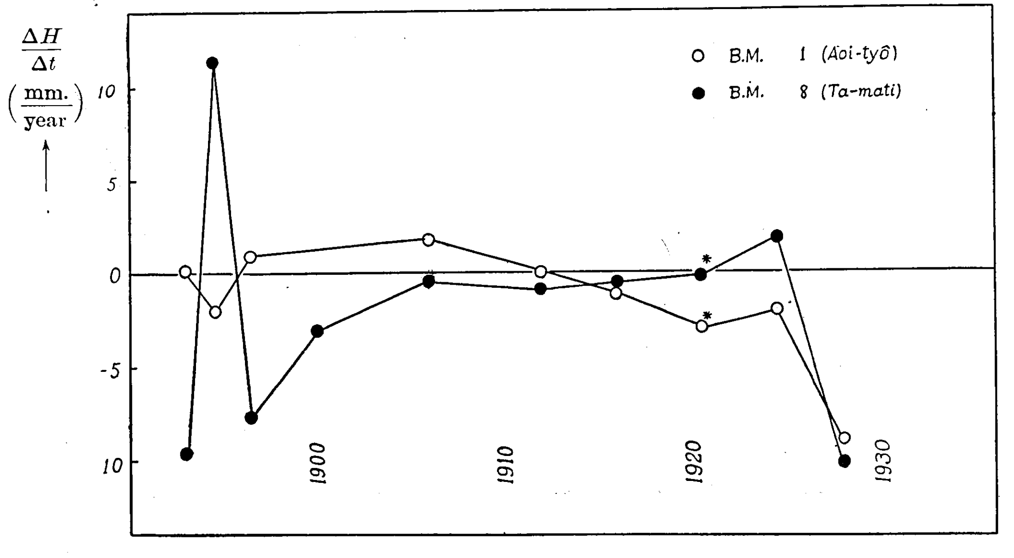

Fig. 2d. The time variation of $\frac{\Delta H}{\Delta t}$: Type IV.
The asterisks mean as in the case of Fig. 2a.

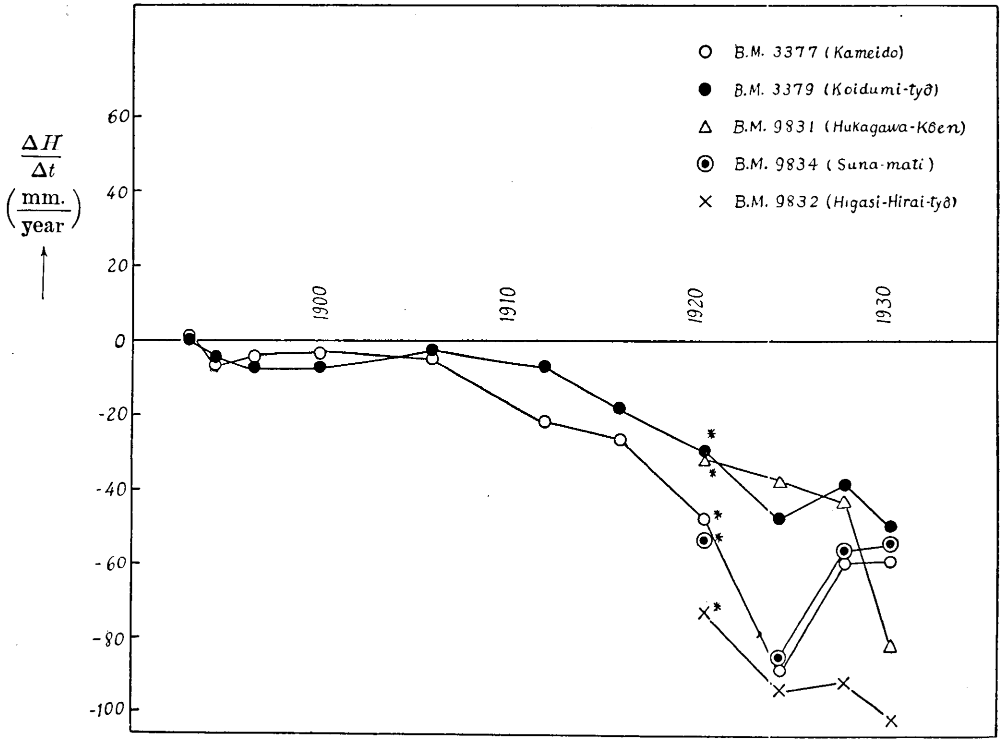

Fig. 2e. The time variation of $\frac{\Delta H}{\Delta t}$: Type V.
The asterisks mean as in the case of Fig. 2a.

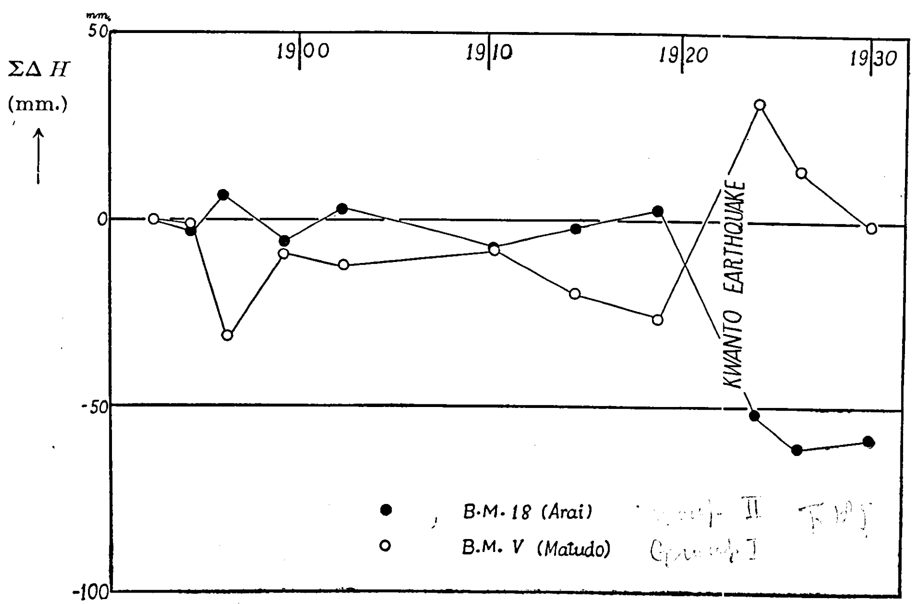

Fig. 2f.
Vertical displacement integrated.

3379, B. M. 3378, B. M. 3377, B. M. 3376, B. M. 3375, B. M. 3368, B. M. 3367 B. M. 0 (Sinzyuku-mati), B. M. 3370, B. M. 3366, B. M. 26 etc. and they are represented by the mark ● in Fig. 1.

ii) Type II. As shown in Fig. 2b, the vertical displacements which are considered as due to the direct effect of the Kwantô Earthquake are, for this type, distinctly shown by abrupt increases in the rate of depression. After the earthquake, however, the movements subsided gradually. The bench-marks belonging to this 2nd type are distributed generally in W or SW of Tôkyô, i. e., B. M. 10, B. M. I, B. M. 11, B. M. 12, B. M. 13, B. M. II, B. M. 18, B. M. 19 etc., shown by marks ◎ in Fig. 1.

iii) Type III. As the curves in Fig. 2c show, the vertical displacements of B. M. 21, B. M. III and B. M. J–22, which are situated at Itabasi, are such that the components which may be due to the acute movement at the time of the Kwantô Earthquake are so remarkable as described in ii). Depression of the earth's crust shown by the result of the levelling survey of 1923 were again shown in the results of the survey of 1926, corresponding to the vertical displacements during 1923–1926. In the result of the survey of 1930, the vertical displacements of these bench-marks are much smaller, i. e., the vertical movement represented by displacements of these bench-marks seems to have ceased. A similar variation is also shown by that of $\Delta H/\Delta t$ of B. M. 3, situated at Huzimi-tyô. For this bench-mark, however, the movement which may be considered to be due to the acute mevement at the time of the Kwantô Earthquake is not clearly noticeable and an elevation during 1926–1930 is more or less remarkable. These bench-marks belonging to this 3rd type are represented by marks ⊙ in Fig. 1.

iv) Type IV. The curves in Fig. 2d show the time variations of $\Delta H/\Delta t$ of B. M. 1, situated at Aio-tyô, and B. M. 8, situated at Ta-mati. As shown in the figure, the movement during 1918–1923, including the effect of acute movement at the time the Kwantô Earthquake, was depression, the movement during 1923–1926 was evidently upward and that during 1926–1930 was again depression. These bench-marks of Type IV are represented by marks ⊕ in Fig. 1.

As for the bench-marks belonging to Groups iii) and iv), the type of time variation of $\Delta H/\Delta t$ may be regarded as some modifications of type II.

v) Type V. The variation of $\Delta H/\Delta t$ of other bench-marks (Fig. 2) are such that the effect of the Kwantô Earthquake, even if it existed, is not evident. The post-seismic rates of depression of these bench-marks, however, are so remarkable in Honzyô, Hukagawa and its vicinity that even the least value of them amounts to 40 mm. per year in round number.

The bench-marks of which the variations of $\Delta H/\Delta t$ are in such a manner as mentioned above are B. M. J-5, B. M. 6, B. M. J-0, B. M. J-7, B. M. 26, B. M. 3365 etc., represented by marks ◑ in Fig. 1. As for B. M.'s 9831, 9832, 9833 and 9834, the pre-seismic data of the vertical displacements are not sufficient in number for the comparison with the post-seismic series of data, as in the case of the other bench-marks. Hence, these bench-marks are included in Group v, for convenience's sake, as the post-seismic variations of their $\Delta H/\Delta t$ are similar to those of other bench-marks belonging to this group.

The difference in modes of vertical movements of the bench-marks belonging to the different groups are also shown by the curves representing the integrated values of vertical displacements from the time of the first survey. Fig. 2f shows the curves of $Y=\sum\Delta H$ plotted as ordinates taking the time as abscissa, where ΔH means the vertical displacements of the bench-marks during each time interval of the successive surveys. The curves in Fig. 2f show variation of Y of B.M. V, situated at Kana-mati, and B. M. 18, situated at Arai, of which the modes of variations of $\Delta H/\Delta t$ are typical of those of the bench-marks belonging to Group I) and Group II) respectively.

It may be remarked that the types III), IV) and V) of the variations of $\Delta H/\Delta t$ may be regarded as intermediate between the two extreme types I) and II), of which the variations of $\Delta H/\Delta t$ are approximately in negative correlation with each other. For the types III), IV) and V), amounts of $\Delta H/\Delta t$ are generally smaller than those of $\Delta H/\Delta t$ of Types I) and II), and the bench-marks belonging to Groups iii), iv) and v) are distributed in the region situated between the two regions where the bench-marks belonging to Groups i) and ii) are respectively distributed.

3. The distribution of the bench-marks and their types of the time variations of $\Delta H/\Delta t$ suggest us the following mode of deformation of the earth's crust which prevailed in Tôkyô and the environs in the recent years: The crust was first tilted toward SW during 1918–1923, including the effect of the Kwantô Earthquake, if any, and then was tilted in the approximately reversed sense during 1923–1926. According to the results of the surveys carried out after the survey of 1926, i. e., the surveys of 1930 and 1931, the tilting of the earth's crust in this region is generally not remarkable, and yet the conspicuous local depres-

sion in Honzyô and Hukagawa[4] has maitained its activity.

4. A similar mode of deformation of the earth's crust is also obseved in the secular variation of the area of rhombus enclosed by a special set of geodetic base-line which is installed in the compound of the Tôkyô Astronomical Observatory at Mitaka.

All of the lateral sides and one of the diagonals of the rhombus are arranged in the manner as shown in Fig. 3. Since the year 1916 up to 1931, the measurements of the lengths of lateral sides and the diagonal NS with the accuracy up to 0.01 mm have been repeated 18 times. From the results of the measurement, the areal change per unit area of each of the equilateral triangles NES and NWS was calculated for the time intervals corresponding to those of two successive levelling surveys carried out along the routes which contain the bench-marks mentioned in the preceding paragraphs.

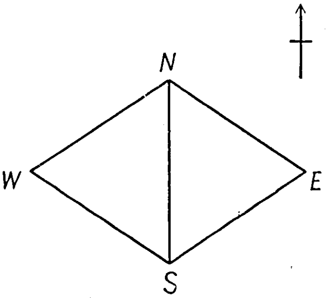

Fig. 3.
The Rhombs of a Special Set of Base-line at Mitaka. $\overline{NE}$, $\overline{ES}$, $\overline{SW}$, $\overline{WN}$ and $\overline{NS}$ being very nearly 100 m.

The calculation of dS/S, the areal change per unit area, is made as Mr. C. Tsuboi[5] shows, by using the relation

$$\frac{dS}{S}=\frac{ds}{75000},$$

Table III. $\frac{dS}{S}$ of Each Triangle of the Rombus at Mitaka.

Time interval	Triangle NES	Triangle NWS	Average
1916·IV–1918·II	– 0·083 × 10^{-5}	0·173 × 10^{-5}	2·8 × 10^{-7} per year
1918·II–1924·I	5·387	4·867	8·7
1924·I–1925·XII	0·053	0·107	4·2
1925·XII–1930·II	. 0·413	0·640	1·2
1930·II–1931·X	– 0·227	1·640	4·2

4) As for the local depression in Honzyô and Hukagawa Prof. A IMAMURA discussed, in his investigation, the tilting of Kôtô Block in association with the recent seismic activity in this region. A. IMAMURA, *Jap. Journ. Astro. Geophys.*, 8 (1931), 177.

The present author has dealt with the same problem and the result will be informed later in this Bulletin.

5) C. TSUBOI, *Proc. Imp. Acad.*, 6 (1930), 367 ; *ibid.*, 7 (1931), 155.

where ds is half the change in periphery of the triangle measured in mm. The calculated values of dS/S for each of the two triangles and their mean values for different time intervals are shown in Table III, and the variation of averaged values of dS/S with respect to time is shown by the curve in Fig. 4a.

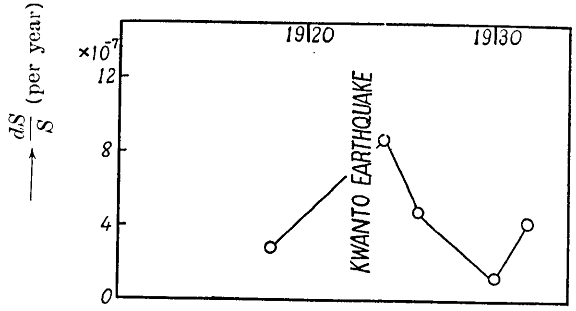

Fig. 4a.

$\frac{dS}{S}$ per year of the Area of the Rhombus at Mitaka.

The curves in Fig. 2f representing the total amounts of vertical displacements for B. M. V and B. M. 18, are seen, at a glance, to be positively correlated with the curve representing the integrated values of dS/S of the area of the rhombus at Mitaka, shown in Fig. 4b.

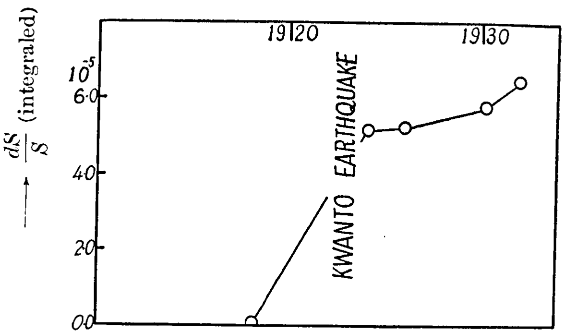

Fig. 4b.

$\frac{dS}{S}$ of the Area of the Rhombus at Mitaka.

As for the rhombus at Mitaka, the vertical displacements of Points E, S and W relative to Point N are also measured 8 times since the year 1916. From these data, the directions and magnitudes of tilting of each triangle are calculated for the different time intervals corresponding to those between two successive surveys along the levelling routes in Tôkyô and the environs.

The vector diagram of the tilting of each triangle is shown in Fig. 5, and numerical values of the magnitudes and azimuths of them are given in Table IV. In this figure, we notice that the tilts of the earth's crust in this region was directed towards SW during 1921 XI–1923 X. If we take the time interval from 1918 X to 1923 X, the tilt of the crust was directed approximately towards W. This tilt of the crust was nearly recovered by the tilt in the reversed sense of the same azimuth during 1923 X–1925 XII. Since then the crust was again tilted to NW.

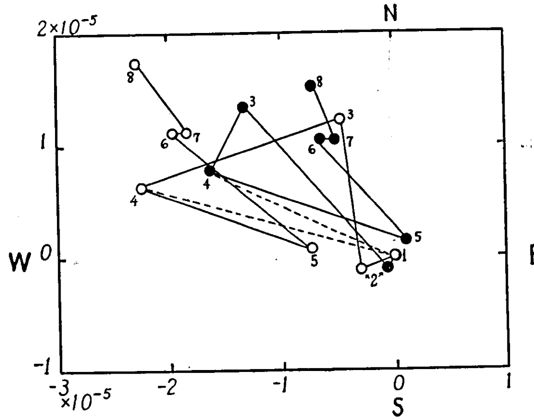

Fig. 5.

Vector Diagram indicating the Tilting of the Area of the Rhombus at Mitaka.

○ Tilting of the Triangle NES

● ,, ,, ,, NWS.

The numerical figures are representing the dates when the vertical displacement of the points E, S, and W are measured.

1:	1981·X	5:	1927·XII
2:	1920·XI	6:	1929·III
3:	1921·XI	7:	1930·II
4:	1923·X	8:	1931·X

Table IV. Tilting of the Rombus at Mitaka.

Time Interval	Tilting of NES		Tilting of NWS	
	Magnitude	Azimuth referred to N	Magnitude	Azimuth referred to N.
1918·X–1920·XI	$0{\cdot}32\times10^{-5}$	250°	$0{\cdot}12\times10^{-5}$	210°
1920·XI–1921·XI	1·33	353	1·92	319
1921·XI–1923·X	1·83	252	0·60	210
1923·X1927·XII	1·62	110	1·86	110
1927·XII–1929·III	1·62	310	1·17	320
1929·III–1930·II	0·12	90	0·12	90
1930·II–1931·X	0·75	314	0·52	340

The fact that the sense of the direction of the tilt of the earth's crust during 1923–1927 was reversed in comparison with the tilt during 1921–1923 or that during 1918–1923, is coincident in sense with the general mode of the time variation of $\Delta H/\Delta t$ of the bench-marks in Tôkyô and the environs.

It may be suggested from the facts mentioned above that there may exist a general crust movements in Tôkyô and the environs including Mitaka, which may be represented by the general mode of time variations of $\Delta H/\Delta t$ of the bench-marks and those of dS/S and tiltings of the earth's crust at Mitaka.

5. Recently Prof. T. Terada[6] pointed out that there is a probable correlation between dS/S of the area of the rhombus at Mitaka and the frequency of conspicuous earthquakes in Kwantô District. Since the time variation of $\Delta H/\Delta t$ of the bench-marks is parallel with that of dS/S of the rhombus at Mitaka, it may be expected that the former will also be correlated with the frequency of occurrence of earthquakes in Kwantô District.

The number of conspicuous earthquakes which occurred in Kwantô District was counted since the year 1911, and the mean values of the numbers of these earthquakes per year were obtained for the time intervals corresponding to those between the successive levelling surveys during which the vertical displacements of the bench-marks were measured had taken place. The result is shown in Fig. 6. It may be remarked that relatively frequent occurrence of conspicuous earthquakes in 1911–1915 compared with the later epoch may partly be due to the difference of the scale of intensity adopted for classifying the earthquakes. Hence, several per cents of the number of earthquakes in 1911–1915 might be discounted. Whatever the matter, the time variation of the frequency of occurrence of earthquakes is noticed to be similar in its general feature with that of $\Delta H/\Delta t$ of the bench-marks.

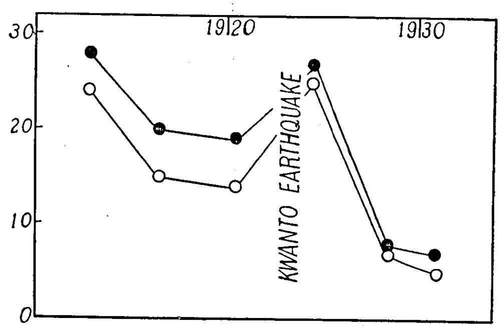

Fig. 6.
Frequency of Conspicuous earthquakes in Kwantô District.
● Including the conspicuous earthquakes of which the epicentres are located in Kasima-nada.
○ Kasima-nada Earthquakes are excluded.

This statistical relation between $\Delta H/\Delta t$ of the bench-marks and the number of occurrence of conspicuous earthquakes, of course, does not lead to a conclusion that the deformation of the earth's crust precedes

6) T. TERADA, *Proc. Imp. Acad.*, **7** (1932), 8.

or follows the occurrence of the earthquake, but it may at least show that the deformation of the earth's crust is sometimes associated with the occurrence of earthquake.[7] Hence, the vertical displacement of the bench-mark, ΔH, during the time interval Δt may consist of $\Delta_c H$, the the vertical displacement due to chronic movement, and $\Delta_a H$, the vertical displacement due to acute movement such as associated with the occurrence of the earthquake. Moreover, $\Delta_a H$ may in its turn consist of Δh_1, $\Delta h_2, \ldots \Delta h_n$, where Δh_n is the vertical displacement associated with a single earthquake, n being the number of earthquakes during the time interval Δt. If Δh_n of a certain bench-mark is constant for any conspicuous earthquake occurred in Kwantô District while the earthquakes of minor scales contribute nothing to the values of Δh_n, $\Delta_a H$ will be linearly proportional to the number of conspicuous earthquakes occurred during the same time interval. Consequently a linear relation between $\Delta H/\Delta t$ of the bench-marks and the frequency of occurrence of the earthquakes may be expected, when $\Delta_c H$ is small. Such a consideration, however, wants verification by evidences from many other sides, which are at present lacking, but for the statistical relation pointed out above.

6. The results of the present investigation are summarized as follows:

a) Five different types in the time variations of $\Delta H/\Delta t$ of the bench-marks in Tôkyô and the environs are pointed out. The majority of the bench-marks show the time variations of types I) and III), of which the modes of the time variations are in approximately opposite senses.

b) From the distribution of the bench-marks having different types of the time variations of $\Delta H/\Delta t$, the general mode of movement or tilting of the earth's crust in this district is suggested, i. e., it might have taken place in such a manner that the crust was tilted to W or SW during 1918–1923, including the effect of acute movement at the time of the Kwantô Earthquake. Then, it was tilted back during 1923–1926, and since that time the general movement is not noticeable, while the local depression in Honzyô and Hukagawa became remarkable.

c) The general mode of the time variations of $\Delta H/\Delta t$ of the bench-marks in this region is similar to those of the time variation of dS/S and also of tiltings of the area of the rhombus at Mitaka. It is

7) In his investigation, Prof. A. IMAMURA discussed the tilting of Kôtô Block in association with the occurrence of the earthquake. A. IMAMURA, *Jap. Journ. Astr. Geophys., loc. cit.*, (4).

also similar to the time variation of fluctuations in frequency of occurrence of conspicuous earthquakes in Kwantô District.

In conclusion, the present writer wishes to express his sincere thanks to Professor Torahiko Terada for his kind advices and guidance. Cordeal thanks are also due to Professor Sakuhei Fujiwhara for his kindness in placing the valuable data at the writer's disposal.

---

40. 東京附近に於ける水準點の垂直變動に就て

地震研究所 宮 部 直 巳

東京附近には水準點が六十箇所以上も設置せられてあつて、其等の水準點の高さが、1892 以來十一回乃至十二回觀測され、從つて、その各觀測年次間に起つた垂直變動量が測定されてゐる。是等の素材によつて東京附近に於ける地殼の垂直變動の模樣を調べてみやうといふ試みが本文の內容である。

この目的の爲めに、先づ測定された垂直變動量 (ΔH) を當該期間に相當する年數 (Δt) で除し、平均の年變動量 $\Delta H/\Delta t$ を各水準點に就いて求め、其の時に對する變化の模樣を調べてみた。その結果は次の如く要約される。

i) $\Delta H/\Delta t$ の時に對する變化の模樣は大體五種の型式に分類することが出來る。即ち：

(a) 關東地震前後の測量より得た結果が、それ以前のものに比して上昇の傾向にあるが、關東地震後の變動は、何れも可なりの沈降を示しつゝあるものが比較的多く、そして、其の樣な變化を示す水準點は主として東京の東部又は東北部に分布してゐる。

(b) 次に、關東地震前後の測量では、かなり著しい沈降を示し、以後その沈降の割合が次第に減少し、若しくは上昇となつて、沈降を恢復しつゝある樣に見えるものがある。斯の如き $\Delta H/\Delta t$ の變化を示す水準點は、主として、東京市の西部又は西南部に分布してゐる。(a) の $\Delta H/\Delta t$ の變化を下町型とすれば、(b) のそれは山手型とも稱すべきものであつて、(a) の變化の略逆向きである。

(c) 下板橋に於ける三個の水準點並に富士見町に於ける B. M. 3 は、關東地震前後の測定で、沈降を示したが、地震後の第一回第二回の測量より得たものも矢張り、沈降の傾向を增長してゐる樣に見え、その後の測量で、垂直變動が零に近づいてゐる。

(d) 又、葵町 (B. M. 1) 及び田町 (B. M. 8)に於ける水準點では、關東地震前後の測量より得たる垂直變動量は左程著しからず、その後に上昇となり更に沈降と變じてゐる。かく、(c) 及 (d) 型は (a) 型と (b) 型との中間、若しくは、寧ろ (b) 型に幾きものであると思惟され、それ等の水準點の位置も、(a) 型の水準點の分布區域と (b) のそれとの略中間に位してゐる。

(e) 以上の諸型式の外に、(a) 型の水準點の分布區域又はその附近に、關東地震前後の測量による垂直變動は、著しからず却つて、震後の沈降の著しくあらはれるものがある。之を第五種の e 型とした。これは寧ろ (a) 型に幾きものと思はれる。

ii) 以上の事實から次の如き東京附近の地殼變動の模樣が想像される。即ち、關東地震を夾む期

間内には、地殼は西又は南西に傾き、地震後は漸次之を恢復して静穏になつてきた。但、局部的には垂直變動は却つて増大した個所もある。例へば本所深川に於ける著しき沈降はその一である。

iii) 上述の $\Delta H/\Delta t$ の變化の模樣は、三鷹村における菱形の面積の伸縮 (dS/S の變化)、その地表面の傾斜、及び關東地方に於ける稍顯著以上の地震の發生の頻度等と統計的には關聯するらしく見える。

以上のことから、東京附近の水準點の垂直變動から期待される地殼變動は、もう少し廣い地域にても存在してゐたやうに考へられる。