Study on Method to Evaluate Geo-disaster Risk during the Snowmelt Season

Tsuyoshi TAKAYANAGI
Geo-disaster and Risk Mitigation Laboratory, Disaster Prevention Technology Division

Ryota SATO
Meteorological Disaster Prevention Laboratory, Disaster Prevention Technology Division

To develop a method for evaluating geo-disaster risk during the snowmelt season, changes in groundwater levels were monitored under a cut slope in a snowfall area. Monitoring clarified that during the year the instability of slopes subject to prolonged exposure to snowmelt water was highest due to rising groundwater levels. Based on this insight, a risk evaluation method was developed based on the effective snowmelt index correlated with ground water behavior.

Keywords: maintenance, snowmelt, slope failure, monitoring

1. Introduction

Slopes along railway lines in Japan fail in different ways, such as embankment collapse, cut-slope surface collapse, etc., due to snowmelt (Fig. 1). To improve railway safety in the face of such snowmelt disasters, a method for quantitatively evaluating slope stability during the snowmelt season is necessary.

It is thought that slope failure in the snowmelt season is caused by a rise in pore-water pressure in the ground, which in turn is due to penetration of snowmelt, in the same way as failures caused by rain. This paper reports on the results of research aimed at solving these problems and establishing an appropriate slope management method in the snowmelt season.

![Embankment failure in the snowmelt season in HOKKAIDO](image)

Fig. 1   Embankment failure in the snowmelt season in HOKKAIDO

2. Snowmelt evaluation model

Snowmelt penetration is the main cause of slope collapse, therefore, proper evaluation of snowmelt levels is very important for slope maintenance in the snowmelt season. This research applied the heat balance method to understand snowmelt levels in the region [1]. This method evaluates the melting heat per hour based on "Temperature, Precipitation, Wind speed and Hours of sunshine" obtained from meteorological observation points belonging to the official meteorological agency. Surface snowmelt is then calculated based on the melting heat. Figure 2 shows a conceptual diagram of the melting heat $Q_M$ on the snow cover surface in the heat balance method and the evaluation formula is given by (1).

Snowmelt amount $M_s$ (mm) is calculated by dividing the melting heat $Q_M$ (J / s / m$^2$) by the heat of melting ice at 0°C ($= 0.334 \times 10^6$ J / kg). This method produces a more apposite amount of "bottom snowmelt" by correcting the time it takes for surface snowmelt to reach the ground surface based on the relationship between Darcy’s rule and snow depth.

$$Q_M = Q_R + Q_H + Q_L + Q_P + Q_C$$  \(1\)

- $Q_M$: Melting heat,
- $Q_R$: Net radiation,
- $Q_H$: Sensible heat,
- $Q_L$: Latent heat,
- $Q_P$: Precipitation heat,
- $Q_C$: Transfer heat through snow cover

![Conceptual diagram of melting heat on the snow surface in the heat balance method](image)

Fig. 2   Conceptual diagram of melting heat on the snow surface in the heat balance method
3. Monitoring of soil moisture and water level in the slope

3.1 Observation site

The cut slope selected for observation site in this study had a height of 10 m and was located at the end of a river terrace in Niigata prefecture (Fig. 3). This slope had failed in the past during the snowmelt season.

A boring survey revealed that the geology of the site was composed mainly of three layers, namely: black surface soil and cohesive soil (sandy gravel) on the upper and lower parts of the slope. It was found that the saturated permeability coefficient of the cohesive sandy soil was $k = 1.28 \times 10^{-6}$ m/sec, that of the cohesive soil gravelly soil was $k = 3.66 \times 10^{-6}$ m/sec and that of the surface soil was $k = 1.8 \times 10^{-4}$ m/sec. A ground water level gauge was installed inside the borehole around the site that had collapsed in the past. In addition, a dielectric constant soil moisture meter (SMM) was installed at three points in total on the surface soil of the cut slope where slope protection work had not been carried out. Three soil moisture meters were installed at depths of 0.25 m, 0.5 m and 0.7 m respectively.

3.2 Observation results

Figure 4 shows changes over time of: air temperature, snow depth, bottom snowmelt, volume of moisture content (average value of all sensors), underground temperature (depth 0.25 m), and ground water level, from December 2013 to June 2015. The amount of rainfall was added to the bottom snowmelt amount. For this reason, outside the snowmelt season, bottom snowmelt represents rainfall alone.

Results indicate that the snow depth decreases as the temperature rises in the snowmelt season. The position of the peaks in soil moisture and groundwater level coincide with the time when snow depth reached zero, so it is presumed that there is a close relationship between soil moisture behavior and the snowmelt phenomenon. In the case of the cut slope in particular, it can be inferred that the time of year when slope stability is at its weakest, is when the ground water level peaks at the end of the snowmelt season. Focusing on this moment in particular, although the amount of snowmelt per hour is low, throughout this period it is flowing continuously into the ground.

These observations suggest that the mechanism leading to snowmelt related disasters is as follows: snowmelt that exceeds the amount of water that can be discharged from the ground flows continuously into the ground, significantly increasing the amount of moisture retained in the ground, leading to the slope failures. Therefore, in order to evaluate the risk of a snowmelt disaster, it is necessary to properly evaluate the behavior of soil moisture in ground receiving continuous snowmelt.

4. Method for evaluating geo-disaster risk

This study develops a method for evaluating geo-disaster risk based on effective amounts of snowmelt.

Since the decrease in stability of a slope is closely related to a rise in the level of groundwater, it is important to predict soil moisture behavior in the snowmelt season. The effective snowmelt is one of the indicators that can express
soil moisture behavior with a simple tank model [2]. The calculation formula of the effective snowmelt amount is shown by (2).

\[ R_t = R_0 \cdot (1/2)^{t/T} + r \]

(2)

\( T \): Half-life period (h), \( t \): Lapsed time (h), \( r \): Bottom snowmelt (mm/h), \( R_c \): Effective amount of snowmelt (mm), \( R_0 \): Initial value of effective amount of snowmelt (mm)

An effective amount of snowmelt that is higher than that in a normal year is considered to be a warning to signal there is a risk of slope collapse. A method was therefore devised to establish a warning threshold based on past effective snowmelt data.

In this report, the maximum effective snowmelt levels over the past decade were used to set a warning threshold, and the relationship was examined between this threshold and the effective snowmelt amount from the three most recent snowmelt accidents.

Case 1 is an accident which involved an embankment with a height of 9 m, Case 2 was a cutting slope with a height of 10 m, and Case 3 involved an embankment along a river. The adopted half-life period of the effective snowmelt amount was 24 hours. Figure 5 shows the relationship between the warning threshold and the effective snowmelt amount in the years when the disasters occurred.

Verification of the results revealed that in Case 1 and Case 3 the disasters occurred when the effective snowmelt amount exceeded the warning threshold. On the other hand, in Case 2, the disaster occurred just before the effective snowmelt reached the threshold.

These outcomes indicate that this method could be used to accurately predict a snowmelt related disaster, though in practice, the warning thresholds would need to be adjusted down, to below the maximum effective snowmelt levels of the past 10 years.

5. Conclusion

This study proposes a method for evaluating the amount of snowmelt calculated using weather data obtained from public meteorological stations and also describes the development of a method for quantitatively evaluating snowmelt disaster risk.

References

[1] Yashushi Kurihara, Shigetoshi IIKURA et al. (2013) : "Estimation method of bottom snowmelt amount," Special report of railway technical research institute, Vol.27, No.11.

[2] Makoto Shimamura (2008) : "Improvement of train operational restriction against rain, wind and earthquake disaster," Doctor thesis of Tokyo University.

Authors

Tsuyoshi TAKAYANAGI
Assistant Senior Researcher, Geotechnical Hazard and Risk Mitigation Laboratory, Disaster Prevention Technology Division
Research Areas: Geotechnical Hazard, Reinforced Soil

Ryota SATO
Researcher, Meteorological Disaster Prevention Laboratory, Disaster Prevention Technology Division
Research Areas: Meteorological Phenomenon of Snow