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A Building Block Approach for Crashworthiness Testing of Composites

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FAA Sponsored Project Information

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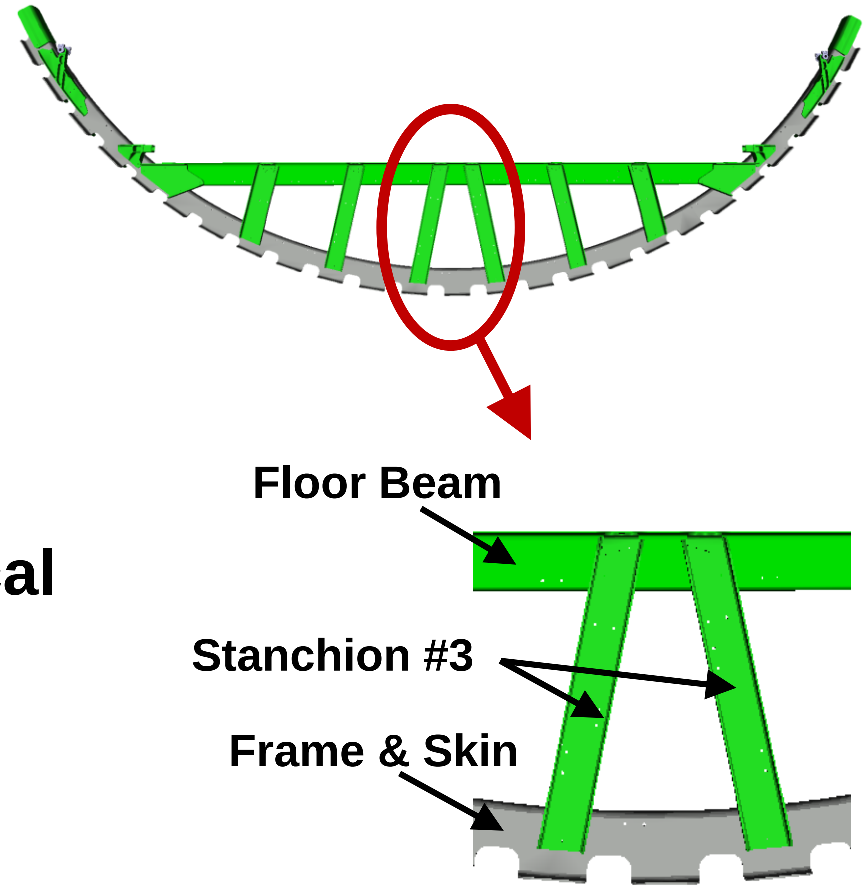
Current CMH-17 Challenge Problem:
Composite Cargo Floor Stanchion

- **Central assembly consisting of four primary members**
  - **Stanchion #3 (primary crush member)**
  - **Floor beam**
  - **Frame**
  - **Skin**
- **Initial sizing based on 6g vertical loading condition (Altair Engineering)**
  - **Cross section geometry**
  - **Laminate ply orientations**
  - **Laminate thickness**



Primary Crush Member: C-Channel Stanchion

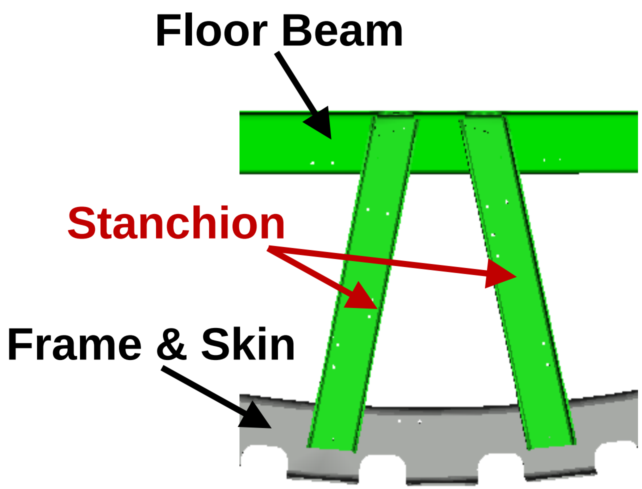
Traditional Design: Use of 0°, ±45°, and 90° plies

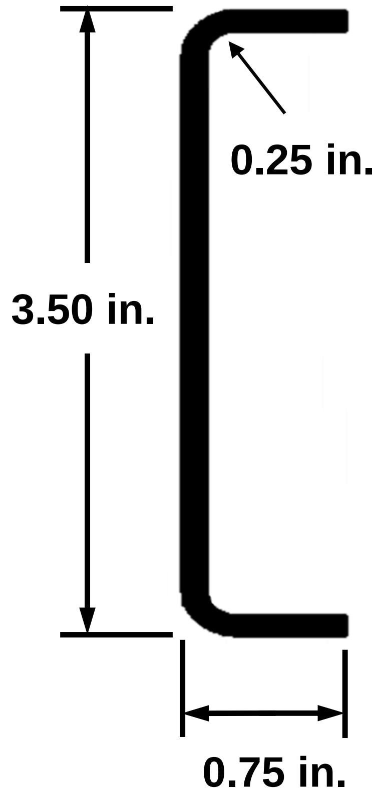
Material: IM7/8552 unitape prepreg

Geometry: C-channel

Laminate: "Hard" laminate

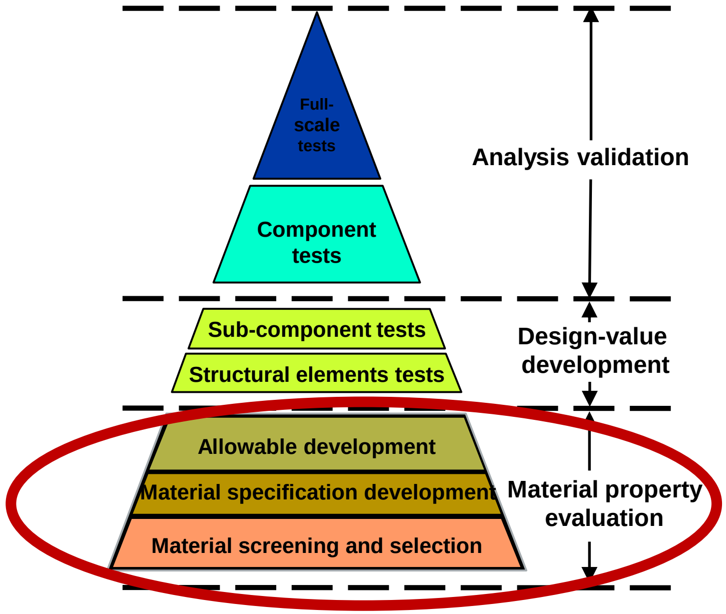
- 50% 0°, 25% ±45°, 25% 90° (50/25/25)
- 16 plies (@ 0.0072 in.), 0.115 in. thickness

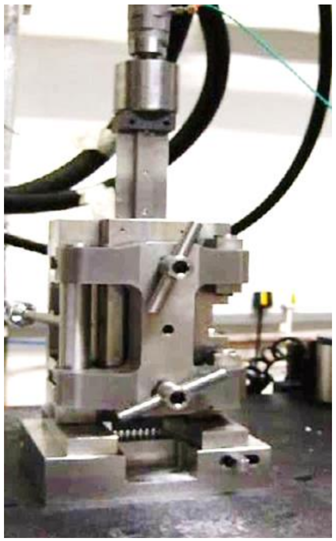


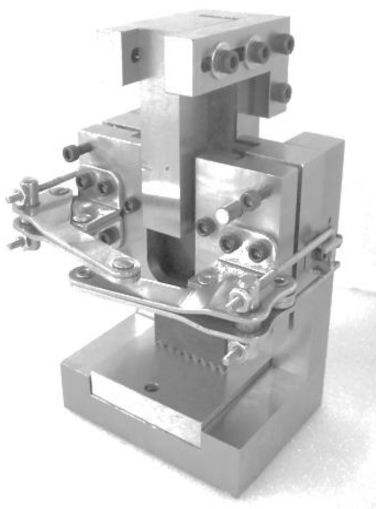


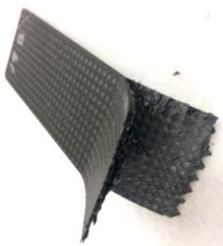
Initial Testing Activities:
Laminate Design for Crashworthiness

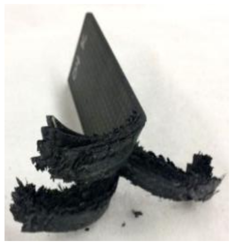
- **Flat-coupon crush testing**
- **Tailor laminate to achieve stable crush, high energy absorption**
- **Mini round-robin to evaluate proposed crush test fixtures and draft standard**





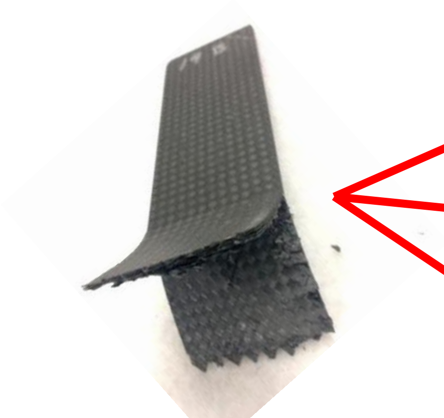


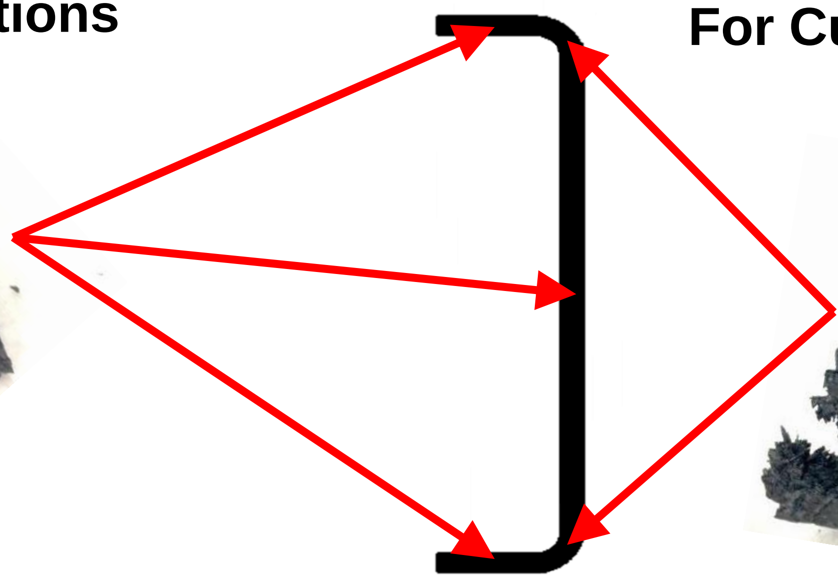




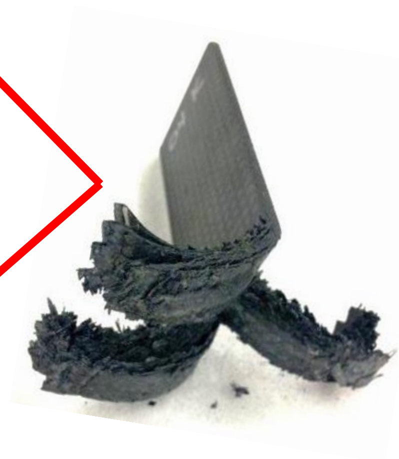
Flat Coupon Crush Testing:
Unsupported and Pin-Supported

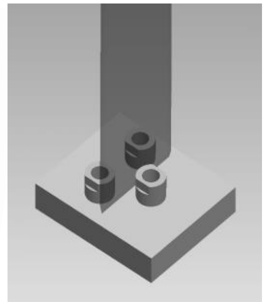
Unsupported Testing
For Flat Sections





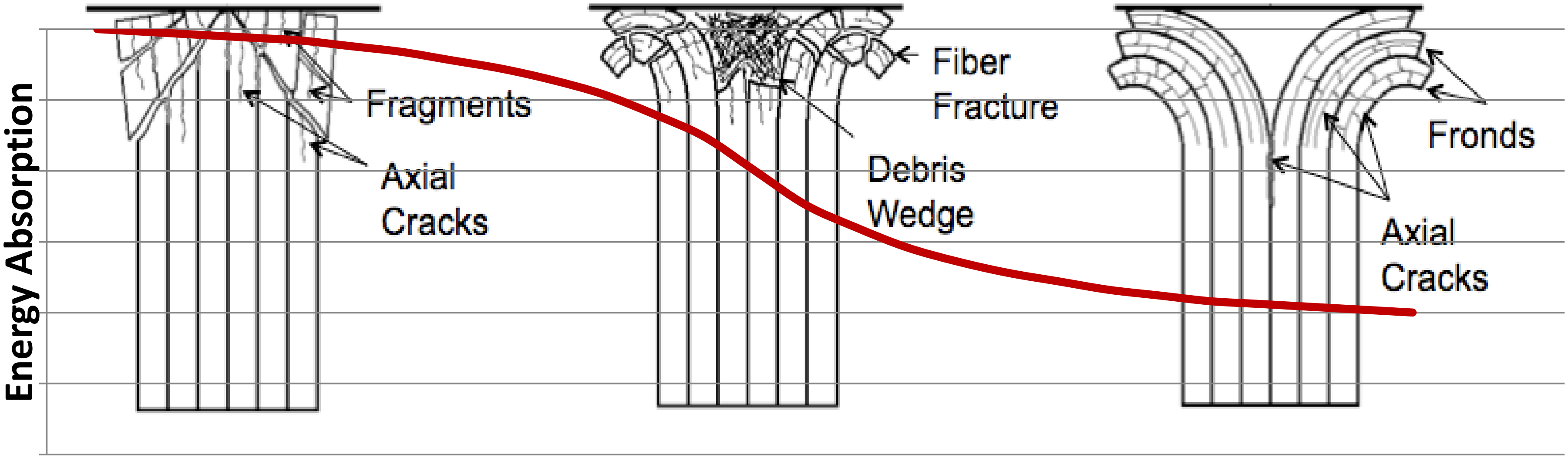
Pin-Supported Testing
For Curved Sections & Corners





- **Measure SEA and Crush Stress for both support conditions**
- **For use in crush predictions of structural members**

Previous Research Results: Crush Modes Affect Energy Absorption



Fragmentation

- Short axial cracks
- Shear failure from compressive stresses
- Extensive fiber fracture

Brittle Fracture

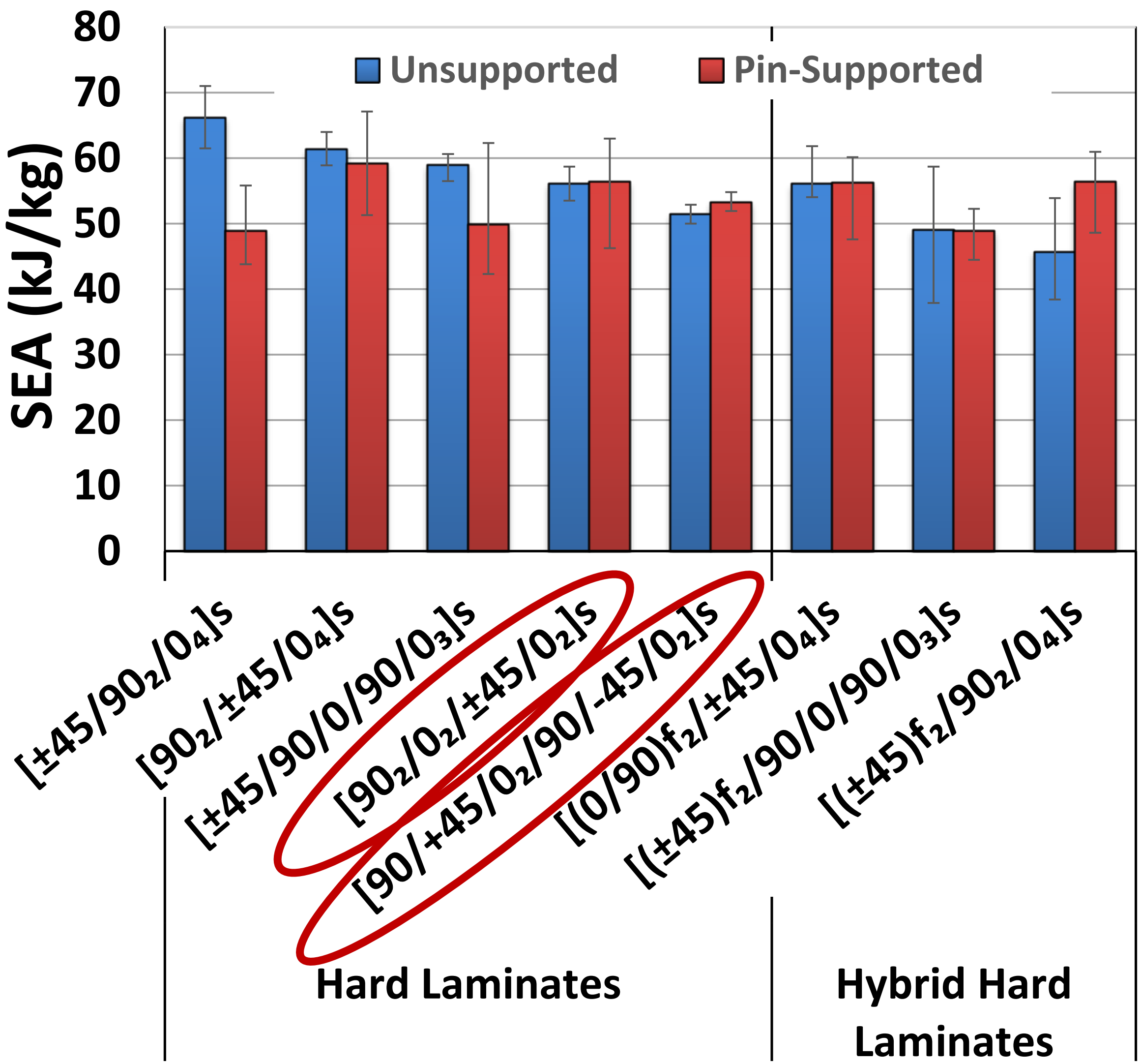
- Intermediate axial cracks
- Combines characteristics from other failure modes

Fiber Splaying

- Long axial cracks
- Frond formation
- Delamination dominated

Flat Coupon Crush Test Results: Hard Laminates

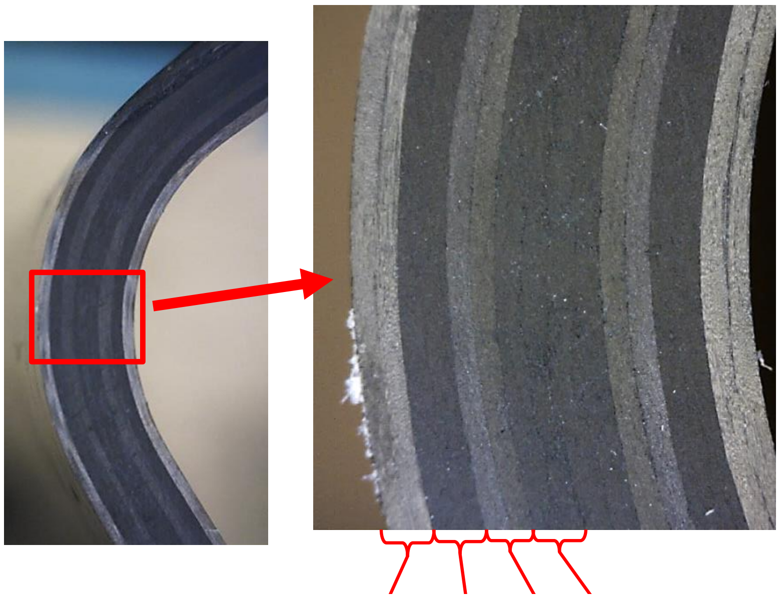
All laminates produced good energy absorption



- **50% 0°, 25% ±45°, 25% 90°**
- **No significant difference due to fabric layers in Hybrid laminates**
- **Minimal variation between laminates investigated**
- **Two laminates selected for further investigation**

C-Channel Stanchion Crush Testing: Specimen Manufacturing

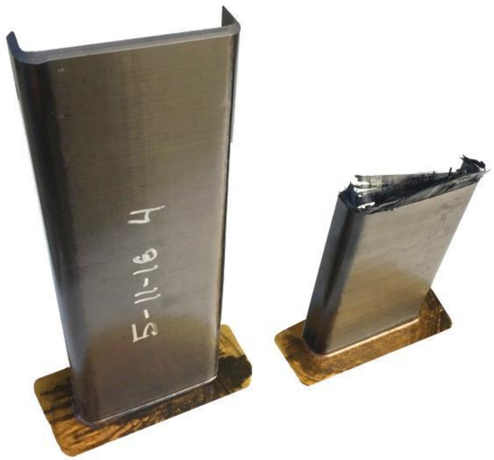
- IM7/8552 carbon/epoxy unitape prepreg, 190 gsm
- $[90_2/0_2/\pm45/0_2]_s$ and $[90/+45/0_2/90/-45/0_2]_S$ "Hard" laminates
- 0.25 in. corner radius, 0.114 in. average thickness
- Layup and cure in accordance with NCAMP specifications
- ~1.5% thickness difference between flat and corner sections (corner thickness slightly lower)



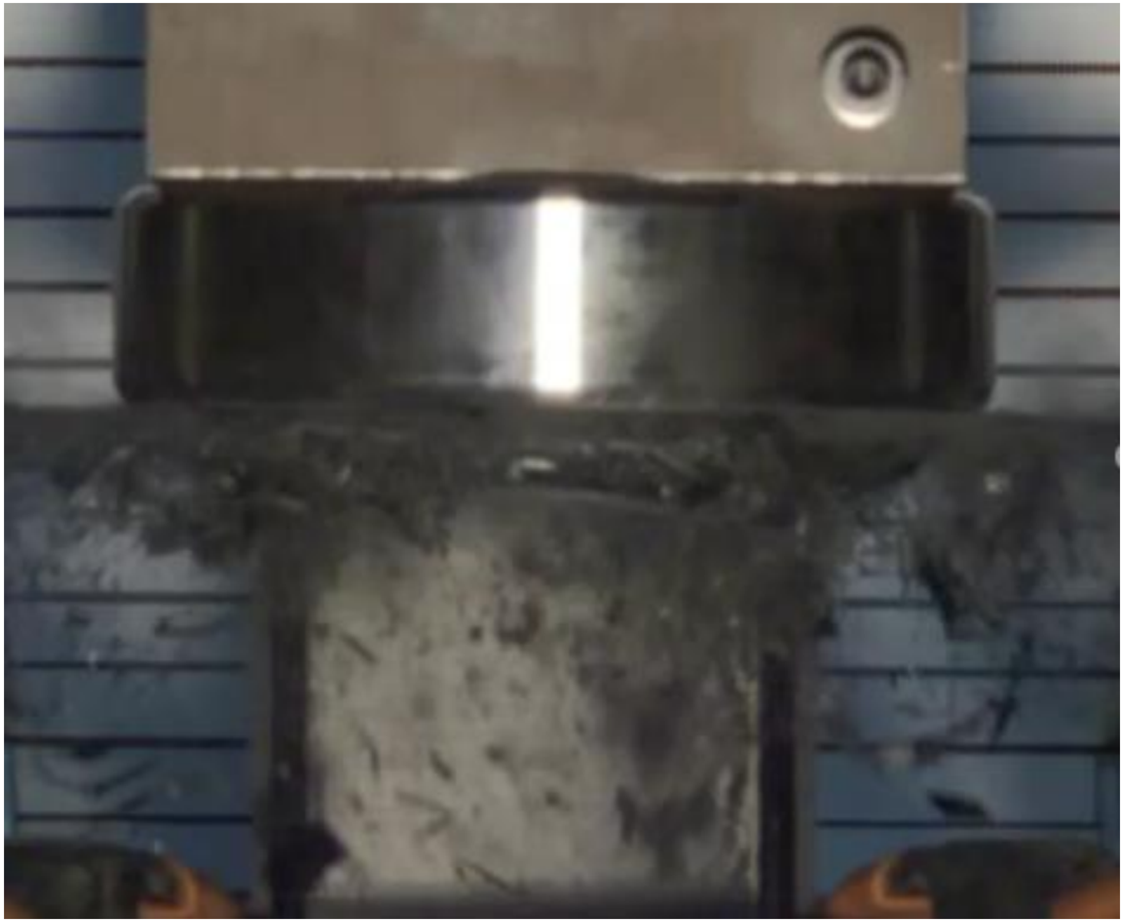
$[90_2/0_2/\pm45/0_2]_s$

Validation of Numerical Crush Modeling Methods:
C-Channel Crush Testing

- University of Utah instrumented drop-weight impact tower
- $[90_2/0_2/\pm45/0_2]_s$ and $[90/+45/0_2/90/-45/0_2]_S$ "hard" laminates
- Three crush velocities
  - 300 in/sec (~10 ft. drop height)
  - 150 in/sec (~2.5 ft. drop height)
  - Quasi-static
- Results to be used to assess numerical analysis capabilities
- High-speed video of crush process



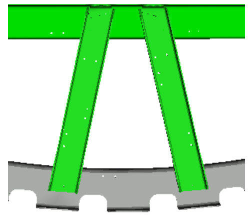
C-Channel Crush Testing:
High-Speed Video of Crush Process

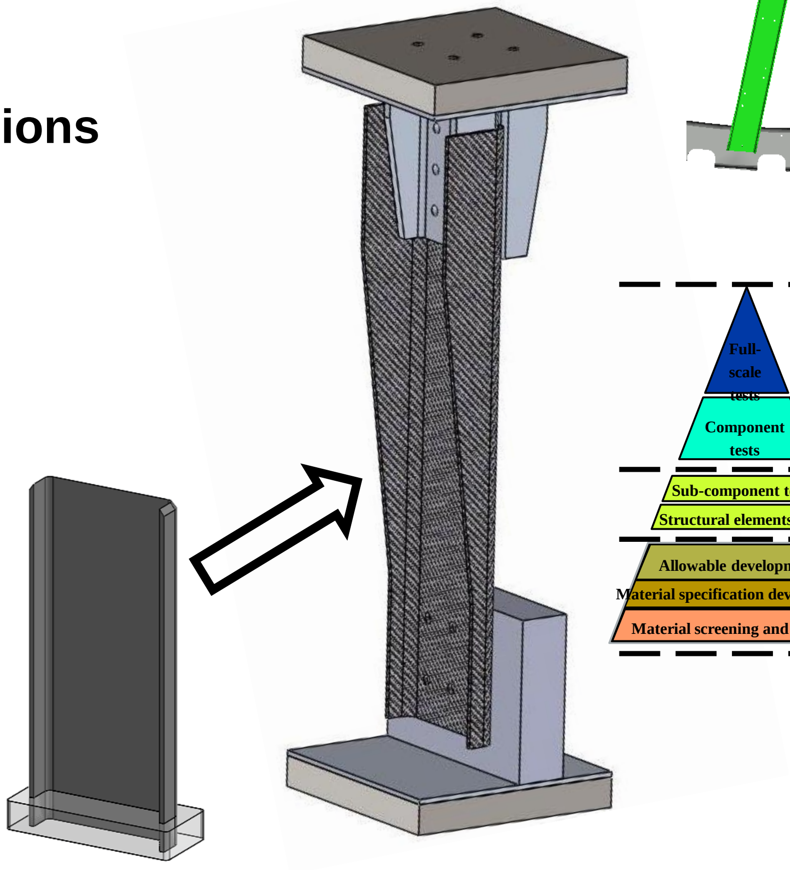


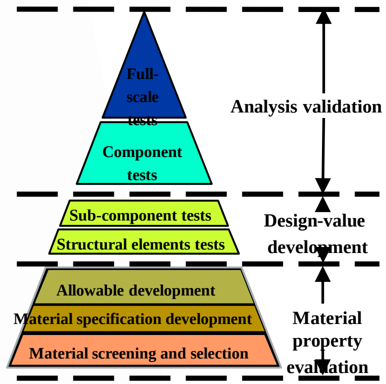
Current Focus:
Crush Testing of Single Stanchion Assembly

Additional considerations include:

- Bolted attachments (top and bottom)
  - Design of bolted connections
  - Design of laminate in bolted regions
- Crush initiator
  - Internal ply-drops
  - Reduced cross-sectional area
  - Produced failure at prescribed location, load level, and failure mode
- Subsequent stable crush of stanchion

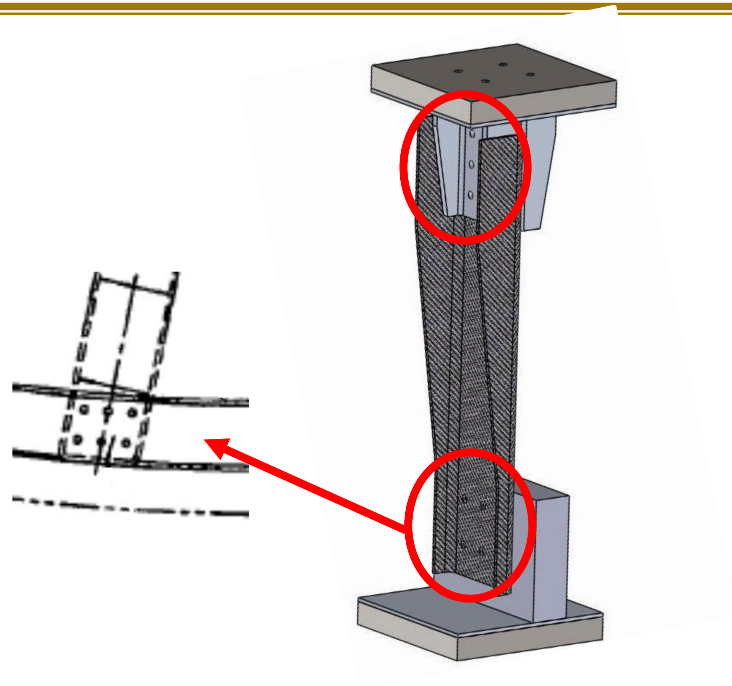


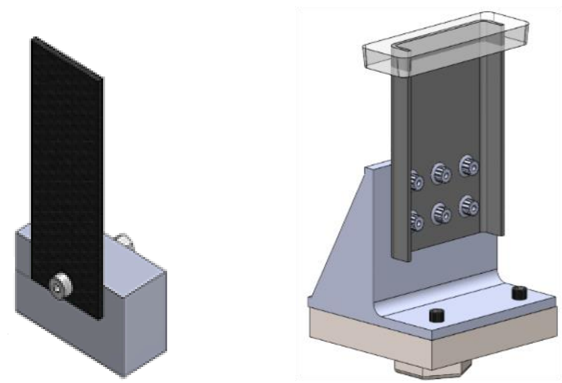




Design of Bolted Attachments:
Dynamic Bearing Testing

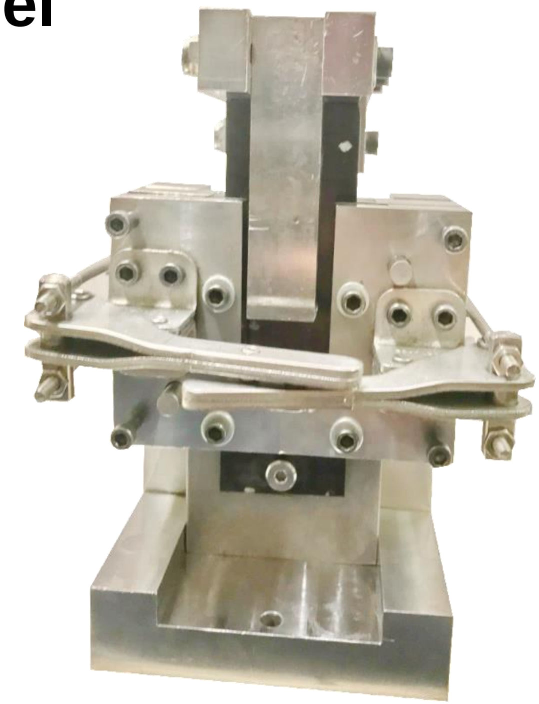
- **Stanchion bolted to the upper floor and lower frame**
- **Bearing failure possible at bolted connections**
- **Investigate dynamic bearing strength and bearing crush behavior**
  - **Single fastener tests to establish dynamic bearing strength**
  - **Bolted C-channel tests to establish joint load capacity**

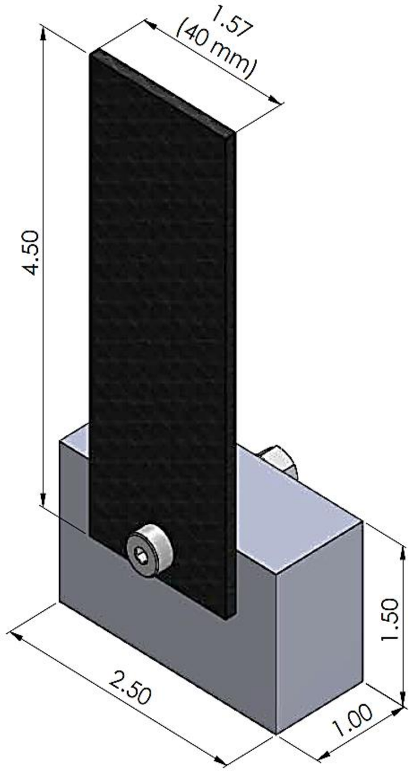




Dynamic Bearing Testing:
Single Fastener/Single Shear Testing

- **Use of Univ. of Utah flat coupon crush test fixture**
- **0.25 in. diameter steel fastener**
- **Test specimen bolted to steel block**
- **Compression loaded**
  - **Quasi-static: 0.4 in/min**
  - **Dynamic: 144 in/sec (drop-weight impact)**

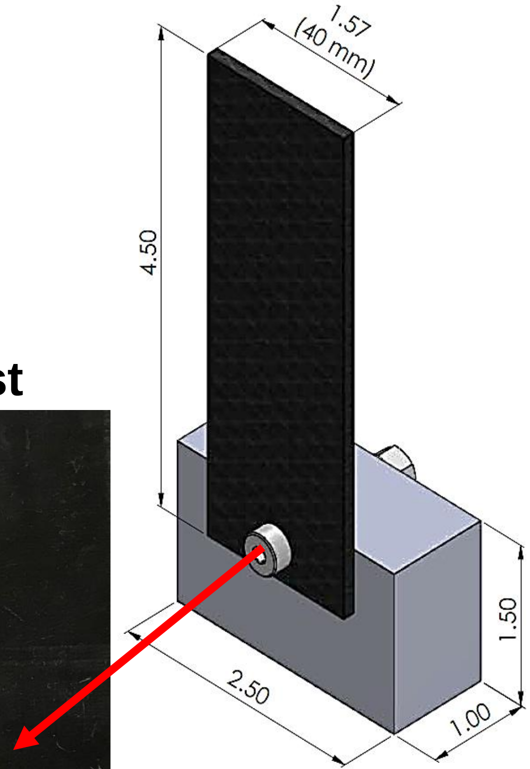




Dynamic Bearing Testing:
Single Fastener/Single Shear Testing

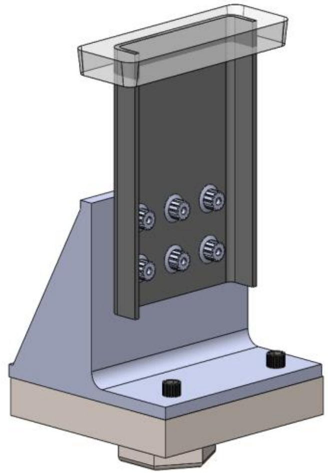
- **Failure of single fastener**
  - **Quasi-static: 3.5 kip**
  - **Dynamic: 4.1 kip**
- **Failure by fastener tearing through the laminate**
- **No visible degradation to the fastener**
- **Stanchion will consist of six fasteners. Therefore, the desired dynamic peak load would be 24.3 kip**

Post Test



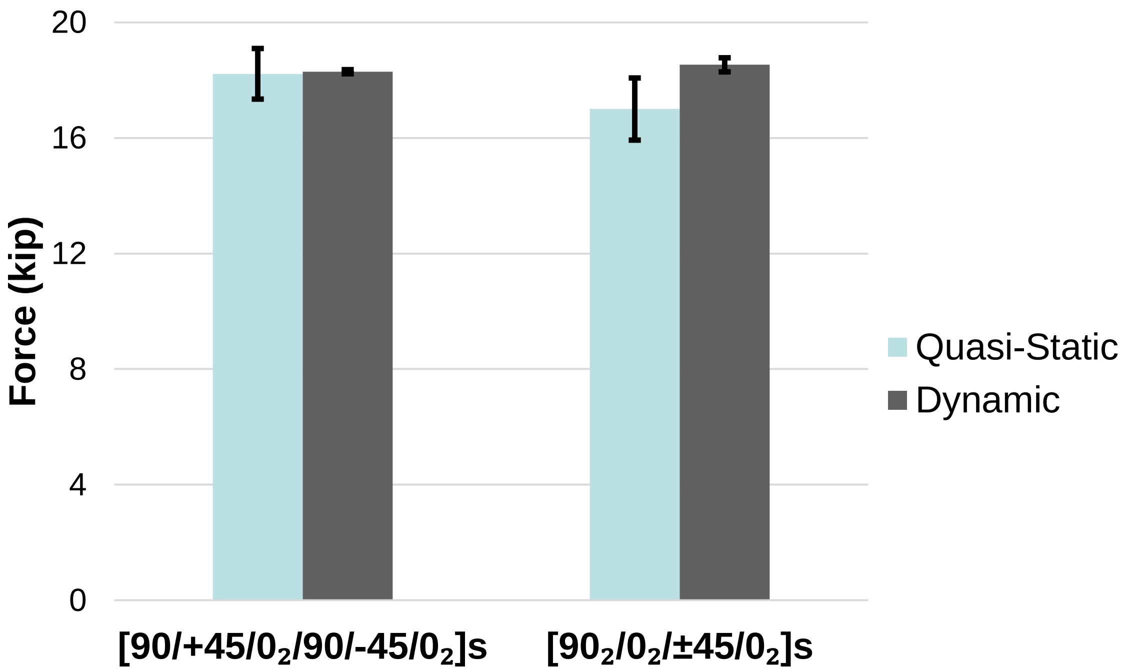
Dynamic Bearing Testing:
Bolted C-Channel Test

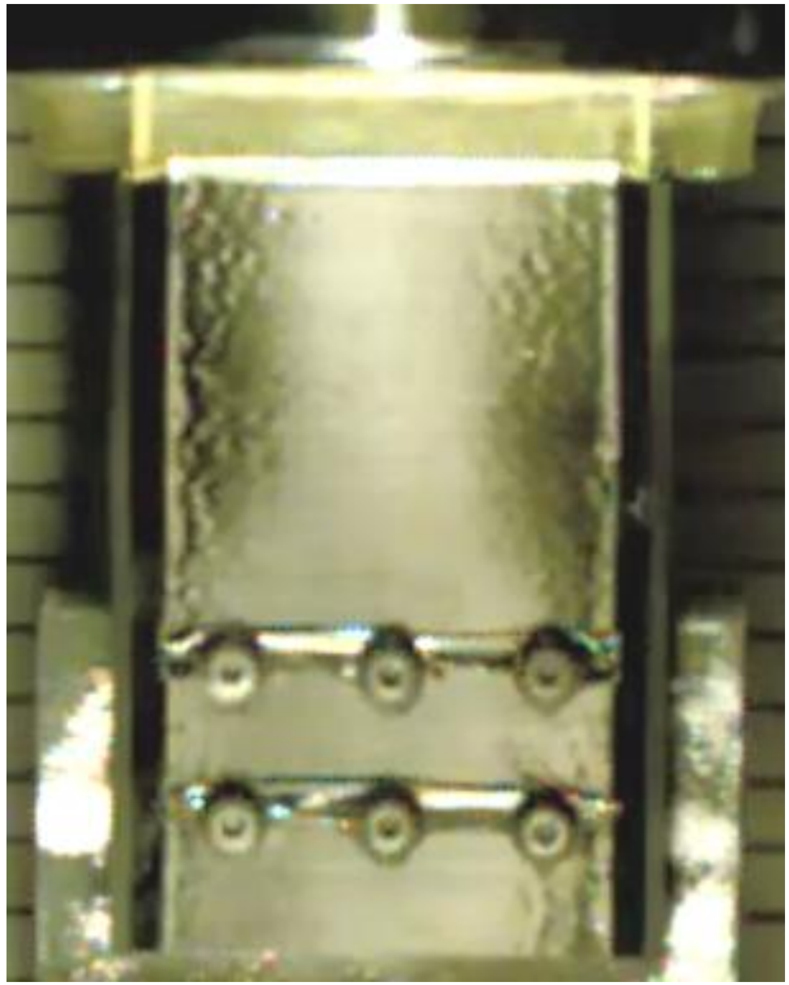
- Single-shear testing of bolted joint design
- Six 0.25 in. diameter bolts, two rows three columns
- Top of channel potted to prevent end crushing
- Establishment of dynamic and quasi-static joint performance
  - Initial failure load
  - Failure mode and location
- Testing of two selected "hard" laminates
- Of use for assessing numerical modeling methods



Bolted Joint Dynamic Testing:
Summary of Results To Date

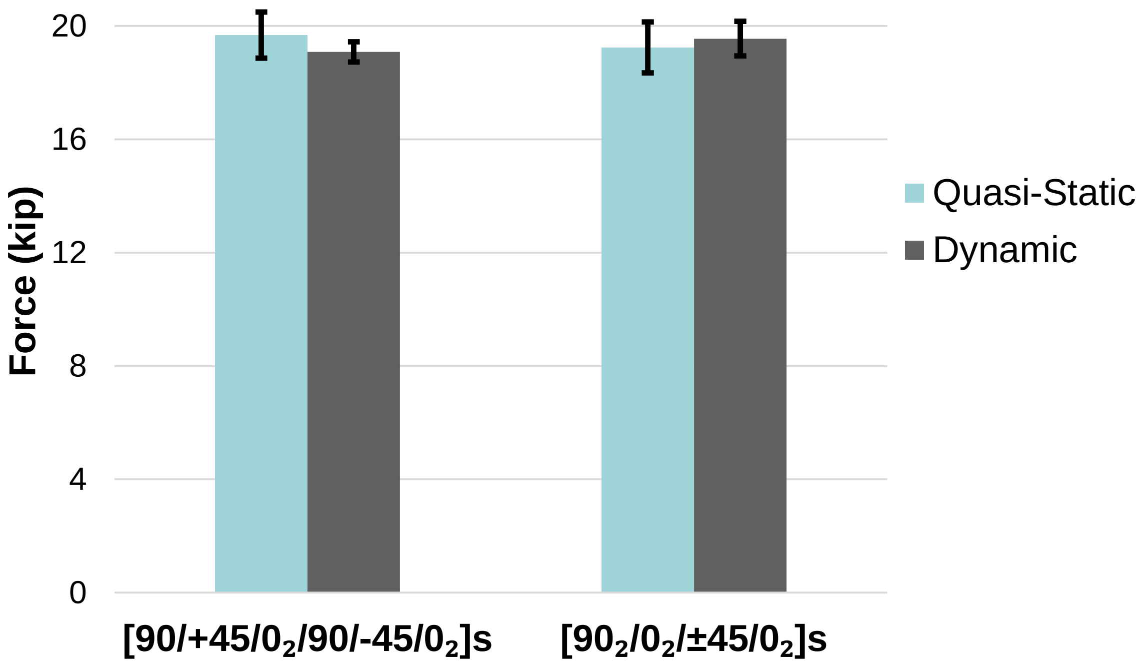
- **Similar failure mode in all tests**
- **Similar max. bearing loads for two hard laminates tested quasi-statically and dynamically**

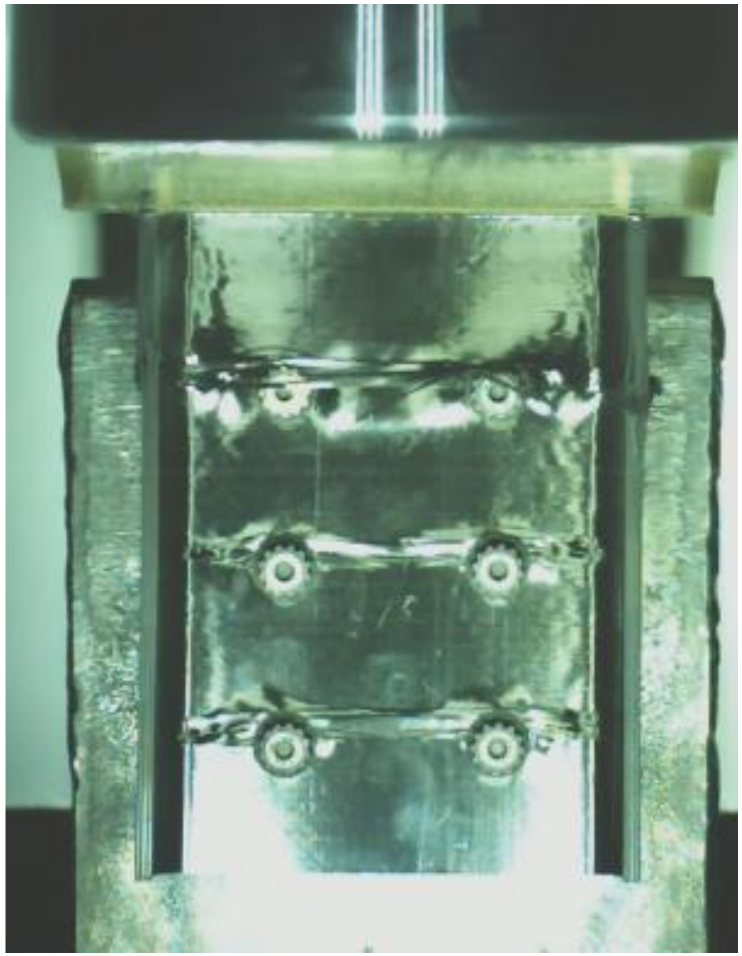




Bolted Joint Dynamic Testing:
Summary of Results To Date

- **Bearing design with 3 rows and 2 columns**
- **Similar failure as previous bolted design**
- **Slight increase in peak failure loading**
- **Similar failure modes in all tests**





Bolted Joint Dynamic Testing: Summary of Results

- **By changing the bearing configuration**
  - **Quasi-static peak increased by 10.5%**
  - **Dynamic peak increased by 5%**
  - **Below the theoretical 6 bearings value by 4.9 kip**
  - **Not a significant peak load increase**
    - **Proposing a bearing parameter change to increase the dynamic peak value**
- **Again, of use in assessing modeling capabilities**

Current Focus:
Bolted Joint Design and Validation

- **Investigate use of quasi-isotropic laminate in bolted region of stanchion**
- **Additional ±45° layers for increased bearing strength**
- **Desire to continue all 0° layers throughout stanchion into bolted region to retain compression strength**
- **Options under investigation:**
  - **Replace 90° plies with ±45° plies**
  - **Additional ±45° plies added to laminate**

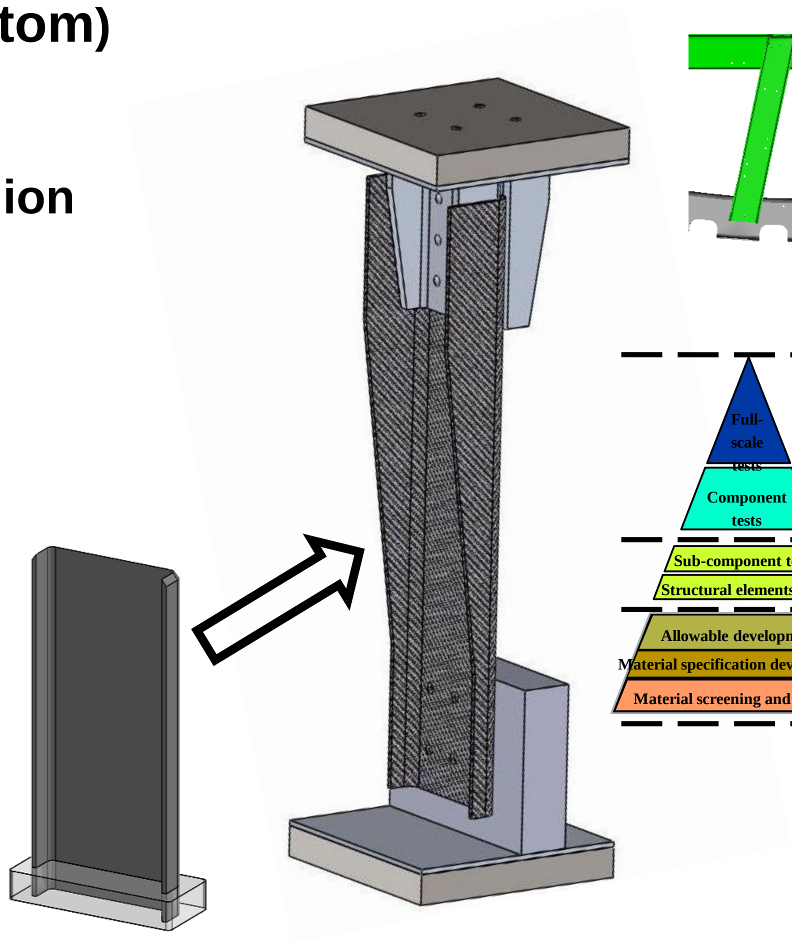
Joint (add. 45s)			
45	45	45	45
-45	-45	-45	-45
45	45	45	45
0	0	0	0
0	0	0	0
90	90	90	90
-45	-45	-45	-45
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
-45	-45	-45	-45
90	90	90	90
0	0	0	0
0	0	0	0
45	45	45	45
-45	-45	-45	-45
45	45	45	45

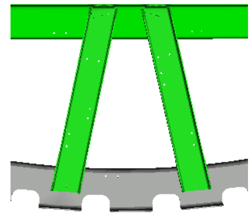
Joint (Quasi)			
45	45	45	45
90	90	90	90
0	0	0	0
0	0	0	0
90	90	90	90
-45	-45	-45	-45
45	45	45	45
-45	-45	-45	-45
-45	-45	-45	-45
45	45	45	45
-45	-45	-45	-45
90	90	90	90
0	0	0	0
0	0	0	0
90	90	90	90
45	45	45	45

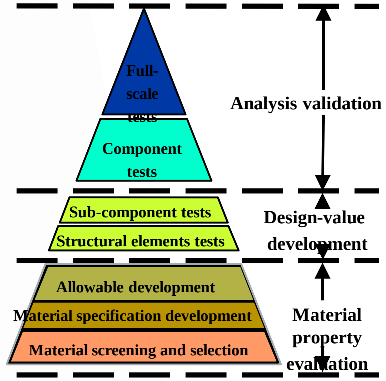
Current Focus:
Crush Testing of Single Stanchion Assembly

<u>Additional considerations include</u>:

- Bolted attachments (top and bottom)
  - Design of bolted connection
  - Design of laminate in bolted region
- Crush initiator
  - Internal ply-drops
  - Reduced cross-sectional area
  - Produced failure at prescribed location, load level, and failure mode
- Subsequent stable crush of stanchion

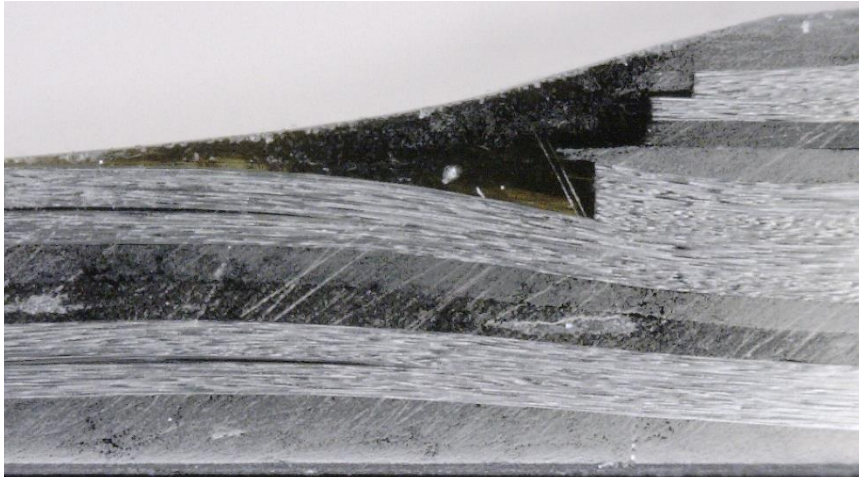


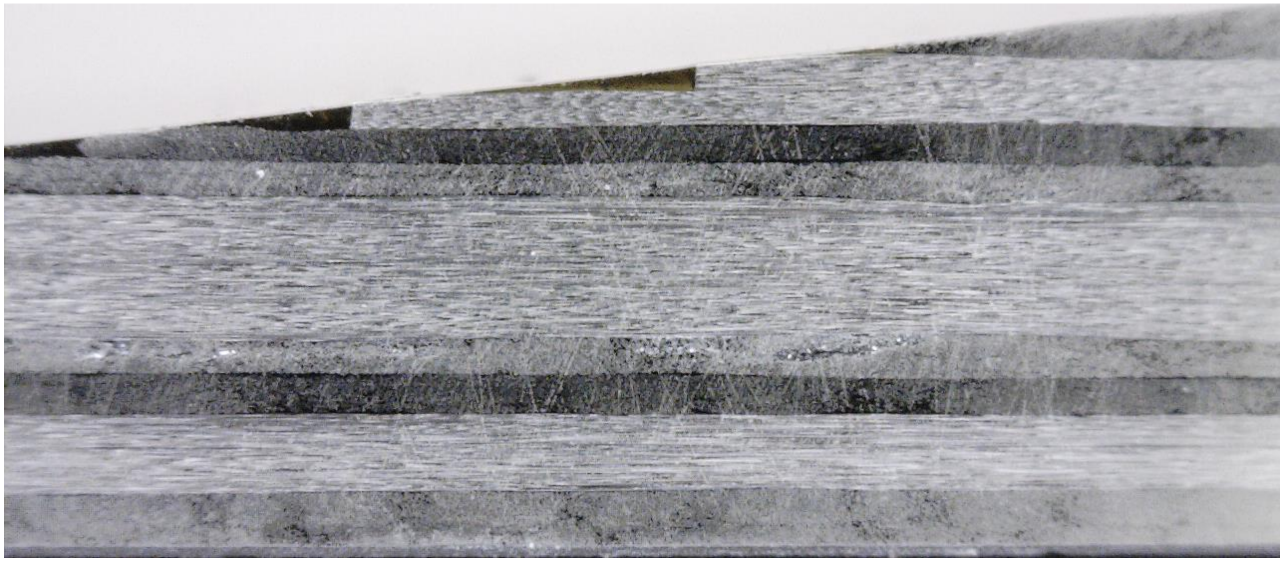




C-Channel Stanchion Crush Initiator:
Use of Laminate Ply-Drops

- Ply-drop regions in stanchion laminate
- Produces laminate failure under dynamic compression loading
- Serves as a crush front for subsequent stanchion crushing
- $[90_2/0_2/\pm45/0_2]_s$ laminate





C-Channel Stanchion:

Ply-Drop Crush Initiator Design

- Investigated dropping outermost 4, 6, and 8 plies of 16 ply "hard" laminate
- Multiple ply drop configurations
  - Different thicknesses at either ends
  - Same thicknesses at both ends and a ply-drop region in the center
  - Full thickness change (90° step) vs. staggered ply drops
  - Variable length ply drop regions

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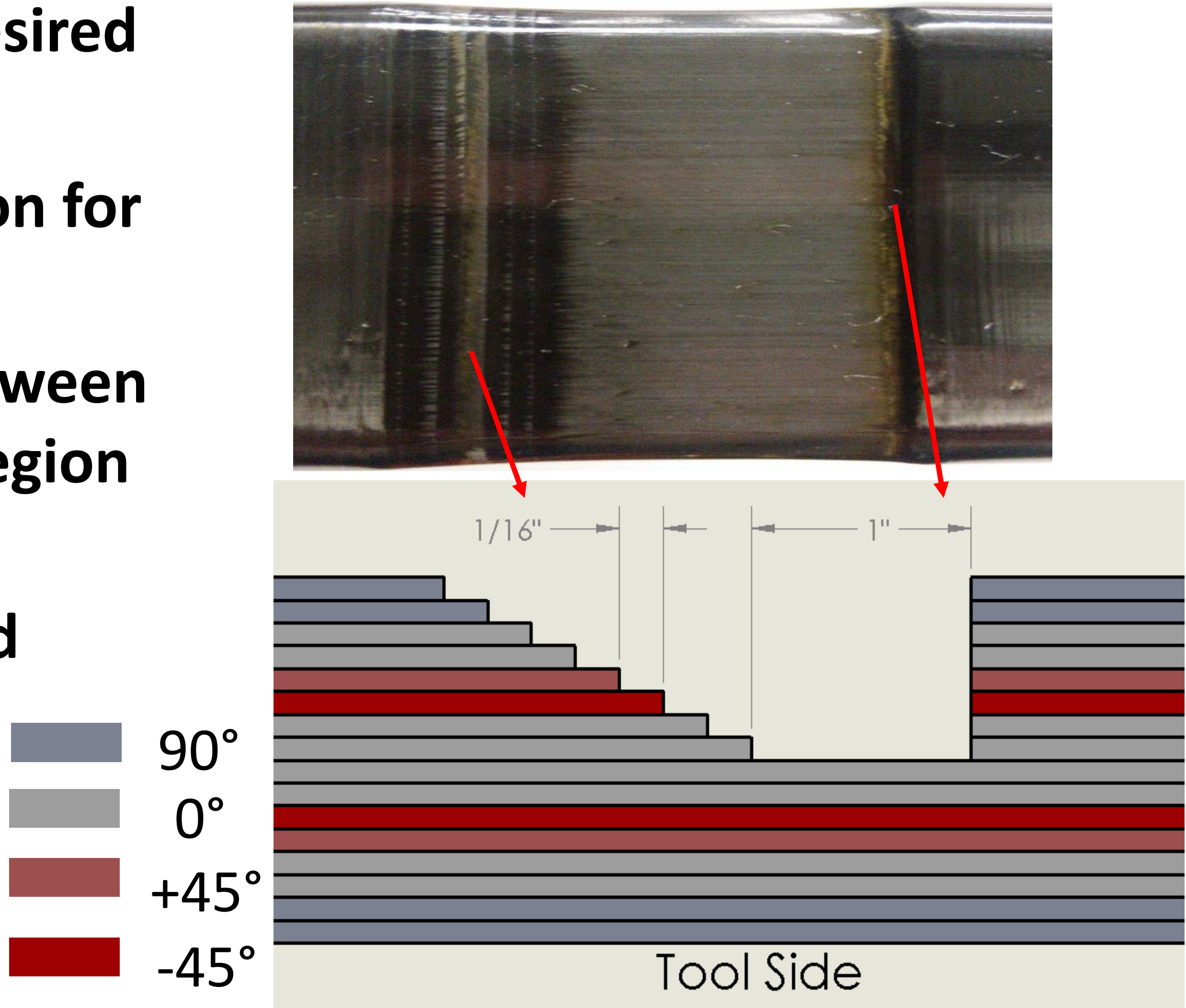
Ply-Drop Crush Testing:
90° Ply-Drop and Tapering

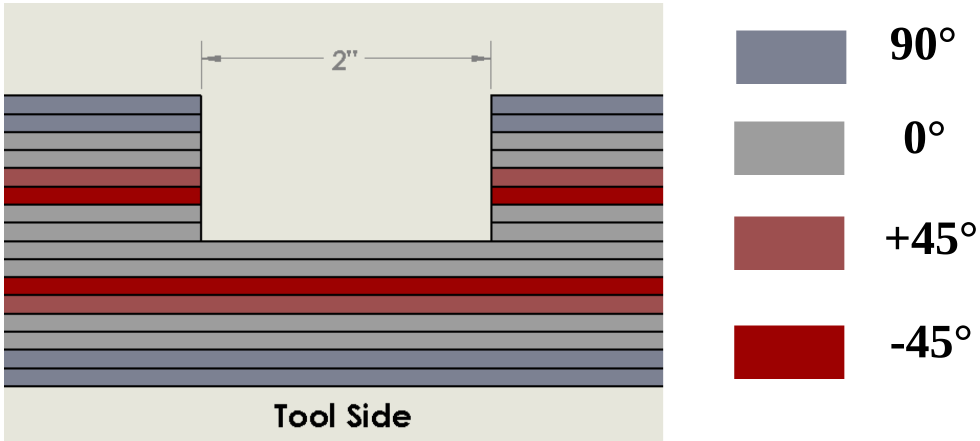
- **90° ply-drop used at desired failure location**
- **Tapered thickness region for laminate build-up**
  - **1/16 in. spacing between ply drops in taper region**
- **Of use for predicting the location, mode, and load level at failure**

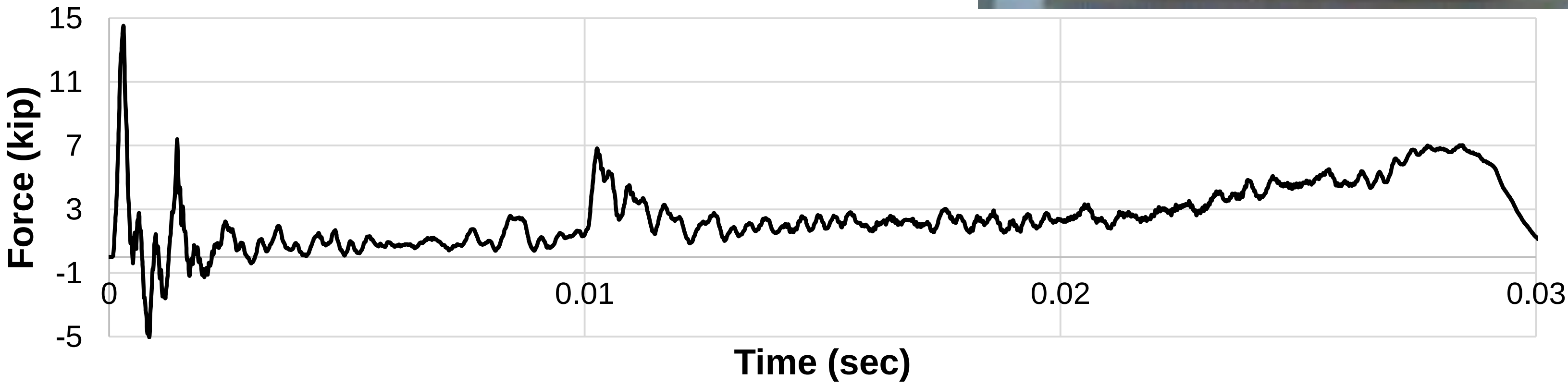


Example Ply-Drop Crush Test:

Double-Side 90° Ply-Drop

- **Initial failure occurs at lower ply-drop**
- **Peak load: 14.5 kip**





Current Focus:
Crush Testing of Single Stanchion Assembly

<u>Additional considerations include</u>:

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  - Design of laminate in bolted region
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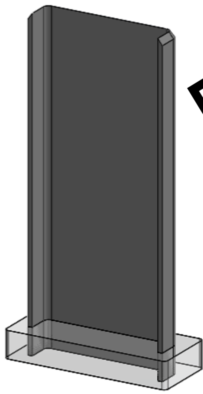
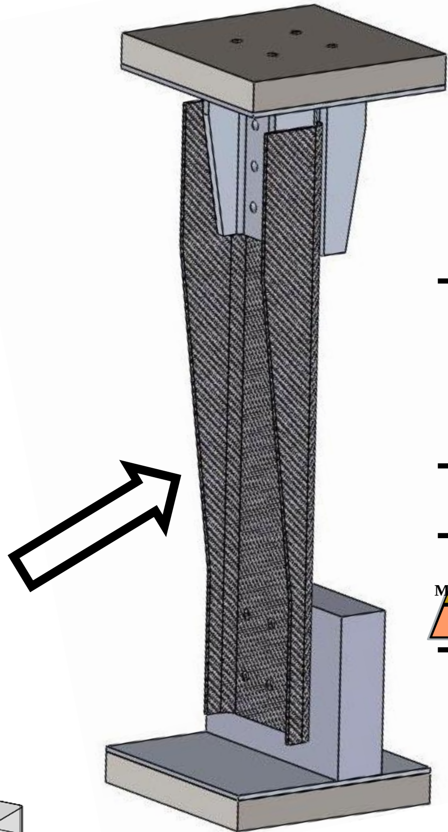
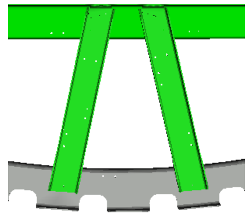
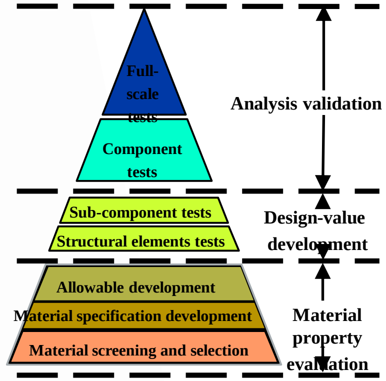
  - Internal ply-drops
  - Reduced cross-sectional area
  - Produced failure at prescribed location, load level, and failure mode

Subsequent stable crush of stanchion





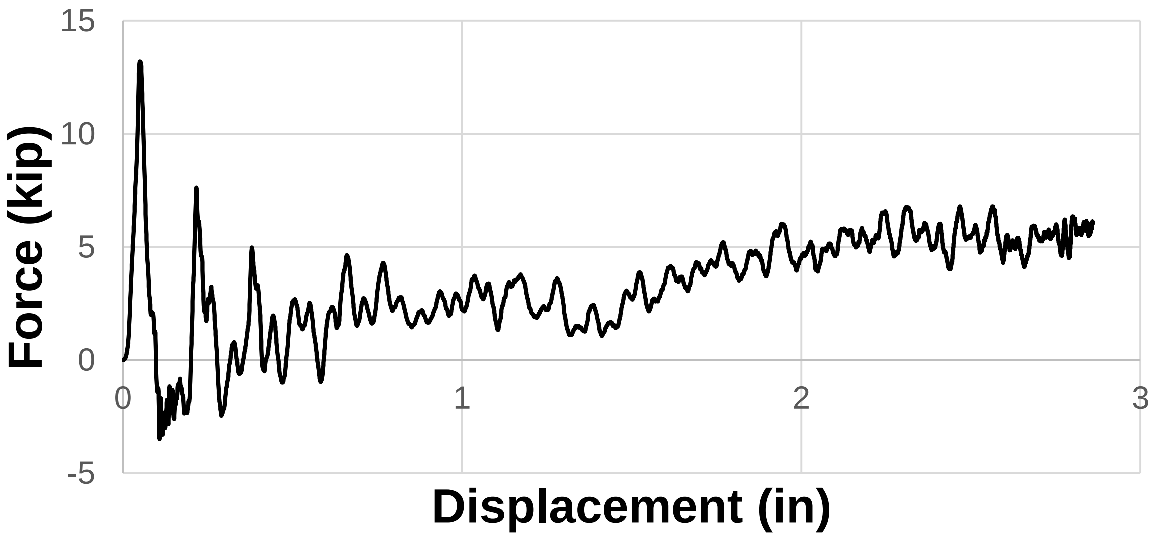




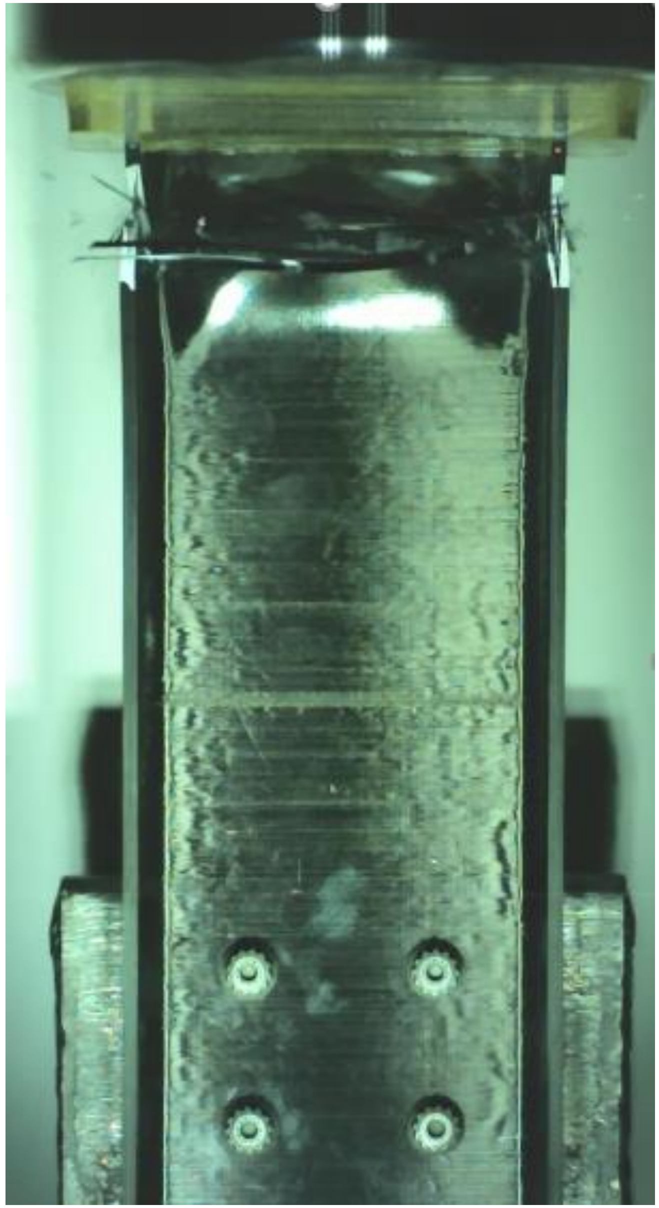
Pre-Stanchion Assembly Testing:

Bolted Joint with Ply-Drop

- **Failure at prescribed location.**
- **Subsequent stable crushing.**
- **Minimal deflection of bolted region.**

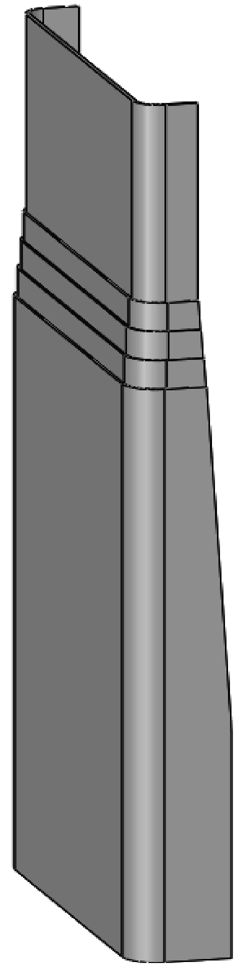


	Avg. Peak Failure
Bearing (dynamic)	20.0 kip
Ply-drop (8 plies)	15.4 kip



Upcoming Testing:
C-Channel with Reduced Cross-Section

- Configuration of bearing stacking sequence to be quasi-isotropic or addition of ±45's
- Use of ply-drop configuration selected from previous testing
- Reduction in flange height in region of crush initiation
- Tapered flange height to promote stable crush behavior
- Designed to fail at ply drop region and display stable crush in region with increasing cross sectional area
- Test results to be used to assess numerical modeling capabilities



BENEFITS TO AVIATION

- **Building block approach for developing composite crush structures for crashworthiness**
- **Coupon-level test methods for use in initial crashworthiness assessment of candidate composite materials and laminates**
- **Documentation of building block approach for crashworthiness design and experimental validation in CMH-17**
- **Dissemination of research results through FAA technical reports and conference/journal publications**

Questions?

Don't forget to fill out the feedback form in your packet or online at www.surveymonkey.com/r/jamsfeedback

Thank you.

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