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Effect of secondary aftershocks on aftershock decay in the rate- and state-friction model

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To explain the temporal evolution of an aftershock sequence, a model based on the rate- and state-dependent constitutive law [Dieterich, 1994, JGR] seems attractive and is frequently used in present studies. As well known, an aftershock activity decay follows an inverse power law (Omori-Utsu law) [Utsu, 1961, Geophys. Mag.], and the Dieterich model successfully reproduces such decay.

In the Dieterich model, normally we simply assume that a stress change rate is constant in time. Under this simple assumption, the temporal decay of an earthquake sequence derived from the Dieterich model is asymptotically close to the special case of the Omori-Utsu law; its p-value is limited to 1. In real aftershock sequences, however, variation of the p-value is observed in many studies. Hence, to fit comprehensively an earthquake sequence derived from the Dieterich model with general aftershock sequences, incorporating an inconstant stress change rate is suggested by several studies [e.g., Dieterich, 1994, JGR; Helmstetter and Shaw, 2009, JGR].

Dieterich [1994, JGR] suggests another idea to generate an earthquake decay with $p \neq 1$. The occurrence of a (large) aftershock causes a stepwise stress increase in an aftershock area, and an expected seismicity rate derived from the Dieterich model also increases abruptly. As a result of multiple increases of seismicity rate in the decay of seismicity rate following a mainshock, an apparent p-value could be variable (see Figure 7 of Dieterich [1994, JGR]). In this study, this idea that the effect of secondary aftershocks provides the variety of the p-value is examined.

The aftershock sequence of the 1995 Kobe earthquake during a four-year period after the occurrence of the mainshock is analyzed. Hypocentral information of each of the aftershocks is determined by Japan Meteorological Agency. Considering the detection capability of the aftershocks, we analyze those of which magnitude (M) is 2.5 or larger; the number of analyzed events is 1590.

We suppose that the amount of stress step ($DCFF$) caused by the aftershock is proportional to an exponential function of its magnitude: $DCFF = a\exp(bM)$. With an incorporation of the stress changes caused by the aftershocks, we apply the Dieterich model to the observed aftershock sequence. The parameters a and b and other parameters involved in the original Dieterich model are estimated by the maximum likelihood method. As a result of the application of this model, the slope of the aftershock decay slightly increases and p-value is estimated at 1.05. Using AIC we compare the goodness-of-fit of this model with that of a model without stress changes given by the aftershocks, and find that the former model is significantly better than the latter; the difference of the AICs is 122.46. However, the p-value estimated from the Omori-Utsu law is 1.20. Only a consideration of the secondary aftershock effect would be inadequate to explain the wide variety of the p-value observed in real aftershock sequences.