Improvement of computational efficiency in 3D Finite-difference method using variable grid

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As a method of seismic wave simulation, the 3D finite-difference method has been widely used. As long as a uniform grid size is used in an entire computational region, the grid size is determined by the shortest wavelength in the computational region. Even if low velocity region occupies only a small part of the entire region, the same gird size for the low velocity region is also used in the other part of the computational region in which such a small grid size is not necessary. As the computational memory and time are roughly proportional to the cube and forth, respectively, of the inverse of grid size, using unnecessarily small grid size results in a waste of computational resources. Aoi & Fujiwara (1999) used fine grid near the surface where the velocity is low, and grids whose spacing is several times coarser in the deeper high velocity region. Then they connect these two regions with linear interpolation. They achieved a significant reduction of computational resources. Since they use the same time step in both fine and coarse regions, computational resources are still wasted to some extent. The author introduces a method in which different time steps can be used in the regions where grid sizes are different from region to region. By using this technique, a reduction in computational resources is further improved.

Aoi & Fujiwara divided an entire computational region into a shallow fine grid region and a deep coarse grid region. In this study, on the contrary, a fine grid region (Region-II) is embedded in a coarse grid region (Region-I) and the location and size of the Region-II are specified arbitrary. In each region, a displacement-stress type staggered grid formulation of 2nd-order accuracy both in space and time is used. A grid size for the Region-I is two times larger than that of fine grids. In order to connect these two regions by linear interpolation, pseudo-grids with the coarse grid size (pseudo-grid-I) are added one layer inside the boundary between regions-I and II. Pseudo-grids with the fine grid size (pseudo-grid-II) composed of two layers are also added outside the boundary. These pseudo-grids I and II are auxiliary used to compute displacements near the boundary between regions I and II. As a boundary condition at the outer-most part of the Region II, we adopted stress free condition. The computational procedure at each time step is shown bellow. Notice that the size of the grids in the Region-I is two times larger than that in Region-II and thus the necessary time increment in the Region-I is two times of that in the Region-II.

(1) At t = 2n*dt: Suppose that from t=0 to this time step, all the displacements in the Region-I, II and the pseudo-grid-II are computed.

(2) At t = (2n+1)*dt: Displacements in the Region-II and the pseudo-grid-II are computed. No displacement in the Region-I is calculated at this time step. This is the most important point of this study.

(3-1) At t = (2n+1)*dt: Displacements in the Region-II are computed. Although displacements in the pseudo-grids-II are affected by the stress-free boundary condition at the outermost grids of the pseudo-grids-II, any displacements in the Region-II are not affected. (3-2) Then, at the same time step, displacements in the pseudo-grids-I (coarse grid) are computed by an interpolation of the displacements in the Region-II. (3-3) At the same time step, displacements in the Region-I are computed. When displacements next to the boundary between regions I and II are computed, displacements in the pseudo-grids-I are used. (3-4) Finally at the same time step, displacements in the pseudo-grids-II are computed by the interpolation of displacements in the coarse grid Region-I which spatially overlap with the pseudo-grids-II. Following the procedure described above, all the displacements in the Region-I, II and the pseudo-grid-II at t = (2n+1)*dt are computed.

(4) Repeat steps (1) through (3-4).

Reference: Aoi & Fujiwara (1999), BSSA, 89, 918-930.