Performance of Slope Behavior Indicators in Unsaturated Pyroclastic Soils

Luciano PICARELLI\textsuperscript{1} \textsuperscript{D} http://orcid.org/0000-0001-6670-1895; e-mail: luciano.picarelli@unina2.it
Emilia DAMIANO\textsuperscript{1} \textsuperscript{D} http://orcid.org/0000-0001-8361-3694; e-mail: emilia.damiano@unina2.it
Roberto GRECO\textsuperscript{1} \textsuperscript{D} http://orcid.org/0000-0002-7380-4515; e-mail: roberto.greco@unina2.it
Aldo MINARDO\textsuperscript{2} \textsuperscript{D} http://orcid.org/0000-0002-8966-9143; e-mail: aldo.minardo@unina2.it
Lucio OLIVARES\textsuperscript{1} \textsuperscript{D} http://orcid.org/0000-0003-0723-0872; e-mail: lucio.olivares@unina2.it
Luigi ZENI\textsuperscript{2} \textsuperscript{D} http://orcid.org/0000-0001-8356-7480; e-mail: luigi.zeni@unina2.it

1 Department of Civil Engineering, Design, Home Building and Environment, Seconda Università di Napoli, Aversa 81031, Italy
2 Department of Industrial and Information Engineering, Seconda Università di Napoli, Aversa 81031, Italy


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Abstract: Landslide risk is increasing in many parts of the world due to growth of population and infrastructures. Therefore, an effort has to be made in developing new and cheap sensors for areas susceptible of landslides to continuously control the slope behaviour, until approaching failure conditions. The paper reported experimental data from small-scale physical models about the performance of Time Domain Reflectometry (TDR) and optical fibres, which act as the indicators of the incoming failure of slopes covered by unsaturated granular soils. Obtained results appear encouraging, since both sensors provide continuous information about the state of the slope, in terms of water content profiles and ongoing deformations, induced by rainwater infiltration, even immediately before the triggering of a fast landslide.

Keywords: Unsaturated granular soils; Slope monitoring; Rapid landslide; Optical fibre; Time Domain Reflectometry; Probe

Introduction

In modern society, natural and anthropogenic risk is growing, because of an unavoidable increase in exposure. Among natural hazards, rainfall-induced landslides affect large areas worldwide and are responsible of huge losses, and the related hazard seems to increase due to climate change (IPCC 2011). A response to the societal demand of security requires the development of reliable criteria for risk mitigation, which can be achieved through active or passive works. Nonetheless, these measures are often impractical due to economic, morphological or environmental constraints.

Thanks to the development of new and accurate sensors and effective systems of timely data transfer, the demand for early warning systems is increasing as a useful measure for risk mitigation (Sassa et al. 2008; Picarelli et al. 2009). A crucial aspect of this approach is the capability to reliably predict location and occurrence of the
phenomenon in due time. Unreliable predictions, resulting in false or missing alarms, are still limiting the use of early warning systems (Gasparini et al. 2007).

Real-time prediction of landslide occurrence can be obtained through the monitoring of either the potential trigger or the slope response to such a trigger. For rainfall-induced landslides, precipitation, here indicated as the precursor, represents the trigger, while water content, pore pressure change, displacement and displacement rate can be regarded as indicators of the slope response.

Examples of operating early warning systems exist, some based on comparison of measured precipitations to empirical thresholds (Keefer et al. 1987; Wilson et al. 1993; Wiley 2000; Ortigao and Justi 2004), others on monitoring of indicators (Flentje et al. 2005). In some cases, integrated systems based on both monitoring of incoming precipitations and of changes in soil state are being used to establish different levels of warning (Brand et al. 1984; Iwamoto 1990; Baum et al. 2005; Chleborad et al. 2008). A recent review about operating early-warning systems in Europe is reported in Alfieri et al. (2012).

Shallow landslides are a typical consequence of extreme rainfall events, but the identification of empirical rainfall thresholds for the prediction of their triggering is rarely feasible, as historical rainfall data associated to slope failures are required. Such landslides usually occur along steep slopes covered with unsaturated granular deposits, as in the case of landslides which occurred during the last decades in the hilly area of Campania, Southern Italy (Calcaterra et al. 2004; Cascini and Ferlisi 2003; Crosta and Dal Negro 2003; Guadagno et al. 2005). Figure 1 shows the location of the largest landslides which occurred during the last decades. Here the involved slopes are covered with loose air-fall granular deposits originated by the eruptions of some volcanic complexes (Rolandi et al. 2003; Di Crescenzo and Santo 2005). In many cases, the failed soil mass attained a size of tens of thousands cubic metres and reached a velocity of metres per second (Faella and Nigro 2003). Such slopes are in equilibrium thanks to the contribution of soil suction to shear strength, which allows stability of slopes steeper than the friction angle of the material (Olivares and Picarelli 2003). Owing to the rainfall infiltration, a landslide can be suddenly triggered, as the resisting force no longer balances the driving force. In fact, the increase of water content causes an increase of soil weight and a decrease of suction and associated cohesion (Fredlund and Rahardjio 1993).

The continuous monitoring of suction and/or of water content, as indicators of stability conditions, can therefore provide useful information. It is well known that these two variables are related through the non linear soil water retention curve (SWRC). Owing to the steep slope of the transition zone of the SWRC, near saturation small changes in suction correspond to great changes in water content. In the considered slopes, failure usually occurs in saturated or nearly saturated conditions. Monitoring data show that during the wet season, soil suction drops to very small values (Damiano et al. 2012; Sorbino and Nicotera 2013) of a order of a few kPa, while water content still remains far below saturation (Greco et al. 2014; Pirone et al. 2014). Thus, monitoring of water content seems more suitable than suction to reveal the incoming failure.

Traditional monitoring performed with