Modeling and numerical simulation of two-layer debris flows

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Flows of granular materials, in combination with an interstitial fluid, are ubiquitous in both nature and industry and show a rich variety of complex phenomena. To investigate such flows, various depth-integrated models are usually employed. However, it is often observed that for such granular-fluid flows the interstices of granular materials in the lower layer are filled by the fluid phase, while in the upper layer only granular materials with pores occur. It is well known that the dynamic behaviours of fluid-saturated and dry granular flows are fairly different. A single-layer depth-integrated model may be no longer reasonable for describing these flows.

In the present study, a two-layer model is derived. The lower fluid-saturated granular layer is described by a mixture theory of density preserving solid and fluid constituents, in which the fluid phase is modelled as a Newtonian fluid and the granular phase is considered as a Coulomb friction material. The interactive force between both the constituents of the mixture is composed of viscous drag force and buoyancy force. The upper single-phase granular material is assumed to obey the Coulomb friction law, in which the dilation effect is ignored. At the interface of the mixture lower layer and the granular upper layer, the jump conditions are described. This interface is a material free surface for the fluid phase, but for the solid phase, mass transfer across the interface occurs. The proposed governing equations are integrated along the depth direction, respectively for both the layers, and simplified by employing the shallow layer approximation and the two-layer model equations are derived.

A shocking-capture high-resolution TVD scheme is employed to numerically solve the resulting equations. Flows on an inclined surface merging into a horizontal run-out zone are investigated. Through the analysis of numerical results, dynamic behaviours, particularly the temporal and spatial distributions of the thicknesses of both the layers, volume fractions of both the constituents in the lower layer are discussed. Some important phenomena are found and the acquired results can be base to fully understand the physical essence behind nature debris flows.