Infrastructure Owners/Design Perspective

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Owner/Designer’s perspective
• Why use FRP rebar for Bridges & Public Infrastructure
• Availability of Design Guidance & Tools
• Cost Justification (Service Life, LCC, etc.)
• What do we still need?
• Typical Project Examples
Why use FRP rebar for Bridges and other Public Infrastructure

PREVIOUS PROBLEM STATEMENT (from Nanni)

- Failure mechanism for structures exposed to aggressive environments is often corrosion of the steel reinforcement
- Chlorides from de-icing salts or seawater penetrate concrete and reach steel
  - Via cracks
  - Via concrete porosity
- Corrosion is accelerated by carbonation of concrete that lowers the pH
  + Low electro-magnetic interference;
  + Lower ownership costs.
Why use FRP rebar for Bridges and other Public Infrastructure

- Florida maintains more than 185 million sq.ft. of bridge area
- Florida has more than 4,000 miles seawall bulkheads

<table>
<thead>
<tr>
<th>State</th>
<th>Hard shore (km)</th>
<th>Hard shore (%)</th>
<th>Sheltered shore (km)</th>
<th>Sheltered shore (%)</th>
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</table>

Why? ... Inevitability of Corrosion

Figure 1 from: Corrosion Mechanism in Reinforced Concrete
(from Maia & Alves, 2017)
Infrastructure owners are seeking:

- increased service-life (50 → 75 → 100+ years...);
- reduced maintenance & repair liability;
- resilience;
- and sustainability (sometimes!)

Traditional construction materials cannot reliably meet all these challenges without periodic intervention (corrosion mitigation & re-strengthening):

- **USA** - total annual cost of corrosion was reported as $276 billion in 2002*.
  - Bridge decks maintenance due to corrosion is around $2 billion;
  - Substructure another $2 billion (FHWA, 2002) – mostly from seawater.
- **China** - annual cost of corrosion is also estimated at ¥2 trillion (approximately US$290 billion) (CAS 2014)**.


Why? …some Infrastructure Facts

The 200 Year Bridge
Florida DOT Transportation Budget FY 2019/2020
➢ 49% for combined Maintenance, Repair, Rehabilitation and Deficient Bridge Replacement (hatched areas).

- Highway Reconstruction, Rehabilitation and Resurfacing [$2.7B]
- Repairs of 85 bridges/Replacement of 22 Deficient bridges [$1.1B]
- Maintenance and Operation of existing facilities [$1.1B]
- Capacity Expansion - 102 new lane miles & bridges [$3.2B]
- Other - Rail, Transit, Seaports, Aviation, etc. [$1.8B]

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

www.ascegrandchallenge.com
Why? …some Infrastructure Facts

Bridges

America’s Bridges by Age

Structurally Deficient Bridges

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

Why? …some Infrastructure Facts

Hutchins Center Working Paper #54 – INFRASTRUCTURE COSTS:
“…we find that spending per mile on Interstate construction increased more than three-fold (in real terms) from the 1960s to the 1980s [1990]
…the increased spending per mile coincides with the rise of “citizen voice” in government decision-making in the early 1970s. And rising incomes and housing prices nearly completely statistically explain the increase in costs. We also largely rule out several common explanations for rising costs, such as increases in per-unit labor or materials prices.”

FIGURE 1. INTERSTATE CONSTRUCTION SPENDING PER MILE INCREASES OVER TIME (2016 US DOLLARS)

FIGURE 4. SPENDING PER MILE AND HIGHWAY WAGE AND MATERIALS PRICES

https://www.brookings.edu/research/how-high-are-infrastructure-costs/ (August 2019)
Fiber-Reinforced Polymer (FRP) composites have been successfully utilized for durable bridge applications for more than 30 years, 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).
Early applications can be the foundation for refining true durability models.

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

- Ulenbergstrasse Bridge, Düsseldorf, Germany 1986 (GFRP-PC)
- Shinmiya Bridge, Japan 1988 (CFCC-PC)
- Beddington Trail Bridge, Calgary, Alberta 1993 (CFCC & CFRP-PC)
- Hall’s Harbor Wharf, Bay of Fundy, Nova Scotia 1999 (GFRP-RC)*
- McKinleyville Bridge, West Virginia 1998 (GFRP-RC)*
- Val-Alain Bridge, Quebec 2004 (GFRP-RC)

* One of the 11 Bridges in the ACI-SDC Study of FRP-RC Bridges (see Nanni’s presentation)
Availability of Design Guidance & Tools

• Mandatory *(language)* Specifications
  - Currently there are mostly only Guide Documents in the USA.

• Uniform Approval Processes
  - Manufacturer Approval vs Product Approval

• Reliable Design Tools
  - Commercial vs. Agency based design programs
Availability of Design Guidance & Tools

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- Uniform Approval Processes
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- Reliable Design Tools
  - Commercial vs. Agency based design programs

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

- Uniform Approval Processes
  - Manufacturer Approval vs Product Approval

https://mac.fdot.gov/smoreports
### Availability of Design Guidance & Tools

- **Accessible & Reliable Design Tools**
  - Commercial vs. Agency/Institution based design programs

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<th>Design Tool</th>
<th>Version</th>
<th>Release Date</th>
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- **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 Specifications.

Analyzes and designs fixed or pinned bent caps, including lateral 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.

https://www.fdot.gov/structures/proglib.shtm
LCC & LCA also can show the sustainable (economic and environmental) advantage of composite structures in the coastal environment:

Example LCC & LCA Comparison of CSteel-RC/PC versus FRP-RC/PC bridge (0.6% Effective Discount Rate), adapted from Cadenazzi et al. 2019.
LCC & LCA also can show the sustainable (economic and environmental) advantage of composite structures in the coastal environment:

What do we still need (refinement in design limits)?

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- Strength percentile
- Res. Fact. concr. failure
- Res. Fact. FRP failure
- Res. Fact. shear failure
- Environmental reduction
- Creep rupture reduction
- Fatigue reduction
- Bond reduction
- Crack width limit [mm]
- Clear cover [mm]
- Strain limit in shear reinf.

*(1) ACI 440.5-08 Table 3.1*
What do we still need (gaps in design and deployment)?

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

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

- Connections (post-installed - dowels)
- Fatigue refinement
- Importance of Elastic Modulus
- Bent Bars
- Scalability of production
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)?

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

Recommended creep-rupture stress limit \(0.30f_{fm}\) 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.

DOI: 10.1061/(ASCE)CC.1943-5614.0000971.
© 2019 American Society of Civil Engineers.
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

FDOT Transportation Innovation Initiative:

**FRP – Design Innovation**

### Fast Facts: Glass Fiber Reinforced Polymer & Carbon Fiber Reinforced Polymer

- **Project Location:** FDOT District Three, Collier County, Florida
- **Agency:** Florida Department of Transportation
- **LDP:** [https://www.fdot.gov/structures/innovation/FRP.shtm#link9](https://www.fdot.gov/structures/innovation/FRP.shtm#link9)
- **Project Description:**
  - These FRP reinforced concrete beam replacement joints were manufactured and designed to improve shear resistance of bridges. Initially, FRP joints were installed on a bridge on SR 940. Test results demonstrated that the new FRP joints increased the bridge’s load capacity.

### Fast Facts: Glass Fiber Reinforced Polymer

- **Project Location:** FDOT District Three, Collier County, Florida
- **Agency:** Florida Department of Transportation
- **LDP:** [https://www.fdot.gov/structures/innovation/FRP.shtm#link9](https://www.fdot.gov/structures/innovation/FRP.shtm#link9)
- **Project Description:**
  - This project involved the replacement of a concrete bridge with a FRP bridge. The new design significantly improved the bridge’s load capacity and durability.

- **Project Location:** FDOT District Three, Collier County, Florida
- **Agency:** Florida Department of Transportation
- **LDP:** [https://www.fdot.gov/structures/innovation/FRP.shtm#link9](https://www.fdot.gov/structures/innovation/FRP.shtm#link9)
- **Project Description:**
  - This project involved the installation of FRP reinforcement in existing bridges to improve their load-bearing capacity. The FRP materials were selected for their high strength-to-weight ratio and durability in corrosive environments.
Project Examples - Halls River Bridge

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

- **External FRP Laminate Repairs**
  - 1990’s
- **Fender Systems**
  - 2000’s
- **CFRP-PC**
  - 2015
- **GFRP-RC**
  - 2016
- **Composite Bridge Girders**
  - 2016
- **BFRP-RC**
  - 2020

** FLAGSHIP PROJECT **

**HRB Hybrid Composite Beams (2017)**

HRB GFRP-RC Diaphragms for HCB (2018)
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.
Homosassa, FL 2017-19 (GFRP-RC & CFRP-PC)
Five-span vehicular bridge

Fast-Facts: https://www.fdot.gov/structures/innovation/FRP.shtm#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 BFRP 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.shtm#link9
Project Examples - NE 23rd Ave/Ibis Waterway

CIP continuous flat-slab bridge:

Fast-Facts: [https://www.fdot.gov/structures/innovation/FRP.shtm#link9](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 (Segment 3)

Fast-Facts: https://www.fdot.gov/structures/innovation/FRP.shtm#link9
Questions?

FDOT FRP Design Contact:

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Tallahassee, FL.
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FDOT Materials and Manufacturer Approvals

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