A NEW CAMX FOR A NEW TIME

COMBINED STRENGTH. UNSURPASSED INNOVATION

CAMX THE COMPOSITES AND ADVANCED MATERIALS EXPO

SEPTEMBER 21-24 2020

A VIRTUAL EXPERIENCE
Advancements in composite infrastructure deployment in Florida

Steven Nolan, P.E.
Senior Structures Design Engineer
Florida Department of Transportation
ABSTRACT

Advancements in composite infrastructure deployment in Florida:

Previous FDOT education presentations at CAMX focused on isolated pilot demonstration projects for new construction of highway infrastructure using Fiber-reinforced Polymer (FRP) composites. This presentation will highlight the ever-expanding range of applications and materials thru mid-2020, and the maturing of FDOT specifications for design and construction. Highlights include the adoption of new specifications for Basalt-FRP reinforced concrete as part of a federally sponsored innovation grant, and developing Composite Bridge Beam competitive design and bidding strategies.

The latest advancements in full-scale testing and research support for FRP in prestressed precast bridge beams and piles continues to expand the range of product applications and owner design solutions for improved durability and lowering life cycle costs. Refinements to the design specifications continue to be explored to provide economically competitive solutions for low-bid government procurement systems, while developing education tools for designers, contractors, and owners. Supporting case studies will be presented from a range of completed design and construction projects.
LEARNING OBJECTIVES

Advancements in composite infrastructure deployment in Florida

i. Describe the common infrastructure applications of composites that most interest highway agency owners.

ii. Identify design resources, guidelines and specifications for infrastructure applications and potential improvement areas.

iii. List recent successful Florida infrastructure applications with extensive use of FRP as examples for broader implementation.
OUTLINE

1. Expanding Range of Reliable FRP Materials & Structural Solutions
2. Recent Full-Scale Testing and Research on Beams and Piles
4. Education Tools for Designers, Contractors, & Owners
5. Recently Completed Projects
6. Projects Ready/Under Construction
7. New Projects in Design
8. Lessons Learned from the Real World
Expanding Range of Reliable FRP Materials & Structural Solutions

i. GFRP rebar & improved properties
ii. BFRP rebar implementation
iii. Improving CFRP strand & bar performance and economy
iv. Pultruded & Molded Structural Components
Expanding Range of Reliable FRP Materials & Structural Solutions

i. GFRP rebar & improved properties

Elastic Tensile Modulus:

• Current design guidance for minimum stiffness in **ACI 440.1R-15**, shows ranges $E_f = 5.1 - 7.4 \text{ msi}$.  
  but **ASTM D7957-17** implemented at $E_f \geq 6.5 \text{ msi}$.  
  **CSA 807-19** has three grades with the highest (Grade III) $E_f \geq 8.7 \text{ msi}$.  
  FDOT will be raising **Spec 932-2** limits in mid-2021 to more closely match Grade III for straight bars.
Expanding Range of Reliable FRP Materials & Structural Solutions

i. GFRP rebar & improved properties

Elastic Tensile Modulus

✓ Smaller bars =
  • Higher strength
  • Better crack control
  • Better fit-up (*especially for bent bars* bend radius must be > 3 bar diameters)

✓ Less bars (*reducing congestion*)
✓ Higher allowable shear stresses
✓ Lower deflections

Why is this important for FDOT?

← Improves efficiency in design requiring either
Expanding Range of Reliable FRP Materials & Structural Solutions

i. GFRP rebar & improved properties

**Tensile Strength:**
- Current design guidance for minimum strength is highly variable. **ACI 440.1R-15** shows 70 - 230 ksi.
- **ASTM D7957-17** implemented minimum strengths based on rebar size[&#], ranges 77 - 124 ksi.
- **CSA 807-19** has three grades with the highest (Grade III) range 125-145 msi.
- FDOT will be raising **Spec 932-2** limits in 2021 to more closely match Grade III for straight bars.
Expanding Range of Reliable FRP Materials & Structural Solutions

i. GFRP rebar & improved properties

**Tensile Strength:**
- May need higher bond strength standard
- ...?
Expanding Range of Reliable FRP Materials & Structural Solutions

i. GFRP rebar & improved properties

ii. BFRP rebar implementation

932-3.2 Bar Sizes and Loads: The sizes and loads of FRP reinforcing bars shall meet the requirements in Table 3-1. The measured cross-sectional area, including any bond enhancing surface treatments, shall be determined according to Table 3-2.

<table>
<thead>
<tr>
<th>Bar Size Designation (Di)</th>
<th>Tensile Strength (ksi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material Type</td>
<td>Minimum Guaranteed</td>
</tr>
<tr>
<td></td>
<td>Tensile Load (kips)</td>
</tr>
<tr>
<td></td>
<td>BFRP Bars</td>
</tr>
<tr>
<td></td>
<td>CFRP Bars</td>
</tr>
<tr>
<td>85</td>
<td>6.1</td>
</tr>
<tr>
<td>81</td>
<td>13.2</td>
</tr>
<tr>
<td>81</td>
<td>20.9</td>
</tr>
<tr>
<td>81</td>
<td>30.9</td>
</tr>
<tr>
<td>81</td>
<td>33.3</td>
</tr>
<tr>
<td>8</td>
<td>57.1</td>
</tr>
<tr>
<td>8</td>
<td>69.1</td>
</tr>
<tr>
<td>8</td>
<td>70.1</td>
</tr>
<tr>
<td>8</td>
<td>70.1</td>
</tr>
<tr>
<td>8</td>
<td>70.1</td>
</tr>
</tbody>
</table>

Prestressing: Steel

High Modulus Carbon
High Strength Carbon
Basalt
Aramid
S-Glass
E-Glass
Pultruded & Molded Structural Components

Advancements in composite infrastructure deployment in Florida
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<table>
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<tr>
<th>Type</th>
<th>Nominal Diameter (in)</th>
<th>Nominal Cross Sectional Area (in²)</th>
<th>Nominal Ultimate Load (P₀) (kips)</th>
<th>Nominal Ultimate Tensile Stress (ksi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Strand - 5.0mm Ø</td>
<td>0.20</td>
<td>0.02540</td>
<td>9.1</td>
<td>36400</td>
</tr>
<tr>
<td>7-strand - 7.23mm Ø</td>
<td>0.310</td>
<td>0.04850</td>
<td>17.8</td>
<td>3740</td>
</tr>
<tr>
<td>7-strand - 10.85mm Ø</td>
<td>0.434</td>
<td>0.090</td>
<td>33.12</td>
<td>36756</td>
</tr>
<tr>
<td>Single Strand - 9.5mm Ø</td>
<td>0.38</td>
<td>0.110</td>
<td>35.0</td>
<td>318</td>
</tr>
<tr>
<td>7-strand - 12.5mm Ø</td>
<td>0.49</td>
<td>0.1178</td>
<td>43.34</td>
<td>37042</td>
</tr>
<tr>
<td>Single Strand - 12.7mm Ø</td>
<td>0.50</td>
<td>0.196</td>
<td>59.0</td>
<td>301</td>
</tr>
<tr>
<td>7-strand - 15.2mm Ø</td>
<td>0.60</td>
<td>0.179</td>
<td>66.24</td>
<td>36944</td>
</tr>
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i. GFRP Pile prestressing, spirals and splicing

ii. FRP Shear and Confinement Rebar – Beams & Slabs

iii. Durability Sampling and Testing of Submerged Rebar
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Durable Solutions and Life Cycle Cost Evaluation

i. Service Life Expectations for Structures
ii. Alternative strategies
iii. Life Cycle Cost policy and comparisons

GUIDE SPECIFICATION FOR SERVICE LIFE DESIGN OF HIGHWAY BRIDGES, 1ST EDITION
Item Code: HBSLD-1

This guide specification is intended to offer design recommendations for agencies wishing to implement service life design principles and detailing recommendations. It was developed to incorporate quantitative approaches, along with proven deemed-to-satisfy provisions, into a single comprehensive design document for implementation on a national level. It also establishes a framework for service life design, while providing opportunities for refinement and expansion, especially as new models capable of simulating deterioration mechanisms become available.
Education Tools for Designers, Contractors, and Owners

i. FRP Designer Training

ii. Structural Design and LCC Tools

iii. Technology Transfer Participation

GFRP-Reinforced Concrete Design for Bridges

Guest Speaker (1): Prof. Antonio Nanni
Inaugural Senior Scholar
Professor and Chair
Department of Civil, Architectural & Environmental Engineering
University of Miami

Biography
Prof. Nanni is a structural engineer interested in construction materials and their structural performance and field application, including monitoring and renewal, with a focus on the sustainability of buildings and civil infrastructure. During the past 30+ years, he has studied concrete and advanced composite-based systems as the principal investigator on a number of projects sponsored by federal and state agencies and private industry. Editor-in-chief of the Journal of Materials in Civil Engineering (American Society of Civil Engineers) and serves on the editorial board of other technical journals. He has advised more than 60 graduate students pursuing master’s and doctoral degrees in the field, published more than 220 papers in refereed journals, published more than 950 papers in conference proceedings and co-authored two books.

CFRP-Prestressed Concrete Design for Beams and Piles

Guest Speaker (2): Prof. DJ Belarbi
Distinguished Professor
Department of Civil and Environmental Engineering
University of Houston

Biography
Dr. Abdeljalil (DJ) Belarbi is a Distinguished Professor of Civil Engineering at the University of Houston. He has taught more than 14 different undergraduate and graduate courses on subjects related to civil and structural engineering. His primary research contributions focus on the constitutive modeling, analytical and experimental investigations of RC and PC structures. A Fellow of ACI, ASCE, and SEI. In addition to his involvement in ACI 440, he is currently the Co-Chair of ACI-440-E (professional development), Chair of ACI-ASCE 445 (Shear and Torsion), member of ACI 318-E (Section and Member Strength). The recipient of numerous awards and honors including the 1995 Outstanding Paper Award of the Earthquake Engineering Research Institute (Earthquake Spectra Journal) and the Honorable Mention for Outstanding Paper from The Masonry Society.

Advancements in composite infrastructure deployment in Florida
Education Tools for Designers, Contractors, and Owners

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GFRP-RC in development → Box Culvert v4.0 11/07/2018 Exe (Zip) (Mathcad 15)

CFRP-PC Beta version ** (V6.0 coming Fall 2020) → Prestressed Beam v5.2 11/07/2018 Exe (Zip) (Mathcad 15)

GFRP-RC included (Worksheet 3b) → Bent Cap v1.0 11/07/2018 Exe (Zip) (Mathcad 15)

GFRP-RC included → Retaining Wall v4.0 06/01/2020 Zip (Exe) (Mathcad 15)

** Available on request

Used with FDOT Standard Plan Index 400-289 (formerly Index 289) to design concrete box culverts, wingwalls, headwalls, and cutoff walls in accordance with the AASHTO LRFD Bridge Design Specification.

Used with FDOT Standard Plan Index 450-010 to 450-299 (formerly Index 20010 to 20299) to design simple span prestressed beams (Florida-I, AASHTO, Florida Bulb-T, Florida-U, Florida Double-T, Flat Slab, Inverted-T, FSB) in accordance with the AASHTO LRFD Bridge Design Specification.

Analyzes and designs fixed or pinned bent caps, including hangers and loads, in accordance with the AASHTO LRFD Bridge Design Specifications.

Used with FDOT Standard Plan Index 400-010 (formerly Index 6010) to design and analyze cast-in-place retaining walls in accordance with the AASHTO LRFD Bridge Design Specification.
Education Tools for Designers, Contractors, and Owners

i. FRP Designer Training

ii. Structural Design and LCC Tools

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Other Design Software:
Adoption of FRP analysis or design enhancements:

– FBMP *(BSI)* pending

– DeepEx *(Deep Excavation, LLC)* pending
  - DeepFND 2021: ~September 2020
  - DeepEX 2021: ~Jan 2021
  - RC-Solver 2021: ~Oct. 2020

– Michigan DOT/LTU CFRP-Beam Design Mathcad:
  [https://mdotjboss.state.mi.us/SpecProv/trainingmaterials.htm](https://mdotjboss.state.mi.us/SpecProv/trainingmaterials.htm) (also see TRB Webinar Dec 3, 2019)
Education Tools for Designers, Contractors, and Owners

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Life-Cycle Cost (LCC) analysis & LCA can show the sustainable (economic and environmental) advantage of FRP structures in the coastal environment:

Example LCC & LCA Comparison of Carbon Steel-RC/PC verses FRP-RC/PC bridge (adapted from Cadenazzi et al. 2019)
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Education Tools for Designers, Contractors, and Owners

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1. Research & Bridge Code Development:
   - **TRB AKB30 & AASHTO COBS T-6 & T-10**

2. National Training – **AASHTO COBS T-6 & TRB ABK10**:
   - **CFRP-PC Design** - Under NCHRP 20-44 program for report implementation assistance for CFRP-1, has FHWA & AASHTO T-6 support.
   - **GFRP-RC Design** - not eligible under this program, so State DOTs and FHWA are working on it.

3. **AASHTO Guide Specs Review Panels**:
   - **NCHRP 12-121**: Developing Specs for FRP Auxiliary Reinf. in PC Girders. (2020-2022)

4. **CAMX**
   - 2016, 2017, 2018, 2019, 2020 (Featured Speaker/Panel)

5. **International**:
   - International Workshop on GFRP Bars for Concrete Structures (2017, 2019, 2021)
   - Lyon (FR) LMC²/AFGC GFRP-RC workshop (2019)
   - International Bridge Conference (2018 FRP Workshop)

6. **TRB Annual Meetings**:
   - Committee Meeting participation AFF30, AFF80
   - FRP Workshops: 2019 & 2020
   - Technical Sessions: 2018 & 2019

7. **TRB 2019 Webinar - Advanced Structural Materials for Concrete Bridges**:

8. **ACI coordination** (informal)
   - 343 & 440 Committees (Bridge & FRP) 2020 Fall Convention
   - Strategic Development Council – Forum 46 (2019)

9. **State Level Engagement**:
   - FTBA/Contractors (2017 & 2018)
Example Projects

- 40th Ave NE over Placido Bayou
- Arthur Drive over Lynn Haven Bayou **
- Bakers Haulover Cut Bulkhead Replacement **
- Cedar Key Bulkhead Rehab **
- Halls River Bridge **
- NE 23rd Ave over Ibis Waterway
- PortMiami Tunnel Retaining Walls **
- South Maydell Dr over Palm River
- SR-A1A Flagler Beach Seawall (Segment 3) **
- SR-5 (US-17) over Trout River **
- SR-5 (US 41) over Morning Star and Sunset Waterways
- SR-5 (US 41) over North Creek
- SR-30 over St Joe Inlet
- SR-312 over Matanzas River **
- SR-520 over Indian River Bulkhead Rehab
- Sunshine Skyway Seawall Rehabilitation **
- UM Innovation Bridge **
- UM Fate Bridge **
- UM i-Dock **
- US-1 over Cow Key Channel

Current & Completed Projects in Florida

** completed

More projects added every month
Recently Completed Projects

i. Bridge Superstructures (US-1/Cow Key, US-41 Link-Slabs)

ii. Bridge Foundations (NE23rd Ave/Ibis)

iii. Seawalls (SR-A1A@Flagler Beach, Sunshine Skyway South)
Projects Under Construction

i. Bridge Superstructures (US41/North Creek, SR-105 Link-Slabs, 40th Ave NE/Placido Bayou)

ii. Bridge Foundations (NE23rd Ave, Maydell Dr.)

iii. Seawalls (SR30/St Joe Bay Inlet, Pinellas Bayway E)
New Projects in Design

i. Pedestrian Piers (North Bridge, Jupiter)

ii. Prestressed Bridges (Earman Canal, Barracuda)

iii. CIP Bridges (Turkey Creek)

iv. Bridge Foundations (4th St over Big Island Ga)
New Projects in Design

i. Pedestrian Piers (North Bridge, Jupiter)

ii. Prestressed Bridges (Earman Canal, Barracuda, 30A)

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ii. Bridge Foundations (4th St over Big Island Gap)
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Lessons Learned from the Real World

i. Designer Issues
   • Lack of designer training, software tools, and national consensus design codes.

ii. Material & Testing Issues
   • Costs for FRP rebar supply to public agencies are typically higher since no centralized certification standards for manufacturers, so additional testing and approvals are invoked by individual agencies.

iii. Constructability Issue
    1. Unit costs for FRP rebar are very high for small quantities due to the project testing requirements.
    2. Many construction contractors do not understand the lead times involved for FRP rebar.
    3. Higher modulus of elasticity can improve competitiveness of GFRP vs. other corrosion-resistant solutions.
    4. Stirrup bends and closed shapes or multiple bends still not standardized.
    5. Tie-wire (plastic ties are slower, more expensive, and less secure)
    6. Coupling of bars for phased construction is essential for broader deployment or will rely on SS solutions.
    7. Adhesive anchors are often needed, but not codified for FRP rebar. Field proof testing/gripping is a challenge, especially for bent bars.
    8. Shear reinforcing requires much closer spacings and often multiple legs overlapping causing rebar congestion
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Topic #8

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   • Lack of designer training, software tools, and national consensus design codes.

ii. Material & Testing Issues
   • Costs for FRP rebar supply to public agencies are typically higher since no centralized certification standards for manufacturers, so additional testing and approvals are invoked by individual agencies.

iii. Constructability Issue
   1. Unit costs for FRP rebar are very high for small quantities due to the project testing requirements.
   2. Many construction contractors do not understand the lead times involved for FRP rebar.
   3. Higher modulus of elasticity can improve competitiveness of GFRP vs. other corrosion-resistant solutions.
   4. Stirrup bends and closed shapes or multiple bends still not standardized.
   5. Tie-wire (plastic ties are slower, more expensive, and less secure)
   6. Coupling of bars for phased construction is essential for broader deployment or will rely on SS solutions.
   7. Adhesive anchors are often needed, but not codified for FRP rebar. Field proof testing/gripping is a challenge, especially for bent bars.
   8. Shear reinforcing requires much closer spacings and often multiple legs overlapping causing rebar congestion
   9. Non-metallic lifting devices for heavy civil components are not available
   10. Replacement of easily damaged bars in the field is a common need
Lessons Learned from the Real World

i. Designer Issues
   • Lack of designer training, software tools, and national consensus design codes.

ii. Material & Testing Issues
   • Costs for FRP rebar supply to public agencies are typically higher since no centralized certification standards for manufacturers, so additional testing and approvals are invoked by individual agencies.

iii. Constructability Issue
   1. Unit costs for FRP rebar are very high for small quantities due to the project testing
   2. Many construction contractors do not understand the lead times involved for FRP rebar
   3. Higher modulus of elasticity can improve competitiveness of GFRP vs. other corrosion resistant solutions
   4. Stirrup bends and closed shapes or multiple bends still not standardized
   5. Tie-wire (plastic ties are slower, more expensive, and less secure)
   6. Coupling of bars for phased construction is essential for broader deployment or wide-scale projects
   7. Adhesive anchors are often needed, but not codified for FRP rebar. Field proof testing/challenge, especially for bent bars
   8. Shear reinforcing requires much closer spacings and often multiple legs overlapping causing rebar congestion
   9. **Non-metallic lifting devices for heavy civil components are not available**
   10. Replacement of easily damaged bars in the field is a common need

**Topic #8**
Lessons Learned from the Real World

i. Designer Issues
   • Lack of designer training, software tools, and national consensus design codes.

ii. Material & Testing Issues
   • Costs for FRP rebar supply to public agencies are typically higher since no centralized certification standards for manufacturers, so additional testing and approvals are required by individual agencies.

iii. Constructability Issue
   1. Unit costs for FRP rebar are very high for small quantities due to project testing requirements.
   2. Many construction contractors do not understand the lead times involved for FRP rebar.
   3. Higher modulus of elasticity can improve competitiveness of GFRP vs. other corrosion-resistant solutions.
   4. Stirrup bends and closed shapes or multiple bends are not standardized.
   5. Tie-wire (plastic ties are slower, more expensive, and less secure)
   6. Coupling of bars for phased construction is essential for broader deployment.
   7. Adhesive anchors are often needed, but not codified for FRP rebar. Field proof testing/gripping is a challenge, especially for bent bars.
   8. Shear reinforcing requires much closer spacings and often multiple legs overlapping causing rebar congestion.
   9. Non-metallic lifting devices for heavy civil components are not available.

10. Replacement of easily damaged bars in the field is a common need.
THANK YOU FOR WATCHING

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