AE 737: Mechanics of Damage Tolerance

Lecture 21-22 - Finite Elements

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schedule

- 12 Apr - Finite Elements in Fracture
- 14 Apr - Finite Elements in Fracture, HW 7 Due
- (19 Apr) Class Canceled
- 21 Apr - Exam Review
- 26 Apr - Exam 2

finite element techniques

finite element methods in fracture

- Direct method (use near-tip stress field)
  - Requires very fine mesh near the tip to be accurate
  - Can be made feasible with specialty elements

fem in fracture

- Crack closure method
  - An energy based method
  - Calculate energy to close crack one element away from crack tip
  - Can have a courser mesh than direct method

more information

- More information can be found in my AE837 Notes
  - direct method theory link[1]
  - direct method screencast demos link[2]

[1] https://ndaman.github.io/fracture/exam%202/lecture11.html
[2] https://ndaman.github.io/fracture/exam%202/lecture12.html

fem in fracture

- J-integral method
  - Many FE codes give a convenient method to calculate the J-integral
  - Learn about this in 837, but gives a mesh-independent way to calculate stress intensity
  - link[3]

[3] https://ndaman.github.io/fracture/exam%202/lecture13.html

fem in fracture

- Cohesive elements
  - Specialty elements act like an adhesive between two materials
  - Used to model crack propagation when crack path (and material behavior) are known

fem in fracture

- XFEM
  - eXtended Finite Element Method
  - Can predict crack growth in any direction
  - Adds extra physics model inside an element (fine mesh not necessarily required)

other advanced techniques

- peridynamics
- phase field
- remeshing

direct method

- We already know that the stress field near the crack tip is

$$\sigma_{yy} = \frac{K_I}{\sqrt{2\pi x}}$$

- We can solve this for K_I and we should (in theory) be able to calculate K_I
- We will get a unique K_I value for every point (x) along crack plane

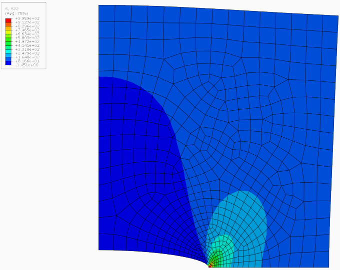
direct method

- For this method to be accurate, we need to capture the singularity at crack tip
- This requires a very fine mesh (computationally expensive)
- Alternatively, many FE packages include "singularity" elements which allow a coarse(r) mesh

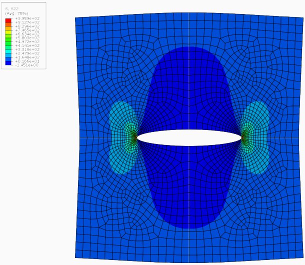
modeling tips

- Use symmetry in your model to reduce node count
- Center-crack can be modeled using on 1/4 of the model
- Use biased node seeding (more nodes near tip)

symmetry



symmetry



analyzing results

- If our results are accurate, we should be able to calculate the same K_I at any point
- To ensure convergence, we plot the calculated K_I vs. x (distance from crack tip)
- In the region where this plot is a horizontal line, we consider a converged K_I

analyzing results

- It is also possible to consider the crack opening displacement

$$u_y = \frac{K_I(\kappa + 1)}{4G\pi}\sqrt{-2\pi x}$$

- Where κ is to easily differentiate between plane stress and plane strain

$$\kappa = 3 - 4\nu \quad \text{(plane strain)}$$
$$\kappa = \frac{3 - \nu}{1 + \nu} \quad \text{(plane stress)}$$

a few other examples

- Mixed-mode fracture link[4]
- Plasticity link[5]

[4] https://ndaman.github.io/fracture/exam%202/lecture16.html
[5] https://ndaman.github.io/fracture/exam%202/plasticity.html