Japan Geoscience Union Meeting 2012
(May 20-25 2012 at Makuhari, Chiba, Japan)
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HDS26-P09 Room:Convention Hall Time:May 21 17:15-18:30

3-D simulations of tsunami generation using an unstructured mesh FEM: investigation of the 2011 Tohoku-Oki Earthquake

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For a detailed investigation of tsunami generation processes caused by fault motion in a large earthquake, a three-dimensional tsunami generation and propagation simulation approach using an unstructured mesh finite element method is proposed. The present method is applied to the 2011 off the Pacific coast of Tohoku Earthquake (M9.0) and the validity of the method is tested.

In simulations of tsunamis resulting from earthquakes, the sea bottom deformation is calculated from faulting parameters, using for example the equations of Okada (1985), and the free surface deformation is often assumed to equal this. However, this assumption is not always true. When the timescales for the bottom deformation are large, when the horizontal spatial scales of the deformation are small, or when the water depth is large, the free surface deformation tends to be smaller than the bottom deformation. For example, Saito and Furumura (2009) quantitatively evaluated this 'filtering' effect. One of their conclusions was that the filtering effect is important when the horizontal scale of the deformation is smaller than ten times the water depth, in the case of a short deformation timescale.

In the 2011 Tohoku Earthquake, it is indicated that a large slip in a shallow part of the crust caused short wavelength tsunami waves (e.g. Fujii et al., 2011; Maeda et al., 2011). To properly deal with this kind of short wavelength initial water height distribution, it is necessary to take account of the difference between the bottom and free surface deformations induced by the filtering effect.

An analytical solution based upon an approximation is sometimes used to calculate the free surface deformation from the bottom deformation to take into account the filtering effect (e.g. Takahashi, 1942; Kajiura, 1963). The effect can be modeled realistically by solving the full 3-D equations without any approximation (e.g. Takahashi and Furumura, 2009). However, the computational cost of solving the 3-D equations in a wide source region like the 2011 Tohoku earthquake is very large. Therefore, in this study, the 3-D incompressible Navier-Stokes equations are solved using an unstructured mesh finite element method, which can efficiently refine the mesh and hence position computational degrees of freedom at points to maximize accuracy and minimize computational expense. The unstructured mesh also enables accurate reproduction of the complex bathymetry near the trench. In the simulations, the bottom deformation is imposed as an inflow boundary condition for velocity, which is caused by the movement of the sea water just above the sea bottom (Saito and Furumura, 2009). In the vertical direction, the nodes should be placed so that the sea bottom boundary layer and the vertical velocity and pressure profiles are efficiently resolved.

In this presentation, a comparison between analytical solutions from linear potential theory and the simulation results, an application of the present method to the 2011 Tohoku earthquake generated tsunami, and the computational performance including the parallel efficiency will be reported.

Keywords: unstructured mesh, finite element method, tsunami, simulation, the 2011 off the Pacific coast of Tohoku Earthquake