საქართველოს მეცნიერებათა ეროვნული აკადემიის მოამბე, ტ. 11, №2, 2017
BULLETIN OF THE GEORGIAN NATIONAL ACADEMY OF SCIENCES, vol. 11, no. 2, 2017

Geophysics

Laboratory Research of Landslide Activation Model

Nodar Varamashvili*, Tamaz Chelidze, Marina Devidze*, Victor Chikhladze*, Zurab Chelidze***

* *M. Nodia Institute of Geophysics, Ivane Javakhishvili Tbilisi State University, Tbilisi, Georgia*
** *Academy Member, M. Nodia Institute of Geophysics, Ivane Javakhishvili Tbilisi State University, Tbilisi, Georgia*

ABSTRACT. Simple models of mass movement and seismic processes are important for understanding the mechanisms for their observed behavior. In the present paper, we analyze the dynamics of a single-block and Burridge-Knopoff model on horizontal and inclined slope. We investigated the stick-slip process: triggering of instabilities by recording acceleration and acoustic emission, accompanying the slip events. Besides, we imposed an external periodical mechanical loading by seismic vibrators to initiate sliding of movable (slidable) plate, at several locations of the fixed plate separately or jointly. Simple landslide model triggering effect depends on the spring stiffness, inclination angle, number and location of vibrators, triggering signal amplitude. Triggering effect also depends on the sliding plate exposure (parking) time before beginning of vibration forcing: this test mimics activation of landslides by seismic waves. *© 2017 Bull. Georg. Natl. Acad. Sci.*

Key words: seismic process, landslide, stick-slip, triggering, Burridge-Knopoff, accelerometer, acoustic emission

Landslides are one of the most catastrophic natural processes: they damage and often completely destroy human settlements and affect economic activities, especially in mountains. Recognizing that more than 10% of the earth's population resides in mountains or piedmont regions [1], the threat of landslides is one of the most critical in Caucasus. Many recent and past giant landslides are related to earthquakes and volcanic eruptions [2]. Large-scale experiments and field observations show that the landslide may reveal stick-slip motion [2,3]. Analysis of the experimental data, obtained by investigating of spring-slider system motion led to empirical law, named rate- and state-dependent friction law [4-6].

To analyze the stick-slip process, a mathematical model, proposed by Burridge-Knopoff is also used [7,8] (Fig.1). Sliding blocks are arranged on a massive fixed platform and pulled by the upper platform [9]. The upper platform moves with a constant loading velocity v. The blocks of mass m are connected to the upper plate by linear springs with spring constant k_p. The blocks are also connected to each other by linear springs with springs of natural length a and the constant k_c. Frictional force F acts between the fixed plate and each block.

The Burridge-Knopoff (BK) model is convenient, as it allows simulating many scenarios of rupture without being too expensive in regard to the computing

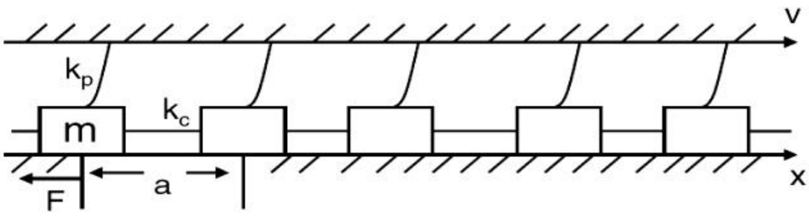


Fig.1. The schematic presentation of Burridge-Knopoff model [9]

time. Thus, we have the ability to explore the parameter space of the system more broadly and observe the emergent dynamics introduced by the friction law.

Experimental Setup

Experiments were conducted on a Burridge-Knopoff laboratory device for the models consisting of one, two or three basalt plates (Fig.2). Registration was made with the help of accelerometers and piezo sensors. On a single sliding plate model three accelerometers were attached to the plate, which recorded *x*, *y* and *z* components. Plates were pulled via the upper platform. The experiments were also conducted for the model of the three sliding plates. To each plate, one accelerometer was attached, which measures the x component of the acceleration. The pulling force of the upper platform was also recorded, using the digital sensor, fabricated in our laboratory. Accelerations, acoustic emissions and pulling force recording are presented in Fig. 3. The information was recorded on the 8-channel oscilloscope PicoScope 4824.

To study the phenomena of stick-slip and triggering on BK model under the influence of gravitational forces, we assemble laboratory equipment with an inclined and horizontal fixed plane (Fig. 2). AE sensors were attached to the upper and lower corners of the large (fixed) plate and accelerometers were attached to the sliding plate. The sliding block was held at rest during some time (repose, parking time) on the fixed plate, which was inclined at the angle of inclination close to, but still less than critical. Triggering forcing was applied to a seismic vibrator, attached either to the sliding or to the fixed (immovable) plate. On the fixed plate we can attach seismic vibrators at 8 locations with any configuration. In experiments the inclination slope of fixed board was measured.

We carried out one series of experiments with the inclined fixed plane for different locations of the triggering source (vibrator). Periodic external impact was applied to the fixed (immovable) plate. Forcing perform seismic vibrators, located at one of the 6 differ-

Fig. 2. Experiments on the Burridge-Knopoff (BK) model with registration of accelerations, acoustic emissions and pulling force: 1. pulling force measuring dynamometer; 2. upper (movable) platform; 3. Picoscope; 4. acoustic sensor; 5. immovable (static) plate; 6. movable (slidable) plate; 7. power supply; 8. pulling system.

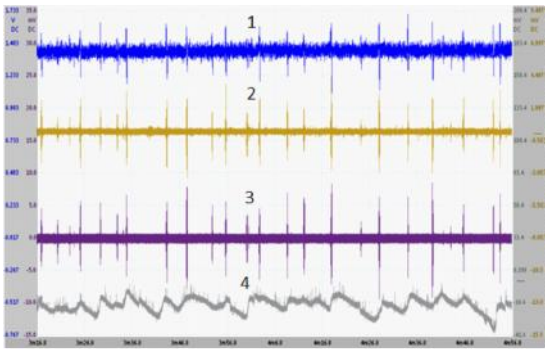
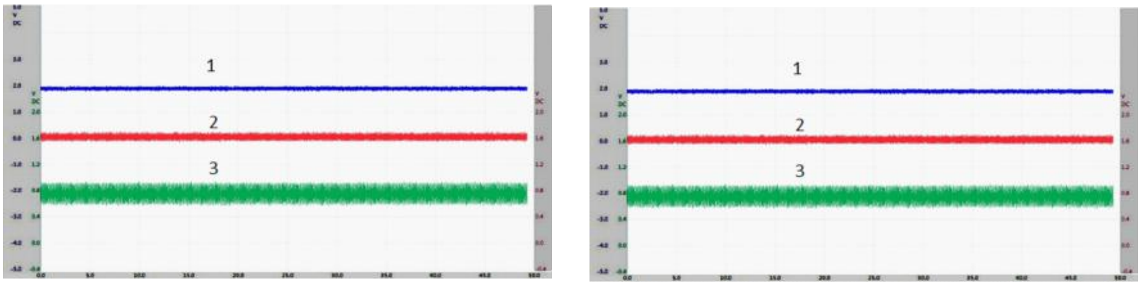


Fig. 3. The single plate BK-system experiments: recordings of accelerometers, acoustic emission and pulling force: 1 – acceleration; 2, 3 – acoustic emission; 4 - pulling force.



a. b.

Fig. 4. Recordings of 3 components of the accelerometer (1 -along the movement; 2 – across the movement; 3 – vertical direction): a) seismic vibrator is placed on the rear surface of the fixed plate (there is no sliding), b) the seismic vibrator is placed on the upper surface of the fixed plate.

ent points on the external surface of the plate and 2 points on the rear surface of the plate.

In all experiments we vary frequency on seismic vibrator as 1, 2, 3, 4, 5 Hz. Maximal voltage at the vibrator was ~8 V.

When seismic vibrator is attached to the upper surface of the immovable plate (tilted at the angle 26.65°), the slidable plate starts slipping at the frequency of 5 Hz, in a few (1-2) minutes after switching the seismic vibrator on. The longer we keep the sliding plate fixed before application of mechanical forcing, the longer the vibrator must operate to start sliding. When seismic vibrator was placed far enough from the sliding plate position, triggering period increased noticeably (5-10 minute range). When seismic vibrator was attached to the rear surface of the fixed plate, even a few tens of minutes (in some experiments) could not trigger plate slipping.

We found also that the change of environment (room) humidity h and accordingly, the sliding surfaces moisture, changes the slip critical angle from 26.65° at $h\approx28\%$ to 28.90° at $h\approx35\%$. The experiments results were fundamentally the same, but the slipping critical angle changed (increased) significantly, probably due to additional surface tension of water films.

Fig. 4 shows that when the vibrator is applied to the upper or rear surface of the fixed plate, the accelerometer on the small sliding plate shows different perturbation amplitude, needed for slip initiation. As can be seen, the strong disturbance, applied to the upper surface, triggers sliding and the same impact, applied to rear surface does not cause triggering.

Lastly, we conducted series of experiments with a fixed plate, inclined at the angle 28.90° (i.e. close to the critical tilt angle), for different exposure (parking) times (1, 10, 20, 30 sec). The results of experiments (Fig.5) show that the increase of the exposition time of the sliding block causes the growth of the triggering time duration, but the effect is not well expressed. Future experiments with a longer exposure times are necessary for obtaining reliable results.

Besides, it is necessary to study systematically the impact of such factors, as humidity, sliding surfaces conditions, amplitude of the triggering signal, etc. to get more or less full pattern of landslide activation by mechanical vibration.

Conclusions

In the paper, we studied experimentally the stick-slip dynamics of a single-block and Burridge-Knopoff

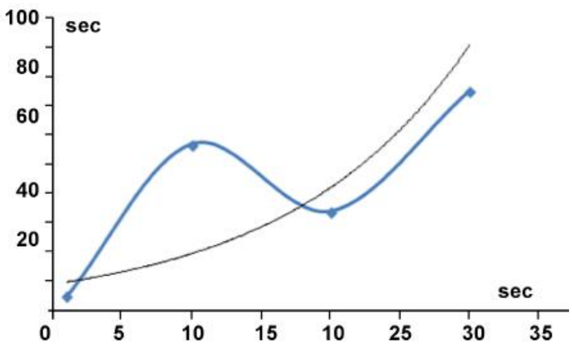


Fig. 5. Sliding plate repose time (horizontal axis) versus triggering (vibration) duration, necessary for initiation of slip (vertical axis), for four different exposition times. The dotted line is an exponential trendline.

model on horizontal and inclined fixed block. We investigated triggering of instabilities by recording acceleration and acoustic emission, accompanying the slip events. Besides, we imposed an external periodical mechanical loading by seismic vibrators at several locations of the fixed plate separately or jointly and studied the impact of such forcing on the sliding plate movement. Triggering effect revealed by this simple landslide model depends on the spring stiffness, inclination angle, number and location of vibrators, triggering signal amplitude and moisture of the sliding surface. The greater the distance from the vibrator to a sliding plate, the more time is needed for triggering slip. At attaching seismic vibrator to the fixed plate's rear surface triggering event does not take place at all. Along with the growth of the sliding plate repose time triggering time increases also. We guess that by attaching seismic vibrator on the upper surface, we arise intensive surface waves, which (as in the case of an earthquake) cause a sliding plate perturbation and triggering (slipping). By attaching seismic vibrator to the rear surface of the fixed plate, smaller amplitude perturbation reaches the sliding plate, which cannot trigger slip. We show that triggering effect also depends on the sliding plate exposure (parking) time before beginning of vibration forcing: this test mimics activation of landslides by seismic waves.

In order to understand better the physical mechanism of triggering we need more powerful source of forcing and carrying out experiments in various experimental conditions.

Acknowledgement. This work was supported by Shota Rustaveli National Science Foundation grant, FR/258/9-160/13, 2014 and #216732, 2016.

გეოფიზიკა

მეწყრების აქტივაციის კვლევა ლაბორატორიულ მოდელზე

ნ. ვარამაშვილი*, თ. ჭელიძე, მ. დევიძე*, ვ. ჩიხლაძე*, ზ. ჭელიძე***

** ივანე ჯავახიშვილის სახელობის თბილისის სახელმწიფო უნივერსიტეტი, მიხეილ ნოდიას სახელობის გეოფიზიკის ინსტიტუტი, თბილისი, საქართველო*

*** აკადემიის წევრი, ივანე ჯავახიშვილის სახელობის თბილისის სახელმწიფო უნივერსიტეტი, მიხეილ ნოდიას სახელობის გეოფიზიკის ინსტიტუტი, თბილისი, საქართველო*

მასების მოძრაობის და სეისმური პროცესების მარტივი მოდელები მნიშვნელოვან როლს თამაშობენ მათი მექანიზმების შესასწავლად. წარმოდგენილ სტატიაში გაანალიზებულია ჰორიზონტალურ და დახრილ სიბრტყეზე ზამბარა-ბლოკის და ბურიჯ-კნოპოვის მოდელის დინამიკა. ჩვენ ვიკვლევდით სტიკ-სლიპის პროცესს, არამდგრადობების ტრიგერირებას, სრიალის თანმხლები აკუსტიკური ემისიის ჩაწერის საშუალებით. ასევე ხდებოდა თითოეული მოსრიალე ბლოკის აჩქარების ჩაწერა აქსელერომეტრების საშუალებით. ჩვენ, სეისმური ვიბრატორების საშუალებით, შეგვიძლია მოვდოთ გარეშე პერიოდული მექანიკური დატვირთვა მოსრიალე ფილაზე

და/ან უძრავი ფილის რამდენიმე წერტილში ცალ-ცალკე ან ერთად. მეწყრის მარტივი მოდელის ტრიგერირების ეფექტი დამოკიდებულია ზამბარის სიხისტეზე, დახრის კუთხეზე, ვიბრატორების რაოდენობაზე, მათ განლაგებასა და ტრიგერირების სიგნალის ამპლიტუდაზე. ტრიგერირების ეფექტი ასევე დამოკიდებულია მოსრიალე ფილის შეყოვნების (უძრავ მდგომარეობაში ყოფნის) დროზე. ეს კვლევა ასახავს მეწყრის აქტივაციას სეისმური ტალღებით.

REFERENCES

1. Gerrard A.J. (1990) Mountain environments. Belhaven Press, London.
2. De Blasio F. V. (2011) Introduction to the Physics of Landslides. Springer.
3. Helmstetter A., Sornette D., Grasso J.-R., Andersen J. V., Gluzman S., Pisarenko V. (2004) Slider block friction model for landslides: Application to Vaiont and La Clapie‘re landslides. *Journal of Geophysical Research,* **109**, B02409, doi: 10.1029/2002JB002160.
4. Dieterich J.H. (1979) Modeling of rock friction 1. Experimental results and constitutive equations. *Journal of Geophysical Research,* **84**, B5: 2161-2168.
5. Ruina A. (1983) Slip instability and state variable friction laws. *Journal of Geophysical Research,* **88**: 10359-10370.
6. Chelidze T., Lursmanashvili O., Matcharashvili T., Devidze M. (2006) Triggering and synchronization of stick slip: waiting times and frequency-energy distribution. *Tectonophysics,* **424**: 139-155.
7. Matsukawa H. and Saito T. (2007) Friction, Stick-Slip Motion and Earthquake. *Lect. Notes Phys.* **705**: 169–189.
8. Burridge R. and Knopoff L. (1967) Model and theoretical seismicity. *Bulletin of the Seismological Society of America,* **57**(3): 341-371.
9. Varamashvili N., Chelidze T., Devidze M., Chelidze Z., Chikhladze V., Surmava A., Chargazia Kh., Tefnadze D. (2015) Mass-movement and seismic processes study using Burridge-Knopoff laboratory and mathematical models. *Journal of Georgian Geophysical Society,* **18**: 19-27.

Received February, 2017