Strain energy released by an earthquake: Contributions of random slip fluctuations

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Strain energy in the lithosphere is the source of earthquake generation. For example, the shear strain energy change caused by the interplate coupling along the Nankai Trough, Japan affects the seismicity in the inland area (Saito et al. 2018 JGR). The aftershocks of the 2016 Kumamoto earthquakes were activated by the shear strain energy brought by the mainshocks (Noda et al. 2018 ACES; Tanaka et al. 2018 JpGU). The strain energy change caused by an earthquake is one of the most fundamental quantity for earthquake mechanics. When the stress change occurs uniformly on the earthquake fault (constant stress drop), a simple theoretical equation gives the relation between the seismic moment, initial stress, stress drop, and the strain energy liberated by the earthquake (e.g., Aki and Richards 2002). This relation leads that the strain energy released by an earthquake is proportional to the seismic moment. However, for actual earthquakes, the stress change on the fault is considerably heterogeneous.

The present study theoretically investigates the relation between the strain energy released by an earthquake and the seismic moment when the stress change is not uniform on the fault plane due to heterogeneous slip distribution. We assume that the initial stress is homogeneous in space and suppose that the heterogeneous slip distribution is given by the sum of the reference slip distribution causing the constant stress drop and the randomly fluctuating slip distribution. We adopt a stochastic approach using an ensemble of the slip fluctuations characterized by the power spectral density functions such as Gaussian and von Karman type function. The derived theoretical relation gives a scaling law of the strain energy with the power spectral density function of the slip fluctuation. This deduces the following results. (1) When an earthquake contains randomly fluctuating slip distribution, the liberated strain energy is smaller than that of the constant stress-drop earthquake. (2) This indicates that a representative value of stress drop becomes large due to the randomly fluctuating slip distribution in the view point of the energy partition. This study refers to this stress drop as effective stress drop. This was also reported by some studies such as Noda et al (2003 GJI) and Hirano and Yagi (2017 GJI). This study derived a theoretical equation of the effective stress drop with the power spectral density function of the random slip fluctuation. (3) When the stress change is not constant on the fault, the strain energy is not proportional to the seismic moment unless the correlation distance of the slip fluctuation is proportional to cube root of the seismic moment. (4) The energy balance gives a value of the initial stress that is required for the earthquake generation. In order to generate an earthquake, the initial stress needs to be larger than the sum of the half of the effective stress drop and the apparent stress (the apparent stress is given by rigidity, radiation energy, and seismic moment (Wyss and Brune 1968,1971)).

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