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Viscoelastic effects on stress on the active faults around the Tokyo metropolitan area after the 2011 Tohoku earthquake

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Beneath the Japan islands, the Pacific plate descends from the east and the Philippine sea plate descends from the south, causing interaction of two slabs at depth. The 2011 M9 Tohoku earthquake in northern Japan had a source region with a length of ˜500 km and a width of ˜200 km and forced broad lithospheric and mantle regions to deform. In addition, seismicity rates in the surrounding regions drastically increased. As the effect of the Tohoku earthquake on crustal deformation and seismicity in the Japan region is so large, it is required to quantitatively evaluate the temporal change of stress due to this earthquake. On the other hand, the mechanism of postseismic deformation is considered to be afterslip around the source region, viscoelastic stress relaxation in the asthenosphere and so on. Here, we investigate the effects of slab geometry and 3D heterogeneity on the inversion of inferred coseismic slip, the resulting broad coseismic deformation and the propagation of stress throughout the region.

We construct a 3-D finite element model (FEM) to generate Green functions for use in a coseismic inversion study that allows the influence of complex slab geometry as well as heterogeneities in elastic structure on inferred slip. We utilize the large, land-based Japan GPS array as well as seafloor geodetic constraints in the inversion. We are particularly interested in how coseismic seafloor constraints influence inversion results. Our FEM considers a region of 4500 km x 4900 km x 670 km, incorporating the Pacific and the Philippine sea slabs by interpolating models for the Tohoku region and the Nankai trough, as well as the Kuril, Ryukyu and Izu-Bonin arcs. As the geometry of the plate boundaries, we used the model interpolating the existing local plate boundary models. As the crustal thickness, we simply take the uniform value of 30 km for the continental plate and 6 km for oceanic plates. For the underlying mantle, we give the elastic constants according to the PREM model. The slabs are assumed to have 5 % higher P- and S-wave velocity than the surrounding mantle. The model region is divided into about 500,000 tetrahedral elements with average dimension ranging from 5-100 km. We also test the role of gravity on coseismic results, with initial results suggesting that gravitational loading is not an important factor because of the shallow dip of the upper Pacific slab. Based on the coseismic slip obtained by the inversion, we computed the temporal change of the Coulomb failure stress change on the active faults in the Tokyo metropolitan area considering viscoelastic relaxation in the asthenosphere. Our long-term objective is to study the influence of the Tohoku earthquake on evolution of stresses throughout Japan due to both coseismic and postseismic processes, the latter including afterslip and viscoelastic relaxation. An accurate accounting of coseismic slip is very important to such an endeavor.

Keywords: 2011 Tohoku earthquake, Coulomb failure stress change, Crustal structure, Active fault, Finite element modeling, Viscoelasticity