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LANDSLIDE EARLY WARNING SYSTEM

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Abstract: *The landslide consists of rock wedge threatening two roads which are important for local transportation. The present work encompasses all the components of an early warning system, including the geological knowledge, the risk scenarios, the kinematic characterization of the landslide, the choice and installation of the monitoring system, the setting of appropriate alarm levels and the definition of plans of civil protection. The focus is on practical and logistical issues met in all these phases and the counter-measures adopted. At present the system consists in 13 wire extensometers, 1 thermometer, 1 rain gauge and 3 cameras. Should a velocity threshold be exceeded by two or more sensors, the attention level would be entered, causing improved monitoring and surveillance. In case the behaviour of the landslide changes and, by using expert judgment and forecasting methods, an imminent failure is hinted, then an alarm is issued and the upper road is closed.*

Keywords - *warning system, protection, monitoring*

I. Introduction

In landslide prone areas, risk mitigation must often face problems related to economical resources, environmental impact and logistic issues. This is particularly true for structural counter-measures, which aim at mitigating the risk by reducing the probability of failure (bolts, anchors, piles etc.), by preventing the landslide from reaching the elements at risk (barriers, ditches, retaining walls etc.) or by reinforcing existing buildings. On the other hand, early warning systems (EWSs) are an alternative cost-effective means to reduce the risk with a low environmental and economical impact. In some cases, for instance when a landslide is so large that it cannot possibly be stabilized, they can even be the only solution.

Several definitions of EWS can be found in the literature. Medina Cetina and Nadim (2008) define them as "monitoring devices designed to avoid, or at least to minimize the impact imposed by a threat on humans, damage to property, the environment, or/and to more basic elements like livelihoods." According to United Nations International Strategy for Disaster Reduction (UNISDR, 2009) they are "the set of capacities needed to generate and disseminate timely and meaningful warning information to enable individuals, communities and organizations threatened by a hazard to prepare and to act appropriately and in sufficient time to reduce the possibility of harm or loss. Whatever the definition, EWSs always work as risk mitigation tools by acting on the exposure of the elements at risk, especially people, by keeping them away from the dangerous area in case of expectation of an imminent collapse.

However it must be clear that an EWS is not just a cluster of monitoring systems or the forecast of failure, but it also involves other aspects such as the identification of risk scenarios, emergency plans, societal considerations, public awareness, etc. Each one of these components is necessary; if any element fails, the whole chain would collapse and would render the system useless. For example, a lack in the monitoring or forecasting can cause a missing event or conversely a false alarm and the consequent loss of confidence in the system. On the other hand, a bad planned evacuation can produce damages and economic losses; this explains why redundancy is so important, so that a single rupture of a chain's ring should not com- promise the whole chain.

II. Monitoring and movement pattern

A first monitoring campaign had been carried out since 2003. A topographic monitoring was performed through 27 control points localized within the landslide area; moreover 10 wire extensometers were installed across the main fractures .

Measurements obtained from the topographic benchmarks from spring 2004 to spring 2007 showed that the fastest moving part was the eastern one, close to the back fracture, and as moving westward the displacements decreased Moreover, the benchmarks located on the eastern side revealed that the vertical dis- placements prevailed upon the horizontal ones, while the contrary occurred on the western side.

The extensometers gave similar results and during the period March 2005 to May 2007 recorded the highest velocity of 1.2 mm/day nearby the eastern limit of the back fracture. Here, the opening measured by the extensometers represented the 50−65% of the displacements recorded by the topographic measurements (Graziani et al., 2009b).

During summer 2007, the monitoring system has been re-configured, with the aim of making it as suitable as possible for early warning purposes (Balducci et al., 2011).

As the most indicative parameter of instability was believed to be the opening of fractures bounding and within the unstable mass, a wire extensometric monitoring was preferred. Furthermore extensometers are characterized by a quite easy installation and employment within an early warning procedure, low vulnerability and high reliability.

The technology available for EWS is so accessible and advanced that the main limitation is often represented by logistic issues (Nadim and Intrieri, 2011). While setting up the system for managing data, a few of these issues have been dealt with, as described in the following part. The system was initially designed to be fully wireless; nevertheless, the high incidence of multi-path phenomena made it necessary to avoid radio transmissions in areas with strong obstacles.

At present 13 extensometers and a thermometer−rain gauge station are installed on the landslide. The location of each extensometer is shown in Fig. 5A, together with the main fractures. A video surveillance system is also active in real-time with remote connection.

Extensometers E10n, E9n, E8n, E7n, E12, E15 and E11 (from W to E) are located in correspondence of the back fracture. E14 and E13 measure the aperture of a secondary fracture just below the main one. A crack within the landslide body is monitored by extensometers E4 and E3, while another one in the lowest part by E2. The extensometer E1 is positioned at the NW corner of the landslide and the meteorological station outside the unstable mass.

III. METHODOLOGY

The sensor network is based on five sets of macro-components: radio processors, transducers, analog-digital converter, data-logger and gateway. The radio processors adopted are MICA2 MPR400CB (produced by Crossbow). These were installed after an accurate field transmission test, and were integrated with cable connections in those areas where permanent obstacles did not guarantee an efficient wireless communication.

The current transducers are Celesco PT8101-0020, capable of a measuring range of 500 mm. The choice of such a long range was influenced by the will to avoid any intervention of repositioning. Adopting a 16 bit A/D converter allowed us to provide a resolution of 0.007 mm even using transducers with this range. Thanks to the high resolution and the good repeatability, these linear position transducers may be used in this type of applications, even if the EWS needs small velocity threshold values.

The extensometers positioned on the upper part of the slope (E11, E12, E13, E14, E15, E7n, E8n, E9n and E10n) are connected through cables to a data-logger installed on the top of the landslide and are powered by a set of solar panels. The other instruments (E1, E2, E3, E4, thermometer and rain gauge) are radio connected to another data-logger installed in a rest area close to the road at the base of the slope and each of them is provided with its own solar panel Data collected by the data-loggers are transmitted by a gateway (RS232 MIB 510 by Crossbow) via GPRS to an ftp server. Redundancy is therefore implemented at this point, as data are stored in more delocalized storage systems.

Since the nodes are installed within the landslide body, they are subject to the impact of rolling stones and to the multi-path effect due to the high roughness of the soil and to the presence of vegetation. Tough steel shelters were used to limit instrument damages and increase robustness.

The sensors of the WSN make an acquisition every 60 s, but only a 5 min mean datum is sent to the data-logger in order to save energy. In fact, a WSN implies an energy consumption proportional to the measurement frequency, as each operation activates the radio pro- cessor, the A/D converter and the transducer. The power supply is another important aspect of an EWS that must be taken care of, since interruptions of the monitoring due to a lack of energy can be very critical during the periods when the landslide is most active.

IV. THE EARLY WARNING SYSTEM

In order to guarantee safety conditions to the personnel involved in the retaining wall construction and to keep a low residual risk after its completion, an EWS has been speciﬁcally designed for the Torgiovannetto rockslide. Before starting with the actual design of the EWS, a few design criteria will be pointed out. Simplicity was adopted as a criterion here. In fact, in emergency conditions everything must be simple and straight-forward; the action to be taken must be clear and fast, and misunderstandings or human errors are not tolerable. Furthermore, trying to forecast the imminent failure of a landslide and to alert people is a very com- plicated task; for this reason some simpliﬁcations must be done. Creating an EWS that reﬂects all the possible features of a landslide can bring very little improvements and even compromise the whole system. Simplicity can be implemented in many different ways within an EWS, as in the choice of few warning levels or of schematic thresholds.

V. Conclusion

In order to reduce the residual risk imposed to the Provincial Road 249/1 by the Torgiovannetto landslide, an EWS has been implemented. The Torgiovannetto landslide is a 182,000 m3 rockslide which has been studied since 2004. During these years many data have been collected and there is now a good knowledge of the threat and associated risks, which are necessary in order to design the most suitable EWS.

The EWS currently in use adopts 13 wire extensometers, 1 thermometer, 1 rain gauge, and 3 cameras. The system automatically acquires data every minute and uploads them on an ftp. Aiming at simplicity, only 3 warning levels have been deﬁned (ordinary level, attention level and alarm level). Velocity thresholds have been deﬁned just for the attention level, while the alarm level can be reached only following expert judgment mainly based on empirical forecasting methods. Beside expert judgment, redundancy and data averaging have been added in order to reduce the possibility of false alarms. For the same reason rainfall data are not included as thresholds, due to a loose correlation between them and potential failure. However ground water content simulations and weather forecasts are considered before entering the alarm level.

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