31. *Results of the Precise Levellings executed in the Tanna Railway Tunnel and the Movement along the Slicken-side that appeared in the Tunnel.*

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(Read March 17, 1931 & Sept. 15, 1931.—Received Sept. 20, 1931.)

One of the most important and interesting subjects in earthquake researches may be the deformation of the earth's crust and the movement of land blocks that are produced in a meizo-seismal, and neighbouring regions. A considerable part of recent studies in the field of seismology is more or less related to this subject. After the Tango earthquake, which occured on March 7th. 1927 in the Tango penninsula, levelling and triangulation surveys over an extensive area including the epicentral region have been repeated several times. The surveys have revealed a number of interesting features of the movements of the earth's crust in each time they were repeated, and the results were closely studied by many authors[1]. Since the time of this earthquake, levelling surveys were carried out in every case of remarkable earthquakes[2] and volcanic eruptions,[3] and the results obtained have always given valuable data for the investigation of the deformation of the earth's crust. Tiltmeter observation may be another method of power to investigate the motion of land blocks. Such observations were already enforced with many interesting results in several reseaches[4].

In the case of the recent earthquake of North Idu, which occured on Nov. 26 th. 1930, various surveys were also performed in order to find out the deformation of the earth's crust, i. e. levelling surveys arround the Idu penninsula and across the epicentral region of the earthquake, triangulation over an area of about 1400 km. squares, including 4 first

1) C. Tsuboi, *Bull. Earthq. Res. Inst.*, 8 (1930), 153; T. Terada & N. Miyabe, 8 (1930), 338.

2) Land Survey Department, *Bull. Earthq. Res. Inst.*, 9 (1931), 109; 8 (1930), 375.

3) C. Tsuboi, *Bull. Earthq. Res. Inst.*, 8 (1930), 237.

4) M. Ishimoto & R. Takahasi, *Bull. Earthq. Res. Inst.*, 8 (1930), 427; M. Ishimoto, *Bull. Earthq. Res. Inst.*, 4 (1928), 203; 8 (1930), 222.

order triangulation points and 17 second order triangulation points. Beside these surveys carried out by the hand of the Land Survey Department of the Imperial Army, levellings and triangulations were executed several times by Mr. Tsuboi in the Tanna Basin, where the largest fault appeared in the case of the earthquake.

In the present communication are described the results of the precise levellings effected in the Tanna tunnel. The tunnel is being excavated in nearly E-W direction through the epicentral region of the recent earthquake for the purpose to connect Atami to Misima, and the excavation had been proceeding from the two ends of the tunnel. At the time of the earthquake, the heading of the pioneer drift of the west part of the tunnel was being driven right under the Tanna Basin. The heading of the east side of the tunnel was under Mt. Takiziyama, leaving the central 1300 m. unexcavated. The presence of the tunnel has offered a special opportunity for the parallel observation, on the ground and in the earth, not only of the nature of seismic waves of after-shocks, but also of the deformation of the earth's crust produced at the time of and after the earthquake.

In Fig. 1 is shown the size and form of the bench-marks used for the present levellings in the tunnel. It is made of gun-metal to prevent it from rusting by the enormously damped air in the tunnel. Its working surface *a* was covered with vaseline when it is not in use. The bench-marks as a whole is ring-shaped with a handle *b* at its one side. To the handle *b* is screwed an iron bolt of 2 cm. in diameter and 30 cm. long. The bolt was buried horizontally into the side-wall of the tunnel, to such a depth as to make the centre of *a* 9 cm. apart from the wall. The plantation of the bench-marks was carried on under great care to minimize the effect

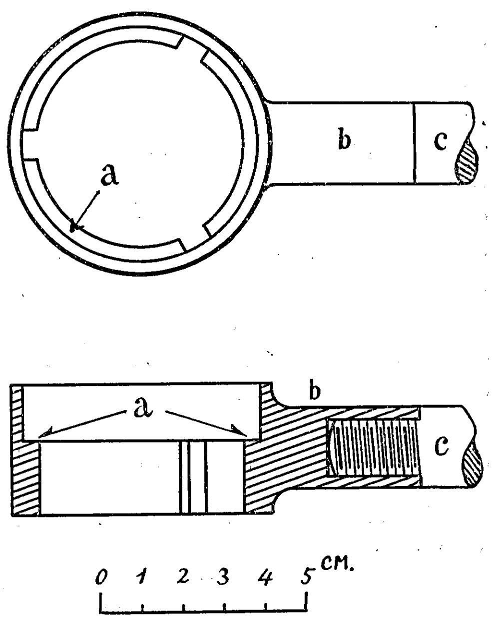

Fig. 1. Bench-mark.

of shrinkage of the mortar used, and to make the plane of the working surface *a* horizontal as accurately as possible.

It would have been the best way for the original purpose of the survey to plant these bench-marks to the natural wall of the tunnel not lined with other materials. In the present case, however, almost all the strata penetrated by the tunnel are of soft materials, such as sand, volcanic scolia, agglomerate and clay. It could not therefore be expected that the bench-marks planted in such materials are held rigidly enough to permit such precise measurement as is required in this case. Moreover, because the main tunnel is lined with concrete, the natural rock wall is to be met with only in drain drifts which lie parallelly to and on both side of the main tunnel. Dangers and difficulties may accompany the works in the drain drifts, as the water flowing in them is of considerable amount even in usual time. Under these circumstances, we have decided to plant the bench-marks in the side-wall of the main tunnel, and to deduce the movement of the earth's crust from the deformation of the tunnel wall. This concession may perhaps be permitted to some extent, as the lining of the tunnel is parted every 10 meters by construction joints and can

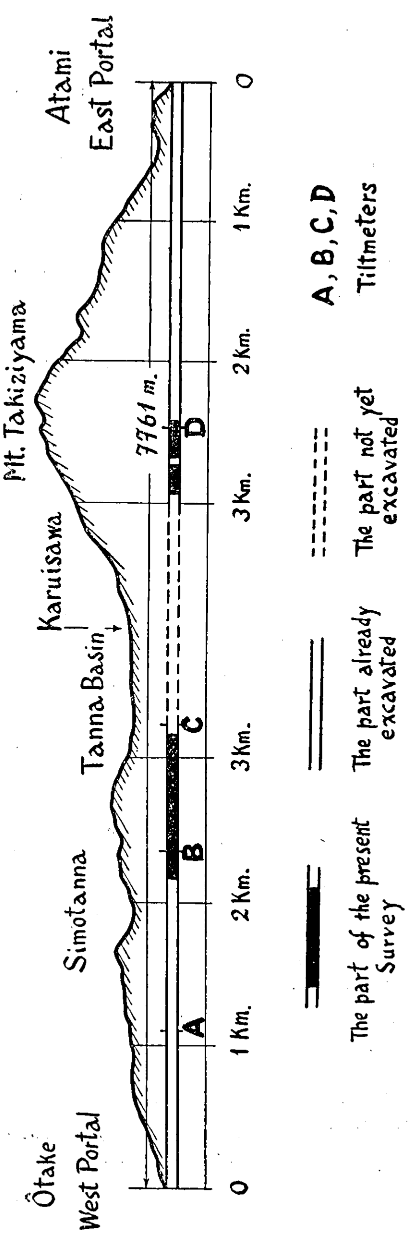

Fig. 2. Profile of the Tanna Tunnel.

move freely at these joints. It is to be regretted that the surveys were not executed along the entire length of the tunnel, but were restricted to the part of the tunnel indicated in Fig. 2 by thick lines, whose total length is 1500 m.

Two forms were employed in the plantation of bench-marks. In one of the forms, the bench-marks were planted along the gradient line of the tunnel so that the relative height of the bench-marks to the observer is always constant. In the other form, bench-marks are planted in level. The relative height of bench-marks to the observer becomes therefore in this form higher and higher by the amount, the gradient of the tunnel times the interval of two consecutive bench-marks, as the observer goes from one bench-mark to the next. When the height of bench-marks became inconvenient for measurements, the level is lowered and the bench-marks were again planted in level. From No.-3 bench-mark to No. 15 in the west side of the tunnel and from No. 30 bench-mark to No. 42 in the east side, the former form of plantation was adopted. Other bench-marks were planted according to the latter form. Intervals of two successive bench-marks are all 20 m.

Rate of tilting of a land block is generally less than a second of arc per month, even in such rather active period as after a great earthquake. The largest rate of tilt measured at Itô by a tiltmeter during the Itô earthquake is $0''.7$ per day, and the largest monthly rate was $4''.5$. At Kawana, 4 km. south of Itô, they were $0''.7$ and $6''.0$ respectively.[5] These are rather particular cases of the phenomena. The largest tilting motion following the Kwantô Earthquake was observed at Kamogawa block, in the Bôsô penninsula, and the mean rate of tilt was $0''.01$ per month.[6]. The Kôtô block[7], which forms the south-west end of Tôkyô, tilts secularly by the velocity of about $0''.04$ per month. This is probably the largest value of secular tilt which have ever found by levelling surveys.

If the velocity of tilt of a land block be $0''.1$ per month, monthly observations will find changes in height difference of two successive bench-marks lying on that block of the amount of only 0·05 mm., when the bench-marks are 20 m. apart. This amount is so small that even the first order levelling instrument can hardly detect it In the present measurement it was necessary, therefore, to use a measuring intrument of higher accuracy than the first order levelling instrument. In this aim a new instrument was made as described in the following.

5) R. TAKAHASI & M. ISHIMOTO, *Bull. Earthq.Res. Inst.*, 8 (1930), 427.
6) N. MIYABE, *Bull. Earthq. Res. Inst.*, 9 (1931), 263.
7) A. IMAMURA, *Disin*, 3 (1931), 141; *Proc. Imp. Acad.*, 7 (1931), 1.

The instrument consists essentially of a flexible metal pipe 25 m. long, 1 cm. thick in internal diametre connecting two measuring parts of identical construction. The instrument as a whole forms therefore a U-tube. In Fig. 3 is shown the measuring part. In the figure H_1,H_2 are steel nails with which the measuring part hangs on the working surface of a bench-mark. There are three H_1's and three H_2's on the outer surface of the cylinder L. When the instrument is filled with a suitable quantity of water, when it is hanged on bench-marks, water surfaces appear at the window C which is covered with a sheet of plate glass. The water surface reflects the image of a needle N, when viewed obliquely from beneath. The position of the needle, when brought in contact with its image by means of the micrometer screw S, can be read off by the indices F, G. The micrometer screw is made of stainless steel and its pitch is 0.5 mm. The index G is graduated into 50 divisions so that the smallest division correponds to 0·01 mm. When two successive bench-marks to be measured are planted nearly in level, H_1 nails are used in both measuring parts. If the bench-marks to be measured were planted along the slope of the tunnel, H_1 is used at one measuring part and H_2 at the other to bring the water surfaces to the windows C, C′ in both measuring parts. Other part of the instrument is of brass, except the packing P, which is of caoutchouc. The calibration of the screw S was carried out using a dividing engine made by Société Genèvoise, and the error of the screw proved not to exceed 0·01 mm. By laboratory tests this instrument proved to be capable of determining the position of the water surface so accurately as to 0·001 mm. but in field works the fractions of divisions was not read for the sake of simplicity and rapidity of the measurements.

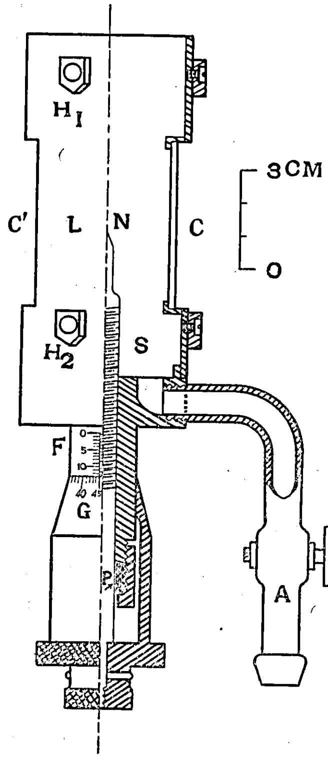

Fig. 3. Measuring part of the instrument.

Now in Fig. 4 let C be the vertical distance between the upper nail H_1 of the instrument and the position of the needle when the index

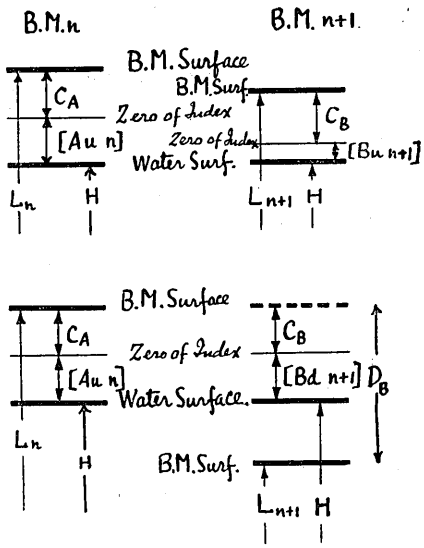

Fig 4.

reading is zero. Let D be the distance between the upper and the lower nails, H be the height of the water surface in the instrument, and $[Au\ n]$ be the reading of the index of the measuring part A at the bench-mark No. n when the *upper* nail is used. Then the difference $L_n - L_{n-1}$ in height of the bench-marks No. n and No. $n+1$ is given by

$$L_n - L_{n+1} = \{H + [Au\ n] + C_A\} - \{H + [Bu\ n+1] + C_B\}$$
$$= [Au\ n] - [Bu\ n+1] + (C_A - C_B),$$

when the bench-marks are planted nearly in level. Interchanging the measuring parts, we have similarly

$$L_n - L_{n+1} = [Bu\ n] - [Au\ n+1] - (C_A - C_B).$$

Therefore by addition we get

$$2\,L \equiv 2\,(L_n - L_{n+1}) = \{[Au\ n] - [Bu\ n+1]\} + \{[Bu\ n] - [Au\ n+1]\} \quad (1)$$

and by substraction

$$\varDelta \equiv -2\,(C_A - C_B) = \{[Au\ n] - [Bu\ n+1]\} - \{[Bu\ n] - [Au\ n+1]\}. \quad (2)$$

When the bench-marks to be measured are planted along the slope of the tunnel, we have instead of (1) and (2),

$$2\,L \equiv 2\,(L_n - L_{n+1})$$
$$= \{[Au\ n] - [Bd\ n+1]\} + \{[Bu\ n] - [Ad\ n+1]\} + (D_A + D_B) \quad (3)$$

and

$$\Delta' \equiv -2(C_A - C_B) + (D_A - D_B)$$
$$= \{[Au\, n] - [Bd\, n+1]\} - \{[Bu\, n] - [Ad\, n+1]\}. \qquad (4)$$

In the above equations the suffixes A, B are used to distinguish the quantities related to the measuring part A from those related to B. The quantities expressed in (2) and (4) do not involve other quantities than instrumental constants and serve for the direct check of the results of observation. In the present instrument $\Delta = -60{\cdot}3$ and $\Delta' = -81{\cdot}2$.

The observed quantities are recorded in such form as follows.

B. M.	D Pos.		R Pos.		Diff.	2L	Δ or Δ′	Remark
30	Au	2758	Bu	2350	+0484	+1028	−60	8ʰ 35ᵐ
31	Bu	2274	Au	1806	+0544			
31	Au	0927	Bu	0712	−1694	−3307	−81	9ʰ 05ᵐ
32	Bd	2621	Ad	2325	−1613			
32	Au	1978	Bu	2072	+0296	+0673	−81	9ʰ 20ᵐ
33	Bd	1682	Ad	1695	+0377			
n	(1)		(4)		(3) = (1) − (2)	(7) = (3) + (6)	(8) = (3) − (6)	
n+1	(2)		(5)		(6) = (4) − (5)			

Observations were executed several times in such schedule as follows:

I levelling	Dec. 29–30, 1930	D only		
II ,,	Jan. 7—9, 1931	,,	10 days	West side only
III ,,	Feb. 5–12, ,,	D and R	32 ,,	
IV ,,	Mar. 3—9, ,,	,,	28 ,,	
V ,,	Apr. 13–18, ,,	,,	40 ,,	
VI ,,	July 18–24, ,,	,,	90 ,,	

In the above table "D and R" shows that the observation was carried out in direct and reversed positions of the instrument and "D only" shows that the observation was carried out only in the direct position. The height difference between two consecutive bench-marks is able to be obtained by the "D only" observations as well as the "D and R" ones, when the instrumental constants are known. In this view the "D only" observation was carried on in the first and second surveys to save time and labour, but the results were not satisfactory, being of unexpected low accuracies resulting from some causes which cannot be elliminated in the missing condition of the check method.

Results of each levelling are given in the following table.

Table I. Height differences between successive bench-marks. (Unit=0·005 mm.)
(*......Renewed bench-marks.)

B. M.	I	II	III	IV	V	VI
East side						
10						
11		−2794	2797	2782	2765	2726
12		−2654	2657	2642	2634	2626
13		+4950	−4905	4919	4915	4918
14		−1848	1887	1864	1893	1906
15		—	4158	4164	4161	4166
16		−0494	0514	0516	0514	0511
17		−0144	0174	0140	0142	0119
18		+4552	4547	4538	4551	4552
19		−2644	2660	2686	2735	2828
20		+1558	1508	1515	1500	1466
			:			
30		+1080	1028	1033	1012	0949
31		−3268	3307	3300	3296	3285
32		+0698	0673	0682	0679	0693
33		−0928	0961	0960	0963	0970
34		+0610	0613	0600	0602	0603
35		−0270	0283	0285	0276	0251
36		+0412	0378	0381	0378	0368
37		−3440	3499	3484	3494	3512
38		+3190	3155	3127	3088	2995
39		+0230	0269	0285	0330	0400
40		+4792	4841	4857	4870	4917
41		+6140	6138	6133	6128	6126
42						
West side						
−3						
−2	—	3554	—	—	—	1296*
−1	−3652	3700	—	—	—	3872
0	—	+5542	5519	5487	5463	5420
1	+2566	2580	2468	2447	2422	2384
2	−0970	0996	1081	1149	1202	1300
3	−0612	0618	0688	0699	0751	0799
4	+6280	6286	6291	6280	—	4463*
5	−5372	5393	5455	5475	—	3783*
6	+4468	4416	4413	4401	4381	4364
7	−0088	0128	0145	0153	0157	0087

(to be continued.)

Table I. (*continued.*)

B. M.	I	II	III	IV	V	VI
West side						
8	−5276	5298	5328	5339	5340	5451
9	+0724	0662	0659	0646	0642	0639
10	−4660	4694	4686	4689	4694	4723
11	+3574	3568	3565	3561	3564	3557
12	−3024	3044	3068	3074	3059	3069
13	−2000	2030	2030	2027	2056	2046
14	+0696	0638	0646	0649	0645	0639
15	—	−5633	5640	5650	5645	5642
16	—	—	6678	6679	6674	6742
17	−2742	2744	2753	2744	2737	2722*
18	−0294	0304	0317	0311	0319	0314
19	+3770	3836	3841	3843	3840	3844
20	−1968	—	1965	1948	1932	1898
21	+3758	3782	3762	3778	3788	3808
22	—	−3244	3283	3275	3277	3254
23	+5606	5610	5655	5659	5662	5700
24	−0886	0866	0924	0930	0908	0913
25	−2660	2642	2673	2661	2659	2647
26	+2046	2030	2035	2059	2049	2058
27	+2536	2530	2542	2545	2549	2556
28	−0700	0716	0695	0695	0698	0702
29	−2266	2294	2290	2288	2286	2292
30	+2398	2334	2332	2341	2347	2349
31	+1594	1574	1545	1530	1533	1514
32	−2578	2574	2553	2540	2514	2483
33	+0392	0402	0387	0405	0420	0437
34	−3652	3672	3682	3681	3671	3680
35	−4616	4674	4769	4767	4786	4809
36	−1442	1446	1424	1407	1389	1254
37	+2040	2108	2160	2210	2282	2398
38	+1314	1360	1386	1422	1484	1557
39	+0346	0360	0265	0237	0202	0139
40	+0414	0342	0173	0108	0013	−0132
41			−5083	5061	5043	5005
42			—	—	—	—
43			+5781	5796	5794	5831
44			−2929	2945	2961	2992
45			−4329	4321	4313	4272
46			+3365	3373	3380	3359
47			−1732	1730	1727	1763
48			−1260	1273	1273	1299
49			−0743	0735	0722	0728
50			−2593	—	1237*	1233

Table II. Variation of height differences between successive bench-marks. (Unit=0·005 mm.)

B. M.	II-I	III-II	IV-III	V-IV	VI-V
East side					
10		− 3	+ 15	+ 17	+ 39
11		− 3	+ 15	+ 8	+ 8
12		− 45	+ 14	− 4	+ 3
13		− 41	+ 23	− 29	− 13
14		—	− 6	+ 3	− 5
15					
		− 20	− 2	+ 2	+ 3
16		− 30	+ 34	− 2	+ 23
17		− 5	− 19	+ 13	+ 1
18		− 16	− 26	− 49	− 93
19		− 50	+ 7	− 1	− 34
20					
		− 52	+ 5	− 21	− 63
30		− 39	+ 7	4	+ 11
31		− 25	+ 9	− 4	+ 14
32		− 33	+ 1	− 3	− 7
33		+ 3	− 13	+ 2	+ 1
34					
		− 13	− 2	+ 9	+ 25
35		− 34	+ 3	− 3	− 10
36		− 59	+ 15	− 10	− 18
37		− 35	− 28	− 39	− 93
38		+ 39	+ 16	+ 45	+ 70
39					
		+ 49	+ 16	+ 13	+ 47
40		− 2	− 5	− 5	− 2
41					
42					
West side					
− 3					
− 2	—	—	—	—	—
− 1	—	—	—	—	—
0	—	− 23	− 32	− 24	− 43
1	+ 14	−112	− 21	− 25	− 38
2	− 26	− 85	− 68	− 53	− 98
3	− 6	− 70	− 11	− 52	− 48
4	+ 6	+ 5	− 11	—	—
5	− 21	− 62	− 20	—	—
6	− 52	− 3	− 12	− 20	− 17
7	− 40	− 17	− 8	− 4	+ 70

(*to be continued.*)

Table II. (*continued.*)

B. M.	II–I	III–II	IV–III	V–IV	VI–V
West side					
8	− 22	− 30	− 11	− 1	−112
9	− 62	− 3	− 13	+ 6	− 3
10	− 34	+ 8	− 3	− 5	− 29
11	− 6	− 3	− 4	− 2	− 6
12	− 20	− 24	− 6	+ 15	− 10
13	− 30	0	+ 3	− 24	+ 5
14	− 58	+ 8	+ 3	− 4	− 6
15	—	− 7	− 10	+ 5	+ 3
16	—	—	− 1	+ 5	—
17	− 2	− 9	+ 9	+ 7	+ 15
18	− 10	− 13	+ 6	− 8	+ 5
19	+ 66	+ 5	+ 2	− 3	+ 4
20	—	—	+ 17	+ 6	+ 44
21	+ 24	− 20	+ 16	+ 10	+ 20
22	—	− 39	+ 8	− 2	+ 23
23	+ 4	+ 45	+ 4	+ 3	+ 38
24	+ 20	− 58	− 6	+ 20	− 03
25	+ 18	− 31	+ 12	+ 2	+ 12
26	− 16	+ 5	+ 24	− 10	+ 09
27	− 6	+ 12	+ 3	+ 4	+ 7
28	− 16	− 26	− 5	− 3	− 4
29	− 28	+ 4	+ 2	+ 2	− 6
30	− 64	− 2	+ 9	+ 6	+ 2
31	− 20	− 29	− 15	+ 3	− 19
32	+ 4	+ 21	+ 13	+ 26	+ 29
33	+ 10	− 15	+ 18	+ 15	+ 17
34	− 20	− 10	+ 1	+ 10	− 9
35	− 58	− 95	+ 2	− 19	− 23
36	− 4	+ 22	+ 17	+ 18	+ 35
37	+ 68	+ 52	+ 50	+ 72	+116
38	+ 46	+ 26	+ 36	+ 62	− 73
39	+ 14	− 95	− 28	− 35	− 58
40	− 72	−169	− 65	− 95	−145
41			+ 22	+ 20	+ 36
42			—	—	—
43			+ 15	− 05	+ 40
44			− 16	− 16	− 31
45			+ 08	+ 08	+ 41
46			+ 08	+ 7	− 16
47			+ 2	+ 3	− 36
48			− 13	0	− 26
49			+ 8	+ 13	− 6
50			—	—	− 4

By these results, height differences between two consecutive bench-marks were plotted against time taken in abscissa. The origin of height difference is taken arbitrary. In Fig. 5, thus constructed, the inclination of curves indicates therefore the velocity of variation of height difference

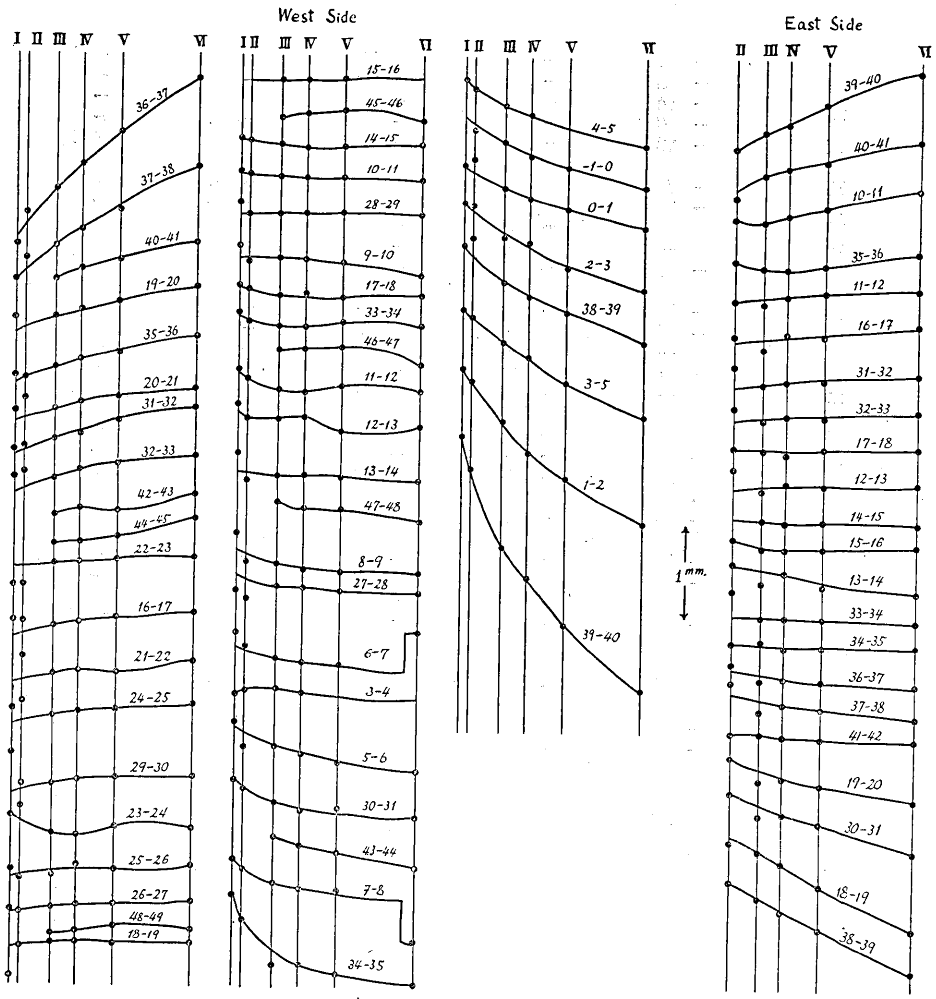

Fig. 5. Time-variation of height difference between two successive bench-marks.

of the corresponding bench-marks. Generally speaking, the variation of height difference is more rapid in the west side of the tunnel than in the east side. The velocity of tilting is showing clearly an exponential-like decrease in the west side while in the east side it is rather linear and constant.

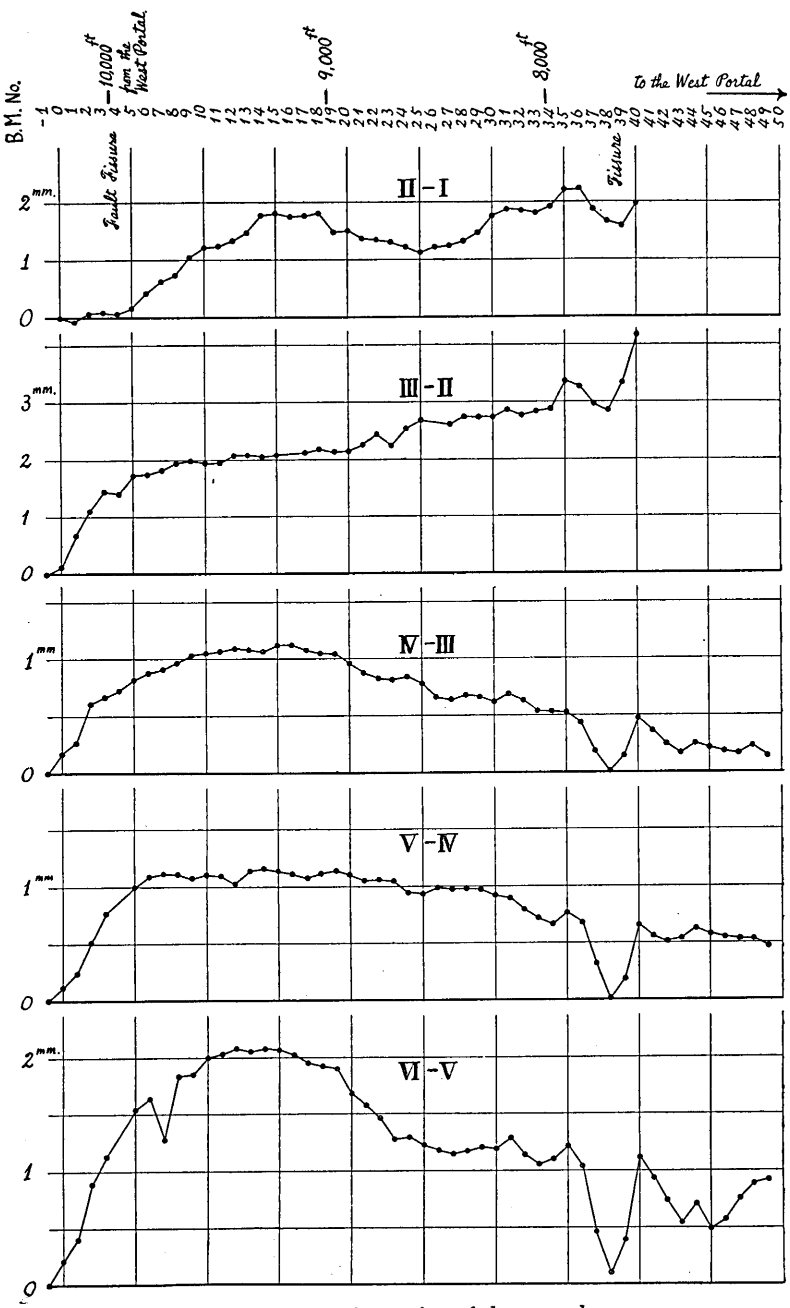

Fig. 6. a. Deformation of the tunnel.
(West side).

Now we will study what deformation of the tunnel was disclosed by each survey. Fig. 6 represents the deformation of the tunnel found by each levelling when the tunnel is assumed to be straight at the time of the immediately preceeding survey. Fig. 6 was obtained by successive addition, in each column of table II, of variations of height differences between successive bench-marks, assuming that the height of the initial one of a series of bench-marks is unchanged. It is very remarkable that these curves are very much similar in form to each other. The tunnel seems to be deforming always to the same shape. The I-II and II-III curves are less accurate than the other curves, because the first and second surveys are the " D only " ones. The curves are therefore not so similar with the others. If we make, however, adjustments to these curves, by extrapolating the corresponding variations of the height differences from Fig. 5, we obtain the curves which are satisfactorily simillar with others.

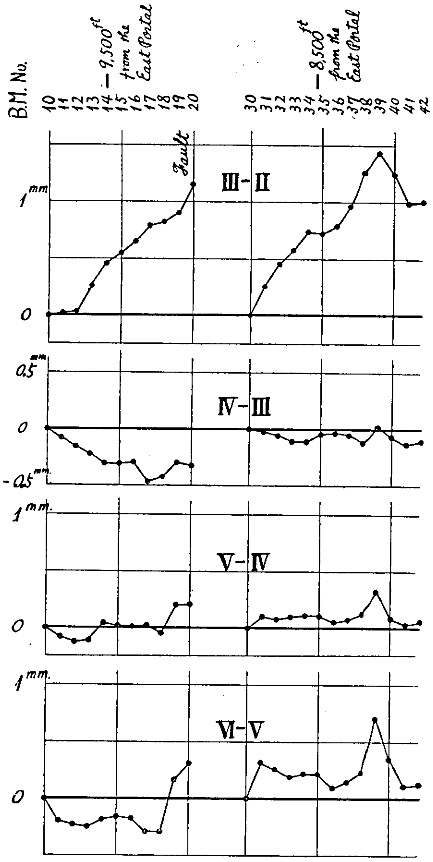

Fig. 6. b. Deformation of the tunnel. (East side).

Comparison of the deformation of the tunnel with the geology of the tunnel shown in Fig. 7 leads us to an interesting consequence. Deformations are mostly combined with faults or with the place where the strata make sudden change in strength, and the remaining part of the tunnel is generally less active. This fact leads us to the consideration that the the yielding of the earth's crust occurs for the most part at some particular weak lines, though slight bending deformations may be seen in the remaining part. These weak lines form therefore the boundaries of so-called land blocks. This consideration harmonizes very beautifully with

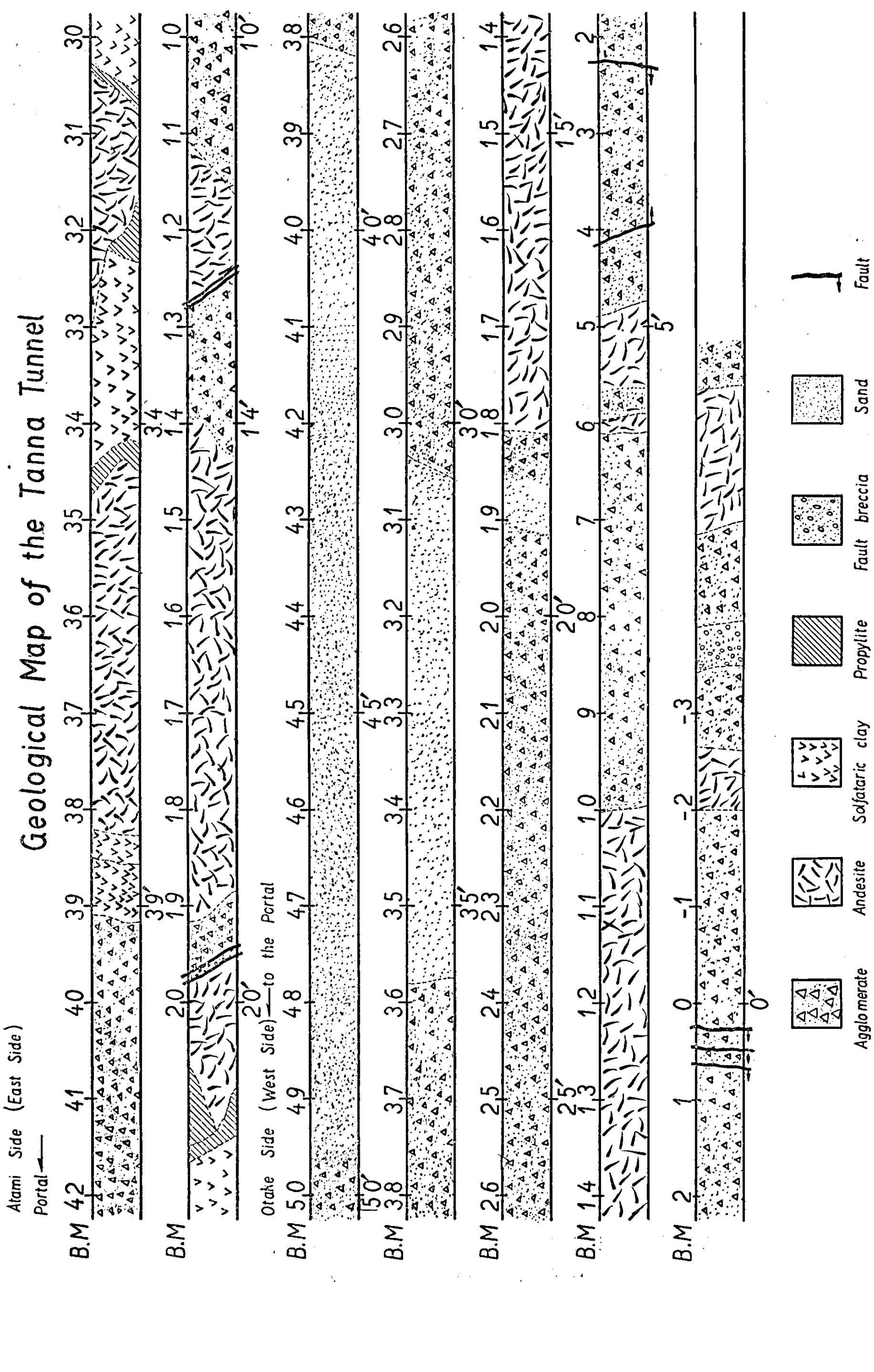
Geological Map of the Tanna Tunnel
Atami Side (East Side)
Portal
Otake Side (West Side)—to the Portal
B.M
Agglomerate
Andesite
Solfataric clay
Propylite
Fault breccia
Sand
Fault

Fig. 7.

the idea hetherto considered by many authors regarding the movement of land blocks, and elucidates what deformation occurs in and at the boundary of land block.

Some deformations are of course due to the sinking of the lining of the tunnel into weak strata which the tunnel penetrates.

Immediately after the earthquake, tiltmeters were installed at the points **A B C D** (Fig. 2) in the tunnel. The direction of tilt recorded by these tiltmeters coincide at **B** with the local tilt revealed by the present observation, but at **D** it is opposite. The amount of tilt recorded by the tiltmeter is always far larger than that revealed by the present observation for the same period.

In Fig. 8, the result of the precise levelling is given which were carried on by the hand of the Land Survey Department of the Imperial Millitary along the route which passes through the epicentral region

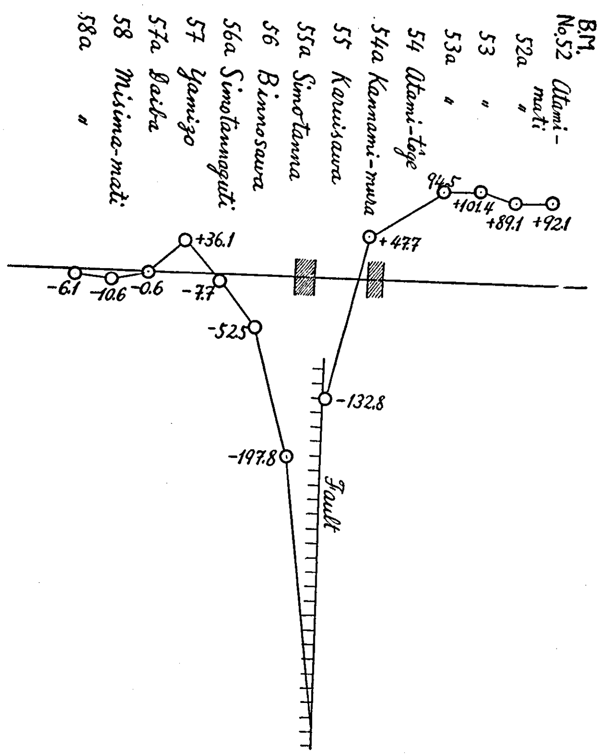

Fig. 8. Change in height of bench-marks produced by the Idu Earthquake. (unit in mm.)

of the earthquake and is approximately parallel to the tunnel. In the figure the shaded parts of the route correspond to the region of our levelling. As seen in the figure, the parts were subjected to remarkable tilting in the case of the earthquake. It is to be noted that the land block which tilted so remarkably with the occurrence of the earthquake becomes immobile so quickly as discovered by the present survey, though there is remaining a slow movement which is decreasing with time.

Movement of the slicken-side of a fault that appeared in the tunnel.

Accompanying to the earthquake, faults and fissures appeared not only on the earth's surface, but in the tunnel. At the point between the bench-mark No. 3 and No. 4 in the west side of the tunnel vertical dislocation of the amount of 40 cm. ca. was measured. The most remarkable fault in the tunnel appeared near the heading of the third south drain drift of the west side. The displacement, which was nearly in horizontal direction, was as large as 2·70 m. that the drain tunnel was completely shut by a fresh slicken-side. Two dial-guage indicators were attached to this slicken-side as seen in the photograph, (Fig. 9) in order to measure the horizontal and vertical movements of the fault.

Fig. 10 represent the movement of the slicken-side thus observed, that is the movement of the east side block of the fault, when the west side is regarded as immoble. The direction of the motion is north-down as seen in the figure. The direction is in the same quadrant with the movement of the block in the case of the earthquake. The total amount of displacement since the beginning of this year to this time is a little more than 1 mm.

In concluding this paper, the writer wishes to express his sincere thanks to Professor K. Suyehiro, the director of our Institute for the stimulation of the present research, to Professor M. Ishimoto for his invaluable advices, and to the party engaged in the excavation of the tunnel for the various facillities given for the present works.

The writer's heartfull thanks are also due to Mr. K. Kakuma for his devoting assistance in the field work, and to Messrs. A. Zitukawa, M. Otuka, R. Takei and M. Iwasita for their kind help in the field work and in preparing the figures contained in this paper.

Fig. 9.

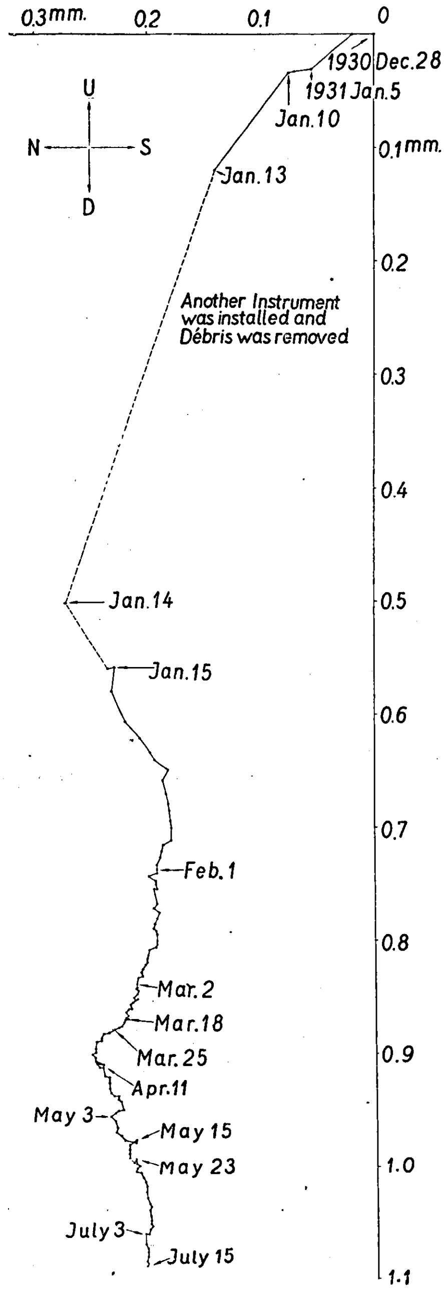

Fig. 10. Movement of the slicken-side that appeared in the tunnel.

31. 丹那隧道內に於ける精密水準測量の結果、及び同隧道內に現れた斷層鏡面の運動

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昭和五年十一月廿六日北伊豆地方に起つた激震後の地殼の運動を調査する目的を以て、十二月以來次の如く合計六回に亘つて、丹那隧道內に於て水準測量を爲した。其の時日を擧げれば

第一回 昭和五年十二月廿九日—卅日
第二回 昭和六年一月七日—九日
第三回 同 二月五日—十二日
第四回 同 三月三日—九日
第五回 同 四月十三日—十八日
第六回 同 七月十八日—廿四日

である。測量爲された範圍は本文第二圖中黑線を以て示してある。地塊の運動を精査するには一等水準以上の精度を必要とする爲、此の測量に於ては第三圖に示す如き特別の器械を製作使用した。測量の結果は第六圖に示された如くである。此圖は前回の測量の時、隧道が直線であつたと假定した時の隧道の變形を示すものである。此等の結果を第七圖に示す處の隧道內の地質圖と比較する事に依つて地殼の運動に依る變形は特殊の弱線のみが其の大部分を受持つて、他の部分は殆んど變形に與からない事が判明する。此等の弱線は即ち地塊の境界を爲すものであらう。

北伊豆地震に伴つて、地表にも亦隧道內にも斷層が現れた。隧道內に現れた斷層の中、最も著しきものは大竹口南側水拔導孔最奧に現れたものである。此處では導孔は新しい斷層鏡面の出現によつて完全に閉塞されて終つた。此の斷層鏡面の上下及び垂直の運動を測定する爲にダイアル、ゲーヂ二個を取付けた。第十圖に示すものは其に依つて測定された斷層鏡面の運動で、西側が不動と考へた時の斷層東側の地塊の運動を示してゐる。本年一月中旬以來の運動の總量は一粍餘に上つてゐる。