Modeling Fatigue

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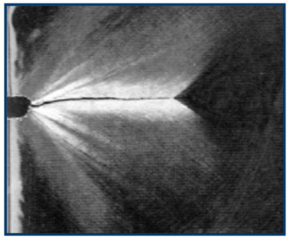
Modeling fatigue?

A. Using computational science to explore the physical phenomenon of crack growth?

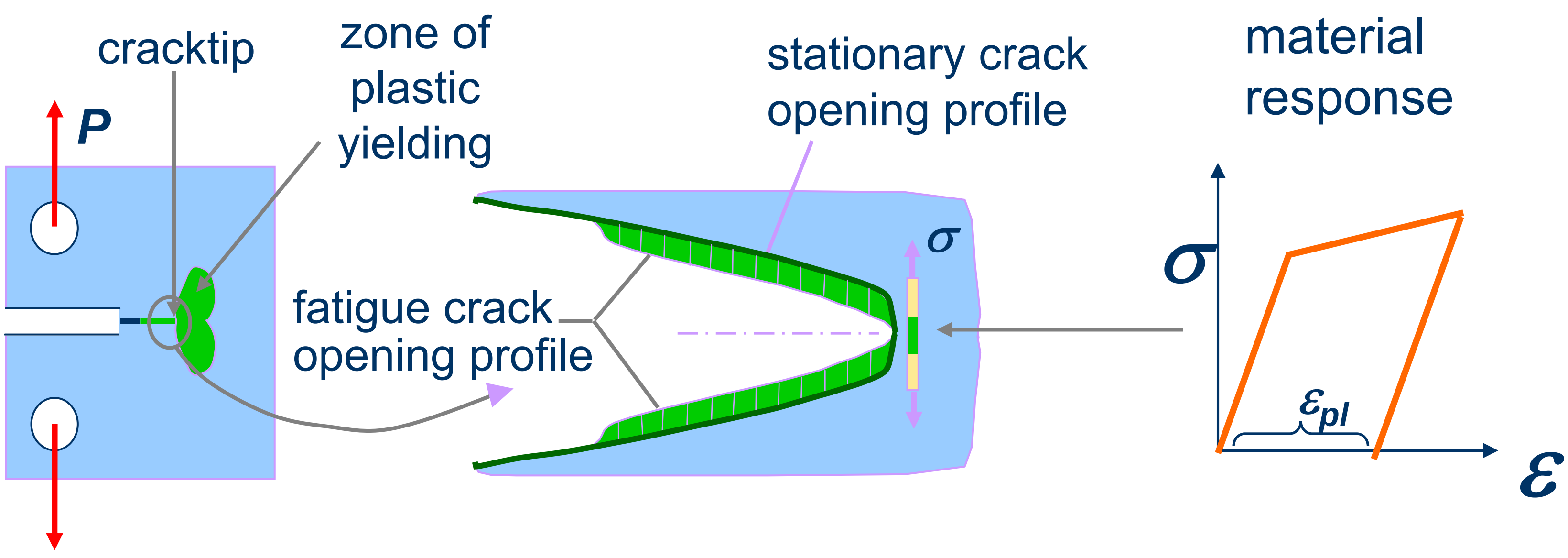


B. Complacency in computational modeling?

C. A military fashion show?

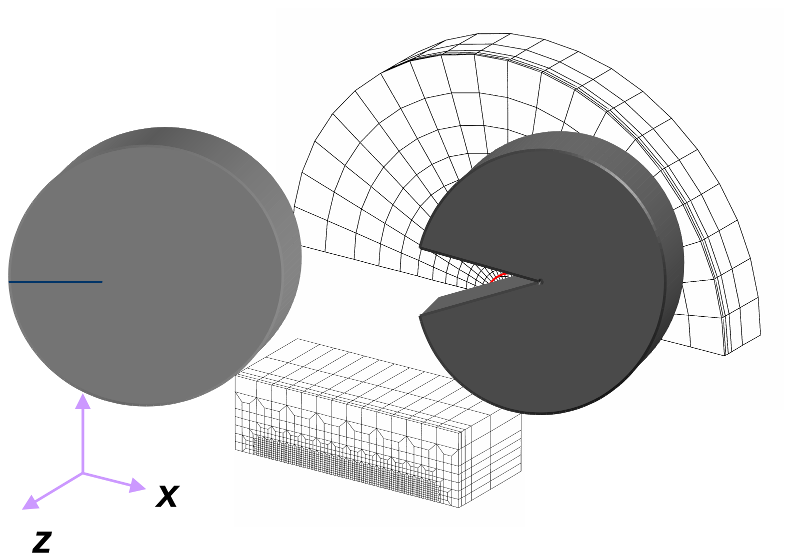
Plasticity Induced Crack Closure (PICC)

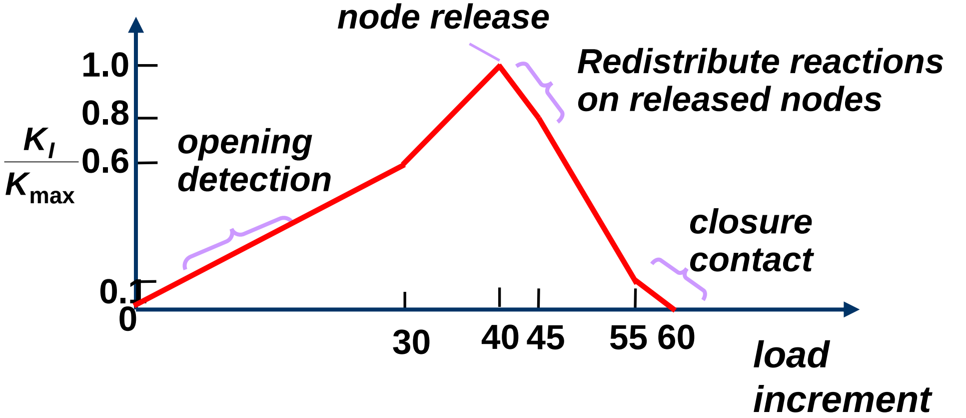
- Fatigue crack growth occurs over many cycles of loading and unloading
- Permanent deformation at crack tip affects rate of crack growth in metals



Computational modeling of PICC

- Discretization of domain into finite element mesh
- Boundary conditions to apply loading cyclically
- Crack growth element by element
- Contact imposed to prevent overlap
- Monitor crack opening and closing





History of PICC modeling

- Finite element modeling of PICC began in mid-70's
- Simplistic model – limited by computational constraints?
- Early analyses studied effect of element size on results
  - Mesh criterion for converged results established as ratio of element size to plastic zone size
  - Some more recent results have "confirmed" this mesh criterion

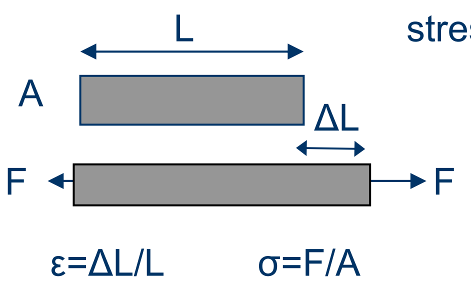
Mesh studies only valid for specific models?

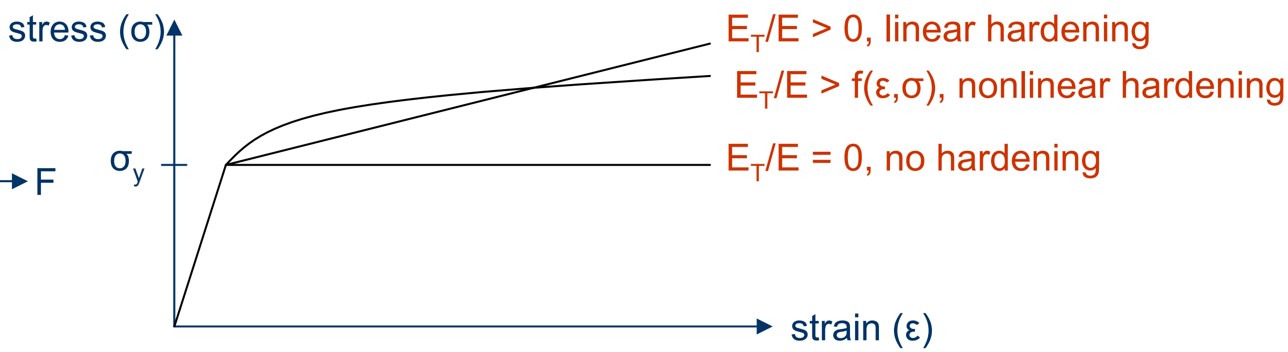
specimen geometry, small strain formulation, simple material model, 2D analysis

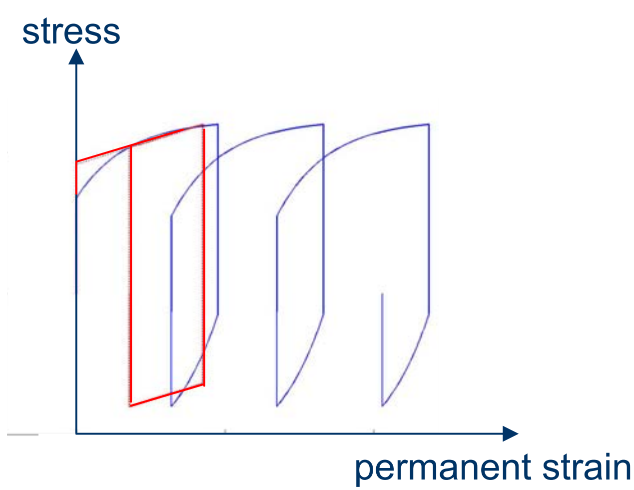
Current research trends

- Nearly 50 papers on finite element modeling of PICC since 1999
- Computational resources allow for larger, more complicated models
- Many researchers apply earlier mesh criterion without confirming applicability
- Researchers that do investigate mesh dependence often find that
  - Previous criterion not always valid
  - Mesh independent results may not be possible
- Some researchers advocate idea of “best mesh size” – one for which numerical results “agree” with experiments results
  - Violates underlying principle of finite element analysis
  - Accurate experimental results are often as elusive as converged numerical results

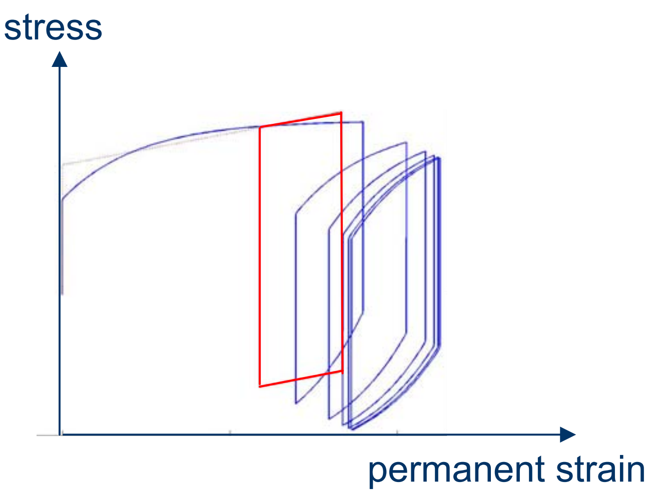
Material models





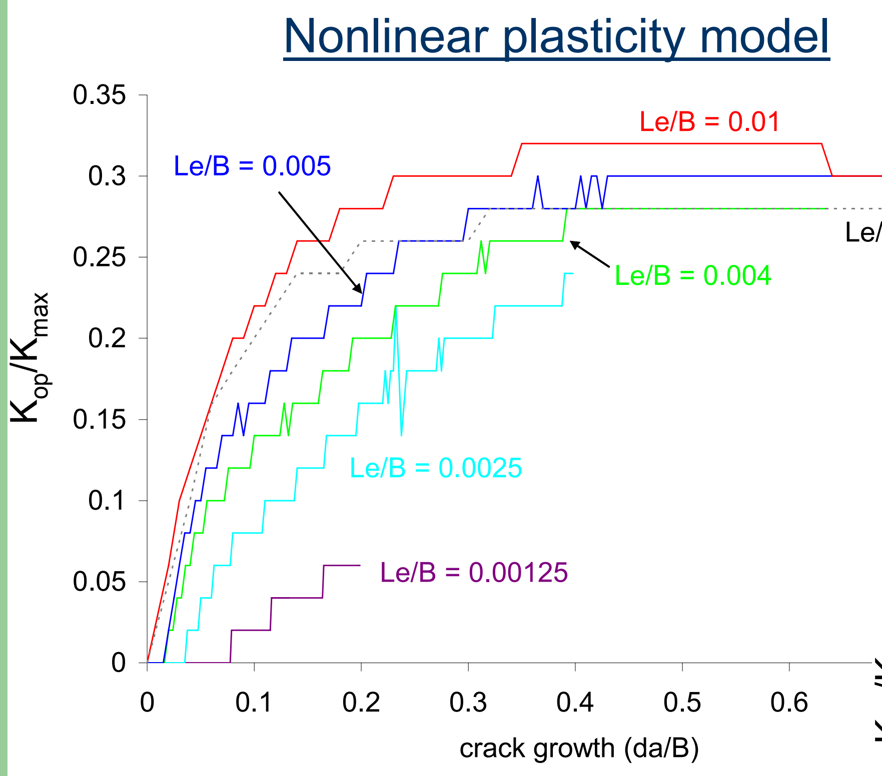


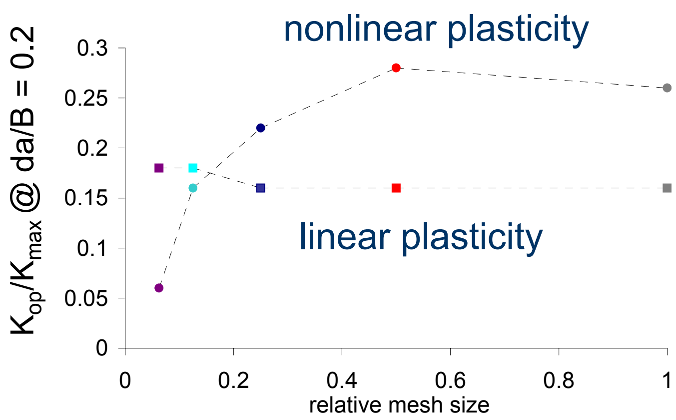
Ratcheting under nonsymmetric stress-controlled cycling

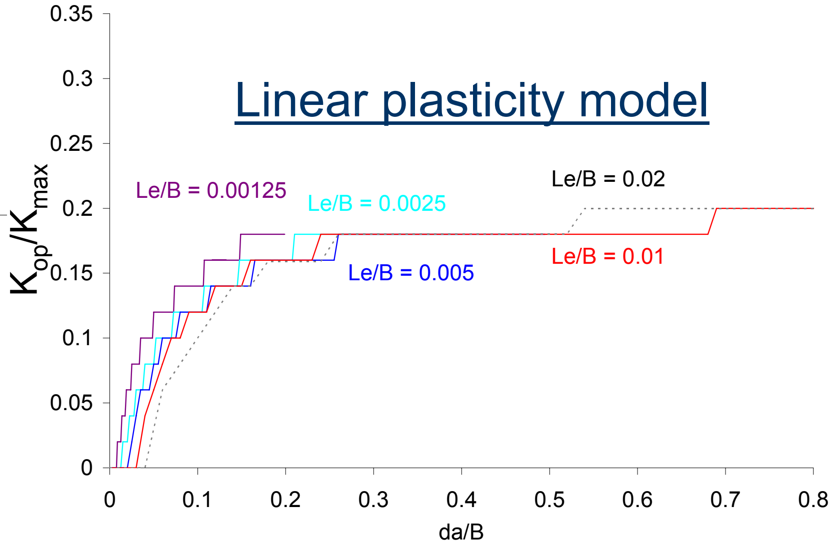


Relaxation of mean stress under nonsymmetric strain-controlled cycling

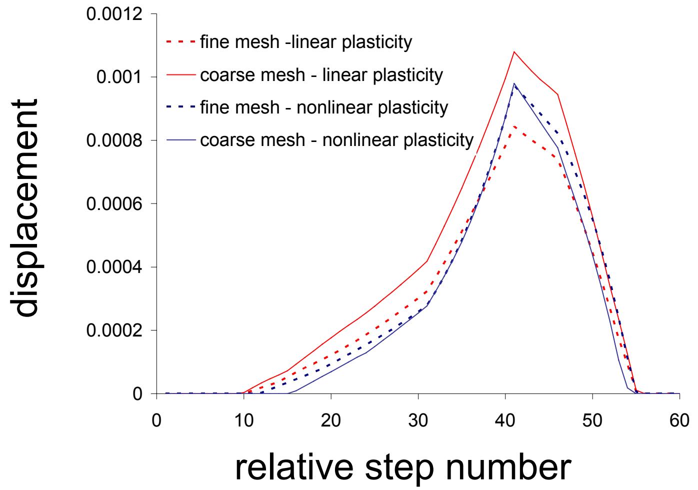
Mesh dependence – Opening loads

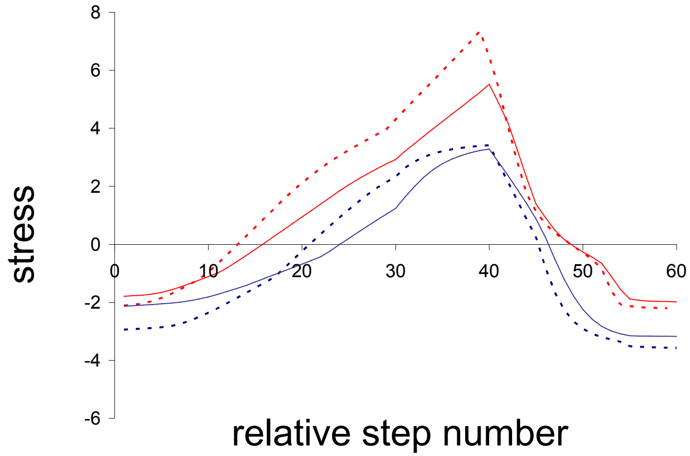


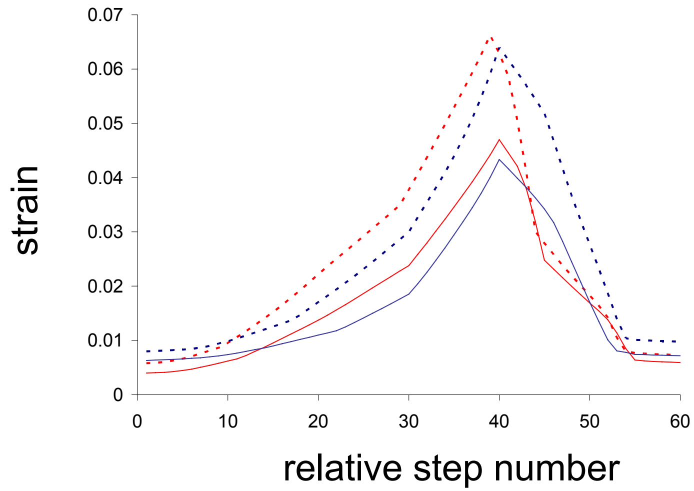




Mesh dependence of primary fields

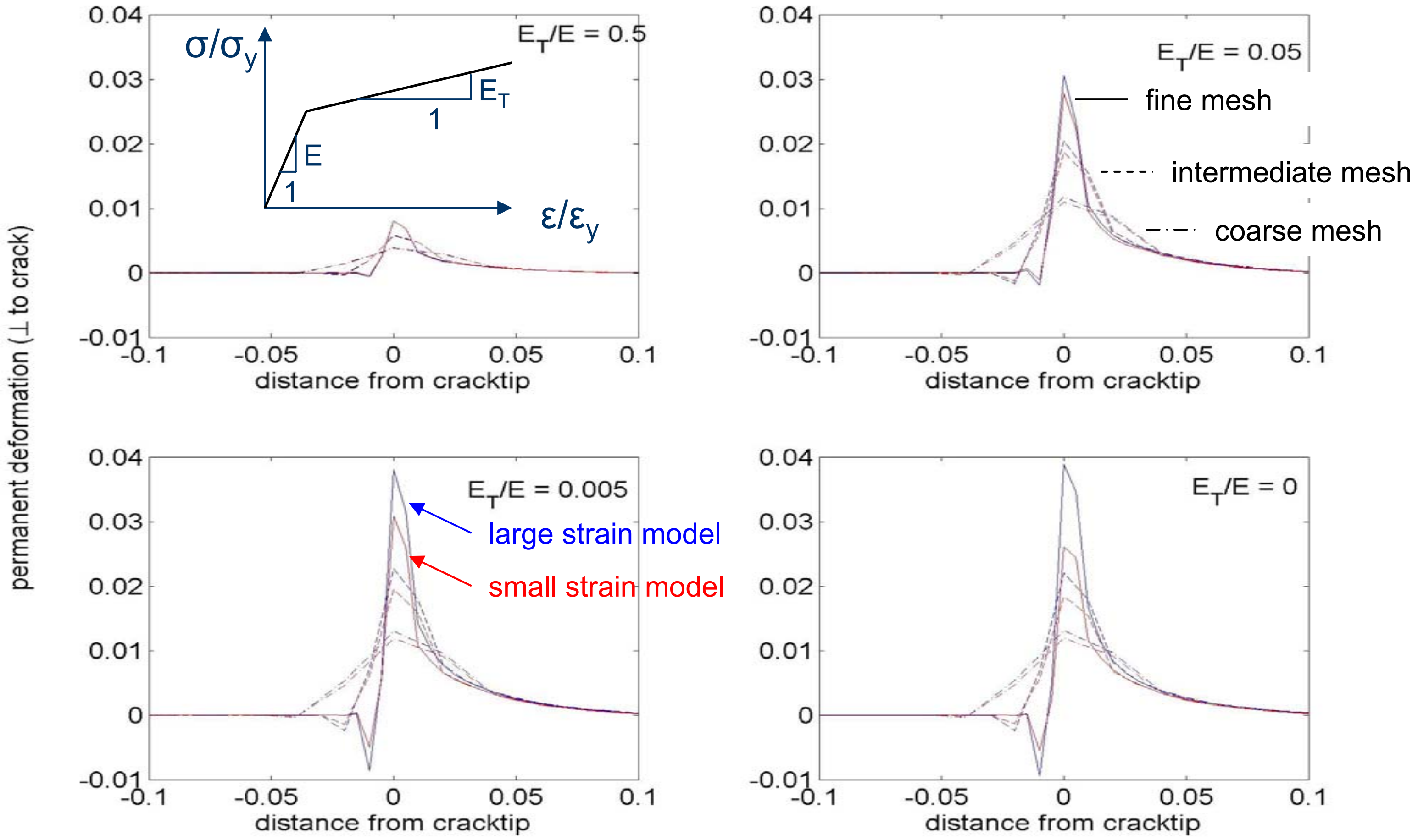




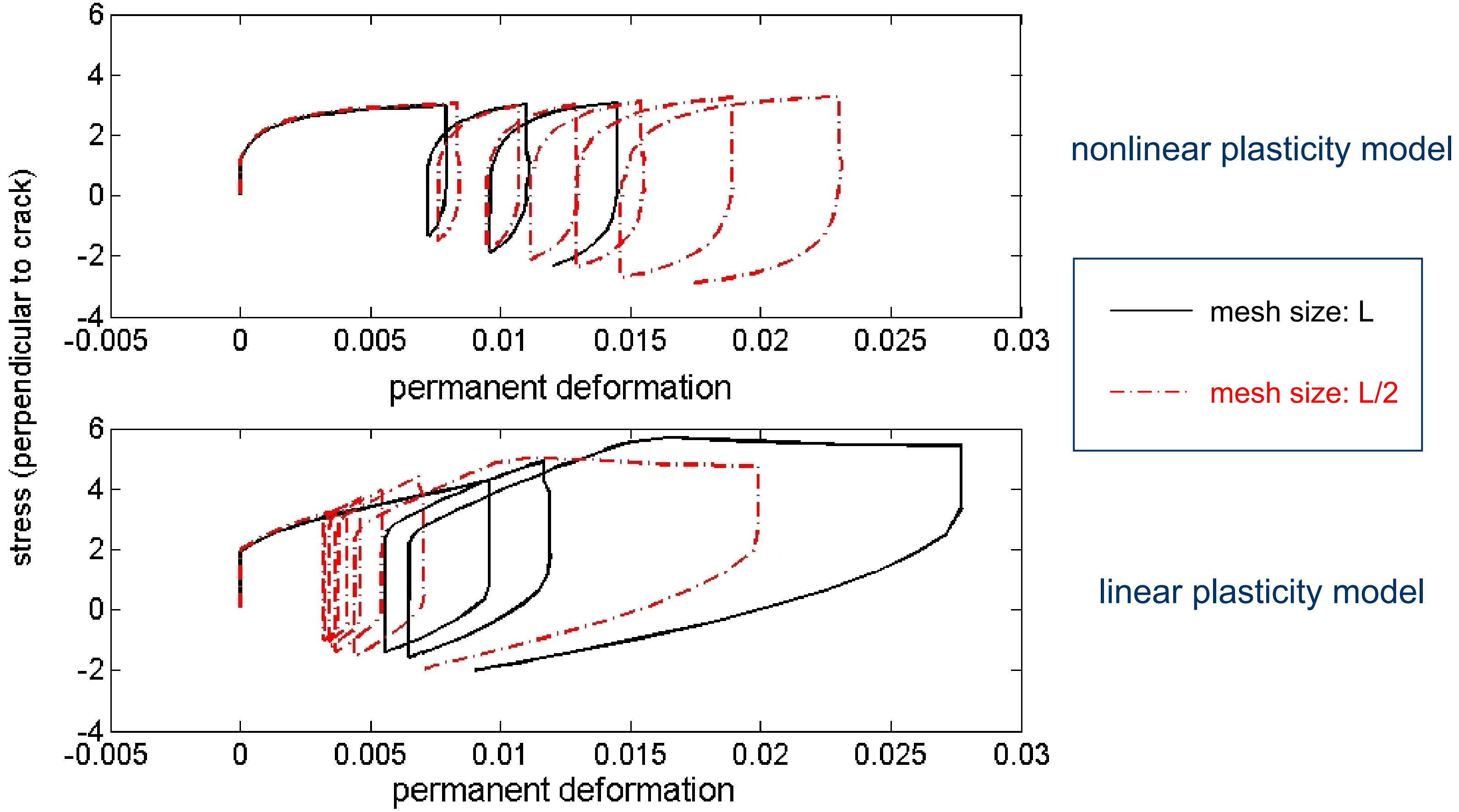


Displacement, stress, and strain measured perpendicular to crack at one integration point over one cycle

Effect of post-yield modulus



Effect of cyclic ratcheting



Factors affecting mesh dependence

- Slope of stress-strain behavior at large strains
- Cyclic ratcheting (number of cycles increases with decreasing mesh size)
- Specimen geometry
- Dimension of problem (2D vs 3D)
- Magnitude of applied load

The evolution of solution resolution

- Improvements in hardware and algorithms may lead to new solutions to old problems
- Carefully developed methods may be used injudiciously
- More questions than answers …
  - When should assumptions be challenged?
  - When do small changes in problem lead to large changes in solution properties?
  - How vigorously should we seek to validate a method?
  - Is it time for a coffee break?

Thank you!

- DOE and Krell Institute
- Civil and Environmental Engineering department at UIUC

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Robert H. Dodds, Jr

Keith Hjelmstad