D104

Nonlinear Behaviors Strongly Modulated by Precursory Shear Deformation: Mechanisms and Implications for Time Prediction of Landslides

○Chengrui CHANG, Gonghui WANG

1. Introduction

Accelerating rates of geophysical signals are observed and perceived as precursors before a range of material failure phenomena including landslide (Voight, 1988; Bell, 2018). However, forecasting a hazardous landslide is a difficult task because of the nonlinear time dependency, geometrical and geological complexity, and seasonal effects (Crosta and Agliardi, 2003). Since Saito and Uezawa (1961) pioneered an empirical approach to forecast a landslide, a series of phenomenological models had been proposed for time prediction based on the accelerating behavior. Among them the Voight model (Eq. 1) has been widely used to physically describe the accelerating behavior preceding diverse forms of failure:

$$\ddot{\Omega} = A\dot{\Omega}^{\alpha} \quad (1)$$

where A and α are empirical parameters and Ω refers to a measurable quantity (displacement, tilting angle, seismic events, etc.). The dot denotes the derivation of Ω to time. The Voight model has also been validated by the retrospective analysis of volcano eruptions, landslides, and laboratory data.

Nevertheless, due to the large unknowns in the key parameters of α and A, the time prediction through this model remains great uncertainty. As a fundamental physical law governs a variety of material failures (soil, metal, alloy, ice, etc.) (Voight, 1989), the model might be a powerful tool to reveal the underlying mechanism of failure. Therefore, in this study, we endeavor to deliver a better understanding of the physical meaning of the parameters and intrinsic process of failure by examining the nature of these two parameters.

2. Materials and Methods

The mixture of silica sand No.7 (SS7) with different content of bentonite (SS7: Bentonite = 10:0, 9:1, 8:2, and 7:3, respectively) was used for ring shear tests. A natural clayey soil (Kinokawa sample) comprising highly weathered schist was taken from a nature landslide site in Kinokawa area, Wakayama Prefecture. And a clayey sample of weathered serpentinite was also used. Details regarding this sample are introduced in Wang et al (2010).

Three experimental approaches were conducted to reproduce the creep behavior on the pre-consolidated samples. We employed a normal-stress-controlled method (NSC) to decrease the normal stress on the mixtures (SS7 + Bentonite) or serpentinite in a drained condition. Similarly, we conducted the pore-water pressure-controlled tests (PWPC) on Kinokawa sample to mimic the creep behavior of slopes due to the increasing groundwater table. The nature of the NSC and PWPC is to decrease the effective normal stress to trigger material failure. And the shear-stress-controlled tests (SSC) were conducted on Kinokawa sample. The parameters of Equation (1) are determined by a retrospective analysis of the kinematic feature in tertiary creep following the Voight model.

3. Results

The results of one tests are exampled in Figure 1 to reveal the kinematic property of Kinokawa sample in a PWPC test with the monotonically increased pore-water pressure. We find that: (1) an inflection point in the time-velocity curve in tertiary creep which indicates the curvature changes (Figs. 1a-1b); (2) a piece-wise log-linear model for the velocity and acceleration during the tertiary creeping period has been identified, and the relationship between velocity and the acceleration could be further divided into three stages, which give different values of α and A following the Voight model (Fig. 1c);

(3) an outstanding dilation against a very short displacement appears in stage I, where the α value is small, on the contrary, the dilation becomes much less evident against a large displacement and the corresponding α-value is much greater (Figs. 1c-1d). The results obtained on SS7 in NSC tests are similar, which are not presented here due to the space limitation.

Figure 2 illustrates the details in an SSC test on Kinokawa sample. It is noted that the sample shows continuous contraction slightly (Fig. 2a), and stage I is not detected in the double-log plot (Fig. 2b).

4. Summary

We successfully reproduced tertiary creep behaviors by differing experimental approaches on ring shear apparatus. Our observations highlight a hitherto little-studied aspect of the Voight model, which is competent to describe an amount of accelerating behaviors preceding diverse material failures spanning multiple scales. They provide insights into the physical processes controlling failure and the basis for failure forecasts. We detected the variability of key parameters in the Voight model, which may reflect the evolution of dominant shear mechanisms when a material is approaching failure. We infer that the initial shear deformation in a lower displacement portion is more distributed accompanied by a small α value, then the shear starts to be localized with a larger corresponding α value.

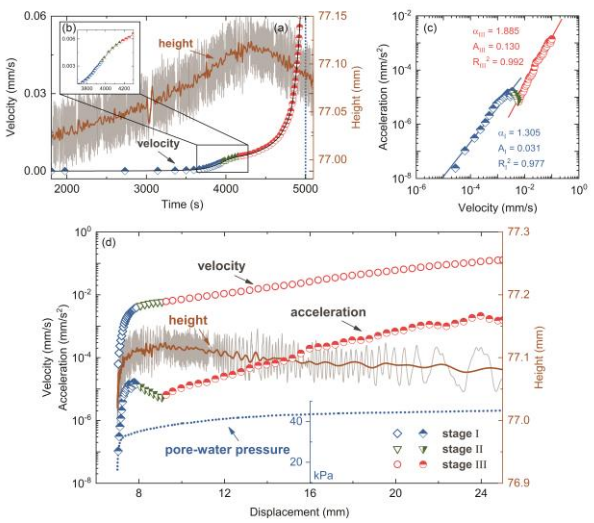

Figure 1. The kinematic features and height variation of the Kinokawa sample in a PWPC test, note the piece-wise log-linear model of velocity and acceleration in Fig. 1c.

Acknowledgments

The first author would like to express his special thanks of gratitude to Prof. Toshitaka KAMAI and Dr. Issei DOI for their insightful discussions and suggestions, and to Mr. Chao HUANG for his consistent support on experimental work. Financial support for this study was partially provided by a New Exploratory Research Grant (2020H-03) from Disaster Prevention Research Institute, Kyoto University.

Reference

Bell, A.F., 2018. Predictability of landslide timing from quasi-periodic precursory earthquakes. Geophysical Research Letters, 45, 1860-1869.

Saito, M., Uezawa, H., 1961. Failure of soil due to creep. In: Proceedings of the 5th International Conference on Soil Mechanics and Foundation Engineering, Montreal, pp. 315-318.

Voight, B., 1988. A method for prediction of volcanic eruptions. Nature, 332: 125-130.

Voight, B., 1989. A relation to describe rate-dependent material failure. Science, 243: 200-203.

Wang, G., et al., 2010. Shear-rate-dependent strength control on the dynamics of rainfall-triggered landslides, Tokushima Prefecture, Japan. Earth Surface Processes and Landforms, 35: 407-416.

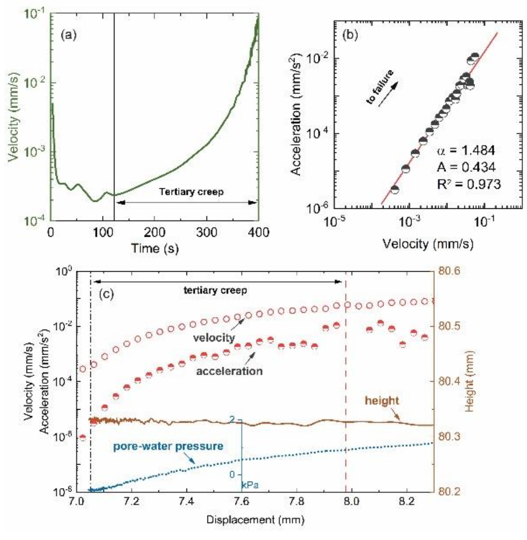

Figure 2. The kinematic features and height variation of the Kinokawa sample in a SSC test, note the divergence in double-log plot was not identified (Fig. 2b).