Report of Project #13144 " Exploring Inelastic response of the Calico and Pinto Mountain Faults to the 1992 Landers Earthquake Rupture"

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Abstract

Using 3D dynamic rupture models, we investigate inelastic response of compliant fault zones to nearby ruptures. The condition for inelastic response to occur is that the fault zone rocks are close to failure in the initial stress field, which is consistent with previous 2D studies. However, plastic strain can occur along the entire fault zone at shallow depth, while it can only occur in some portions of the dilatational quadrant of the rupture at depth. Near-surface plastic strain in the compressive quadrant enhance surface displacement moderately, while plastic strain extending to depth in the dilatational quadrant can enhance surface displacement significantly. Fault-parallel sympathetic motion or reduced fault-parallel retrograde motion in conjunction with enhanced vertical motion in the displacement field are signals of inelastic response of compliant fault zones in the dilatational quadrant, which can be used to distinguish two types of response. Although the amplitude of surface displacement is roughly proportional to fault zone width and depth for narrow and deep fault zones in elastic models, the dependence of surface displacement on fault zone width and depth is complex for wide and shallow fault zones in elastic models and for all fault zones in inelastic models. Inelastic response along a portion of the Calico fault zone can give a better match to observed residual LOS displacement, suggesting that portion of the Calico fault zone may have experienced inelastic deformation during the Landers event.

Technical Report

Using 3D dynamic rupture models, we investigate conditions for inelastic response of compliant fault zones to nearby ruptures, distribution of plastic strain within the fault zones, manifestation of inelastic response in surface displacement, dependence of surface displacement on fault zone geometry and properties, and possible inelastic response of the Calico and Pinto Mountain fault zones to the 1992 Landers earthquake rupture. We address most of these questions in idealized 3D strike-slip fault models, in which a compliant fault zone is 6 km away from and is parallel to the rupturing vertical strike-slip fault. We extract small-scale deformation signals, i.e., residual displacements, by subtracting the final displacement field (i.e., the static solution) of a reference model from that of a target model. The compliant fault zone is present in the target model, while the fault zone is absent in the reference model. Other aspects of the two models are same. By so doing, the residual displacement field characterizes effects of the compliant fault zone on the surface displacement field of an earthquake rupture. We use EQdyna, a finite element method code that has been verified in the SCEC/USGS dynamic code verification exercise, to perform dynamic rupture modeling. The simulations run long enough to obtain the static displacement field due to an earthquake rupture.

Our 3D models show that the condition for inelastic response to occur is that the fault zone rocks are close to failure in the initial stress field. This is consistent with that found in 2D models [Duan, 2010; Duan et al., 2011]. However, plastic strain can occur along the entire fault zone at shallow depth, while it can only occur in some portions of the dilatational quadrant of the rupture at depth in 3D models (Figure 1). In 2D models, plastic strain can only occur in some portions of the dilatational quadrant. Plastic strain at shallow depth along the entire fault zone in 3D models can be understood, because the confining pressure is small at shallow depth and thus dynamic stress perturbation from the nearby rupture has large potential to cause yielding of fault zone rocks at shallow depth. Near-surface plastic strain within the fault zone in the compressive quadrant enhance surface displacement moderately, while plastic strain extending to depth in the dilatational quadrant can enhance surface displacement significantly (Figure 2). It is feasible to distinguish elastic and inelastic responses in the dilatational quadrant solely from observable surface displacement fields. In the fault-parallel horizontal displacement field, elastic response causes retrograde motion (i.e., opposite to the long-term slip sense of the fault system), while inelastic response can cause sympathetic motion (i.e., same as the long-term slip sense) if plastic strain is strong or reduced retrograde motion if plastic strain is weak. For the reduced retrograde motion case, inelastic response enhances vertical displacement (subsidence). These are illustrated in Figure 3. Thus, either sympathetic motion or reduced retrograde motion in conjunction with enhanced vertical motion in the displacement field is the manifestation of inelastic response of compliant fault zones. Our parameter-space study shows that although the amplitude of surface displacement may be roughly proportional to fault zone width and depth for narrow and deep fault zones in elastic models (i.e., elastic response of fault zones), the dependence of surface displacement on fault zone width and depth is complex for wide and shallow fault zones in elastic models and for all fault zones in inelastic models. Dynamic rupture models of the 1992 Landers earthquake (Figure 3) are built to reproduce the first-order features in slip distribution and rupture propagation revealed in kinematic inversions [e.g., Wald and Heaton, 1994]. Preliminary results from coarse element size (e.g., 500 m spacing along the fault strike and depth) simulations show that inelastic response along a portion of the Calico fault zone can give a better match to observed residual LOS displacement, suggesting that portion of the Calico fault zone may have experienced inelastic deformation during the Landers event. Higher resolution simulations (e.g., 200 m spacing along the fault strike and depth) will be performed in the near future to better resolve residual displacements associated with the compliant fault zones in the East California Shear Zone.

References cited above

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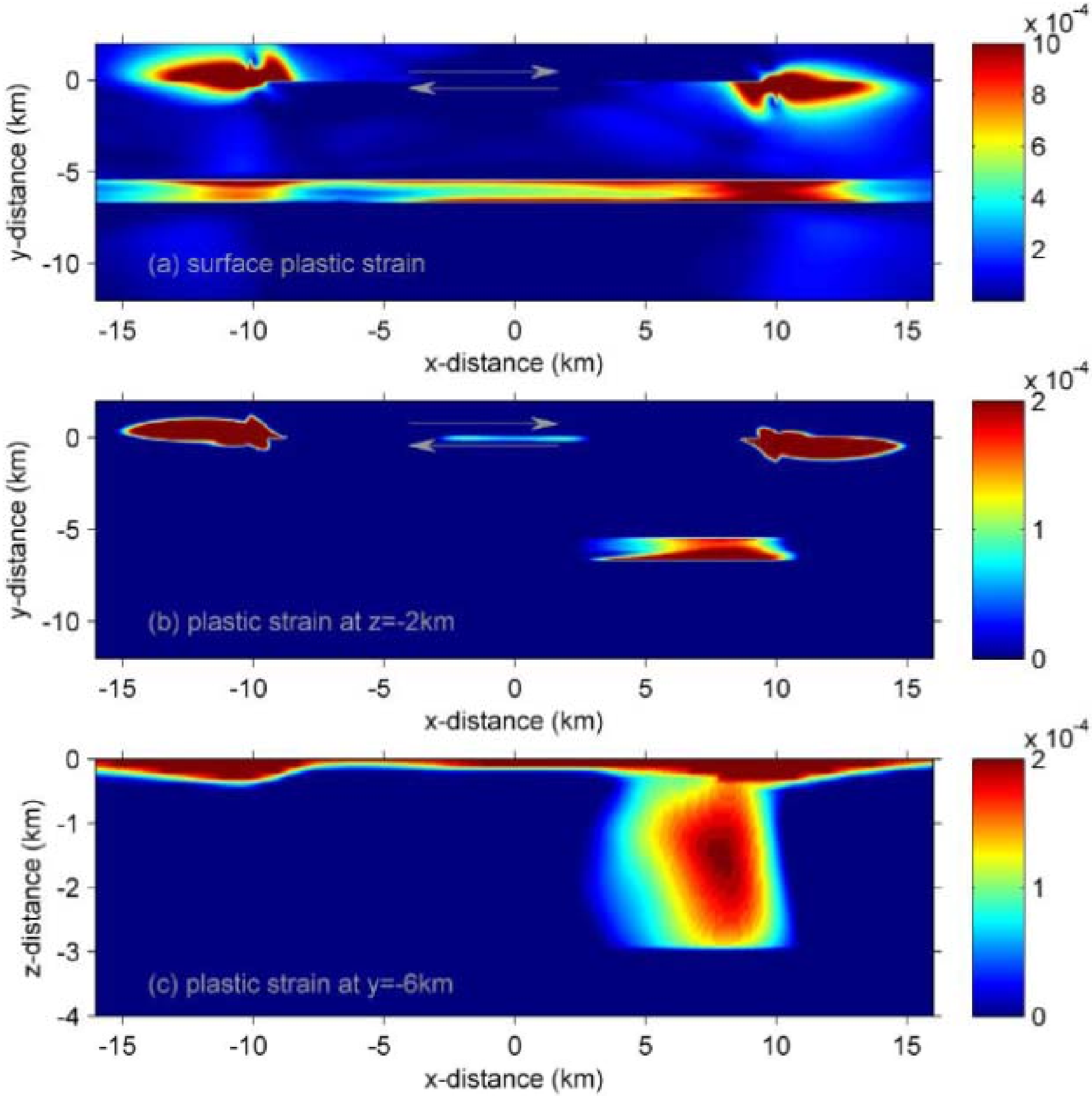

Figure 1. Plastic strain distribution in a 3D strike-slip faulting model in which a vertical strike-slip fault (arrows in a and b showing the right-lateral slip on the fault) is embedded in an inhomogeneous elastoplastic medium containing a compliant fault zone whose center is 6 km away from the rupturing fault. The fault zone is 1.2 km wide and extends to 3 km depth from surface. The seismic velocities in the fault zone are reduced by 40% compared with those in the surrounding host rocks. (a) Map view on the Earth's surface. Plastic strain occurs at the two ends of the rupturing fault and along the entire fault zone near the surface. (b) Map view at the depth of 2 km. Plastic strain occurs at the two ends of the rupturing fault and only along a portion of the fault zone in the dilatational quadrant. (c) Cross-section view along the middle of the fault zone. Plastic strain occurs along the entire fault zone at shallow depth and only a portion of fault zone in the dilatational quadrant at depth. (From Kang and Duan, 2014).

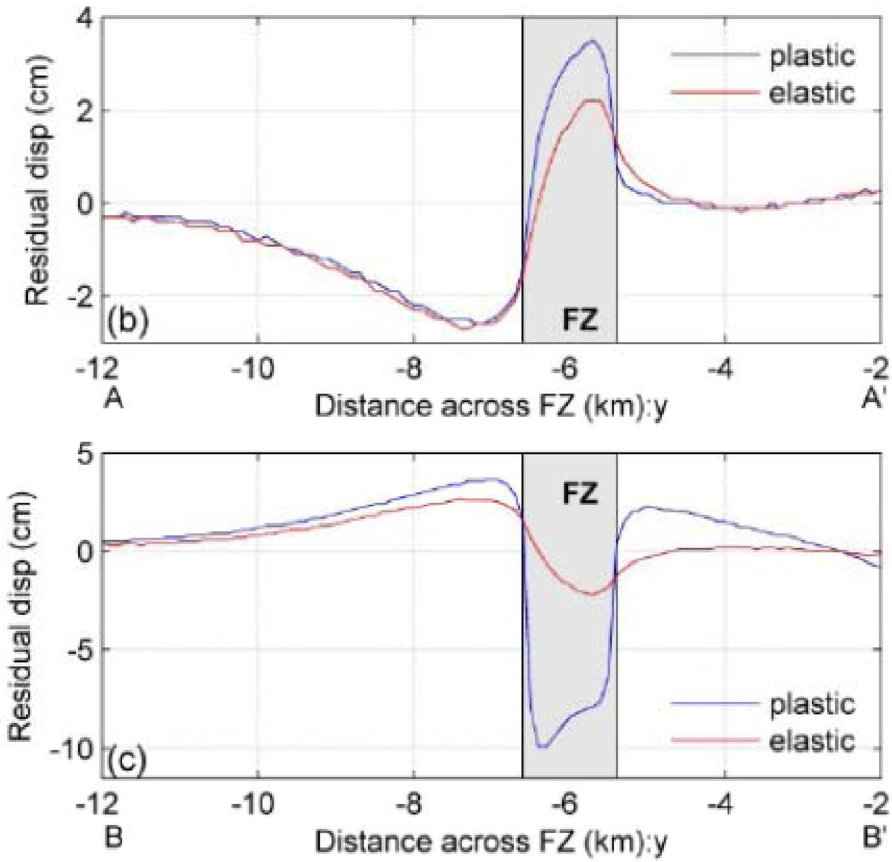

Figure 2. Vertical surface residual displacements along two profiles across the compliant fault zone from the elastic model and elastoplastic (i.e., plastic in the legend) model. Plastic strain distribution is shown in Figure 1 in the elastoplastic model. Shaded bands delimit the fault zone width. AA' is in the compressive quadrant of the rupture (i.e., at x = -9.5 km, see Figure 1), and BB's is in the dilatational quadrant of the rupture (i.e., at x= 9.5 km). Near-surface plastic strain enhance uplift along AA' moderately, while plastic strain extending to depth along BB' enhance subsidence significantly. (From Kang and Duan, 2014).

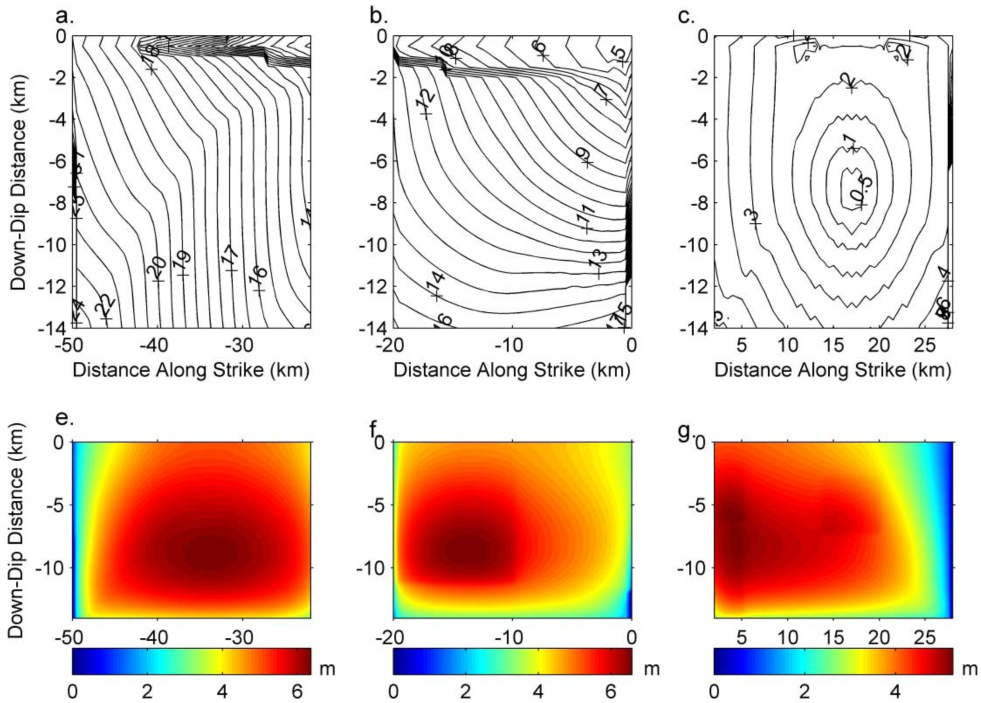

Figure 3. Rupture time contours (in second, a, b, c) and the final slip (e, f, g) on the Camp Rock, Emersion, and Johnson Valley faults from our preferred spontaneous rupture model for the 1992 Landers earthquake rupture. These rupture propagation and slip distribution results are comparable with those obtained by kinematic inversions. This preferred spontaneous rupture model allows us to capture dynamic stress perturbation in the surrounding region for fault-zone inelastic response study.

Intellectual Merit

This project investigates inelastic response of a compliant fault zone to nearby ruptures in three dimensions. Previous InSAR studies assume elastic response of fault zones, while seismic studies suggest response of fault zones to nearby ruptures can be beyond elasticity. Recent studies on inelastic response of fault zones are in two dimensions. This project advance science in this topic by exploring conditions for inelastic response to occur, distributions of plastic strain within the fault zone, effects of inelastic response of fault zone on surface displacement field in three dimensions. Preliminary results on the compliant fault zones in the East California Shear zone to the 1992 Landers earthquake suggest a portion of the Calico fault zone may experience inelastic deformation during the 1992 event, which may allow us to place some constraints on the absolute stress level in the crust if the fault zone rock strength can be experimentally determined in the future.

Broader Impacts

This project provides partial financial support for a female PhD student (Jingqian Kang) to finish her PhD research on this topic. One paper has already been published from this project in Toctonophysics, and the second paper from the project will be soon submitted to a peer-reviewed journal.

Publications from this project

Kang, J., and B. Duan (2014), Inelastic and elastic response of compliant fault zones to nearby earthquakes in three dimensions: a parameter-space study, *in preparation*.

Kang, J., and B. Duan (2014), Inelastic response of compliant fault zones to nearby earthquakes in three dimensions, *Tectonophysics*, 612-613: 56-62, doi:10.1016/j.tecton.2013.11.033.

Kang, J., and B. Duan (2012). Inelastic response of compliant fault zones to the nearby earthquake: Theoretical investigation in three dimensions, Abstract presented at *2012 Fall Meeting*, AGU, San Francisco, Calif., 3-7 Dec.