Determination of the Effectiveness of Landslide Preventive Engineering Works Using the Electrical Resistivity Method in the Kushibayashi Landslide Area

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Abstract

We carried out repeated surveys, using the electrical resistivity method, at each stage of a series of landslide preventive engineering works, as one means of making it possible to operate the necessary works in the most effective way when landslide preventive engineering works were required for the specific purpose of draining the underground water contained in the landslide area. Besides, by carefully weighing our surveyed results obtained at each stage of the preventive engineering works, we proceeded to determine the merits and demerits, or effectiveness, of preventive engineering works at each given stage of operation, and we tried to utilize our surveyed results obtained at given stages in deciding whether there is any necessity of making any adjustments or modifications for forthcoming preventive engineering works.

1. Introduction

When any landslide preventive engineering works for any kind of landslide are to be carried out, it gives rise to a problem of great importance and considerable interest for us to make a deliberate study of, and for us to know the effectiveness of such preventive engineering works once completed, because the results of such study can provide us with invaluable information for further preventive engineering works to be carried out in future. As one means of studying this problem we can keep on carrying out specific investigations and surveys uniterruptedly, with the specific purpose of obtaining some basic data with respect to landslide preventive engineering works even after such works have once been completed, and we can determine the effectiveness of particular preventive engineering works once completed on the basis of the results thus obtained. Needless to say, it becomes necessary for the various measuring instruments to be protected from any damage or marked change caused by the preventive works, especially when these instruments might cause obstruction of the operation of the preventive engineering works, and when different varieties of investigations, such as electrical resistivity surveys, horizontal surveys of underground temperature distribution and seismic prospecting are to be carried out, sufficient consideration should be given in all cases to the effect that they could be performed by using the same measuring points as those previously used when particular preventive engineering works were carried out before.

Having the aforementioned view in mind, the present writers had the opportunity of carrying out repeated surveys using the electrical resistivity method for the purpose of obtaining some confirmed data with respect to the landslide and its preventive engineering works in one landslide area called Kushibayashi, situated in the locality of Ogotocho, Otsu City, Shiga Prefecture. Later, surveys of the same kind were carried out in repetition four times in all by us during the period when preventive engineering works were being undertaken and after the works were completed respectively. As a result of these repeated surveys we found that the survey using the electrical resistivity method is an extremely useful method of determining the effectiveness of landslide preventive engineering works primarily designed to drain the underground water. For this reason, we are now going to make a report of the results of our study accomplished in this brief paper.

2. General Description of the Kushibayashi Landslide Area

The description of the 'Kushibayashi landslide area' may be briefly outlined as follows. This area is situated to the north of Otsu City, facing the west shore of Lake Biwa, and on the east side of the so-called stretch of Shiga Hill, which is limited by a straight fault scarp about 70 m in height from Katata to Sakamoto (Fig. 1). This stretch of Shiga Hill is characterised by a partial exposure

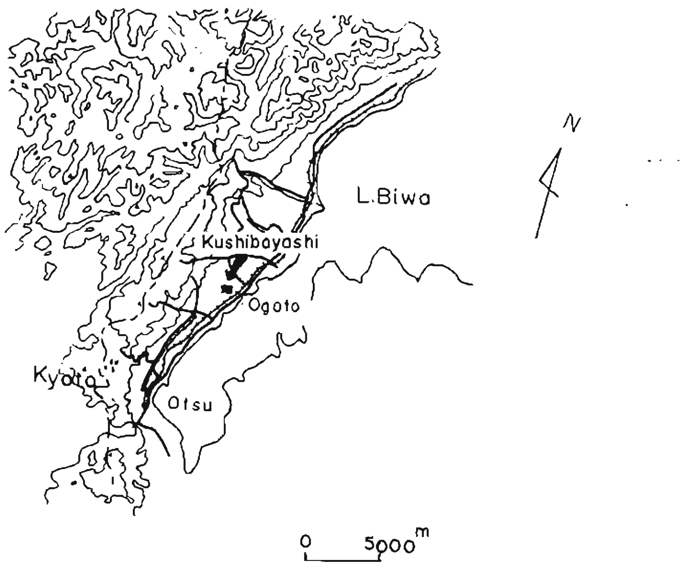

Fig. 1 Index map.

of the original surface of the lacustrine terrace, being still in the process of hill making, and in its vicinity degradational landslides occur here and there. The geology is mostly composed of the Old Biwako Formation, chiefly of silty clay interposed with a stretch of sand layer here and there.

The landslide in this locality occurred on 22nd June, 1967. The state of its breaking out was something quite different from what has been commonly known. In particular, it happened in such a dry season when there was not even a single drop of rain from the middle part of April of that year, which caused the water-level of Lake Biwa to be as low as minus 35 cm from the mean water-level. Even if viewed only from this point of view, it must be said that this particular landslide area awakens great interest. A variety of surveys —— geological and topographical as well as geo-physical —— have been carried out in this landslide area in order to clarify the possible cause of this particular landslide and to establish adequate preventive countermeasures. As a result, we assumed as follows: that the existence of both an unstable vally-bed and a weakened layer was the primary cause, and that the underground water was the contributing cause. The mechanism of this landslide was explicable to the effect that, when the ground in this area was just in such a critical state that a slide movement might be on the point of starting at any time owing to the ground being weakened by the underground water, because another contributing cause of trifling nature happened to give its influence, a sudden movement of the soil mass occurred as an initial phase of this landslide movement: in reality a bulldozer had been in operation in this landslide area immediately before the landslide movement. According to having supplied a considerably large quantity of the underground water and surface water, such as rainfall and drainage, the sliding soil mass had been creeping slowly as the second phase of the landslide movement. Thus we contemplated that the only effective preventive engineering works to check the soil movement taking place in this landslide area were: effective drainage of the underground water and suitable disposal of the drained surface water. The reason was assumed that immediate drainage of the underground water and surface water, such as rainfall and drained water, was the most practical and effective form of preventive engineering works; not only to check the creeping movement, which was regarded as characteristic of the secondary movement of this landslide, but also to prevent the possible break out of another sudden slide movement owing to groun being weakened on account of the underground water being abundant in this particular area.

Based on the results of these investigations, the Shiga Prefectural Government Office has put in hand a number of preventive engineering works, such as the construction of two water-collecting wells, lateral boring from each well to expedite the efficiency of draining the underground water existing in the shallow ground, and the making of drains specifically designed to dispose of the surface water. At present the landslide movement has almost been stopped, and the favorable effect of the preventive engineering works has been distinctly observed.

In carrying out several kinds of preventive engineering works, we recognized that it was very necessary to grasp the condition of the underground water, both before each stage of the preventive engineering works was carried out and during the period of each stage of its progress. Thereupon electrical resistivity surveys were carried out from time to time, and based on each result, effective preventive engineering works were carried out at each stage.

3. Localities of Investigation and Method of Survey

(1) *Localities of investigation*

Localities of investigation, using the method of electrical resistivity to estimate the state of the subsurface at this landslide area and to grasp the condition of the underground water contained therein, are shown in Fig. 2, in which as

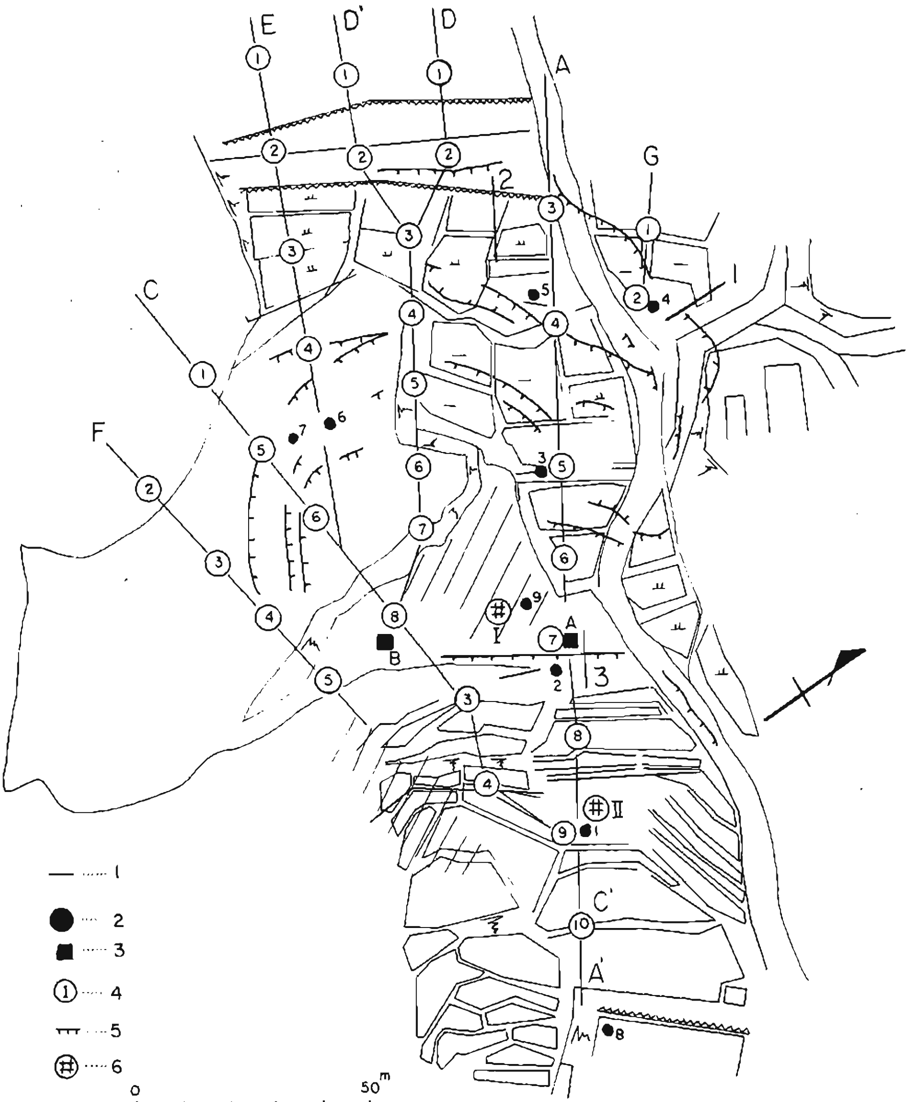

Fig. 2 Stations of measuring apparatus, and measuring points and lines of electrical resistivity survey.
1. Extenso-meter 2. Internal strain meter 3. Tilt-meter
4. Measuring points of electrical resistivity survey
5. Cracks causing landslide 6. Water-collecting-well

many as thirty-three measuring points were selected.

(2) *Method of survey*

The electrical resistivity survey consisted of 3-electrodes with a maximum measuring electrode span of 20 m. The farthest electrode was set approximately

300 m from the northwest boundary of this landslide area. The instrument used for the electrical resistivity survey was a 'Proportional Ground Resistivity Measuring Machine', Type 3244, made by the Yokokawa Electrical Co. Ltd.

(3) *Analysis of the surveyed results*

The results obtained by the above-mentioned measuring method were analysed in the manner described below. As a method of expressing the results obtained by the electrical resistivity method we adopted what we call 'the method of the same electrode span'. Its basic conception runs as follows: all measured values at each measuring point, apprent resistivity values, taking the electrode span ($=a$m) to be constant, were plotted on one sheet of a map on which all measuring points were indicated. The distribution-chart of the apparent resistivity values, which was obtainable by drawing the lines of the same apparent resistivity values, was basically conceived to express the approximate distribution of the apparent resistivity values at a certain depth in proportion to the electrode span concerned. In other words, this method is adopted to make a study and to have knowledge, by changing a certain electrode span, of the corresponding change taking place in the way of the distribution of the apparent resistivity values at a certain depth in proportion to the given change in electrode span.

The low apparent resistivity part of the landslide area was got by a survey including the soil mass having a high water content, and it can safely be determined that such a part must be rich in underground water, or that the mass of soil there must have been well advanced in turning to be of clayey soil. Hereupon, viewed from this point of view, we shall proceed to interpret the results of each electrical resistivity survey carried out in this landslide area.

4. Results of the Surveys

(1) *Results of the first survey*

The first survey was carried out on 13th, July, 1967, i.e. on the twenty-first day after this landslide had occurred. The first aim of this survey was to assume the underground structure of this landslide area and also to know the location of existing underground water. The obtained results were to be utilised to provide practical and useful information for landslide preventive engineering works to be carried out in the future.

Figs. 3, 4, 5, 6 and 7 show our surveyed results as expressed by the above-mentioned method of the same electrode spans. From these we can see that the apparent resistivity valnes of this landslide area were 1.7 kΩ-cm - 15.4 kΩ-cm. When the contour lines of the same apparent resistivity values were plotted, we could see that the range of the apparent resistivity values of 3 kΩ-cm or lower were in almost the same vicinity where the mass movement had mainly occurred in this landslide area. It was also found that those localities that showed low apparent resistivity values were found to exist in a limited zone, regardless of the distance between the electrode spans. When the extent of the zones of the apparent resistivity values which was obtained from the distribution-chart of each of apparent resistivity values, such as $a=2$, 5, 10, 15 and 20 m, was plotted on one sheet of a map to make an easier understanding possible, we

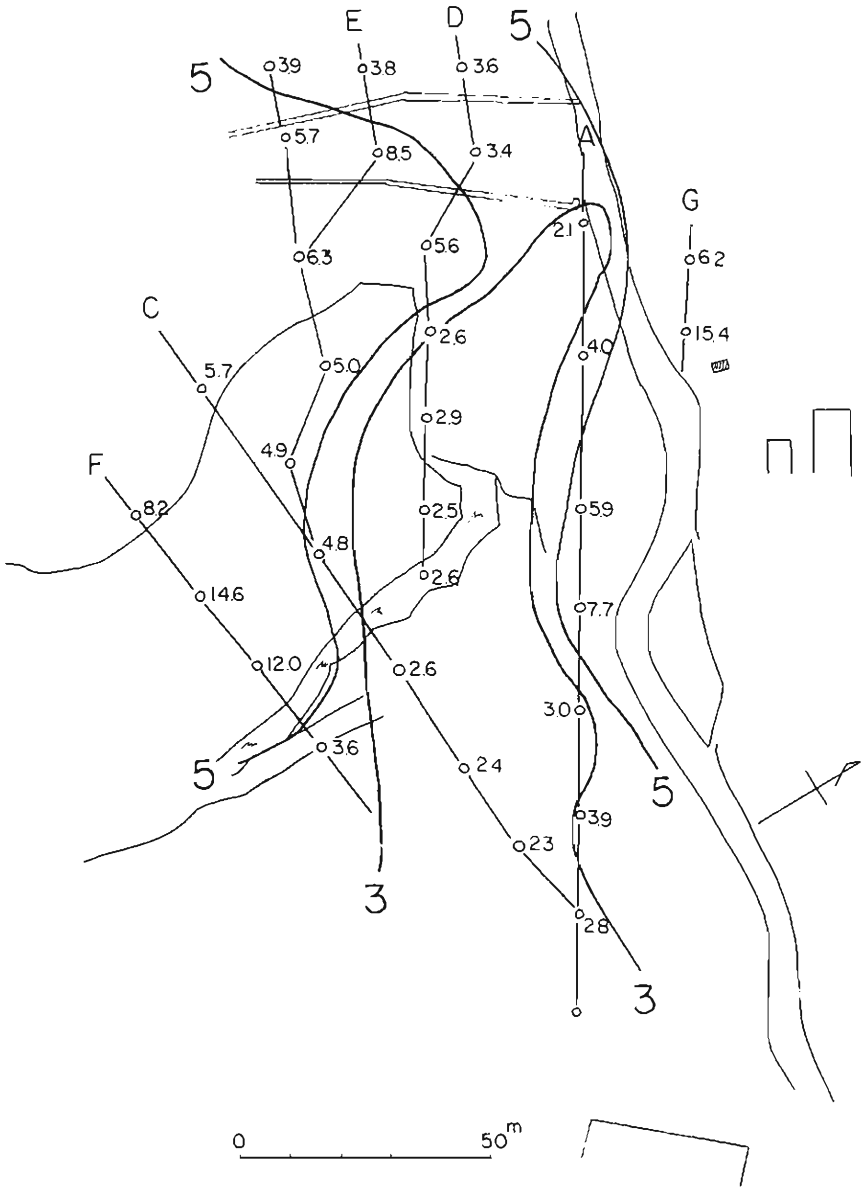

Fig. 3 Horizontal distribution of apparent resistivity values (a=2m) (unit of numbers=kΩ-cm).

obtained Fig. 8, which shows that there evidently existed two zones of low apparent resistivity values in this landslide area. In other words, it was assumable, based on the above-mentioned interpretation, that these two zones showing low apparent resistivity values were the places where the influence of underground water was exerted to the greatest extent.

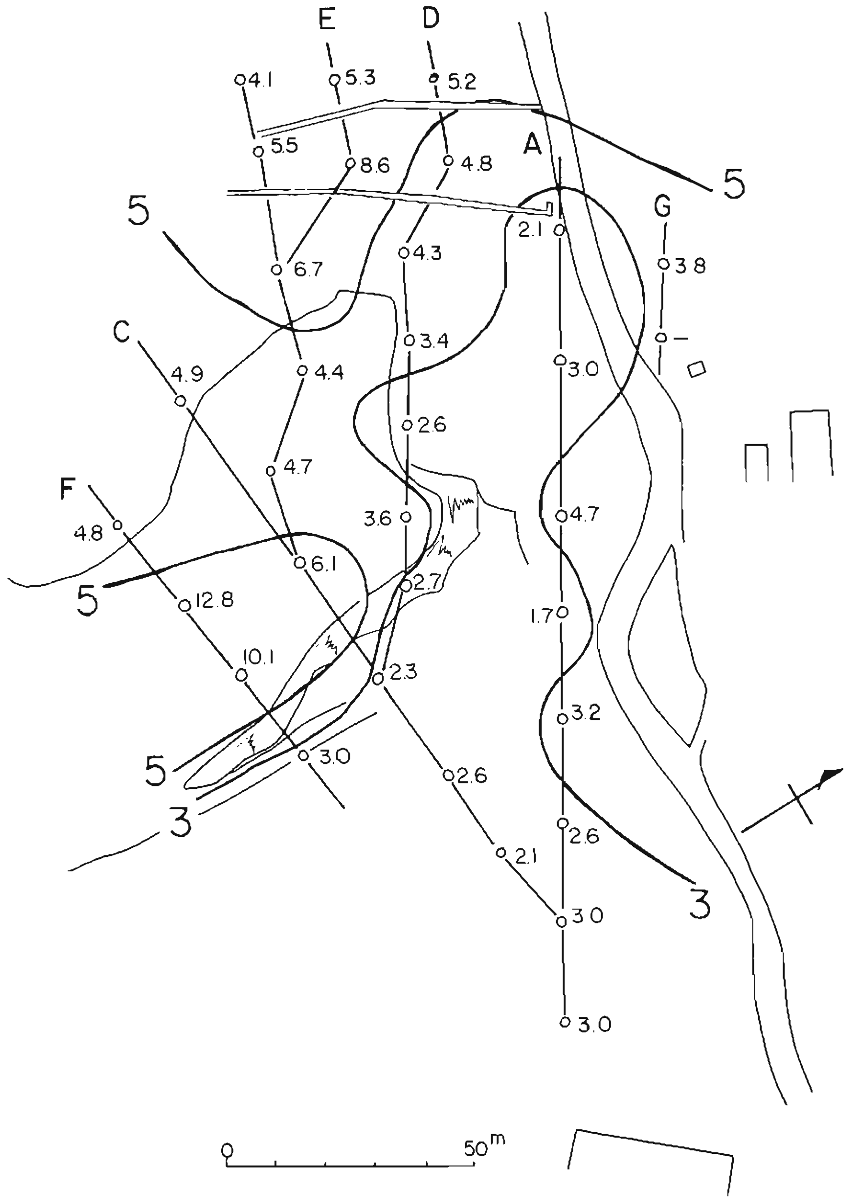

Fig. 4 Horizontal distribution of apparent resistivity values (a=5m) (unit of numbers=kΩ-cm).

After putting all results of various surveys together with respect to the distribution of the low apparent resistivity values, the horizontal distribution of underground temperature and the investigation of the underground water, it was deduced that the construction of a water-collecting well (No. 1) at the location indicated on Fig. 2 might be the most effective countermeasure.

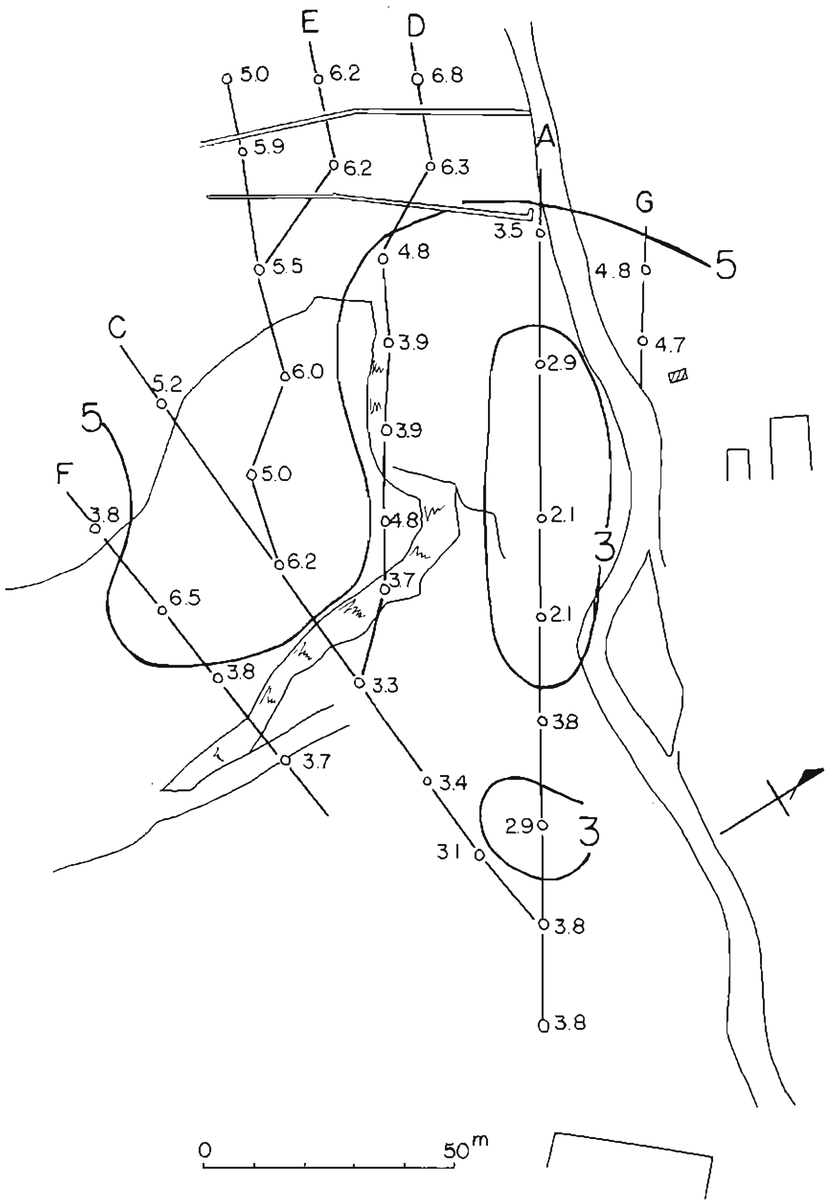

Fig. 5 Horizontal distribution of apparent resistivity values (a=10m) (unit of numbers=kΩ-cm).

(2) *Results of the second survey*

The second survey using the electrical resistivity method was carried out on 13th, June, 1968, i. e. one year after the construction of the said water-collecting well. The aim of this second survey was to find out the effectiveness of operation of the drainage of the underground water by this well. Needless to

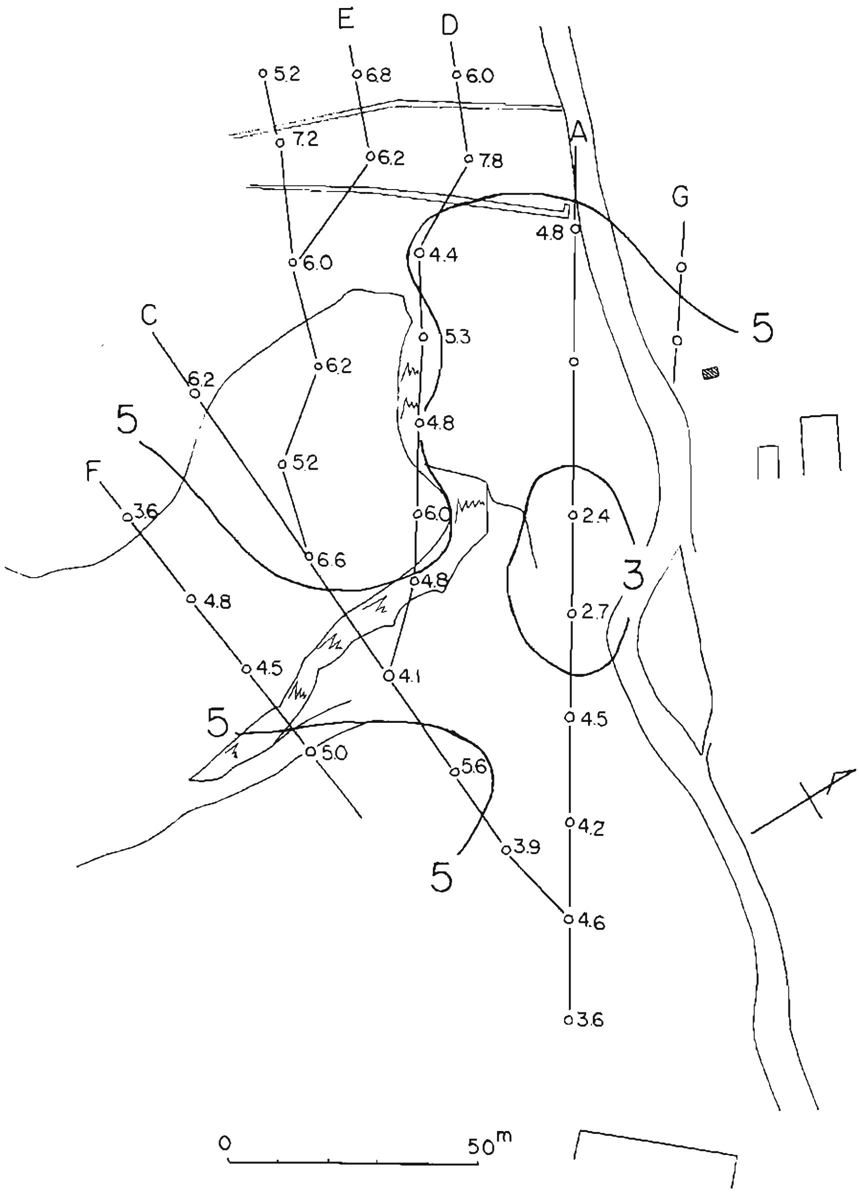

Fig. 6 Horizontal distribution of apparent resistivity values (a=15m) (unit of numbers=kΩ-cm).

say, all measuring points, electrode spans and instruments were exactly the same as those in the case of the first survey.

By expressing the surveyed results obtained by the method of the same electrode span, and by arranging the zones of the low apparent resistivity values which were obtained at each electrode span on one sheet of a map, we obtained

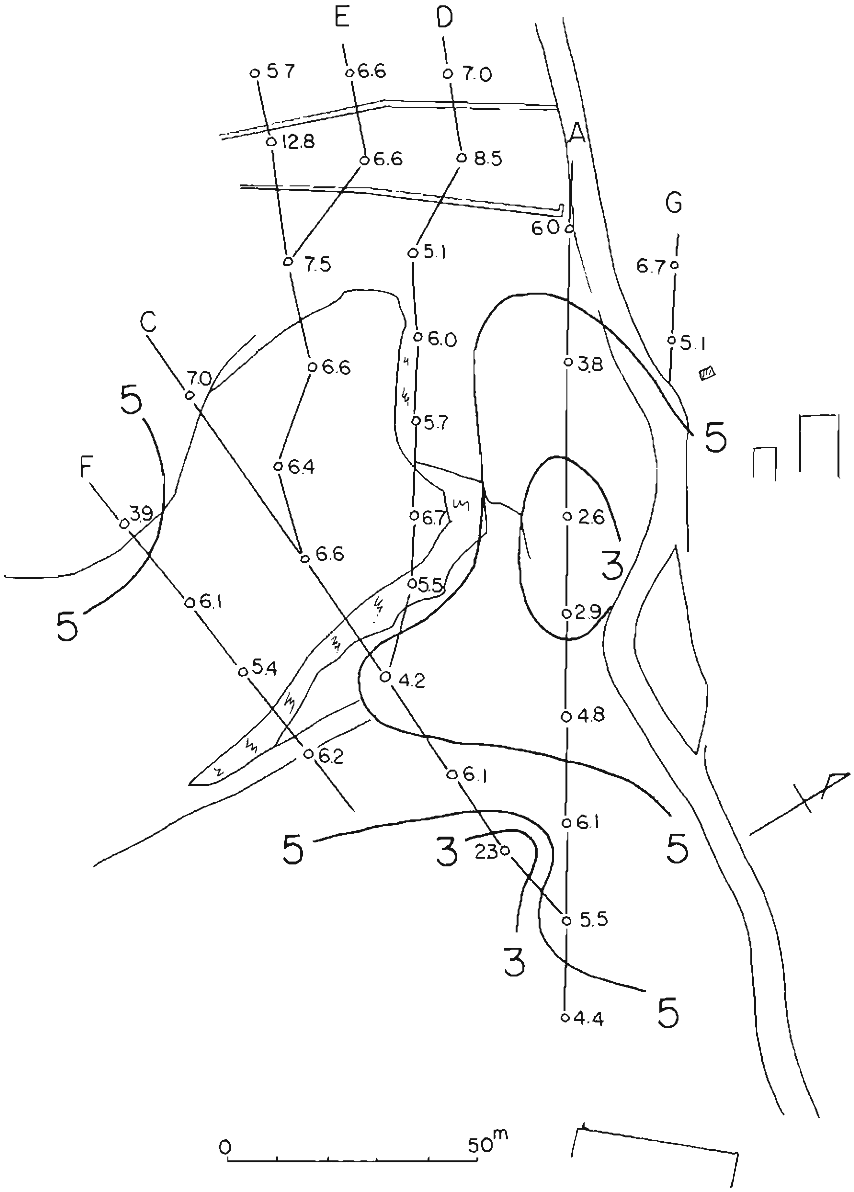

Fig. 7 Horizontal distribution of apparent resistivity values (a=20m) (unit of numbers=kΩ-cm).

Fig. 9. From this, we can see that in almost all cases the zones of the low apparent resistivity values in the case of electrode spans from 2 to 20 m were distributed in one locality. In addition, when we compared the results of the first survey with those of the second survey, the zone of the low apparent resistivity values in the upper part of this landslide area (in the northwest

Fig. 8 Horizontal distribution of low apparent resistivity values of 3kΩ-cm or lower (a=2, 5, 10, 15, 20m) on 13th July 1967.

direction) was no longer found; but conversely it was found to have extended to the southwest direction, and moreover the low apparent resistivity values were found to a great extent even in the case of electrode spans of 10 m or less. In other words, it led us to the conclusion that the state of the underground water, after the water-collecting well had been constructed, was that the underground water in this landslide area had become richer and penetrated downward deeper, with the exception of the upper part of the landslide area, compared with the corresponding underground water state in those days when the first survey had been carried out. These facts were, indeed, quite contrary to our initially expected results. Because of the reason stated

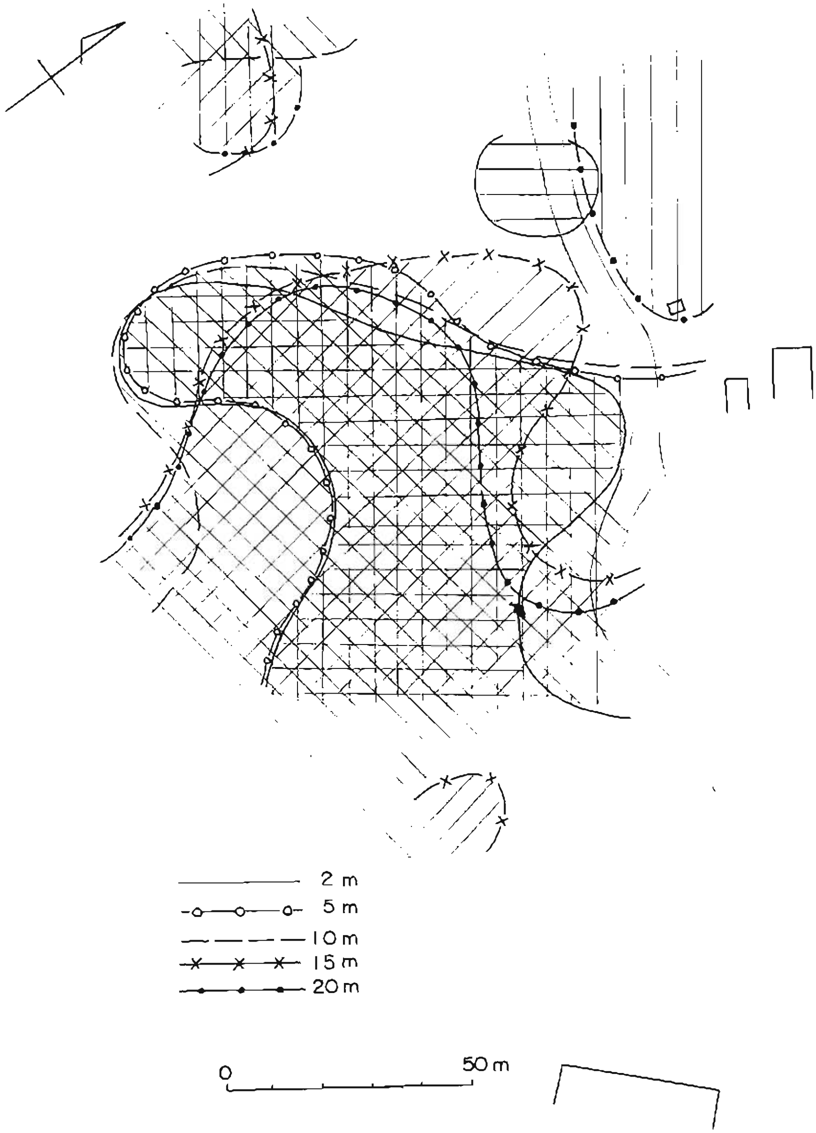

Fig. 9 Horizontal distribution of low apparent resistivity values of 2kΩ-cm or lower (a=2, 5, 10, 15, 20m) on 13th June 1968.

later in Section V of this paper, we made our recommendation to the Prefectural authorities, advising them to make lateral borings at this water-collecting well as far as to reach the landslide area as expeditiously as possible.

(3) *Results of the thrid survey*

The third survey using the electrical resistivity method was carried out on

20th, October, 1968, i. e. after a lapse of one month after a lateral boring for pumping was made at the well. The borings in the well were made at each depth of 5 m and 10 m, these boring lengths being 30 m and 50 m respectively. The survey at this time was carried out with the aime of seeing the effectiveness of draining the underground water by means of lateral boring at this water-collecting well. Measuring points, electrode spans and utilized instruments were the same as before.

By expressing the surveyed results obtained by the method of the same electrode span, and by arranging the zones of the low apparent resistivity values which were obtained at each electrode span on one sheet of a map, we obtained Fig. 10. From this we can see that the zones of the low apparent resistivity values in the case of electrode spans of 15 m or less no longer existed, with the exception of a very small part, and that even in the case of a short electrode span the way the results of the first and second surveys were distributed were found to be quite different. If we compared the results of the second survey with the third survey, the zone of the low apparent resistivity values at a deep layer ($a=15$ m or more) was no longer observable, and the above fact shows that lateral boring at the water-collecting well did indeed serve the purpose effectively for slope stability. On the other hand, however, it was observed that the underground water extensively distributed in a shallow layer, were quite unable to be drained yet.

Under such circumstances, it was decided to construct another water-collecting well (No. 2) at the location indicated on Fig. 2, in order to accomplish perfect drainage of the remaining underground water in this landslide area that was still contained in the shallow part, and to achieve slope stability.

(4) *Results of the fourth survey*

The fourth survey using the electrical resistivity method was carried out on 24th, April, 1969. Our specific two-fold aims of the survey were to examine the state of the underground water in the hilly area which had previously been cut before the occurrence of the landslide, and to make a study of the effectiveness of draining the underground water by means of the above-mentioned water-collecting well No. 2. By expressing the surveyed results obtained by the method of the same electrode span, by arranging the zones of the low apparent resistivity values which were obtained at each electrode span on one sheet of a map, we obtained Fig. 11. From this we can see that such a zone that showed low apparent resistivity values was found as a whole to have been changed to a lower part of the landslide area, and it was also found that the low apparent resistivity zones existed to a greater extent around the well in the same manner as observed at the time of the second survey, and moreover that they spread downward to a deeper layer than before. It was assumable that the cause could be the same results of the second survey as discussed later. In this way it was decided to carry out lateral borings at the well in order to reach such a zone in the same way as in the case of the second survey.

5. Discussion

Though we have got much knowledge about the landslide mechanism and

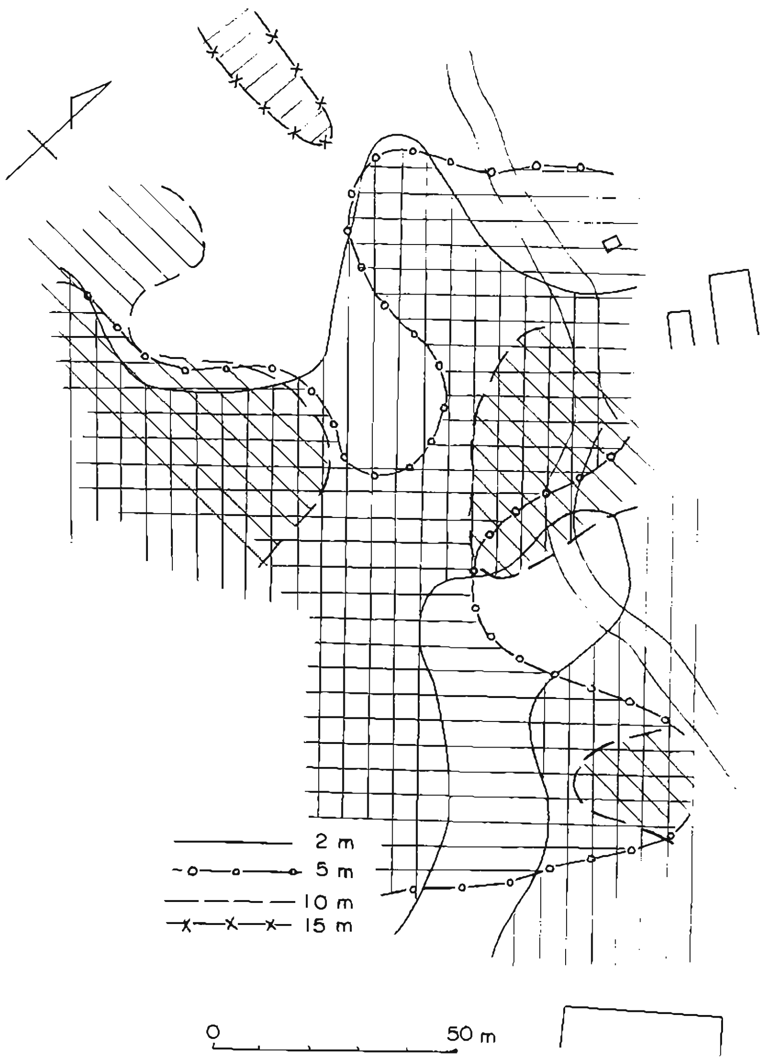

Fig. 10 Horizontal distribution of low apparent resistivity values of 3kΩ-cm or lower (a=2, 5, 10, 15, 20m) on 20th Oct. 1968.

underground water vein condition, we now think that we have to present a short discussion about the results of these surveys.

As a result of the construction of water-collecting well No. 1 based on the results of the first survey, we could drain the underground water in such a great quantity that water kept overflowing from the well. And so our first aim was tentatively achieved. However, the underground water collected at this well was simply left to overflow naturally, and no effort was ever made to pump out the excessive collected water artificially, so that it could be led to and disposed of by a ditch or drain. For this reason, there was the fear that the

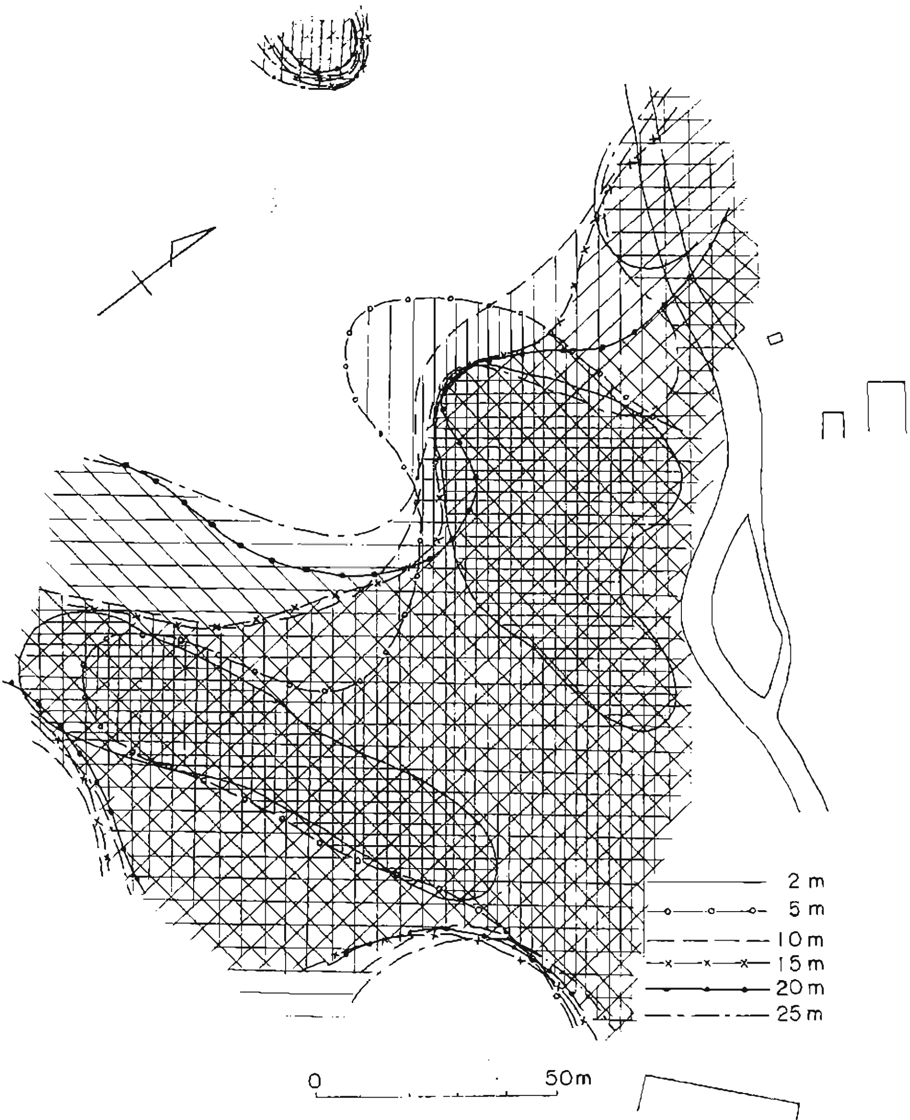

Fig. 11 Horizontal distribution of low apparent resistivity values of 3kΩ-cm or lower (a=2, 5, 10, 15, 20m) on 24th Apr. 1969.

collected underground water might again penetrate into the sliding mass, and that it might have the worst influence on the landslide phenomena. Under such circumstances, the second survey using the electrical resistivity method was carried out. The results of this survey are shown in Fig. 9, in comparison with the results of the first survey with the second survey (Fig. 8). It was found that the zone of the low apparent resistivity values, i. e. 3 kΩ-cm or lower, have spread to the whole landslide area, and that the aforementioned anxiety came to be plain by means of the second survey using the electrical resistivity method. In other words, there was nothing wrong in collecting the underground water by constructing the well in the landslide area, but because of a careless delay in making adequate preventive engineering works, most of the water once collected on purpose with all our efforts, was allowed to go back again to the landslide area. According to the above, it was assumed that the underground water which used to be held in a great quantity rather at the shallow part of the landslide area before the well was drained and then collected at the well, and subsequently that it was forced to penetrated further down into the deeper part, the water causing the solidity of the deeper mass of soil to weaken. Because of a fear that such circumstances might, contrary to our expectation, result in collecting the underground water only to activate the landslide movement again, it was immediately decided to install a motor-pump in the water-collectind well, in order to drain out the underground water more quckly. Furthermore, after the water in the well was completely drained out another lateral boring was made for the purpose of pumping out such underground water that had been conversely supplied to the soil mass in landslide area. Such underground water that had been collected was being drained afterwards, without allowing it to go back to the landslide area again, by means of a lateral boring specifically designed at the bottom part of this well. It was at the time when these preventive engineering works were completed that the third survey was carried out. When the results of this survey were compared with those of our foregoing survey in the same manner as we did before, it was found, as far as the underground water held in the deeper layer was concerned, that the zone of the low apparent resistivity values had not been shown to exist, and that it made possible for us to interpret that the effectiveness of the preventive engineering works based on the results of the second survey was excellent in every respect. Nevertheless, it was further found that the zones of the low apparent resistivity values were still in existence, in the same conditions as ever, both in the terminating and uppermost part of the landslide area. This carried the implication that it was impossible to carry out perfect drainage of the underground water held in the upper or shallow part only by means of the water-collecting well.

On the other hand, according to the results of the first survey, we observed that there existed two zone of low apparent resistivity values (Fig. 8). In one of them water-collecting well No. 1 was constructed, and it resulted in success in draining a great quantity of underground water, but in the other nothing particular was planned or done. Although this unattended zone of low apparent resistivity values could not be plainly detected as a zone of low apparent resistivity values as far as the result of the third survey was concerned, owing to the effects of well No. 2, it was quite assumed that there must still have existed a tolerable quantity of underground water in this neighborhood. This thought led us to decide and construct another No. 2 well, having the purpose accomplishing perfect drainage of the underground water contained in this landslide area. Just one month after the construction of the No. 2 well, the fourth survey using the electrical resistivity method was carried out. The results changed and were different from those obtained by the second survey, as pointed out before. As shown in Fig. 11, it was seen, for one thing, that the zone of the low apparent resistivity values had changed towards the lower part of the landslide area to a greater extent than it existed as shown in the results of the previous survey; and for an other, that there existed two separate zones, namely the one stretching from the hilly area towards well No. 2, and the other spreading existensively throughout the lower part of the landslide area. It was assumed that the reasons for these facts were, as in the case when well No. 1 was constructed, because the underground water was forced to be collected in an excessive quantity in and around this water-collecting well No. 2; also assumable was that the underground water once collected was conversely being moved back again to the landslide area, as was the case with our previous circumstances. This expedited the decrease in solidity of the sliding mass, and this indication came to be detected in the observed results by means of internal strain meters, which had been set in the terminating part of this landslide area. Because it could be presupposed that, if left to the natural course of development, it would be quite possible that the sliding mass would start moving, two lateral borings were made within this well on different levels (upper and lower) for the intake purpose, and at the same time another type of lateral boring was designed and made almost at the bottom of this well, so that the water once collected could be disposed of by naturally flowing-out. As a result, it became possible for all the water once collected here to be disposed of without delay to the drain leading the water to a place other than the landslide area.

In this way two sets of water-collecting wells were designed and constructed, based on our repeated surveys using the electrical resistivity method within this landslide area, and the underground water that used to be held in this landslide area came to be nearly all drained away. Neverthless, speaking of the particular underground water contained in the shallow layers, it was still impossible to make its draingage perfect, leaving a certain problem still to discussed and solved.

6. Conclusion

Taking one landslide area called 'Kushibayashi' as an example, we carried out repeated surveys using the electrical resistivity method at every stage of a series of landslide preventive engineering works, as one means of making it possible to operate the necessary works in the most effective way when landslide preventive engineering works are required for the specific purpose of draining the underground water contained in such landslide areas. Besides, by carefully weighing our surveyed results obtained at each stage of the preventive engineering works, we proceeded to determine the merits and demerits, or effectiveness, of the preventive engineering works at each given stage of operation, and we have tried to utilize our surveyed results obtained at each given stage in deciding whether there is the necessity of making any adjustment or modification for forthcoming preventive engineering works.

As a result of all these efforts, it has been learned that repeated surveys using the electrical resistivity method carried out at each stage of the operation of preventive engineering works were extremely useful. We have gathered the following knowledge by carrying out the electrical resistivity surveys at each stage of the preventive engineering works: 1) we could know exactly the effectiveness of the works at each stage. 2) We could obtain confirmed information about how we must modify and adjust the works for carring out more effective works before shifting to the next stage of the works.

Whenever any landslide preventive engineering works are to be carried out with the specific aim of draining the underground water, we think, as our conclusion, that it would in no event be futile to make it a point to carry out a series of electrical resistivity surveys at each stage of the preventive engineering works, because these repeated surveys would not merely help to carry out landslide preventive engineering works in a more and more effective manner, but also serve the purpose of carrying out such planned works in the most effective and economical way, which otherwise always require an enormous amount of expenditure.

Acknowledgements

In carrying out frequent surveys in the Kushibayashi landslide area as a model case for this brief paper, we wish to make mention of Mr. Otsuji, Chief of the Cultivation Section of the Shiga Prefectural Government Office, and several other officers working in that office, to express our thanks for the great cooperation and assistance which they gave us. We are also indebted to the official engineer, Mr. Toshifumi Konishi, who provided us with data obtained from the electrical resistivity surveys.