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Aseismic slip on rate-weakening interfaces

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2. Dislocation driven semi-infinite fault with with free end

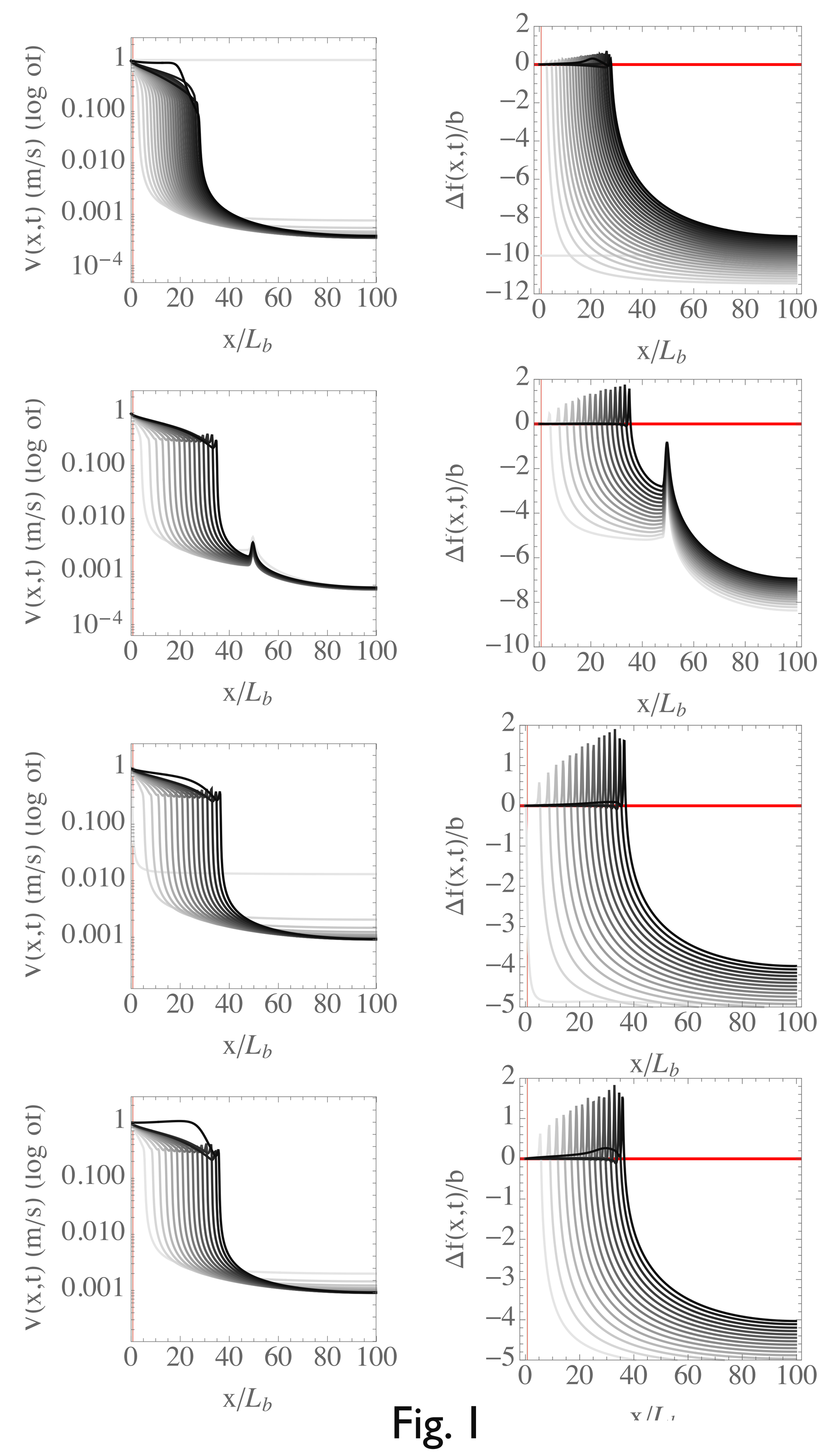


Fig. 1

Large faults: we find that initially locked faults exhibit a stable creep propagation over long distances along the fault before nucleating an instability in slip velocity. The creep run-out distances, before nucleating an instability, are considerably larger than the elasto-frictional nucleation length-scales inferred by linear stability analyses of steady-sliding and predicted by nonlinear analysis of slip instabilities. After nucleation of the first dynamic rupture, the subsequent aseismic creep run-out distances are larger than the first creep event (Fig. 1). The aseismic slip propagation, driven by a tectonic dislocation at one end, remains unaffected by conditions at the other end for large faults. Fig. 2 indicates how the creep propagation distance varies with initially Δf_{in} for large faults.

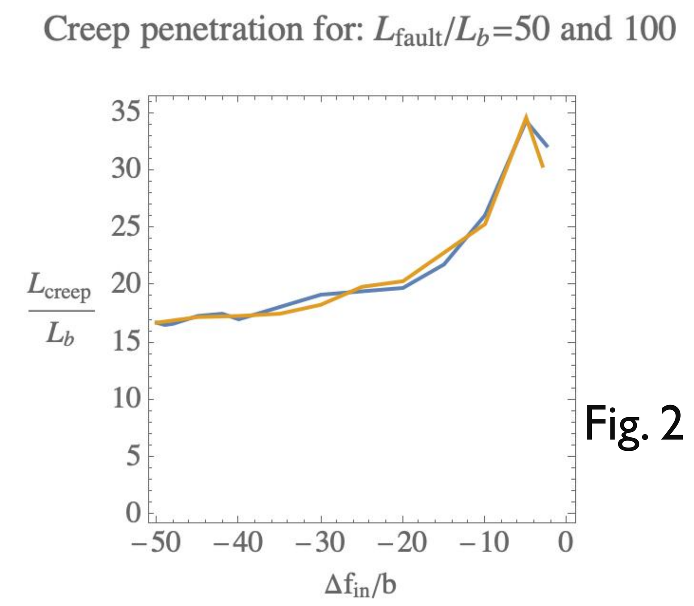


Fig. 2

3a. Finite fault with the other end buried/locked

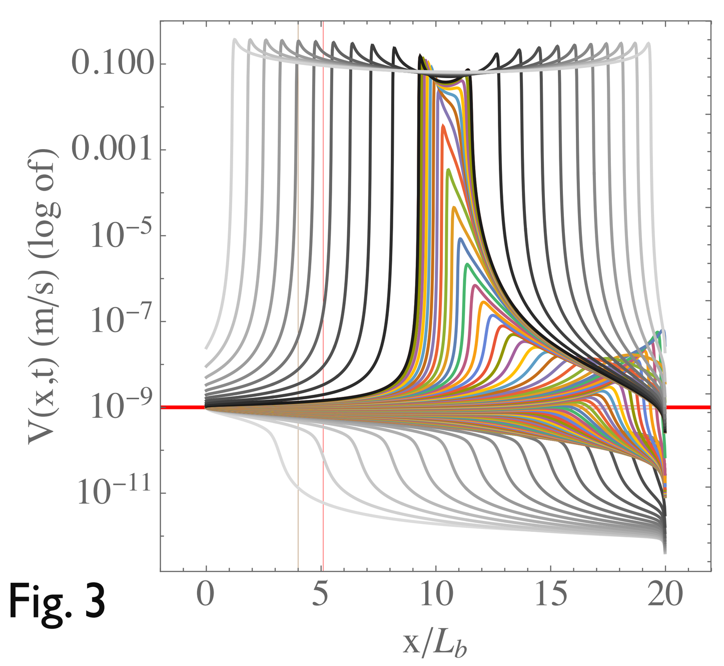


Fig. 3

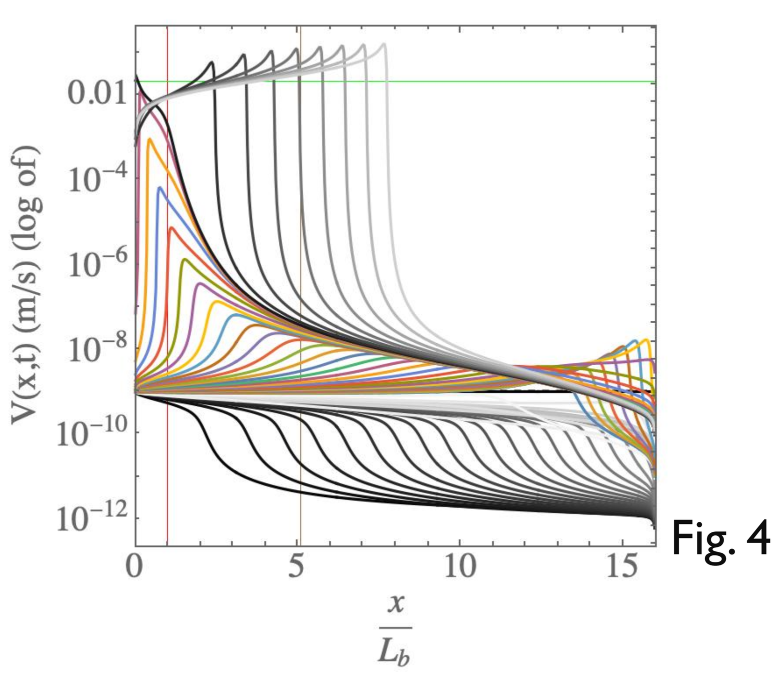


Fig. 4

A strictly locked end has interesting consequences on dislocation-driven creep advance. In this case, the slow aseismic creep provokes instability only when the finite-fault size exceeds a cut-off size, Lc. Further, on such finite-faults of size larger than standard nucleation length-scales but lesser than the cut-off size, Lc, a propagating creep could fail to nucleate an instability, and instead, could continue to lock or exhibit a long sustained spatio-temporal type oscillation, breathing type evolution of slip rate.

3b. A breathing type slip-rate evolution

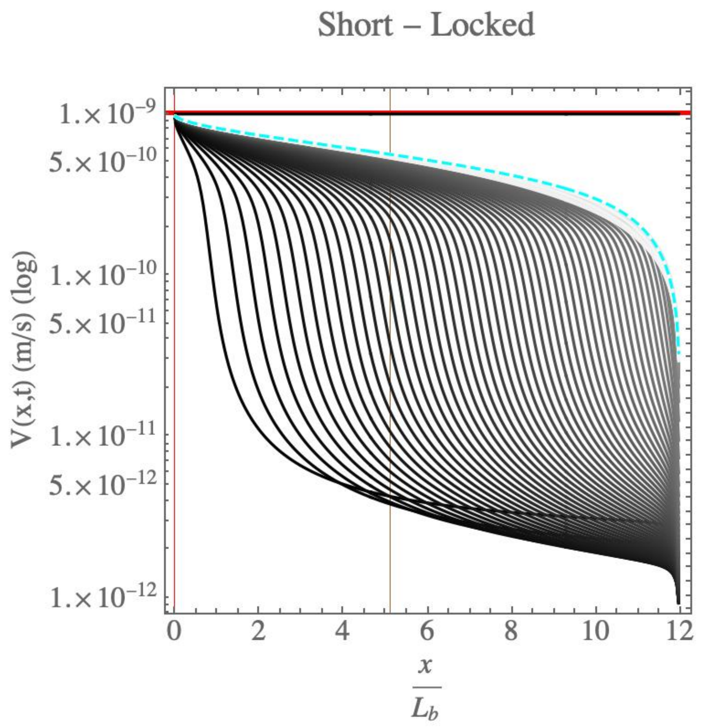
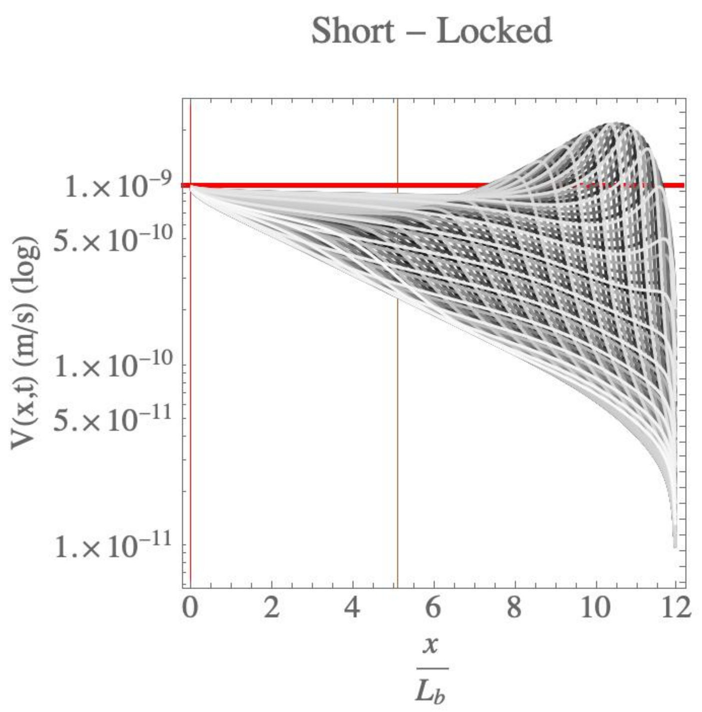


Fig. 5



1. Introduction

We highlight how slow aseismic slip travels long distances on rate-weakening interfaces. We considered model faults with sliding rate- and state-dependent interfacial shear strength. The slip is driven by a tectonic dislocation (accrued at a constant rate at one end) on a finite fault with the other end either locked or free. We also consider scenarios where slip is driven by dislocations imposed at both the ends or spatially localized external stress.

Shear stress and its rate on the fault

$$\tau(x,t) = \tau_b(x,t) + \tau_{el}[\delta(x,t),t] - \frac{\mu'}{2c_s}V(x,t)$$

$$\frac{\partial \tau}{\partial t} = \frac{\partial \tau_b}{\partial t} + \frac{\partial \tau_{el}}{\partial t} - \frac{\mu'}{2c_s}\frac{\partial V}{\partial t}$$

Medium's (elastic) response to slip

$$\tau_{el}[\delta(x,t),t] = \frac{\mu'}{2\pi}\int_{-L/2}^{L/2} \frac{\partial\delta(x',t)/\partial x'}{x'-x}dx'$$

Shear strength under constant normal stress

$$\tau_s(x,t) = \sigma f(V,\Theta) \qquad \frac{\partial \tau_s}{\partial t} = \sigma\frac{\partial f}{\partial t}$$

Friction Coefficient

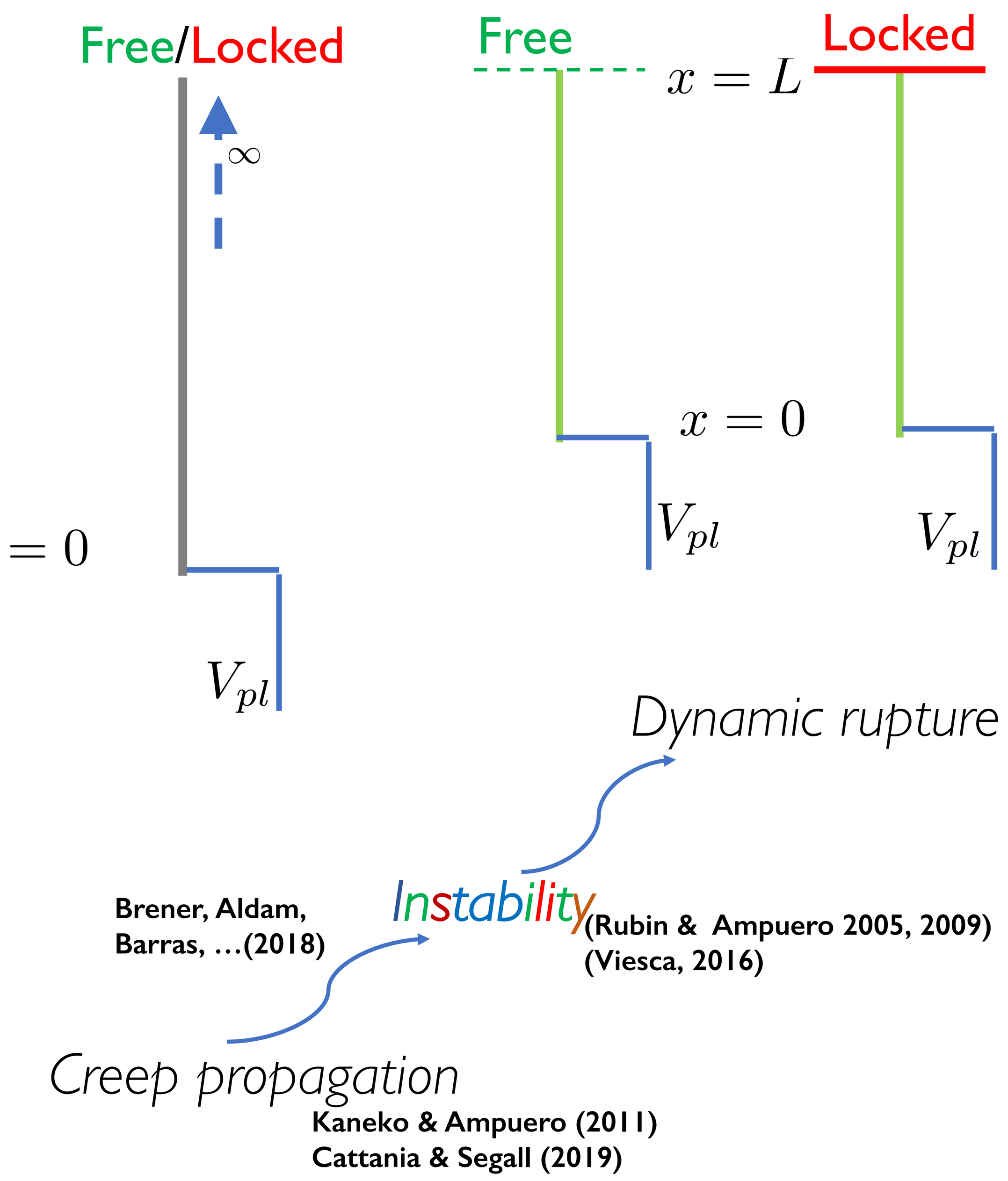
$$f(V,\theta) = f_o + a\ln\left(\frac{V(x,t)}{V_o}\right) + \Theta(x,t)$$

Steady state behavior

$$f(V) = f_o + (a-b)\ln\left(\frac{V(x,t)}{V_o}\right)$$

Deviation from steady-state sliding

$$\Delta f(x,t) = f(V,\Theta) - f(V)$$



4 Finite faults with the other end free

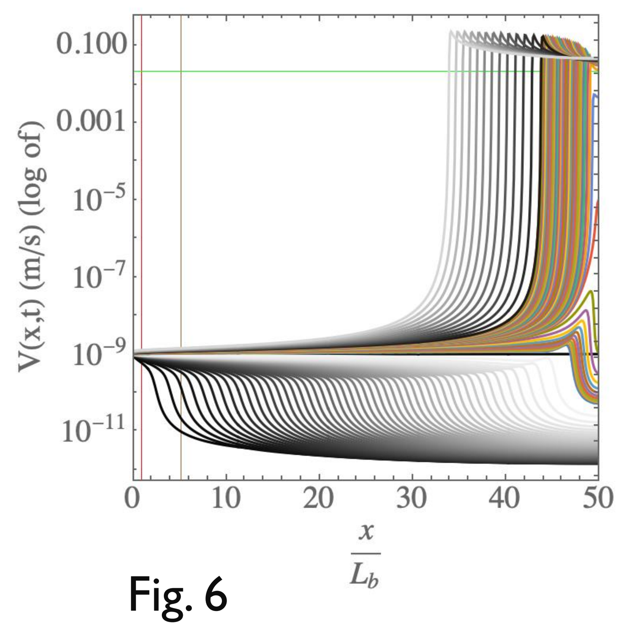


Fig. 6

A finite fault driven by dislocations at both the ends (or a finite-fault with free-surface at the other end), transition to instability does not involve such breathing type oscillation of slip rate.

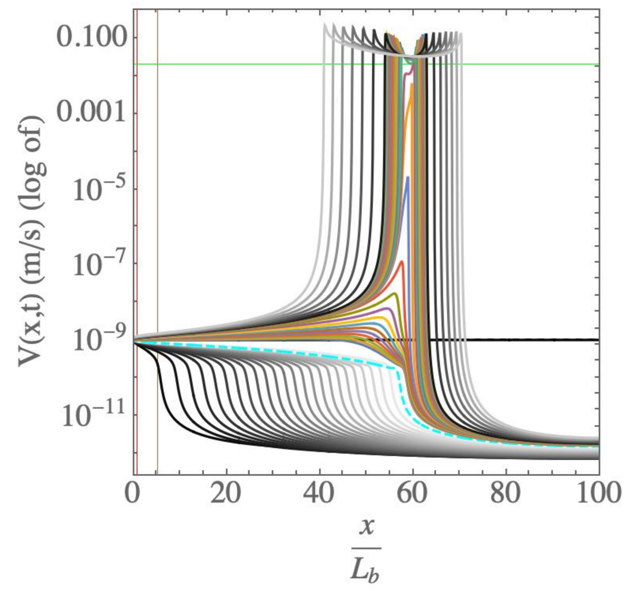


Fig. 7

Large faults with the other end free

5. Dislocations drive slip from two ends

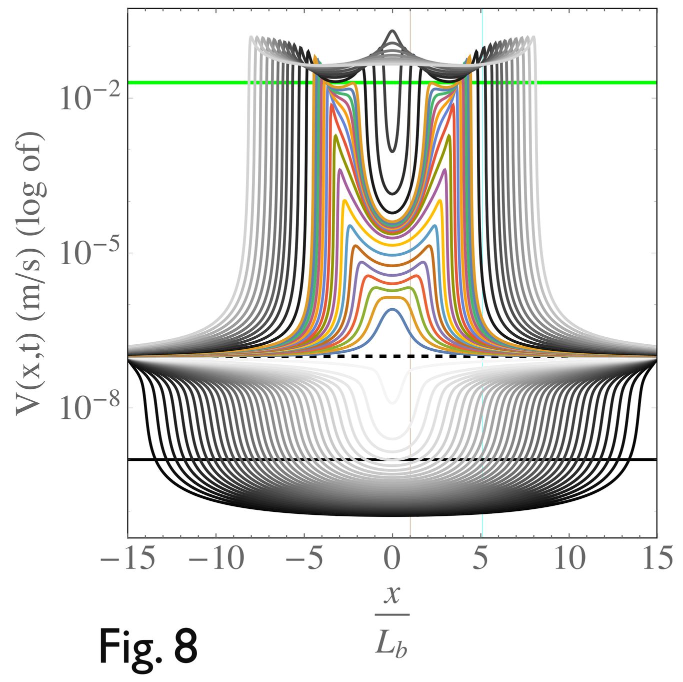


Fig. 8

6. Equivalent crack model for the creep propagation

Here we consider a long (semi-infinite) fault where the slip is driven by an imposed dislocation at the one end. We look for the elasto-dynamic stress transfers in a coordinate $\zeta = v_r t - x$ that moves with the tip of the rupturing front.

$$\tau[\delta(\zeta)] = \tau_{ex} + \frac{\mu'\sqrt{1-v_r^2/c^2}}{2\pi}\int_0^\infty \frac{\delta'(\tilde{\zeta})}{\tilde{\zeta}-\zeta}d\tilde{\zeta} \qquad \text{where}$$

v_r is the rupture speed.

Following Garagash (*Phil. Trans. Roy. Soc.*, 2020), we consider an equivalent crack that slips under imposed dislocation and an effective stress drop, $\Delta\tau_{eff}$, from background stress to steady-state sliding at an effective slip rate. When slip occurs, we have

$$F(l,v_r,t) \equiv \frac{V_{dis}\cdot t}{\pi l(t)} + \frac{\Delta\tau_{eff}}{\mu'} - \frac{K_c}{\mu'\sqrt{\pi l/2}} = 0$$

where the toughness is determined from friction conditions and rupture speed., given by

$$K_c = \frac{E(1-v_r^2/c^2)}{(1-v_r^2/c^2)^{\frac{1}{4}}}\sqrt{2\mu G_c} \qquad \text{where} \qquad G_c = \frac{\Delta f_p}{b}(b\bar{\sigma}D_c)$$

We obtained slip rate of the equivalent crack, given by

$$V = \frac{1}{\mathcal{P}}\left[\sqrt{\frac{\xi}{1-\xi}} + \frac{2}{\pi}\mathcal{P}\sin^{-1}\left(\sqrt{1-\xi}\right)\right] \quad \text{where} \quad \mathcal{P} = \frac{K_c v_r}{\mu'\sqrt{\pi l/2}}$$

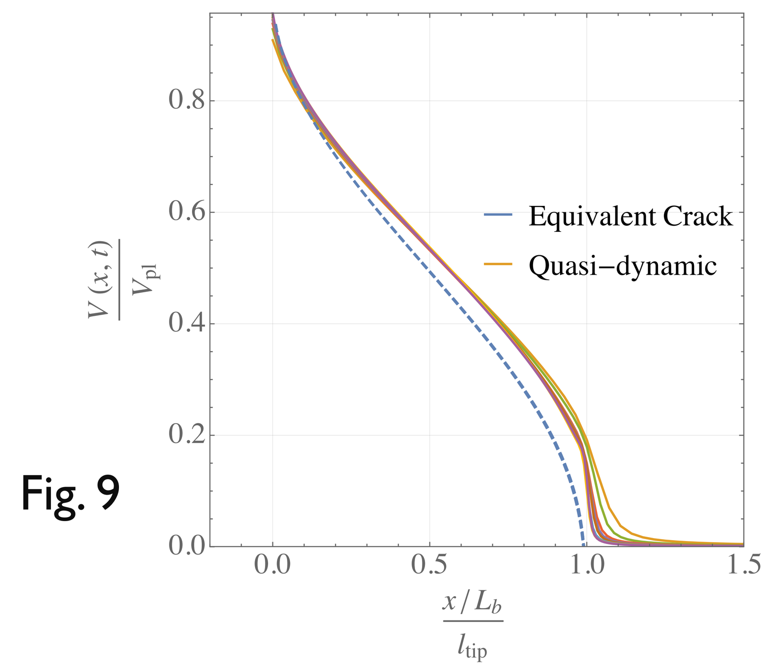


Fig. 9

7. Notations

effective normal stress: σ
shear traction: τ
shear strength: τ_s
friction coefficient: f
State Variable: Θ
Direct effect: a
Evolution effect: b
Away from steady-state sliding: Δf
slip rate: V
rupture speed: v_r
wave speed: c
coordinate: ζ, x

Fracture energy: G_c
Fracture toughness: K_c
Stress Intensity Factor: K
Rupture length: l
Peak Friction departure: Δf_p
Friction evolution slip scale: D_c
Elliptic Integral IInd kind: E

8. References

1. Rubin and Ampuero (JGR, 2009)
2. Kaneko and Ampuero (JGR, 2011)
3. Brener et. al. (2018)
4. Bar-Sinai et. al. (2019)
5. Cattania and Segall (JGR, 2019)
6. Garagash (PTRS, 2020)