PREDICTING THE FAILURE OF SLOPE USING THE TRS SENSOR

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Abstract

This research is conducted to develop the qualified data analysis system for predicting the behaviour and failure of slopes. The data were acquired from TRS (translation, rotation and settlement) sensors and were transmitted to the control centre using real-time monitoring technology utilizing the CDMA communication system.

The use of appropriate mathematical modelling has been useful in creating a predictive capacity for landslides. Through observation and analysis of a real-time measured time series, a reasonable mathematic model was selected to predict landslide behaviour.

Two theoretical models are suggested; the polynomial function and the growth model. These models are judged to be most suitable for the description and analysis of measured deformation from an active landslide. This paper describes the application of these models to field data extracted from a slope in Nerupjae, South Korea. Analysis of the results confirmed good correlation between measured field data and predictive models.

Introduction

Throughout the years geotechnical engineers have collected considerable amounts of data from monitoring engineering projects that are prone to landslides. Despite the fact that in the civil engineering, practice substantial amounts of data has been accumulated, the effective use of these data to facilitate the prediction of future landslides has not been adequately addressed. The frequent occurrence of catastrophic landslides in recent years in Korea has reiterated the urgent need for geotechnical professionals to forecast, more accurately, the sliding event. A review of current works shows that existing predictive methods for landslides have seldom been based on basic physical principles or concepts. However, observations have confirmed repeatedly that the classical *growth* models simulating the phenomenon of *growth* could be applicable in providing a predictive capacity. For example, the deformation of rock

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avalanche *grows* exponentially or with power function, for certain period. According to a model devised by Verhulst, the deformation of a landslide with the foot of the slope facing a river may follow the logistic distribution. The present paper shows the methodology involved in utilizing two kinds of theoretical models for the description and analysis of monitoring data and how the resulting information can be interpreted to facilitate prediction.

Prerequisites for Prediction Modelling

The selection of an appropriate mathematical model is vital for the accurate prediction of landslides. It would be erroneous to assume that a particular model is suitable the prediction behaviour on the basis of *best fit* to data acquired in the field. It would be equally misleading to assume suitablity if the residual sum of squares is a minimum between the data and the model. It is important to understand fitting and prediction are entirely different concepts. Fitting provides an indication of ability to model past and present behaviour and fitting well suggests good interpolated estimation. It could be groundless to extrapolate such interpolation to the estimation into future behaviour.

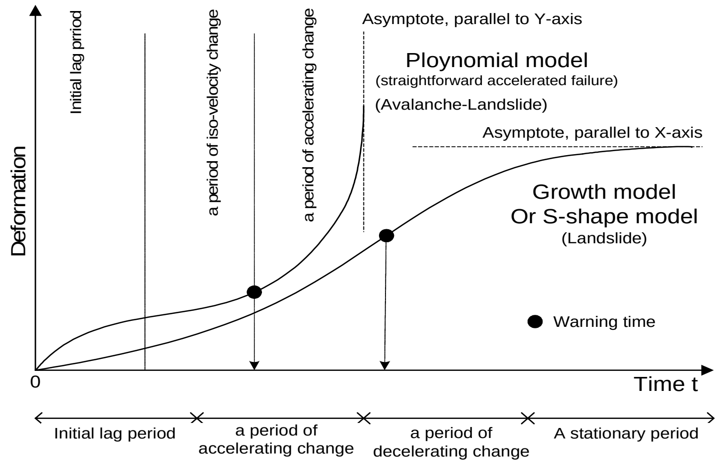
A more reliable way to achieve a more accurate prediction is to acquire a better fundamental understanding of the movement mechanisms and of landslide itself. As an example these can take the form of a linearity tendency, a periodical fluctuation, a season transform, a growing tendency or some form of efficiently proved differential equations. Through the effective use of observation and analysis of a real-time measured time series, it is possible to select a reasonable mathematic model to prediction the behaviour of a landslide. By fitting the suggested model to the raw data and adopting other relevant parameters in the model, the prediction of failure time can be achieved routinely[1, 2].

Two proposed models

From experience, the deformation for a landslide with the characteristics of an avalanche is mainly presented as "straightforward accelerated failure", with little or no inherent or natural constraint. The deformation appears to follow exponential, power or polynomial growth. On the other hand, the deformation of a landslide into a riverbed or subjected to unavoidable inherent or natural constraint shows approximately an S-shaped curve. Both failures have inflection points and maximum curvature points in their respective deformation curves as shown in Fig. 1.

For predicting a landslide based on deformation observed in the early stage, the determination of an appropriate model and its "best-fit" parameters is still a frequently used method. The key is to select a best-fitted model considering both engineering geology survey and minimizing the squared errors between model and data. Two models are proposed; 3-degree polynomial models

Fig.1 Sketch map of slope movement process [3]



For "straightforward accelerated failure" case(polynomial model), we assume the time function of the deformation N as

$N(t) = a_3t^3 + a_2t^2 + a_1t + a_0$ (1)

The coefficients(a_3,a_2,a_1,a_0) could be determined by curve fitting technique by spread sheet. The next step in the analysis is to determine the asymptote and maximum points in this curve. In this case, the asymptote indicates the failure of slope. Since the asymptote is the infinity of the deformation curve of slope, the maximum deformation of slope result in failure. As the profile of the curve approaches the point of rapid gradient change, then it is assumed that landslide will be imminent. To find out the point of curve slope change, Eq. (2) is rearranged,

$dN/dt = 3a_3t^2 + 2a_2t + a_1$ (2)

For "Failure with Inherent" case(growth model), we also assume the time function of the deformation N as

$N(t) = a_7t^3 + a_6t^2 + a_5t + a_4$ (3)

In this case, the value of a^7, has minus value compared to a^3 of the polynomial model. This model has also asymptote, therefore, the next step in the analysis is to determine the asymptote and maximum points in this curve. In this case, the asymptote means also the failure of slope. Because asymptote is the maximum value of deformation curve of slope, it will result in failure. At the point of curve gradient change, landslide warnings should be alerted.

Applied Measuring System

Fig. 2 shows the specially developed measurement transducer called the TRS sensor. It is designed to measure parameters such as displacement(translation), rotation, settlement (hence TRS). By adding the specific measuring sensor for rotation, TRS sensor could forms the 3D vector which facilitates the understanding of slope movement and tendency. This TRS sensor is applied to the Nerupjae case study (Fig. 3).

Fig. 2 TRS sensor

Fig. 3 TRS sensor applied in Nerupjae

16 No. TRS Sensors and a rain gauge were installed to analyze the slope behaviour in Nerupjae, Jaechon, which is the cut-slope adjacent to a national road. The deformation shape versus time of Nerupjae has followed the typical 3-degree polynomial equation. Fig. 4 shows the slope view, sensor and the deformation graph. The data was analyzed, and that of sensor

No. 12 showed the typical failure type. It is 3-degree polynomial having the deformation equation of trend line by time is $y = 1E\text{-}08x^3\text{-}3E\text{-}05x^2 + 0.0316x\text{-}0.3472$, and $R^2 = 0.929$. As can be seen in Fig. 5, the trend line of the slope deformation is very close to the asymptote, this suggest that the failure is imminent.

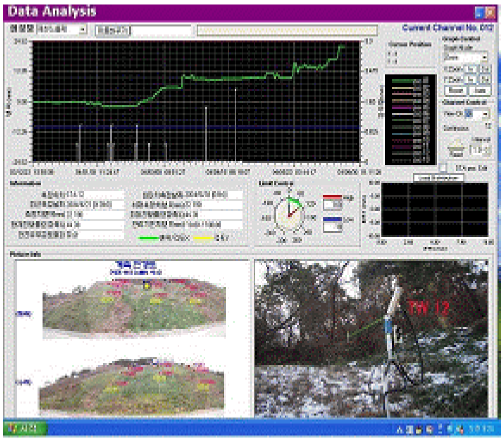


Fig. 4 Computer screen of TRS sensor

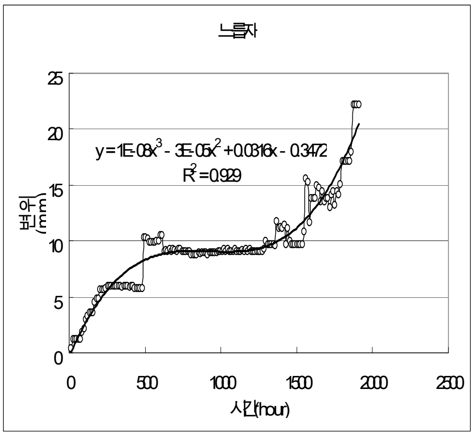


Fig. 5 Data analysis of Nerupjae

Summary

Compared with other pure mathematic models, the presented model is a better representation especially, based on polynomial function form, and similarly, it was found that dD/dt and the asymptote in the curve perform key roles in predicting the landslide. Again, compared with other existing models, the suggested models are more generalized and simple since they are 3-degree polynomial functions.

However, there are still influential factors not involved in the presented model, for example, geometric shape, amount of precipitation, etc, On occassions the presented model still shows some instability. This presented model only considers the monitoring data from the tertiary creeping stage not including data from the first and second stages. In addition, the physical meaning of *a* value is not yet clear. Therefore, there are still problems and questions to be investigated in the future.

The equations of the deformation trend line of Nerupjae by time is represented to the 3-degree polynomials ($y=ax^3 + bx^2 + cx + d$).

As you can see in Table 1, the trend line is believable because of high R^2 value.

Table 1. Summary of Nerupjae

field	failure model	trend line	R^2
Nerup	polynomial	$1E\text{-}08x^3\text{-}3E\text{-}05x^2$ +0.0316x-0.3472	0.929

The coefficient 'a' of Nerupjae equation is plus value, therefore, the asymptote of Nerupjae is located at x-axis(time-axis), also the trend line of the field was going to the asymptotes, it is estimated that their failures are very close.

References

[1] Saito M, and Uezawa H, "Failure of soil due to creep", Proceedings of the International Conference on Soil Mechanics and Foundation Engineering(1961), Vol. 1, pp315~318

[2] Voight B., "A method for prediction of volcanic eruption", Nature (1988), No.332, pp.125-130

[3] Fukuzono T., "Recent studies on time prediction of slope failure", Landslide News(1990) , No.4, pp.9-12