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Strain localization during rapid shearing of a saturated rock layer: Preferred instability wave length and shear band thickness

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It is well admitted that strain localization during slip occurs as the result of a plastic instability (Rudnicki and Rice, 1975). An interesting question arises concerning the actual thickness of the zone of localized deformation.
In this paper we analyse the stability of undrained adiabatic shearing of a rock layer. This corresponds to the situation when the slip event is sufficiently rapid and the shear zone broad enough to effectively preclude heat or fluid transfer as it is the case during an earthquake or a landslide. Stability of undrained shearing in a classical Cauchy continuum has been first analyzed by Rice (1975) who showed that instability occurs when the underlying drained deformation becomes unstable (i.e. in the softening regime of the corresponding drained stress-strain curve). However Vardoulakis (1986) has shown that Rice's linear stability analysis, if performed at the state of maximum deviator, leads to a sharp transition from infinitely stable to infinitely unstable behaviour, as the growth coefficient in time of the instability is infinite for the infinitely small wave length limit. This indicates that the problem is mathematically ill-posed. The origin of this undesirable situation can be traced back to the fact that conventional constitutive models do not contain material parameters with dimension of length, so that the shear band thickness (i.e. the extent of the plastically softening region) is undetermined. Then it appears necessary to resort to continuum models with microstructure to describe correctly localization phenomena (Vardoulakis and Sulem, 1995). These generalized continua usually contain additional kinematical degrees of freedom (Cosserat continuum) and/or higher deformation gradients (higher grade continuum). In this study, the kinetics of a granular material is described by a Cosserat continuum and we incorporate the effect of shear heating due to the dissipation of the frictional work. It is shown that shear heating has a destabilizing effect and that instability can occur in the hardening regime if the amount of dilatant strengthening is not sufficient as compared to the effect of thermal pressurization of the pore fluid (Sulem, 2010). It is shown that the linear stability analysis with macro and micro inertia terms leads to the selection of a preferred wave length of the instability mode corresponding to the instability mode with fastest (but finite) growth coefficient (Sulem et al. 2011). The selected wave length is compatible with observed shear band thickness in fault zones and earth slides.

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