Postseismic effects of viscoelastic relaxation and afterslip following the 2011 Tohoku-oki earthquake, Japan, on the 2016 Fukushima-oki and North Ibaraki Earthquakes

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In 2016, two earthquakes of normal fault type occurred: Mw7.0 Fukushima-oki earthquake on November 22th and Mw5.9 North Ibaraki earthquake on December 28th, which appear to be affected by the 2011 Tohoku-oki earthquake. What is the mechanism of these earthquakes to take five years to occur after the Tohoku-oki earthquake? Investigation of the mechanism is also important for the prediction of the future seismic activity. Our previous study on postseismic deformation using finite element model revealed viscosity structure beneath the Japanese islands and 3-year cumulative afterslip distribution, which enable to evaluate regional stress change.
First, we calculated temporal change in stress field due to viscoelastic relaxation in the asthenosphere after the Tohoku-oki earthquake. Results showed area of shear stress increase broaden with time. At the hypocenter of the North Ibaraki earthquake, shear stress increased 0.2 MPa in five years. On the other hand, shear stress did not change at the Fukushima-oki earthquake, which is located closer to the Tohoku earthquake. Elastic response to three-year cumulative afterslip is also calculated. We observed 0.4 MPa increase at the Fukushima-oki earthquake, and 0.2 MPa at the North Ibaraki earthquake.
Next, we calculated Coulomb stress change on each fault plane. Fault parameters (strike, dip, rake) are taken from Hi-net mechanism solutions and selected the nodal plane consistent with aftershock distribution. In the case of Fukushima-oki earthquake, we assumed strike = 52.1˚, dip = 37.6˚, and rake = -86.5˚, and in the case of North Ibaraki earthquake, strike = 317.3˚, dip = 31.4˚, and rake = -118.8˚. Just after the 2011 Tohoku-oki earthquake, Coulomb stress on both fault planes was calculated positive. However, earthquakes did not occur at this time, which implies that more stress was needed. The five-year viscoelastic effects brought about Coulomb stress decrease of 0.16 MPa at the fukushima-oki earthquake and increase of 0.11 MPa at the North Ibaraki earthquake. On the other hand, calculation of elastic response to three-year cumulative afterslip showed the Coulomb stress increase of 0.29 MPa at the Fukushima-oki earthquake, and increase of 0.15 MPa at the North Ibaraki earthquake. In general, afterslip continues with gradual decay. If we assume no significant change in spatial pattern of the afterslip, Coulomb stress will increase a little further at five years.
Sum of the viscoelastic and afterslip effects on Coulomb stress change is 0.13 MPa at the Fukushima-oki earthquake and 0.26 MPa at the North Ibaraki earthquake. These results mean that postseismic stress loading was added to the coseismic stress to contribute to the earthquake generation. However, the driving mechanism is different between the two earthquakes: the primary role was played by the afterslip in the case of Fukushima-oki earthquake, while viscoelastic relaxation and afterslip equally contributed to the North Ibaraki earthquake.

Keywords: 2011 Tohoku earthquake, Finite element modeling, Viscoelasticity, Afterslip, Coulomb stress

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