Implementing Plastic Yielding in a Finite Element Code and Applying it to Dynamics of Faults With Bends

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Benchun Duan and Steven M. Day (SDSU)

(bduan@rohan.sdsu.edu)

SUMMARY

Limitations on material strength may play an important role in rupture dynamics on geometrically complex faults. Furthermore, non-linear material response off the fault may place physical limits on earthquake ground motion amplitudes. In this study, we implement plastic yielding off the fault in a finite element code. We have verified the code by comparing with Andrews (2005) on a planar fault model. Then, we apply this code to a non-planar fault model with kinks, we find that kinks are locations of large plastic deformation. Distribution of plastic strain near kinks can be significantly different and interaction of two sides of a kink plays an important role. By comparing to an elastic calculation, we find that off-fault plastic yielding reduces radiation from a kink and thus particle velocity within several hundred meters of the fault.

NONELASTIC DYNAMIC FEM

- Basic structure of the program:
  See Duan (2006) and Duan and Oglesby (2006).

- Main revisions are:
  (1) Initial stress (in equilibrium) is assigned to all elements, not to fault nodes.
  (2) Internal elastic stress must be calculated from velocity, not displacement.

- Implementation of off-fault plastic yielding:
  (1) A Coulomb yield criterion similar to Andrews (2005) is used.
  (2) Viscous damping (Duan, 2006; Duan and Oglesby, 2006) and Maxwellian viscoplasticity (Andrews, 2005) are used to regularize the numerical simulation. We find that viscous damping is enough on a planar fault model, but viscoplasticity is required on faults with bends.

VALIDATION

by good agreement with Andrews (2005), but we only used viscous damping to regularize calculation in this model.

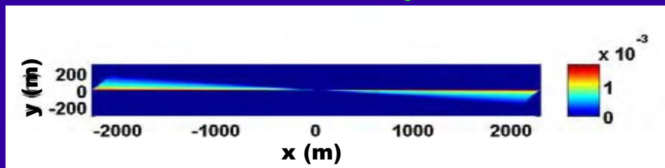

Figure 1(a). Magnitude of plastic strain at time 0.89 s on a planar fault. Rupture starts at x = 0 km.

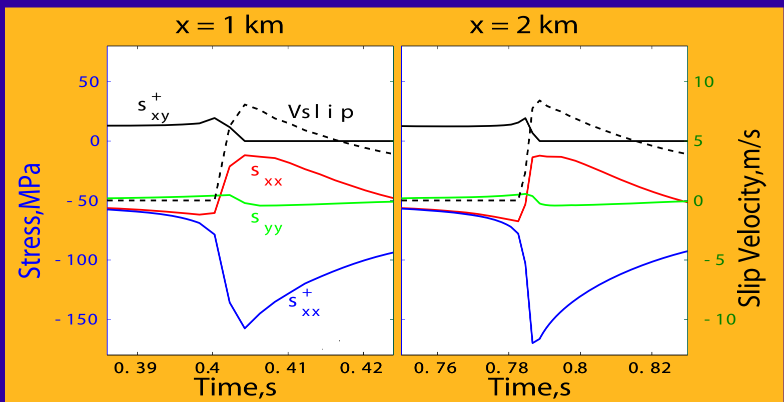

Figure 1(b). Time histories of stress and slip velocity on the fault at two locations. Off-fault plastic yielding places a limit on slip velocity.

ELASTOPLASTIC VS. ELASTIC RESULTS OF FAULTS WITH BENDS

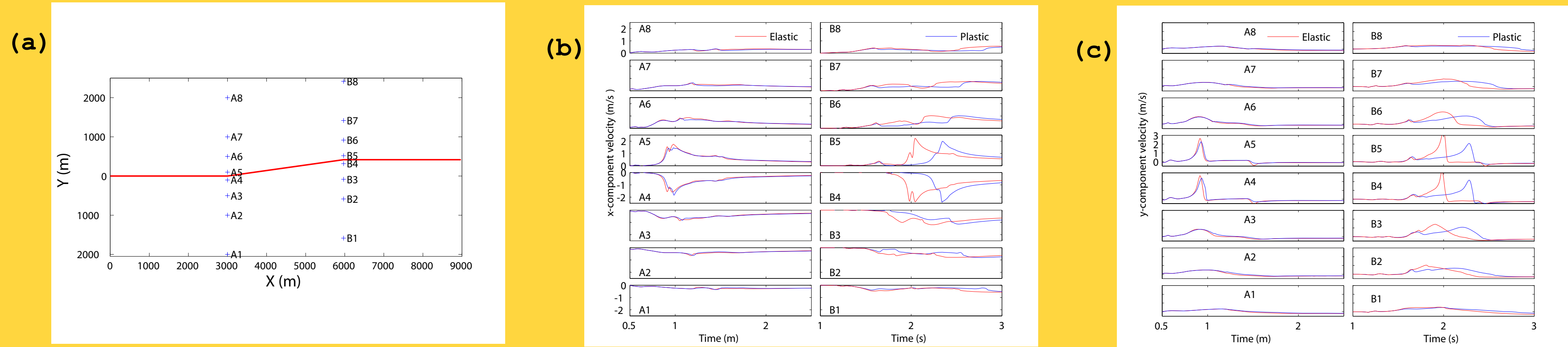

Figure 2. Model and nodal time histories. (a) 2D Fault model and locations of nodes shown. Red line is the fault trace. Grid size is 5 m. Slip weakening friction law is used, except for the nucleation zone. Rupture starts at x = 1000 m. Uniform initial stress conditions: -100 MPa for xx and yy components, 45 MPa for xy component. Internal coefficient of friction is 1.0. Cohesion is 0 MPa. Static and dynamic frictional coefficients are 0.6 and 0.3, respectively. (b), (c) are time histories of X, Y components of velocity. Plastic yielding reduces particle velocity within several hundred meters of the fault.

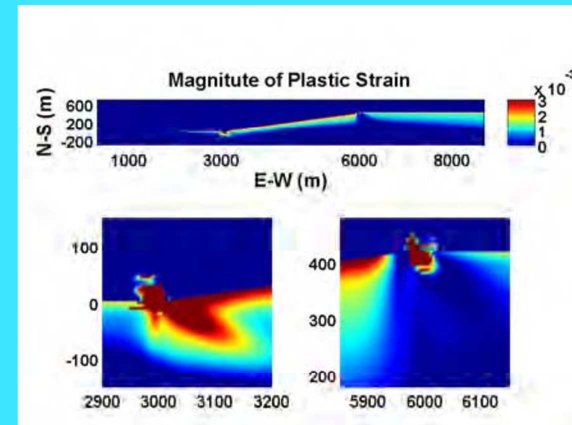

Figure 4. Distribution of magnitude of plastic strain at time 0.485 s. At two kinks, different features are observed. Plastic deformation is greater along the bend segment.

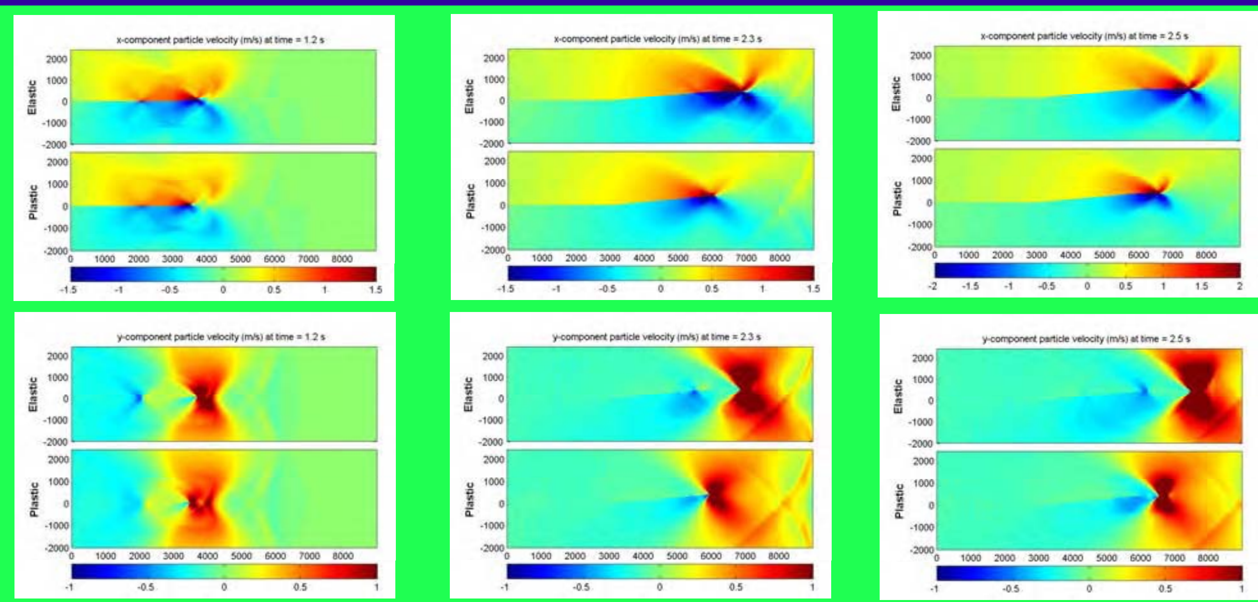

Figure 3. Snapshots of wave fields at times (a) 1.2 s, (b) 2.3 s, and (c) 2.5 s for x-component (top panels) and y-component (bottom panels) of velocity. Backward rupture from 1st kink can be seen in (a), and radiation from 2nd kink can be seen in (b) and (c), particularly in bottom panels. Off-fault plastic yielding reduces radiation from the fault and the kinks.

References

Andrews, D. J. (2005). Rupture dynamics with energy loss outside the slip zone, J. Geophys. Res., 110, B01307, doi:10.1029/2004JB003191.

Duan, B. (2006). The dynamics of geometrically complex fault systems over multiple earthquake cycles, Ph.D. thesis, University of California, Riverside.

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