Poroelastic rebound following the 2011 Tohoku-oki earthquake (Mw=9.0) as deduced from geodetic data and its application to infer the Poisson's ratio

(測地データにより推定された 2011 年東北地方太平洋沖地震（Mw=9.0）に伴う間隙弾性反発とそのポアッソン比の推定への応用)

Hidayat Panuntun

京都大学理学研究科地球惑星科学専攻 2019 年 3 月学位授与

INTRODUCTION

Elastic properties of host rocks are one of the mechanical properties that control the response of a material to the applied stress. In the real Earth, direct observational constraints on the in situ mechanical properties of the rocks are limited. Advances in space geodetic technique have helped us to determine three dimensional positions with millimeter level of precision and have allowed us to depict small-scale surface deformation phenomena. Precise monitoring of crustal deformation, which reflects the response of the material of the crust to stress change due to such as an earthquake, then may serve as a natural laboratory for geoscientists to probe the Earth crust mechanical properties and improve our understanding of the postseismic deformation phenomena.

The availability of both spatial and temporal dense geodetic observations makes the 2011 Tohoku-oki earthquake as one of the best recorded events in the modern era of space geodetic observations. Several studies [e.g., *Evans and Meade*, 2012; *Ozawa et al.*, 2011; *Silverii et al.*, 2014] concluded that early phase of transient deformation (up to ~140 days following the mainshock) is well described solely by afterslip. Since viscoelastic relaxation tend to be another major contribution, especially in case of earthquake with magnitude larger than 7.5, *Diao et al.* [2013], *Shirzaei et al.* [2014], *Yamagiwa et al.* [2015], and *Freed et al.* [2017] modeled the postseismic deformation of the 2011 Tohoku-oki earthquake by combination of afterslip and viscoelastic relaxation. Poroelastic rebound, as another proposed postseismic deformation mechanism, has never been properly investigated by most of previous Tohoku-oki earthquake studies.

METHOD

Incorporating poroelastic rebound in postseismic deformation analysis arises one critical question; what is the appropriate set of Poisson's ratios should be used for poroelastic rebound modeling? Here we constructed analysis strategy to infer appropriate value of undrained and drained Poisson's ratios. Grid search approach was used to find the optimum rheological and mechanical properties that that fit best to the data. In this case, we use observed geodetic data (GEONET and GPS/A) 140 days after the mainshock from 12 March 2011 to 30 July 2011. By using this method, we can investigate the contribution of afterslip, viscoelastic relaxation, and poroelastic rebound more quantitatively. We also estimated pore-pressure relaxation and compared it with the observed groundwater level to probe the relaxation time of poroelastic rebound.

RESULT AND DISCUSSION

We showed that 0.34 and 0.25 are the statistically optimal undrained and drained Poisson's ratios, respectively and produced sensible contribution of poroelastic rebound to the postseismic deformation. Although afterslip played dominant role in the early phase of postseismic deformation, poroelastic rebound is considered to generate a few to ten centimeters of displacements. Poroelastic rebound has larger contribution at near-field GPS stations, and more significant contribution to the vertical component rather than horizontal component. Estimated Poisson's ratios are consistent with those of previous studies in the point that estimated undrained Poisson's ratio are about ~1.4 times larger than drained Poisson's ratio. The maximum surface displacement due to the poroelastic rebound with estimated Poisson's ratios is as large as ~36 cm horizontally and ~21 cm vertically and is found in the vicinity of the rupture area. We concluded that geodetic data are capable of inferring the first order approximations of the Poisson's ratios of poroelastic rebound.

Barometric disturbances, meteorological effects (e.g., precipitation), and crustal deformation can generate variation in the observed groundwater level. We show that groundwater level was not well correlated either with barometric disturbances or precipitation. Because the maximum coseismic pore-pressure change in this study (~10 MPa) is exceeding the minimum threshold (10 KPa [e.g., *Toda et al.*, 1998]), it is possible that pore-pressure change due to the earthquake play major role in the groundwater level variations. The inferred pore-pressure relaxation is consistent with observed groundwater level for 140 days following the mainshock. If the occurrence of poroelastic rebound physically depend only on the fluid flow and pore-pressure relaxation, it implied that the resulting poroelastic rebound had lasted at least throughout this period.

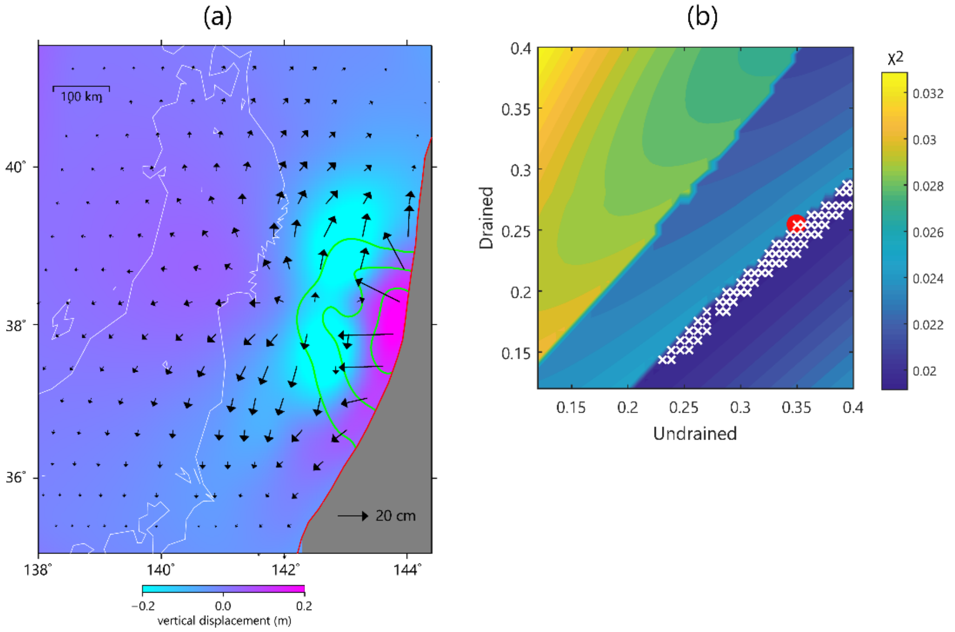

Figure 1. Predicted poroelastic rebound using optimal Poisson's ratios. (a) Predicted horizontal (arrows) and vertical (color image) displacements of poroelastic rebound. The green contour shows coseismic slip at 15 m intervals. The red line shows the Japan Trench. (b) Optimal undrained and drained Poisson's ratios from grid-search calculation. The χ^2-values are shown by a colored scale. The red circle indicates the optimum values of the undrained and drained Poisson's ratios. White crosses show acceptable combinations of undrained and drained Poisson's ratios based on a chi-square test for a confidence interval of 60%.