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Elastic waveform modeling in frequency domain with an efficient MATLAB code

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Seismic waveform modeling is a key tool to estimate subsurface characteristics, not only for hydrocarbon explorations but also for proper managements of seismic hazards and civil engineering infrastructures. Modeling in frequency domain found to be effective for its numerous advantages compared to that in time domain. Once triangular factors of impedance matrix have been calculated, multiple sources can be processed with the minimum computational costs. Monochromatic and band limited modeling at desired frequencies are implemented in a straightforward manner and the attenuation behavior of elastic media can directly be dealt with considering complex valued elastic parameters. However, discretizing the computational domain requires more grid points to achieve acceptable accuracy and a program with robust algorithm is needed to minimize the modeling time and cost. We used 25-point finite difference stencils to discretize the elastic wave equation in frequency domain to develop an effective MATLAB package for elastic waveform modeling. By using array-processing abilities of MATLAB, we efficiently computed the large impedance matrix for realistic model sizes. In order to solve the system of equations impedance matrix is factorized to lower and upper triangular matrixes, then forward and backward substitution results in horizontal and vertical displacements. Since the impedance matrix has a band structure and very sparse pattern, using efficient ordering schemes to reduce fill-in during factorization is necessary. We used METIS library together with SuiteSparse library for sparse LU factorization. METIS uses a multilevel nested dissection algorithm to calculate a fill reducing ordering which brings a superior performance to the program. SuitSparse includes several factorization and solution modules, such as UMFPACK, SparseQR, and CHOLMOD, for sparse matrixes and linear system of equations. We used UMFPACK and SparseQR modules in our modeling code for problems with different sizes. Once the factors have been calculated, several seismic sources could be modeled by solving for multiple right hand sides. Reflections from truncated boundaries appear in the solution of the wave equation which must be suppressed by boundary conditions. In order to truncate the computational area we applied Perfectly Matched Layers (PML) on the boundaries. Complex valued velocities based on Kolsky-Futterman model were used to consider attenuation effects in the seismic waveforms. Marmousi2 example (Figure 1) confirmed the efficiency and accuracy of the MATLAB code. We have cropped the original model to focus on the more complex area in the center of the geological model; the final model in the example is 6600 m long and 3200 m deep. A snapshot of wave propagation and shot gathers of horizontal and vertical components of the displacement recorded at the surface are shown in the Figure 1. As is obvious in the horizontal displacement component, strong Rayleigh waves appear in the seismograms and travel near surface with low velocity. Based on the results of Marmousi2 example and several other models which have already tested the program, the developed MATLAB package can be used for fast and accurate elastic waveform modeling.

Keywords: seismic, waveform modeling, frequency domain, finite difference, perfectly matched layers