Properties of Inelastic Yielding Zones Generated by In-plane Dynamic Ruptures

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1 MODEL SETUP

1.1 Friction laws

Slip-weakening friction law (SWF):

\[ f = \begin{cases} f_s - (f_s - f_b) \frac{V}{V_L} & \text{if } V \geq V_L, \\ f_b & \text{if } V < V_L, \end{cases} \]

where \( V \) is the sliding velocity, \( f_s \) is the static friction coefficient, \( f_b \) is the static friction coefficient, and \( V_L \) is the shear velocity. For the shown pulse case in Fig.2(b), \( V \) approaches a constant along strike for the pulse case while \( T \) approaches a constant along strike for the pulse case. The yielding zone thickness \( T \) is linearly increasing with the rupture distance \( x \).

1.2 Mohr-Coulomb type yielding and viscoplastic rheology

Yielding occurs when the maximum shear stress \( \tau_{\text{max}} \) exceeds the strength \( \tau_0 = (\mu - \sigma_0)\sigma_{\text{vol}} \). T is the fracture surface, \( \sigma_{\text{vol}} \) is the shear stress relative to the fault. Sym

2 RESULTS

2.1 Influence of rupture style (crack vs. pulse)

Fig.2: Plastic strain distribution for (a) a crack-like rupture and (b) a pulse-like rupture (after the nucleation phase). The yielding zone thickness \( T \) linearly increases with the rupture distance \( x \), whereas the inferred angle \( \theta \) approaches a constant along strike for the pulse case while \( T \) approaches a constant along strike for the pulse case. Fig.3: Energy rate vs. time for the crack case of Fig. 2a and pulse case of Fig. 2b. Definitions of different energy components are shown in the Table 1. \( E_{\text{vol}} \) is the rate of energy mismatch between different components.

2.2 Location of the yielding zone

Fig.4: Plastic strain distribution for crack-like ruptures under (a) \( \theta = 10^\circ \) and (b) \( \theta = 45^\circ \). For both cases \( \alpha_1 = 1.01, \alpha_2 = -4.5, \) and \( c = 0 \).

2.3 Extent of the yielding zone

Fig.5: Empirical scaling relation between the ratio of yielding zone thickness to rupture distance \( T/L \) and seismic radiation efficiency \( S = (\tau_0 - \tau_d)/(\tau_0 - \tau_c) \). For both cases \( \alpha_1 = 1.01, \alpha_2 = -4.5, \) and \( c = 0 \).

2.4 Off-fault decay of the potency density

Fig.6: Off-fault variation of plastic potency density \( \rho_y \) along fault normal direction for the crack cases of Fig.4. Hypocentral locations are linearly mapped into colors: from \( X = 60 \) (blue) to \( X = 180 \) (red).

2.5 Microfracture orientation

Fig.7: Inferred microfracture orientation (aligned to the direction of the maximum compressive stress during failure) for the crack cases of Fig.4.

3 SUMMARY

- Off-fault yielding is primarily located on the compressional and extensional side when \( \theta \) is low and high, respectively.
- For crack-like ruptures, \( T/L \approx 1/S^2 \) with fixed rock cohesion, \( T/L \) decreases with increasing the rock cohesion. For the shown pulse case in Fig.2(b), \( T \) approaches a constant along strike.
- Plastic potency density decays logarithmically with fault normal distance \( r \) for low and high, respectively.
- When \( \theta \) is moderate to high for large strike-slip faults, the inferred angle \( \theta \) of microfractures is higher than \( \theta \) on the extensional side and is expected to increase with the rupture speed.
- Material contrast across the fault can modify above yielding zone properties. When \( \theta \) is moderate to high, yielding zone is more extensive on the stiff side while the inferred angle \( \theta \) is higher on the compliant side.