Failure of Notched Laminates Under Out-of-plane Bending

Tim Kennedy, Oregon State University
Presentation at the 11/5/09 AMTAS Meeting

FAA Technical Monitors: Curt Davies & Lynn Pham

Industrial Sponsor: Boeing Commercial Airplane Company

Technical Advisers:
Gerry Mabson, Boeing
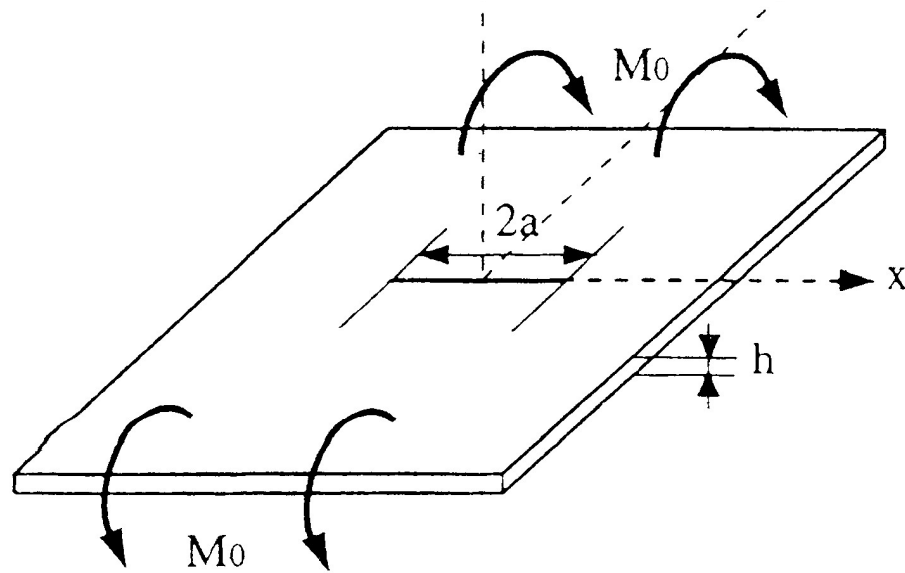**Tom Walker, NSE Composites**
Larry Ilcewicz, FAA

Objective: For out-of-plane bending of notched laminates, determine the modes of failure and evaluate the capability of current models to predict failure

Experiments: Four-point bending

Modeling: Progressive Damage Development

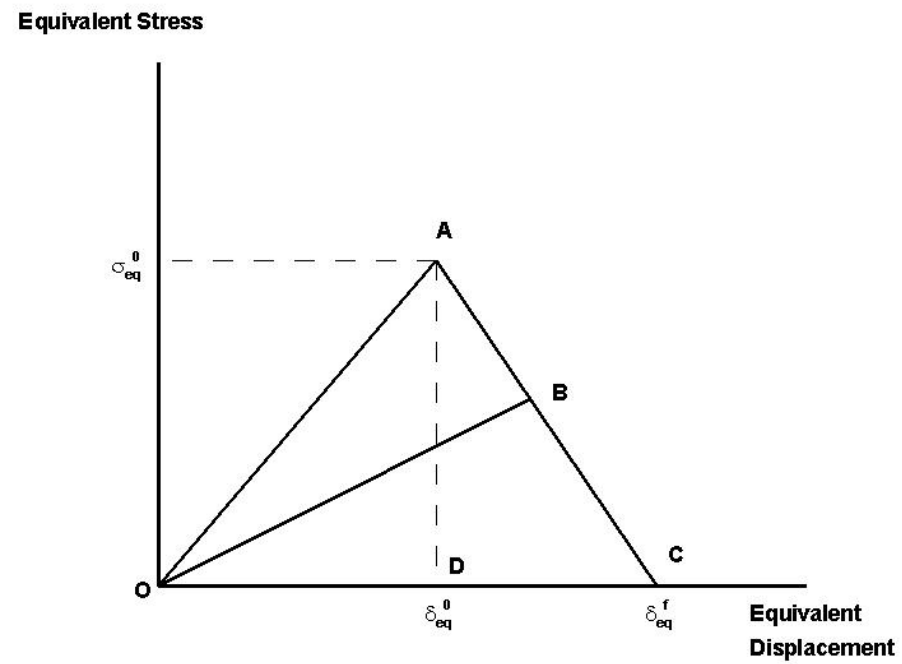# Experiments: Four-point Bending Tests

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

ABAQUS Progressive Damage Model

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

Damage Evolution

Strain Softening

Sensitivity Study of Damage Model Parameters

Strengths (Damage Initiation)

X_T, X_C = tension and compression longitudinal strengths

Y_T, Y_C = tension and compression transverse strengths

S_L, S_T = longitudinal and transverse shear strengths

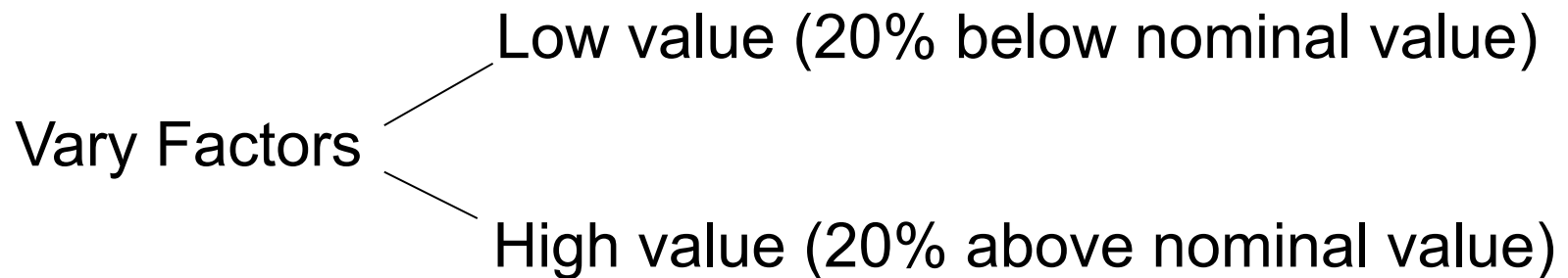**Dissipation Energies (Damage Evolution)**

G_{LTc}, G_{LCc} = longitudinal tension and compression
            dissipation energy rates

G_{TTc}, G_{TCc} = transverse tension and compression
            dissipation energy rates

Design Of Experiments Methodology

Response – Failure Load Under Bending

10 Factors - $X_T, X_C, Y_T, Y_C, S_L, S_T, G_{LTc}, G_{LCc}, G_{TTc}, G_{TCc}$

Low value (20% below nominal value)

Vary Factors

High value (20% above nominal value)

Full Factorial 2^{10} = 1024 Numerical Experiments

Fractional Factorial 2^{10-6} = 16 Numerical Experiments
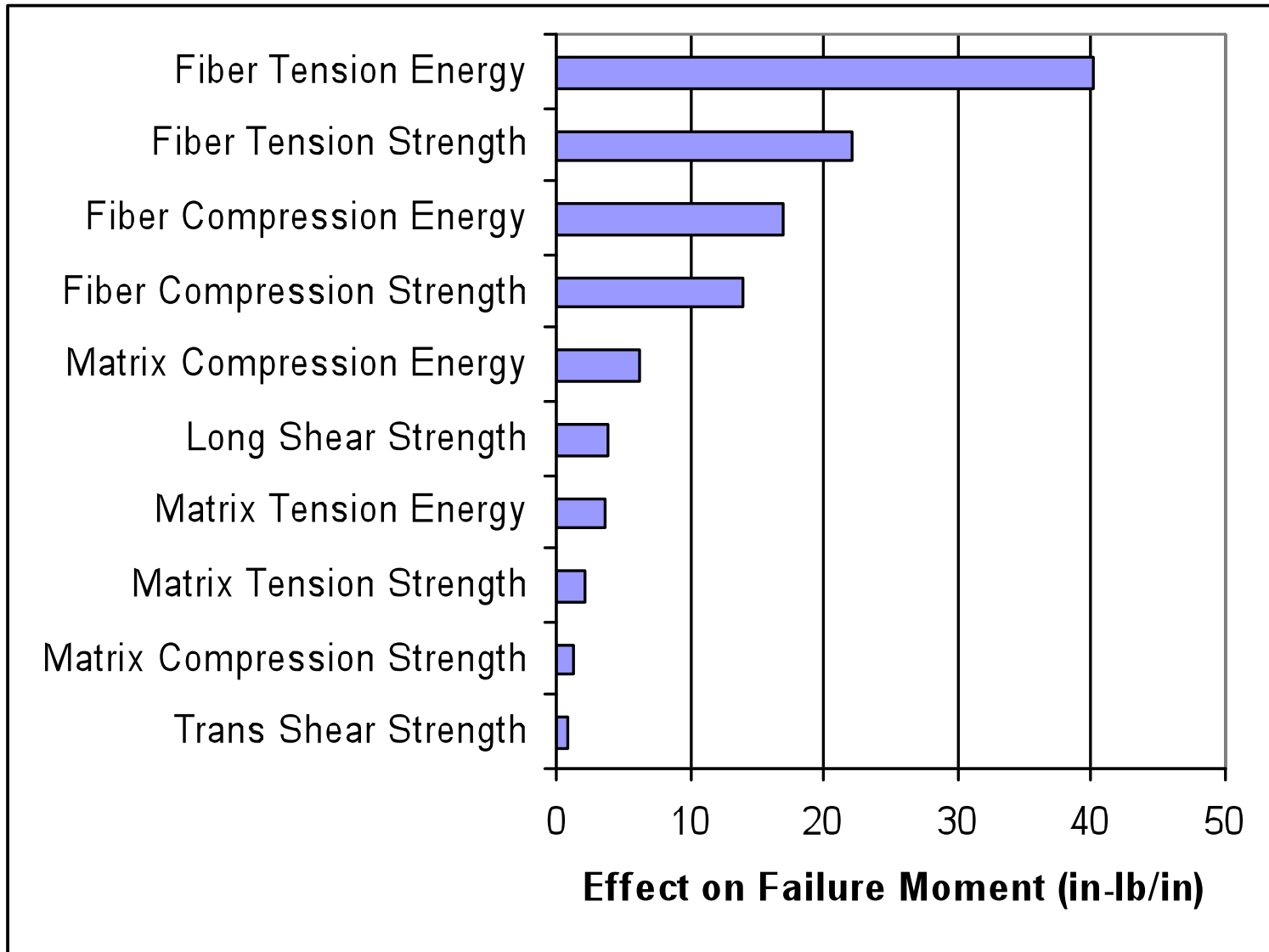
Carbon Fiber/ Epoxy Matrix Composite (T300/913)

20-ply Laminate [-45/0/0/45/90/-45/0/0/45/90]$_s$

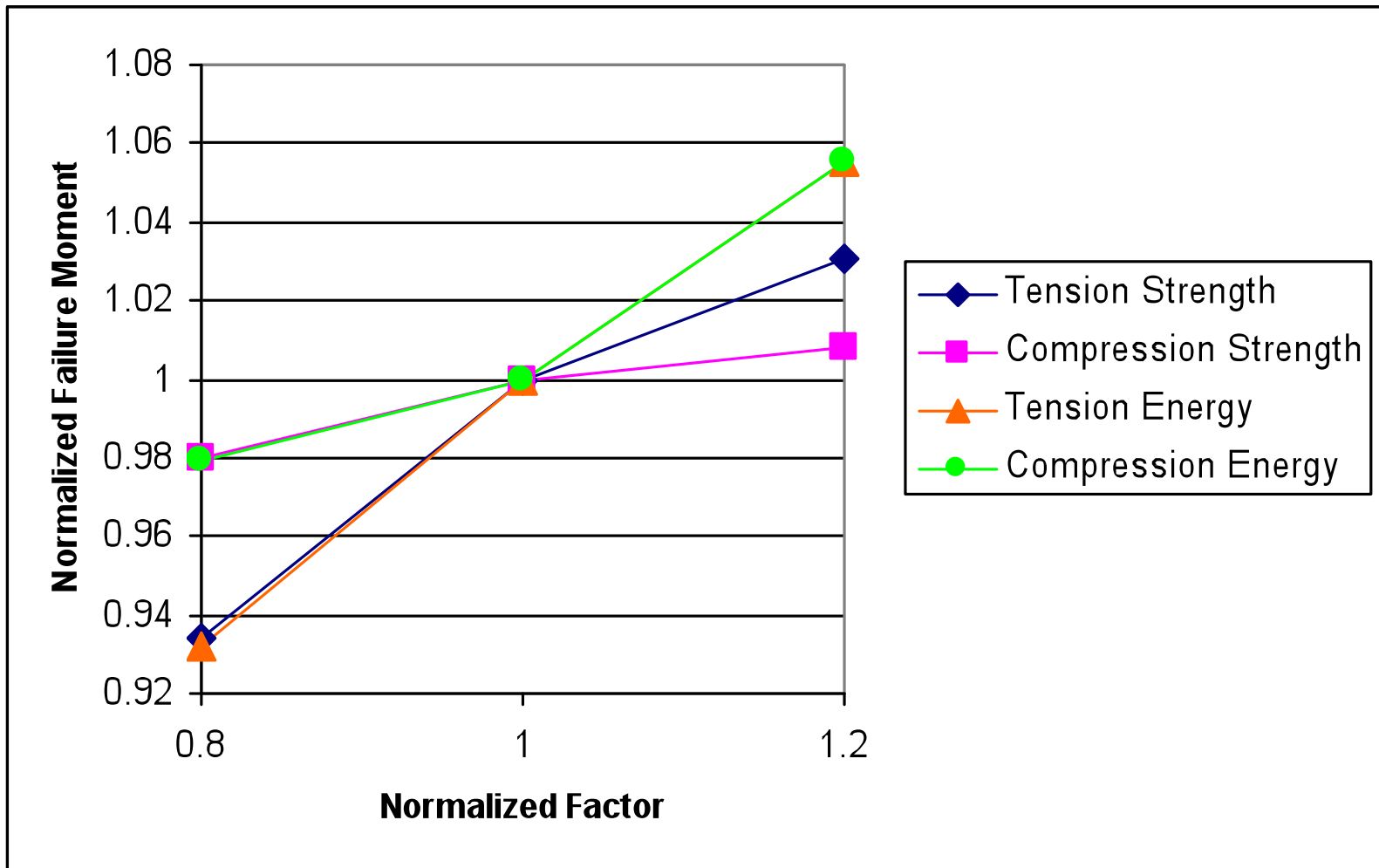Bending Stiffness D_{11} = 3473 in-lb, D_{22} = 1602 in-lb

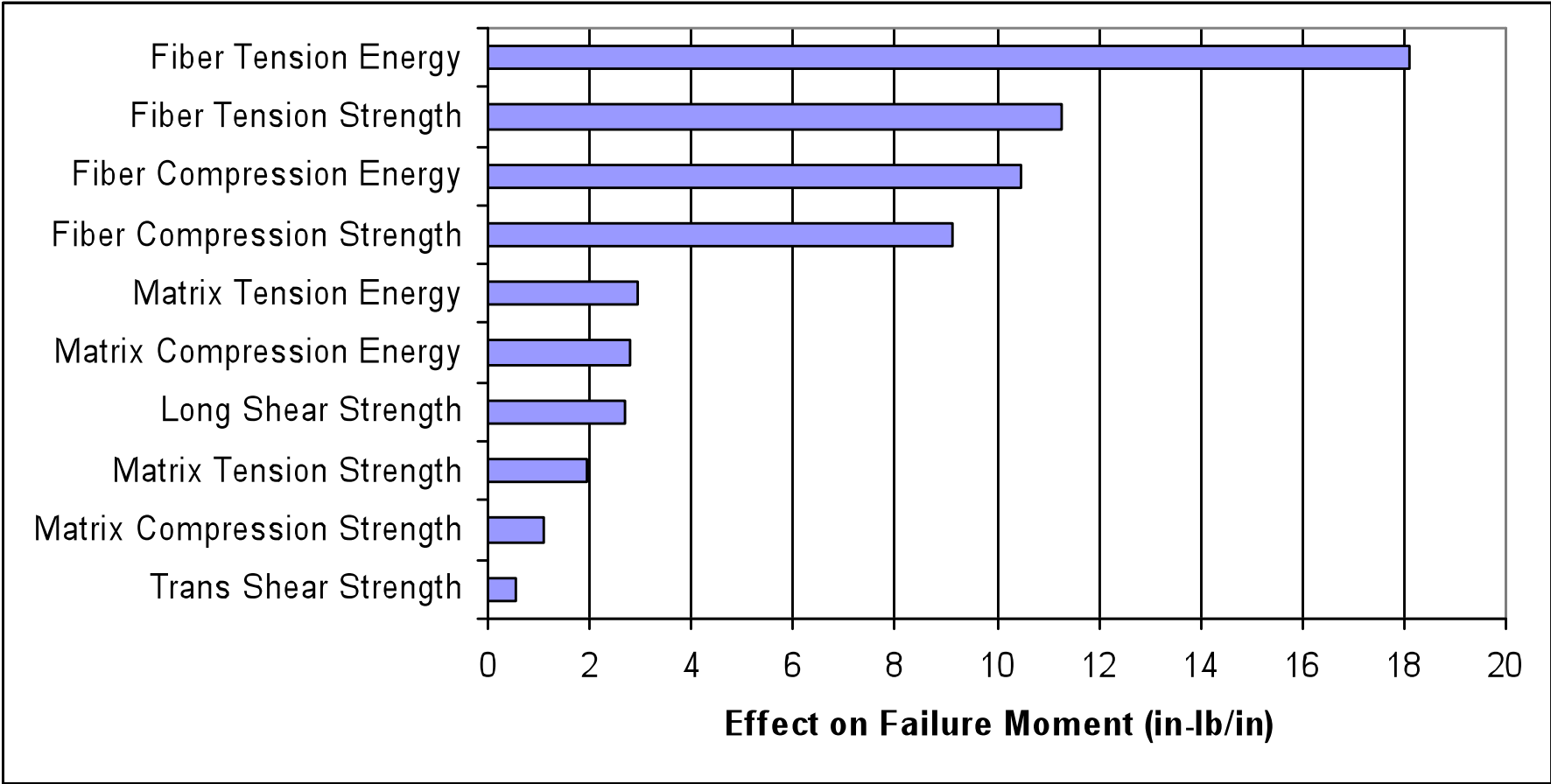Test both stiff and soft directions

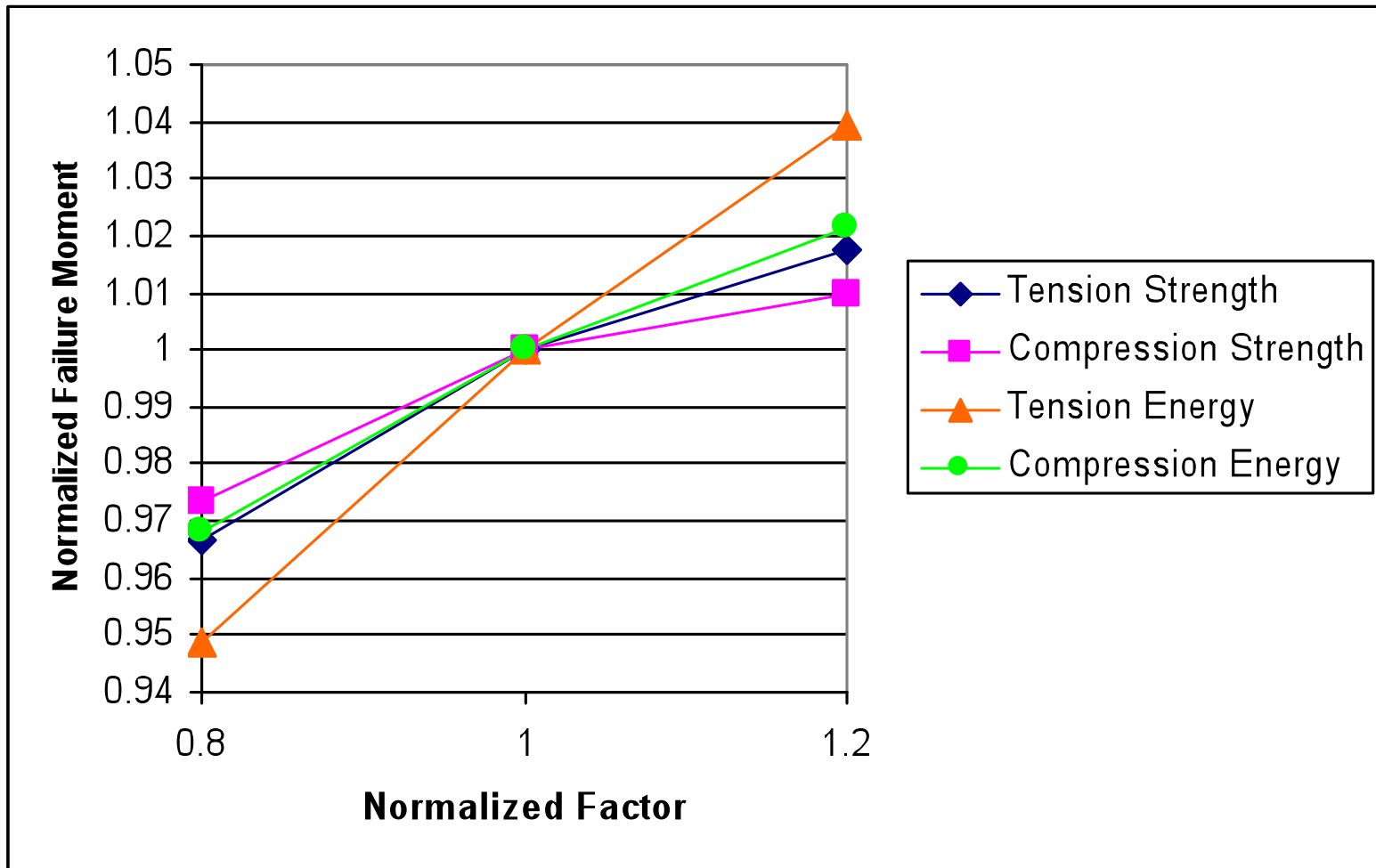Notch Length = 1 inch

Stiff Direction

	Effect on Failure Moment (in-lb/in)
Fiber Tension Energy	
Fiber Tension Strength	
Fiber Compression Energy	
Fiber Compression Strength	
Matrix Compression Energy	
Long Shear Strength	
Matrix Tension Energy	
Matrix Tension Strength	
Matrix Compression Strength	
Trans Shear Strength	

Soft Direction

Effect on Failure Moment (in-lb/in)

Soft Direction

INSTRON

5500R

INSTRON

BMS 8-276 Carbon Fiber Tape

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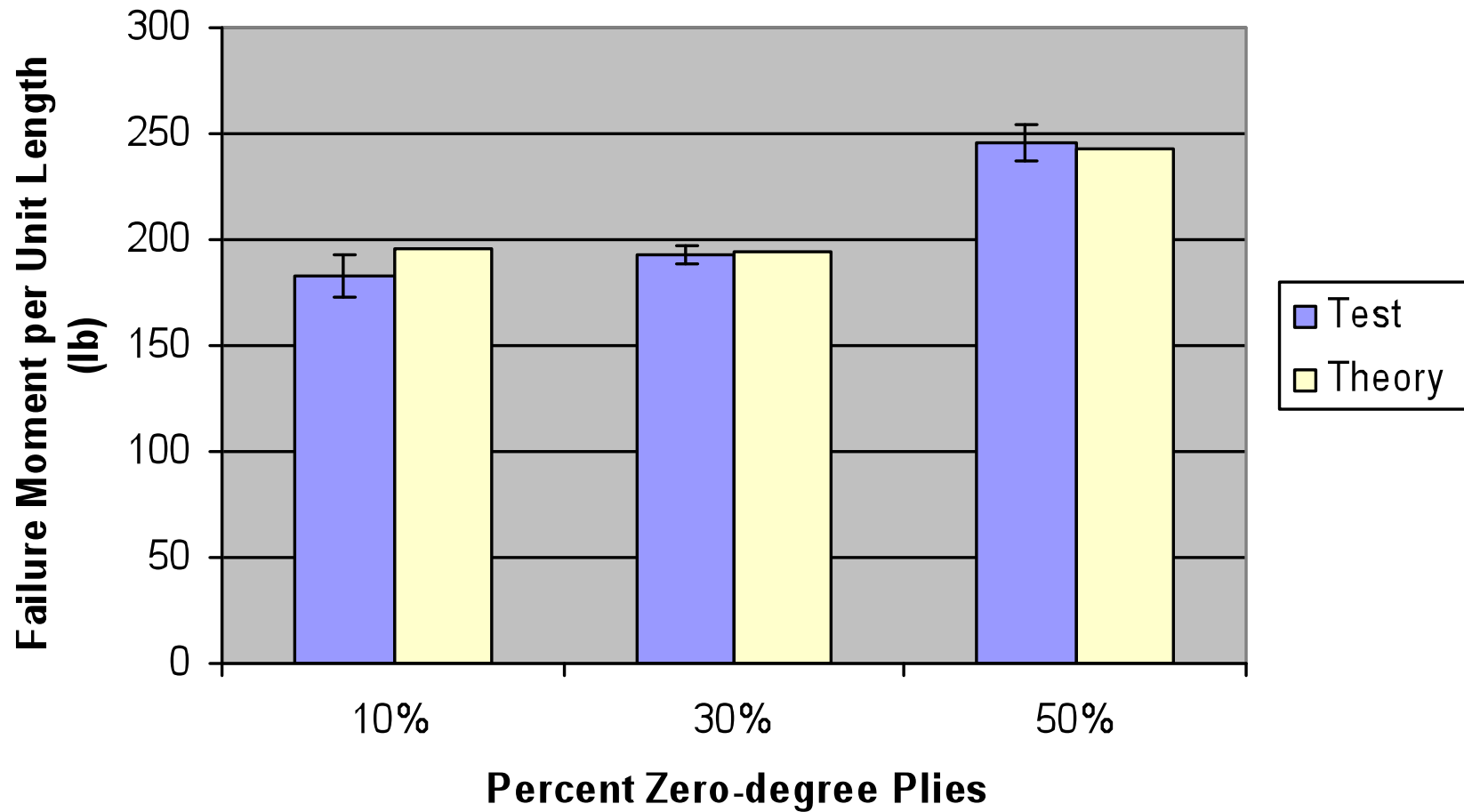- **30% 0° Plies**
- **50% 0° Plies**

Laminate Thicknesses
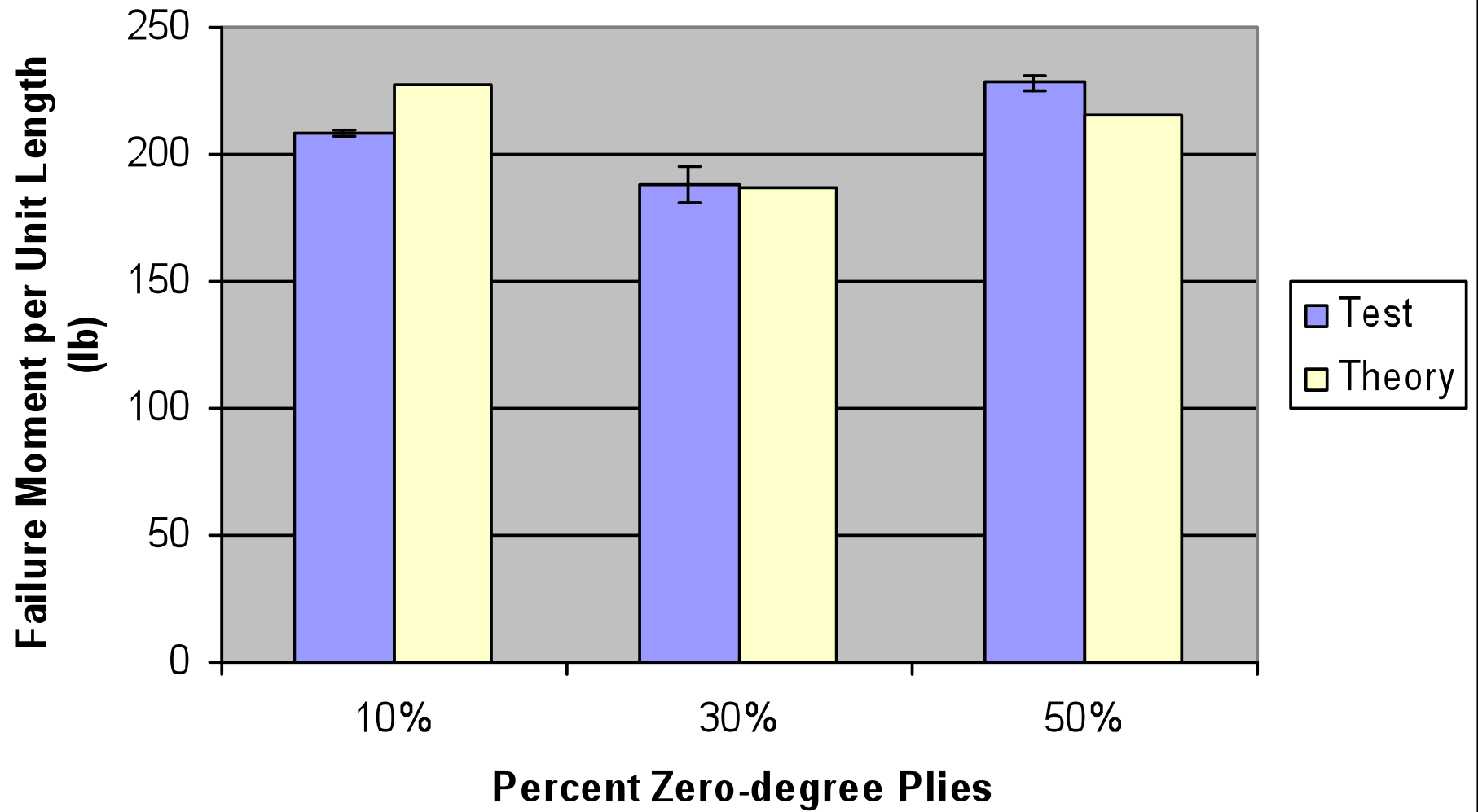- **20 plies Thick**
- **40 plies Thick**
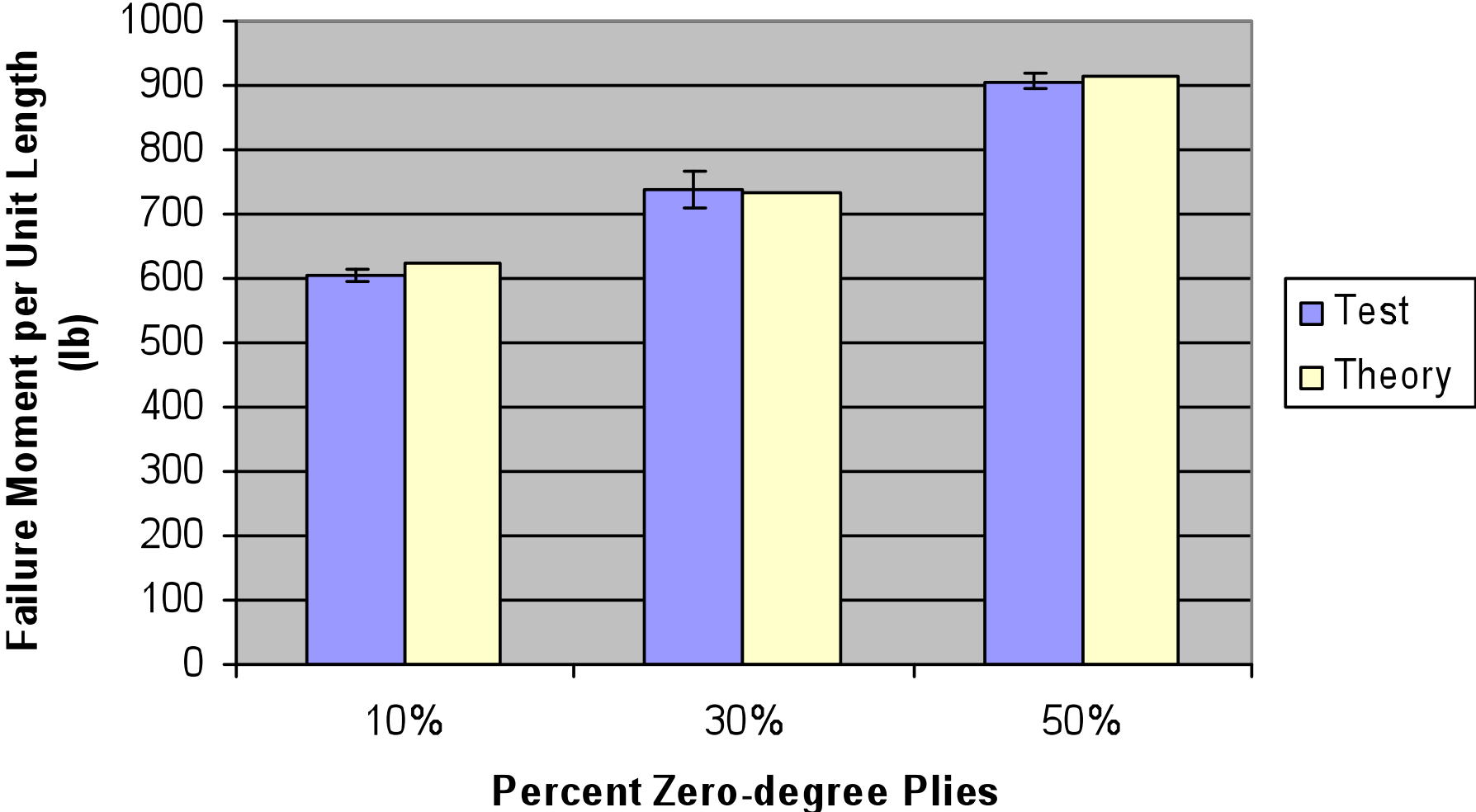
Notch Lengths
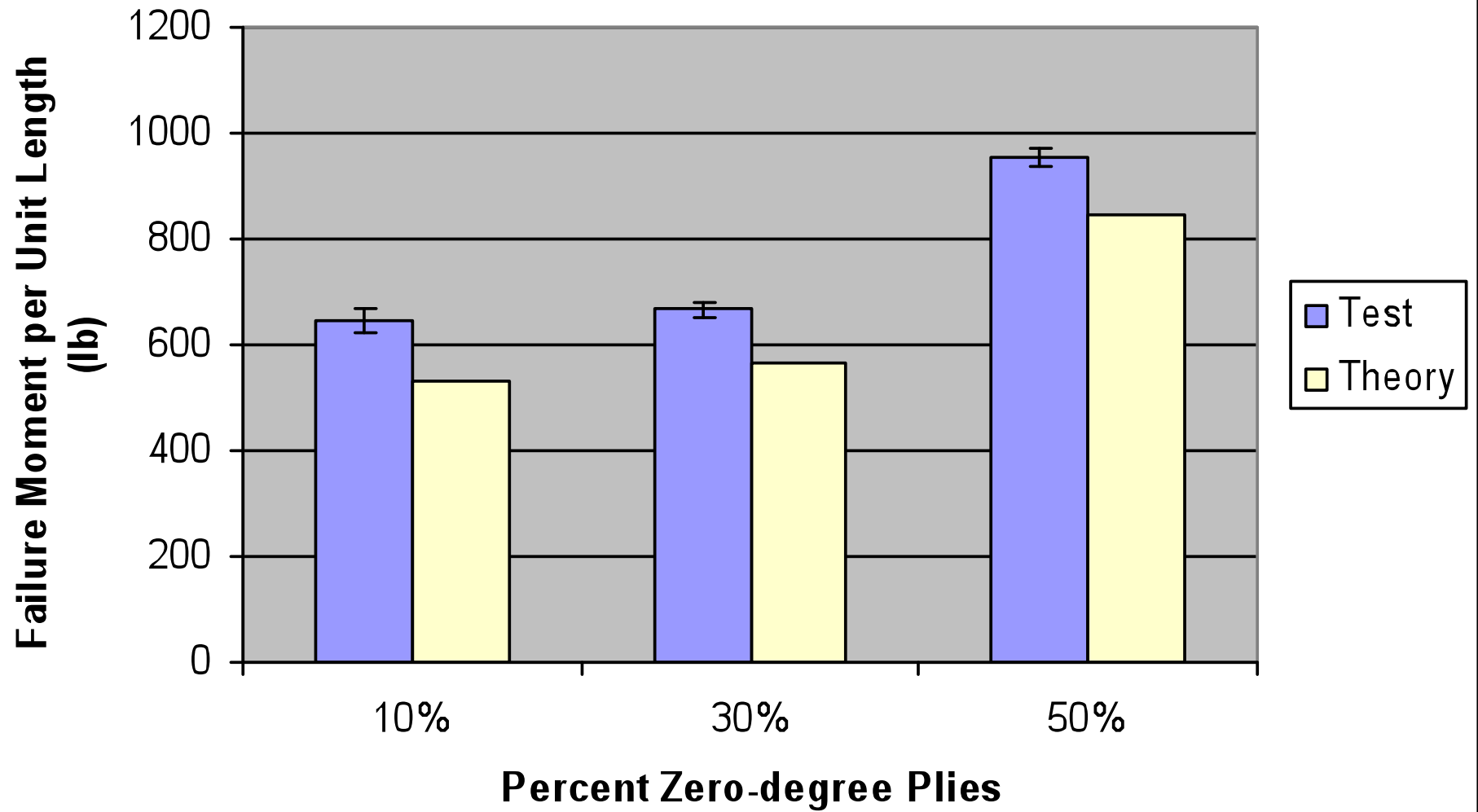- **1 inch**
- **4 inches**

20 Plies Thick with1-inch Notch

Failure Moment per Unit Length (lb) vs. Percent Zero-degree Plies

Legend: Test, Theory

20 Plies Thick with 4-inch Notch

Failure Moment per Unit Length (lb) vs. Percent Zero-degree Plies

Legend: Test, Theory

40 Plies Thick with1-inch Notch

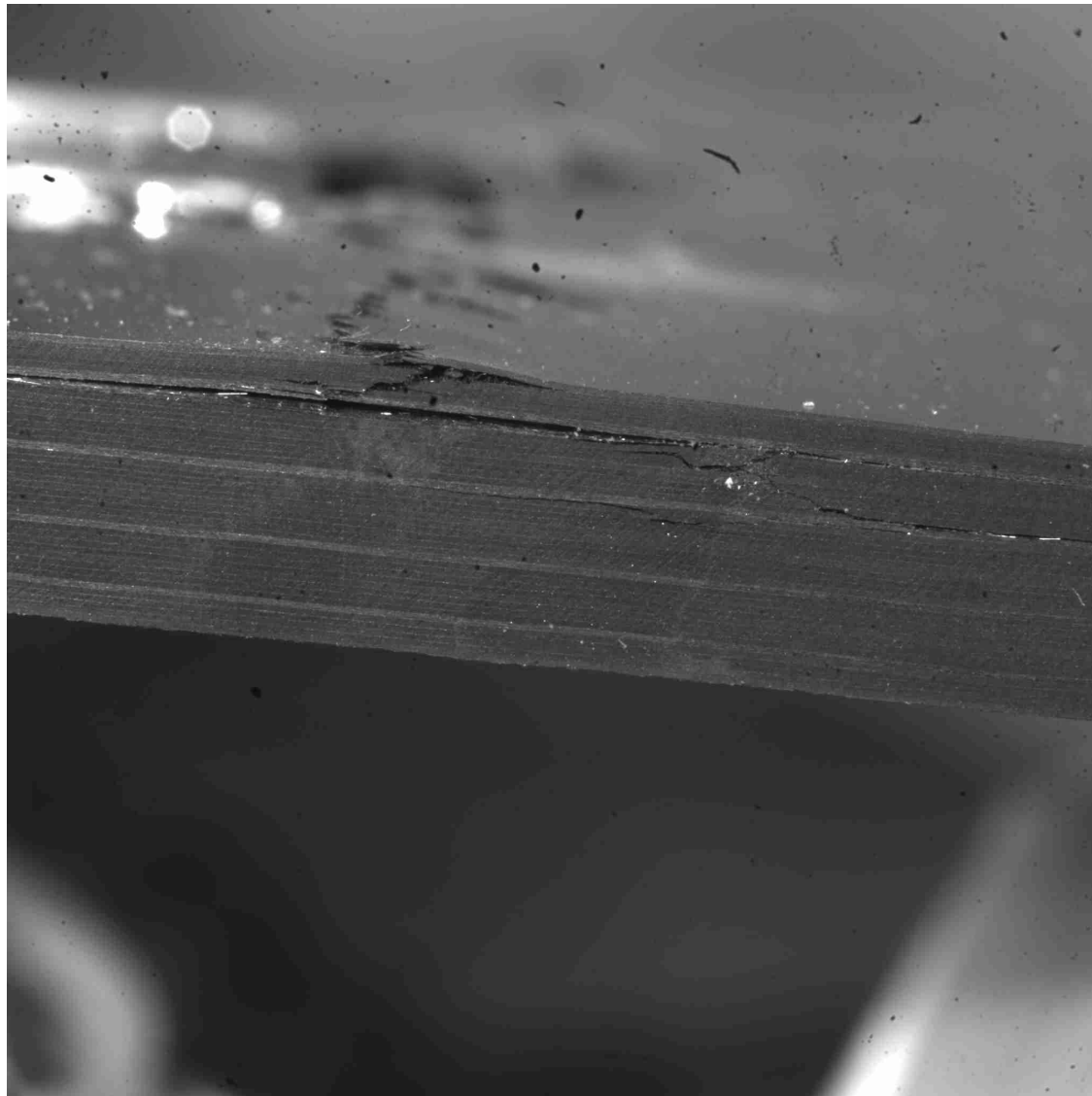Failure Moment per Unit Length (lb) vs. Percent Zero-degree Plies
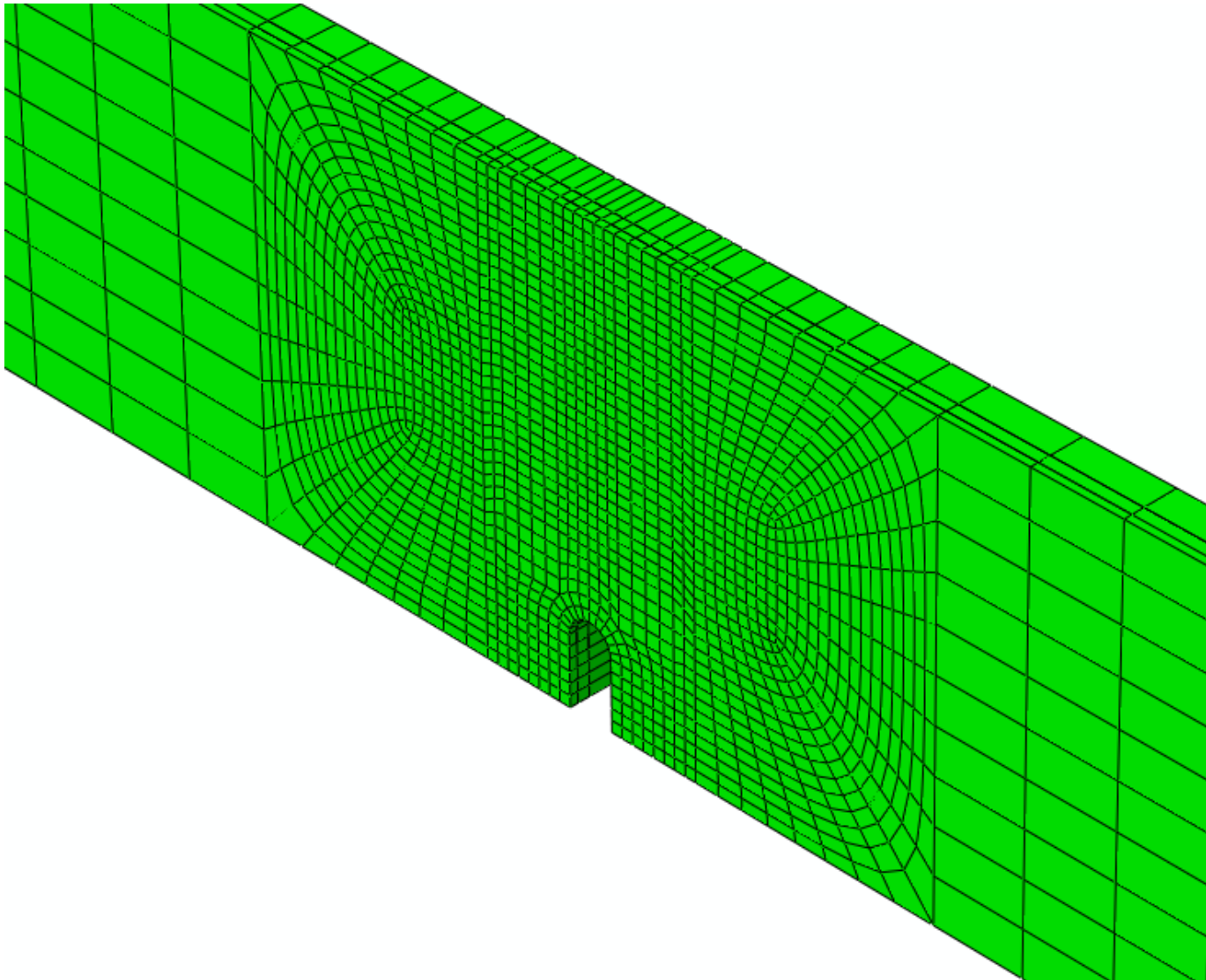
Legend: Test, Theory

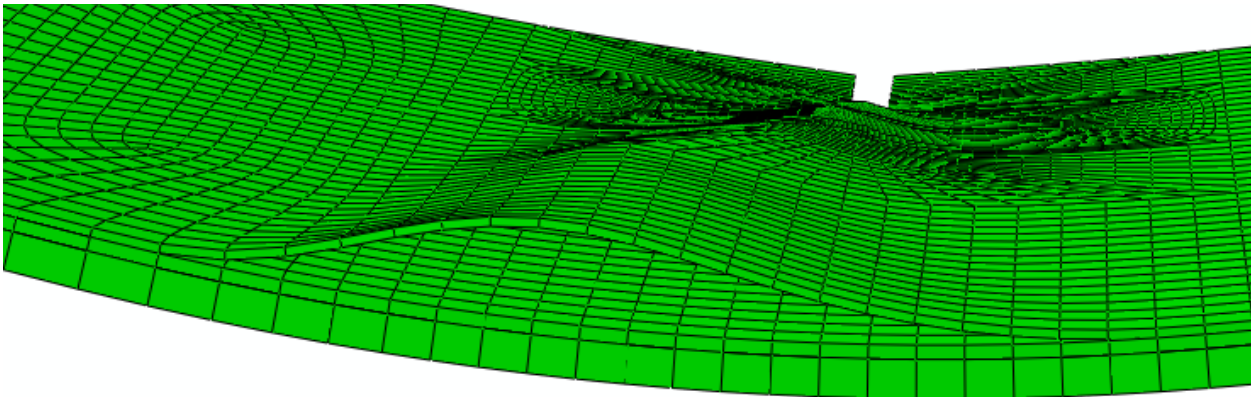**40 Plies Thick with 4-inch Notch**

40-Ply Laminate

FEA Model with Delamination Interfaces

Delamination Buckling

FUTURE WORK

Progressive Damage Modeling With Multiple Delamination Interfaces

PI – John Parmigiani