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Crustal Deformation Analysis Method with High-fidelity 3D Model and Application to Estimation of Coseismic Slip

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Coseismic slip distribution is estimated by combining crustal deformation analysis in a large scale with the detailed data of the crust and the observation data of crustal deformation. Observation data with high accuracy have been accumulated, not only on the ground (e.g. GEONET: operated by GSI) but also on the seafloor (e.g. DONET: operated by JAMSTEC). In addition, geometry and material data in 1km grid of the crustal structure of the Japanese islands have been developed. However, in spite of the detailed crustal data, crustal deformation analyses have been performed by using simplified crustal structure model like homogeneous half-space. Therefore in this research, by using accumulated data and the technique of high performance computing, we developed a method for generating a high-fidelity 3D finite element (FE) model of crustal structure. A method for crustal deformation analyses with the generated model is also proposed. Then an application of the proposed method to estimation of coseismic slip distribution is shown.

We use FE analysis because it has an advantage in analyzing complex geometry of crustal structure. Assuming crustal structure to be a linear elastic body, we perform static analysis of coseismic crustal deformation due to fault dislocation. For high-fidelity 3D FE model generation, we developed an automatic FE model generation method using background grids by extending the method of (Ichimura et al. 2009). Tetrahedral elements are used near the surfaces to represent the geometries of the crust well, while voxel elements are used in the homogeneous areas, in order to achieve a good balance between reduction of the number of elements and reproduction of the geometry. Our method is verified by comparing the results with the analytical solution in a half-space (Okada, 1985).

To perform this computation fast using an FE model with large degree-of-freedom (DOF), firstly we solved the problem by CG method with a simple preconditioning, parallelizing it by OpenMP. However, this computation took a long time, so we improved the method by introducing adaptive preconditioner and single precision arithmetic. As a result, the computation time is significantly reduced.

As an application example, we estimated coseismic slip distribution in the 2011 Tohoku earthquake using Northeast Japan models. The models are generated by the proposed method, and their DOF are more than 150 million. We applied the estimation method used in (Sato et al. 2010). In comparison of estimation results using our high-fidelity model and conventional homogeneous half-space, significant difference could be seen in the estimation results.

As future work, ambiguity of the geometry and material properties of the crust should be taken into consideration.

Keywords: Inversion analysis of coseismic slip, High-fidelity 3D Crustal Structure Model, Crustal Deformation Analysis