



Industrial Advisory Board (IAB) Meeting

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

Investigators



Ana De Diego
Research Analyst



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Francisco De Caso
Principal Scientist



Antonio Nanni
Professor and Chair

Approach and Industrial Relevance

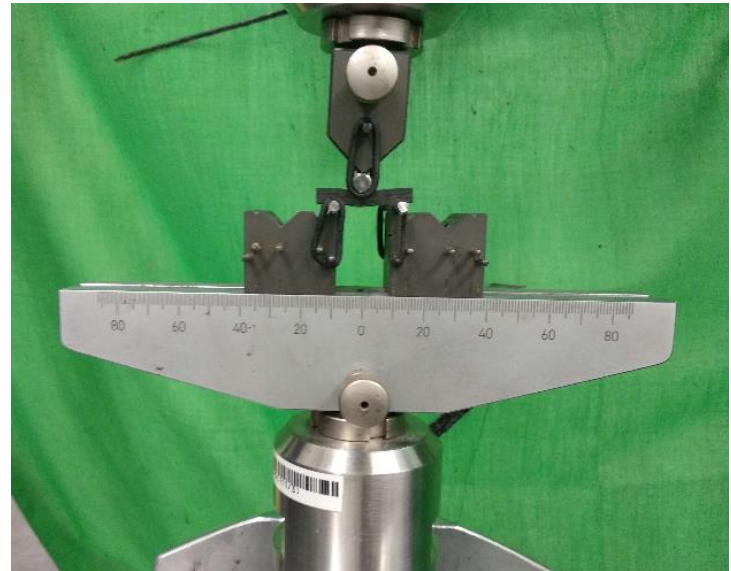
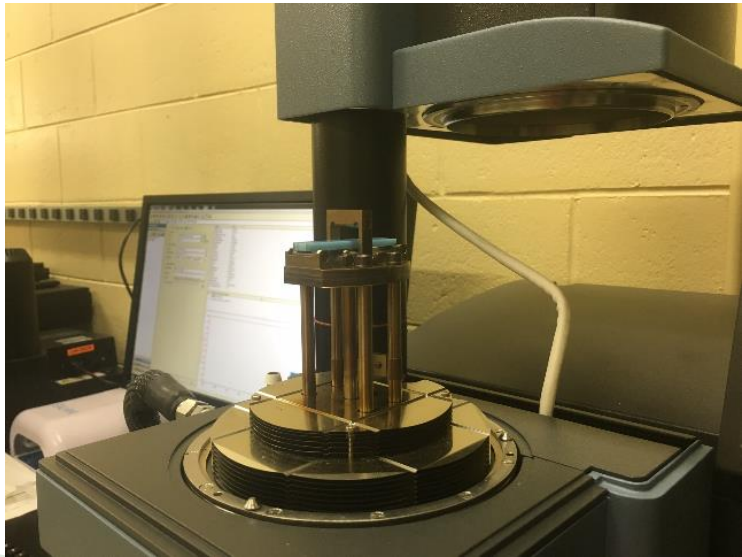
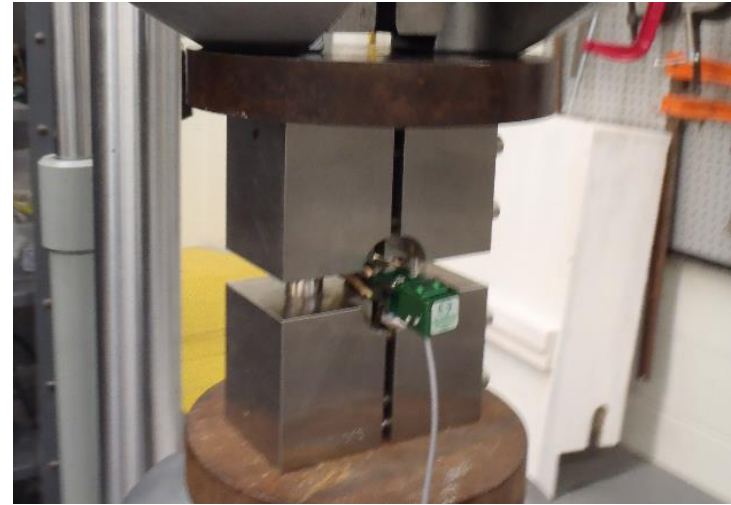
- Multi-manufacturer **testing database**: build experimental and guaranteed material results
- **Normalize and standardize** test methods, data analysis, and material specification data sheets: contents and procedures;
- **Parameter relationships** development, by studying relationships between physico-mechanical 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



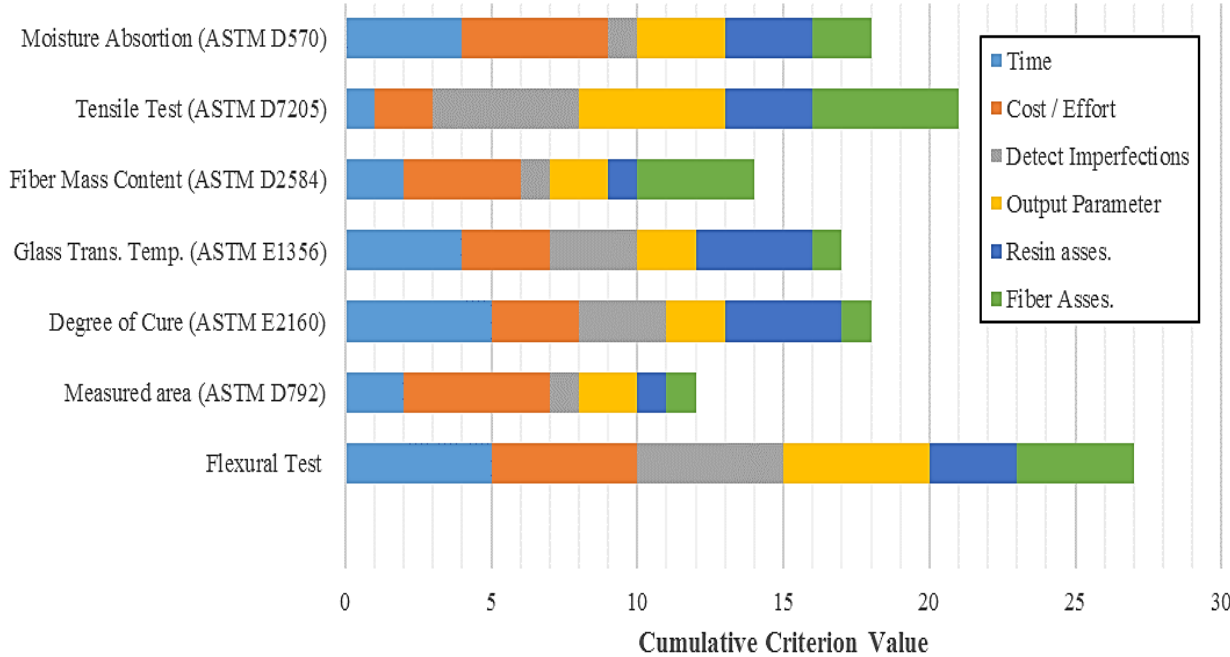
Testing



Testing – Flexure



QC assessment criterion for FRP bar

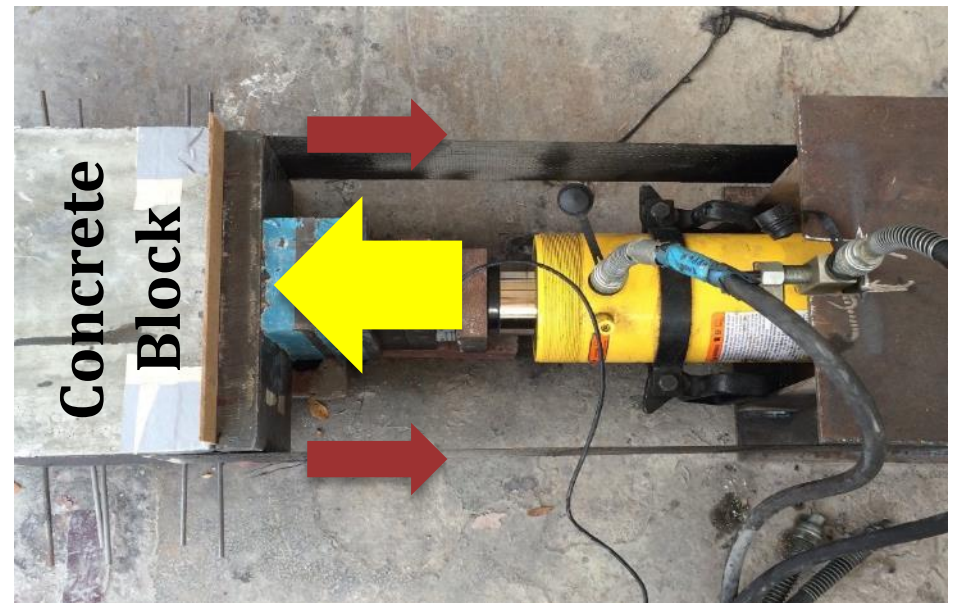
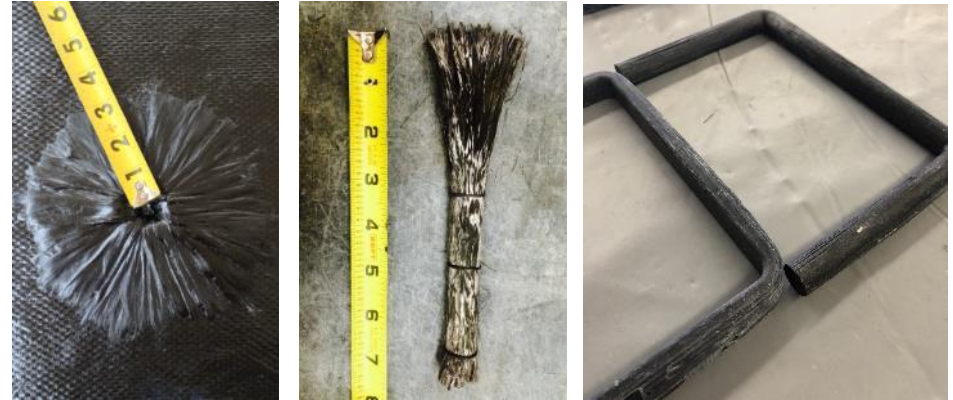


Addition: Evaluation and significance of horizontal shear strength for QC/QA ASTM D4475

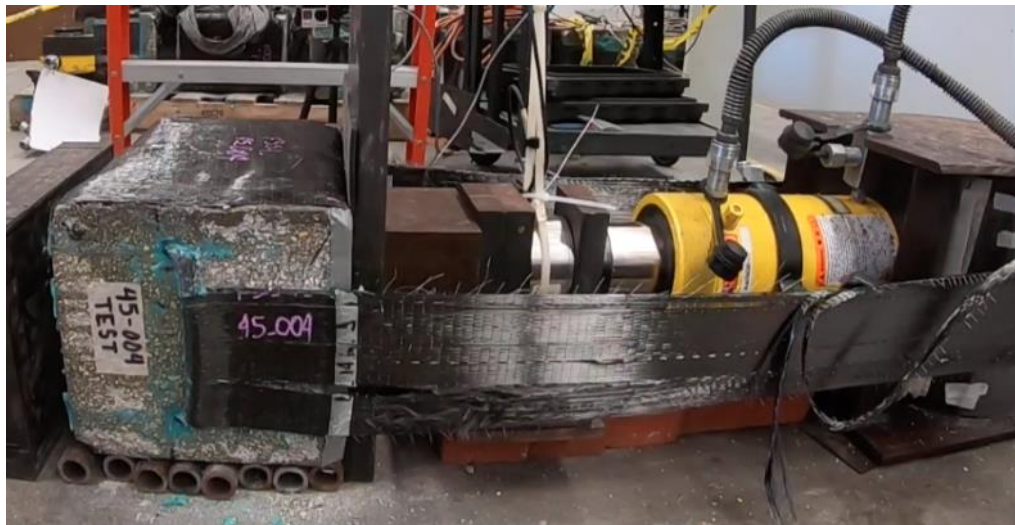


External FRP Anchor Characterization

- **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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CHARACTERIZATION OF COMPOSITES FOR
INFRASTRUCTURE APPLICATIONS**

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**#2 DETERMINING DURABILITY OF
COMPOSITES FOR
INFRASTRUCTURE APPLICATIONS**

Investigators



Ana De Diego
Research Analyst



Roger Solis
Research Assistant



Francisco De Caso
Principal Scientist



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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]

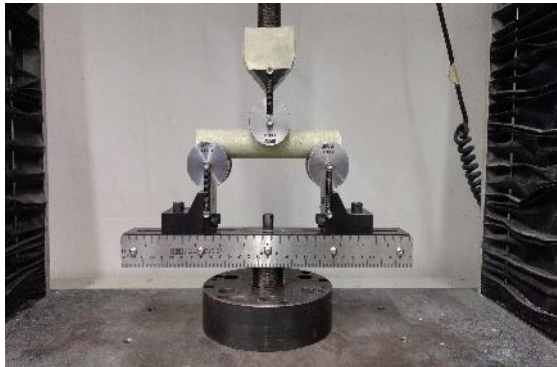
Internal Composites: Multi-Parameter Characterization



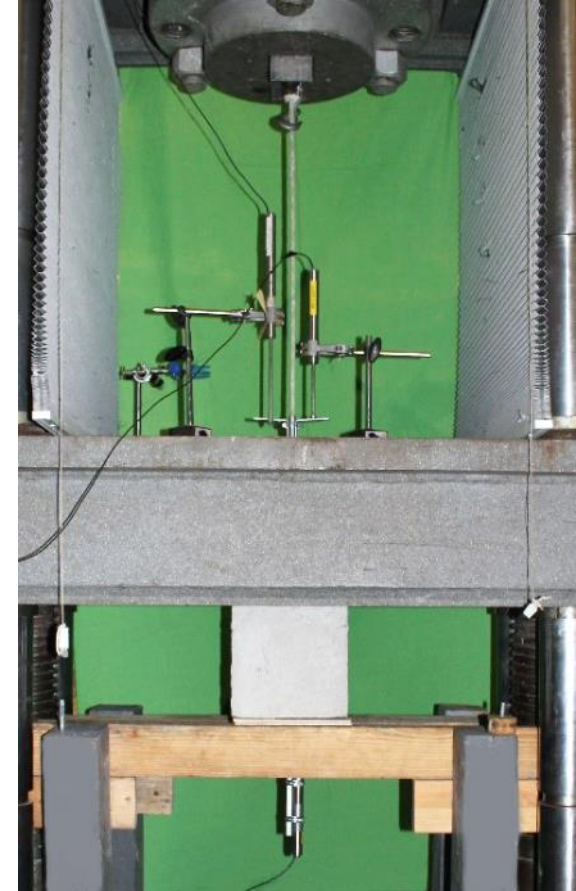
Tensile strength & E modulus
(ASTM D7205)



Transverse shear strength
(ASTM D7617)



Horizontal shear strength
(ASTM D4475)



Bond strength
(ASTM D7913)

Internal Composites: Multi-Parameter Characterization



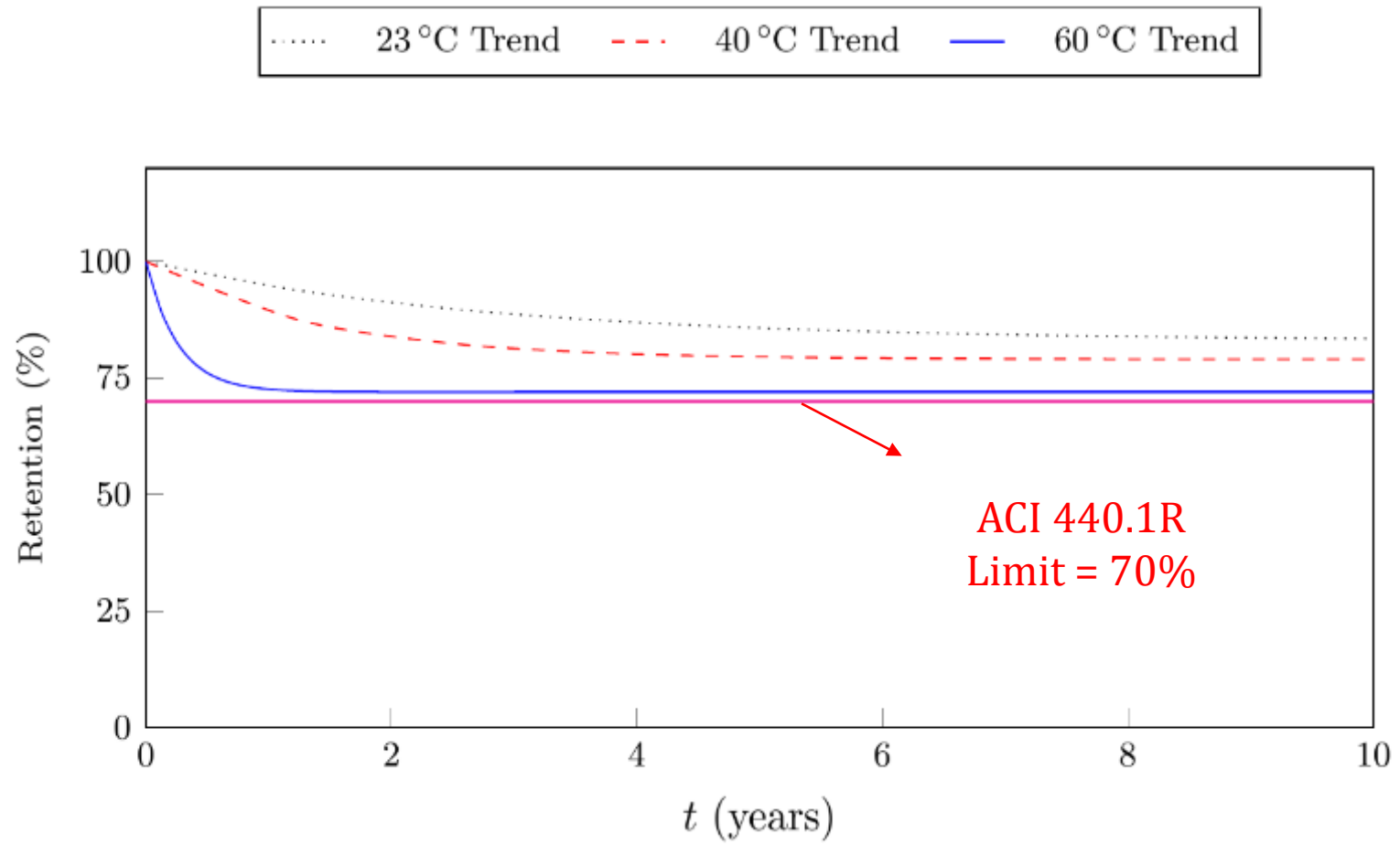
Tensile test post alkaline exposure
without load



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 >20,000 hrs

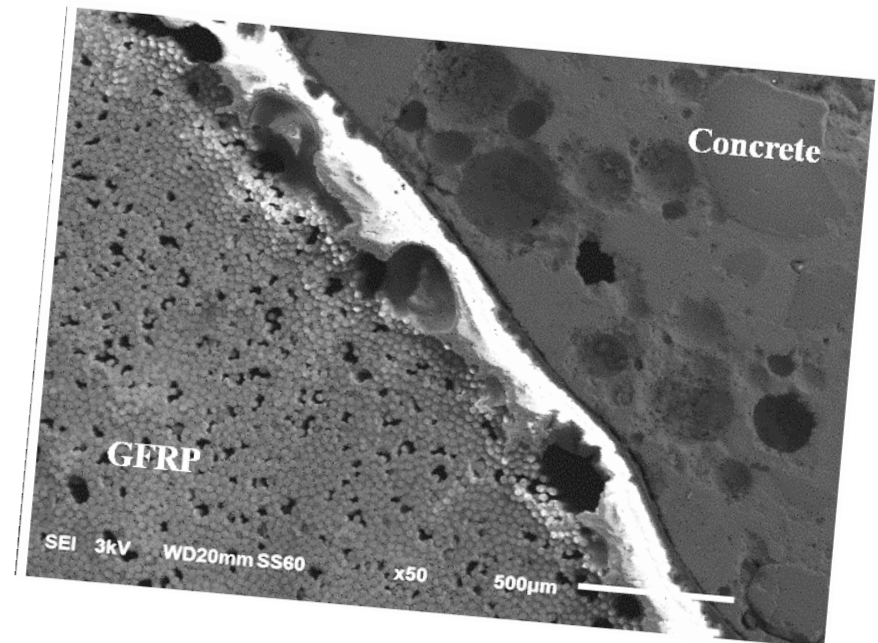
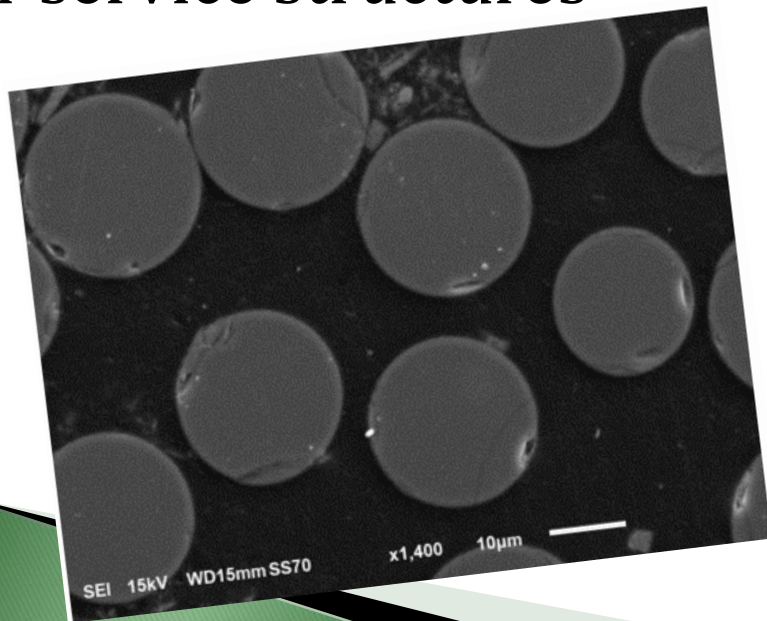
- Salt Water (Immersion 73°F)
- Ultraviolet Resistance (4 hrs @140°F FS 40 UV-B - 85%)
- Alkalinity (Immersion pH=12.5- 73°F)
- Water Resistance (100% RH, 100°F)
- Dry Heat (0% RH, 140°F)
- Freeze and Thaw cycles

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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**DETERMINING DURABILITY OF COMPOSITES
FOR
INFRASTRUCTURE APPLICATIONS**

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**#3 IMPLEMENTATION OF COMPOSITES
THROUGH EXPERIMENTAL TESTING AND
DESIGN**

Investigators



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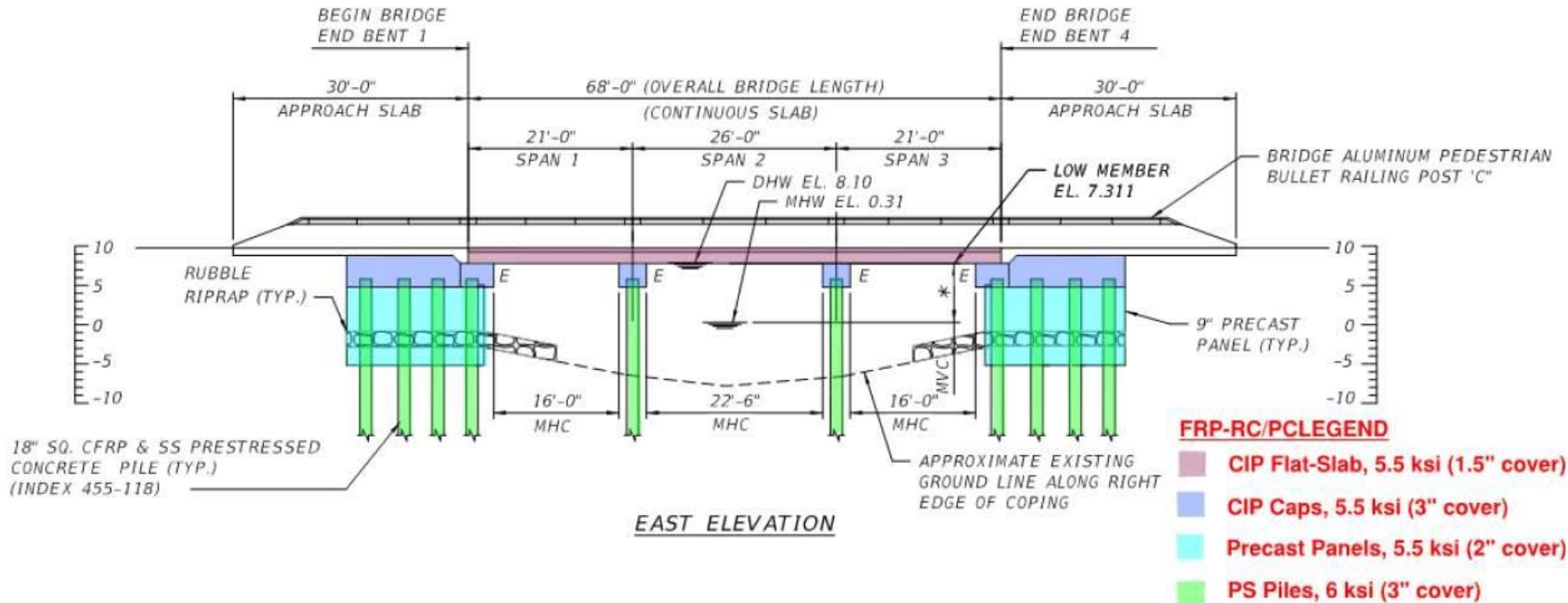


Approach and Industrial Relevance

- ▶ **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



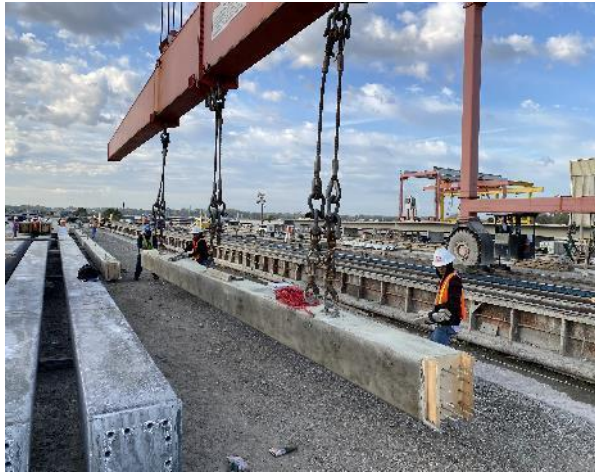
Three-span IBIS-Waterway Bridge with CIP Continuous Flat-Slab, CIP-Caps, Precast Panels and PC-Piles (two with GFRP)

Coiled GFRP Tendons for PC Piles



- Casting of PC piles at Gates, Jacksonville

- Coiled No. 4 GFRP bars utilized as tendons



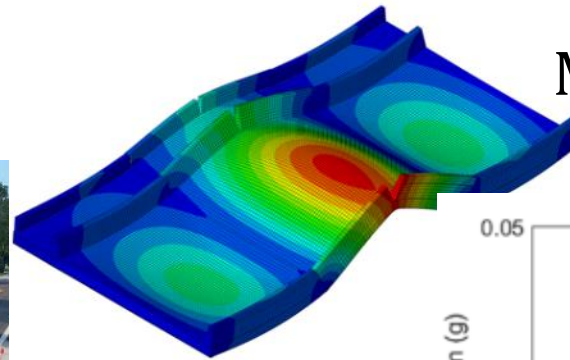
- GFRP un-coiled and spliced with seven-wire steel strand prior to stressing

IBIS-Waterway Bridge

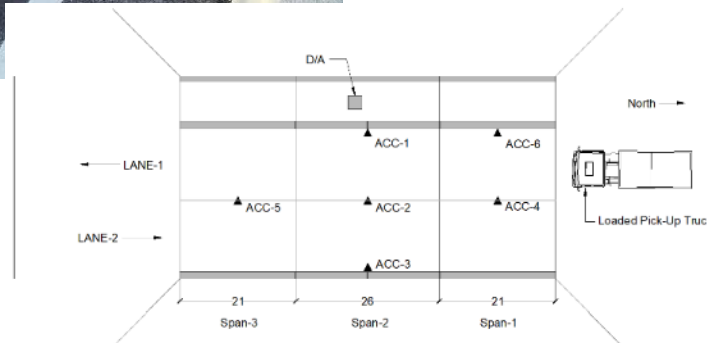
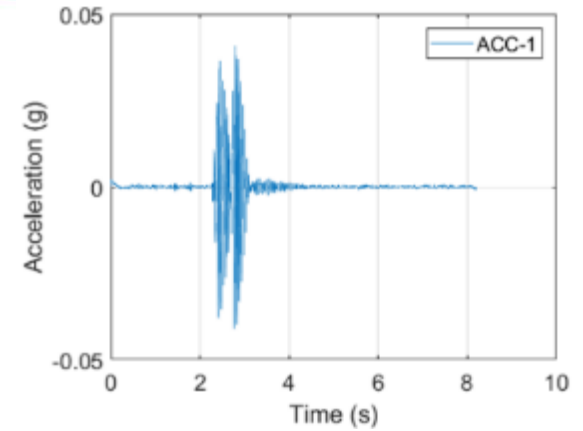
Frequency Testing



May 1, 2021



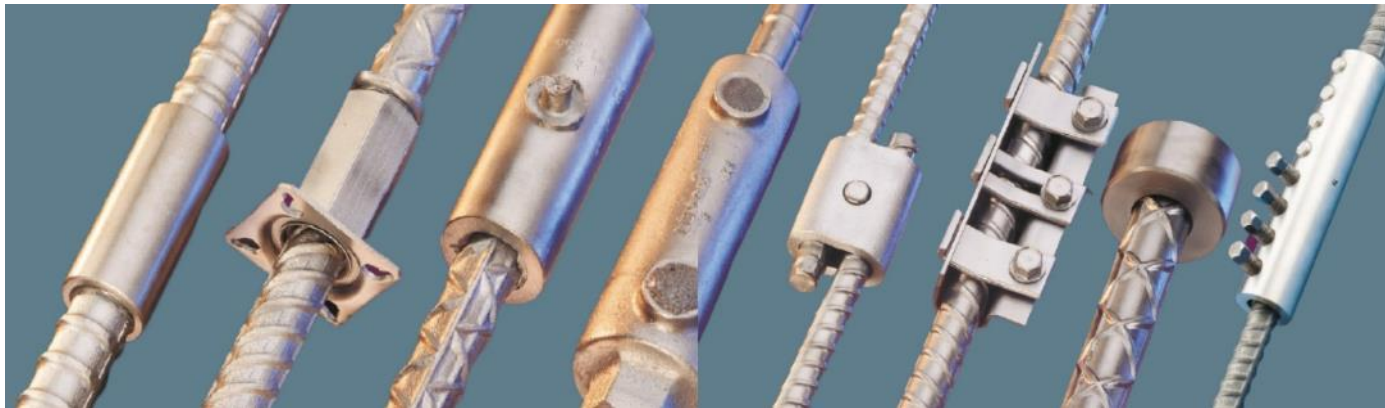
Mode I



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**<<



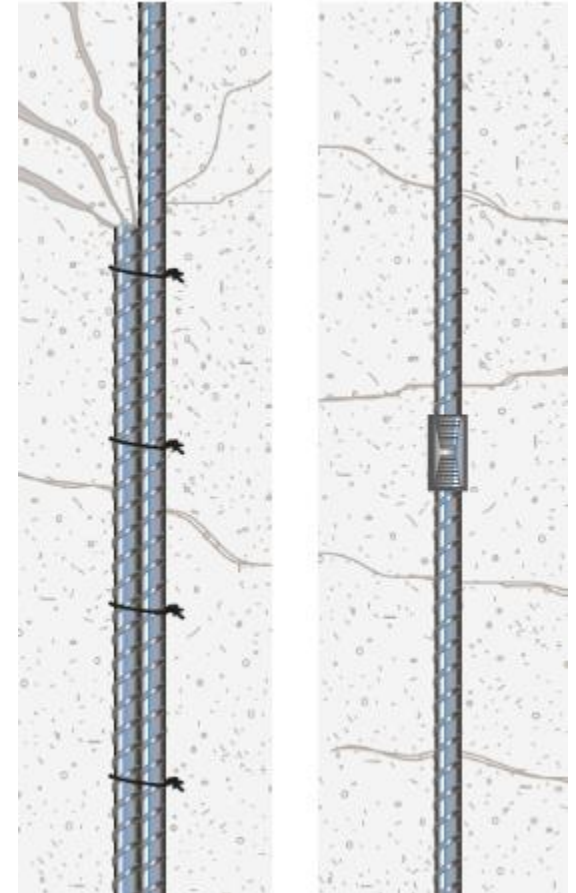
Splicing Methods

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

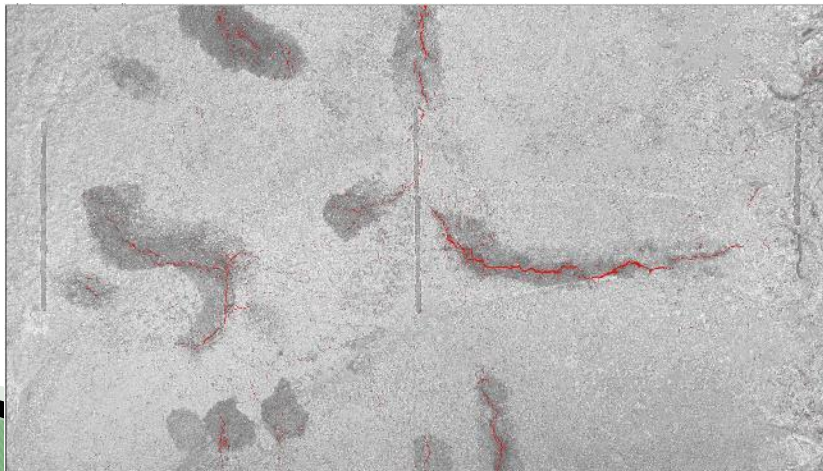


Many Remaining challenges

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)
 This standard is issued under the final designation C1579, the number immediately following the designation indicates the year of original approval or the year of last revision, a number in parentheses indicates the year of last reapproval. A percentage number in brackets indicates an editorial change since the last revision or reapproval.

1. Scope
 1.1 This test method compares the surface cracking of fiber reinforced concrete panels with the surface cracking of control concrete panels subjected to prescribed conditions of restraint and moisture loss that are severe enough to produce cracking before final setting of the concrete.
 1.2 This test method can be used to compare the plastic shrinkage behavior of FRP with that of steel reinforcement.
 1.3 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.
 1.4 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 and health practices and determine the applicability of regulatory limitations prior to use. (Warning—certain hydraulic cementitious mixtures are caustic, and may cause chemical burns to skin and tissue upon prolonged exposure.)

2. Referenced Documents
 2.1 ASTM Standards:¹
 C125 Terminology Relating to Concrete and Concrete Aggregates
 C1343 Test Method for Slump of Hydraulic Cement Concrete
 C1903 Test Method for Making and Curing Concrete Test Specimens in the Laboratory
 C400/C400M Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance

3. Summary of Test Method
 3.1 Panels of control concrete and fiber reinforced concrete are prepared in a prescribed manner and are exposed to controlled drying conditions after finishing. The drying conditions (see Note 1) are intended to be severe enough to induce plastic shrinkage cracking in test panels made of control concrete. The evaporation rate from a fiber water surface is measured by pans placed next to the panels in the environment.

Note 1—The reported parameter in this method is the rate of evaporative water loss, which is controlled by the atmospheric conditions surrounding the test specimens. Since the concrete specimens will not always have the same rate of water evaporation as the rate of water evaporation from the pans, the test results are reported as the ratio of water evaporation from the test panels to the water evaporation from the pans. The test results can also be reported and compared, however, the rate of evaporation from the test panels should be reported.

3.2 The test is terminated at the time of final setting of the concrete determined in accordance with Test Method C400/C400M. At 24 h from initial mixing, the average crack width and the average crack width for the control concrete panels is determined.

3.3 A cracking reduction ratio (CRR) is computed from the average crack width for the fiber-reinforced concrete panels and the average crack width for the control concrete panels.

4. Significance and Use
 4.1 The test method is intended to evaluate the effects of evaporation, restraint, and early autogenous shrinkage on the plastic shrinkage cracking performance of fiber reinforced concrete up to and for some hours beyond the time of final setting (see Terminology C125).
 4.2 The measured values obtained from this test may be used to compare the performance of concretes with different mixture proportions, concretes with and without fibers, concretes containing various amounts of different types of fibers,

*A Summary of Changes section appears at the end of this standard.
 Copyright © ASTM Int'l (all rights reserved). www.astm.org
 DOI: 10.1520/C1579-13
 This standard is copyrighted by ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19380. For more information, contact ASTM Customer Service at www.astm.org.

The technical content was developed in accordance with the procedures established in the Standard Practices for the Development of International Standards, Units and Terminology based on the work of the International Technical Committee on Steel (TC11) Committee.

City, mph
 25
 20
 15
 10
 5
 0

Relative Humidity, %
 100
 80
 60
 40
 20
 0

Concrete Temperature, °F
 100
 90
 80
 70
 60
 50
 40

Air Temperature, °F
 40 60 80 100

in.-lb Units
 0.8

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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Student



Roberto Rodriguez
Graduate
Student



Francisco De Caso
Principal
Scientist



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)



PROPOSED REVISIONS TO THE ACCEPTANCE CRITERIA FOR FIBER-REINFORCED POLYMER (FRP) BARS FOR INTERNAL REINFORCEMENT OF CONCRETE MEMBERS

AC454

Proposed February 2017

Previously approved June 2016, May 2015 and June 2014

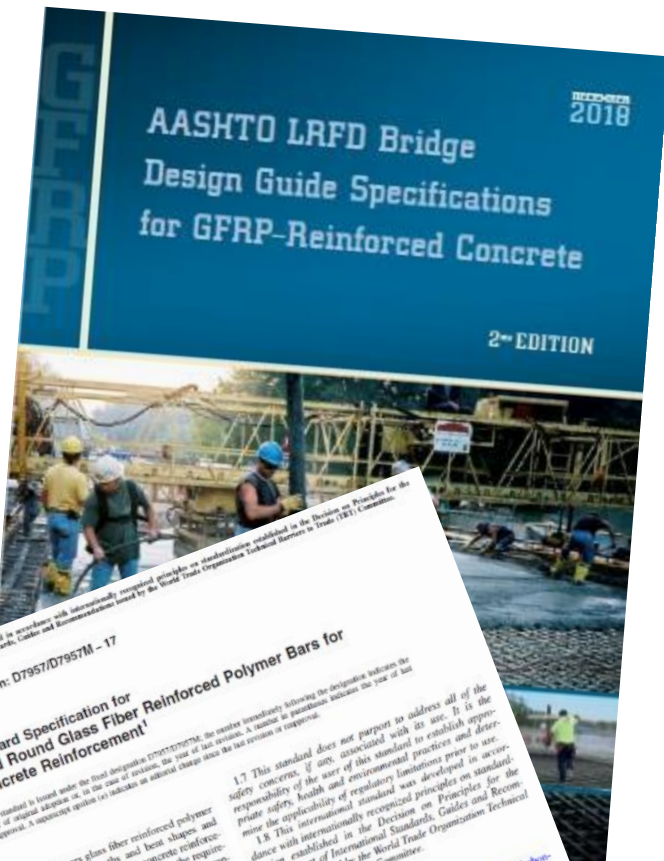
PREFACE

Evaluation reports issued by ICC Evaluation Service, LLC (ICC-ES), are based upon performance features of the International Family of Codes. (Some reports may also reference older code families such as the BOCA National Codes, the Standard Codes, and the Uniform Codes.) Section 104.01 of the International Building Code reads as follows:

The provisions of this code are not intended to prevent the installation of any materials or to prohibit any design or method of construction not specifically prescribed by this code, provided that any such alternative has been approved. An alternative material, design or method of construction shall be approved where the building official finds that the proposed design is satisfactory and complies with the intent of the provisions of this code, and that the material, method or work offered is, for the purpose intended, at least the equivalent of that prescribed in this code in quality, strength, effectiveness, fire resistance, durability and safety.

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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 described herein.
1.2 Bars produced according to this standard are qualified using the test methods and certification of production lot footnotes which provide explanatory material. These notes and of bars are completed using the test methods and must meet the requirements given in Table 2.
1.3 The text of this specification reference 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.
- 2.1 ASTM Standards:
2.1.1 ASTM Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement
2.1.2 ASTM Terminology Relating to Chemical-Resistant Nonmetallic Materials
2.1.3 ASTM Test Method for Water Absorption of Plastics (Relative Density) by Displacement
2.1.4 ASTM Test Methods for Ignition Loss of Cured Reinforced Resin
2.1.5 ASTM Test Methods for Composite Materials
2.1.6 ASTM Terminology for Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars
2.1.7 ASTM Test Method for Transverse Shear Strength of Fiber-Reinforced Polymer Matrix Composite Bars
2.1.8 ASTM Test Method for Bond Strength of Fiber-Reinforced Polymer Matrix Composite Bars to Concrete
2.1.9 ASTM Test Method for Strength of Fiber-Reinforced Polymer Matrix Composite Bars in Bond Locations
2.1.10 ASTM Test Method for Strength of Fiber-Reinforced Polymer (FRP) Bent Bars in Bond Locations


¹ This specification is under the jurisdiction of ASTM Committee D10 on Construction Materials and is the direct responsibility of Subcommittee D10.10 on Concrete and Masonry. Approved August 1, 2017. Published August 1, 2017. Original approved in 2017. DOI: 10.1533/STANDARDS.D7957M-17.

² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service for assistance. For more detail of ASTM Standard, contact Customer Service, 100 Barr Harbor Drive, West Conshohocken, PA 19380. Copyright © 2017 ASTM International, part of the standard's Document Summary page on the ASTM website.

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 Reinforcement¹

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 approval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or approval.

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

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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. 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 Bond Locations

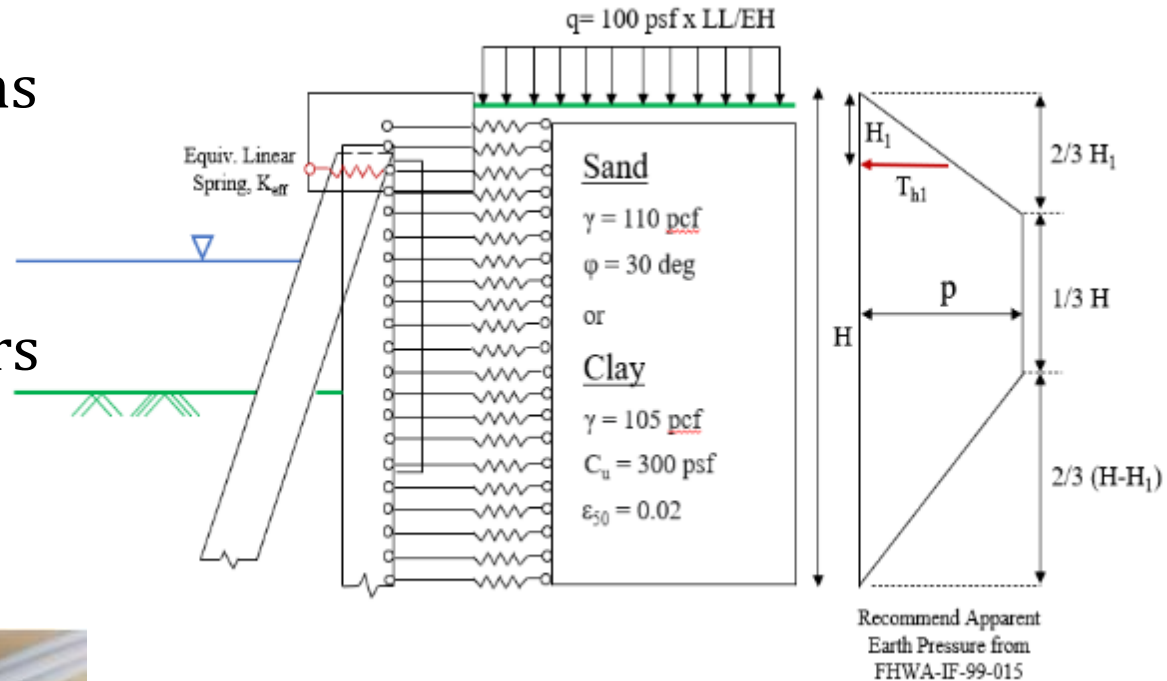
² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For Annual Book of ASTM Standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For Annual Book of ASTM Standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org.

DESIGN: GFRP-PC Piles for Seawalls

Partially prestressed =
combine GFRP tendons
and GFRP bars

Hybrid = combine steel
tendons and GFRP bars

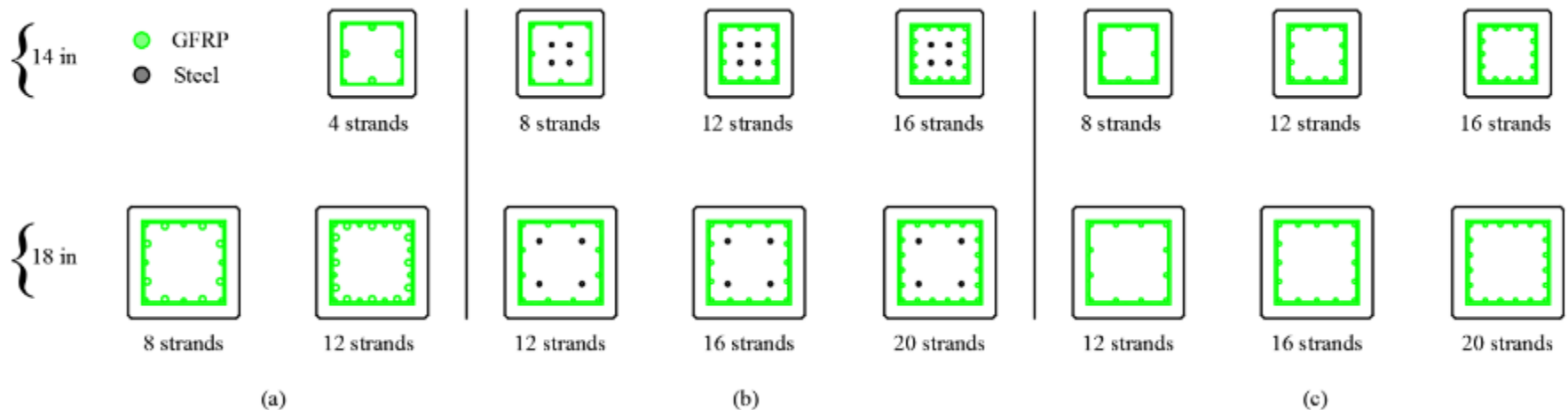
Fully Prestressed = GFRP
tendons



NCHRP IDEA
Project 207

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

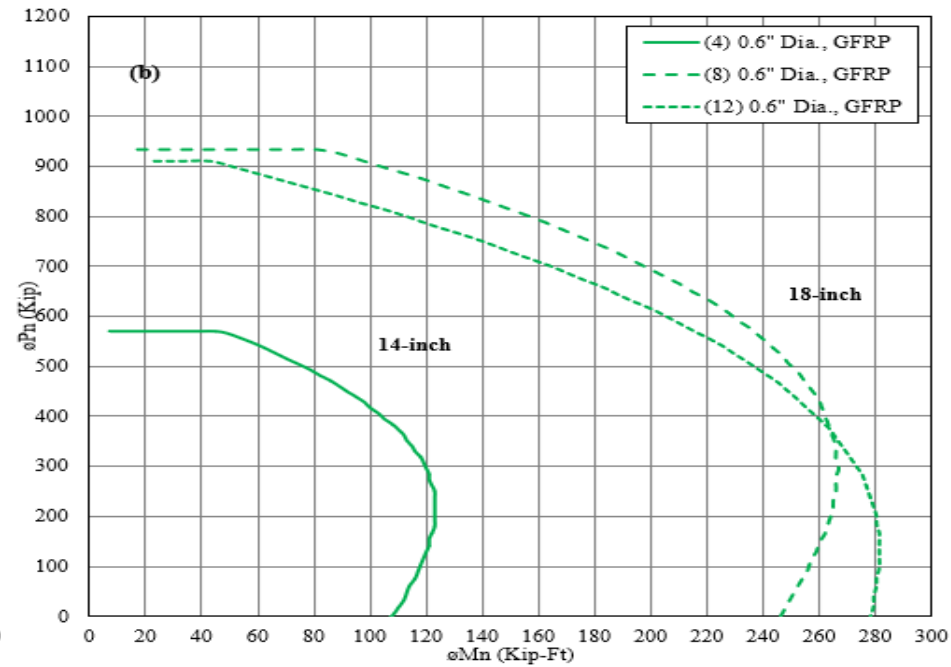
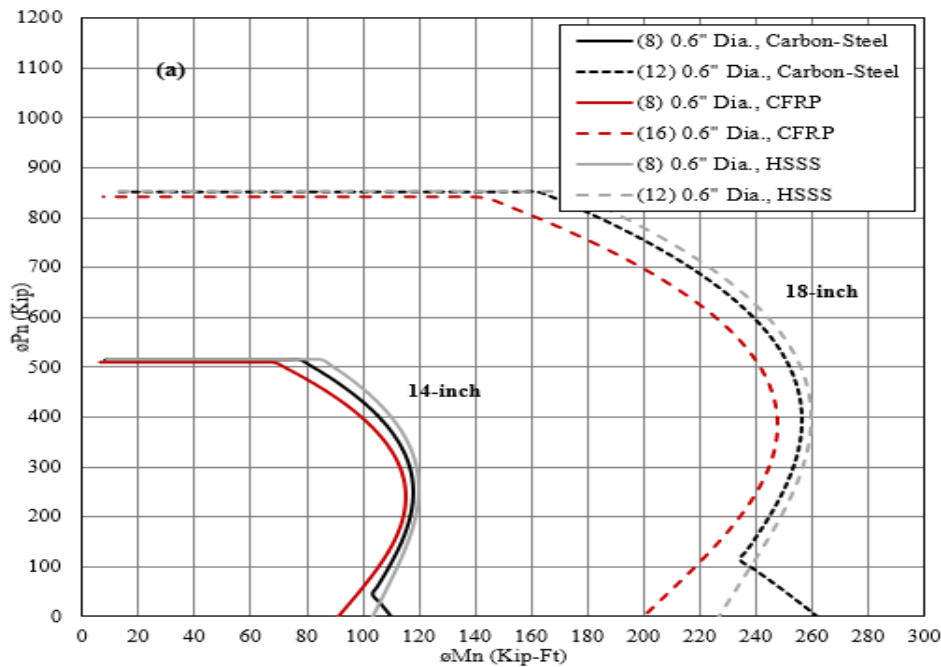
GFRP-PC Piles for Seawalls



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



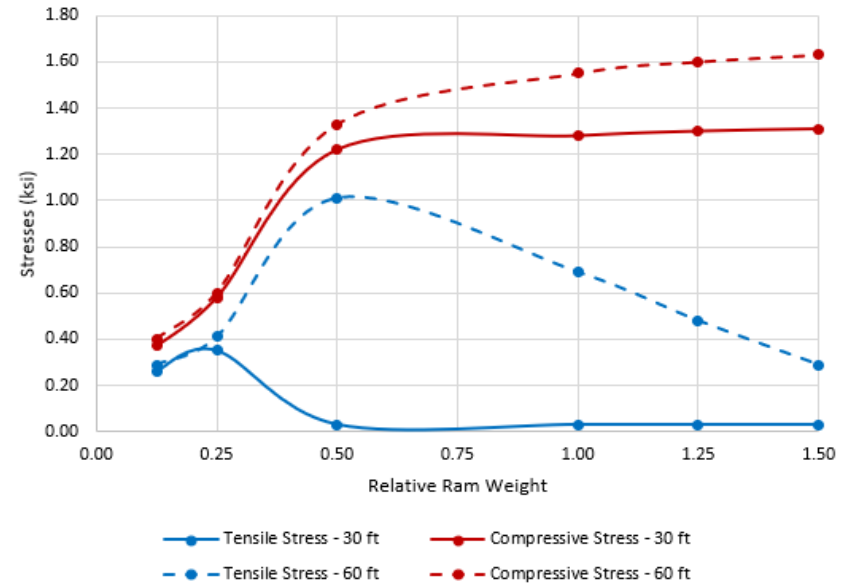
P-M Diagrams for Existing and Proposed Pile Configurations

(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



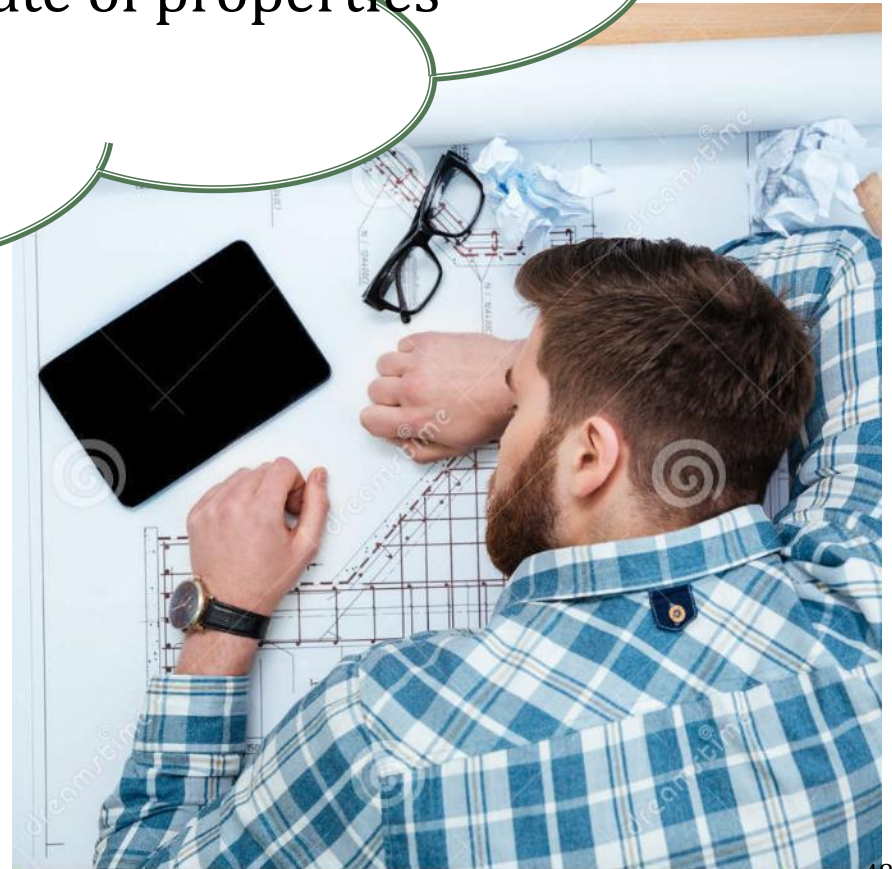
GRLPWEAP 2010: Tension and Compression Stresses as a Function of Relative Ram Weight

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!!!**





Industrial Advisory Board (IAB) Meeting

**PROPELLING USE OF FRP WITH
MEANINGFUL CODES AND GUIDELINES**

L.I.F.E. forms