Source parameters of small earthquakes estimated from inversion method using stopping phases

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The source parameters, most importantly the rupture velocity, of small earthquakes have been estimated by analyzing seismograms recorded by the dense seismic networks operated in the aftershock area of the 1984 western Nagano earthquake, central Japan. An inversion method using stopping phases (Imanishi and Takeo, 2001) was applied to these data. The outline of the method is as follows. We assume that rupture begins at one focus of an ellipse fault and spreads circularly with a constant rupture velocity, eventually terminating on the elliptical boundary. In this model, the difference of the arrival times between the two stopping phases is dependent on the average value of rupture velocity, the radius of major semi-axes of ellipse and its ellipticity. These parameters are estimated by a nonlinear least-square inversion method. To detect the stopping phases on seismograms, we use the relation of Hilbert transformation between the two stopping phases. Since we need high frequency components to identify the stopping phases, we used seismograms recorded by 800m deep borehole station in the detection of the stopping phases. We also used surface recordings to determine the differential time between the direct S wave and the peak of displacement pulse.

We analyzed earthquakes ranging in size from Mw1.0 to Mw2.5 which were observed at relatively short epicentral distances (mostly less than 5 km). Static stress drops range from approximately 0.1 to 10 MPa, where these static stress drops do not vary with seismic moment. The aspect ratio of fault geometry is greater than 0.8, suggesting that the assumption of circular crack model for small earthquakes is valid as a first order approximation. It should be noted that the average rupture velocities decrease with decreasing seismic moment.

It has been the subject of considerable controversy whether the dynamics of small and large earthquakes is different or not. This difference is reflected in the observed ratio of seismic moment to radiated seismic energy which is called the scaled energy. The observation shows that the scaled energy for small earthquakes is 10 to 100 times smaller than that of large earthquakes. Kanamori and Heaton (2000) interpret this observation as a difference in frictional behavior during rupture between small and large earthquakes, while Ide and Beroza (2001) suggest that this arise from underestimation of energy due to limited recording bandwidth. Sato and Hirasawa (1973) derived a relationship between rupture velocity, stress drop and seismic energy for a circular crack model, where the seismic energy is dependent on square of rupture velocity. Using their equation and source parameters estimated in this study, we calculated the scaled energy. Although these estimations are dependent on the assumption of the circular crack model, they are not related with recording bandwidth. Note the estimated scaled energy is well consistent with the observed trend. We suggest that the dependency of rupture velocity on seismic moment is a cause of small-scaled energy for smaller earthquakes in addition to underestimation due to limited recording bandwidth. It is necessary to study the mechanism why the rupture velocity varies with earthquake size.