Analysis of Landslide Movement by Means of Repeated Levelling

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1. Introduction

Needless to say, landslide movement is normally identified by morphological characteristics and measured by self-recording instruments set in the landslide region. As the setting of the instrument is numerically limited, the records do not always show the movement of the whole landslide region. In order to analyse the movement of a landslide region, a test field has been set up at Nagoo, situated along the middle course of the River Tenryu in Central Japan, and leveling and geomorphological and geological investigations have been conducted.

The Nagoo landslide has been in motion since 1960 and vertical movements have been more pronounced than horizontal ones. To prevent landslide disasters, self-recording instruments have been set up by the prefectural government at three different places in the region concerned. From the analysis of the records and geological surveys, several characteristics of Nagoo landslide have been made clear, as follows:

1) The Nagoo landslide is in the Crystalline rocks.
2) The history of the landslide movements is unknown.
3) Recent movement began in the winter of 1960 in the dry season.
4) Relationship between rainfall and movement is not so clear.
5) Vertical movement is more dominant than the horizontal one.
6) Beneath this landslide region a mine is being operated.

In order to investigate the vertical movement, leveling was carried out during following periods : July 19th. to 27th., September 26th. to 30th. and December 20th. to 23rd. in 1965. The results of these three levellings are reported in this paper and another survey is going to be conducted in the near future. For levelling, 31 bench-marks are set up in and around the landslide area and one of them outside of landslide region is used as a control bench-mark.

2. Outline of Geomorphology and Geology of the Area Surveyed

The reservior behind Akiba Dam, constructed on the middle reaches of the River Tenryu, forms Lake Akiba. The hamlet of Nagoo is situated on the eastern side of this lake, on a gentle slope 250 to 350 metres above the surface of the lake. This gentle slope is surrounded by steeper slopes and, taking the geology into account, is considered to have been formed by a past landslide. Along the middle course of the River Tenryu, there are many gentle slopes of such a type considered to be formed by a similar process.

Rocks of the area are Crystalline schists, and at Nagoo Black schist which has a monoclinal structure with a strike almost due north and a dip to the west. The geology of the landslide area was investigated in detail by seismic prospection, and four strata each of which had different propagation velocities were classified. The lower most stratum (4.0 - 5.0 km/sec) is solid rock (Black schist), and the third stratum (3.0 - 3.5 km/sec) is slightly weathered rock. These two strata compose the basal rock which is distinguished from the upper and looser strata. The height above the sea-level of the upper surface of the third stratum is shown in figure 2 by contour lines. These contour lines show that there are two buried ridges and there is a shallow valley between them.

Upon the vasal rock lies the second stratum (1.5 - 1.8 km/sec) which is considered to be a sediment such as talus, for it is too thick to be a weathered zone of the basal rock which has never been removed. The uppermost stratum (0.1 - 0.6 km/sec) is surface soil or weathered sediment. The thickness of the first and second strata is shown in figure 2 by isopach lines. According to the buried topography of the upper surface of the basal rock and the thickness of the upper loose strata mentioned above, the landslide area can be devided into four geomorphologically and geologically different units: A, B, C and D zones from north to south.

A-zone covers that slope of the upper surface of the basal rock which faces the Kambagi-zawa, a tributary of the River Tenryu. The upper two strata are thick at the southern part of this zone (unknown at the northern part) amounting to 50 - 60 metres.

B-zone coincides with the buried ridge and the thickness of the upper strata in this zone is 30 - 50 metres which is smaller than in A or C-zone.

C-zone coincides almost with a shallow valley. The thickness of the upper strata amounts to 40 - 60 metres.

D-zone covers a wide and vague ridge. The thickness of the upper strata is 10 - 40 metres and is the thinnest among the four zones.

The topography of the land surface does not always coincide with the above mentioned zoning, for small valleys develop with no relation to the topography of the upper surface of the basal rock.

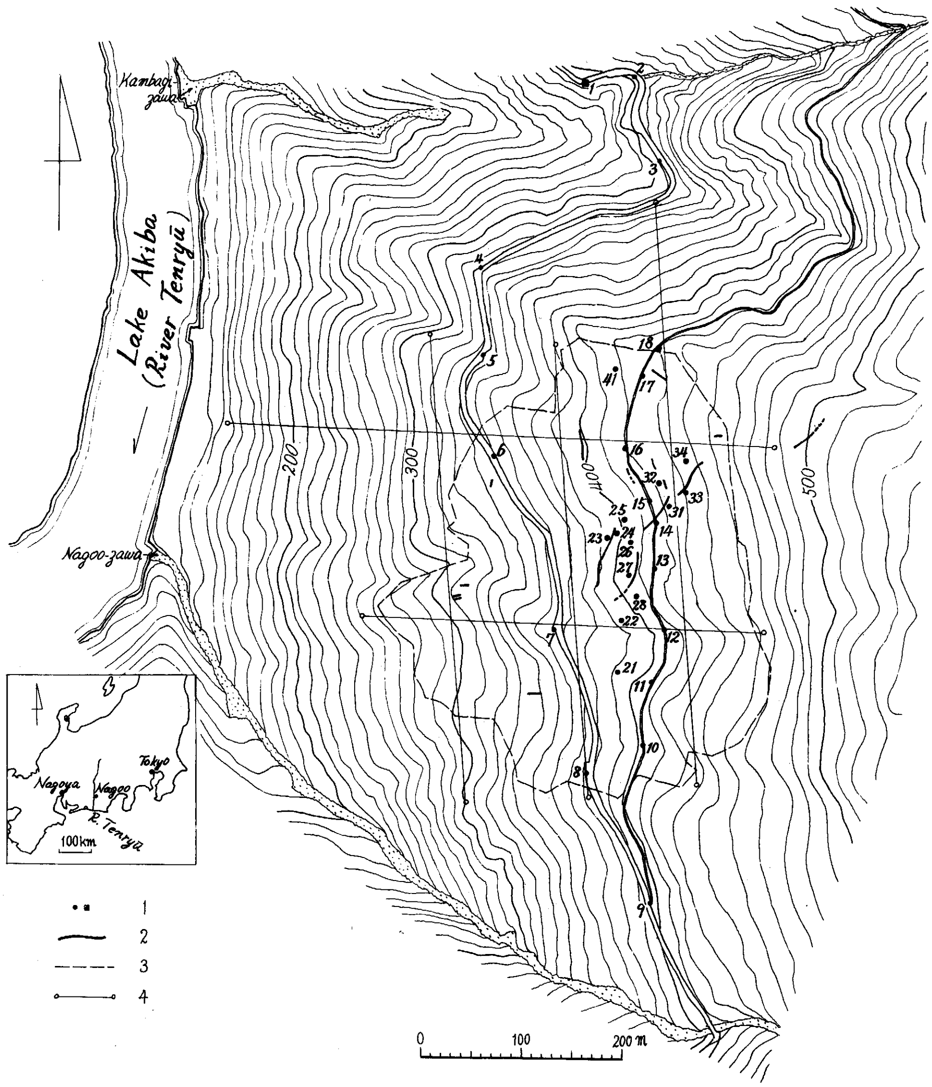


Fig. 1 Topographic map of Nagoo
1: bench-mark 2: crack 3: boundary of the landslide area fixed by the prefectural government 4: survey line of seismic prospection

3. Cracks in the Ground

The landslide area fixed by the authorities is shown in figure 1. A few cracks appeared at first in the southwestern part of this area in 1960. In October, 1962, large cracks made their appearance in the central and northeastern part of this area. These large cracks stretch in the direction NE–SW and set themselves in echelon. The northwestern side of these cracks fell 90 cm. or so against the opposite side and the depth of the cracks reached 5 metres or more.

Since 1963, no such large cracks as those which appeared in 1962 reoccured, but small cracks made their appearance mainly in the northwestern part of the landslide area. Several cracks are found in stone wall along the main road, but it is unknown when they appeared.

Looking the distribution of cracks in each zone, they appeared first in D-zone, large ones are concentrated in C-zone, and in A and B-zone only small cracks are found.

4. Leveling

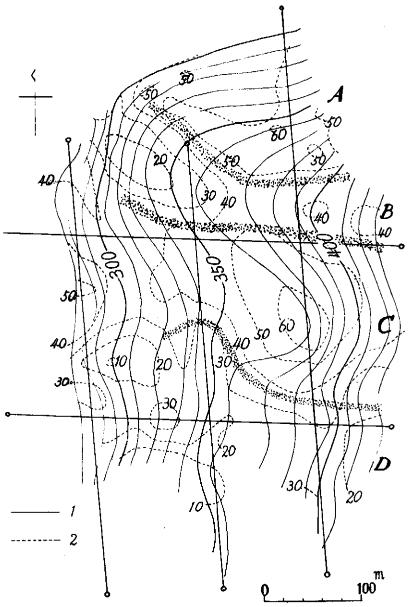
As shown in figure 1, the main route of leveling (with 18 bench-marks) was selected along the road and in addition a few sub-routes (with 13 bench-marks) were selected. One end of the main route started from the bench-mark set on basal rock exposed to the north of the Kambagi-zawa. This first bench mark was considered an immovable point, and the displacements of other bench-marks were measured with reference to it.

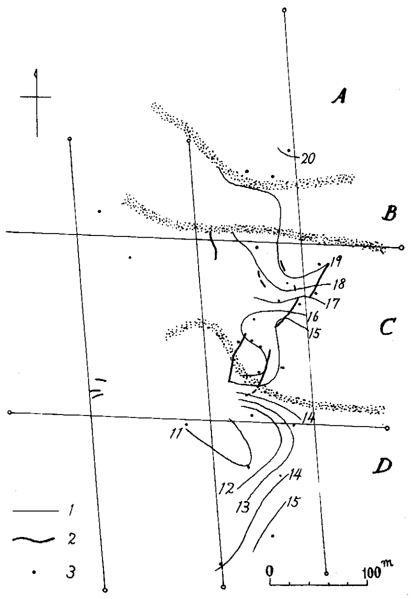
Leveling was conducted three times at different periods mentioned above. The results are shown in table 1. Accuracy in leveling is important to conclude whether displacement occured or not. During each leveling the main route was surveyed twice, i.e. in both directions, and two values were got as the vertical distance between any two bench-marks. The differences in the two values of the vertical distance between the 18th bench-mark and the first were 9.6 cm. in July, 0.6 cm. in September and 0.5 cm. in December. The maximum difference in the two values of the vertical distance between neighboring bench-marks along the main route were 3.6 cm. in July, 1.4 cm. in September and 1.3 cm. in December. In a toral of 51 sections (17 sections x 3 times), the differences were less than 1.7 cm. in 50 sections and less than 1.0 cm. in 45 sections. The mathematical mean of the two values of vertical distance between neighboring bench-marks was taken as that between them, and the vertical distance between any bench-mark and the reference point was the cumula-

Table 1. Displacements of bench-marks with reference to the first bench-mark

Number of bench-mark	Displacement (cm)		Number of bench-mark	Displacement (cm)	
	July - Sept.	Sept. - Dec.		July - Sept.	Sept. - Dec.
1	0.0	0.0	17	-19.3	-1.2
2	-0.4	-0.4	18	-20.3	-1.6
3	-0.7	-0.6	21	-11.0	+0.4
4	-3.9	-2.7	22	-11.2	-0.1
5	-5.3	-3.0	23	-16.5	-1.6
6	-12.4	-3.1	24	-15.7	-0.6
7	-10.9	-2.0	25	-15.7	-1.2
8	-13.7	-1.5	26	-15.9	-0.2
9	-14.0	+0.5	27	-16.2	-0.6
10	-15.8	+0.1	28	-14.4	-0.2
11	-13.7	0.0	31	-16.4	+0.5
12	-13.2	0.0	32	-18.8	-0.8
13	-14.8	+11.6*	33	-17.2	+0.8
14	-14.6	-0.5	34	-19.2	-0.8
15	-17.1	-1.8	41	-19.6	-0.2
16	-18.3	-1.6			

* This bench-mark was reset before December's leveling.





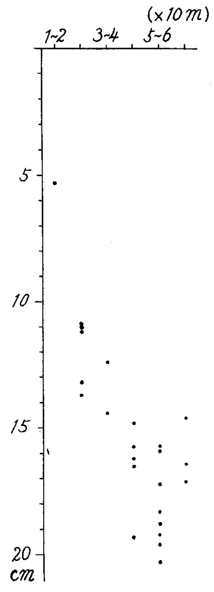


Fig. 2 Topography of the upper surface of the basal rock and the thickness of the upper and loose strata 1: upper surface of the basal rock (in metres above sea-level) 2: thickness of the upper and loose strata (metre)

Fig. 3 The amount of subsidence during July's and September's leveling 1: amount of subsidence (cm) 2: crack 3: bench-mark

Fig. 4 Relation between the amount of subsidence (ordinate) and the thickness of the upper and loose strata (abscissa) tive sum of these vertical distances along the traverse (with due regard to sign). Probable error in the vertical distance between the first and the 18th bench-mark was calculated using those of each section. Results were as follows: 1.5 cm. in July, 0.9 cm. in September and 0.8 cm. in December.

It is shown in table 1 that between July's and September's leveling some subsidence of the ground was observed, but no movement was observed between September and December. The amounts of subsidence during the former period are shown in figure 3 by iso-subsidence lines. According to table 1 and figure 3 the characteristics of the displacement of the ground during the former period can be summarized as follows:

1) Between the 5th and the 6th bench-marks the amount of subsidence increases abruptly.
2) All bench-marks higher than the 5th subsided and the higher they are, the greater the subsidence.
3) The four zones, stated previously, show characteristic iso-subsidence lines, and the amount of subsidence is related to the thickness of the upper two strata at the point ($r = 0.77$, cf. figure 4).

A-zone: The amount of subsidence is 20 cm. or thereabouts, the largest in the landslide area, and iso-subsidence lines show that the ground inclined towards the north or northeast. The reason why there is not a large crack in this zone is explained by the uniformity of the subsidence.

B-zone: There is no bench-mark in this zone.

C-zone: The amount of subsidence is 15 - 19 cm., the largest after A-zone, and varies at every bench-marks. The fact that there are many cracks and especially large cracks concentrate in this zone is explained by the thickness of upper loose strata and unequal subsidence which causes the distortion of the earth. The direction of the cracks does not, however, always coincide with the iso-subsidence lines, and so the movement of the earth when cracks made their appearance is not quite the same as that during Jury's and September's leveling. The direction of the movement of the landslide deduced from iso-subsidence lines or from cracks is north or northwest in this zone, and it differs from that in A-zone. This is supposed to indicate that the moving masses in C-zone and that in A-zone are independent.

D-zone: The amount of subsidence is 11 - 15 cm. the smallest among the four zones, and is small in northern and large in southern part. This indicates the ground inclined towards the southeast.

5. Records of Self-recording landslide-meters*

Three landslide-meters have been set in Nagoo landslide area since May, 1964. The movement recorded by these meters have no relation to one another. The relation between the movement and rain-fall for a few days before the movement was examined and it was found that the second and the third meters had recorded a movement after a heavy rain, but its magnitude had no relation to rain-fall, and also many movements which did not follow a period of rain were recorded.

The heaviest rain since the meters were set up was on the 17th. and the 18th. of September, 1965, and 442 mm's rain-fall was recorded at the neighboring hamlet of Nagoo. During and after this rain, the second meter recorded a total of 7.4 mm's movement, the largest recorded by this meter, but the first and the third meters recorded only about 1 mm's movement which was not large among those recorded by these meters. How the data recorded by three meters express the real movement of the landslide must be examined further.

6. The Proximate Cause of the Landslide

The hamlet of Nagoo is situated, as previously stated, on a gentle slope formed by the past landslide. This gentle slope is surrounded by steeper slopes facing valleys and also it is the upper surface of loose and weathered sediments of talus type which rest on basal rock, that is, Black schist. These conditions in geomorphology and geology are considered to be favourable for landslides. The proximate cause which gave rise to the landslide must be investigated.

During Jury's and September's leveling some subsidence was observed. During September's and December's leveling, on the contrary, almost no subsidence was observed. The cause of the large subsidence during the former period seems most likely to be the heavy rain (above 400 mm) which fell on the 17th. and the 18th. of September, immediately before September's leveling. Actually, on those days, three visible landslides occured near Nagoo. But the movement of Nagoo landslide before July, 1965, known from the landslide-meters or from the villagers, can not always be connected with heavy rain, and some movements occured even in winter, the dry season of this district.

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* Both ends of a wire, which is stretched in the direction of maximum inclination, are fixed to the ground and the change in length (stretching) of the wire is recorded by a meter.

300 metres below the ground at Nagoo, there are the galleries of a mine which were once suspected to be the cause of the subsidence. But it is difficult to consider the galleries to be the immediate cause of the subsidence due to their depth. If galleries are responsible for the subsidence, the process is thought to be as follows: ground water seeps away through the galleries and the ground water surface sinks at Nagoo, then the upper loose strata decreases slightly in volume causing subsidence. According to the villagers, springs discharges in Nagoo have decreased. This may indicate lowering of the ground water surface, as previously stated. Does deficiency of ground water cause landslides (or subsidence of the ground) as well as excess of it, but through another process ?

7. Conclusions

Nagoo landslide is the re-activity of a former landslide area which is identified by geomorphological and geological characteristics. According to re-leveling in 1965, during July and September the bench-marks in the landslide area subsided by 10 - 20 cm., and during September and December, on the contrary, the amount of subsidence was less than 3 cm.. This means that the ground scarcely subsided during the latter period.

The amount of subsidence during the former period is related to the thickness of the loose talus sediments and is distributed characteristically in four zones respectively, which were devided according to the geomorphological and geological conditions.

Cracks in the ground are concentrated in the places where the loose sediments are thick and the amount of subsidence varies from point to point. The proximate cause of the landslide is yet unknown, but for the present, excess and deficiency of ground water are supposed to be likely causes.

This paper is dedicated to Prof. Teizo Murata and Prof. Mutsumi Hoyanagi on the happy occasion of their 60th birthdays.

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