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From solid to granular gases: the steady state for granular materials

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In this work, we assume, as in Berzi et al. (2011), that the energy of the system is dissipated throughout two mechanisms: frictional sliding and collisions among grains. When the first mechanism prevails, the material behaves like a solid and the behaviour can be interpreted in the framework of standard constitutive relationships of geomechanics, and, in particular, under steady condition, of critical state theory. On the other hand, when deformations are rapid and the material flows like a granular gas, the energy is totally dissipated by collisions. Under these conditions, the role of collisions has been successfully modeled by using the kinetic theories. When both the mechanisms coexist, we assume that their contributions can be linearly added in the expression of granular stresses and modeled, independently, in the context of the critical state theory and the kinetic theory of granular gases, respectively.
According to this approach, the critical state can be interpreted as a particular "steady state" for which the granular temperature vanishes, as well as the shear rate. Starting from this consideration, a classic rigid visco-plastic model is derived with a new definition of the fluidity parameter, which is proved not to be constant, but to depend on the concentration.
The physical mechanical meaning of the different constitutive parameters has been analysed and their mutual relationships taken into consideration. Also, a qualitative phase diagram has been drawn in the concentration-normal stress plane.
The theory has been proved to be capable of reproducing, qualitatively and quantitatively, numerical simulations on disks and physical experiments on incline flows of glass spheres taken from the literature. Finally, the theory has been used to study the steady state of simple shear flows of spheresunder pressure, concentration- and stress ratio-imposed.