Stress concentration at the perimeter of asperity and its effect on rupture process

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Stress concentration is expected to occur at the perimeters of asperites due to surrounding aseismic sliding. To understand the mechanics of earthquakes generated by asperity rupture, I consider stress concentration at the perimeter of a circular asperity. Sammis and Rice (2001), Johnson and Nadeau (2002), and Chen and Sammis (2003) presented fracture mechanical models for asperity rupture. Although a similar approach is taken in the present study, a different result is obtained because of different assumptions such as the extent of coseismic slip outside the asperity. We consider a circular asperity of radius r on a planar fault in an infinite uniform elastic medium. The fault is stuck at the circular asperity, while stable sliding occurs with constant frictional stress outside the asperity. When the loading velocity across the fault is V_{pl}, the stress intensity factor K at an edge of the asperity is proportional to $V_{pl}tr^{-1/2}$ at the time t from the onset of loading. Asperity rupture or an earthquake occurs when K reaches the critical value K_c at time $t = T_r$. The remote slip at this time can be written by $u=V_{pl}T_r$, and the coseismic slip at the asperity is the same as u. If the frictional stress outside the asperity is constant, coseismic slip propagates there. However, the friction outside the asperity shows velocity strengthening, and postseismic sliding occurs there. Accordingly, the seismic moment M_0 of the asperity rupture is given by $Gupir^2$, where G is rigidity. Using the critical stress intensity factor K_c, M_0 is proportional to $r^{5/2}K_c$, the stress drop of a circular crack model is proportional to $r^{-1/2}K_c$, and T_r is proportional to $r^{1/2}K_c/V_{pl}$. If K_c is independent of asperity radius, we have stress drop proportional to ${M_0}^{-1/5}$, and T_r proportional to ${M_0}^{1/5}$. These relations contradict with nearly constant stress drop empirically obtained for usual earthquakes, but similar to the scaling relations for small repeating earthquakes in California obtained by Nadeau and Johnson (1998). Using the scaling laws, the fracture energy is estimated to be approximately $10^7 J/m^2$. In contrast, size dependent K_c is allowed, and stress drop is assumed to be independent of earthquake magnitude, the present model leads to fracture energy proportional to ${M_0}^{1/3}$.

The present model assumed that the asperity rupture is controlled by stress concentration at an edge of the asperity. The above results come from low strain energy accumulated inside the asperity. The stress concentration at an edge of the asperity depends on its curvature. If an asperity is not circular and has geometrical irregularity, a local high stress concentration occurs at the region with a small curvature. In this case, partial rupture of the asperity may take place even if the strength (fracture toughness) and the frictional properties are uniform over the asperity. This kind of partial rupture is confirmed in numerical simulations.