The seismic moment, stress drop, and strain energy release for the rupture of asperities

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Seismic moment and stress drop are known as the most fundamental physical quantities characterizing seismic events. The seismic moment of an event is clearly defined as the product of its rupture area (*S*), average fault slip (*D*), and the rigidity of the surrounding elastic medium (Aki, 1966; Kostrov, 1974), but the stress drop is not (Madariaga, 1979), which depends on adopted source models. In the simplest case of a circular crack model with uniform stress drop, the stress drop is proportional to *D* and the inverse of the square root of *S*, and so independent of seismic moment (e.g., Kanamori & Anderson, 1975). However, with the simplest model, Nadeau & Johnson (1998) found a clear dependence of average stress drop on seismic moment from a detailed analysis of repeating earthquakes along the Parkfield segment of SAF. This empirical scaling relationship for average stress drop is contrary to what is commonly assumed in seismology: that is the stress drop is independent of earthquake size.

Since then, many seismologists (e.g., Sammis & Rice, 2001; Anooshehpoor & Brune, 2001; Beeler, Lockner & Hickman, 2001; Johnson & Nadeau, 2002) tried to explain the observed size-dependence of stress drop by theoretically considering the loading and rupture processes of asperities, but didn't succeed. The size-dependence of stress drop seems to result from an inappropriate assumption for background slip rates [1]. Aside from that, in these theoretical studies, the asperity is modeled as a completely locked small patch surrounded by freely creeping zones. In such modeling, steady tectonic loading causes stress singularity just inside the locked patch and broad slip-deficit distribution on the surrounding freely creeping zones. The rupture of the asperity suddenly releases the concentrated stress at the small locked patch and causes fault slip so as to cancel the slip deficit distributed on the surrounding zones without stress drop. Even in such a case, we can clearly define the seismic moment by multiplying the integral of coseismic slip over the whole fault plane by the rigidity of the surrounding medium. In contrast, the definition of average stress drop is multiple (Noda, Lapusta & Kanamori, 2013), which suggests that the static stress drop on fault may not be the fundamental physical quantity.

Recently, on the basis of theoretical consideration to the equation of motion in continuum mechanics, we derived a fundamental equation that the volume integral of static stress changes caused by a seismic event over the whole elastic region is mathematically equivalent to its moment tensor [2]. Applying the fundamental equation to the energetics of shear faulting, we can obtain a quantitative relationship between the work done for shear faulting and the change in elastic strain energy in the surrounding region. This means that we should use the volume integral of static stress changes or the total strain energy change as the fundamental physical quantity characterizing seismic events.

References:
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