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Effects of the slope toe evolution on the behaviour of a slow-moving large landslide

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Ability to predict accelerations for slow-moving landslides is a crucial requirement in the hazard management process and, in particular, in the establishment of early warning systems. Variation of pore water pressure within the slope is frequently recognized as the main cause for accelerations to occur and quantitative relationships among groundwater level and landslide velocity are pursued. In this sense numerical models can provide realistic predictions only if the involved physical processes are correctly taken into account and distinctive features are well reproduced, such as the frequently observed hysteresis in the groundwater level - velocity relationship.

To this regard, the paper presents recent developments on the modelling of a slow-moving large landslide (Vallcebre, in Eastern Pyrenees - Spain). Efforts have been devoted to an improved analysis of the phenomena observed during the continuous monitoring of the study case. In particular, attention has been paid on the analysis of the effects of the slope toe evolution on the overall stability of the landslide and on the movement rates. Geomorphologic observations showed that the landslide has been pushing the torrent at its toe toward the opposite bank, shifting its bed for several meters. This caused the landslide toe to override the opposite slope and to assume a back tilted shape. Due to the reached configuration, landslide movements result in mass accumulation at the slope toe, which in turn is affected by local instability phenomena mainly caused by torrent erosion.

A time-dependent 2D numerical model has been developed with the purposes to quantitatively analyse how toe mass variations can influence movement rates and to verify whether mass accumulation can represent an auto-stabilizing mechanism for the slope. In the proposed formulation, the sliding mass is modelled as composed of two rigid blocks sliding on two different planes: the toe mass on the back titled slope and the landslide body. The blocks are in contact through a separation boundary which position is assumed fixed during the analysis. Different shearing resistance angles can be set for the three surfaces. The model allows performing parametric studies in which the sensitivity to changes in the involved initial masses, slope inclinations, shearing resistance parameters can be assessed. A finite difference approach is used to discretize the time. For each time increment, changes in model parameters are allowed, including variations in shearing resistances, groundwater level and block masses (in order to simulate toe erosion). During each iteration, the overall stability of the system is checked computing the Factor of Safety, assuming that the percentage of mobilized shear strength is the same for the three surfaces. If the system is not stable or if it is not at rest (i.e. velocity is greater then zero), the velocity of the system is computed solving the momentum equations for the two blocks taking into account destabilising and resisting forces, the mechanical interaction between the blocks and viscous components. Computed velocities are iteratively used to compute mass accumulation at the toe, which in turn results in a change of the stability condition of the system.

The model is being used to analyse several events observed during the monitoring. In particular, we considered the case of accelerations detected for rainfall events that did not lead to significant raising of the groundwater level, but that could have caused the torrent flow and the consequent erosion of the toe to increase. The model is also in use to asses if the observed hysteretic behaviour - in terms of groundwater level variations and measured velocities - can be related to the transient mass increase of the toe.