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Quantitative testing critical-taper wedge theory with distinct-element modeling and the role of dynamics in controlling wedge tapers

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Critical-taper wedge mechanics (e.g. Davis, et al. 1983, Dahlen 1990) provides fundamental relationships between the observed tapered geometries of fold-and-thrust belts and accretionary wedges and their detachment and wedge strengths. This theory has given diverse insight into kinematics, roles of erosion and sedimentation, and the morphology of compressive mountain belts, much of which has been aided by extensive analog and numerical modeling. The field has grown large, with several thousand papers addressing real-world, analog, and numerical wedges (cf. Buiter 2012). The majority of the insight has been qualitative, but nevertheless quite influential in our current understanding of mountain belts and submarine wedges. In contrast, quantitative applications of wedge theory, either to nature or models, has been rather limited because of the complexity of most wedge equations. It it is easy to become "lost in parameter space" with many strength parameters that are difficult to constrain or have ambiguous meaning, given real-world data and observations.

Recently wedge theory has been recast into a very simple form (Suppe 2007; Yeh and Suppe 2014) that provides an unambiguous relationship between the observed covariation of surface slope α with detachment dip β and the wedge W and fault F strengths with few assumptions. In the real world we have limited knowledge of strengths, forces, fluid pressures and earthquake history, or the relationship between strength heterogeneity and structural style, or to what extent the strength of a wedge is an evolving macroscopic property (e.g. folding, imbrications and strain localization) or a material property. The well-defined relationship between wedge taper and global strength makes numerical wedges an ideal tool for the study of compressive mountain belts.

In this work: [1] We successfully test this simpler quantitative wedge theory over a very wide range of wedge strengths and structural styles using distinct-element numerical models; [2] We show how we obtain fault and wedge strengths (W, F) directly from observations of surface slope α with detachment dip β in several active thrust belts and accretionary wedges, including the Niger delta, Taiwan, and the Tohoku earthquake offshore of Japan, all of which demonstrate that wedges are strong, but the detachments are very weak, with F/W=0.1 or less. [3] We compare the geometry-derived W & F values to those derived from monitoring forces within the numerical model and along its base. We observe that wedge taper is controlled dynamically as friction along the base varies between the assigned quasi-static value and much lower values during slip events. The time- and spatially-averaged dynamical basal friction is observed to be equal to that derived from wedge geometry. Therefore it appears that critical wedge taper reflects the dynamical strengths that exist during wedge growth.