Crustal Deformation Modeling Tutorial

PyLith: Introduction to Dynamic Spontaneous Rupture

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COMPUTATIONAL INFRASTRUCTURE for GEODYNAMICS

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Quasi-static → Dynamic

- Dynamic simulations include inertia → seismic waves
- Formulation
  - Implicit time stepping → explicit time stepping
  - System Jacobian: sparse stiffness matrix → lumped (diagonal) mass matrix
- Solver
  - Solver is trivial (Jacobian is uncoupled)
  - No need for PETSc solvers

Dynamic Simulation Parameters

Example of setting dynamic parameters in a `.cfg` file

```
[pylithapp.timedependent]

formulation = pylith.problems.ExplicitLumped

normalizer = spatialdata.units.NondimElasticDynamic
normalizer.shear_wave_speed = 1.0*km/s
normalizer.wave_period = 1.0*s
normalizer.density = 3000.0*kg/meter**3

[pylithapp.timedependent.formulation.time_step]
total_time = 12.0*s
dt = 0.05*s
```

Dynamic Simulation Stumbling Blocks

Dynamic simulations are less forgiving than quasi-static simulations

- Mesh resolution depends on shear wave speed and minimum period

$$dx \leq aL_{min} = aV_s T_{min} \tag{1}$$

$$a \sim 1/12 - 1/10 \tag{2}$$

- Courant-Friderichs-Lewy condition controls stable time step

$$dt < \min(dx/V_p) \tag{3}$$

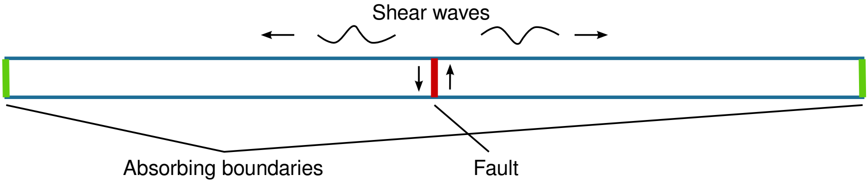
- Mesh must resolve the cohesive zone of the rupture
  Rupture must propagate at least 3–5x discretization size over time stress drops to nominal sliding level
- 2-D simulations can run on a desktop/laptop
- 3-D dynamic simulations generally require a cluster

Dislocation in a Bar

Deformation limited to shear component, no axial deformation

- Prescribed initial fault tractions exceed friction criterion
- Steady-state sliding on fault with uniform strain

$$T_i - T_f = \tau_{xy} = T_d = \dot{u}\rho V_s \quad (4)$$



Dislocation in a Bar

Files are in `src/pylith/examples/bar_shearwave/quad4`

- Meshing via CUBIT
- Common parameter files
  - `pylithapp.cfg`
  - `dynamic.cfg`
- Simulation parameter files
  - `dynamic_staticfriction.cfg`
    `pylith dynamic.cfg dynamic_staticfriction.cfg`
  - `dynamic_slipweakening.cfg`
    `pylith dynamic.cfg dynamic_slipweakening.cfg`
  - `dynamic_ratestateageing.cfg`
    `pylith dynamic.cfg dynamic_ratestateageing.cfg`
- Visualization with ParaView

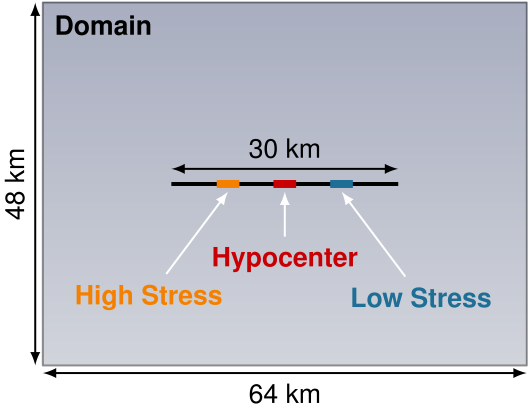
SCEC Benchmarks

http://scecdata.usc.edu/cvws/

- SCEC benchmarking effort led by Ruth Harris (USGS) and Ralph Archuleta (UCSB)
- 2-D and 3-D code verification exercises for dynamic spontaneous rupture simulations
- Wide variety of benchmarks
  - Vertical strike-slip fault
  - Dipping normal fault
  - Slip-weakening friction
  - Rate and state friction
  - Heterogeneous initial fault tractions
  - Depth-dependent background stress field
  - Elastic, isotropic bulk rheology
  - Drucker-Prager elastoplastic bulk rheology
  - Fault branching
  - Subshear and supershear rupture

SCEC Benchmark TPV205-2D

2-D horizontal slice through vertical strike-slip fault



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SCEC Benchmark TPV205-2D

Files are in CIG SVN repository
http://geodynamics.org/cig/short/3D/PyLith/benchmarks/trunk/dynamic/scecdynrup/tpv205-2d
See workshop agenda for link to zip archive with files

- Meshing via CUBIT
- Parameter files
  - `pylithapp.cfg`
  - `tri3.cfg` (cell type)
  - `tri3_200m_gradient.cfg` (cell type and resolution)
  - `friction.spatialdb`
  - `tractions.spatialdb`

    `pylith tri3.cfg tri3_200m_gradient.cfg`
- Visualization with ParaView

Benchmark Comparison

http://scecdata.usc.edu/cvws/cgi-bin/cvws.cgi