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Particle based method for shallow landslides: theoretical effect of sliding surface lubrification by rainfall

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Predicting natural hazards such as landslides, floods or earthquakes is one of the challenging problems in earth science. With the rapid development of computers and advanced numerical methods, detailed mathematical models are increasingly being applied to investigate complex process dynamics such as flow-like landslides or debris flows. The term landslide has been defined in the literature as a movement of a mass of rock, debris or earth down a slope under the force of gravity. Landslides occur in nature in very different ways. It possible to distinguish landslides through two main parameters: material involved and type of movement. Landslides can be triggered by different factors but in most cases the trigger is an intense or long rain. Rainfall induced landslides deserved a large interest in the international literature in the last decades with contributions from different fields, such as engineering geology, soil mechanics, hydrology and geomorphology. In the literature, two approaches have been proposed to evaluate the dependence of landslide occurrence on rainfall measurements. The first approach is based on physics-based models and the second approach relies on the definition of empirical thresholds. For what concerns the simulation of the landslide propagation, most of the numerical methods are based on Eulerian continuous models, with an implicit representation of the discontinuities, where only the influence of some physical elements, such as deformability or strength, are considered through constitutive laws. An alternative to these continuous approaches is to use Lagrangian discrete-particle methods which represent the material as an ensemble of interacting elements (also called units, particles or grains). The model then explicitly reproduces the discrete nature of the discontinuities, which are represented as the boundary of each element. These methods are inspired by models of granular material, for which a discrete Lagrangian models is very near to their physical description. The resulting numerical method is similar to that of molecular dynamics. This approach is particularly suited for the inclusion of nonlinear elements such are instantaneous change of velocities, constitutive relations among different quantities, chemical reactions, etc. This flexibility was also exploited in the modelization of continuous material by means of "mesoscale" models (smoothed particle hydrodynamics or the mesoscopic lattice gas). A method widely used in the simulation of granular material dynamics is the so-called Discrete Element Method (DEM). DEM is very closely related to Molecular Dynamics (MD): the first method is generally distinguished by its inclusion of rotational degrees-of-freedom as well as stateful contact and often complicated geometries, while the second uses an interaction potential (for example Lennard-Jones potential). In this paper we present a model, based on MD theory, applied to the study of the starting and progression of shallow landslides, whose displacement is induced by rainfall. The main hypothesis of the model is that the static friction decrease as result of the rain: in this way the rain acts as a lubricant. Although the model is still schematic, missing known constitutive relations, its emerging behavior is quite promising. The results are consistent with the behavior of real landslides: the proposed model is particularly effective to modeling the evolution of the slow shallow landslides induced by rainfall. In our simulations can be observed emerging phenomena such as fractures and detachments. In particular, the model reproduces well the energy and time distribution of avalanches, analogous to the observed Gutenberg-Richter and Omori distributions for earthquakes. These power laws are in general considered the signature of self-organizing phenomena. As in other models, this self organization is linked to a large separation of time scales.

The main advantage of these particle methods is given by the capability of following the trajectory of a single particle, possibly identifying its dynamical properties.