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GPU-based solution of Biot's elastodynamic equations to account for fluid pressure diffusion

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Elastodynamic hydro-mechanical coupling based on Biot's theory describes an upscaling of the fluid-solid deformation at a porous scale. Examples of applications of this theory are near surface geophysics, CO2 monitoring, induced seismicity, etc. The dynamic response of a coupled hydro-mechanical system can produce fast and slow compressional waves and shear waves. In many earth materials, a propagating slow wave degenerates into a slow diffusion mode on orders of magnitude larger time scales compared to wave propagation. In the present work, we propose a new approach to accelerate the numerical simulation of slow diffusion processes. We solve the coupled Biot elastodynamic hydro-mechanical equations for particle velocity and stress in the time domain using the finite volume method on a rectangular grid in three dimensions. The MPI-based multi-GPU code is implemented using CUDA-C programming language. We prescribe a fluid injection at the center of the model that generates a fast propagating wave and a significantly slower fluid-diffusion event. The fast wave is attenuated due to absorbing boundary conditions after what the slow fluid-diffusion process remains active. A Courant stability condition for the fast wave controls the time-step in the entire simulation, resulting in a suboptimal short time step for the diffusion process. Once fast waves are no longer present in the model domain, the hydro-mechanical coupling vanishes in the inertial terms allowing for an order of magnitude larger time steps. We accelerate the numerical simulation of slow diffusion processes using a pseudo-transient method that permits to capture the transition in time step restrictions. This latest development enables us to simulate quasi-static and dynamic responses of two-phase media. We present benchmarks confirming the numerical efficiency and accuracy of the novel approach. The further development of the code will capture inelastic physics starting from the dynamic events (earthquake modeling) to quasi-static faulting.