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MICRO-MACRO METHODS FOR STATES AND TRANSITIONS: FROM PARTICLES TO CONTINUUM

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ABSTRACT

The behavior of particulate and granular matter – like sand, powder, suspended particles/colloids – is of considerable interest in a wide range of industries and research disciplines. These materials are intrinsically disordered, often come with a wide distribution of particle sizes, shapes, or materials/mixtures. Granular matter can behave both solid- or fluid-like, including all the various transitions between these states. The related mechanisms/processes in particle systems are active at multiple scales (from nanometers to meters, from micro-seconds to hours) and understanding them is an essential challenge for both science and application, i.e., finding the reasons for natural/industrial disasters like avalanches or silo-collapse.

In order to understand the fundamental micro-mechanics one can use particle simulation methods, where often the fluid between the particles is important too, but neglected here. However, large-scale applications (due to their enormous particle numbers) have to be addressed by coarse-grained models or by continuum theory. To bridge the gap between the scales, so-called micro-macro transition methods are necessary, which translate particle positions, velocities and forces into density-, stress-, and strain-fields. These macroscopic quantities must be compatible with the conservation equations for mass and momentum of continuum theory. Furthermore, some additional non-classical fields might be needed to describe the micro- structure or the statistical fluctuations, e.g., the fabric or the kinetic energy, before one can reach the goal of solving application problems.

From a theoretical point of view, our understanding of the rheology of granular matter has greatly improved in the recent years; a remaining key question is how to extend the flow rheology to deal with different mechanical responses that naturally occur in many granular processes. Due to their discontinuous and inhomogeneous nature, granular systems can behave like solids, if a network of contacts develops within the medium, or like fluids whenever the grains are largely spaced and free to move in any direction, interacting only through inertial collisions.

However, all the diverse transitions from fluid to solid, and back from solid to fluid, as well as the transient evolutions between those states are still not fully understood. Some examples of such multi-scale micro-macro phenomena are flows of particles/fluids in narrow channels/pores, dosing of cohesive fine powders in vending machines, avalanche flows or stopping on inclined slopes, rheology testing in ring-shear cells, as well as the study of nonlinear elasto-plastic material mechanics related to the failure of solids.