15. *Land Deformation of the Neighbourhood of Muroto Point after the Nankaido Great Earthquake in 1946.*

By Atusi OKADA,
Earthquake Research Institute,
and
Takesi NAGATA,
Geophysical Institute.

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Abstract.

Leveling surveys of the neighbourhood of Muroto Point, Shikoku were carried out seven times after the Nankaido great earthquake in 1946. The results of the surveys together with those before the earthquake show that the remarkable northward tilting of this locality, about 6.2″ in magnitude, accompanying the earthquake is has been gradually recovering, and the present rate of southward tilting nearly constant, being 0.035″/year, which is almost equal to that for the pre-earthquake period. The main results are graphically represented in Figs. 4 and 5.

Introduction.

In their previous paper[1], the writers dealt with a remarkably regular deformation of Muroto Point which was associated with the great earthquake on December 21, 1946. According to the results of precise leveling surveys made in 1895, 1929 and 1932, Muroto Point had been inclining in the direction of S 10° E with an almost constant velocity of 0.035″/year for more than 40 years before the earthquake, while the abrupt change accompanying the earthquake was exactly opposite in sense, namely the point inclined by about 6.2″ in the direction of N 10° W.

After the earthquake, leveling surveys were repeated four times, namely in January, February, March and July in 1947, and their results show that the Point was again inclining in about a S 10° E direction with a fairly large velocity compared with that of the pre-earthquake period. According to T. Okuda,[2] on the other hand, the land deformations occurring simultaneously with the earthquake over the whole area of Shikoku are

1) T. NAGATA and A. OKADA, *Bull. Earthq. Res. Inst.*, **25** (1947), 85.
2) T. OKUDA, *Bull. Geograph. Survey Bureau*, **2** (1951), 239.

just opposite in sense to those during the pre-earthquake period. This fact may suggest that the land deformation is closely related to the mechanism of occurrence of the earthquake. Then, Muroto Point, which showed the most remarkable and regular deformation within Shikoku, may be considered to be the most typical sample of the land deformation relating to seismicity in this district.

Under this circumstance, precise leveling surveys were repeatedly carried out in 1949, 1950 and 1952 in order to clarify the character of the after-earthquake movement.

Procedure and results of leveling surveys.

The leveling route concerned here is about 22 km from BM No. 5136 to BM No. 5147 along the seashore of Muroto Point, as will be seen in Fig. 1. The said route forms the two sides of a triangle, wherefore a tilting motion as a whole of the earth's crust in this locality can be definitely detected, and further a warping deformation with an east-west axis, if any, ought to be detected also. On the contrary, a warping deformation with a north-south axis, would not be detected so far as we rely on the leveling survey in our networks.

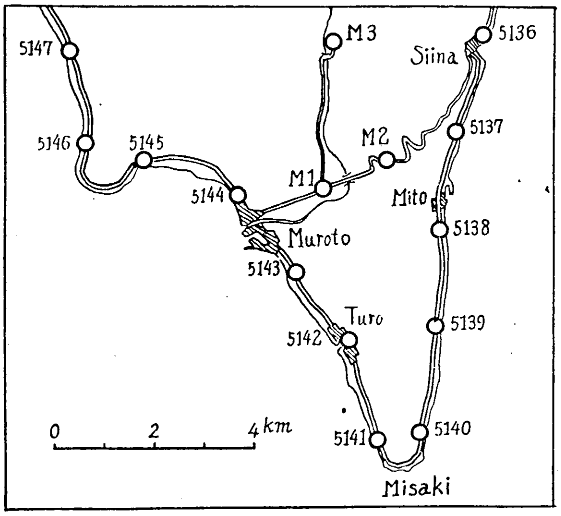

Fig. 1. Leveling route in the neighbourhood of Muroto Point.

In order to remedy the above-mentioned defect, the Geographical Survey Institute set newly three bench marks M_1, M_2 and M_3 in November, 1947 at the localities respectively shown in Fig. 1. Along all the routes including the branch routes mentioned above, the first-class precise leveling surveys (by means of a Zeiss level) were carried out in April 1949, January 1950 and December 1952. Throughout all the surveys, BM No. 5136 was always chosen as the reference point for height measurement. In Table I, the relative heights of each bench mark with respect to BM No. 5136 at respective epochs are summarized together with those obtained by the

Table I.

Relative heights of each bench mark in the neighbourhood of Muroto Point.

BM \ Date	1947 (I)	1947 (II)	1947 (III)	1947 (VII)	1949 (IV)	1950 (I)	1952 (XII)
	m	m	m	m	m	m	m
5136	—	+1.4388	—	+1.4432	+1.4327*	+1.4262**	+1.4254***
5137	−1.3874	−1.3782	−1.3784	−1.3812	−1.3845*	−1.3944**	−1.3989***
5138	−0.1831	−0.1884	−0.1870	−0.1860	−0.1894*	−0.1921**	−0.1925***
5139	+2.0786	+2.0597	+2.0556	+2.0538	+2.0561*	+2.0439**	+2.0428***
F.46	−1.3576	−1.3480	−1.3539	−1.3504	−1.3485*	−1.3488**	−1.3476***
5141	+3.7490	+3.7526	+3.7574	+3.7534	+3.7535*	+3.7636**	+3.7674***
5142	−2.2820	−2.2759	−2.2738	−2.2914	−2.2892*	−2.2861**	−2.2834***
5143	−2.1830	−2.1325	−2.1196	−2.1352	−2.1319*	−2.1239**	−2.1234***
5144	—	+4.2170	—	+4.3220	+4.2177	+4.2236	+4.2244
5145	—	−3.5878	—	−3.5835	−3.5817	−3.5810	−3.5798
5146	—	+0.0362	—	+0.0294	+0.0424	+0.0449	+0.0456
5147							
				1947 (XI)	1949 (IV)	1950 (I)	1952 (XII)
				m	m	m	m
5144				+ 9.5149	+ 9.5196*	+ 9.5236**	+ 9.5235***
M_1				+27.8332	+27.8377*	+27.8416**	+27.8417***
M_2				−37.2607	−37.2561*	−37.2536**	−37.2550***
5136							
				m	m	m	m
M_1				+21.8736	+21.8743	+21.8865	+21.8871
M_2							

* The closing error −0.0070 m is uniformly distributed.
** 〃 −0.0031 〃
*** 〃 +0.0050 〃

former surveys. Here, the closing errors, shown in the lowest lines of the table, are distributed uniformly along the closed leveling route.

The secular change of land deformation is represented by the difference of the height at each epoch from that in 1929 for each bench mark. The result is shown in Fig. 2 and Table II, where it is assumed that the reference point BM No. 5136 remains constant throughout the whole period. As for M_1, M_2 and M_2, the change of their height at each epoch from the value of the first survey in November 1947 is shown in Fig. 2 and Table II, while the change of height of M_3 given there is only the relative value compared with that of M_1.

It will be obvious from these results that the remarkable land

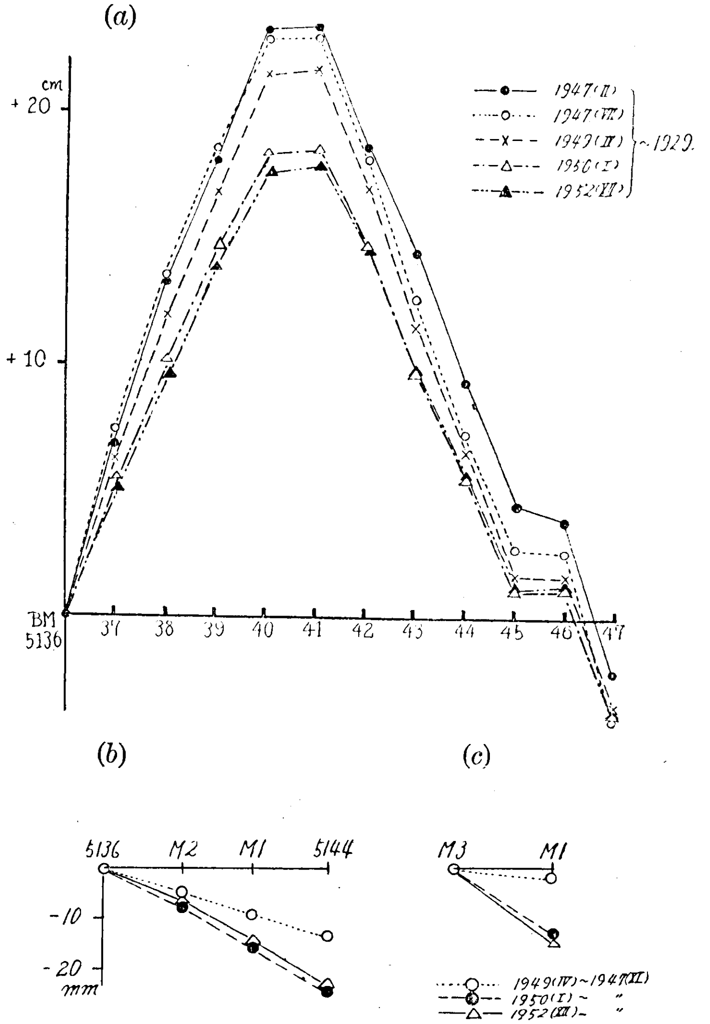

Fig. 2. Change in height of bench marks at various epochs reckoned from 1929.

deformation occurring simultaneously with the earthquake has been recovering with time. It may also be noticed, if the time interval between successive surveys is taken into consideration, that the velocity of the recovery has been gradually decreasing.

Analysis of the results.

By comparing the results given in Fig. 2 with the form of the leveling route shown in Fig. 1, one may notice that the secular change during the

Table II.

Change of height of bench marks at various epochs from that in 1929 (above) and from that in 1947 (below). (The height of BM 5136 is assumed to be zero throughout the whole period).

	(BM)	1947 (II) -1929	1947 (VII) -1929	1949 (IV) -1929	1950 (I) -1929	1952 (XII) -1929
(*a*)	5136	mm 0.0	mm 0.0	mm 0.0	mm 0.0	mm 0.0
	5137	+ 67.8	+ 72.2	+ 61.7	+ 55.2	+ 54.4
	5138	+131.7	+133.1	+119.3	+102.9	+ 97.6
	5139	+180.3	+184.1	+166.9	+147.8	+142.1
	F 46	+231.3	+229.2	+214.3	+183.0	+176.2
	5141	+233.4	+228.9	+215.9	+184.3	+178.7
	5142	+184.8	+181.1	+168.2	+146.7	+144.9
	5143	+144.0	+124.8	+114.1	+ 95.7	+ 96.6
	5144	+ 93.8	+ 71.9	+ 64.5	+ 54.1	+ 55.5
	5145	+ 43.5	+ 26.6	+ 14.9	+ 10.4	+ 12.6
	5146	+ 37.5	+ 24.9	+ 15.0	+ 11.2	+ 12.8
	5147	− 21.6	− 41.0	− 37.9	− 39.2	− 36.9
	(BM)	1949 (IV) -1947 (XI)	1950 (I) -1947 (XI)	1952 (XII) -1947 (XI)		
(*b*)	5136	mm 0.0	mm 0.0	mm 0.0		
	M_2	− 4.6	− 7.1	− 5.7		
	M_1	− 9.1	−15.5	−14.2		
	5144	−13.8	−24.2	−22.8		
(*c*)	M_1	mm 0.0	mm 0.0	mm 0.0		
	M_2	+ 0.7	+12.9	+13.5		

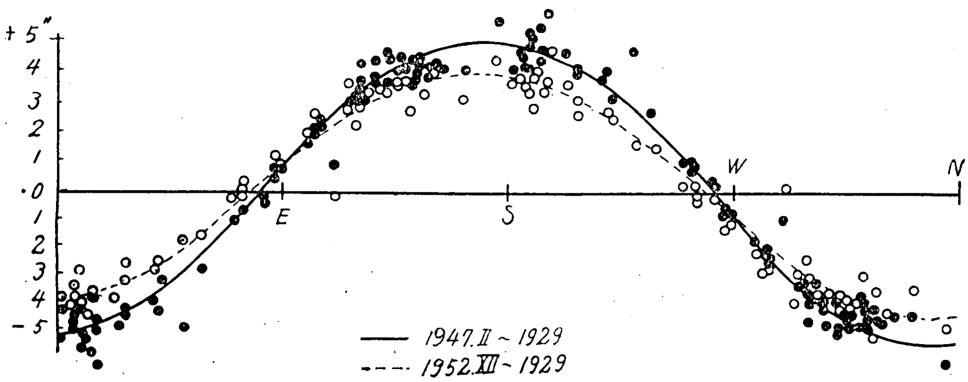

Fig. 3. Tilt along lines connecting each two bench marks during asigned period. (After Miyabe's method)

Table III.
Magnitude and direction of tilt of the neighbourhood of Muroto Point, reckoned from the level of 1929.

Period	Magnitude of tilt (φ)	Direction of tilt (A)
1929-1947 (II)	4.95″	S 10°E
1929-1947 (VII)	4.42″	S 10°E
1929-1949 (IV)	4.20″	S 2°E
1929-1950 (I)	3.73″	S
1929-1952 (XII)	3.62″	S 12°E

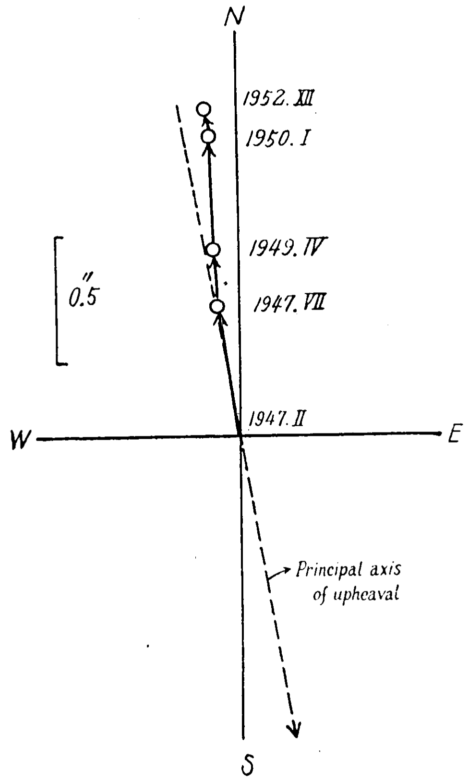

Fig. 4. Vector representation of tilting motion in the neighbourhood of Muroto Point after the earthquake.

post-earthquake period as well as the abrupt deformation simultaneous with the earthquake mainly consist of a simple tilting motion and hardly any warping deformation can be detected. This argument will be more decisively expressed by the examples shown in Fig. 3, where the change of all bench marks during 1929~1947 (full circles) and 1929~1952 (hollow circles) are represented with the aid of Miyabe's method.[3] The magnitude (φ) and direction (A) of tilting at respective epochs of the earth's crust of Muroto Point reckoned from the reference condition in 1929, thus determined from the sine curves obtained by Miyabe's method, are summarized in Table III. The tilting change of Muroto Point during the period of about six years after the earthquake is vectorially represented in Fig. 4, where the origin of coordinate corresponds to the epoch of February 1947, and the direction of a broken arrow indicates that of the tilting motion during 1929~1947 February.

As will be seen in this result, the direction of tilting change after the earthquake has been kept practically constant and it is almost opposite to that of the co-earthquake tilt. On the other hand, the rate of progress of tilting φ was fairly large for about one year after the occurrence of

3) N. MIYABE, *Bull. Earthq. Res. Inst.*, **2** (1931), 253.

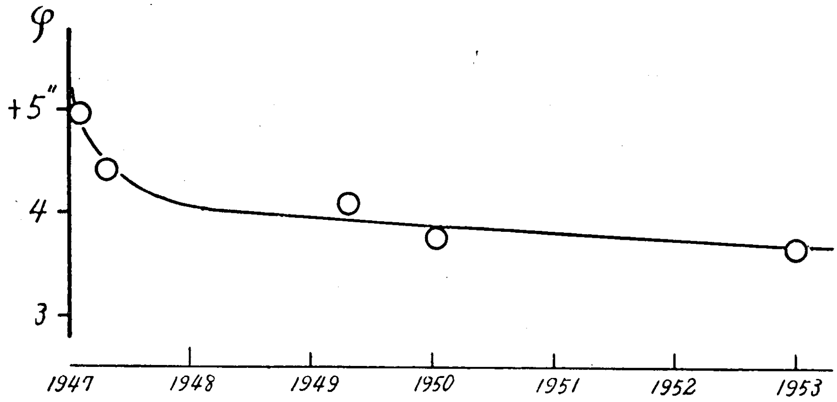

Fig. 5. Amount of tilt (into the direction of N 10° W) of the neighbourhood of Muroto Point after the earthquake.

the earthquake, but it has been diminishing gradually with time, as will be seen in Fig. 5. The empirical formula fitting the observed relation between φ and time is given by

$$\varphi = 3.90'' + 1.65'' e^{-2.232t} - 0.0348''t \,, \qquad (1)$$

where t denotes the time in unit of year reckoned from the time of occurrence of the great earthquake. It will be worthwhile to note that the third term of the above equation is practically effective for the recent years (i.e. after 1950), and it is just the same as the rate of progress of tilting motion of the same locality in the same direction during the pre-earthquake period. In other words, the rate of the after-earthquake tilting has almost recovered to the pre-earthquake steady value of about 0.035″/year, which had continued more than 40 years.

Some discussions.

The empirical formula (1) gives the amount of tilt for the after-earthquake period reckoned from the level in 1929. However, a number of observations suggest us that the pre-earthquake tilting of 0.035″/year into S 10° E direction had continued nearly uniformly until the time just before the occurrence of the earthquake. Hence, if we reckon from the level just before the earthquake in 1946, the amount of tilt for the after-earthquake period is given by

$$\varphi = 4.50'' + 1.65'' e^{-2.232t} - 0.0348''t \,. \qquad (2)$$

This means that the northward tilting of 6.15″ occuring with the earthquake could be recovered if the present southward tilting continued for about 130 years.

The tilting motion dealt with here is not only a local phenomenon within the neighbourhood of Muroto Point, but also represents the general aspect of land deformation of a much larger area of the south-east part of Shikoku. Therefore, the northward and southward tilts result respectively in an upheaval and a subsidence of Muroto Point. Actually, the co-earthquake northward tilt there resulted in an upheaval of Muroto Point of about one meter. Since about one third of the tilt was recovered by 1953, the amount of subsidence of the Point during the period of six years after the earthquake must be about 30 cm.

According to old records the mode of land deformation accompanying both the great earthquake of 1707 and of 1854 in this district was almost the same as for the present one; namely, Muroto Point upheaved by more than one meter at the time of earthquake and gradually subsided during the interval of the earthquakes. Then, it will be seen that in this district a great earthquake accompanied by marked land deformation of a definite type has occurred periodically with a period of 100 to 150 years.

On the other hand, the old beach lines on the marine terrace along the sea coast of the neighbourhood of Muroto Point show the evidence of the periodic upheavals of this locality through a long time of many thousand years.[4] Thus, it may be assumed that a land deformation of the vicinity of Muroto Point and an occurrence of great earthquake will be directly connected to a geotechtonic motion in this district which has continued and is still going on. Consequently, it can hardly be doubted that a great earthquake will occur again in this district about 100 years from now and it will be accompanied by a land deformation quite similar to that of 1946. From this view point, studies of conceivable mechanism of the relation between earthquakes and land deformation in this district should be conducted.

Acknowledgement.

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4) G. IMAMURA, "Japan Island", p. 50, Tokyo, 1944.

15. 1946年南海道大地震後における室戸岬近傍の地殼変動

地震研究所 岡田 惇
地球物理学教室 永田 武

四国室戸岬近傍の精密水準測量を，1946年12月の南海道大地震以後7回繰返して施行した．これ等の測量成果と地震以前に行われた測量の結果とから次の事が言へる．

(i) 地震前は40年以上の期間にわたって，S 10° E の方向へ 0.035″/年 の割合で傾動していた．

(ii) 大地震に伴って，丁度反対の N 10° W の方向へ約 6.2″ 急変した．

(iii) 地震後は再び S 10° E の方向へ傾動しつゝある．地震発生の時を時間 t の原点にとって，t を年単位で表わせば，地震直前に比して，任意の時 t における傾角 (N 10° W 方向を正とする) φ は

$$\varphi=4.50''+1.65''e^{-2.232t}-0.0348''t$$

で表わされる．即ち現在は，地震前におけると同じく 0.035″/年 の一定速度で S 10° E 方向への傾動が進行しつゝある．