Center for Integration of Composites into Infrastructure

## Industrial Advisory Board (IAB) Meeting

# #1 PHYSICO-MECHANICAL CHARACTERIZATION OF COMPOSITES FOR INFRASTRUCTURE APPLICATIONS

# Investigators


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# Approach and Industrial Relevance

- Multi-manufacturer **testing database**: build experimental and guaranteed material results
- **Normalize and standardize** test methods, data analysis, and material specification data sheets: contents and procedures;
- **Parameter relationships** development, by studying relationships between physico-mechanical parameters and use experimental data for validation
- **Improve** minimum requirements by experimental evidence
- **Develop** QC testing protocols (New scope)
- **Validate** element test protocols (New scope)

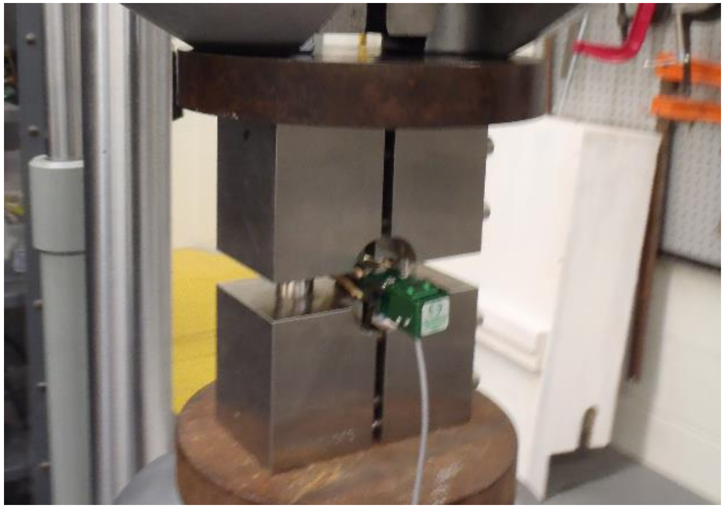
**SPONSORS:** Arkema, Creative Pultrusions, ACMA, Galen, Structural Technologies, Structural RS, Owens Corning Infrastructure, QuakeWrap, Simpson Strong-Tie, LiteForm Technologies, TUF-N-LITE, Miller & Long Company

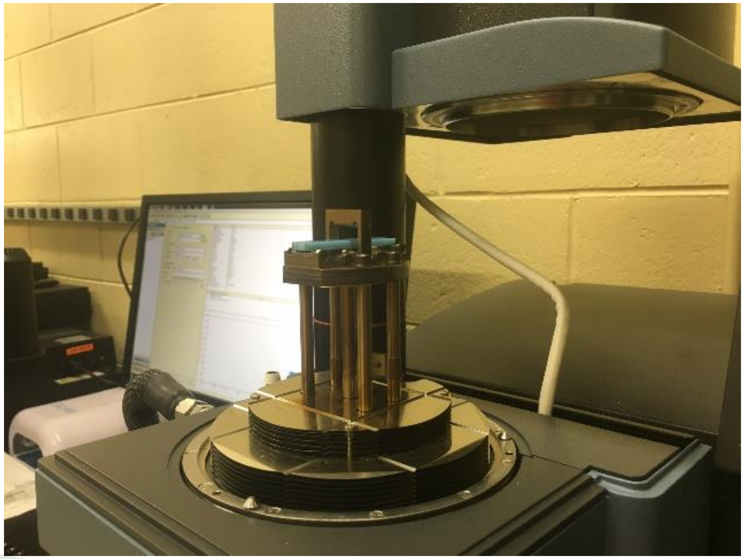
# Testing

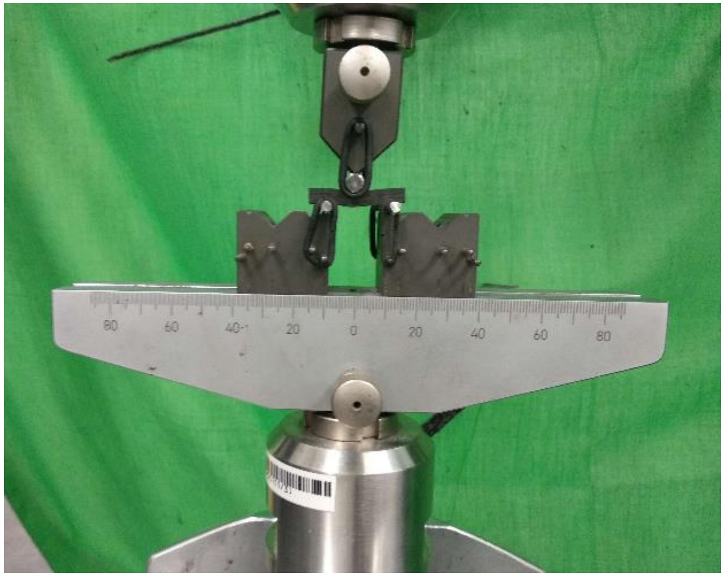
SAFETY GLASSES REQUIRED
INSTRON
33R


Max. Pressure: 69 MPa / 10,000 psi


# Testing

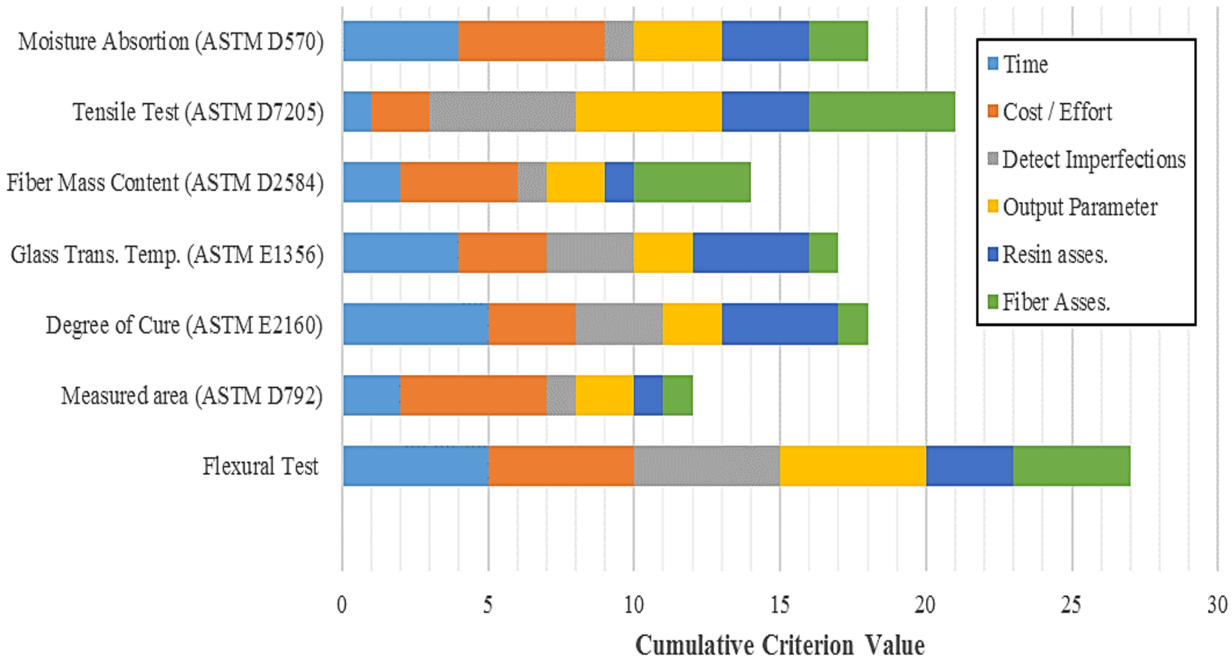




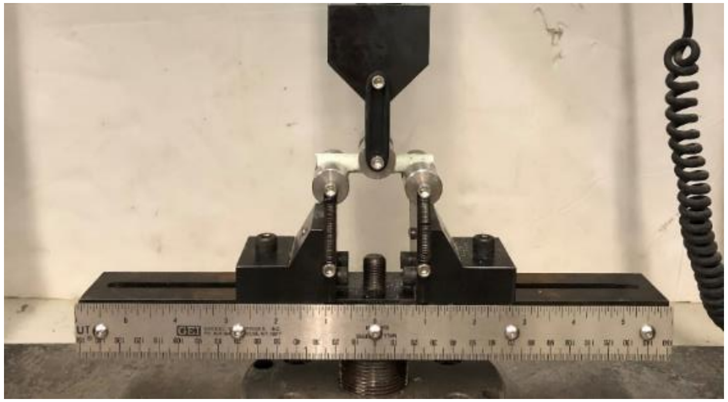


# Testing – Flexure


# QC assessment criterion for FRP bar

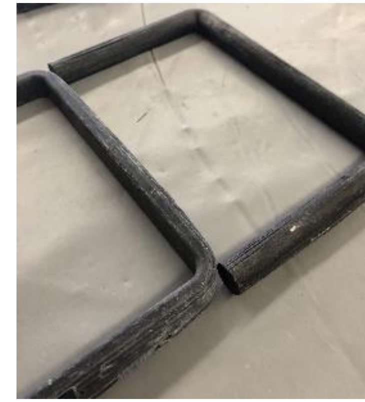


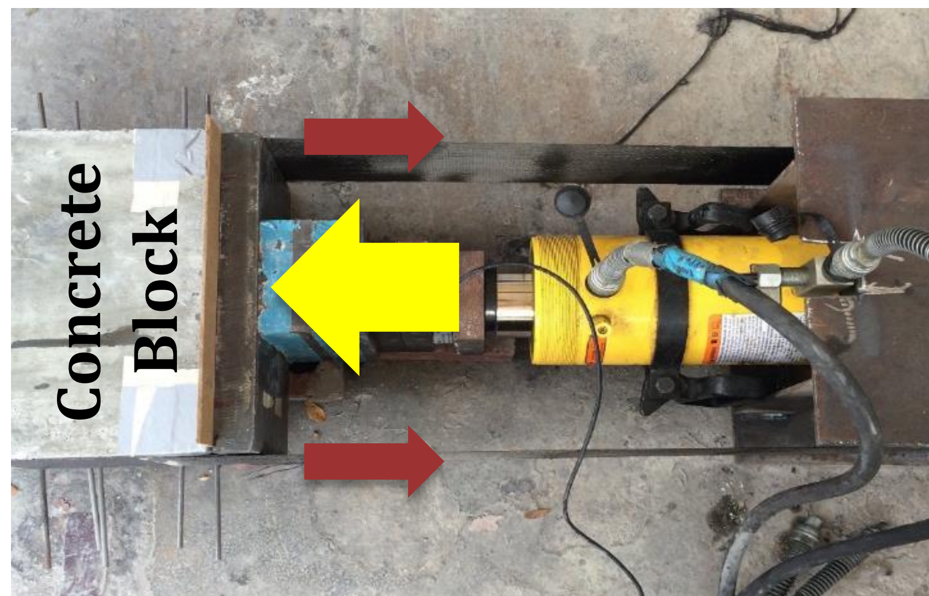

**Addition**: Evaluation and significance of horizontal shear strength for QC/QA ASTM D4475



# External FRP Anchor Characterization

- **Direct Double Shear Test** aimed at generating interfacial shear stress between concrete substrate and externally-bonded FRP
- Enhancement given by FRP anchor analyzed in terms of peak load compared to specimens w/o anchor
- Deformation and strain achieved by FRP laminate provide higher level of effectiveness when compared to specimens w/o anchor





# External FRP Anchor Characterization




# On going… Conclusions

**Internal FRP applications**

- Specs to higher available characteristic values
- Glass and basalt FRP bars show equivalent performance and thus specifications
- Manufacturing QC/QA practice is needed
- Tests and specifications applied to bent portion of bar is pending
- Example of the process from certification to field use for an FRP bar being developed:
  - Certification
  - Qualification
  - Quality assurance

# On going... Conclusions

**External FRP applications**

- Witness panel testing best practices need to be defined
- Characterization of FRP feasible for different types of anchorage systems
- Increase in load capacity with anchors of more than 30%
- Need to develop relationships to include multi-scale modeling for anchor testing
- Specimen preparation guidelines and standardization needed

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## Industrial Advisory Board (IAB) Meeting

# PHYSICO-MECHANICAL CHARACTERIZATION OF COMPOSITES FOR INFRASTRUCTURE APPLICATIONS

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## Industrial Advisory Board (IAB) Meeting

# #2 DETERMINING DURABILITY OF COMPOSITES FOR INFRASTRUCTURE APPLICATIONS

# Investigators

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Antonio Nanni
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# Approach and Industrial Relevance

- **Validate service life** using accelerated test data and compare with real-life exposed samples
- **Validate strength reduction factors** adding value to composites durability and specifications

**SPONSORS**: Arkema, Miller & Long Company, Structural Technologies, Simpson Strong-Tie, ACMA, Galan, QuakeWrap, Tokyo Rope, Structural RS, TUF-N-LITE LLC, Owens Corning Infrastructure, Basalt Engineering LLC, Bluegrass Composites, Inc.

# Service Life Prediction: Organic Composites

- Evaluation of applicability of Arrhenius Model

$$k = Ae^{\left(\frac{-E_a}{RT}\right)} \longrightarrow ln\left(\frac{1}{k}\right) = \frac{E_a}{R}\frac{1}{T} - ln(A)$$

Where:

K rate constant, [mol/(L s)]

T Absolute temperature, [K]

A Arrhenius factor (constant for every chemical reaction), [L/(mol s)]

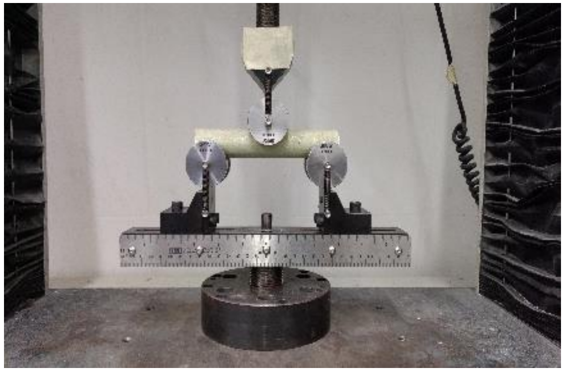
R universal gas constant, [J/(mol K)]

$E_a$ activation energy for the reaction happening, [J/mol]

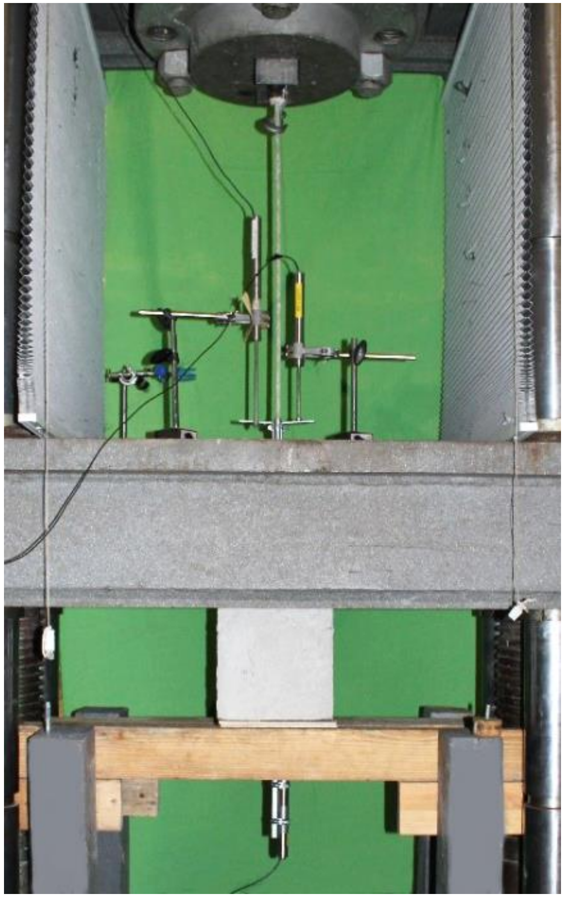
# Internal Composites: Multi-Parameter Characterization

Tensile strength & E modulus
(ASTM D7205)

Transverse shear strength
(ASTM D7617)



Horizontal shear strength
(ASTM D4475)



Bond strength
(ASTM D7913)

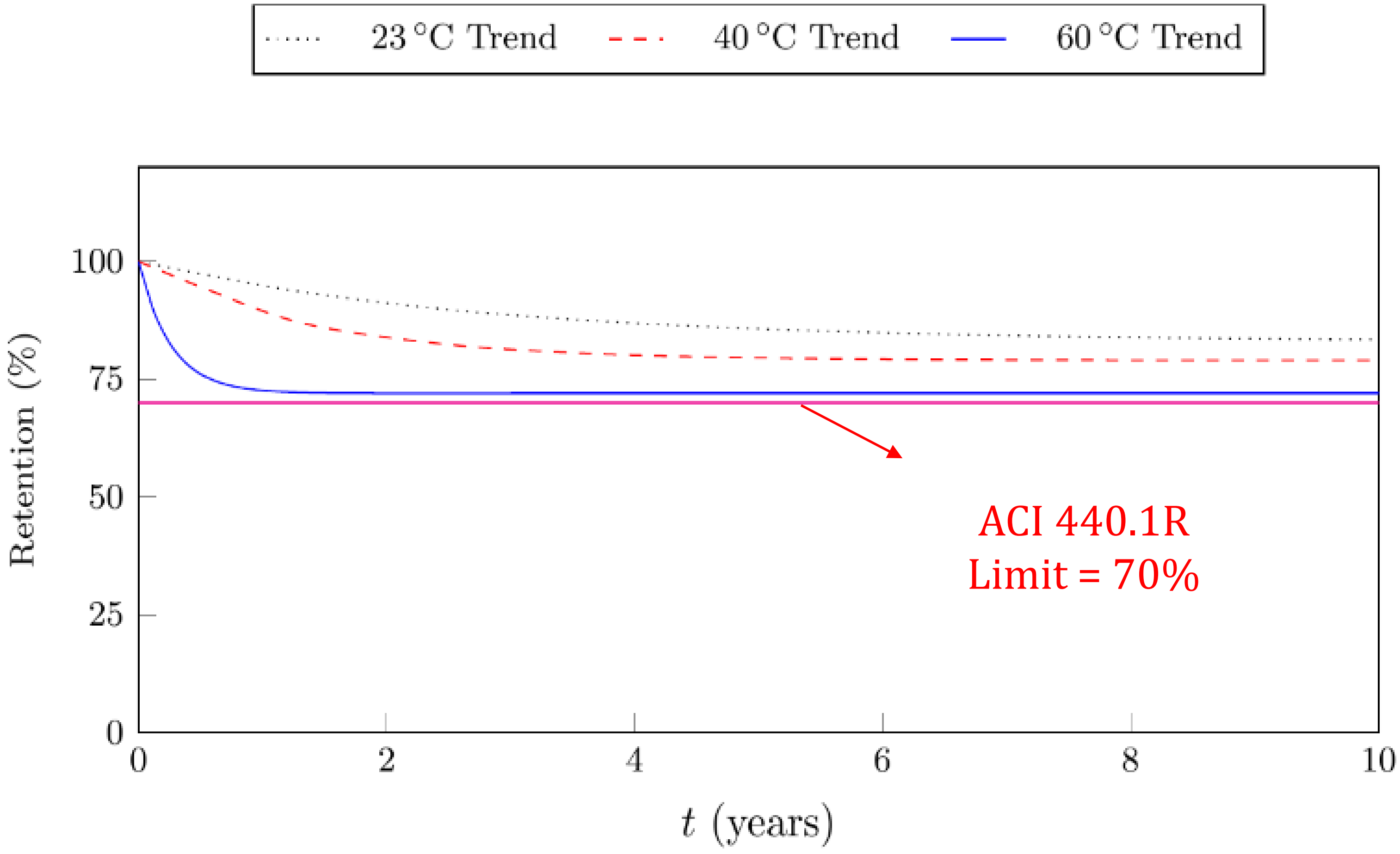
# Internal Composites: Multi-Parameter Characterization

Tensile test post alkaline exposure **without** load

Tensile test post alkaline exposure **with** load

# Service Life Prediction – GFRP rebar

- Prediction based on tensile strength retention



# External Composites: Multi Exposure Characterization

Accelerated conditioning protocols include (on going):

## Exposures <u>>20,000 hrs</u>

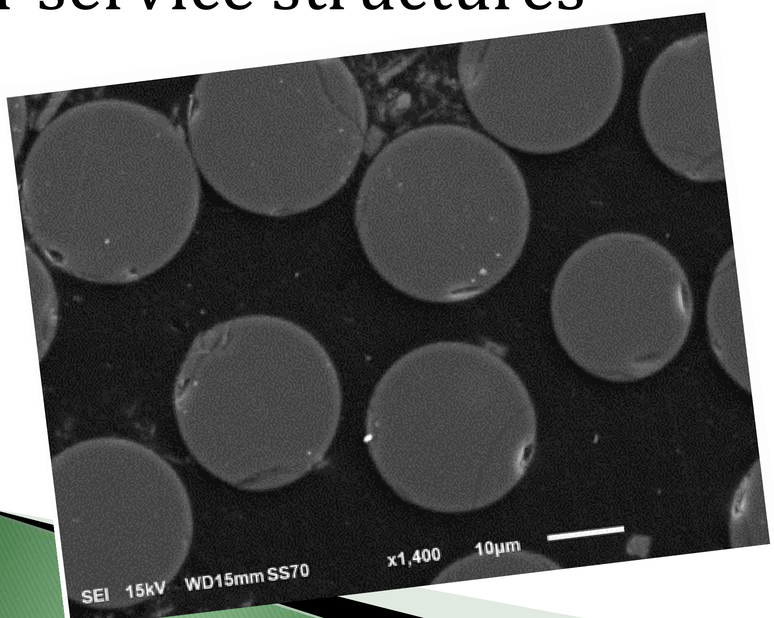
- Salt Water (Immersion 73ºF )
- Ultraviolet Resistance (4 hrs @140ºF FS 40 UV-B - 85%)
- Alkalinity (Immersion pH=12.5- 73ºF )
- Water Resistance (100% RH, 100ºF)
- Dry Heat (0% RH, 140ºF)
- Freeze and Thaw cycles

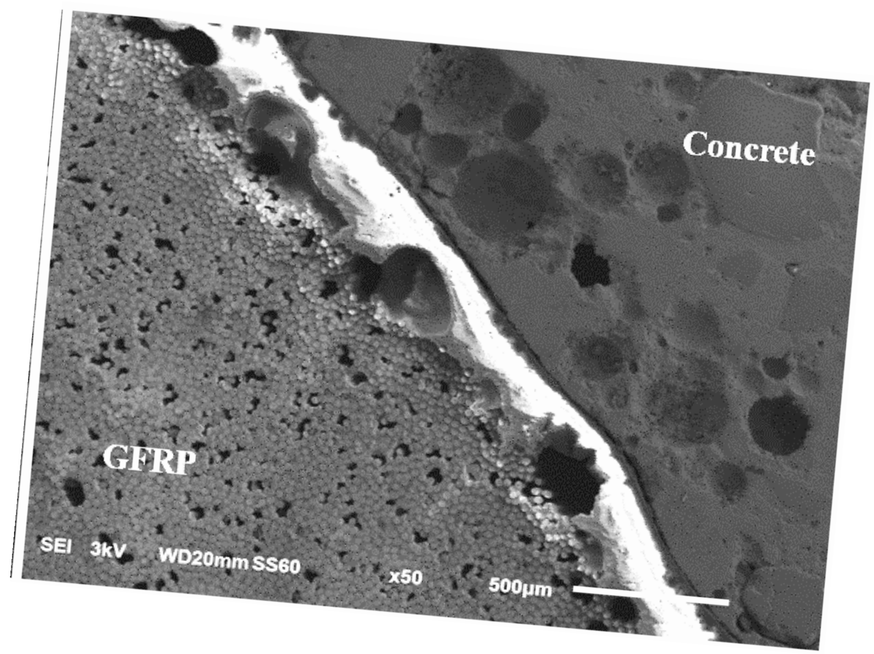
## Tests

- Direct Tension
- Interlaminar Shear
- Lap Splice
- Shear Bond
- $T_g$

# Conclusions – Internal Reinforcement

- Degradation in accelerated seawater exposure is bar dependent
- Bars **retain 70 % of the tensile strength capacity** (ACI 440.1R-15 limit)
- Durability models should be **calibrated** with data from in-service structures



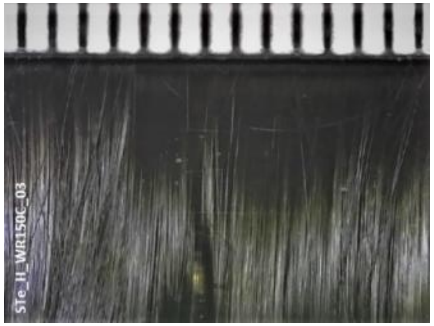



# Conclusions – Internal Reinforcement

- Results indicate reduction in tensile strength of 2.13% over a period of 17 years of service **corresponding to drop in strength of 12.5% over a period of 100 years** (degradation rate assumed linear)


# Conclusions – External Strengthening

- Microscopic visual surface evaluation reveals no significant degradation post 10,000 hrs. exposure
- Strength retention within existing spec limits
- Use of composites in aggressive environments (e.g., oil industry) growing



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# #3 IMPLEMENTATION OF COMPOSITES THROUGH EXPERIMENTAL TESTING AND DESIGN

# Investigators

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Hossein Roghani
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Professor and Chair

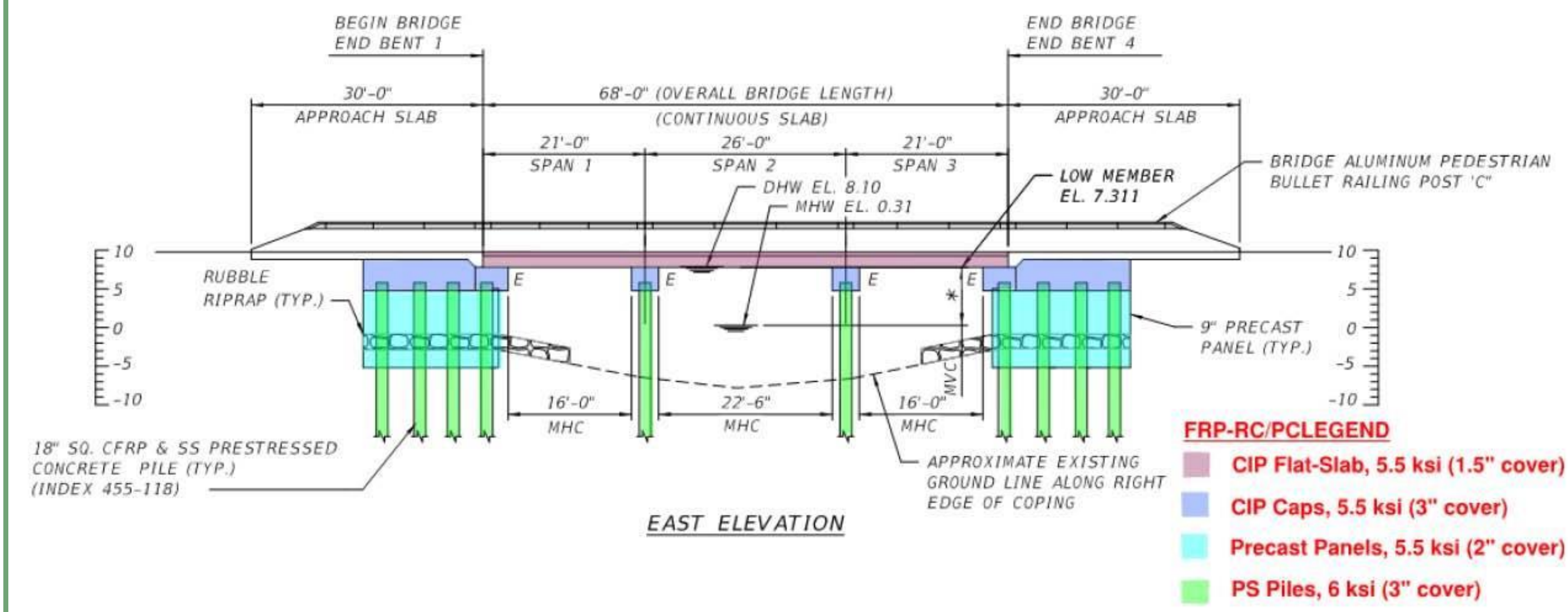
Francisco De Caso
Principal Scientist

# Approach and Industrial Relevance

- **Monitor and learn** during the in-situ implementation of FRP in coastal structures
- **Identify knowledge gaps** and barriers to implementation from a pre-, during-, and post-project processes
- **Validate design protocols** in infrastructure and residential construction projects
- **Resources** support development of: a) FDOT fast-facts to disseminate easily accessible information; and, b) course content and training tools (NEW Scope)
- **Define and Measure** procurement and construction parameters that differ between composites and traditional reinforcement (NEW Scope)

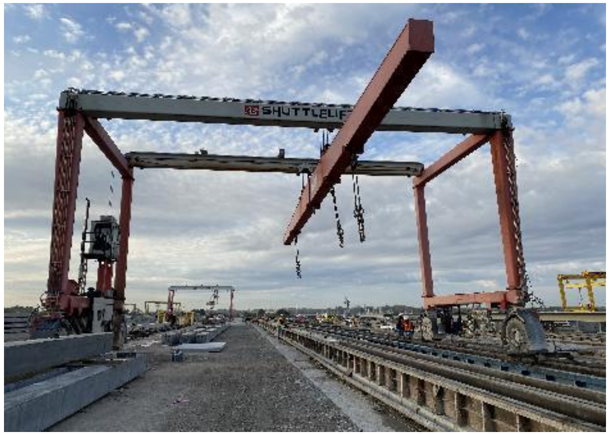
**SPONSORs:** ACMA, Galan, TUF-N-LITE LLC, Owens Corning Infrastructure, Basalt Engineering LLC, Bluegrass Composites, Inc. LiteForm Technologies, Miller & Long Co.

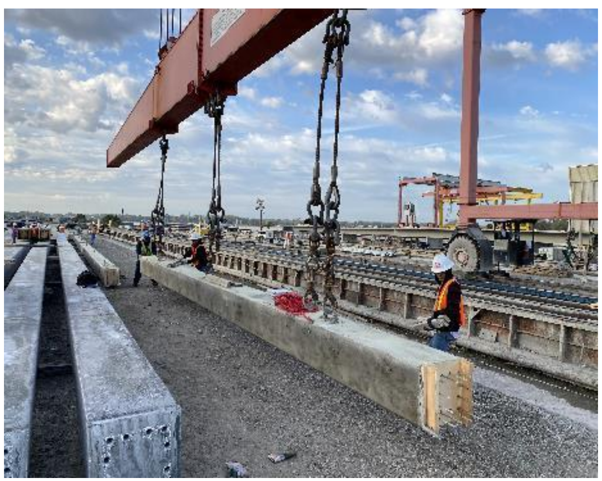
# IBIS-Waterway Bridge




Three-span IBIS-Waterway Bridge with CIP Continuous Flat-Slab, CIP-Caps, Precast Panels and PC-Piles (two with GFRP)

# Coiled GFRP Tendons for PC Piles

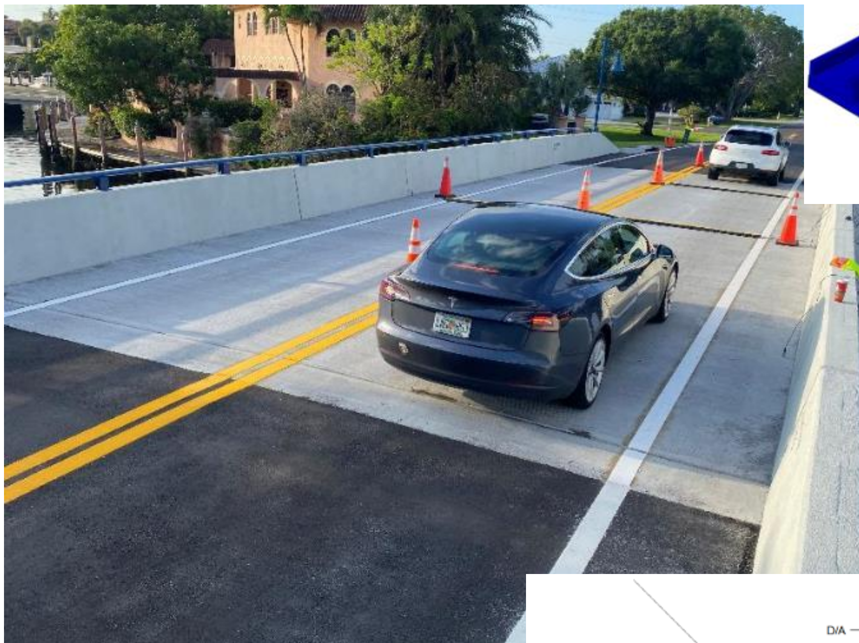




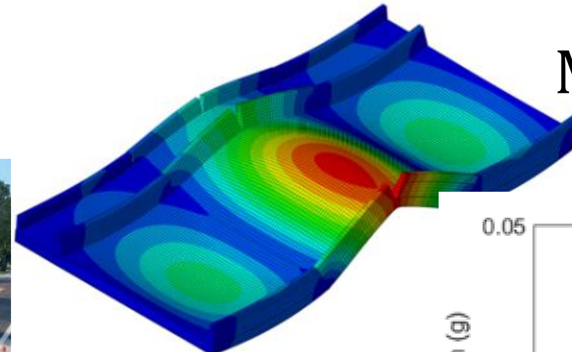
- Casting of PC piles at Gates, Jacksonville
- Coiled No. 4 GFRP bars utilized as tendons
- GFRP un-coiled and spliced with seven-wire steel strand prior to stressing

# IBIS-Waterway Bridge

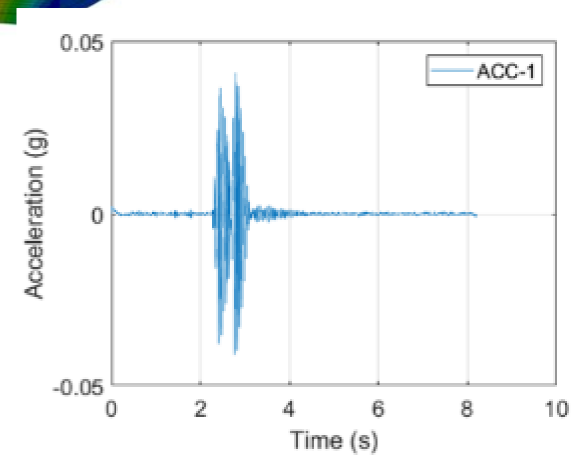
## Frequency Testing

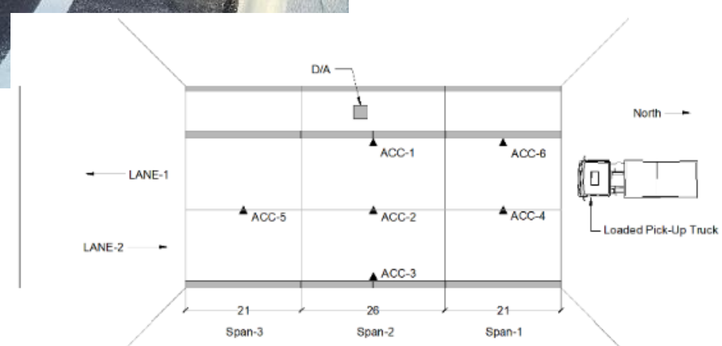


May 1, 2021



Mode I

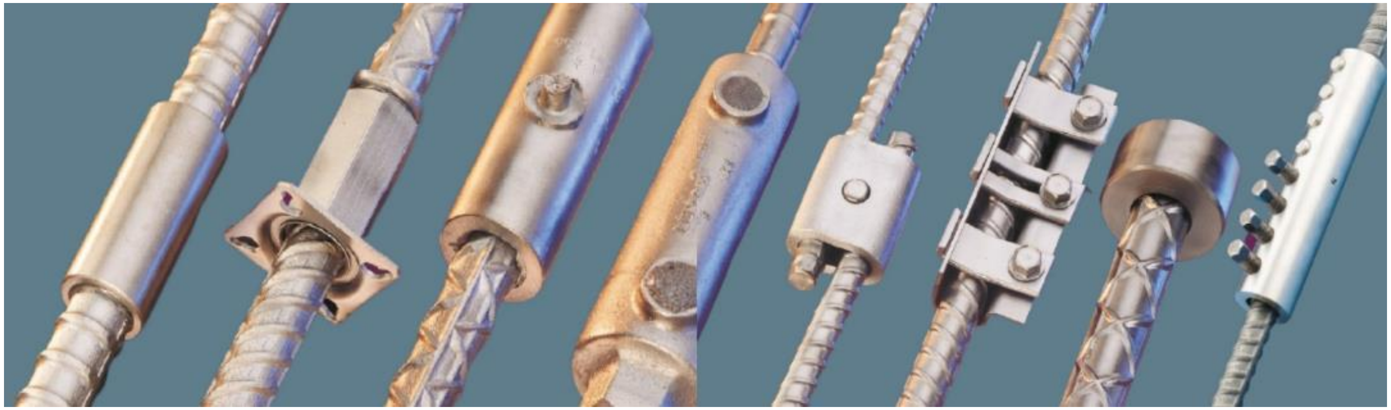



Bridge average natural frequency 17.5 Hz (Mode 1)

# GFRP Remaining Challenges…

- Cannot be bent at fabricator or in-situ (e.g., stirrups are pre-bent at pultruder’s)
- Longer development lengths
- Low transverse strength
- **>> Splicing of GFRP bars with mechanical couplers<<**



# Splicing Methods

**Lap splices**

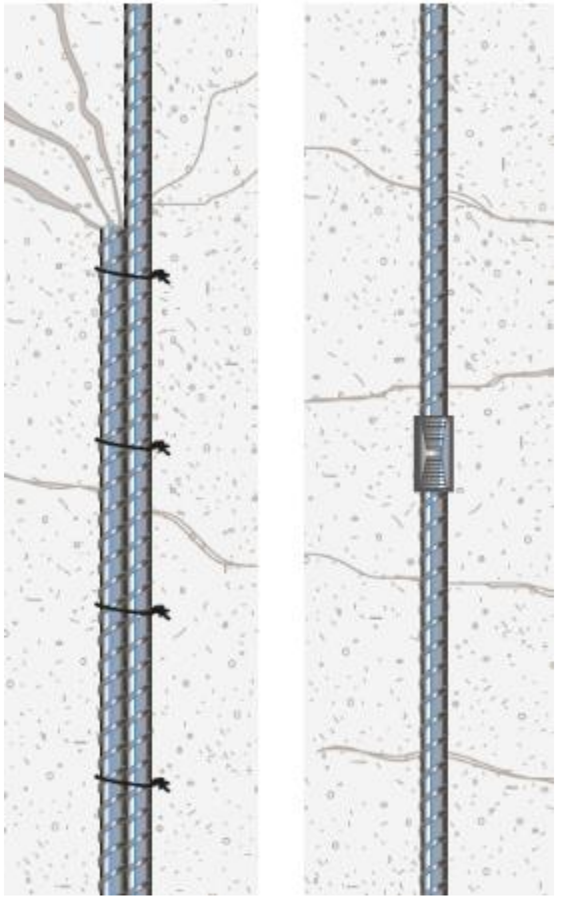
✓ Cause congestion at splice locations

✓ Long lap length function of bar diameter

**Mechanical couplers**

✓ Reduce congestion in heavily reinforced elements

✓Allow staged construction



# Swaged Coupler

**Purpose**

Investigate the feasibility of splicing No.4 GFRP bars

**Installation**

Swaged coupler installed by deforming a steel sleeve onto the bar ends with hydraulic press

**Outcome**

Tension transferred between two bars through swaged sleeve

# Swaged Coupler

**PC Applications**

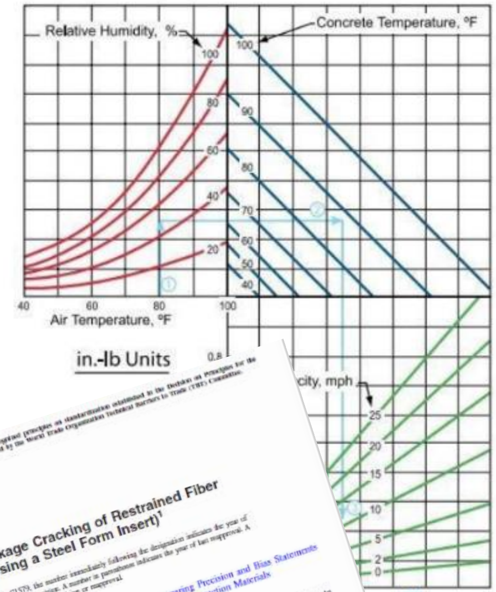
Used at precast plants for splicing FRP bars or strands with steel strands

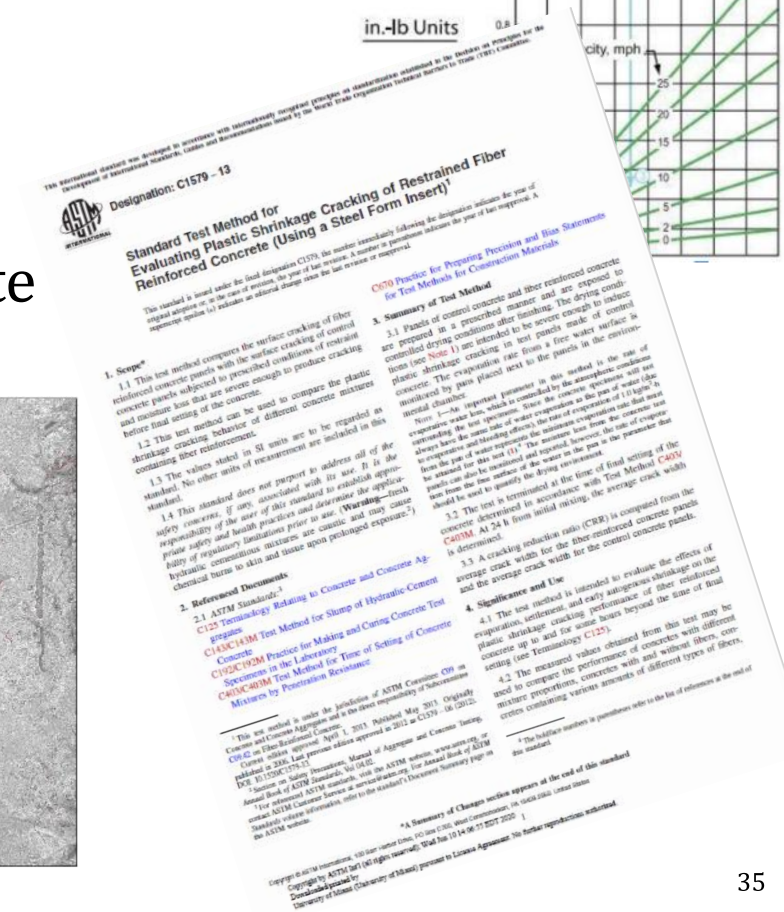
**Many Remaining challenges**

Coupler material, deformation pressure, and length of coupler

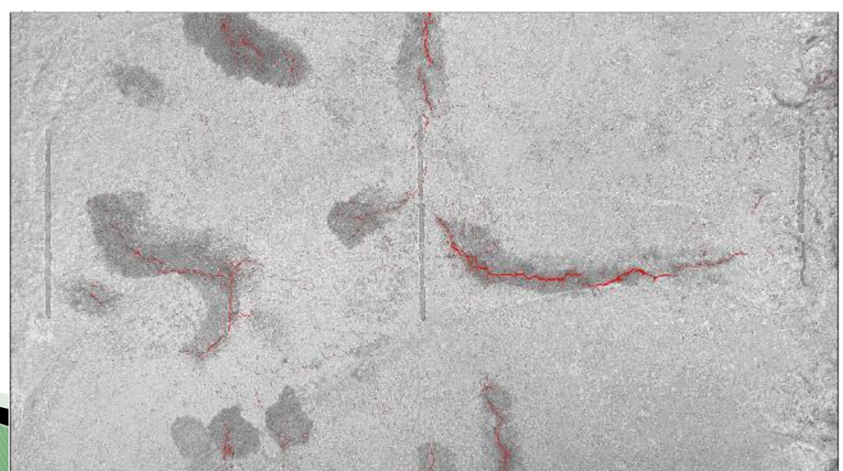
# FRP as Secondary Reinforcement (on going)

- Define minimum FRP reinforcement requirements (AC521)
- Verify spacing and minimum area of reinforcement
- Implement and adapt existing ASTM methods
- Crack quantification
- Experimentally measure and evaluate crack formation





Designation: C1579 − 13

Standard Test Method for
Evaluating Plastic Shrinkage Cracking of Restrained Fiber Reinforced Concrete (Using a Steel Form Insert)[1]



# Resource Development

- Lunch and Learn sessions
- Half- and Full- day design training courses
- Webinars
- Design aids and examples
- Certificates (PDHs)


# Conclusions

- Projects with deployment of FRP RC and PC elements increasing and being studied
- Work in progress to overcome remaining challenges such as mechanical splices
- FRP secondary reinforcement for flat work and temperature/shrinkage crack control
- Development of tools and tech transfer resources

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# #4 PROPELLING USE OF FRP WITH MEANINGFUL STANDARDS AND GUIDES

# Investigators

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Antonio Nanni
Professor and
Chair

# Approach and Industrial Relevance

- **Expand** existing guides/standards to include all possible FRP-RC applications (i.e., design a bridge entirely GFRP reinforced)

- **Update** existing provisions to reflect better materials and manufacturing (i.e., make design & construction more efficient and economical) with support of structural testing

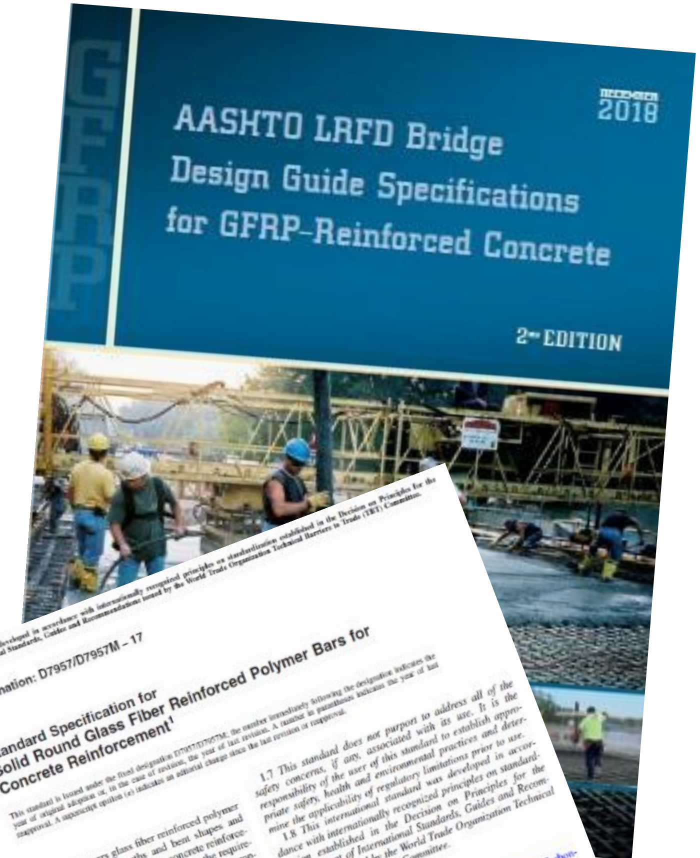
- **Harmonize** with national (ACI, ASTM, AASHTO, ICC-ES), and international (CSA, *fib*, AFGC) documents (i.e., ease material certification and design; enlarge market and facilitate deployment)

- **Develop** guides to bridge knowledge gaps allowing further implementation of composites into infrastructure

**SPONSORS:** Arkema, ACMA, Galan, TUF-N-LITE LLC, Owens Corning Infrastructure, Basalt Engineering LLC, Bluegrass Composites, Inc, Miller & Long Company

# Deliverables

- ICC-ES AC521 (Proponent)
- ICC-ES AC454, 2020 (Revision Contributor)
- FDOT, Dev 932 and 933, 2020 (Contributor)
- ASTM D7957 Revision (Task Group Lead)
- ACI 440.2R (Basalt FRP) (Proponent)
- AASHTO GFRP-RC (Contributor)
- TMS 402 Appendix D (Contributor)





# ASTM D7957-2017 REVISION

- Differentiation between straight and bent bars
- Performance-based provisions with addition of other resins and fibers
- Inclusion of high-modulus and higher strength requirements
- Editorial changes

This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

Designation: D7957/D7957M – 17

## Standard Specification for Solid Round Glass Fiber Reinforced Polymer Bars for Concrete Reinforcement[1]

This standard is issued under the fixed designation D7957/D7957M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

### 1. Scope

1.1 This specification covers glass fiber reinforced polymer (GFRP) bars, provided in cut lengths and bent shapes and having an external surface enhancement for concrete reinforcement. Bars covered by this specification shall meet the requirements for geometric, material, mechanical, and physical properties described herein.

1.2 Bars produced according to this standard are qualified using the test methods and must meet the requirements given by Table 1. Quality control and certification of production lots of bars are completed using the test methods and must meet the requirements given in Table 2.

1.3 The text of this specification references notes and footnotes which provide explanatory material. These notes and footnotes (excluding those in tables) shall not be considered as requirements of the specification.

1.4 The following FRP materials are not covered by this specification:

1.4.1 Bars made of more than one load-bearing fiber type (that is, hybrid FRP).

1.4.2 Bars having no external surface enhancement (that is, plain or smooth bars, or dowels).

1.4.3 Bars with geometries other than solid, round cross sections.

1.4.4 Pre-manufactured grids and gratings made with FRP materials.

1.5 This specification is applicable for either SI (as Specification D7957M) or inch-pound units (as Specification D7957).

1.6 The values stated in either inch-pound units or SI units are to be regarded as standard. Within the text, the inch-pound units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

*1.7 This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health and environmental practices and determine the applicability of regulatory limitations prior to use.*

*1.8 This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

### 2. Referenced Documents

2.1 *ASTM Standards:*[2]

A615/A615M Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement
C904 Terminology Relating to Chemical-Resistant Nonmetallic Materials
D570 Test Method for Water Absorption of Plastics
D792 Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement
D2584 Test Method for Ignition Loss of Cured Reinforced Resins
D3171 Test Methods for Constituent Content of Composite Materials
D3878 Terminology for Composite Materials
D7205/D7205M Test Method for Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars
D7617/D7617M Test Method for Transverse Shear Strength of Fiber-reinforced Polymer Matrix Composite Bars
D7705/D7705M Test Method for Alkali Resistance of Fiber Reinforced Polymer (FRP) Matrix Composite Bars used in Concrete Construction
D7913/D7913M Test Method for Bond Strength of Fiber-Reinforced Polymer Matrix Composite Bars to Concrete by Pullout Testing
D7914/D7914M Test Method for Strength of Fiber Reinforced Polymer (FRP) Bent Bars in Bend Locations

[1] This specification is under the jurisdiction of ASTM Committee D30 on Composite Materials and is the direct responsibility of Subcommittee D30.10 on Composites for Civil Structures.
Current edition approved Aug. 1, 2017. Published August 2017. Originally approved in 2017. DOI: 10.1520/D7957_D7957M-17.

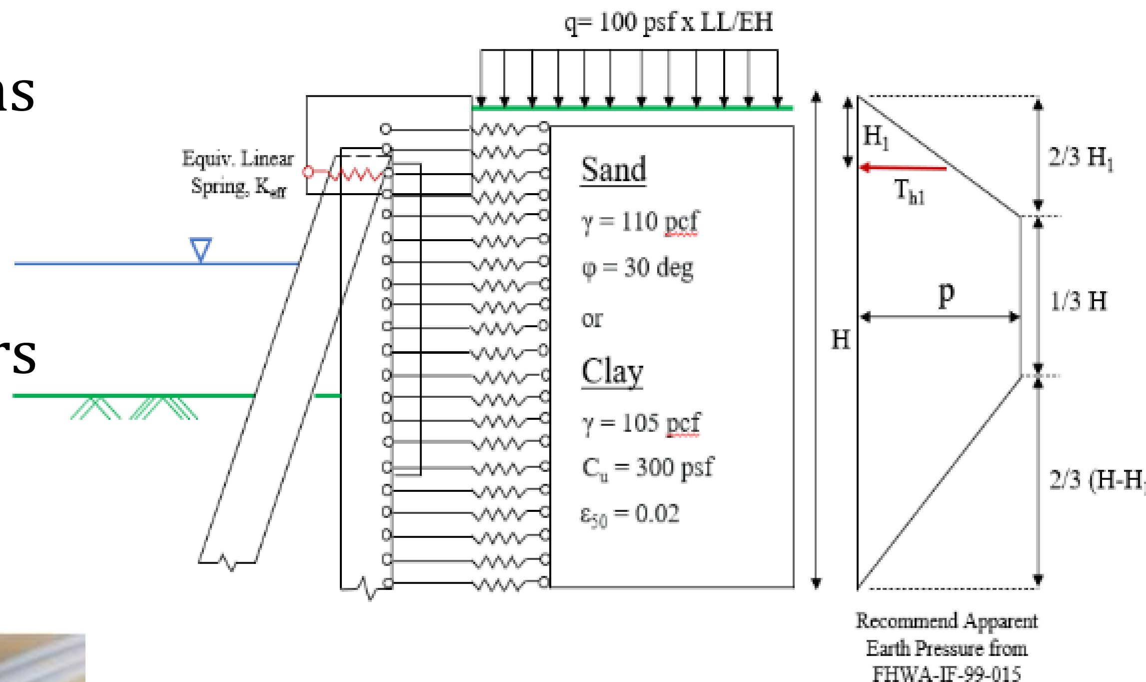
[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

# DESIGN: GFRP-PC Piles for Seawalls

**Partially prestressed** =
combine GFRP tendons and GFRP bars

**Hybrid** = combine steel tendons and GFRP bars

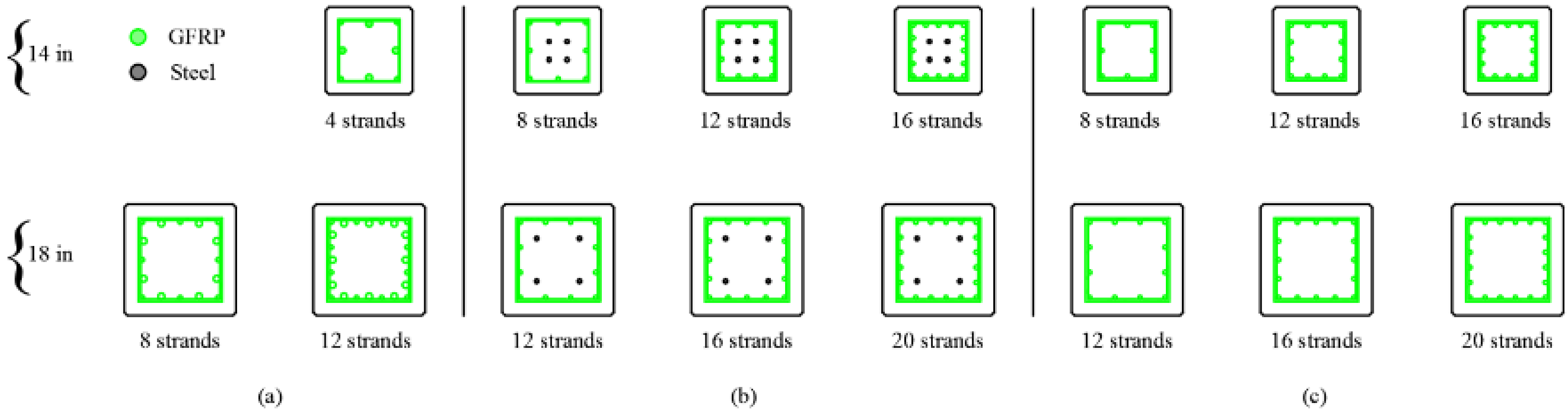
**Fully Prestressed** = GFRP tendons




Schematic of Solider Pile/Battered Pile Wall System and Modeling Approach

NCHRP IDEA Project 207

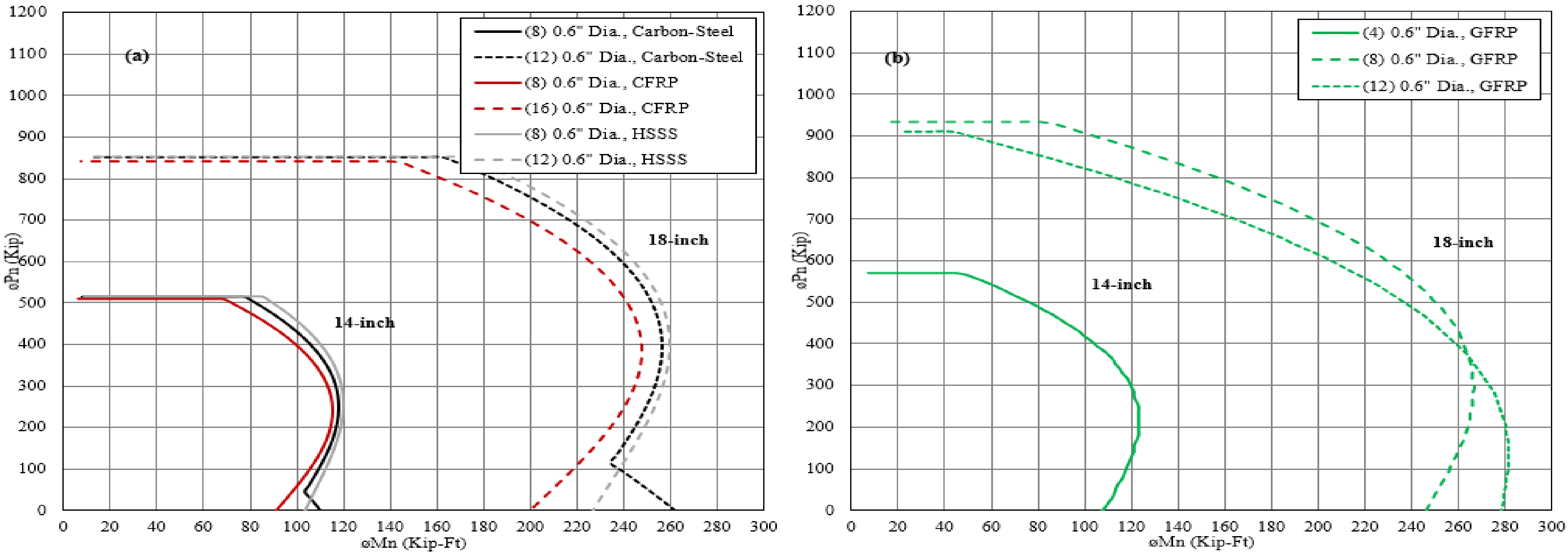
# GFRP-PC Piles for Seawalls




**Pile Configurations** for concrete strength $f'_c$ = 6,000 psi with 0.6" diameter GFRP or steel strands

- (a) **Partially Prestressed** with GFRP strands and #8 GFRP bars
- (b) **Hybrid** with a 5-in clear cover for steel strands and GFRP bars
- (c) **Fully Prestressed** with GFRP strands

# GFRP-PC Concrete Piles for Seawalls



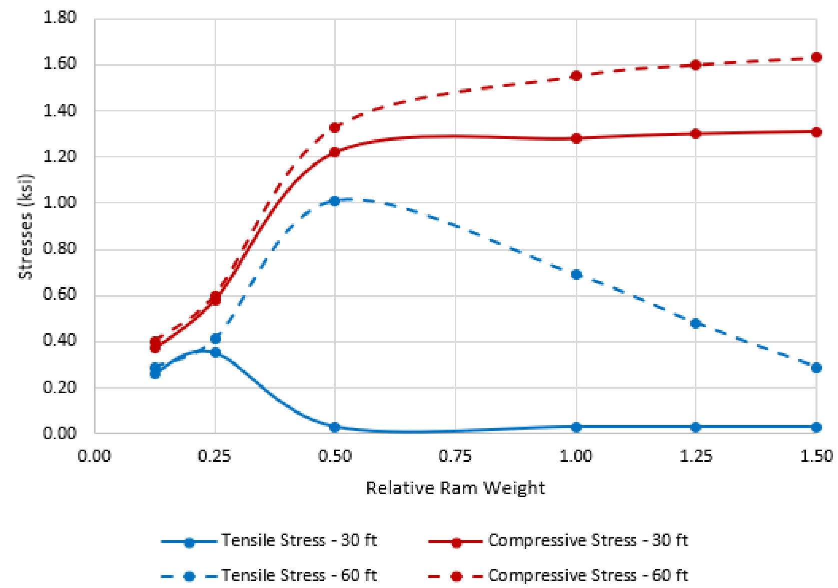

**P-M Diagrams for Existing and Proposed Pile Configurations**

(a) Existing FDOT PC with carbon steel, stainless steel and CFRP strands

(b) Partially prestressed GFRP piles

# Preliminary Conclusions: GFRP-PC Piles

- Strength of partially, hybrid and fully prestressed piles sufficient in resisting lateral load from bulkhead
- Drivability of short GFRP-PC piles feasible for installation lengths less than 30 ft
- Hybrid and fully prestressed configurations need further evaluated




GRLPWEAP 2010: Tension and Compression Stresses as a Function of Relative Ram Weight

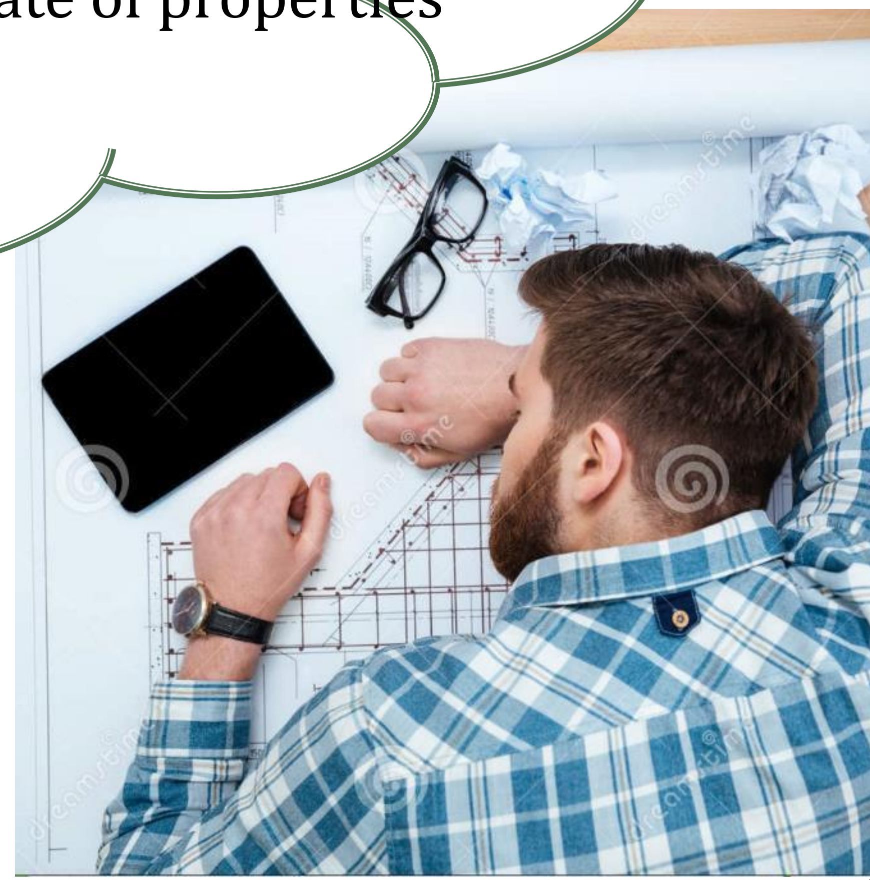
# Overall Conclusions

- Continuing development of FRP specs
- Safe and cost-competitive design
- Harmonization and update of properties
- New applications

Dreaming is nice, but…

**Adoption**

**makes it real!!!**



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# PROPELLING USE OF FRP WITH MEANINGFUL CODES AND GUIDELINES

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