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Numerical Modeling of Detachment Folding: a 2D Approach with Application to Incremental Coseismic Fold Growth in Taiwan

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The actively growing Tungshih anticline located at the northern tip of the 1999 Chi-Chi earthquake rupture in western Taiwan provides a rare opportunity to study coseismic growth of a nascent fault-related fold. Good quality seismic data collected before the earthquake provides excellent control on the subsurface geometry and surface deformation has been characterized by surveying, accurate mapping by radar, and by surface DEM analysis of the overlying Daan River flood plain and adjacent level farm fields from photos taken before and the day after the event. Thus we have a very good idea of the geometry of the Tungshih anticline both prior to- and after the Chi-Chi earthquake. It is therefore an ideal structure in which to study the incremental or coseismic evolution of a fault-related fold.

The Tungshih anticline is a 1 km wide low-amplitude detachment fold that experienced about 12 m of uplift 8 m of shortening during the Chi-Chi event. Surface folding of the back-limb dammed the overlying Daan river, causing it to change course and eventually cut down to near its pre-earthquake base-level. Seismic profiles of the fold show it to be broad, approximately parallel in form above a detachment in the Chinshui Shale, which is the fault of the northern Chi-Chi rupture. The post-Chi-Chi surface expression of the anticline as defined by folding of the old river-bed is box-shaped with a wide and flat-topped uplifted portion that is flanked by moderately dipping fore- and back-limbs, that underwent hinge migration on the back limb and limb rotation on the fore limb. Thickness-relief analysis of the fold indicates that of the 217 m total shortening consumed in the fold 20% was accomplished by pure shear and 80% in flexural-slip. Furthermore an additional 361 m of the slip passes through the anticline with a 115 m step in the Chinshui shale detachment, contributing additional volume to the fold core. These results suggest that the anticline could have grown in about 27 Chi-Chi-like earthquakes with 8 m slip terminating in the fold and about 45 non-Chi-Chi events with 8 m slip passing through the fold.

In order to understand the incremental, but not necessarily dynamical, development of the Tungshih and other similar anticlines we are developing 2D numerical models similar to this structure using both idealized initial states (flat layers, level ground surface, etc.) and deformed states derived from the natural prototype (seismic profiles, surface data, etc.). We are taking this two-pronged approach because while our main goal is to re-create the last 12 m increment of growth on the Cholan structure, having knowledge of the nature and extent of the strains (damage to the rockmass) required to get to this initial pre-Chi-Chi state will likely be important with regard to setting up the 'natural' example model. In other words—knowing where the rockmass is weakened or anisotropic due to prior deformation will aid in defining the character and distribution of material properties in our incremental model.

We are using both continuum and discrete modeling methods and are examining the feasibility of developing a coupled continuous/discrete model in which deeper the levels of the structure is modeled as a continuum and the near surface is simulated using a bonded particle-based method. The particle nature of the discrete formulation lends itself particularly well to addressing the inherently discontinuous nature of shallow-level deformation. Both techniques rely on finite-difference formulations, which we believe have significant advantages over traditional finite-element modeling approaches.

Results expected from this modeling work include, among others: 1) better understanding of the mechanical con-

trols of the evolution of detachment folds in general; 2) knowledge of the slip-transfer mechanisms at core of the Tungshih anticline and mechanical conditions that allow us to re-create the surface deformation documented at Cholan; 3) an understanding of the mechanical properties (both rockmass, bedding interface and fault) required to produce incremental models of fault-related fold growth.