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Laboratory modeling of landslide and seismic processes triggering

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Abstract

The modern concept of seismic and landslide processes relays mainly on the model of frictional instability. 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 stick-slip process: triggering of instabilities by recording acoustic emission, accompanying the slip events. Also acceleration was recorded on each sliding plate using attached accelerometer. In the case of the inclined slope experimental model, a seismic vibrator, which produces low frequency impact (forcing) was attached to the sliding or/and immovable plate. We can impose an external periodical mechanical loading to sliding plate and at several points of fixed plate individually or together. Simple landslide model triggering effect is depend on inclination angle, numbers of vibrators, distribution and triggering signal amplitude

Introduction

In the last years it has been shown that the triggering of dynamic events by weak external forcing is ubiquitous and is observed in biological systems, lasers, electronic networks, etc. The aim of the study was modeling landslides and landslides' triggering processes. For many countries around the world landslides are one the most severe of all natural disasters, with large humanitarian and economic losses. The earth surface is not static, but dynamic system and landforms change over time as a result of weathering and surface processes (i.e., erosion, sediment transport and deposition). The fast mass-movement has a potential to cause significant harm to population and civil engineering projects. Large-scale experiments and field observations show that the landslide may reveal stick-slip motion [Helmstetter et al., 2004; Fabio Vittorio De Blasio, 2011]. Analysis of the experimental data, obtained by investigating of spring-slider system motion has lead to empirical law, named rate- and state-dependent friction law [Dieterich 1979, Ruina 1983].

To study the stick-slip process, a mathematical model, proposed by Burridge-Knopoff is also used [Burridge R. and Knopoff L. 1967; Erickson et al., 2010, Matsukawa, H., Saito, T., 2007] (Fig.1). Plates are arranged on a massive platform and pulled by the upper platform. The upper plate 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 acts between the lower plate and each block.

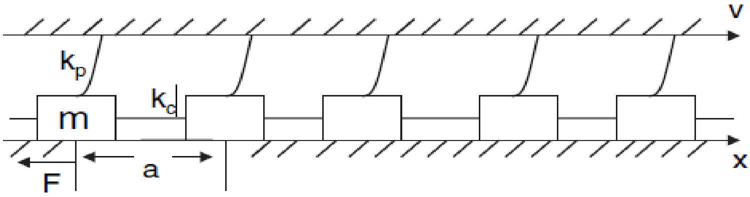


Fig.1. The schematic presentation of Burridge-Knopoff model

The Burridge-Knopoff model is convenient, as it allows us to simulate many scenarios of rupture without being too expensive in regard to computing 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.

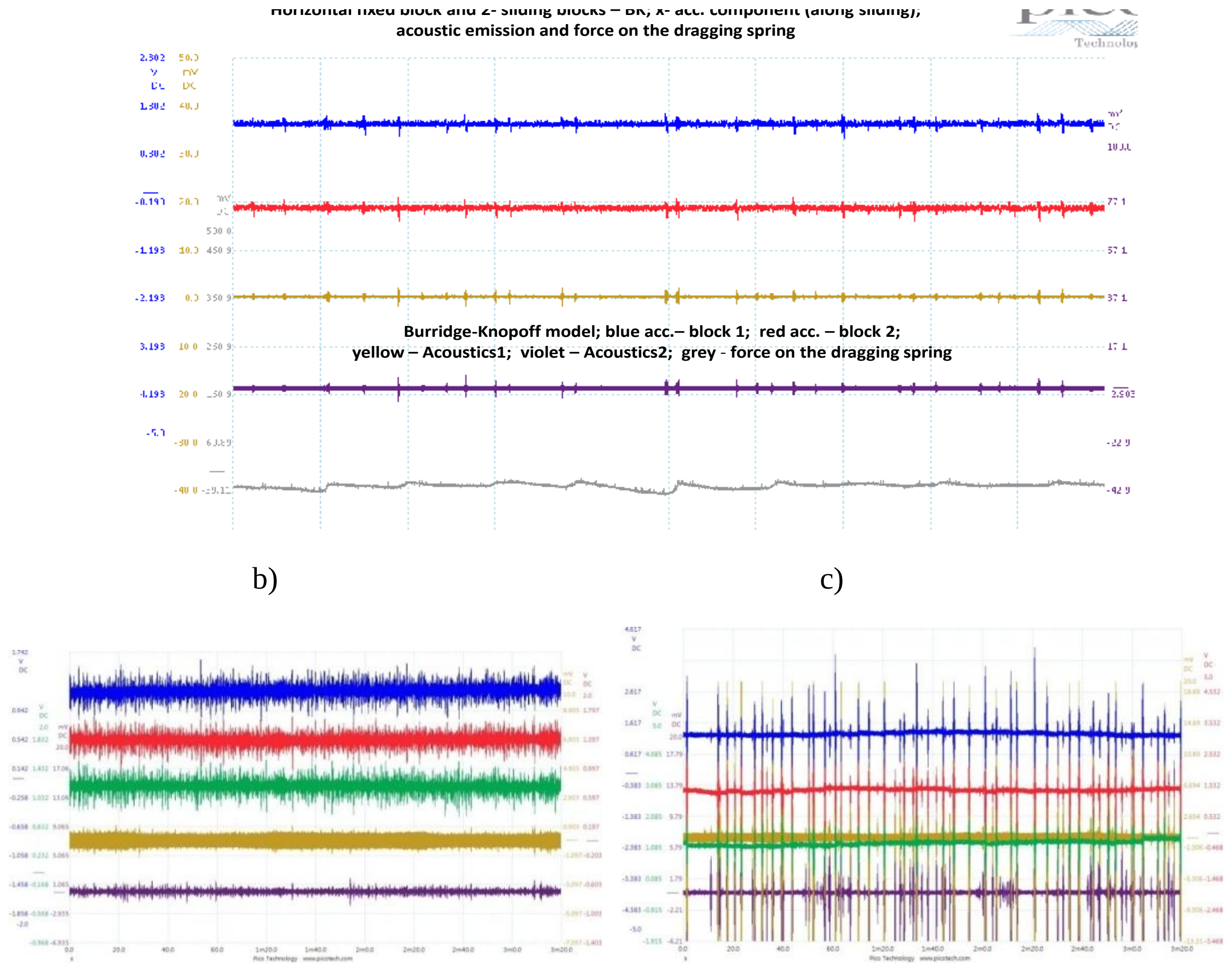
Experimental setup

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. In one plate model three accelerometers were attached on the sliding 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 plates. To each plate was attached one accelerometer, which measures the x component of the acceleration. Was also recorded the pulling force, using fabricated in our laboratory sensor (dynamometer). Accelerations, acoustic emissions and pulling force recording are presented in Figure 3. Mass of the each sliding plate $\approx 335\, g$, spring constants $k_c \approx 360\frac{N}{m}$ and $k_p \approx 155\frac{N}{m}$. Dragging velocity was $v \approx 1\, mm/s$.

Fig.2. The Burridge-Knopoff experiments with accelerations, acoustic emissions and pulling force registration (with clean surfaces of plates and with a layer of sand between the plates)

Burridge-Knopoff stick-slip experiments were conducted for the horizontal position of fixed and sliding plates with clean surfaces and with a layer of sand between the sliding plates (Figure 3 b, c). The information was recorded on a 8-channel PicoScope 4824.

a)



b) c)

Fig.3. The Burridge-Knopoff experiments accelerometers, acoustic emission and pulling force data recordings: blue and red curve – acceleration, yellow and violet acoustic emission and grey – pulling force.

To study the phenomena of stick-slip and triggering of Burridge-Knopoff model under the influence of gravitational forces we collected laboratory equipment with an inclined and horizontal plane (Figure 6). These settings may help to learn the process of landslide stick-slip motion triggering under different conditions on the sliding surface between basalt plates and under the influence of gravitational forces. The acoustic emission and acceleration arising during sliding of upper plate was recorded. To this goal piezo sensors were attached to the upper and lower corners of the large (fixed) plate and accelerometer were attached to the sliding plate. At the critical angle of inclination of the system triggering forcing was applied by a seismic vibrator attached to the sliding or on the fixed (immovable) plate. On the fixed plate we have 8 seismic vibrator attached. Seismic vibrators can have any configuration. The information was recorded on a 8-channel PicoScope. In experiments the inclination slope of boards was measured.

Fig. 4. Laboratory model for series of Burridge-Knopoff experiments under the influence of gravitational forces. Middle figure shows the seismic vibrator attached to the sliding plate.

Experimental results for one- and three plate models under the influence of gravitational force are presented in Fig.7. The critical angle of slip is different for one- and three plate models. Triggering of sliding close to the critical slope, but still stable, is triggered by a seismic vibrator. Namely, the system was left close to the critical angle for 45 minutes. Then, to the attached seismic vibrator a forcing of 20 Hz frequency and 1.6 V intensity was applied. The information was recorded on a 8-channel PicoScope. As can be seen from Fig.7 during the experiment several intermediate slips took place. The beginning of sliding of system of plates was caused by influence of the seismic vibrator. The seismic vibrator played the role of a trigger in slip.

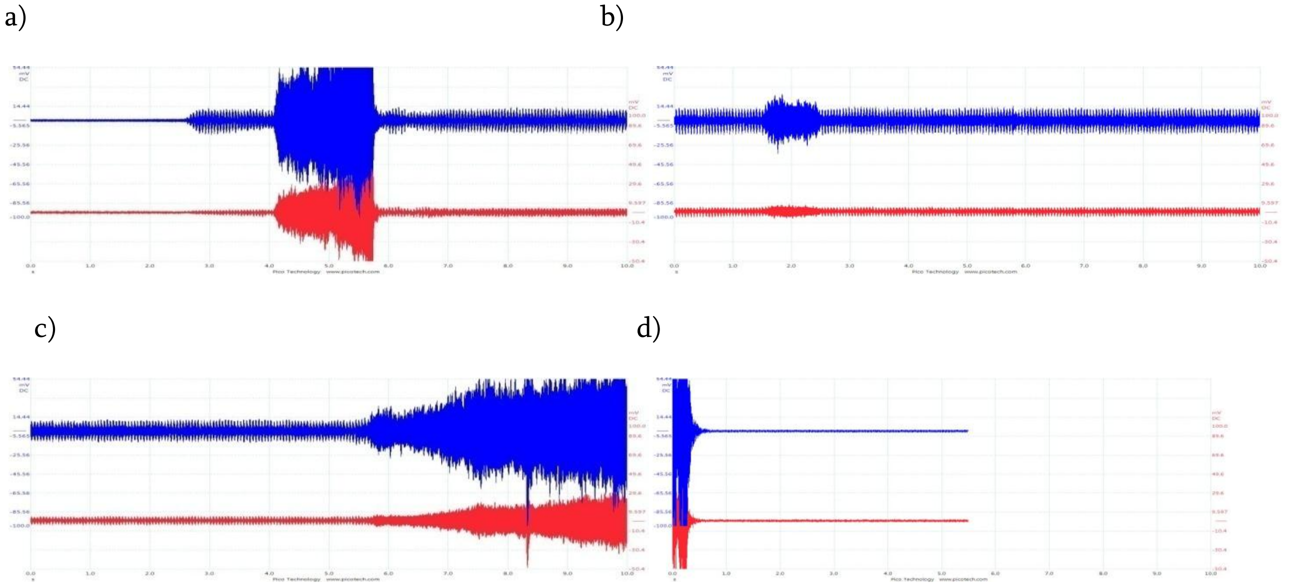


Fig.5. a) The record the acoustic emission occurred on the one-plate model, b), c), d) record the acoustic emission, when sliding occurred on three-plate model.

We carried out experiments on the inclined plane. Periodic external impact is applied to fixed (immovable) plate. Forcing performs seismic vibrators. For the external influence we arrange 6 different points on the external surface and 2 points on the rear surface of the fixed plate. We carried out experiments on the impact, applied at different points of the fixed plate and also in the some cases, on the standby time at the critical angle of the sliding.

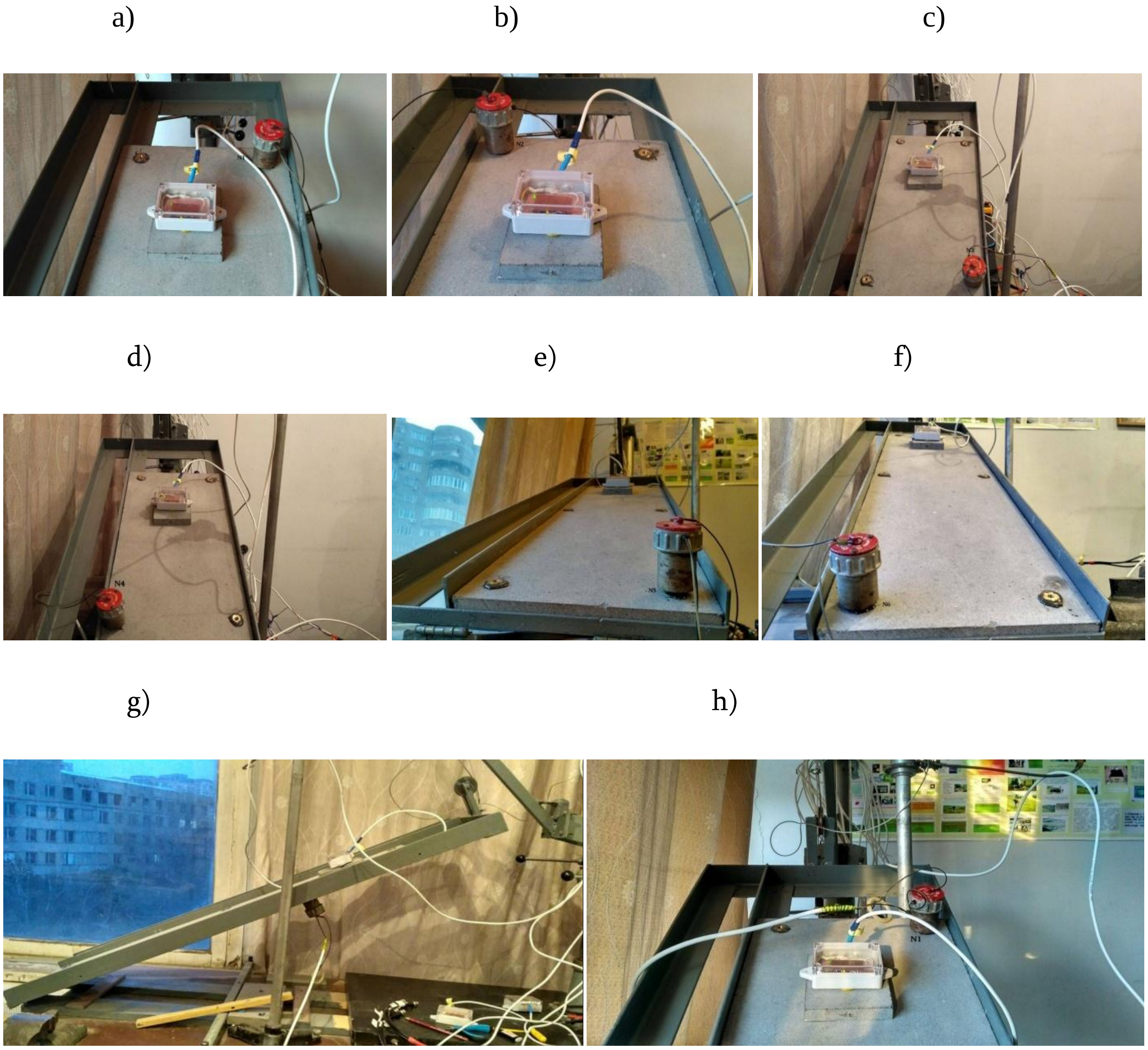


Fig.6. Triggering experiments on the inclined model. a.b.c.d.e.f.g.- seismic vibrator attached at different points. h. experiments by the other critical slip angle.

Experiments, presented in Fig.6 a., b., c., d., e., f., were carried out by attaching seismic vibrators on a upper surface of fixed plate at 6 different points. In all the experiments we changed frequency on seismic sensor in 1,2,3,4,5 Hz range. Maximal voltage ~8V.

In a), b), c), d) experiments the upper plate starts slipping at the frequency of 5 Hz, from1 to 2 minutes after the switching seismic vibrator on. The longer is kept the upper plate, the longer must operate a vibrator to start sliding. The tilt angle was 26.65°.

In e), f) experimentis seismic vibrator is placed far enough from the sliding plate position, therefore triggering period increased noticeably (5-10 minute range).

In g) experiments seismic vibrator attached to the back surface of the fixed plate could not trigger plate even after a few tens of minutes in some experiments. When we switch the vibrator to the c) or d) position slipping begins after 1-2 minutes.

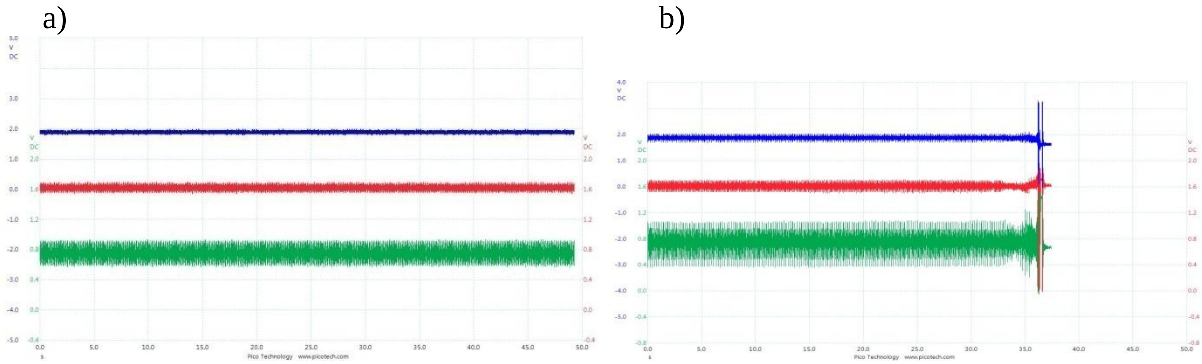


Fig. 7. Recordings of the accelerometer: a) seismic vibrator is placed on the outer surface of the fixed plate according to “d” condition; b) the seismic vibrator is placed on the rear surface of the fixed plate.

Figure 7 shows that when the vibrator is applied on the top and back surface of the fixed plate, different perturbation amplitude reach the accelerometer attached to the moving plate. As can be seen, high values disturbance causes in one case triggering sliding, in another case triggering is absent.

h) A few days later, when it the environment humidity and accordingly, the plate surface moisture was changed (increased), slip critical angle increased from 26.65° to 28.90°. Experiments results were fundamentally the same, but slipping critical angle, probably, due to the additional force of water surface tension between surface water on the fixed and sliding blocks, increased appreciably.

Conclusions

For each experiment we have files of large volume with records of accelerations and acoustic data. Data recording in a digital form was made at the sampling rate 2 kHz. First gravitational experiments taking into account a parking phase (prior to the impact of the seismic vibrator) proceeded about 50 minutes. In gravitational experiments duration of the parking phase under the external periodical influence depends on the location of the seismic vibrators, the frequency and amplitude of the periodic signal, sliding plate delay time, moisture of the sliding surfaces. The greater the distance from the vibrator to a sliding plate, the more activation time is needed for triggering slip. Along with the growth of the sliding plate delay time increases triggering time. By attaching seismic vibrator to the fixed plate rear surface triggering event does not occur at all. We guess, that by attaching seismic vibrator on the upper surface, we arise 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, to the small plate reaches only weak perturbation (Fig 7), which can not cause slip triggering. Thus, more powerful impact (forcing) and relevant experiments are needed.

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მეწყრის და სეისმური პროცესის ტრიგერირების ლაბორატორიული მოდელირება

ნოდარ ვარამაშვილი, თამაზ ჭელიძე, დიმიტრი ამილახვარი, ლევან დვალი

რეზიუმე

სეისმური და მეწყრული პროცესების თანამედროვე კონცეფცია ძირითადად დაფუძნებულია არასტაბილური ხახუნის მოდელზე. მასების მოძრაობის და სეისმური პროცესების მარტივი მოდელები მნიშვნელოვან როლს თამაშობენ მათი მექანიზმების შესასწავლად. წარმოდგენილ სტატიაში ჩვენ ვაანალიზებთ, ჰორიზონტალურ და დახრილ სიბრტყეზე ზამბარა-ბლოკის და ბურიჯ-კნოპოვის მოდელის დინამიკას. ჩვენს ვიკვლევდით სტიკ-სლიპის პროცესს, არამდგრადობების ტრიგერირებას, სრიალის თანმხლები აკუსტიკური ემისიის ჩაწერის საშუალებით. ასევე ხდებოდა თითოეული მოსრიალე ბლოკის აჩქარების ჩაწერა აქსელერომეტრების საშუალებით. დახრილი ექსპერიმენტული მოდელის შემთხვევაში სეისმური ვიბრატორები, რომლებიც იძლევიან მცირე სიხშირის ზემოქმედების საშუალებას, მიმაგრებული იყო მოსრიალე და უძრავ ფილებზე. ჩვენ შეგვიძლია მოვდოთ გარეშე პერიოდული მექანიკური დატვირთვა მოსრიალე ფილაზე და/ან უძრავი ფილის რამდენიმე წერტილში ცალ-ცალკე ან ერთად. მეწყრის მარტივი მოდელის ტრიგერირების ეფექტი

დამოკიდებულია დახრის კუთხეზე, ვიბრატორების რაოდენობაზე, მათ განალაგებაზე და ტრიგერირების სიგნალის ამპლიტუდაზე.

Лабораторное моделирование тригерирования оползневых и сейсмических процессов

Нодар Варамашвили, Тамаз Челидзе, Димитри Амилахвари, Леван Двали

Резюме

Современная концепция сейсмических и оползневых процессов в основном связана с моделью нестабильного трения. Простые модели движения масс и сейсмических процессов имеют важное значение для понимания механизмов их наблюдаемого поведения. В настоящей работе мы анализируем динамику моделей пружина-блок и Бурриджа-Кнопова на горизонтальной и наклонной плоскости. Мы исследовали процесс стик-слип, тригерирование неустойчивостей путем записи акустической эмиссии, сопровождающие события скольжения. Также записывали ускорение каждой скользящей плиты с помощью прикрепленного к плите акселерометра. В случае наклонной экспериментальной модели сейсмические вибраторы, которые производят низкочастотное воздействие, были прикреплены к подвижному и неподвижному плитам. Мы можем наложить внешнюю периодическую механическую нагрузку, на подвижную и/или неподвижную плитам, в нескольких точках по отдельности или вместе. Эффект тригерирования простой модели оползня зависит от угла наклона, числа вибраторов, их распределения и амплитуды сигнала тригерирования.