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Acoustic pulses detecting methods in granular media

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Abstract

The prevention of loss to life and property due to natural calamities is viewed very seriously in many countries of the world. There are many uncertainties in the forecasting of when a movement in a landslide will occur. Acoustic emission (AE) is a natural phenomenon that occurs when a solid subjected to stress experiences non-elastic deformation – fracturing or stick-slip. Acoustic emissions carry information about location, intensity and mechanisms of deformation occurring in a material. The aim of our research is attempt to construct a sensitive acoustic emission registrator. One of the goals of our experiment is optimization of equipment to use them in the field and work for development of a landslides' acoustic early warning system.

Introduction

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. Landslides are important natural geomorphic agents that shape mountainous areas and redistribute sediment (Sidle And Ochiai, 2006). Large-scale experiments and field observations show that the landslide may reveal a slow steady slip, episodic stick-slip or sudden acceleration.

Problem description

Landslides are sources of considerable hazards for human life, economy and infrastructure in mountainous areas, such as Georgia. This is why understanding of properties, statistics, and dynamics of this process in order to reveal its physical nature, to predict landslides or to decrease mass movement risk is an important scientific and practical problem.

Landslides occur in hills/mountains in response to a wide variety of terrain conditions and triggering processes like heavy rainstorms, earthquakes, floods and unsafe developmental activities. With growing population, urbanization and human interventions in terms of developmental activities over unstable slopes, landslides pose increasing risk to human lives, buildings, structures, infra-structures and environment (**Anderson and Holcombe, 2013)**. Changing climatic conditions manifested in the form of global warming, glacial melting, erratic and uneven rains, extreme temperature conditions etc. are also extending these risks to even unexpected areas. Large scale deforestation along with faulty management has led to increased vulnerability to landslides.

Fig.1. The landslide in Dariali Gorge in northern Georgia, on the Greater Caucasus range 17 May 2014. It severed the road connecting Georgia and Russia causing large economic losses and several deaths

Acoustic emissions (AE) is a natural phenomenon that occurs when a solid is subjected to large enough stress. This external stress, causes fracturing or stick-slip on various scale and a sudden release of sound waves resulting in acoustic/microseismic activity, which can be detected by transducers.AE are transient, high-frequency, elastic waves‘ bursts generated by the rapid release of stored elastic energy. In brittle materials like rocks, crack formation and crack propagation generate AE. In granular materials, frictional sliding and rolling are sources of AE. Another source of AE in the nature is the breaking of roots.

Acoustic emissions carry information about location, intensity, and deformation mechanisms occurring in a material. It is a non-invasive method and gives real-time information on what is happening during deformation. In rock mechanics, AE monitoring has been successfully used to identify various stages of the failure process, such as crack initiation, crack growth, and crack propagation prior to global failure.

Traditional methods of monitoring slope movements have included surface surveying and sub-surface instrumentation techniques. However, many of these methods lack the sensitivity to detect deformation at low pre-failure strain rates. Over 40 years research has been conducted on the use of AE to monitor soil movements. Interesting work has been carried by Chelidze et al., (2012) out. The most notable contributions in terms of field of AE monitoring were provided by Koerner *et al.* (1981) and Dixon *et al.* (2003).

Detecting AE generated by a developing shear surface within a slope is not an easy task. As AE propagates through soil, it suffers from a loss of signal amplitude: attenuation is high in soil because it is a particulate (granular) medium and energy is lost as AE travels across boundaries from one particle to another. The use of a waveguide to provide a path of low attenuation from the source of the AE (within a soil slope) to the sensor (usually situated above ground surface) has become a standard practice in AE research. The presence of a waveguide, typically a metal pipe inserted within an unstable slope, also greatly increases the monitoring ability of the AE sensor.

Dixon *et al.* (1996) outlined two generic types of waveguides; passive and active. A passive waveguide does not introduce additional sources of AE, and thus all detected AE is assumed to originate from the surrounding soil slope. In comparison, the active waveguide uses an annulus of high AE-responsive backfill material around the waveguide. As the slope deforms the waveguide, AE is assumed to originate from the backfill only.

Kousteni (2002) showed that gravel emitted higher levels of AE than sand.

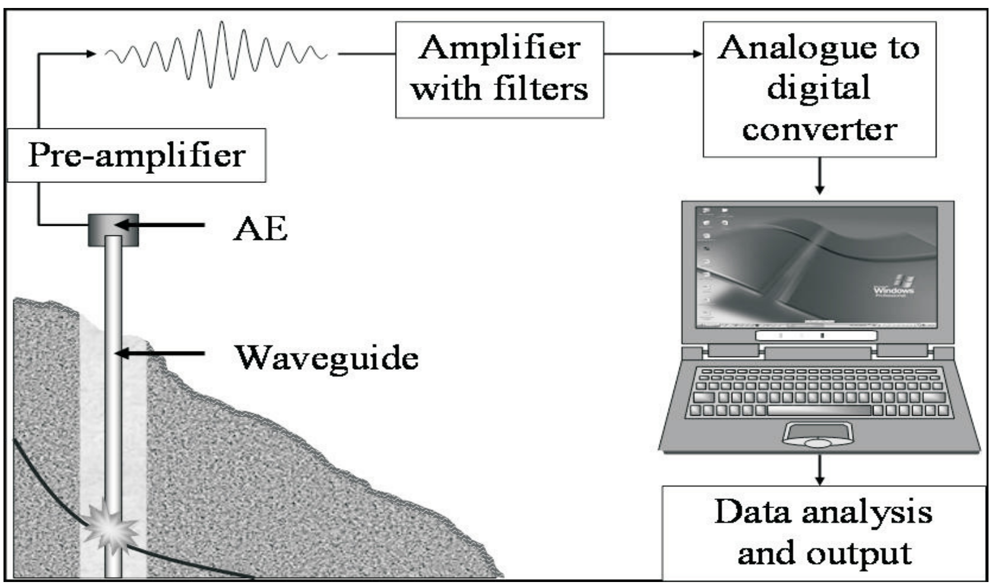


Fig. 2. Components of an AE monitoring system (Dixon et al., 2003)

Figure 2 shows a schematic representation of a typical AE instrumentation system. AE originating from the deformation of a backfill within the active waveguide propagates along a steel waveguide to a piezoelectric sensor secured to the top of the metal waveguide. The AE signal is then amplified by a preamplifier and an amplifier to enable the signal to travel down the lengths of cable without being subsequently affected by background or electrical noise. Finally the AE is converted to a digital signal for subsequent analysis and manipulation using real time data acquisition software.

Experimental setup

The main goal of our study is registration and monitoring of landslide slow motion (creep) by recording the acoustic emission. For this goal we early developed the special equipment (Varamashvili et al., 2013), by which occurred landslide modeling process and registration occurred during this acoustic emissions. The goal of acoustic monitoring is to record acoustic signals generated by preliminary displacement of geologic formations before activation of the fast phase of landslides

The similar technique based on the recording of the acoustics generated by displacement in the gravel coating around acoustic sensor was earlier developed by Loughborough University team, but it demands drilling of relatively deep borehole down to the sliding surface. This procedure is quite expensive. Our objective was to develop a cost-effective version of the mentioned method. The idea is to use two sensitive acoustic probes grounded on different depths, one on the depth of several meters and other close to the day surface. The former probe is the basic and the role of latter one is to distinguish signals of surface origin, which in this case are considered as noise.

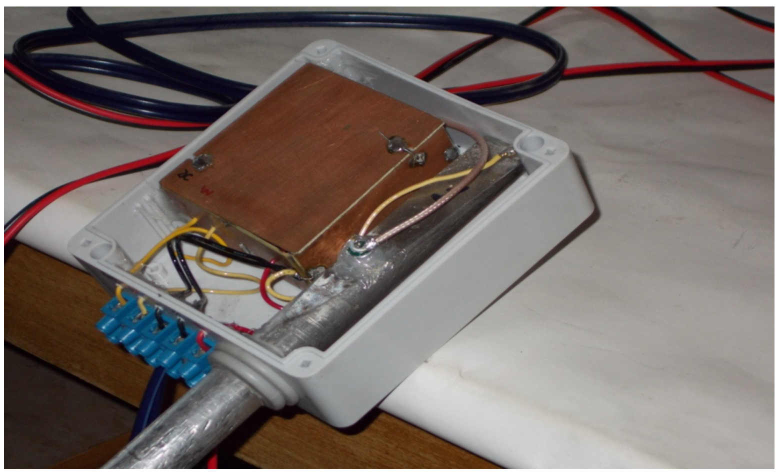


Fig.3. Acoustic sensors

The probes are constructed from thick-wall stainless steel tube (Fig.3) containing acoustic sensor. The length can be chosen according to the depth of investigation by screwing additional sections to the tube containing basic sensor. The length of these sections is 1.5 m; the maximal depth of probe is of the order of 4 m.

The diameter of the tubes is 20 mm and the thickness of the walls is 2 mm. In order to transfer surface acoustic wave without significant loss the contact of sections is performed with maximal accuracy. This ensures strong contact between sections and minimizes acoustic energy losses.

The upper part of the basic probe is manufactured as a cylinder rod with an inclined cut. The precise finish of the cut surface guarantees good contact of acoustic sensor with probe tube. Investigation of various types of acoustic sensors in laboratory led to conclusion that for the frequency range of interest, i.e. frequencies generated by displacements in the gravel coating (5-25 KHz) the best solution is the capacity capsule-microphone, glued with his sensitive membrane side to the surface of the upper end of the probe.

Electronic module consists of low-noise amplifier, buffer amplifiers of output for signal wavetrains and precision peak-integrator and DC voltage output for recording in the data logger. The integrator fixes in its memory the maximal value of obtained signal and after this the signal decays by the rate 5% per minute. Fixing on data logger the readings with the sampling rate 1 per minute allow obtaining the necessary information on the variation of acoustic noise in the time domain. This method allows saving the power, what is important in field conditions. There are two outputs for fixing signal in two different ways. Signal output 1 allows obtaining acoustic waveform recording by application of high quality ADC. It is also possible to record acoustic signals in the real-time regime, when signal from the output 1 is transferred to the USB recording oscilloscope with the input ADC module capable to record acoustic signals up to the frequency 100 KHz. The signal from output 2 can be recorded simultaneously by another channel of the same USB oscilloscope with input set to DC regime.

Registration of acoustic pulses occurring at small shifting of the landslide soil was produced by the acoustic sensor, which was attached to the USB oscilloscope (Fig.4), with which after using special processing software information is sent to computer.

The goal of our experiment the increase in sensitivity of the acoustic sensor by changing its mechanical parts. For this goal plastic small volume was filled with gravel (Fig.4a). At its center was placed aluminum stem with small cross-section, on which was fixed electronic block of the acoustic sensor. In one experiment on an aluminum rod was fixed aluminum radiator (Fig4b), which increases the useful area of the sensor and therefore, in our opinion, its sensitivity. In a second experiment, nothing was fixed to the aluminum rod.

a. b.

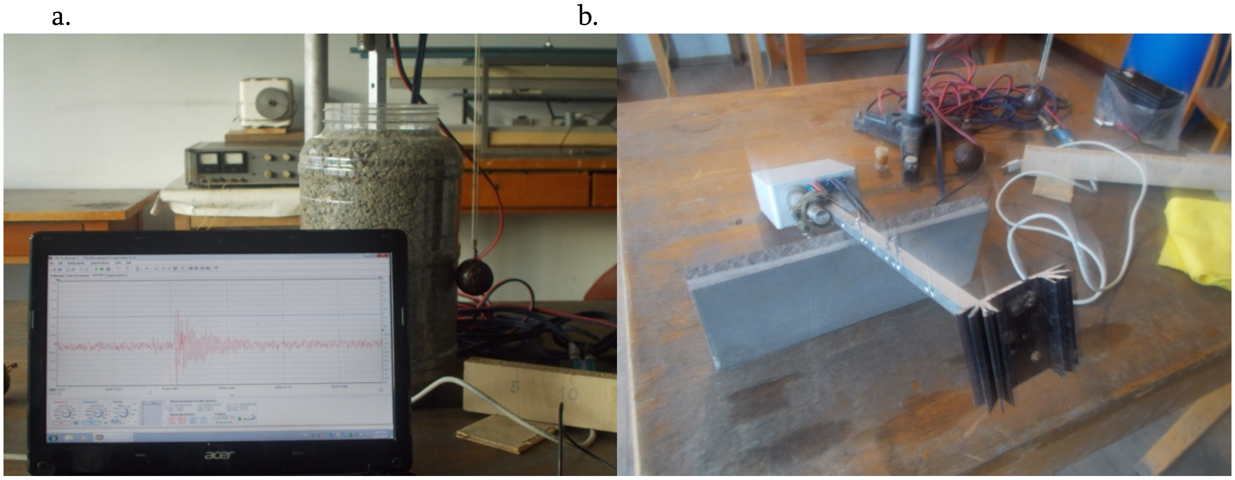


Fig.4. aexperimental equipment, b)acoustic sensor with fixed aluminum rod and radiator for increasing sensitivity

On the gravel-filled, plastic container made mechanical impact from the outside, using a pendulum, and recorded an acoustic signal by the sensitive sensor or conventional acoustic sensor. Pendulum used to effect could be measured (Fig.4). Mass of the pendulum $m \approx 175\ g$, length of $l \approx 50\ cm$. Pendulum collision with the upper plate was realized from different distances: 10, 15, 20 and 25 cm.

It is interesting 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 to calculate

1. What height the pendulum reaches at various deviations from the initial position

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

At 10 cm deviation the pendulum rises to a height of $h \approx 2.10^{-2}m$, corresponding potential energy equals $E_p = mgh$. pendulum speed at collision with a plate $v = \sqrt{2gh} \approx 0.63\ \frac{m}{s}$, the value of pulse which the pendulum delivers to the plate $p \approx 0.11\ kg.\frac{m}{s}$. From analysis we conclude that the pendulum-equipment interaction duration time is $t \approx 0.125s$. Accordingly, the impact force is: $F = \frac{p}{t} \approx 0.88\ N$

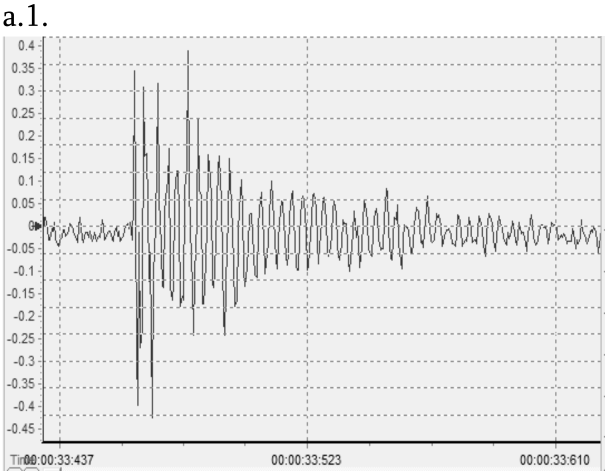
Table1.Gradations of the pendulum deviations and corresponding forcing values on the container

Deviation cm	10	15	20	25
Heigh, m	2.10^{-2}	$4{,}5.10^{-2}$	$0{,}8.10^{-1}$	$1{,}25.10^{-1}$
Pendulum forcing, N	0.88	1.33	1.77	2.21

Results analysis

Experimental equipment is described above (Fig.4). Records of acoustic signal waveform using USB oscilloscope;

a.1.



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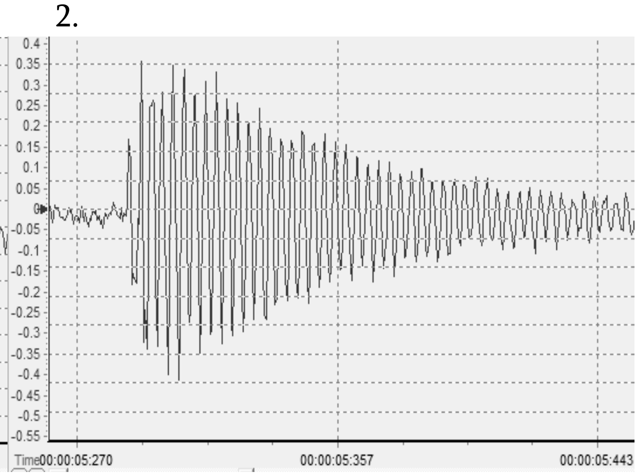
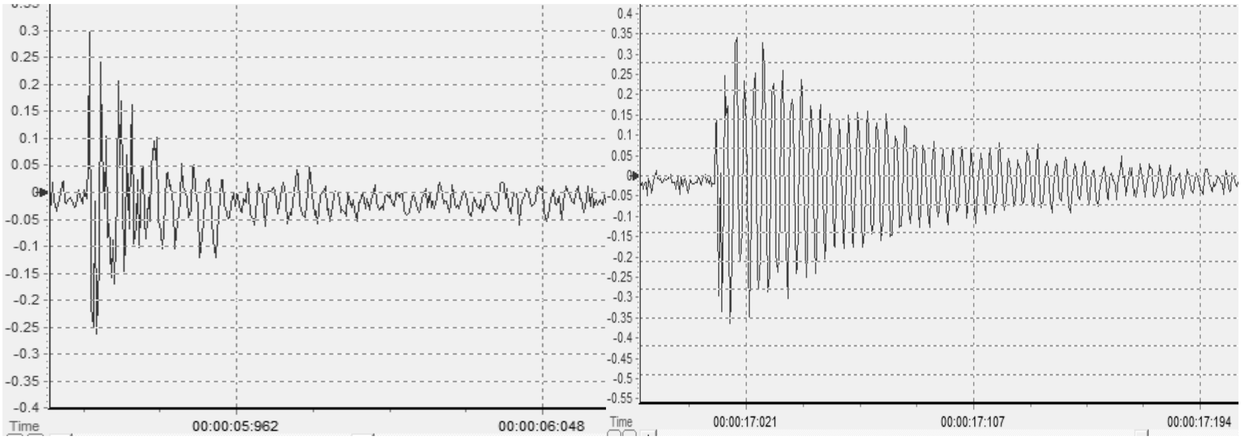
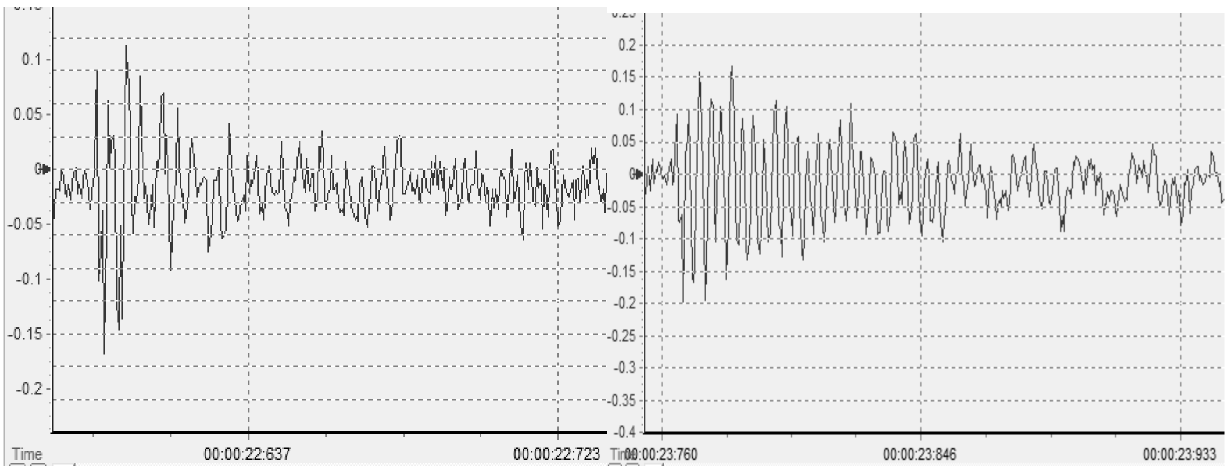


b.



c.



d.

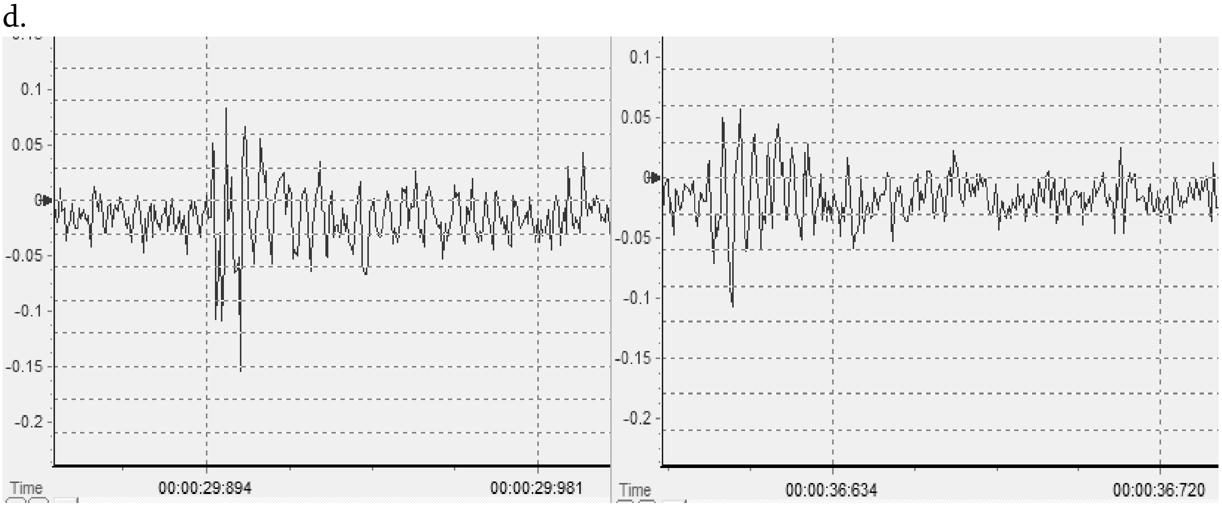


Fig.5. Recording acoustic pulses encountered in collisions on a plastic container from different distances: 1 column-sensitive sensor, 2 column-conventional sensor, a) Pendulum deviation of 25 cm, b) deviation of 20 cm, c) deviation of 15 cm, d) deviation of 10 cm; x-axis is time in sec, y-axis is the acoustic signal intensity in volts.

As can be seen from Fig5, the difference of sensitive and conventional sensor records is not significant. Especially for the large deviation of the pendulum. By small (10 cm) deviation (case d) the amplitude of the sensitive sensor records is larger than normal sensor records. This may be due to the fact that by the strong collision a pendulum with a plastic container sensor begins to vibrate, which causes a change in the amplitude and spectrum of the acoustic signal recording. For weak pendulum collisions vybrate not occur and there is a registration occurred acoustic emissions. At this time of great importance to the sensor receiving surface area and its orientation with respect to the acoustic emission source. A series of experiments are planned to look for a sensitive sensor for optimum shape. Our guess is that in this direction, it is possible to develop monitoring and early warning acoustic system for revealing landslide incipient slipping.

Refereces

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მარცვლოვან გარემოში აკუსტიკური იმპულსების დეტექტირების მეთოდები

ნოდარ ვარამაშვილი, თამაზ ჭელიძე, ზურაბ ჭელიძე

რეზიუმე

სტიქიური უბედურებების შედეგად მსხვერპლისა და ზარალის თავიდან ასაცილებლად პრევენციული ზომები სერიოზულად განიხილება მსოფლიოს ბევრ ქვეყანაში. არსებობს ბევრი გაურკვევლობა მეწყრის დასრიალების დროის პროგნოზირებაში. აკუსტიკური ემისია არის ბუნებრივი მოვლენაა, რომელიც ხდება, როდესაც მყარი სხეული იმყოფება დაძაბულობის ქვეშ. აკუსტიკური ემისია ატარებს ინფორმაციას სხეულში მიმდინარე დეფორმაციის მექანიზმის, ადგილმდებარეობის და ინტენსივობის შესახებ. ჩვენი კვლევის მიზანია მაქსიმალურად მგრძნობიარე აკუსტიკური იმპულსის რეგისტრატორის კონსტრუირების მცდელობა. ჩვენი ექსპერიმენტების ერთ-ერთი მიზანია აპარატურის ოპტიმიზაცია რათა მოვახერხოთ მისი გადატანა საველე პირობებში და ვიმუშაოთ მეწყრის დასრიალების წინასწარი შეტყობინების აკუსტიკური სისტემის შექმნაზე.

Методы детектирования акустических импульсов в сыпучих средах

Нодар Варамашвили, Тамаз Челидзе, Зураб Челидзе

Резюме

Предотвращение потери жизни и имущества в результате стихийных бедствий в настоящее время рассматривается очень серьезно во многих странах мира. Есть много неопределенности в оценке момента, когда произойдет движение оползня. Акустическая эмиссия является естественным явлением, которое происходит, когда твердое тело подвергается деформации. Акустическая эмиссия несет информацию о локализации, интенсивности и механизме деформации, происходящей в материале. Цель нашего исследования попытка конструирования чувствительного регистратора акустической эмиссии. Одна из целей нашего эксперимента, оптимизация оборудования для использования его в полевых условиях и создание акустической системы раннего оповещения активизации оползня.