Research Group Profile

Structures and Geomechanics at Stanford University

Discontinuities, Contact, Friction

Problem

Material failure and/or damage typically involve some form of discontinuous deformation. A class of problems that has attracted significant attention involves intense inelastic deformation concentrated within a very narrow zone. Shear bands, compaction bands, and mixed-mode bands are examples of discontinuous deformation that do not produce stress-free surfaces; in contrast to opening mode fractures and cracks. A robust finite element solution methodology is required that captures these different forms of discontinuity. The methodology should accommodate existing discontinuities as well as those that grow with the state of stress. In fault rupture propagation the coefficient of friction is known to depend on the velocity of sliding and possibly on state variables; a robust solution methodology should therefore also be able to accommodate such a variable coefficient of friction.

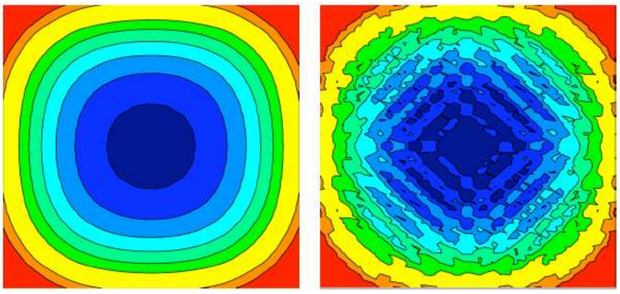
Approach

We use a fixed-grid finite element approach in which fine-scale discontinuity is allowed to pass through the interior of coarse-scale mesh. Two techniques for embedding a discontinuity into a finite element are available: the assumed enhanced strain method and the extended finite element method.

The assumed enhanced strain method involves a local enrichment and is appropriate for deformation band-type of discontinuity. The method is capable of representing shear-induced dilation and compaction of materials inside the band. The extended finite element method is a global enrichment and is appropriate for frictional cracks, faults, or fractures. The method can be combined with nonlinear contact mechanics algorithm for frictional contact.

Core Competencies

- **Embedded discontinuities, assumed enhanced strain, extended finite element method, stabilized finite elements, large deformation.**
- **Inelastic material modeling, crack tip and crystal plasticity, contact algorithm.**
- **Saturated and unsaturated porous media, coupled analysis, iterative solvers.**



Stabilized (left) and unstabilized (right) contact pressures on a pair of smooth cubes pressed against each other (after Liu and Borja 2010).

We have implemented a state- and velocity-dependent friction law in the context of the above two enrichment techniques. We have also used the polynomial pressure projection stabilization technique. Employed successfully in previous work for Stokes flow and coupled solid-deformation/fluid-diffusion problems, we here use this technique for stabilizing the normal and tangential components of traction on the contact faces.

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Recent Findings

We find that stabilized low-order finite elements for frictional contact with the extended finite element method and polynomial pressure projection technique minimize if not completely eliminate spurious oscillation of contact pressure for both stick and slip conditions, with structured and unstructured meshes, and with equal and unequal line segments. Furthermore, the technique works well with Lagrange multipliers, penalty, and augmented Lagrangian methods of nonlinear contact mechanics. Test problems considered include 2D plane strain, 2D plane stress, and full 3D frictional contact problems.

Impact

Discontinuities in materials manifest themselves in different forms and in various scales. It would not be prudent to treat them with brute force in a finite element simulation. Instead, it is important to recognize the multi-scale nature of the problem and employ enrichment techniques, either local or global, on a coarse-scale background finite element grid. The enrichment technique we propose may be used not only for the simulation of simple mechanical processes but also for capturing multi-physics processes including failure in variably saturated slopes and the physics of fault zone processes.

Current Research Team Members:

- Ronaldo I. Borja (Professor)
- Fushen Liu (Ph.D. Candidate)
- Helia Rahmani (Ph.D. Candidate)
- Martin Tjioe (Ph.D. Candidate)

Recent Graduates and Co-workers:

- Jose E. Andrade (Ph.D. 2006), now at Northwestern University
- Craig D. Foster (Ph.D. 2006), now at University of Illinois at Chicago
- Pablo F. Sanz (Ph.D. 2008), now at Exxon Mobil
- Joshua A. White (Ph.D. 2009), now at Lawrence Livermore National Laboratory

Current Research Collaborators:

- David D. Pollard (Stanford), Collaborations in Mathematical Geosciences, NSF
- Edward Kavazanjian, Jr. (ASU) and Jeffrey C. Evans (Bucknell), Network for Earthquake Engineering Simulations Research, NSF
- Keith Loague (Stanford) and Wei Wu (BOKU, Vienna), Variably Saturated Slopes, NSF and FWF (Austria) Research.

Selected Publications

1. R.I. Borja and A. Aydin, "Computational modeling of deformation bands in granular media, I: Geological and mathematical framework, *Comput. Methods Applied Mech. Engrg.*, Vol. 193, 2004, 2667-2698.
2. R.I. Borja, "Assumed enhanced strain and the extended finite element methods: A unification of concepts," *Comput. Methods Applied Mech Engrg.*, Vol. 197, 2008, 2789-2803.
3. J.A. White and R.I. Borja, "Stabilized low-order finite elements for coupled solid-deformation/ fluid-diffusion and their application to fault zone transients," *Comput. Methods Applied Mech. Engrg.*, Vol. 197, 2008, 4353-4366.
4. F. Liu and R.I. Borja, "Stabilized low-order finite elements for frictional contact with the extended finite element method," *Comput. Methods Applied Mech. Engrg.*, 2010, in press, doi: 10.1016/j.cma.2010.03.030.

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