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Acoustic early warning telemetric system of catastrophic debris flows in mountainous areas

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Abstract

The paper is devoted to creation of Acoustic Early Warning Telemetric System of catastrophic debris flows in mountainous areas, namely, for Durudji valley (East Georgia). The field test of the system shows that it is capable to register acoustic pulses in the range 10-1000 Hz and transmit the signal on the distance of 10-15 km.

Introduction

Each year debris-flows (mud-flows, earth-flows) cause a lot of disasters in mountainous areas all over the world (see special issue of Journal of Physics and Chemistry of Earth, vol.25, No.9, pp. 705-797, 2000). Periodically thousands of populated areas, roads, oil and natural gas pipeline routes, high voltage electric lines and agricultural lands are under the heavy influence, sometimes with catastrophic impact of hazardous geological processes. Catastrophic mass-movements not only periodically strongly damage the environment but they also are followed by human losses. Thus it is of great importance to create reliable and cost-effective early warning systems for monitoring mass-movements in potentially dangerous areas.

The territory of Caucasus due to the development of large-scale hazardous geological processes, their frequent reoccurrence, growth of population and land use as well as of large engineering constructions belongs to the hardest hit mountainous regions in the world. The annual economical losses due to geomorphological hazards in Georgia are of order of 100 million USD.

Basin of r. Duruji in Eastern Georgia (Fig. 1) is the classical example, illustrating the intensity and power of debris flows and their catastrophic consequences, directly threatening the town of Kvareli located on the eastern part of the accumulation zone of the mass flow as well as the objects of agricultural designation. In the last 115 years there were 31 cases of large debris-flows; the associated human losses reach 200 mln USD. The preventive activity in the last years, due to difficulties in economy, was practically abandoned. Thus creation of effective early warning/ monitoring system (EWS/MS) for the region is of vital importance.

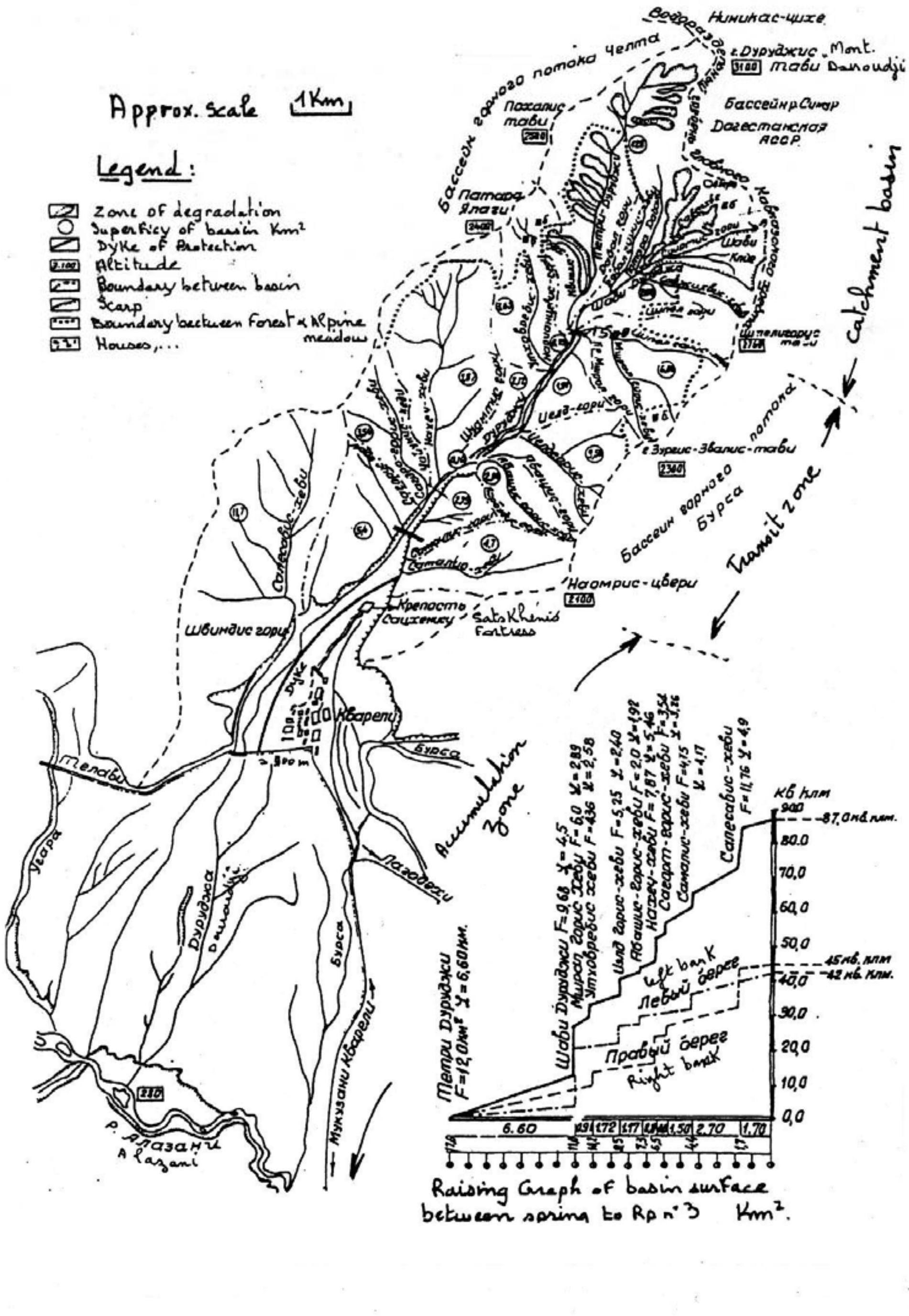

Fig1. Douroudji debris basin (Eastern Georgia).

Equipment

There are a lot of methods in monitoring mass-movements: geodesy, extensometry, Global Positioning Systems, laser and radar interferometry, etc (Malet ,Maquaire and Calais, 2001, Savvaidis, 2003; Tonnellier and Malet, 2010). The accuracy of most precise techniques approaches 0.1 mm. The cost of such systems is high enough. Besides direct measurements of displacements, it is possible to register the accompanying effects, for example, acoustic emission, generated by the mass-movement; these methods are less expensive. Recently several such systems for registration of dynamical geomophological processes have been developed, namely, seismometers, piezoelectric or magnetoelectric sensors and acoustic microphone sensors. The best signal (S) to noise (D) ratio (S/D) was obtained for acoustic sensors.

It is established that the debris-flows generate soil vibration in the low-frequency range (0-100 Hz); according to (Itakura et al., 2000) the maximum in the power spectrum is obtained in the vicinity of 40 Hz.

Taking into account the results of field observations of acoustic emission (AE) during catastrophic debris-flows (Itakura et al., 2000; Lavigne et al., 2000; Betri et al., 2000; The sound of the underground, 2010) Institute of Geophysics and European Centre of Geodynamical Hazards of High Dams carried out analysis of existing systems and the debris-generated AE monitoring equipment, consisting of acoustic sensors, special filters and low-noise amplifiers (LNA) and a notebook, has been assembled. The principal scheme of electronic block is shown in Fig 2.

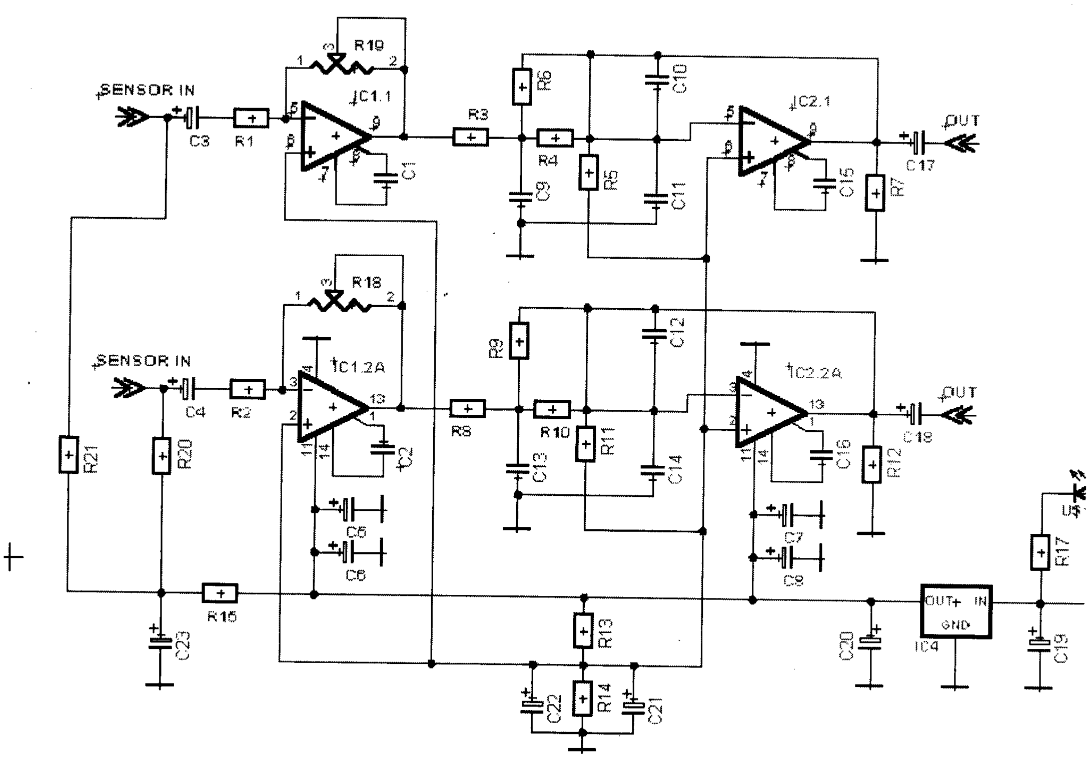

Fig.2. The principal electronic scheme of electronic block for recording acoustic emission during catastrophic debris-flows with special filters and low-noise amplifiers.

The main requirements to the system were: minimal energy consumption, authonomous functioning, maximal linearity of amplitude-frequency characteristics (AFC) of sensors and amplifiers in the used frequency range, maximal signal to noise ratio. To fulfill these requirements the capacity microphones were used as sensors, due to the linearity of their AFC in the range 10-1000 Hz. Microphone heads were installed directly on the card of the primary low-noise amplifier in the waterproof casing of the sensor (metal casing of a length 60-70 cm and external diameter 3.5-4 cm). The power (stabilized voltage 9 V) is supplied to LNA through waterproof connector by the signal coaxial cable. The current consumption by two sensors does not exceed 10 mA). Location of LNA in the close vicinity to sensors allows using long signal cables without risk of spoiling signal to noise ratio; in turn this makes it possible to place sensors relatively far from each other (at the distance 150-200 m). Two-sensor system of registration is much more reliable for recognition of mass-movement initiation.

Filters are necessary for debris-induced signal bandwidth assignment and reduction of possible noise from the long signal cable. After processing of the signal by input LNA and filters the signal is amplified by scale amplifier in order to match the system output to the recorder characteristics.

The whole system (Fig.3) is powered by 12 V battery and consumes no more than 40-45 mA.

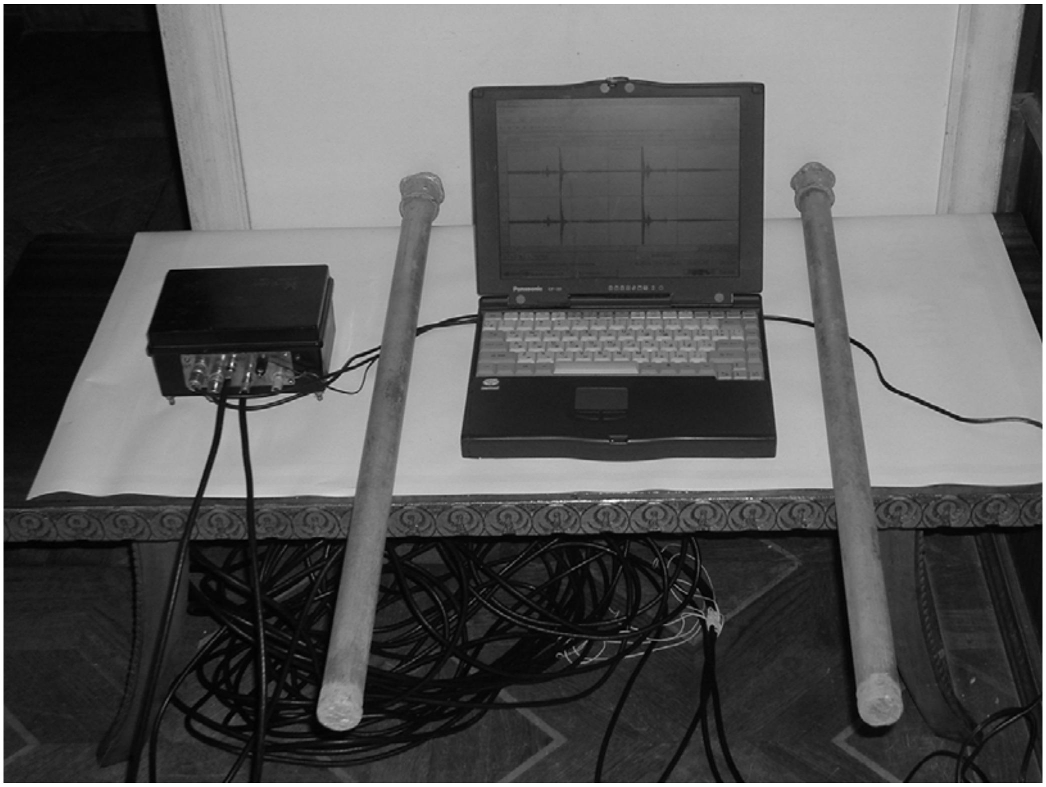

Fig. 3. The field acoustic system for debris-flow EWS, including the electronic unit with amplifiers and filters, two sensors and notebook

Field test of sensors

During field tests the microphone sensors were installed inclined in pits at the depth of 0.7 m; they were separated by the distance of 5 m. Acoustic signal was initiated by dropping of the weight (mass 7 kg) from the 1.2 m high approximately in the middle point between sensors. During the experiment microphone sensors were installed in two pits at the depth of 0.7 m. The distance between sensors was 1 or 5 m. The acoustic signal was generated by dropping the weight (with a mass 7 kg) from the 1.2 high at various separations from the sensors along the normal to the line, connecting sensors. The normal was located approximately at the middle point between sensors. Fig. 4 presents recordings of the sensors and the moments of acoustic signal initiation. The records correspond to following separations of the source and sensors

1) record take 001 – 2,5 m
2) record take 002 – 0,5 m
3) record take 003 – 4 m
4) record take 004 – 9 m

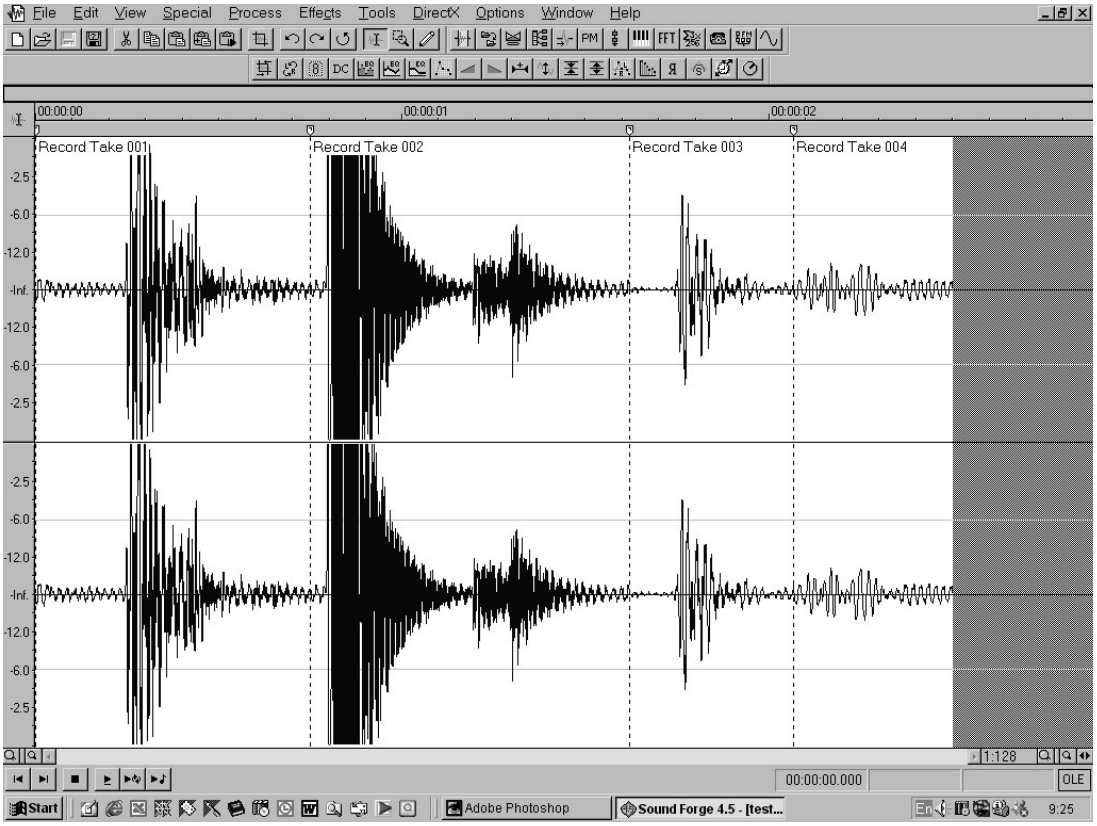

Fig. 4. The recordings of acoustic signals during field tests of EWS

Registration and processing of the acoustic signal was realized on the sound card of notebook using the program Sound Forge. Acoustic signal’s amplitude substantially decreases with a distance: according to Itakura et al (2000) the decrease follows exponential law.
It seems that the sensitivity of the system suffice to register the initial stage of catastrophic debris flow.

The analysis of frequency content of the recorded signals shows that the maximal emission in the field tests corresponds to 70 Hz.

Developing EWS Communication System

During development of EWS system for Dourouji valley we used the experience obtained by the Ministry of Internal affairs, which for several seasons organized temporary observations at the source of debris flow. The special team was placed at the source and the communication with rescuer centre at the city of Kvareli was realized by radiotelephone. These observations prove that the frequency…157-170 MHz was good for communication between observation site and rescuer centre for special case of Dourouji valley orography. This frequency was approved as satisfactory for developing EWS system in the area.
The EWS Communication System should answer to following requests, taking into account the inaccessibility of observation site for regular visits:

i. possibility of operative change of device parameters and warning tasks
ii. necessity of permanent observation of natural process
iii. autonomy of data transfer system and minimization of power consumption
iv. high requirements to protection of sensors and transfer system from bad weather conditions

Accordingly, the flow block of the system looks like following:

i. active shift sensors with phantom power supply (AD)
ii. signal adder (Σ), phantom power supply scheme (E_+), codec modulator (C/M)

iii. synthesiser-modulator of radio channel (SYN), HF power amplifier (PA HF) and filter (F HF) and antenna-feeder device (ANT)
iv. system of self-contained power supply

Active mass-movement sensors with phantom power supply (AD)
For high reliability of system two active shift sensors are used. They are manufactured as water-proof devices – see Fig.3.

Signal adder (Σ), phantom power supply scheme (E_+), codec modulator (C/M)
Signal adder (Σ) adds signals from two active sensors which are placed at different locations. The phantom power supply scheme (E_+), provides the supply of power to sensors by the same coaxial cables, which connects signal adder with two sensors. The frequency range of wanted signal is 1-300 Hz. Translation of such LF signal by radiofrequency needs large energy consumption. Besides, it is hard to put this information into radio devices. It seems optimal to shift the spectra of data into standard modulation range of radio(-)telephony, namely, 350-3.5 Hz. Obtained narrow-range radio signal satisfies all conditions and norms of radio transfer of data and is also low consuming solution (narrower the range, less energy is consumed at the same transfer distance). The range shift is provided by codec-modulator; the demodulated signal can be recorded directly on the standard PC sound card.

Syntheziser-modulator of radio channel (SYN), HF power amplifier (PA HF) and filter (F HF) and antenna-feeder device (ANT)
Digital synthesiser of frequency provides forming of frequency of radiochannel for data transmission and frequency modulation by codec signal.
From the output of synthesiser-modulator the signal is sent to economic power amplifier of class “C” to minimize the power consumption. The amplified signal passes HF filter at the output of power amplifier and enters the antenna-feeder device (ANT).
Fider is of minimal length in order to decrease HF power losses. Antenna is chosen of limited amplification as the large number of directed elements increase the area of antenna, which may worsen the resistance of the system to the strong wind.
System of self-contained power supply
Data transfer system gets power from the battery 12V/50 AH. For charging of battery in the day time will be used solar panels of calculated power no less than 80 W. The large power of solar batteries is needed for normal functioning of the whole system in the night time.
For optimization of the battery charging the solar panels are connected to the sysyem by DC/DC converter, which controls the charging current and voltage. This allows optimization of solar panels power consumption.
In the power system the battery protection scheme is foreseen; it switches off the appliance load when the battery voltage drops lower than 9.5 V. The scheme restores the power supply automatically when the voltage rises up to 12.6 V
Field test of transmission system
The test of transmission system has been carried out. The acoustic signal due to artificial source (weak shock, slipping) was successfully transmitted from settlement Napetvrebi to Tbilisi over the distance of 15 km. This equals the distance from the Duridji debris flow sources to settlement Kvareli (Fig.1), which means that the system is capable to issue the alarm in case of debris flow initiation. This gives around 10-15 min of time for action before the debris mass reaches Kvareli.
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Акустическая телеметрическая система раннего оповещения для катастрофических селей в горных районах

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Резюме

Работа посвящена созданию акустической телеметрической системы раннего оповещения для катастрофических селей в горных районах, а именно для долины реки Дуруджи (Восточная Грузия). Полевые испытание системы показало, что она способна регистрировать акустические импульсы в диапазоне 10-1000 Гц и передавать сигнал на расстояние 10-15 км.

მთიან რეგიონებში კატასტროფული ღვარცოფების აკუსტიკური ტელემეტრული წინასწარი შეტყობინების სისტემა

თამაზ ჭელიძე, ნოდარ ვარამაშვილი, ზურაბ ჭელიძე

რეზიუმე

სამუშაო ეძღვნება მთიან რეგიონებში სახელდობრ მდინარე დურუჯის ხეობაში (აღმოსავლეთი საქართველო) აღძრული კატასტროფული ღვარცოფების აკუსტიკური წინასწარი შეტყობინების ტელემეტრული სისტემის შექმნას. სისტემის საველე გამოცდა გვიჩვენებს, რომ მას შეუძლია 10-1000 ჰც დიაპაზონში აკუსტიკური სიგნალის რეგისტრირება და გადაცემა 10-15 კმ მანძილზე.