FAILURE OF NOTCHED LAMINATES UNDER OUT-OF-PLANE BENDING

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The Joint Advanced Materials and Structures Center of Excellence

Failure of Notched Laminates Under Out-of-Plane Bending

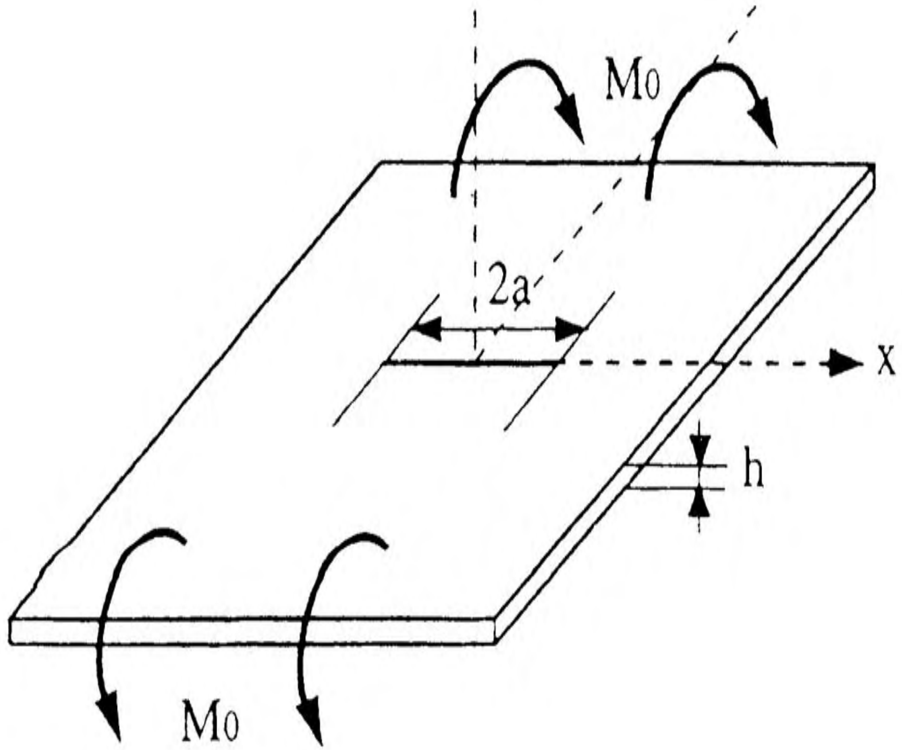
- Motivation and Key Issues
  - Design tools for composite aircraft structure subjected to out-of-plane loading
- Objective
  - Determine the modes of failure and evaluate the capability of current models to predict failure
- Approach
  - Four-point Bending Tests
  - Stress Concentration Factor Calculations
  - Progressive Damage Modeling

FAA Sponsored Project Information

- Principal Investigators & Researchers
  -Tim Kennedy & Sergio Gonzalez
- FAA Technical Monitor
  - Curt Davies and Lynn Pham
- Other FAA Personnel Involved
  - Larry Ilcewicz
- Industry Participation
  - Gerry Mabson (Boeing)
  - Tom Walker (NSE Composites)

Bending of a Notched Laminate

Notch Lengths: 2a = 1 inch & 2a = 4 inches



Test Specimens

BMS 8-276 Carbon Fiber Tape

Laminate Types

- **10% 0° Plies**
- **30% 0° Plies**
- **50% 0° Plies**

Laminate Thicknesses

- **20 plies Thick**
- **40 plies Thick**

Notch Lengths

- **1 inch**
- **4 inches**

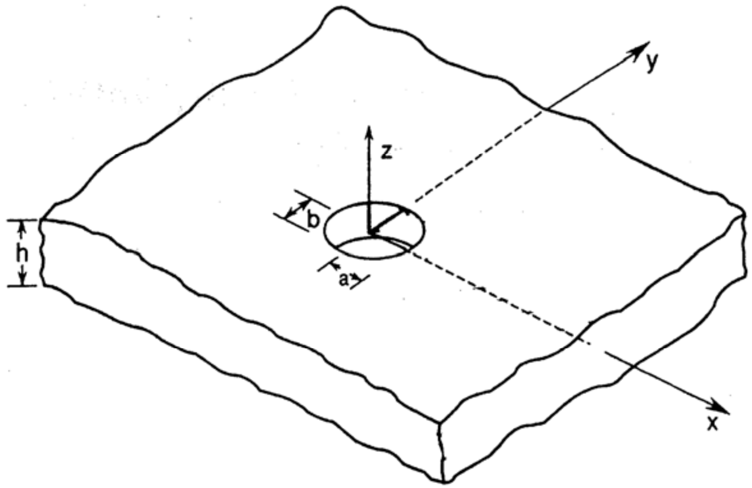
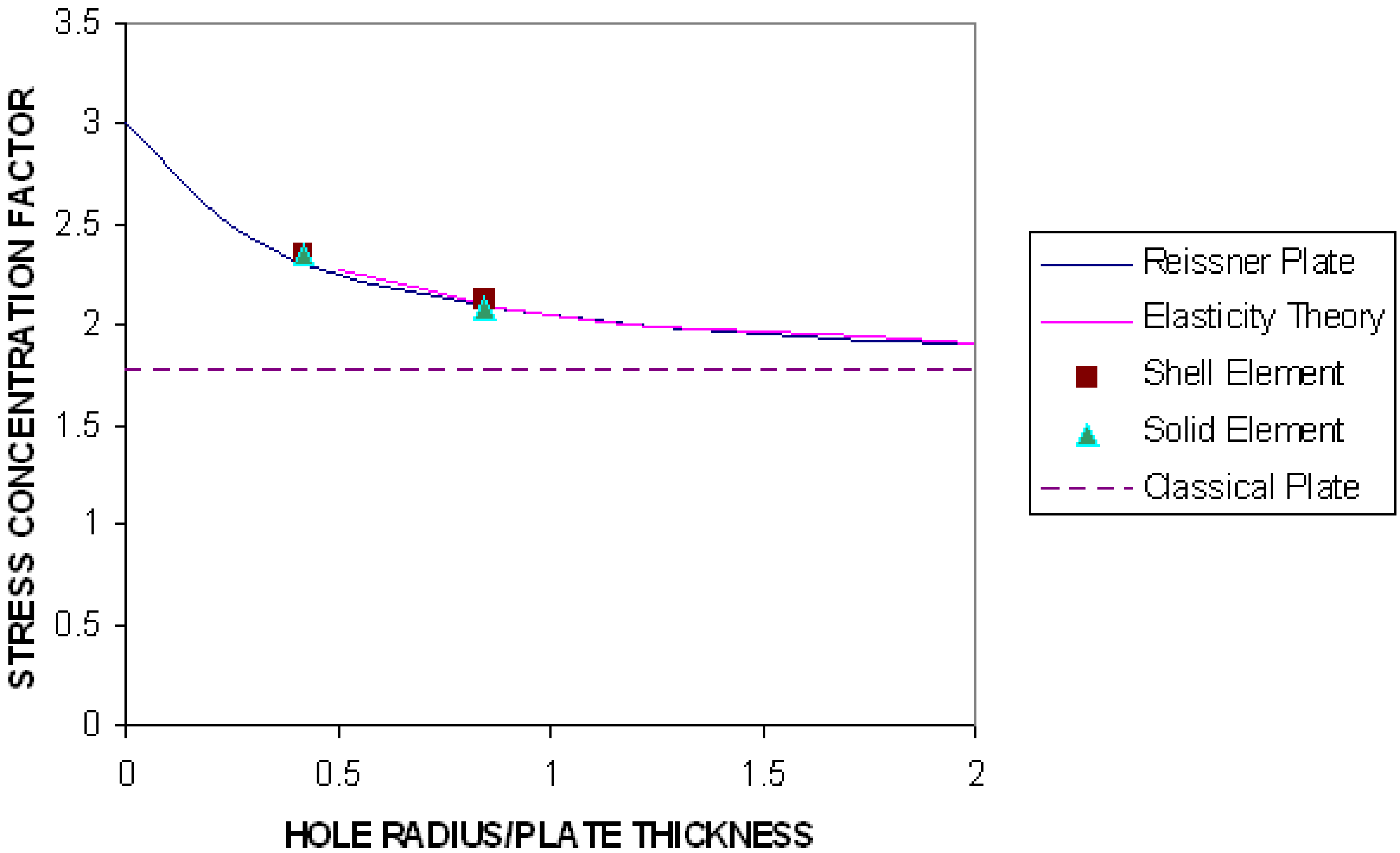
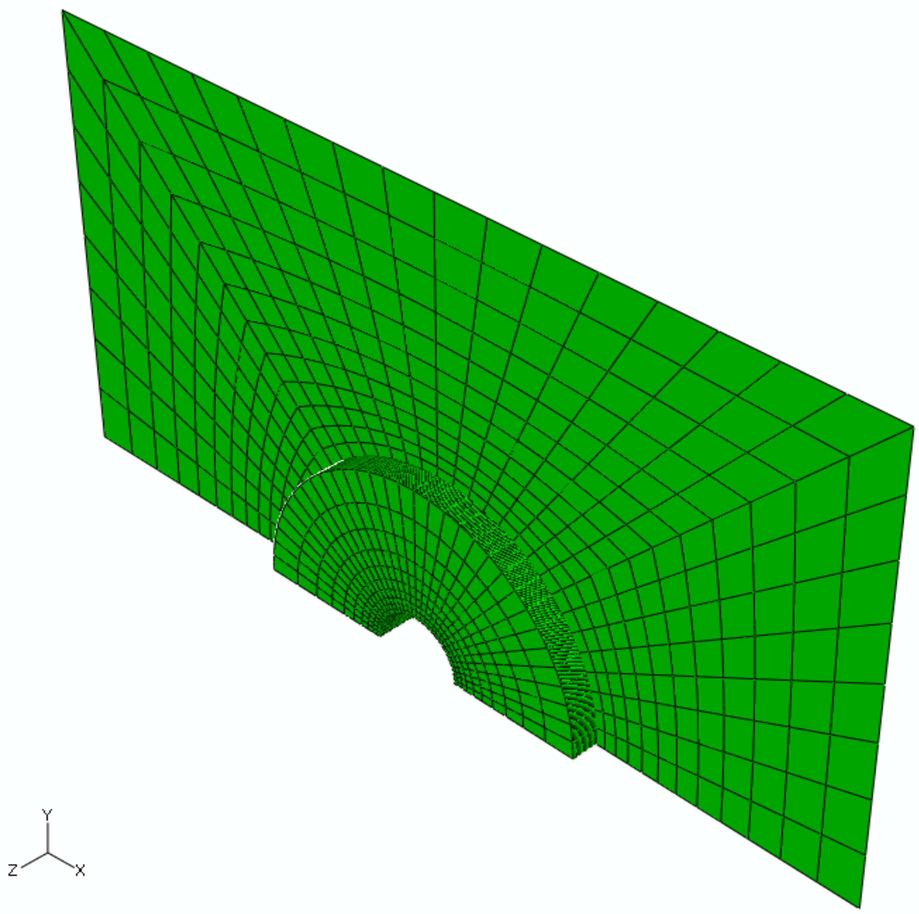


Plate Theory
- Without transverse shear effects (CPT)
- With transverse shear effects (RPT)

Stress Concentration Around a Circular Hole



Mesh for 0.25-in Diameter Hole



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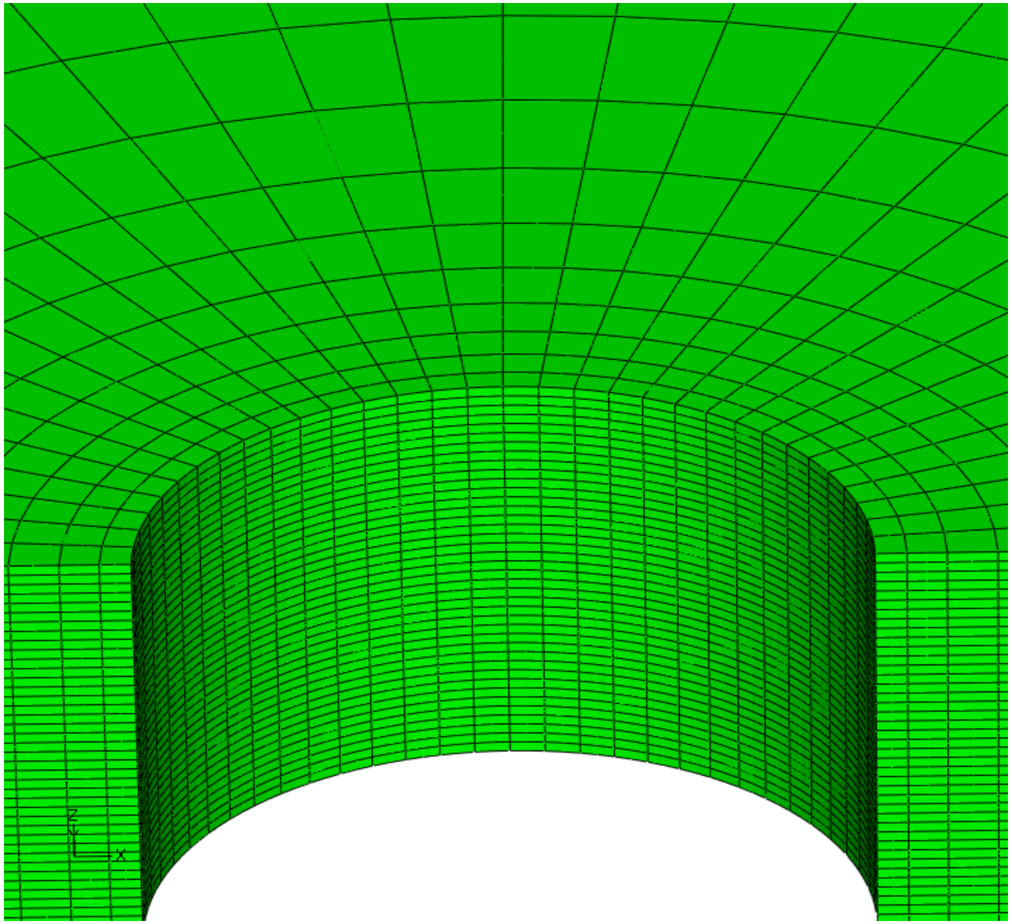
3-D Solid Elements Around Hole



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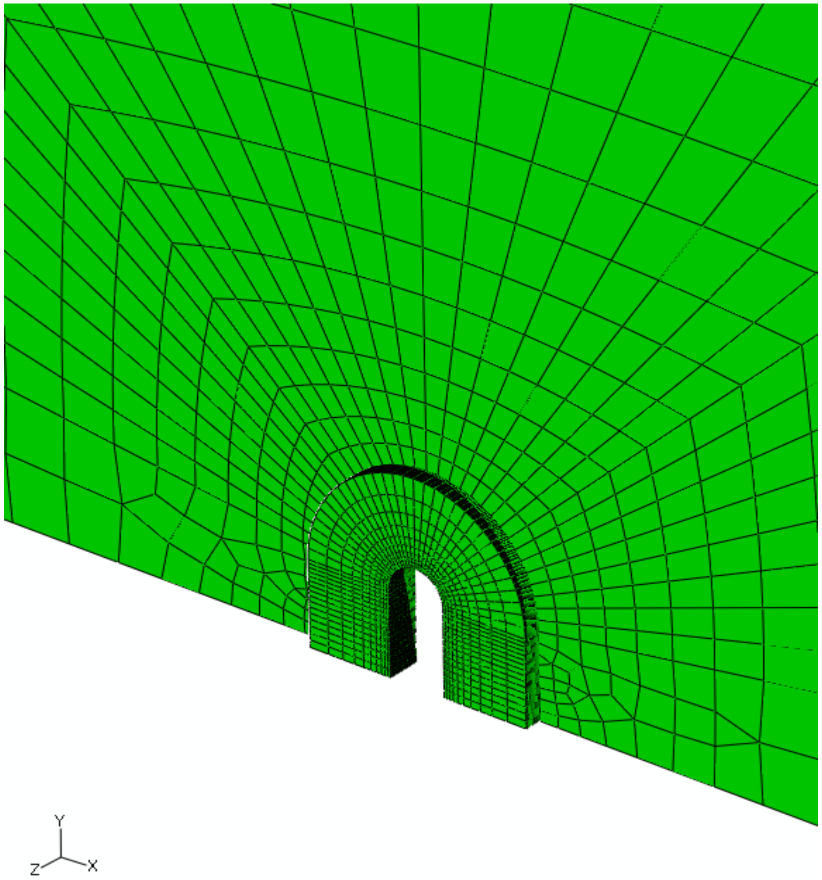
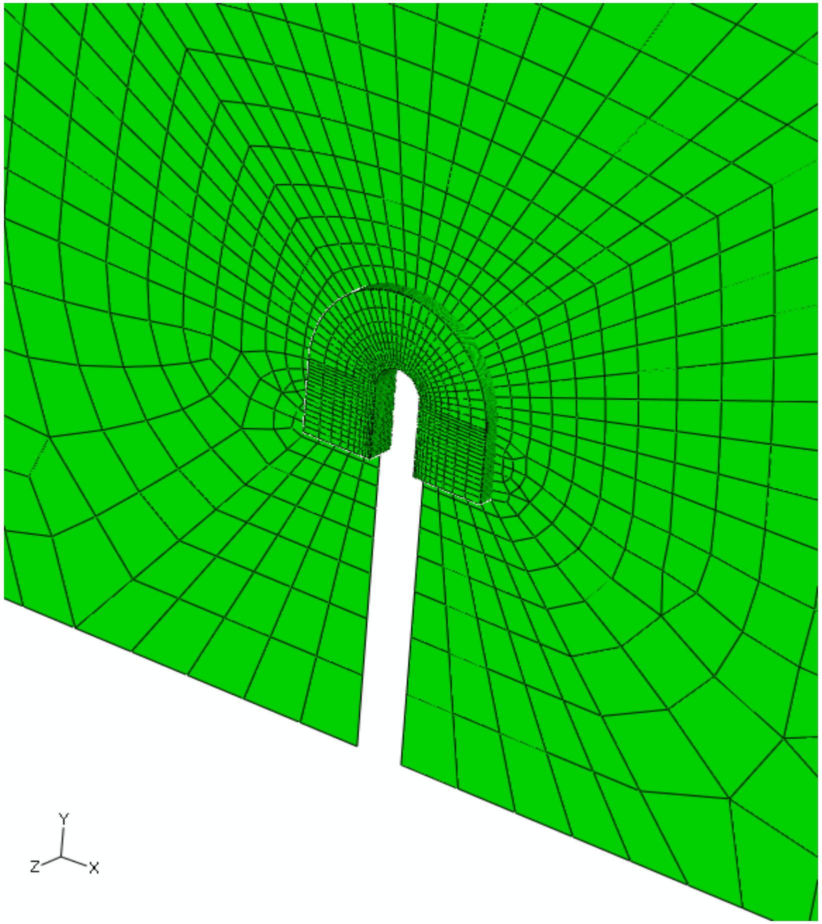
Mesh for 1–in Long Notch



Mesh for 4-in Long Notch



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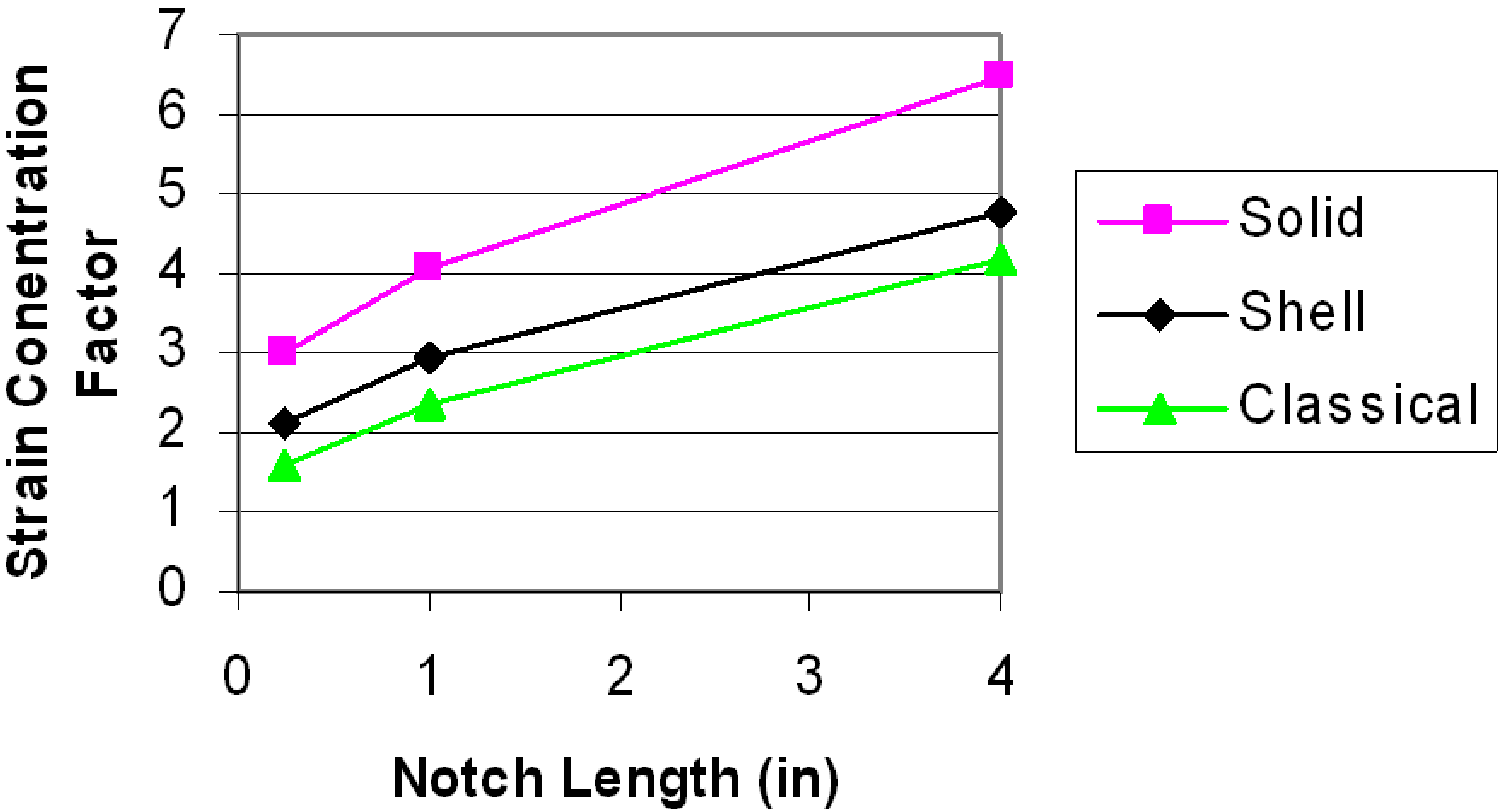
Design for Membrane Loading

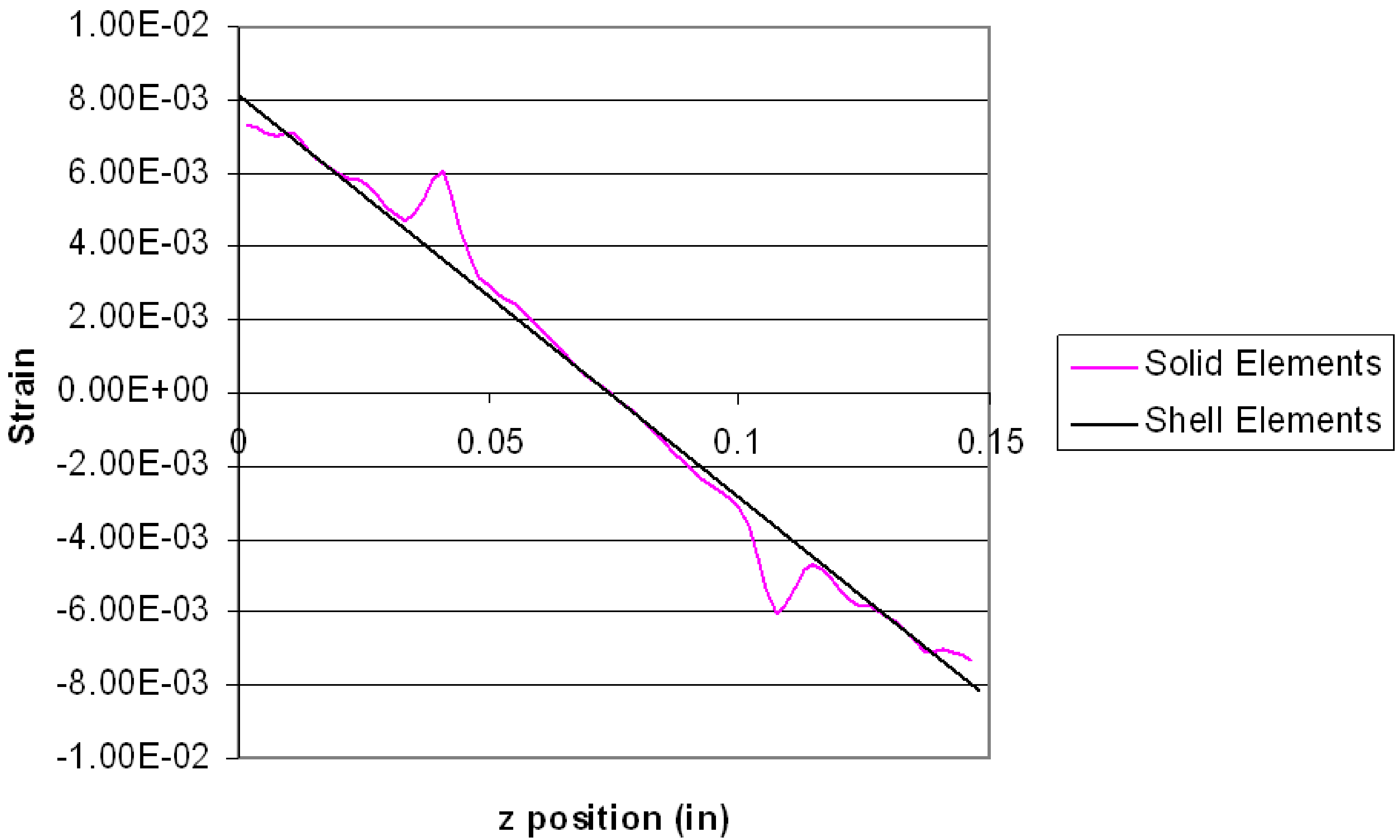
Far Field Strain $\varepsilon_{allowable} = a + b/K + c/K^2$

K = Strain Concentration Factor at Hole

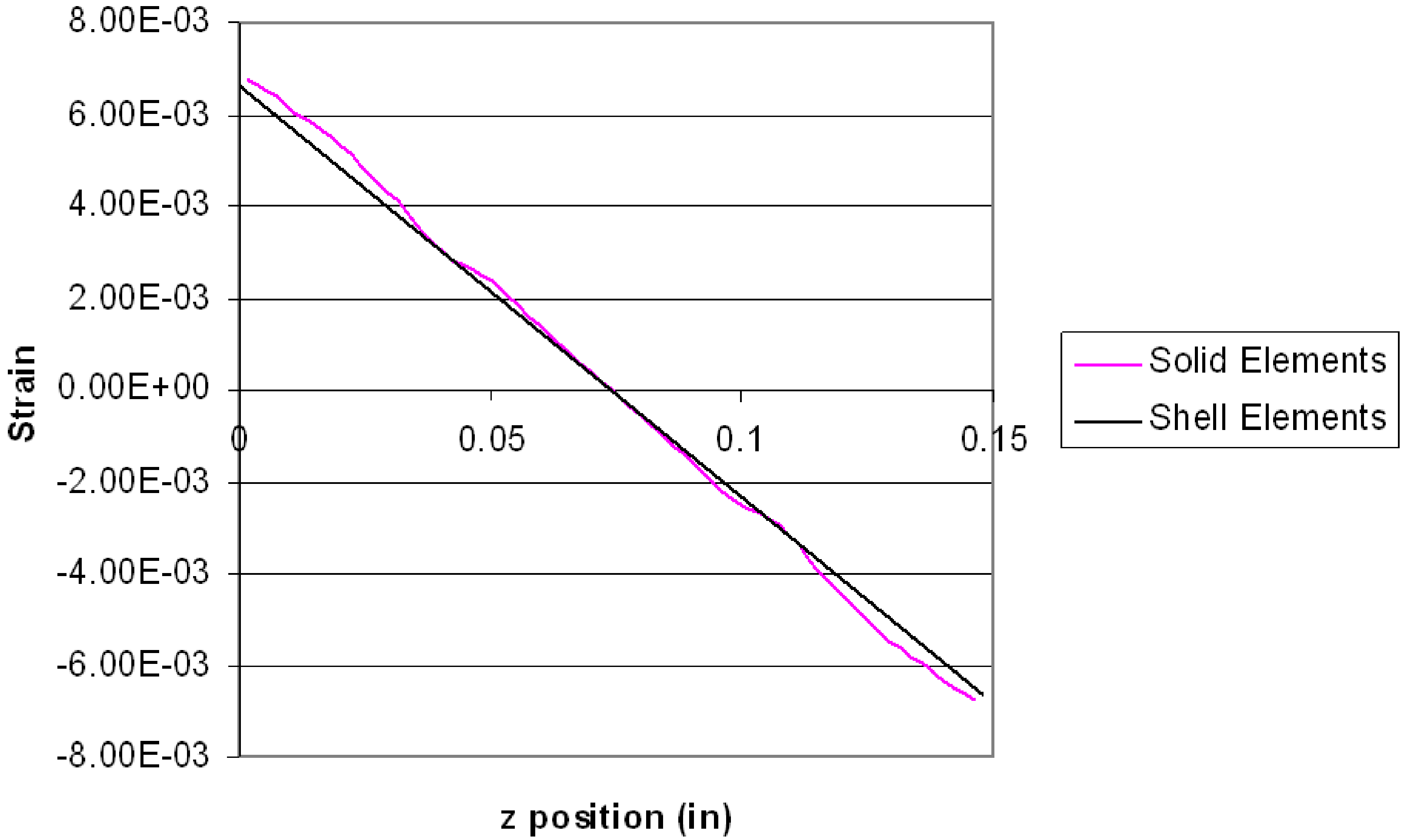
20 Plies with 10% 0-degree



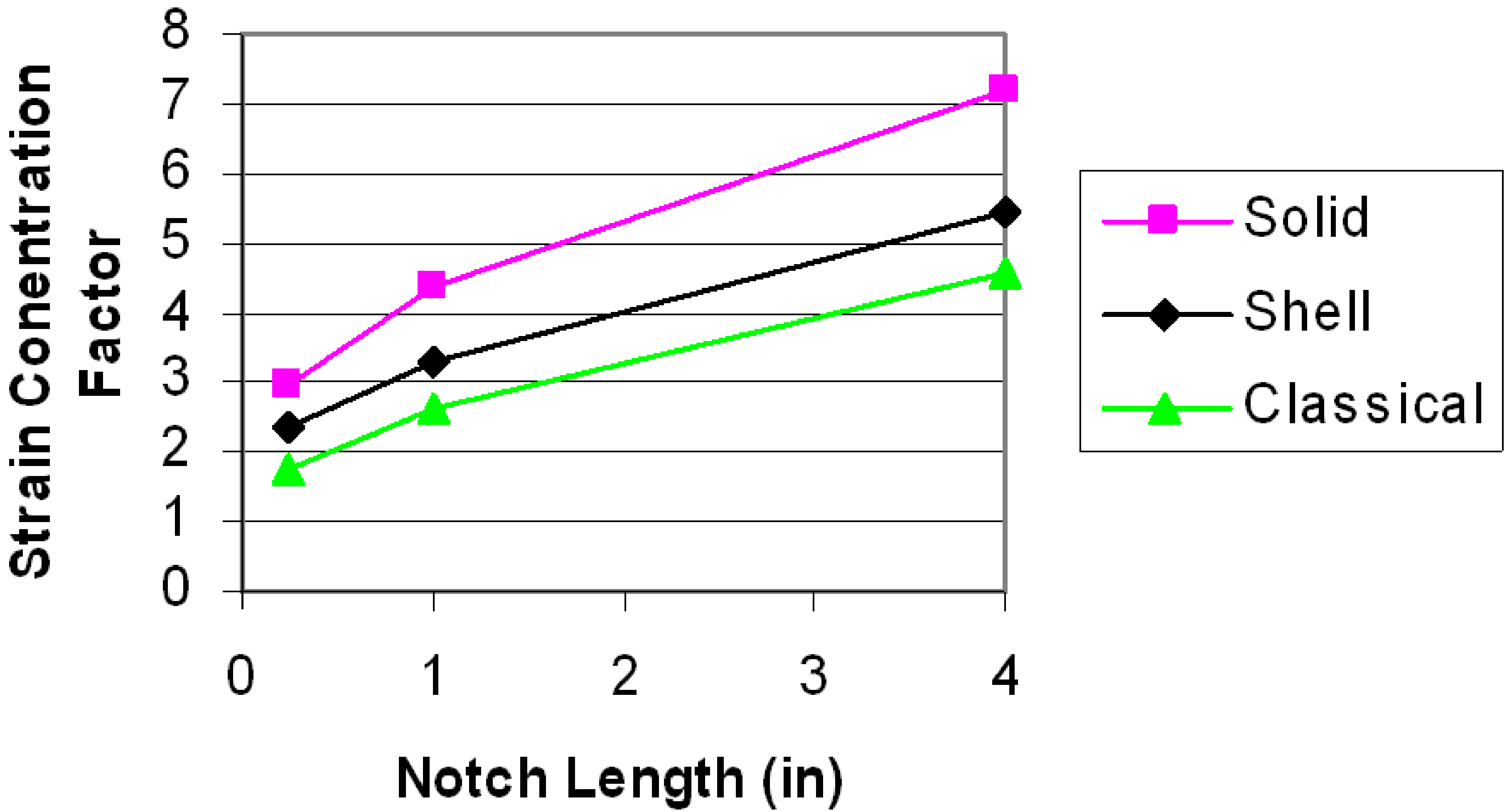
Strain Distribution Through Thickness at Hole



Strain Distribution Through Thickness Near Hole



20 Plies with 30% 0-degree



Conclusions on Strain Concentration Factors

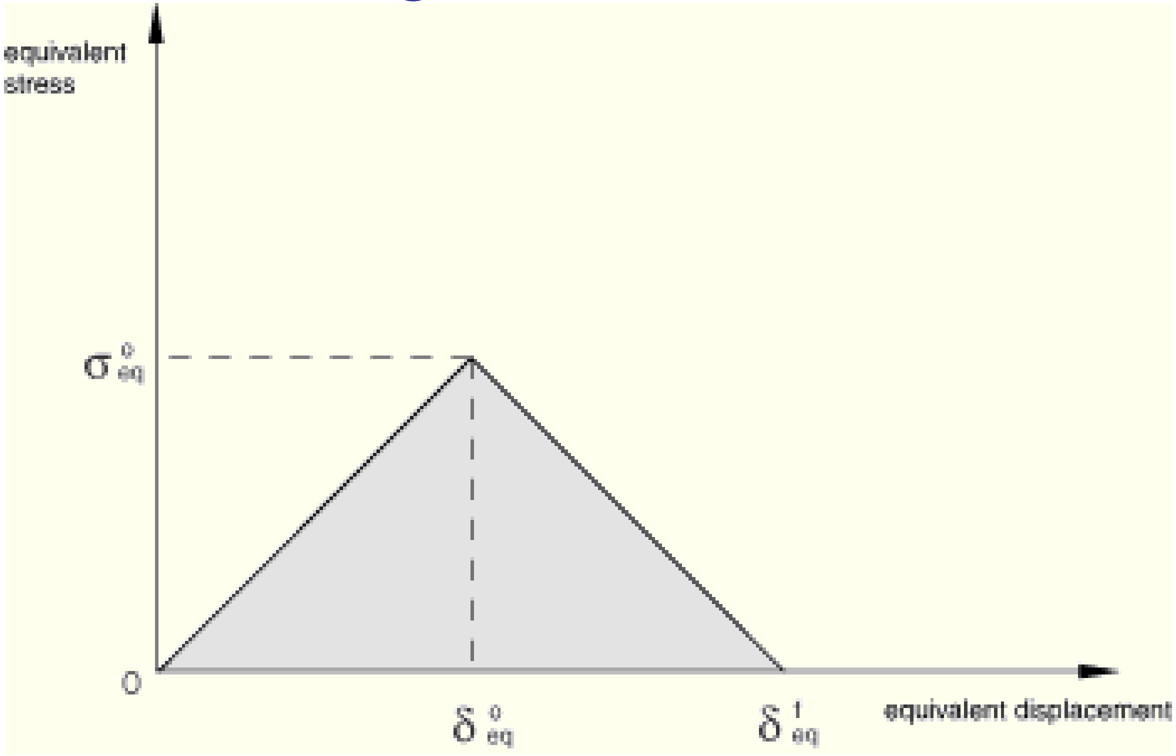
- Classical plate theory under-predicts strain concentration factors
- 3-D effects have an influence at the edge of the notch

ABAQUS Progressive Damage Model

- Damage Initiation – Hashin Theory
  - Fiber Tension
  - Fiber Compression
  - Matrix Tension
  - Matrix Compression

Damage Evolution

Strain Softening



Damage Evolution

- Damage Parameters: d_f, d_m, d_s

$$\mathbf{C_d} = \frac{1}{D}\begin{bmatrix} (1-d_f)E_1 & (1-d_f)(1-d_m)\nu_{21}E_1 & 0 \\ (1-d_f)(1-d_m)\nu_{12}E_2 & (1-d_m)E_2 & 0 \\ 0 & 0 & (1-d_s)GD \end{bmatrix},$$

4-Point Bending Test Fixture

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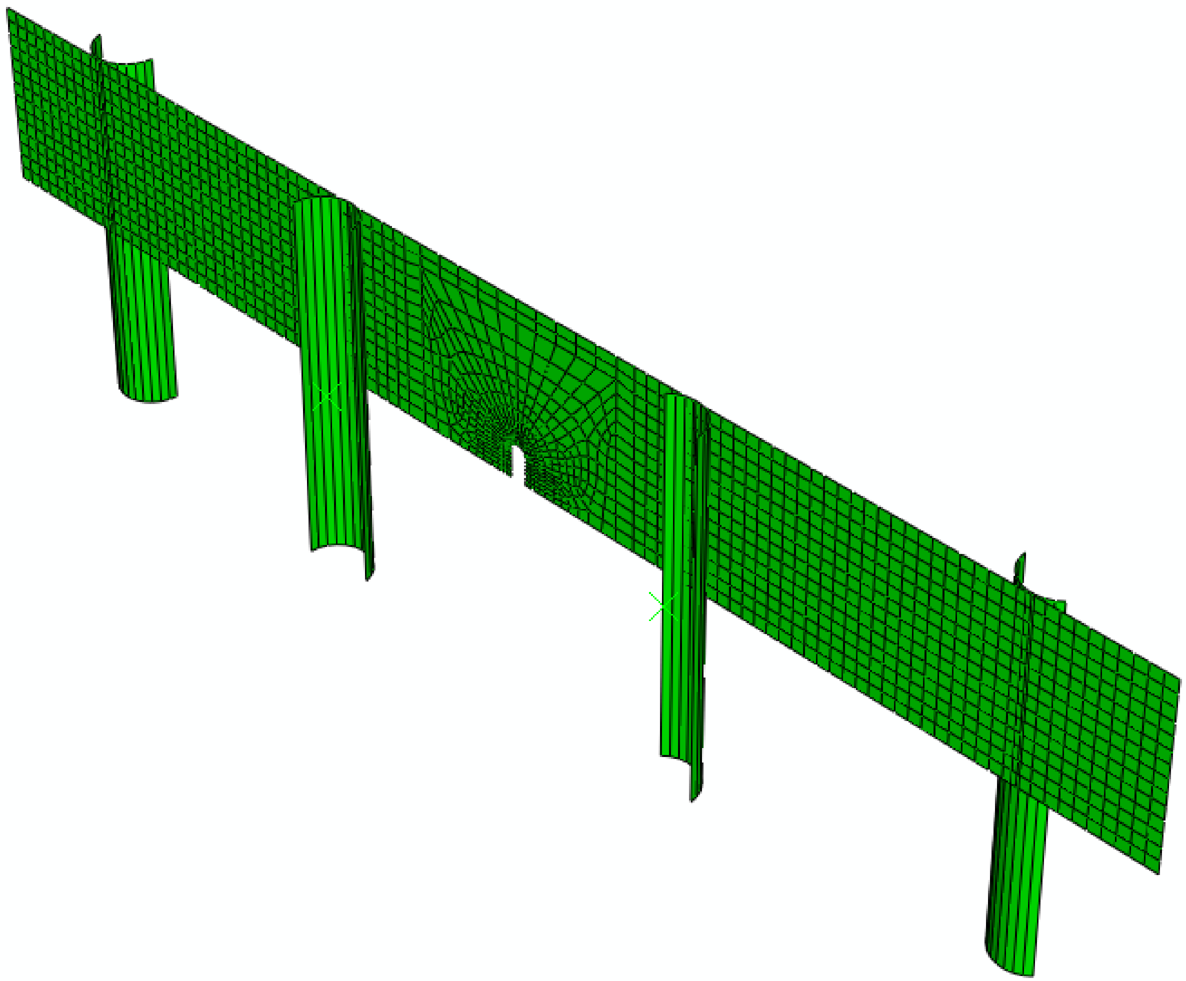
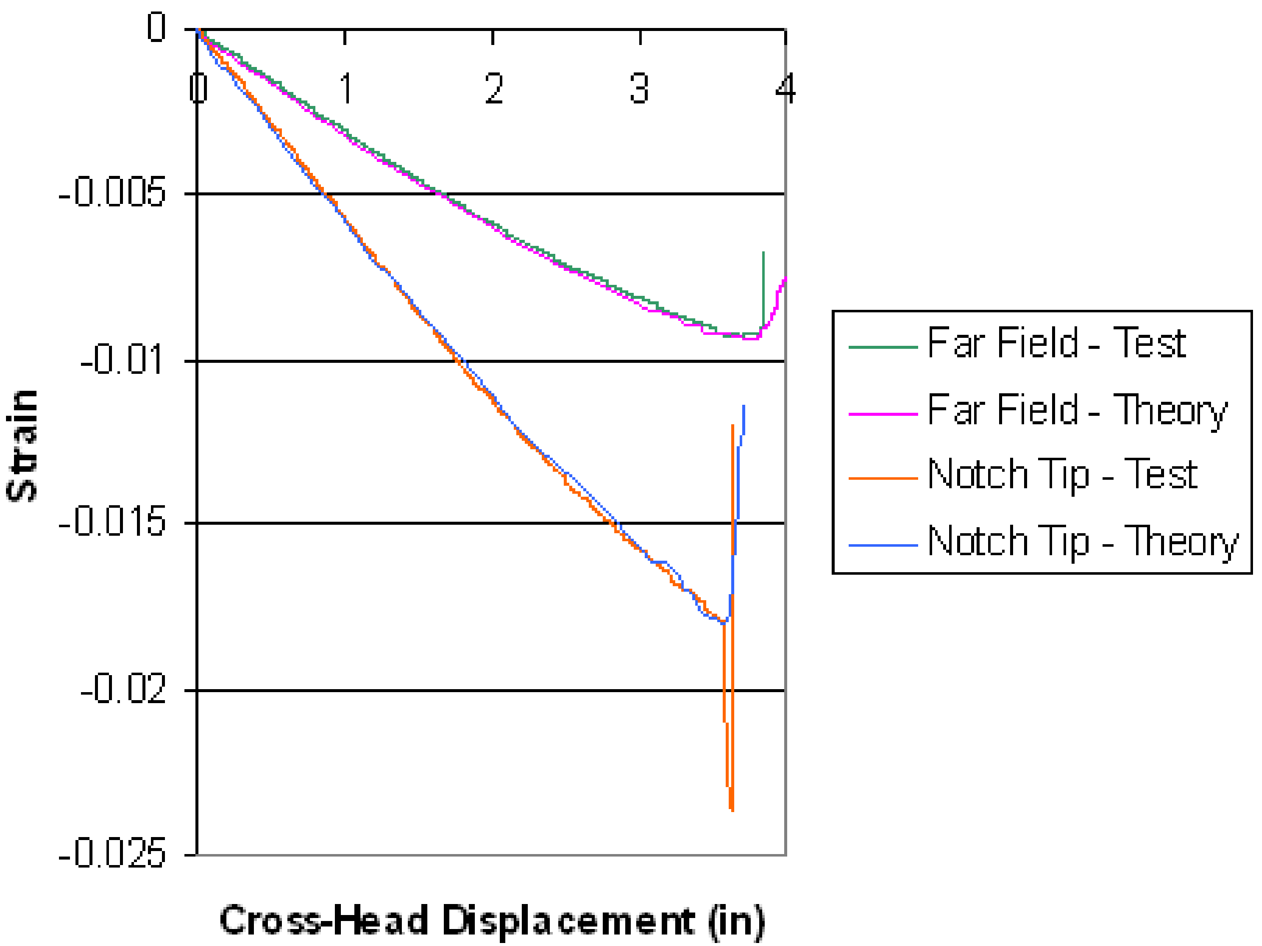
Simulation of the 4-point Bend Test



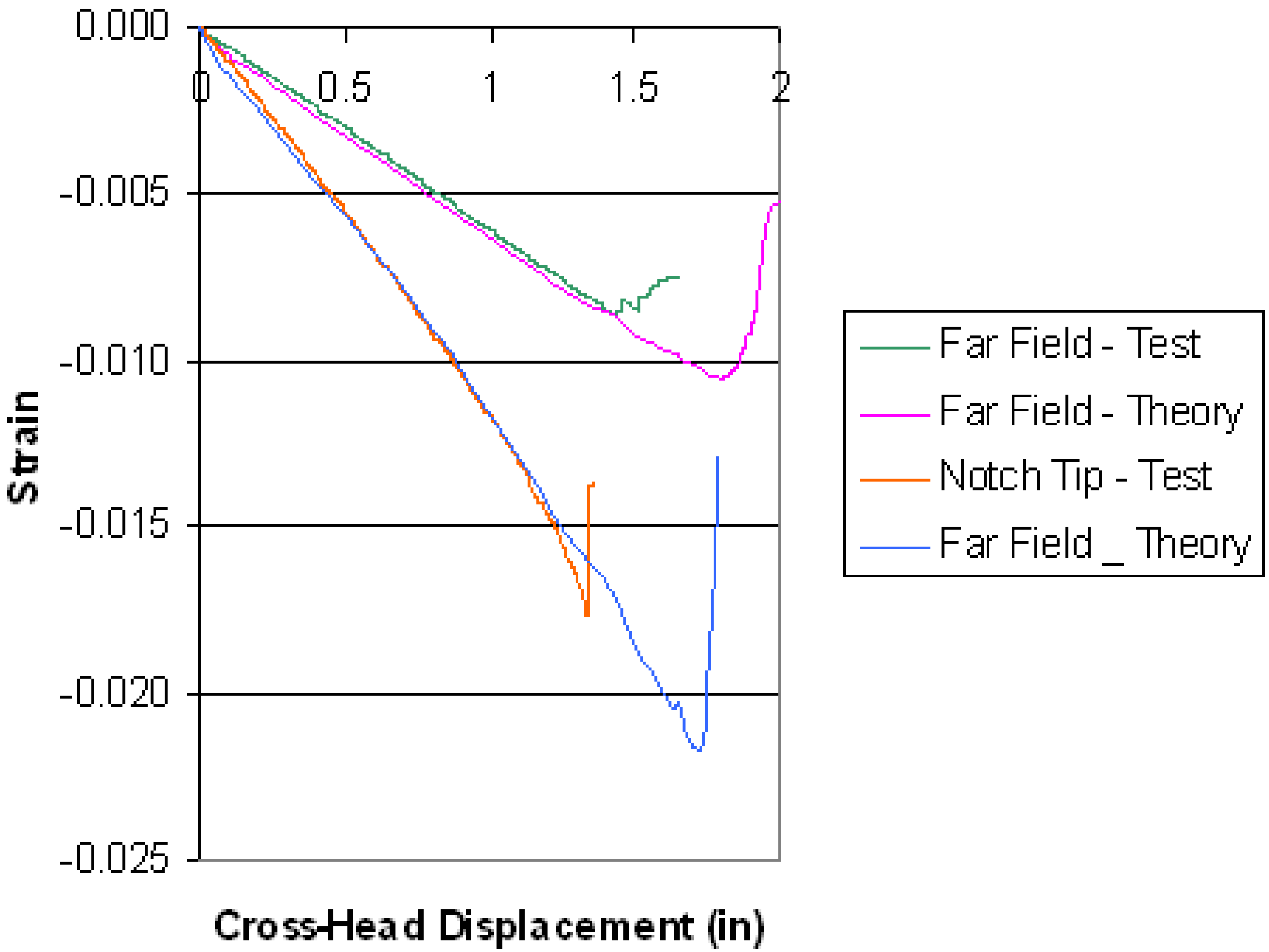
Laminate Test Matrix

Laminate	% 0-deg plies	No. of Plies	Notch Length	Test Completed
F1	10	20	1 in	
P1	30	20	1 in	X
N1	50	20	1 in	X
F*1	10	40	1 in	X
AR1	30	40	1 in	X
AN1	50	40	1 in	X
F4	10	20	4 in	
P4	30	20	4 in	X
N4	50	20	4 in	X
F*4	10	40	4 in	
AR4	30	40	4 in	
AN4	50	40	4in	

Strain Growth in Laminate P



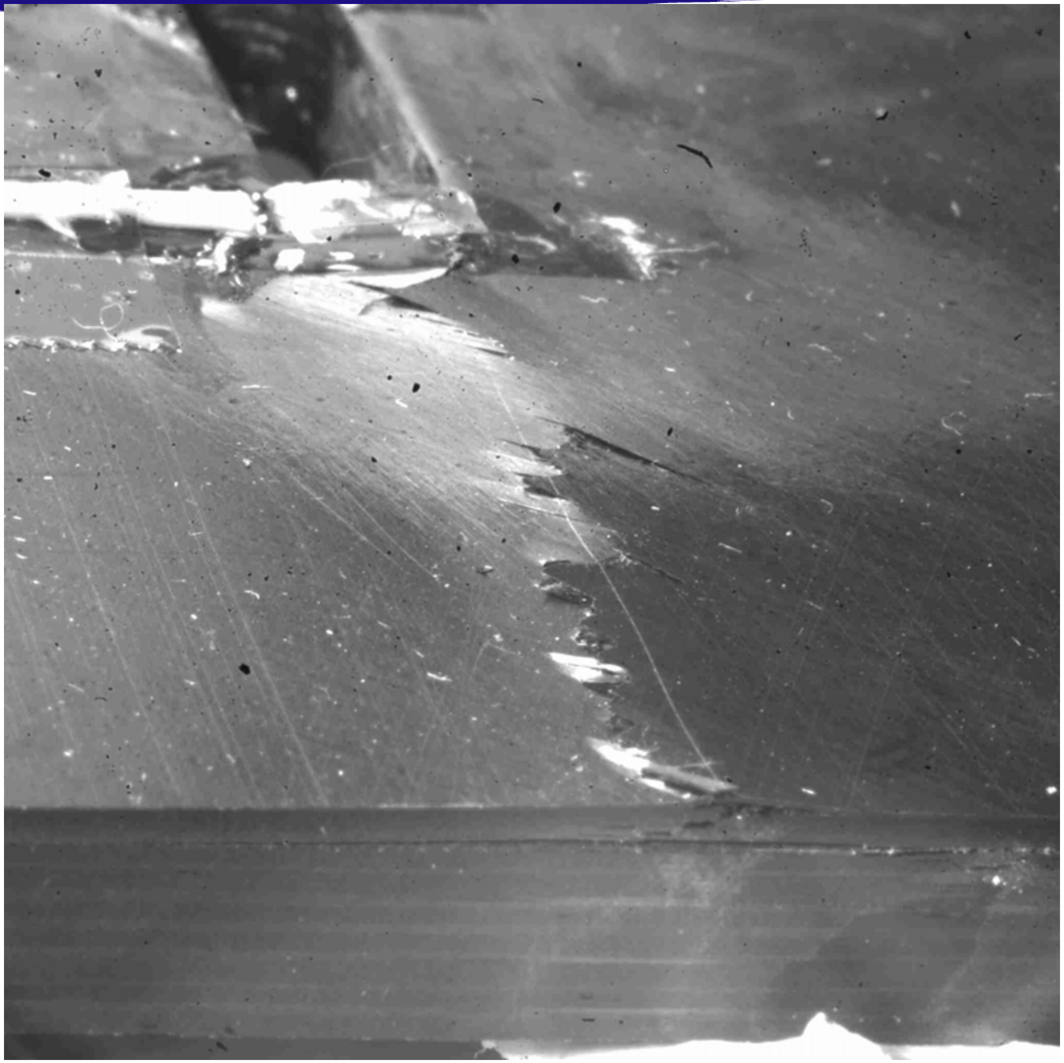
Strain Growth In Laminate F*



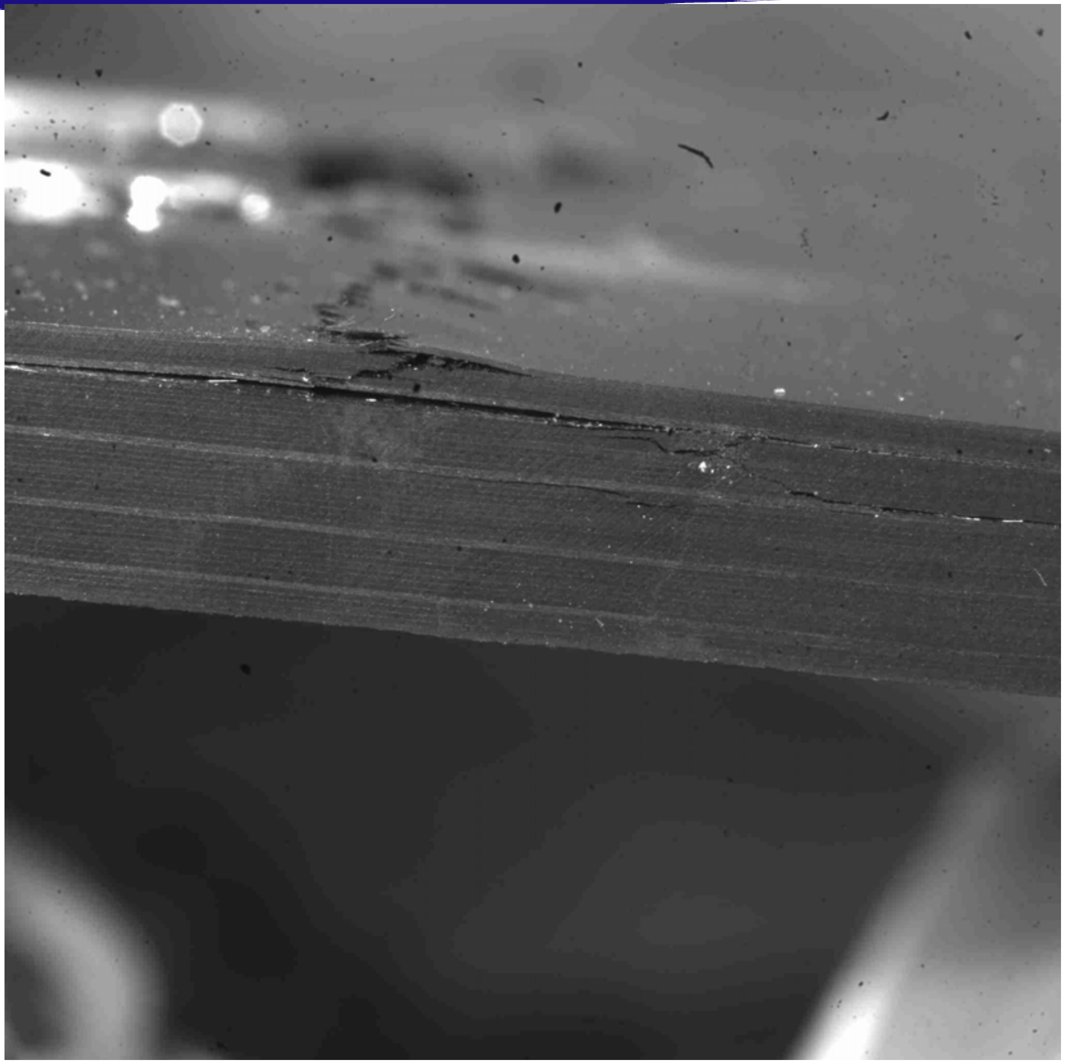
Laminate Failure Moment

Laminate	Test Failure Moment	Theory Failure Moment	Difference
P1	192 in-lb/in	189 in-lb/in	1.6%
N1	263 in-lb/in	273 in-lb/in	3.8%
F*1	634 in-lb/in	747 in-lb/in	17.8%
AR1	712 in-lb/in	960 in-lb/in	34.8%
AN1	901 in-lb/in	1272 in-lb/in	41.1%
P4	168 in-lb/in	165 in-lb/in	1.8%
N4	224 in-lb/in	222 in-lb/in	0.9%

Compression Side Failure



Compression Side Failure



A Look Forward

- Remaining Work to Complete Project
  - – 41 Four-point Bending Tests
  - – Damage Model with Delamination

Questions?