Pore fluid pressure change coupled with poro-elasto-plastic deformation in the fault zone

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We study the spatio-temporal change of pore fluid pressure in the fault zone on the basis of 1D poro-elasto-plasticity theory. This is an extension of our study presented at the 2019 JpGU meeting. Since only the shallow fault zone is considered, time-independent plasticity theory is assumed. We assume the fault plane at y=0 and that the xy and yy components of the remotely applied stress increase uniformly with time (Fig. 1). It is required to consider the equilibrium equation, the yielding criterion, the plastic flow rule, and the fluid diffusion equation coupled with the elasto-plastic deformation. We will assume a linear hardening Mohr-Coulomb criterion that has a feature of effective normal stress dependence; see the straight segment of yield curve in Fig. 2. Rock experiments have shown that the internal friction angle f_m is lower for higher porosity. In addition, it seems reasonable to assume that the porosity is higher at locations closer to fault for low-porosity rocks found in shallow fault zones. We therefore assume lower values for f_m at locations closer to the fault. This assumption suggests that the yielding first occurs near the fault plane and the zone of plasticity expands outward with the stress accumulation. Figures 3 and 4 show examples of calculated fluid pressure distribution immediately after the onset of yielding and at 250 and 500 years afterwards. The permeability far from the fault is assumed to be 10^{-21} m^2 in both figures. In Fig.3, the change rates of the xy and yy stress components are assumed to be 0.01 MPa / year and -0.003 MPa / year. The two short straight lines denote the extension of plasticity zone at 250 and 500 years after the plasticity onset. Figure 4 shows the case when the change rate of the yy stress component is larger. Specifically, the change rates of the xy and yy stress components are set to 0.003 MPa / year and -0.006 MPa / year in Fig.4. Comparison between the two figures suggests that the fluid pressure change is larger when the change rate of shear component is larger. It is also found that the fluid pressure change can almost be ignored in Fig.4. These figures show that the degree of the fluid pressure change strongly depends on the direction and magnitude of the stress applied remotely. As exemplified in Figs.3 and 4, our calculations show that the fluid pressure in the vicinity of the fault plane continues to decrease with time. This means that the fault is more stabilized with increasing time and brittle fracture is unlikely to occur there according to the concept of effective stress. This suggests that the porosity should be negligibly low in a narrow zone surrounding the fault plane in more realistic model, which prevents the occurrence of yielding in the narrow zone, which is now called the fault core. If the yielding never occurs in the fault core and it is impermeable, the stress and fluid pressure in the fault core will be the same as those at infinity due to the one-dimensional nature of our model. In addition, the above-stated our analysis is applicable outside the fault core. The possibility of the occurrence of brittle fracture will therefore increase with time in the fault core. It is known in rock plasticity that the yield curve closes in the stress space for sufficiently large compressive effective normal stress; see the dotted curve (called cap) in Fig.2. It is also known that the volumetric plastic strain increment becomes negative on this cap. Hence, once the stress point moves from the Mohr-Coulomb straight line to the cap curve, the fluid pressure begins the elevation. When the yielding occurs on the cap for the first time (straight line A in FIG. 2), the fluid pressure rises simultaneously with the occurrence of plasticity. We will discuss the details on the effect of cap in my talk.

Keywords: pore fluid pressure, plasticity, fault zone

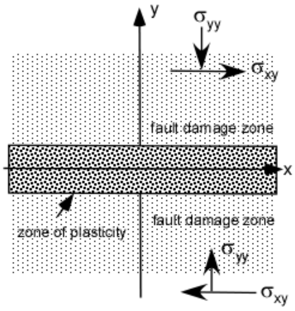

Figure 1

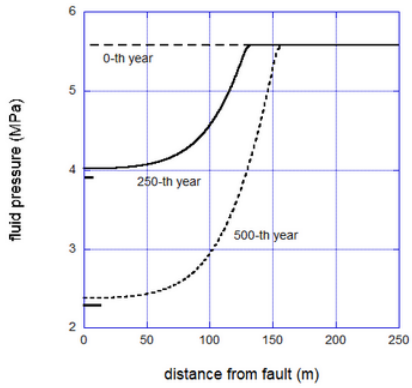

Figure 3

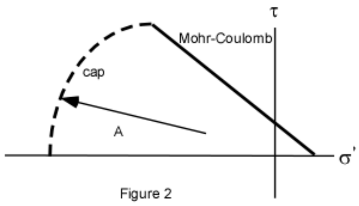

Figure 2

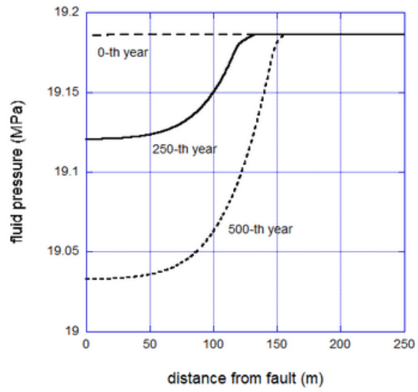

Figure 4