Numerical simulation of dynamic triggering of slow slip events in California (and New Zealand)

Meng (Matt) Wei

In collaboration with Yajing Liu, Pengcheng Shi, Yoshihiro Kaneko, Jeff McGuire, Roger Bilham
Simulation of dynamic triggering using rate-and-state

• Gomberg et al., 1998; Spring-slider model
• Perfettini et al., 2003 (a,b); 1D fault in 2D medium, earthquakes
• Wei et al., 2015; 1D fault in 2D medium, creep events on SAF system
• Wei et al., under review; 1D fault in 2D medium, slow slip events in New Zealand
• Recent manuscripts from Japanese groups
• Other (?) tremor (?)
Dynamic perturbation

\[ \frac{d\theta}{dt} = 1 - \frac{V\theta}{D_c} - \alpha \frac{\theta}{b\sigma} \frac{d\sigma}{dt} \]  

(1)

where \( \alpha \) is an empirical factor, \( \sim 0.2 \) for \( f = 0.6 \).

The concept is that, as normal stress increases, there will be an introduction of a new population of asperity contacts of younger ages than that is already present before the extra loading, and therefore the average age of all contacts (old + new) decreases.

Linker & Dieterich, 1992
We solve the coupled equations (1) and (3) during dynamic perturbations, note that

\[
\tau = \sigma \left[ f_0 + a \ln(V/V_0) + b \ln(V_0\theta/D_c) \right] = \tau_0 - \sum K_{ij}(\delta_j - V_{pl}t) - \eta V \tag{2}
\]

Take time derivative of the above equation and organize, we get

\[
\frac{dV}{dt} = \frac{1}{a\sigma/V + \eta \left[ - \sum K_{ij}(V_j - V_{pl}) - \frac{b\sigma}{\theta} \frac{d\theta}{dt} + \frac{d\tau_0}{dt} - f_{rc} \frac{d\sigma}{dt} \right]} \tag{3}
\]

where \( f_{rc} \equiv f_0 + a \ln(V/V_0) + b \ln(V_0\theta/D_c) \).

We solve the coupled equations (1) and (3) during dynamic perturbations, note that

\( \frac{d\sigma}{dt}, \frac{d\tau_0}{dt} \) and \( \sigma \) are also time-variable. Time step is inversely proportional to max

slip rate on the fault but kept at 0.002 second during dynamic perturbation.
Observations in California (creep events)

Wei et al., 2013
Creep events on the Superstition Hills Fault

Slip model using InSAR data

Wei et al., 2009
We propose shallow heterogeneity as the source of creep events

Two points:
- Wesson, 1988;
- Brodsky and Mori, 2007

Geological origin: rhyolite intrusion (well log) near SHF; stratigraphic data from the southern Salton Trough

Wei et al., 2013
Superstition Hills Fault – dynamically triggered by many earthquakes

Wei et al., 2015
We can reproduce the dynamic triggering with realistic perturbations.

Wei et al., 2015
Also reproduce the different characteristics of triggered and spontaneous event

Wei et al., 2015
Size of triggered events scales with the maximum Coulomb stress of perturbations; becomes seismic if perturbation is large enough

Wei et al., 2015
A dynamic threshold on triggering

Wei et al., 2015
New spontaneous events last summer
Triggered event by the Tres Picos M 8.2, 3000 km away
The 2016 Kaikoura earthquake dynamically triggered SSE

Modified from Wallace and Beavan, 2010; Wallace et al., 2017

Wei et al., under review
Threshold changes during perturbation

Once the perturbation amplitude exceeds an initial threshold, prolonged stress perturbations tend to decrease the triggering threshold hence promote dynamic triggering of SSEs. Therefore, shallow SSEs are more likely to be dynamically triggered than their deep counterparts because of enhanced stress perturbation (magnitude and duration) from the sedimentary wedge.

Wei et al., under review