BULLETIN OF THE EARTHQUAKE
RESEARCH INSTITUTE
Vol. 46 (1968), pp. 651-661

28. *Electro-Optical Measurement of Horizontal Strains Accumulating in the Swarm Earthquake Area (4).*

By Keichi KASAHARA, Atusi OKADA, Mutsuro SHIBANO,
Koichi SASAKI, Shigeo MATSUMOTO and Masayo HIRAI,
Earthquake Research Institute.

(Read April 25 and September 12, 1967, and March 26, 1968.
—Received March 26, 1968.)

Abstract

The authors have repeated Geodimeter surveys in the Matsushiro and its adjacent areas since October, 1965. The present paper deals mainly with the surveys after 1966, as the data for the earlier period were reported in the previous three papers.

The base-lines of Sorobeku, Nishiterao and Zozan changed their length for −6.4, −1.3 and +3.2 cm, respectively, during the period November, 1966—March, 1968. These changes agree, in the sense, with those noticed after the climax of ground deformations in October of 1966. We may therefore conclude that the base-line lengths, which once effected great changes (Sorobeku : +116 cm, Nishiterao : +72 cm, Zozan : −22 cm), have recovered their deformation for about ten percent of the respective peak value.

Surveys on the Wakaho, Nakano, and Omachi networks are reported together with the preliminary data obtained from the newly constructed Akashina and Sakaki networks.

1. Introduction

The authors have been carrying out Geodimeter surveys in the northern part of Nagano Prefecture since October, 1965, as part of the ERI's expeditions for the Matsushiro swarm earthquakes. As reported in the previous three papers[1), 2), 3)], they repeated the surveys in Matsushiro

1) K. KASAHARA and A. OKADA, "Electro-Optical Measurement of Horizontal Strains Accumulating in the Swarm Earthquake Area (1)," *Bull. Earthq. Res. Inst.*, **44** (1966), 335-350.

2) K. KASAHARA, A. OKADA, M. SHIBANO, K. SASAKI and S. MATSUMOTO, "Electro-Optical Measurement of Horizontal Strains Accumulating in the Swarm Earthquake Area (2)," *Bull. Earthq. Res. Inst.*, **44** (1966), 1715-1733.

3) K. KASAHARA, A. OKADA, M. SHIBANO, K. SASAKI and S. MATSUMOTO, "Electro-Optical Measurement of Horizontal Strains Accumulating in the Swarm Earthquake Area (3)," *Bull. Earthq. Res. Inst.*, **45** (1967), 225-239.

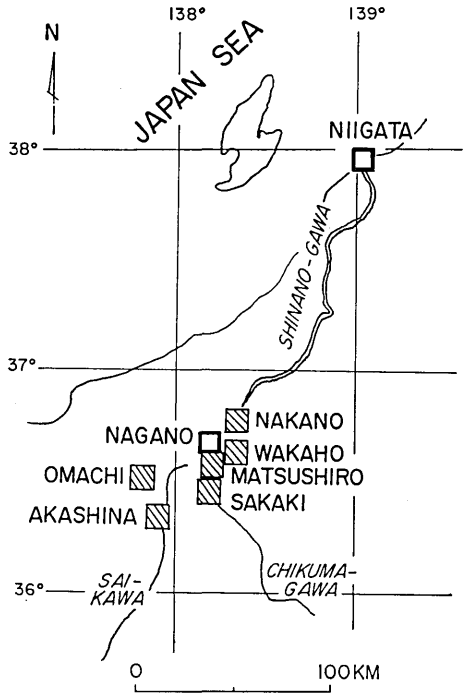

Fig. 1. Base-line networks constructed in the northern part of Nagano Prefecture.

eleven times during the period October, 1965 to November, 1966 and successfully discovered notable evidence for accumulation of horizontal strains there. Following these surveys they conducted four more surveys in the same area during the period of 1967-1968 (March), in order to observe strain events in the phase of decaying seismic activity since November of 1966. The supplementary networks at Wakaho, Nakano and Omachi were also resurveyed one or two times in the same period.

Since the earlier period of expeditions, the scientists concerned feared development of the seismic activity into the adjacent areas. Taking new data of micro-earthquake observations and of precise levelings into consideration[4),5)], the Akashina and Sakaki networks were added to watch strain accumulation in the western and southern parts of the Matsushiro area, respectively. Fig. 1 illustrates the location of these networks.

4) The Party for Seismographic Observation of Matsushiro Earthquakes and the Seismometrical Section, "Matsushiro Earthquakes Observed with a Temporary Seismographic Network. Part 4," *Bull. Earthq. Res. Inst.*, **45** (1967), 887-917.

5) I. TSUBOKAWA, *et al.*, "Levelling Resurvey Associated with the Area of Matsushiro Earthquake Swarms. (2)," *Bull. Earthq. Res. Inst.*, **46** (1968), 417-429.

2. Field work

2.1. Replacement of Geodimeters.

The authors introduced a Geodimeter, model 6, into their field work in early summer of 1967, which enabled them to survey in the daytime by use of a mercury lamp unit. Replacement of the previous Geodimeter (model 4) by the new one has been done after careful tests in an experimental field[6]. In the previous papers the authors have reduced the measured distances for atmospheric conditions but not for the instrumental constants of their Geodimeter and reflectors. This simplified reduction was permitted because they always operated the same set of instruments and were interested in changes of base-line lengths rather than their absolute values.

For successful replacement of the instruments, therefore, all the base-line lengths published in the previous tables have been reduced for the constants of the older set and are reproduced in Tables 1(a)-(d) of the present paper. The authors have not effected the altitude reduction that is necessary for standard geodetic work, so that the distances (D) given in the following tables represent the base-line lengths measured in the three-dimensional space.

2.2. Repetition of surveys.

Matsushiro network. Surveys were repeated four times on the base-lines of Sorobeku, Nishiterao and Zozan as follows.

Survey XII March 21-22, 1967,
Survey XIII August 2, 1967,
Survey XIV September 1, 1967,
Survey XV March 3, 1968.

The surveys XII and XIV were done by use of the Geodimeter model 4, whereas the XIII and XV surveys were made by the new instrument. As discussed above, the field readings were corrected for the atmospheric conditions as well as for the instrumental constants and are listed as D in Table 1(a). ΔD in the same table denotes the change in D counted from the first survey's data.

The authors previously noted that the sense of ground deformations

6) K. KASAHARA, A. OKADA, M. SHIBANO, K. SASAKI, S. MATSUMOTO and M. HIRAI, "Observation of Horizontal Strain Accumulation by Electro-Optical Means. 2nd Report," *Bull. Earthq. Res. Inst.*, **46** (1968), 741-758.

Table 1(a). Matsushiro Network

Base Line		Zozan		Nishi-terao		Sorobeku	
No.	Date	D	⊿D	D	⊿D	D	⊿D
		m mm	mm	m mm	mm	m mm	mm
I	Oct. 6-7, 1965	2381.536 (±4)	0	3153.635 (±6)	0	3062.041 (± 5)	0
II	Nov. 15	.524 (±4)	− 12	.643 (±9)	+ 8	.063 (± 9)	+ 22
III	Dec. 9	.559 (±7)	+ 23	.674 (±4)	+ 39	.124 (± 3)	+ 83
IV	Mar. 2, 1966	.531 (±3)	− 5	.661 (±3)	+ 26	.150 (± 3)	+ 109
V	Apr. 12-13	.494 (±2)	− 42	.737 (±3)	+102	.252 (± 3)	+ 211
VI	Apr. 18	.491 (±1)	− 45	.734 (±4)	+ 99	.283 (± 2)	+ 242
VII	May 5-6	.478 (±2)	− 58	.796 (±2)	+161	.362 (± 3)	+ 321
VIII	July 3	.458 (±4)	− 78	.920 (±4)	+285	.501 (± 2)	+ 460
IX	Sep. 6-7	.369 (±3)	−167	3154.132 (±1)	+497		
	7-8	.364 (±0)	−172			.924 (± 7)	+ 883
	8-9	.350 (±2)	−186				
X	Oct. 13-14	.324 (±1)	−212	.351 (±2)	+716	3063.189 (± 2)	+1148
XI	Nov. 12	.317 (±2)	−219	.337 (±3)	+702	.142 (± 3)	+1101
XII	Mar. 21-22, 1967	.335 (±2)	−201	.303 (±2)	+668	.136 (± 3)	+1095
XIII	Aug. 2	.354 (±2)	−182	.322 (±2)	+687	.082 (± 2)	+1041
XIV	Sep. 1	.326 (±2)	−210	.255 (±2)	+620	.103 (± 3)	+1062
XV	Mar. 3, 1968	.347 (±1)	−189	.323 (±2)	+688	.077 (± 2)	+1036

Table 1(b). Wakaho Network

Base Line		Shimowada		Ohashi		Nuruyu	
No.	Date	D	⊿D	D	⊿D	D	⊿D
		m mm	mm	m mm	mm	m mm	mm
I	May 8, 1966	3293.831 (±3)	0	1890.628 (±2)	0	2027.182 (±3)	0
II	Jul. 5-6	.780 (±6)	− 51	.625 (±2)	− 3	—	—
III	30-31	.829 (±4)	− 2	.622 (±3)	− 6	.165 (±3)	−17
IV	Nov. 4	.646 (±2)	−185	.601 (±2)	−27	.150 (±3)	−32
V	Mar. 24, 1967	.682 (±1)	−149	.604 (±2)	−24	.175 (±3)	− 7
VI	Mar. 2, 1968	.726 (±1)	−105	.605 (±1)	−23	.201 (±1)	+19

has been reversed in October-November of 1966, just after the third climax of the swarm activity[7]. As a result of the reversal, strains accumulated in the three base-lines until the climax period had been recovered for about several percent of the peak value in the next one month. This recovering deformation has been developed a little more in these seventeen months as proved by the contraction of Sorobeku

7) *loc. cit.*, 3).

(−6.4 cm) and Nishiterao (−1.3 cm) as well as by the extension of Zozan (+3.2 cm) after November, 1966.

Wakaho network. The authors resurveyed the Wakaho network on March 24, 1967 and on March 2, 1968 (see Table 1(b)). Base-lines changed their lengths 3–10 cm during this period, which exceeded the supposed errors of observation. There was no evidence of active and monotonous accumulation of horizontal strains, so far as the present data are concerned. Mode of strain accumulation seemed more complicated here than in Matsushiro, as proved by the ΔD of the respective base-lines changing rather randomly in time. (Fig. 5(a))

Nakano network. Surveys were repeated two times on the Nakano network (Table 1(c)). The detected strains are much smaller here than those in the former two areas, being almost comparable to the supposed observational errors. (Fig. 5(b))

Omachi network. The authors added one survey on this network, five months after the previous one. They observed no large strains along the Shimizuzawa base-line. ΔD for the other two base-lines are a little larger than the observational errors, in this period, suggesting a need for reexamination by further surveys. (Fig. 5(c))

Table 1(c). Nakano Network

Base Line		Okura		Imai		Sakurazawa	
No.	Date	D	ΔD	D	ΔD	D	ΔD
		m mm	mm	m mm	mm	m mm	mm
I	Mar. 4, 1966	1717.422 (± 2)	0	2156.669 (±4)	0	3684.111 (±4)	0
II	Apr. 13	.407 (± 2)	−15	.681 (±3)	+12	.087 (±1)	−24
III	Oct. 16	.383 (± 2)	−39	.680 (±2)	+11	.054 (±2)	−57
IV	Mar. 25, 1967	.412 (± 1)	−10	.644 (±1)	−25	.113 (±4)	+ 2
V	Oct. 3	.418 (± 1)	− 4	.683 (±2)	+14	.109 (±1)	− 2

Table 1(d). Omachi Network

Base Line		Shimizuzawa		Kashimaohashi		Taira	
No.	Date	D	ΔD	D	ΔD	D	ΔD
		m mm	mm	m mm	mm	m mm	mm
I	Nov. 6-8, 1964	4353.645 (±2)	0	5109.521 (±4)	0	4226.790 (±3)	0
II	Oct. 9-10, 1966	.591 (±3)	−54	.485 (±4)	−36	.790 (±3)	0
III	Mar. 19, 1967	.605 (±4)	−40	.525 (±1)	+ 4	.831 (±1)	+41

2.3. Newly constructed networks.

Akashina network. As briefly discussed in the introduction to the present paper, possibilities of spatial development of the seismic activity were often pointed out by the expedition party, as anomalous land uplift and micro-earthquake activities were discovered in the adjacent areas. A base-line network was constructed in July, 1967, in the Akashina area where these anomalous events had been noticed since early spring of 1967.

The network is very similar to others in its structures, having three base-lines arranged in the fan-shape (Fig. 2(a)). Table 2(a) gives their initial lengths as well as the changes, ΔD, which occurred in these

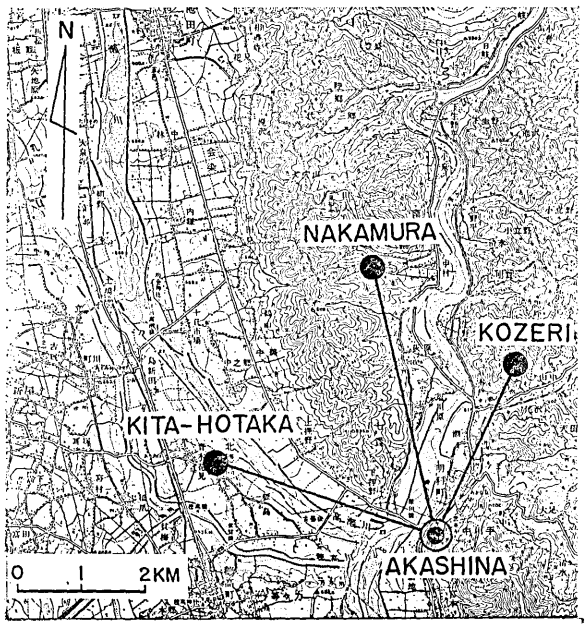

Fig. 2(a). Structure of the Akashina base-line network.

Table 2(a). Akashina Network

Base Line			Kozeri		Nakamura		Kitahotaka	
No.	Date		D	ΔD	D	ΔD	D	ΔD
			m mm	mm	m mm	mm	m mm	mm
I	Jul. 30,	1967	2431.772 (±2)	0	4181.411 (±3)	0	3555.802 (±4)	0
II	Feb. 29,	1968	.795 (±3)	+23	.395 (±2)	−16	.823 (±2)	+21

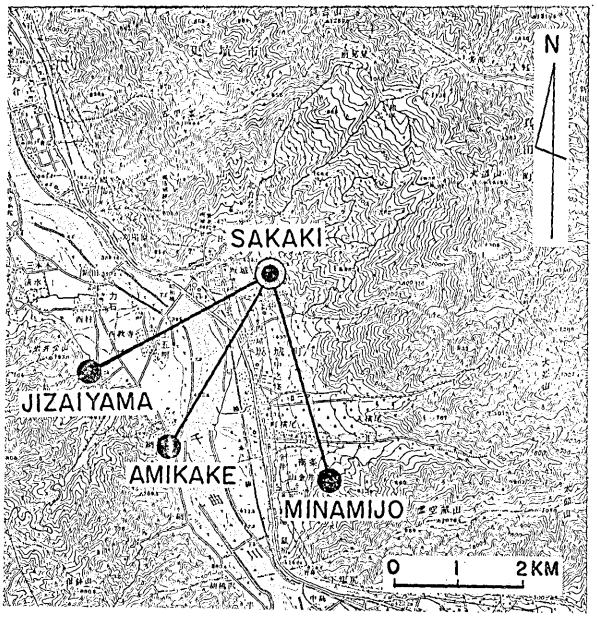

Fig. 2(b). Structure of the Sakaki base-line network.

Table 2(b). Sakaki Network

Base Line		Jizaiyama		Amikake		Minamijo	
No.	Date	D	ΔD	D	ΔD	D	ΔD
		m mm	mm	m mm	mm	m mm	mm
I	Aug. 1, 1967	3146.279 (±2)	0	—	—	3224.813 (±2)	0
II	Mar. 4, 1968	.283 (±1)	+ 4	2922.979 (±1)		.826 (±1)	+13

eight months. Briefly speaking, the authors have not found out definite evidence of active strain accumulation in the present area. The data seem to indicate the east-west extension and the north-south contraction, although their magnitude is almost comparable to observational errors. (Fig. 6(a)).

Sakaki network. Another network was constructed in the Sakaki area in order to examine the possibility of southwestward spreading of the swarm area. Fig. 2(b) illustrates arrangement of the network, whereas the data are given in Table 2(b). No evidence of active strain accumulation is obtained so far as the present data are concerned. Further repetition of the surveys will provide us with more definite conclusions on our questions. (Fig. 6(b))

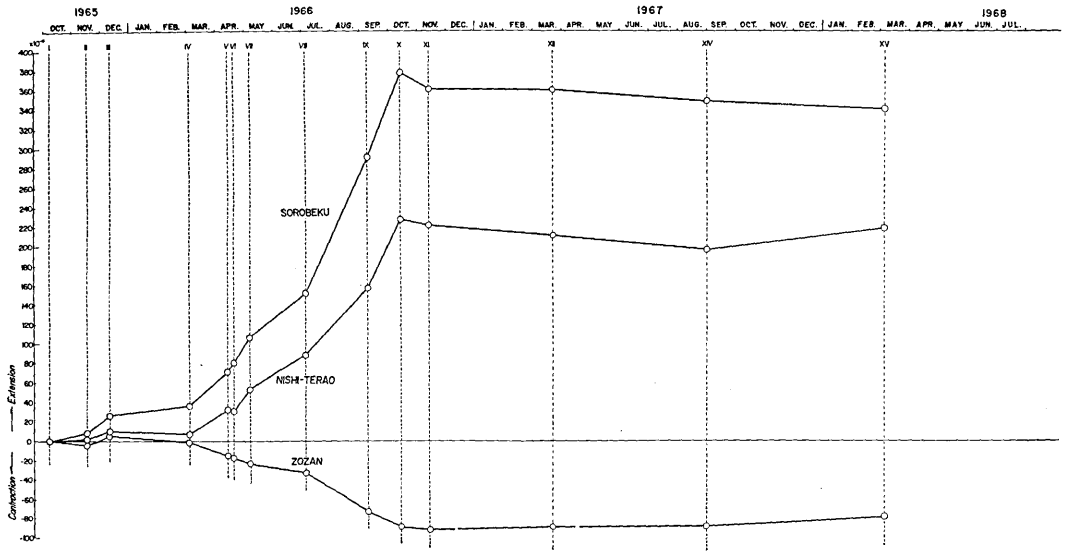

Fig. 3. Accumulation of horizontal strains (Matsushiro).

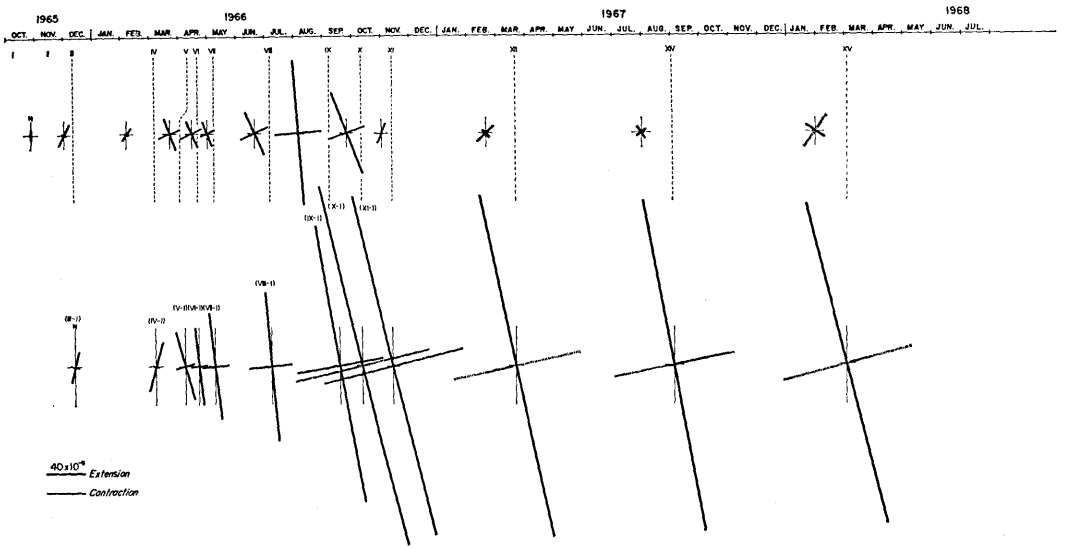

Fig. 4. Principal axes of horizontal strains computed for various periods of the repeated surveys (Matsushiro). Figures in the upper and lower groups illustrate partial and cumulative features, respectively.

2.4. Mode of strain accumulation.

Linear strains along the respective base-lines are computed from the observational data and are illustrated in the following figures. The principal axes of strains are also computed for the Matsushiro network and are displayed in Fig. 4, together with the previous data.

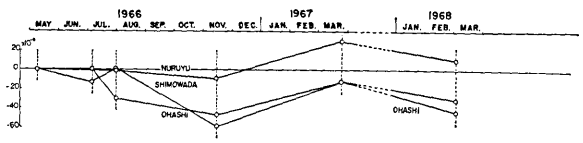

Fig. 5(a). Accumulation of horizontal strains (Wakaho).

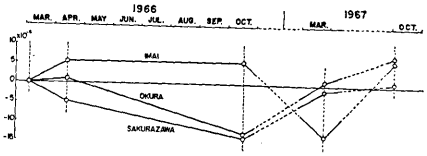

Fig. 5(b). Accumulation of horizontal strains (Nakano).

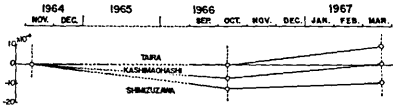

Fig. 5(c). Accumulation of horizontal strains (Omachi).

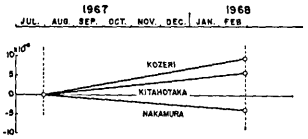

Fig. 6(a). Accumulation of horizontal strains (Akashina).

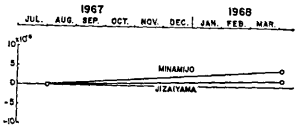

Fig. 6(b). Accumulation of horizontal strains (Sakaki).

3. Conclusions and acknowledgement

The authors repeated Geodimeter surveys in the Matsushiro and its adjacent areas for the purpose of observing horizontal strains associated with the swarm activity. From the recent surveys, which were conducted during the period November, 1966—March, 1968, the following conclusions may be derived.

1) Strain accumulation in the Matsushiro area reversed its sense in autumn of 1966, just after reaching its maximum value. Since then, the deformations of the reversed sense have continued there, reducing their time rate quickly. As a result of these adjustments, about ten

percent of the previously accumulated strains has been recovered up to the present time. The recovering mode of the ground deformations has been recognized by levelings, too, harmonizing well with the decaying seismic activity in the same locality.

2) Strains have not been accumulated so much in the other five networks. So far as the present data are concerned, there is no strong evidence for active and monotonous accumulation of the earth's strain in either of the localities. In some of them, however, strain accumulation at a much lower rate may exist, which will be studied more definitely by further repetition of surveys.

The authors sincerely thank the members of the Matsushiro Branch of Nagano City Office, the Health Section of Nakano City Office, the General Affairs Section of Toyono Town Office, the Mountain Museum of Omachi City Office, the Akashina Town Office, as well as the Sakaki Water-Works Branch of Nagano Prefectural Office for their kind cooperation given in the above-mentioned field work. The authors are also grateful to Messrs. Masakazu Ohtake, Masaru Kobayashi and Kaname Sakai of the Hokushin Observatory of Micro-Earthquakes and Crustal Deformations for their helpful assistance during the surveys.

---

28. 群発地震活動に伴う地殻変動の観測 (4)

地震研究所
笠原慶一
岡田悖
柴野睦郎
佐々木幸一
松本滋夫
平井正代

松代群発地震に関する調査の一環として，筆者らはジオジメーターによる光波測量を 1965 年秋以来繰り返してきた．1966 年 11 月までの実施結果については既に報告が済んでいるから，本報ではそれ以降 1968 年 3 月にいたるまでの作業について報告する．

前報までに取り上げられた測量はすべてジオジメーター 4 型によるものであったが，1967 年夏に同 6 型が購入されたので，水銀灯光源の使用と相まって昼間作業が可能になり観測能率は著しく高められた．4 型から 6 型への切り替えは今期における大きな改善であったが，これに伴って両型間の器差の相違が問題となった．当初から筆者らの直接的関心が基線長そのものでなく，その時間的変動の検出にあったので，4 型のみ使用する限りでは器差に対する補正は必ずしも必要でなかった．それがこの切り替えに伴って改めて考慮しなければならなくなったのである．このため第一回測量当時にさ

かのぼって器差補正を行い，新しい基準に統一されたのが第 1(a)～(d)，2(a)～(b) 表の数値 (D) である．

松代地域の可候（そろべく）・西寺尾・象山の三基線は 1966 年 11月—1968 年 3 月の期間にそれぞれ −6.4, −1.3, +3.2 cm だけ長さが変化した．これらの変化量はわれわれの測定誤差をやや上回る程度のものであるが，その変化の向きは 1966 年末における様相，すなわち，同年 9～10 月の第三活動期を頂点として歪集積の様相が反転したその継続と見ることができる．結局のところ，当時から現在 (1968 年 3 月) までに最盛期における歪量の約 10 パーセントに相当する回復が行われたことになる．このような変動の回復は水準測量においても認められており，同地域の地震活動が次第に衰退しつつある事実と対応して興味深い．

上記に比べて周辺地域にある他の 5 つの基線網においてはそれほど顕著な変動は認められなかった．現在までのデータに関する限り，これらのどの地域にも活発で一方的な歪集積は起こっていないようである．もっともこれら基線網のあるものにおいては，緩漫な歪集積が起こっていると見られるふしもある．このことは，測量を繰り返すことによって，さらに明確な判定が下されるであろう．