Armature en PRF pour Renforcer la Floride

Presenter: Steven Nolan, P.E.
Senior Structures Design Engineer
Florida Department of Transportation
Member of TRB’s AFF80 – Standing Committee on Structural FRP
Speaker Bio: Steven Nolan, P.E.

Registered Professional Engineer in Florida since 2001. Originally from Australia with an engineering degree from the University of New South Wales (Sydney) 1989. A Construction Engineer for a heavy civil contractor for several years before emigrating to the USA in 1996 and joining FDOT. Currently leads the implementation of Advanced Materials for Bridge applications within the State Structures Design Office.

Chair of the statewide Structural Advance Materials Technical Advisory Group (SAMTAG), which coordinates deployment and monitoring of the 8 technologies of immediate interest to FDOT including UHPC, FRC, and various BFRP, GFRP & CFRP composite reinforcements. His 23 years with FDOT also includes in-house bridge design; PM structural research projects; development of many of the FDOT precast and prestressed concrete Design Standards; and participation in NCHRP and NIST Technical Panels;

Member of: Transportation Research Board (TRB) AFF80 Committee on Structural FRP; Bridge Engineering Institute’s (BEI) International Advisory Committee; fib; reviewer for ASCE Journal of Composite Construction. Provides technical support for FDOT members on AASHTO’s T-6 (FRP Composites) and T-10 (Concrete Design) Committees on Bridges and Structures. Co-author and presenter for numerous papers on FRP and Prestressed Concrete related to bridges and coastal structures including most recently: ACI-SDC Forum 46, BEI-2019; TRB (2018-2019); 2018 fib-Congress, ASCE-Florida, IALCCE-2018, IBC-2018; ABC-UTC Conferences (2014-2015); CAMX Conferences (2015-2019); and FDOT Transportation Symposium & Design Training Expo's (2013-2019).
Owner/Designer’s perspective

• Historical French-Floridian Bridge Technology Sharing
• Why use FRP rebar for Bridges & Public Infrastructure
• Available Design Guidance & Tools
• Cost Justification (Service Life, LCC, etc.)
• What do we still need?
• Typical Project Examples
Historical French-Floridian Bridge Technology Sharing

1st Sunshine Skyway (1950-1954)

2nd Sunshine Skyway (1984-1987)

Brotonne Bridge (1977)

Fig. 2. Pictured is Eugene Freyssinet.

Florida Keys Bridges

Until 1978, all precast concrete segmental bridges were built by the balanced or progressive cantilever method, with the exception of smaller overpass structures. The first designs produced by Figg and Muller Engineers were for the Florida Keys bridge replacement program and included the Long Key Bridge, Seven-Mile Bridge, Channel Five Bridge, and Niles Channel Bridge.

Courtesy: PCI Journal “Jean Muller: Bridge Engineer” (March-April 2006).
Historical French-Floridian Technology Sharing

2nd Sunshine Skyway (1984-1987)

https://www.youtube.com/watch?v=l20u-07tFhw&feature=emb_title
Historical French-Floridian Technology Sharing

• 2013 FDOT French Study PT-Duct Flexible Filler (wax) Tour

2013 Florida Representatives

• Poutre-Dalles System (PDS) for prestressed-slab units.
  • 2004 FHWA Scan Tour inspired adoption of similar PDS by Minnesota DOT\(^1\) in 2005;
  • Later adoption by FDOT in 2013 with a modified concept – Florida-Slab Beam (FSB) - 70 bridges designed to-date.

https://www.matiere-tp.com/beam-slab/

An example of the coastline paradox. If the coastline of Great Britain is measured using units 100 km (62 mi) long, then the length of the coastline is approximately 2,800 km (1,700 mi). With 50 km (31 mi) units, the total length is approximately 3,400 km (2,100 mi), approximately 600 km (370 mi) longer.

**France-Florida Comparisons**

- **Population:**
  - France = 65 Million
  - Florida = 21 Million

- **Area:**
  - France = 643,800 km²
  - Florida = 170,300 km²

- **Coastline (shoreline):**
  - France = 4,853 km (7,330 km)
  - Florida = 2,170 km (13,576 km)

New Zealand:
- Population = 4.7 Million
- Area = 268,000 km²
- Coastline = 15,134 km (17,209 km)

[2] NOAA

**FLORIDA POPULATION GROWTH**

- California: 39.56 million (2018)
- Texas: 28.7 million (2018)
New Zealand:
Population = 4.7 Million
Area = 268,000 km²
Coastline = 15,134 km (17,209 km)
Florida GFRP-RC Projects

Fast-Facts sheets for selected projects available:

- 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

** completed
Why use FRP rebar for Bridges and Structures

- Florida maintains more than 17,000,000 m² (185M ft²) of bridge area
- Florida has more than 6,500 km (4,000 miles) seawall-bulkheads

WebTable 3. Shoreline hardening and population statistics by state (1)

<table>
<thead>
<tr>
<th>State</th>
<th>Hard sheltered share (km)</th>
<th>Sheltered share (%)</th>
<th>Hand shielded share (km)</th>
<th>Hard open share (km)</th>
<th>Open share (km)</th>
<th>Hard open share (km)</th>
<th>Total share (km)</th>
<th>Hard share (%)</th>
</tr>
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<tbody>
<tr>
<td>Atlantic</td>
<td>477</td>
<td>1907</td>
<td>25</td>
<td>0</td>
<td>0</td>
<td>477</td>
<td>1907</td>
<td>25</td>
</tr>
<tr>
<td>Connecticut</td>
<td>287</td>
<td>2163</td>
<td>13</td>
<td>5</td>
<td>45</td>
<td>11</td>
<td>292</td>
<td>13</td>
</tr>
<tr>
<td>Delaware</td>
<td>29</td>
<td>54</td>
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<td>0</td>
<td>0</td>
<td>29</td>
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</tr>
<tr>
<td>Florida</td>
<td>2694</td>
<td>11,365</td>
<td>24</td>
<td>58</td>
<td>628</td>
<td>9</td>
<td>2,752</td>
<td>11,993</td>
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<tr>
<td>Gulf</td>
<td>356</td>
<td>2606</td>
<td>14</td>
<td>442</td>
<td>26,383</td>
<td>17</td>
<td>478</td>
<td>26,383</td>
</tr>
</tbody>
</table>

Why? ...Inevitability of Corrosion

Figure 1. a) Components for corrosion; b) Electro-chemical process of corrosion; c) Generation of stress inside the concrete; d) Evolution of cracks as corrosion progresses; e) Cracks due to corrosion; f) Spalling due to corrosion; g) Delamination due to corrosion.

Figure 1 from: Corrosion Mechanism in Reinforced Concrete (Maia & Alves, 2017)
Fiber-Reinforced Polymer (FRP) composites have been successfully utilized for durable bridge applications for more 30+ years worldwide, demonstrating their ability to provide reduced maintenance cost, extended service life, and significantly increase design durability.

**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 rock fiber with epoxy resin systems).
Available Design Guidance & Tools

• **Mandatory (normative) Specifications**
  - Currently there are mostly only Guide Design documents in the USA.

• **Uniform Approval Processes**
  - Manufacturer Approval vs Product Approval

• **Reliable Design Tools**
  - Commercial vs. Agency based design programs
• Mandatory Specifications needed
  - Currently there are mostly only Guide Design docs in the USA

Available Design Guidance & Tools

- Uniform Approval Processes
  - Manufacturer Approval vs Product Approval

- Reliable Design Tools
  - Commercial vs. Agency based design programs

https://www.fdot.gov/structures/innovation/FRP.shtm
Available Design Guidance & Tools

- Uniform Approval Processes *(National based systems preferred)*
- Manufacturer Approval vs Product Approval

https://mac.fdot.gov/smoreports
Available Design Guidance & Tools

- Accessible & Reliable Design Tools

- Commercial vs. Agency/Institution based design programs

** Available on request

- **Box Culvert v4.0** 11/07/2018
  - **GFRP-RC in development**
  - 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.

- **Prestressed Beam v5.2** 11/07/2018
  - **CFRP-PC Beta version**
  - 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.

- **Bent Cap v1.0** 11/07/2018
  - **GFRP-RC included (3b)**
  - Analyzes and designs fixed or pinned bent caps, including lateral loads, in accordance with the AASHTO LRFD Bridge Design Specifications.

- **Retaining Wall v3.3** 11/07/2018
  - **GFRP-RC Alpha version**
  - 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.

https://www.fdot.gov/structures/proglib.shtm
Typical GFRP-RC Tools

Projects using Pile-Bent Cap Design Tool:
- 40th Ave NE over Placido Bayou
- Halls River Bridge **
- NE 23rd Ave over Ibis Waterway
- SR-5 (US 41) over North Creek
Typical GFRP-RC Applications and Details

Projects using Bulkhead Cap standards:

- Bakers Haulover Cut Bulkhead Replacement **
- Halls River Bridge **
- NE 23rd Ave over Ibis Waterway
- SR-5 (US 41) over North Creek
- SR-30 over St Joe Inlet
- SR-520 over Indian River Bulkhead Rehab
- Sunshine Skyway Seawall Rehabilitation

Figure 1  Typical Cap Details

Standard Plans Instructions
Index 455-440  Precast Concrete Sheet Pile Wall (CFRP/GFRP & HSS/GFRP)

Topic No. 625-010-003
FY 2020-21

- All reinforcing shall be GFRP #5 bars minimum.
- ** Minimum number of longitudinal bars shown. Indicate actual number and spacing of bars on plans.
- Include a plan note allowing use of a single closed stirrup in lieu of paired open stirrups.
• LCC & LCA also can show the sustainable (economic and environmental) advantage of composite structures in the coastal environment:

Example LCC & LCA Comparison of Carbon Steel-RC/PC verses FRP-RC/PC bridge (0.6% Effective Discount Rate), adapted from Cadenazzi et al. 2019.
Cost Justification (Service Life, LCC, etc.)

- LCC & LCA also can show the sustainable (economic and environmental) advantage of composite structures in the coastal environment:

Cost Justification (Service Life, LCC, etc.) - Younis et al., 2018

Table 4
Summary of LCCA results.

<table>
<thead>
<tr>
<th>Design alternative</th>
<th>Present costs ($/m²)</th>
<th>LCC ($/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Material</td>
<td>Construction</td>
</tr>
<tr>
<td>RC1</td>
<td>90</td>
<td>135</td>
</tr>
<tr>
<td>RC2</td>
<td>389</td>
<td>135</td>
</tr>
<tr>
<td>RC3</td>
<td>174</td>
<td>108</td>
</tr>
</tbody>
</table>

RC1 = Traditional concrete mix with carbon-(black) steel rebar; RC2 = Traditional concrete mix with SS rebar; RC3 = Concrete with seawater & RCA with GFRP rebar.


(Baseline scenario with discount rate = 0.7%)
What do we still need? (gaps in design and deployment)

- Connections (post-installed anchors – **ACI 318 Chapter 17/ACI 355.4**)
- Fatigue limits
- Importance of Elastic Modulus
- Bent Bars
- Scalability of production

Halls River Bridge - Traffic Railing Retrofit:

1700+ Dowel Holes
What do we still need?
(gaps in design and deployment)

- Connections (post-installed dowels bars – *ACI 318 Chapter 17/ACI 355.4*)

Importance of Elastic Modulus
Bent Bars
Scalability of production

[Lat. 26.8080459, Long. -80.055929]
What do we still need? (gaps in design and deployment)

- Connections (mechanical couplers)
- Fatigue refinement
- Importance of Elastic Modulus
- Bent Bars
- Scalability of production

What do we still need? (gaps in design and deployment)
What do we still need?
(gaps in design and deployment)

- Connections (coupling, post-installed)
- Fatigue limits - refinement
- Importance of Elastic Modulus
- Bent Bars
- Scalability of production

Recommended creep-rupture stress limit \((0.30f_{fu})\) can also be applied for limiting the fatigue stresses in GFRP-reinforced elements subjected to fatigue cyclic loads owing to the similarity between the fatigue and creep-rupture strengths of FRP bars (GangaRao et al. 2006; Rostasy et al. 1993). Additional studies on the fatigue behavior of GFRP bars, however, are essential to support future adjustments of the stress limit.

B.Benmokrane, V.L.Brown, K.Mohamed, A.Nanni, M.Rossini, Carol Shield (ASCE-JCC)
What do we still need?
(gaps in design and deployment)

- Connections (coupling, post-installed)
- Fatigue limits
- Importance of Elastic Modulus
- Bent Bars (thermo-set/plastic)
- Scalability of production

Figure: Parametric analysis of flexural design algorithms per AASHTO GFRP-RC 2nd edition for HRB Bent Cap

Project Examples – Fast Facts Sheets

Fast Facts:
Glass Fiber Reinforced Polymer

Fast Facts: https://www.fdot.gov/structures/innovation/FRP.shtml#link9
Project Examples - Port Miami Tunnel Entrance Walls

Watson Island, Miami – 2014

Wall 6 under construction & Typical Cross-section of Retaining Walls 5 and 6

Fast-Facts: [https://www.fdot.gov/structures/innovation/FRP.shtm#link9](https://www.fdot.gov/structures/innovation/FRP.shtm#link9)
Elevation view of Innovation Bridge with FRP reinforcement in the auger-cast-piles, bent-caps, double-tee stems and flanges, deck overlay and curbs.

**Innovation Bridge**

Fast-Facts: [https://www.fdot.gov/structures/innovation/FRP.shtml#link9](https://www.fdot.gov/structures/innovation/FRP.shtml#link9)
Project Examples - NE 23rd Ave/Ibis Waterway

CIP continuous flat-slab bridge:

Fast-Facts: https://www.fdot.gov/structures/innovation/FRP.shtm#link9
Project Examples - SR-A1A Secant-Pile Seawall

Auger-Cast Pile GFRP-RC Secant Wall

SR-A1A Flagler Beach Seawall

Fast-Facts: [https://www.fdot.gov/structures/innovation/FRP.shtm#link9](https://www.fdot.gov/structures/innovation/FRP.shtm#link9)
Project Examples - Halls River Bridge

Homesassa, FL 2017-19 (GFRP-RC & CFRP-PC)
Five-span vehicular bridge

Fast-Facts: https://www.fdot.gov/structures/innovation/FRP.shtm#link9
Homosassa, FL 2017-2019 (GFRP-RC & CFRP-PC)

Five-span vehicular bridge entirely constructed using corrosion-resistant solutions and mostly FRP reinforcement including:

- CFRP-PC bearing piles;
- CFRP-PC/GFRP-RC sheet piles;
- Hybrid HSCS-PC/GFRP-RC sheet piles;
- GFRP-RC bulkhead caps;
- GFRP-RC pile bent caps;
- GFRP-RC bridge deck
- GFRP-RC traffic railings
- GFRP-RC approach slabs
- GFRP-RC gravity wall.
• Halls River Bridge – demonstrating **Durability** thru FRP materials...
Project Examples - Halls River Bridge

• Halls River Bridge - modelling Resiliency thru potential for Adaption!

Showing the effect of a 1.8 m (6-ft) RSL

• Shows current MHW (blue) and 1.8 m projected RSL (dashed redline)

• with possible Adaption Strategy using 1.5 m raised bulkhead (right-side).
<table>
<thead>
<tr>
<th>What Natural Hazards Impact Our Transportation System?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nearly 1,000 coastal communities in the U.S. are projected to experience flooding more than 26 times per year by 2035.</td>
</tr>
<tr>
<td>In 2018, the Global Mean Sea Level was 3.2 inches above the 1993 average. Since 2000, tidal flooding across Florida has increased by 352%. Florida is among the top 10 states most impacted by wildfires.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>What Types Of Extreme Weather Can Affect The Mobility Of Floridians?</th>
</tr>
</thead>
<tbody>
<tr>
<td>The amount of precipitation during heavy rainstorms has increased by 21% in the Southeast over the last 60 years.</td>
</tr>
<tr>
<td>By mid-century, the Southeast is expected to experience up to 50 more days per year of temperatures exceeding 90 degrees.</td>
</tr>
<tr>
<td>Florida has been impacted by 40% of all U.S. hurricanes.</td>
</tr>
</tbody>
</table>

- Florida is the 3rd most populated U.S. state, and our population is expected to increase nearly 30% to 27 million by 2045. To plan for a resilient transportation future, we need to understand important trends and conditions today.
- Florida is the 14th largest economy on the planet (Florida Senate President - Bill Galvano).
Des Questions?

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