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The hydrological response to precipitations of a layered shallow sloping deposit: physical experiments and mathematical modeling

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Although rainfall-induced landslides are frequent, so that they can be probably considered the most widespread natural hazards, fortunately the occurrence of an extreme rainfall event only rarely corresponds to the triggering of landslides. This is due to the fact that slopes, although often considered as separated systems in the stability analyses, are actually part of a larger, more complex hydrological system, with which continuously exchange water. Indeed, most of the slopes do not fail, and when they are subjected to heavy precipitation, effective draining mechanisms spontaneously develop, such as overland and subsurface runoff, and sometimes even new preferential flow paths originated by mechanical processes, such as piping erosion or deformation cracks. Hence, the triggering of a rainfall-induced landslide requires these dynamically evolving (non-linear) drainage processes to be incapable of releasing the excess of water (and pressure) accumulating within the slope.

For the case of shallow sloping covers, the capability of the slope to effectively drain the infiltrating water depends on the hydraulic properties of the involved soils (hydraulic conductivity and water retention curves) and on the hydraulic boundary conditions (at the base of the cover, where it lays upon the bedrock, and at the foot of the slope), which are in turn strongly influenced by the initial moisture state (often indicated as a predisposing cause), owing to the non-linearity of the hydraulic processes. Such an already complex picture is furthermore complicated by heterogeneity.

In this study, we focus our attention onto the effects of a layered soil cover with contrasting hydraulic properties on the infiltration and drainage processes in a shallow pyroclastic deposit. This is a typical situation along many pyroclastic-covered slopes of Campania (southern Italy), which present alternations of ashes (silty sands) and pumices (sands with gravel) deposited by volcanic eruptions, and where shallow landslides are sometimes triggered by intense and long-lasting precipitations. Several studies have already pointed out that layering may play a crucial role in the development of the infiltration process, as the coarse-grained pumice layers may behave as capillary barriers, leading to the formation of perched saturated zones.

The hydrological behavior of such kind of layered slopes is investigated by means of small-scale infiltration experiments carried out in an instrumented flume in the laboratory. The interpretation of the experimental results is made with the help of a mathematical model of 2-D Richards equation, which allows shedding some light in the hydraulic properties of the pumices, which are hardly measurable with standard laboratory techniques. The obtained results show how, depending on initial moisture conditions, slope inclination angle and applied rainfall intensity, the response of the slope may be very different, and that the formation of a capillary barrier is not always observed.