Relationship between Groundwater Flow and Internal Structure of Landslide Mass by Combined Geophysical Survey Method

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Abstract

In this study, we performed two geophysical survey methods, 1-m-depth ground temperature survey and surface-wave seismic survey, in Nishi-ikawa landslide, for better understanding relationship between the dynamics of groundwater flow and internal structure of landslide mass. We installed 31 thermocouples at the 1 m depth along 3 cross survey lines on the landslide, and has been continuously monitoring. In this paper, we pointed out the E-line in this landslide, and found that the distribution of groundwater flow was vein-like. Furthermore, we carried out surface-wave seismic geophysical survey at this lines. We pointed out phenomena by these surveys as following: (1) in the rainy summer season, the ground temperature briefly changes associating with the rainfall-infiltration process, but goes back to almost the same temperature as that of the isothermal layer at the 1 m depth. This indicates that groundwater in this landslide may have two differing sources. (2) Veins groundwater flow are located on those areas with low shear wave velocity as revealed by the surface-wave seismic geophysical survey. Especially, there is one monitoring point (E7) at which 1 m depth ground temperature lowered after each heavy rain. Decreasing behavior is consistent with the increasing of water level observed in a borehole nearby. Therefore, we concluded that groundwater from isothermal layer increases along weak structure zone in the landslide mass.

Keywords: 1-m depth ground temperature, surface-wave, heavy rain, borehole water level, extruding flow

1. Introduction

It is well known that in many cases the landslide movement is regulated by variation of groundwater. There are many cases the groundwater in landslide mass is shown as a water surface profile. However, it seems that actual groundwater flow exists as vein-like shape in a natural slope (e.g. Takeuchi, 1980; Furuya et al, 2006). It seems that such groundwater flow is controlled by internal structure of landslide mass. Therefore, detecting of location and behavior in groundwater flow are needed to evaluate detailed slope stability.

In this study, we carried out two geophysical survey methods, continuous monitoring of ground temperature at the depth of one meter and surface-wave seismic survey, at the Nishi-ikawa landslide to clarify relationship between groundwater flow and internal structure of landslide mass in the crystalline schist area. The variation of ground temperature at one meter depth was caused by inflow of groundwater (increase of borehole water level) in deep layer (approximately isothermal layer) from results of these methods.

2. Test site

Nishi-ikawa landslide is located in the middle of Shikoku Island, southwestern Japan shown in Fig. 1. This landslide was reactivated by the cutting on the lower part of an old landslide. The Nishi-ikawa landslide consists mainly of green schist and partially of pelitic schist where had been well studied through drillings and various monitoring since 1973 (Suemine et al, 1980; Suemine, 2004). Maximum depth of this landslide mass is approximately 16 m by estimated by pipe strain gauge monitoring. The 1-m-depth ground temperature survey had also been carried out on January 2000 to examine the location of veins of groundwater flow (Furuya et al., 2013). In Fig. 1, those areas with the ground temperature being higher than the average one meter depth ground temperature (8.5˚C) were highlighted and estimated to be the veins of groundwater flow (Furuya et al., 2013). Especially, over 9.0˚C, high temperature area, is indicated by arrows, which is direction of estimated vein of groundwater flow. Furthermore, continuous monitoring of ground temperature at the same depth has been carried out at three survey lines (C, E, and I line (shown in Fig. 1)) since 30 April 2010 (Furuya et al., 2014).

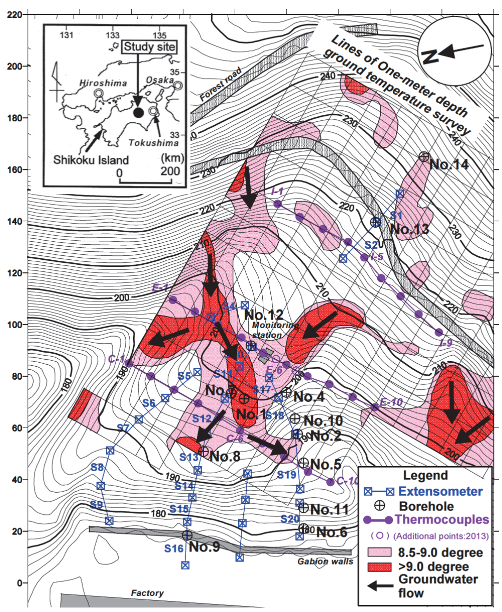

Fig. 1 Plan of the Nishi-ikawa landslide

3. Methodology

3.1 Continuous monitoring of ground temperature

The principle of detecting groundwater flow by soil temperature monitoring, details are described in Takeuchi (1980), is based on the monitoring the differences in the 1 m depth ground temperatures disturbed by veins of groundwater. Furuya et al. (2014) re-explained that the ground temperature in the vicinity of the groundwater vein tends to be lower than the average ground temperature from summer to autumn because flowing groundwater temperature is lower than normal ground temperature at a depth of 1 m. In contrast, the ground temperature in the vicinity of the groundwater tends to be higher in winter to spring as compared to the temperature of the surrounding ground because flowing groundwater temperature is higher than normal ground temperature at a depth of 1 m. Takeuchi (1980) has pointed out that 1-m-depth ground-temperature surveys can be conducted when the ground temperature difference between the normal ground temperature at a depth of 1 m and the flowing groundwater temperature exceeds 2.5˚C on summer and winter seasons in the mid-latitude. We installed 29 thermocouples at three monitoring lines since 2010 which based on the estimated result of the 1-m depth ground temperature survey and two additional thermocouples at east and west part of point E6 since 2013 (Fig. 1). The monitoring was performed as following:

- In each survey line, the interval between each monitoring point is 10 meters. However, 5 meters interval from E5 to E7. Total measurement points are 31.
- Using sensors are T-type thermocouple. These are installed at the depth of one meter in each measurement point. The temperature measuring range is -40~ +125 ˚C with a precision of ±0.5˚C.
- Maximum sampling interval is 2 seconds for all the 31 points.

The measurement has been carried out since 30 April 2010. However, there are missing data resulting from the disconnection by animals, lightning damages or other factors in the monitoring period.

In this study, we used precipitation data of the Ikeda dam site monitoring station, Ministry of Land, Infrastructure, Transport and Tourism, which was located 2.5 km far from the Nishi-ikawa landslide. In addition, we used record of borehole water level at No. 4 (recorded on chart paper) to examine the relationship between 1-m-depth ground temperature at the point E7 and behavior of groundwater level.

3.2 Surface-wave seismic survey

To investigate the internal structure of the landslide mass, we carried out the surface-wave seismic survey known as multichannel analysis of this wave at the E line for ground temperature monitoring in 2014. We used 24 geophones (Natural Frequency: 4.5 Hz) in this survey. These were set on 2 meters intervals along the monitoring line of ground temperature, and wooden hammer (approximately 8 kg) was used for exciter of seismic motion. The hummer points were outside of measurement line and also intermediate between the geophones. After then, profile of the underground structure was estimated by exclusive software. The equipment and software were following:

- Seismograph: McSEIS-SXW 24ch type K (OYO Corporation).
- Software: SeisImager_e (ditto).

4. Results and Discussion

4.1 Variation of ground temperature at the one meter depth in heavy rain

Furuya et al. (2014) have pointed out ground temperature at the depth of one meter in the point I1 and E7 were decreasing after a heavy rain in summer season, and these phenomenon might be effected by vein of groundwater flow. We focus the hourly data at the point E7 where locates near water level monitoring in borehole No. 4.

Fig. 2 shows the result of hourly time series changes relationship between ground temperature at the point E7, precipitation, and borehole water level at the No. 4 for the period of 19 June to 14 July 2013. In this figure, the heavy rain occur on 19 to 21 June (Cumulative precipitation is 149mm). The normal ground temperature at the depth of 1 m without effected by groundwater flow is increasing period in a mid-latitude area of north hemisphere during this period. The ground temperature at the point E7 is increasing 20 to 21 June. After increasing, this temperature is decreasing approximately 11 days except 26 June with a slightly strong rainfall. On the other hand, increasing borehole water level at the No. 4 occurs approximately 1 day late compared with ground temperature. Decreasing of ground temperature occurs also approximately 1 day after the increasing of borehole water level at the No. 4.

Fig. 3 shows the result of time series changes between same data items for the period of 1 to 31 August 2014. In this figure, the heavy rains occur on 1 to 3 (Cumulative precipitation is 314mm: Typhoon Nakri) and 9-10 August (Cumulative precipitation is 175mm: Typhoon Halong). There are twice significant decreasing ground temperature on 2 to 3 and 9 to 11 August. Especially 2 to 3 August, decreasing of ground temperature is 3.65 ˚C (19.40 to 15.75 ˚C) compared with between before start of increasing and end of decreasing. In this process, increasing of borehole water level at No. 4 begins a little after increasing of ground temperature at the point E7. During 8 to 10 August, variation process of between borehole water level and ground temperature is similar to the case of 2 to 3 August.

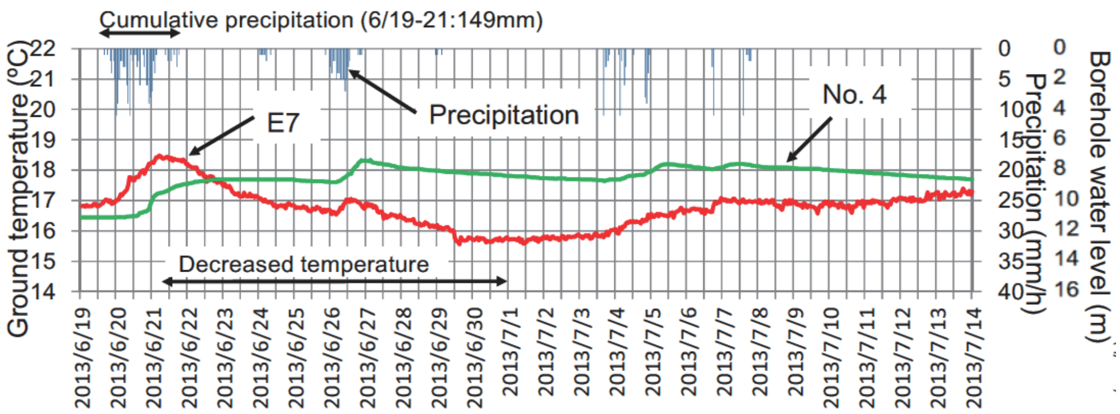

Fig. 2 Time series change of hourly monitoring results between ground temperature (E7), Borehole water level (No. 4), and precipitation (19 Jun to 14 July, 2013)

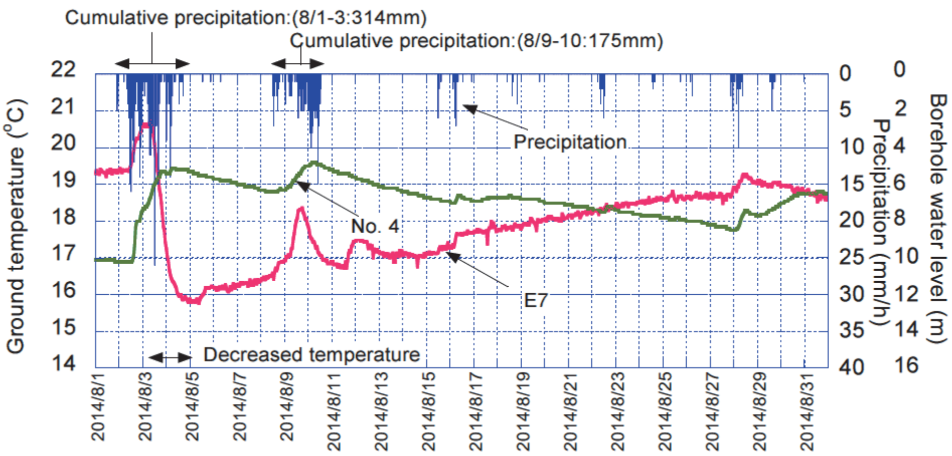

Fig. 3 Time series change of hourly monitoring results between ground temperature (E7), Borehole water level (No. 4), and precipitation (1 to 31 August, 2014)

It is recognized that peak value of normal ground temperature at the depth of 1 m without effected by groundwater flow in a mid-latitude area of north hemisphere, especially Japan, appear on August to September (Takeuchi, 1996). Lowest air temperature on 5 August in AMeDAS Ikeda by Japan Meteorological Agency was 22.5 ˚C. Takeuchi (1996) have been pointed out that isothermal temperature was 12.49 ˚C at the Nishi-ikawa landslide. From these monitored value, the process of ground temperature variation is that 1) Increasing process is caused by infiltration of rainfall from ground surface, 2) Decreasing process might be caused by increasing borehole water level (Expansion of the groundwater flow vein) in-flowed from deep layer such as isothermal layer. It is probably to be the same process on 9 to 10 August 2014 and 16 to 21 June 2013 (shown in Fig. 2).

4.2 Internal structure of landslide mass by surface-wave seismic survey

Fig. 4 shows the result of shear-wave (S wave) profile at the E line. In this figure, it doesn't correspond with between the expansion distances of surface-wave seismic survey and total length of measurement points of E line. This reason is that cable for surface-wave seismic survey were set on the surface. Therefore, the latter length is longer than the former. There are two high velocity parts (approximately Vs>400 m/s) in the mass. These parts are possibly consisted with hard material such as rock/large bolder. On the other hand, relatively low velocity (approximately 160 to 300 m/s) part is existed, which surrounded dotted lines. In particular, shallow part (shallower than 5 meter) of dotted lines area are distributed to the lateral direction (approximately under the point E4 to E8), and deep part (deeper than 5 meter) are distributed to the vertical direction (around under the point E6). From relative low velocity distribution, this area are evaluated to weak (loose) material zone by characteristics of the propagation velocity in a material.

4.3 Supply source of groundwater flow to generate a significant difference of soil temperature

As significant decreasing ground temperature after heavy rain at the point E7 were monitored, we dug two test boreholes (Depth: 2.55 m) to confirm surface ground condition by auger boring at 1.8 m east side of the point E7 and 1.0 m west side of this point on 11 May 2014. Table 1 shows one result which describe groundwater level of these boreholes by this drilling work. In this table, the east side of the point E7 is low groundwater level during 11 to 12 May 2014 (2.55 to 2.38 m). On the other hand, the west one is high groundwater level on same period (1.27 to 1.25 m). We monitored rate of recovery after pumping at this borehole, which value is 75 cc/min. These results means that it doesn't exist homogeneous groundwater surface in the mass of Nishi-ikawa landslide. Furthermore, groundwater temperature in the east side of the point E7 was 13.5 ˚C. This temperature is similar to isothermal temperature. On the other ward, low temperature of groundwater consist in deep layer, normally, is existing in the shallow layer at the east part of point E7.

From above survey and monitoring results, although there are a little effect of rainfall infiltration, decreasing process of ground temperature at the 1 m depth during heavy rain is relate increasing

Table 1 Borehole water level at the both side of point E7

Location / Date	11 May	12 May	Note
East side of the point E7	GL-2.55m	GL-2.38m	—
West side of the point E7	GL-1.27m	GL-1.25m	Rate of recovery: 75cc/min

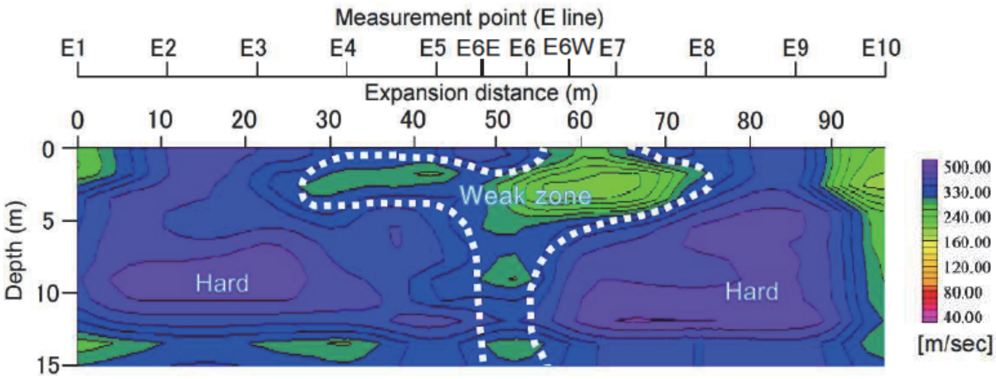

Fig. 4 Result of shear-wave velocity profile at the E line by surface-wave seismic survey

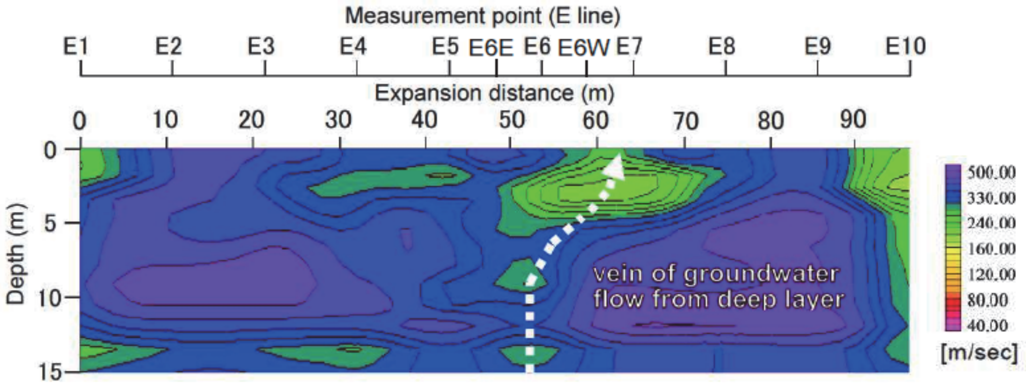

Fig. 5 Estimated vein of groundwater flow path flow deep layer around the point E7

(inflowing) of groundwater from deep layer. Fig. 5 shows presumed increasing of groundwater flow path from deep layer at the E line of Nishi-ikawa landslide. In this figure, groundwater path from deep layer should be estimated by white dotted line through in the relative low velocity (weak) part in the landslide mass like vein shape. The size of this vein might not be large by the result of drilling at the both side of point E7. It seems that increasing of the groundwater from deep layer, probably, is extruded effect as piston-flow like by some force.

5. Conclusions

We carried out two geophysical survey methods, 1-m-depth ground temperature survey and surface-wave seismic survey, in Nishi-ikawa landslide, for better understanding relationship between the dynamics of groundwater flow and internal structure of landslide mass. These results found that there is one monitoring point (E7) at which ground temperature at the one meter depth lowered after heavy rain. This point located low velocity zone (weak structure) from surface to deep layer by the result of surface-wave seismic survey. We concluded that groundwater from isothermal layer increases along weak structure in the landslide mass. We will consider the age of groundwater from deep layer and reproducibility confirmation of phenomenon in the future study.

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