The increasing of computational efficiency of the finite-difference schemes for seismic wave propagation

Jozef Kristek, Peter Moczo, Martin Gális
Comenius University Bratislava [1]
Slovak Academy of Sciences [2]

A b s t r a c t: We have increased the computational efficiency of our finite-difference scheme by developing and implementing two essential features – a. PML, b. discontinuous spatial grid.

a. The PML may be split or unsplit, classical or convolutional, with the general or special form of the stretching factor. We show relations between different formulations of the PML with respect to their three key aspects.

We derived two variants of the split formulations for the general form of the stretching factor. The L-split variant has the stretching factor on the left-hand side of the equation of motion and constitutive law, the R-split variant on the right-hand side. Both variants naturally lead to convolutional formulations in case of the general form of the stretching factor. The L-split variant reduces to the well-known classical split formulation in case of the special form of the stretching factor. The R-split formulation remains convolutional even for the special form of the stretching factor.

The R-split formulation eventually leads to the equations identical with those obtained straightforwardly in the unsplit formulation.

We present a time discretization of the unsplit formulation which is a slightly algorithmically simpler alternative to the time discretization presented by Komatitsch and Martin (2007). The latter is shown in the form consistent with our discretization. We implemented the algorithm in our 3D velocity-stress staggered-grid finite-difference scheme. The interior grid is solved with the 4th-order whereas the PML with the 2nd-order scheme in space, both being the 2nd-order in time.

[1] Department of Astronomy, Physics of the Earth and Meteorology, Faculty of Mathematics, Physics and Informatics, Mlynská dolina F1, 842 48 Bratislava, Slovakia, kristek@fmph.uniba.sk, moczo@fmph.uniba.sk, martin.galis@fmph.uniba.sk

[2] Department of Seismology, Geophysical Institute, Dúbravská cesta, 845 28 Bratislava, Slovakia

b. We have developed an algorithm of the spatial discontinuous grid for the 3D 4th-order velocity-stress staggered-grid finite-difference modeling. The ratio between the grid spacings of the coarser and finer grids can be an arbitrary odd number. The key feature of the algorithm is the application of the Lanczos downsampling filter. The concept of the Lanczos downsampling filter is general and robust – its effect on the stability should not be dependent on a particular algorithm of the discontinuous grid.

The algorithm allows for large numbers of time levels without inaccuracy and possible eventual instability due to numerical noise that is generated at the contact of the two grids with different spatial grid spacings.

The algorithm of the discontinuous grid is directly applicable also to the displacement-stress staggered-grid finite-difference scheme.

We demonstrate the performance of the algorithm with the simulations of the wave propagation due to the single vertical force acting at the free surface of the homogeneous viscoelastic halfspace and with the simulations of the seismic motion in the structurally complex model of the Grenoble valley, France.

Key words: finite-difference method, PML, discontinuous spatial grid, computational seismology, theoretical seismology

References

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