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Authors
Toomey, Aoife
Daley, Tom
Wang, Xiuming

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Modelling Borehole Wave Propagation using a 3D Variable-Grid Finite-Difference Scheme

Aoife Toomey[1], Tom Daley[1] & Xiuming Wang[2]
[1] Earth Science Division, Lawrence Berkeley National Laboratory
[2] CSIRO Petroleum, Australia

Generating accurate synthetic seismograms for wave propagation in a three-dimensional fluid-filled borehole is difficult using conventional uniform-grid finite-difference schemes. The low-velocity modes generated in the borehole require very fine sampling to avoid numerical dispersion. The need for accurate discretisation of the borehole and casing also calls for fine grid spacing. In uniform-grid finite-difference schemes this fine grid spacing must be used throughout the model, which restricts such models to small dimensions, unrealistic velocity structures, or long wavelengths due to computer memory limitations. Using a variable-grid finite-difference scheme improves computational efficiency by partially avoiding oversampling of the wavefield in high velocity materials. The grid spacing is tailored to the velocity model, allowing the use of fine grid spacing inside the borehole and coarser grid spacing in the rock formation. We have implemented the variable-grid scheme of Pitarka (1999) in a parallel, 3D anisotropic finite-difference code, allowing large models with complex velocity structure to be tackled.

First, the accuracy of this scheme for simple plane-layered geometries is verified by comparison with results obtained using the pseudo spectral method. The suitability of the scheme for acoustic logging problems is then assessed: finite-difference results for monopole and dipole sources in an open borehole are compared with analytical results obtained using the real axis integration method. Finally, the method is applied to an investigation of the modes generated in a borehole penetrating a fractured zone. Data from single well seismic surveys has suggested that this method holds promise for locating gas-filled fracture zones (Majer et al, 1997). Anomalous high amplitude reflections observed in CDP stacks of single-well data, but not on well logs, were found during subsequent drilling to coincide with the location of a vertical fracture at some distance from the well. We use the variable-grid finite-difference scheme to investigate whether a fractured zone may act as a type of low-velocity wave guide which traps energy, giving rise to high amplitude low-velocity arrivals which may be of use in detecting productive fracture zones.