Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

SSS27-01 Room:201B Time:May 22 09:00-09:15

High-frequency seismogram envelope synthesis of early aftershock sequences

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The detection of early aftershocks is challenging because their waveforms are hidden by the large amplitude of coda waves of the mainshock and are obscured due to the occurrence of a large number of events in a short time interval. The lack of early aftershocks in an earthquake catalog could bias the analysis and modeling of aftershock activity. In order to investigate the excitation of early aftershocks quantitatively, it is better to regard the early aftershock sequence as a continuous energy radiation process rather than discrete earthquake occurrence. In this study, we theoretically synthesize envelopes of 1-16 Hz seismograms by convolving the energy of coda waves excited by an impulsive source with the energy radiation function of an aftershock sequence. The radiative transfer theory, which accounts for the spatio-temporal distribution of the multiply scattered wave energy, is used to describe the coda excitation process. The scattering coefficient and the intrinsic absorption factor used in this theory are independently estimated from the coda wave of small earthquakes. The Omori-Utsu law, the Gutenberg-Richter law, and an omega-square source spectrum are used to describe the energy radiation function. The p- and c-values of the Omori-Utsu law and the b-value of the Gutenberg-Richter law are chosen based on results reported in the literature.

When the seismogram of an Mw7 mainshock is observed at hypocentral distances of 10-30 km, our theoretical modeling shows that the energy of scattered waves dominates over the energy excited by the early aftershocks in the first 30-100 s after the mainshock. At this lapse-time range, the envelope amplitude decays exponentially according to the functional form of the radiative transfer equation. The envelope amplitude increases as the dominant frequency decreases because the lower frequency energy is effectively excited for larger earthquakes and the attenuation of coda wave is slower at lower frequencies. On the other hand, the energy excited by early aftershocks becomes dominant after 30-100 s after the mainshock. At these later times, the envelope amplitude decays as a power-law due to the functional form of the Omori-Utsu law. Since smaller aftershocks occur more often than larger ones according to the Gutenberg-Richter law, the amount of the higher frequency component of the seismogram envelope with respect to the lower frequency counterpart increases at later times. These theoretical characteristics are confirmed by the analysis of the continuous waveforms of the 2008 Mw6.9 Iwate-Miyagi earthquake and its early aftershocks recorded by Hi-net stations.

Keywords: early aftershocks, seismogram envelope, high frequency, coda wave, Omori-Utsu law, Gutenberg-Richter law