Analysis of thermo-hydraulic effects on diversity of dynamic earthquake ruptures in a poroelastic medium

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We previously found that we can simulate self-healing slip in a thermo-poroelastic medium when the thermal expansion coefficients are assumed based on laboratory data on crustal rocks. We also found that the dependence of physical properties such as the drained bulk modulus and the thermal expansion coefficient on porosity is crucial for the occurrence of slip healing; other researchers failed to take account of the porosity dependence of these properties (e.g., Lachenbruch (1980), Mase and Smith (1985, 1987)). It was also found in our study that diversity in dynamic earthquake ruptures emerges because of the existence of two qualitatively different feedbacks. These two feedbacks govern the system behavior if fluid flow and pore expansion are negligible.

Now we study the two dimensional anti-plane problem for the treatment of the dynamic crack tip growth. We use the boundary integral equation method (BIEM) developed by Cochard and Madariaga (1994) in our numerical analysis to evaluate the fault slip. We investigate the spatio-temporal change of fault slip and how it is reflected in radiated elastic waves. We then calculate seismic efficiency considering energy balance among potential energy, heat energy, fracture energy and seismic wave energy.

It is found in our present study that the slip stops spontaneously except near the extending crack tip in our model, which is quite similar to our findings obtained in the 1D simulation. On the other hand, if we assume the classical Griffith crack, the slip is found to increase linearly with time on the crack center as long as the crack tip continues to grow. It can therefore be concluded that our slip model can simulate the Heaton pulse successfully. We observe two noteworthy phenomena about the radiated wave field. First, the difference between the two crack models is obvious, especially near the arrival of waves. The model including thermo-hydraulic effects shows a gradual onset near the arrival of S waves. Second, oscillation continues longer after the stopping phase arrives in our model than in the Griffith model. Hence, the degree of thermo-hydraulic effects may be estimated from the observation of radiated seismic waves. We also find in our study that the increase of stress intensity factor tends to cease after some time even if the crack tip continues to grow. This behavior suggests that a slight spatial inhomogeneity in the fracture strength can more easily arrest the crack tip growth in our model than in the Griffith crack model. Seismic efficiency is found to be much larger when thermo-hydraulic effects are taken into account than when they are not considered.