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A model for size-effects in steadily flowing granular media: formulation and basic validation

Kamrin, Ken, kkamrin@mit.edu, MIT

ABSTRACT

The particle-size dependence of the flow of a collection of dry grains is easily seen in several contexts, and because of the often non-negligible size of grains relative to their macroscopic geometry, it can be a dominating effect. Here, we develop and demonstrate basic results of a new theory for granular material deformation, which focuses on quantitatively predicting developed flows. Central to the model is a nonlocal “fluidity” variable — akin to an order parameter — whose dynamics are governed by a grain-size dependent differential equation. Through a dependence of the flow rule on the fluidity, the plasticity attains a particular nonlocal character, which enables a newfound level of modeling predicitivty. While the model is inspired by recent approaches within the emulsions community, we show that the features of the theory arise from a thermomechanical virtual power description. We demonstrate how stability analysis of the fluidity field in a thin granular pile enables quantitative modeling of the size-dependence of static strength, a well-known effect. A simplified, steady-state-only version of the model is implemented in a number of prototype, inhomogeneous flow geometries in 2D. Quantitative prediction of the steady flow and stress fields is demonstrated in all test cases, under multiple loading magnitudes, without adjustment of the model parameters.