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Rheology and kinematics of dense granular fault gouges with DEM: shear bands formation and evolution

Nathalie Casas[1,2], Guilhem Mollon[1,3], and Ali Daouadji[2]
[1]LaMCoS, INSA Lyon / Univ. Lyon / CNRS UMR5259, Villeurbanne, France (nathalie.casas@insa-lyon.fr)
[2]GEOMAS, INSA Lyon / Univ. Lyon, Villeurbanne, France
[3]Laboratoire de Géologie, École Normale Supérieure/CNRS UMR 8538, Paris, France

Earthquakes happen with frictional sliding, by releasing all the stresses accumulated in the pre-stressed surrounding medium. The geological third body (i.e. fault gouge), coming from the wear of previous slips, acts on friction stability and plays a key role in this sudden energy release. A large part of slip mechanisms is influenced, if not controlled, by fault gouge characteristics and environment. We aim to link third body properties (geological, mechanical, physical…) to its rheological behavior by testing numerically different types of dense geological third body (% of porosity, % of cohesion, grains shapes…) with distinct contact laws. Different granular samples are generated to simulate a mature fault gouge with mineral cementation between particles. The gouge is then inserted between two rock walls to realize direct shear experiments with Discrete Element Modelling in the software MELODY2D (Mollon, 2016). A dry contact model is considered to investigate mechanisms without fluid (displacement-driven and under constant confining pressure). Researches are based here on a millimeter-scale portion of gouge, considering that the output values could be used in another model at larger scale.

The peak strength can be sharp, short, and intense for dense and highly cohesive cases (angular particles, 15% initial porosity) and relatively low for ultra-dense samples (polygonal particles, 0% initial porosity). The observed regimes also correspond to an evolution of the amount of ductility within the sample. A very dense or highly cohesive sample behaves as a brittle material, whereas a typical cohesionless and porous geological layer tends to behave as a ductile material. The evolution of gouge characteristics truly influences the shape and formation time of Riedel shear bands. A change in contact laws between particles (%cohesion, friction) modifies the entire kinematics of Riedel bands formation. Indeed, with cohesion between particles, Riedel bands are directly linked to the importance of the dilation phase, depending itself on the initial porosity present within the sample (Casas et al., 2020). Then, increasing friction not only changes the principal orientation or Riedel bands but makes them more numerous within the gouge. It also leads to a more sudden post-peak weakening, which is prone to switch the fault behavior from a ductile aseismic response to a brittle seismic slip, depending on the stiffness of the surrounding medium. Global stiffness of the gouge also has an important role to play on Riedel bands formation, and it can be defined as a combination of multiple parameters such as initial porosity, shape and size of particles, numerical stiffness, gouge thickness… The local Breakdown energy, or

energy needed to weaken the fault, is also calculated to be connected to Riedel bands formation.