Japan Geoscience Union Meeting 2012
(May 20-25 2012 at Makuhari, Chiba, Japan)

SSS27-15 Room:103 Time:May 23 14:30-14:45

Temporal change in shallow subsurface structure detected by coda wave interferometry

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Understanding of shallow subsurface structure is important for prediction of earthquake strong motion, elucidation of transport process of underground water, and so on. On the other hand, recent progress in theoretical and observational researches on seismic interferometry reveal the possibility to detect subtle ($<$ 1%) change in subsurface seismic velocity. This high sensitivity of seismic interferometry to the medium properties may thus one of the important ways to directly observe the time-lapse behavior of shallow crustal structure. In this presentation, we report the long-term variation of subsurface velocity and co-/post-seismic change associated with the 2011 off the Pacific coast of Tohoku earthquake revealed by applying the coda wave interferometry to the NIED KiK-net data.

In this study, we use the acceleration data recorded at KiK-net stations operated by the National Research Institute for Earth Science and Disaster Prevention (NIED). Each KiK-net station has a borehole whose typical depth is about 100m, and two three-component accelerometers are installed at the top and bottom of the borehole. To estimate the very shallow subsurface velocity between two sensors and its temporal change, we apply the coda wave interferometry (e.g., Schuster et al., 2004). Although, recently, Nakata and Snieder (2012) apply the deconvolution method to KiK-net data, in this study, we adopt cross-correlation method to obtain stable results. In the data processing, we select 1005 earthquakes that occurred between January 2004 and December 2011, and compute the cross-correlation function between surface and downhole records using five 2sec-long successive time windows starting from twice the S-wave travel time for each earthquake. Because the seismic coda wave, which appears after the body wave arrivals, are considered to be composed of multiply-scattered waves, the ensemble average of cross-correlation functions can be regarded as the Green function between two sensors. From the averaged cross-correlation functions, we estimated the near-surface velocity at frequency bands of 2-4, 4-8, 8-16Hz, and we also measure the temporal velocity change using time-stretching method.

Each obtained averaged cross-correlation function shows a clear wave packet traveling between borehole sensors, and its travel time is almost consistent with that of S-wave calculated from the borehole log data. During the period we analyze, two remarkable temporal variations are observed in the averaged cross-correlation functions: One is the co-/post-seismic change associated with large earth-quake, especially the 2011 off the Pacific coast of Tohoku earthquake occurred in March 2011, and another is seasonal/annual variation. It has been widely known that the strong motion due to large earthquakes causes rapid decrease and long-term recovery of shear wave velocity (e.g., Sawazaki et al., 2009). Our results also show the similar behavior with sudden velocity decrease of typically about 5-15% and gradual recovery which still continues at the end of 2011. In contrast, the observed seasonal/annual variation is about one order of magnitude smaller than the co-/post seismic change. Obtained near-surface velocity is smallest in the summer season, and the fraction of velocity change shows negative correlation to the precipitation, which is indicative of the effect of underground-level and corresponding change of effective pore-pressure at the shallow subsurface. These results demonstrate that the seismic interferometry is a useful tool to monitor shallow subsurface structure.

Acknowledgment: We used KiK-net data provided by the National Research Institute for Earth Science and Disaster Prevention.

Keywords: Seismic interferometry, Shallow subsurface structure, Temporal change