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ON MICRO-EARTHQUAKES OBSERVED IN ADVANCE OF JIZUKIYAMA LANDSLIDE, NAGANO CITY, ON JULY 26, 1985

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SUMMARY

A disastrous landslide occurred on a slope of Jizukiyama in the northern part of Nagano city, on July 26, 1985. Before a few days of it's occurrence, several micro-earthquakes were observed in the landslide area, which might be resulted from micro-fracture in hard rocks underlying the slope. Moreover, before 6 hours and 3 hours of the landslide, the micro-earthquakes of mganitude of about 1 were recorded at the Shinetsu Seismological Observatory, where was located 1.3 km apart from the landslide area. These micro-earthquakes played an important rôle in soil movement of the slope, which was observed to predict the slope collapse.

INTRODUCTION

The landslide of 350 m width and 700 m long occurred in the urban hill side area of Jizukiyama in Nagano city. As soil volume of 5×10^6 cubic meters flowed down to residental area, 26 lives were lost, and 50 houses were destroyed. Landslide is the result of such causes as rainfall or melting of snow, local geology, development of urban, etc. These conditions were also true for this landslide. Geology in this area shows tuff breccia in the Tertiary period, which is covered by slope debris. A thin clayey layer sensitive to slope sliding was found to be put in tuff breccia from geological investigation.

As several micro-earthquakes were observed for the first time, prior to the occurrence of landslide, a description is made for the characteristics of the seismic motion.

Extensive studies (Refs.1,2) have been performed to predict the occurrence time of slope collapse from soil mass movement observed by extensometer. The movement is suggested to be similar to strain-time curve in creep experiment which rupture occurs in the tertiary. In this paper, a discussion is extended to a possibility for the prediction of the slope collapse in considering the effect of micro-earthquakes.

OBSERVATION OF MICRO-EARTHQUAKES IN LANDSLIDE AREA

Cracks and settlements began to appear on highway constructed on the slope of Jizukiyama since 1981. In particular, the extent of slope movement enlarged from the spring in 1985. Thereafter the failure zone gradually became clear so that the sliding area could be expected. Moreover, it rained over 30 days in a longer period of 10 June to 20 July, of which the total amount of precipitation

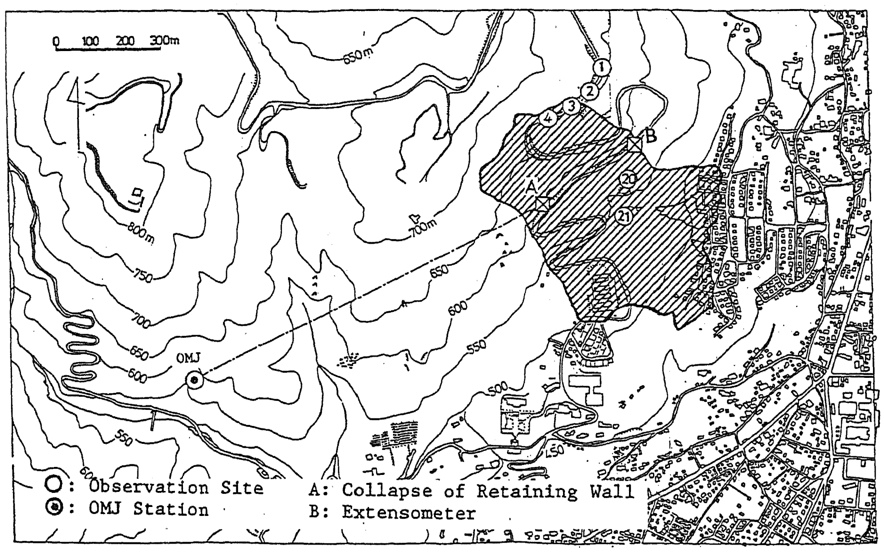


Fig.1 Lnadslide Area and Observation Site

came up about 520 mm. The rain fall in that year attributed to make weaken the soil strength under the slope. After heavy rain on 20 July, a small scale of mud flow produced in an extent of 25 m in width and 150 m in length at the site B in Fig.1, and gave a shock to inhavitants in the vicinity. After good weather spelled for a week, the disastrous landslide occurred at 17h, July 26, 1985, as seen in Fig.1.

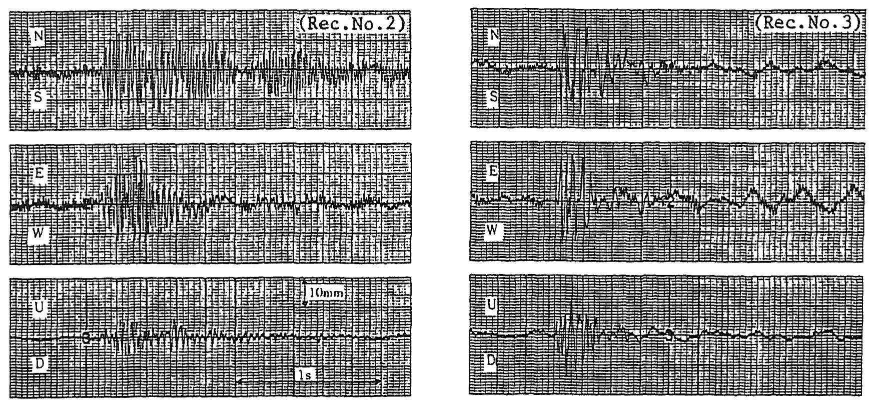
Prior to the landslide occurrence, the micro-earthquakes were observed in a period of 23 to 25 in July, 1985, using 1 sec.period seismometer of three components. Location of observation was the sites of No.1 to No.4, No.20 and No.21 on the slope, as shown in Fig.1. There were already many cracks on the highway road in the upper part of slope, so it was not easy to find a place to install the seismometers. In Fig.2, and the data are given comprehensively in Table 1.

P and S waves are fairly well clarified from the records, P-S time intervals are in a range of 0.2 sec. to 1.8 sec. Amplitude is so much larger that the distinction is clear from noise due to microtremors. Though the direction of ground motion in three components is generally not evident, it seems to begin in downward motion for U-D component in many cases. This may be appropriate in considering an effect of sliding fracture in rocks under the slope. Next a linear relation is nearly realized between P-S time intervals and and duration of seismic motion in Fig.3. Assuming the Oomori's coefficient to be about 1.85, as stated later, the distance from the observation site to the seismic source may be estimated to be 100 m$\sim$300 m. In the instance of micro-earthquake of 16h29m, July 23, the spectra show predominant amplitude in the frequency of 20 to 40 c/s, as seen in Fig.4. Thus these micro-earthquakes are understood to generate from microfarcture in hard rocks under the slope of Jizukiyama. The most lower frequency of 3 c/s in the spectra is due to noise of microtremors, which is proper to the near-surface structure.

MICRO-EARTHQUAKES OBSERVED AT SITE OFF LANDSLIDE AREA

Before 6 hours and 3 hours of the disastrous landslide, the micro-earthquakes were observed in a vault of the Shinetsu Seismological Observatory, Tokyo University, where located 1.3 km in the direction of south-west from the land-

(a) Site No.1 : 1985 JUL 23, 16:29 (b) Site No.3 : 1985 JUL 23, 17:22



Sensibility: 330 μkine/cm Sensibility: 165 μkine/cm

Fig.2 Micro-earthquakes Observed Prior to Landslide

Table 1 Micro-earthquakes Observed in Landslide Area

Record No.	Site No.	Occurrence Time (Y,M,D,H,M)	P~S Time (sec)	Duration (sec)	Initial Motion (U: upperward) (D: downward)
1	No. 1	1985.7.23, 16 : 29	0.05	0.2	D
2	No. 1	1985.7.23, 16 : 29	0.12	1.8	D?
3	No. 3	1985.7.23, 17 : 22	0.14	1.6	D
4	No. 3	1985.7.23, 17 : 28	0.04	0.2	D?
5	No. 3	1985.7.23, 17 : 29	0.10	0.8	D
6	No. 4	1985.7.23, 17 : 54	0.20	0.8	U
7	No. 20	1985.7.24, 16 : 18	0.05	0.2	D?
8	No. 20	1985.7.24, 16 : 19	0.06	0.4	D?
9	No. 20	1985.7.24, 16 : 19	0.09	0.6	U

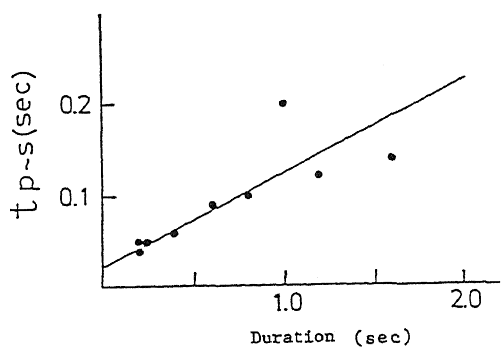


Fig.3 P-S Time Interval and Duration of Seismic Motion

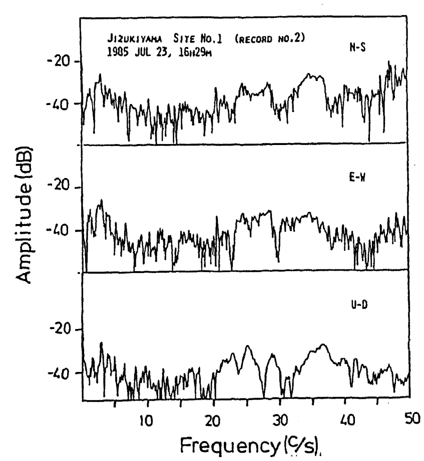


Fig.4 Spectra of Micro-earthquake

slide area. The site is indicated by 'OMJ' in Fig.1. An example of records is shown in Fig.5, of which the arrival times are 08h37m26s (M=1.2) and 15h12m01s (M=1.0) on July 26. No one felt these shocks, though workmen were in operation on the slope. There was a fact observed by Nagano Prefecture that the upper part of retaining wall anchored in the Earth ('A' marked in Fig.1) collapsed and fell down toward the road at the nearly same time as the first shock. Moreover, the retaining wall again fell away at 15h17m, which was about 5 minuites retard from the occurrence of the second shock.

Taking P-S time interval to be 0.7 sec for the first shock in Fig.5 and the distance to be 1.3 km, the Oomori's coefficient 1.85 is obtained. Thus the velocities are found to be 2.8 km/sec for P waves, and to be 1.1 km/sec for S waves which is on the basis of the value found from super sonic measurement for core sample in test boring.

On the other hand, ground motion during the landslide is recorded, as seen in Fig.6. It is a part of record having maximum amplitude in a period of 17h28m to 17h35m, which agrees to the time approaching violent slide movement. According to the observation of Nagano Prefecture, the slope collapse at 17h28m near the site B in Fig.1 is reported. As the collapse gives repeatedly impulsive force to the ground surface, wave forms appear to be random and irregular.

Spectra of the micro-earthquakes and the microtremors during landslide are compared for U-D component in Fig.7. The predominant frequency of about 1.6 c/s is commonly obtained in those spectra, and is attributed to the structure, through which the seismic waves propagate. It's thickness mav be estimated to be about 150 m, according to the 1/4 wavelength law. On the other hand, in the range of frequency higher than 1.6 c/s, there is a remarkable difference between the micro-earhquakes and the microtremors during landslide. The spectrum amplitude in the latter is less than in the former. Moreover, the first shock of 08h37m seems to much larger than the second shock of 15h12m in the frequency of 2 to 10 c/s. It may be due to the difference of magnitude and focal depth, and then it can be said that the first shock has larger in magnitude and deeper in depth than the second shock.

OCCURRENCE OF MICRO-EARTHQUAKES AND SOIL MASS MOVEMENT IN LANDSLIDE AREA

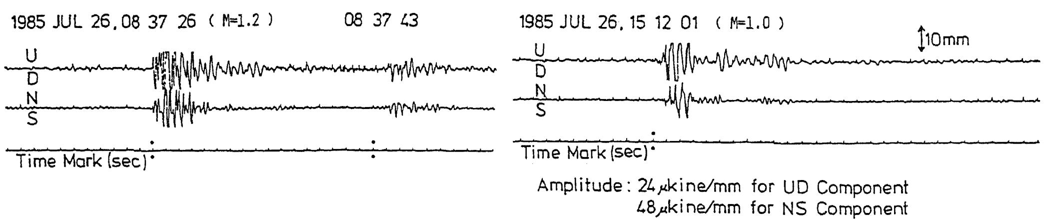
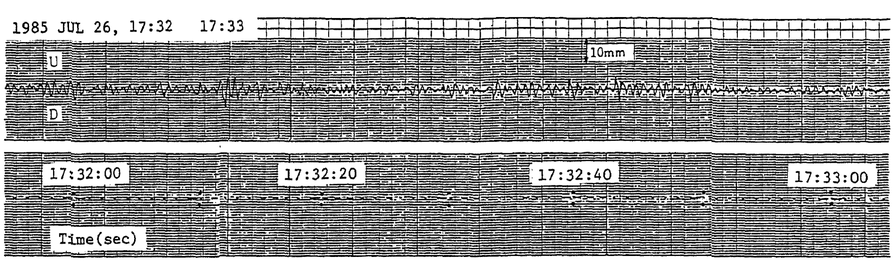


Fig.5 Micro-earthquake Observed at OMJ Station



Sensibility: 240 μkine/cm

Fig.6 Microtremors during Landslide, Observed at OMJ station

Many extensometers are installed to measure a variation of distance between two points selected on the slope of Jizukiyama. The soil mass movement does not necessarily show the similar tendency of those observations. Typical measurement at the site B in Fig.1 is made from 00h on July 26 until the occurrence of landslide, as seen in Fig.8. The time variation which is gentle in the begining, becomes gradually steeper, and at last the velocity of soil mass movement approaches the infinity toward the collapse of slope. From a comparison of this curve with a strain-time curve in other creep experiments under constant stress, a linear part in the curve has been regarded as the secondary creep in the absence of the primary creep, and non-linear part the tertiary creep. A bending in the curve is found at the point A in the transitional state of mass movement, which corresponds to the occurrence of the first micro-earthquake of 08h37m. It may be considered that the soil mass movement begins to accelerate by an action of the micro-earthquake. On the other hand, the influence of the second micro-earthquake of 15h12m is not clear, because the soil mass moves rapidly at this time.

As a qualitative explanation of the occurrence of landslide, a model is given schematically in Fig.9, in which a sliding motion is along a circular slip plane. Yield zone F(Ref.3) presumed near the deepest point of the slip plane may be considered to be formulated by the weathering in a longer period. If the micro-earthquakes occur in hard rocks, the frictional force will reduce on account of the increase of pore-pressure, and the deformation of overlying rocks will be in progress. The soil mass mainly moves in the vertical direction (from D to F zone), before the micro-earthquake. While a possibility may be suggested that the

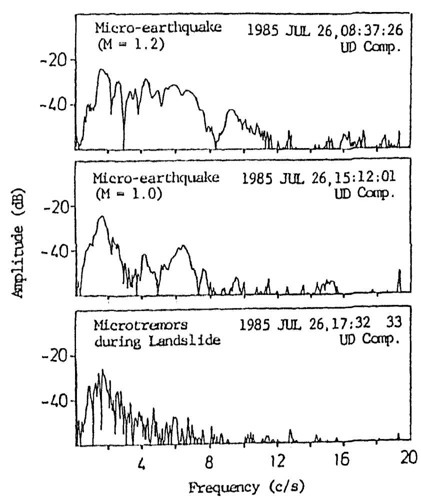


Fig.7 Spectra of Micro-earthquakes and Microtremors

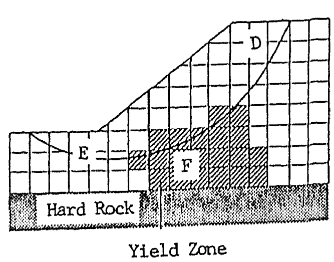


Fig.9 Model of Occurrence of Landslide

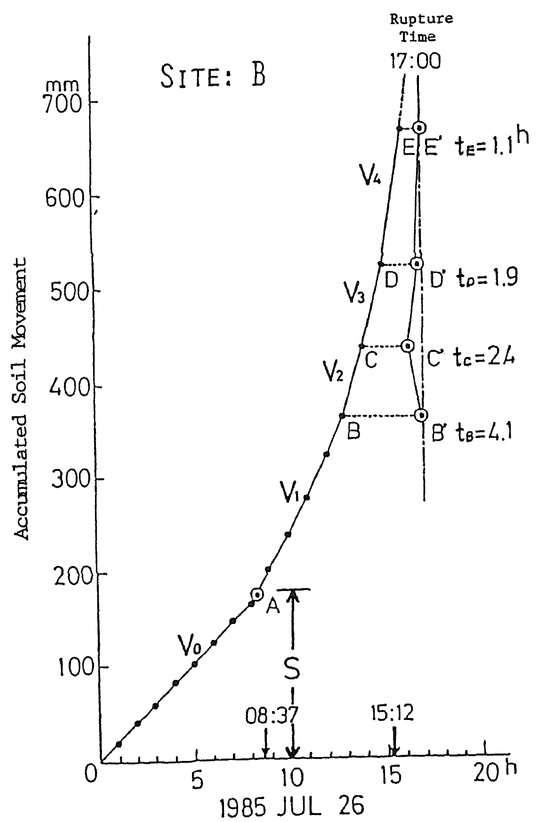


Fig.8 Accumulated Soil Mass Movement at Site B

sliding movement begins to traslate in the horizontal direction (from F to E zone) after the micro-earthquake. To make larger such movement, the sliding action in addition to the creep deformation seems to be necessary. Accordingly the micro-earthquake may be effective to make accelerate the slope movement.

A treatment is made to predict the occurrence of landslide from the soil mass movement taking into consideration of the effect of micro-earthquake. As shown in Fig.8, the curve of observation is divided into a group of linear segments, and the movement velocities are successively taken as V_1 , V_2 , V_3 , V_4 , etc. for each segment beyond the critical movement S at the point A. Here this value is regarded as a limited one of rupture in the creep deformation. If the movement accompanying the increase of velocity is attributed to the sliding motion along the slip plane, the effect of creep deformation is apparently hidden in this curve. However, the creep is expected to be in progress in non-disturbed soil mass in the remainder. Assuming that the deformation due to creep develops with the same velocity as the sliding movement, the rupture time may be graphically obtained in Fig.8. As an example, when determining from the point B, it is found from the ratio $t_B = S/V_1$ on the elongation of segment $\overline{AB}$. In this case, the prediction may be possible before about 4.1 hours of the occurrence of landslide. Continuing the same process, the rupture rises at the points of C', D' and E' corresponding to the points of C, D, and E respectively. Thus the obtained result is in good agreement with the occurrence time of landslide. It is shown that the landslide could be predicted from the observation of soil mass movement, if the critical point translating from the creep deformation to the sliding movement is found.

CONCLUSION

Prior to the landslide, the micro-earthquakes are observed in the slope area, where the occurrence of landslide had been already expected. They have the frequencies higher than 20 c/s, and are interpreted to be caused by micro-fracture in hard rocks underlying the slope.

Just before the landslide, the micro-earthquakes of magnitude of about 1 recorded in the vault of the seismological station, Tokyo University, at the distance 1.3 km from the landslide area. One of those plays an important rôle in the variation of soil mass movement with time observed in the landslide area. It is suggested that the seismic observation is useful to make clear the mechanism of the landslide, and is available to predict the occurrence time of landslide.

ACKNOWLEDGMENT

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REFERENCES

1. Saito,M., "Prediction of Slope Collapse due to Tertiary Creep (in Japanese)", Landslide, 4, no.3, 1-8, (1967).
2. Saito,M., "Prediction of Occurrence Time of Slope Collapse (in Japanese)", Soil and Foundation, 17, 29-38, (1969).
3. Mitchell,R.J., Earth Structure Engineering, Allen & Unwing.Inc., (1983).