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77. The Geophysical Prospecting for Landslide

On the Kebioka Landslide Mainly

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Abstract

Several geophysical investigations at the Kebioka landslide where there were no remarkable phenomena of soil displacement were carried out. An assumption was put by the electrical and the opographical survey. Following this assumption, survey plans were decided and were carried out. This is a very effective method of getting valuable data for a landslide and its mechanism.

Measurements have been taken since Aug. 1, 1963 and fortunately, during this term little soil displacement occurred. The records of tiltmeters and tensometers were analyzed before and after the soil displacement. The records of the tiltmeter in the displacement area varied little before and after displacement.

According to tensometer records, the first soil displacement occurred in the lower part of this landslide. From the records before and after soil displacement the law of the relation between diurnal variation of tensometer and the landslide displacement was not obeyed. The nature of this landslide is explained by the crustal structure and the stream of underground water in this region.

1. Introduction

The investigation of the landslide or the landcreep[1] has been advanced greatly by geological, soil mechanical and geophysical surveys during the past ten years. By geological and the topographical study, the classification of landslide phenomena[2] and the predisposition in the nature of the soil are investigated. By soil mechanical study, information for engineering the control landslides is obtained. The geophysical investigation of landslides unites these purposes and its objects are as follows. (1) to get adequate data for proving the results of geological survey. (2) to explain landslide displacements. (3) to investigate technical methods of forecasting a landslide by the data analysis of preliminary phenomena of landslides. (4) to investigate the main factors which cause displacement.

Geophysical apparatus to investigate landslides has been improved[3),4)], and has been able to account for some phenomena of landslides[5),6)] in detail. Several prospectings and many measuring apparatuses are necessary for investigating the nature of a landslide but at landslide investigations, adequate observing and measuring networks are generally few, one of the reasons being lack of operators to take the measurements of a landslide, the other the enormous cost of setting up instruments.

After landslides or landcreeps have occurred, investigation is usually carried out but it is not in time. It is difficult however for us to know whether and when a landslide will occur. From this point of view, as the landslide occurring in the tertiary formation is a creep movement, and occurs once or twice at regular seasons during a year. Therefore, the subject of forecasting a landslide is studied in a tertiary type landslide[7].

This author has investigated the possibility of movement occuring at the Kebioka landslide region where there is no clear landslide phenomena, by carrying out the measurement by tiltmeters, extensometers and internal strainmeters since Aug. 1, 1963.

The landslide movement occurred in Jan. 20, 1964. In this paper, this author studies the resistivity value of slide layers and the preceding phenomena of slide movement by tiltmeters and tensometers.

2. Geological and topographical condition under which the study was mainly carried out

The Kebioka landslide is situated at Muraoka-cho, Mikata county, Hyōgo Pref.. The soil of this region is of tertiary formation which is shale, sandstone, tuffaceous, breccia and combinations of these. The inclination of this landslide is about 15°.

Some parts of this region are interpenetrated with basalt. Weathered layers-the layers of pebbles and clay and pebbles mixed-are weathered gradually from the lower layer toward the upper. The slide layer occurs in this weathered layer of clay and pebbles mixed.

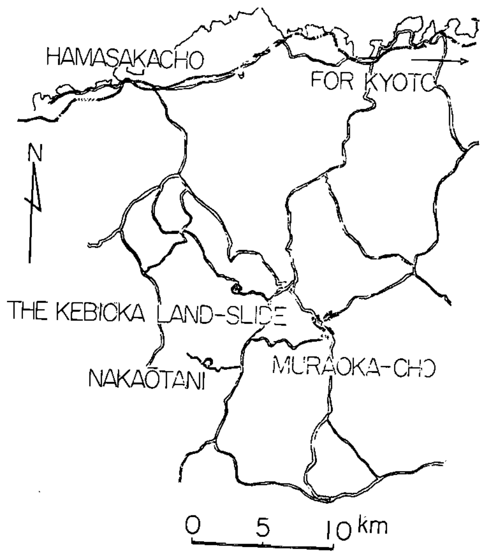

Fig. 1. The place of the Kebioka landslide region.

3. Electrical resistivity method

In order to understand the crustal structure of a landslide region, an electrical survey has been carrid out as the first stage of a study of landslides. The merits of this survey are as follows. (1) an economical method to get information about crustal structures. (2) very speedy etc..

The resistivity values of the bed rock which means the unmoving underground soil vary from 0.1 kΩ-cm to 20 kΩ-cm and also those of the slide layer are changeable. The resistivities of bed rocks however depend on the geological and the water vein conditions, so when we determine the depth of bed rocks, it is not enough to define only by the resistivity values. Furthermore, in some topographical and geological conditions, it is difficult to determine the boundary between the bed rock and slide layer. Many electrical prospectings to get the crustal structure for landslide have been carried out at landslide areas in tertiary formation zones, and as a result, the resistivity values of the slide zone are seen to be 0.6~3 kΩ-cm, and the resistivity

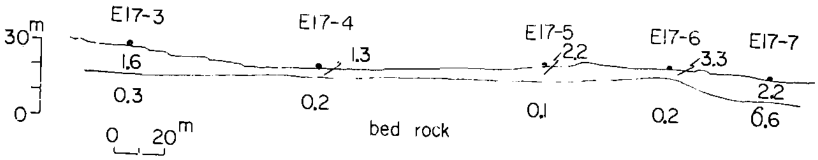

Fig. 2. Crustal structure at E-17 span in the Matsunoyama landslide (bed rock shown as under 0.3 kΩ-cm).

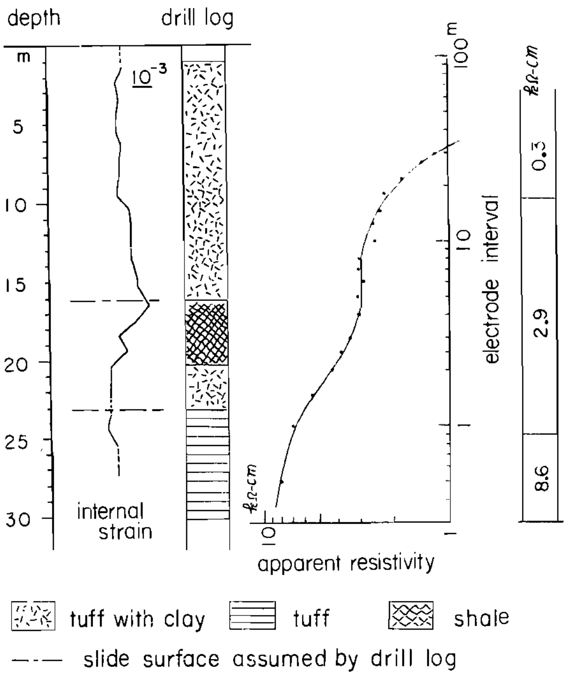

Fig. 3. Comparison of the depth of the slide surface measured by various methods (at Usagiguchi No. 5 drill hole of the Matsunoyama landslide).

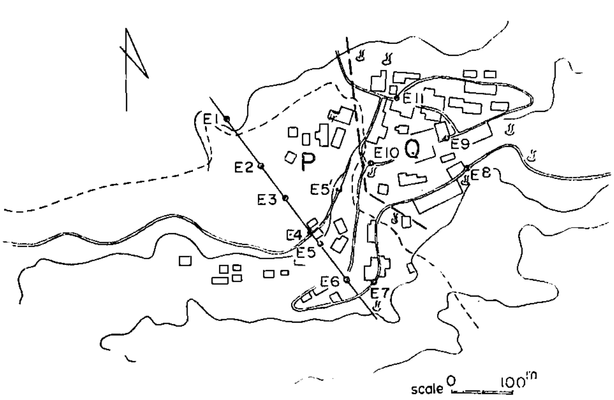

Fig. 4. Disposition of the instruments.

layers below 0.1 kΩ-cm in it suggest what is the unmoving rock layer[8] (what we call bed rock) (see Figs. 2 and 3). The reason why the bed rocks in the landslide area are found to be about 0.1 kΩ-cm layer is now under study.

The electrical surveys were carried out to study the crustal structure and other features by measuring at 12 stations at the Kebioka landslide region (see Fig. 4). The relation between apparent resistivities and electrodes interval are shown in Fig. 5. In Fig. 5, apparent resistivity curves of E-1~7 show higher values than those of E-8~12. The situations of E-1~7 and E-8~12 are different from each other, the former station group is situated at the west area of this landslide region and the latter at the opposite side of it. This means that the east part of this landslide region differs from the west in its geological and crustal structures. On the other hand, from topographical prospect-

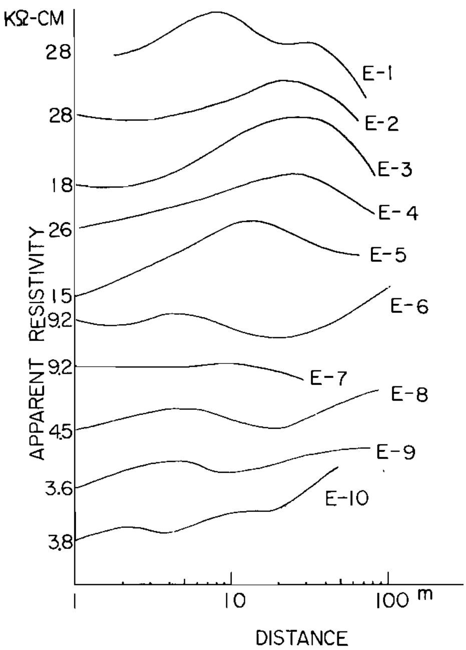

Fig. 5. Apparent resistivity curves ($\rho a - a$ curves).

ing it is clear that there is a cliff at the northeast part of this region, one of the landslide topographies. It suggests a landslide occurred here about a hundred years ago.

Considering these things, this author assumes that *P* area, the west part of this region, is liable to landslide movement and *Q* area, on the contrary, the east part of this area, has less inclination towards landslide movement and if it occurs in this area, the phenomenon of the displacement is different from that of *P* area.

The situations of E-1~7 that were surveyed by electric resistance at *P* area are on the span running from south to north as in Fig. 4. The results by vertical sounding on this span, is shown in Fig. 6. The assumed clay layer was not found. The thickness

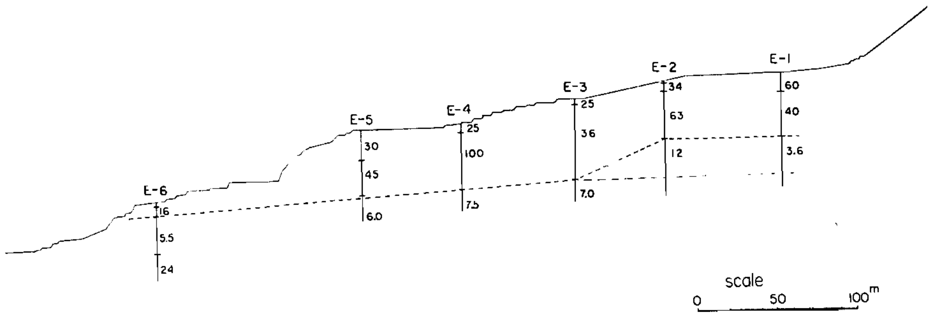

Fig. 6. Crustal structure by vertical soundings at the Kebioka landslide.

from ground surface to bed rock is about 40 m at E-1. If the depth line of bed rocks at E-3 and E-4 is elongated, it joins the ground surface on the same height as the Trout pond (S_3). If we elongate a cliff line in *Q* area to *P* area, the line passes near to E-2. Along this line, it was assumed that under E-2 there was an interpenetration of basalt rock, so electric horizontal soundings were carried out near E-2 and showed the results in Fig. 7.

This landslide region is able to be divided into two areas, *P* and *Q*. If a displacement of a soil block occurs, *P* area will become liable to landslide displacement. There is a discontinuous layer by an interpenetration of basalt near E-2 running from west to east and vertically, so it can be assumed that E-1 is the top of this landslide, and E-6 and the Trout pond are the terminal part of it.

4. On the underground water at the Kebioka landslide region

One of the main factors causing a landslide is the condition of underground water, then the investigations have been carried out on underground water and a water stratum condition, in order to understand the relation between the variation of an underground water table and a landslide movement, and in order to pump the underground water out by a horizontal boring. But there are few effective methods to give us information as to the ground water and water vein.

In the Kebioka landslide region, there are eight springs as shown in

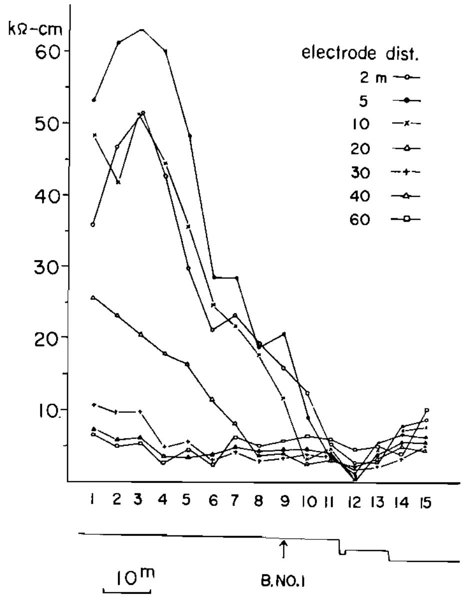

Fig. 7. Horizontal sounding near No. 1 drill hole.

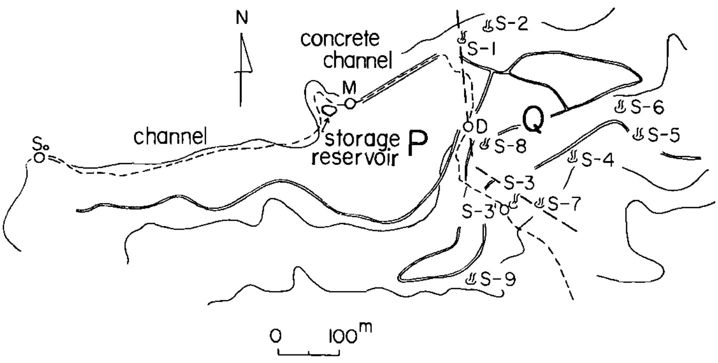

Fig. 8. Spring points and tracers projected points.

Fig. 8. Two springs are in *P* area and the others are in *Q* area. The outflow discharge of each spring is under 1 *l*/min., except at a spring in the Trout pond (S_3). The outflow discharge of S_3 is about 140 *l*/min.. There is a strong spring (S_0) in the northwest part 2 km away from this region and it is drinkable. Almost the S_0 water flows along the channel which passes through the upper part and the center of this region (see Fig. 8). This rate of discharge flow is about 546 *l*/min. at the concrete channel near point *M* and the current velocity is 88 cm/sec..

There is a fine permeability layer under *P* area, according to electric survey which is a storage reservoir in which the water seeps somewhere near the water channel (see Fig. 8). From this phenomena, the author assumes that the water of the channel seeps and outflows at the Trout pond (S_3).

Projecting NaCl into S_0 streaming to the water channel, the water samples which were got from each spring in this region were examined by measuring the electric conductivity. The results of these examinations indicated that there is a notable variation in the electric conductivity at S_3, but at the other springs there was no variation in it. Furthermore, the travel times from S_0 to M, D, S_3 and S_3' were calculated respectively. Next we projected fluorescence-soda into point M of the channel, and measured the travel times from point M to D, S_3 and S_3'. Last, fluorescence-soda is projected into D point to S_3 and S_3' respectively. These results are shown in the following table.

Projecting point	Measuring point	Travel time (min.)
S_0	S_3, S_3'	120, 75
M	S_3, S_3'	75, 35
D	S_3, S_3'	45, 15

By measuring the travel times of the tracer from S_0, M and D to S_3 and S_3', it is clear that the waters projected tracers into channel at S_0, M and D permeate into the underground and flow out at S_3. In order to know how much water of the channel between D and S_3' streams into S_3 as underground water, Q_R, Q_S, C_R and C_S are measured. These notations are as follows.

Q_R : the discharge of the channel water between D and S_3'
Q_S : the discharge of S_3
C_R : the fluorescence-soda concentration of the water course
C_S : the fluorescence-soda concentration at S_3 outflow discharge
q : the discharge of seepage water from the channel to S_3

Then we can obtain $q=1.2\%$, on the assumption that the law of the constancy of the tracer mass is maintained. From these results about underground water, the assumption that the water of the channel seeps and outflows at the Trout pond (S_3) is justified.

Furthermore, q/Q_S is calculated as 12%, which means that 88% of the outflow discharge at S_3 has different sources from the water channel between D and S_3' and that it is probable that it flows into S_3 as seepage water through the water channel between S_0 and D. The sources of the outflow in the Trout pond are being studied from this point of view. From the relation between the crustal structure and the underground water condition, Fig. 9 gives a general idea.

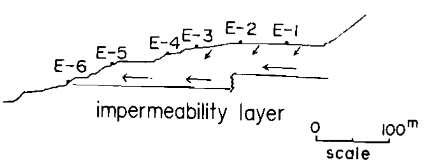

Fig. 9. General plan of underground water course.

5. Internal strainmeter

In order to know the depths of the slide surface at two drill hole points, measurements by internal strainmeters have been carried out since March 18, 1964 and their stations are shown in Fig. 11. The depths are 60 m and 100 m at No. 1 and No. 2 respectively. The calculated values are shown in Fig. 10. From this Fig. 10, it is clear that the depthes of the slide surfaces are about 40 m and 75 m at No. 1 and No. 2 respectively.

According to the geological condition at No. 1 drill hole, the slide surface was 16.5 m. By measuring the internal strainmeter however it is clear that the depth of the slide surface is about 40 m and this depth is the boundary between basalt and weathered basalt. At No. 2 drill hole the depth of the slide surface was 22 m from the geological condition. By measuring the internal strainmeter however the depth of the slide surface appears as about 75 m. Here the depth of the slide surface measuring by the internal strainmeter gives the largest displacement place in this vertical section.

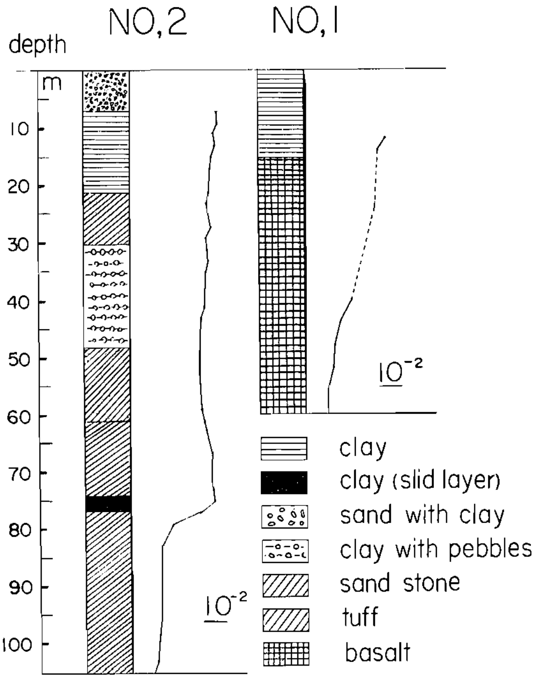

Fig. 10. Drill logs and calculated values of internal strain at No. 1 and No. 2 drill holes.

From this result this landslide seems very complicated a phenomenon. The landslide mechanism measured by the internal strainmeter will be discussed in another paper.

6. The stage of the movement of the ground surface observed by tensometers and tiltmeters

The stage of the movement of the ground surface was observed by four Bubbletube-type tiltmeters and five tensometers. Each station was decided on the basis of the assumption obtained by the geophysical survey (see 3). That is, concerning tiltmeters, one is set outside *P* and *Q* areas (K-1), two at the northern

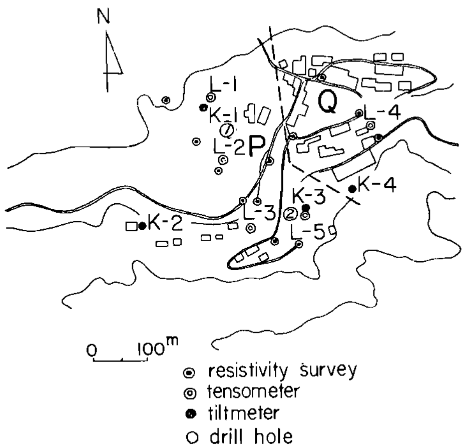

Fig. 11. Dispositions of tiltmeters and tensometers.

part (K-2) and the southern (K-3) of P area respectively, and the other at a place in Q area on the same contour line as K-3, and as to tensometers, one at the upper part, the middle, and the lower of P area respectively, another at the center of Q area and another at K-3 in order to examine the relation between the tensometers and tiltmeters (see Fig. 11).

Measurement by each apparatus has been carried on since August 1, 1963. Meteorological observation has been done at Gotenyama, Muraoka 10 km away from Kebioka.

6.1. Tiltmeter

The apparatus is designed to show an actual ground inclination of 6′ as 360°. These four tiltmeters recorded no remarkable change from August 1, 1963 to January 31, 1964. An inclination of 0.4′/day was marked at K-2 (Feb. 1~Mar. 1) and K-3 (Mar. 1~Apr. 1) (Fig. 12-a, b). K-2 shows the inclination as rising eastward and K-3 as falling eastward. This fact shows that the movement takes its direction from north to south, according to the set position of the tilmeters K-2 and K-3.

Besides, it was noticed that rainfall has little influence on the inclination and difference of locality has a deeper effect (see Fig. 13). We can say in general that if the variation of inclination in a sliding area is above 6′/day, it is caused by a slide movement but, all variations measured by these tiltmeters are below 6′/day. In the next chapter, it is explained how this idea can not be applied to this landslide.

6.2. Extensometer

As to the sensitivity of the extensometers, 1 mm on the recording paper

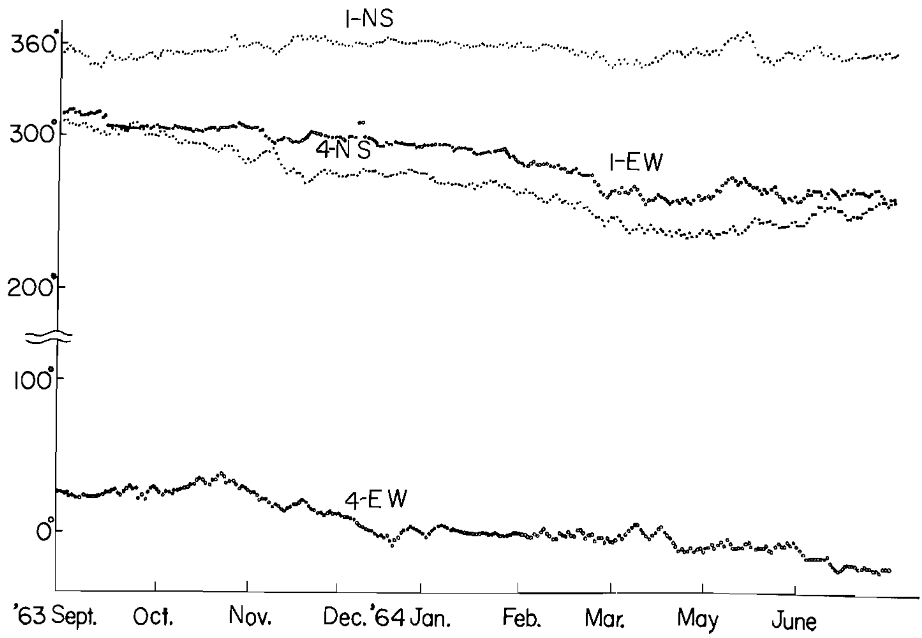

Fig. 12-a.

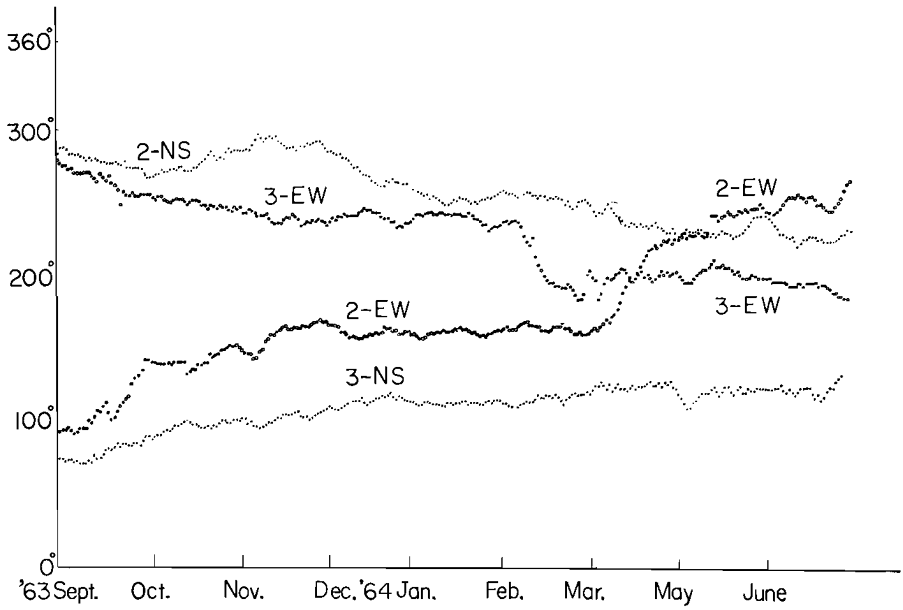

Fig. 12-b.

Fig. 12 (a, b). Variations of the ground-strain.

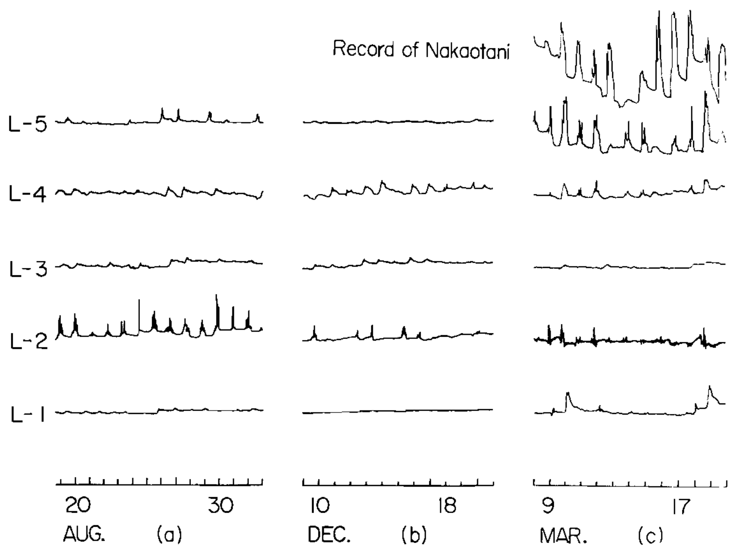

Fig. 13 (a, b, c). Diurnal variations of the ground strain.

is 10^{-5} as a mean value, because the magnification is five and the distance between two points is 20 m.

The observation was begun in August 1, 1963 and has been continued up until the present. Fortunately, as the extensometer recorded the movement of the ground between January 20 and February 29, the mechanism of the movement and the phenomena before the movement could be investigated.

(1) Diurnal variation and movement

According to the records of these five extensometers, their extent of diurnal variation is different from one another. In Augst, 1963, range recorded on the extensometers L-2, 4 are large and those of L-1, 3, 5 are small and in October those of L-1, 5 almost come to zero. When it becomes colder, those of L-2, 4 become remarkably irregular (see Fig. 13 (a, b, c)). Immediately after the sliding movement, the period of L-2, whose amplitude had been the largest of all until that point, becomes short and gradually returns to the period before the movement. L-1 shows rather large diurnal variation, but it also gradually comes to zero. L-4 has little change in both amplitude and period, after the movement. The amplitude of L-5 becomes large suddenly after the movement and this is maintained.

As to the amplitude of diurnal variation, this author assumes that the variation is caused by that of the temperature on the surface of the ground, and applies this theory to these ground strain values observed. In the case of L-5, it is considered that, after the landslide, some changes occurred and consequently effected the sudden change in temperature. At the Nakaotani landslide area, Muraoka-cho, extensometers are set on both sides of the crack and the record obtained shows the same amplitudes as that of L-5 (see Fig. 13-c). According to this fact, the phenomenon of L-5 is attributed to the change in temperature caused by the nearly occurrence of a crack[9].

The investigation of the data of L-3, 2 makes clear that the value of landslide movement is not determined by diurnal variation. If a landslide movement happens as in L-2, 3, however, the variation of amplitude seem to indicate the displacement. The cause of diurnal variation is to be investigated more precisely.

(2) Extensometer and landslide movement

Between January 20 and February 29, a landslide movement occurred. Its records by extensometers are shown in Fig. 11. In this period, there had been much rain, snow and thaw simultaneouly, as shown in Fig. 14, a very rare weather condition. Snow fell to a depth of 2.7 m and melted almost immediately during February and rain fall reached 100 cm. Generally landslides occur at a thaw time, the rainy season (June-July) and the season of tyhoons (October). This landslide movement is one of those usual cases. As it occurred at a thaw time, it was most influenced by thaw, especially running water on the surface of the earth.

In order to show the mechanism of a landslide movement, it is important to know whether it is caused by a pressing movement from above or a pulling one from the below and its neighborhood. As for the Kebioka landslide, the latter obviously occurred first. The values of these displacements increase in order the of L-1, L-3, L-2. L-5 is in the east apart from the main area and generates expansion and contraction within an elastic limit of soil block. L-4 set at Q area provides data for proving the validity of the idea that the landslide area was divided into two soil blocks gained from the result of electric investigation and the assumption on the basis of that idea.

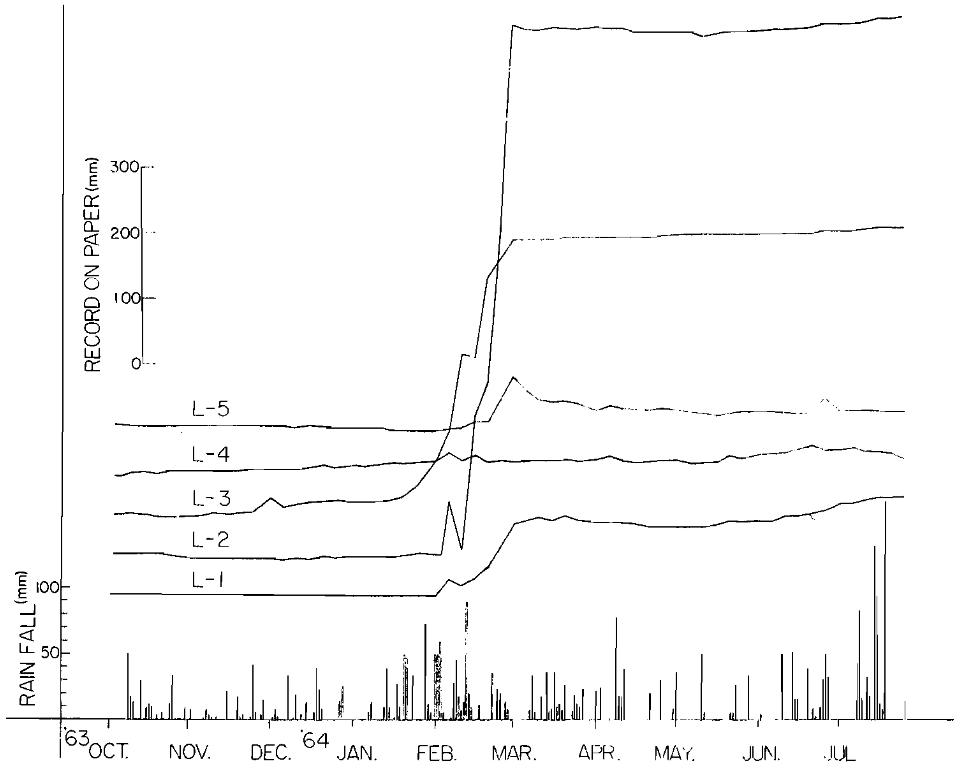

Fig. 14. Ground surface displacements.

Consequently, L-1, 2 and 3 are in the direction of the main area of the landslide and L-1 is in the upper part of it, L-2 in the middle and L-3 in the lower. As for K-1 and K-3 in Fig. 12 (a, b), on the assumption that the soil block swells at the end of the main movement, it can be well explained that K-2 situated in west of the main area falls westward and K-3 in east of it falls eastward. As K-4 was rather distant from the moving soil block and K-1 was in the upper part of it, both of them are considered to have hardly moved from February to March. Comparing the variation K-1 with that of L-1, however, it cannot be concluded that the inclination is small because it belongs to the upper part. It is necessary to study this fact more fully in future.

7. Discussion

The aim of this investigation was to explore the possibility of displacement in this landslide region the outline of which is not known.

In order to know the outline about the range of this landslide and the geological and topographical conditions of this region, an electric resistance survey and geological survey were carried out.

From these results, assumptions were made and according to these assumptions, measuring apparatuses were set up and several kinds of observation were carried out, in order to confirm the assumptions, or the limitations of this kind of electric prospecting. The results of these surveys indicate that the electric resistance survey and the geological survey are effective methods of determing a landslide condition and to determine the prospecting schedules.

The surface displacements of this landslide were observed by tensometer. These displacement values concern expansion and contraction between two points, and not absolute displacement values. At the center of this landslide the tiltmeter recorded about 10^{-2} expansion. The first soil displacement occurred in the lower part of P area, and the next displacement occurred in the middle and upper part of this area. By an internal strainmeter, the depths of the slide surface are defined to be 40 m at boring hole No. 1 and 75 m at boring hole No. 2 respectively. The stage of the internal soil displacement measured by the internal strainmeter will be discussed in another paper.

On the soil displacement of $10^{-2}-10^{-3}$ as mean values, the author investigates the records of diurnal variations by tensometers paying attention to diurnal variations before and after the landslide displacement but the results did not give new information. As the diurnal variations of L-5 greatly increased after displacement, it seems that the diurnal variation shows some phenomena of the variation of a soil condition.

It is reasonable to suppose that the local temperature variation causes the diurnal variation, so it is necessary to investigate the nature of the diurnal variation in order to examine the relation between diurnal variations and landslide phenomena.

The inclination of the soil block in the landslide area is not recorded by tiltmeters and furthermore, all of the tiltmeters did not indicate beforehand phenomena of soil displacement. These facts imply that the tiltmeter is not suitable for getting prior information of landslide phenomena. But this result is obtained from a soil displacement of $10^{-2}-10^{-3}$ as mean values, so a rather small displacements such as this seems to be a pre-movement itself.

Acknowledgement

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