Separation of Plastic, Viscous, and Elastic Strains From Observed GNSS Data in the Niigata-Kobe Tectonic Zone

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We generally consider the following three mechanisms for crustal deformation: elastic, viscous, and plastic deformation. The viscous deformation and the plastic deformation are collectively called inelastic deformation. Geodetic data, which measure crustal deformation, include the deformation due to all these three mechanisms, and the separation to each component has been a challenging problem.

In a simple form, this problem arises in the analysis of crustal deformation after a large earthquake, or more generally, during an earthquake cycle. Fukahata et al. (2004, GJI) developed an inversion method to separately estimate elastic deformation due to slip on the plate interface and viscous deformation due to the viscoelastic relaxation during an earthquake cycle. Yamagiwa et al. (2015, GRL) applied the method to GNSS data associated with the co- and post-seismic deformation of the 2011 Tohoku-oki earthquake. The separation of these components in general form has been more difficult. However, Noda and Matsu'ura (2010, GJI) developed a formulation to separately estimate elastic deformation and inelastic deformation from observed geodetic data. Recently, from the comparison of GNSS data in the northern NKTZ before and after the 2011 Tohoku-oki earthquake, Meneses-Gutierrez and Sagiya (2016, EPSL) have successfully separated inelastic deformation from observed geodetic data. The strain-rate paradox of Japan (Ikeda 1996, Active Fault Res), the geodetically estimated east-west contraction rate is nearly one order faster than the geological one, is also strongly related to this separation problem, because the geodetic data include deformation of all the mechanisms, while the geologically estimated contraction rate only reflects inelastic deformation.

In this study, we succeed in separating plastic deformation as well as viscous deformation in the northern NKTZ using GNSS data before and after the 2011 Tohoku-oki earthquake, under the assumptions that elastic deformation is principally caused by the plate coupling along the Japan trench and that plastic deformation ceased after the Tohoku-oki earthquake due to the stress drop caused by the earthquake. The cessation of plastic deformation can be understood with the concept of stress shadow used in the field of seismic activity. The separated strain rates are about 30 nanostrain/yr both for the plastic deformation in the preseismic period and for the viscous deformation in both the pre- and post-seismic periods, which means that the inelastic strain rate in the northern NKTZ is about 60 and 30 nanostrain/yr in the pre- and post-seismic periods, respectively. This result requires the revision of the strain rate paradox in Japan. The strain rate was exceptionally faster before the Tohoku-oki earthquake due to the effect of plastic strain, and the discrepancy between the geodetic and geologic strain rates is much smaller in usual time, when the plastic strain is off. In oder to estimate the onset timing of plastic deformation, the information on stress history is essentially important.

Keywords: plastic strain, inelastic strain, Niigata-Kobe Tectonic Zone, CFF, strain-rate paradox, Tohoku-oki earthquake

