Dynamic Modeling of Earthquake Sources

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Numerical Model Validation Using Foam Rubber Models

Numerical source modeling techniques are difficult to validate due to the scarcity of near-source recordings of large earthquakes and because key dynamic properties of faults cannot be measured in the earth (e.g. prestress and frictional properties). While the numerical methods underlying dynamic earthquake simulations have frequently been tested against analytic solutions to linear problems, few opportunities exist to validate the methods for appropriate nonlinear, frictional-interface problems. Brune and Anooshehpoor have constructed foam rubber scale models of earthquakes, and these controlled experiments provide detailed, subsurface recordings of rupture propagation and fault motion unavailable for real earthquakes. Additionally, there are few, if any, important physical properties of the foam rubber models that cannot be measured and used to construct numerical models.

Foam Rubber Model

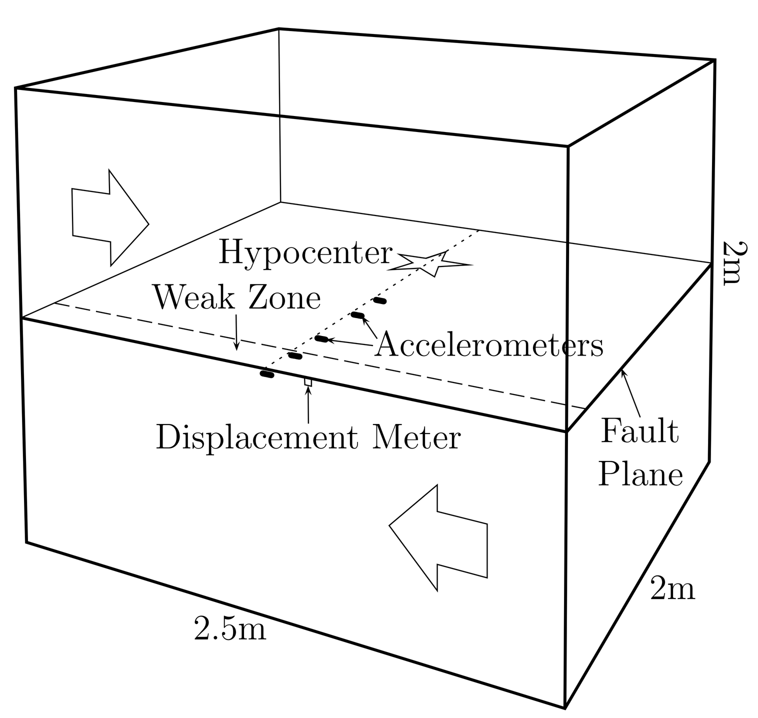
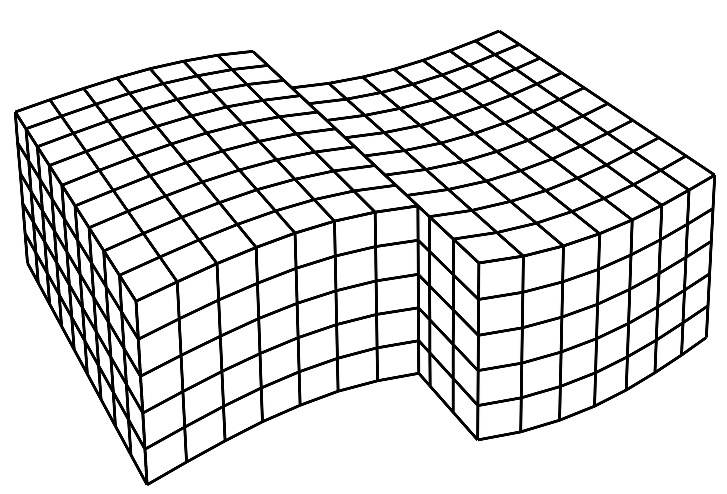


Diagram of foam rubber model setup for simulating strike-slip earthquakes. A weak zone on the fault is present near the model edge corresponding to the surface of the earth. In the weak zone frictional resistance and prestress are greatly reduced. These experiments were performed by Brune and Anooshehpoor, 1998.

Numerical Method



We model a strike-slip fault using second order finite-difference approximations for a 3D viscoelastic solid, and incorporating and slip-weakening fault boundary condition.

Equations of Motion

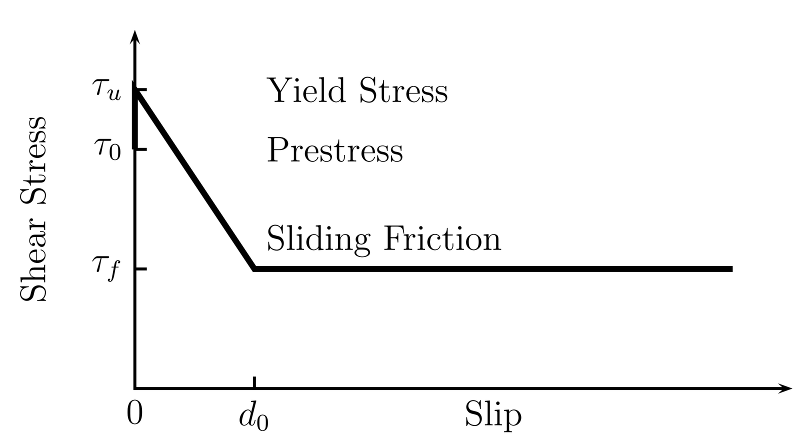
Conservation of Momentum

$$\sigma_{ij,j} = \rho \ddot{u}_i$$

Viscoelastic Solid

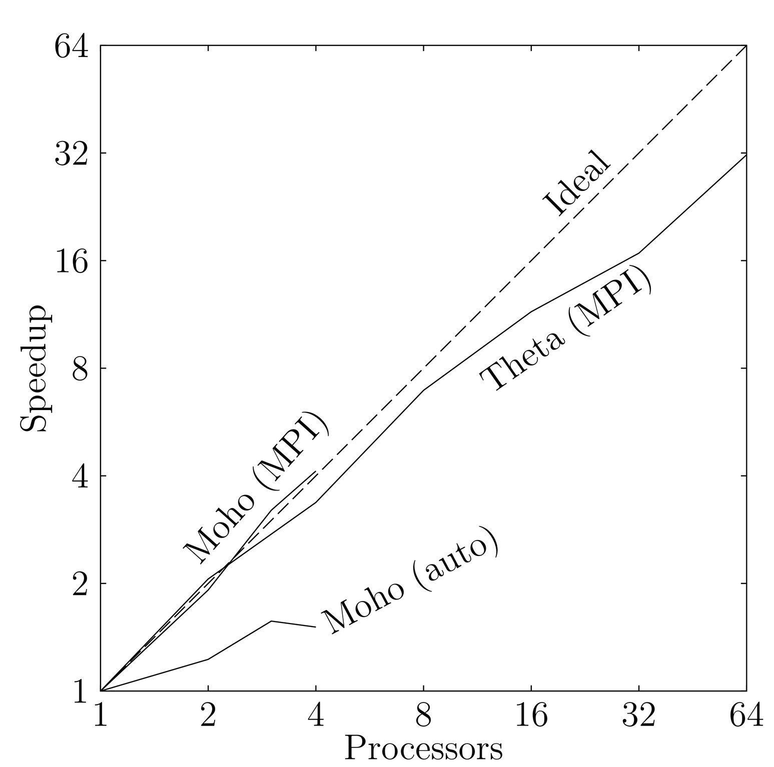
$$\sigma_{ij} = \lambda(u_{k,k} + \gamma \dot{u}_{k,k})\delta_{ij} + \mu(u_{i,j} + \gamma \dot{u}_{i,j} + u_{j,i} + \gamma \dot{u}_{j,i})$$

Fault Boundary Condition



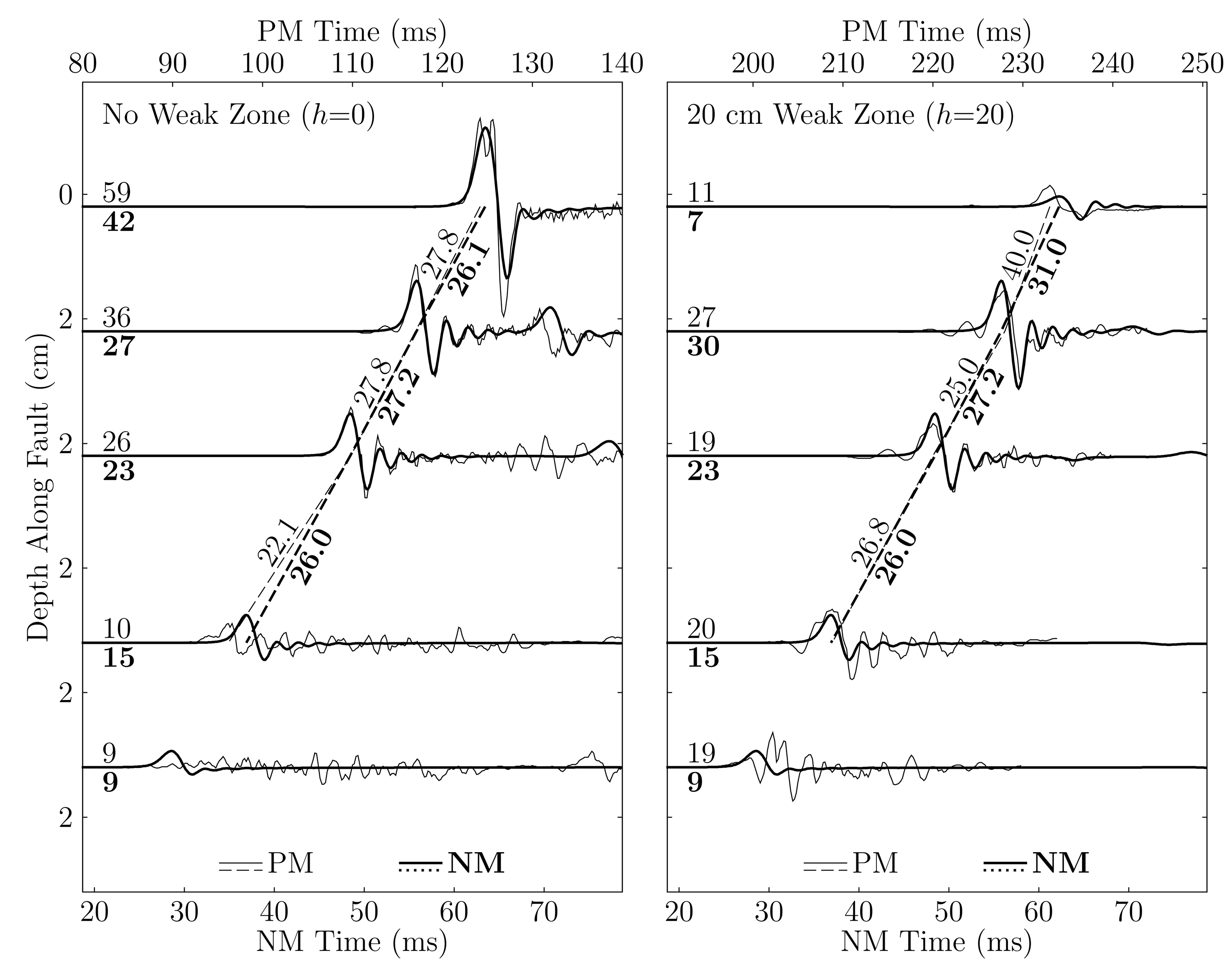
Plot of the slip-weakening fault boundary condition. The curve represents the coefficient of friction as a function of the amount of slip on the fault.

Code Parallelization



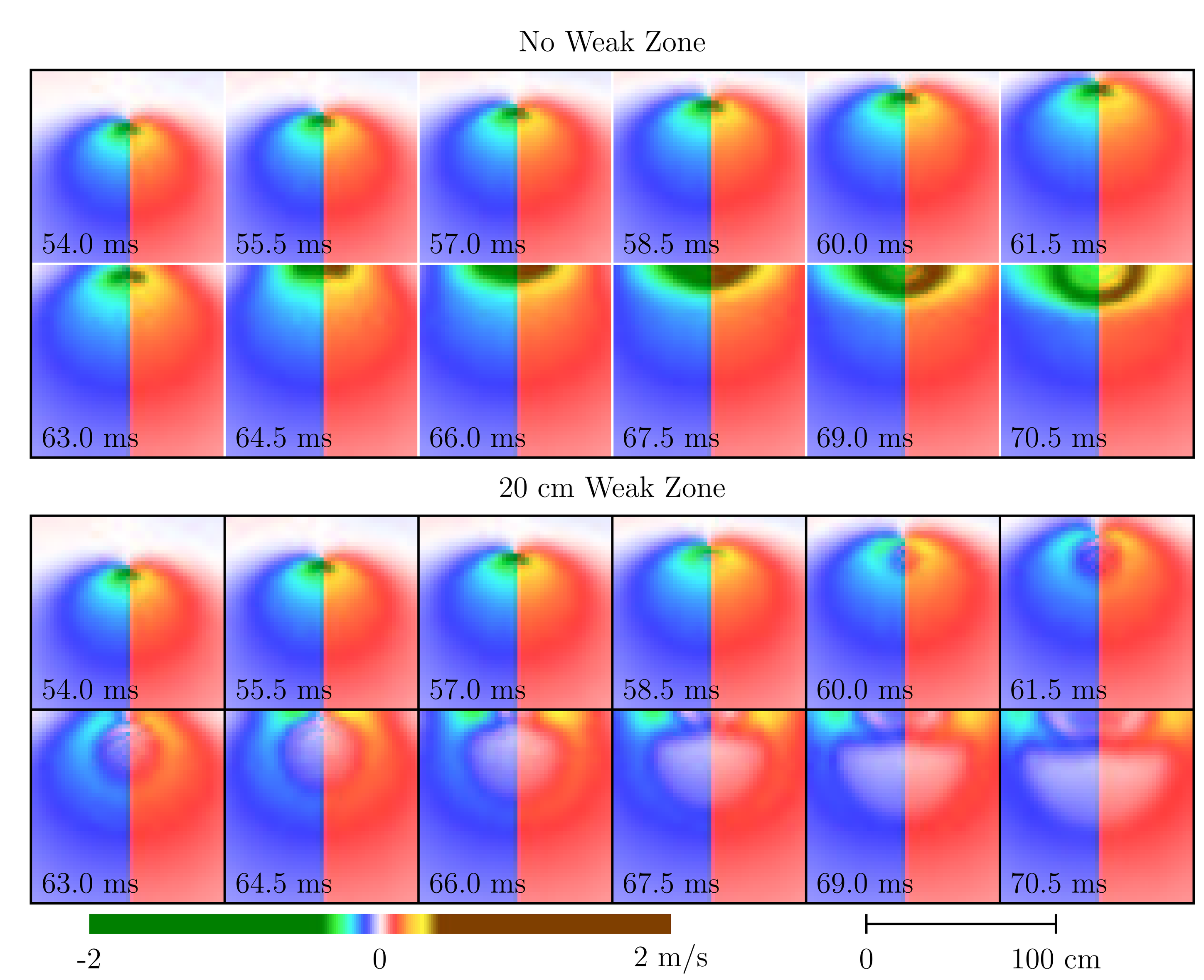
The large range of important length scales in earthquake problems requires significant computational expense. Current trends in super-computing are leading toward multiprocessor machines. Automatic compiler parallelization of codes does not always provide optimal results and explicit code parallelization may sometimes be needed. explicit parallelization was implemented using Message Passing Interface (MPI). Scalability benchmarks were performed on two shared memory machines: a four processor Sun Enterprise 450 (Moho), and a 64 processor SGI Origin 2000 (Theta).

Acceleration Records



Comparison of acceleration records showing good agreement between the physical foam rubber model (from Brune and Anooshehpoor, 1998) and the numerical model. Dashed lines connect points of maximum positive amplitude and indicate the velocity of the main pulse.

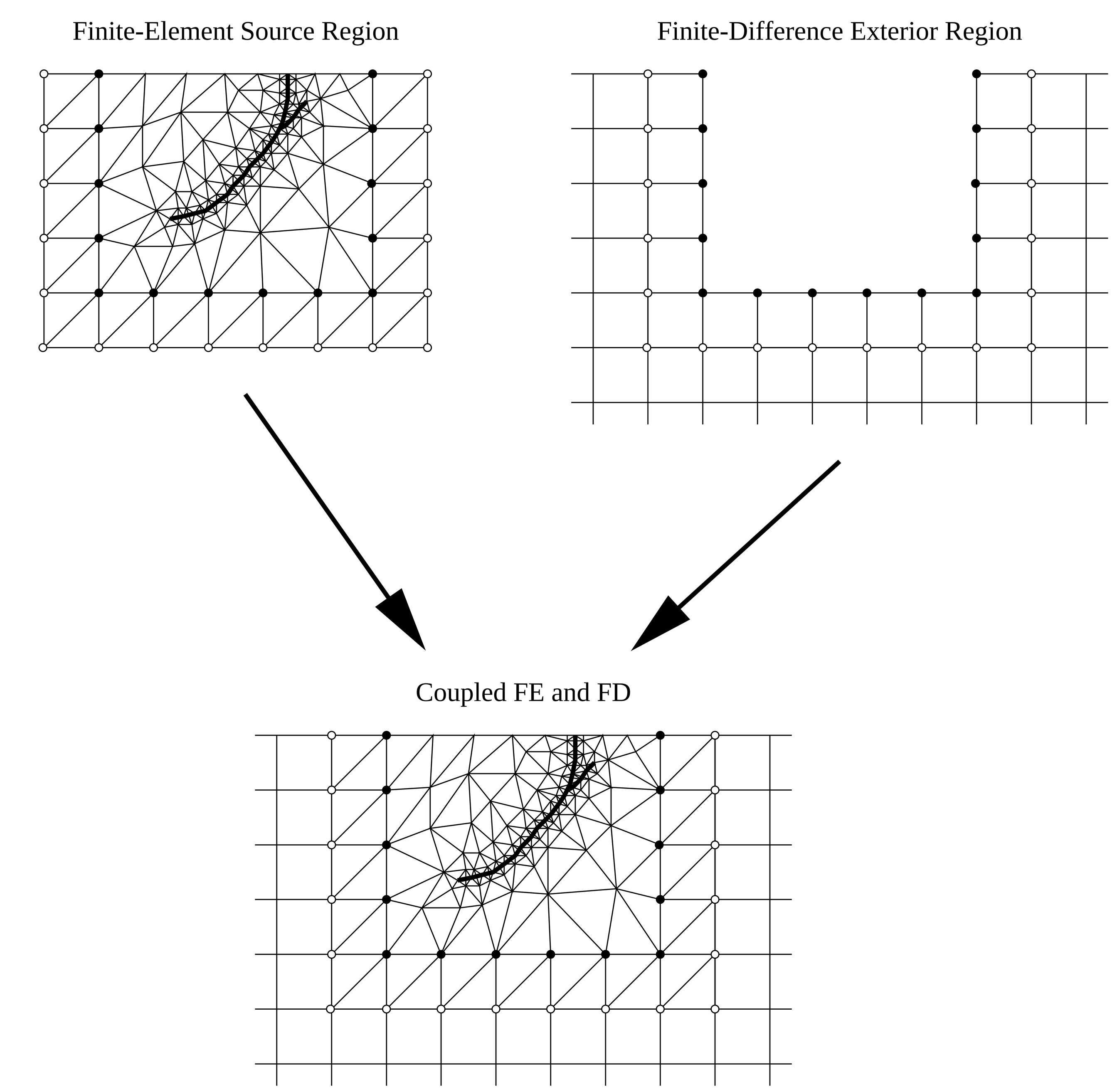
Snapshots of Particle Velocity



Cross-section snapshots of along-strike particle velocity. The top panel shows the case with no weak zone and the bottom panel shows the case with a 20 cm weak zone. The rupture front can be seen entering the weak zone at 58.5 ms in the bottom panel.

Finite-Element and Finite-Difference Code Coupling

Work is underway to combine the power and flexibility of a Finite-Element (FE) method in the source region with the efficiency of Finite-Difference (FD) in the far-field. The variable spacial discretization of FE can resolve finer detail where needed such as on the fault plane and in low velocity zones. Additionally, FE can incorporate complicated geometries allowing fault models to have kinks and bifurcations. Forth order FD is used outside the source region for efficient modeling of seismic radiation and attenuation. We use the Dyna3D code and Kim Olsen's $O(h^4)$ FD code.



Schematic diagram of code coupling method. 2D is shown for simplicity although simulations will be 3D. Filled circles are a boundary condition on the FD solution imposed by the FE solution. Conversely, open circles are a boundary condition on the FD solution imposed by the FE solution. Boundary conditions are enforced once per FD timer-step. The FE time-step will generally be much shorter than the FD time-step due to stability requirements of the finer spacial discretization.

Acknowledgments

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