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On the Ground Deformation and Phenomena Forerunning Natural Disasters (Earthquake, Rock-falling and Landslide)

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Abstract

By observing crustal deformation in underground galleries and ground deformation at the landslide zone using extensometers and tiltmeters, before the occurrence of an earthquake, rock-falling or landslide, some peculiar changes of ground-strain and ground-tilt which may be regarded as these forerunning phenomena were observed. When sufficient data for these forerunning phenomena are detected and any pattern between the forerunning phenomena and the occurrence of the disasters is found, it will be of definite help in predicting such disasters.

In this paper some examples of peculiar changes in ground-strain and ground-tilt observed before the occurrence of a great earthquake, a rock-falling and a landslide are examined along with some geophysical investigations on landslide.

1. Introduction

All through her history, Japan has frequently suffered many kinds of natural disaster, and each of these has caused a large number of casualties and an enormous amount of damage in a moment. It is certain that natural disasters will occur in the future in a similar way. Though modern science can protect people from these disasters to some extent, it seems to be entirely impossible to banish all disasters. Therefore, disasters must be prevented as far as possible by ourselves. Predicting the occurrence of disasters is an urgent necessity for the nation as one of the preventive measures for eliminating the damage on the occurrence of disasters. But the prediction of a disaster occurrence is quite difficult without knowing three elements, the place and the time of the disaster occurrence and the magnitude of the disaster. To know them, the study of the cause and mechanism of disaster occurrence is the first problem and then there is a possibility that we shall be able to foretell the disaster occurrence. But it is indeed a very difficult problem for us to foretell disaster occurrence when most of the substances under the ground are yet scarcely explored. Looking over the process of disaster occurrence in the past, disasters don't occur suddenly, but before them forerunning phenomena are often observed. So if we detect those signs by any method, we shall be able to foretell to some extent the disaster.

From this stand point, the studies aim at founding a gateway to the prediction of earthquakes and volcanic eruptions by detecting forerunning phenomena possibly occurring immediately or immediately prior to them with geophysical measurements. Recently, a project for "Earthquake Prediction" is underway by a group of scientists who are particularly interested in the problem, i.e. "Earthquake Prediction Research Group".

Though earthquakes, rock-falls and landslides always different in dimensions, they are a caused by destruction of rocks and land blocks, and the energy for destruction in needed. It is thought that these energy can't instantly accumulat but will gradually accumulat. With the accumulation of energy, the material in the neighbourhood of those rocks and land blocks is deformed and this deformation will naturally influence the ground surface. Accordingly, the forerunning phenomena will be detectable by the observation of those deformations in the neighbourhood of the ground surface. This writer could detect peculiar changes before the occurrence of a great earthquake and rock-falling by observation of the ground deformation and had already published those phenomena in another paper. After that, the writer could detect the same phenomenon before the landslide-occurrence by the observation of ground deformation at a landslide zone.

So the writer will discuss the peculiar changes (forerunning phenomena) before the occurrence of earthquake, rock-falling and landslide and will report the results of the investigations and observations at a few landslide zones.

2. Ground deformation before and after the Yoshino Earthquake on July 18, 1952

For the purpose of studying the prediction of earthquakes, since 1951, this writer has begun to observe the crustal deformation by the super-invar-bar extensometers consisting of 6 components and the tiltmeters with horizontal pendulum of Zöllner suspension type mainly at the Ide Observatory, a reformed drift of an abandoned copper mine located at Ide-cho, Tsuzuki-gun, Kyoto Prefecture. On July 18, 1952, a great earthquake occurred called the Yoshino Earthquake. Its epicentre was at the southern part of Nara Prefecture, 135.80°E, 34.10°N, a distance of about 70 km from this observatory and its focal depth and seismic magnitude were about 70 km from the ground surface and 7 Pasadena Scale respectively. (See Figs. 1, 2.) The result of this observation by those extensometers before and after the earthquake at

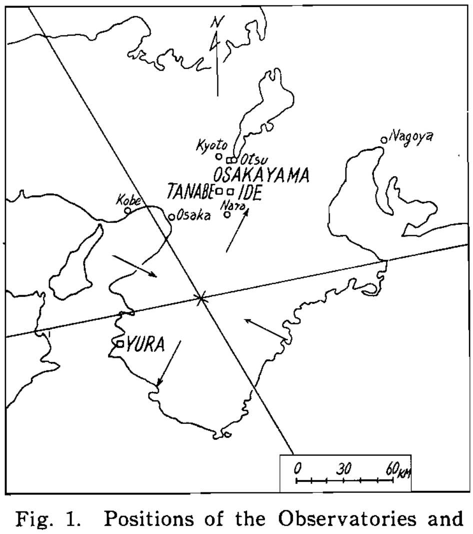

Fig. 1. Positions of the Observatories and epicentre of the Yoshino Earthquake and directions of initial ground motions in its earthquake. (The crossing full lines show the nodal lines.)

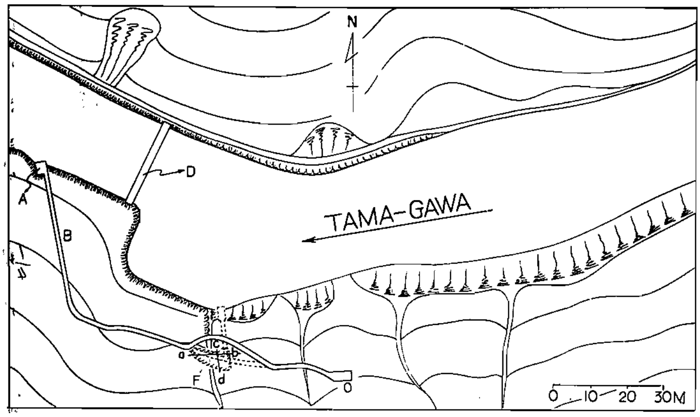

Fig. 2. Illustration of the Ide Observatory and location of rock-falling.
A : -Recording room, B : -Drift, F : -Part of rock-falling,
O : -Observing room, D : -Sabo-dam

the Ide Observatory are shown as in Fig. 3. As this figure shows, peculiar variations were found several months before and after the earthquake-occurrence. Especially, the peculiar change is shown in the variation of extensometer-5 set up toward hypocentre. The ground-strain gradually became large about March and it suddenly increased from the middle of June. Soon after, on July 13, just 5 days before the earthquake-occurrence, the direction of variation turned to the contrary direction, and the earthquake occurred on July 18. After that the variation of strain continued in the same direction for several months and the ground-strain recovered to some extent. The same remarkable variations of ground-strain were observed by extensometers 1 and 3 (set up nearly toward hypocentre) and shown in volume dilatation-V calculated from the record observed by extensometers 1, 2 and 3 (which were set up rectangular co-ordinate axis). The peculiar changes were not shown clearly in the other components orthogonal in the direction of hypocentre. On the other hand, the peculiar change of ground-strain before and after the Yoshino Earthquake was also observed by Prof. I. Ozawa at the Osakayama Observatory about 20 km distance from the Ide Observatory.

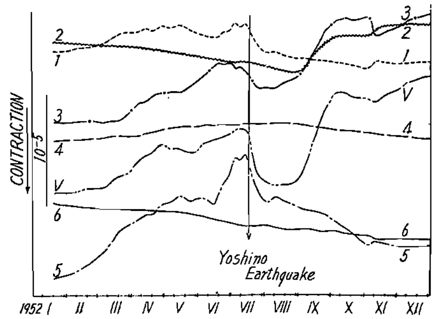

Fig. 3. Variations of linear strains and volume dilatation of which eliminated annual variations and variations caused by rainfall at Ide.
1 : -Vertical, 2 : -Horizontal・N88°E, 3 : -Horizontal・N2°W, 4 : -Dip 50°・N88°E, 5 : -Dip 66°・N2°W, 6 : -Horizontal・N77°W, V : -Volume dilatation (1+2+3)

And in the case of Yoshino Earthquake some remarkable changes in ground-tilt were observed before the earthquake-occurrence. As shown in Fig. 4 the ground at Ide continued a downward tilting in an S-direction from around

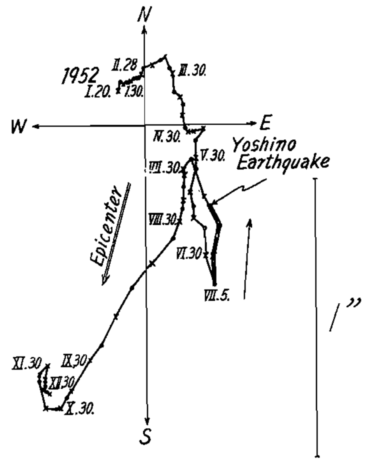

Fig. 4. Variation of ground-tilt at the Ide Observatory.

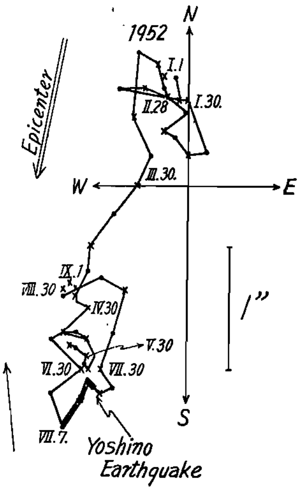

Fig. 5. Variation of ground-tilt observed at the Osakayama Observatory (by Prof. I. Ozawa).

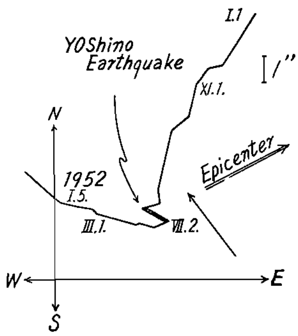

Fig. 6. Variation of ground-tilt observed at the Yura Observatory (by Dr. K. Hosoyama).

March until July 5 just 13 days before the earthquake-occurrence, since then its tilting direction has turned in the contrary direction. After the earthquake-occurrence its tilting motion continued in the same direction until July 25 but since that data has turned its tilting direction in an S again. Such peculiar changes of ground-tilt were observed by Prof. I. Ozawa at the Osakayama Observatory and by Dr. K. Hosoyama at the Yura Observatory. Those observations are shown in Figs. 5 and 6, i.e. the ground-tilting direction turned on July 8 at the Osakayama Observatory and on July 2 at the Yura Observatory, and after that the Yoshino Earthquake occurred. In 1935 F. J. W. Whipple calculated elastico-dynamically the deformation on the surface of an elastic body that will be deformed by the nucleus of the seismic force which is equivalent to the crack-model studied by the late Dr. T. Shida. In these ways, the writer has obtained the distributions of the ground-strains and ground-tilts at the time of the Yoshino Earthquake. Those ground-tilting directions accompanied by this earthquake at three observatories should be in the directions indicated by arrow marks in Figs. 4, 5 and 6. Looking again at those variations observed at the three observatories, the tilting directions changed in the direction theoretically calculated from the beginning of July about half a month before the earthquake occurred. Besides, the date of change in the ground-tilting direction is early in propotion to the epicentral distance. (Yura : 60 km, July 2 ; Ide : 72 km, July 5 ; Osakayama : 98 km, July 7) From these facts, it is thought that it takes a long period for the propagation of ground-strain. From the results of the observations mentioned above, the accumulation of earthquake energy became greater from around April in the neighbourhood of hypocentre, and the crustal deformation became greater. With the approach of the earthquake-occurrence the accumulating rate of energy was rapid and the changes of strain increased suddenly. At last the rocks in the neighbourhood of hypocentre were gradually destroied and then the accumulated energy was released gradually. At this time, the mode of crustal deformation changed from the process of accumulation to process of release. For example the direction of change in the crustal deformation turned to the opposite. After a series of destructions on a small scale, a great destruction (earthquake) occurred and its energy was released. The crustal strain also returned to its former state.

Therefore, it is thought that the ground in the neighbourhood of the hypocentre begins to deform similarly to the deformation at the occasion of earthquake which will occur in several days. Some clue should be found for the prediction of earthquakes by studying of the variation of crustal deformation after the turning of its direction.

3. Ground deformation before and after the occurrence of rock-falling

On Dec. 24, 1954, a part of the drift was broken and rock-falling occurred about 15 m in the length at the Ide Observatory. (See Figs. 2 and 7.) Repair work was begun immediately but the workers were inexperienced. Fragments of fallen rocks were carried out of the drift until interrupted by an openning which came in the hillside on Jan. 17, 1955. During this work, the amount of rocks carried out was about 450 m³. After this difficult repair, the observing room could safely be entered on Jan. 31 for the first time since rock-falling. Fortunately the records before and after the rock-falling could be obtained due to a self-recording system. In Figs. 8 and 9, the variations of linear strains, volume dilatation and tilting (of which eliminated annual variations and secular variations) are shown. As these figures apparently show, the peculiar changes of crustal deformation are found from about Dec. 7 before the rock-fall occurred and after the rocks were carried out of the drift, those changes became bigger. From these facts, it is believed that the rocks near the rock-fall have been gradually destroy several days before rock-fall occurred. In the case of the rock-falling just as in the case of the earthquake the strain of nearby rocks changed. It is thus deduced that a rock-falling occurrence can be predicted

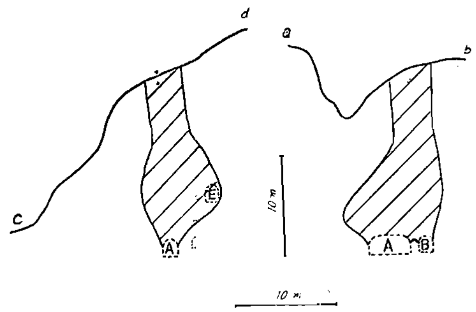

Fig. 7. Vertical sections a–b and c–d on the part of rock-falling.
A : –New drift, B : –Old drift, E : –Dead drift

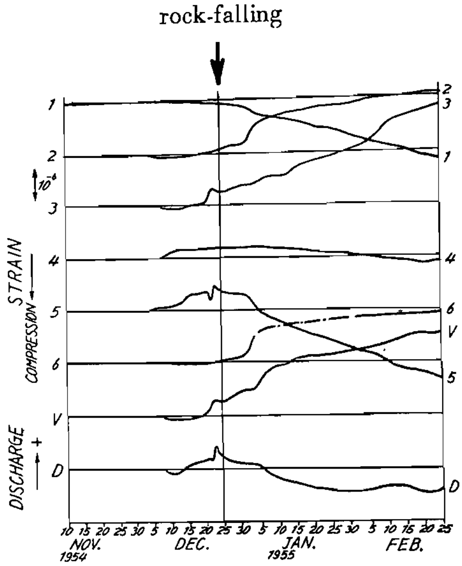

Fig. 8. Variations of ground-strain and discharge of mine water before and after the occurrence of rock-falling. 1, 2, —, 5, 6 : -Linear strain, V : -Volume dilatation, D : -Discharge of mine water

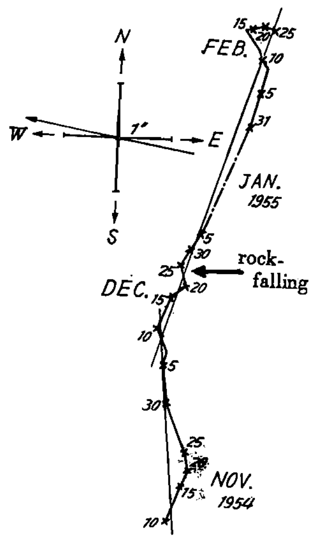

Fig. 9. Variation of ground-tilt before and after the occurrence of rock-falling. (Single arrow shows the direction to place of rock-falling.)

to a certain extent by the observation of rock-strain.

4. Ground deformation at the landslide zones

As mentioned above, the phenomena caused by the destruction of rocks as in earthquakes and rock-fallings, the energy for destruction of rocks is accumulated for a long time prior to the occurrence. After that, destruction on a small scale occurs in rocks for a time and then the destruction on a large scale, i.e. a great earthquake or rock-falling occurs and gives rise to great disaster. So, if the geophysical quantities which have something to do with destructive phenomena are continually observed, it is thought that the phenomena forerunning great earthquakes and rock-fallings can detect to some extent these disasters. Landslides are different from earthquakes and rock-fallings, and are not caused by the destruction of rocks but by the sliding of land blocks. The ground surface is deformed and also strained. Therefore, the writer tried to detect the ground deformation before the landslide-occurrence (forerunning phenomena) and to study the prediction of landslide-occurrence in the interest of geophysical investigation at a few landslide zones.

4-1. Ground deformation in the neighbourhood of the penstock at a water power plant

a) Outline

In November 1959, a geophysical investigation on landslide was begun in the neighbourhood of the penstock at an unfinished water power plant in Kochi Prefecture. The purpose of this investigation was surveillance, realizing that it will not serve directly for landslide because a landslide had once occurred in this area and might occur there again. (See Photo. 1.)

Photo. 1. Distant view of the neighbourhood of the penstock.

The geological structure in this area consists of a shale zone and the alternation zone of sandstone and shale. In the higher part of the penstock is a sandy shale zone, in the center part is an alternation zone of sandstone and shale, and in the lower part is a shale zone.

First, the investigation was begun by geophysical prospecting to know the crustal structure near the penstock. Seismic prospecting was carried out mainly in the center and lower parts. As the crustal structure in the higher part was already known by seismic prospecting. The crustal structure, as found by the investigation, is shown in Fig. 10.

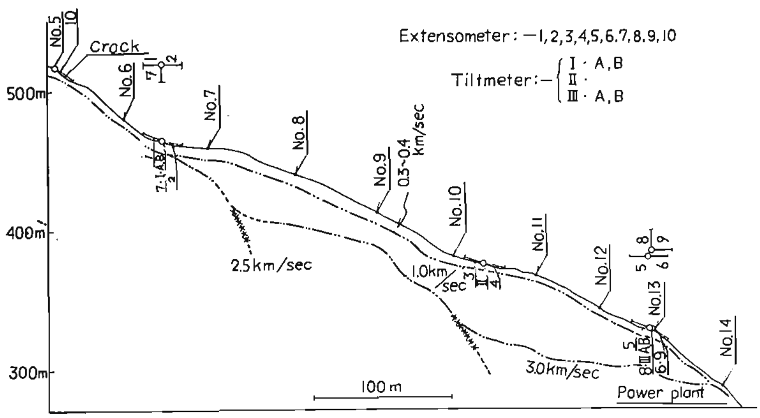

Fig. 10. Crustal structure along the penstock and disposition and distribution of the instruments. (No. 5~No. 14 : -Anchor block)

From this, it is believed that the zone covered on the layer with P-wave propagation velocity of 1.0 km/s is sliding. Also the shallow zone seemed to be a sliding layer therefore investigation of the propagation velocity and the damping coefficient of P-wave and S-wave was carried out to see the change according dry or wet conditions respectively. By these investigations, every characteristic and bearing power of the subsoil was made for a comparative study under each condition.

Secondly electrical prospecting was carried out to investigate the distribution of ground water within 70 m depth from the ground surface, but the water bearing layer could not be found in this zone because of its extreme depth.

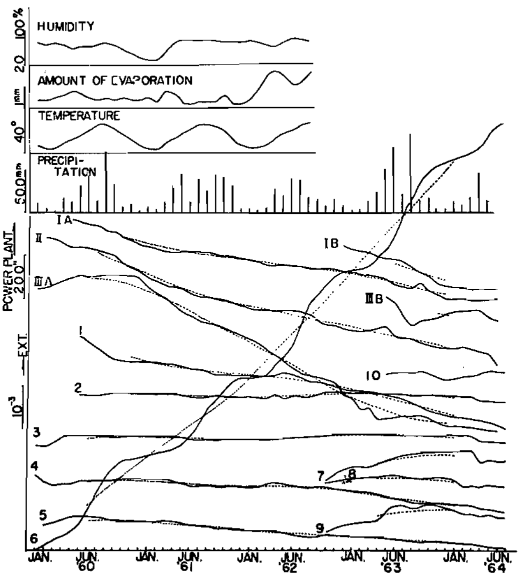

Fig. 11. Variations of the ground-strains (1, 2,……, 9, 10) and ground-tilts (I-A, I-B, II, III-A, III-B).
—— : -Observed value, …… : -Secular variation

After these investigations, by using 6 extensometers (1,…, 6) and 3 tiltmeters (I-A, II, III-A) which are set up along the penstock near the fractured zone, observation of the ground deformation has been going on since the end of 1959. (See Fig. 10.) Those instruments were especially made for the observation of ground deformation in landslide zones and used the self-recording system. The variations of ground deformation observed by them are shown in Fig. 11. In this figure, the variations shown with —— and …… are those of the monthly mean values obtained from daily observed values and are the running average of 13 months, monthly values. As these variation show, the changes in components 1 and 6 are larger than the others. From these facts, it is believed that the higher part near the extensometers 1 and 2, and the lower part near the steep slope zone from extensometer 6 are sliding. The sliding movement of the higher part is smaller than that of the lower part and is not so dangerous, but on the contrary, the sliding movement on the lower part needs to be carefully watched due to the landslide of the steep slope. The crack near anchor block No. 5 needed to be carefully observed for future change. Extensometer 10 was set up in parallel with the penstock below its anchor block to watch the ground-strain. Extensometer 7 between the anchor block of extensometers 1・2 and the saddle of penstock was set up to observe the ground-strain in the orthogonal direction to the penstock. Tiltmeter I-B was set up here to observe ground-tilt in the orthogonal direction to the penstock. (See Photo. 2.) To observe the ground-strain near the extensometers 5 and 6 in more detail and knowing the movement of anchor block No. 13, extensometer 8 and extensometer 9 were set up in the orthogonal direction to the penstock, and in parallel direction to it (or extensometer 6) respectively. One end of each of these extensometers was fixed to anchor block No. 13. Tiltmeter III-B was set up here to observe ground-tilt in the orthogonal direction to the penstock. From the observations, it was found that the variation in extensometer 9 is

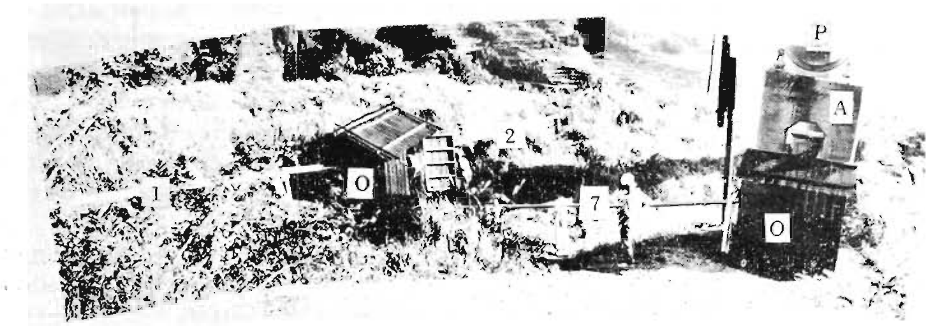

Photo. 2. Disposition of the observing instruments in the neighbourhood of No. 7 anchor block.
1, 2, 7 : -Super-invar wire, O : -Observing room, P : -Penstock, A : -Saddle

small compared with 6, so it is thought that the landslide in this neighbourhood is the superficial phenomenon.

b) Studies and examinations on the ground deformation

The annual variations of ground-strain and -tilt obtained from the observations by six extensometers and three tiltmeters which have been used from the start are as shown in Fig. 12. Generally, these variations are periodic, and the extension and contraction of the secular variation make the phase of annual variation contrary. In order to clear up the cause of the annual variation, we investigated the relationship of the meteorological

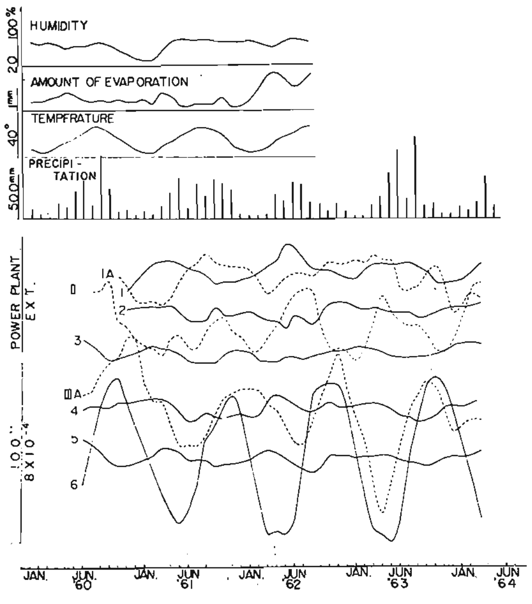

Fig. 12. Annual variations of the ground-strains (——) and the ground-tilts (- - -).

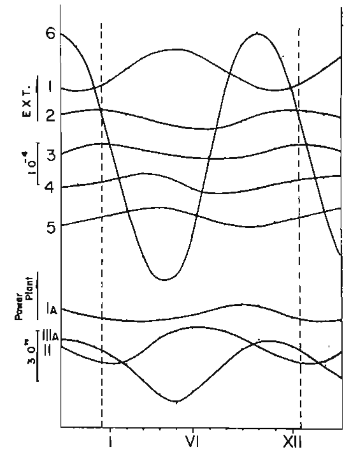

Fig. 13. Averaged annual variations of the ground-strains (1, 2,—, 5, 6) and the ground-tilts (I-A, II, III-A).

elements. It seemed to be connected to the precipitation and temperature, though it was not too clear. This problem will demand more study. Next, the average forms of annual variations for each every year are shown in Fig. 13. The most remarkable point on these variations is that the larger the amplitude of annual variation, the larger the secular variation. Therefore, when we examine landslide movement, it is dangerous to discuss after only short observation. This problem is presented in consideration of the annual variation.

The variations of the ground deformation, the temperature on the ground surface, the temperature in the office of water power plant and precipitation are shown in Fig. 14 to determine on the effect of rainfall and daily variations of groud deformation. In this figure, the dotted lines show the variation of observed value every two hours and the real lines show the series of running means each 26 hours (13 observed values at every two hours). Accordingly the difference of both shows the daily variation. In Fig. 15, these daily variations are shown. In this figure, the effects of rainfall are found clearly in every component. On components 1 and 6 in which the secular variations are large, the changes caused by rainfall do not return to the preceding state but gradually accumulat. The other components in which the secular variations are small, the changes return to the preceding state several days after. Therefore whether it is an elastic characteristic or not seems to determine whether it promotes a landslide or not. On the component in which the change was caused by rainfall extension, the secular variation extended gradually. On the contrary when the change was caused by rainfall contraction, so was the secular variation. In finding the daily

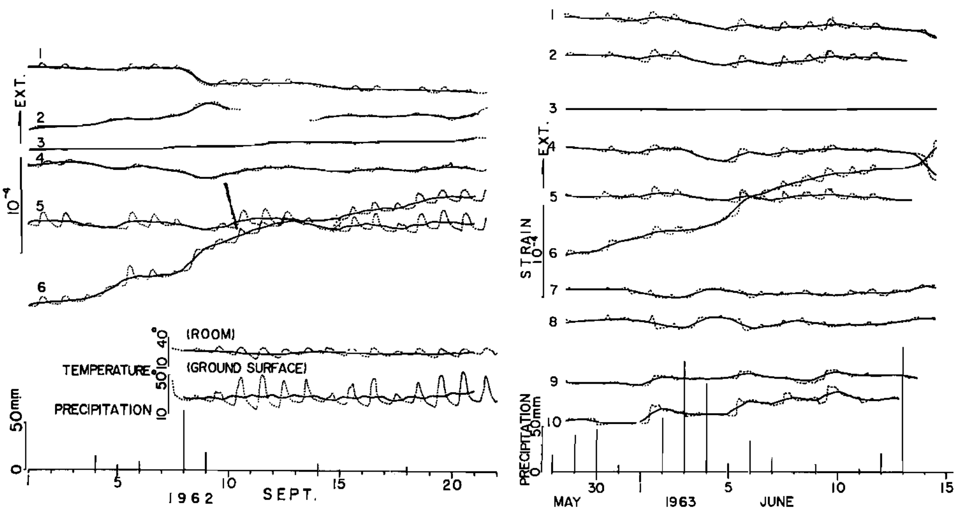

Fig. 14. (a) Fig. 14. (b)

Fig. 14. Variations of the ground-strain, the temperature and the precipitation.
⋯⋯ : -Observed value at every two hours,
—— : -Variation of which eliminated daily variation

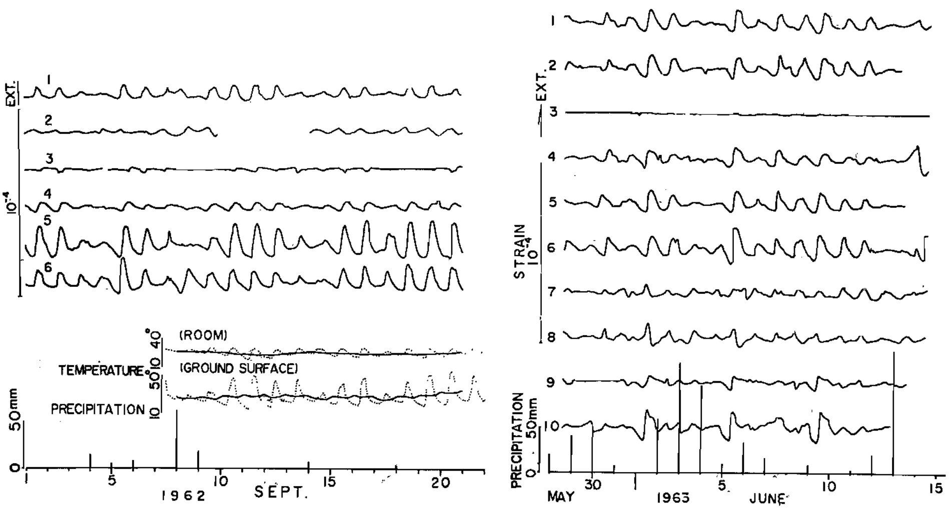

Fig. 15. (a) Fig. 15. (b)

Fig. 15. Daily variations of the ground-strain, temperature and precipitation.

variations of ground deformation, it seems that they are identified with the temperature on the ground surface. Above all, it is believed that where daily variations are large secular variations are also large. It means that the ground deformation in this place is changable.

The landslide is not going occur in this zone, but it might occur in the future. So the key to the prediction of landslide occurrence will be found by more studies with various data.

4-2. The investigation of landslide in Shimizudani zone (Kamenose landslide zone)

a) Outline

The vicinity where the Yamato runs westward gathering many streams in the Nara basin and flows into the plains of Ōsaka acrossing the Ikoma range is generally called "Kamenose" and forms a ravine. The left bank of the Yamato is Ōji-cho, Kitakatsuragi-gun, Nara Prefecture and is a mountainous area having Mt. Myojin and Mt. Nijo. At the base of this area, the important routes of communication and transportation of the Kansai district such as the National Railway Kansai-Line and National Road Route 25 concentrate. The right bank is Toge, Kashiwara City, Ōsaka Prefecture and is a hill zone commanding a distant view of the mountains of Shigi and Ikoma in the North. Here owing to the fertile soil and sunniness from the south, this hill is well suited to the cultivation of fruit-trees and has for long been famous for the production of grapes, peaches and oranges. (See Photo. 3.)

The geological structure in this area is complicated. The upper most zone is covered by the Ōsaka Group consisting of clay and pebbles, the next zone is formed by the Nijo Groups consisting of two-pyroxene andesite,

Photo. 3. (a)

Photo. 3. (b)

Photo. 3. Distant views of Kamenose Landslide area.

hypersthenite-andesite, gravel beds and Donzurubo beds made from lava and volcanic ash thrown up by the volcanic activity in the Late Miocence of the Tertiary period and the bed rock is granite-gneiss.

Owing to such geological structure, this hillside that seems to be quiet, has been prone to landslide and has often suffered great damages. For example an area of 32 ha centered around the Toge village slide owing to the landslide which has been active since the end of 1951. This landslide was the "Kamenose Landslide" which created a sensation at that time. In the activity of landslide, the ground was cracked, upheaved and depressed in almost all of the area. The wells and irrigation ponds ran dry and some houses collapsed. The inhabitants in this area left their houses and took refuge. The National Road on the other side of Yamato River and the riverbed were upheaved and the river width narrowed.

In the upper stream area, houses and fields near the bank were flooded by the rise in water level of about 4 m. The Kamenose Tunnel (about 500 m in length) of the Kansai Line was especially destroyed and the traffic was entirely interrupted. As a result the railroad of the Kansai Line was forced to move to the opposite bank because it was too difficult to repair. The remains of the eastward mouth of old Kamenose Tunnel are shown in Photo. 4. After the rainy season in 1932, such great landsliding was gradually ending. The displacement caused by this landslide was about 33 m at the maximum sliding point.

Photo. 4. Eastward mouth of the old Kamenose Tunnel.

After this, there was not such a remarkable slide, but in 1951, in the west side of old Kamenose Landslide zone, i.e. an area (about 4 ha) surrounded by Umanose, Busshōdo and Shimizudani, the sliding began again. This landslide was called "Toge Landslide". The writer took part in this investigation. This landsliding activity was stopped by the preventing works in the construction of Sabo-dam in Shimizudani, etc. But during recent years, the sliding activity has again became remarkable. Damages have occurred to the road surface of the National Road and to the Yamato River bed. The upper stream bed has become submersed due to the upheavals. Therefore, at the request of local people the Ministry of Construction took a fundamental measure for the prevention of landslides, and made a soil mass removal plan in this area for stabilization, the investigations to carry out this plan has begun. The writer tried to investigate the geophysical point of view from various aspects.

b) The seismic prospecting

First of all, seismic prospecting along 9 traverse lines shown in Fig. 16 were carried out to find the crustal structure in this area. These traverse lines were chosen so they could be compared with the results of investigation by vertical drilling. Also to know the crustal structure near the survey lines of ground-strain by the extensometers mentioned later. Late in March, 1963 (the dry season) and early in July, 1963 (the wet season), seismic prospecting was carried out along 3 traverse lines (I, A, B) by the same method. This was done to find whether each geophysical characters (seismic wave velocity, amplitude, and period, etc.) change or not in the dry and wet season. After that, about the middle of May, 1964, seismic prospecting was carried out along 6 other traverse lines (II, III, IV, C, D, E) to find the crustal structure of whole area. These results are shown in Fig. 17. As shown, in this area the zone of about 10 m in depth from the surface was a clay layer with pebble. Its propergation velocity P-wave was 0.4～0.6 km/s. The zone below was a cataclasite layer with 2.4～2.7 km/s velocity P-wave, and the fractured zone with 1.2～1.5 km/s velocity which seemed to be

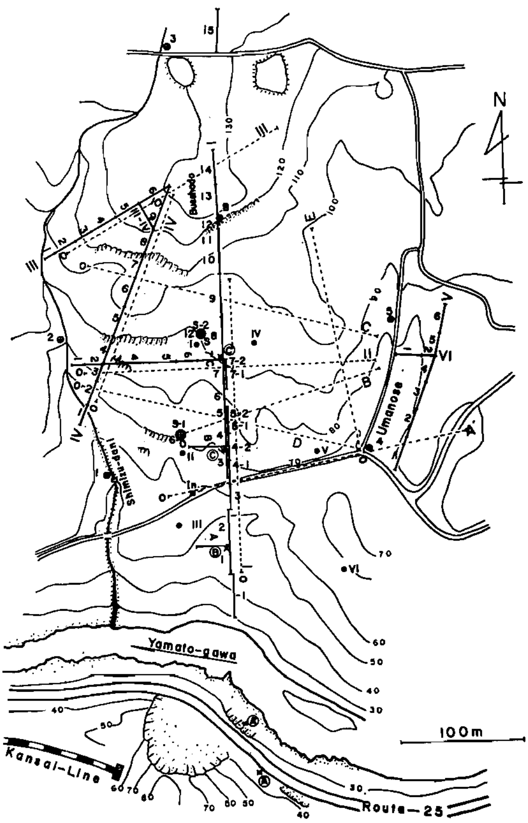

Fig. 16. Disposition and distribution of the instruments and traverse lines of seismic prospecting.
I : -1, 1, 2, ……15, II : 1, 2,---7 (=c), III : 1, 2,---6, Ⅳ: 1, 2,---10, Ⅴ: 1, 2,---6, Ⅵ: 1, 2, III-Ⅳ, A, B, S :-Extensometer, ×: Ⓐ, Ⓐ′, Ⓑ, Ⓒ, Ⓒ′:-Tiltmeter, ⊕: 1, ---5, 6, 12 : -Observing well of groundwater level, ● : Ⅰ, Ⅱ,---, B : -Travelling post, In : -Portable underground inclinometer, ⊕ S-1 : -Shaft-No. 1, ⊕ S-2 : -Shaft-No. 2, --- : -Traverse line of seismic prospecting

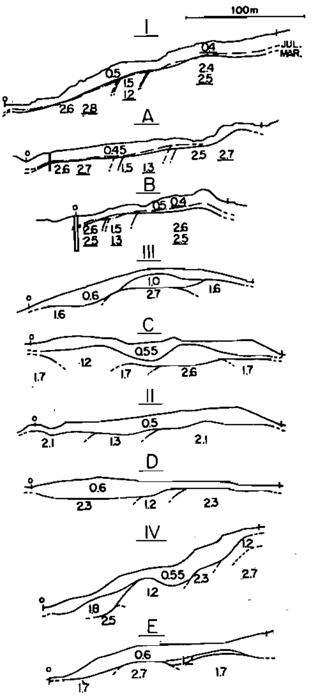

Fig. 17. Crustal structure obtained by seismic prospecting. (Each value shows the propagation velocity of P-wave and value with under line shows it in July.)

crashed when the older landslide was caught in this layer. This fractured zone is shown in Fig. 24 to be published later on. As shown, it passes through the steep cliff and is distributed NW-SE, dividing this area into two blocks.

c) The ground-strain observed by extensometers

As shown in Fig. 18, the observations of ground-strain are being carried out by 53 extensometers set up along 6 survey lines in the landsliding and neighbouring Umanose area. (See photo. 5.) The observation along the survey line I was begun in April, 1963 (Some of it was begun in August, 1963.) and the observations along the other lines (II~VI) was begun in May, 1964. Because of the soil mass removal works, which began in September, 1963, observation along the survey line I were suspended for about 8 months.

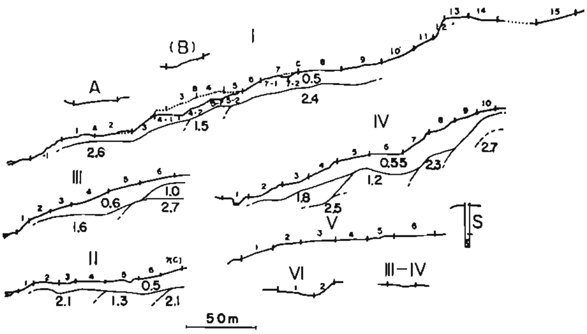

Fig. 18. Geological section along the survey line of ground-strain. Each value shows the propagation velocity of P-wave (unit : km/s).
(…… : Surface before removal works)

Photo. 5. (a)

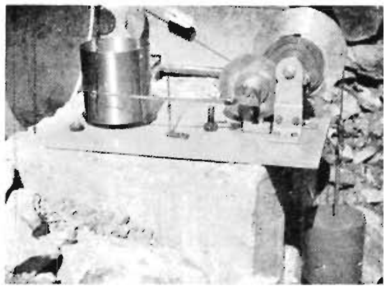

Photo. 5. (b)

Photo. 5. Extensometer.

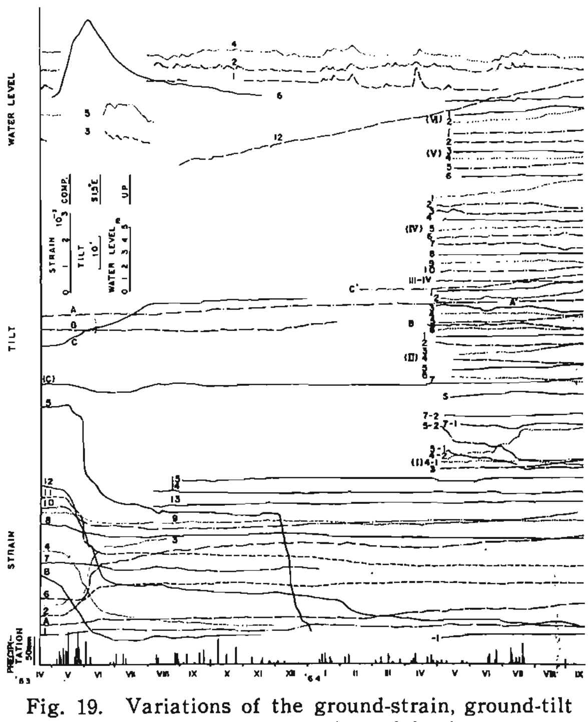

Fig. 19. Variations of the ground-strain, ground-tilt and ground water level and precipitation.

The instruments under extensometer 7, set up again in April, 1964, were changed because these works altered the natural features. Also, the extensometer V was set up vertically in shaft No. 2. The geological sections along each survey line of ground-strain are shown Fig. 18. Sections I~IV are shown with the crustal structure because the seismic prospectings were already carried out along these traverse lines. The variations of ground-strain observed by these extensometers are shown in Fig. 19. Hence, every variation was enlarged from May to June, 1963 and little variation was found after that. If these variations are compared with the daily precipitation observed in this area (showed in the same Fig. 19), it can be found that a large variation occurred during the rainy season. Last year there was much rain, in its rainy season the total precipitation was about 600 mm. On the contrary there was little rain this year, in this season the total precipitation was only 200 mm. In addition the effect of soil mass removal appear.

d) The ground-tilt observed by tiltmeters

In order to investigate the ground-tilt caused by the landslide, observations began in April, 1963 by setting up three self-recording tiltmeters with horizontal pendulum of the Zöllner suspension type. Tiltmeters B and C were set up on the survey line I, A was set up on the opposite side of the Yamato Rive which is on an extended line from I. The observation of B was interrupted for a time by the soil mass removal works, so A and C were moved to A′ and C′ and the observations are being carried out from there. The result of the observation is also shown in Fig. 19. The variation of C has been enlarged during the rainy season of 1963 just as with the extensometers.

e) The trial manufacture of a portable underground inclinometer and the result of observation by it

In a landsliding area, a method to investigate the depth of slip surface is to put a vinyle chloride pipe deep into the ground and by measure its bend. At the slip surface the vinyle chloride pipe is naturally bent by the shearing force created by the relative motion of both layer. Accordingly the strain gauges are usually put on both sides of pipe and the bend is found by observing the difference of both changed values of strains. But if the direction of the bend is to be determined more in detail, the number of strain gauge must be increased, so it is not a convenient method. The writer invented a simple underground inclinometer to remove this disadvantage in finding the bend of the pipe. The mechanism of this instrument is shown in Fig. 20. It is made of a pendulum that suspends weight W from which the spring clung by combined upper and lower flat springs S_1 and S_2, and these devices are in a water-proof case. Two flat springs are directed at right-angles to each other and a gauges G are stuck on both their sides. When the instrument is lowerd along the pipe, the water-proof case tilts, the flat springs with strain gauges are bent and so the strain gauges in part deform where the pipe is bent. If the relation between the angle of inclination and the deformation of the gauge is to be found, the inclination of pipe will be obtained by the variation in the strain of gauges. If we measure the inclination at every depth, the bend of pipe can be found. But it is necessary that the water-proof case should be in the same direction and contact with pipe at the same time. So this writer fixed two guide rails diamterically in the vinyle chloride pipe and also fixed two guide rolles with the flat springs on the upper and the end sides of the case so that the rollers move up and down along the rails. In Fig. 21 the sensitivity of this instrument (the relation between the angle of inclination and

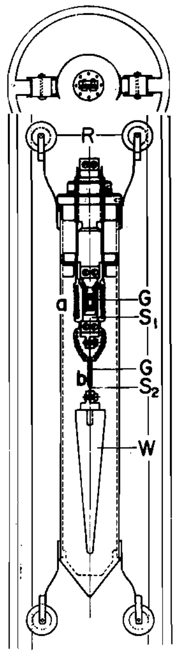

Fig. 20. Illustration of the portable underground inclinometer.
a : ——a-component
b : ——b-component
G : ——Strain gauge
S_1, S_2 : ——Flat-spring
W : ——Weight
R : ——Guide roller

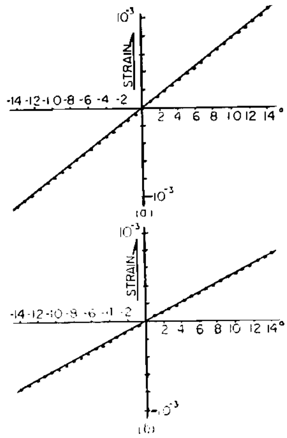

Fig. 21. Sensitivity of the portable underground inclinometer. (Relation between the angle of inclination and strain)

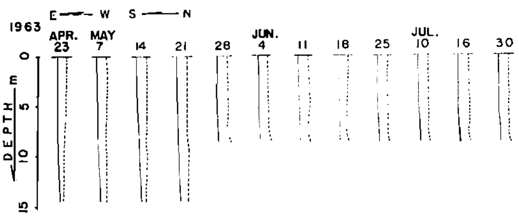

Fig. 22. Variations of the subsurface strain. (Deformation of the vinyle chloride pipe)

strain) is shown. Where (a) is the sensitivity on upper spring and (b) is that on lower spring which directs right-angle to upper spring. In this experiment, the tilting motion in any direction was just the same to that obtained by resultant of two components.

It was inserted into a vertical drilling hole dug by the side of the road and in the western part of the seismic prospecting traverse line A. A vinyle chloride pipe, 75 mm in diameter, was buried 15 m in the depth and was measured once a week since April, 1963, using this instrument. These results are shown in Fig. 22. At the first time, the instrument could be lowered from the ground surface, but after rainfall at the beginning of May, the bend was found at 10 m. This bend became larger day by day and began to raise. At last on May 28, this instrument could not be lowered deeper than 8.5 m. This means that there was a slip surface at 8.5 m.

f) The observation of ground water level

The landslide is affected by the ground water level. So, in order to know their relation, the wells 1~5 (75 mm in diameter) shown in Fig. 16 were drilled in this area and the observations of water levels began in April, 1963. Especially observed were wells I, III and V which formed a regular triangle in order to determine the direction of underground stream. The ground water level indicators used in this area are the float type and the pen self-recording system. It can record 1/3 and 1/6 of the actual change. The water level of well-6, i.e. shaft No. 1 (3 m in diameter, 30 m in depth) was dug in the center of this area and used to observe the measurement. At the first observation, the ground water levels of 1, 2 and 4, 3 and 5, and 6 were about 3~4 m, 12~13 m and 29 m under the surface respectively. But after the rainfall from the beginning of May, observing wells 3 and 5 were bent by the landslide caused by long rain and the rope touched the wall of well. Therefore observations had to cease. Unfortunately, the movement of water level was too large for these indicators to observe the ground water level during the most important period. After that, shaft No. 2 was dug in July, 1963 and ground water level indicators 3 and 5 were moved to shaft No. 1 and No. 2 as No. 6 and No. 12 and the observation was begun again. But the observation for shaft No. 1 was suspended for a time because it had to be dug 15 m deeper on December 15. The result of these observations are shown in Fig. 16.

g) The soil mass removal plan in 1963

The removal plan of the Ministry of Construction in this area aimed at perfect stabilization by removing about 600,000m³ of soil mass during the next 5 years. Due to this plan, in August, 1963 a plan was established to

TABLE 1.

Ground-strains observed by extensometers and amounts of contraction and horizontal displacement calculated from those variations.

Mark of extenso-meter	a Strain (×10⁻³)		b Amount of contraction (mm)		c Amount of horizontal contraction (mm)		d Horizontal displacement (from Busshōdo) (mm)	
	IV—VII	V—VI	IV—VII	V—VI	IV—VII	V—VI	IV—VII	V—VI
1	0.20	0.19	4.9	4.7	4.9	4.7	− 32.6	− 34.2
2	1.24	1.22	32.0	31.5	31.8	31.3	− 37.5	− 38.9
(2′)	1.88	1.65	51.0	44.8	44.1	38.7	− 69.3	− 70.2
3	2.52	2.08	70.0	57.8	63.4	52.4	−113.4	−108.9
4	−2.64	−2.21	−58.1	−48.7	−56.6	−47.4	−176.8	−161.3
5	−3.90	−3.67	−39.0	−36.7	−39.0	−36.7	−120.2	−113.9
6	1.63	1.38	25.8	21.8	22.3	18.9	− 81.2	− 77.2
7	−0.21	−0.25	− 6.1	− 7.2	− 6.0	− 7.1	−103.5	− 96.1
8	−0.52	−0.42	−15.6	−12.5	−15.6	−12.5	− 97.5	− 89.0
9	−0.42	−0.38	−12.5	−11.3	−12.3	−11.1	− 81.9	− 76.5
10	−0.81	−0.74	−20.1	−18.4	−18.4	−16.8	− 69.6	− 65.4
11	−2.12	−2.11	−38.2	−38.0	−33.1	−32.8	− 51.2	− 48.6
12	−3.94	−3.43	−52.8	−46.0	−18.1	−15.7	− 18.1	− 15.7

remove about $60{,}000m^3$ of soil mass in the first year. This plan was decided from the results of various investigations from March to July and the survey and other investigations by th Ministry of Construction. This writer will describe the outlines.

First, looking at the ground deformation, the effects of rainfall are remarkable as shown in Fig. 16 and these effects appeared on about May 14 about 10 days after the beginning of rainy season and continued until about June 25. In Table 1 shows the amount of strain (a), amount of contraction (b), amount of horizontal contraction (c) and horizontal displacement (d) of the fixed point on the river side of each extensometer, supposing that the fixed point of extensometer 12 on Busshōdo is a standard. IV–VII each changed from April 18, 1963 to July 31 and V–VI each changed caused by the rainfalls from May 14 to June 25. 2′ is the value in the middle section of 2 and 3 which was not a extensometer, but obtained by averaging the changes of extensometers 2 and 3. According to these, in Fig. 23, the strain, horizontal displacement of each point in the geological section along the survey line of ground-strain are shown. In this figure, IV–VII are shown with ▬ and V–VI are shown with ——, and the upward change is the displacement toward the Yamoto River. From this we can understand the distribution of strains, that is, the section from the extensometer 12 on Busshōdo to the extensometer 7 is the tensile zone, the span of extensometer 6 is the compressive zone, 5 and 4 are the tensile zone and from 3 to 1 is compressive zone. The change of strain became gradually smaller (from the higher to the lower). Considering the distribution of ground-strain, the landslide block in this area is devided in two, i.e. the higher block from Busshōdo to extensometer 6 and the lower block from extensometer 5 to extensometer 1. And the sliding of the higher block is checked near extensometer 6 and the sliding of the lower block from extensometer 5 is checked at extensometers 3, 2 and 1. As the result of the seismic prospecting, it is believed that the crashed zone (P-wave propagation velocity : 1.2~1.5 km/s) gets across near extensometers 5 and 4 (See Fig. 24.) and has influence on the landsliding of the lower block.

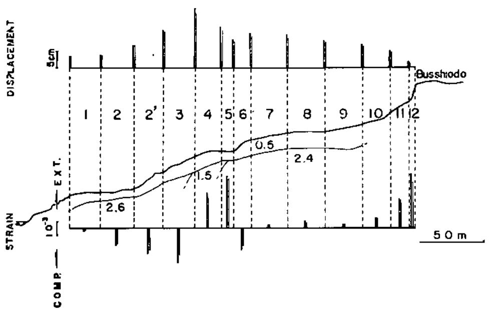

Fig. 23. Geological section along the survey line I for investigation of ground-strain, disposition of the extensometers, variations of the ground-strain and displacement of each block.
1, 2,– – –, 11, 12 : –Extensometer
▬ : –Variations of the ground-strain and the displacement from April to July
—— : –Variations of the ground-strain and displacement from May 16 to June 26
Each value shows the propagation velocity of P-wave (unit : km/s). Variation of 2 is presumed from variations of 2 and 3.

Travelling posts were also set up at I, II, ..., VI and B in order to know the movement of ground surface in this area as shown in Fig. 16. Since

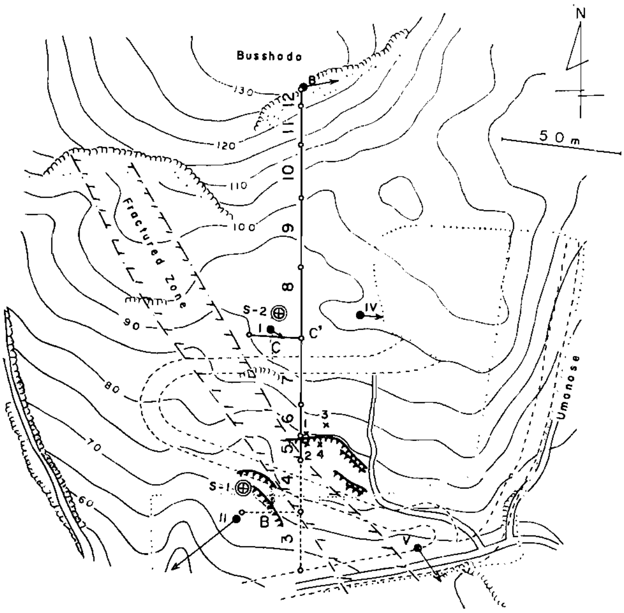

Fig. 24. Topographical map in the neighbourhood of fractured zone.
3, 4,---, 11, 12, B, C : -Extensometer, C′ : -Tiltmeter, ●-I, II, IV, V B : -Travelling post, → : -Direction of the displacement, ⊕-S-1 : -Shaft -No. 1, ⊕-S-2 : -Shaft -No. 2
: -Crack, : -Area of the removal of soil mass

October 20, 1960, a periodical survey has been done twice a year. The surveys in 1963 were those of Feburary 22 and July 30. The displacements of each post for about half a year are as follows.

Post I : -	toward S58.°00′E	13 cm	
II : -	S52.°00′W	68 cm	
III : -	S36.°00′W	75 cm	
IV : -	S87.°00′E	18 cm	
V : -	S35.°00′E	35 cm	
VI : -	N35.°00′E	13 cm	
B : -	N80.°30′E	13 cm	(From October 20, 1960 to July 30, 1963)

If the displacement of posts these is calculated in the direction of the survey line of ground-strain with these values, (suppose a large displacement of posts II and III) it is almost similar to the value believed to be in d-value of Table 1.

Then considering the depth of slip surface, according to the observation of the underground tiltmeter mentioned above, the vinyl chloride pipe was deformed at a depth of 8.5 m. According to the standard pentration test when the vertical observing hole was drilled, the N-value was about 20 to 8 m in the depth, but from here it suddenly increased to about 70. From the result of the seismic prospecting (See Fig. 17.), the boundary surface is found at the first layer (0.45 km/s) and the second layer (2.6 km/s) is near the 8.5 m depth. From the result of the geotechnical soil test of materials extracted by vertical drilling, at 9 m depth a discontinuous change was recognized. The mean ground water level in this observing hole was at

7.7 m depth and the natural water content ratio of soil increased from 20% to 40% there. On the other hand, the underground tiltmeter was inserted in the wells and tried to observe the bend of wells. Though the direction of bend was not too clear, the pipes were bent at about 7.6 m depth in well 1, 5.4 m depth in well 2, 14.5 m depth in well 3, 3.4 m depth in well 4 and 14.0m depth in well 5. These depths are similar to the boundary surface of the first layer and the second layer, believed to be from the crustal structure obtained by the seismic prospecting traverse lines which ran near these wells. Therefore, it seemed that the slip surface was almost the boundary surface of both layers, and the first layer (P-wave velocity: 0.4~0.6 km/s) was sliding. The depth at which the ground water sprang in the drilling works of the observing wells was at 5.0 m depth in well 1, 3.5 m in well 2, 12.0 m in well 3, 2.5 m in well 4 and 11.0 m in well 5. These depths were more shallow than the maximum deformation depth of the well and the natural water content ratio of the soil extracted from the underground-tilt observing hole was larger in the shallow place than in the slip surface. Hence it seemed that on the slip surface the water bearing layer was distributed and the landslide was affected by the water.

Therefore the removal of soil mass of the first layer was concluded to be a good way for stabilization of the slope. From the viewpoint of stability, it was generally best to remove the soil mass in higher part, but from the viewpoint of increased efficiency and economy, the removal of soil mass in lower part near National Road was profitable. As mentioned above, it was believed that in this landslide area the landslide block was devided in two, i.e. the higher block and the lower block and the landsliding of the higher block was checked near extensometer 6, so the landsliding of this block wouldn't be affected by the removal of a little soil mass in the lower block. Accodingly, as a result of careful consideration about the transporting road etc, ground near extensometers 3 and 4 was to be cut off first. After that, the operation was to move to east and then to move to the western slope of Umanose and then to move to the north. But in this case, the small landslide near extensometers 5 and 4 was expected because the zone from

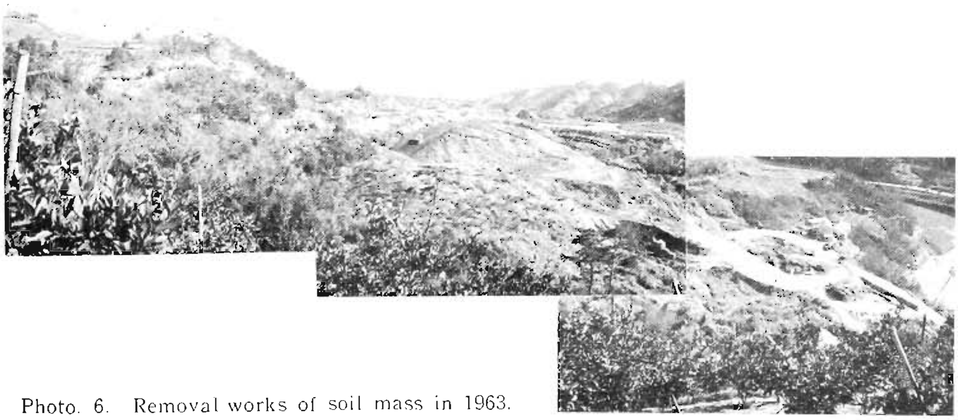

Photo. 6. Removal works of soil mass in 1963.

extensometer 3 to extensometer 1 was a compressive zone which checked the landsliding of the higher block. So much care, was taken in the removal works which have been carried on since the middle of September. The first construction was to make a transporting road which led to the National Road and the next was to cut off the slope to expand the city road near the shaft No. 1. These projects removed about 5,000 m^3 soil mass to the east along the city road until the beginning of November. From the end of December to the middle of Feburuary, 1964, about 30,000 m^3 soil mass in the western slope of Umanose, and from the middle of Feburuary to the end of March, about 25,000 m^3 soil mass in a little hill on the east of shaft No. 2 were removed. A total of 60,000 m^3 soil mass was removed. (See Photo. 6.)

Photo. 7. Cracks occurred in the neighbourhood of Shaft No. 1.

h) The landslide due to soil mass removal and phenomena forerunning its landslide

The removal works near extensometers 3 and 4 were finished in the beginning of November. During this period cracks occurred along the crashed zone in the south-east of shaft No. 1. (See Photo. 7.) But it was nothing to worry about. After that, a project to dig down the shaft No. 1 (30 m in the depth) 15 m deeper was begun on December 15 and work progressed without incident the first day. The next day, in the midst of digging operation an unpleasant rumbing of the earth was heard in the bottom of the shaft and there was a feeling that a landslide might occur, so the project was stopped. Everything was in good order on the surface. On December 17, on the boundary between the compressive zone and tensile zone the extensometer 5, many cracks were found along the crashed zone, (See Photo. 8 and Fig. 24.) soon the posts 1 and 2, 3 and 4 were set up, facing

Photo. 8. (a)

Photo. 8. (b)

Photo. 8. (c)

Photo. 8. Cracks occurred in the neighbourhood of extensometers 5 and 6 (On the bounday between the compressive zone and tensile zone.)

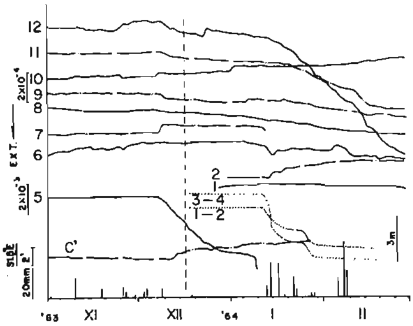

Fig. 25. Variations of ground-strain and ground-tilt before and after the crack-occurrence and the precipitation.
1, 2, 5,- - -, 11, 12 : -Ground-strain, C′ : -Ground-tilt,
1-2 :-Distance between Post 1 and Post 2,
3-4 :-Distance between Post 3 and Post 4

each other across a main crack in order to observe the variation of gap of crack. The result of these observations is shown in Fig. 25. The distances 1-2, 3-4 between these posts were suddenly extended on January 12 and they moved about 3 m during the next 5 days and increased about 1 m during the 3 days after January 25, showing the change of about 4.5 m horizontally, about 2 m vertically (See Photo. 8.), but the change has gradually decreasing since then. In Fig. 25, the variations of ground-strain and -tilt observed by extensometers and tiltmeters are shown in addition. From these variations the forerunning phenomena before the occurrence of crack (i.e. the occurrence of landslide) were observed. The extensometer 5 which crossed over the crack changed to the extension from about December 7, 10 days before the occurrence of the cracks and then the cracks occurred. After that it still continued to be tensile, but the rate of variation decreased at the end of the year. From about January 3, the rate again increased and on January 9 the observation became impossible because of the great extension. After that the gap of crack opened suddenly on January 12. Extensometer 6 set up in the compressive zone which is above to the crack showed the compression till about December 7, and after that the variation stopped for a while, but from about January 5 it changed to the extension. Extensometer 7 also showed the compression from about December 9 and after that from about January 6 it showed the extension. In these variations observed by other extensometers and tiltmeters the variation of changing rate was found before December 7 and after January 6. The ground surface was gradually deformed from about December 7 and it was broken on 17th making cracks. From about January 6, the deformation became large and was enlarged on 12th. The variation of ground-strain and -tilt occurred long before the occurrence of the landslide. So from the observations of ground-strain and -tilt the key for the prediction of landslide-occurrence may be found. In conclusion, it also seems that the landsliding of the higher block was checked near extensometer 6.

i) Variation of ground deformation caused by rainfall

Looking Fig. 19 showed above, we find that the ground deformation was affected by rainfall. The weekly average rate of changes in ground-strain, ground water level in the shaft-No. 1 and precipitation of each week in the period from April 24, 1963 to August 27 are shown in Fig. 26. Where, for example the value of April 30 is the averaged value of rate of change during a week from April 27 to May 3 in the case of ground-strain, observed value of April 30 in the case of ground water level and the total precipitation during a week before the date of April 30 (i.e. from April 24 to April 30) in the case of precipitation. From these results, each variation of ground-strain is found to be affect by rainfall, their effects are different in each place and the two have a close connection with each other, but the relation between them is complicated. The variation of water level is similar to the variation of precipitation but its variation occurs about two weeks after

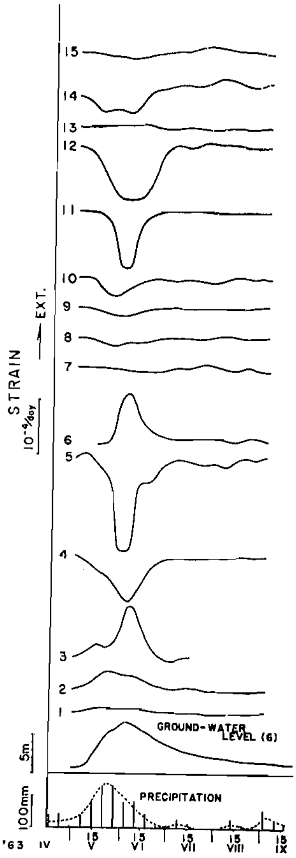

Fig. 26. Variations of the changing rate of ground-strain, the gorund-water level and the precipitation of each week.

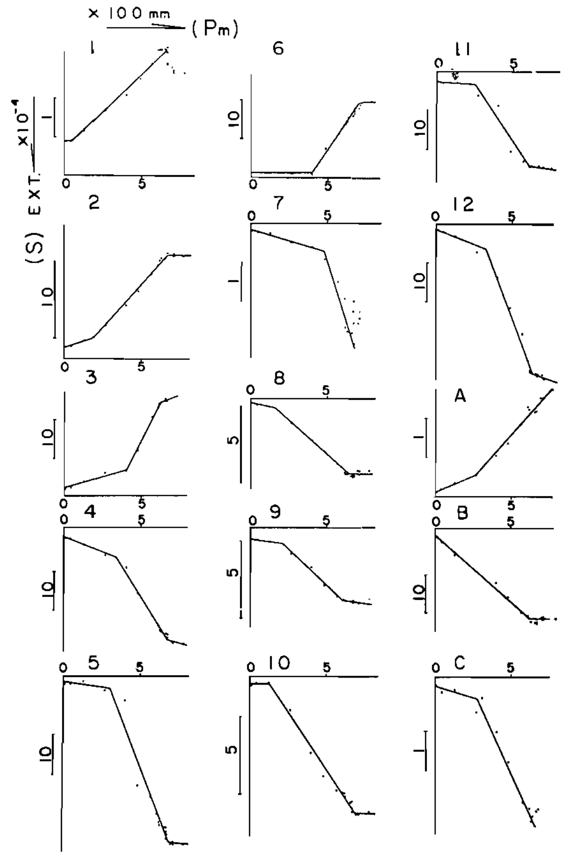

Fig. 27. Relation between the ground-strain and the successive accumulation of weekly precipitation.

the rainfall. Next, in order to study the ground-strain caused by rainfall, the relations between the successive accumulation of weekly precipitation and the ground-strain is shown in Fig. 27. From these figures we find that the ground-strain increases or decreases with the increase of the succesive accumulation of precipitation. Afterward when the successive accumulation of precipitation amounted to a definite value, the variation rate of the ground-strain suddenly decreased or its variation stopped. It is believed that this phenomenon is due to the increase of the water content ratio in the soil with the permeation of water, but at last the water content quantity amountes to the saturation point. G. Kajikawa has tried to obtain the relationship between the moisture ratio (%) and the internal frictional angle (ϕ) and between the moisture ratio (%) and the cohesion (c) on the soil in that area. (See Fig. 28.) According to this report, after the water content ratio increased more than some value, ϕ and c became suddenly small and the soil inhered the plasticity. So it is belived that the results of the variation in the water content ratio of soil, (caused by rainfall) and the form of slip surface etc. complicate each other. At this point a landslide occurs and the ground strains. Accordingly, it is considered that the ground-strain does not change much when there is not as much rain as in the rainy season of 1964.

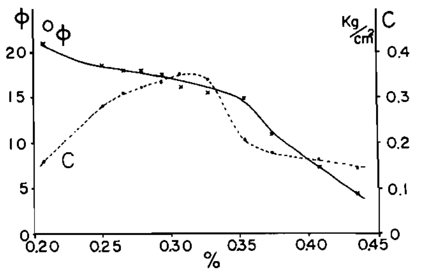

Fig. 28. Relation between the moisture ratio (%) and the internal frictional angle (ϕ) and the moisture ratio and the cohesion (c) on Kamenose soil. (after G. Kajikawa)

5. Conclusion

The prediction of accidental disasters, which bring fear and anxiety, is one of the effective measures toward preventing damages and is immediately necessity to the nation. The writer has been observing the ground-strain and ground-tilt by use of extensometers and tiltmeters for a long time. From the result of these observations, the peculiar variations are found which seem the forerunning phenomena to an earthquake and a rock-falling. Recently, the writer also found the peculiar variation which seems the forerunning phenomena a landslide by observation of the ground deformation at a landslide zone. Like the earthquake, rock-falling and landslide, in the case of phenomena caused by destruction of rocks and land blocks, the energy for destruction is accumulated gradually. After that, the great destruction occurs and its energy is released. Accordingly, the ground deformation occurs with this action. It is believed that if observations of the peculiar variations in ground-strain and ground-tilt carefully kept, the forerunning phenomena can be detected and a clue is found to the prediction of earthquakes, rock-fallings and landslides.

Acknowledgements

In conclusion the writer wishes to express his cordial thanks to the Honorary Professor K. Sassa for his kind guidance and instruction throughout this study, also wishes to thank Professor S. Yoshikawa, Professor I. Ozawa, Professor S. Yamaguchi and all the stuff of Disaster Prevention Research Institute of Kyoto University for their advice and encouragement. The writer also wished to thank the persons concerned with this study for their co-operation and help.

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