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Processing the ground vibration signal produced by debris flows: the methods of amplitude and impulses compared

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ABSTRACT

Ground vibration sensors have been increasingly used and tested, during the last few years, as devices to monitor debris flows and they have also been proposed as one of the more reliable devices for the design of debris flow warning systems. The need to process the output of ground vibration sensors, to diminish the amount of data to be recorded, is usually due to the reduced storing capabilities and the limited power supply, normally provided by solar panels, available in the high mountain environment. There are different methods that can be found in literature to process the ground vibration signal produced by debris flows. In this paper we will discuss the two most commonly employed: the method of impulses and the method of amplitude. These two methods of data processing are analyzed describing their origin and their use, presenting examples of applications and their main advantages and shortcomings. The two methods are then applied to process the ground vibration raw data produced by a debris flow occurred in the Rebaixader Torrent (Spanish Pyrenees) in 2012. The results of this work will provide means for decision to researchers and technicians who find themselves facing the task of designing a debris flow monitoring installation or a debris flow warning equipment based on the use of ground vibration detectors.

1. Introduction

Debris flows are a type of mass movement that may occur in mountain torrents and propagate along their channel. They generally appear as waves of highly concentrated dispersions of poorly sorted sediment in water that display very steep fronts, which consist mostly of boulders. Behind the bouldery front the number of blocks gradually decreases and the surge becomes charged with pebble-sized fragments and then more and more diluted until it appears only as muddy water (Johnson, 1970; Takahashi, 1991). Debris floods are phenomena of massive bedload transport, that can also be described as very rapid surging flows of water in a steep channel, heavily charged with debris (Hungr et al., 2013; Abancó et al., 2014). A debris flood may transport quantities of sediment comparable to a debris flow, in the form of massive surges. However, the transport is due to tractive forces of the water that overlies the sediments. Therefore the peak discharge of a debris flood is more similar to a water flood, while debris flow discharges may be ten times larger than major water floods (VanDine, 1985; Hungr et al., 2013).

Debris flows can be really destructive phenomena, capable of seriously damaging roads, railways, villages and other infrastructures. The frequent occurrence of debris flows in different areas of the planet has encouraged the installation of several monitoring facilities worldwide to gather reliable field data (Berti et al., 2000; Hürlimann et al., 2003; Hu et al., 2011; Suwa et al., 2011; Yin et al., 2011; McCoy et al., 2013; Navratil et al., 2013; Comiti et al., 2014). Monitoring data may in fact provide fundamental information for a better theoretical understanding of the phenomenon (e.g. Arattano et al., 2006; Lin et al., 2005) but also for the design of active and passive countermeasures, the delineation of hazard zones, etc. (Tsai et al., 2011). Among the different types of countermeasures, warning systems have received particular attention, given their lower cost in comparison with active countermeasures (Hungr et al., 1987) and their potential, particular efficacy in the protection of all those infrastructures (like railways and roads) that would not require too much alert time to give a warn and so defend their users.

Different types of devices that can be used to monitor debris flows, but ground vibration detectors present several advantages. It is very well known that the occurrence of a debris flow is accompanied by strong ground vibrations that this particular type of mass movements induces in the ground during its propagation (Johnson and Rodine, 1984; Suwa and Okuda, 1985). These vibrations can be conveniently detected by ground vibration sensors

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placed in the surroundings of the torrent, usually along the banks. The installation of an array of ground vibration sensors at a proper distance from the torrent bed may allow the estimation of important parameters such as the velocity of the main front and the mean velocity of the entire debris flow wave. A network of ground vibration sensors may also detect the presence of subsequent surges behind the main front and, given the proportionality between the intensity of ground vibration and the flow height, it may also give, after a calibration, information on the evolution of flow height with time and even on the magnitude of the event.

When the debris flow reaches the sensor network and passes through the cross section where a ground vibration sensor is placed, it produces a significant increase of the signal detected by the sensor itself. Usually this increase is way above the environmental noise that is present before the debris flow occurrence and this helps to clearly recognize the phenomenon. This has promoted some research efforts worldwide to use ground vibration sensors as tools to detect the occurrence of debris flows (LaHusen, 1996; Suwa et al., 2000; Cui et al., 2005; Bessason et al., 2007; Huang et al., 2007; Chou et al., 2010; Kogelnig et al., 2011; Fang et al., 2011; Navratil et al., 2013) and so to provide information useful for both theoretical ends (Arattano and Franzi, 2004), and practical purposes, such as the identification of warning algorithms (Badoux et al., 2009; Abancó et al., 2012).

Actually, before the arrival of the debris flow at the sensor site, a gradual increase of the signal can be usually observed. This rise starts in advance, several tens of seconds before the passage of the debris flow through the cross section where the sensor is installed. Therefore a ground vibration sensor may also be used to detect the occurrence of a debris flow tens of seconds earlier than other type of devices, such as radars, ultrasonic sensors, trip wires, pendulums etc. that start their recording only when the debris flow has reached their position. This earlier detection might be very precious if the detectors, because of some specific field condition, had to be forcedly placed very close to the infrastructure to protect, for instance a road where the traffic had to be stopped through the activation of a cross light. In this latter case, in fact, stage or contact sensors could not grant enough time to activate the alarm. The presence of a high check dam or a natural fall upstream from the sensor position might even allow the detection of the arrival of the debris flows some hundreds of second before, since the fall of the debris flow from them could be detected by the ground vibration sensors (Arattano, 2003). These specific capabilities of ground vibration sensors have encouraged more and more the investigation of their potentialities as possible debris flow warning tools and has also stimulated the research of warning algorithms based on the detection of ground vibration (Arattano and Marchi, 2008; Badoux et al., 2009; Abancó et al., 2014).

The ground vibration detectors that have been employed so far to monitor debris flows include geophones, seismometers, accelerometers, underground microphones, hydrophones (Itakura et al., 2005). Among these latter sensors, however, given their relatively cheap cost and robustness, geophones have become those most commonly employed. Their output is a voltage that is directly proportional to the ground vibration velocity. The latter can be derived from the voltage through a transduction constant, that is provided by the company that produces the device. The output voltage that comes from the geophone is an analogical signal that is usually digitalized at a convenient frequency rate before it is recorded in a data-logger. Moreover, after having been digitalized, the signal is often also conveniently processed to reduce the amount of data that has to be stored in the data-logger. In fact, in high mountain environment where debris flows monitoring devices are usually installed, power supply is generally provided only by solar panels and there are reduced storing capabilities.

Reaching a proper and effective use of the output signal of a ground vibration sensor for both monitoring and warning purposes, however, still requires some research efforts. Many research issues, in fact, still need to be addressed, such as the method of installation of the geophones on the ground or the more proper level of amplification of the signal to adopt (Abancó et al., 2014; Arattano et al., 2014). Among the different issues that still need to be solved there is certainly the more convenient way to process the voltage signal that represents the output of a ground vibration sensor. This specific issue will be addressed in the following, after the presentation of the two main processing methods of the ground vibration signal produced by debris flows. Both methods will be then applied to the geophone raw data of a debris flow occurred in the Rebaixader Torrent (Spanish Pyrenees) on July 4, 2012.

2. Methods and data

2.1. The need of processing the geophone raw data

In Fig. 1 the typical output of a geophone placed along a torrent bank is shown that is produced by the occurrence of a debris flow in the torrent. This signal is in analogical form and was recorded through the use of a magnetic tape (Arattano, 1999). Nowadays magnetic tapes are no more used and the recording occurs only in digital form.

The frequencies of a signal produced by a debris flow usually range from 10 to 80–100 Hz (LaHusen, 1996; Huang et al., 2007; Abancó et al., 2014; Comiti et al., 2014). Applying the Nyquist rule to obtain a data set representative of the original signal, a sampling frequency of at least 160–200 Hz would be required. To reduce the large amount of data derived from those high sampling rates, the processing of the digitalized signal becomes essential.

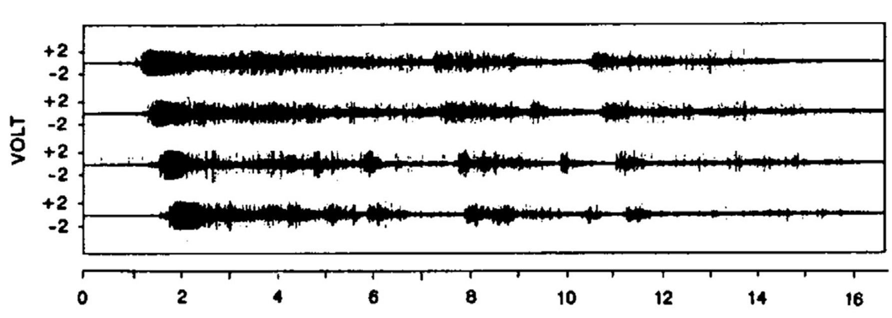

Fig. 1. Output of four seismic detectors placed at a distance of 100 m from each other along the right bank of a torrent reach of the Moscardo Torrent for a debris flow occurred on June 22, 1996 (after Arattano, 1999).