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The influence of heterogeneity on the strength and stability of faults

Daniel Faulkner[1], John Bedford[1], Nadia Lapusta[2,3], and Valère Lambert[2]
[1]Department of Earth, Ocean and Ecological Sciences, University of Liverpool, Liverpool, UK
[2]Seismological Laboratory, California Institute of Technology, Pasadena, California, USA
[3]Department of Mechanical and Civil Engineering, California Institute of Technology, Pasadena, California, USA

Heterogeneity of fault zones is seen at all scales in nature. It may manifest itself in terms of the variability of material property distribution over the fault, of stress heterogeneity brought about by the history of previous earthquake ruptures, and of fault geometry. In this contribution, we consider the effect on fault strength and stability of small-scale heterogeneity in laboratory experiments and large-scale heterogeneity from numerical dynamic rupture modeling. In model laboratory faults at slow slip rates (0.3 and 3 microns/s), the area occupied by rate-weakening gouge (quartz) versus rate-strengthening gouge (clay) was systematically varied and the results compared with homogenized mixtures of the two gouges. We found that the heterogeneous experimental faults were weaker and less stable than their homogenized counterparts, implying that earthquake nucleation might be promoted by fault zone heterogeneity. In elasto-dynamic numerical simulations of sequences of earthquakes and aseismic slip based on rate and state friction but with enhanced dynamic weakening (EDW) through pore fluid pressurization, uniform material properties on the fault plane are assumed, and heterogeneity spontaneously develops by stress variations along the fault arising from differing histories of motion at points along the fault. In these models, ruptures spontaneously nucleate in favorably prestressed regions. Larger ruptures - that result in greater degrees of EDW - are capable of propagating through areas of lower shear stress that would arrest smaller events. This behavior leads to a relationship between rupture size and the average shear stress over the rupture plane before the earthquake occurs. Faults that host larger events may overall appear to be driven by lower average shear stress and hence appear ‘weaker’. It is clear that the apparent fault strength and stability is difficult to predict from either simple homogeneous gouge experiments, or from scaling up of these results. Heterogeneity at all scales will affect the slip behaviour of faults.