



Modeling Fatigue

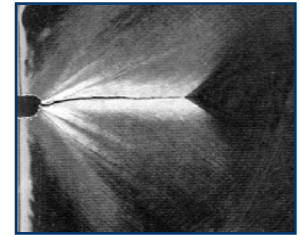
Kristine Cochran



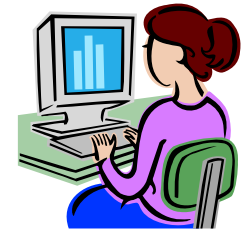
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Modeling fatigue?

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



B. Complacency in computational modeling?

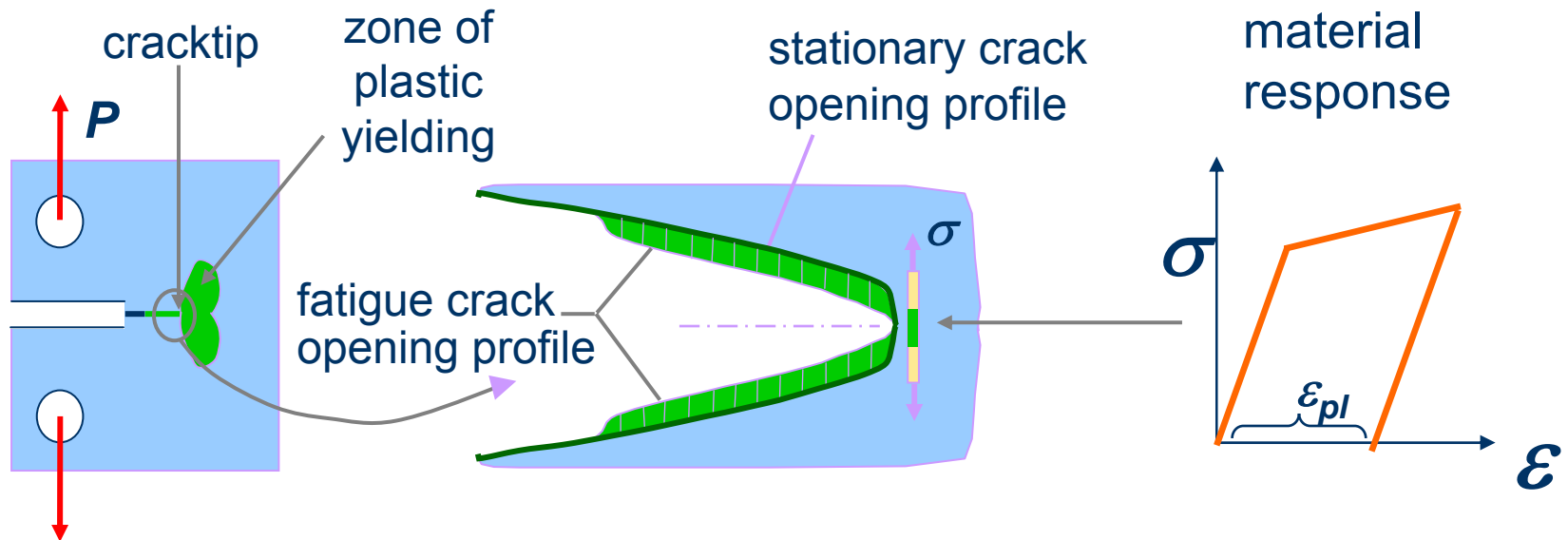


c. A military fashion show?



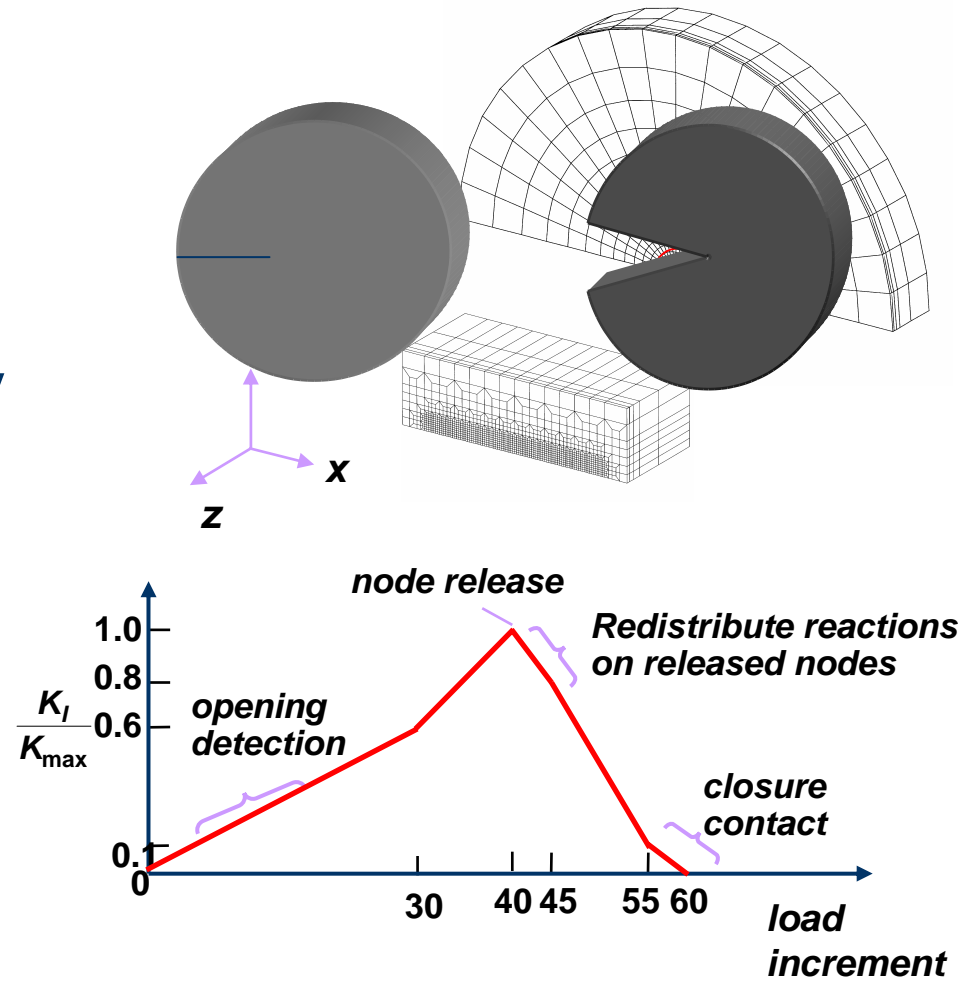
Plasticity Induced Crack Closure (PICCC)

- 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

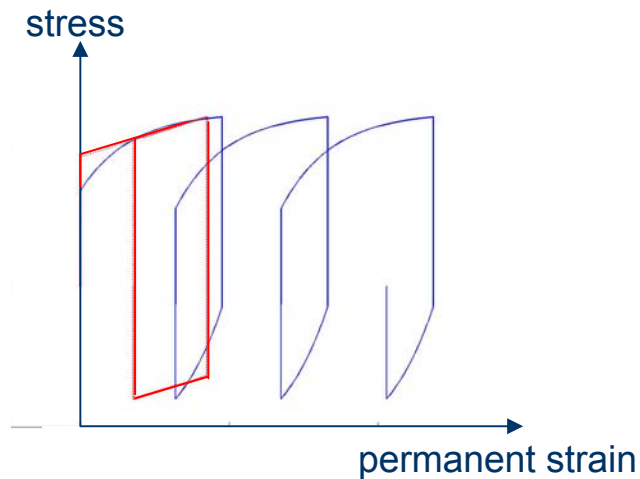
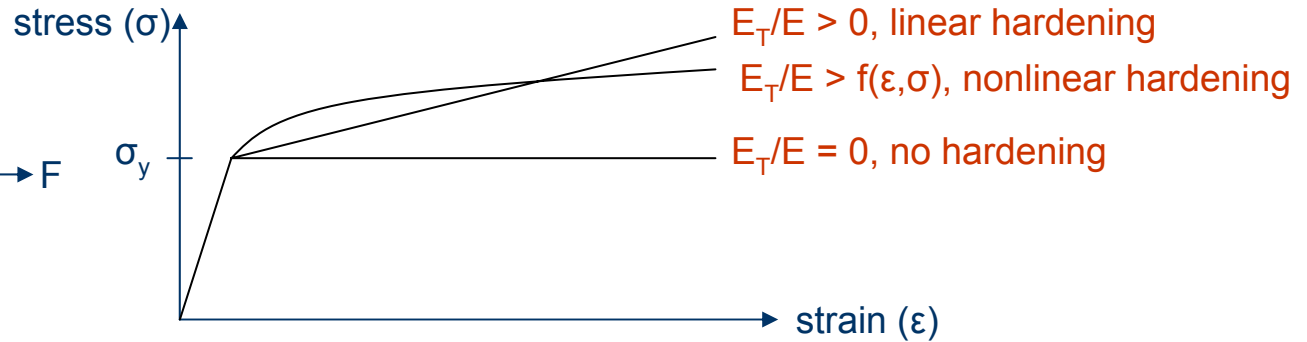
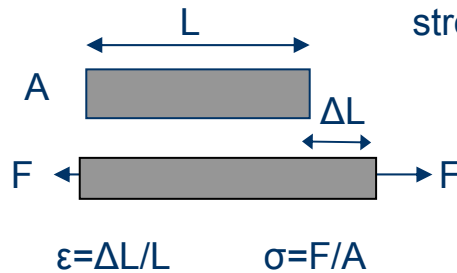
Mesh studies only valid for specific models?

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

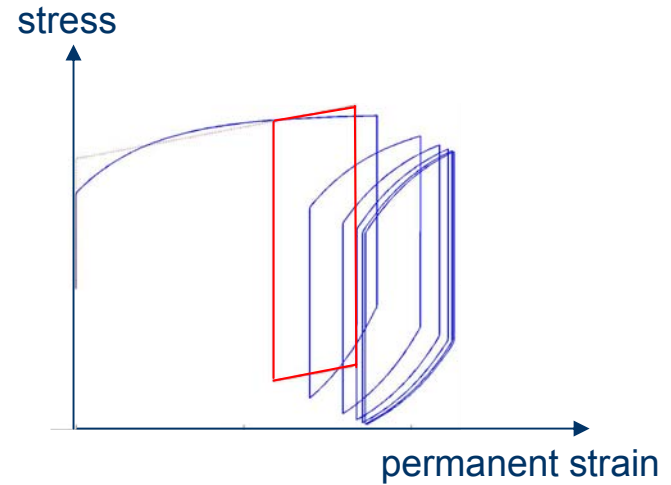
Current research trends

- 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



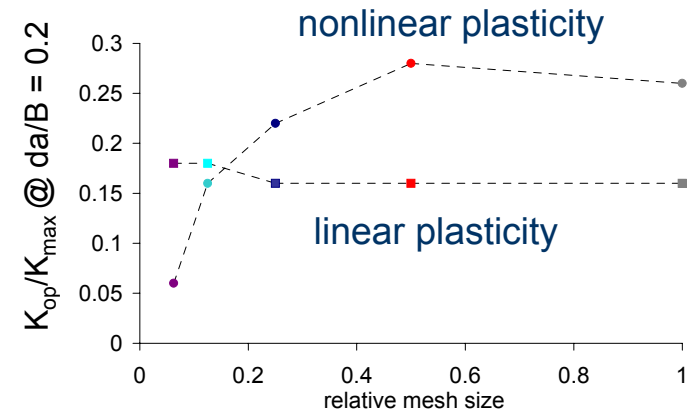
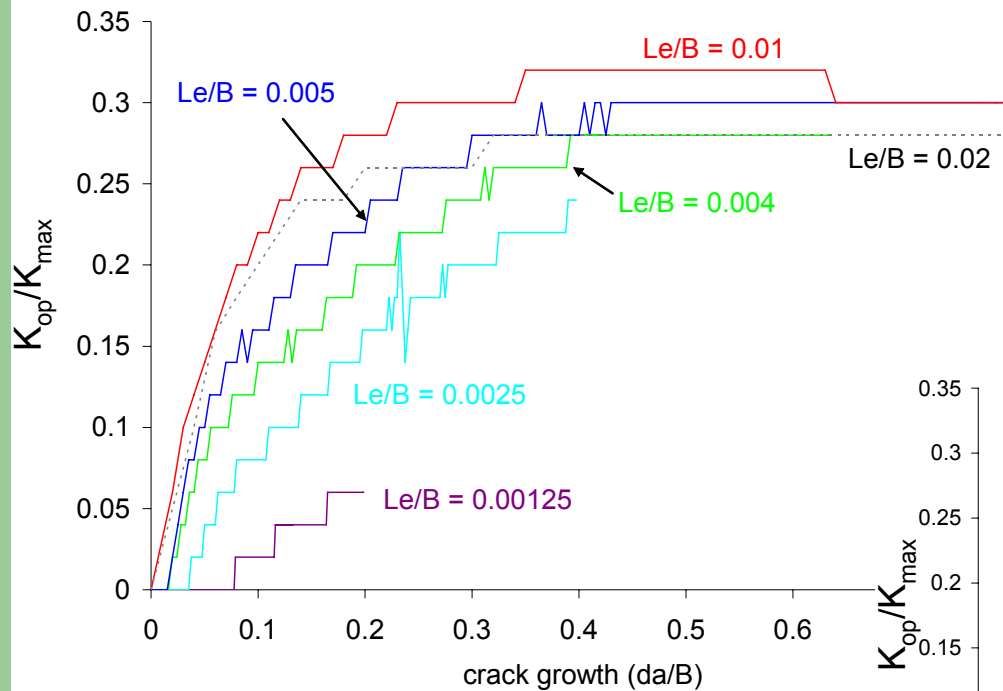
Ratcheting under nonsymmetric stress-controlled cycling



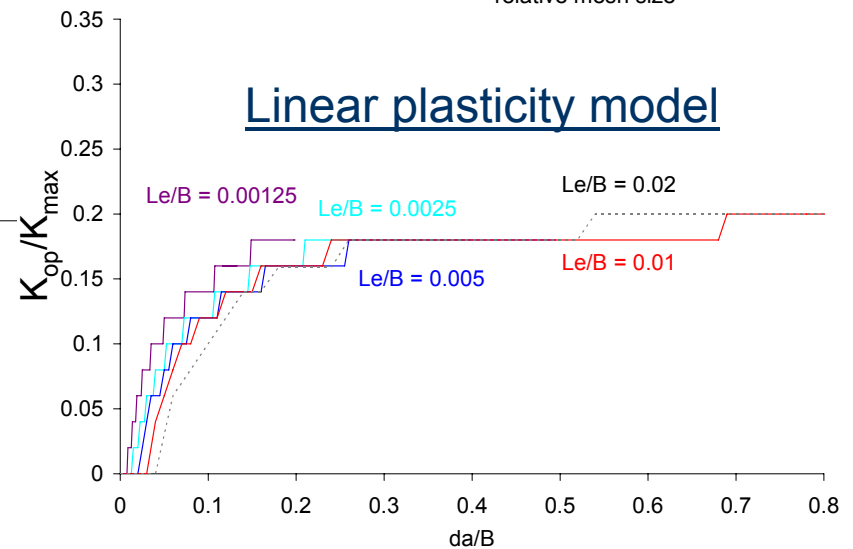
Relaxation of mean stress under nonsymmetric strain-controlled cycling

Mesh dependence – Opening loads

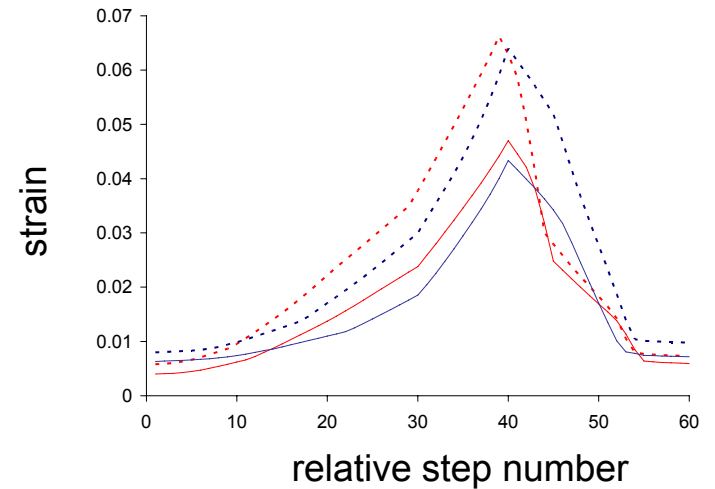
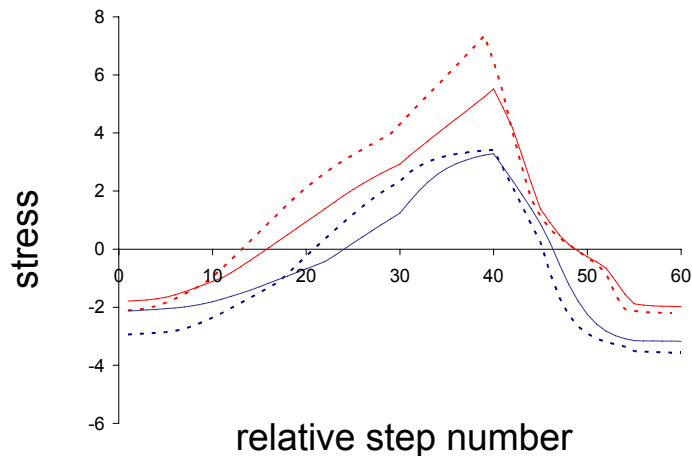
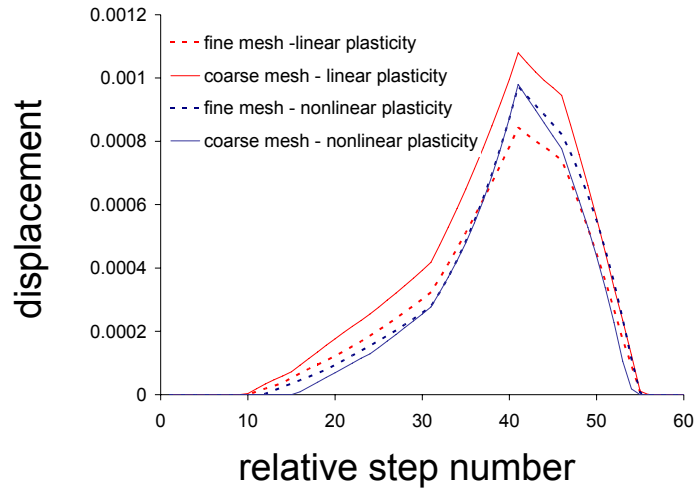
Nonlinear plasticity model



Linear plasticity model

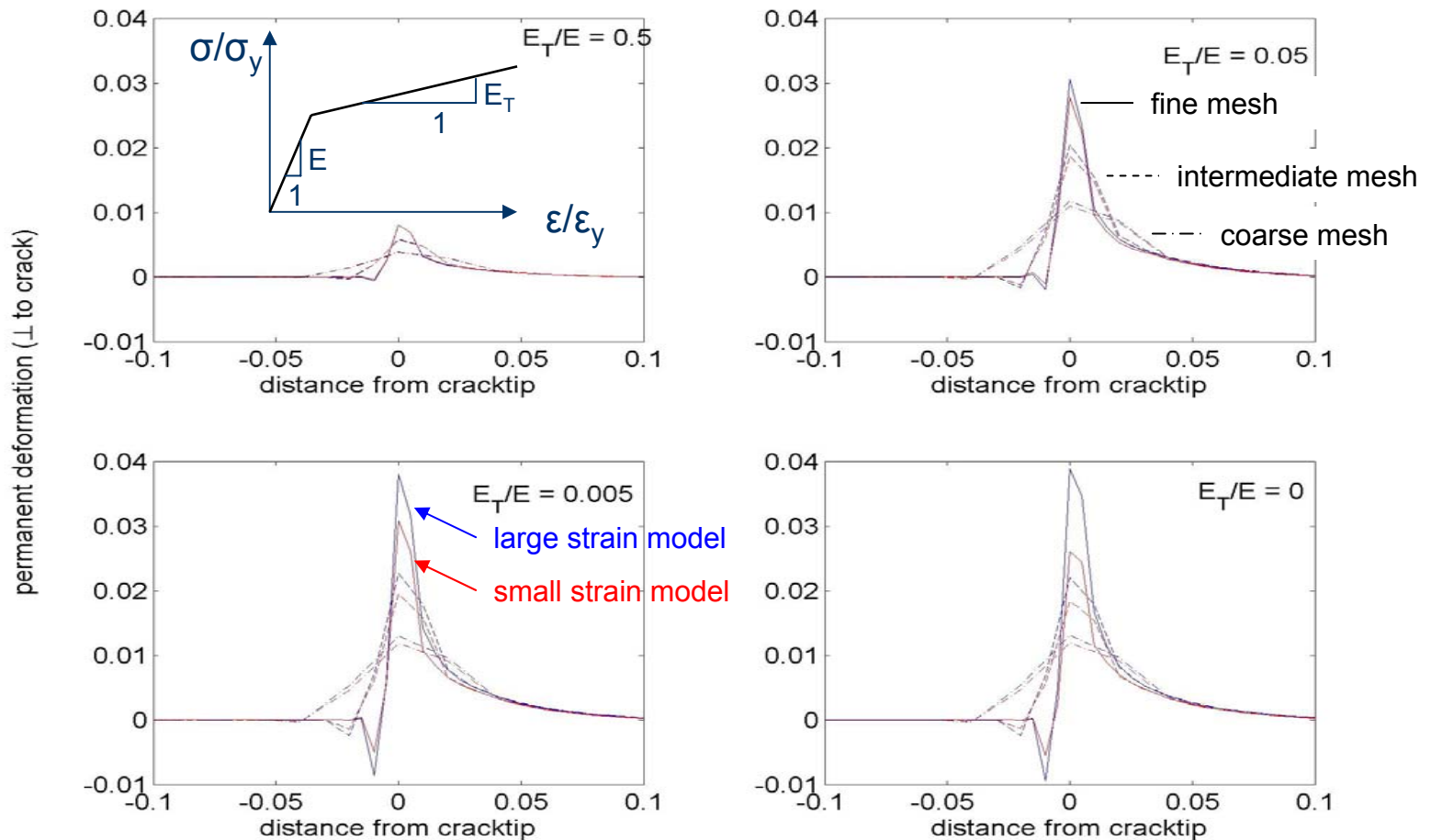


Mesh dependence of primary fields

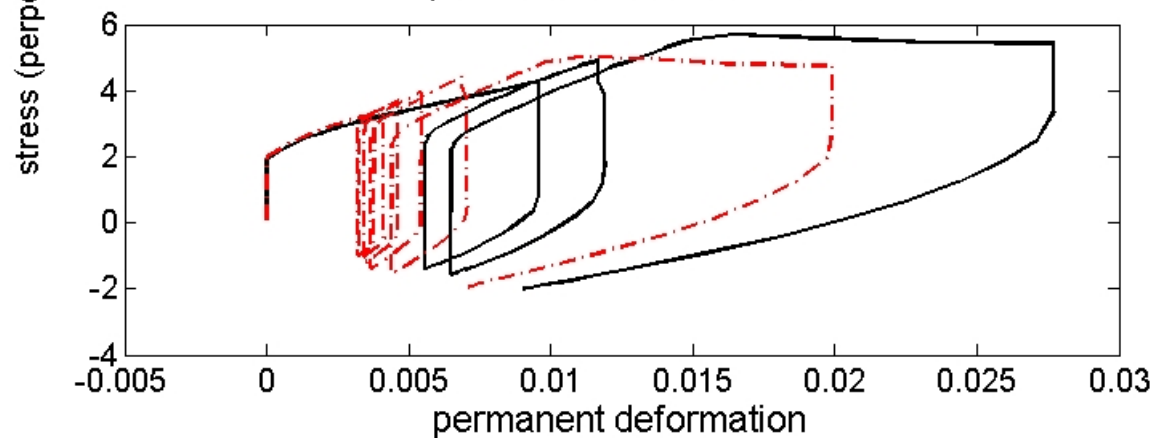
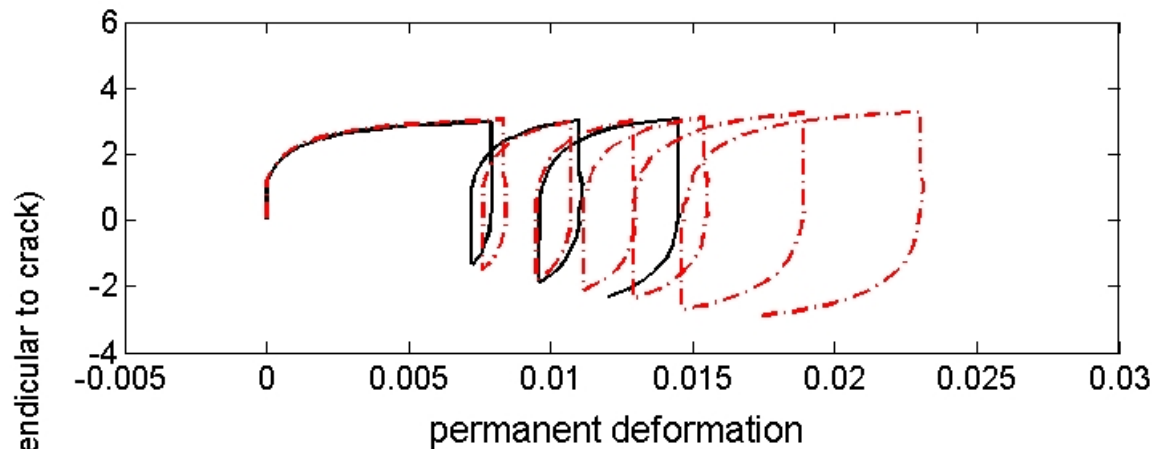


Displacement, stress, and strain measured perpendicular to crack at one integration point over one cycle

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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