Active monitoring of upper crust using ACROSS-seismic array system

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Temporal variations of S- and surface-wave travel times were continuously monitored using ACROSS source and seismic array. We made an experiment lasting 5 months at a site near the Nojima fault which ruptured during the 1995 Kobe earthquake (M7.2). Elastic waves generated by ACROSS vibrators are received by two seismic arrays. One is located at about 293m northwest and the other is about 290m southwest of the vibrators. Each array consists of ten seismometers that are three component velocity sensors with natural frequency of 4.5Hz. In this experiment, we used solar-battery systems to enable the long-term experiment, and we succeeded in continuous data recording without any trouble.

To obtain the signal in time domain, in which P, S and some later phases were included, we executed the following procedure in the frequency domain. We extracted the ACROSS signals from the every stacked data. The extracted signal was divided by the force generated by the source. In this study, we used the spectrum of the theoretical force calculated from the frequency-modulated rotation. We regarded the result as a transfer function (or band-limited impulse response) between the source and the receivers. Applying appropriate window function and inverse Fourier transformation, we could obtain S wave and big surface wave.

We calculated cross-spectral densities (CSD) among the traces on the section including S or surface waves and detected travel time variation of a few milliseconds such as big delay by the rainfall and its gradual recover and daily variations that correlate well to atmospheric temperature. However, the near-source variations are very similar to the travel times variations observed at the N-array sensor. To remove the effect of near-source region, we tried to apply the record of near-source seismometer as the source function. Then, especially for the S wave, the fluctuation of variation was drastically reduced within 1ms. For the surface wave, although the delay by the rain still existed, the daily variations were reduced.

For this experiment period, water injection was conducted twice in the same site. However, we could not detect a travel time variation caused by the injected water.

On the other hand, to emphasize later part of ACROSS signal, we stacked the data of all N-array sensors for every one hour and transformed its envelope using Hilbert transform. We may detect some wave in phase around 8, 13,16-second in the envelope. As random noise or coherent noise or signal appears in the later part of envelope, we examined these possibilities one by one. Then, we figured out that coherent noise appeared in the later part of the envelope and its amplitude was three orders of magnitude smaller than the maximum amplitude. Additionally, we figured out that the amplitude may be indicator of an appropriate source function. The uncertainty of the source function used this study was about 1 percent.