Advanced Scientific Computing Research
Applied Mathematics
FY 2007 Accomplishment

Serpentine – Simulating seismic wave propagation in complex geometries

Anders Petersson [*], Lawrence Livermore National Laboratory
Bjorn Sjogreen, Lawrence Livermore National Laboratory
Daniel Appelo, Lawrence Livermore National Laboratory

Summary

This project develops and analyzes numerical methods for wave propagation in complex materials and geometries with applications to seismology, acoustics and electro-magnetics. Our focus is on efficient finite difference methods on regular Cartesian grids combined with embedded boundary technology to handle complex geometrical shapes.

Simulation of wave propagation phenomena is essential for the success of many DOE programs such as strong ground motion prediction for the Enhanced Test Site Readiness Program, the Yucca Mountain Program and the Global Nuclear Energy Partnership, underground explosion monitoring and underground facilities characterization. Simulating wave propagation is also important in non-destructive evaluation, with application to locating imperfections in National Ignition Facility optics. There are also future applications that could benefit from elastic wave simulations, such as sub-surface characterization for carbon sequestration via seismic reflection and geothermal energy applications.

During the past year, LLNL researchers developed mesh refinement capabilities for seismic wave propagation modeled by the three-dimensional elastic wave equation in domains with complex material properties. In seismic applications, the gains in computational efficiency from local mesh refinement can be tremendous. The wave propagation speeds are commonly the lowest in shallow sedimentary basins near the surface and become about eight times higher below the Mohorovičić (MoHo) discontinuity, which separates the earth’s crust and mantle. Because the wave length of seismic waves is proportional to the wave propagation speed, the computational mesh only needs to be fine in the sedimentary basins and can be coarsened as the wave speed increases away from the surface. Near the bottom of the computational domain (below the MoHo) the mesh can be eight times coarser in each direction, which leads to a substantial speedup and memory reduction if the mesh is refined locally. Computations on a layered model of the earth have been demonstrated to run 162 times faster when a locally refined mesh is used compared to the corresponding fixed fine mesh calculation. Such improvements can make desktop calculations possible for problems that previously required massively parallel machines, and can enable much more detailed simulations to be carried out on the highest end computers.

Apart from the compressional (P or primary) and shear (S or secondary) waves which

---

[*] (925) 424-3804, andersp@llnl.gov

travel through the earth, there are also surface (Rayleigh and Love) waves which travel along the topography (mountains and valleys) of the earth. Since the use of mesh refinement in our method dramatically improves the effective resolution of seismic simulations, advances in computing power will soon enable us to capture detailed topographic effects (visible at frequencies above 0.5 Hz). Significant effects due to topography can be observed at these frequencies, as shown in fig. 1. With resolution at frequencies exceeding 1 Hz, we can also start to perform studies relevant to predicting the safety of large structures such as nuclear power plants, tall buildings, bridges, dams and levees. However, these calculations will require the accurate geometric representation of the relevant topographical and other features, as well as proper representation of mathematical boundary conditions at the surfaces.

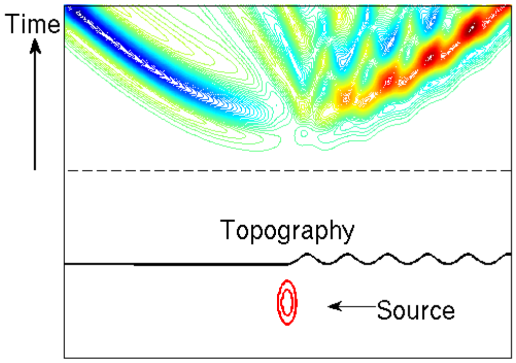

Figure 1: Vertical displacement along the surface due to an earthquake source. Note the secondary reflected waves due to the undulating surface on the right.

During the past year we developed accurate embedded boundary and overset grid techniques for satisfying the stress-free conditions along the surface of two-dimensional domains with complicated shapes and we are currently generalizing these techniques to three space dimensions. One major advantage of the embedded boundary technique is that the stress-free conditions at the boundary can accurately be satisfied without the need to construct a computational mesh which follows the boundary. The embedded boundary technique is therefore easier to automate to handle complicated geometries.

During next year we plan to extend our embedded boundary capability by satisfying jump conditions across material discontinuities such as the MoHo. In a more general form, jump conditions also govern the multi-physics coupling between solid and fluid at the bottom of an ocean, which enables an accurate study of low frequency noise traveling through the SOFAR channel in the ocean.

Apart from developing methods for seismic waves, the Serpentine project also applies its techniques for solving acoustic wave propagation with application to non-destructive evaluation as well as electro-magnetic wave propagation.

For further information on this subject contact:

Dr. Anil Deane, Program Manager
Mathematical, Information, and Computational Sciences Division
Office of Advanced Scientific Computing Research
Phone: (301) 903-1465
deane@mics.doe.gov