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Effects of seismic velocity anomaly zone below Northeast Japan on displacement of the 2011 Tohoku earthquake

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2011 M9 Tohoku earthquake, Japan, has the 500-km long and 200-km wide source region and large deformation was observed over the Japanese islands. Japan is deployed with dense GPS observation network. Analyzing the spatial features of the crustal deformation data, we can obtain not only information of the source of the Tohoku earthquake but also that of crustal structure. The Northeast Japan arc is formed by the subduction of the Pacific plate below the Eurasian plate. The volcanic front is located along the Ou Range. Studies of seismic tomography has revealed low velocity region below the volcanic front due to the intrusion of hot materials and high velocity region below the Pacific coast due to crustal thinning and ascending of mantle materials. In this study, we construct a finite element model incorporating 3-D crustal structures and examine the effect of crustal heterogeneity on the surface deformation using slip distribution obtained from inversion of the surface displacements due to the Tohoku earthquake. We utilize the large, land-based Japan GPS array as well as seafloor geodetic constraints in the inversion. 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. 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. As for the elastic structure, we used PREM model. To represent high and low velocity zone under the Pacific coast and volcanic front, respectively, we introduced 80-km thick region in the model. We also computed with the associated layered structure model to check the effect of crustal heterogeneity. We obtained almost the same slip distribution for both the layered and crustal heterogeneity models, indicating that the deviation of the displacement due to crustal heterogeneity from layered model does not affect slip inversion. Using these results, we calculated surface deformation for models. We compared the two results by patterns of residual displacements, which is obtained by subtracting computed displacements from observed displacements. In the case of layered model, most of Northeast Japan shows eastward residual vectors and the westward vectors can be found along the Pacific coast. These residuals are diminished in the crustal heterogeneity model, so this model better explains the observation. In this way, we can extract information of detailed elastic structure by using broad surface deformation field data. This will allow us to calculate more realistic stress state in the crust.

Keywords: 2011 Tohoku Earthquake, Crustal deformation, Finite element modeling, Seismic velocity structure, Northeast Japan arc, Active fault