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80. *Electro-Optical Measurement of Horizontal Strains Accumulating in the Swarm Earthquake Area (2).*

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Abstract

The authors have repeated Geodimeter surveys in the Matsushiro area since October, 1965. Their purpose is the study of accumulation of horizontal strains there at various stages of the seismic activity. The present paper will deal mainly with the strain events observed from March of this year, since the data for the earlier period was reported in the previous paper.

Generally speaking, the mode of strain accumulation in the present period does not differ much from that previously observed. That is to say, extension predominated in the NS-direction whereas a considerable amount of contraction was observed in the EW-direction. As for the amount of strain accumulation, however, the present period shows an activity much higher than the previous one. Length of the Sorobeku base-line, for example, increased as much as 35 cm during the period March to July inclusive, and another 43 cm during the following two months. So that the total extension of this baseline after October, 1965, reached 89 cm indicating the average linear strain to be 290×10^{-6}.

Strain data thus obtained for the three independent base-lines enable us to study the horizontal deformations as a plane-strain problem. Computed principal axes harmonize very well with the seismic force system there. Strain energy associated with the deformations is roughly estimated to be comparable with the energy released by the seismic activity.

It is hard to believe that the earth's crust is deformed elastically to such a high strain rate as above-mentioned. We must naturally take non-elastic deformation into consideration for understanding the present event. A fracture zone that has developed remarkably since last spring is notable from this point of view. According to geologists' reports, the systematically arranged fractures seem to suggest a buried fault of strike-slip type that crosses the Sorobeku base-line obliquely. Actual conditions and characteristics of the presumed fault should be urgently studied by taking all the available data into consideration.

The authors constructed supplementary networks in the Wakaho and Nakano areas in order to watch strain accumulation in localities adjacent to the present seismic area. Data from the surveys on these networks are also discussed briefly.

1. Introduction

The authors have been carrying out Geodimeter surveys in the northern part of Nagano Prefecture since last autumn. These are part of the ERI's expeditions for the Matsushiro swarm earthquakes, the purpose of which is to observe horizontal strains in the seismic area at various stages of the swarm activity. Several years ago, the authors noticed an electro-optical distance measuring technique and realized its usefulness for observing tectonic movements and started basic tests by it[1]. Thus the Matsushiro swarm gave them the first opportunity to prove the usefulness of the proposed technique for this sort of expedition.

The first Geodimeter network in this district was constructed in Matsushiro Town in early October, 1965, with its master station at the top of Minakami-yama, a small hill located in the central part of the seismic area. Three reflector stations were distributed around it so that they formed a fan-shaped base-line network, side length being ca. 3 km (Fig. 1). Surveys were then repeated for nine times up to the present time following the standard scheme of operation as described previously[2]. The present paper will report upon and discuss the data from the recent five surveys mainly, since the first four surveys have already been reported in the previous paper[3].

Several months later, two more networks were constructed in the Nakano and Wakaho areas as illustrated in Fig. 1. From the beginning of the expeditions the scientists concerned feared that the activity in Matsushiro might trigger off a more disastrous earthquake in some area adjacent to it. Anomalous land upheaval that was observed by

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[1] K. KASAHARA and A. OKADA, "Observation of Horizontal Strain Accumulation by Electro-Optical Means. 1. Construction of base-line network in central Honshu, Japan", *Bull. Earthq. Res. Inst.*, **44** (1966), 1149-1165.

[2] *loc. cit.*, 1).

[3] 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.

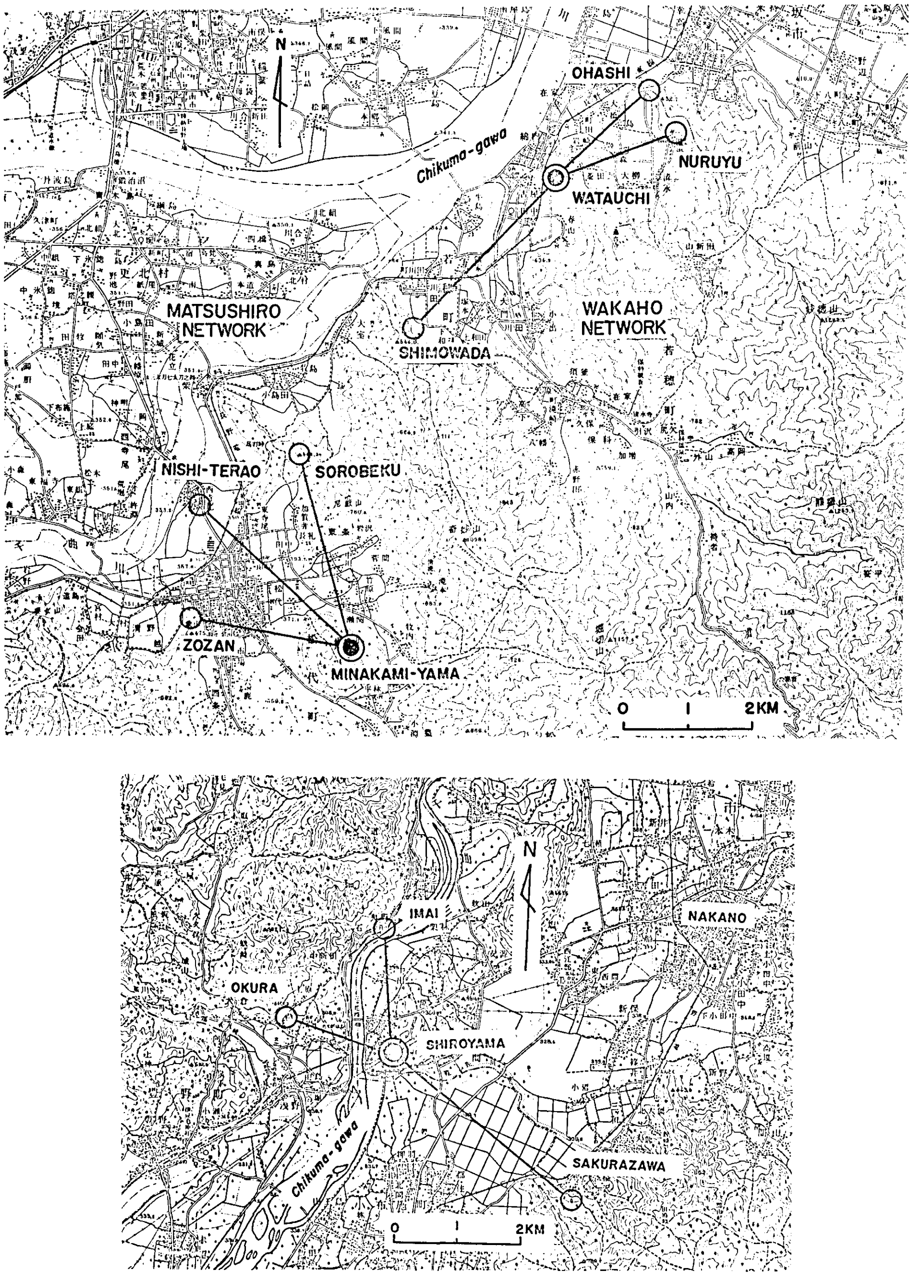

Fig. 1. Structure of the base-line networks.
Upper: Matsushiro and Wakaho networks.
Lower: Nakano network.

precise leveling at several localities around Matsushiro[4] was considered serious from this point of view. Thus the supplementary surveys were started to gather more information about land deformation in the northern part of Nagano Prefecture.

2. Field Work

2.1. Repetition of surveys

The Matsushiro network Surveys were repeated for five more times following the previous work. Periods of the respective surveys are as follows,

Survey V	April 12-13, 1966,
Survey VI	〃 18, 1966,
Survey VII	May 5-6, 1966,
Survey VIII	July 3, 1966,
Survey IX	September 6-9, 1966.

These periods were chosen carefully so that they might coincide with turning-points of the seismic activity as closely as possible. It is hard, of course, to always do this in practice. In the present case, however, the authors could choose the periods of surveys fairly satisfactorily working from diagrams of the daily number of felt (or unfelt) shocks reported by the other authors[5]. For example, we experienced the second climax of the activity in March-April, this year, which released a tremendous number of shocks, including many with magnitude 4 or 5. It was just before this climax that the fourth survey was conducted, while Survey VII was worked out in May, at the decaying stage of this particular activity. More notable are the periods of Surveys V and VI, which were chosen in the middle of the climax period so that they might have the highest peak of the climax between them. We may therefore study characteristics of strain accumulation at various stages of seismic activity separately. Survey VIII was scheduled in July in order to observe deformations at the stage of reducing activity.

The third climax started at the end of July and is still going on. Its most notable feature is the activated surface phenomena, such as

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[4] I. TSUBOKAWA *et al.*, Read at the Monthly Meeting of the Earthquake Research Institute, September 27, 1966.

[5] T. HAGIWARA *et al.*, Read at the Monthly Meeting of the Earthquake Research Institute, September 27, 1966.

development of the fracture zone⁶⁾, land slides⁷⁾, anomalous ground tilt⁸⁾, and acceleration of local land upheaval with its center at the northeastern foot of the Minakami-yama Hill⁹⁾. Thus the ninth survey was conducted in September to collect data on horizontal strains associated with the present activity. In this survey the authors planned to repeat distance measurements daily for a week with the hope of observing detailed features of strain accumulation in time. They could not accomplish their object fully because visibility along the light paths became poorer after the second day. As for the Zozan base-line, however, they could repeat surveys with difficulty up to the third day (see Table 1 (a)).

The base-line length (D) at the respective period are given in Table 1 (a) together with the previous data for comparison. These are the data after atmospheric correction effected in the scheme described in the first paper¹⁰⁾. In the same table are also given the changes in the base-line lengths counted from the first survey's data (ΔD).

The most extensile base-line among the three is as before the Sorobeku line. Its extension between March and July was ca. 35 cm, while another extension of 43 cm was observed in only two months since July. Total extension counted from October last year amounts to 89.2 cm though we must consider as uncertain one or two centimetres as observational errors. The Nishi-terao base-line is less active than Sorobeku, but it still gained 49.7 cm in the past eleven months. The Zozan base-line indicates the least change. We notice, however, that it is in a shortening sense in contrast with the former two.

Therefore, the present deformations agree with the previous ones with respect to their general mode. As for the time-rate and integrated amount of deformation, the former is much more active than the latter, reflecting development of the swarm activity. These points will be discussed in detail in the next section.

The Nakano network The first and second surveys were made in March and April, respectively. As can be seen in Table 1 (b) the base-lines of Okura and Imai increased their lengths for 0.2 and 1.2 cm, respectively,

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6) K. NAKAMURA, *et al.*, Read at the Monthly Meeting of the Earthquake Research Institute, September 27, 1966.

7) R. MORIMOTO, *et al.*, Read at the Monthly Meeting of the Earthquake Research Institute, September 27, 1966.

8) T. HAGIWARA and J. YAMADA, Read at the Monthly Meeting of the Earthquake Research Institute, September 27, 1966.

9) *loc. cit.*, 4).

10) *loc. cit.*, 3).

Table 1. Changes in Base Line Length.

(a) Matsushiro Network.

No.	Date	Zozan		Nishi-terao		Sorobeku	
		D	ΔD	D	ΔD	D	ΔD
		m mm	mm	m mm	mm	m mm	mm
I	Oct. 6-7, 1965	2381.612(±3)	0	3154.286(±5)	0	3062.912(± 4)	0
II	Nov. 15	.602(±6)	− 10	.293(±8)	+ 7	.938(±10)	+ 26
III	Dec. 9	.624(±2)	+ 12	.318(±4)	+ 32	.994(± 2)	+ 82
IV	Mar. 2, 1966	.609(±3)	− 3	.310(±4)	+ 24	3063.025(± 3)	+113
V	Apr. 12-13	.574(±2)	− 38	.388(±2)	+102	.128(± 3)	+216
VI	Apr. 18	.570(±0)	− 42	.383(±4)	+ 97	.159(± 1)	+247
VII	May 5-6	.557(±2)	− 55	.455(±2)	+169	.238(± 3)	+326
VIII	Jul. 3	.534(±3)	− 78	.569(±4)	+283	.376(± 2)	+464
IX	Sep. 6-9	.449(±2)	−163	.783(±1)	+497	——	
		.440(±0)	−172	——		.804(± 4)	+892
		.430(±2)	−182	——		——	

(b) Nakano Network.

No.	Date	Okura		Imai		Sakurazawa	
		D	ΔD	D	ΔD	D	ΔD
		m mm	mm	m mm	mm	m mm	mm
I	Mar. 4, 1966	1716.675(±10)	0	2155.596(±4)	0	3685.689(±6)	0
II	Apr. 13	.677(± 1)	+ 2	.408(±3)	+12	.671(±1)	−18

(c) Wakaho Network.

No.	Date	Shimowada		Ohashi		Nuruyu (A)		Nuruyu (B)	
		D	ΔD	D	ΔD	D	ΔD	D	ΔD
		m mm	mm	m mm	mm	m mm	mm	m mm	mm
I	May 8	3293.666(±2)	0	1890.526(±0)	0	2027.005(±3)	0		
II	Jul. 5	.626(±2)	−40	.527(±1)	+ 1			2026.350(±1)	0
III	30-31	.672(±3)	+ 6	.470(±3)	−56	.004(±3)	− 1	.367(±2)	+17

whereas the Sakurazawa bese-line was shortened for 1.8 cm. The observational error of the present technique being 1-2 cm as discussed previously[11], we need a longer interval for repeating surveys to observe strain accumulation in this area more significantly.

The Wakaho network Surveys on the Wakaho network have been made three times since April, 1966. Generally speaking, the distance

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[11] *loc. cit.*, 1).

changes here are far less than the Matsushiro's data, though not so small as in Nakano. Therefore, we may tentatively presume that the area of major deformation as observed in Matsushiro is not so wide as to extend northeastward beyond the Wakaho area. This presumption seems reasonable from the seismological point of view, since the northeastern boundary of the seismic area falls on the said locality, too.

It was interesting to note that the Shimowada base-line was subject to a considerable amount of contraction between Surveys I and II, whereas it turned in an extensile sense later as given in Table 1(c). The base-line to Ohashi underwent contraction in the period between Surveys II and III, after its inactivity during the earlier interval. Surveys on the third base-line were not very successful, on the other hand. The station mark at Nuruyu was repositioned from A to B to make the second survey, because the former mark was once supposed to be missing through an accident. Mixed use of the two monuments created a little confusion in the interpretation of the data, which will be discussed later.

3. Discussion

3.1. Linear strains along the base-lines

Fig. 2 illustrates the accumulation of linear strains along the three base-lines in Matsushiro, where the authors assumed that the observed changes in the base-line lengths were due to a uniform strain of the ground. This assumption, however, is not very reasonable as will be remarked upon later, but let us accept it temporarily to derive the following discussion (3.1-3.3).

It has already been mentioned that the most active extension is observed on the Sorobeku base-line, the base-lines to Nishi-terao and Zozan being less active in this order, the latter rather contractive. The strain of Sorobeku is surprisingly high as can be seen in the figure. It exceeded 100×10^{-6} (i.e. 10^{-4}) by the end of last April and reached 290×10^{-6} during this September. The Nishi-terao and Zozan lines were strained to 160×10^{-6} and -80×10^{-6}, respectively, by this month. It is interesting that the strains were not accumulated uniformly in time, the gradient of the curves changing remarkably from period to period, suggesting close relationship between the deformations to the development of seismic activity there.

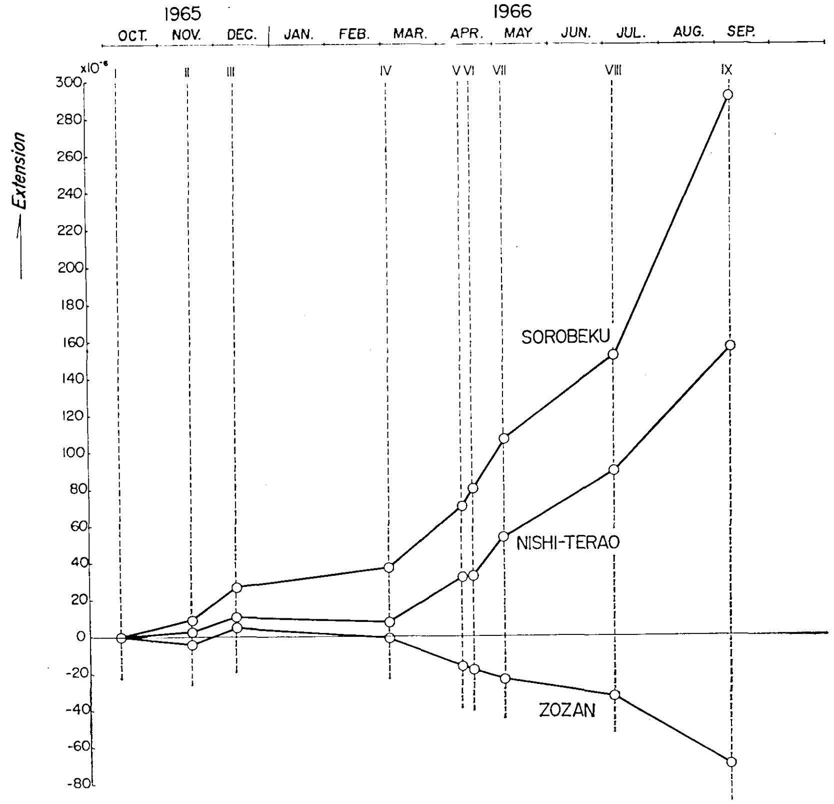

Fig. 2. Accumulation of horizontal strains (Matsushiro).

3.2. Principal axes and other strain components

As we have assumed uniformity of strains in the Matsushiro area, it is possible to compute the principal axes and other strain components by dealing with the above-stated data as a plane-strain problem. Results of the computation are schematically drawn in Fig. 3, in which the direction and the amplitude of the axes are given for various stages (figures in the upper and lower series represent the partial and cumulative features, respectively). Here again, a huge amount of strain accumulation is illustrated impressively by a series of principal axes' patterns with magnitude developing in time.

Good harmony between their directions with the seismic force system in Matsushiro are recognizable as well as in the previous case, namely, the positive and negative axes are approximately in the NS- and EW-directions, respectively. However, careful examination of the figure will

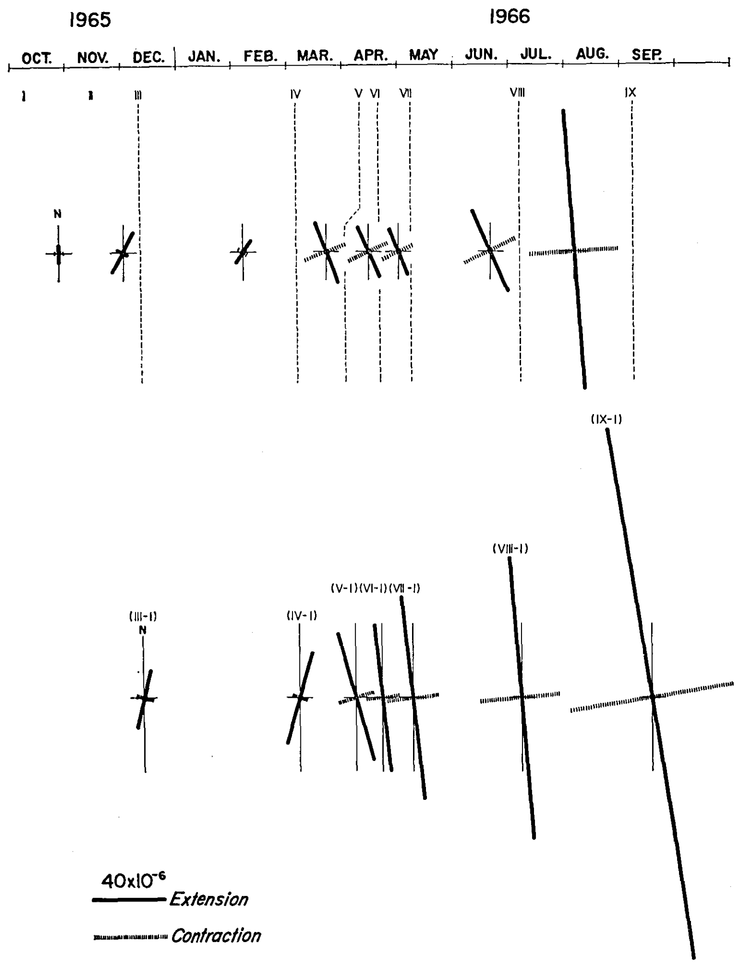

Fig. 3. Principal axes of horizontal strains computed for various periods of the repeated surveys (Matsushiro). Figures in the upper and lower groups illustrate partial and cumulative features, respectively.

tell us that the axes' directions after March show counter-clockwise rotation from the previous directions. Difference of directions between the two groups is not very large, but the systematic arrangement of these patterns seems to suggest that their essential bearing reflects major changes in rock-mechanical properties of the seismic region. Growth of the negative axis relative to the positive one, which is noticed on the patterns after March, might be further evidence for what happened under the ground. Fig. 4, illustrating time variation of the dilatational

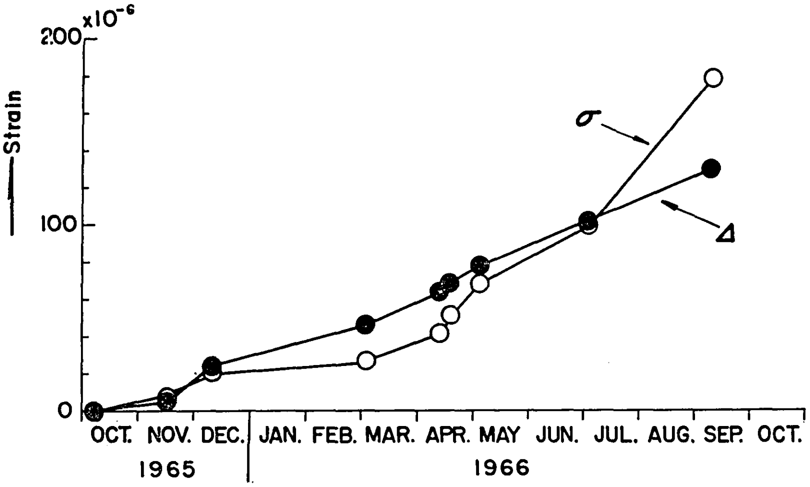

Fig. 4. Strain components accumulated in time (Matsushiro).

(Δ) and shear (σ) components, enables us to see the present effect in a different way. Dilatation is accumulated fairly uniformly in time as represented by a straight line. The curve for shear is more irregular in its feature with a steep slope in April-May when we observed the negative principal axis of nearly equal (absolute value) amplitude to that of the positive (see Fig. 3).

Unfortunately we have little knowledge on rock-mechanical features of fracturing at depth, so that we cannot derive further information from the present effect.

3.3. Strain rate and strain energy at various stages of seismic activity

We noticed briefly, in the foregoing section (3.1), a close relationship of the strain's time rate to seismic activity at the respective stage (see also Fig. 2). To make this point clearer, the authors computed the average rate of strain accumulation (Sorobeku) for each period between the successive surveys and compared it with the daily number of unfelt shocks also averaged for the corresponding period (Fig. 5). It is unmistakable that the two curves rise and fall in parallel always except in the latest period. The lower curve in July-September maintains an unexpectedly low level in spite of the third climax of seismic activity involved in it, this being because the high level data during August was cancelled by relatively low level data in July as a result of averaging.

Even if we take this effect into account, the level of the curve is still too low to maintain parallelism with the upper curve. That is to say, the strain rate in the third climax period is extraordinarily high—much higher than that expected from the seismicity level in the same period.

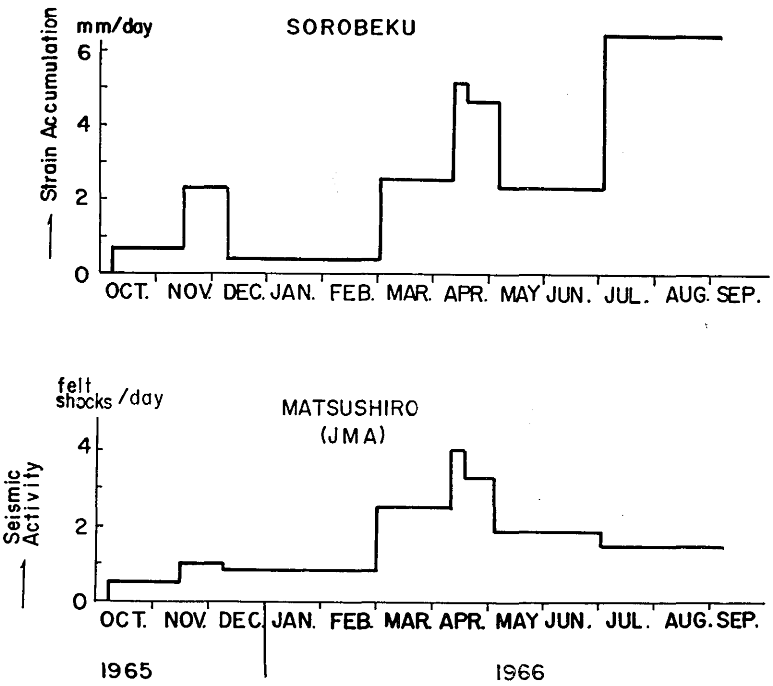

Fig. 5. Time rate of linear strain (Sorobeku base-line) compared with the seismic activity (daily number by JMA averaged for the periods corresponding to those of the surveys).

This tendency is illustrated more evidently in Fig. 6 which plots energy of the accumulated strain against the released seismic energy. The strain energy used for drawing the figure was computed from the linear strain along the Sorobeku line assuming, simply, that the change in strain energy counted from October, 1965, is represented by the formula as follows:

$$E_{strain}=\frac{1}{2}\mu\varepsilon^2 V ,$$

where, ε, μ, and V represent the Sorobeku's strain, an elastic constant, and the volume of the strained medium, respectively. In practice, V

and μ were taken as 3.3×10^{17} c.c. and 5×10^{10} c.g.s., respectively. Thus the energy is computed for each period of the surveys by putting the observed value of ε into the formula. The seismic energy was derived, on the other hand, from the data by T. Hagiwara *et al.*[12]. We notice that the first several plots are well explained by a broken line, suggesting a fairly good proportionality of E_{strain}'s accumulation to that of E_{seis} in the earlier period. In the later period, however, E_{strain} based on the same parameters is obviously too large to be explained by the above-mentioned line. The present effect might be explained by various speculations. The simplest of them would be the reduction of effective elasticity in the seismic region. In other words, we may suppose that the non-elastic part of the deformation became predominant in the base-rocks as the result of numerous fractures there.

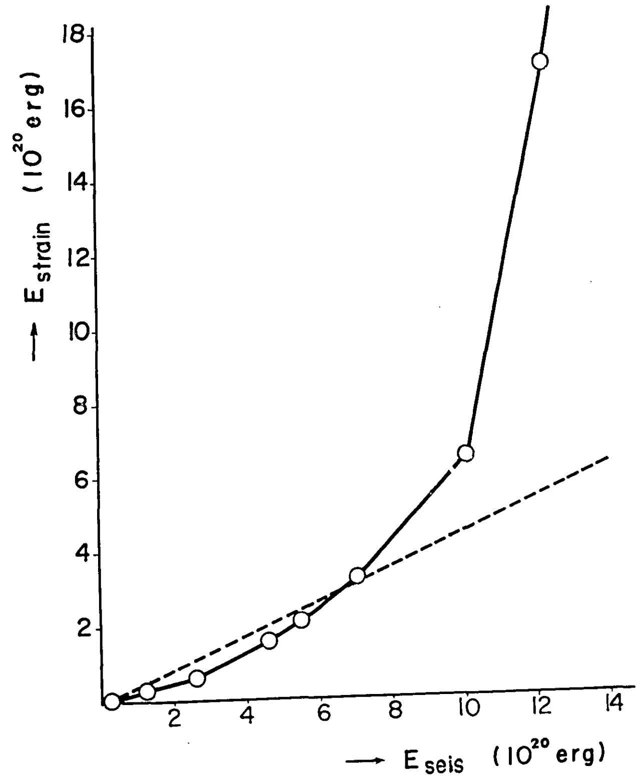

Fig. 6. Comparison of the released seismic energy with the strain energy (cumulative sum, Matsushiro).

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[12] *loc. cit.*, 5).

This is not necessarily an unreasonable supposition. From the physical point of view, firstly, strains observed in Matsushiro appear too high to be considered as elastic deformations of rocks. As is well-known, ordinary rock have an ultimate strain of the order of 10^{-4}. The largest strain observed at Matsushiro reached 290×10^{-6}, which is three times as large as the standard value of ultimate strain. It is very likely, therefore, that non-elastic parts of the deformation including fracture play an important role in the present event, otherwise the ground cannot easily undergo such a high rate of deformation.

A fracture zone that has developed remarkably since last spring is notable from this point of view. According to geologists' reports[13], the systematically arranged fractures seem to suggest a buried fault of strike-slip type that crosses the Sorobeku base-line obliquely. Introduction of faulting in depth will result in an extensive revision of the foregoing discussion, leading to a better understanding of physical processes in the seismic region.

3.4. Strains observed in the Nakano and Wakaho areas

Fig. 7 illustrates linear strains along the base-lines in Nakano, from which we learn that the deformation in this area was very inactive last March and April. Quantitative analyses of the strains are hard to work out in the present case as the observed strains are so small that they

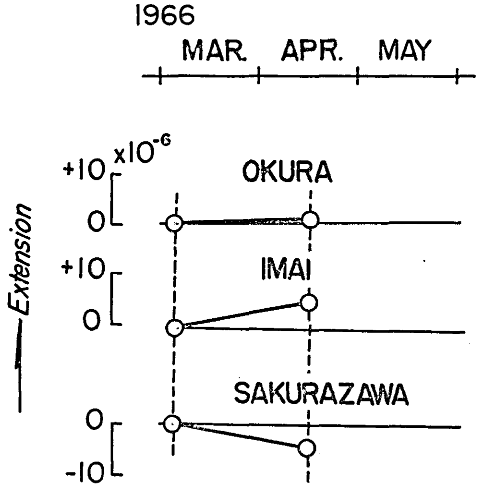

Fig. 7. Accumulation of horizontal strains (Nakano).

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[13] *loc. cit.*, 6).

are of a magnitude comparable to possible errors in observations.

Deformations in the Wakaho area seem a little more active than those in Nakano so far as the present data are concerned. Data in Table 1 were reduced to linear strains to draw Fig. 8. Principal axes of strain were also derived from them and are illustrated in Fig. 9. Because of an accident on the station mark at Nuruyu (A), a new mark (B) was substituted tentatively for (A) to carry out Survey II. Another point to be remarked upon is the improper arrangement of the three base-lines, although it was the only possible arrangement in the present valley. As can be seen in Fig. 1, they form a badly distorted Y-shape, meeting at low angles with each other. These circumstances would make the strain analyses so erroneous that the principal axes in the figure are only for qualitative reference.

The patterns seem to suggest that the positive and negative axes

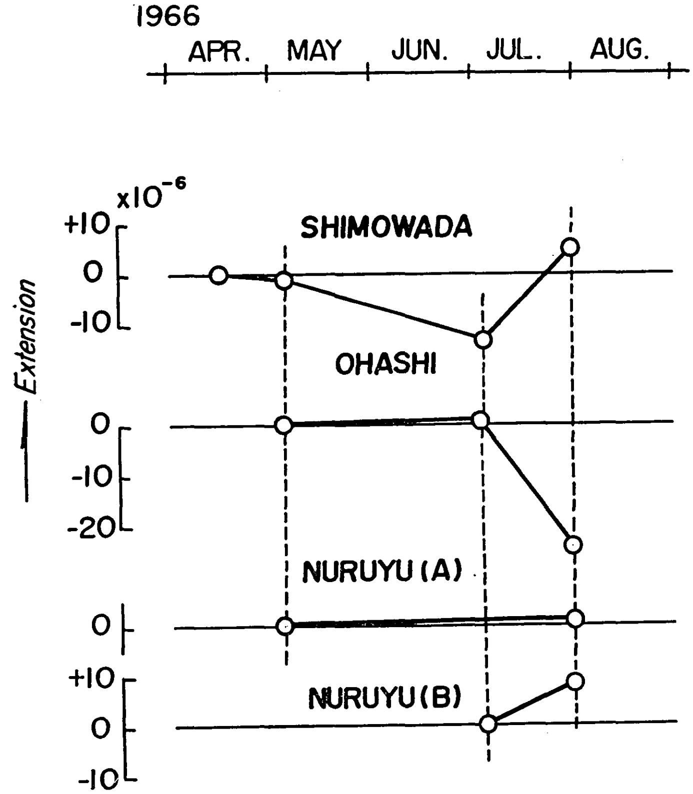

Fig. 8. Accumulation of horizontal strains (Wakaho).

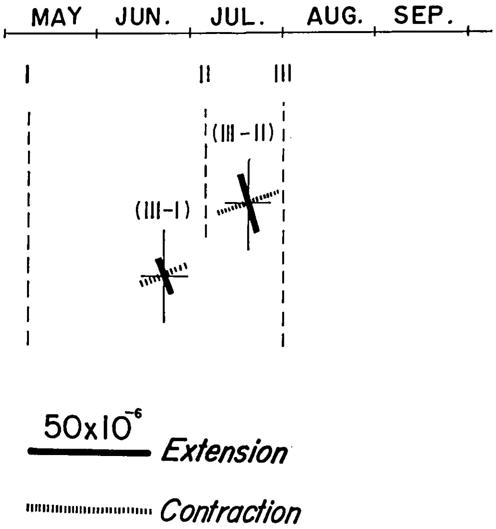

Fig. 9. Principal axes of horizontal strains (Wakaho).

here are in the directions nearly parallel to those in Matsushiro (cf. Fig. 3). We may therefore presume that the horizontal deformation with the common mode (extensile in NS, and contractive in EW) "leaks" out from Matsushiro toward the present area with its magnitude reducing.

4. Conclusions and acknowledgement

The author repeated Geodimeter surveys on the networks in Matsushiro and its adjacent areas for the purpose of observing horizontal strains associated with the activity of swarm earthquakes. Through the surveys they found out the following as notable evidence.

1) Mode of strain accumulation in the present period does not differ much from that observed previously. As for the amount of strain accumulation, however, the present period shows activity much higher than the previous one reflecting remarkable acceleration of the seismic activity.

2) Significant changes in the principal axes' features before and after March seem to suggest some essential changes of rock-mechanical conditions had taken place in the epicental region.

3) Surveys on the supplementary networks failed to find any significant indication for active deformation there, except a slight suggestion of strain accumulation (not very active) in the Wakaho

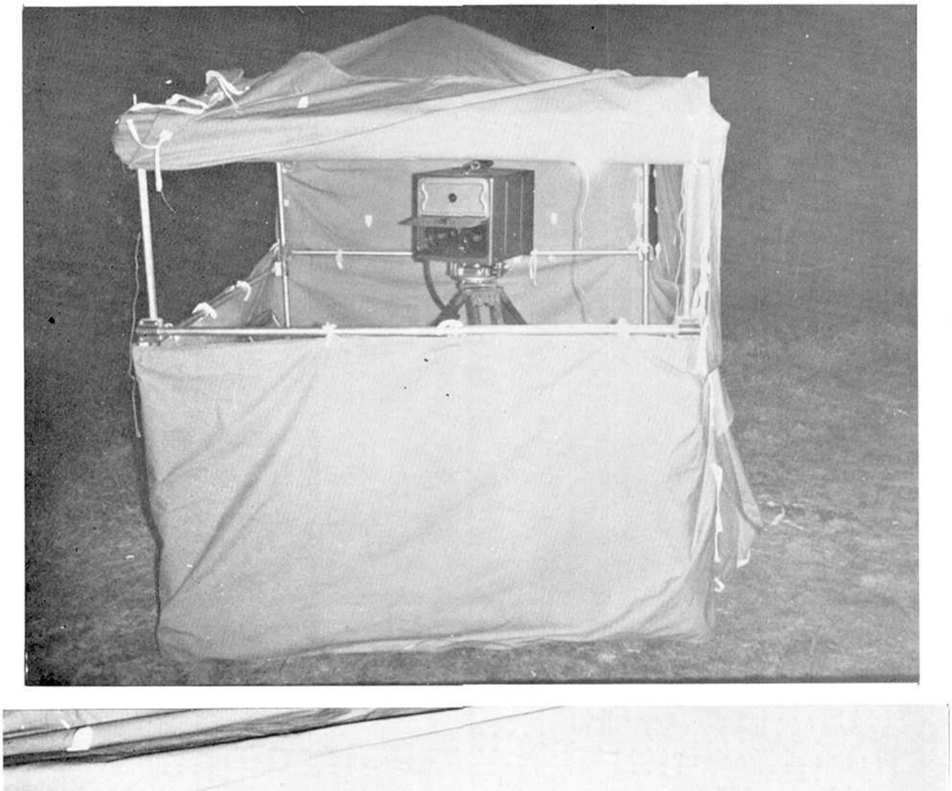

Fig. 10. Structure of the master station at Nakano (upper) with a Geodimeter in operation (lower).

area. Judging from such evidence, the active deformation associated with the Matsushiro earthquakes is probably limited within the epicentral area, and does not extend further north beyond Wakaho.

The authors acknowledge with many thanks members of the General Affairs Section of the Matsushiro Town Office, the Health Section of Nakano City Office, the General Affairs Section of Toyono Town Office and Mr. Muto of the Minakami-yama Shrine for their kind cooperation given to the above-mentioned field work. The authors are also grateful to Messrs. Tamotsu Daikubara and Tomomi Hara of the Technical Division of this Institute for their useful assistance during the surveys.

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80. 群発地震活動に伴う地殼変動の観測 (2)

地震研究所
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佐々木幸一
松本滋夫

1. まえがき

松代群発地震に関する綜合調査の一環として，筆者らはジオデメーターによる光波測量を昨年秋以来実施して来た．地震活動の経過に伴う土地の水平変動の消長を明らかにするのがその目的である．これら結果の一部 (1965年10月—1966年3月) はすでに第一報に報告したのであるが，引き続き1966年4月 (第V回観測) 以降9月 (第IX回観測) に至る間の結果を報告する．この期間中には松代群発地震の第2活動期 (4月—5月)，および第3活動期 (8月—9月) が含まれている (後記参照)．

第1報においても触れた通り，群発地震活動の経過に伴つて，調査対象をひろく北信地域一帯にひろげる必要が生まれてきた．この目的のために中野市周辺および若穂町にも基線網が追加設置されたので，それらに対する測量結果もあわせて報告する．

2. 観　測

松代基線　第1図に示す可候，西寺尾，象山の3基線について測量が繰り返えされた．本報告の主対象になる計5回の測量は次の通りである．

第V回	1966年	4月12—13日
第VI回	〃	4月18日
第VII回	〃	5月5—6日
第VIII回	〃	7月3日
第IX回	〃	9月6—9日

このうち第V—VI回の測量時期は第2期活動の最盛期に相当する．7月末から始つた第3期の活動では，皆神山北東麓附近に大規模な地割れの進行や地盤の傾斜・隆起が顕著になつた．このような時期における水平変動の進行状況を詳細に調べるために，第IX回の作業では特に基線長測定を毎日繰りかえすことが計画された．実際には，気象状況が思わしくないため象山基線に対する測量を3日間連続して行うに止まつたが，それでも1日に約1cmの割り合いで変動が進行しているらしい結果がもたらされた (第1表参照)．

第1表(A)は松代基線網に対するこれら測量結果に必要な気象補正を加えたものを，前報記載分と併わせて示している．各測量当時の基線長(D)，または第1回当時からの通算変動量(ΔD)からわかる通り，可候基線は依然として三者中最もはげしい変動を続けている．3月—7月間の変動量は約35cm，その後9月までにはさらに43cmの伸張を示しており，昨年10月から通算すれば過去11ヵ月間の伸張は実に89cmに達する．同期間中に，西寺尾基線は約50cmの伸張を，また象山基線は約18cmの収縮を見せている（いずれも1～2cmの測量誤差を含む）．

したがつて，水平変動は大局において前期に類似した方位特性を保ちつつ，その大きさだけが地震活動の進展に対応する消長を見せたということになろう．

中野基線　要調査地域の拡大に伴つて今年3月に新設されたこの基線網(第1図)に対しては，3月および4月に測量が行なわれた．その結果は第1表(b)に示されている．測定精度が1～2cmあることを考慮にいれると，両回の比較から求められる基線長変動量(0～2cm)が有意義であるかどうかの判定は難かしい．今後測量を反覆した上で検討する予定である．

若穂基線　第2活動期の頃から若穂町地域の地震活動が目立つようになつた．それに伴う変動の進行を監視し，併せて松代地域に見られる水平変動がどの程度北方にまで分布しているかを明らかにする目的で，今年4月以降若穂基線網が追加設置された(第1図)．現在までに計3回の測量が実施されているが，その結果は第1表(c)に示されている．この間，温湯標石の数値が2組あるのは，同地区標石に支障があつて，副標石を一時的に併設したからである．

このため各回測量結果を比較する上に困難がないでもないが，大局的に見る限り，本地域の変動は量において松代・中野両地域の中間にあり，方位特性はほぼ松代地域でのそれに類似しているようすがうかがえる．

3. 考察

3.1. 歪量の時間的変化　松代地域の三基線に対する測量結果から算出した歪量の時間的変化を第2図に示してある（昨年10月起算）．地殻歪を基線網内で均一と見なしたことは従来通りであるが，後述するようにこの仮定は再考の余地がある．しかしながら，さし当り歪の均一性を仮定した上で以下の考察を進めることにしよう．

最も変動の著るしい可候測線では，早くも4月に100×10^{-6}（すなわち，10^{-4}）を越える歪集積が認められた．その後も伸張は一方的に進行して，9月現在290×10^{-6}に達している．一方，西寺尾・象山の両基線では通算160×10^{-6}および-80×10^{-6}の歪集積が各々認められた．第2図からわかる通り，これら歪の集積は一方的進行の様相を示しながらも，進行速度の増減において地震活動の消長を反映している点は興味深い．

3.2. 歪主軸と歪成分　前報同様の仮定と手続きによつて歪主軸や各種歪成分を求めた．第3図は歪主軸の大きさと方向を表わしたもので，上列は各測量時期相互間の変動に対応するもの，下列は1965年10月から起算した集積歪に対応する歪主軸である．最大，最小主軸はそれぞれ南北，東西に近い方向にあることが明瞭である．さらに詳細に検討すると，当初どちらかと言えば北北東—南南西の方向をもつていた最大主軸が3月頃を境に反時計回りに回転し，その後ではむしろ北北西—南南東に転じている点がまず注目される．この事実は震源域における歪状態の本質的変化を反映するものかも知れず，他種の情報（たとえば発震機構における変化の有無）と対照することが望まれる．

同図中実線で示される伸びの主軸が破線の縮み主軸を絶対値において，大幅に上回つている事実は極めて明瞭であるが，詳しく見れば両者の比率は必ずしも時間的に一定してはいない．その点を明らかにするため，面積伸張(Δ)およびずり歪(σ)の両成分を求めた結果が第4図である．ひとくちに言うならば，面積伸張がほぼ一定した進行速度をもつて増大してきた反面，ずり歪の方は消長がはげしいようである．これもまた震源機構を調べるひとつの手がかりになるかもしれない．その意味でも，岩石力学に関する知識の一層の充実が望まれる．

3.3. 歪の進行速度・エネルギーと地震活動の消長　可候基線を例にとり，過去9回の測量にはさまれる8期間毎に求めた歪進行の日平均速度と有感地震回数の日平均値とを比較したのが第5図である．少なくとも今年7月頃までのところ，両者はかりよい平行関係にあることが認められるけれども，それ以降は前者が極度に高い値を示している．

同じ傾向は歪エネルギーの集積状況についても明らかである．例えば，第6図は前報同様の手続き

によつて求めた歪エネルギー (E_{strain}) と，別の研究資料から得られる地震エネルギー (E_{seis}) とを対応させつつ記入したものである．

初期の頃，両者間にはほぼ破線で近似される比例関係が見受けられたのに，その後この関係は次第に成立しなくなつている．E_{seis} に比べて E_{strain} が異常に大きくなつて来ている結果から考えると，計算の基礎になつているパラメーター (特に剛性率) を不変と仮定している点に再考の余地がありそうである．その見地から，地震活動の進展につれて震源域を構成する岩石の状態にも変化があり，実効的剛性率が次第に低下してきたと仮定すれば，E_{strain} と E_{seis} との関係を適当に保つことも可能である．

この想像は必ずしも無理なものではない．10^{-4} を地殻変形 (弾性的) の上限値と見なす従来の常識から考えれば，最近の歪集積値は明らかに大きすぎる．このように異常な値のすべてが弾性変形によると考えるよりは，破砕やクリープを含む非弾性的変形が震源域の地殻に混在し，しかもその占める割り合いが次第に増大して来た結果と考える方が当を得ているかもしれない．事実，今年春先から皆神山東麓に現われ出した地割れ群は成長の一途をたどり，潜在断層が同地帯下で活動している可能性は次第に濃くなつて来ている．

3.4. 中野・若穂地域での観測結果 中野基線網での歪集積を示す第7図に見られる限りでは，3月—4月期におけるこの地域の変動はそれほど活発でない．むしろ若穂地域の方がそれより活動的なように見受けられる (第8図)．基線が特定方向に偏在しすぎること (第1図) や，前記の標石支障が温湯にあつたことなどの事情から確言は困難であるけれども，一応のめやすとして算出した歪主軸の特性が松代地域のそれに類似している点は興味深い，主軸値そのものが松代に比べて格段に小さいことは疑問の余地がない，松代を中心に進行している水平変動の分布も若穂地域がほぼその東北限界と考えても大過なさそうに思われる．

4. むすび

松代およびその周辺地域で光波測量を繰り返した結果，群発地震活動に伴う水平変動の特性がさらに明らかになつた．まず松代地域について見れば:

(1) 水平変動は進行の一途をたどつている．群発地震の第二，第三活動期に相当する3—4月，7—9月頃の基線長変化はとりわけ著るしいものであつた．結局のところ，可候·西寺尾·象山の三基線は過去11ヵ月間に +89 cm，+50 cm，−18 cm の基線長変化と $+290\times10^{-6}$，-70×10^{-6} の歪集積とを示した．

(2) 水平変動の方位特性は前期のものと大差なく，ほぼ南北方向に最大の伸縮を，東西方向に収縮を示している．さらに詳しく見れば，その中にも系統的な変化がある．例えば3—4月頃を境に，最大主軸が以前の北北東—南南西から北北西—南南東にその向きを転じている傾向は注目に値する．

また，中野・若穂地域に追加設置された基線網について見れば:

(3) 両者共松代のように著るしい変動は認められない．若穂での変動が若干あり，しかもその方位特性が松代のそれに類似している点から推定すると，松代地域での著るしい水平変動はそれほど広く周辺地域にまで分布しているものとは見られず，北東方向については若穂あたりがその限界ではないかと想像される．

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