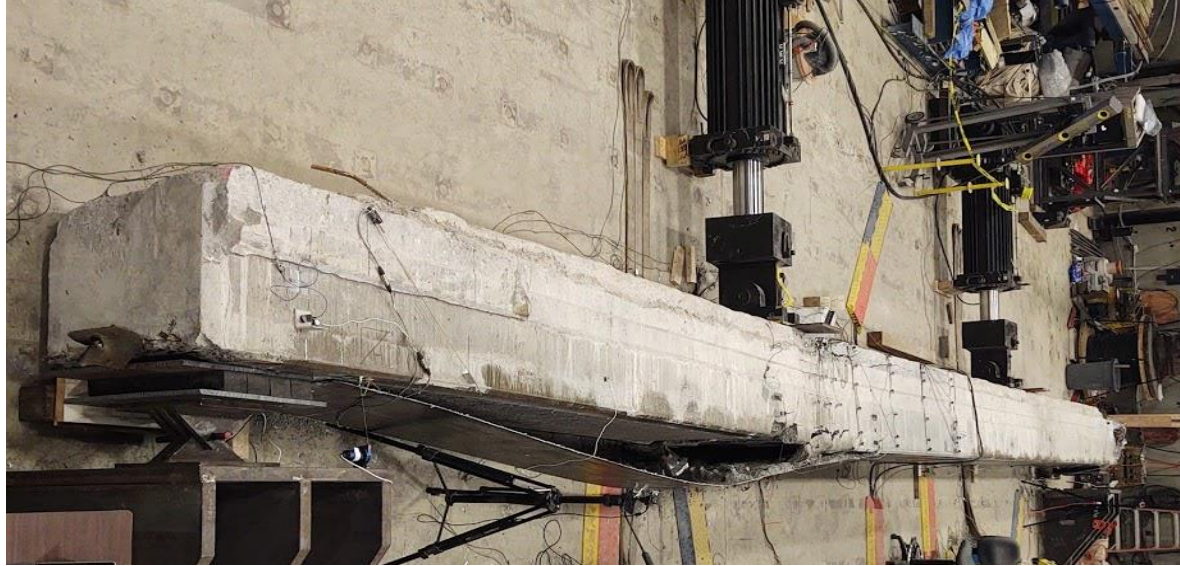


Tests of Decommissioned Box Beams Strengthened with CFRP Anchors and Laminates

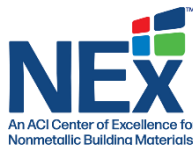


Sina Yousefianmoghadam, [Andreas Stavridis](#), Scott Arnold, Serge Roux

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Boston, MA
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**Department of
Transportation**



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➤ Erdman Anthony

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- Catherine Gauron

Outline

➤ Test Structure



➤ Retrofit Strategy

➤ Test Results

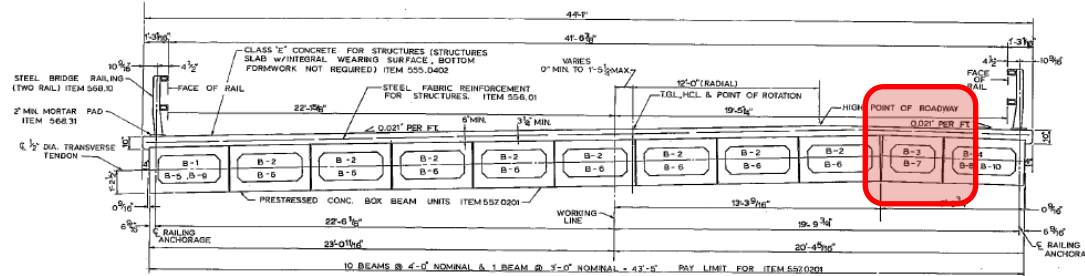
➤ Conclusions



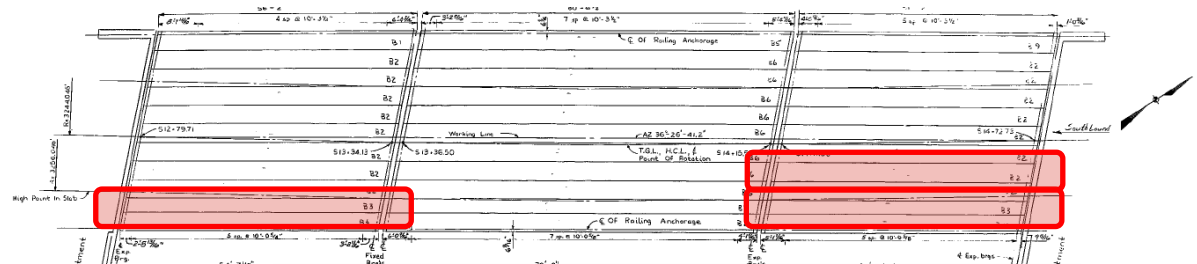
Test Structure

- Prestressed concrete box beams
- Deteriorated due to harsh winters
- Three 56-ft.-long beams extracted for retrofit with a FRP system

- Two 3-ft wide
- One 4-ft wide



Deck Section



Plan View

- DOT Objectives:
 - Increase flexural capacity by 30%
 - Avoid shear failures
 - Realistic application for the field



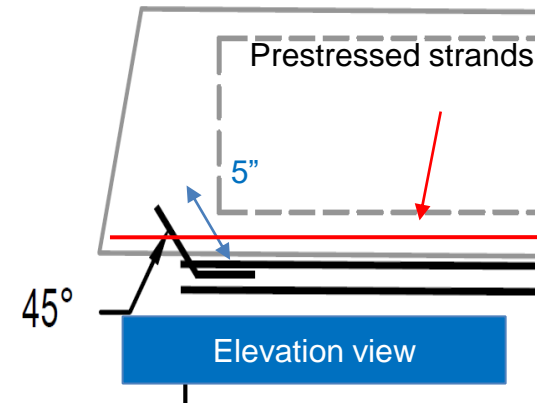
Beam Removal



Retrofit Design Considerations

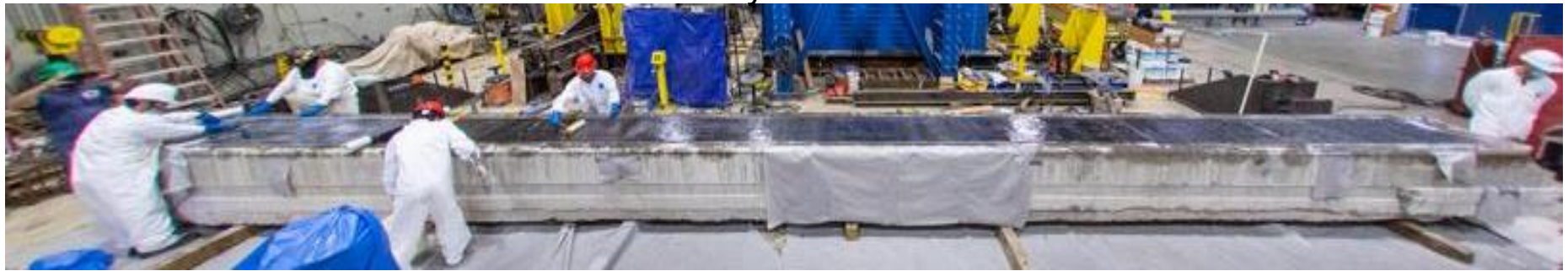
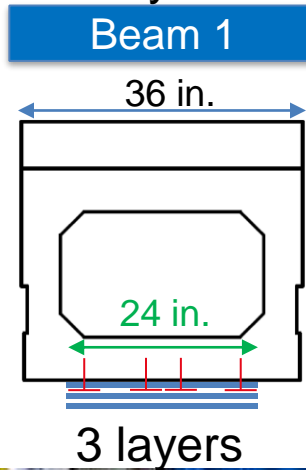
- Laminate
 - Material
 - Thickness
 - Width
 - Length

- Anchor
 - Size
 - Embed. depth
 - Embed. angle
 - Fan opening
 - Layout
 - Locations
- 5 inches
- 45 degrees
- 60 degrees
- Varied
- Solid sections, initially



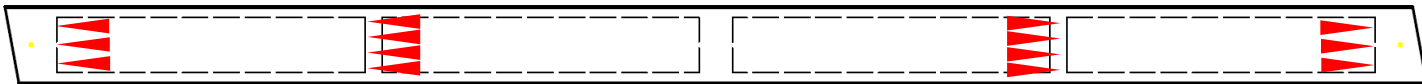
Retrofit Design

- The laminate thickness and anchor layout varied between the beams

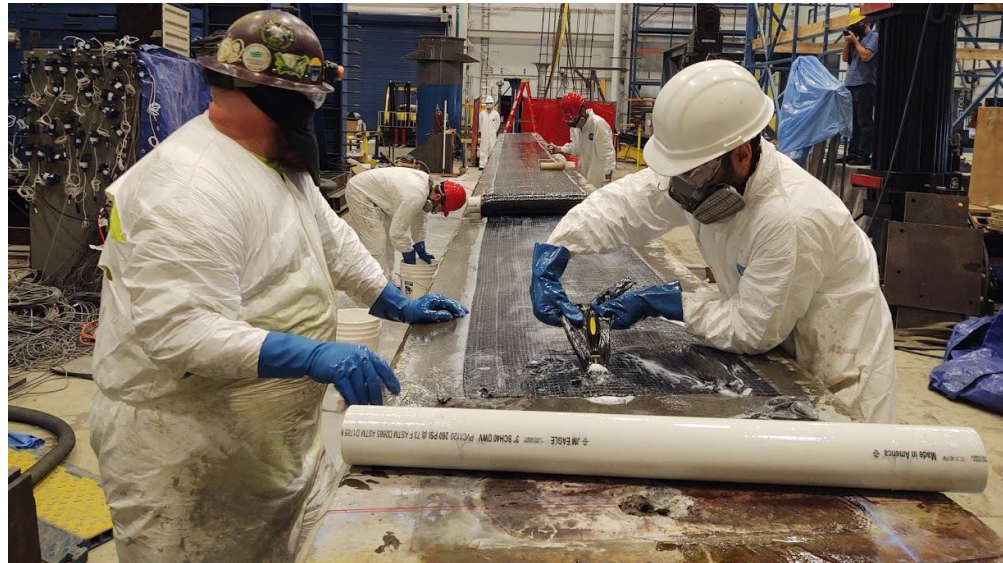


Anchor/Laminate
Ratio
0.5

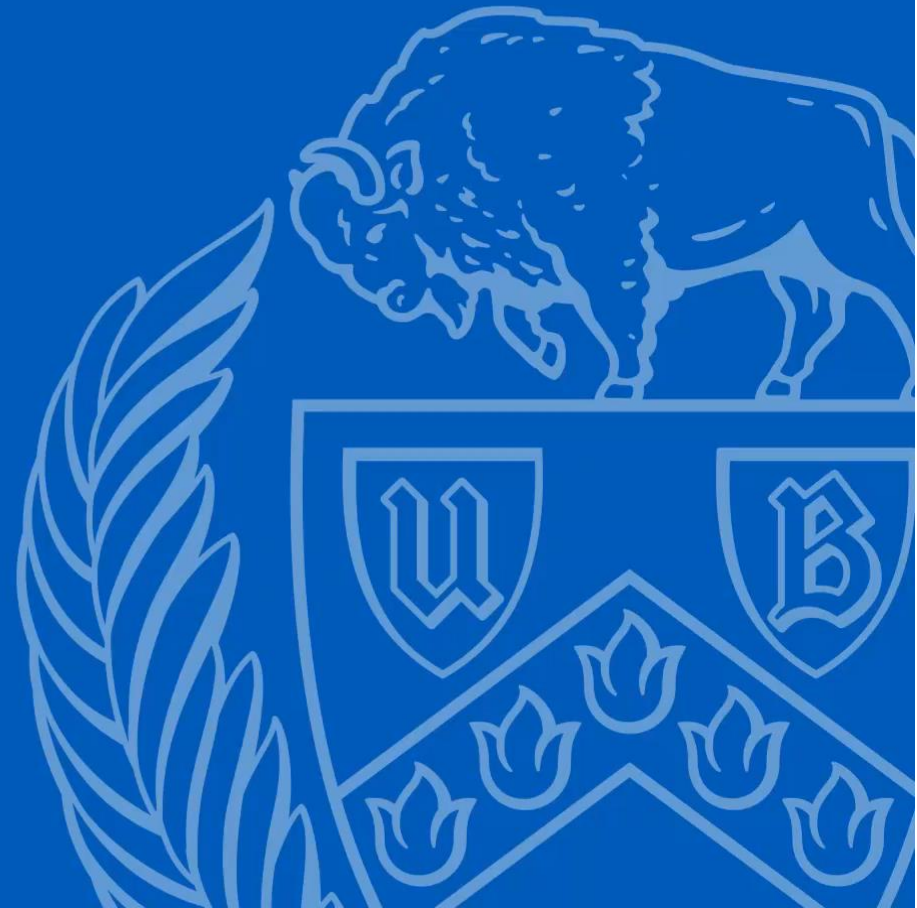
Beam 1



Retrofit Application Sequence

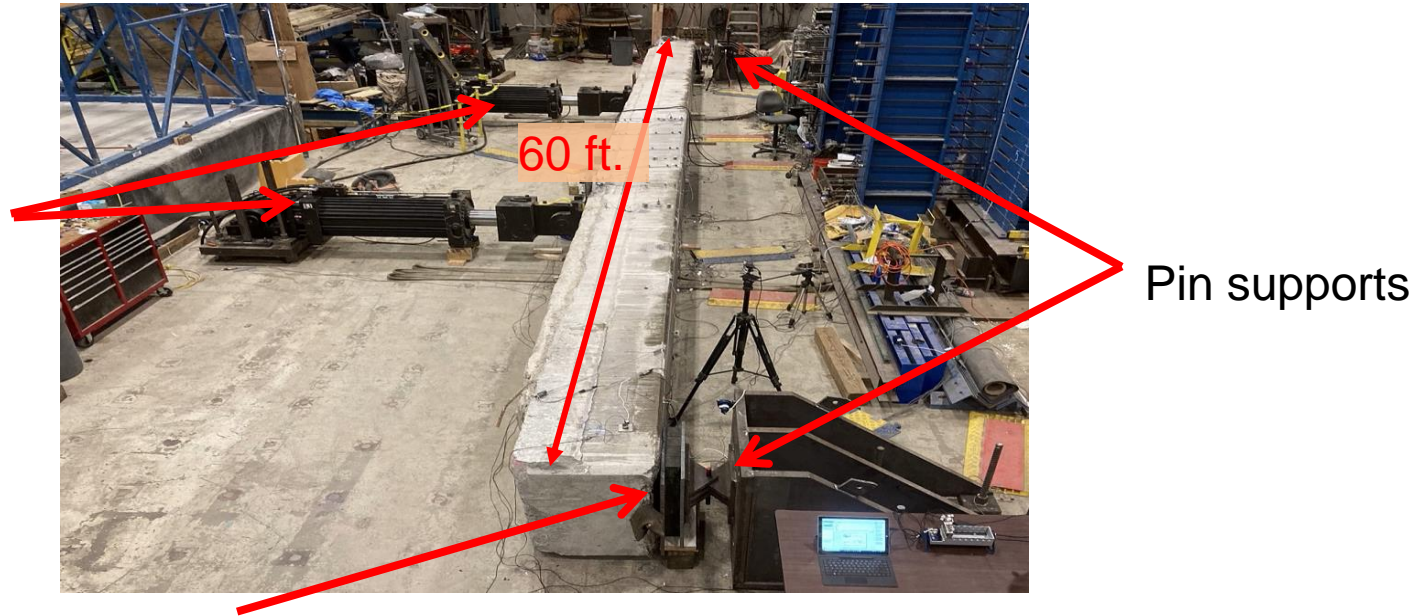


Retrofit Application Process



Test Setup

- Four-point-bending tests were conducted until failure

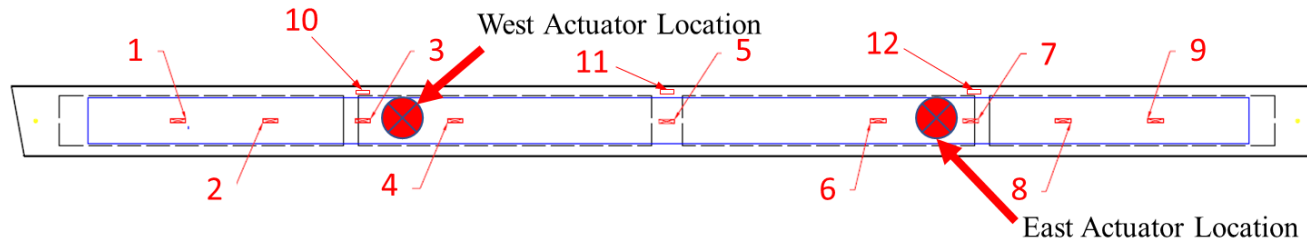


450 kip
actuators

Pin supports

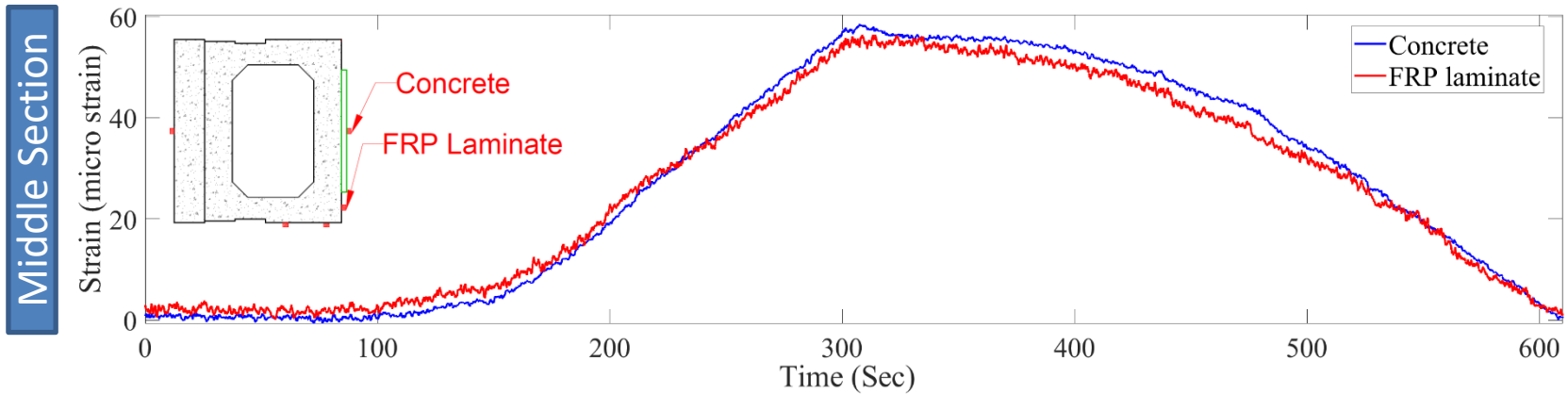
Elastomeric pad
obtained from bridge

- Beam deformations and strains from the concrete and FRP laminate were measured



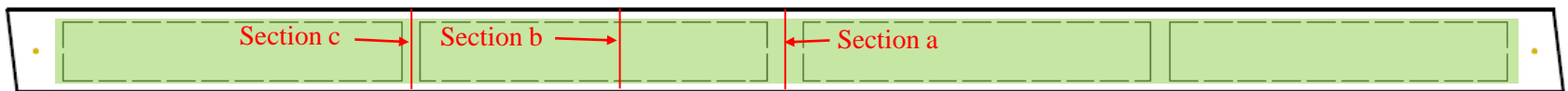
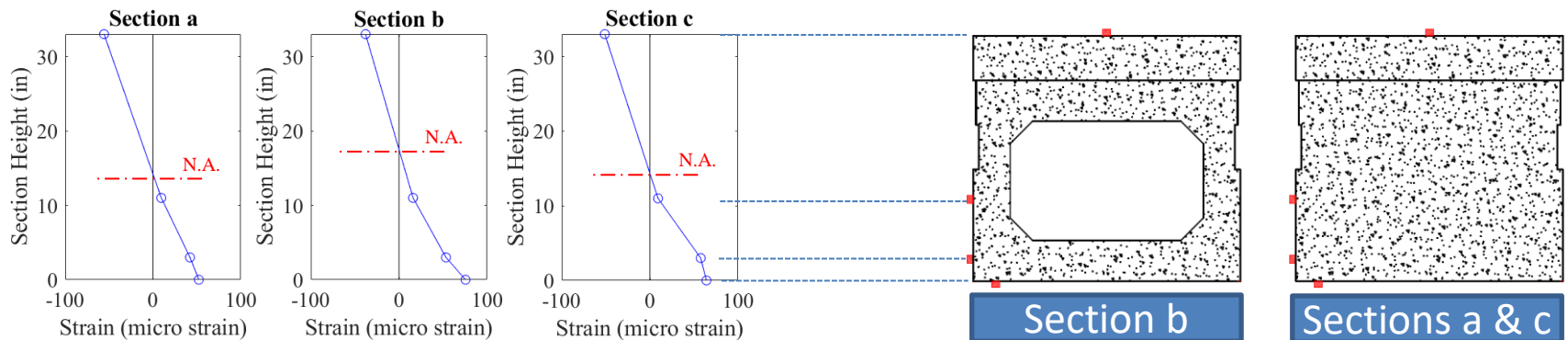
Service-Level Tests

- FRP-concrete strain compatibility was also investigated



- Strain profiles were obtained at three sections at peak force

- ~linear
- N.A. varied between sections



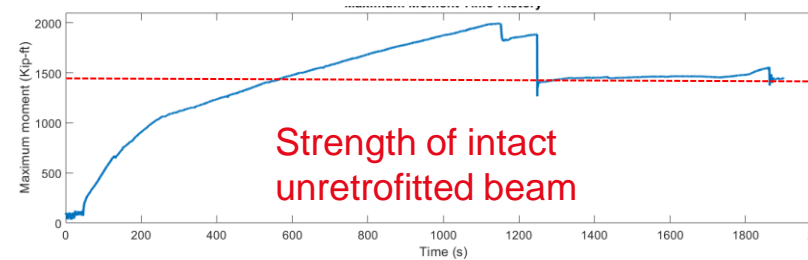
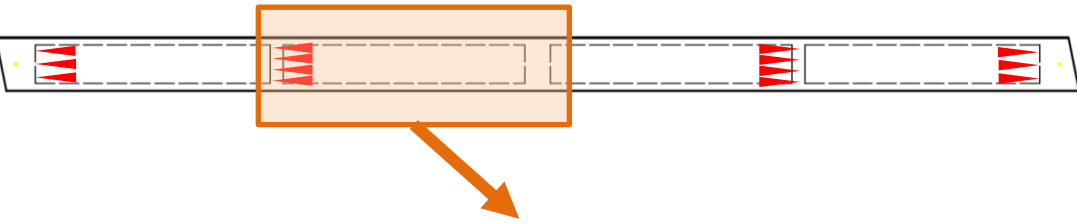
Testing: Beam 1



Beam 1 Failure Test



Beam 1: Failure Pattern and Strength



Concrete cover pulled by the FRP

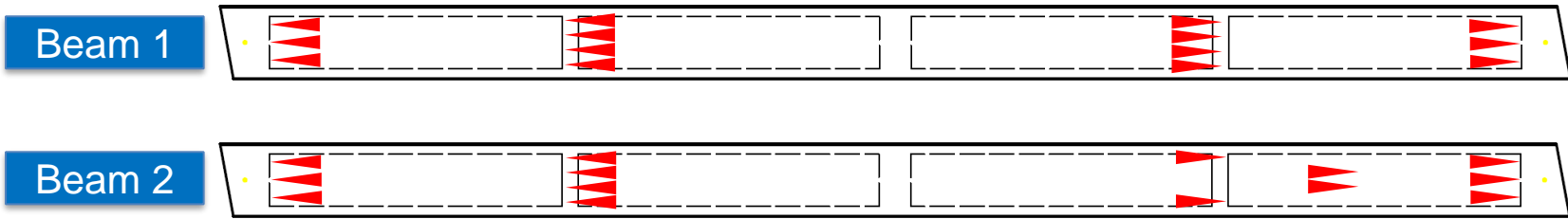
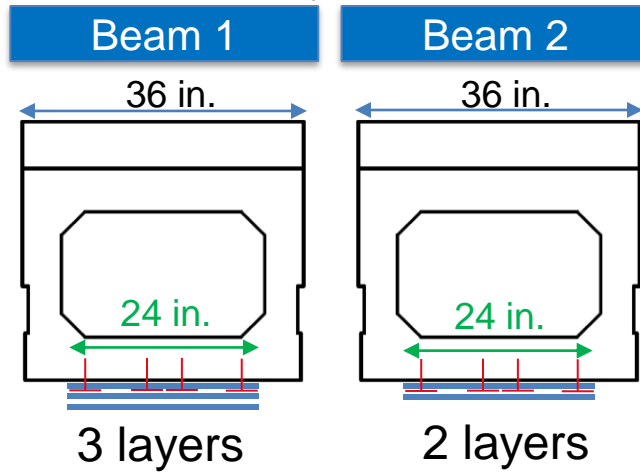


FRP anchors pulled concrete away



Retrofit Design

- The laminate thickness and anchor layout varied between the beams



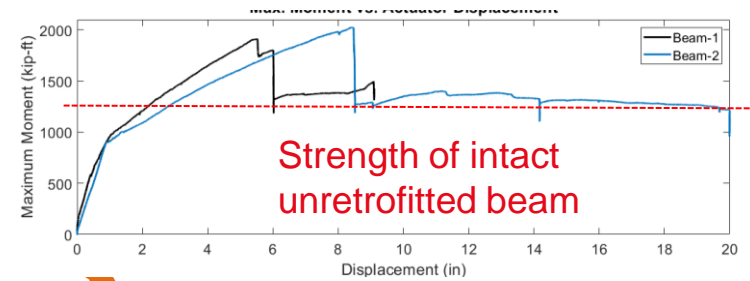
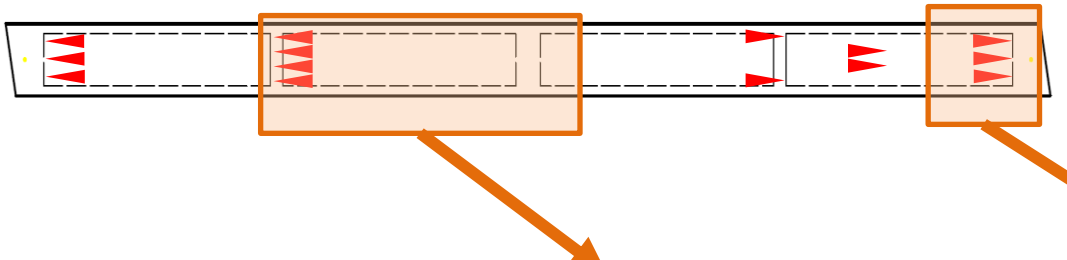
Anchor/Laminate Ratio

0.5

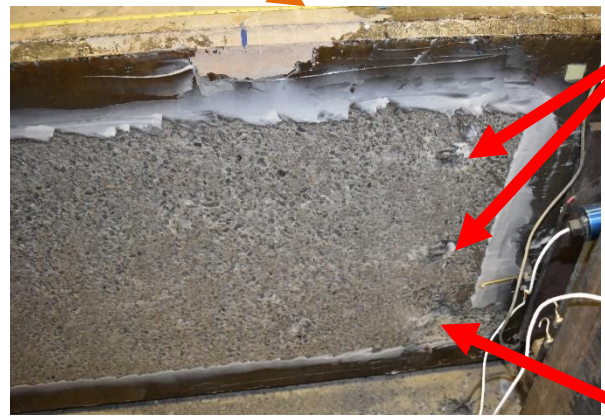
0.8

Beam 2 Failure Test Normal Speed

Beam 2: Failure Pattern and Strength



Concrete cover pulled by the FRP



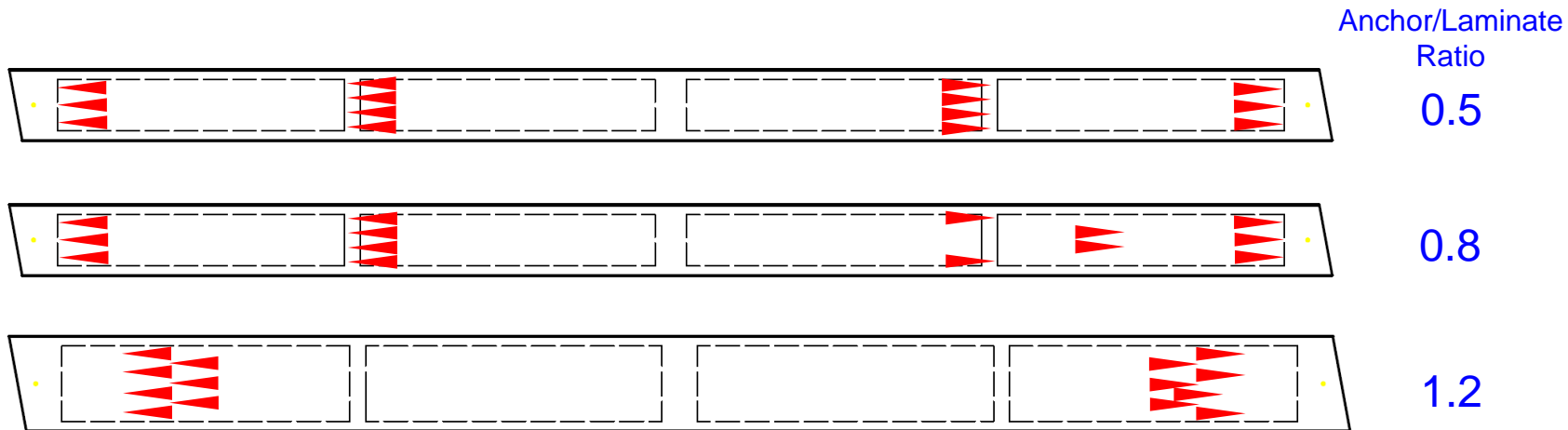
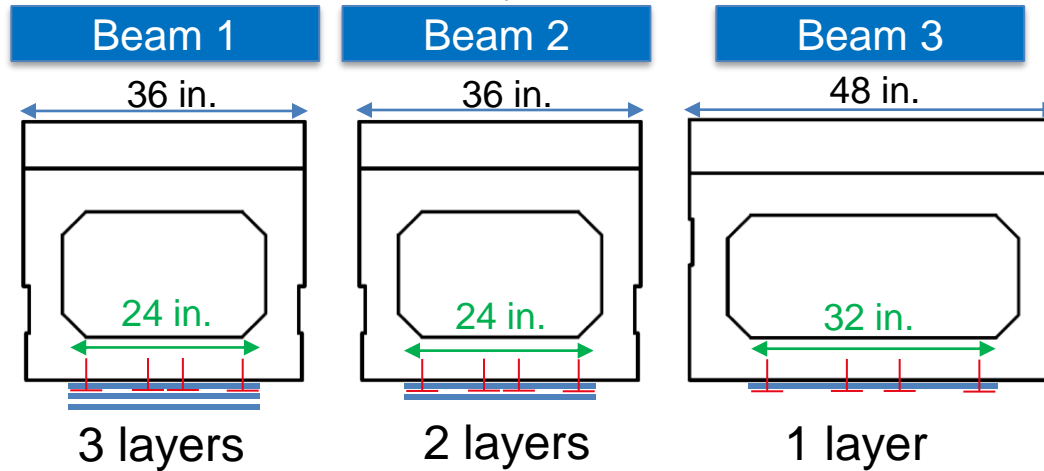
Ruptured anchors

Pulled-out anchor



Retrofit Design

➤ The laminate thickness and anchor layout varied between the beams

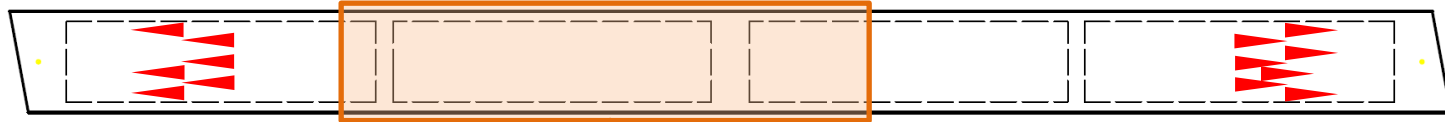


Testing: Beam 3

Beam 3 Failure Test Normal Speed



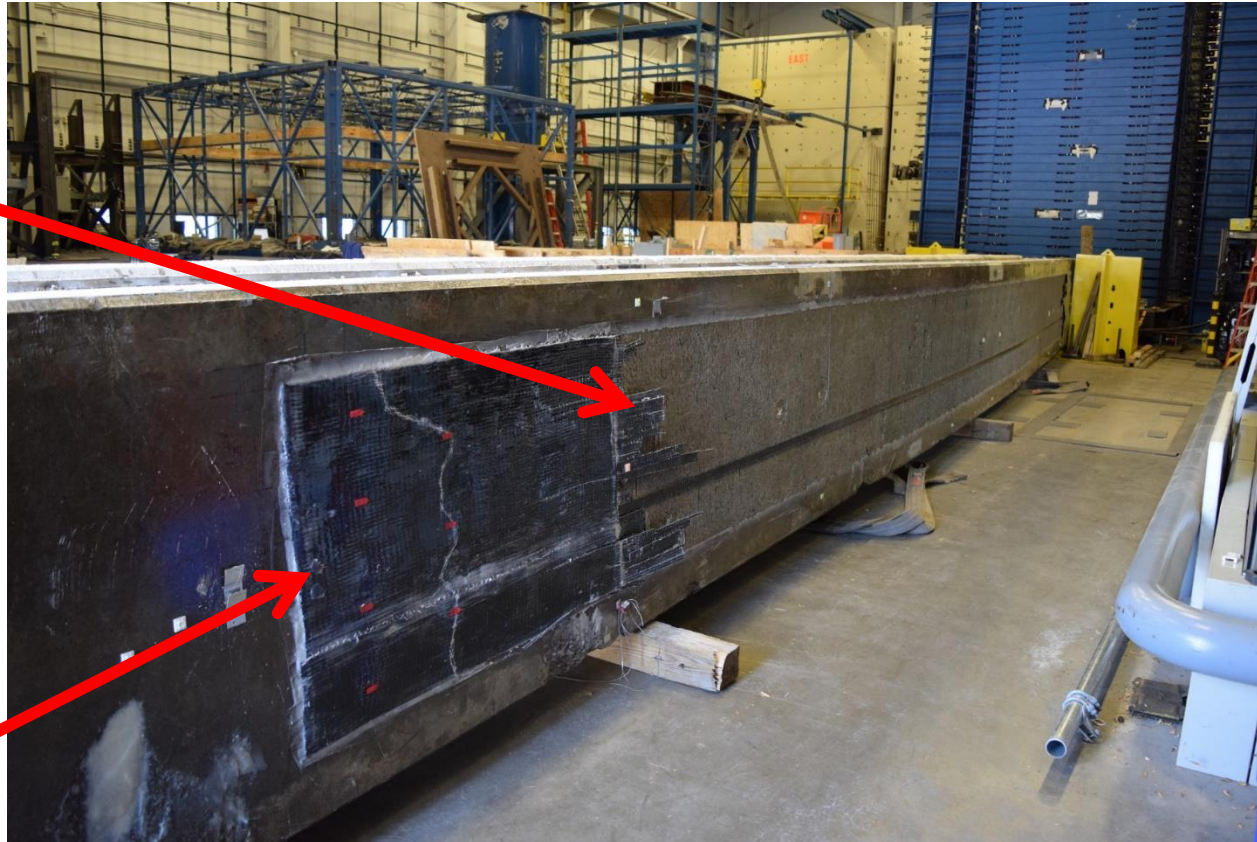
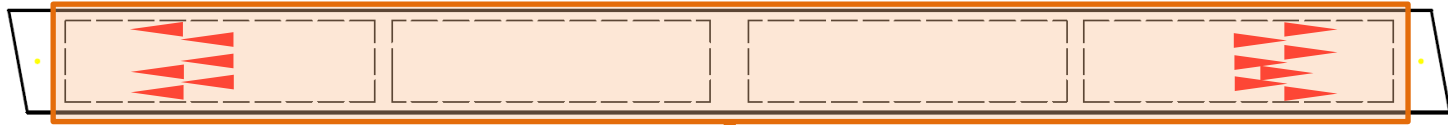
Beam 3: Failure Pattern



Ruptured laminates

Uniformly cracked concrete at mid span

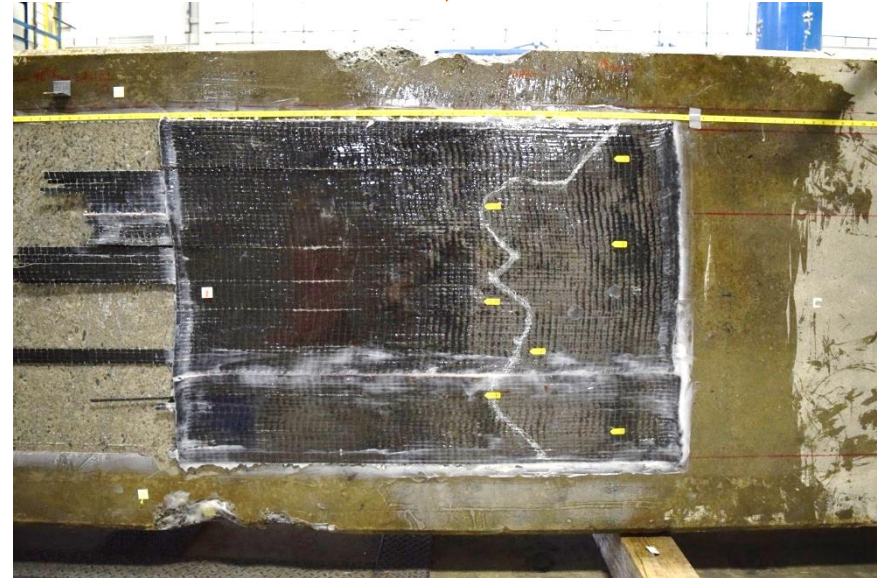
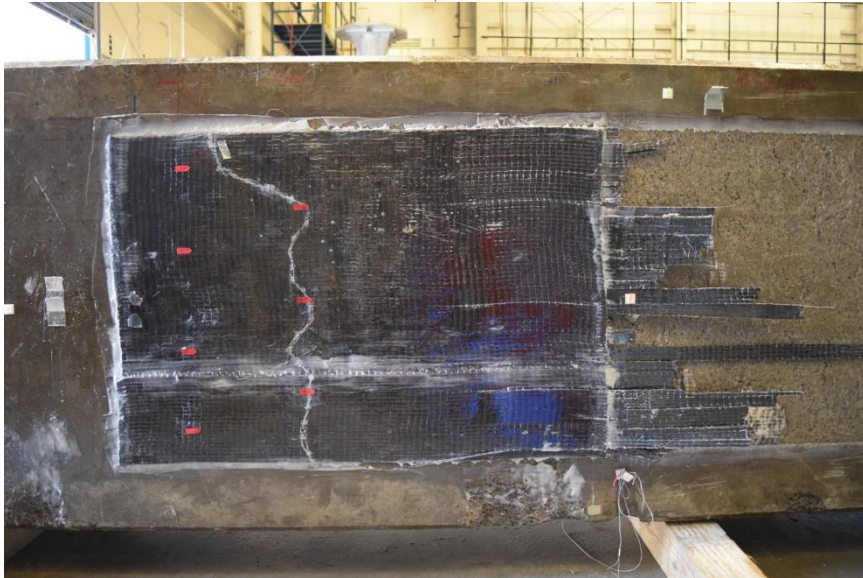
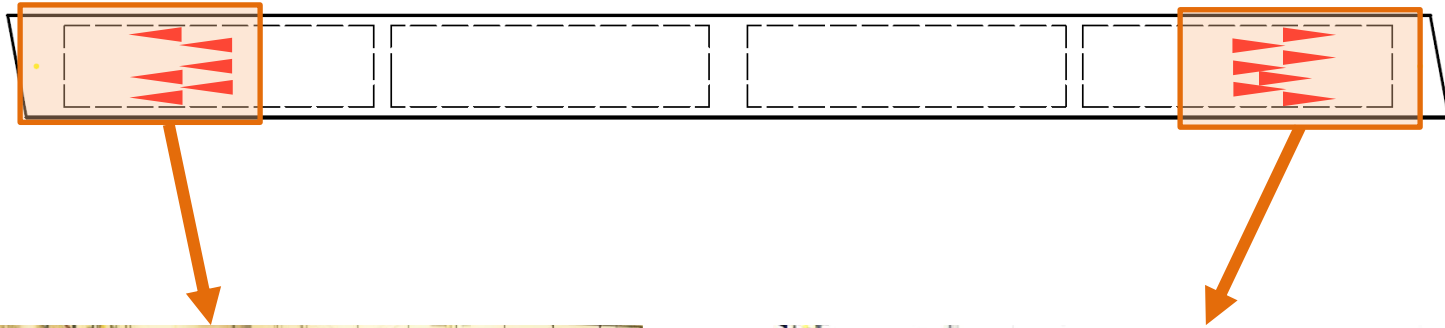
Beam 3: Failure Pattern



Ruptured
laminate
remains

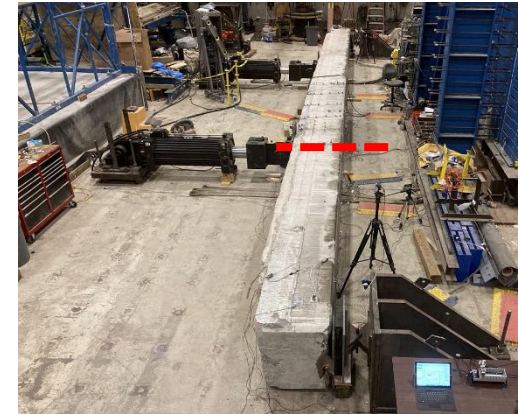
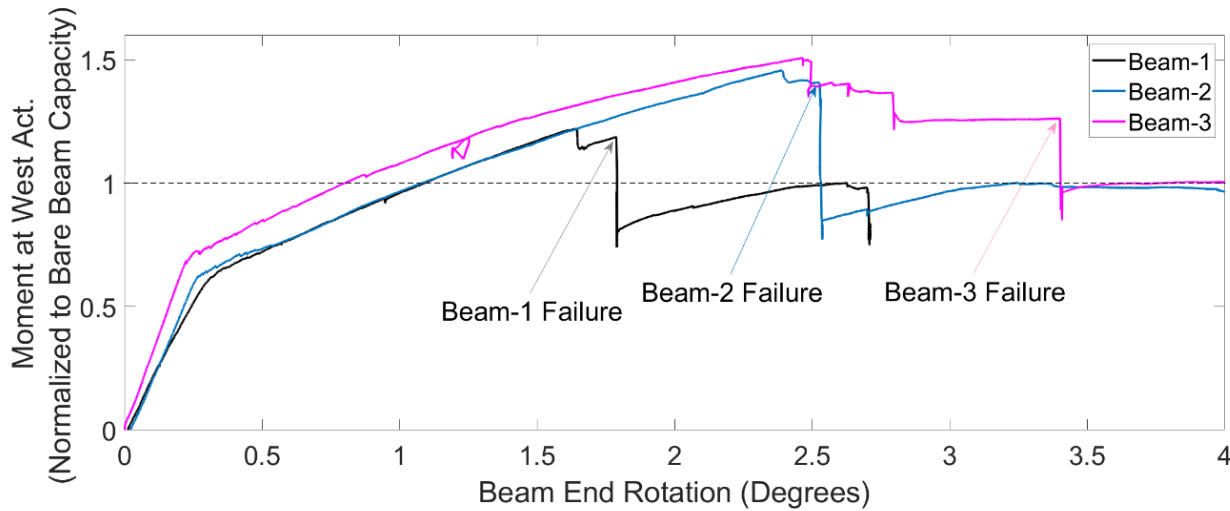
Anchored
end zone

Beam 3: Failure Pattern



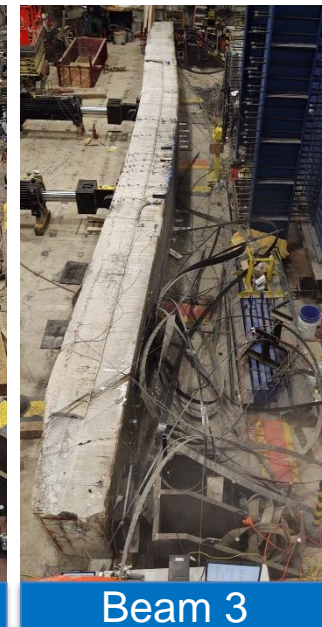
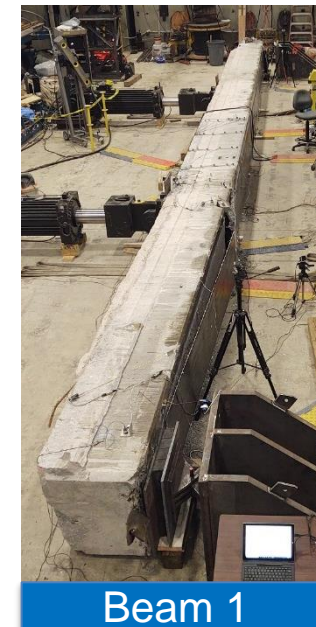
- Anchor locations are shown by **red** and **yellow** stickers
- White line defines the boundary between the debonded and undebonded laminate

Comparison of Behavior



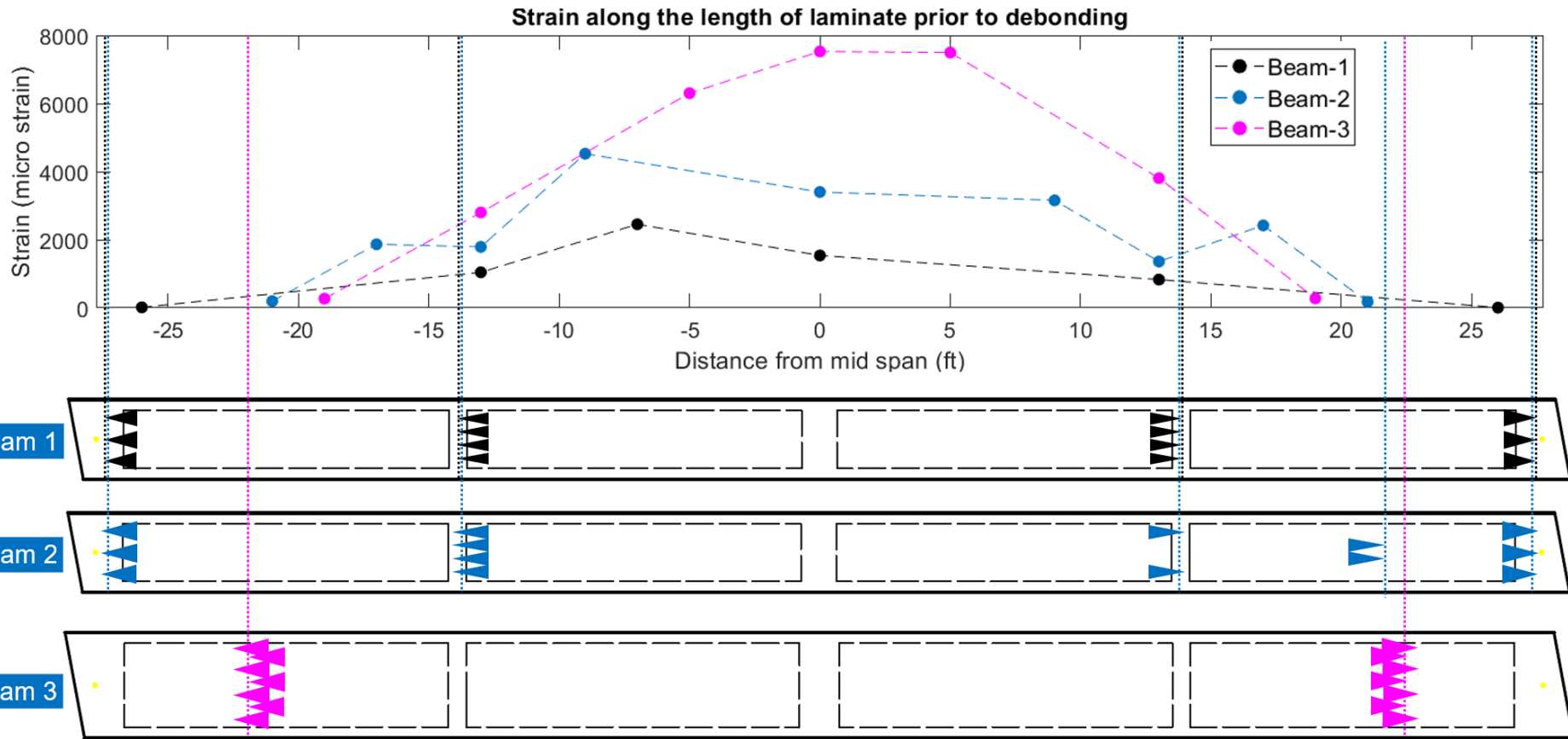
Specimen	Anchor to laminate ratio	Laminate area per beam width (sq. in/ft)	Capacity increase wrt. bare beam (at peak)	Capacity increase wrt. bare beam (at failure)
Beam 1	0.5	1.9	22%	19%
Beam 2	0.8	1.3	46%	41%
Beam 3	1.2	0.6	50%	26%

- Higher capacities achieved by using thinner FRP
- Ductility has almost doubled from Beam 1 to Beam 3



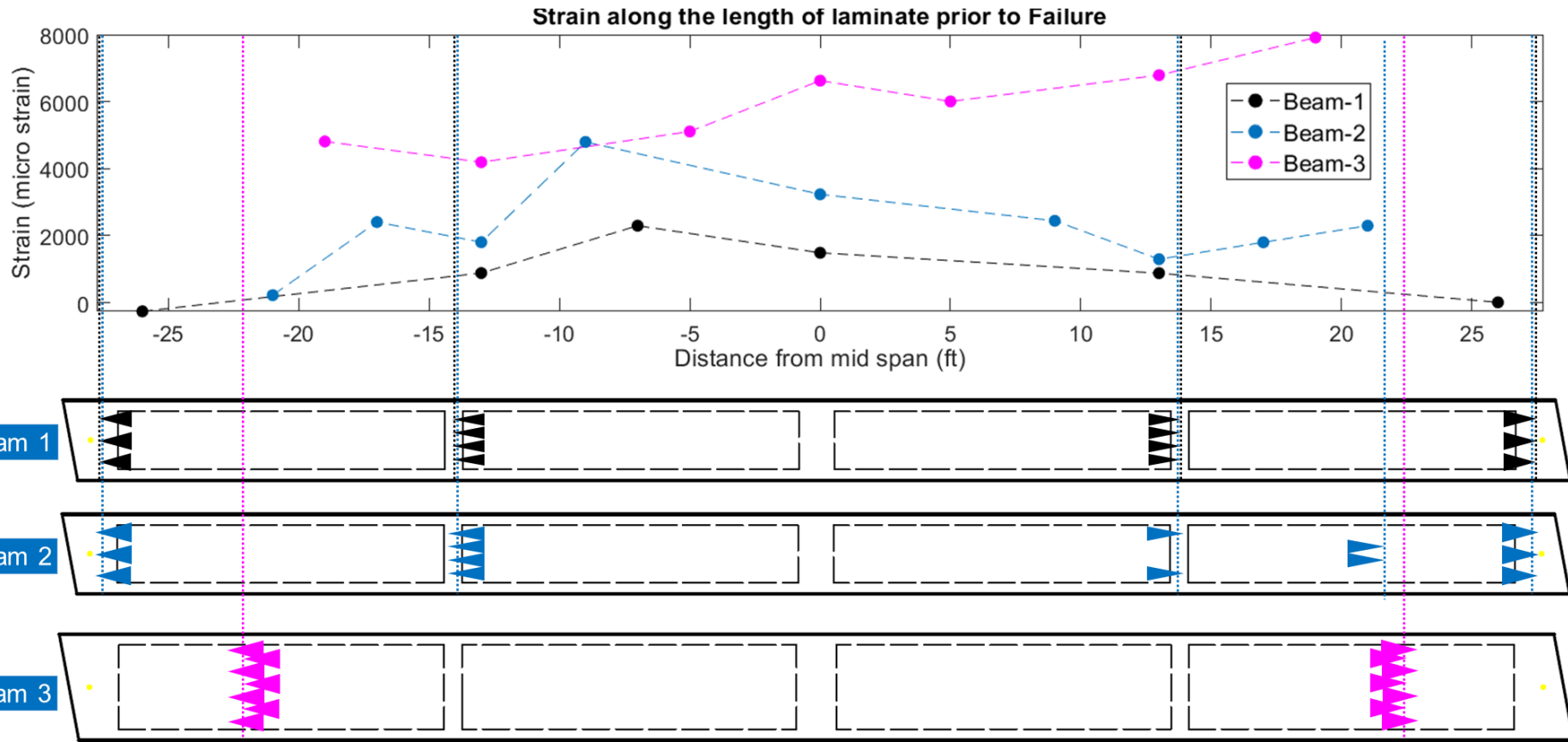
Comparison of Behavior

➤ Strain profiles along the length of the beams were obtained : [Pre-debonding](#)



Comparison of Behavior

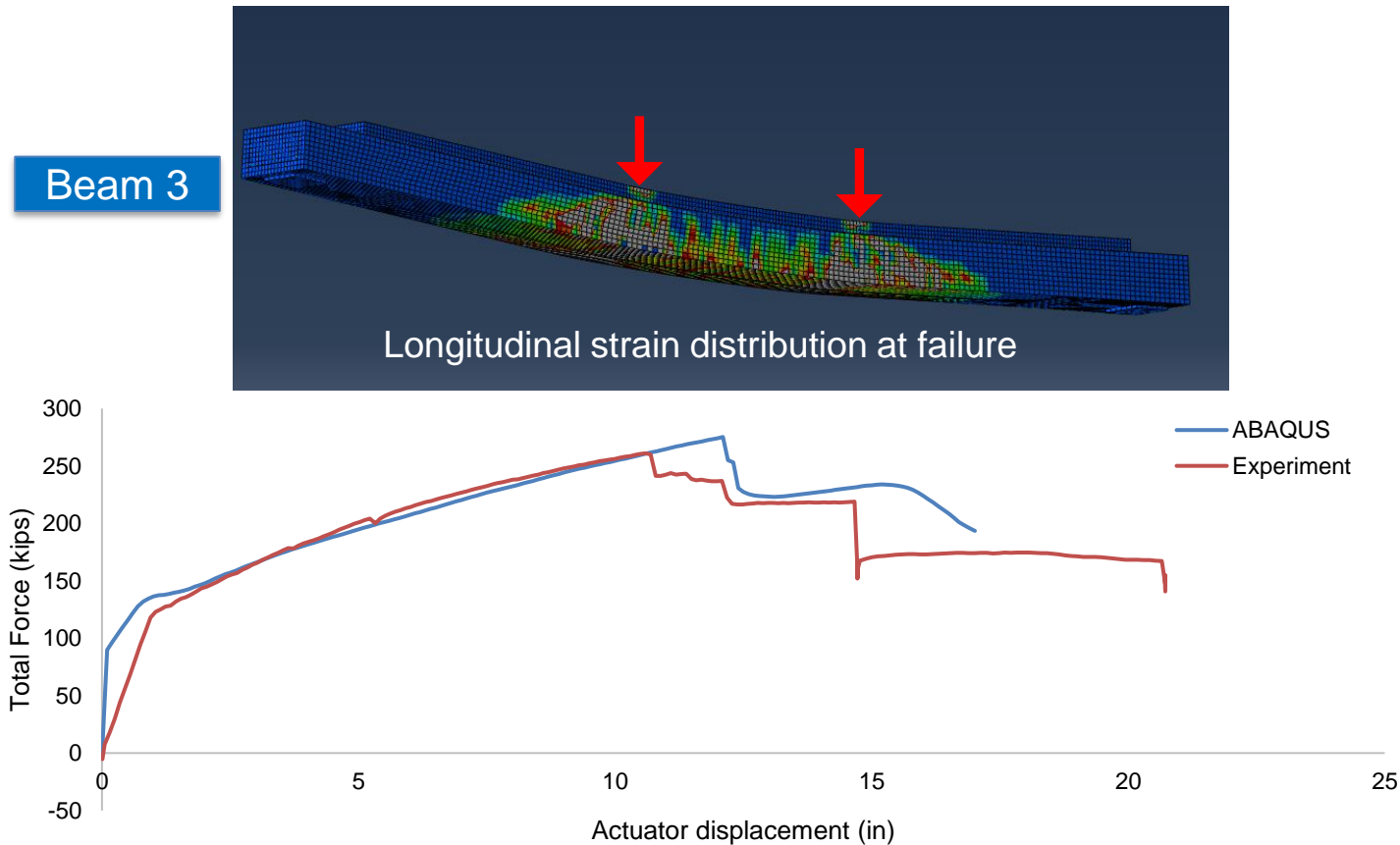
➤ Strain profiles along the length of the beams were obtained : **Pre-failure**



➤ FRP capacity is best used in Beam 3

Numerical Modeling

- ABAQUS is used to develop finite element models of the beams
 - All details are included except for shear reinforcement
 - Concrete properties are based on those of extracted specimens



- Additional work needed to model the anchors

Conclusions

- Load capacity increased significantly in all configurations
- Anchors delayed the failure following debonding
- Increase in the laminate area increases the bond stress, facilitating the debonding
- FRP laminate rupture was achieved with the anchor/laminate ratio of 1.2
- Arrangement of anchors plays an important role in the performance of the retrofit
- Numerical modeling is ongoing

Thank you

