How we learned to stop worrying and start loving bulk nonlinearities

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The Finite Difference (FD) and Boundary Integral (BI) methods have been extensively used in computational earthquake dynamics. The FD method provides a powerful tool for simulating a variety of rupture scenarios including nonplanar faults and bulk plasticity. However, it requires the discretization of a significant portion of the bulk to avoid artificial boundary reflections. This makes simulation of large scale ruptures computationally prohibitive. For the BI method, the explicit numerical representation is confined to the crack path only, with the bulk elastodynamic response expressed in terms of integral relations between displacement discontinuities and tractions along the crack. This leads to significant computational saving especially when the spectral formulation of the method [Lapusta et al. 2000] is used. The spectral boundary integral equation method [SBIE], however, works only for linear elastic bulk and planar fault surfaces. Here, we propose a novel hybrid numerical scheme that combines FD and the SBIE to enable treating fault zone nonlinearities and heterogeneities with higher resolution and in a more computationally efficient way.

In the proposed method, we enclose the near-fault bulk inhomogeneities (e.g. non-planar faults surface, off-fault plastic zone, or low velocity zones) in a virtual strip that is introduced for computational purposes only. Only this strip is then discretized using the finite difference method while the virtual boundaries of the strip are handled using the independent formulation of the SBIE method which simulates each half space independently. The finite difference solution of the strip provides traction to the virtual boundaries. These tractions are used as input for the SBIE to compute the displacements which are in turn applied to the virtual strip as Dirichlet boundary conditions to advance the solution to the next time step. We illustrate the accuracy and efficiency of the method using several examples. By leveraging the flexibility of bulk methods and the computational superiority of boundary methods we expect the hybrid approach to enable the integration of high resolution fault zone physics in elastodynamic simulations and to facilitate cycle simulations of faults in the presence of bulk nonlinearities at a reasonable computational cost.

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