Role of softness and cohesion in rheology of wet granular flows

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Wet granular materials show distinct behavior in nature depending on the amount of interstitial fluid and the softness of the materials. However, field studies of such flows under varied condition are difficult. Discrete Particle simulations can be useful to establish basic principles qualitatively and as guidance for improving rheological models. We study the rheology from our simulation in a split bottom shear cell set-up of slow quasi-static to rapid granular shear flows using the Discrete Element Method (DEM). We introduce varying amount of cohesion due to liquid bridges into our simulations to study the transition from dry to wet. Likewise, we modify softness to study the flows from soft snow to hard rocks.

While traditionally the inertial number I [1], i.e. the ratio of stress to strain-rate time scales, describes the flow rheology under quasi-static to inertial conditions, we observe that other dimensionless numbers are also needed to describe the flow. The local compressibility p^* which is the ratio of the softness and stress time scales and the bond number *Bo* quantifying local cohesion as the ratio of cohesive force to stress time scales are two such dimensionless numbers. We study the rheology of granular materials in terms of these three dimensionless numbers. A surprising creep or relaxations anomaly in the μ(I) rheology for quasi-static, slow flow, i.e. small I is resolved by a new correction factor. The trends are combined and shown to collectively contribute to the rheology as multiplicative functions.

Inter-particle cohesion also has a considerable impact on the compaction of soft materials. Cohesion causes additional stresses, leading to an increase in volume fraction due to higher compaction. This effect is not visible in a system of infinitely stiff particles. In addition, we observe an opposite trend, decreasing the volume fraction due to increased cohesion for frictional particles, which we attribute to the cohesion-enhanced role of friction, leading to strong dilatancy.

Constitutive relations for granular flow seem to be quite complicated due to their strong stress-strain history dependence and non-linear behavior. In fact, there exists no universal constitutive relation for dry or wet granular materials, but only equations reflecting the behavior under certain conditions. However, the parametric rheology model can capture the generic, system-independent flow behavior within the range of validity of its parameters since it encompasses multiple micro-mechanical effects at the same time. Thus the fluid-like flow of different kinds of materials can be predicted by implementing the present steady-state rheology model in a continuum solver.

References

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