Seismic and mass-movement processes stimulation modeling

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ABSTRACT

In this abstract, we present the results of laboratory experiments on the mechanical initiation of mechanical plate (slip) with moisture change.
Experiments were conducted on a Burridge-Knopoff laboratory model for the system consisting of one fixed basalt plate, upper moving platform and one, two or three sliding basalt plates (Fig.1). Plates were pulled via the upper platform. Experiments were conducted also on simple spring-slider system. To study the phenomena of stick-slip and mechanical stimulation under the influence of gravitational force we collected laboratory equipment with a inclined and inclined fixed plate. On this both models we can impose an external periodic mechanical loading to a sliding plate and at several points of fixed plate separately or jointly. The data on stimulation of landslide with moisture changing were collected using inclined fixed plate. We could change inclination angle from 0° to 80° as well as the moisture of a slip surface.
Stimulation and synchronization of instabilities in experimental systems were investigated by recording acoustic emission, accompanying the slip events. Besides, to each plate was attached on one accelerometer, which measures the x component of the acceleration. We can also measure pulling force in the spring-slider and Burridge-Knopoff experiments. In experiments Three-axial accelerometer MXR9500G/M and piezo sensors were used. Experiments on the standard spring-slider system and Burridge-Knopoff system subjected to a constant pull and superimposed to it weak mechanical petability force show that at definite conditions, the system manifests the effect of phase synchronization of micro-slip events with the weak periodic excitation and triggering effect by prolonged excitation. The quality of stimulation and synchronization depends on the intensity and frequency of the applied field. With increasing external mechanical forcing one can see reduction of the waiting time before the slip (in gravitational experiments) increasing phase synchronization of the first arrivals (onsets) of stick-slip generated acoustic pulses. In the landslide modeling experiments with changing humidity we see that at low humidity the critical slip angle of slip increases, Evidently, a threshold humidity exists, which facilitates slip process.
We concluded that our laboratory experiments give a sound principal basis for interpretation of field data on the control of seismic and mass-movement regime by relatively weak natural or artificial perturbations.

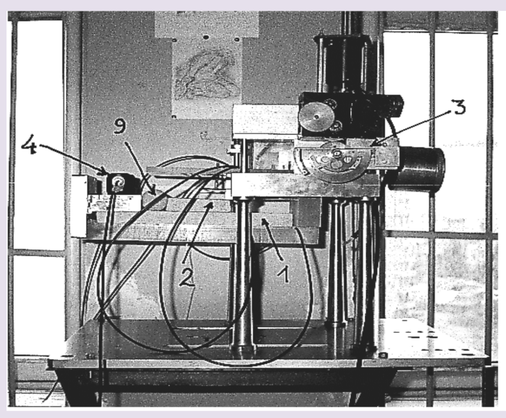
ELECTRICAL TRIGGERING

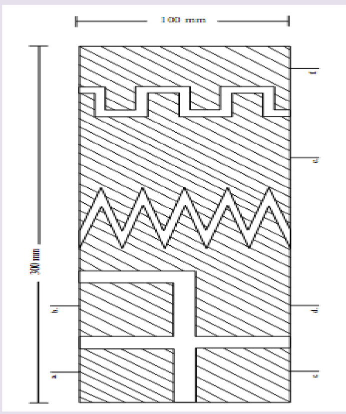
EXPERIMENTAL SETUP

The experimental set up was designed in such a manner that the mechanical system could easily be driven to the critical state where the triggering of mechanical instability by some weak impact such as electrical pulse became more probable. The system consists of two pieces of rock; the upper piece can slip on the fixed supporting Sample.

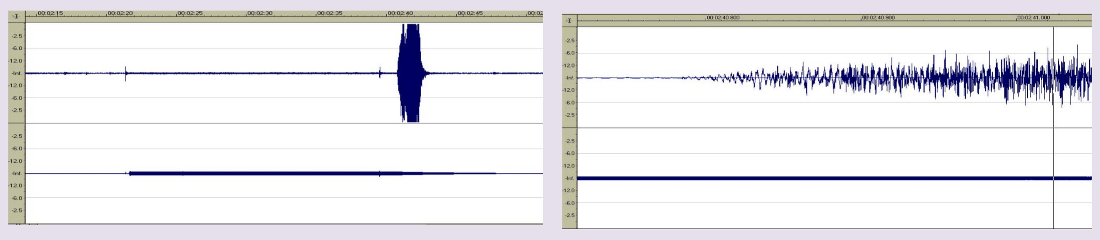
The electrical part consists of a EM pulse generator and acoustic signal amplifier. The signal from the standard generator with amplitude 0.5-5 V is applied to the input of the amplifier and goes out from the output with amplitude up to 1300 V. Another amplifier was designed to record acoustic signals from the sensors, which respond to the slip events.

Electrodes were applied: (a) to the bottom of the supporting sample in a coplanar manner or to the sides of the supporting sample (the first mode); (b) to the upper surface of the sliding sample and the bottom of the supporting one (the second mode). In most cases supporting and slipping blocks were prepared from basalt, these samples were saw-cut and roughly finished. The slipping block has 10cm length, 10cm width and was 2cm thick. The height of surface protuberances for basalt was in range of 0.1-0.2 m. m





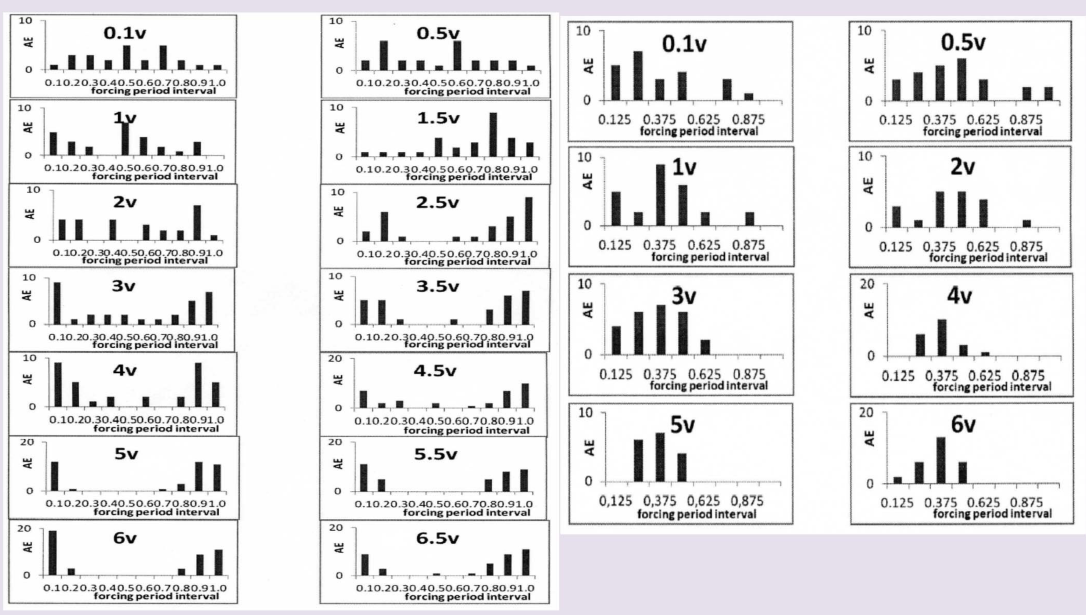
•Mechanical setup for slip initiation on an inclined surface: 1 - supporting (fixed) sample; 2 - slipping sample; 3 – slope regulating unit; 4 - acoustic sensor; 9 – shock absorber.
•The configuration of electrodes, located under the supporting sample.



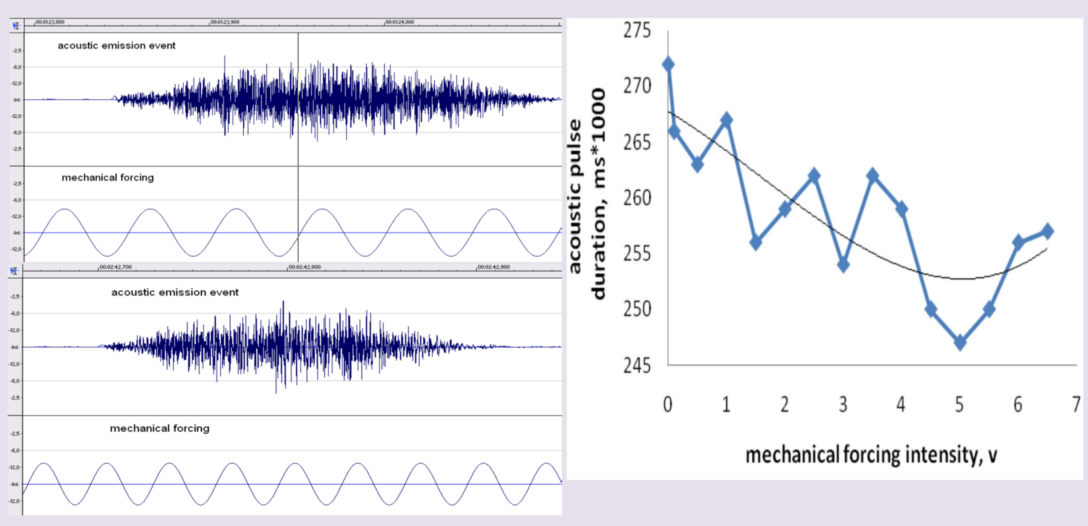
Recording of acoustic emission generated by the electromagnetically initiated slip of the basalt sample (upper traces). Lower trace shows EM pulse switching on (thick lines) and switching off (thin lines) periods. The slip was initiated just after active period; Right panel is the initial part of the same recording for stretched time axis.

MECHANICAL TRIGGERING, SYNCHRONIZATION

We investigated (mechanical) triggering and synchronization of instabilities in experimental spring-slider system by recording acoustic emission, accompanying the slip events; Experimental setup represents a system of two horizontally oriented plates. The maximum dragging force of the order of 4 N was applied to the upper (sliding) plate; in addition, the system was subjected to periodic mechanical perturbations of various amplitude. The mechanical forcing was much weaker compared to the driving force.



•Distribution of acoustic emission onsets relative to forcing period phases (in decimals) for different intensities of normal forcing.
•Distribution of acoustic emission onsets number relative to the forcing period phase (in decimals) for different intensities of tangential forcing.



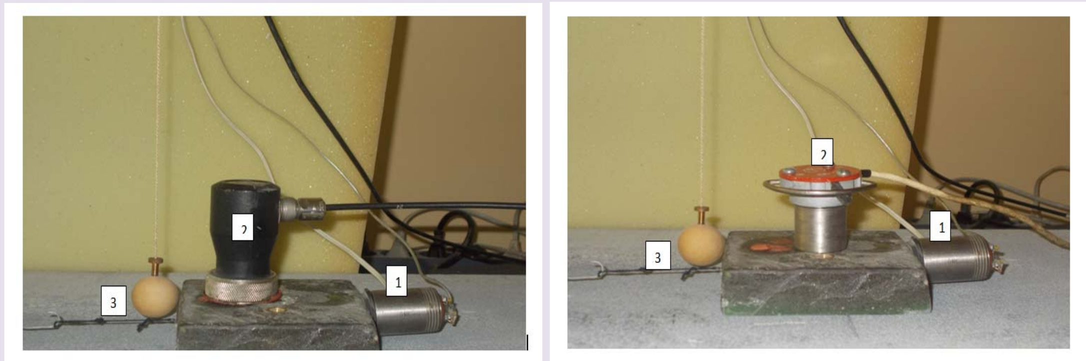
•A single acoustic emission pulse (upper channel) and mechanical forcing (lower channel) on the expanded part of recording shown in Figure. In both cases vibrator was powered by the voltage 4 V: (upper) normal forcing, (down) tangential forcing.

•Mean duration of stick-slip generated acoustic pulses for different intensity of normal forcing, with a trendline.

EVALUATION

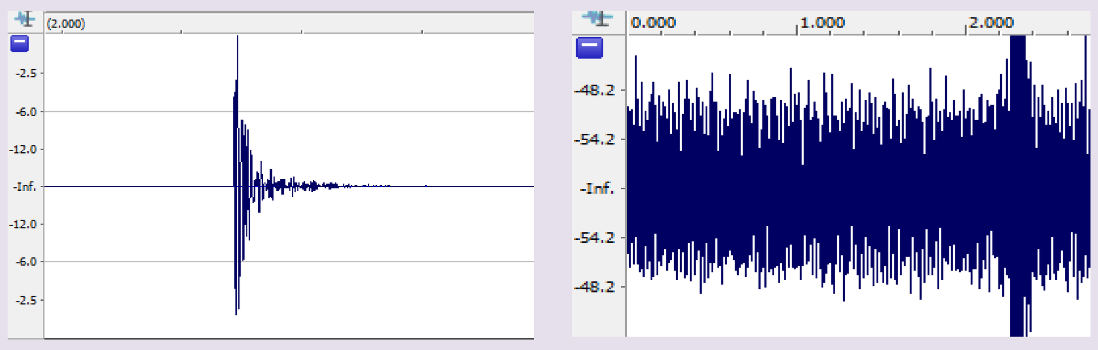
VIBRATOR CALIBRATION WITH PENDULUM

To determine the order of forcing magnitude of the seismic vibrator attached to the upper plate the following experiment was carried out. The impact produced by the collision of the pendulum with sliding (upper) plate was assessed. Mass of pendulum m≈15 g, length of pendulum l≈50 cm. On Figures are presented experiments, when registration was carried out using a piezo sensor or seismic sensor. Pendulum collision with the upper plate was realized from different distances: 1,2,3,4,5,6,7 and 8 cm. Our goal is to calculate force the pendulum is acting on the plate. The magnitude of this force will be different for different collision distances. It is necessary to carry out the following calculations:
We need calculate
1.What height the pendulum reaches at various deviations from the initial positions
2.Corresponding potential energy
3.Speed at collision of the pendulum weight with a plate
4.The value of impact momentum (pulse) which the pendulum passes to the plate (about a half of the full pulse)
5.Finally, knowing the duration of the collision it is possible to calculate the force



•Seismic vibrator (1) is attached to the sliding plate to which 2.5 v voltage is applied. Registration of the acoustic signal is produced using piezo sensor (2). Calibration of the acoustic signal is produced using pendulum (3).

•Seismic vibrator (1) is placed on the sliding plate to which is applied 2.5 v voltage. Registration of the acoustic signal is produced using seismic sensor (2). Calibration of the acoustic signal is produced using pendulum (3).



(left) expanded record of acoustic signal generated during clash of 1 cm deviated pendulum using seismic sensor;
(right) expanded record acoustic signal on piezo sensor under action of seismic vibrator to which 2.5 v voltage is applied with accompanying noise;
(y – axis acoustic signal intensity in dB, x – axis time in ms).

Figure shows recording made by a USB oscilloscope when the pendulum was deviated by 1 cm. On seismic vibrator 2.5 v voltage is applied. At 1 cm deviation the pendulum rises to a height of $h \approx 2.10^{-4}m$, corresponding potential energy equals Ep=mgh. Pendulum speed at collision with a plate $v = \sqrt{2gh} \approx 0.06\ \frac{m}{s}$, the value of pulse which the pendulum delivers to the plate $p \approx 4{,}5.10^{-4}kg.\frac{m}{s}$. From analysis we conclude that the pendulum-plate interaction duration time is t≈0.025 s. Accordingly, the impact force is $F = \frac{p}{t} \approx 2.10^{-2}N$.

Table1. Gradations of the pendulum deviations and corresponding forcing values on the plate

Deviation cm	1	2	3	4	5	6	7	8
Heigh, m	2.10^{-4}	8.10^{-4}	18.10^{-4}	32.10^{-4}	5.10^{-3}	$7{,}2.10^{-3}$	$9{,}8.10^{-3}$	$12{,}8.10^{-3}$
Pendulum forcing, N	2.10^{-2}	$2{,}7.10^{-2}$	6.10^{-2}	$7{,}5.10^{-2}$	8.10^{-2}	11.10^{-2}	13.10^{-2}	15.10^{-2}

As can be seen a the signal resulting from the collision of a pendulum with a plate is clearly recorded in the corresponding channel. Acoustic pulse generated during clash of 1 cm deviated pendulum is shown. Effect of mechanical vibrator is shown on Figure. Seismic vibrator is a bit more far from recording piezo sensor than a location of pendulum collision. The effect on the piezoelectric transducer from the collision of a pendulum with a plate is much stronger than an effect of the seismic vibrator.
Based on Figure we can calculate the ratio of the intensity values of acoustic signal arising at the collision of the pendulum on the plate and the resulting from acoustic vibrator forcing.
As can be seen the amplitude of the acoustic pulse from pendulum clash is approximately -2 dB and the amplitude of (noisy) vibrator forcing is approximately -50 dB. The difference between them is 48 dB, which means that amplitude of a vibrator signal is 300 times smaller than that of pendulum clash. Hence we obtain for 1 cm pendulum deviation:

$$F_v \approx 3.10^{-3}F_q \approx 6.10^{-5}N$$

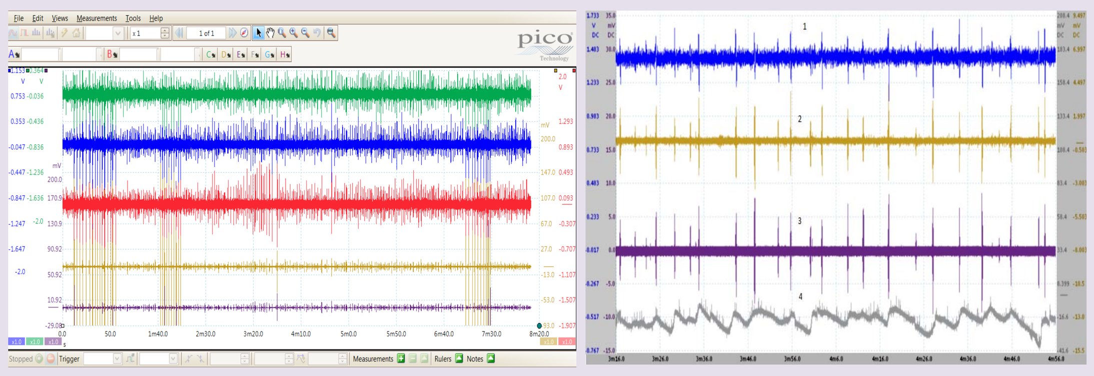
Where F_v is the magnitude of the vibrator forcing on the plate and F_q is the magnitude of the collision force of deflected by 1 cm pendulum.

MASS-MOVEMENT AND SEISMIC PROCESS MODELING

•Experiments on the Burridge-Knopoff (BK) model with registration of acceleration and acoustic emission 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;
•Arrangement of BK model: 1 – static plate, 2 – moving plate, 3 – upper platform, 4 - accelerometer, 5 – spring to upper platform, 6 – spring between slidable plates;
•Inclined experimental device: 1 – static plate, 2 – slidable plate with accelerometer, 3 – seismic (triggering) vibrator, 4 – mechanism for inclination change;

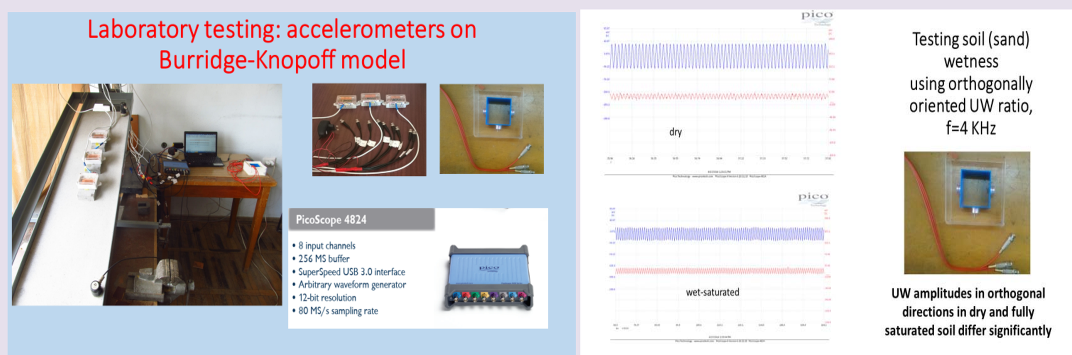
Currently, we carry experiments on a Burridge-Knopoff model in our laboratory. The model consists three basalt plates, which are connected with each other by springs. The basalt plates are pulled using the top moving platform. Plates are also connected by springs on this platform. Pulling speed can be varied from 0.05 mm/sec to 1mm/sec. This model is made to simulate the seismic processes. It is also possible to simulate the seismic processes with this model.

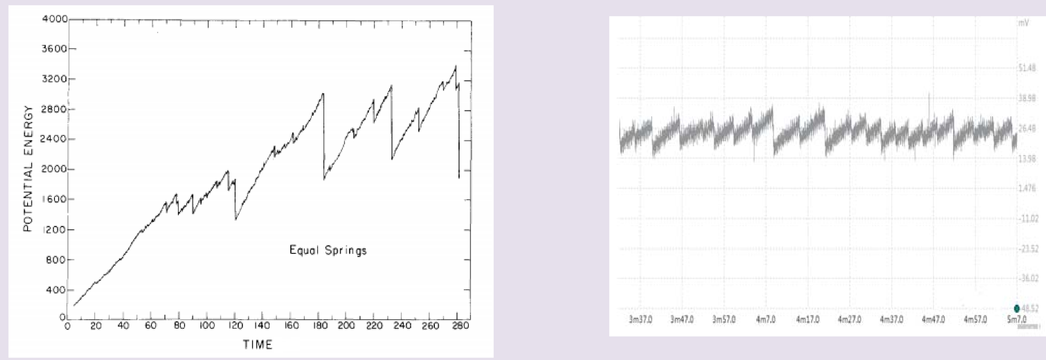
Burridge-Knopoff laboratory model is presented on above figures. We register acceleration of plates using accelerometers. One accelerometer is attached on each plate which detects acceleration along the main movement. Registration of the signal is carried out on 8-channel picoscope. Accelerations were recorded on the first three channels of the picoscope. Registration of the acoustic emission (AE) was done with the help of a piezo sensor. Two sensor were attached to different ends of a large static plate. The fourth and fifth channels were used for recording the AE. The impact was produced by the collision of the pendulum with static (lower) plate. We can calculate the magnitude of pendulum collision force using known methods.



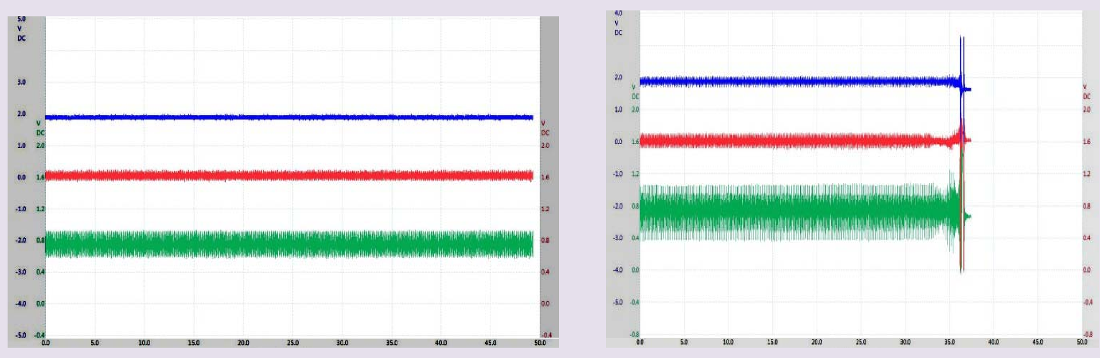
The figure shows recording of the acceleration and acoustic emission on the 8 channel picoscope. In the figure the signals with large amplitude present recordings the pendulum collision on the bottom plate. A series of experiments and data processing is being done on the presented experimental setup.

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

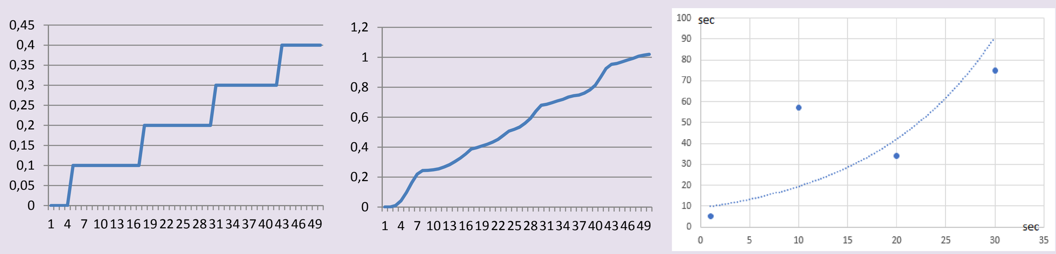




•Left - Potential energy as a function of time for the mass-spring (BK) system with all springs equal (Burridge and Knopoff, 1967)
•Right - Pulling force as a function of time for BK system with all springs equal (our experiment).



Recordings of the accelerometer: (left) seismic vibrator is placed on the rear surface of the fixed plate, (right) the seismic vibrator is placed on the upper surface of the fixed plate.



•Numerical simulation of displacement (ordinate) versus time (abscissa) for one block, •the same calculations carried out for moving the center of gravity of the system in conditional units the Burridge-Knopoff model of four plates (abscissa – time, ordinate – displacement).

•Sliding plate exposition 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.

Landslide modelling experiment: (i) by dry sand critical slip angle is approximately 26° degree; (ii) By moderate saturated sand critical slip angle is approximately 60° degree

conclusions

•Series of strong EM pulses were applied to the mechanical system driven close to the critical state, namely to the (dry) rock sample placed on the inclined supporting sample at the slope angle less than, but close to critical slip angle. The electrical field was applied so that current lines were either parallel (the first mode) or normal (the second mode) to the slip surface. It has been found that in the first mode the EM impact initiates slip with probability P≈0.07 at the voltage ΔV=1.3 kV and with probability P≈ 0.2 at ΔV≈10 kV. On the other hand, in the second mode the application of EM pulse hampers the slip considerably. The upper sample was stable even at the angle, that was larger than the critical one.
•The regular phase shift is observed between the forcing sinusoid and the onsets of acoustic pulses; at the forcing normal to the slip plane, the initiation of motion is concentrated in the area of minimum of the forcing sinusoid, which differs from the case of tangential forcing, when the concentration of AE pulses takes place in the rising section of forcing sinusoid.
•It was also found that an increase of forcing intensity causes shortening of (average) pulse duration.
•Intensity of forcing on the sliding plate is several orders of magnitude less than the applied pulling force and the ratio of the forcing to the main driving force is in the range $10^{-4} - 10^{-8}$ N.
•We investigated: triggering of instabilities by recording acceleration and acoustic emission, accompanying the slip events. Triggering effect revealed by this simple model depends on the spring stiffness, inclination angle, number and location of vibrators, triggering signal amplitude moisture of the sliding surface. The greater the distance from the vibrator to a sliding plate, the more time is needed for triggering 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.

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