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Continuous monitoring of a large active earth flow using an integrated GPS - automatic total station approach

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Landslide monitoring has evolved as a crucial tool in civil protection to mitigate and prevent disasters. The research presents an approach to continuous monitoring of a large-scale active earth flow using a system that integrates surface measurements obtained by a GPS and an automatic total station. With the data obtained from the system the landslide can be monitored in near-real-time and surface displacements can be directly utilized to provide early warning of slope movements and to study the behavior of the landslide, e.g. to predict timing and mechanisms of future failure.
The Valoria landslide located in the northern Apennines of Italy was reactivated in 2001, 2005 and 2007 damaging roads and endangering houses. A monitoring system was installed in 2007-2008 in the frame of a civil protection plan aimed at risk mitigation. The system consists of an automatic total station measuring about 40 prisms located in the landslide to a maximum distance of 1.800 km; one double-frequency GPS receiver connects in streaming by wireless communication with 4 single-frequency GPS in side the flow. Until December 2007 the monitoring network was operated with periodic static surveying followed by the data post-processing. From September 2007 until March 2008 the landslide deformation was evaluated by periodic surveys with the total station and the GPS system. This first measure showed that the displacements were influenced by the rainfall events and by the snow melting. The total displacements measured vary from centimeter scale in the crown zone, where retrogressive movements were in progress, to over 50 m in the flow track zone. Starting in March 2008 data acquisition by the total station system and GPS were automated in order to allow continuous and near-real-time data processing. The displacement data collected in one and a half year of continuous operation show different acceleration and deceleration phases as a result of the pore water pressure distribution inside the landslide.
From March 2008, the total station and the GPS receiver were predisposed for the continuous monitoring. The successive deformation continued constantly and some monitored points recorded decimeter of cumulative displacements in May. In June the displacements progressively decreased due to the absence of the precipitation. Abundant rainfalls in July 2008 (200 mm of rainfall in 50 days) drove a new instability in the landslide. As a result some landslide sectors experienced accelerations measuring total displacements between one decimeter and ten meters in 20 days. Following this event acceleration was recorded at the end of October 2008, when 550 mm of cumulative rain fell in 40 days. During this event the velocity of the material varied between cm/day to m/day and the maximum reacted displacement was 15 m. Through the monitoring with data acquisition every 3 hours it was also possible to evaluate the continuous transfer of mass from the upper part of the slope to lower part. Measurements showed the reactivation of a downslope portion only one day after reactivation occurred upslope at a distance 200 m.
The utilized monitoring system has proven reliable for continuous monitoring of an active earth flow with large deformations ranging up to meters for day also during the paroxysmal phases. Moreover, the complex behavior of the flow in the active phase and in each acceleration and deceleration phase was highlighted. For instance, the timing and intensity of movement propagation downslope as an effect of mass transfer and successive loading of lower slope portions was evidenced many times. This information cannot be obtained with borehole monitoring

systems which are normally damaged when displacement exceeds some decimeters, nor can it be computed with comparable spatial coverage and data availability timing using other high precision methods, such as laser scanners or ground-based SAR. Another advantage of the adopted monitoring approach over other techniques is the wide angle of operation provided by the strategically beneficial location of the master station, that allows for full coverage of the landslide, from the head zone to the toe. Moreover, the monitoring system deployed in Valoria provides real time data availability, and is therefore an effective solution for development of an early warning system at a cost that, today, is still lower than that required for real-time ground based SAR.