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Monitoring of fast moving landslides in the Pyrenees

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***Abstract* – The paper presents the experience of two instrumented sites in the Pyrenees where debris flows and rock falls occur frequently. The first one is the debris-flow monitoring system in the Rebaixader catchment, Central Pyrenees, Spain, installed since summer 2009. It consists of sensors registering meteorological and infiltration data as well as geophones, radar, ultrasonic sensors and a video camera focusing on the detection and dynamics of the flows. 24 torrential flows (debris flows and debris floods) and also 5 block falls have been detected. The second site is a recently installed rockfall monitoring system at the Forat Negre couloir, in Andorra la Vella, Principality of Andorra. It consists of 5 geophones and a video camera. For the same area high resolution point clouds obtained by remote techniques such as digital photogrammetry and Terrestrial Laser Scanner additionally permit the assessment of rockfall volumes and geometry, overcoming access restrictions.**

I. INTRODUCTION

Fast-moving landslides such as debris flows and rock falls represent an important fraction of natural hazards worldwide. Many studies exist on the initiation/detachment, propagation and accumulation/deposition processes. Nevertheless, some aspects with high degree of complexity, related to the kinematics and dynamics of the phenomena still remain poorly understood. The existence of real event data is necessary for the understanding and characterisation of these processes, the calibration of numerical models or the scaling of the findings of laboratory studies. However given the high velocity and short reaction time of these phenomena, their collection is hindered. To fill this gap, the use of instrumentation and monitoring techniques for rapid movements is being continuously developing and spread, and forms the basis for alert systems.

Real-time seismic techniques using accelerometers or geophones and microphones are used to reconstruct and measure the rockfall processes after an event takes place [1]. Periodic or real time remote sensing techniques, carried out by means of laser scanners, photogrammetry and satellite images [2] can also be used for the observation of changes on the terrain relief.

As resumed by [3] most of the existing debris flow monitoring systems are situated in the European Alps.

Less monitoring systems exist for rockfalls. Some of them are in the Alps [4], [5], [6], [7], Norway [8] and USA at the Yosemite Natural Park [9].

The afore-mentioned case-studies mainly focus on sensors related to in-situ measurement of debris flow initiation/ rock detachment and flow dynamics/rock fall kinematics. In addition to this, numerous geomatic techniques like laser scanning and photogrammetry have been applied for rockfalls [2] and for debris flows in a less extent.

In this paper the experiences from two instrumented catchments and slopes in the Pyrenees, the Rebaixader torrent, for debris flows, and the couloir of Forat Negre, for rock falls, are presented (Fig 1). At first place, the main technical aspects of the applied monitoring techniques are described. Then some monitoring data and characteristics of the recorded events are presented and evaluated. The outcomes and experiences are discussed with a view to provide some hints for the installation and function of similar systems.

II. THE REBAIXADER CATCHMENT

A. General aspects

The Rebaixader catchment is located in the Central Pyrenees and drains an area of 0.53 km^2 into the Noguera Ribagorçana River. The catchment has the typical morphology of a torrential system (Fig. 2). Debris flows and boulder falls initiate in a steep (from 30 to 70º) scarp developed in a large moraine.
Source material is a sandy boulder glacial (till) deposit which is more than 15 m thick. The latter suggests that sediment availability is not a limiting factor for debris flows and boulder falls. The channel zone, below the source area, is strongly incised and sloping about 21º.

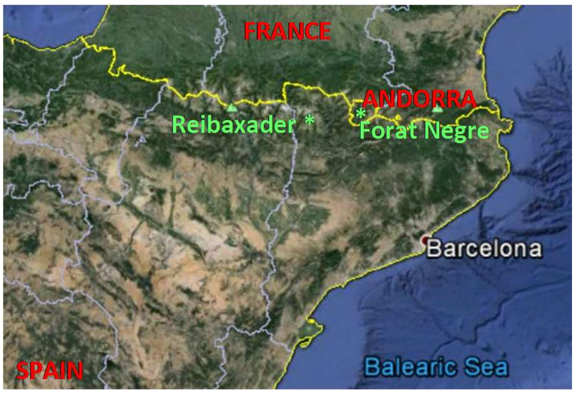

Fig 1. Location of the two study sites (in green).

The meteorological conditions of the site are affected by its vicinity with the Mediterranean Sea, the west winds from the North-Atlantic and the orographic effects of the Pyrenees. The annual precipitation in the area ranges from 800 to 1200 mm.

The selection of this site for the installation of the monitoring systems was made on the grounds of these criteria: the frequent debris flow activity, the relatively easy accessibility of the site, the small distance between the initiation, transit and accumulation zones (about 1 km), and the absence of any torrent control measures that would disturb the debris-flow dynamics.

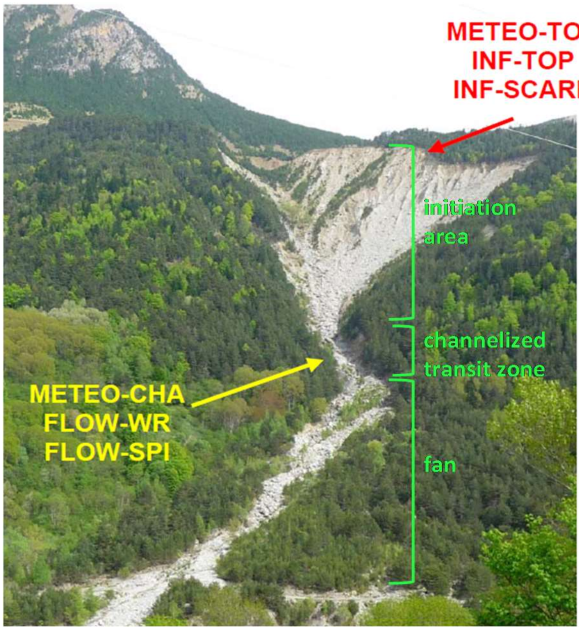

Fig. 2. Overview of the Rebaixader.

B. Monitoring system

The installation of the Rebaixader monitoring system started in summer 2009 and since then it has been continuously improved. Currently it incorporates a total of six different stations (Fig. 2), distributed as (i) two meteorological and two infiltration stations recording data on the initiation mechanisms and (ii) two stations serving for flow detection and characterization of the flow dynamics. At its first phase, a wired sensor network was installed that was comprised of geophones, an ultrasonic device, and a meteorological station. In 2011, a video camera complemented it. During 2012, the system was upgraded to include a wireless network related to the initiation mechanisms. In June 2012, a new seismic acquisition system was further added. A comprehensive description of the system can be found in [10].

Though the initially installed wired sensor network has standard characteristics which are commonly encountered in other monitoring systems, the wireless monitoring system presents some innovative aspects emanating from its adaptation to the specific needs of debris flow monitoring. This new class of sensor network devices has been provided with wireless communication capabilities, showing ultra-low power consumption) and long-range communication (200–500 m). The wireless monitoring system is established by seven nodes, which communicate in a multi-hop fashion to deliver the information into a gateway. The wireless communication is based on the IEEE802.15.4 protocol at 2.4 GHz. The gateway offers enhanced computational and storage capabilities as well as 3G modem communication to the data centre. Eventually, the data is transmitted periodically to a backend system in a database that provides metadata and a safe backup strategy. The network can be remotely managed via a web-based user interface.

Focusing on the initiation of the mass movement and its triggering, the first meteorological station called METEO-CHA was installed in 2009 in the transit zone. It comprised a rain gauge of 0.1 mm resolution and an air temperature sensor. In 2012, the temperature sensor was replaced with a device measuring both temperature and relative humidity of the air. The METEO-CHA station included a Campbell Scientific CR200 datalogger and GSM modem for data transmission. As an important drawback, the effect of the snowmelt in spring cannot be correctly analysed by this type of rain gauge. Therefore, during 2012, a second meteorological station called METEO-TOP was installed at the top of the side moraine. It includes an ultrasonic device for snow height measurements, a rain gauge, and a temperature sensor, all connected to the same wireless network.

During 2012, two additional stations were installed to analyse the infiltration of water into the ground, the pore water pressure, and the soil temperature. The INF-TOP is located at the top of the lateral moraine and the INF-SCARP was positioned inside the scarp, in an area where geomorphologic indicators (i.e., presence of shrubs and small trees) suggest a low activity. Both stations consist of three soil moisture sensors and two sensors registering both suction and soil temperature, in order to measure saturation mechanisms and freezing–thawing effects. Both stations were integrated into the wireless network. The meteorological and infiltration data are recorded at a constant sampling rate of 5 min.

To obtain data on the flow behaviour three types of devices were installed in the channel transit zone along a reach of about 175 m. Two monitoring stations were established: the FLOW-WR in 2009, and later, the FLOW-SPI, in summer 2012.

The FLOW-WR station implies a method for geophone ground motion recordings. The method presented by [11] was followed, according to which the ground vibration is transformed into impulse per second (IS) timeseries. This is an alternative to the commonly applied method of ground velocity signal being directly recorded at 250 samples per second [11], which was used at FLOW-SPI. The main advantages of the transformation, in the first case, are that besides flow front data, it provides information for precursory waves or secondary surges, impact of big boulders etc., differentiating between types of response (e.g. debris flow, debris flood and rock falls), it reduces the size of the data file up to 2 or 3 orders of magnitude, it avoids seismic noise, and it is less power-consuming.

The station FLOW-WR incorporates 5 unidirectional geophones (Geospace 20 DX) measuring vertical ground velocity, installed on the right bank of the torrent, about 8–25 m away from the currently active channel. Four geophones are mounted inside a metal sheet box, which is fixed on bedrock, while the fifth geophone is mounted directly on bedrock. They are connected by wires to a datalogger (Campbell Scientific CR1000).

The datalogger scans the number of impulses at the geophones each second (IMP/s) and checks if a given threshold is exceeded in any of the geophones. If it does, the station switches to a high frequency recording mode (“event” mode), with a sampling frequency of one second. Otherwise, data is cumulated and recorded every 60 min. The use of a recording threshold allows to reduce the amount of data to be processed and to minimize false positives (i.e. false alarms in a warning system). After a calibration period, the threshold was set to 20 IMP/s during three consecutive seconds.

An ultrasonic device has also been incorporated to monitor the flow depth. The device is hanged 6 m over the channel bed by means of a steel cable mount and connected by wire to the datalogger. The sampling frequency of this sensor is the same as for the geophones (i.e. each second during event mode). Images of the events are provided in visible and infrared light by the day/night camera, which is also connected to this network. The camera takes a daily picture of the selected channel reach and, when in “event” mode, it gets switched on video recording by the datalogger. The daily pictures and event videos are saved in a memory card, which is downloaded at field surveys.

The station FLOW-WR is powered by three 12 V batteries with 24 Ah capacity, which are recharged by three 20W solar panels.

At the beginning of summer 2012, the new station FLOW-SPI was installed. This station consists of three geophones located on the left torrent bank about 3 to 5 m from the active channel (Fig. 2), one on bedrock and two in soil. The geophones are connected to a 24-bit broadband seismic recording unit (Spider produced by WorldSensing), which allows digitizing the three channels at 250 samples per second and synchronizes time by a GPS. Data can be visualized and downloaded by the gateway of the wireless network described in the previous section. A GPS receiver is also used in the FLOW-WR station for synchronization with the FLOW-SPI one.

C. Monitoring results

Since 2009, 7 debris flows, 17 debris floods and 5 rock falls (Fig. 3) have been recorded by the Rebaixader torrent aforementioned monitoring systems, after more than 30 field visits and 350 triggers. The rock falls corresponded to big boulders falls that fell from the glacial deposit in the source area and upon reaching the channel zone they activated the “event” mode of the monitoring system distinguishing easily them from torrential flows.

The coexistence of debris flows and debris floods is remarkable for the study site and more problematic. Their characterisation of the events was based on [12] terminology recommendations and the distinction between them is further discussed by [13]. Since the monitoring system and data interpretation have been continuously improving, the distinction procedure was adapted over the years. In the following, the most important criteria of this classification are described.

The data analysis included various steps. First, the geophone and ultrasonic data were analysed and compared

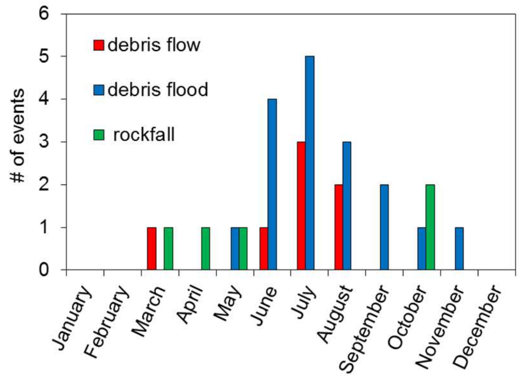

Fig 3. Recorded events by the Reibaxader monitoring system

with debris flow features observed at other monitoring sites and described in the literature [11]. Upon the evidences of an event, a field survey was carried out. During this reconnaissance, morphologic changes in the scarp, channel, and fan were described and photos were taken at eight control points. The video images were checked to verify the process classification (since summer 2011).

A specific analysis of the data for ground vibration records, volume estimates and site-effects (mainly due to the distance from the flow path, the underground material, the assembly of the geophones or the ground vibration thresh) are given by [10] and [13], respectively for the FLOW-WR and the FLOW-SPI systems. Here, just two major groups of information which are related to the implementation of an early warning or alarm system are presented: ground vibration records and triggering rainfall characteristics.

Fig. 4 shows the typical transformed IS ground vibrations curves for the three types of processes recorded at the site.

Type A curve describing debris flows is characterised by three flow phases: a) a first phase of stationary level of no or very low IS values, b) an abrupt increase of the impulses, reaching values over 100 IMP/sec in less than 5 seconds, followed by c) a slow exponential decrease. While some of the events show all three phases, others, especially the “small-magnitude” debris flows, only show clear A-curves in Geo4, the geophone located in the most downstream position in the channel zone. This suggests a delay in the full development of well-defined front.

Type B curve representing debris floods consists of a first phase of gradual increase of IS, which is followed by a gradual decrease. The peak number of impulses of this type of curves strongly depends on the geophone location along the channel and the characteristics of the event (distance between geophone and the flow path or volume of the event). This type of curve is considered as associated with debris floods or immature phases of debris flows. Besides the shape of the curve, the peak of IMP/sec time series at Geo4 is useful to distinguish between debris flows and debris floods. The values of peak vibration in this geophone never exceeded 100 IMP/sec for debris floods, while the values ranged from 130 up to 211 IMP/sec for debris flows.

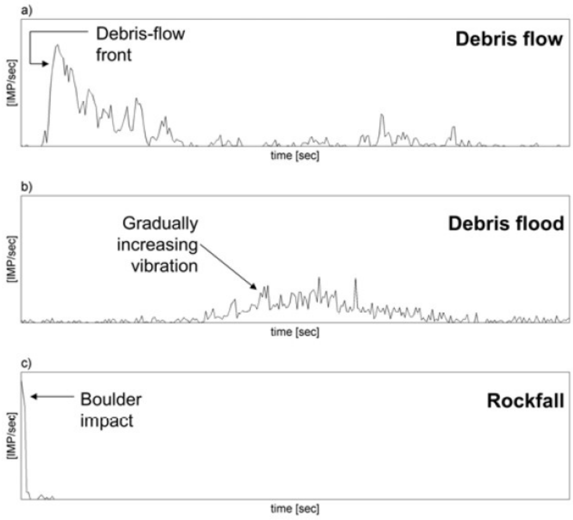

Fig. 4. IS signal patterns during a (a) debris flow (b) debris flood and (c) rockfall (Modified from [14])

Type C curve describing rockfalls is defined by a very short duration (2 to 5 sec) and very high values of IS (> 100-150 up to 190 IMP/sec). Video images and geomorphological reconnaissance show clearly that this type of curve is related to rockfalls [15]. Highest values of vibration corresponding to rockfalls and the shortest durations of vibration were recorded in Geo1, the uppermost geophone.

Further records are presented in Fig. 5. Most of them present similar durations. In general, the events last several hundreds of seconds, around 10 minutes. Exceptionally, the debris-flow event registered on the 11th of July 2010 lasted approximately 10 times this value. Thus false alarms can be avoided establishing a minimum of 3 second of ground vibration. Nevertheless, the rest of the registers suggest that there are no differences between debris flows and debris floods in terms of duration of the IS signal.

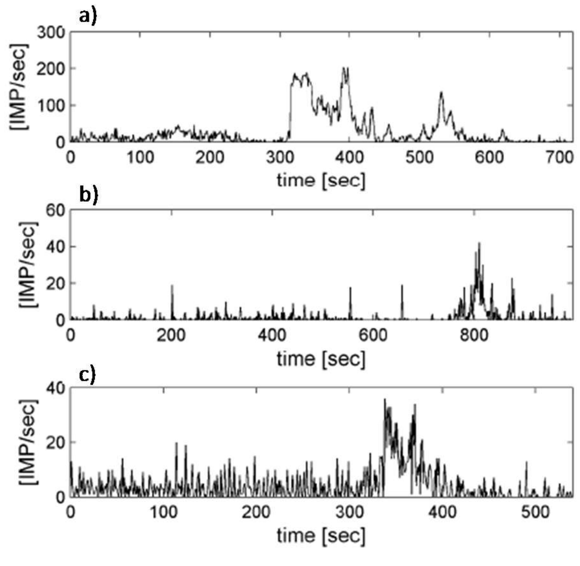

Fig. 5. Time plots of the ground vibration during some debris flows, (a) and (b), and a debris flood, (c), at Rebaixader.

Important differences of the ground response could be observed between events of the same type, even during the same event, for each geophone. This can be associated with different geomorphological situations as the location of geophone on bedrock or on a boulder and the distance between the geophones and the active channel.

A comparison of the maximum IS values with the flow volume indicates an increasing trend of IS with larger volumes, applying for the geophones located on bedrock and close to the active channel. The exception is the 4th July 2012 event (total mobilized volume of about 16200 m^3), which can be attributed to the accumulation of material in the torrent head since the beginning of summer 2012.

The data recorded at station METEO-CHA show that the debris flows and debris floods in the catchment were triggered by short high-intensity rainstorms in summer. In contrast, no correlation was observed between rainfall and rockfall occurrence. The duration of rainfalls triggering flow processes was always smaller than 220 minutes for both and mostly around 2 hours for debris flows. Critical hourly rainfall amounts initiating debris flows are about 15 mm/h for summer and even lower than 10 mm/h for spring. Snowmelt and soil thawing further affect the flow. Antecedent rainfall (3-day and 10-day measurements) was neither found to correlate well with the triggering of torrential flows. Additional events are required to further rainfall establish the thresholds for Rebaixader site.

III. THE SOLÀ D'ANDORRA SLOPE: FORAT NEGRE COULOIR AND BORRASSICA

A. Setting and activity

The Solà d'Andorra is a rocky slope, about 2 km long, above the urban areas of Andorra la Vella and Santa Coloma in the Principality of Andorra. Various rockfall scars, chutes, screes and talus deposits indicate the occurrence of a high rockfall activity in the area (Fig. 6). The slope is very steep, up to almost 85° in some locations, and the bedrock is granodiorite. The maximum observed rockfall volume at the slope during the last decades has been 1000 m^3. The general average frequency is 1 event every two years. Zones with intense activity are Borrassica, Bassera Mateu and the Forat Negre couloir [16]. A rockfall that occurred in 1997, causing major damage of a building, raised the public awareness of the risk and the local authorities were mobilized to take action against rockfalls. A prevention policy was applied through three work plans [17]: the rockfall master plan (related to construction permissions), the mitigation plan (with reference to the installation of structural protective measures) and the surveillance plan focused on the location of possible future rockfalls and documentation of past ones [18]. More recently, in April 2008, a major rockfall about 200 m3 of detached mass, destroyed completely the rock barriers and damaged an unoccupied building located in a high hazard area according to the rockfall master plan.

B. Monitoring network

The installation of the Forat Negre monitoring system started in 2012 and its objective was to obtain more accurate data on the rockfall frequency, including small rockfalls, which are not detected by the surveillance plan. This monitoring network is similar to the one applied at the FLOW-WR station of the Rebaixader catchment. It comprises 5 geophones, a video camera, three infrared spot-lights, a rain gauge and a thermometer, all connected to a datalogger and a GPRS modem for data transmission (Fig. 6). As in the Rebaixader site, the raw signal of the geophones is transformed to impulses per second and the system is programmed to run, switching between “event” (recording every second) and “no event” mode.

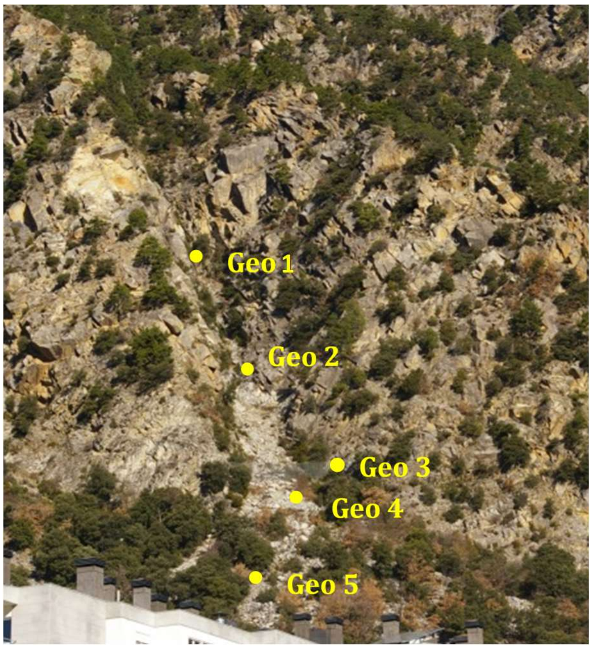

Fig. 6 Forat Negre couloir and location of the geophones of the monitoring system.

The geophones are distributed downhill, three of them located at the bottom of the couloir and two in the upper part of the talus slope, along a distance of about 90 m. By being close to the source walls the recording of small rockfalls is allowed. An additionally effort is needed in that case, in order to filter out false positives (due to severe hail or animals, for example).

Currently the recording threshold of the monitoring system, which triggers the “event” mode, is being calibrated. It is actually set on 20 IMP/sec. So far, the collected data have indicated only small rockfalls (five events) in the Forat Negre, identifiable by very strong vibration (> 100 IMP/sec) and affecting a very small area (recorded by one or two geophones). More than 80 false positives were recorded, which suggests that a greater IMP/sec threshold should be established. As events around Forat Negre occur every 3.5 years on average [16] important rockfall events can be anticipated in the next few years.

C. Periodic rockfall monitoring

Within the aforementioned surveillance plan, undertaken by the Andorran Government, helicopter flights are programmed each year to: (a) compile an inventory of potential rockfall zones, (b) inspect the rockfall events that occurred between consecutive flights, (c) identify possible new rockfalls, (d) revise the state of rockfall barriers, especially of those near the sources, and (e) propose new protection measures. Images of 10 Mp resolution, obtained during the flights of 2014 and 2015, were used for the acquisition of a point cloud of the terrain relief (1 point every 10 cm). The software Agisoft served to this aim.

Fig. 7. Reconstructed volume of the 2014 event at Borrassica. The photogrammetric model and the LIDAR point cloud are shown.

Point clouds were additionally obtained using a Terrestial Laser Scanner at two different field campaigns (in 2009 and 2010). The used device was an Optech Intelligent Laser Ranging and Imaging System (OPTECH-ILRIS3D), composed by a transmitter/receiver of infrared laser pulses and a scanning device. The average scanning distance from the slope was less than 600 m. Points were obtained every less than 1 cm approximately.

The superposition of the photogrammetry model with the TLS obtained point cloud, and the reconstruction of the missing rock mass, permitted the volume characterisation of a rockfall event that occurred in 2014, during which a rock of about 15 m^3 detached from Borrassica. Fig. 7 shows the photogrammetric model and the Lidar point cloud that permitted the reconstruction of that volume.

IV. CONCLUSIONS

Some experiences that derived from the monitoring of the Reibaxader catchment and the Solà d’ Andorra slope are mentioned here, mainly with respect to the network installation and calibration, as well as the data interpretation.

The distinction of the system between “event” and “no-event” mode is possible and necessary to minimize power supply needs and optimize data processing. To this aim and for these monitoring systems a ground velocity threshold was used, in order to avoid registering false alarm data.

The power provided by solar panels can be especially insufficient during winter. Alternatively, the use of wireless sensor networks is proposed for their low power demand and for avoiding having wires crossing the channel bed.

The design of a monitoring system as far as it concerns the placement of the sensors is important for the capturing of data. The type of the hazard (debris flow, rockfall etc.) with its respective initiation and propagation mechanism should be taken into account for this. Geophones are very robust non-invasive sensors and thus can be placed at some distance from the torrent/couloir and without complex structures.

Geophones are efficient in detecting, distinguishing and characterizing different types of fast moving landslides, in function of the IMP/s measurements. In most cases, a positive correlation between IMP/s and event volume was indicated too. However, for characterizing the debris flow height, additional sensors like ultrasonic, radar, or laser devices are necessary. Visual (video) information, despite of showing quite high power consumption and large data volume, is also necessary for interpreting data correctly.

The definition of critical thresholds of the ground velocity, to switch into the "event" mode in the monitoring systems is very important to reduce false positives (false alarms). At the Rebaixader site, this has been possible for debris flows and (large) rock falls but not for debris floods. In conclusion such monitoring systems can be adapted for alarm systems.

V. ACKNOWLEDGEMENTS

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VI. REFERENCES

[1] D.Arosio, L.Longoni, M.Papini, L.Zanzi (2015) "Analysis of Microseismic Activity Within Unstable Rock Slopes". In Modern Technologies for Landslide Monitoring and (Ed. M. Scaioni), 2015, pp 141-154

[2] M.Scaioni et al."Modern Technologies for Landslide Monitoring and Prediction". Springer Natural Hazards, 2015, pp. 249

[3] M. Hürlimann,C. Abancó, J.Moya, I.Vilajosana "Results and experiences gathered at the Rebaixader debris-flow monitoring site", Central Pyrenees, Spain. Landslides, 2014, 11:939–953.

[4] T.Spillmann, H.Maurer, A.G. Green, B.Heincke, H. Willenberg, S.Husen, "Microseismic investigation of an unstable mountain slope in the Swiss Alps". Journal of Geophysical Research 112, Paper no. B07301, 2007.

[5] D.Amitrano, M. Arattano, M. Chiarle, G. Mortara, C. Occhiena, M.Pirulli, C.Scavia, "Microseismic activity analysis for the study of the rupture mechanism in unstable rock masses."Natural Hazards and Earth System Science, 2010. 10, 831–841.

[6] A.Helmstetter, S.Garambois, "Seismic monitoring of Séchilienne Rockslide (French Alps): Analysis of seismic signals and their correlation with rainfalls" Journal of Geophysical Research 115, Paper no. F03016, 2010.

[7] M.Walter, U. Schwaderer, M.Joswig, "Seismic monitoring of precursory fracture signals from a destructive rockfall in the Vorarlberg Alps, Austria". Natural Hazards and Earth System Science, 2012, 12, 3545–3555.

[8] L.H. Blikra, "The Åknes rockslide: Monitoring, threshold values and early warning" In Proceedings of 10th International Symposium on Landslides and Engineered Slopes(pp. 1089–1094). Xi'an, P.R. China, June 30–July 4, 2008.

[9] V L.Zimmer, B.Collins, G.Stock, N.Sitar, "Rock fall dynamics and deposition: an integrated analysis of the 2009 Ahwiyah Point rock fall, Yosemite National Park, USA" Earth Surface Processes and Landforms, 2012. Volume 37, pages 680-691

[10] C.Abancó, M.Hürlimann, B.Fritschi B, C.Graf , J.Moya "Transformation of ground vibration signal for debris-flow monitoring and detection in alarm systems" 2012. Sensors12(4):4870–4891

[11] L.Marchi, M.Arattano. AM. Deganutti "Ten years of debris-flow monitoring in the Moscardo Torrent (Italian Alps)", 2002, Geomorphology 46(1–2):1–17

[12] O.Hungr, S.Leroueil, L.Picarelli, "Varnes classification of landslide types, an update". In: Eberhardt E, Froese CR, Turner AK, Leroueil S (eds) XI International Symposium on Landslides and Engineered Slopes. CRC, Banff, pp 47–58, 2012.

[13] C.Abancó, M.Hürlimann, J.Moya "Analysis of the ground vibration produced by debris flows and other torrential processes at the Rebaixader monitoring site (Central Pyrenees, Spain)", 2013, Nat Hazards Earth Syst Sci Discuss 1:4389–4423

[14] C.Abancó (2013) "Monitoring and geomorphologic characterization of debris flows at catchment scale" PhD thesis. Universitat Politècnica de Catalunya. https://upcommons.upc.edu/handle/10803/128677

[15] M.Hürlimann, C.Abancó, J.Moya "Rockfalls detached from a lateral moraine during spring season. 2010 and 2011 events observed at the Rebaixader debris-flow monitoring site (Central Pyrenees, Spain)", 2012, Landslides 3:385–393

[16] J.Corominas, R.Copons, J.Moya, JM.Vilaplana, J.Altimir, J.Amigó "Quantitative assessment of the residual risk in a rockfall protected area", 2015, Landslides 2 (4), 343-357

[17] R.Copons, J.M.Vilaplana, J.Corominas, J.Altimir, J.Amigó "Rockfall hazard management policy in urban areas: the Andorran experience". In Landslide Hazard and Risk (Ed. T.Glade, M.Anderson and M.Crozier). John Wiley & Sons Press, 2005, pp. 675-698.

[18] R.Copons, J.M.Vilaplana, "Rockfall susceptibility zoning at a large scale: From geomorphological inventory to preliminary land use planning". Engineering Geology, 102, 3-4, 142-151, 2008.