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Can kinematic approaches be used to predict shear fracture orientations for use in discrete fracture network models?

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Structural geologists typically invoke the Mohr-Coulomb failure criterion to explain the orientations of shear fractures. Nevertheless, there have been recent attempts to explain shear fracture orientation in terms of finite strain or strain increment. In these models, spatial variations in shear fracture orientation are explained by spatial variations in the orientations of lines of no finite elongation (LNFE), and/or zero extension directions. We test these models by analysing the orientations of conjugate cataclastic deformation bands that cut unconsolidated sand and gravel at McKinleyville, California, and dip shallowly towards the north-northeast and south-southwest. The acute dihedral angle between the two sets of deformation bands is 47° and is bisected by the sub-horizontal, north-northeast directed incremental and finite shortening directions. Trishear models of fault propagation folding above the McKinleyville fault predict two sets of LNFE that plunge steeply and shallowly to the south and north. These predictions are inconsistent with deformation band orientations and suggest that deformation bands did not form parallel to these LNFE. During plane strain, zero extension directions with acute dihedral angles of 47° develop when the dilatancy rate is 4.3. Experimental dilatancy rates for Vosges sandstone (cohesion > 0) and unconsolidated Hostun sand suggest the deformation bands either developed parallel to zero extension directions or in accordance with the Mohr-Coulomb criterion, assuming initial porosities of 22% and 39%, respectively. However, an empirical relationship between dilatancy rate, relative density and mean stress suggests that dilatancy rates for Vosges sandstone overestimate the dilatancy rate at McKinleyville. Deformation bands at McKinleyville likely developed either in a Mohr-Coulomb orientation, or an intermediate orientation bounded by the Mohr-Coulomb and Roscoe angles. These results suggest that approaches based on strain or strain increment (i.e. kinematic models) should be used with caution when predicting shear fracture orientations, and should not be used to populate discrete fracture network (DFN) models without careful consideration of their validity.