Innovative Use Of FRP For Sustainable Precast Concrete Structures

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FRP MATERIALS

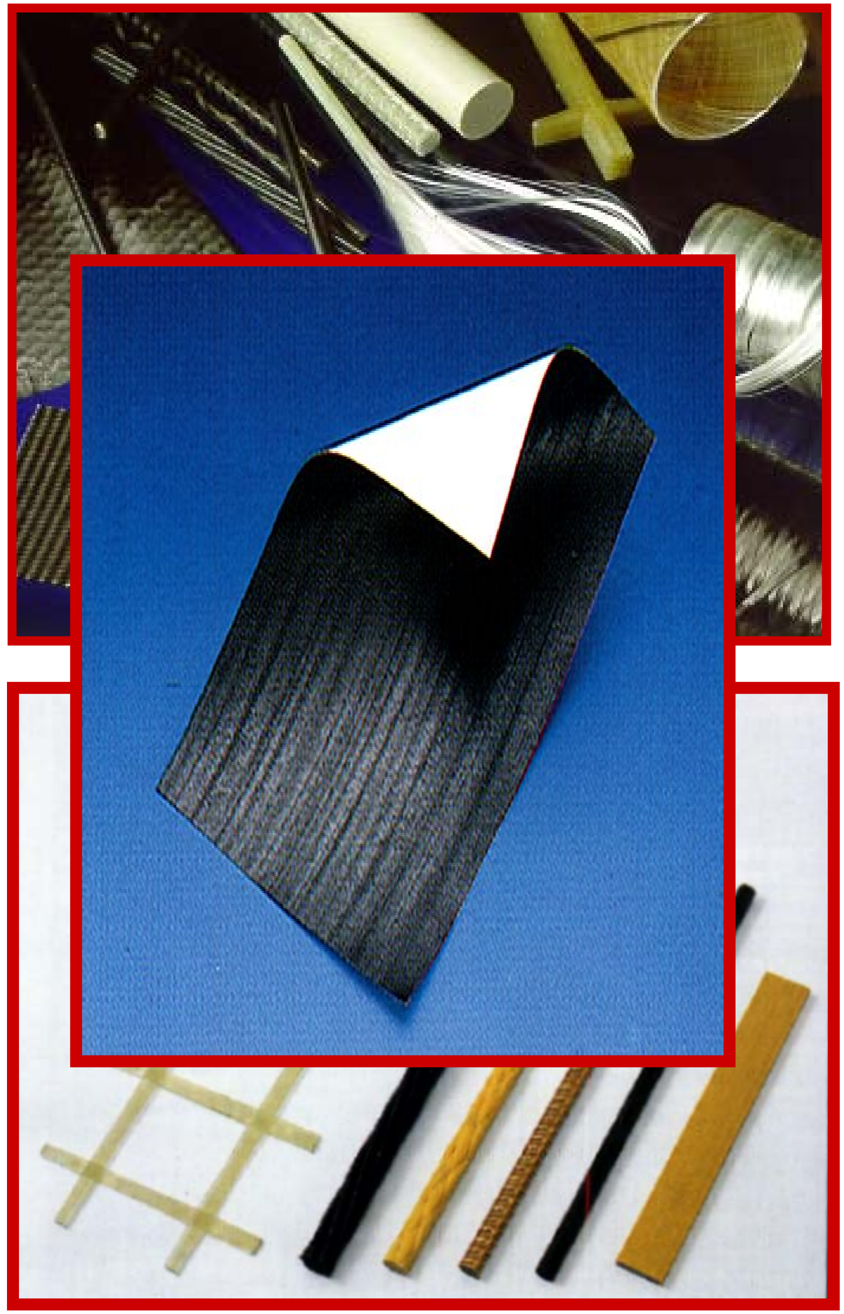
Fibers: GFRP
CFRP
AFRP

+

Resins: Epoxy
Polyester

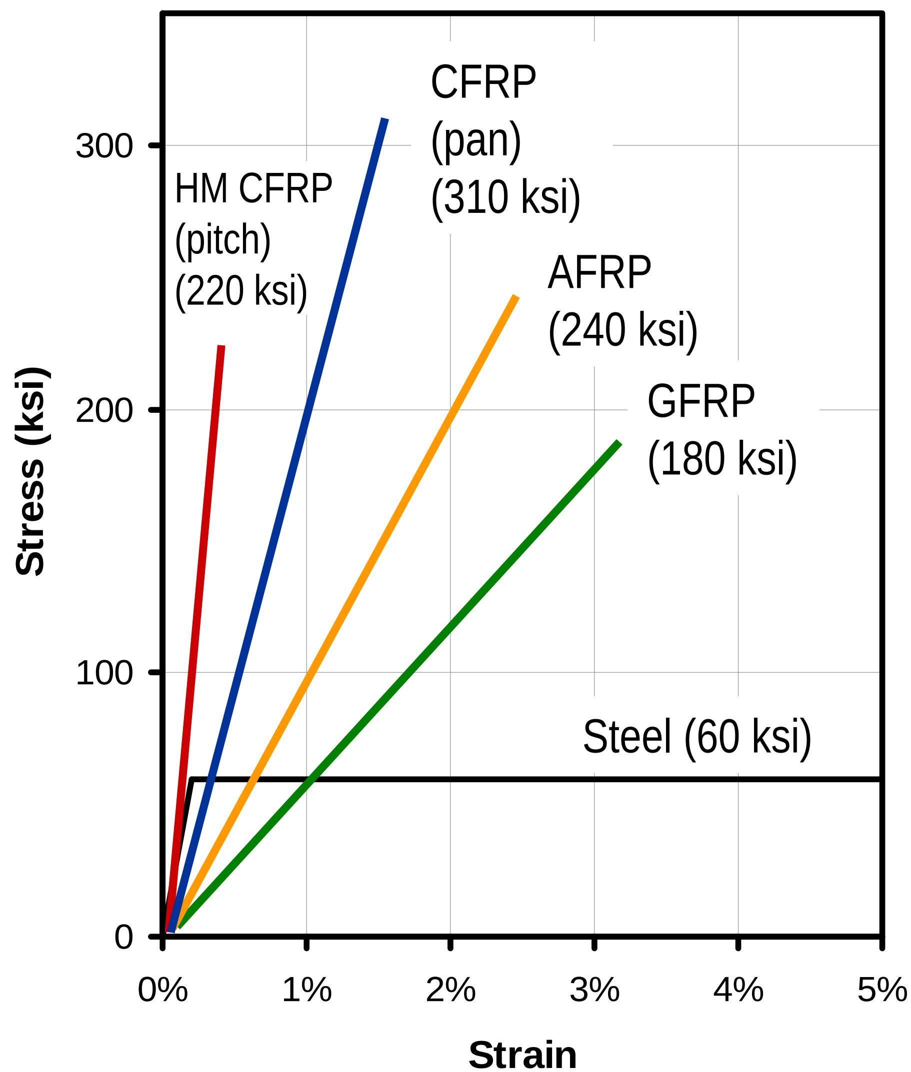
↓

Fiber Reinforced Polymers:
Bars, Tendons, Grids, Laminates ……



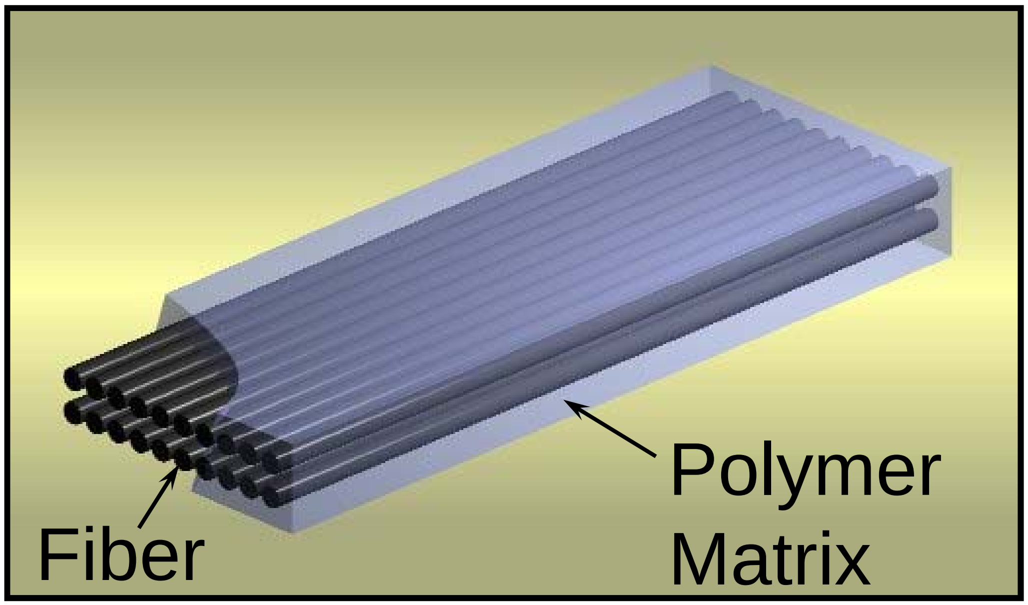
FRP MATERIALS

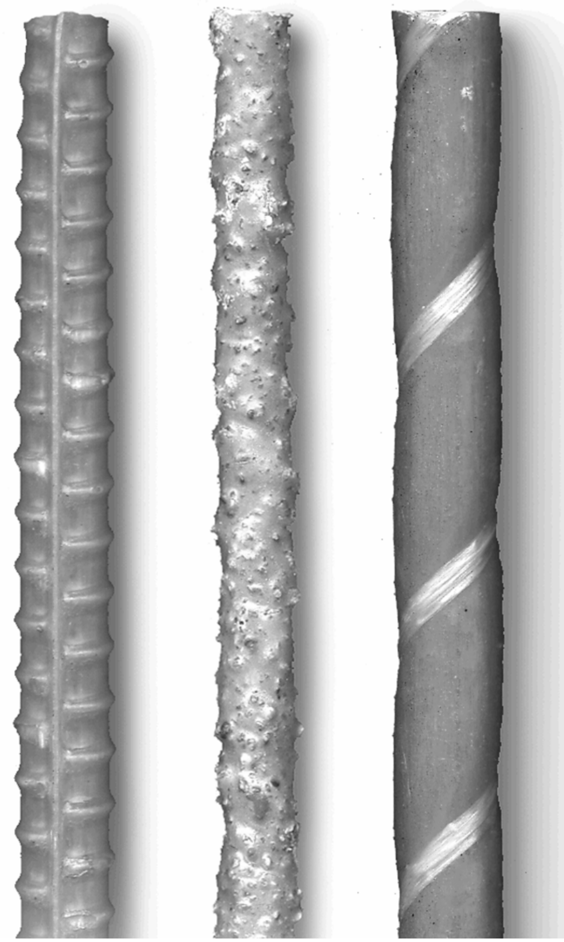
- High strength-to-weight ratio
- Excellent durability
- Non-magnetic
- Low-transversal resistance (temporary works)



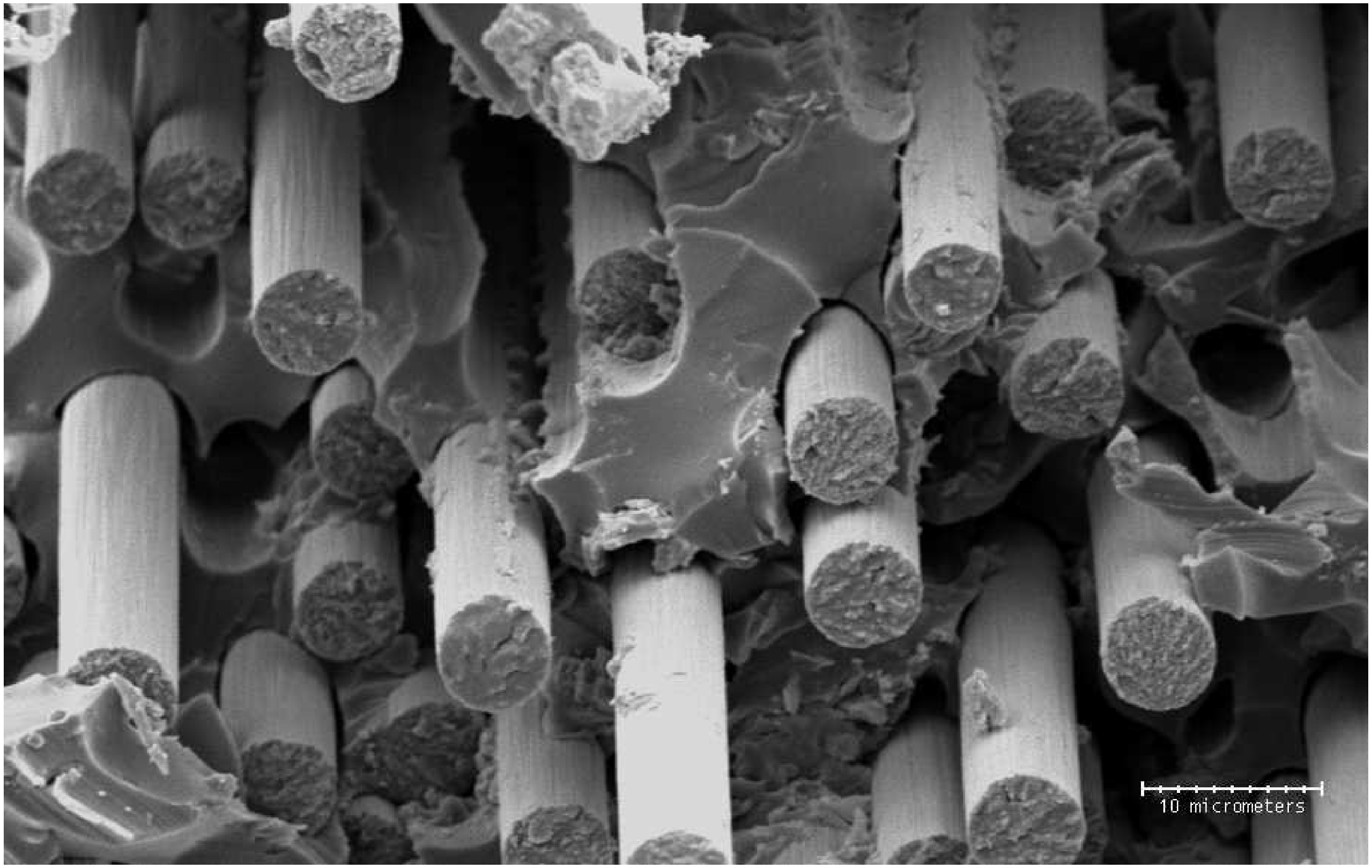
FRP MATERIALS

FRP – Fiber Reinforced Polymer





SEM IMAGE: CARBON/EPOXY



Earlier Applications

- Bridge Girders
- Concrete Filled Precast Piles
- Utility Poles

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1993 Beddington Trail Bridge

First Bulb-Tee bridge girder pre-tensioned with CFRP tendons, and monitored using Fiber Optic Sensors

1993 Beddington Trail Bridge

No signs of degradation when tested in July 2008, after **15 years** of service

1997 Taylor Bridge

Instrumentation of the girder before casting

- First AASHTO Girder prestressed with CFRP tendons
- CFRP stirrups and deck reinforcement
- GFRP reinforced barrier walls
- Monitored using Fiber Optic Sensors

1998 PCI Innovative Design Award

Earlier Applications

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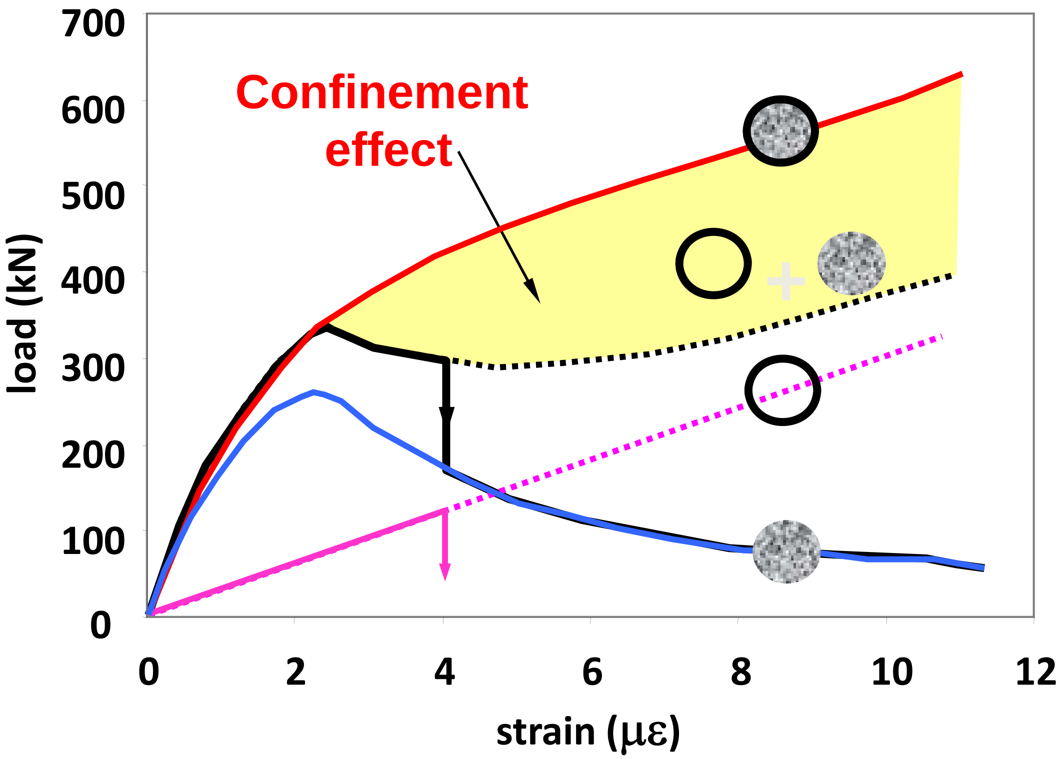
Concrete Filled Precast Piles



Axial Resistance

Bending Resistance

Route 40 Bridge, Virginia

Earlier Applications

- Bridge Girders
- Concrete Filled Precast Piles
- Utility Poles

Power line poles

Power line poles

Recent Advances In Precast

- Double-Tee beams

- Wall Panels
  - Composite
  - Non-composite

- Architectural Cladding

Recent Advances in Precast

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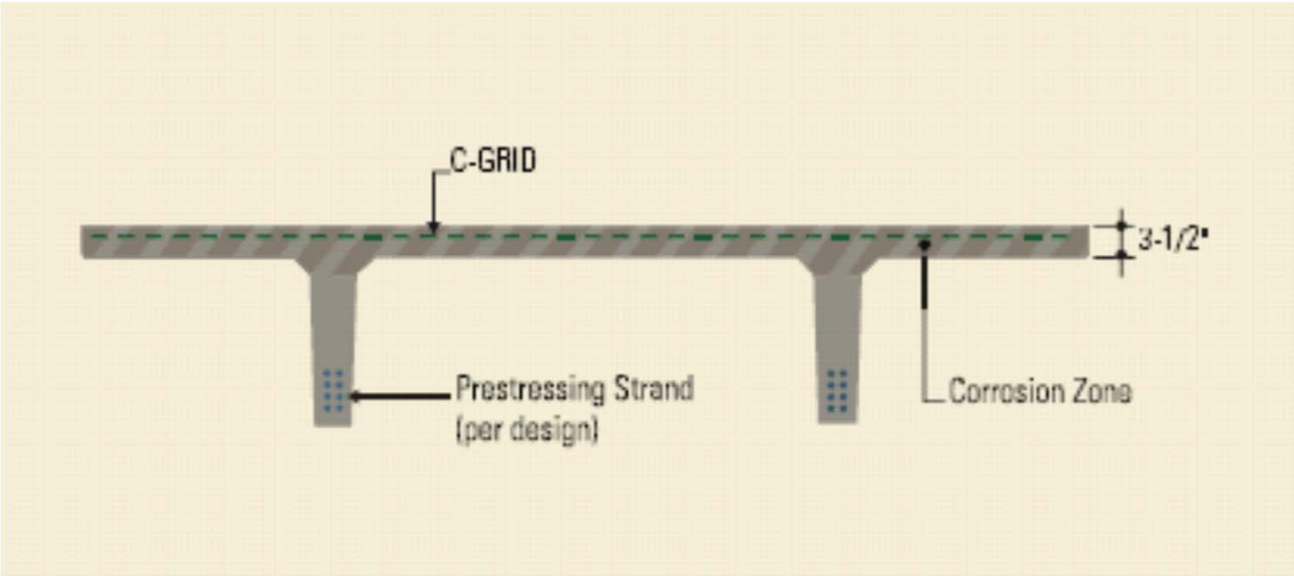
Double-Tee's in Parking Structures

“Corrosion Free” Double-Tee

Thin flange susceptible to chloride penetration

CFRP Grid replacement for WWF conventional steel



Carbon Fiber Grids

Carbon grids are manufactured in an automated process:

- High production volume
- High quality control

Pre-topped Double Tees

Pre-topped Double Tees

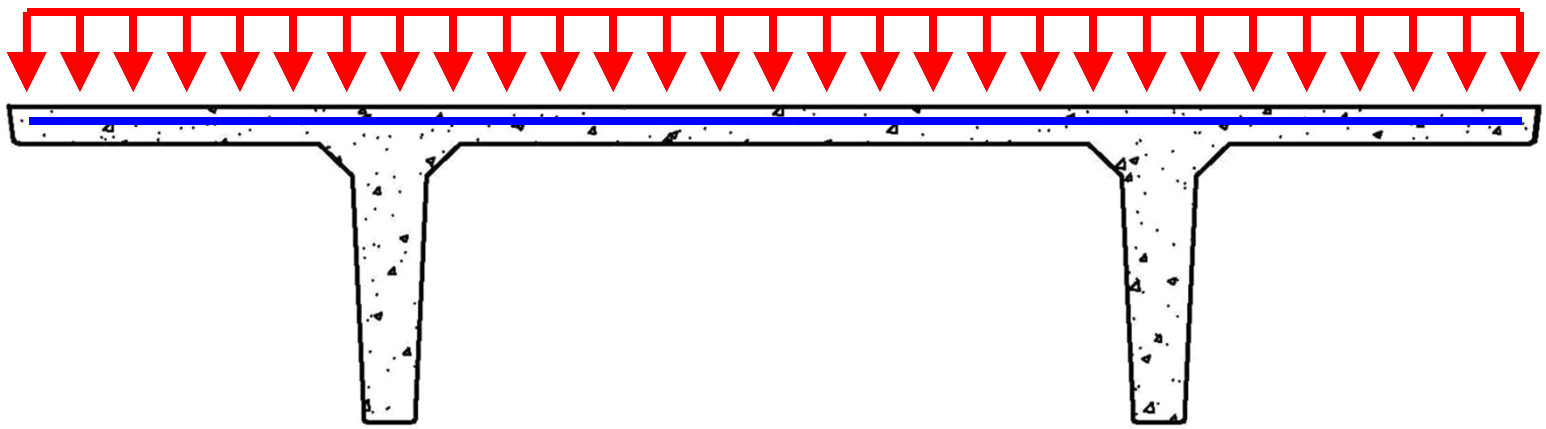
Carbon Fiber Installation

- Embedment and finishing machine to place the grid
- More precisely for optimum performance
- More consistent; less opportunity for human error

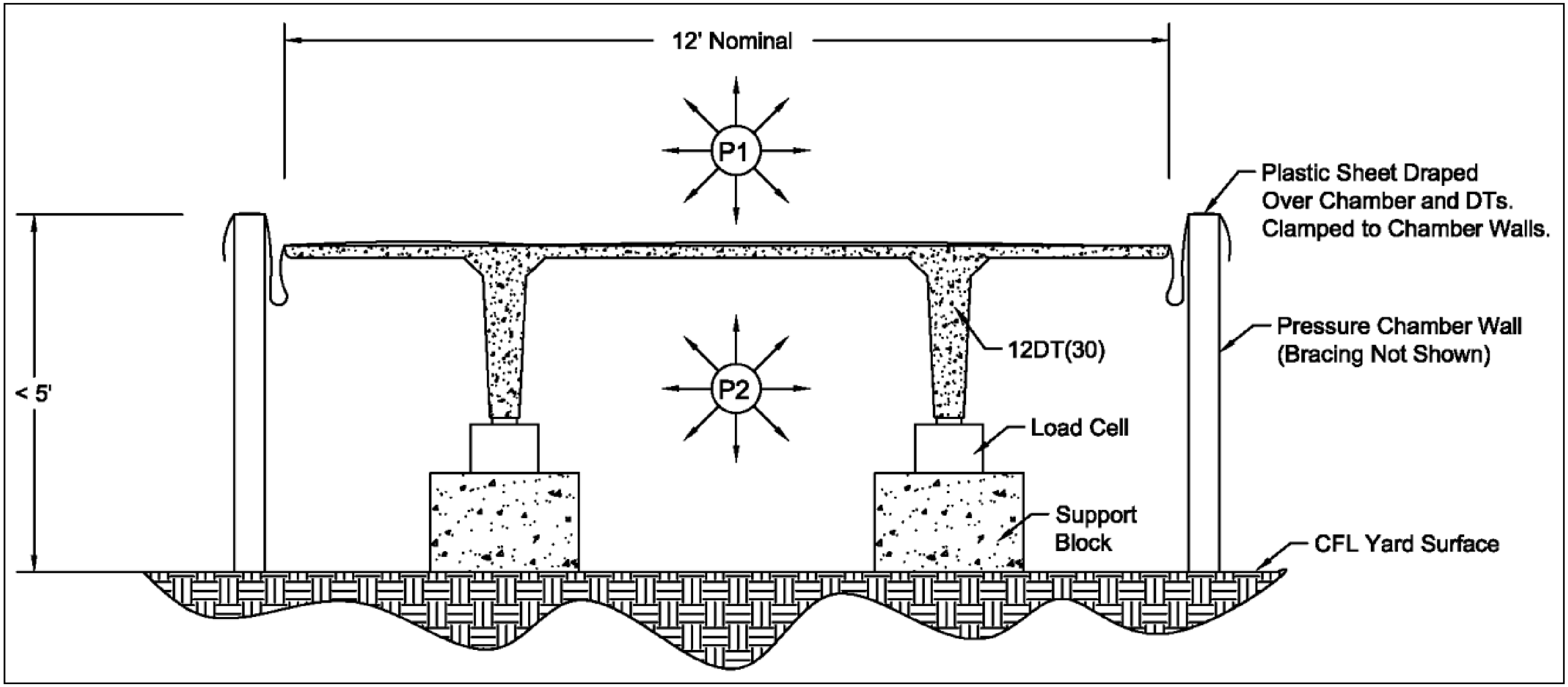
Research and Development at NCSU

Flanges reinforced with CFRP grid

Uniformly distributed applied load



Experimental Program



Testing Program

Testing Program

Initial Cracking:

DT1

DT2

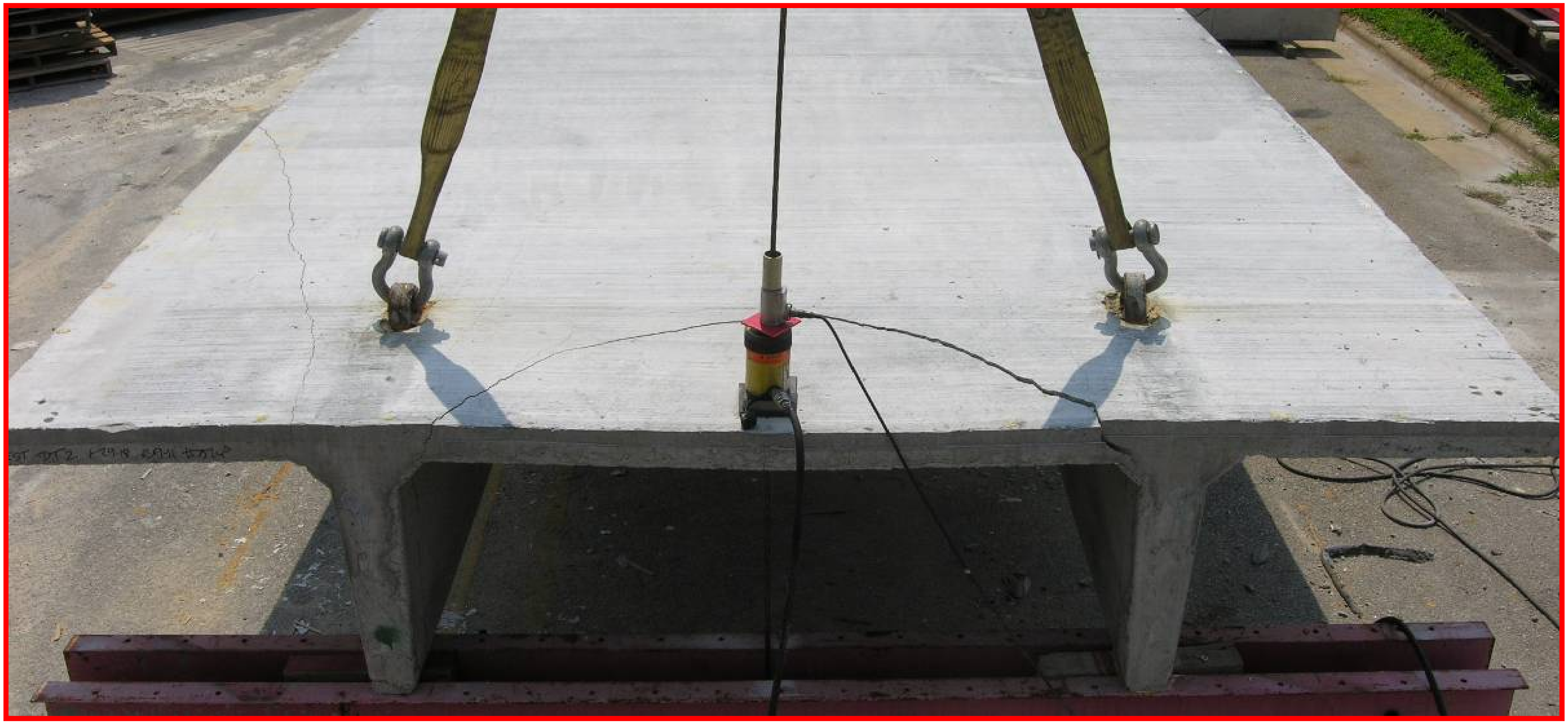
Test Results

Failure Mode DT1
2” thick flange

Test Results

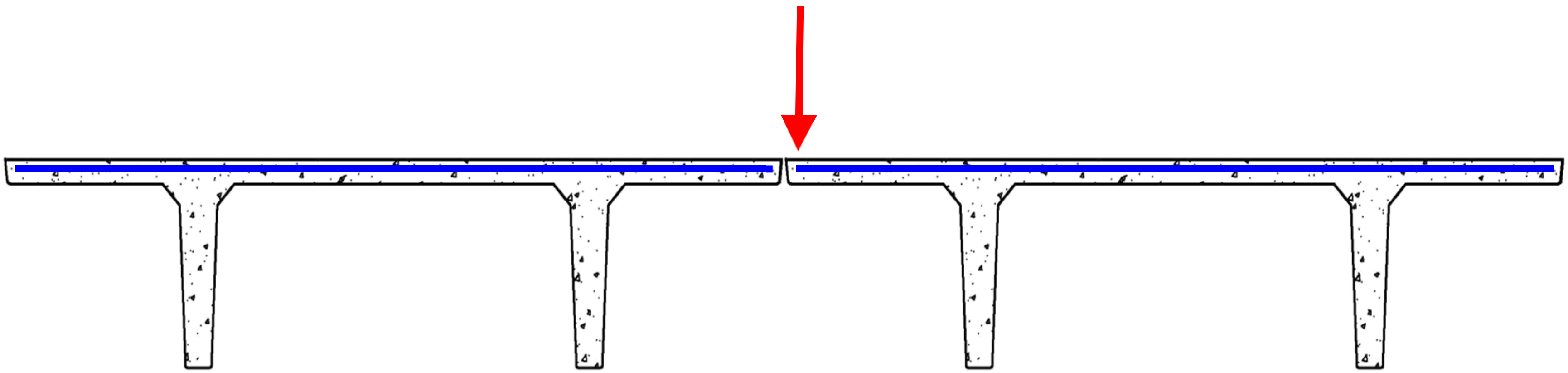
Failure Mode DT1
2” thick flange

Concentrated Load Test

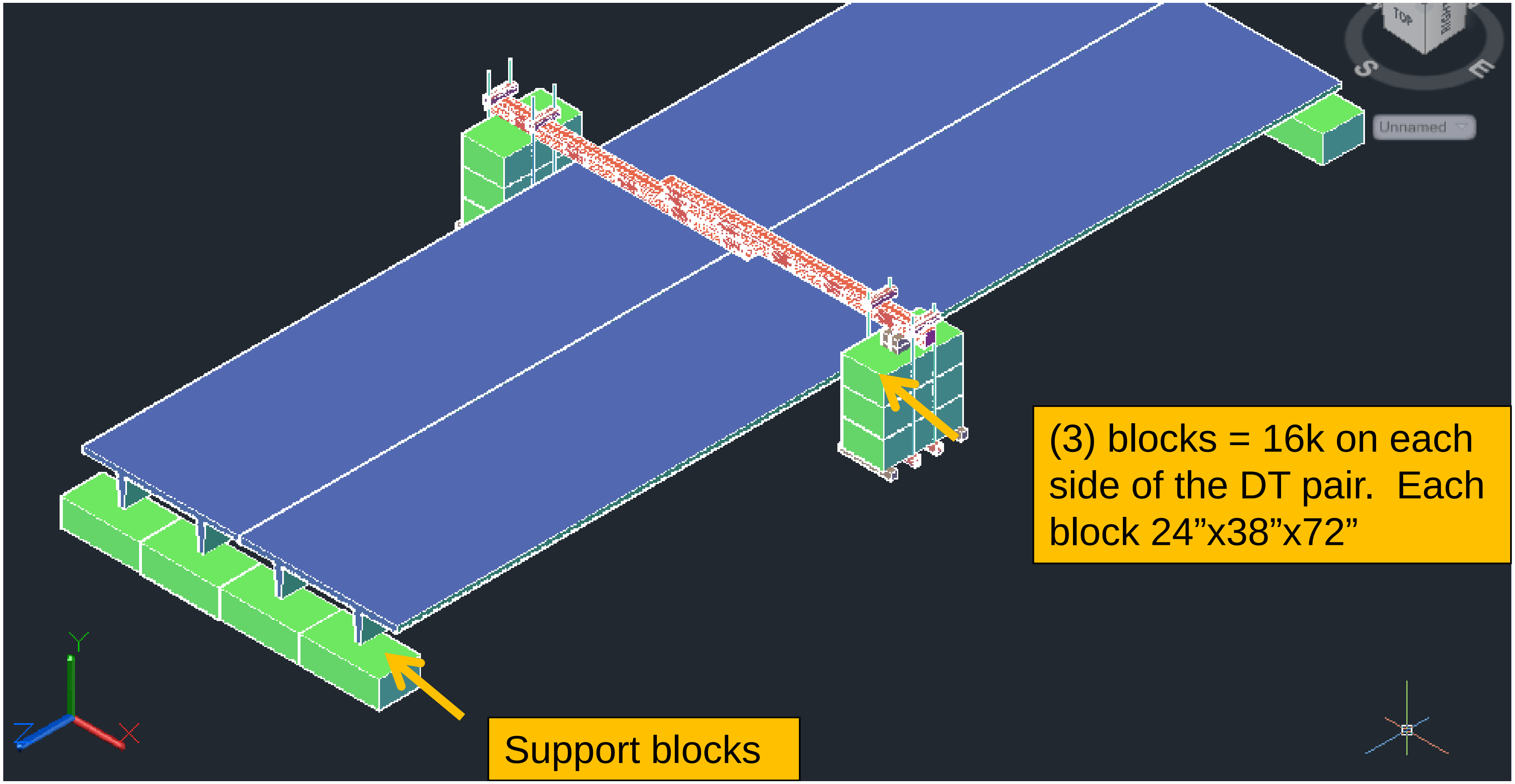


Failure load = 11,300 lbs

Connected DT



Field Testing



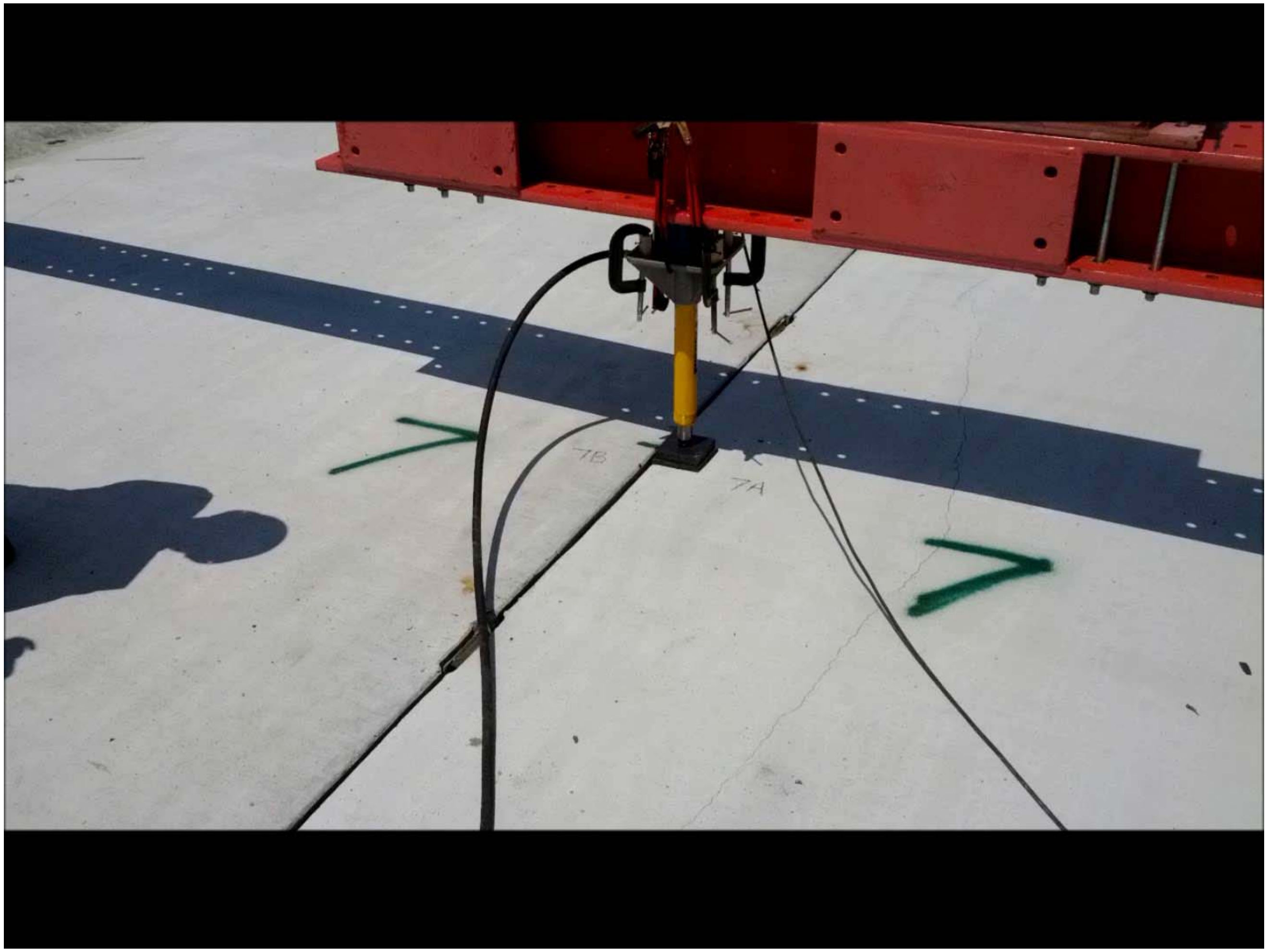
(3) blocks = 16k on each side of the DT pair. Each block 24”x38”x72”

Support blocks

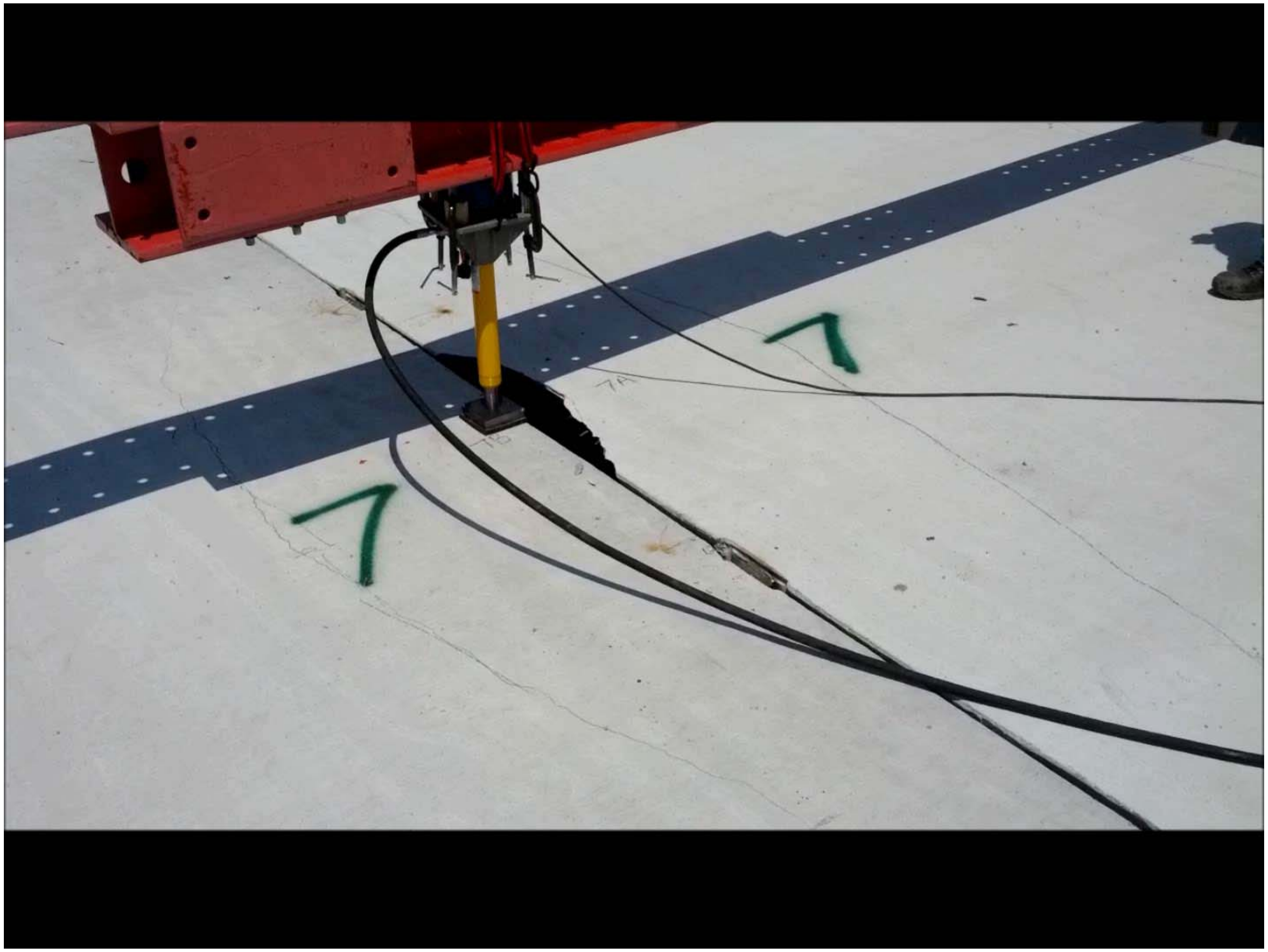
Test Setup

Test Setup

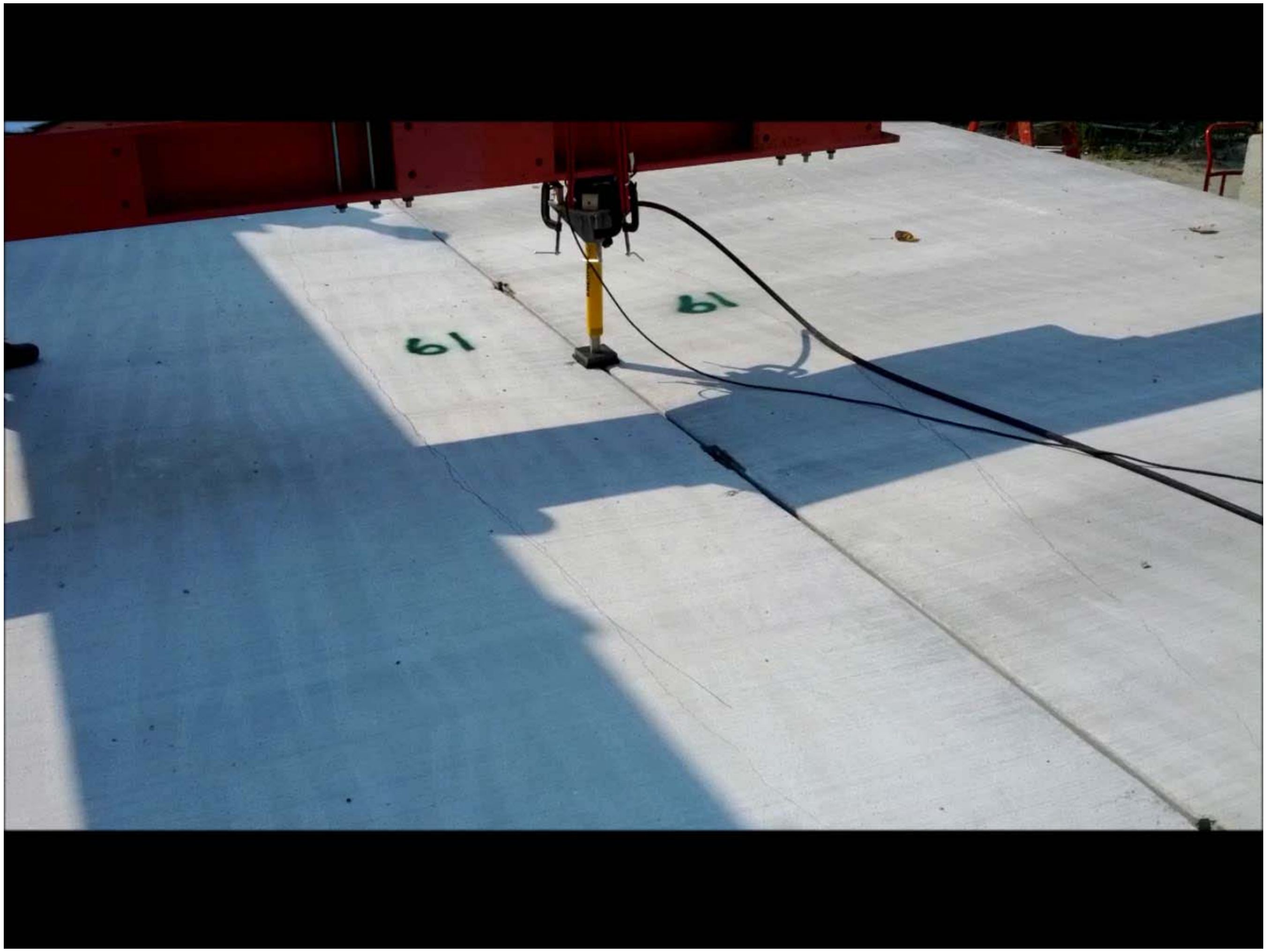
Mid-span - Between Connectors



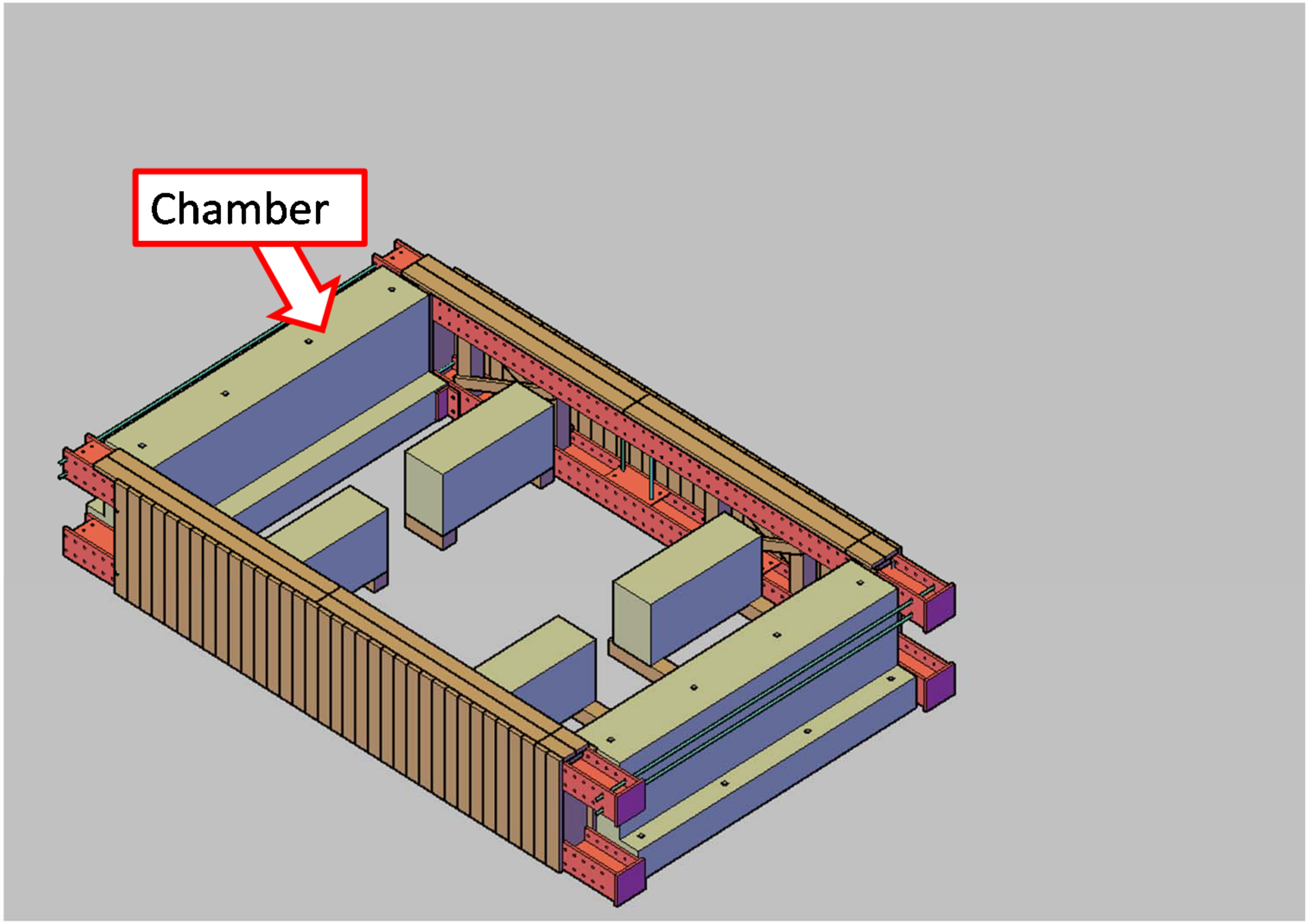
Midspan - Between Connectors

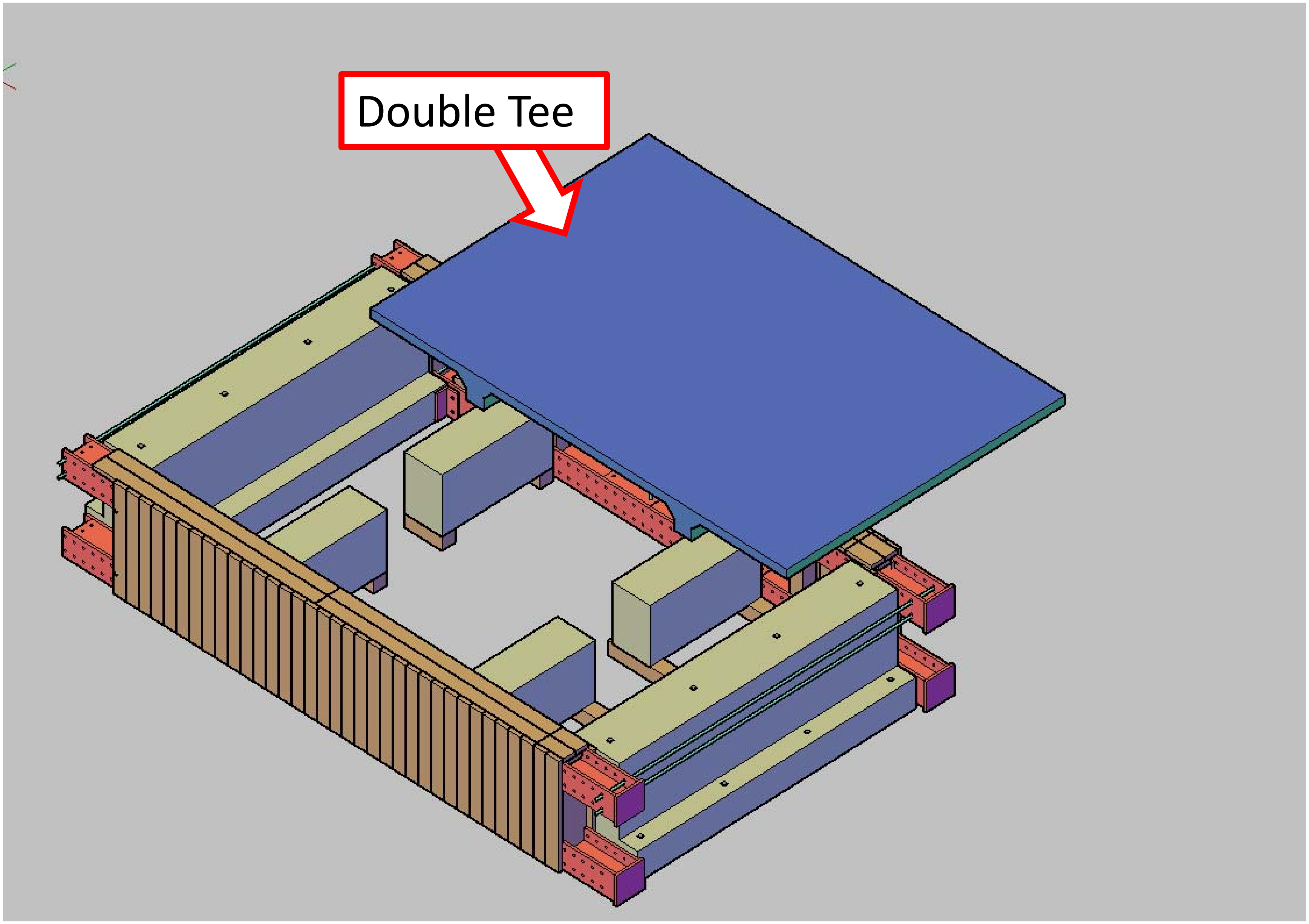


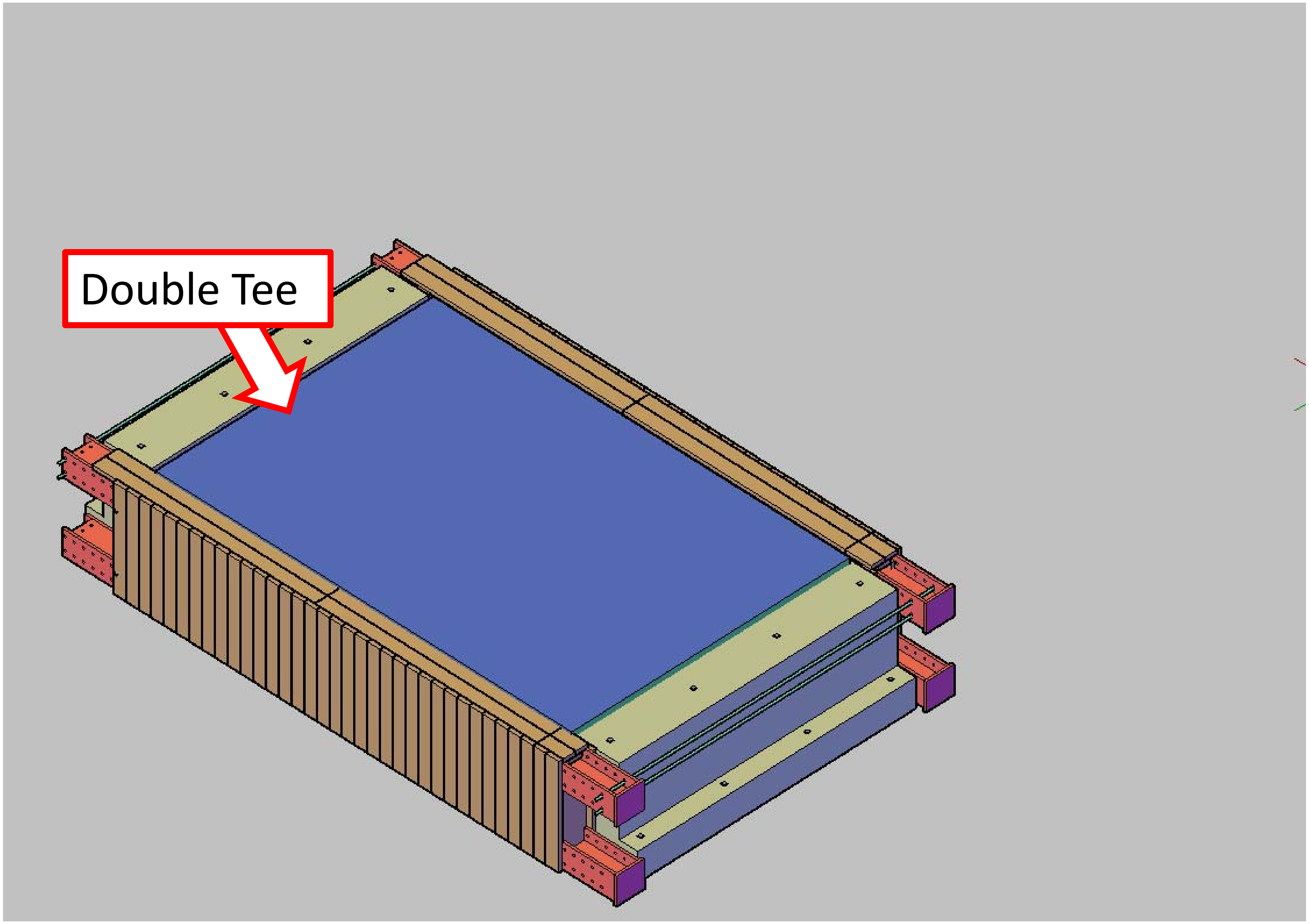
Mid-span - Between Connectors Spanning the Gap

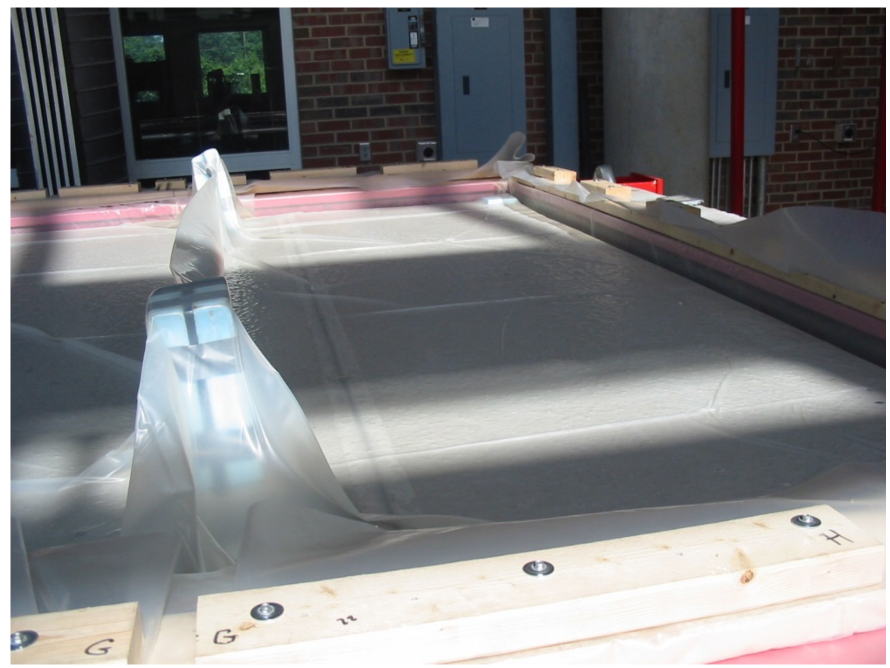


Recent Testing under Uniform pressure

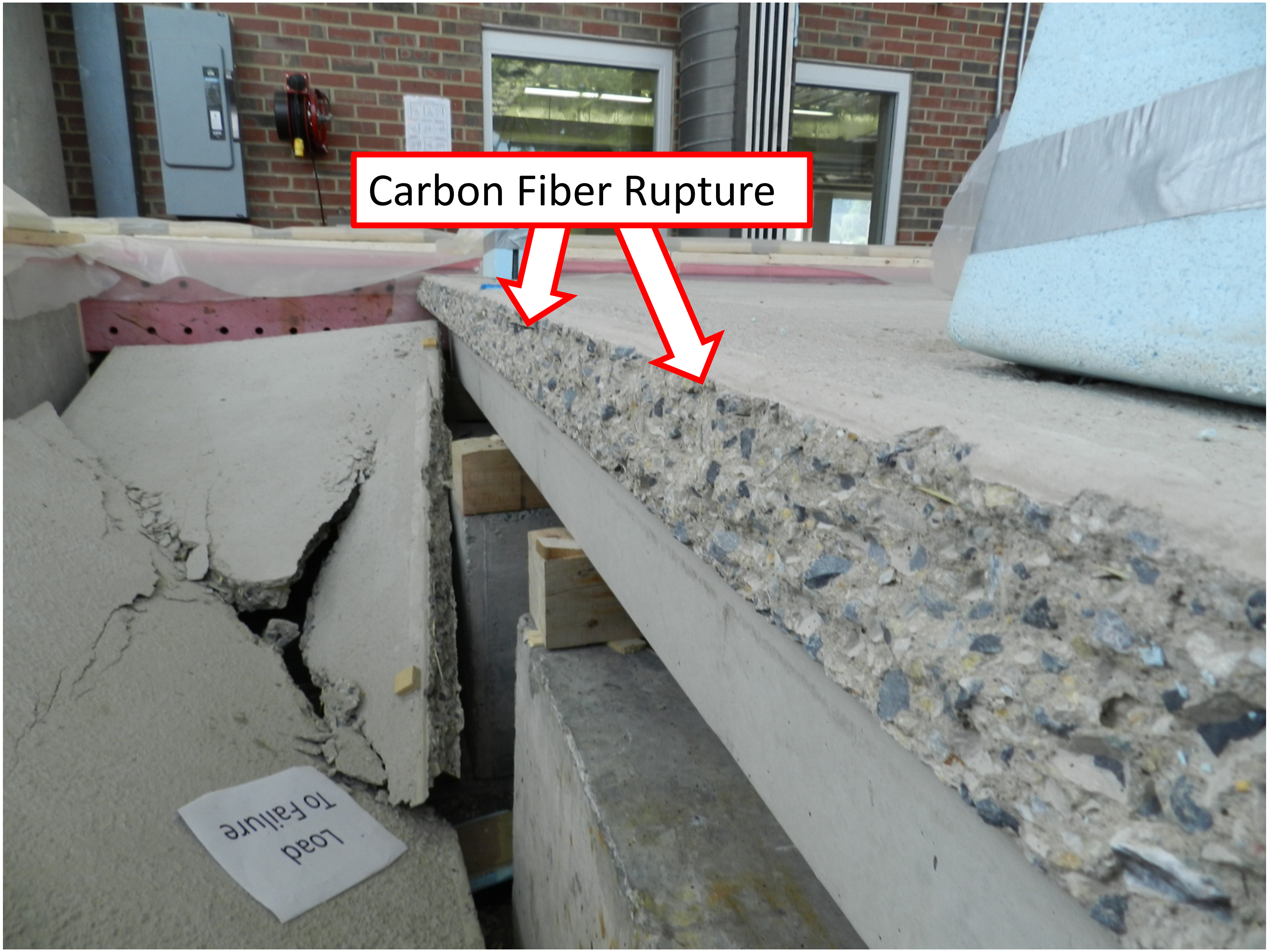



Double Tee


Double Tee


G
G
H


Load
To Failure

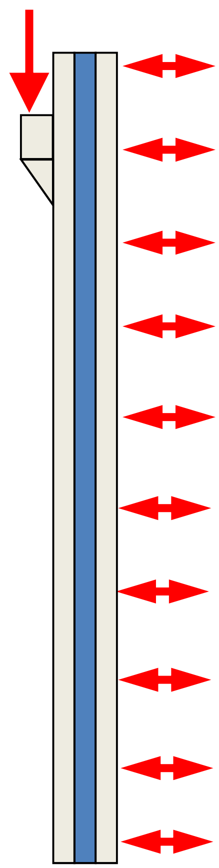

Carbon Fiber Rupture
Load
To Failure

Recent Advances in Precast

- Double-Tee beams
- Wall Panels
  - Composite
  - Non-composite
- Architectural Cladding

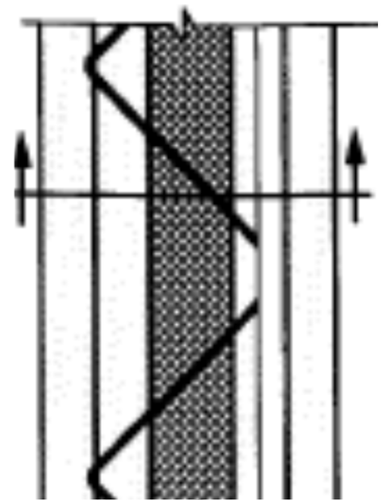
Prestressed Concrete Sandwich Load Bearing Panels

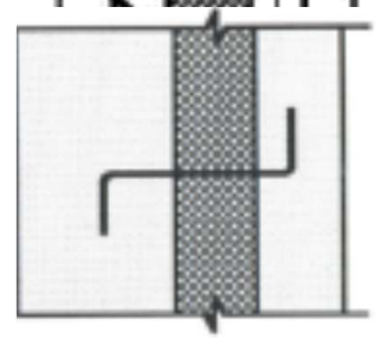
- Resist vertical and lateral loads
- Provide building envelope
- Consists of two concrete wythes and a layer of rigid foam.
- Composite action achieved by shear connectors

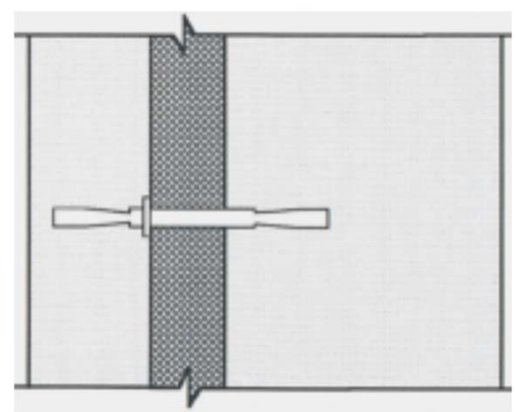


Typical Wythe Connectors

– Steel truss connectors
  - Thermally inefficient, Structurally efficient
– Steel tie connectors
  - Thermally and structurally inefficient
– Discrete GFRP connectors
  - Structurally inefficient, Thermally efficient
– Concrete solid zones
  - Thermally inefficient

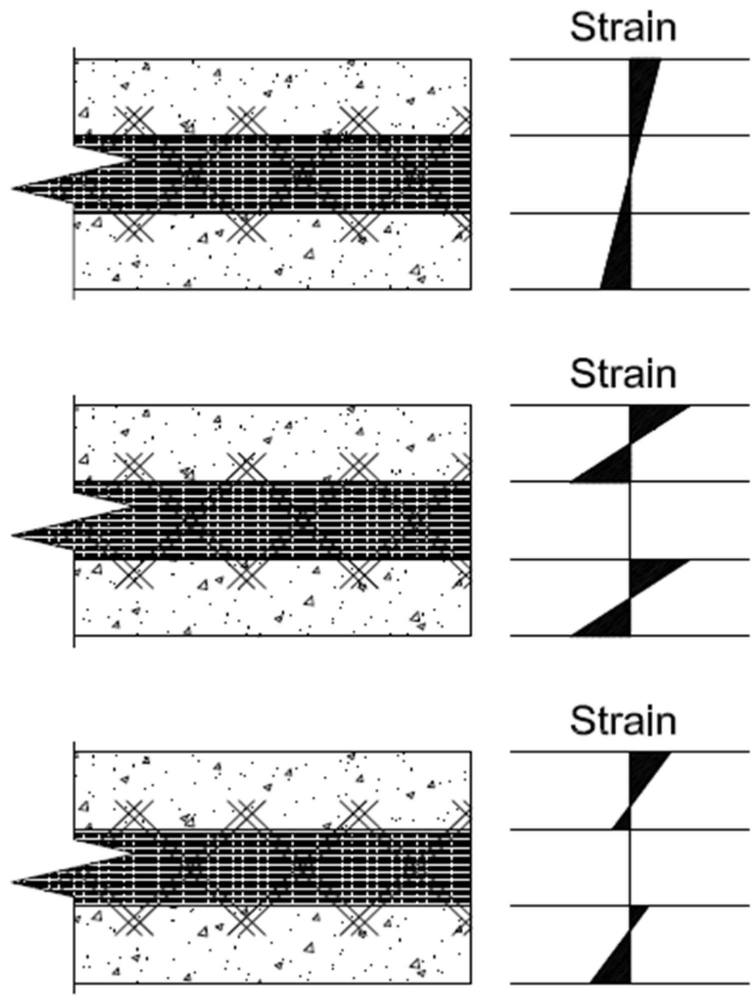






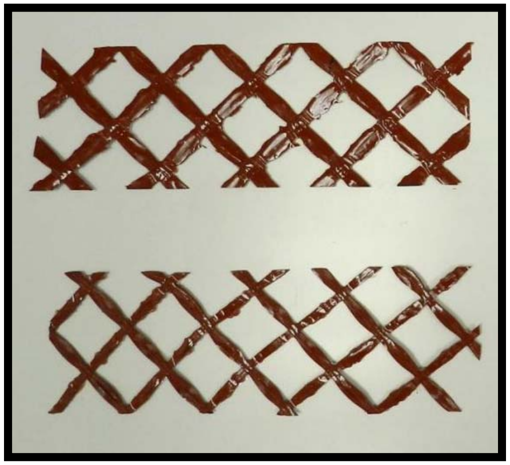
Composite Action

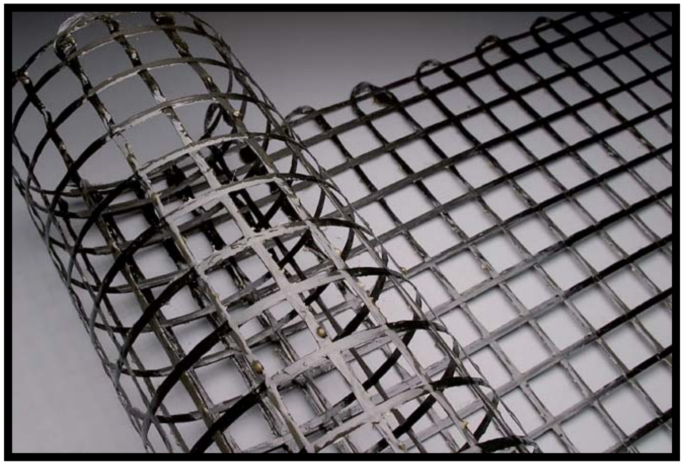
- Fully Composite
  - Structurally efficient
  - Thinner, lighter panels possible
- Non-Composite
  - Structurally inefficient
  - Each wythe resists applied moment independently
- Partially Composite
  - Capacity falls between full and non-composite panels



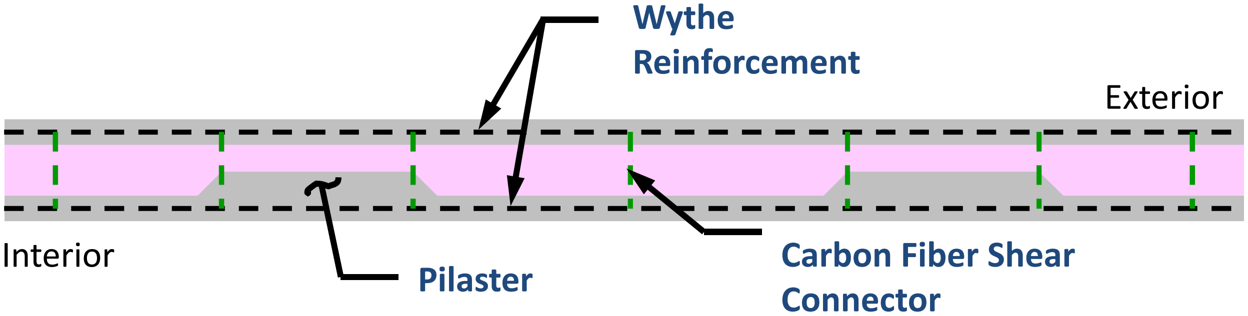
GFRP Shear Grid

- Orthogonal FRP Grid
- Cut at a 45-degree angle to develop a truss action
- Provides composite action
- Structurally and thermally efficient





Insulated Sandwich Panel

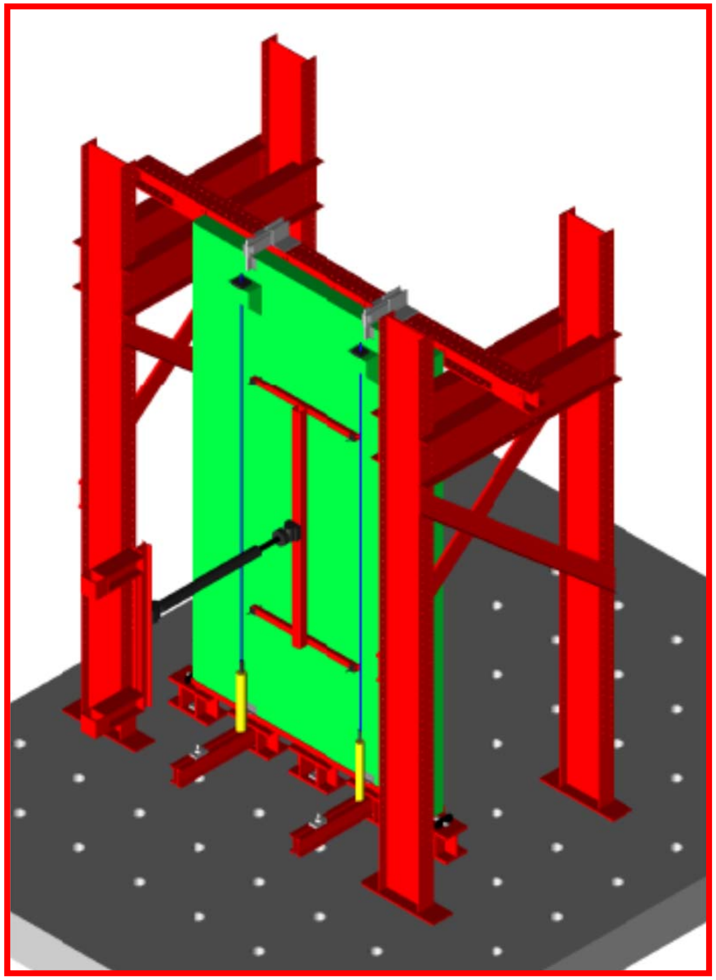


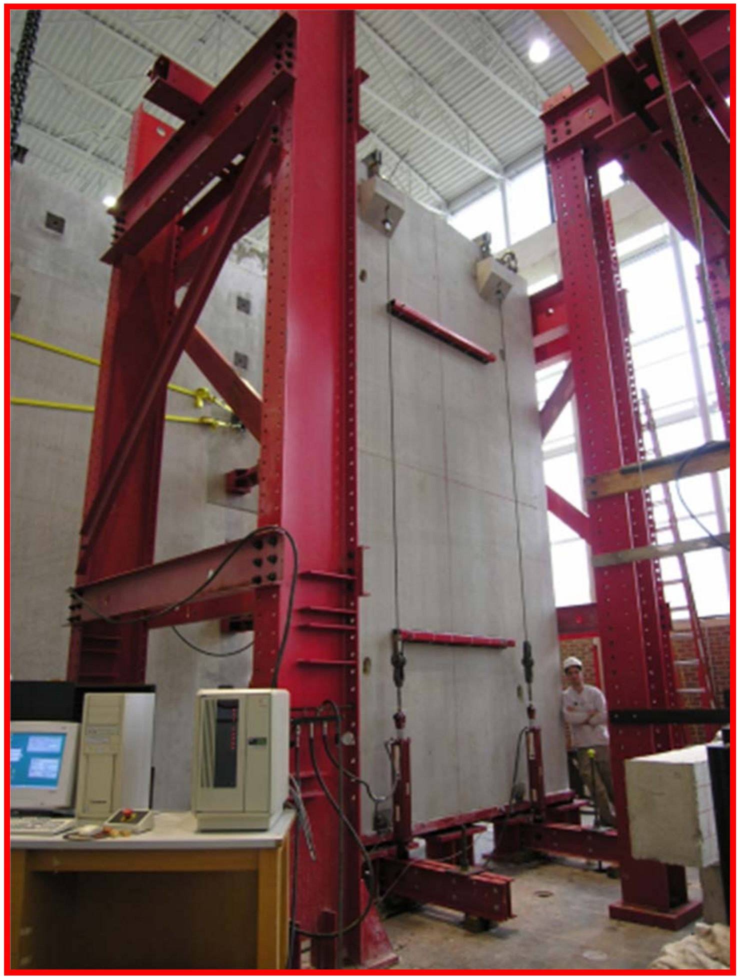
Carbon fiber grid shear connectors…

•provide composite action between wythes; and

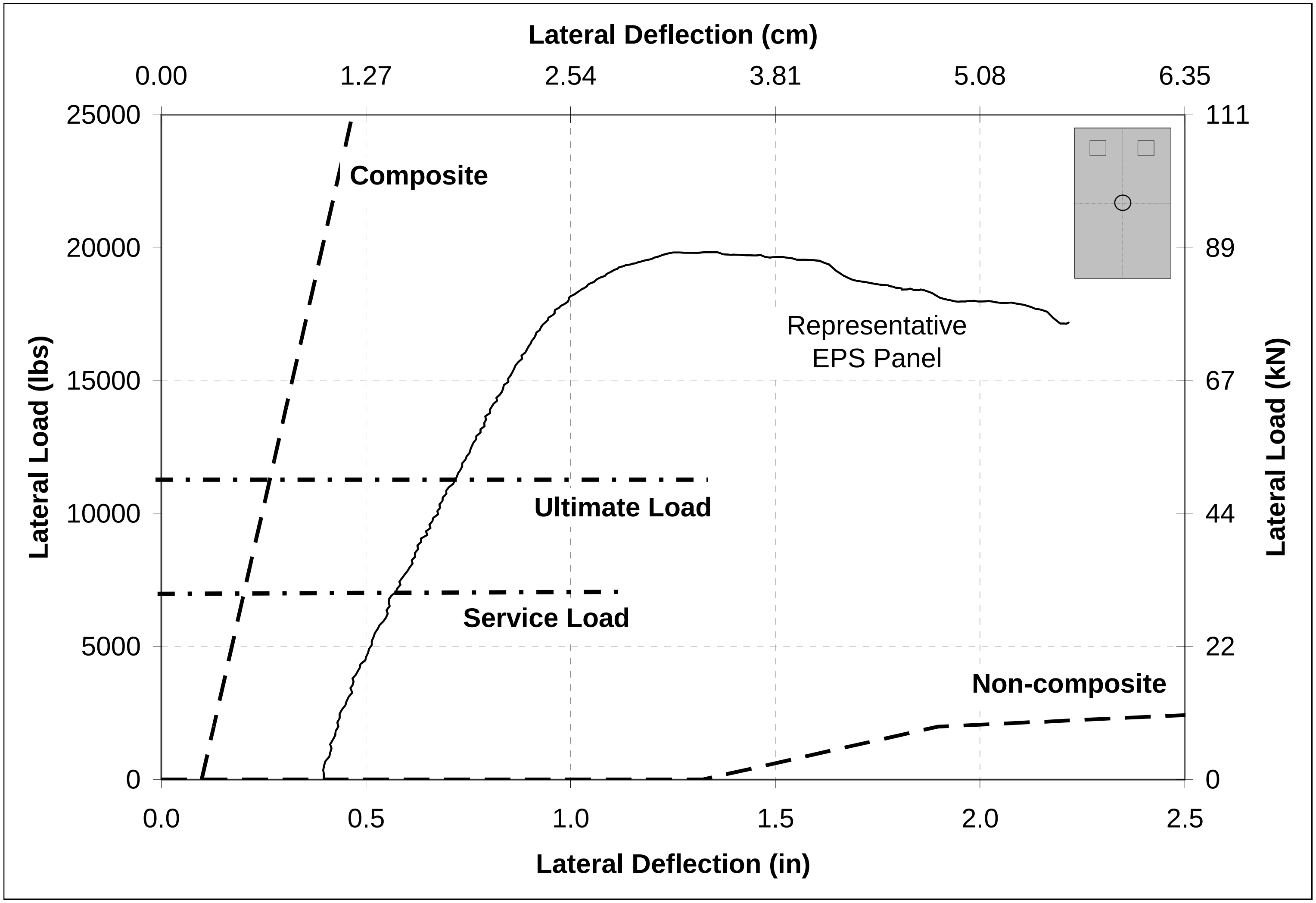
•increase insulation value due to low thermal conductivity of the connector.

Experimental Program

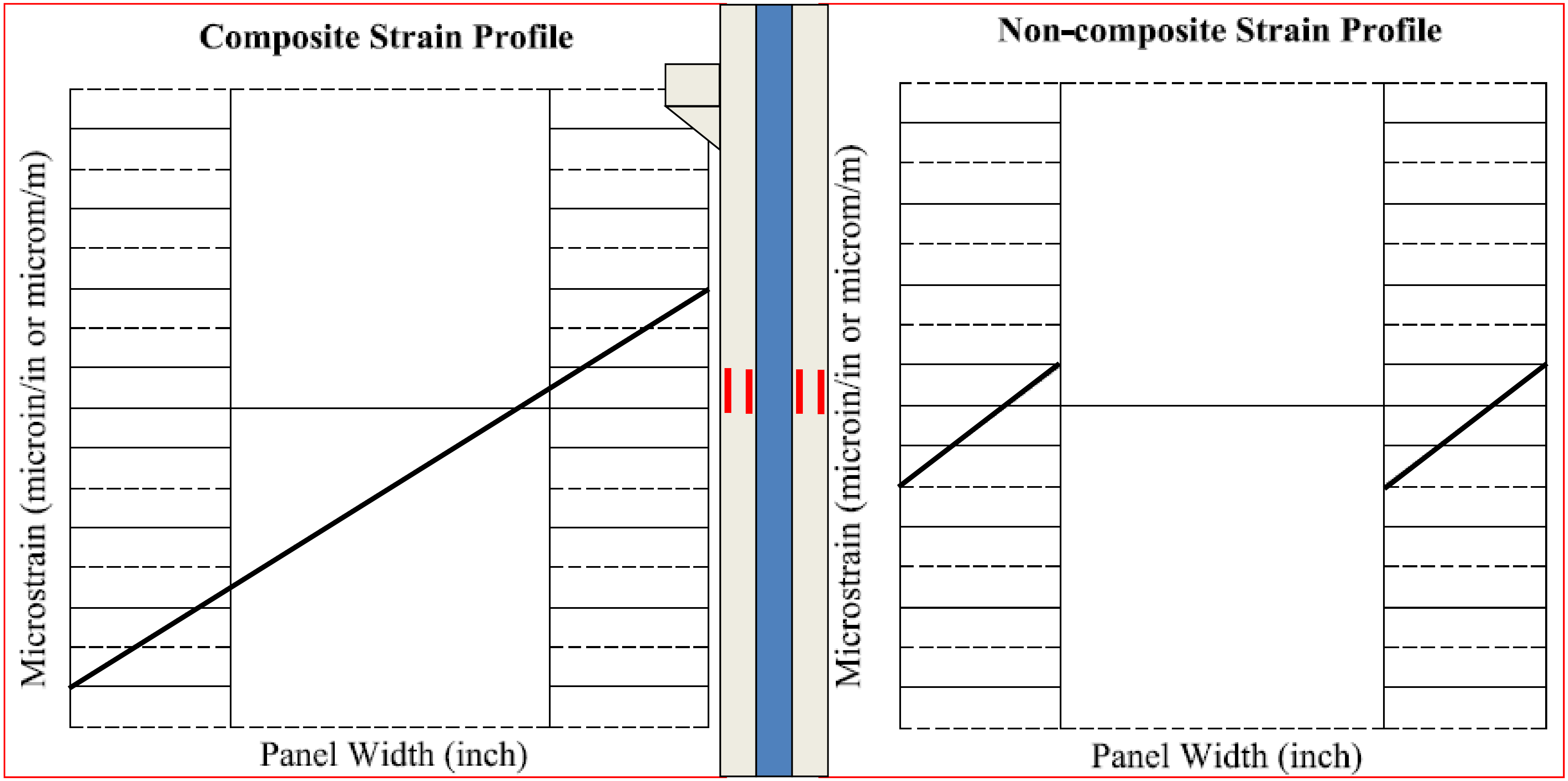




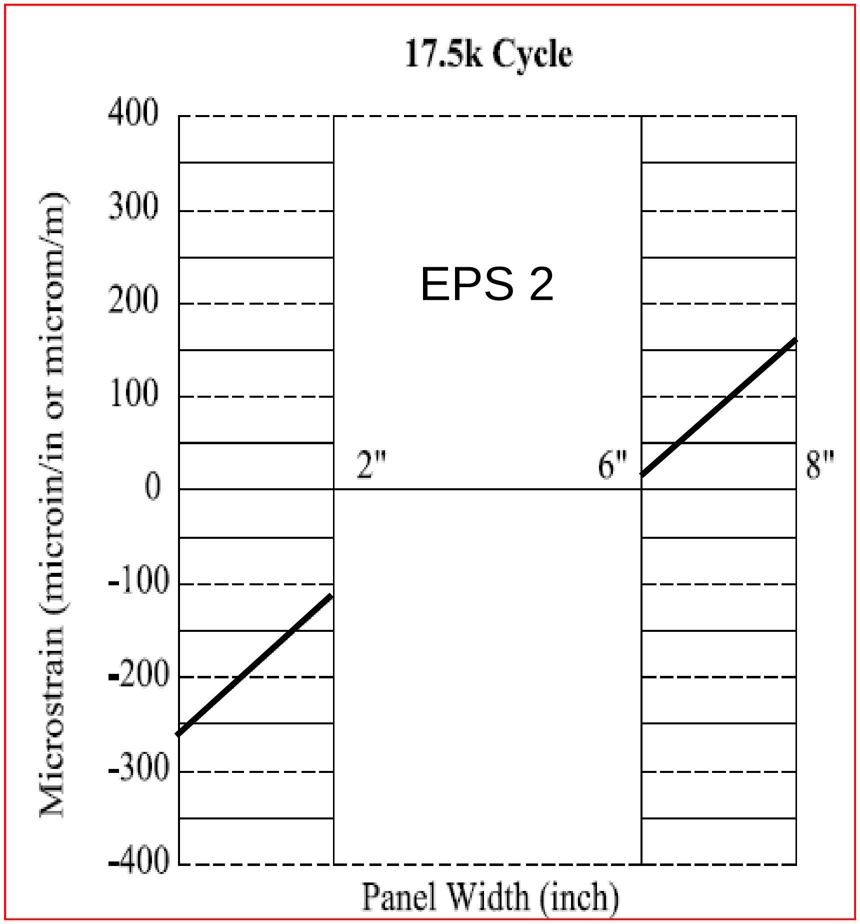
Overall Panel Behavior



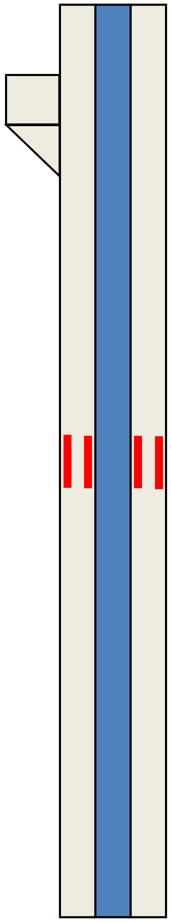
Degree of Shear Connection



Experimental Results

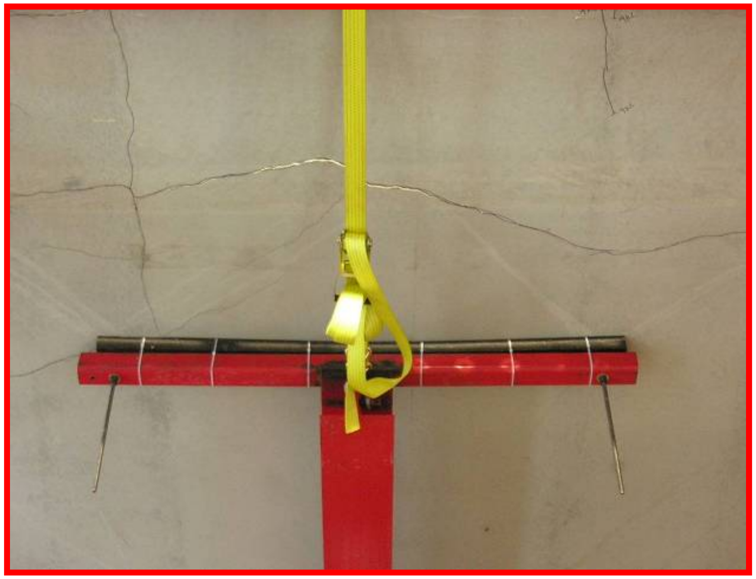


$1.2D+0.5L_r+1.6W_{150}$



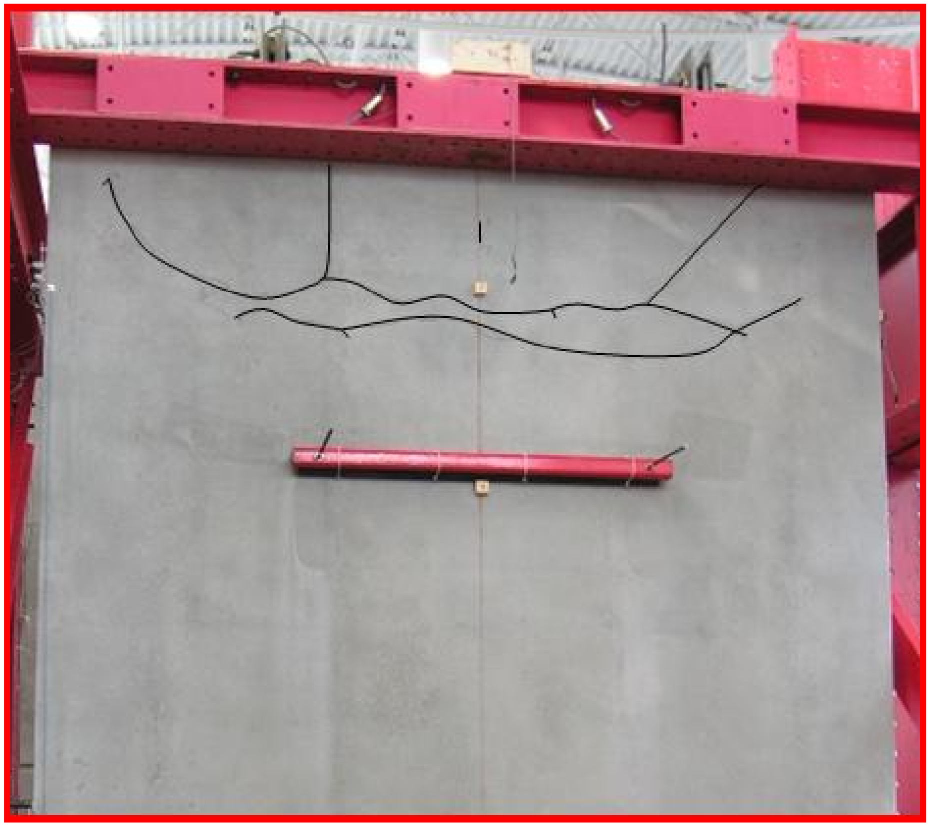
Failure Modes

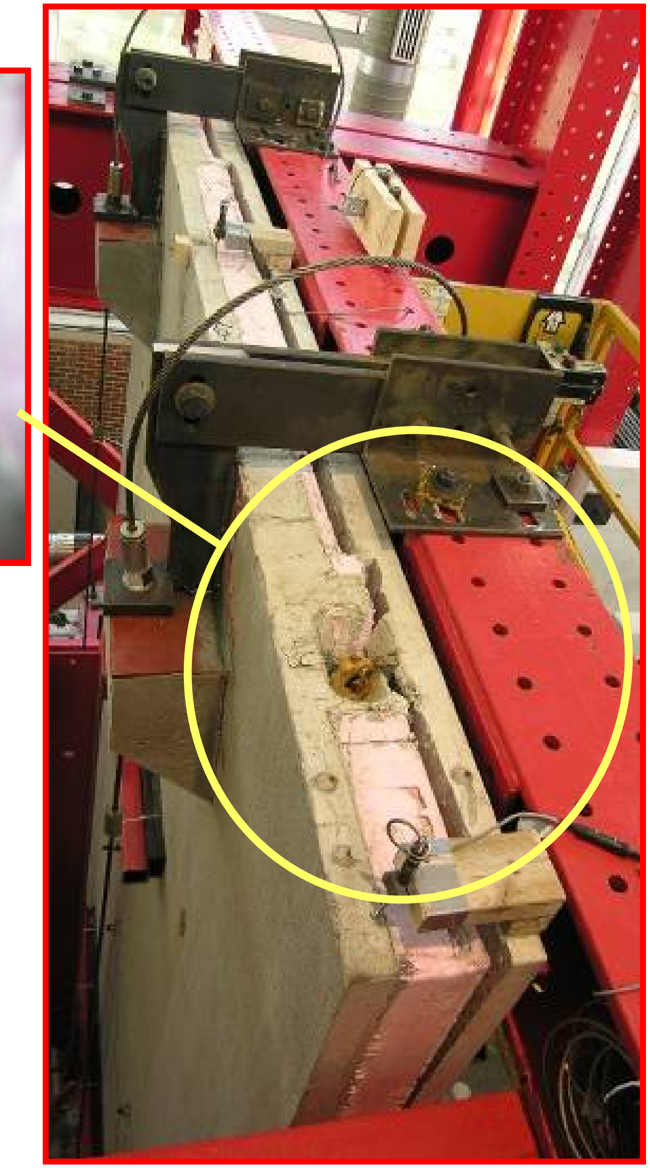
Flexural-shear failure



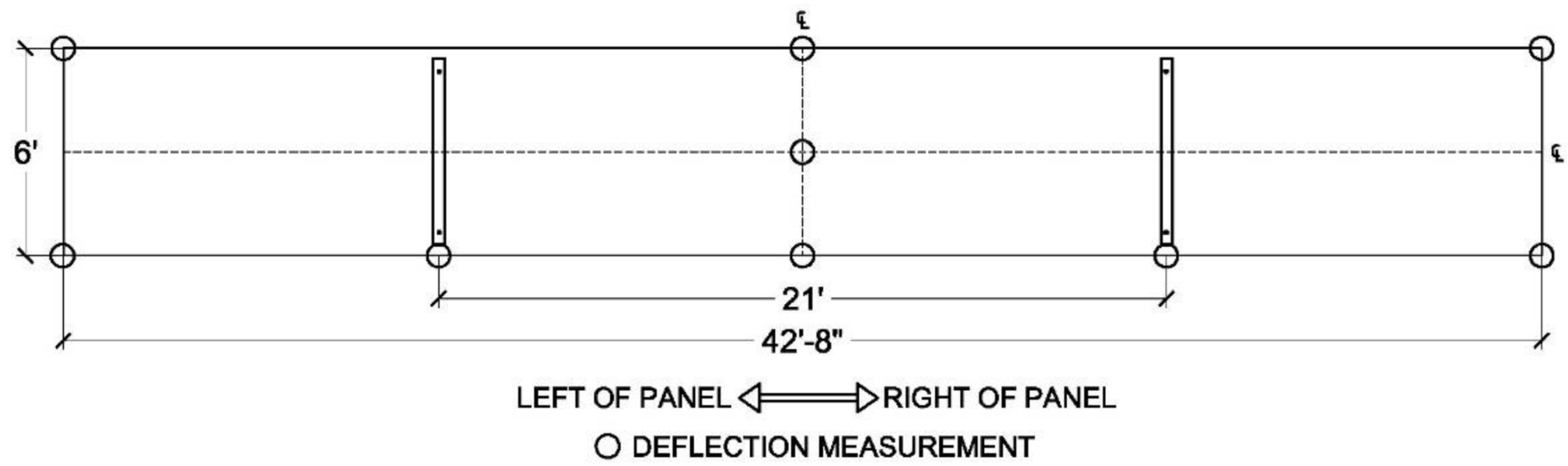
Failure Modes

Panel Separation

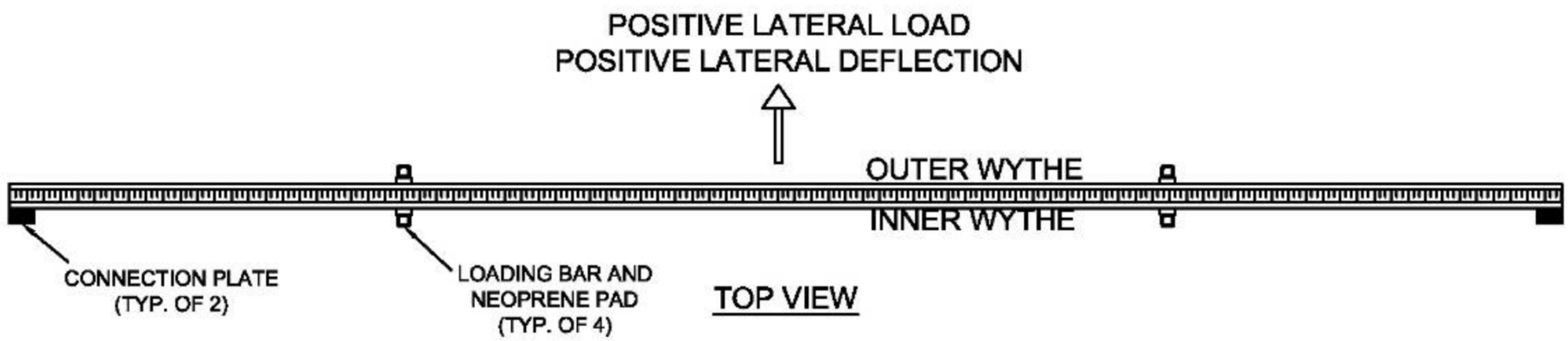




42 ft Sandwich Panel



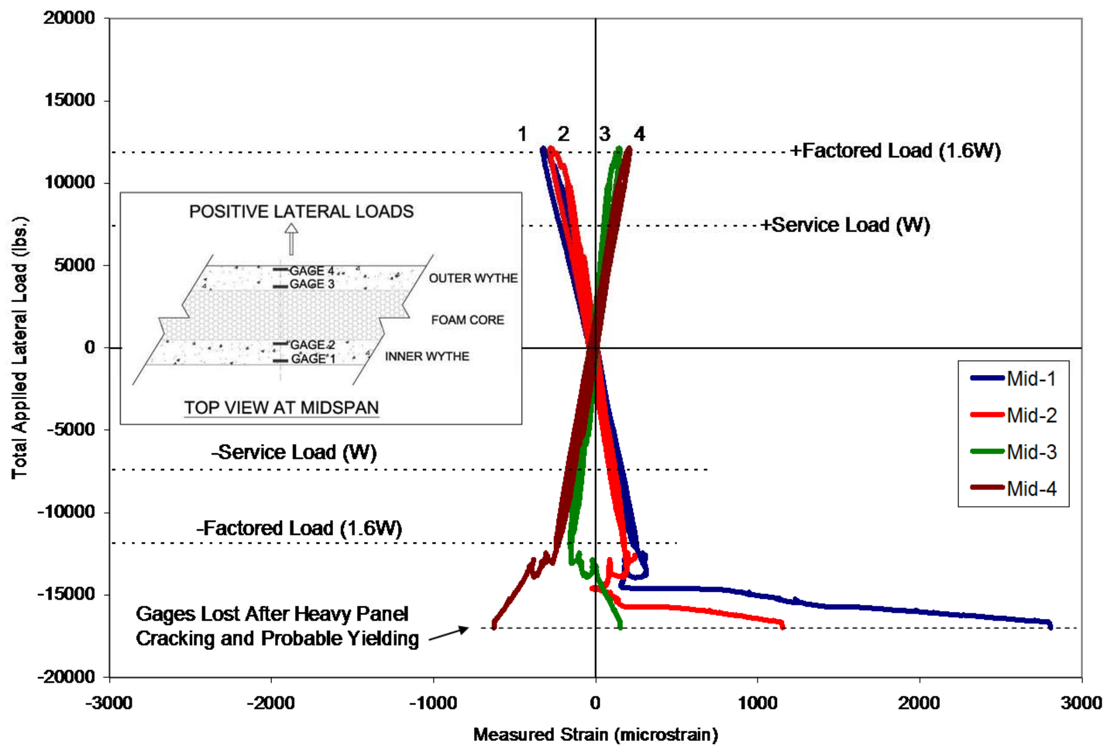
ELEVATION: VIEW OF INNER WYTHE



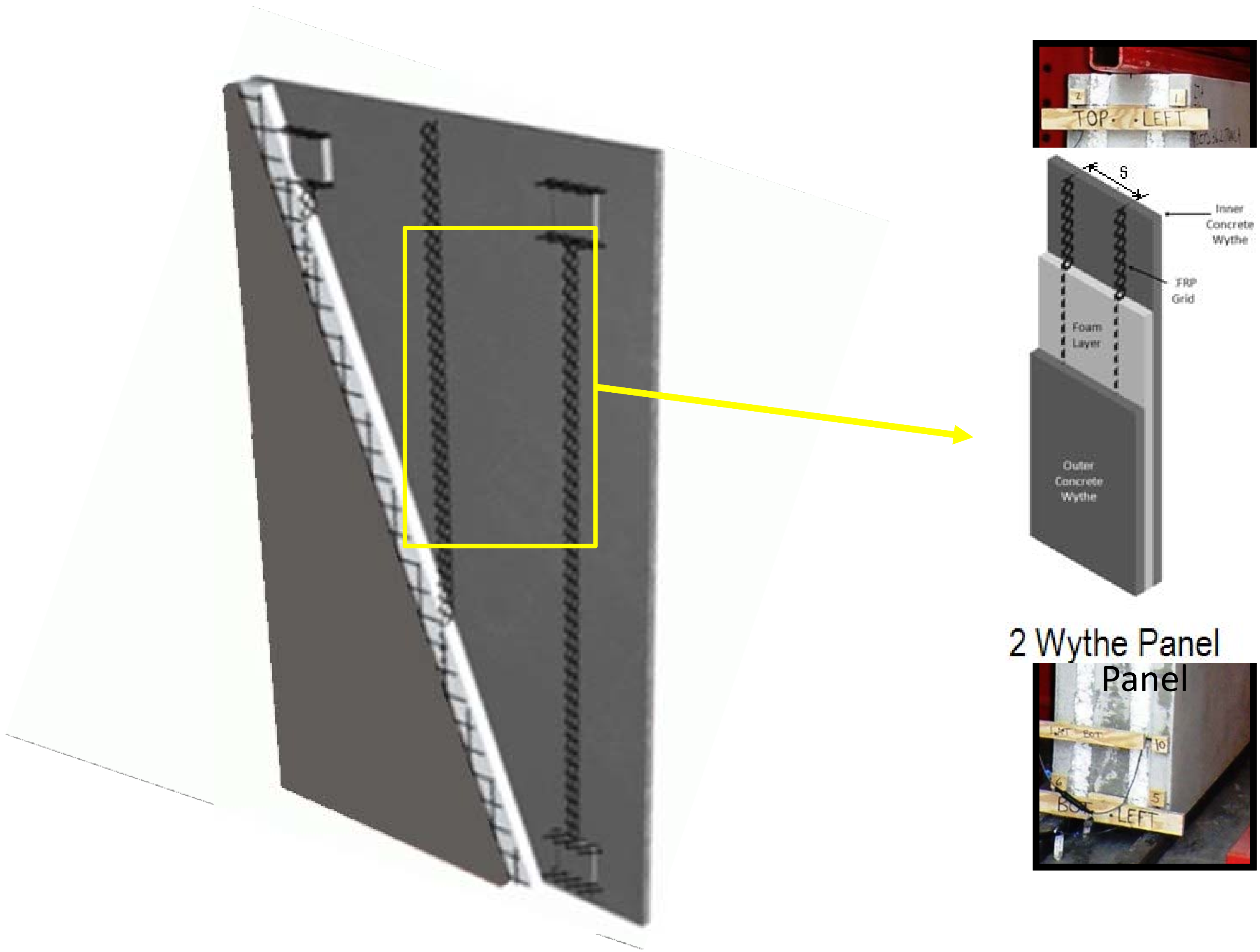
TOP VIEW

42 foot panel tests

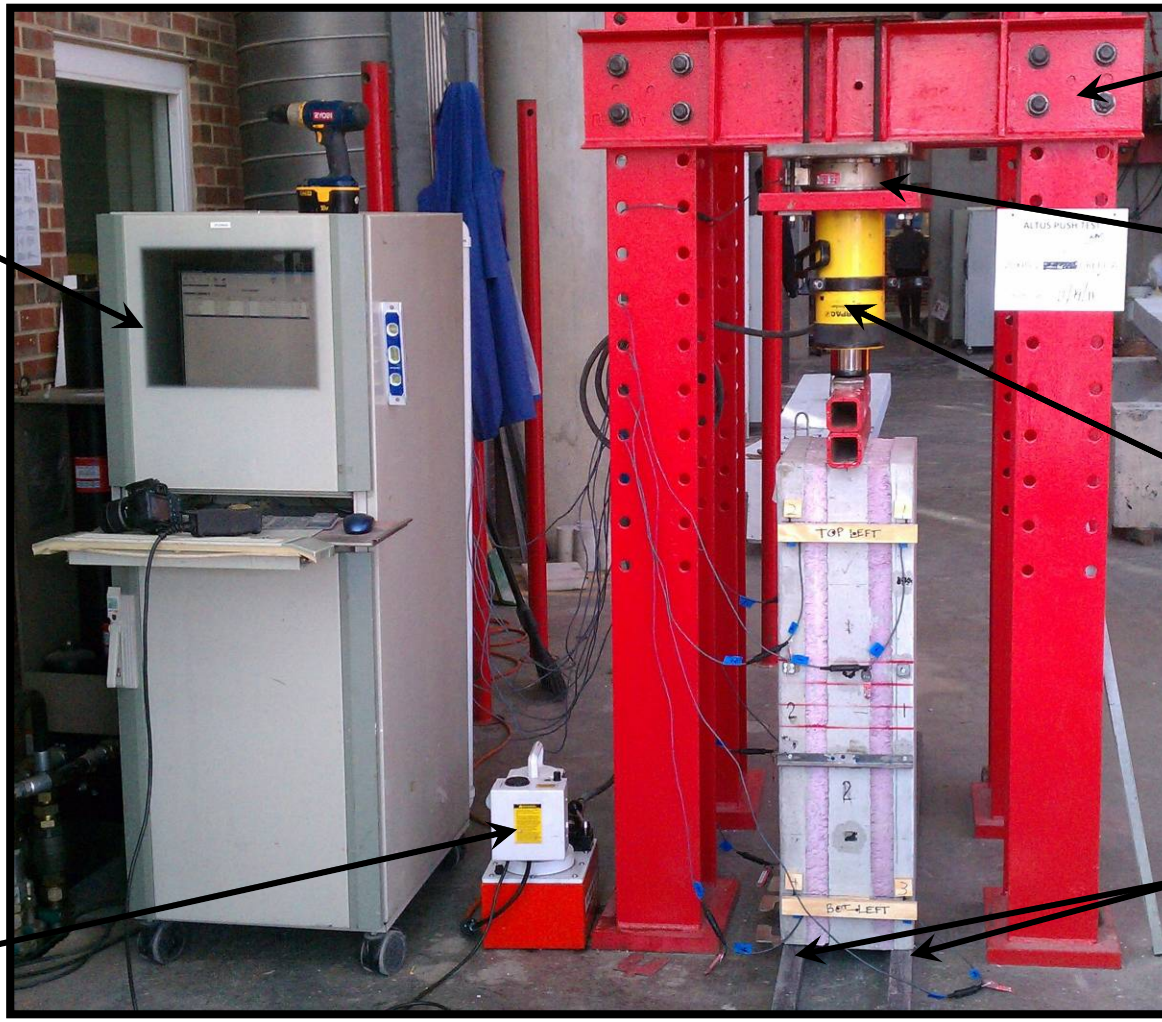
Strains on Panel Edge at Midspan



Typical Precast Concrete Sandwich Panel



Push-out Specimens



Experimental Program

to study the effect of the various parameters

Insulation Type
High Density EPS (32 kg/m^3)
Sandblasted XPS
Untreated XPS

Grid Spacing
300 mm
600 mm

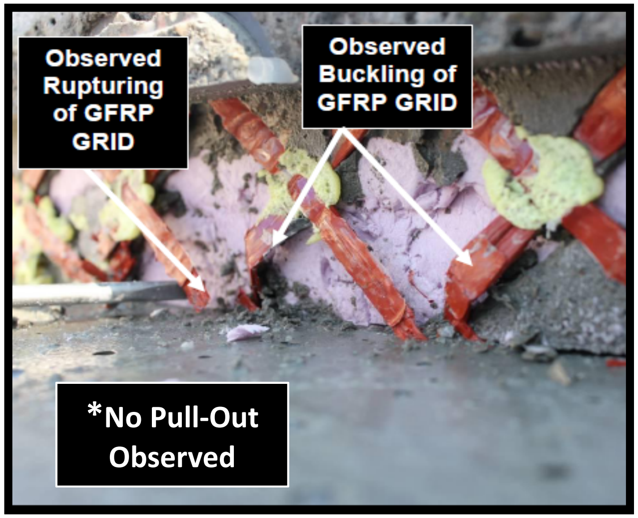
Insulation Thickness
50 mm
100 mm
150 mm *HD EPS only*

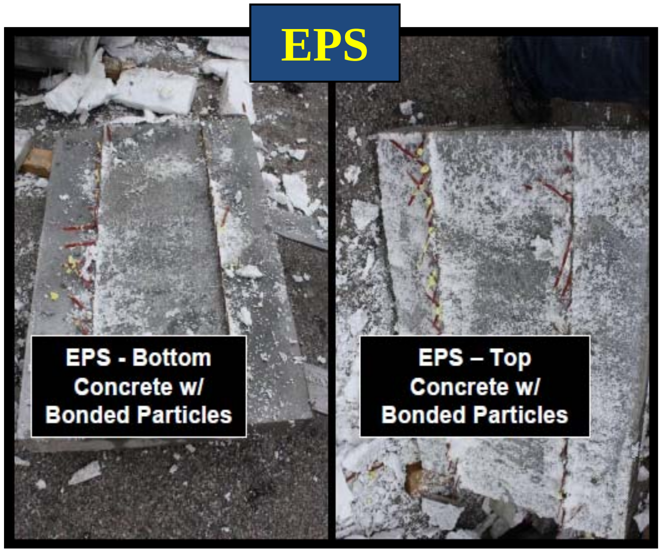
Bond of the Rigid Foam
Push Out Specimens with no GFRP Grid

Grid Type
High Strength : 10mm strand at 35mm spacing
Normal Strength : 10mm strand at 53mm spacing
CGRID

Aging Effect (Freeze-Thaw)
4 Specimens with -29 ºC to 60 ºC Freeze Thaw Cycles

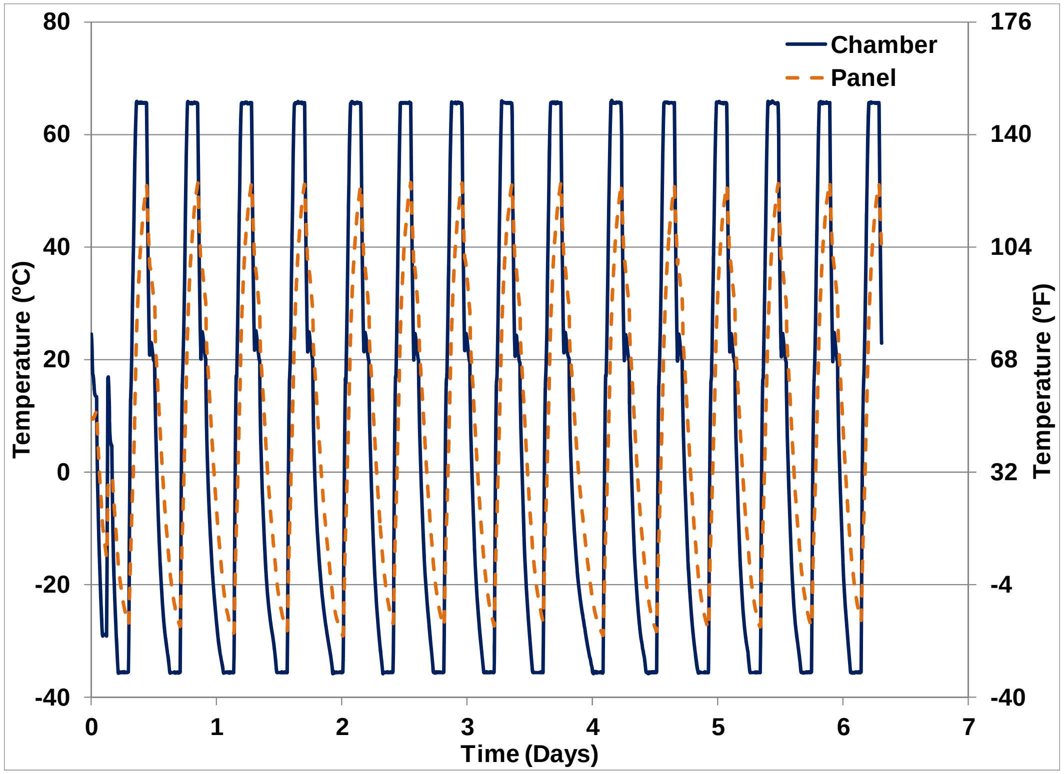
Typical Failure Modes





Long Term Behavior

Thermal Cycles



Thermal Cycles

Environmental Chamber for Freeze-Thaw Cycles

Proposed Shear Flow Design Equation

$$\boldsymbol{q_n = \gamma_{type} * \gamma_{thickness} * \gamma_{spacing} * q_{baseline}}$$

q_n = nominal shear flow capacity of grid $\left[{}^{kN}/_{m}\right]$

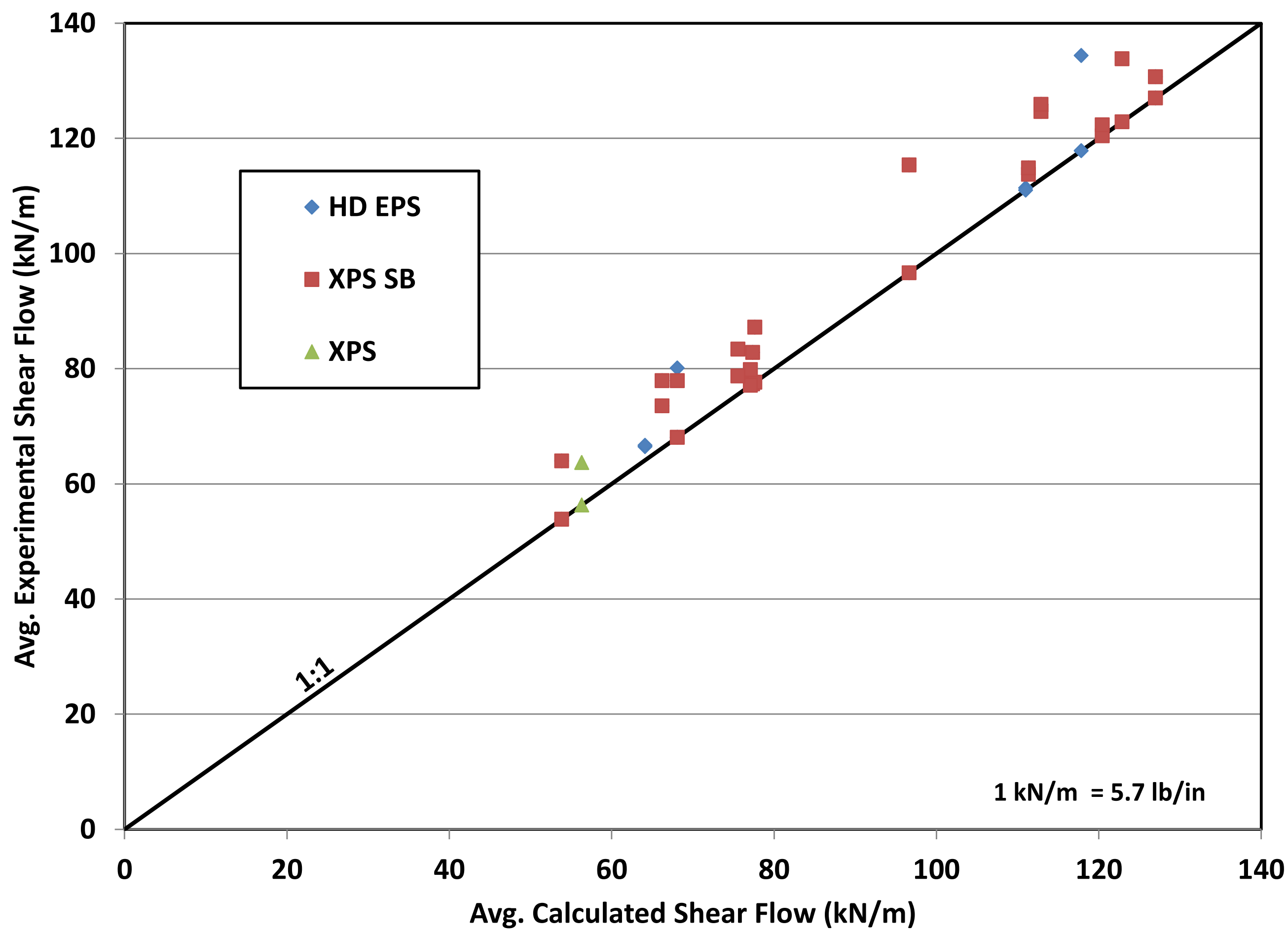
γ_{type} = design coefficient for insulation type

$\gamma_{thickness}$ = design coefficient for insulation thickness

$\gamma_{spacing}$ = design coefficient for grid spacing

$q_{baseline}$ = shear flow baseline [based on avg of specimens with same grid]

Accuracy of the proposed Equation



Recent Advances in Precast

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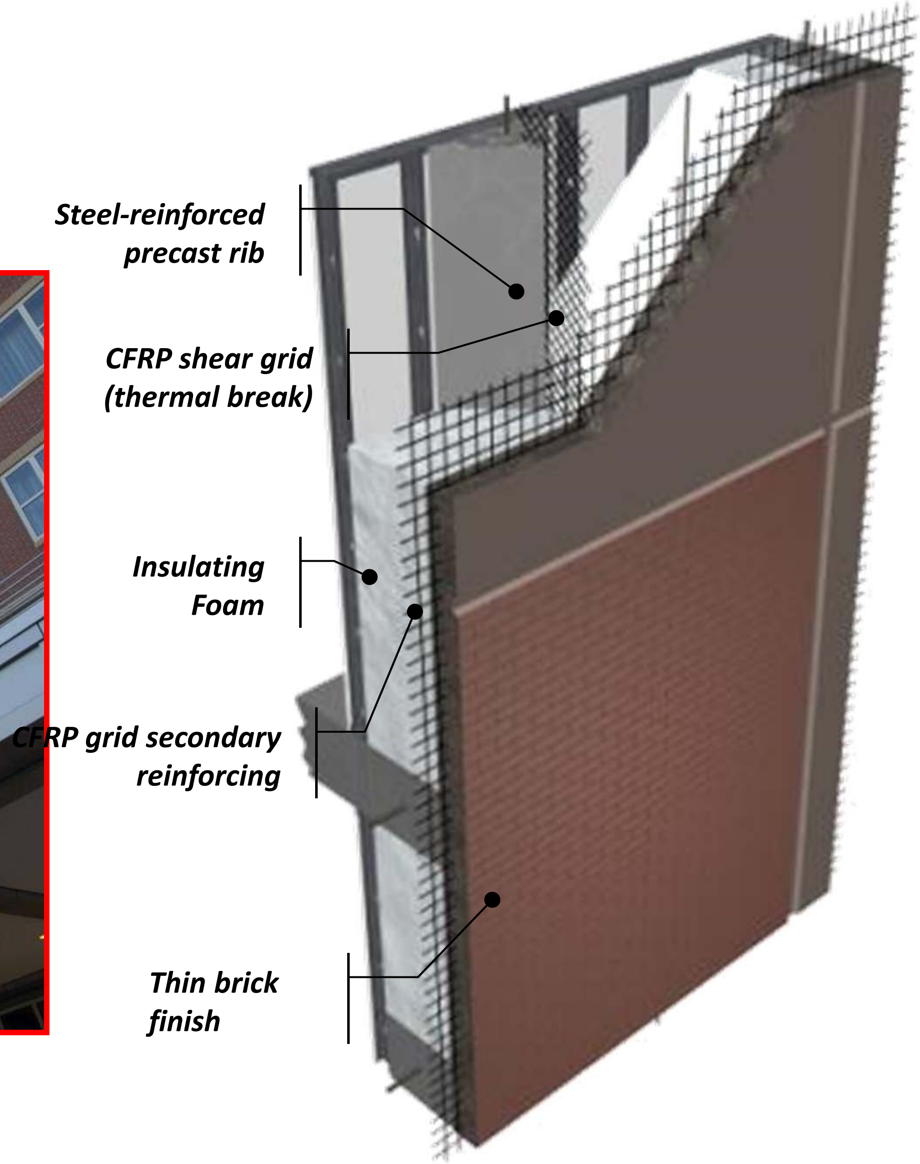
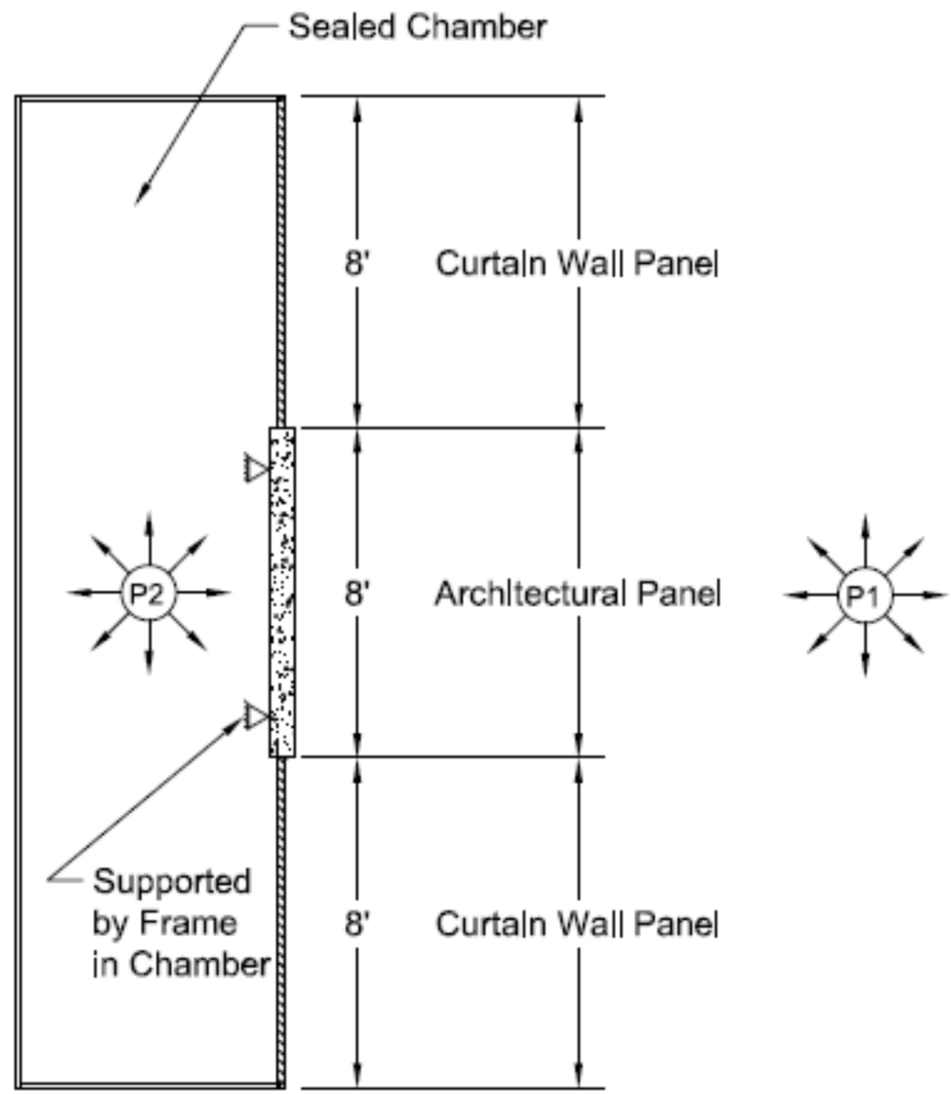
Insulated Architectural Cladding



Manufacturing Process

Test Setup At NCSU



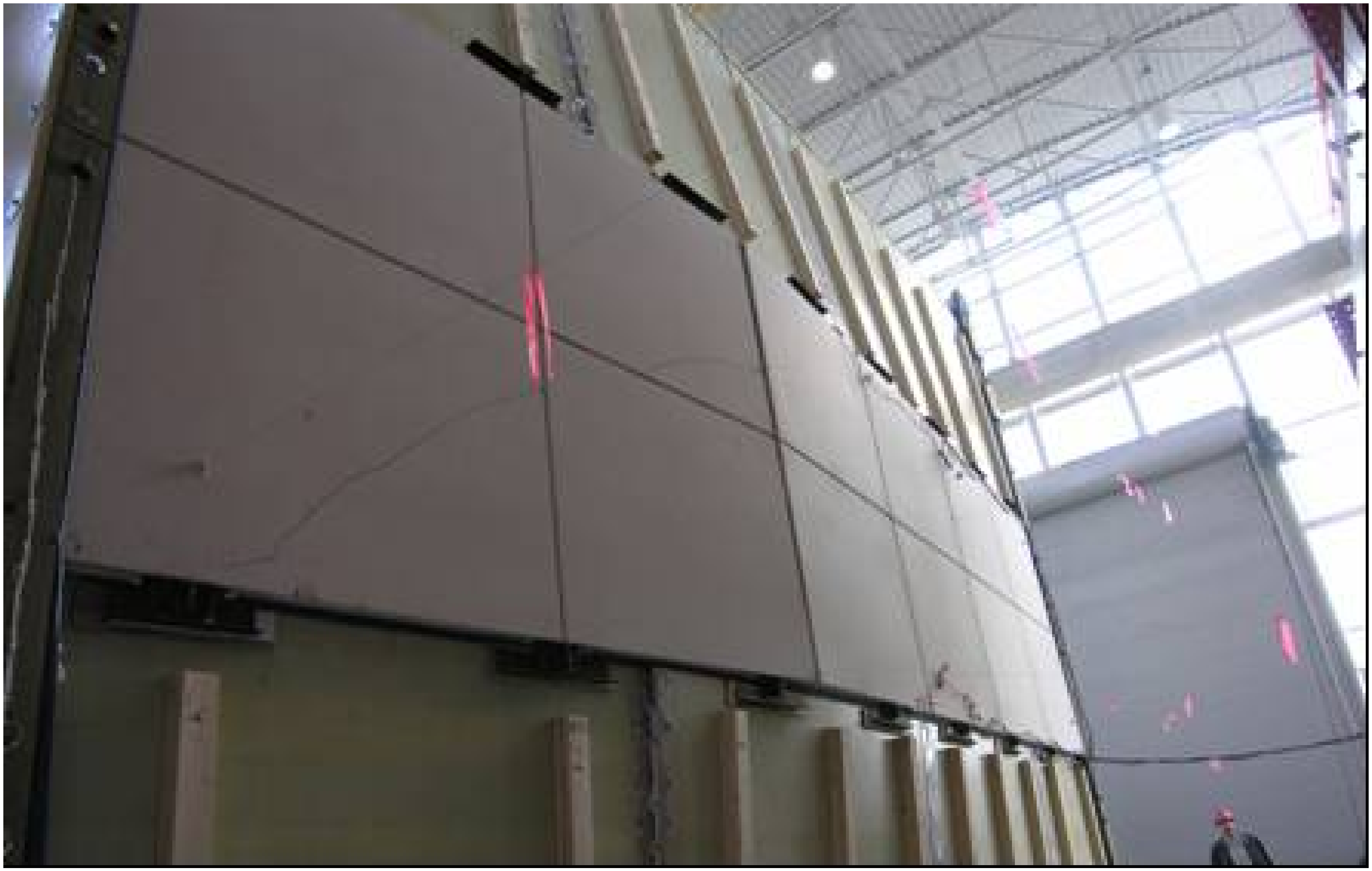
Full-Scale Experimental Validation

± 1.2 kPa cyclic loading

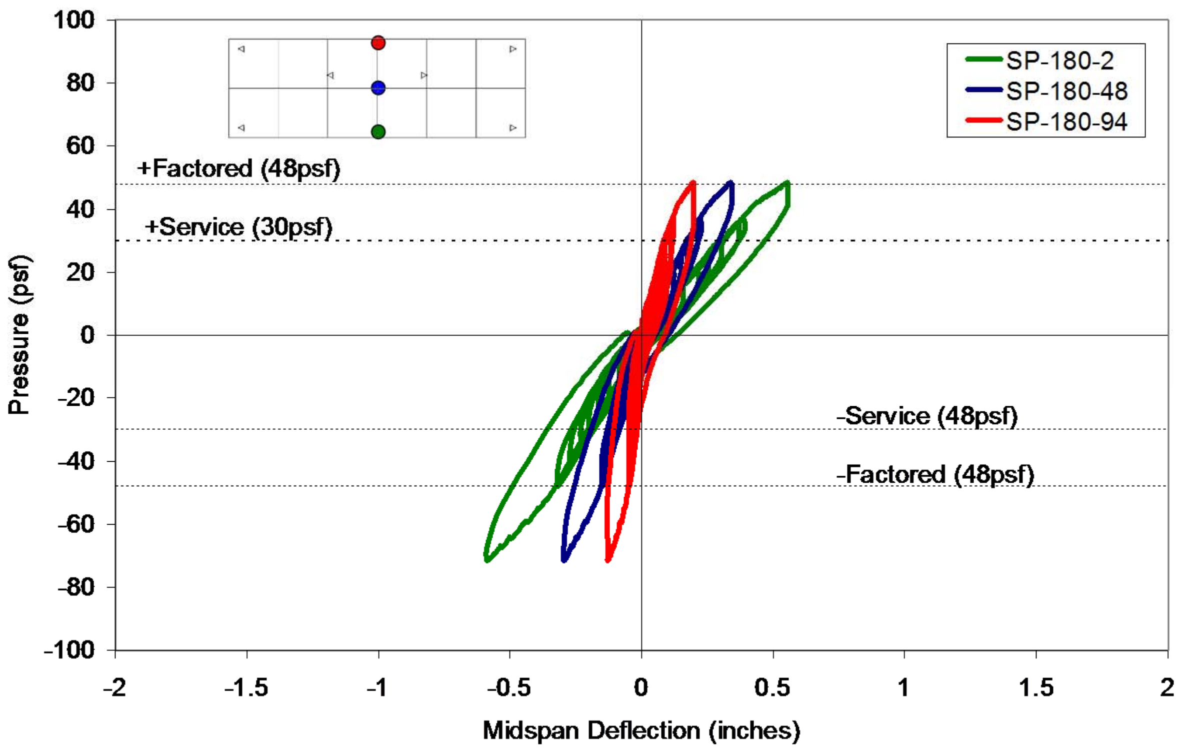
2.5 kPa static loading

Specimen after Sustaining Factored Load in Both Directions (No Cracks)

Final Crack Pattern



Pressure vs. Deflection



Failure due to Pullout of End Connections

ProLogis Distribution Warehouse

LOCATION:
South Brunswick, N.J.

ARCHITECT:
Arco Design Build, Conshohocken, Pa.

SIZE:
751,000 sq. ft.

Proximity Hotel

LOCATION:
Greensboro, NC

ARCHITECT:
Centrepoint Architecture

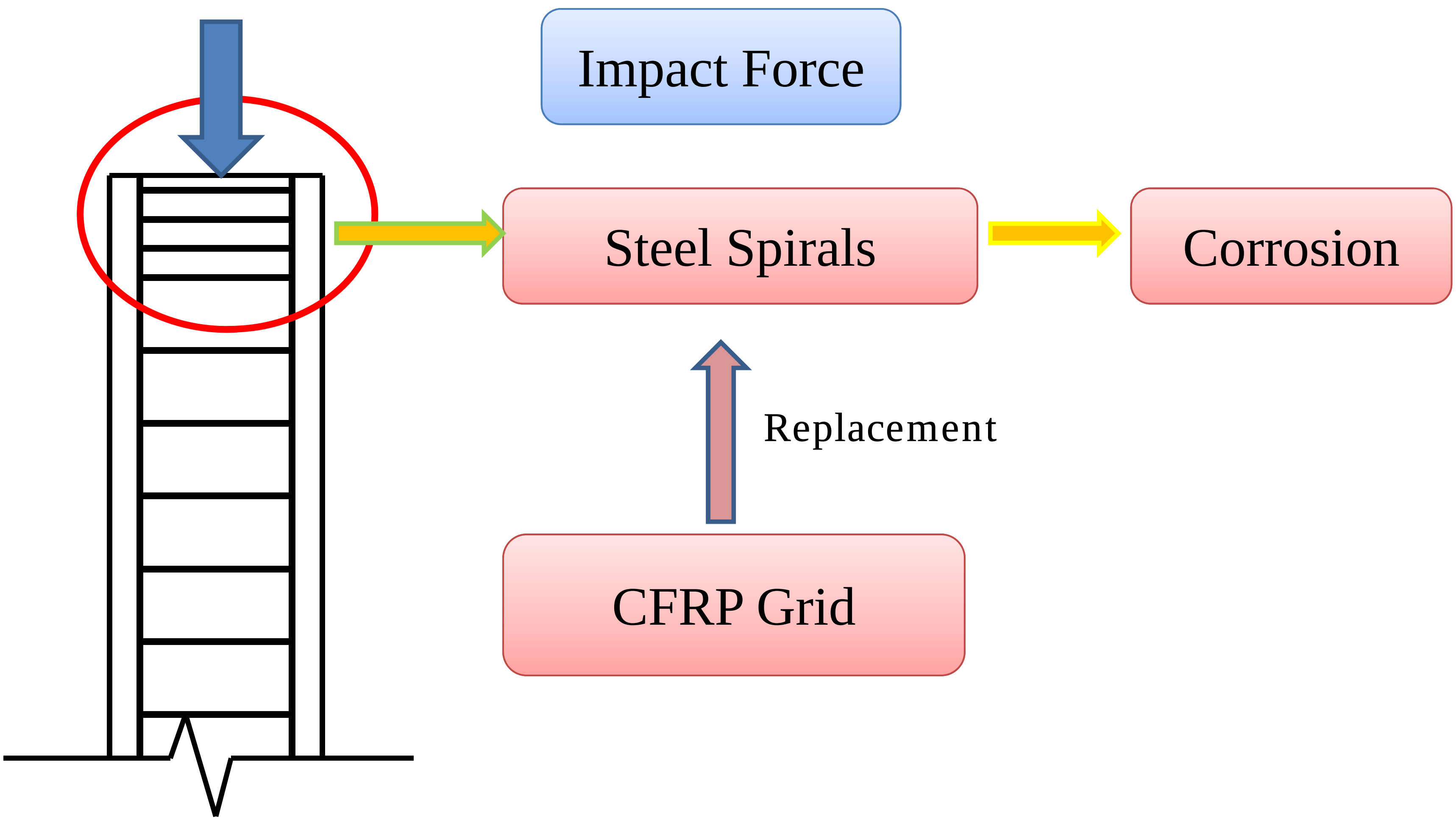
SIZE:
118,000 sq. ft.

SURFACE AREA:
55,000 sq. ft.

AWARDS:
LEED® Platinum, USGBC GreenSite Project of the Year, 2010

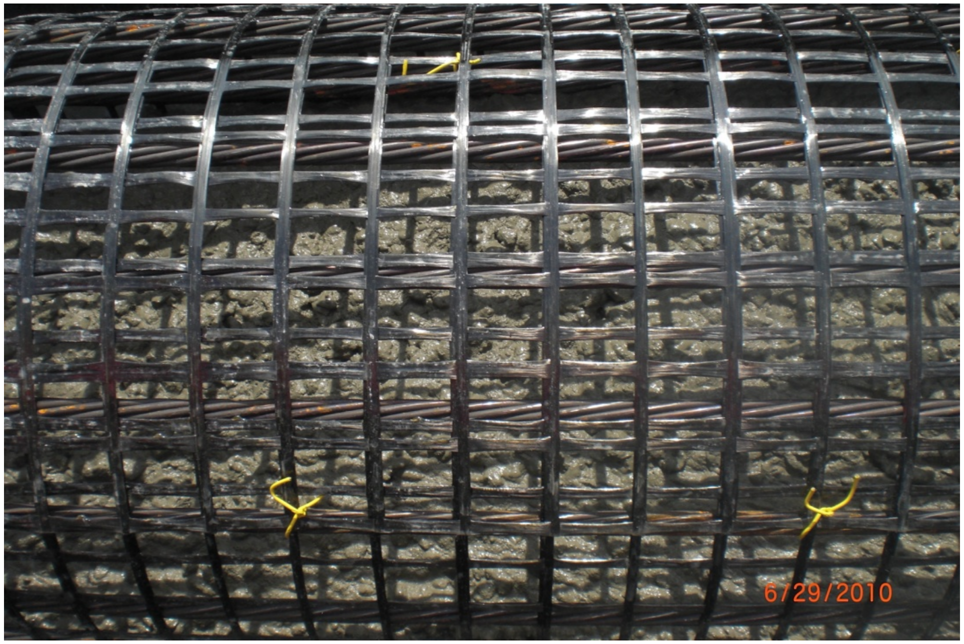
Under Development

- Precast Prestressed Concrete Piles


Impact Force
Steel Spirals
Corrosion
Replacement
CFRP Grid

Testing of Pile Specimens

•Prestressing and CGRID for Confinement

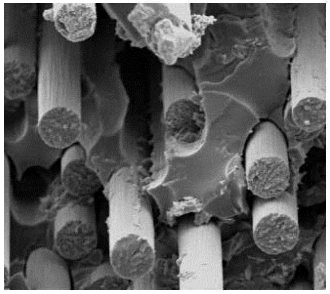


Casting with SSC

Testing by FDOT

Testing by FDOT

Closing Remarks



Innovative use of FRP will lead to significant advancements in design, construction and sustainability of precast concrete structures and bridges.

Questions?