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Structure-preserving spectral element method in attenuating seismic wave modeling

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This work describes the extension of the conformal symplectic method to solve the damped acoustic wave equation and the elastic wave equations in the framework of the spectral element method. The conformal symplectic method is a variation of conventional symplectic methods to treat non-conservative time evolution problems which has superior behaviors in long-time stability and dissipation preservation. To construct the conformal symplectic method, we first reformulate the damped acoustic wave equation and the elastic wave equations in their equivalent conformal multi-symplectic structures, which naturally reveal the intrinsic properties of the original systems, especially, the dissipation laws. We thereafter separate each structures into a conservative Hamiltonian system and a purely dissipative ordinary differential equation system. Based on the splitting methodology, we solve the two subsystems respectively. The dissipative one is cheaply solved by its analytic solution. While for the conservative system, we combine a fourth-order symplectic Nyström method in time and the spectral element method in space to cover the circumstances in realistic geological structures involving complex free-surface topography. The Strang composition method is adopted thereby to concatenate the corresponding two parts of solutions and generate the completed numerical scheme, which is conformal symplectic and can therefore guarantee the numerical stability and dissipation preservation after a large time modeling. Additionally, a relative larger Courant number than that of the traditional Newmark scheme is found in the numerical experiments in conjunction with a spatial sampling of approximately 5 points per wavelength. A benchmark test for the damped acoustic wave equation validates the effectiveness of our proposed method in precisely capturing dissipation rate. The classical Lamb problem is used to demonstrate the ability of modeling Rayleigh-wave propagation. More comprehensive numerical experiments are presented to investigate the long-time simulation, low dispersion and energy conservation properties of the conformal symplectic method in both the attenuating homogeneous and heterogeneous mediums.