2013 SCEC Final Report – Project 13035

Investigation of causes and effects of transient deformation on the Superstition Hills Fault with physics based model

Meng Wei* and Jeff McGuire

Woods Hole Oceanographic Institution, * Now at University of Rhode Island

Summary

We have made progress on understanding the triggering mechanism of creep events by nearby earthquakes. We first built a database of dynamic and static stress perturbations to the Superstition Hills Fault from real earthquakes that have a known creep response (or lack thereof) from creepmeter, InSAR, and/or field survey data. There is considerable variability in the existence, amount, and along-strike variations in creep events triggered by regional, moderate to large earthquakes. Our dataset spans this variability and has well-documented creep responses. Secondly, we simulated the triggering process by adding realistic static and dynamic stress perturbations to the fault rupture model we have built. The simulations show that static stress perturbations can advance or delay creep events, whereas dynamic perturbations are more effective in triggering than delaying creep events. The magnitude and timing of the modeled perturbations determines the clock change of creep events. The magnitude and interval of modeled creep events changes permanently after static stress perturbation but only for a short period after dynamic perturbations. The Landers, Hector Mine, and El Mayor earthquakes dynamically triggered creep events on the Superstition Hills Fault. The size of triggered slip increases as the dynamic perturbation increases in the direction of unclamping, whereas the scaling is consistent with observations. The most surprising result is that flipping a waveform can reverse the direction of clock change, which indicates that the polarity and incoming angle of waveforms are important factors in triggering creep events. We presented these results at the 2013 AGU fall meeting. A manuscript to GRL is under preparation.

Technical report

Mechanism of creep events

As shown in the report last year, we have made significant progress in understanding the mechanism of creep events on the Superstition Hills Fault (SHF). A widely accepted model [Scholz, 1998] suggests that shallow slow slip events on strike-slip faults result from a conditionally stable zone near the top transition from stable to unstable zone. However, through numerical simulations, we demonstrated that such a model couldn't explain both the rapid afterslip and the creep events recorded by a creepmeter following the 1987 Mw 6.6 Superstition Hills earthquake. In contrast, we found that models which included significant heterogeneity in the shallow frictional properties of the fault, which is probably caused by fine-scale lithological variations, can be consistent with both the afterslip and interseismic creep events observed on the SSH fault. A manuscript was published in Nature Geoscience [Wei et al., 2013].

Dataset of creep events on SHF

We built a database of dynamic and static stress perturbations to the SHF from real earthquakes that have a known creep response (or lack thereof) from creepmeter, InSAR, and field survey data. It is well known that triggered slip occurs on SHF after nearby earthquakes [Rymer et al., 2010; Wei et al., 2011]. A creepmeter was installed by Roger Bilham after the 1987 earthquake. The creepmeter stopped in 1992 due to lack of funding. A new creepmeter was installed in 2004 at the same location also by Roger. InSAR data from ERS, Envisat, and ALOS provide continuous measurements after 1992. We found two new events between 1994-1997 that ruptured the whole fault. There were several small events that only ruptured the northern segment, which we didn't include. To date, this is the most complete dataset of creep events on the SHF (Figure 1).

Triggering of creep events by nearby earthquakes

To simulate the static stress perturbations on the fault by nearby earthquakes, we imposed realistic stress changes on the fault model [Wei et al., 2013] in both normal and shear stress. The perturbation can be added at any time during the earthquake cycle. Following Gomberg et al. [1997] and Perfettini et al. [2003], we applied pulse or wave packets to the fault system, for understanding the basic features of the triggering. The simulations show that static stress perturbations can advance or delay creep events, whereas dynamic perturbations are more effective in triggering slip than delaying creep events. The magnitude and timing of perturbations determines the clock change of creep events. The magnitude and interval of creep events changes permanently after static stress perturbation but only for a short period after dynamic perturbations. These results are consistent with Perfettini et al. [2003].

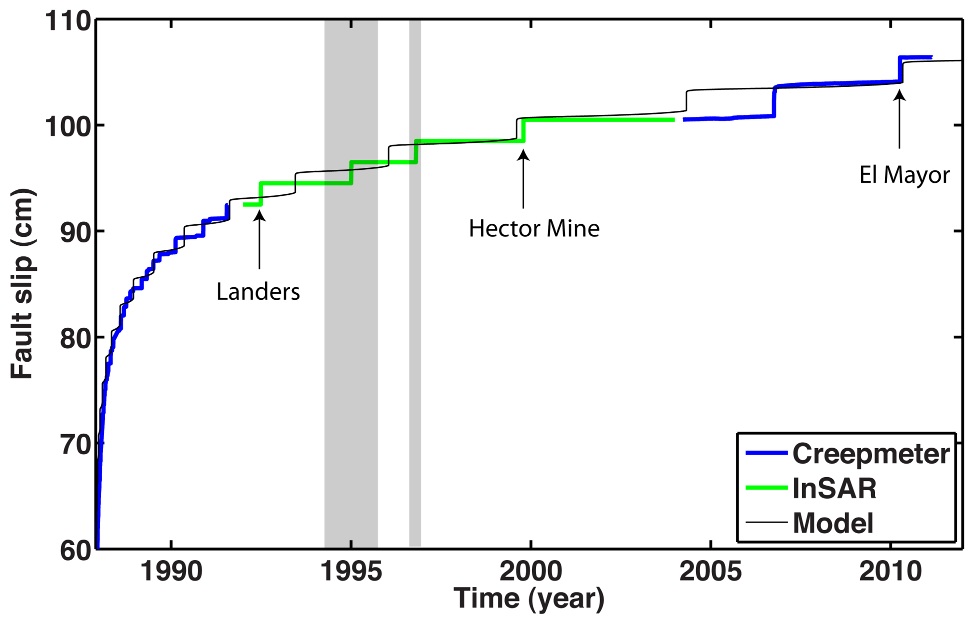

Figure 1. Slip history on the Superstition Hills Fault between 1988-2011. Blue lines are from creepmeter data. Green line is from InSAR observations. Black solid line is a model based on Wei et al. [2013]. Grey bars show the time constraint on that particular creep event by InSAR. Three creep events were triggered by Landers, Hector Mine, and El Mayor earthquakes.

Different from Perfettini et al. [2003], we have realistic cases and observations to compare with. First, to determine whether static or dynamic stress perturbations dominant [Du et al., 2003], we checked the static stress for Landers, Hector Mine, and El Mayor earthquakes on SHF. The first two are very small and El Mayor is negative, which implies that dynamic triggering is the main mechanism for these three cases. Second, observations show that the size of triggered slip increases as the dynamic perturbation increases in the direction of unclamping. Using pulse and wave packet, we have successfully reproduced the observations (Figure 2).

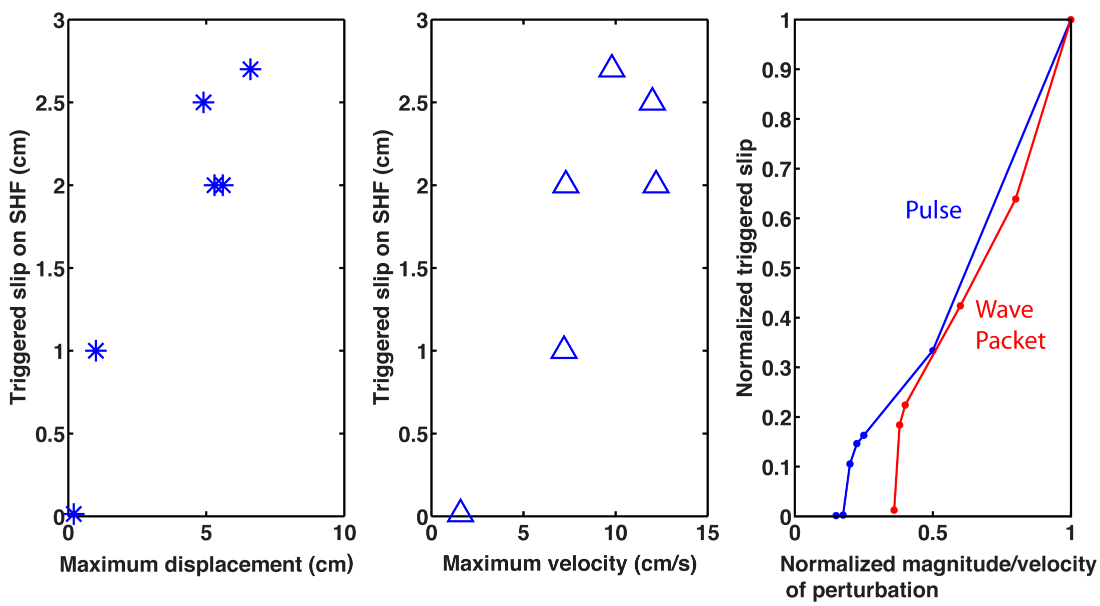

Figure 2. Scaling effect between triggered slip and characteristics of dynamic perturbations on the Superstition Hills Fault by nearby earthquakes. The left two panels are observations. The right panel is the modeling results with pulse and wave packet perturbations. **This shows that our model can reproduce this scaling effect.**

The most surprising results come from the study of the polarity of waveforms. We tried two perturbations with real waveforms. The two perturbations are exactly the same except one is flipped upside down. Simulation shows that flipping a waveform can totally change the direction of clock change (Figure 3). In the field, flipping a waveform is the same as waveform coming from the opposite direction. Therefore, our results indicate that polarity and incoming angle of waveforms are important factors regarding creep event triggering. As earthquakes share the same physics as creep events in the frame of rate-and-state friction, our results can also been applied to earthquake triggering.

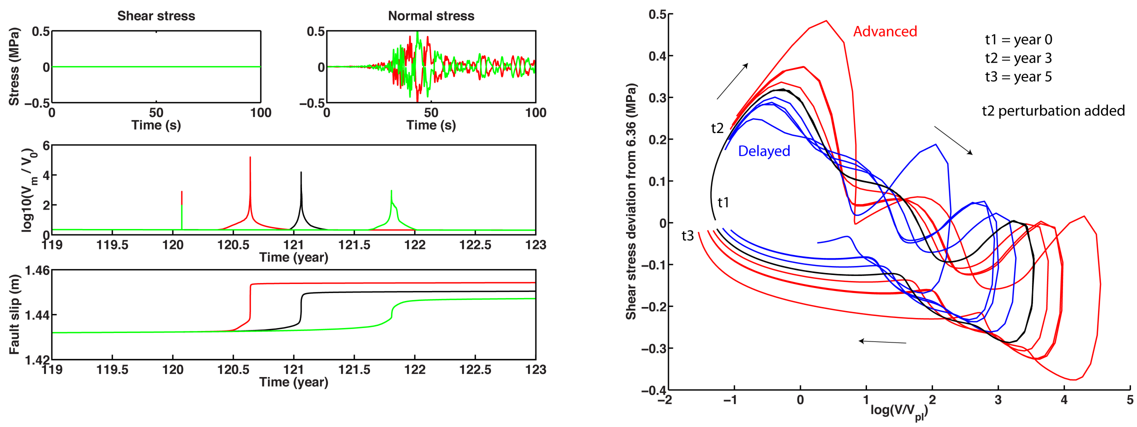

Figure 3. (Left) An example of dynamic perturbations to the fault model. (top) shear stress perturbations, zero in this case and normal stress perturbations. Green and red lines are symmetric regarding to zero axis. (middle) maximum velocity for no-perturbations (black) and two other perturbations in (a,b). (bottom) accumulated slip in the middle of the shallow conditionally stable zone in Model B. **This shows that a flip of the waveform can change the direction of clock change, therefore polarity matters.** (Bottom) Trajectory of different cases in the shear stress – velocity plane at the shallow conditionally stable layer during one creep event. Black solid line is the trajectory with no perturbations. Red lines are cases that the next event is advanced, whereas blue lines are cases that are delayed. Year 0 is about 3 years before the next event. Year 3 is a short time after the transient perturbations. Year 5 is after the next event. **This shows that the accumulated effect of perturbation will determine if the next event is advanced or delayed, regardless of the exact shape of waveform.**

Products supported by this SCEC funding

Wei, M., Y. Kaneko, Y. Liu, and J. McGuire (2013), Mechanism of spontaneous and triggered shallow creep events - implications for shallow fault zone properties, oral presentation S44B-06, presented at *2013 Fall Meeting*, AGU, San Francisco, Calif., 9-13 Dec.

Wei, M., Y. Kaneko, Y. Liu, and J. McGuire, Episodic fault creep events in California controlled by shallow frictional heterogeneity, *Nature Geoscience*, 6, 566–570, doi:10.1038/ngeo1835.

References

Du, W., L. R. Sykes, B. E. Shaw, and C. H. Scholz (2003), Triggered aseismic fault slip from nearby earthquakes, static or dynamic effect?, *J. Geophys. Res*, *108*(B2), 1-21, doi:10.1029/2002JB002008.

Gomberg, J., M. Blanpied, and N. Beeler (1997). Transient triggering of near and distant earthquakes, *Bull. Seismol. Soc. Am.,* 87, 294–309.

Marone, C. J., C. Scholtz, and R. Bilham (1991), On the mechanics of earthquake afterslip, *J. Geophys. Res*, *96*(B5), 8441–8452.

Perfettini, H., J. Schmittbuhl, and A. Cochard (2003). Shear and normal load perturbations on a two-dimensional continuous fault: 2. Dynamic triggering, *J. Geophys. Res.,* 108(B9), 2409, doi:10.1029/2002JB001805.

Rymer, M. J., J. A. Treiman, K. J. Kendrick, J. J. Lienkaemper, R. J. Weldon, et al (2010) Triggered Surface Slips in Southern California Associated with the 2010 El Mayor-Cucapah, Baja California, Mexico, Earthquake, U.S. *Geological Survey Open-File Report* 2010–1333 and *California Geological Survey Special Report* 221.

Scholz, C. H. (1998), Earthquakes and friction laws, *Nature*, 391, 37-42.

Wei, M., D. Sandwell, Y. Fialko, and R. Bilham (2011), Slip on faults in the Imperial Valley triggered by the 4 April 2010 Mw 7.2 El Mayor-Cucapah earthquake revealed by InSAR, *Geophys. Res. Lett.*, *38*(1), L01308, doi:10.1029/2010GL045235.