Stress and pore fluid pressure changes in fault zone preceding the earthquake occurrence

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I theoretically study stress and fluid pressure changes in fluid-saturated fault zone that deforms elasto-plastically. Such study will be useful to gain an insight into the process leading to the earthquake occurrence. I employ poro-elasto-plasticity theory (Coussy,2006) and assume a Capped Drucker-Prager model as the yield criterion (Figure 1). The line segment (A) is described by the equation $f=\tau_J+f_m\sigma_{eff}+\kappa=0$, where f_m and κ are the internal friction coefficient and a function of the hardening variable; $(\tau_J)^2$ and σ_{eff} denote the second deviatoric stress invariant and the effective mean stress. The point I represents the initial state in the elastic region and the yield criterion is satisfied first at point P on A; relatively low effective normal stress is assumed. The stresses τ_J and σ_{eff} move in a direction indicated by the arrow along the line segment A with the increase in the remotely applied stresses. I assume a non-associated flow law; the plastic potential corresponding to the line segment A is given by the equation $g=\tau_J+f_d\sigma_{eff}+\kappa$, where f_d is the dilatancy factor. It is known that the plastic component of volumetric strain is positive on the line segment A, so that the fluid pressure change will be negative there. It is known that f_m is larger for larger values of porosity (Chang et al.,2006). It is also known for low porosity rocks that permeability is higher at locations closer to the fault core, so that it will be allowed to assume that f_m is smaller at locations closer to the fault core. I therefore assume a 1D model such that f_m takes a minimum value just outside the fault core ($|y|=c+0$) and it increases linearly with the distance and attains a constant value (Figure 2). The f_m-increase zone is defined as the fault damage zone. Since the porosity is sufficiently low in the fault core, the value of f_m in the fault core is assumed to be equal to that at $y=\infty$; the boundary at $|y|=c$ is assumed to be impermeable. I also assume the absolute values of the remotely applied principal stresses ($\sigma_1<\sigma_2<\sigma_3<0$) increase quasi-statically with time. Hence, the yield criterion is first satisfied at $|y|=c+0$; the plastic zone expands with further stress accumulation. The plastic deformation never occurs in the fault core during the calculation. In this model, the time scale is governed by the magnitude of permeability. I assume that the increase rate of the maximum principal stress σ_1 that is remotely applied is 0.2MPa/year. Figure 3 shows examples of fluid pressure change at $|y|=c+0$ for the permeability$10^{-18}m^2$. The curve A is the case of plastic hardening. While both B and C are the cases of perfect plasticity, the damage zone width for C is twice as large as that for B. The figure shows that the fluid pressure decrease is larger for smaller degree of plastic hardening or for larger damage zone width. However, the elastic component of fluid pressure change (elevation) is estimated to be about 10MPa at time t/dt=10,000. Hence, the plastic decrease of fluid pressure is almost negligible. The calculation also shows that the values of $|\sigma_1-\sigma_3|$ and $|\sigma_1+\sigma_3|$ in the plastic zone are, respectively, smaller and larger than those in the elastic zone; the difference grows with the expansion of plastic zone. This suggests that the fault damage zone become more stable with the expansion of plastic zone, while the sudden stress and fluid pressure changes formed at $|y|=c$ may damage the impermeable boundary there. However, such stable situation never lasts indefinitely. The yield criterion such as represented by the curve B in Figure 1 seems to be satisfied once stresses exceeds a critical threshold. The plastic component of volumetric strain turns negative on the curve B, so that the damage zone may become unstable. Hence, the stress point is required to move onto the curve B for the occurrence of earthquake. I will show numerical examples of the whole process leading to the earthquake occurrence in the presentation.

Keywords: poro-elasto-plasticity theory, Drucker-Prager model, fault zone

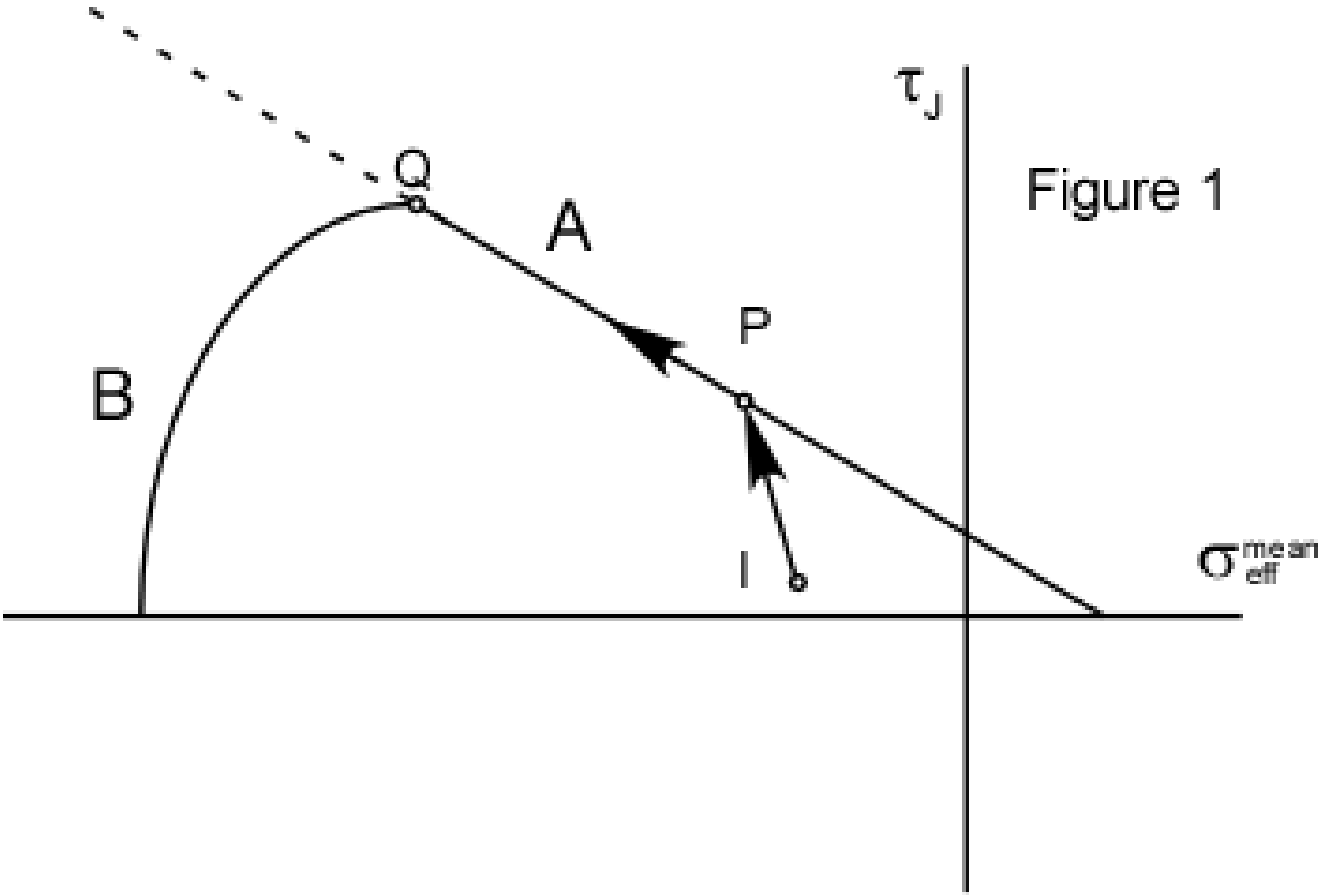

Figure 1

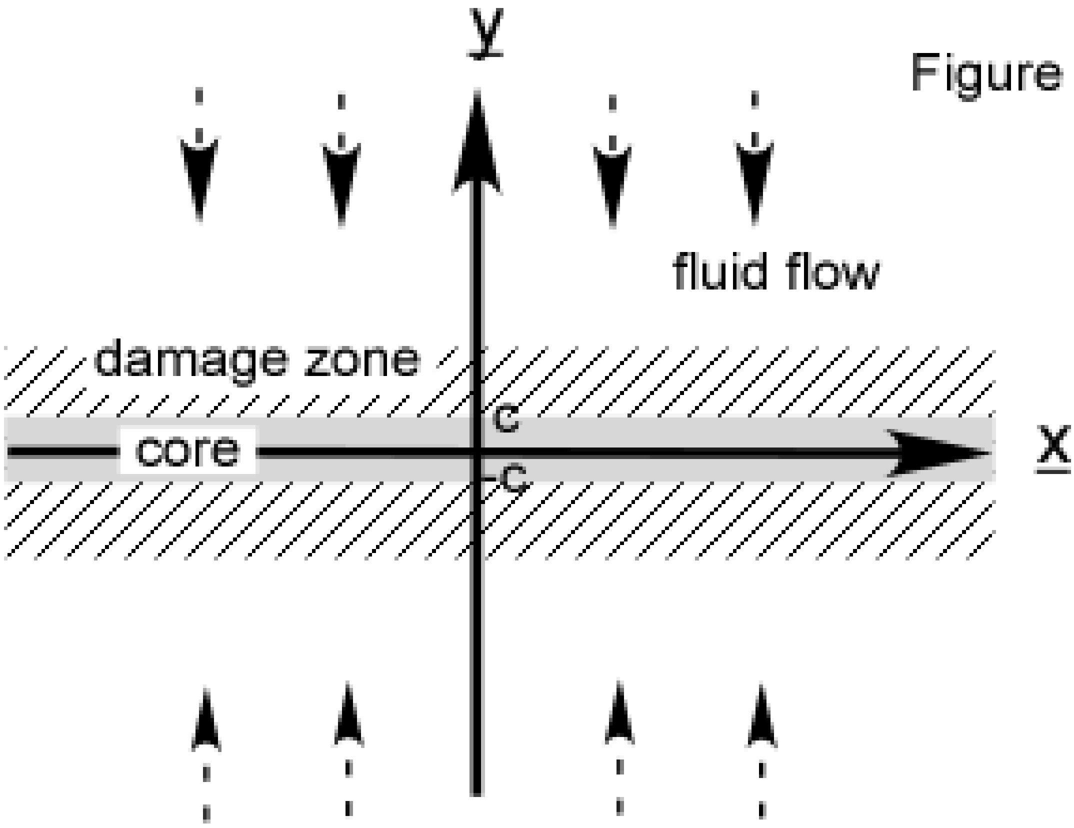

Figure 2

Figure 3