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Additional information

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Hydro-mechanical fault model

- Quasi-static equilibrium

$$\tau(x,t) = \tau^o - \frac{E_p}{4\pi}\int_{a_-(t)}^{a_+(t)} \frac{\partial\delta(\zeta,t)/\partial\zeta}{\zeta - x}\mathrm{d}\zeta$$

- Constitutive law for frictional slip

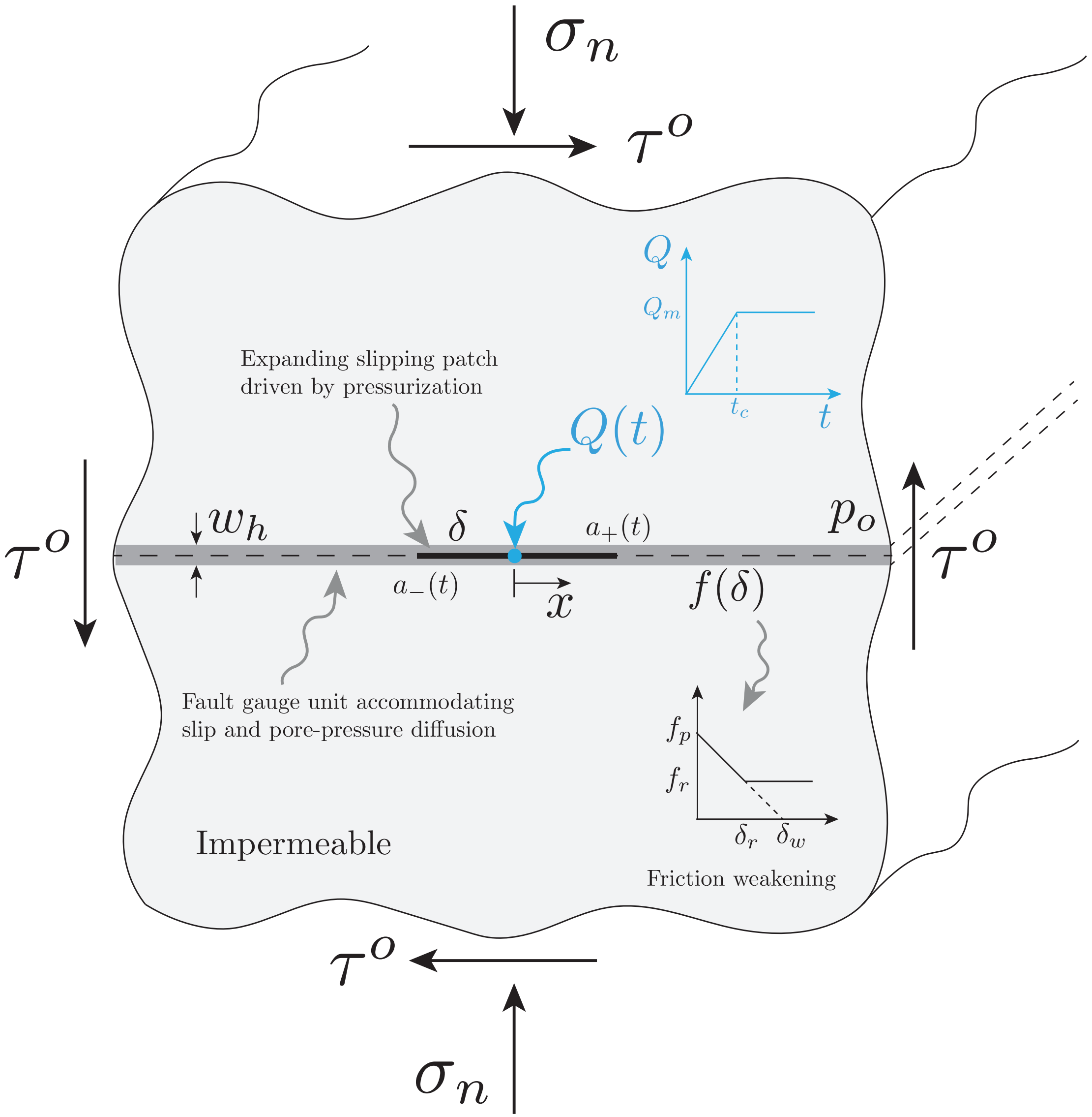
$$\tau(x,t) = f(\delta)\,(\sigma_n - \bar{p}(x,t)), \qquad |x| \le a(t)$$

- Along-fault pore-pressure diffusion

$$w_h c_f \frac{\partial\bar{p}}{\partial x} + \frac{\partial w_h v}{\partial x} = 0, \qquad v = -\frac{k_f}{\mu}\frac{\partial\bar{p}}{\partial x}$$

$$w_h v = \pm\frac{Q(t)}{2}, \qquad \text{at} \quad x = 0^{\pm}$$

$$Q(t) = \begin{cases} \frac{Q_m}{t_c}\cdot t & t \le t_c \\ Q_m & t > t_c \end{cases}$$



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Dimensionless governing parameters

Upon introduction of the following characteristic scales in the governing equations

$$\tau(x,t) = \underbrace{f_p \sigma'_o}_{\tau_p} \cdot \mathcal{T}(x,t) \qquad \delta(x,t) = \delta_w \cdot \Delta(x,t) \qquad \bar{p}(x,t) = \sigma'_o \cdot \Pi(x,t)$$

$$x = a_w \cdot \mathcal{X} \qquad t = t_w \mathrm{T}$$

Slipping patch length-scale

$$a_w = \frac{E_p}{2\tau_p}\delta_w$$

Diffusion time-scale

$$t_w = \frac{a_w^2}{4\alpha}$$

$$\left(\mathcal{T}(\mathcal{X},\mathcal{T}), \Delta(\mathcal{X},\mathcal{T}), \Pi(\mathcal{X},\mathcal{T})\right) = \mathcal{F}\left(\frac{\tau^o}{\tau_p}, \frac{f_r}{f_p}, \frac{Q_m}{Q^*}, \frac{t_c}{t_w}\right)$$

$$Q^* = \frac{2\sigma'_o w_h k_f}{a_w \mu}$$

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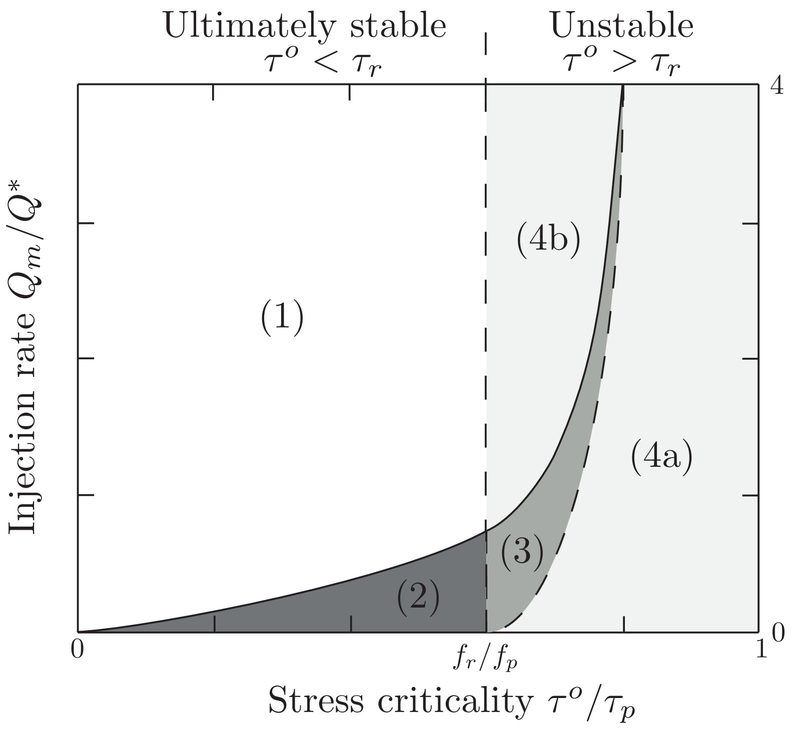
Ultimately Stable fault ($\tau^o < \tau_r$) - $\frac{t_c}{t_w} \ll 1$

$t_c \ll t_w \ll t_n$ Hydro-mechanical response is governed by constant injection rate
$\rightarrow$ Recover [Garagash & Germanovich, JGR, 2012] solution

(1) Aseismic slip only
(2) Nucleation and arrest of a dynamic event
(3) Nucleation, arrest and re-nucleation of unabated event
(4a) Unabated dynamic event not affected by f_r
(4b) Unabated dynamic event affected by f_r



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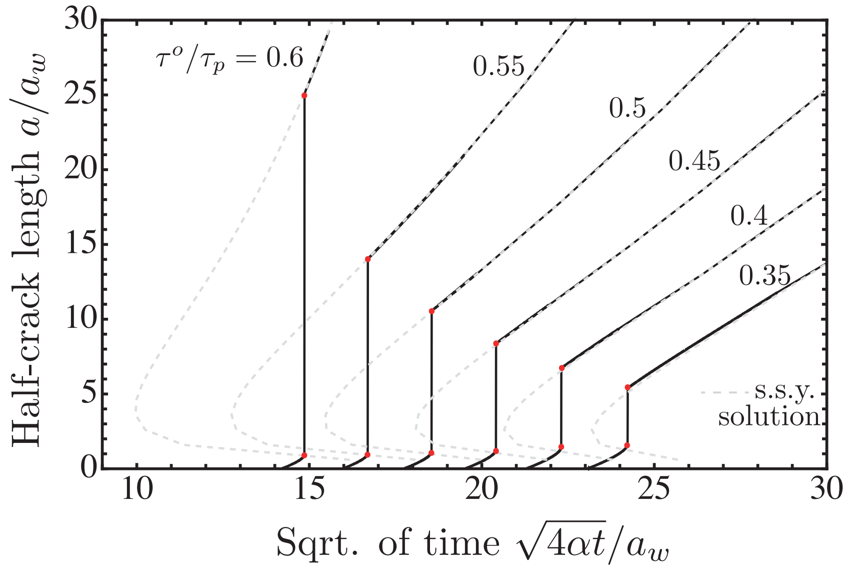
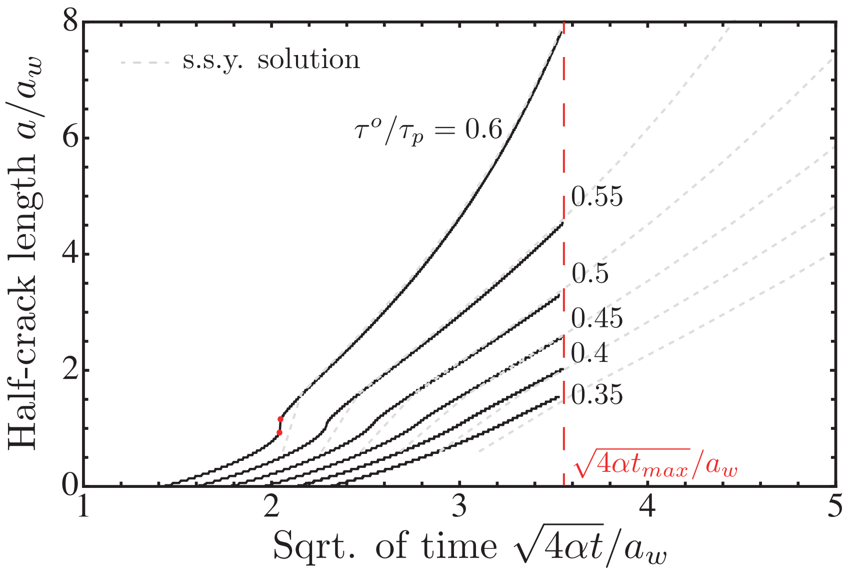
Ultimately Stable fault ($\tau^o < \tau_r$) - $\frac{t_c}{t_w} \ll 1$ (cont'd)

$Q_m/Q^* = 0.05$



$Q_m/Q^* = 0.5$



$f_r/f_p = 0.6$ $t_c/t_w = 0.01$

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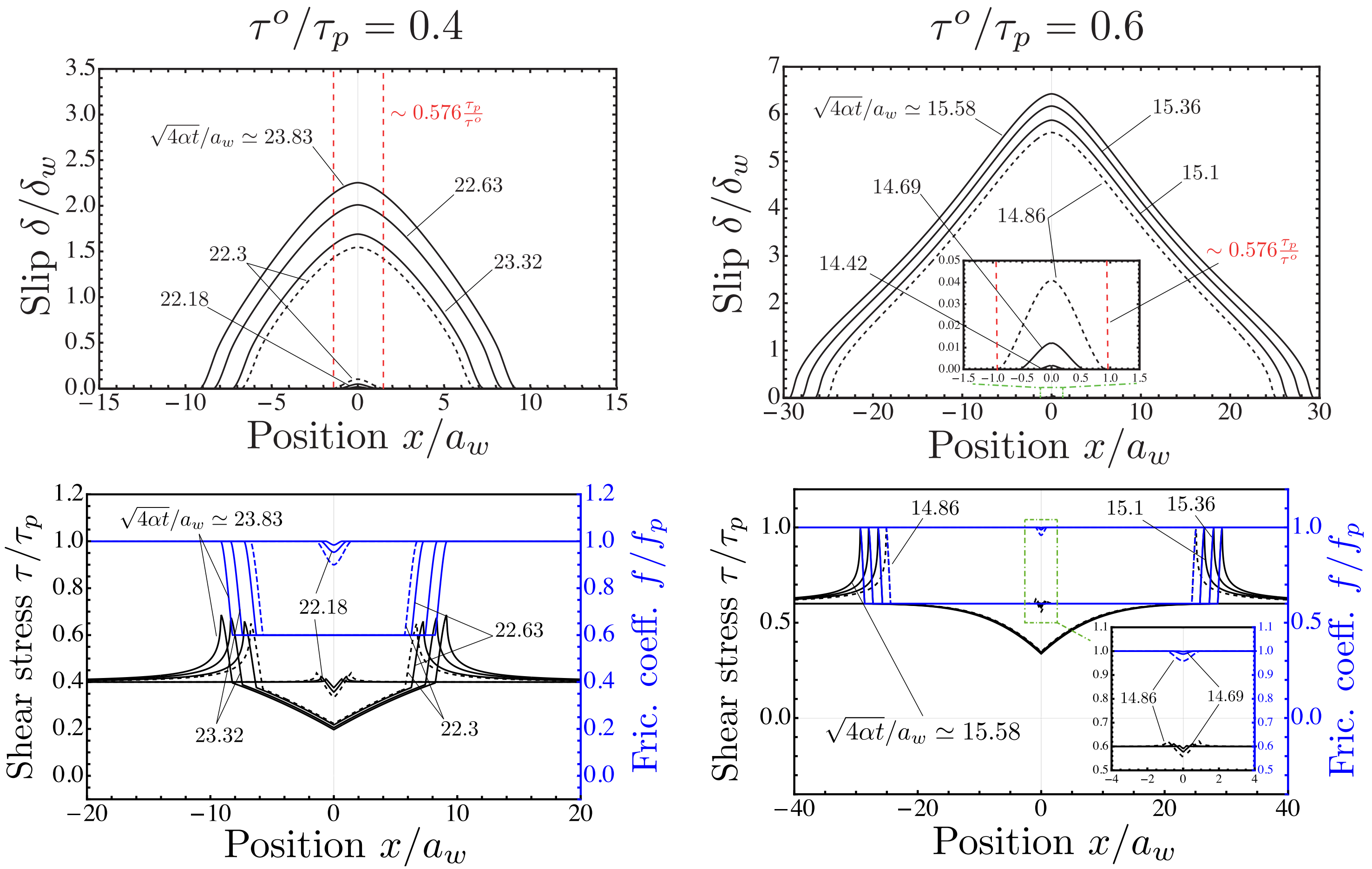
Ultimately Stable fault ($\tau^o < \tau_r$) - $\frac{t_c}{t_w} \ll 1$ (cont'd)

$$\frac{Q_m}{Q^*} = 0.05$$



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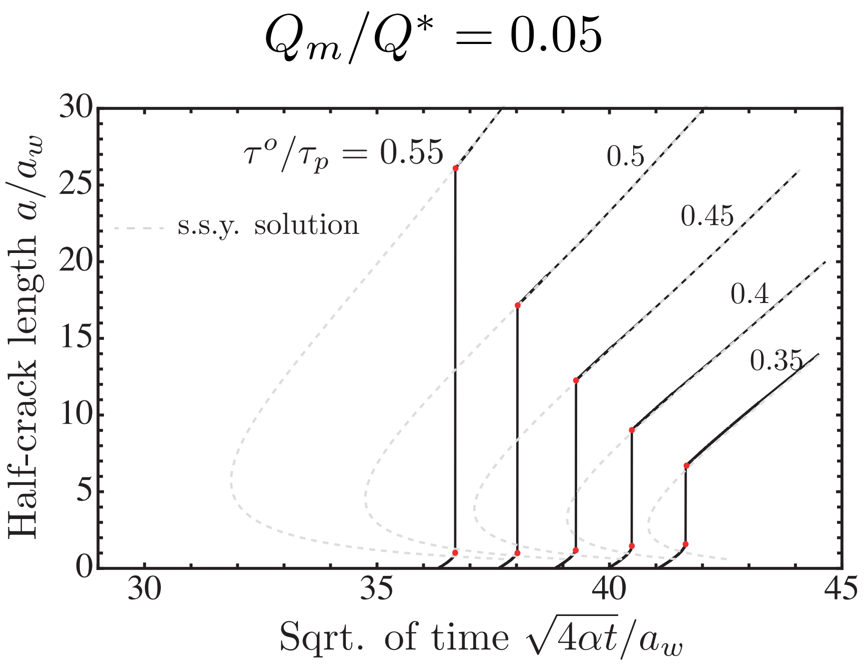
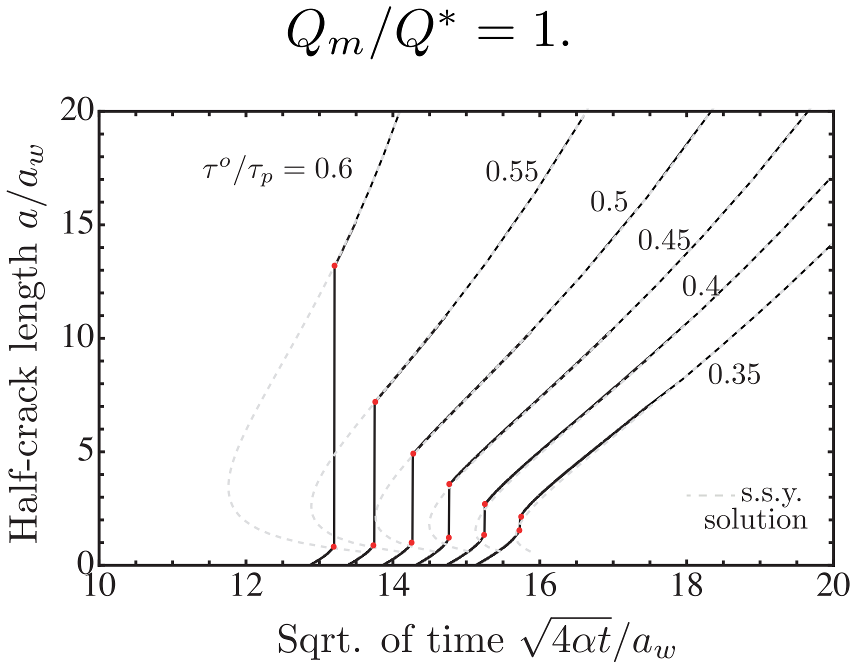
Ultimately Stable fault ($\tau^o < \tau_r$) - $\frac{t_c}{t_w} \gg 1$

$t_n \sim t_c \gg t_w$





$f_r/f_p = 0.6 \qquad t_c/t_w = 2000.$

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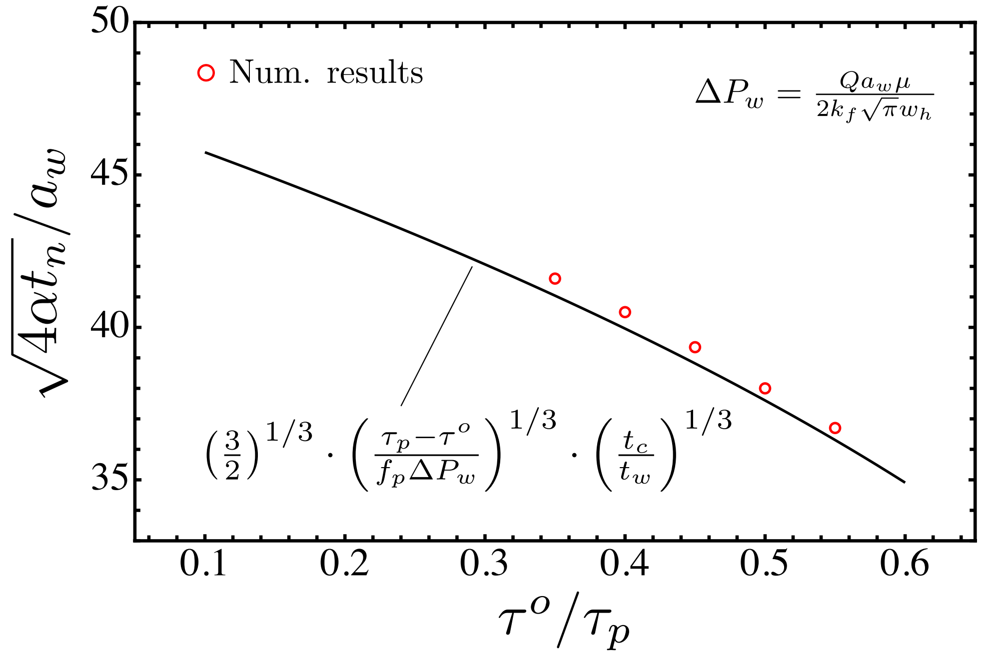
Ultimately Stable fault ($\tau^o < \tau_r$) - $\frac{t_c}{t_w} \gg 1$ (cont'd)

Asymptotic solution: $\frac{\sqrt{4\alpha t_n}}{a_w} \sim \left(\frac{3}{2}\right)^{1/3} \cdot \left(\frac{\tau_p - \tau^o}{f_p \Delta P_w}\right)^{1/3} \cdot \left(\frac{t_c}{t_w}\right)^{1/3} \Longleftrightarrow \frac{Q_m}{Q^*} \ll \sqrt{\pi}\left(1 - \frac{\tau^o}{\tau_p}\right)$



$Q_m/Q^* = 0.05$

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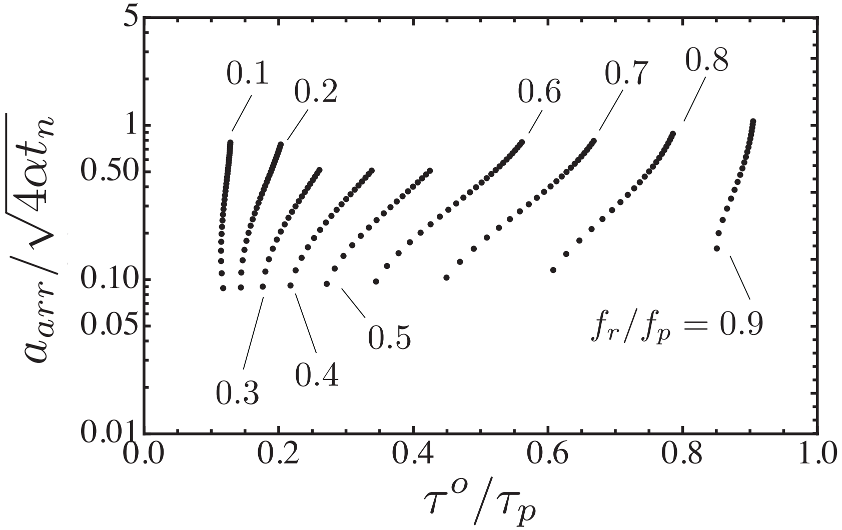
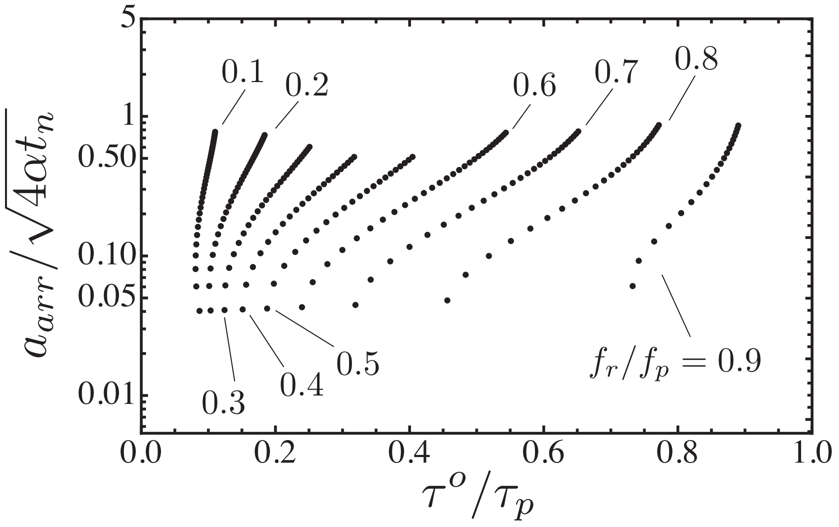
Ultimately Stable fault ($\tau^o < \tau_r$) - $\frac{t_c}{t_w} \gg 1$ (cont'd)

$$Q_m/Q^* = 0.05$$

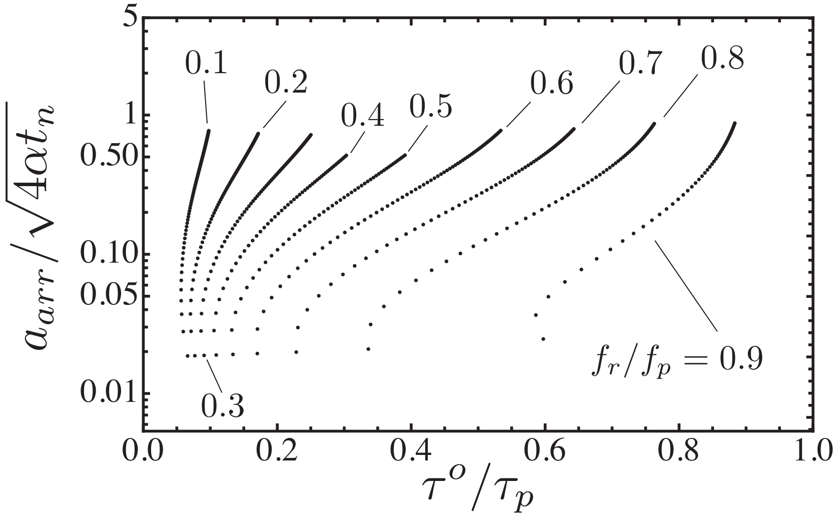
$t_c/t_w = 2 \cdot 10^3$



$t_c/t_w = 2 \cdot 10^4$



$t_c/t_w = 2 \cdot 10^5$



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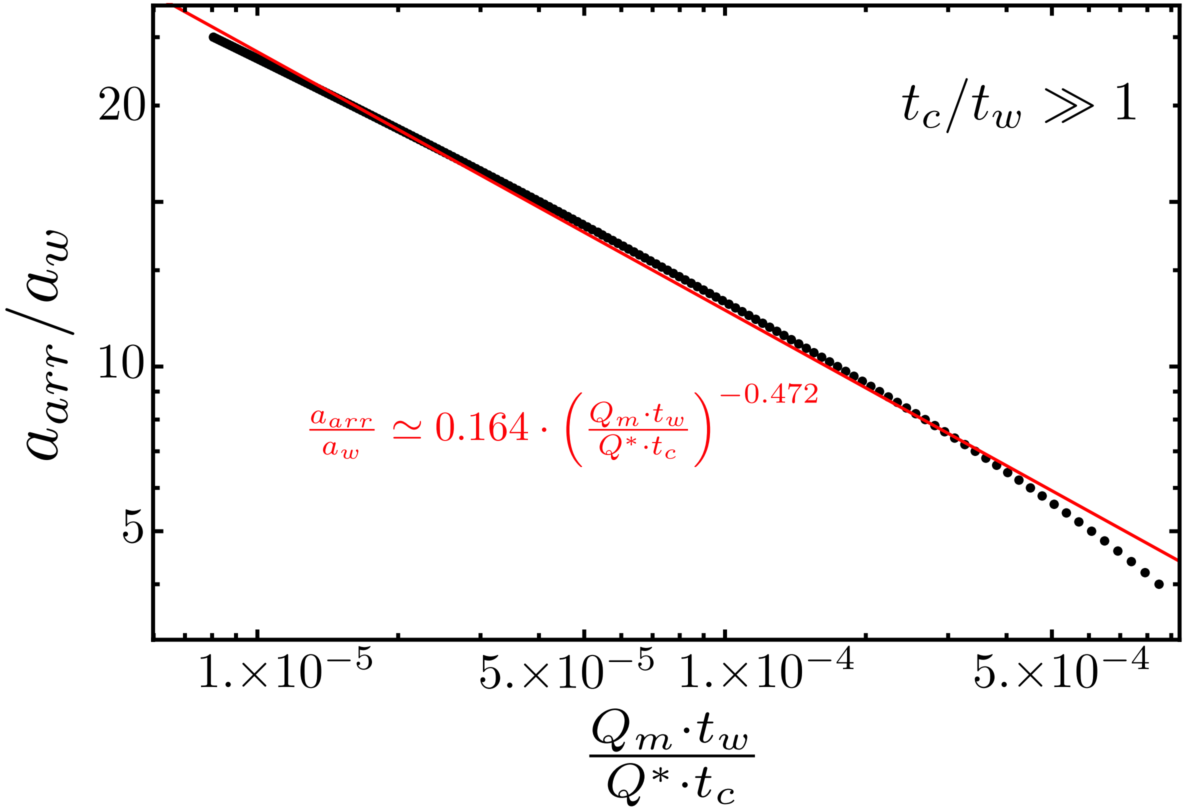
Ultimately Stable fault ($\tau^o < \tau_r$) - $\frac{t_c}{t_w} \gg 1$ (cont'd)

$f_r/f_p = 0.6, \quad \tau_o/\tau_p = 0.55$



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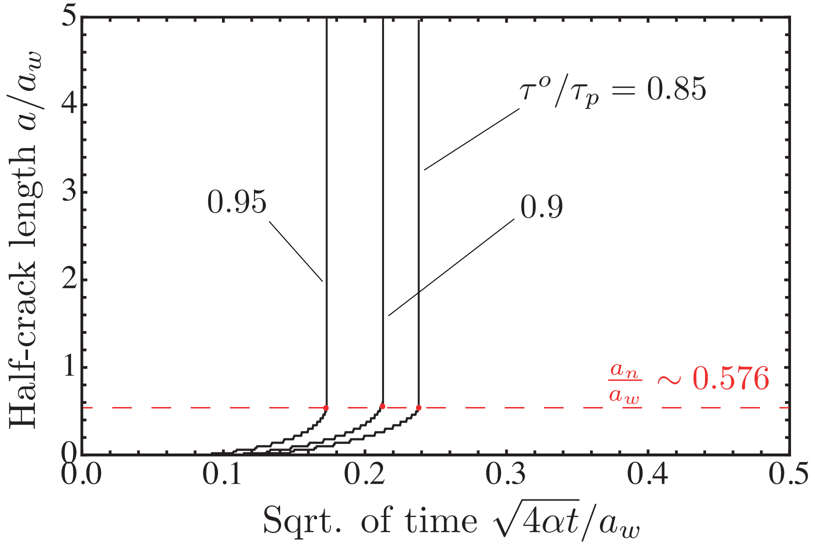
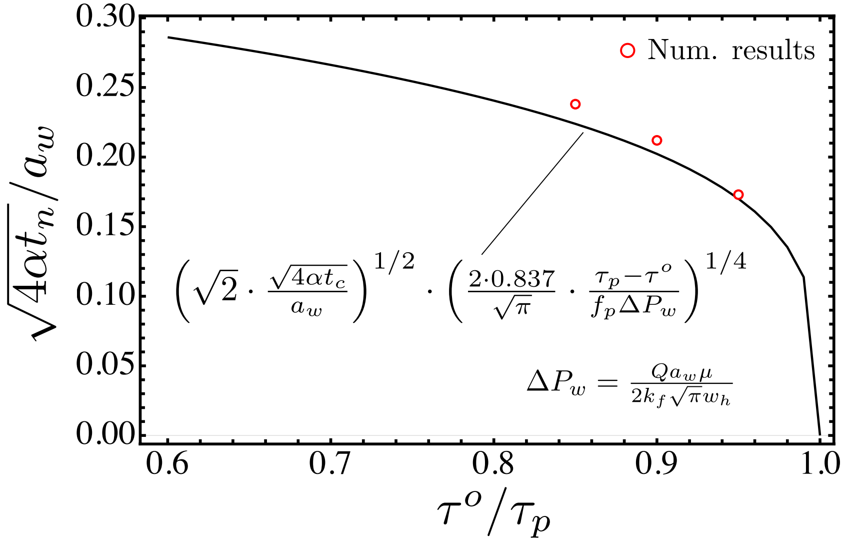
Unstable fault ($\tau^o > \tau_r$)

$$t_n \ll t_w$$

$$\text{Asymptotic solution: } \frac{\sqrt{4\alpha t_n}}{a_w} \sim \left(\sqrt{2}\cdot\frac{\sqrt{4\alpha t_c}}{a_w}\right)^{1/2}\cdot\left(\frac{2\cdot 0.837}{\sqrt{\pi}}\cdot\frac{\tau_p-\tau^o}{f_p\Delta P_w}\right)^{1/4} \Longleftrightarrow \frac{a}{a_w} \gg \frac{\sqrt{4\alpha t}}{a_w}, \quad \forall t$$

$$Q_m/Q^* = 100.$$





$$f_r/f_p = 0.6 \qquad t_c/t_w = 0.5$$

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Bibliography

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2. Ciardo, F., Lecampion, B., Fayard, F., & Chaillat, S. (2020). A fast boundary element based solver for localized inelastic deformations. *Int. J. Numer. Meth. Engng*., 1-23.