FDOT Fiber-Reinforced Polymer (FRP) initiatives for bridge structures

Steve Nolan, P.E. (State Structures Design Office)
ABSTRACT:
FDOT will present the latest developments for fiber-reinforced polymer composite materials for structural applications, primarily for use in bridges. Deployment of external FRP for retrofit, repair and strength restoration began in the 1990's. Application of internal FRP systems for new construction have been researched for at least this long, but practical implementation for bridges and related structures has been limited in Florida to several projects in the last few years. Adoption of FRP for transportation infrastructure has been accelerating nationally as the commercial options and competition expand, and the design guidelines and specifications mature. With the release of ASTM D7957, the update to the 2009 AASHTO LRFD Guide Specification for GFRP reinforced concrete, and the new AASHTO LRFD Guide Specification for CFRP Prestressed Concrete developed under NCHRP Project 12-97, the use of FRP for bridge applications is primed to accelerate significantly in the next few years. The demand for resilient, sustainable infrastructure is increasing beyond just the initial procurement cost. The significant benefits of non-corrosive structural systems with a longer maintenance-free service-life will be highlighted, and the FRP systems that can provide these feature will be identified. Several recently completed FDOT bridge projects will be exhibited, and the Department's efforts for broader FRP deployment under the "Invitation to Innovation" and other initiatives will be summarized.
Overview

1. A Brief History of FRP at FDOT
2. Highway Innovation and Incentive Programs
3. FRP Specifications
4. Specification Harmonization
5. Design Tools
6. Advancements
7. Example FRP Elements
8. Projects
9. FDOT Principles for Broader Deployment
History of FRP at FDOT

FDOT’s Fiber-Reinforced Polymer Deployment Train

External FRP Laminate Repairs
Fender Systems
CFRP-RC
GFRP-PC
Composite Bridge Girders

1990’s
2000’s
2015
2016
2016
2019

Photo Courtesy of Astaldi Construction Corp.
– Halls River Bridge under construction (FDOT FRP-RC/PC & HCB Demonstration project), April 2017.
History of FRP at FDOT - Repair/Strengthening Operations

FDOT’s Fiber-Reinforced Polymer Deployment Train

External FRP Laminate Repairs

1990’s

Now considered routine practice for some applications

FDOT currently references ACI 440.2R-08 (with modifications); AASHTO Guide Spec. (2012) is also available.
FDOT’s Fiber-Reinforced Polymer Deployment Train

External FRP Laminate Repairs

1990’s  2000’s

- FRP can increase Durability
- Extend maintenance-free Service-Life
- Mitigate long-term Risks

History of FRP at FDOT - Need for Corrosion Protection

Old St. George Island Bridge Piling

Gandy Blvd. seawall, (Tampa Bay)

Courtney Campbell Causeway, seawall (Tampa Bay)

New and Old Seven-Mile-Bridge, (Florida Keys)
History of FRP at FDOT - Bridge Fender Systems

**FDOT’s Fiber-Reinforced Polymer Deployment Train**

- **External FRP Laminate Repairs**
- **Fender Systems**

1990’s 2000’s

Fully implemented on FDOT projects.
FRP systems strongly recommended - see SDG 3.14 and DS Index 21930 or SP Index 415-030

(Photos Courtesy of Creative Pultrusion)
History of FRP at FDOT – Carbon FRP-PC

FDOT’s Fiber-Reinforced Polymer Deployment Train

• CFRP-PC Bearing Piles
• CFRP-PC/GFRP-RC Sheet Piles

1990’s

2000’s

2015

External FRP Laminate Repairs
Fender Systems
CFRP-RC

Gate Precast (2017)

Halls River Bridge 18” x 18” bearing piles (2017)

Coupling of CFCC to jacking strands

CFCC strands for HRB sheet piles (2017)
History of FRP at FDOT – Carbon FRP-PC & Glass FRP-RC

FDOT’s Fiber-Reinforced Polymer Deployment Train

- External FRP Laminate Repairs
- Fender Systems
- CFRP-RC
- GFRP-PC

1990’s 2000’s 2015 2016

- CFRP-PC Bearing Piles
- CFRP-PC/GFRP-RC Sheet Piles
- GFRP Caps, Deck, App. Slab…

Halls River Bridge 18”x18” bearing piles (2017)
Gate Precast (2017)
Coupling of CFCC to jacking strands
CFCC strands for HRB sheet piles (2017)
HRB GFRP-RC Bent Cap (2017)
HRB GFRP-RC Deck Casting (2018)
History of FRP at FDOT – Composite Bridge Girders

FDOT’s Fiber-Reinforced Polymer Deployment Train

- External FRP Laminate Repairs
- Fender Systems
- CFRP-RC
- GFRP-PC
- Composite Bridge Girders

1990’s
2000’s
2015
2016
2016

HRB Hybrid Composite Beams (2017)
HRB-GFRP-RC Diaphragms for HCB’s (2018)
### History of FRP at FDOT – Composite Bridge Girders (cont.)

#### FDOT’s Fiber-Reinforced Polymer Deployment Train

- **External FRP Laminate Repairs**
- **Fender Systems**
- **CFRP-RC**
- **GFRP-PC**
- **Composite Bridge Girders**

<table>
<thead>
<tr>
<th>Completion Date</th>
<th>Title (Full Report)</th>
<th>Principal Investigator</th>
<th>University / Agency</th>
<th>Project Manager</th>
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<td>1/31/2018</td>
<td>Bridge Girder Alternatives for Extremely Aggressive Environments</td>
<td>Brown, Jeff</td>
<td>Embry-Riddle Aeronautical Univ.</td>
<td>Potter, William</td>
<td>BDV22 977-01</td>
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</table>

- **1990’s**
- **2000’s**
- **2015**
- **2016**
- **2016+**

- **Non-Proprietary CBG’s**

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- FRP girders await the next step in construction of this bridge.

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- **Cost vs. Girder Depth**

  - Graph showing cost vs. girder depth with data points and lines for different scenarios.
History of FRP at FDOT – Basalt FRP-RC

FDOT’s Fiber-Reinforced Polymer Deployment Train

1990’s
External FRP Laminate Repairs

2000’s
Fender Systems

2015
CFRP-RC

2016
GFRP-PC

2016
Composite Bridge Girders

2019
BFRP-RC

STIC Incentive Project – BFRP-RC Standardization

- Develop Standards & Specifications for basalt fiber-reinforced polymer (BFRP) bars for the internal reinforcement of structural concrete.

https://www.fhwa.dot.gov/innovation/stic/state_innovation.cfm
Highway Innovation and Incentive Programs

Technology Readiness Level (TRL)
Range of National RD&T Programs

Market Ready
- Operationally Proven
- Prototype demo Operational Env.
- Prototype demo Relevant Env.

Demo in Lab
- Components Validated in Lab
- Proof of Concept
- Application Formulated
- Basic principles

IDEA
NCHRP
Synthesis
Dom Sc4n
NCHRP 20-44
NCHRP 20-07
SHRP2
TPF
FHWA R&D
CRADA
SBIR
A.I.
NTPEP
APEL
EDC
STIC
AID
FHWA PO
AMR
HIN Challenge

Chasm between Research & Practice

Source:
Highway Innovation and Incentive Programs

STIC Excellence Award Forward (April 2018):

“America's highway community faces significant challenges: an aging infrastructure, growing traffic volumes and limited staffing and funding resources. Widespread use of innovation and enhanced business processes is essential to meeting customer needs and increasing the efficiency of project delivery.

Initiatives such as Every Day Counts, the second Strategic Highway Research Program (SHRP2) Implementation Assistance Program, the AASHTO Innovation Initiative, and others are designed to promote innovations and support the highway community in putting them into practice. Whether through training, workshops, demonstrations, technical assistance or incentive funding, the result of these initiatives is rapid technology transfer and accelerated deployment of innovation across the nation…”

Highway Innovation and Incentive Programs

**Every Day Counts (EDC):**

**FHWA:** PBES → ABC, UHPC, GRS-IBS…

**Strategic Highway Research Program (SHRP2):**

**TRB, AASHTO & FHWA:**

- Prefabricated Elements-PBES (R04 Report & Toolkit)
- Service Life Design for Bridges (R19A)
- Service Limit State Design Guide Spec./Toolkit (R19B)

**AASHTO Innovation Initiative (A.I.I):**

**AASHTO:** Carbon Fiber-Reinforced Polymer Strands
NCHRP:

**Report 503** (2003): Application of FRP Composites to the Highway Infrastructure
- Dr. Dennis Mertz (lead author) – “Lack of a clear signal of intent or encouragement from government agencies undermines FRP suppliers’ confidence in the viability of a long-term market…”

**Synthesis 512** (2017): Use of Fiber-Reinforced Polymers in Highway Infrastructure
- State-of-the-art review

**US Scan Team Report 13-03** (2017): Advances in FRP Composite Transportation Infrastructure
- NCHRP 20-68A program

What’s in these Programs... involving FRP?

Ideas Deserving of Exploratory Analysis (IDEA):

NCHRP (TRB & AASHTO):
  • Glass FRP Prestressing Strand (MILDGLASS-2018)

Innovative Bridge Research and Construction (IBRC):

FHWA (1998-2006): FRP Bridges are to be revisited and an update report on status issued;

Innovative Bridge Research and Deployment (IBRD):

“Reduce the life cycle cost of infrastructure by 50 percent by 2025 and foster the optimization of infrastructure investments for society”

Together we can close the infrastructure gap!

www.ascegrandchallenge.com
What else is there... (nationally / internationally)

FDOT participation in related technical organizations:

• **AASHTO Committee on Bridge and Structures – T6 FRP** (Member: William Potter)

• **TRB AFF80** – Structural Fiber Reinforced Polymers (Members: Potter, Fallaha & Nolan)

• **ACMA** – Transportation Structures Council & FRP Rebar Manufacturers Council (liaisons → John Busel)

• **ACI 440** – (liaison → Prof. Nanni)

• **Canadian Standards Association** (liaison → Prof. Benmokrane)

• **fib Task Group 5.1** – FRP Reinforcement for concrete structures (liaison → TBA)
Structural Advance Materials TAG mission:

- Advance the safe implementation and broad deployment of innovative structural materials through advisement to the Structures Technical Advisory Group (TAG) and coordination with national and international specification development organization representatives...

Members are to support District Structures Design Engineers (DSDE) make informed choices:

1. Champion & 1 Backup from each District Structures Office
2. Consultants - structures design community
2. State Materials Office materials experts
2. State SDO facilitators & coordinators
1. Structures Research Center representative

~ Friends of the TAG (Collaborators)

...future Construction and Maintenance representatives?
What else is there... (locally)

**FDOT Invitation-to-Innovation** (Design Innovation initiative)

- **FRP Reinforcing Bar & Strands**: Basalt, Carbon & Glass FRP Rebar; Carbon FRP Prestressing

**FDOT Research:**

- **Materials Research Program:**

  - 1/31/2018 Bridge Girder Alternatives for Extremely Aggressive Environments
  - 3/1/2017 Durability Evaluation of Florida’s Fiber-Reinforced Polymer (FRP) Composite Reinforcement for Concrete Structures
  - 8/31/2015 Use of Fiber Reinforced Polymer Composite Cable for Post-Tensioning Application

- **Structures Research Program:**

  - 7/31/2014 Degradation Assessment of Internal Continuous Fiber Reinforcement in Concrete Environment
  - 6/30/2018 Performance Evaluation of GFPR Reinforcing Bars Embedded in Concrete Under Aggressive Environments
  - 3/31/2018 Degradation Mechanisms and Service Life Estimation of FRP Concrete Reinforcements
  - 4/16/2014 Investigation of Carbon Fiber Composite Cables (CFCC) in Prestressed Concrete Piles
  - 11/30/1996 Studies on Carbon FRP (CFRP) Prestressed Concrete Bridge Columns and Plates in Marine Environment
  - 8/1/1995 Durability of CFRP Pretensioned Piles in Marine Environment Volume II
FRP materials of most interest to FDOT (currently):

- **Carbon FRP strands and laminates** (PAN fiber with epoxy or vinyl-ester resin systems)
- **Glass FRP reinforcing Bars** (E-CR fiber with vinyl-ester resin systems);
- **Basalt FRP reinforcing bars** (melt fiber with epoxy resin systems).

Typical stress-strain relationships of different FRPs compared to steel bars (Zhishen et al., 2012)
What else is there... (locally)

**FDOT Standards, Specifications & Projects:**

See **FRP-Design Innovation website** for “one-stop shopping”:

http://www.fdot.gov/structures/innovation/FRP.shtm

- Index$^{DS}$: 22440, 22600 series, D22900, D21310, D22420;
- Index$^{SP}$: 455-440, 455-100 series;
- Specifications 400, 410, 415, 450, 471, 932, 933;
- Projects *(shown in later slides)*
Specifications - CFRP


- Approved 06/28/2018 by AASHTO Committee on Bridges and Structures (thru T-6 sponsorship).

- Approved 06/28/2018 by AASHTO Committee on Bridges and Structures (thru T-6 sponsorship).
Specifications – **BFRP** *(in progress)*

**STIC Incentive Project** – BFRP-RC Standardization


*FDOT #443377-1; includes Research Project BDV30 986-01*

• Develop standard specifications for basalt fiber-reinforced polymer (BFRP) bars for the internal reinforcement of structural concrete.

https://www.fhwa.dot.gov/innovation/stic/state_innovation.cfm
Specifications – FDOT

1. **Structures Manual** – Vol. 4 (FRPG)
2. Construction **Specs.** *(Division II)*
3. Materials **Specs.** *(Division III)*
4. Materials Manual *(Chapter 12)*
   - Production Facility Approvals
5. Standard Plans *(SP)*
   - SP Instructions *(SPI)*
   - Developmental Standards *(DDS & DSP)*
Specification Harmonization – GFRP-RC

• **BDGS-GFRP 2\textsuperscript{nd} Ed.** refers to \textit{ASTM D7957-17} for material specifications
  - Only vinyl-ester GFRP / epoxy GFRP round bars allowed
  - Role separation and eased certification

• Design of GFRP-RC bridge elements follows structure of Bridge Design Specifications for steel-RC/PC (\textit{AASHTO-BDS-17, 8\textsuperscript{th} Ed.}).
  - Same language and integration
  - Familiar environment for the practitioner
Specification Harmonization – GFRP-RC (cont.)

- **Inputs** from existing guidelines/codes:
  - *ACI 440.1R-15* “Guide for the Design and Construction of Structural Concrete Reinforced with Fiber Reinforced Polymer Bars”
  - *CSA S6-14 Section 16* “Canadian Highway Bridge Design Code: Fibre-Reinforced Structures”

- **Coordination** with next-edition (where possible)
  - *ACI 440-19* “Building Code Requirements for Structural Concrete Reinforced with GFRP Bars” (under development)
  - *CSA S6-19 Section 16* “Canadian Highway Bridge Design Code: Fibre Reinforced Structures” (under development)
## Specification Harmonization – GFRP-RC (cont.)

<table>
<thead>
<tr>
<th></th>
<th>AASHTO-GS 2nd 2018</th>
<th>AASHTO-GS 1st 2009</th>
<th>ACI 440.1R 2015 (19)</th>
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<tr>
<td>$f_{fu}^{*}$</td>
<td>99.73</td>
<td>99.73</td>
<td>99.73</td>
<td>95.0 (1)</td>
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<tr>
<td>$\Phi_C$</td>
<td>0.75</td>
<td>0.65</td>
<td>0.65</td>
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<td>$\Phi_T$</td>
<td>0.55</td>
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<td>$\Phi_S$</td>
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<td>0.75</td>
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<tr>
<td>$C_E$</td>
<td>0.70</td>
<td>0.70</td>
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<td>1.0</td>
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<tr>
<td>$C_C$</td>
<td>0.30</td>
<td>0.20</td>
<td>0.20 (0.30)</td>
<td>0.25 (0.30)</td>
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<tr>
<td>$C_f$</td>
<td>0.25</td>
<td>0.20</td>
<td>0.20</td>
<td>0.25</td>
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<tr>
<td>$C_b$</td>
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<td>0.70 (2)</td>
<td>1.0</td>
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<td>$w$</td>
<td>0.28</td>
<td>0.20 or 0.28</td>
<td>0.20 to 0.28</td>
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<td>$c_{c,\text{stirrups}}$</td>
<td>1.5</td>
<td>1.50</td>
<td>2.0 (3)</td>
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<td>$c_{c,\text{slab}}$</td>
<td>1.0</td>
<td>0.75 to 2.0</td>
<td>0.75 to 2.0 (3)</td>
<td>40</td>
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(1) Characteristic Strength; (2) $1/k_b$; (3) ACI 440.5-08 Table 3.1; (19) proposed for 2019 updates
## Specification Harmonization – CFRP-PC

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<th>AASHTO-BDS 8th 2018 (steel only)</th>
<th>AASHTO-GS 1st 2018</th>
<th>ACI 440.4R 2002 (11)</th>
<th>CSA 2014 (19)</th>
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<td>99.73</td>
<td>99.73</td>
<td>99.73</td>
<td></td>
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<tr>
<td>$\Phi_C$</td>
<td>0.75</td>
<td><strong>0.75</strong></td>
<td>0.65</td>
<td>Strength percentile</td>
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<td>$\Phi_T$</td>
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<td>0.75</td>
<td>0.85</td>
<td>Res. Fact. concr. failure</td>
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<tr>
<td>$\Phi_S$</td>
<td>0.75</td>
<td>0.75</td>
<td></td>
<td>Res. Fact. shear failure</td>
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<td>$C_E$</td>
<td>1.00</td>
<td>1.00 (internal)</td>
<td>0.9 (from 440.1R)</td>
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<td>$C_{Ci}$</td>
<td>$0.75_j / 0.70_{serv}$</td>
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<td>0.45</td>
<td><strong>18 ksi</strong></td>
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<td>Fatigue reduction / stress</td>
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<td>Bond reduction</td>
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<td>$w$</td>
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<td>Crack width limit [in.]</td>
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<td>$c_{c,stirrups}$</td>
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<td>$c_{c,strand}$</td>
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<td>3.5 $d_b$</td>
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(1) Characteristic Strength; (19) proposed for 2019 updates
1. Design Programs
- CFRP-PC Beams
- GFRP-RC Flat-Slab
- GFRP-RC Bent Cap
- Retaining Walls soon!

2. SPI “Design Aids”


4. Under development
- Cost Estimating Guidance
- LCC Analysis Guidance
1. Currently includes:
   • Active and Completed FRP-RC/PC projects;

2. Plans to add:
   • Bridge beam FRP repair/ strengthening projects (25+ year history of wet-layup repairs)
   • FRP-Fender Systems
   • HSSS projects

https://fldot.sharepoint.com/sites/FDOT-Design/Structures/SpecialProjects/Lists/FRP%20Rebar%20Project/AllItems.aspx
Recent Advancement - GFRP-RC Specs

2nd Ed. updates reflect:

- Rationally defined creep rupture and fatigue load demands
- Separated Creep $C_c$ and Fatigue $C_f$ and aligned to CSA-14 (0.20 to 0.30 & 0.25 respectively) – Need additional study to improve these conservative limits!
Recent Advancement (cont.) - GFRP-RC Specs

2nd Ed. updates reflect:

- Performances of ASTM-certified materials and increase Compression-Controlled Flexural Resistance $\Phi_C$ alignment to AASHTO BDS-17 (0.65 to 0.75);
- Reduced increased Bond Factor $C_b (= 1/k_b)$ and max. crack width to 0.028 inches.

Now need to:

1. **Rationally increase** Tension-Controlled Flexural Resistance $\Phi_t$ (0.55 to 0.75 ?), and
2. **Increase the minimum** Elastic Modulus…

![Graph showing variation of $\phi$ with tensile strain at failure, $\varepsilon_{\text{ft}}$ in GFRP reinforcement.](image)

Figure C2.5.5.2-1 – Variation of $\phi$ with Tensile Strain at Failure, $\varepsilon_{\text{ft}}$, in GFRP Reinforcement
1. Elastic modulus is a game-changer.
2. Increment shall not come from mere sectional area enlargement.
3. Need to operate within ASTM D7957-17 boundaries.
4. Improve quality of the manufacturing process to answer market demand: stiffness, bond performances, durability.
1. **NCHRP's Innovations Deserving of Exploratory Analysis (IDEA)**

   - GFRP Prestressing - **MILDGLASS** *(University of Miami)*;

   ![Image of GFRP and CFRP strands](image)

   (a) GFRP strand prototype cross section; (b) compared to a CFRP alternative.

   ![Image of sheet pile concepts](image)

   (a) GFRP-PC sheet pile concept; (b) CFRP-PC sheet pile design for Halls River Bridge.
1. *NCHRP's Innovations Deserving of Exploratory Analysis (IDEA)*

- GFRP Prestressing - **MILDGLASS** (*University of Miami)*;

Pull test load:
(a) Displacement diagrams;
(b) Pull strength at varying twist per meter;
(c) Creep displacement over initial value;
(d) Creep rupture logarithmic regression
2. **Next Innovation Deserving of Exploratory Analysis**

   - BFRP Prestressing (perhaps)???
Standardized Elements - Piles

Bridge Bearing Pile Standards

<table>
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<tr>
<th>Part No.</th>
<th>Description</th>
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<td>455-101</td>
<td>Square CFRP and SS Prestressed Concrete Piles - Typical Details and Notes</td>
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<tr>
<td>455-102</td>
<td>Square CFRP and SS Prestressed Concrete Pile Splices</td>
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<td>455-112</td>
<td>12” Square CFRP and SS Prestressed Concrete Pile</td>
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<td>14” Square CFRP and SS Prestressed Concrete Pile</td>
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<td>18” Square CFRP and SS Prestressed Concrete Pile</td>
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<td>455-124</td>
<td>24” Square CFRP and SS Prestressed Concrete Pile</td>
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<td>455-130</td>
<td>30” Square CFRP and SS Prestressed Concrete Pile</td>
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<td>455-154</td>
<td>54” Precast/Post-Tensioned CFRP and SS Concrete Cylinder Pile</td>
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<tr>
<td>455-160</td>
<td>60” Prestressed CFRP and SS Concrete Cylinder Pile</td>
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</tbody>
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SECTION A-A

**ALTERNATE STRAND PATTERNS**

- 16 – 0.6” Ø, CFRP 7-Strand, at 42 kips
- 16 – 1/2” Ø, CFRP Single-Strand, at 41 kips
Standardized Elements - Seawall-Bulkheads

Concrete Sheet Pile Bulkhead Standards

- **HRB Sheet Pile Installation**

<table>
<thead>
<tr>
<th>Structures Foundations - Sheet Pile Wall</th>
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<tbody>
<tr>
<td>455-400</td>
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<td>455-440</td>
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</table>

- **Traditional RC Bulkhead**

- **Traditional RC Bulkhead Cap**
Proposed Elements - Substructures

Waterline footings & columns in saltwater – *need big bars for this!*

#10 bars recognized in **ASTM D7957**;
Will need #11 bars in future;
May also need #14 bars?
Project Example Elements - Piles

Bridge Bearing Pile Projects

- Halls River Bridge (Homosassa)
- NE 23rd Ave/Ibis Waterway (City of Lighthouse Point)
- C Street Bridge (Cedar Key)
- Barracuda Blvd (New Smyrna)
- 40th Ave. N (St Petersburg)
- iDock (Miami)
- Maydell Dr. (Tampa)
Concrete Sheet Pile Bulkhead Projects

- SR24/Channel 3 (Cedar Key)
- Halls River Bridge (Homosassa)
- Bakers Haulover Cut (Miami)
- Skyway Rest Area (Manatee Co.)
- Pinellas Bayway – Structure E
- NE 23rd Ave/Ibis Waterway (City of Lighthouse Point)
- Barracuda Blvd (New Smyrna)
- Maydell Dr. (Tampa)
- 40th Ave. N (St Petersburg)
Project Example Elements - Seawall-Bulkheads

Secant Piles seawall on SR A1A

SR A1A damage after Hurricane Matthew (2016)

Secant Wall Concept Rendering

GFRP Pile cages (Hughes Bros.)
Projects:

- Halls River Bridge (Homosassa)
- NE 23\textsuperscript{rd} Ave/Ibis Waterway (City of Lighthouse Point)
- Barracuda Blvd (New Smyrna)
- iDock (Miami)
- Maydell Dr. (Tampa)?
- 40\textsuperscript{th} Ave. N (St Petersburg)?
Projects:

- Halls River Bridge = **HCB’s** (Homosassa)
- NE 23rd Ave/Ibis Waterway = **Flat-Slab** (City of Lighthouse Point)
- US-1 over Cow Key Channel = **FSB CFRP/GFRP** (Key West)
- 40th Ave. N = **FSB’s**? (St Petersburg)
- Maydell Dr. = **FSB’s**? (Tampa)
FDOT Project Identification & Delivery

1. Environmental condition driven
   • Durability/Magnetic Transparency/LCC

2. Optional precast alternatives
   • Encourage stakeholder buy-in

3. Desire for multiple suppliers
   • Redundancy & Supply chain security

4. Simplify design process/workflow

5. Minimize change for Contractors
   • Business as usual…almost
Projects - Halls River Bridge progress
Projects - **Halls River Bridge progress** (challenges)
Collaborative Projects

FDOT Collaboration Projects:

• **SEACON (2016-2018):** Sustainable Concrete using Seawater, Salt-contaminated Aggregates and Non-Corrosive Reinforcement *(University of Miami & Polimi)* – **Halls River Bridge** was one of the two “Demonstrator” projects;

• **Arthur Drive Bridge in Lynn Haven (2017):** Precast GFRP-RC Piles demonstration *(University of Sherbrook & UNF)*

• **iDock (2018):** GFRP-RC Piles/Caps/Beams *(University of Miami)*
Collaborative Project Example – iDock

Existing Condition - Dock damaged by Hurricane Irma (Miami)
Proposed Dock -

Precast Elements all using FRP reinforcement only:

1. 8~ Piles: 24’x1’x1’
2. 4~ Pile Caps: 8’x2.5’x1’
3. 8~ Slabs:
   1~ unit of 144”x33”x8”
   1~ unit of 132”x33”x8”
   6~ units of 120”x33”x8”
RC Piles -
Precast piles reinforced with GFRP
4 types of piles:
1. Type A: 6~#6 with spirals
2. Type B: 6~#6 with square ties
3. Type C: 6~#8 with spirals
4. Type D: 6~#8 with square ties
Collaborative Project Example – *iDock* (cont.)

**RC Pile Caps** - Cages and cages inside formwork with block-outs
Collaborative Project Example – iDock (cont.)

RC Slabs -
Cages and cages inside formwork with lift points
Completed Precast Elements - Slabs, caps and piles (at the Precaster’s yard)
Looking Beyond Halls River Bridge

Photo Courtesy of Astaldi Construction Corp.
– Halls River Bridge under construction (FDOT FRP-RC/PC & HCB Demonstration project), February 2018.
Principles for Broader Deployment

1. Stewardship
2. Confidence
3. Competency
4. Consistency
5. Codification

\textit{NCHRP Report 503} (2003) identified 11 elements for a draft strategic plan as follows:

1. Buy-in from all strategic plan participants;
2. Acceptance, implementation, and revision of the strategic plan;
3. The means to oversee and manage the strategic plan;
4. A study of the relative costs of FRP versus traditional materials;
5. A database of practical infrastructure-based FRP knowledge;
6. Generic bridge-specific material specifications;
7. Generic bridge-specific design and evaluation methodologies;
8. Generic bridge-specific inspection and repair methods;
9. Training on FRP composite materials for practicing engineers;
10. Education on FRP composite materials for graduate civil engineers; and
11. Continuation of FHWA's Innovative Bridge Research and Construction (IBRC) program.
Principles for Broader Deployment

2018 Strategic Workplan items

1. Endurance Limits
2. Endurance Characteristic Curves and Testing
3. Establishing Consistency
4. Increasing Material Property Qualification Thresholds and Design Limits
5. Cost Estimating
   a. OC initiative for ACMA FRP-RMC
   b. FDOT SDG Chapter 9 update
6. Bar Bends
   a. Complex Shapes
   b. FDOT Index D21310
7. Minimum Bar Sizes for Design Elements
8. Life-Cycle Cost Guidance
9. Minimum Concrete Class

http://www.fdot.gov/structures/Innovation/FDOT%202018%20Winter%20FRP-RC%20Workshop/Default.shtm
Principles for Broader Deployment

1. Stewardship

- Responsible use of public funds = specify FRP where it makes sense;
- Maximize material efficiency = strive for constant improvement;
- Identify additional technical resources for exploitation = getting outside of our "silos".

Bakers Haulover Cut GFRP-RC Bulkhead Cap (2017-18)

Principles for Broader Deployment

1. Stewardship

2. Confidence

- Build Stakeholder confidence = owners, designers, contractors, suppliers, inspectors;

- Supply Chain security = redundancy, scalability, sustainability.
Principles for Broader Deployment

1. Stewardship

2. Confidence

3. Competency
   - Designer qualifications/training = *all minor bridge consultants*;
   - Design Tools = *calculations & estimates*;
   - Contractor & Inspector guidance = *CPAM & training*. 
4. Consistency

- Material reliability = *data gathering and curation*;
- Encourage improved QC = *improved reliability*;
- Simplified verification testing = *improved reliability and efficiency*;
Principles for Broader Deployment

4. Consistency

5. Codification

- Establish “Roadmap” for AASHTO LRFD BDS adoption;
- Coordination with CBS T-6, T-10, & ACI 440;
- Coordination with other national and international authoritative committees = TRB’s AFF80, CSA, fib TG 5.1.
Questions?

FDOT’s Fiber-Reinforced Polymer Deployment Train

- BFRP-RC
- Composite Bridge Girders
- GFRP-RC
- CFRP-PC
- Fender Systems
- External FRP Laminate Repairs

<table>
<thead>
<tr>
<th>Structures Design Office:</th>
<th>Structures Design Office:</th>
</tr>
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<tbody>
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<tr>
<th>State Materials Office:</th>
<th>District Structures Offices:</th>
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<tbody>
<tr>
<td>Chase C. Knight, PhD.</td>
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<td>District Structures Design Engineers</td>
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**FDOT’s Fiber-Reinforced Polymer Deployment Train**

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