IFPRI Project Abstract

Controlling Rheology via Boundary Conditions in Dense Granular Flows

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Project Objective:

In prior work, we have previously shown [1] that nonlocal rheologies [2,3,4] successfully model granular flows across different packing densities, particle sizes and shapes, and shear rates. This success is provided by the measurement and specification of a set of three material properties for a particular set of particles. However, the results of the model depend on *a priori* knowledge of the flow profile, limiting its predictive power. Here we aim to (Q4) understand how changing the roughness and/or compliance of a boundary changes the resulting flow. This will ultimately allow us to determine a set of general principles (Q5) which allow us to correctly set the boundary conditions in nonlinear rheological models, and test their generality in other geometries (Q6).

Approach:

As for our work during the first funding period [1], we perform our experiments in an existing quasi-2D annular shear cell with a rotating inner wall and stationary outer wall. Both walls are laser-cut and are interchangeable to modify roughness, as shown at right. In each experiment, we aim to measure both the velocity (shear) profile and the bulk rheology (shear and normal stresses) in order to characterize the dependence of the boundary conditions on both the particle-shape and boundary-characteristics.

Recent Results:

Graduate student Farnaz Fazelpour has been conducting experiments and data analysis using a variety of particle and boundary conditions, improving our ability to make quantitative measurements of the stress field, and its spatial and temporal fluctuations. These have focused on the use of photoelastic particles, which will allow for direct measurements in all geometries required for the project (different boundary conditions, and different flow geometries). This has required switching over to the use of soft particles, and making improvements to camera, lighting, and particle-tracking, force-inversion techniques that she will need for analyzing the experiments.

There are not new scientific results since December, since we have been out of the laboratory since mid-March, but we now have an improved data-analysis pipeline in place that will speed the analysis of experimental results once we are able to return.

The image series below shows a typical result from photoelastic inversion [1]. For a subregion (middle image) of the annular flow, chosen to allow ~100 pixels across the diameter of each particle) we obtain movies of the birefringence pattern within each disk. Once our image-processing algorithm has determined the best-fit value for each vector contact force, we can produce a reconstructed image for comparison; this is the image shown at the right, in excellent agreement with the original image.
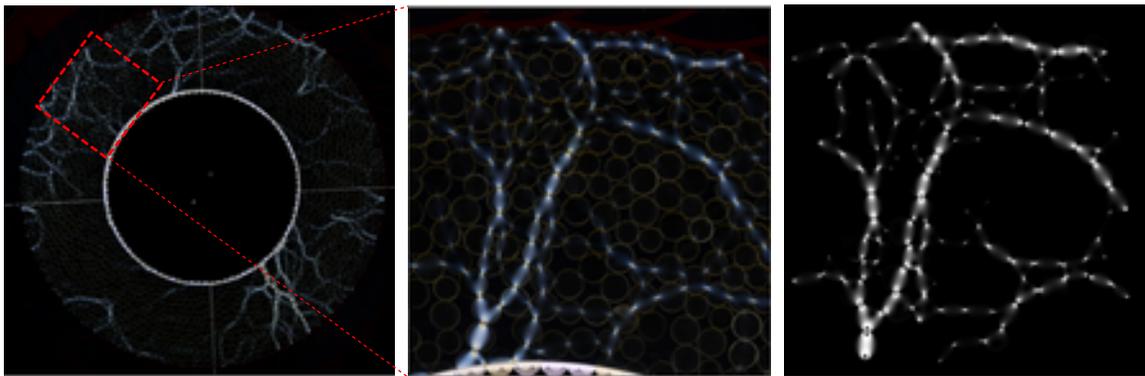
The list of all particles, their contacts, and the interparticle forces are the complete set of data needed to determine the continuum stress tensor field, through a process of coarse-graining [2]. A sample such analysis is shown below, for this same image; note that the orientation of the force chains the magnitude and sign of its contributions to the various tensor components. These stress fields are calibrated in real units (Pa).
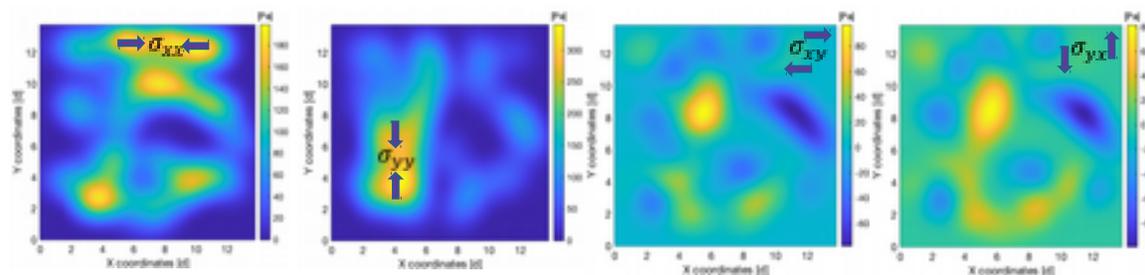
Next Steps:

Once the lab reopens, we will be able to collect long, statistically-independent series of images such as these, performed under a variety of packing densities and boundary conditions, and apply this data analysis pipeline. The results will be continuum stress fields for use in further testing the utility of rheological models (Q6). The improved quantification of the shear and normal stresses will allow us to quantitatively address Q4 and Q5 by performing additional runs.

References:

[1] Daniels, Karen E., Jonathan E. Kollmer, and James G. Puckett. "Photoelastic Force Measurements in Granular Materials." *Review of Scientific Instruments.* 88: 051808. (2017)
[2] Weinhart, Thomas, Remco Hartkamp, Anthony R. Thornton, and Stefan Luding. "Coarse-Grained Local and Objective Continuum Description of Three-Dimensional Granular Flows down an Inclined Surface." *Physics of Fluids.* 25: 070605 (2013)