Time-Dependent Earthquake Probability Controlled by Coseismic Stress Step and Loading Rate

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Traditionally, long-term earthquake probability has been estimated without considering time dependent clustering of earthquakes, and the occurrence of aftershocks or anti-shocks (seismicity rate decreases) caused by recent stress perturbations. In an attempt to overcome these limitations, we have thus developed the stress interaction based earthquake probability, incorporating the rate- and state- dependent friction law.

In interaction-based probability, the coseismic stress step controls the amplification of the probability gain or loss. Meanwhile, regional stress loading rate is inversely proportional to decay time for aftershocks or anti-shocks if the constitutive parameter and normal stress are constant throughout time. Thus, the influence of a stress step lasts longer where the loading rate is slow, and the long-term probability retains the stress-related change longer. A change in the loading rate also causes a change in earthquake productivity (and thus probability), although there is an equilibrium period over which the new seismicity rate is attained. The higher the loading rate is, the shorter the equilibrium time becomes.

We argue that the energetic earthquake triggering by dike inflation during June-August 2000 in and around the Izu Islands, Japan, reveals some of these rate/state dependent friction effects. During the event, the gradual and continuous dike inflation produced a loading rate on the shallow strike-slip faults that was hundreds to thousands times higher than normal, and promoted numerous shallow earthquakes, including five M~6 shocks. Observed seismicity rate increases during this event are hundreds to thousands times greater than usual. In addition, we found that responses to the M~6 coseismic stress step and the change in loading rate near the dike inflation are different than far from the dike. In the highly strained dike region, the impact of a stress step by M~6 shocks appeared only as a spike in the transient aftershock increase, and disappeared within a day. Meanwhile, the moderately strained off-dike regions exhibit long-lasting aftershock sequences. After dike inflation ended and the strain rate returned to normal, we can still observe the long-term aftershock decay process, especially in the off-dike region. These observations in the Izu Islands provide some validation for our interaction-based probabilistic analysis. Other supportive evidence can be seen in the seismicity associated with recent large shocks, such as 1995 Kobe and 1997 Kagoshima (Japan), and 1999 Izmit (Turkey) shocks. We thus offer our method for long-term earthquake hazard analysis.