GNSS observation around the shear zone in southern Kyushu (Follow-up report)

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To estimate crustal deformation around an active shear zone in southern Kyushu, we established a GNSS dense observation network composed by 10 sites and started observation during the period of February to March in 2016. We installed observation instrument on the roof of existing facilities and collected GNSS data of interval of 30 seconds using dual frequency receivers. Bernese GNSS Software (ver.5.2) was used for data processing together with IGS (International GNSS Service) precise ephemerides, earth rotation parameters, CODE (Center for Orbit Determination in Europe) global ionosphere model, and P1-C1 differential code biases. We fixed 4 GEONET sites operated by Geospatial Information Authority of Japan (GSI) as reference points and estimated daily coordinate solutions. However, the 2016 Kumamoto earthquakes occurred about 1-2 months after the beginning of our observation. The coordinate time series of our sites located more than 60 km away from the earthquake source region also recorded a co-seismic step and a subsequent post-seismic transient behavior. Therefore, precisely estimating and removing the post-seismic deformation caused by the earthquakes are required to clarify the steady crustal deformation around the active shear zone.

At first, common mode bias included in the coordinate time series during the observation period (March 20, 2016 - September 30, 2017) was removed. The variation of daily coordinate was reduced to 4.7-7.3 mm from 7.3-9.6 mm for the horizontal component and to 1.2-4.2 mm from 2.1-4.9 mm for the vertical component. After removing common mode biases, annual and semi-annual variations were estimated. Then, we extracted site velocities. While, the visco-elastic deformation of the earthquakes extends to the wide area of Kyushu district (Sutio, 2017), we estimated the deformation using a calculation cord of Fukahata and Matsu' ura (2006). We applied the faults model of the 2016 Kumamoto earthquakes (GSI, 2016) and calculated the temporal behavior of visco-elastic deformation. In this analysis, the post-seismic deformation was calculated in an elastic surface layer with thickness of 25 km overlying a Maxwell visco-elastic half-space with viscosity of $2x10^{18}$ Pa.s, according to Suito (2017). Moreover, because southern GNSS sites of our observation network are located in the western area of Sakurajima, we calculated volcanic deformation due to the volume change of two magma sources under the Aira Caldera using Mogi model.

Savage and Burford (1973) proposed a model for fault movement of a vertical strike-slip fault in a homogenous elastic half-space. This explained that the fault is locked from the surface to a certain depth and is sliding at a constant velocity, which is relative block motion below the locking depth. In this case, surface velocity perpendicular to the fault strike is expressed as a function of arctangent across the fault. Comparing with the velocity profile normal to the shear zone before the 2016 Kumamoto earthquakes, the profile after the earthquakes is well agreed with one before the earthquakes by applying the above mentioned model. This result shows that a steady state deformation at the shear zone continues after the earthquakes. Angela and Sagiya (2016) investigated strain rate in central-northeastern Japan based on GPS data before and after the 2011 Tohoku earthquake and observed inelastic deformation associated with E-W shortening, which is independent of large earthquakes continues throughout the whole time periods. Our result also suggests that a similar phenomenon as shown by them occurs beneath a deep region of the active shear zone.

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