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Collapse of a weakly cohesive granular column

Csanád Szuszik and Ferenc Kun
Department of Theoretical Physics, Faculty of Science and Technology, University of Debrecen, Hungary
(ferenc.kun@science.unideb.hu)

Natural catastrophes like landslides are often caused by the nucleation and propagation of fractures in heterogeneous materials. Landslides are typically initiated by heavy raining events when water penetrates the pores and reduces the cohesion of soils leading to instability and cracking. When it happens on a steep slope, the moving mass could break up into pieces and the landslide gives rise to a debris flow composed of rapidly traveling fragments of soil and rocks. Such devastating catastrophes endanger the infrastructure and take thousands of lives every year.

In order to understand the emergence of landslides and debris flows we investigated the collapse of a granular column under the action of gravity by means of discrete element simulations. In the model, a cylindrical sample of soil is represented as a random packing of spherical particles. Cohesion is introduced by connecting the particles with non-linear spring elements along the edges of Delaunay triangles determined in the initial configuration of the particles. The constitutive law of springs captures the elastic behavior of particle contacts at small deformations, the plasticity beyond a yield threshold, and the gradual softening and final breaking at large separation distances. A very important feature of the interaction is that particle contacts can be healed, i.e. if two particles approach each other within a capture distance, a new cohesive contact is established between them. Computer simulations were performed varying the strength of cohesion in a broad range.

Our calculations revealed that at high cohesion the granular column sinks in, i.e. its height gradually decreases while it undergoes restructuring and flattening, however, in the final state the system keeps its integrity. When the cohesion is sufficiently week, the process of collapse cannot stop: the system breaks up into a large number of fragments which run out at a high speed. The two phases of high and low cohesion represent the mass movement and the debris flow states of real landslides, respectively. We demonstrate that the transition occurs at a critical cohesion showing analogies to continuous phase transitions.