

Performance of the debris flow alarm system ALMOND-F on the Rochefort Torrent (Val d'Aosta) on August 5, 2022

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Abstract. On August 5, 2022 in the Rochefort torrent (Val Ferret, Mont Blanc), a debris flow occurred that invaded the road connecting the valley with the village of Courmayeur. The debris flow interrupted the car traffic and damaged the bridge that crosses the torrent and the aqueduct that serves the municipality of Courmayeur. Due to the recurrence of similar events, in 2017 the Valle d'Aosta Region had decided to install a monitoring and warning system for debris flows, close to the bridge on the Rochefort torrent, to interrupt the traffic in both directions through a pair of traffic lights in case of debris flow. The system, named ALMOND-F (ALarm and MONitoring system for Debris-Flow), has been installed along the torrent, few tens of meters upstream of the bridge. ALMOND-F adopts a warning algorithm that is based on the variation of the seismic signal intensity produced by debris flows and that had been thoroughly tested in previous years in the instrumented area of the Gadria basin. On August 5, 2022 the warning system activated the traffic lights and stopped the traffic about three minutes before the debris flow invaded the road. It is the first time that the ALMOND-F system is utilized in a real risk situation to protect the population, after some years of controlled tests carried out in an instrumented area. Even though this represents an undoubted technological success, the installation of ALMOND-F requires several issues to be addressed to grant the highest level of safety. For instance, the presence of other active debris-flow channels and/or natural risks in the same valley may represent a limitation to the installation of a site-specific alarm system. The installation of the Rochefort torrent, opportunely optimized also on the basis of the feedbacks of the August 5, 2022 debris flow event, could become a useful case study and so provide indications and suggestions on the mitigation of the debris flow risk through the use of warning systems.

1 Introduction

In recent years, a growing number of monitoring sites are adopting seismic sensors for the debris-flow detection [1]. Low-cost and easy-to-install sensors such as geophones are attractive because they can provide monitoring data with high spatial and temporal resolution, at a safe distance from the channel. However, their use in operational alarm systems is still scarce given that instrument maintenance and data analysis require efforts and skills in signal processing [2,3].

Several debris flow events have occurred in the past in the Rochefort torrent [4,5], located close to the village of La Palud, in the municipality of Courmayeur (AO, Fig.1a)). The Rochefort torrent drains a basin of about 2.8 km² and extends between 4014 m a.s.l. (Dente del Gigante) and 1400 m a.s.l. (confluence with the Dora di Ferret); the upper part of the basin hosts the Rochefort Glacier (0.5 km²). Some debris flow events were of considerable magnitude and the Valle d'Aosta Region, at first, and the municipality of Courmayeur, in a second time, have thus decided, in 2017, to install and maintain a debris flow warning system on the torrent. The system can stop the traffic on the road that crosses the torrent, through a pair of traffic lights, and alert the authorities

in case of debris flow, also providing a series of photos, shot in real time by the videocamera connected to the system.

The alarm system that has been installed was designed, realized and tested through a collaboration between the Research Institute for Geo-Hydrological Protection (Istituto di Ricerca per la Protezione Idrogeologica – IRPI) of the Italian National Research Council (CNR) and the private company Siap + Micros S.p.A.

The debris flow warning system, named ALMOND-F (ALarm and MONitoring system for Debris-Flow), is the result of an experimental research on the seismic detection of debris flows that CNR–IRPI began in the 90s. The initial researches were carried out in the instrumented area of the Moscardo torrent (Paluzza, Udine), which is still active nowadays [6] and were then continued in the experimental installation of the Gadria torrent (Lasa, BZ), managed by the Civil Protection Agency of the Autonomous Province of Bolzano [7]. The analysis of the first seismic signals recorded in the Moscardo torrent has evidenced the possibility of developing an algorithm that could recognize the debris flows on the basis of the vibrations that they induce in the ground [8].

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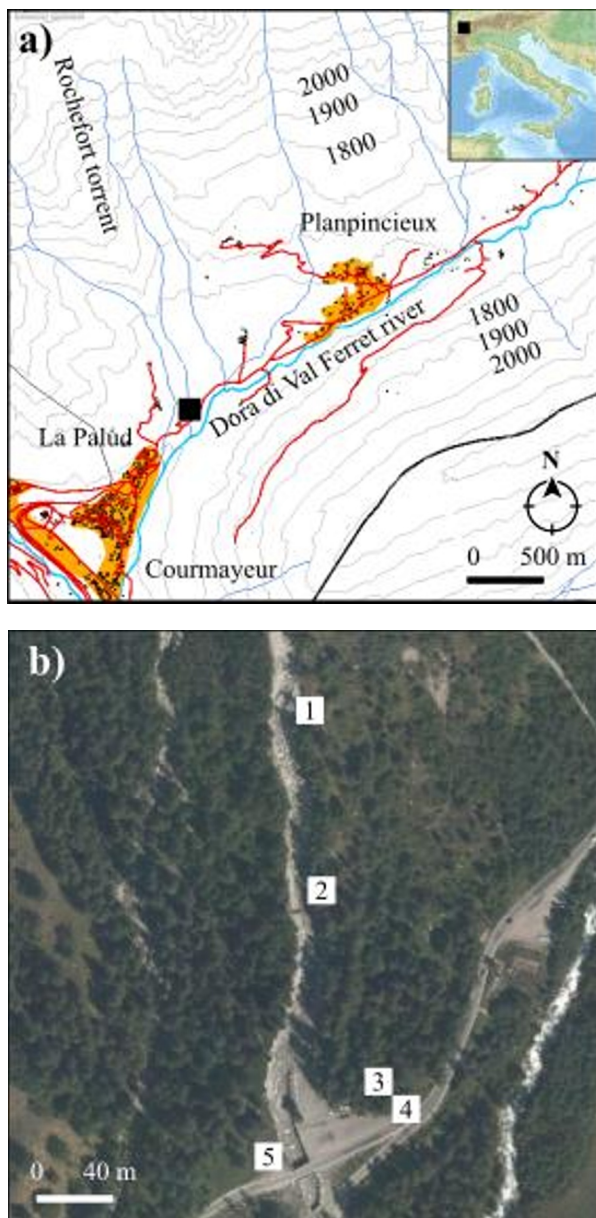


Fig. 1. a) The Rochefort torrent (Courmayeur, AO). The black square indicates the location of the monitoring system (Basemap Geoportale Valle d'Aosta); b) 1,2,3: location of the three geophones, 4: location of the ALMOND-F central unit, 5: location of the bridge

Starting from 2012, research activities were thus concentrated on the individuation of the most efficient method to process the seismic signal for the identification of such an algorithm [9] and, contemporarily on its development [10].

The research activities were carried out in collaboration with a private company that provided the hardware equipment, on which the algorithm could be implemented. The idea was to develop an alarm system, based on the detection of the seismic signal, that could represent a significant advance compared to the systems available at the time and to provide, from the beginning, the conditions for practical application of the algorithm in the field. To this aim, a robust and energetically autonomous equipment was needed that could be

installed even in the harsh conditions typical of Alpine environments.

In order to be able to test both the hardware and different types of algorithms, a special test area was set up in the Gatria torrent [7]. These tests provided the experimental data for the development of an automatic recognition algorithm based on the analysis of the signal-to-noise ratio detected by a linear array of seismic sensors [10].

2 Characteristics of the ALMOND-F alarm system at the Rochefort Torrent

The ALMOND-F alarm system installed on the Rochefort torrent consists of the hardware produced by the company Siap + Micros S.p.A on which is implemented a site-specific version of the algorithm developed by the CNR-IRPI in 2019 [10].

The algorithm operating on the Rochefort torrent processes in real time the seismic signal detected by three different geophonic sensors positioned a few tens of meters away from each other, parallel to the course of the torrent, on the left bank, a few tens of meters upstream of the bridge to be protected (Fig 1b).

The original algorithm [10] was modified and calibrated at the site of the Rochefort torrent, to avoid maintenance interventions on the sensors in case of variation of the background noise, and also to filter the numerous local low-magnitude earthquakes. This modified version of the algorithm has been named EAGLE-DFO (EARly Ground-vibrations to LEad traffic at Debris-Flow Occurrence).

3 Performance of ALMOND-F during the event

On the occasion of the debris flow event of 5 August 2022, the ALMOND-F system demonstrated excellent reliability, recognizing the arrival of the debris flow about 2,5 minutes before its arrival near the first upstream sensor (18:52:28 CEST). The first detection was produced by a precursory surge that propagated about two minutes before the arrival of the main debris-flow front (Fig. 2). The recognition of the debris flow by the algorithm produced the lighting of two traffic lights placed at both ends of the bridge (18:50:00 CEST), thus blocking traffic in both directions about 4 minutes before the arrival of the main front at the road cross-section (18:54:00 CEST).

At the same time, the system sent an e-mail to alert the local authorities of the imminent occurrence of the debris flow, also reporting the occurrence of the event, always by e-mail, to the offices of the CNR-IRPI in Turin and of the system manufacturer Siap + Micros S.p.A.

The videocamera located in correspondence with the control unit (point number 4 in Fig. 1b) also allowed to collect a sequence of images of the arrival of the debris flow and of the invasion of the road as shown in Fig. 3, informing the authorities of the conditions of the road so they could better plan the interventions to be implemented.

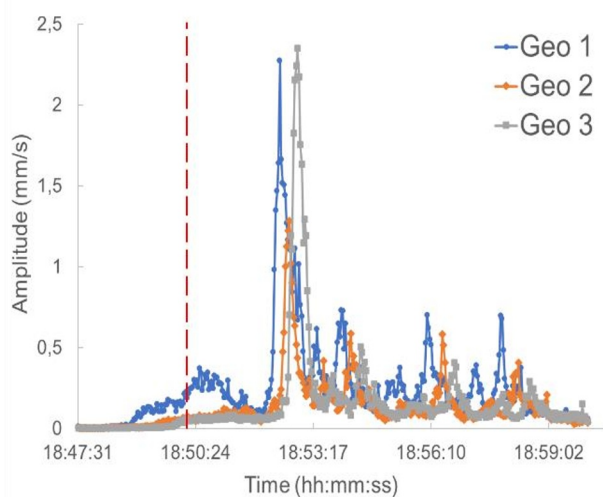


Fig. 2. Envelope of the seismic signal recorded by the three geophones installed along the Rochefort torrent (labeled with 1, 2, 3 in Fig. 1a). The dashed line in the figure represents the detection time.

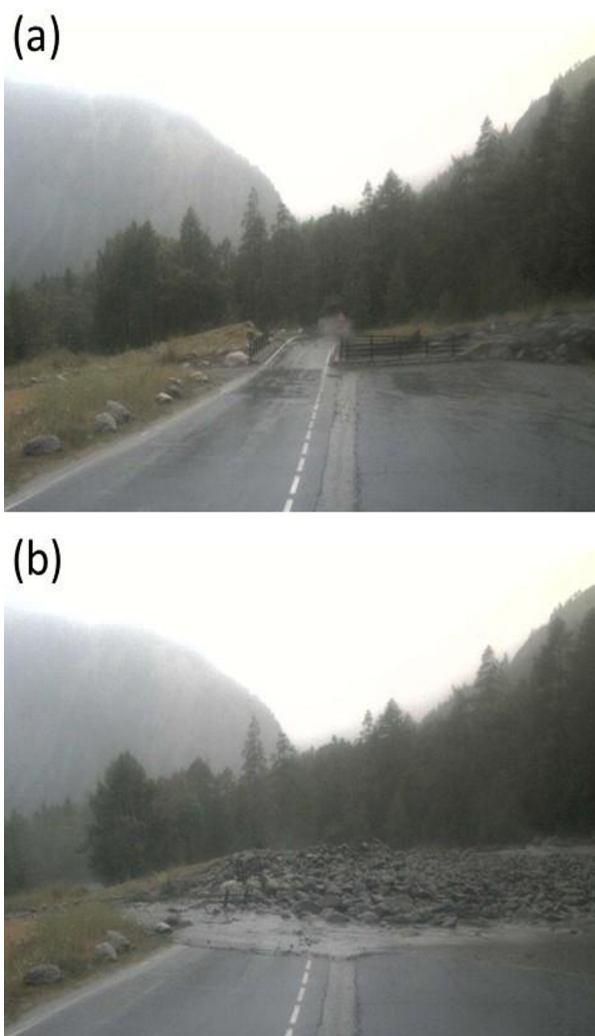


Fig. 3. Sequence of images of the arrival of the debris flow and of the invasion of the road, shot by the videocamera that is

located in correspondence with the ALMOND-F alarm system.

4 Maximizing the effectiveness of a debris flow alert system

The good performance of the alarm system of the Rochefort torrent during the debris flow event of August 5, 2022 undoubtedly constitutes an important scientific and technological success, both in terms of the algorithm performance and hardware reliability.

The EAGLE DFO algorithm did not send any false alarm through e-mail in the five years of operation that preceded the debris flow of August 5, filtering the other different sources of vibration present in Val Ferret (passage of vehicles on the road, earthquakes, torrential floods, passage of animals, etc.). At the same time, the algorithm was able to recognize the occurrence of the debris flow at the first occasion, stopping traffic early enough, and reporting the event to the local authorities.

The possibility of installing the sensors in a safe position, sufficiently far from the torrent bed, also ensured that the system was not damaged by the debris flow, thus making it still functional in the event of a subsequent debris flow wave or event. This is something that can sometimes happen in the following hours or days, as occurred in Valpelline (located about 30 km west of the Rochefort Torrent) during the same meteorological event, when the same two torrents experienced two debris flow events 18 hours apart from each other.

The simple installation of an alarm system in a torrent, however, is not in itself sufficient to guarantee a complete safety with respect to debris flow phenomena of the entire valley that hosts it. In fact, there are issues that must be addressed with extreme care in order to achieve the highest possible level of safety for the valley. One of these is certainly the location of the traffic lights intended to stop the traffic, which must be chosen carefully, taking into account the geo-morphology of the site, the areas affected by any previous debris flows and the advance with which the traffic lights can be turned on before the arrival of the debris flow. Positioning the traffic lights too close to the bridge to be protected could in fact expose drivers to the possibility that some of the flow will reach them anyway. On the other hand, if the traffic lights are too far from the bridge, some drivers may have already passed them when they turn on.

Furthermore, if in the same valley there are other torrents subject to debris flows, scenarios that foresee the occurrence of several debris flows during the same meteorological event must be considered. In fact, drivers stopped by traffic lights could find themselves blocked in a queue or they could choose to make a u-turn, thus being exposed to threats coming from other torrents.

Finally, to be as effective as possible, the installation of a monitoring system must always be accompanied by adequate communication to the general public, so that anyone passing through the area can correctly and unambiguously interpret the indications of danger and exactly what to do.

As already mentioned, it is the first time that the ALMOND-F system has been used in a situation of real risk to protect the population. The alarm installation at the Rochefort torrent could therefore constitute an important case study, also to test people's behaviour in presence of signs of danger. Authorities in charge of risk management and mitigation could draw useful insights from this case study, to provide local administrators with guidelines and an ideal toolbox to deal with debris flow risk mitigation.

Despite the long experimentation conducted over the years in the Moscardo and Gatria torrents [7, 8, 10] to develop the ALMOND-F system, and despite the good functioning of this latter on the occasion of the debris flow of August 5, 2022 in the Rochefort torrent, further tests will be required to verify the full reliability of both the algorithm and the replicability of the system in other Alpine torrents.

The availability of reliable alarm systems is becoming increasingly crucial in a context of climate change [11], associated with growing slope instability, especially in mountain areas [12]. Thus, the possibility to further test the ALMOND-F system and improve its performances will be of great help to increase the number of available and reliable alarm systems and better face the challenges posed by climate change.

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