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Cross-correlation and time-lag analysis of high frequency monitoring data of the Vallcebre landslide (Eastern Pyrenees, Spain) to reveal cause-effect relationships between variables governing slope instability

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The Vallcebre landslide is a slow moving large landslide located 140 km north of Barcelona in the Eastern Pyrenees. Monitoring data of the Vallcebre landslide represent a singular case of multi parameter high-frequency monitoring system set up in 1996 and still ongoing. Data of movements and groundwater levels are measured and recorded with a frequency of 20 minutes in 6 boreholes distributed in the landslide, each one equipped with a wire extensometer and a piezometer, while rainfall is recorded by a specific gauge at the site.

Data from 3 boreholes recorded during three full years of measurements (from 1999 to 2001) have been analyzed by means of a cross-correlation function in order to determine the reciprocal interdependency and the relative time lag between rainfall, groundwater and movement rate maxima and, ultimately, to evidence cause-effect processes occurring along the slope. It should be pinpointed that, in this specific case, rainfall is also a proxy for the discharge level of the stream eroding the toe of the landslide, that is believed to be one of the main instability factors.

The cross-correlation function is a quite simple signal processing tool for measuring similarities of wave-forms as function of an applied time-lag. Specifically, it was applied to study: i) the relations between rainfall and movement rate, so to highlight the relative time lag for rainfall to produce an effect in different points of the landslide; ii) the inter-dependencies between different movement rates in the three boreholes in order to determine the pattern of mobilization of the landslide (from up to down slope and vice-versa); iii) the response of groundwater with respect to rainfall, which reflects the local permeability; iv) the evolution of groundwater levels in the three monitoring points.

Altogether, results confirm and constrain in time the retrogressive trend of movements in the landslide (in agreement with a 2D numerical model previously developed by Ferrari et. al. 2011) and the driving role of stream undercutting the toe of the landslide, as the acceleration of movements at the lower borehole has the shortest time lag with respect to rainfall, disregard the fact that groundwater level raise earlier in the upper piezometers. Finally, the in-depth analysis of time-lags between movement rates along the slope, allowed highlighting compression and tensile phases in different zones along the longitudinal cross section of the landslide.

References:
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