Crustal deformation and stress accumulation on source faults around Hokkaido, Japan, due to coupling at the Kuril trench

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2018 Mw6.7 Hokkaido-Iburi earthquake, Japan, brought about disastrous landslides near epicenter, and a power blackout on the whole Hokkaido island. In order to assess activity of such an intra-plate earthquake, we need to know not only the geometry of local source faults but also stress on them. The geometry model for the source faults over Japan was already published by the Headquarters for Earthquake Research Promotion of the Japanese government. We are now revising the model and adding new source faults in the offshore areas. Stress in the plate interior is essentially formed due to the interplate interaction at plate boundaries. The Kuril trench near Hokkaido has hosted a massive megathrust rupture. GPS observation shows widespread locking region southeast off Hokkaido. Similarities to the preseismic state around the 2011 Mw9.0 Tohoku-oki earthquakes along the Japan trench are pointed out such as decades of subsidence along the southeast Hokkaido and decrease in seismicity in recent years in this region. In order to quantitatively estimate the effect of these plate boundary process, we construct a finite element model (FEM) to estimate regional deformation and stress accumulation rate on source fault around Hokkaido due to the locking along the Kuril trench.

Our model contains the region of 3700 km x 4600 km including the Kuril–Japan trench. The bottom of the model is taken at the depth of 700 km to consider the whole upper mantle. The geometries of the Pacific and Philippine sea slabs under the Northeast Japan –Izu Bonin arcs, and the Southwest Japan –Ryukyu arcs, respectively, are incorporated following the previous studies. The model region is divided into 1000,000 tetrahedral elements. The size of the elements is set 5 km around the slip region and gradually larger close to the boundaries. Fault slip can be modeled by giving constraint equation of displacement discontinuity. Slip region is taken on the upper surface of the Pacific plate shallower than the depth of 80 km. We simply set the Pacific and Philippine sea slabs as the 70-km thick elastic plates over viscoelastic asthenosphere. The continental side is assumed to be elastic-viscoelastic stratified structure. Elastic thickness is tested for the case of 30 and 50 km. Since the interseismic deformation includes the effect of the concurrent viscous relaxation in the asthenosphere, we used response after complete relaxation.

In order to understand the basic feature of crustal deformation around Hokkaido, we compute response to locking of two offshore regions inferred from the past earthquake occurrence: Tokachi and Nemuro. Crustal deformation in Hokkaido obtained from GPS observation shows ~5 cm/yr northwestward movements on the Southeast coast, which decay toward the North and West, except the effect of the 2003 Mw8.0 Tokachi-oki and 2011 Mw9.0 Tohoku-oki earthquakes. This basic feature can be realized in the case of elastic thickness of 50 km and locking rate of 4 cm/yr in Tokachi and 8 cm/yr in Nemuro, respectively. These locking rates form compressive stress fields over the Hokkaido region. The compressive axes are NW-SE in the eastern Hokkaido and E-W in the western Hokkaido. The calculated stress field in the western Hokkaido is consistent with the occurrence of the 2018 Hokkaido-Iburi earthquake. In this study, we also apply the calculated stress field to source fault model around Hokkaido and calculate Coulomb stress to examine the earthquake activities.

Keywords: Kuril trench, Crustal deformation, Finite element method, Viscoelasticity, Coulomb stress

