Commun Nonlinear Sci Numer Simulat 19 (2014) 3346–3361

Contents lists available at ScienceDirect

Commun Nonlinear Sci Numer Simulat

journal homepage: www.elsevier.com/locate/cnsns

Dynamics of landslide model with time delay and periodic parameter perturbations

Srđan Kostić [a,*], Nebojša Vasović [b], Igor Franović [c], Dragutin Jevremović [d], David Mitrinovic [e], Kristina Todorović [f]

[a] *Department of Geology, University of Belgrade, Faculty of Mining and Geology, Đušina 7, 11000 Belgrade, Serbia*
[b] *Department of Applied Mathematics, University of Belgrade, Faculty of Mining and Geology, Đušina 7, 11000 Belgrade, Serbia*
[c] *Department of Theoretical Mechanics, Statistical Physics, and Electrodynamics, University of Belgrade, Faculty of Physics, Studentski Trg 12, 11000 Belgrade, Serbia*
[d] *Department of Geotechnics, University of Belgrade, Faculty of Mining and Geology, Đušina 7, 11000 Belgrade, Serbia*
[e] *Institute for the Development of Water Resources "Jaroslav Černi", Jaroslava Černog 80, 11226 Belgrade, Serbia*
[f] *Department of Physics and Mathematics, University of Belgrade, Faculty of Pharmacy, Vojvode Stepe 450, 11000 Belgrade, Serbia*

ARTICLE INFO

Article history:
Received 11 October 2013
Received in revised form 24 January 2014
Accepted 10 February 2014
Available online 20 February 2014

Keywords:
Landslides
Time delay
Stress perturbation
Rate-and state-dependent friction law

ABSTRACT

In present paper, we analyze the dynamics of a single-block model on an inclined slope with Dieterich–Ruina friction law under the variation of two new introduced parameters: time delay T_d and initial shear stress μ. It is assumed that this phenomenological model qualitatively simulates the motion along the infinite creeping slope. The introduction of time delay is proposed to mimic the memory effect of the sliding surface and it is generally considered as a function of history of sliding. On the other hand, periodic perturbation of initial shear stress emulates external triggering effect of long-distant earthquakes or some non-natural vibration source. The effects of variation of a single observed parameter, T_d or μ, as well as their co-action, are estimated for three different sliding regimes: $\beta < 1$, $\beta = 1$ and $\beta > 1$, where β stands for the ratio of long-term to short-term stress changes. The results of standard local bifurcation analysis indicate the onset of complex dynamics for very low values of time delay. On the other side, numerical approach confirms an additional complexity that was not observed by local analysis, due to the possible effect of global bifurcations. The most complex dynamics is detected for $\beta < 1$, with a complete Ruelle–Takens–Newhouse route to chaos under the variation of T_d, or the co-action of both parameters T_d and μ. These results correspond well with the previous experimental observations on clay and siltstone with low clay fraction. In the same regime, the perturbation of only a single parameter, μ, renders the oscillatory motion of the block. Within the velocity-independent regime, $\beta = 1$, the inclusion and variation of T_d generates a transition to equilibrium state, whereas the small oscillations of μ induce oscillatory motion with decreasing amplitude. The co-action of both parameters, in the same regime, causes the decrease of block's velocity. As for $\beta > 1$, highly-frequent, limit-amplitude oscillations of initial stress give rise to oscillatory motion. Also for $\beta > 1$, in case of perturbing only the initial shear stress, with smaller amplitude, velocity of the block changes exponentially fast. If the time delay is introduced, besides the stress perturbation, within the same regime, the co-action of T_d ($T_d < 0.1$) and small oscillations of μ induce the onset of deterministic chaos.

© 2014 Elsevier B.V. All rights reserved.

---

[*] Corresponding author. Tel.: +381 113219107.
E-mail addresses: srdjan.kostic@rgf.bg.ac.rs (S. Kostić), nvasovic@rgf.bg.ac.rs (N. Vasović), igor.franovic@gmail.com (I. Franović), jevremovic@rgf.bg.ac.rs (D. Jevremović), davidmitrinovic@yahoo.com (D. Mitrinovic), kisi@pharmacy.bg.ac.rs (K. Todorović).

http://dx.doi.org/10.1016/j.cnsns.2014.02.012
1007-5704/© 2014 Elsevier B.V. All rights reserved.

1. Introduction

Landslides constitute a major geologic hazard of strong concern in most parts of the world, posing a serious threat to highway, railway and residential areas. They commonly occur in slopes of different geological and structural setting, and can be triggered by various external factors, such as floods, earthquakes or volcanic eruptions [1]. In order to occur, forces acting on a slope must overcome the friction strength along a possible sliding surface. The traditional way to asses whether a slope is safe or not relies mainly on the use of factor of safety by assuming a limit equilibrium of the soil [2,3]. This analysis commonly uses a simple static Coulomb failure criterion, where shear strength depends on the cohesion c and the angle of internal friction φ [4]. Here, the constant solid friction coefficient is interpreted as an effective average friction coefficient. This failure criterion simply requires reaching a critical stress threshold τ when instability occurs [5]. However, this failure model alone does not explain the time-dependent nature of the failure threshold and it holds only for $V = 0$. This temporal dependence of friction along a rough sliding surface was firstly observed in rock mass, and it has a significant impact on the earthquake nucleation [6]. Apparently, real observations, as well as laboratory experiments, indicate temporal logarithmic increase of friction coefficient during the interseismic interval or quasistationary contact between the block and rough surface in the Burridge–Knopoff model [7]. This type of friction is well described by Dieterich–Ruina rate-and state-dependent friction law, which has been studied extensively for rock joints [8–12]. Besides these experiments for dry rock joints, Skempton [13] observed similar behavior of clays in the ring shear tests, for much slower sliding rate ($V < 0.01$ mm/min), comparing to the results obtained for Burridge–Knopoff model [8,14,15]. Following the results of Skempton [13], it is reasonable to assume that Dieterich–Ruina rate-and state dependent friction law, with logarithmic increase of friction coefficient during the quasistationary contact, also holds for the landslides. Indeed, Chau [16] suggested that Dieterich–Ruina friction law with one state variable can be used to model landslides that occur in natural infinite slope along a plane of weak surface, such as a persistent rock joint, a rock joint filled with wet gouge or soil or a soil interface. Some years later, further research conducted by Chau [17] showed that two state variables are often needed for a more complete description of the shear stress evolution with deformation, motivated by the experiments on quartzite [9], dolomite [18] and granite [12].

Triggering and propagation of shallow landslides is commonly modeled by using a discrete element method [19] or a molecular dynamics approach [20]. In this paper, following the suggestion of Chau [16] and Helmstetter et al. [1], we assume that the sliding process could be described by a single sliding block moving along the rough surface. In particular, we model a landslide as a block resting on an inclined slope forming an angle φ with respect to the horizontal [21–23]. This phenomenological model describes only the landslides with translational slope failures, which can be idealized by infinite slope assumptions like the Vaiont landslide or La Clapiere landslide [1]. Furthermore, we assume that a pre-existing weak plane exists within the slope, and that a landslide occurs as a consequence of the unstable slip of a creeping slope when it is subject to small external perturbation [22,24,25].

As for the nature of friction between the block and the rough surface, we suppose that it could be described by Dieterich–Ruina friction law, but with only one state variable. The effect of the other state variable, as well as the delayed increase in frictional strength, is modeled by introducing the time delay parameter T_d in friction term. This kind of analysis was already applied for the earthquake nucleation model in our previous research [26]. Another reason for inclusion of time delay in friction term is that the delayed increase of static friction coefficient is observed in laboratory experiments, as well as in the quiescent period of seismic stress drop during the recurrence interval [6]. By assuming the analogy between the landslide faults and tectonic faults [27–29], it is plausible that this feature is also inherent for the friction coefficient along the sliding surface. It has to be emphasized that our approach here differs from the research on spring-block Burridge–Knopoff model of earthquake nucleation, primarily because gravitational pull is considered instead of spring–slider system.

Besides the introduction of time delay, the second part of the analysis included the external triggering effect of earthquake, by assuming periodic sinusoidal perturbations of the initial shear stress s_0. The sinusoidal earthquake signal could correspond to long duration shear seismic wave [28,30], or it could be generated by non-natural sources such as vehicle traffic [28]. As far as the authors are aware, this analysis is new and the seismic impact on landslide dynamics has not been investigated in this way so far. However, similar analysis was conducted for some biological systems [31], where periodic

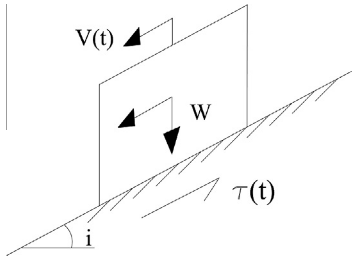

Fig. 1. The single-block model of landslide on an inclined slope with velocity $V(t)$ under gravitational pull.

Download English Version:

https://daneshyari.com/en/article/759047

Download Persian Version:

https://daneshyari.com/article/759047

Daneshyari.com