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Diversity of dynamic earthquake rupture controlled by a single nondimensional parameter

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We found the nondimensional parameter S governing the earthquake source process by taking account of interaction among changes in temperature, fluid pressure, inelastic porosity change and slip. If we change the S value, diversity of dynamic earthquake behaviors appears such as slip-weakening and -hardening behaviors and pulse-like and not pulse-like slip velocity distribution. All observed difference in earthquake rupture may originate in the difference in the S value. We verify this statement in many aspects of dynamic earthquake behavior below.

Slip-weakening and -hardening behaviors are both fundamental ones in earthquake rupture processes from our study. The slip-weakening behavior has been studied from seismological observations in detail [e.g., Ide and Takeo, 1997; Mikumo et al., 2003]. However, the slip-hardening behavior has not attracted much attention among seismologists up to now. These two behaviors are, from our study, can be understood in a unified way from the viewpoint of the difference in the value of S; the value nearly zero and the value larger than unity generate the slip-weakening and slip-hardening behaviors, respectively. Our model should be used henceforth to understand a ’unified’ constitutive law, which includes both the slip-weakening and -hardening behaviors.

Slip velocity distribution on fault planes is sometimes believed to show pulse-like form; e.g., the Landers earthquake and the Northridge earthquake [Wald and Heaton, 1994; Wald et al., 1996]. According to our model, these earthquakes have S values larger than or near unity. This statement is confirmed more firmly by considering the radiation efficiency later. On the other hand, earthquakes showing not pulse-like slip are also known to exist; e.g., the south part of the Chi-Chi earthquake [e.g., Ma et al., 2003; Somerville, 2003]. This statement represents that earthquakes having values S=0 also occur.

The radiation efficiency has been investigated because it reflects earthquake rupture processes. While this value is not expected to exceed unity from the definition, it sometimes exceeds unity [e.g., Singh et al., 2004; Venkataraman and Kanamori, 2004]. This paradox has been attributed to estimation errors of, for example, radiated energy. In our model, when S is large, this paradox is solved by considering the slip-hardening behavior. It should be emphasized that earthquakes having the radiation efficiencies larger than unity in the study of Venkataraman and Kanamori [2004] (the Landers earthquake and the Northridge earthquake) agree well with those showing pulse-like slip, which are concluded to have large S values.

The effects of temperature, fluid pressure, inelastic porosity and slip velocity on dynamic earthquake ruptures have been studied by many authors, while they have frequently studied those effects separately. We suggested that those effects should be treated in a unified way because they interact and the interaction plays fundamental roles in dynamic earthquake rupture. This ’unified-way understanding’ of dynamic earthquake rupture is an important step to promote our understanding of earthquake source physics.