Shear in Granular Couette Cells

by Jeremy B. Lechman and Gary S. Grest, Sandia National Laboratories
Antonio Barbero, Heinrich Jaeger, and Sidney R. Nagel, University of Chicago

Motivation—Slow flows in dense granular materials are of practical concern in a variety of applications such as soil failure and powder processing but are still poorly understood. While progress has been made in understanding rapid flows in terms of kinetic theory, the nature of slow flows limits the use of such approaches. These denser systems often exhibit thin, localized regions of particle motion, shear bands, separating largely solid-like, immobile regions. To understand the flow in dense granular materials, we carried out a combined experimental and simulation study of flow in a split-bottom Couette cell as shown in Fig. 1. Unlike traditional Couette cells with an inner wall that is rotated, an inner ring on the bottom of the cell is used to shear the system. This eliminates the need for an inner wall, which can have a strong effect on the size of the shear zone.

Accomplishment—Using our parallel discrete element simulation code, it is now possible to model the same system sizes as in the experiment. As the fill height H of the particles in the cell increases, the width of the shear band increases and moves away from the outer wall. In Fig. 2, results for the azimuthal surface velocity in piles of various heights from both experiments using glass beads and discrete element simulations are shown. Similar results are found from simulations for the azimuthal velocity as a function of depth within a given pack. Moreover, these azimuthal velocities can be rescaled to fall on a universal curve regardless of the particle properties. This universal curve is in excellent agreement with both experiment and the simulation. The shape of this universal curve is slightly asymmetric. We are presently investigating the origin of this asymmetry.

When shearing shallow packs ($R_s<H/2$) the simulations exhibit an inner region which moves along with the bottom disk in a nearly solid-like fashion, while the region between this inner core and a few particles lining the outer wall is fluidized. Snapshots of this inner core are shown in Fig. 3 by removing the “flowing” particles. Note the change in the shape and width as the height of the pile increases. For higher piles, this inner solid-like region disappears, as evident from Fig. 2. The shape of this inner core is in qualitative agreement with a simple theoretical model based on Janseen’s 1895 model of shear stresses in granular silos, which we investigated in previous studies. These results are also in agreement with nuclear magnetic resonance (NMR) experiments using mustard seeds instead of glass beads to provide the required signal.

Significance—Using a new type of shear cell, we are able to study the development of the shear zone in dense granular flows. The new cell has several advantages over the standard Couette cell. The width of the shear zone can grow arbitrarily large without interference from the boundaries, and the velocity profiles have a universal character independent of particle properties. This suggests that in a single system access to a range of flowing states can be gained, and fundamental questions about the nature of dense granular flow can be addressed. Thus, the new geometry allows more precise measurement of the particle fluctuations which can be tracked either visually from motion on the surface or in the bulk by NMR. The simulations complement the experiments and give more detailed information on the structure of the pack and stresses than can be obtained experimentally. Future work includes studying the effect of cohesive interactions, such as moisture, on the shape of the shear zone.

Sponsors for various phases of this work include: DOE Office of Basic Energy Sciences

Contact: Gary S. Grest; Surface & Interface Science, Dept. 1114
Phone: (505) 844-3261, Fax: (505) 844-1197, E-mail: gsgrest@sandia.gov

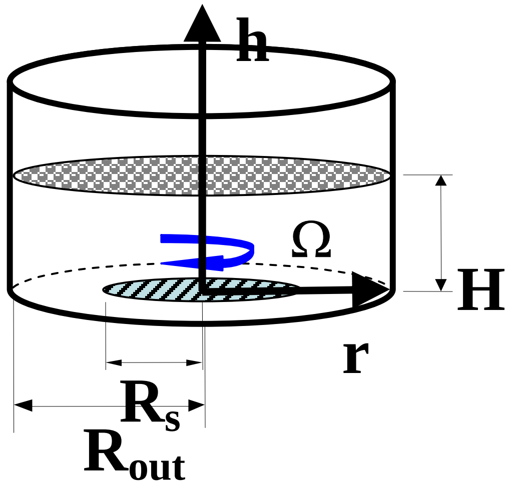

Figure 1. Schematic of split-bottom Couette system; only the inner plate of radius R_s rotates. For the results presented here R_s=30d and R_{out}=39d, where d is the particle diameter.

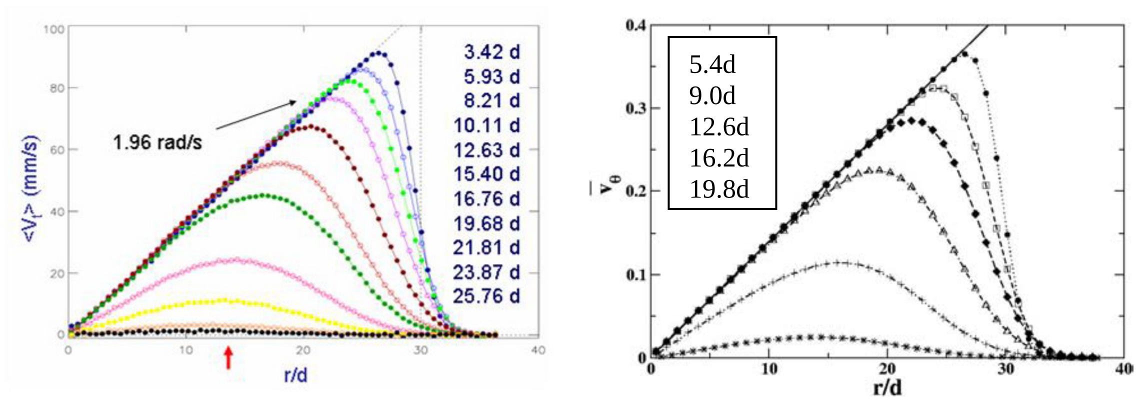

Figure 2. Azimuthal surface velocity profiles for packs of varying height, experiment result for glass beads (left), simulation (right)

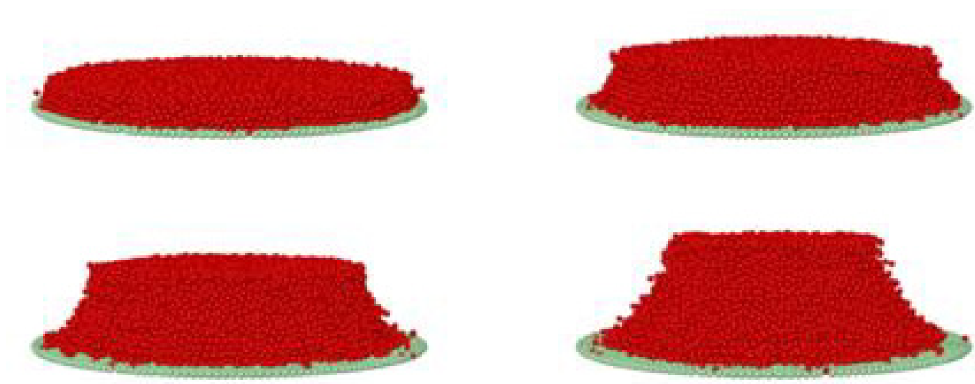

Figure 3. Snapshot of static inner core (red) particles determined by selecting particles which after ~1/4 revolutions had moved less than 0.005d in both h and r directions. Heights of the pile are 5.4, 9.0, 12.6 and 16.2d, where d is the diameter of a particle.