Multi-parametric monitoring of the triggering conditions of weather-induced shallow slides in coarse-grained soils

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Weather-induced shallow landslides in coarse-grained soils are first failure phenomena often occurring as multiple slides in natural slopes over wide areas (e.g. Cascini et al., 2008) or single/multiple occurrences in artificial slopes along transportation corridors. In both cases, diffuse monitoring over the area of interest is required if one wants to predict the possible location of future landslides, for instance to manage risk at regional scale, or the soil conditions leading to triggering for early warning purposes. The selection of the instruments needed to meet the objectives of a monitoring strategy has to consider the accuracy, reliability, and spatial and temporal resolution of different monitoring techniques. Smethurst et al. (2017) identify some key distinctions in the wide range of modes of sensor deployment: i) ground-based vs remotely located sensors; ii) static vs dynamic sensors; iii) surface vs subsurface information; iv) point sensors vs spatial or volumetric monitoring technologies; v) permanently deployed sensors vs manually repeated measurements with temporary sensors; vi) telemetric vs manual data retrieval.

The monitoring devices that are considered herein are ground-based, static, permanently deployed point sensors, used to detect both surface and subsurface information. This study aims at highlighting the role played by these monitoring devices when they are used, singularly or combined together, as tools to assess the conditions of slopes in granular soils leading to shallow first-failure slides. In particular, the influence of the location of the monitoring instruments is assessed in relation to different stratigraphic conditions and to the total or partial saturation of the soil layers. The time-dependent soil parameters considered in this study are the following: positive pore water pressure, suction, soil water content, stress, surface and subsurface displacements. All these parameters can be monitored employing static permanently deployed point sensors and, potentially, using low-cost instruments providing high resolution data in time and space. The focus of the contribution is not on the technology needed to measure the considered parameters but on the meaning of the measurements as potential detectors of soil conditions leading to failure within a slope. To this aim, the study comprises a series of parametric analyses employing: analytical and numerical methods in 1D conditions, and numerical models in 2D conditions.

To define the triggering conditions of weather-induced shallow slides, modelling of the soil-atmosphere interaction is required. Elia et al. (2017) identify three numerical strategies to model the effects of the slope-atmosphere interaction on the thermo-hydro-mechanical state of the slope: 1) hydraulic modelling, which simulates the transient seepage in the slope evolving with the atmospheric conditions by accounting solely for the fluid mass-balance equations and disregarding the effects of the variations in temperature within the soil and the deformation of the soil skeleton; 2) thermohydraulic modelling, which also considers the thermal processes within the soil and the thermohydraulic coupling; and 3) hydromechanical modelling, which accounts also for the coupling of the fluid mass balances with the soil skeleton deformations.

The analytical and numerical analyses performed in this study do not consider the thermohydraulic coupling nor address other important issues of the soil-atmosphere interaction, such as the quantification of the evapotranspiration and the infiltrating water components in relation to weather conditions, vegetation and soil characteristics. The focus of the analyses is limited to the investigation of the soil response to applied boundary conditions. When only hydraulic modelling is performed, the prediction of the groundwater regime in a slope in relation to time-dependent atmospheric conditions is used as input in limit equilibrium slope stability analyses to derive the variation with time of the factors of safety along potential slip surfaces. When the hydromechanical coupling is explicitly considered, the numerical simulations are aimed at reproducing the stress-strain evolution associated with the transient seepage processes induced by changing hydraulic boundary conditions. In both cases, the results of the parametric analyses are used to evaluate the modelled response of a slope at the onset of failure, in different locations and in relation to many monitoring parameters (e.g., pore water pressures, soil water contents, stresses, displacements). The significance of the analyses is also assessed by comparing the model results with data from both scale models tested in the laboratory and case studies of artificial and natural slopes.

The presented results should be seen as an initial contribution towards the far reaching aim of defining and adopting an economically sustainable and technically reliable monitoring strategy for predicting the conditions leading to the triggering of shallow slides in coarse-grained soils over wide areas.

Keywords: landslide, modelling, monitoring, warning.

References

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