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Pre-failure Kinematics Strongly Modulated by Shear Localization: An Experimental Study and Its Implication for the Failure-time Forecast of Landslide

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1. Introduction

Failure-time forecast is a critical and significant goal in landslide science regarding disaster prevention and mitigation, which requires knowledge of geological complexities, material properties, hydrological variations, and other external conditions. Landslides exhibit an extensive variety of kinematics as the materials response to these inter-related variables and factors, which make the failure-time forecast a difficult task. There are, however, well-documented landslide cases, showing accelerating movement over timescales of weeks to decades. Such accelerating behavior universally arises in various forms of failure and natural phenomena, which is commonly perceived as precursory signals to forecast time to failure. A series of phenomenological models has been pioneered by several Japanese scientists (e.g., Saito and Uezawa, 1961; Fukuzono, 1985) to describe the accelerating movements of landslide or other material. By simulating rainfall-triggered landslides in a large flume, Fukuzono (1985) found that surface velocity is proportional to the acceleration in double-log plot in the vicinity of failure. This finding was generalized by the Voight model ($\ddot{\Omega} = A\dot{\Omega}^{\alpha}$) in which Ω denotes measurable quantities (e.g., displacement, tilting angle, acoustic emission count), and dot refers to time derivation (Voight, 1988). Two controlling parameters of α and A, defined by accelerating trend of the quantities, are representative of kinematics prior to major failure. However, this model does not take account of material behavior and failure mechanism, and the physical controls on the parameters (α and A) are unknown. Meanwhile, the picture of the connection between the Voight model and the landslide failure process is far from complete. We address these questions by simulating accelerating creep of soils with novel ring-shear configurations and separating out the quantifiable effects on the values of α and A.

2. Materials and methods

Four types of soil samples were prepared including Silica sand No.7 (abbreviated as SS), and three mixtures consisting of mixing Silica sand No.7 and Bentonite. The total weight ratio of bentonite was varied as 10%, 20%, and 30%, and the mixture samples are termed as M_1, M_2, and M_3, respectively. These samples were employed to change the soil property from sandy material to clayey material.

In this study, ring-shear configuration (DPRI-5) was employed to simulate landslide initiation and activation that are triggered by loading or incision at the toe (increase in shear stress). Total normal stress and shear stress were applied on the sample to simulate in-situ stress state of a given slope before shear test. Then samples were brought to failure by increasing shear stress. To simulate reactivated landslide where shear failure occurred along pre-existing shear zone or sliding surface, shear tests were performed repeatedly, and the soil samples were re-consolidated with complete dissipation of pore-water pressure before the next test.

3. Results

The pre-failure kinematic features were analyzed both in time domain and displacement domain, and the typical kinematic patterns were recognized and documented according to types of time-velocity curve and the relationships between velocity and acceleration in double-log plot.

For the first-time failures, velocity curves fluctuated in tests on SS sample and the kinematic pattern is described as “multi-accelerations”, and SS samples behaved the most significant volumetric variation before shear failure (Fig. 1). By contrast, both the variations in velocity curve and volume curve diminished gradually with the increase in clay content of the sample. Time-velocity curve was relatively smooth for clayey samples, which suggest a more accurate α value for failure-time forecast.

In addition, it was found that the pre-sheared sample frequently manifested a smooth time-velocity curve. The volumetric changes during shear largely reduced for pre-sheared sample irrespective of the types of material and a relatively unchanged α-value is favored (Fig. 2).

4. Summary

In brief, this study provides findings of a laboratory-based examination on a variety of soils by simulating landslide initiation and reactivation. Specifically, pre-failure kinematic behavior was observed and critical parameters of the Voight model were examined. The main conclusions could be summarized as follows.

1) Pre-failure kinematics was in association with the volumetric change in samples. The relatively invariant volume might indicate more localized shear deformation and less asperities.

2) The localized shear zone strongly regulated pre-failure kinematics, which might be attributed to the starting heterogeneity introduced by the pre-sheared history.

3) The variability of α might be related to the process of shear localization.

The observations and analyses indicated that the process of shear localization primarily controls the pre-failure kinematics, and more accurate failure-time forecast could be obtained when the deformation is more localized. These results could improve the understanding of progressive failure process and provide more information for the early warning criteria of types of landslides.

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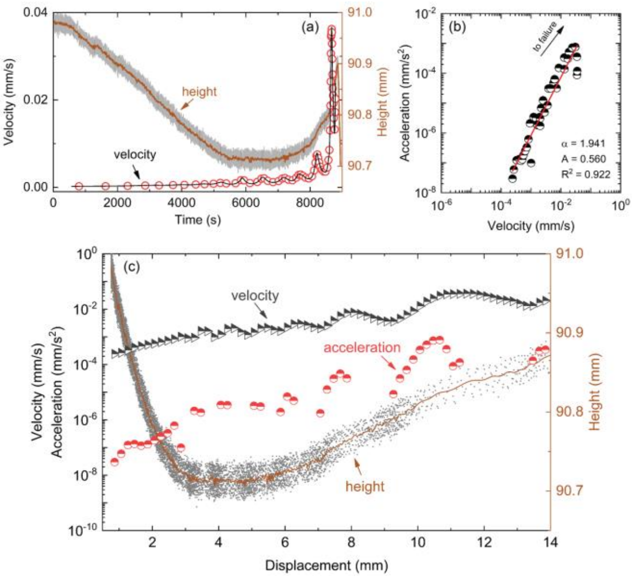

Figure 1. Kinematic features and height variations for SS sample experiencing the first-time shear failure.

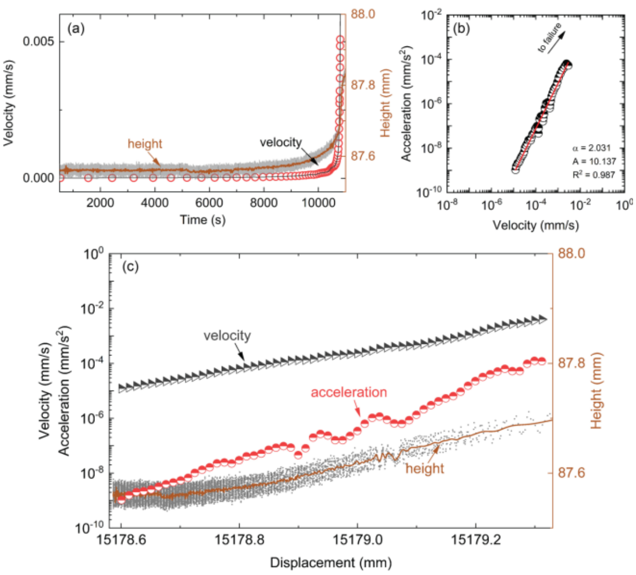

Figure 2. Kinematic features and height variations for SS sample experiencing the repeated shear failure.