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Prediction for shallow landslides based on time history of tilting of slope surface

○Jiren XIE, Taro Uchimura, Gonghui Wang

1、Introduction

Landslides are recurring phenomena and have posed a threat to human lives and property (Keefer et al., 1987; Petley, 2012). In recent years, the losses of properties as well as human lives caused by landslide disasters show an increasing trend, which led to investigations on landslide disaster mitigation and the early warning techniques of landslides (Stähli et al., 2015; Uhlemann et al., 2016; Uchimura et al., 2015; Dixon et al., 2018). The typical countermeasures to mitigate the risks of landslides is to prevent the slope failure by improving the factor of safety, such as retaining walls and ground anchors. However, those countermeasures are not suitable for some large slopes with potential risks of slope failure due to high cost. Therefore, the early warning systems for landslides is a promising way to evaluate the risks of landslides and mitigate the damages caused by landslides (Intrieri et al., 2012; Teuku et al., 2016; Smethurst et al., 2017).

In past decades, early warning systems of landslides using the surface displacement measurement intrumen such as extensometers were widely used in slope monitoring (Angeli et al. 2000; Emanuele et al. 2012; Fukuzono 1985; Okamoto et al. 2004, Saito 1987). The landslide prediction method based on the displacement measurement of slope surface was also proposed, which was deduced from the relationship between the displacement rate and duration remaining before slope failure (Fukuzono 1985; Saito 1987, Voight 1988 & 1989), and the expression is given as

$$\frac{ds}{dt} = \left[A\cdot(\alpha-1)\right]^{\frac{-1}{\alpha-1}}(t_f-t)^{\frac{-1}{\alpha-1}} \qquad (1)$$

Where s is the displacement of the slope surface, $\frac{ds}{dt}$ represents displacement rate. A and α are constant parameters, while t and t_f are the current time and slope failure time respectively.

It is widely reported that the value of α in Equation 1 is close to 2 (Saito 1987; Voight 1989). When α=2 , Equation (1) can be rewritten as

$$\frac{ds}{dt} = \frac{1}{A}\cdot(t_r-t)^{-1} \qquad (2)$$

Although the landslide early warning systems using displacement measurement of the slope surface are effective and validated by some model tests as well as field events, these techniques are not widespread due to high cost and complexity in installation as well as maintaning (Stähli et al., 2015; Uhlemann et al., 2016; Smethurst et al., 2017).

In recent years, with the development of microelectronic techniques, new early warning systems using MEMS (Micro Electro Mechanical Systems) technology have been developed to estimate the risk of slope failure by observing the tilting behaviors of slope surface in unstable parts of slopes (Towhata et al. 2005; Uchimura et al., 2010; Abhirup et al., 2018). Athough the tilting measurement systems have been used in slope monitoring because of the simple installation and low cost, the landslide prediction methods based on the time history of tilting of slope surface is rarely investigated, and still unclear.

2、A new proposed method for landslide prediction

In this study, a new proposed method for landslide prediction based on the time history of tilting of the slope surface, and the formular is expressed as follows:

$$\frac{dt}{|d\theta|} = \frac{-t}{B} + \frac{t_f}{B} \qquad (3)$$

Where $\frac{dt}{|d\theta|}$ is the inverse number of tilting rate, and t means the time. B is a constant parameter, while t_f represents the slope failure time which could be calculated when $\frac{dt}{|d\theta|}=0$.

3、Verification of the new method

To verify this new proposed method for landslide prediction based on the time series of tilting of the slope surface, a couple of laboratory model tests and field tests were carried out, and the slope failure in these tests was induced by applying artificial rainfall. A typical test result was discussed in this paper.

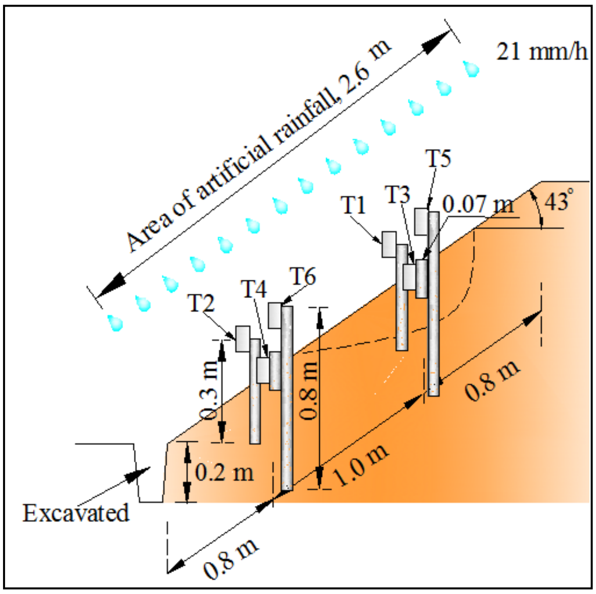

Figure 1. The illustration of the cross section of slope

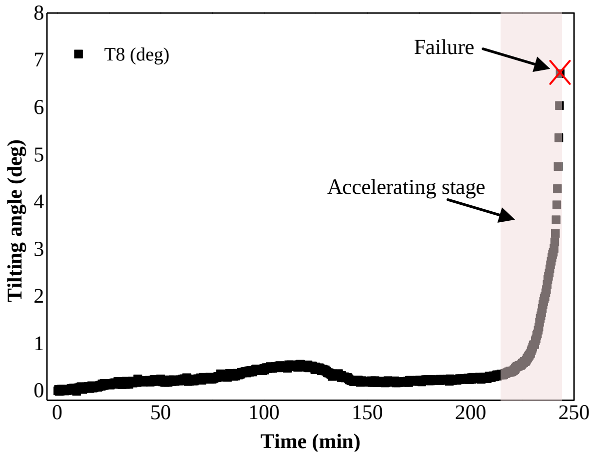

Figure 2. The time history of tilting angle of T8

Figure 1 shows the cross section of the test slope as well as arrangement of the instruments employed in the test, while the time history of the tilting angle measured by T8 which was installed in the failed part of the slope is presented in Figure 2. As shown in Figure 2, a accelerating stage of tilting was indicated before the slope failure. The relationship between the reciprocal tilting rate and time is indicated in Figure 3, which implies a linear trend between these two varibles. The failure time of the slope could be predicted based on the linear trend, which is consistent with the actual failure time.

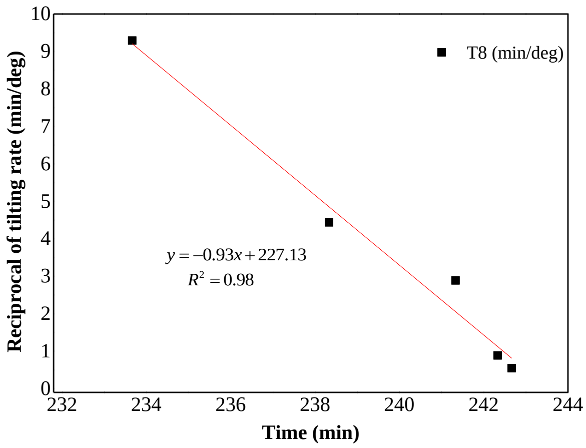

Figure 3. The reciprocal tilting rate against time

4、Conclusions

In this study, A prediction method for the occurrence of landslides based on the time history of tilting of slope surface was developed and validated by the model tests as well as the field test. Based on the results of this paper, it was found that the tilting measurement of the slope is an effective approach to detect the pre-failure behavior of landslides.