Abstract

An experimental study on the rheology and kinematics of dense granular materials is presented in this thesis in the slow flow regime. In this study, we employ an often used experimental set up of the cylindrical Couette Cell, for understanding the rheology of a host of model granular materials, especially under slow flow conditions. Using a multi axis transducer capable of measuring one normal and two shear stress components, we study the wall stress profiles in granular ensembles. In a static granular bed, the stress saturates over certain depth as has been well documented. In the case of slow flow of dense granular media, the stress on the outer wall neither saturates nor follows linear profile of fluids but increases exponentially with the depth, and vertical shear stress acts in the opposite direction upon shearing, as has been first reported by Mehandia et al [1]. With this premise, we further investigate this interesting anomaly in the stress profile through a series of experiments on a modified Couette cell set up. We also observe that the stresses neither saturate like in static granular column nor increase linearly over depth like in fluids, but exponentially rise in slowly sheared granular ensembles.

We probe this anomaly of stress by examining influence of height of granular column, wall friction, and the effect of initial depositional fabric. No significant influence of column height or proximity of the base plate was found on the stress profile. The initial depositional fabric which was explored through four types of filling in the Couette Cell, while shows slight differences in the static stress profiles, reach a state of plastic flow or a critical state shear stress irrespective of the initial fabric. The wall friction effect was studied by shearing the sample under three different boundary roughness conditions. The results show that rheology is influenced by the boundary condition specially at high roughness and high shear rates. We examine the kinematics of granular flow through imaging and report the establishment of an secondary circulation of granular particles orthogonal to the velocity gradient which explains this anomaly in the direction of the wall stress.

We observe periodic stress fluctuations with a frequency nearly equaling to the native frequency of rotation of the inner cylinder. The cause of these fluctuations was investigated through a series of rheological experiments by enforcing a magnified compliance on the inner cylinder. Stress relaxation, stress transients studied through stop-reshear and stop-reverse experiments, and amplitude of stress fluctuations all show depth or mean stress dependence.

Stress measurements are extended to soft granule systems and particles with varied morphology. We use granules of three different shapes and three different rigidities, and compare their response. The rheology of different shaped granules and soft granules show rate independence similar to rigid particle flows. The results from the rheology of different shaped particles suggests a reduction in the shear stress specimen when compared to spherical particles. The rheology of soft particles in slow flow regime exhibited qualitative similarity to rigid particles but had show higher exponential rise of normal stress with depth. Overall, we find the rheological behaviour to be a function of particle shape and rigidity in slow flow regime.