Modeling absolute stress in the Northeast Japan island arc and stress change caused by the 2011 Tohoku earthquake

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Many studies have attempted to know the absolute magnitude of the crustal differential stress and the strength of crustal faults and/or subduction plate interface, and they are still controversial (e.g., Scholz, 2000; Gao and Wang, 2014). Significant stress change (stress rotation) in the fore-arc region in the hanging-wall between before and after the 2011 Tohoku earthquake (M_W9) was observed (e.g., Hasegawa *et al.*, 2012). This phenomenon can be used to constrain the absolute magnitude of the crustal differential stress and the frictional strength of the subduction plate interface. The origin of the lithospheric stress in the subduction hanging-wall is roughly classified into two sources: (1) the mechanical interaction on the plate interface (e.g., friction working on the plate interface) and (2) the gravity effect due to topography and density structure. Therefore, modeling absolute stress considering the gravity as a body force is necessary to access this problem.

This study modeled the absolute stress in the two-dimensional arc-trench cross section of the Northeast Japan (NEJP) island arc caused by the plate subduction and the gravity effect. We modeled it using finite element method (Shibazaki *et al.*, 2007) considering the gravity as a body force and visco-elasto-plasticity to represent ductile and brittle behavior in the crust, mantle, and plate interface. We modeled the stress states due to the steady state plate subduction and the stress changes caused by the interseismic coupling and the coseismic slip of the 2011 Tohoku earthquake. We tested many combinations of the crustal fault strength and the fault strength of the subduction plate interface to constrain the absolute magnitude of the crustal stress and the strength of the subduction plate interface.

The modeling results indicated that the overall crustal strength in the hanging-wall should be at least one order of magnitude stronger than the fault strength of the subduction plate interface otherwise unrealistically large contraction occurred in the hanging-wall caused by the plate subduction.

The model with an effective frictional coefficient μ_{eff}=0.01 on the subduction plate interface produced weak arc-perpendicular extensional stress state in the fore-arc region under the sea because the extensional stress caused by the gravity effect slightly overcame the compressional stress caused by the friction on the plate interface, while arc-perpendicular compressional stress in the inland region was produced due to the dominance of the plate subduction effect. The interplate coupling during 600 years changed the stress state in the deeper part (near the plate interface) of the fore-arc region under the sea to arc-perpendicular compression, which is consistent with the observed earthquakes occurred before the 2011 Tohoku earthquake (Hasegawa *et al.*, 2012). The coseismic slip of the 2011 Tohoku earthquake changed the stress state in this region to arc-perpendicular extension again. To explain the arc-perpendicular extensional stress state in the fore-arc region under the sea observed after the 2011 Tohoku earthquake, the strength (shear stress) of the plate interface after the earthquake should be weaker than 5-15 MPa for 8-20 km depths and weaker than 15-30 MPa for 20-30 km depths, respectively (corresponding μ_{eff} is smaller than 0.02).

Keywords: Absolute stress in inland crust, Strength of inland crust, Fault strength of subduction plate interface, Stress change caused by the 2011 Tohoku earthquake, Finite element method