Friction dynamics in the presence of a third body - Application to earthquakes

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Abstract

The initiation of a sliding motion in the frictional interface between two elastic solids in generally believed to obey the main principles of Liear Elastic Fracture Mechanics (LEFM). In this view, more attention is paid to the fracture energy of the interface than to the details of its frictional behavior. Many experimental, theoretical, and numerical works support this view, but they all rely on the assumption of scale separation that ensures that the contact interface and the process zone at the crack tip are infinitely smaller than the dimensions of the whole system. While this assumption is acceptable in a laboratory context where clean and smooth surfaces are generally considered, it remains to be validated in more practical cases of worn and mature contacts, which typically exhibit a third body. This is in particular the case in the major field of application of such theories: earthquake science. Indeed, this is the context where the dynamics of the porpagation of a sliding rupture have the most dramatic effects, and this is also a situation where we know that interfaces are not clean. The geological third body present in a seismic fault is called "gouge" in the geological terminology, and is the product of rock abrasion and comminution that occured during past slip events on the same fault. We may therefore question the assumptions and results of LEFM in this context. For this purpose, we built a numerical model of a meter-scale laboratory earthquake. This model couples discrete and continuum mechanics in order to represent in the same numerical framework (i) the elastic continuum formed by the intact rock surrounding the fault, which is able to store and release strain energy and to transmit seismic waves during the fault failure, and (ii) the granular/powdery gouge that fills the fault and controls its frictional rheology. We elaborate on previous smaller (20 mm in length) models, which were purely granular (with micrometric grain sizes). These models investigated the various ways sliding can be accommodated within such an interface depending on the local gouge properties (e.g. grains sizes and shapes, contact friction, cementation, porosity, etc.), and derived slip-weakening friction laws associated with these different configurations. This granular model is now considerably upscaled (64 cm of length instead of 20 mm, with the same thickness), and coupled with the elasto-dynamics of the surrounded medium. This allows to load this interface until its frictional peak (thereby storing large amounts of strain energy in the surronding rock), and to trigger a spontaneous frictional instability in the center of the system.

Results show that this instability slowly nucleates before taking the form of a pulse-like rupture front: a laboratory earthquake. The rupture front propagates in an irregular way,

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activating various localization patterns (e.g. inclined Riedel bands, boundary-sliding ,etc.) in the regions of the granular gouge layer that it progessively reaches.The early stages of this propagation occur at a velocity lower than the Rayleigh wave speed, but activate supershear (i.e. approaching the P-wave speed) failures after a certain propagation distance, producing visible mach cones in the surrounding continuum. A comparison with a simpler model replacing the gouge layer by an equivalent friction law leads to different results, with a crack-like friction front and an immediate supershear transition. This difference is attributed to the heterogeneous rheology of the granular layer and to its inherent dilatational behavior. It illustrates that the propagation of fault rupture fronts may be more complex that what LEFM predicts, and that friction is not only fracture.