A Unified Dynamic Numerical Simulation of Seismic, Ocean Acoustics, and Tsunami Waves

Maeda, T[(1)] and Furumura, T[(1)]

(1) Center for Integrated Disaster Information Research, The University of Tokyo , Tokyo, Japan
ph. +81-3-5841-1768 ; fax +81-3-5841-1768 ; email maeda@eri.u-tokyo.ac.jp

We propose a new unified approach for simultaneous simulation of ground motions, ocean acoustics, and tsunami based on a finite difference method (FDM) simulation of equation of motions. Recently developed ocean-bottom cabled tsunami sensors enable us to monitor tsunami waveform on real time. During large earthquakes, recordings of tsunami sensors shows very wide range of frequency signals including seismic waves, ocean acoustics, and tsunami waves, offering us important insights into the understanding of dynamics of the earthquake source in detail. However, most present numerical approach of seismic and tsunami waves are conducted separately and inconsistently using different models; firstly a permanent deformation of ocean bottom is estimated by seismic or geodetic model, and then the result is used as an initial condition of the tsunami model. In this study, we propose a unified approach to simulate ground motion, coseismic deformation, oceanic wave, and tsunami, simultaneously, based on the FDM calculation of equation of motions.

We consider here an elastic model with a water column embedded above the elastic material. The water column is treated as an elastic media with zero rigidity. Using staggered-grid FDM, we solve a linear equation of motion of elastic medium with gravity assuming hydrostatic equilibrium. Because of the existence of gravity, diagonal components of stress tensor in the water column consists of dynamic part and static part which corresponds to the propagation of ocean acoustic waves and isotropic pressure of water under the equilibrium. A nonlinear advection term in the equation of motion is not taking into accounted in the present simulation. Thus, care should be taken when simulating onshore tsunami. If we further assume a fluid incompressibility in the present model, the horizontal displacement of the water column in our scheme coincides with linear, long-wave tsunami equation that is widely used for present tsunami simulations.

Numerical synthesis of seismic wave and tsunami in the unified scheme requires a small time increment and a large number of time steps in the numerical integration in order to express wide frequency range of signals. Since the artificial reflection of seismic waves from model boundaries may affect slow tsunami waves, we used a perfectly matching layer to minimize the artificial reflection of elastic waves from model boundaries. We show here some examples of numerical simulation in 2D model in order to demonstrate the effectiveness of our model. Also note that an extension to 3D model and its parallel computing is straightforward. We set elastic half-space Poisson-solid model with an S-wave velocity of 4 km/s and mass density of 2.7 g/cm^3. Oceanic column has depth of 5000 m, and P-wave velocity is set 1.5 km/s and mass density of 1.0 g/cm^3. A double-couple point source with a thrusting mechanism is set at 4 km below ocean bottom. The results of simulation with snapshots of seismic wavefield and synthetic seismograms demonstrate the process in which elastic waves generated by the source are converted to ocean acoustic waves at the ocean bottom boundary. A permanent deformation due to the earthquake is also developed at the ocean bottom. Then, deformation of sea bottom and ocean acoustic waves due to the earthquake gradually push up sea surface. With the gravity and hydrostatic equilibrium, peak of sea surface elevation starts propagating bilaterally in horizontal directions, which forms tsunami waves. We compared synthesis of tsunami wave with that calculated by using the Navier-Stokes equation assuming an initial tsunami on the sea surface demonstrating an excellent agreement in terms of velocity, amplitude, and dispersion characteristics of tsunami at later lapse time. Also our simulation of elastic equation of motions can produce ocean acoustics and seismic waves with faster wave speed, although they are not simulated by the Navier-Stokes equations under the assumption of incompressibility. In this simulation, we succeeded in synthesizing dynamic process associated with the offshore earthquakes. As introducing more realistic, heterogeneous 3-D velocity structure and bathymetry model, we will then try to reproduce seismic, acoustic and tsunami waves to model observed complex ocean-bottom tsunami recordings.