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Locating the origin of stick slip instabilities in sheared granular layers

Evangelos Korkolis and André Niemeijer
HPT Laboratory, Department of Earth Sciences, Utrecht University, The Netherlands (e.korkolis@uu.nl)

Acoustic emission (AE) monitoring is a non-invasive technique widely used to evaluate the state of materials and structures. We have developed a system that can locate the source of AE events associated with unstable sliding (stick-slip) of sheared granular layers during laboratory friction experiments. Our aim is to map the spatial distribution of energy release due to permanent microstructural changes, using AE source locations as proxies. This will allow us to determine the distribution of applied work in a granular medium, which will be useful in developing constitutive laws that describe the frictional behavior of such materials.

The AE monitoring system is installed on a rotary shear apparatus. This type of apparatus is used to investigate the micromechanical processes responsible for the macroscopic frictional behavior of granular materials at large shear displacements. Two arrays of 8 piezoelectric sensors each are installed into the ring-shaped steel pistons that confine our samples. The sensors are connected to a high-speed, multichannel oscilloscope that can record full waveforms. The apparatus is also equipped with a system that continuously records normal and lateral (shear) loads and displacements, as well as pore fluid pressure. Thus, we can calculate the frictional and volumetric response of our granular aggregates, as well as the location of AE sources.

Here, we report on the results of room temperature experiments on granular aggregates consisting of glass beads or segregated mixtures of glass beads and calcite, at up to 5 MPa normal stress and sliding velocities between 1 and 100 μm/s. Under these conditions, glass beads exhibit unstable sliding behavior accompanied by significant AE activity, whereas calcite exhibits stable sliding and produces no AEs. We recorded a range of unstable sliding behaviors, from fast, regular stick slip at high normal stress (> 4 MPa) and sliding velocities below 20 μm/s, to irregular stick slip at low normal stress or sliding velocities above 20 μm/s. We calculated the source location of each AE associated with significant stress drops (slip events). A very prominent feature, particularly among the large shear displacement experiments, was the development of regions that sustained increased AE activity. Some of these regions remained fixed in space, whereas others kept migrating with increasing shear displacement. We observed that for an arbitrarily small number of consecutive slip events, their associated AEs did not necessarily nucleate in the same region. We believe that the calculated AE source locations reveal the sites where load-bearing microstructures, known as force chains, begin to fail, leading to slip instabilities. The existence of regions of increased AE activity suggests that triggering of force chain failure is controlled to some extent by the loading conditions imposed on the sample by the machine, but may also indicate the lasting influence of previous particle re-organization events on the particles populating these regions.