PANEL PRESENTATIONS ON :
USE OF NON-METALLIC REINFORCEMENT

Infrastructure Owners/ Design Perspective

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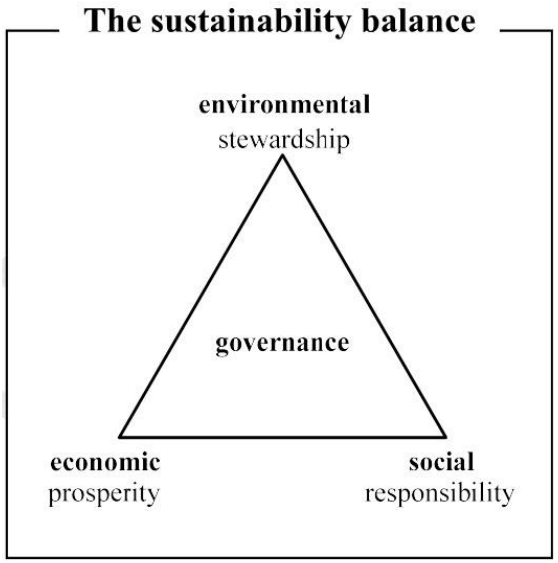


Why use FRP rebar for Bridges and other Public Infrastructure

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.

SERVICE LIFE GREATLY REDUCED BY CORROSION

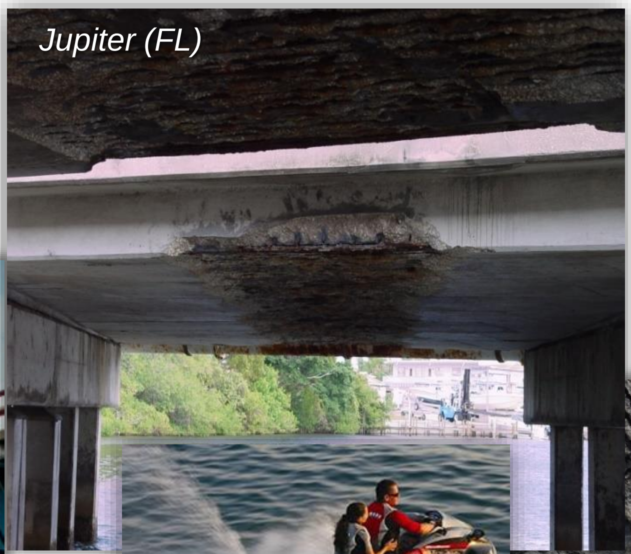
Why use FRP rebar for Bridges and other Public Infrastructure

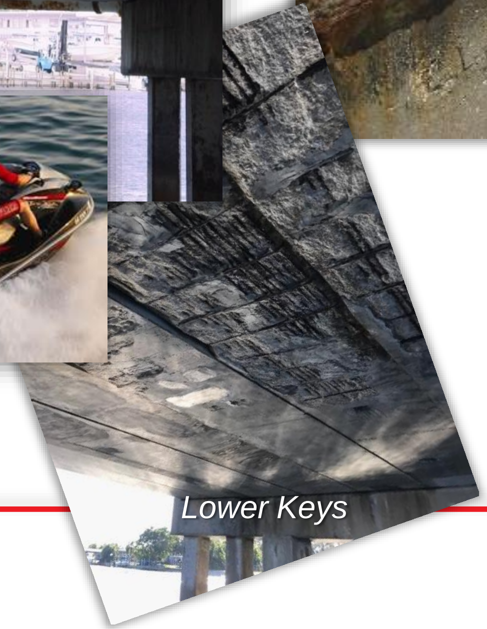
- Florida maintains more than 185 million sq.ft. of bridge area
- Florida has more than 4,000 miles seawall bulkheads

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

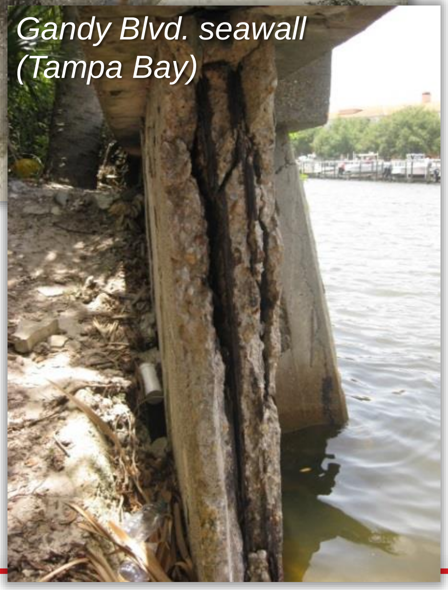
	Hard sheltered shore (km)	Sheltered shore (km)	Hard sheltered shore (%)	Hard open shore (km)	Open shore (km)	Hard open shore (km)	Hard shore (km)	Total shore (km)	Hard shore (%)
Atlantic									
Connecticut	477	1907	25	0	0		477	1907	25
Delaware	287	2163	13	5	45	11	292	2208	13
DC	29	54	53	0	0		29	54	53
Florida*	2694	11 365	24	58	628	9	2752	11 992	23
Gulf									
Alabama							356	2606	14
Florida*							4427	26 383	17

Seven Mile Bridge "New" and Old (Florida Keys)


Jupiter (FL)


Lower Keys


Courtney Campbell Causeway seawall (Tampa Bay)


Gandy Blvd. seawall (Tampa Bay)

(1) Gittman et al. https://esajournals.onlinelibrary.wiley.com/doi/abs/10.1890/150065

Why? …Inevitability of Corrosion

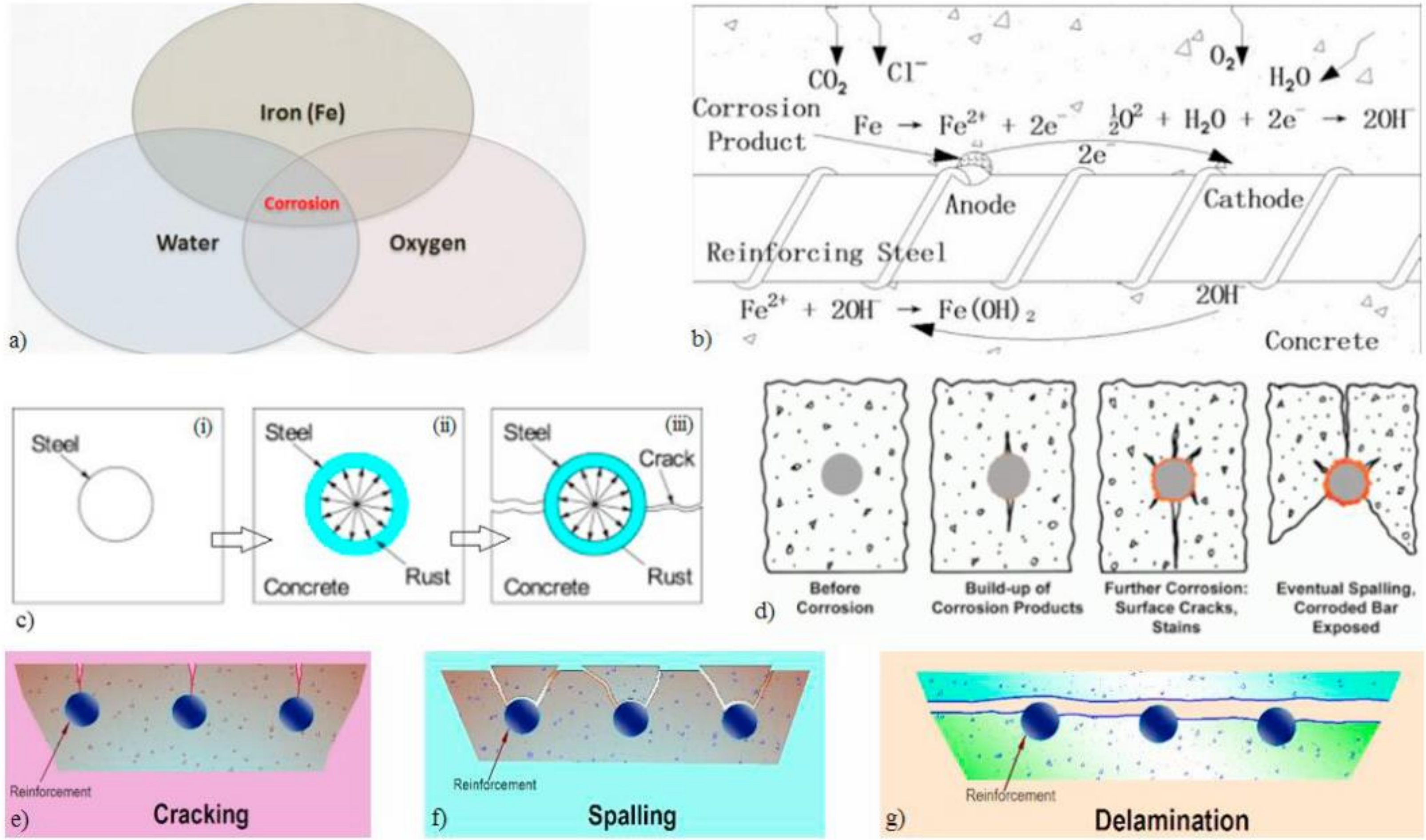
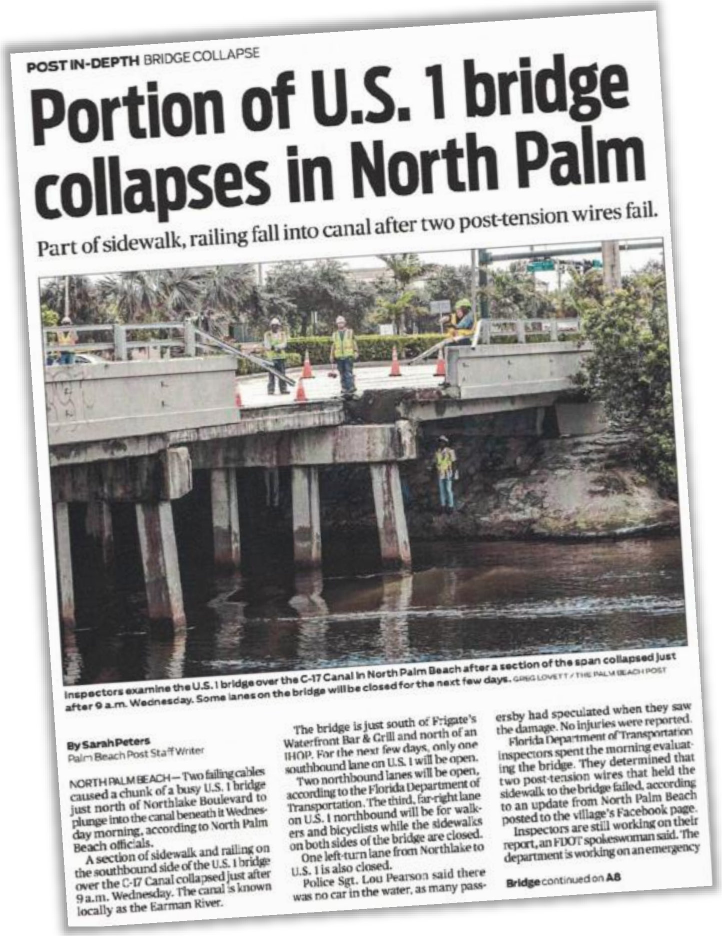


Figure 1. a) Components for corrosion; b) Electro-chemical process of corrosion; c) Generation of stress inside the concrete; d) Evolution of cracks as corrosion progresses; e) Cracks due to corrosion; f) Spalling due to corrosion; g) Delamination due to corrosion.



POST IN-DEPTH BRIDGE COLLAPSE

Portion of U.S. 1 bridge collapses in North Palm

Part of sidewalk, railing fall into canal after two post-tension wires fail.

Inspectors examine the U.S. 1 bridge over the C-17 Canal in North Palm Beach after a section of the span collapsed just after 9 a.m. Wednesday. Some lanes on the bridge will be closed for the next few days. GREG LOVETT / THE PALM BEACH POST

By Sarah Peters
Palm Beach Post Staff Writer

NORTH PALM BEACH — Two failing cables caused a chunk of a busy U.S. 1 bridge just north of Northlake Boulevard to plunge into the canal beneath it Wednesday morning, according to North Palm Beach officials.

A section of sidewalk and railing on the southbound side of the U.S. 1 bridge over the C-17 Canal collapsed just after 9 a.m. Wednesday. The canal is known locally as the Earman River.

The bridge is just south of Frigate's Waterfront Bar & Grill and north of an IHOP. For the next few days, only one southbound lane on U.S. 1 will be open.

Two northbound lanes will be open, according to the Florida Department of Transportation. The third, far-right lane on U.S. 1 northbound will be for walkers and bicyclists while the sidewalks on both sides of the bridge are closed.

One left-turn lane from Northlake to U.S. 1 is also closed.

Police Sgt. Lou Pearson said there was no car in the water, as many passersby had speculated when they saw the damage. No injuries were reported.

Florida Department of Transportation inspectors spent the morning evaluating the bridge. They determined that two post-tension wires that held the sidewalk to the bridge failed, according to an update from North Palm Beach posted to the village's Facebook page.

Inspectors are still working on their report, an FDOT spokeswoman said. The department is working on an emergency

Bridge continued on A8

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

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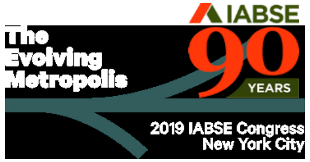
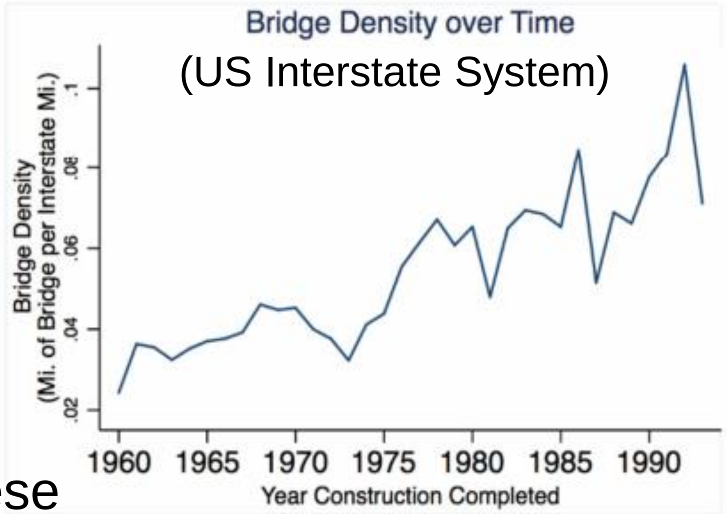
Why? …some Infrastructure Facts

Infrastructure owners are seeking:

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

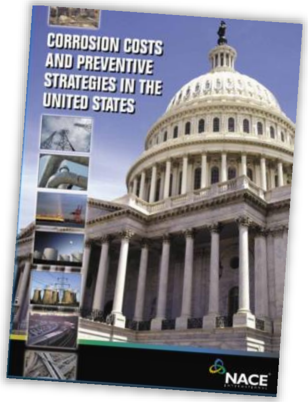


The 200 Year Bridge



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)**.



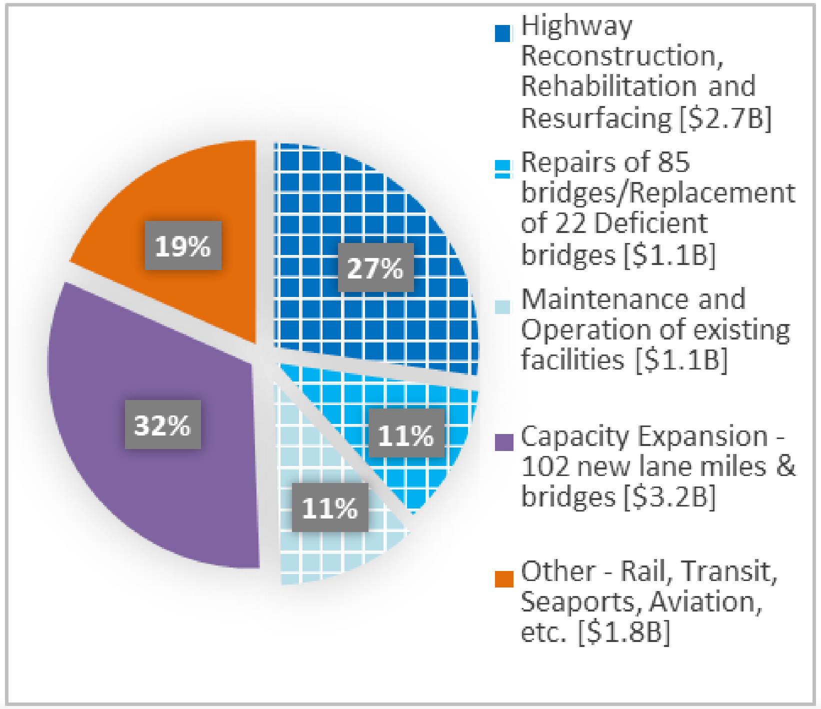
** FHWA/NACE 2002. "Corrosion Costs and Preventive Strategies in the United States"* https://www.nace.org/resources/general-resources/cost-of-corrosion-study

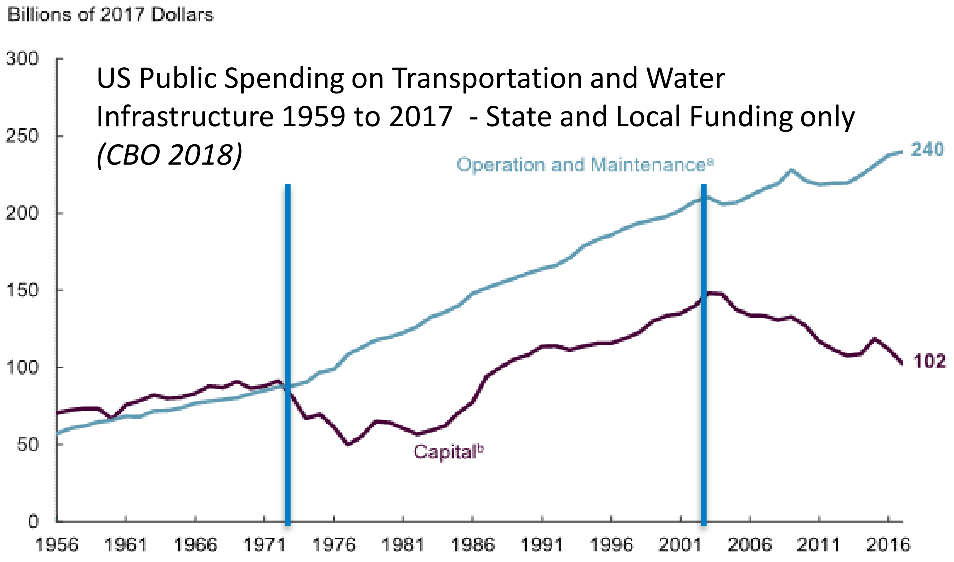
*** CAS. 2014. "Corrosion Status of China and the Control Strategy Research," Chinese Academy of Sciences, Beijing, China,* www.cas.cn

Why? …some Infrastructure Facts

Florida DOT Transportation Budget FY 2019/2020

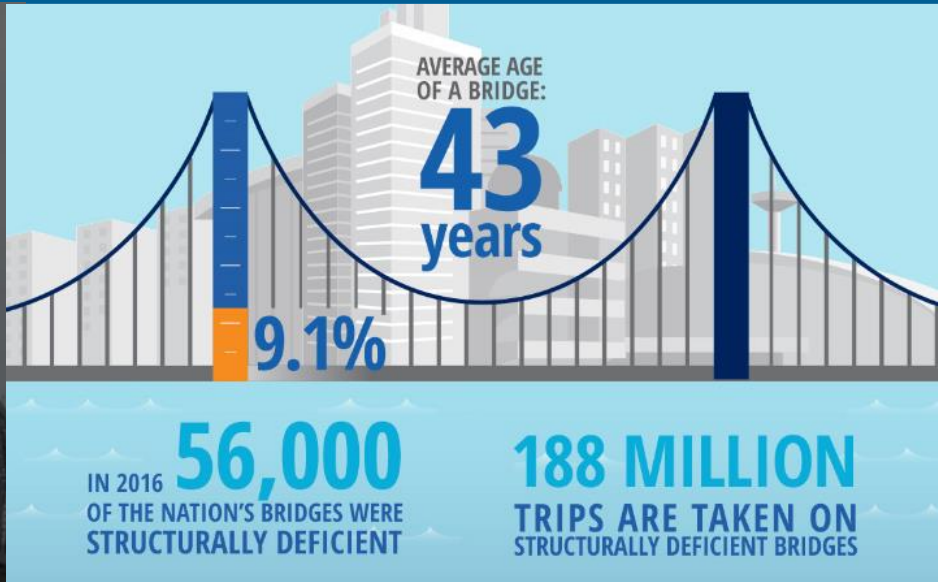
- 49% for combined Maintenance, Repair, Rehabilitation and Deficient Bridge Replacement (hatched areas).

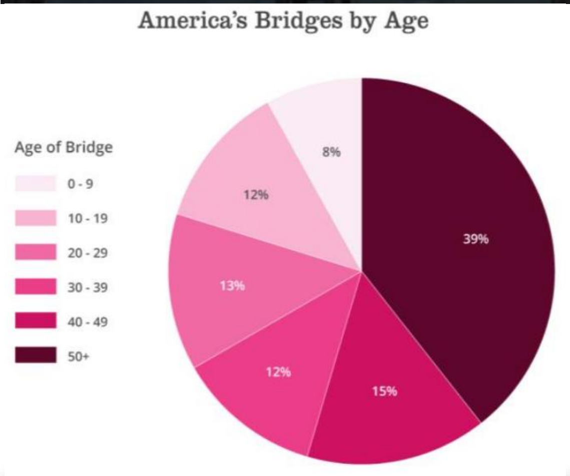


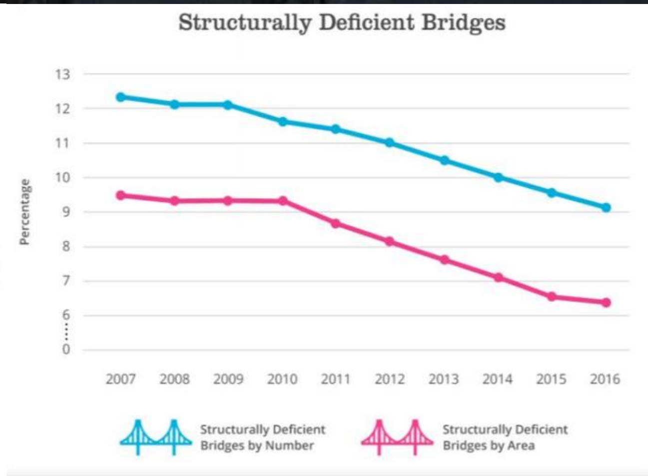


"Reduce the life cycle cost of infrastructure by 50% by 2025 and foster the optimization of infrastructure investments for society"

Why? …some Infrastructure Facts







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

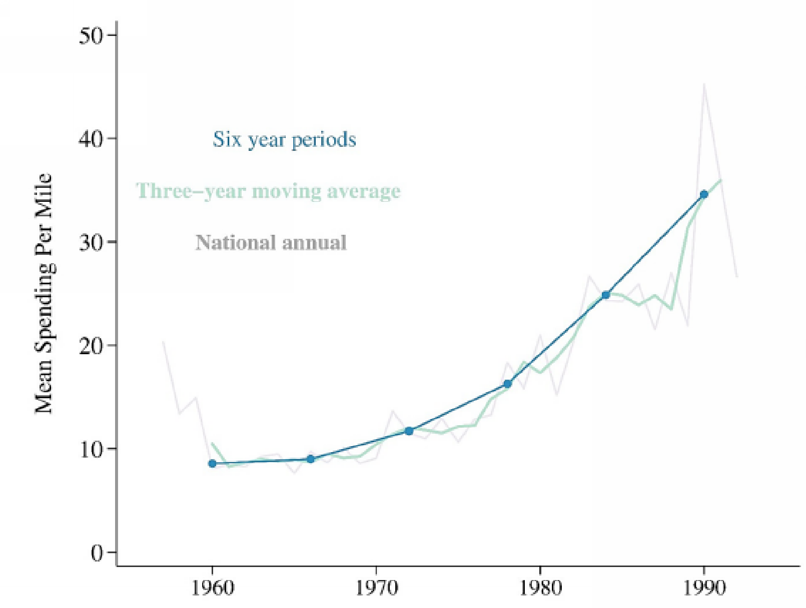
Why? …some Infrastructure Facts

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)



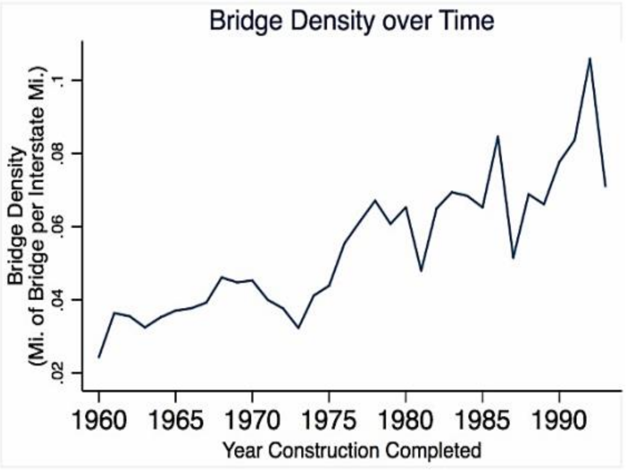
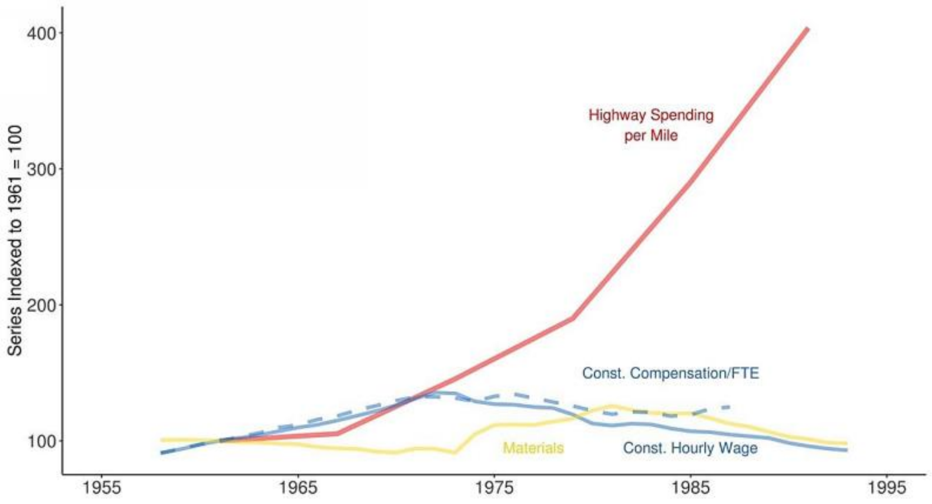


FIGURE 4. SPENDING PER MILE AND HIGHWAY WAGE AND MATERIALS PRICES

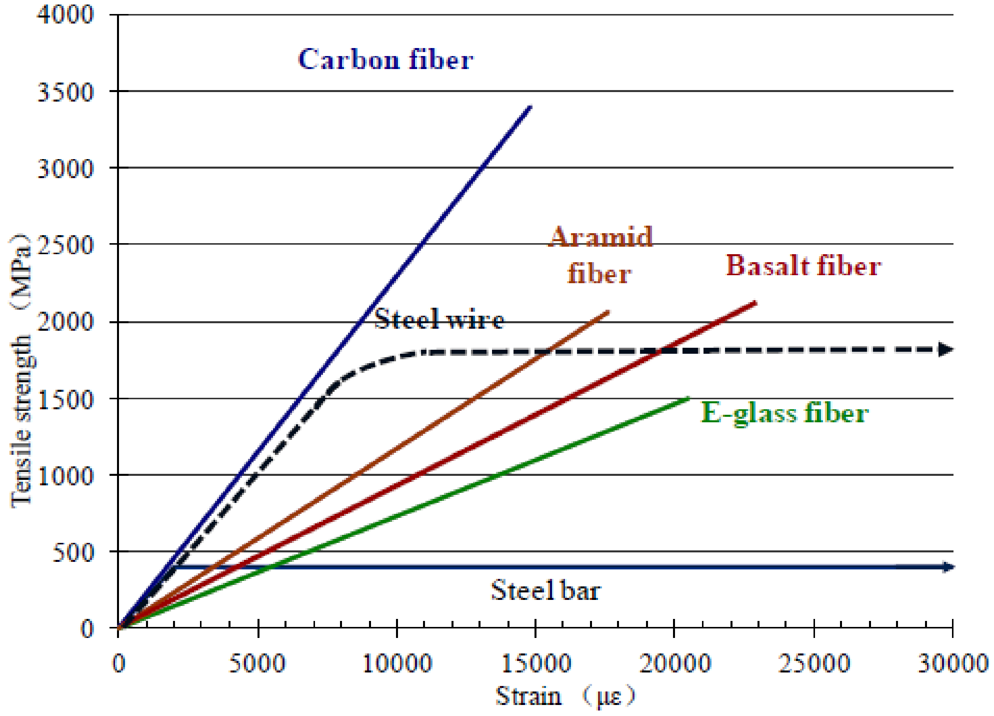


Why? …Drastic Consequences Demand Different Solutions

Fiber-Reinforced Polymer (FRP) composites have been successfully utilized for durable bridge applications for more 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 Application Bridge Examples

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)**

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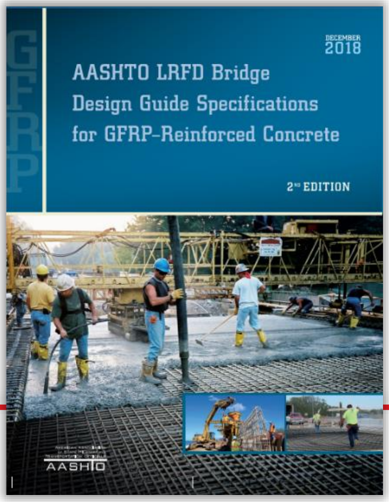
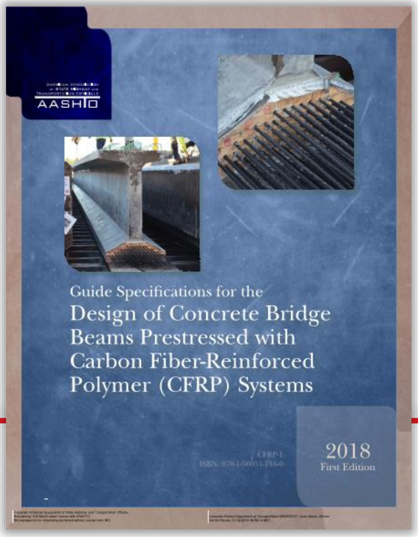
* One of the 11 Bridges in the ACI-SDC Study of FRP-RC Bridges
(see Nanni's presentation)

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





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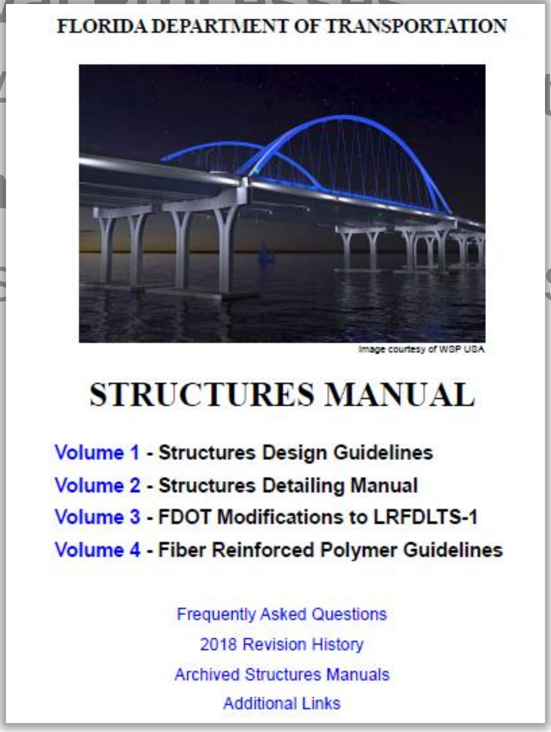

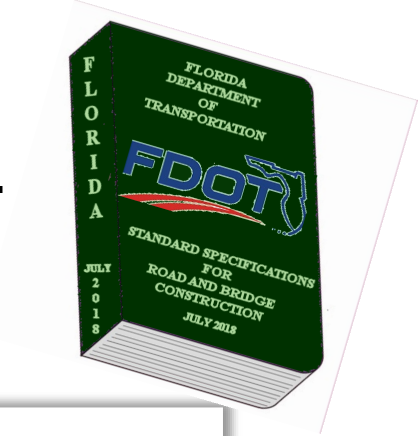

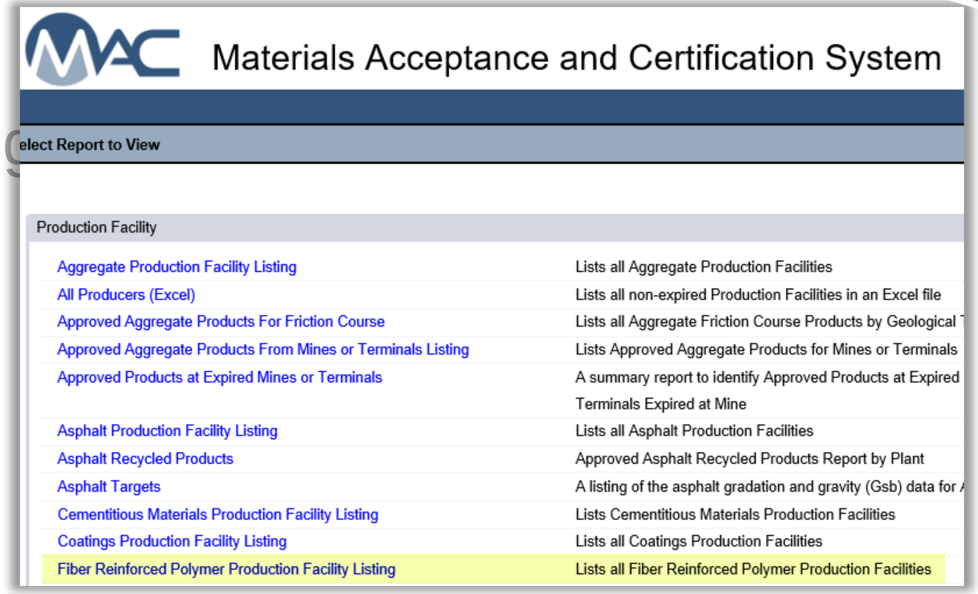

https://www.fdot.gov/structures/innovation/FRP.shtm

Availability of Design Guidance & Tools

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

https://mac.fdot.gov/smoreports

FDOT

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Fiber Reinforced Polymer Production Facility Listing

Office, 5007 N.E. 39th Avenue,

FRP-02 OWENS CORNING (BLYTHEWOOD, SC)

Company: Owens Corning Infrastructure Solutions

Contact: John Amonett **Email:** john.amonett@owenscorning.com

Phone: (419) 819-9739 **Fax:**

Physical Address:

1051 Jenkins Brother
Blythewood, SC 2901

QC Plan Status:

#04 GFRP E
#05 GFRP E
#06 GFRP E
#07 GFRP E
#08 GFRP E

FRP-06 PULTRALL

Company: Pultrall Inc

Contact: ROXANNE FORTIER **Email:** roxanne.fortier@pultrall.com

Phone: (418) 335-3202 ext 231 **Fax:**

Physical Address:

700 9eme rue Nord
Thetford Mines

CANADA

QC Plan Status:

#03 GFRP
#04 GFRP
#05 GFRP
#06 GFRP
#08 GFRP

FRP-12 TUF-BAR INC (EDMONTON CANADA)

Company: Tuf-Bar Inc.

Contact: Nathan Sim **Email:** nathan@tuf-bar.com

Phone: (780) 448-9338 **Fax:**

Physical Address: **Mailing Address:**

5715-76 Avenue 5715-76 Avenue

CANADA CANADA

QC Plan Status: Quality Control Plan ACCEPTED 3/19/2019

#03 GFRP BAR	Glass Fiber Reinforced Polymer Reinforcing for Concrete, #3
#04 GFRP BAR	Glass Fiber Reinforced Polymer Reinforcing for Concrete, #4
#05 GFRP BAR	Glass Fiber Reinforced Polymer Reinforcing for Concrete, #5
#06 GFRP BAR	Glass Fiber Reinforced Polymer Reinforcing for Concrete, #6
#07 GFRP BAR	Glass Fiber Reinforced Polymer Reinforcing for Concrete, #7
#08 GFRP BAR	Glass Fiber Reinforced Polymer Reinforcing for Concrete, #8

FRP-07 PULTRON (DUBAI)

Company: Pultron Composites Ltd

Contact: Bogdan Patrascu **Email:** bogdan@pultron.com

Phone: (714) 880-9533 **Fax:**

Physical Address: **Mailing Address:**

S404 Street
Building 10 Jebel Ali Free Zone South

S404 Street
Building 10 Jebel Ali Free Zone South

UNITED ARAB EMIRATES

QC Plan Status: Quali

#04 GFRP BAR
#05 GFRP BAR
#06 GFRP BAR
#08 GFRP BAR

FRP-08 ATP

Company: ATP

Contact: Aniello Giamundo **Email:** a.giamundo@atp.sa.it

Phone: (811) 948-7131 **Fax:**

Physical Address: **Mailing Address:**

via Campa 34 via Campa 34

ITALY

QC Plan Status:

#03 GFRP B
#04 GFRP B
#05 GFRP B
#06 GFRP B
#08 GFRP B

FRP-14 TUF-BAR INC (ONTARIO CANADA)

Company: Tuf-Bar Inc.

Contact: Jay Christopher **Email:** jay@tufbarcanada.com

Phone: (519) 833-5050 **Fax:**

Physical Address: **Mailing Address:**

7 Erin Park Dr 7 Erin Park Dr

CANADA CANADA

QC Plan Status: Quality Control Plan ACCEPTED 12/11/2017

Availability of Design Guidance & Tools

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

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Structures Design

Structures Design

Programs Library

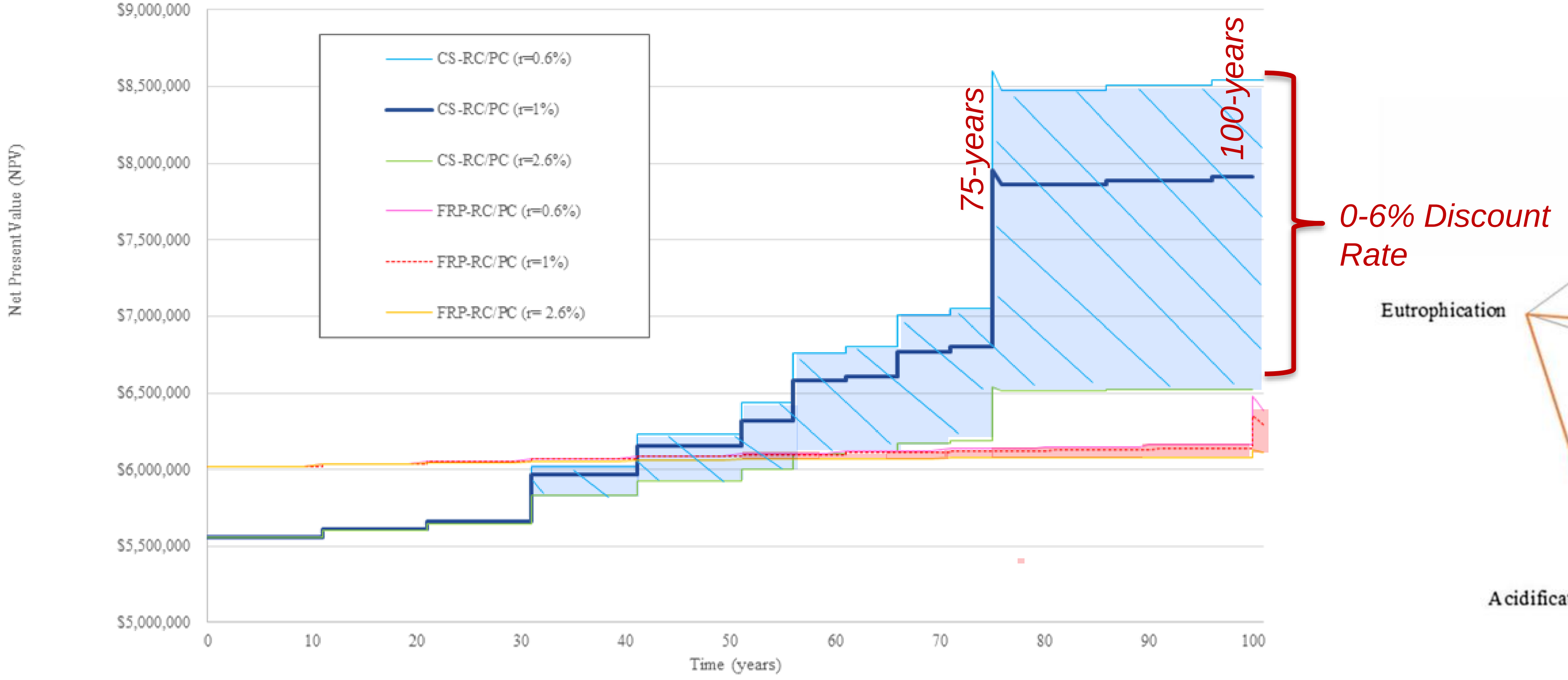
Box Culvert v4.0 *GFRP-RC in development !*	11/07/2018	Exe (Zip) (Mathcad 15)	Used with **FDOT Standard Plan Index 400-289** (formerly **Index 289**) to design concrete box culverts, wingwalls, headwalls, and cutoff walls in accordance with the AASHTO LRFD Bridge Design Specification.
Prestressed Beam v5.2 *CFRP-PC Beta version ** *	11/07/2018	Exe (Zip) (Mathcad 15)	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 *GFRP-RC included (3b)*	11/07/2018	Exe (Zip) (Mathcad 15)	Analyzes and designs fixed or pinned bent caps, including lateral loads, in accordance with the AASHTO LRFD Bridge Design Specifications.
Retaining Wall v3.3 *GFRP-RC Alpha version ** *	11/07/2018	Exe (Zip) (Mathcad 15)	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.

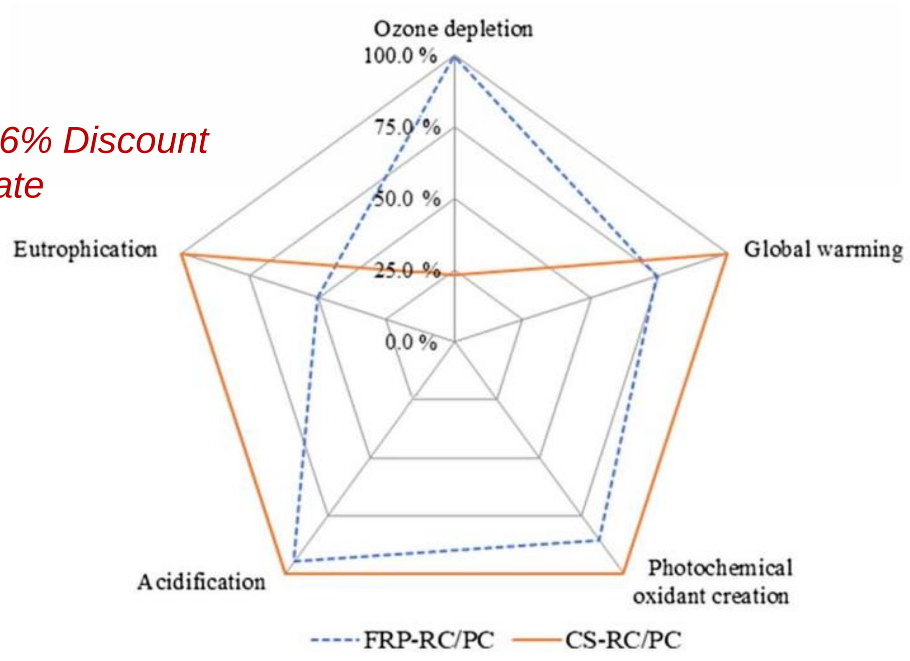
https://www.fdot.gov/structures/proglib.shtm

*** Available on request*

Cost Justification (Service Life, LCC, etc.)

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

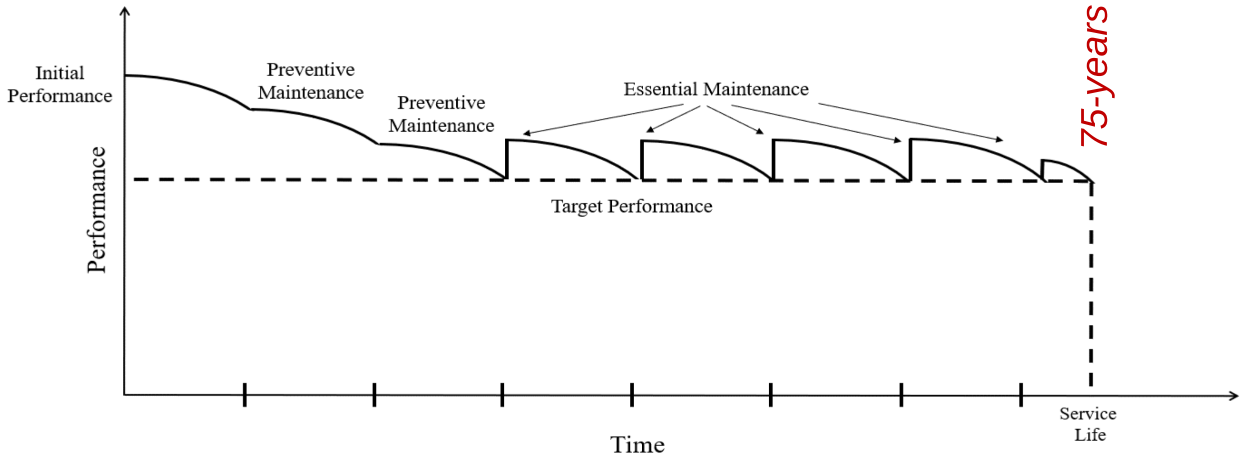




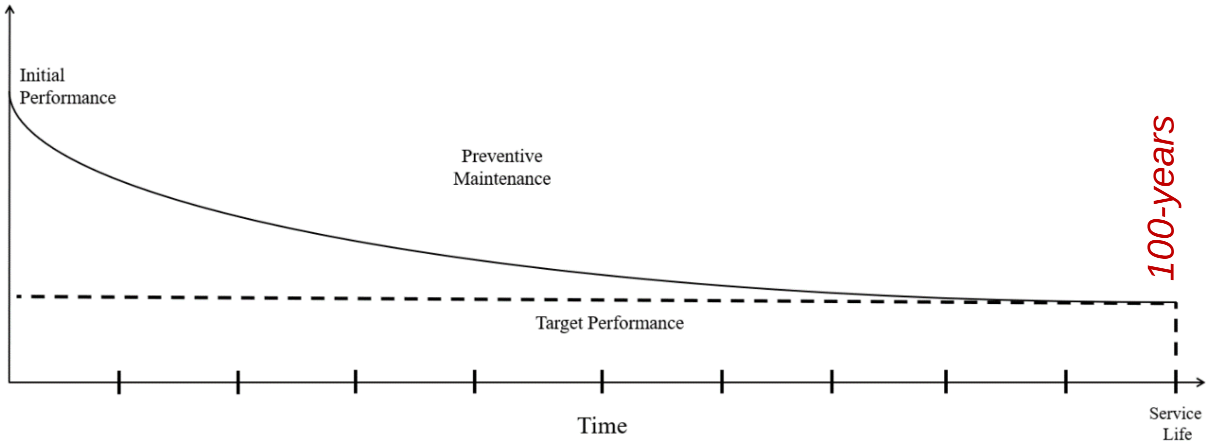
Example LCC & LCA Comparison of CSteel-RC/PC verses FRP-RC/PC bridge (0.6% Effective Discount Rate), adapted from Cadenazzi et al. 2019.

Cost Justification (Service Life, LCC, etc.)

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



CS-RC/PC alternative

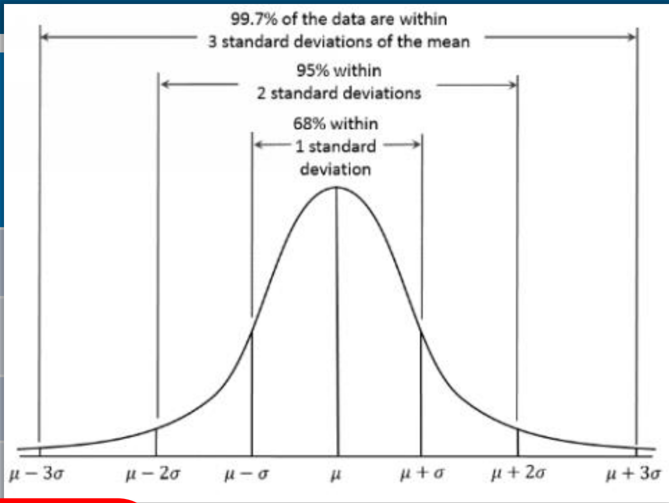


FRP-RC/PC alternative

Charts: Cadenazzi, T., Dotelli, G., Rossini, M., Nolan, S., and A. Nanni. (2019). Cost and Environmental Analyses of Reinforcement Alternatives for a Concrete Bridge. Structure and Infrastructure Engineering.

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

	AASHTO 2nd 2018	AASHTO 1st 2009	ACI 440 Code 2020?	ACI 440.1R 2015	CSA 2014	
f_{fu}^*	99.73	99.73	99.73	99.73	**95.0**	Strength percentile
Φ_C	**0.75**	**0.65**	*0.65*	0.65	0.75	Res. Fact. concr. failure
Φ_T	0.55	0.55	*0.55*	0.55	0.55	Res. Fact. FRP failure
Φ_S	0.75	0.75	*0.75*	0.75	0.75	Res. Fact. shear failure
C_E	0.70	0.70	*0.9*	0.70	**1.0**	*Environmental reduction*
C_C	**0.30**	**0.20**	0.3	0.20	0.25	*Creep rupture reduction*
C_f	**0.25**	**0.20**	0.3	0.20	0.25	*Fatigue reduction*
C_b	**0.83**	**0.70**	0.70 to 0.83	0.70	**1.0**	*Bond reduction*
w	**0.70**	**0.50**	0.70	0.7 to 0.5	0.50	Crack width limit [mm]
$c_{c,stirrup}$	40	40	50	50(1)	40	Clear cover [mm]
$c_{c,slab}$	25	20 to 50	20 to 50	20 to 50(1)	40	Clear cover [mm]
$\varepsilon_{f,shear}$	*0.004*	*0.004*	*0.004*	*0.004*	*0.005*	*Strain limit in shear reinf.*



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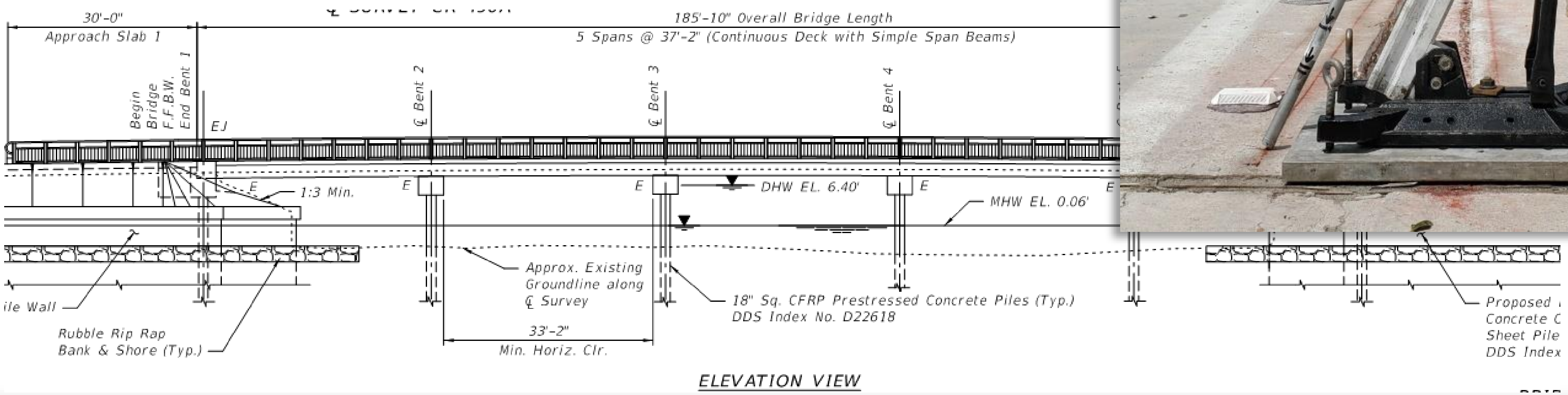
To be finalized

(1) ACI 440.5-08 Table 3.1

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

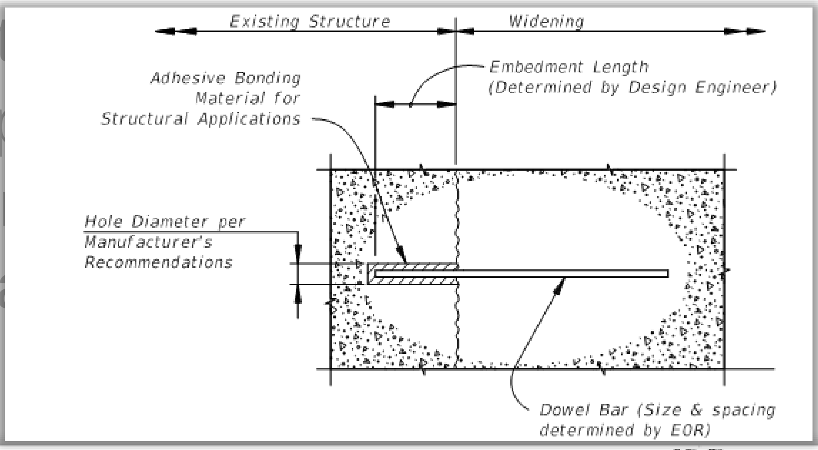
- Connections (post-installed, couplers)
- Fatigue limits
- Importance of Elastic Modulus
- Bent Bars
- Scalability of production

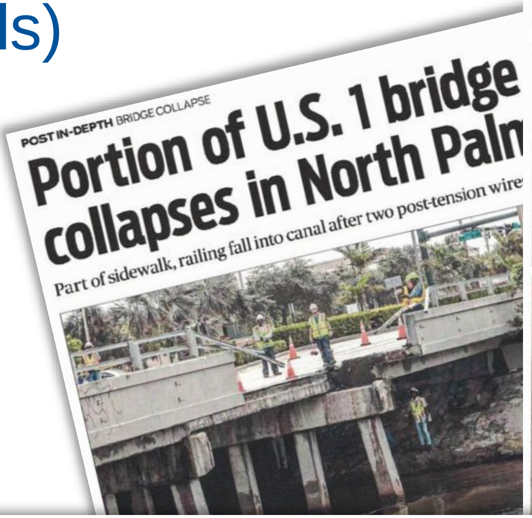
1700+ Holes

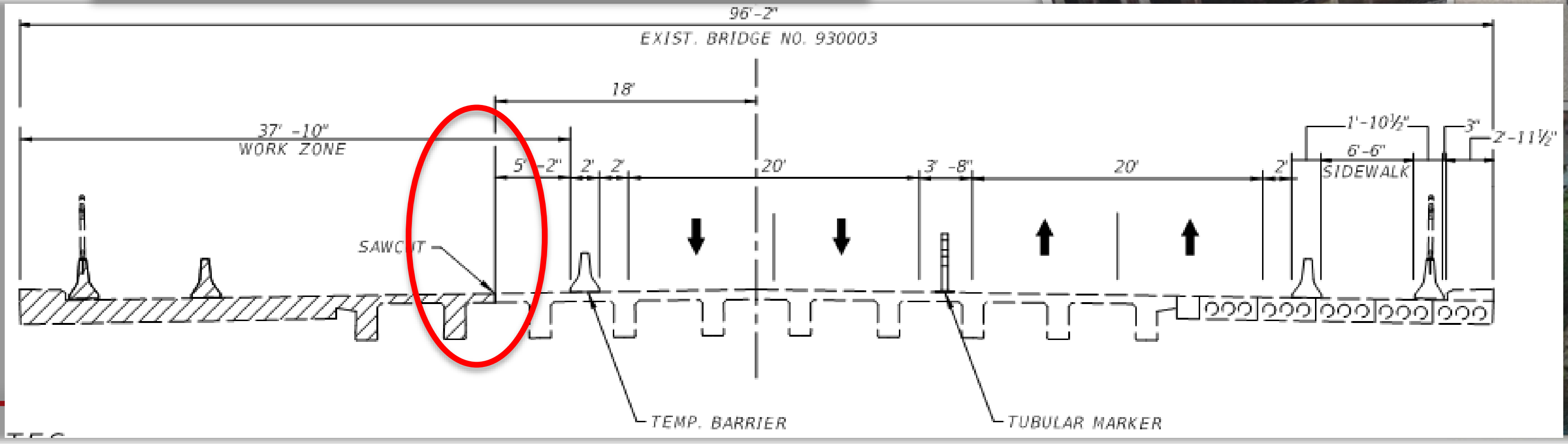


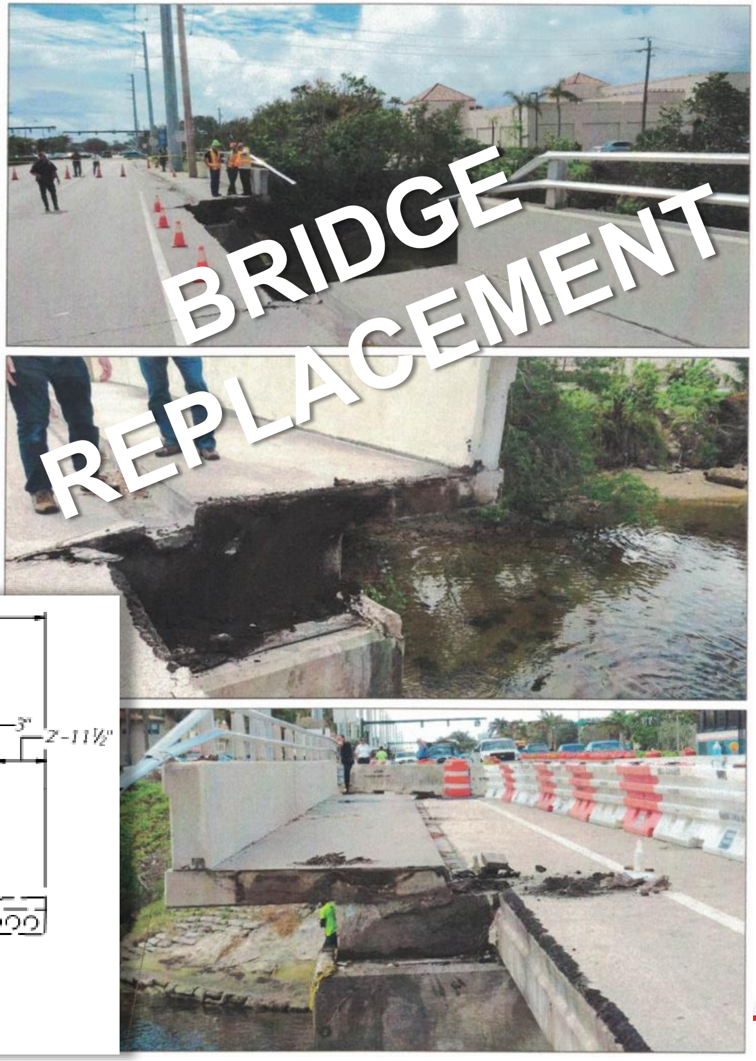
What do we still need (gaps in design and deployment)?

- Connections (post-installed - dowels)
- Fa
- Im
- Be
- Sc









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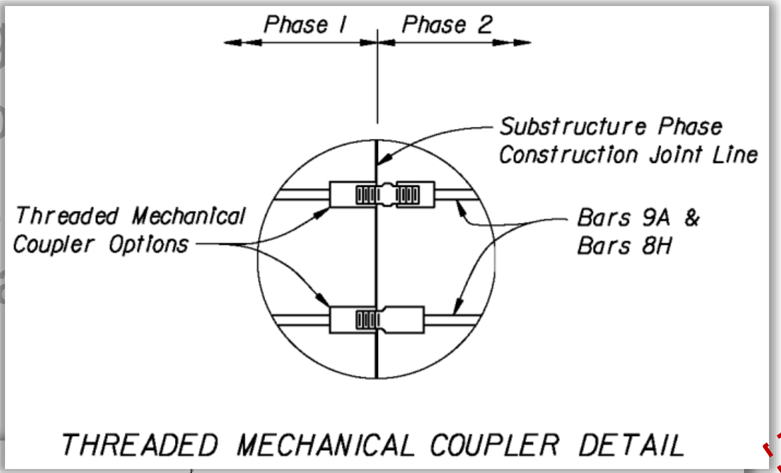
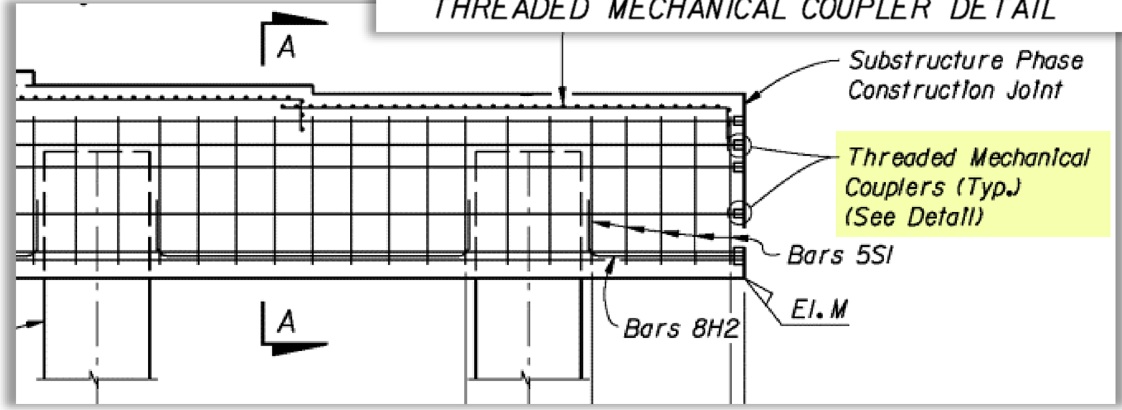
What do we still need (gaps in design and deployment)?

- Connections (mechanical couplers)
- Fatig
- Impo
- Bent
- Scal

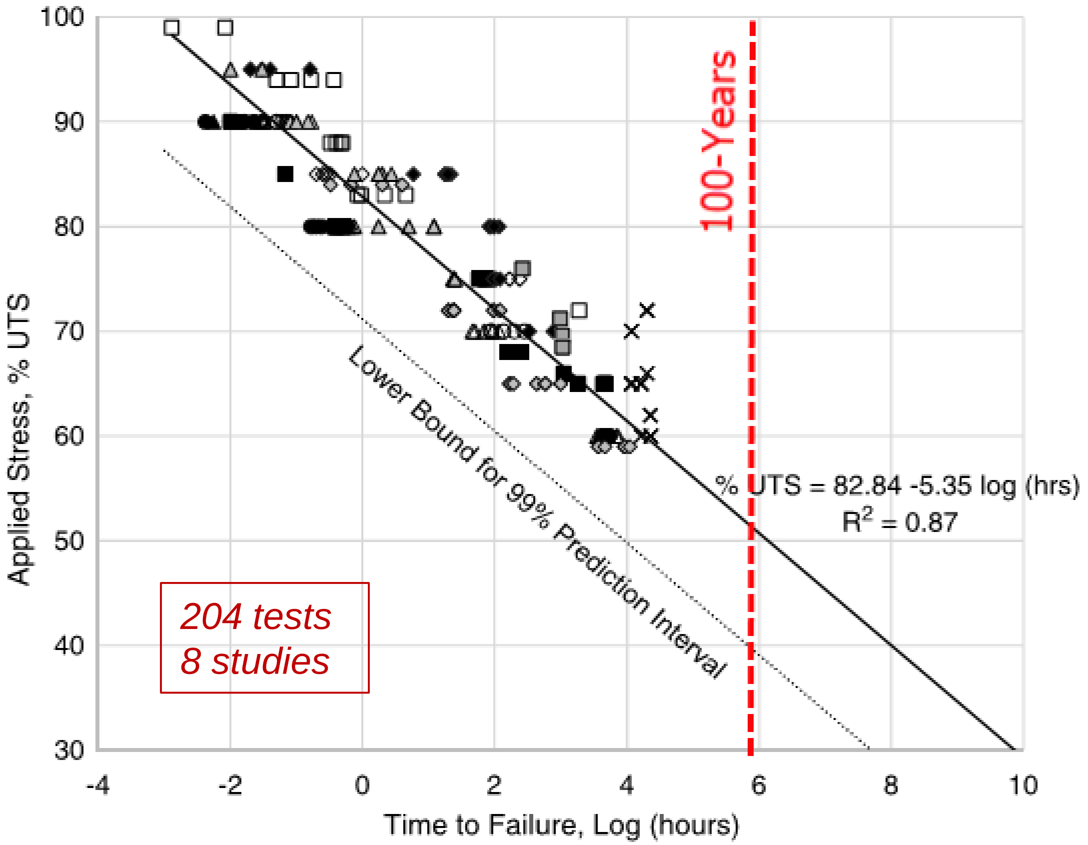




What do we still need (gaps in design and deployment)?

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

recommended creep-rupture stress limit ($0.30 f_{fu}$) 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.



DOI: 10.1061/(ASCE)CC.1943-5614.0000971.

From: "Creep-Rupture Limit for GFRP Bars Subjected to Sustained Loads", (2019)
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

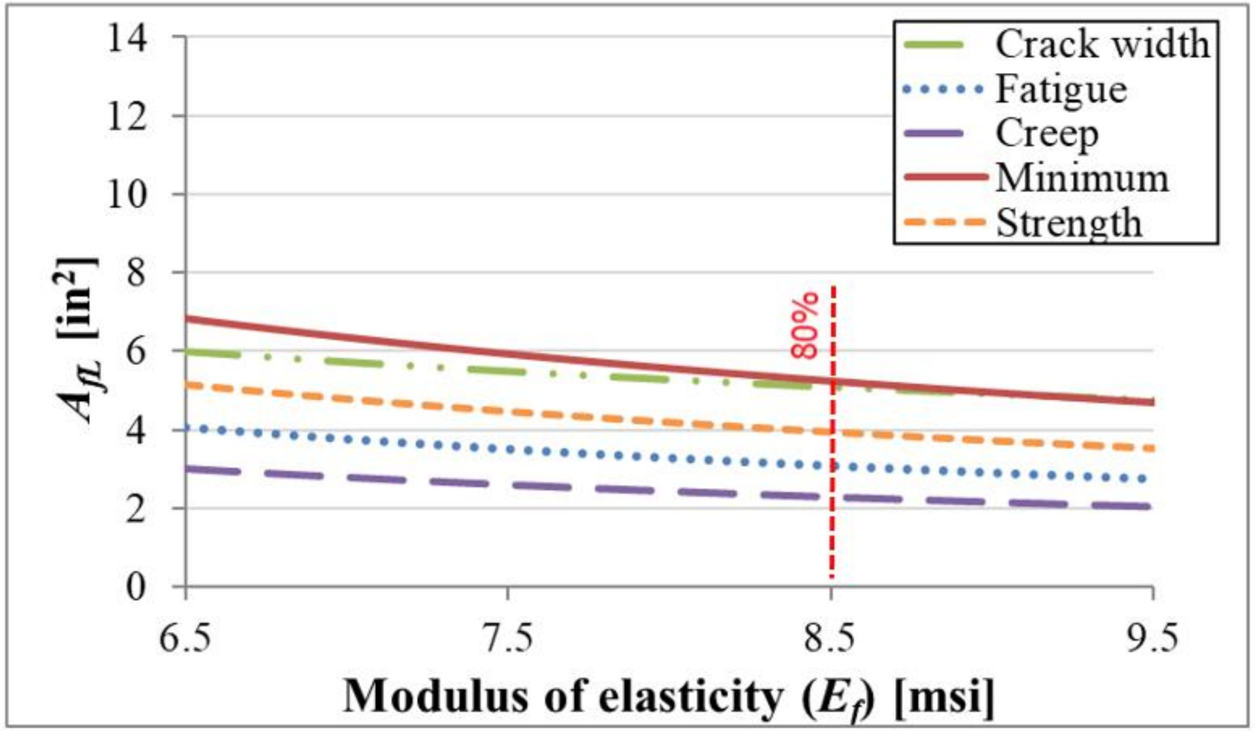
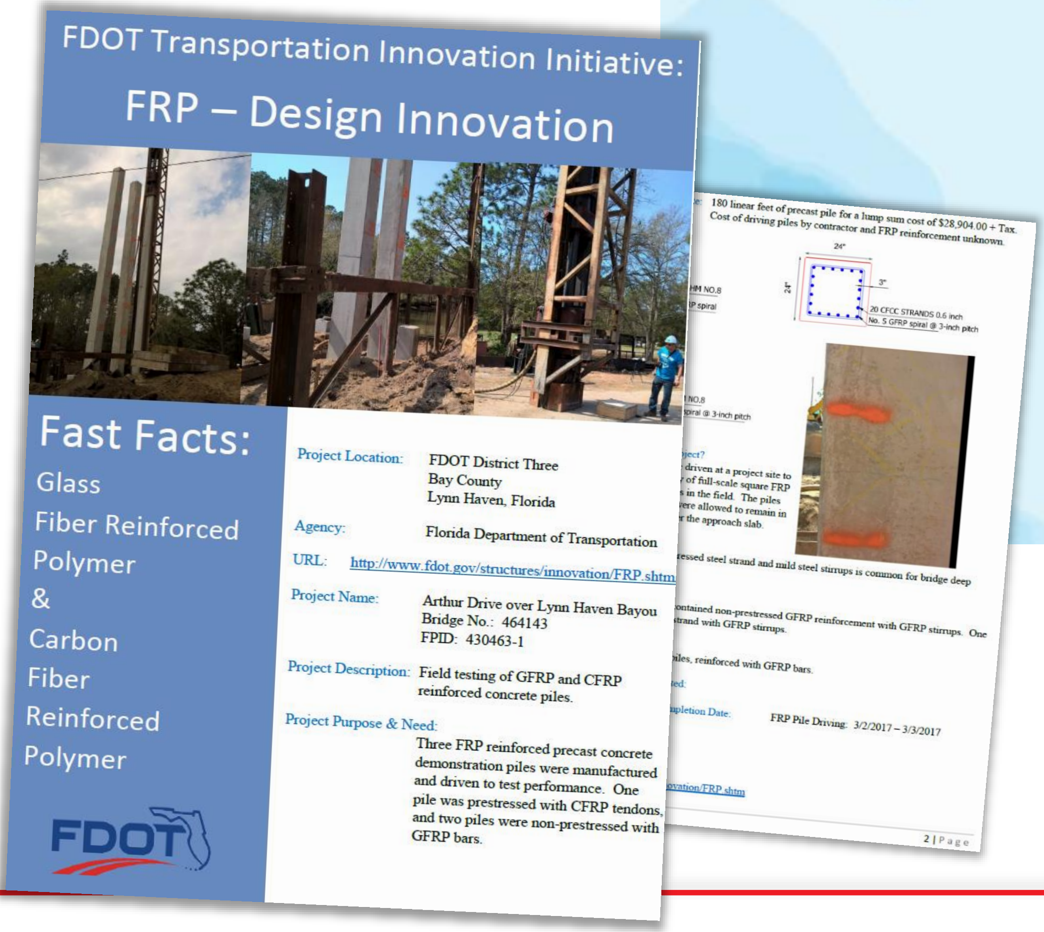
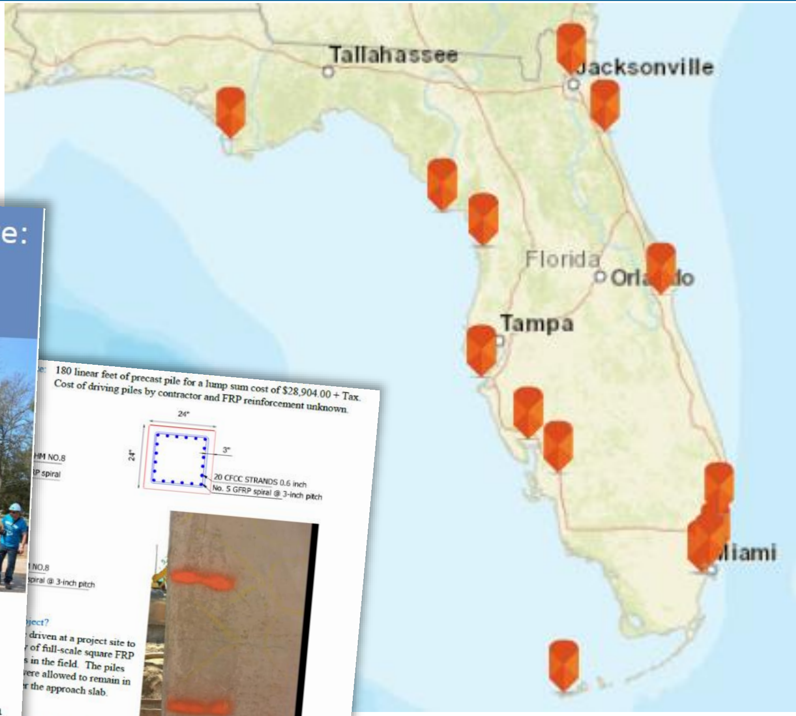


Figure: Parametric analysis of flexural design algorithms per AASHTO GFRP-RC 2nd edition for HRB Bent Cap

From: M.Rossini, F.Matta, S.Nolan and A.Nanni, Extended Abstract *"Overview of Proposed AASHTO Design Specifications for GFRP-RC Bridges 2nd Edition using Case-Specific Parametric Analysis"* (2017)

Project Examples – Fast Facts



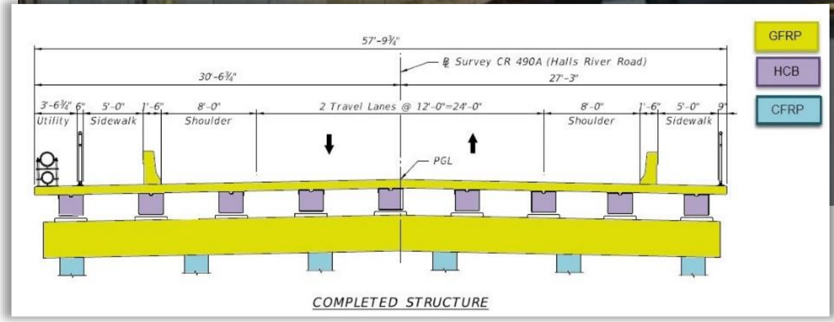


Project Examples - Halls River Bridge

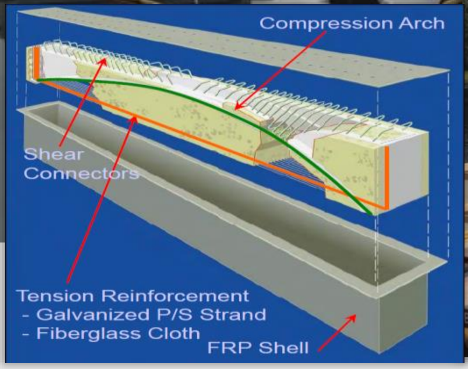
FDOT's Fiber-Reinforced Polymer Deployment Train

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

FLAGSHIP PROJECT



HRB GFRP-RC Diaphragms for HCB's (2018)



HRB Hybrid Composite Beams (2017)

Project Examples - Halls River Bridge

Homosassa, FL 2017-2019 (GFRP-RC & CFRP-PC)

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

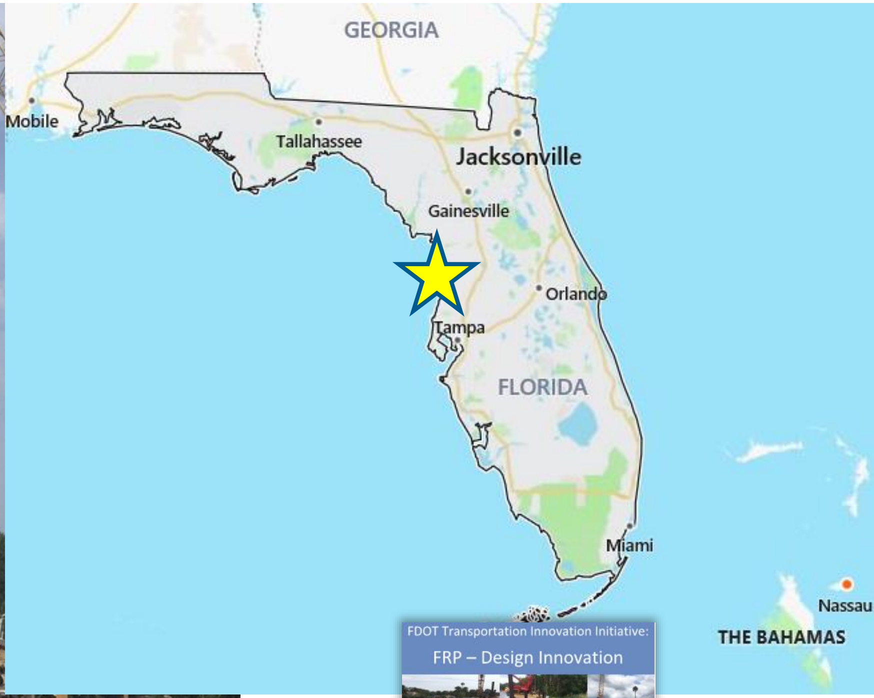
- CFRP-PC bearing piles;
- CFRP-PC/GFRP-RC sheet piles;
- Hybrid HSCS-PC/GFRP-RC sheet piles;
- GFRP-RC bulkhead caps;
- GFRP-RC pile bent caps;
- GFRP-RC bridge deck
- GFRP-RC traffic railings
- GFRP-RC approach slabs
- GFRP-RC gravity wall.

HRB GFRP-RC Bent Cap (2017)


HRB GFRP-RC Deck Casting (2018)

Project Examples - Halls River Bridge

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




FDOT Transportation Innovation Initiative:
FRP – Design Innovation

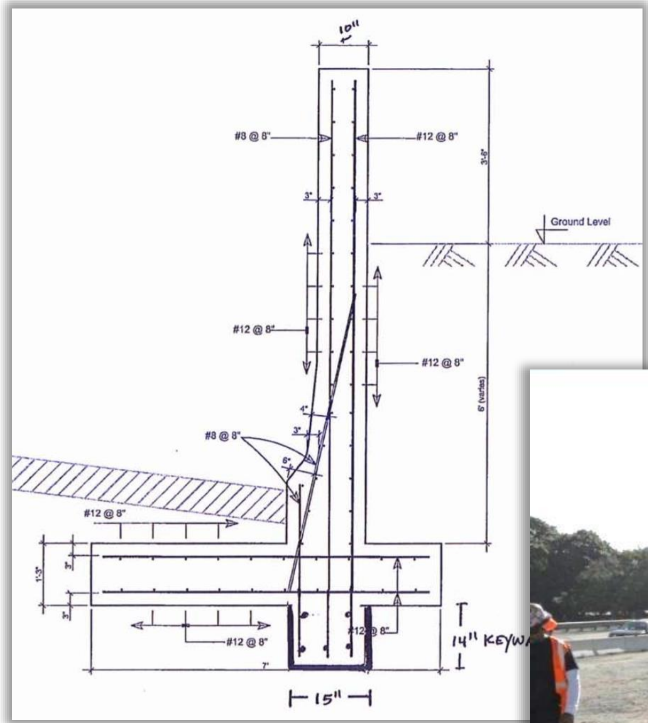
Fast Facts:
Glass Fiber Reinforced Polymer & Carbon Fiber Reinforced Polymer & Hybrid Composite Beam

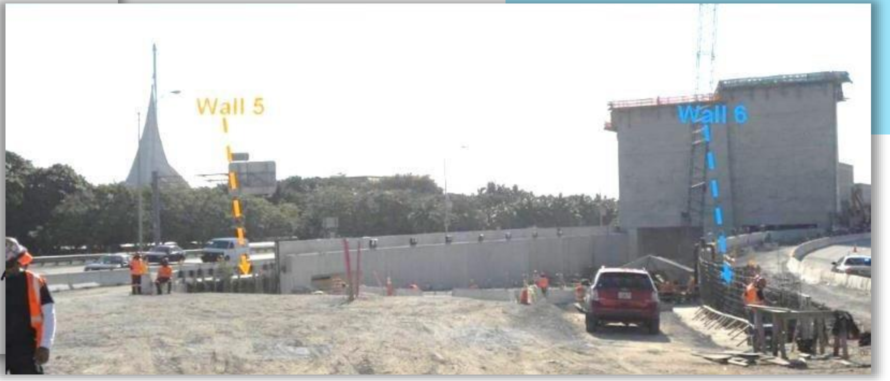
[Halls River Bridge]

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

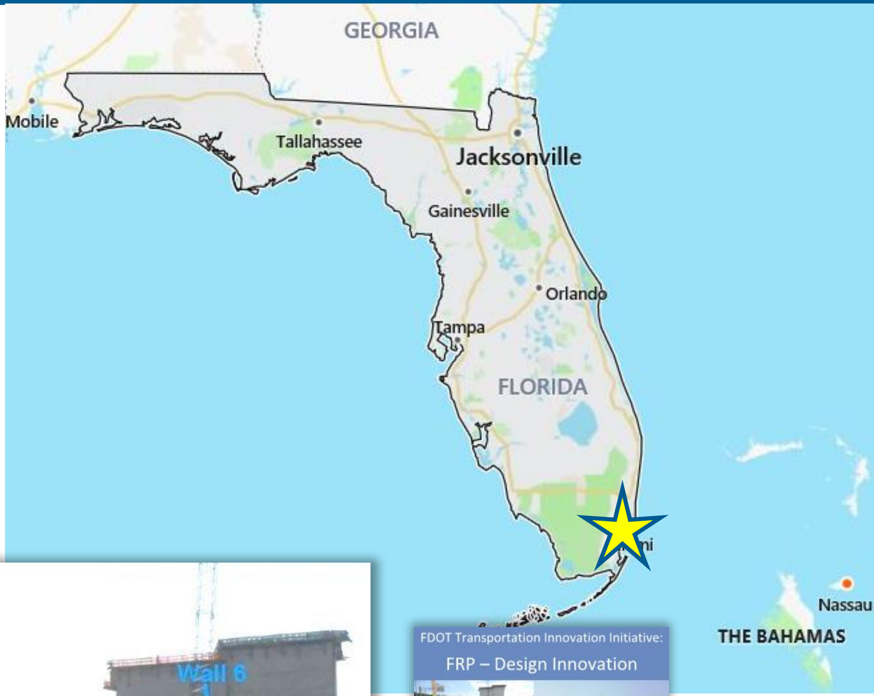
Project Examples - Port Miami Tunnel Entrance Walls

Watson Island, Miami – 2014





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




FDOT Transportation Innovation Initiative:
FRP – Design Innovation
Fast Facts:
Basalt Fiber Reinforced Polymer

[Port Miami Tunnel](#)

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

Project Examples - Innovation Pedestrian Bridge

University of Miami – 2016


FDOT Transportation Innovation Initiative:

FRP – Design Innovation

Fast Facts:

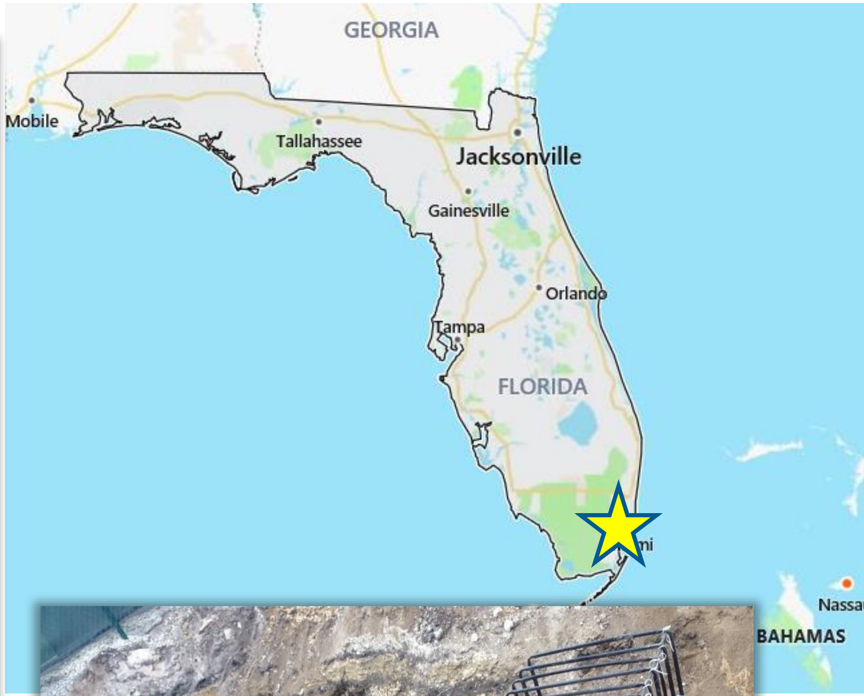
Glass Fiber Reinforced Polymer

Project Location: Coral Gables, Florida

Agency: University of Miami

Project Name: Innovation Pedestrian Bridge

UNIVERSITY OF MIAMI



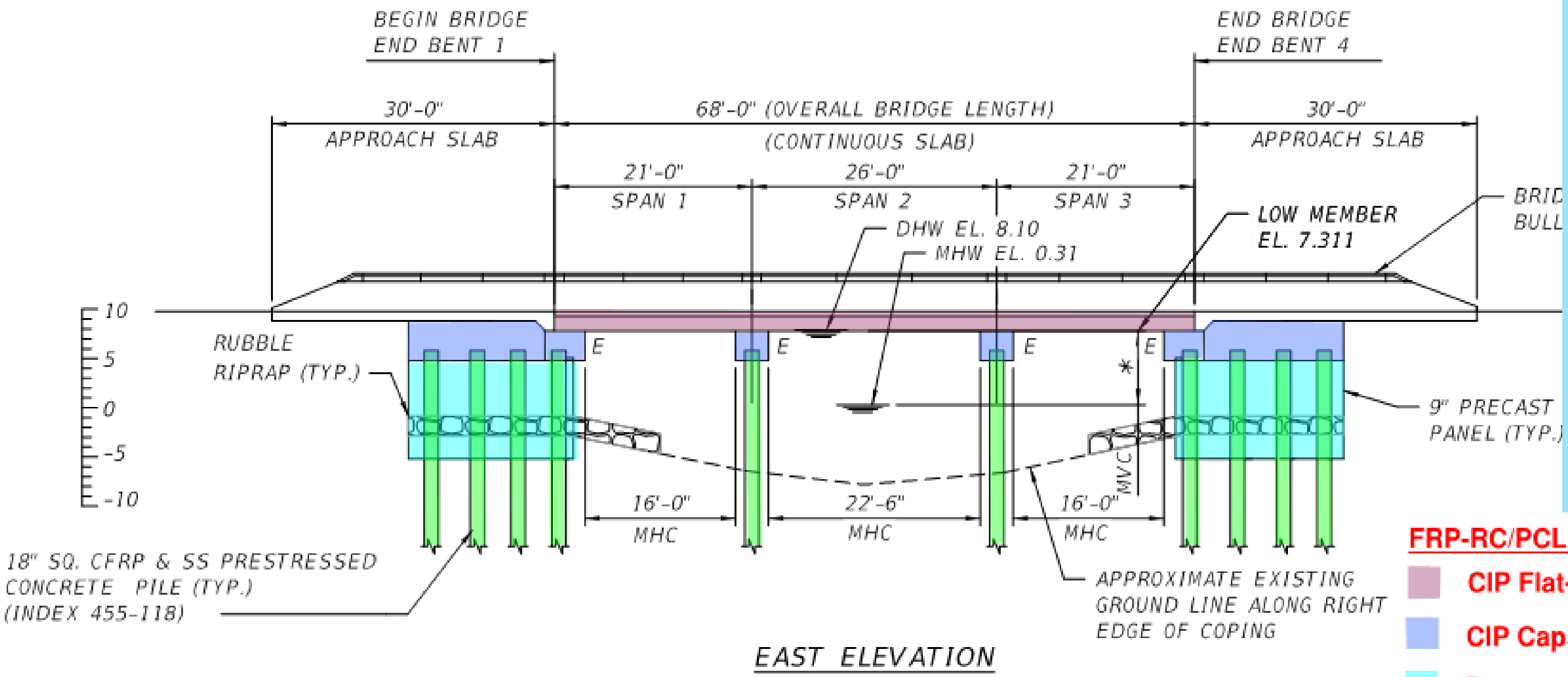
Elevation view of Innovation Bridge with BFRP reinforcement in the auger-cast-piles, bent-caps, double-tee stems and flanges, deck overlay and curbs.

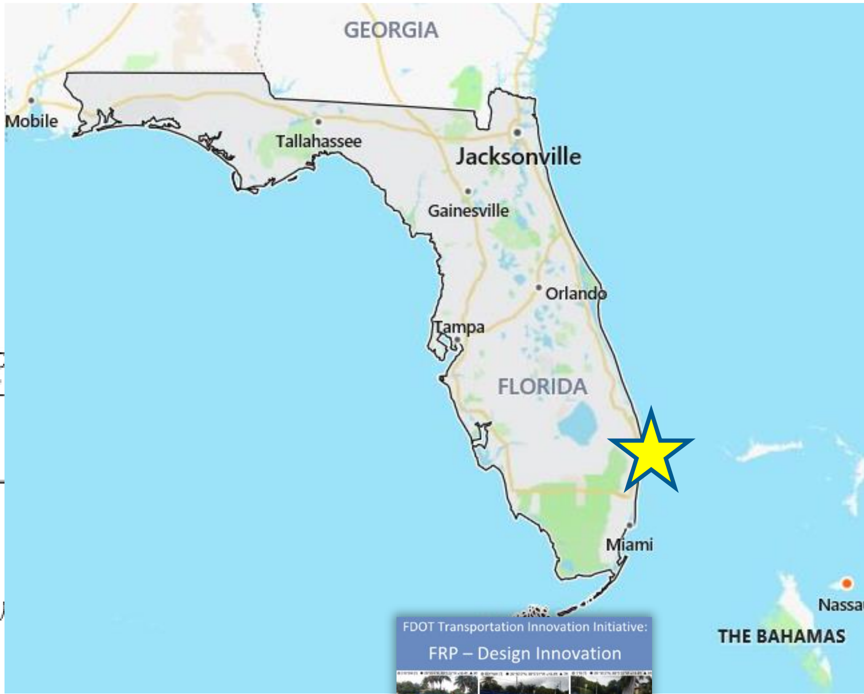
Innovation Bridge

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

Project Examples - NE 23rd Ave/Ibis Waterway

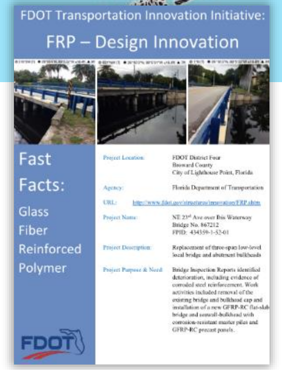
CIP continuous flat-slab bridge:





FRP-RC/PCLEGEND

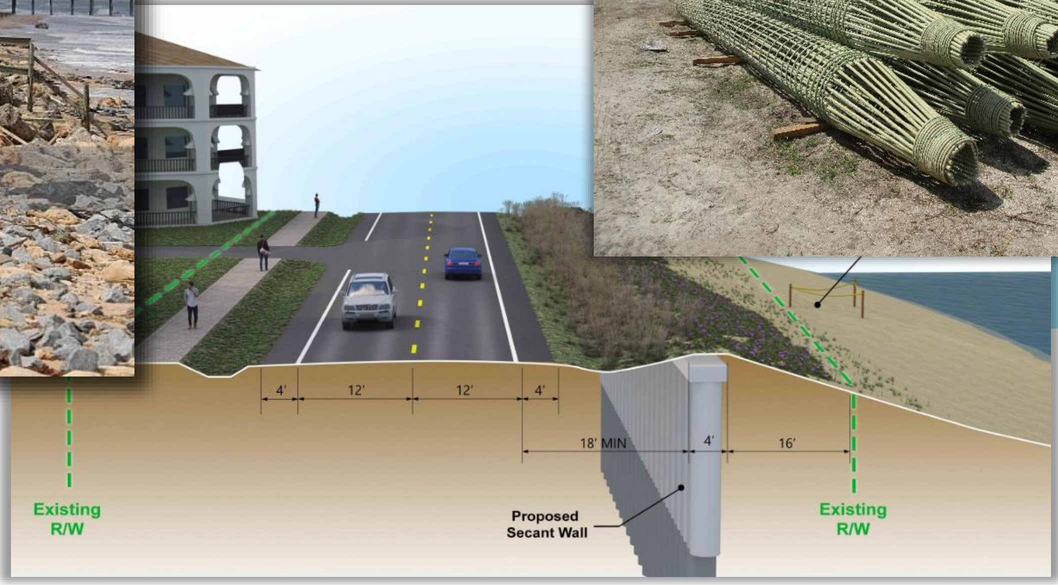
- CIP Flat-Slab, 5.5 ksi (1.5" cover)
- CIP Caps, 5.5 ksi (3" cover)
- Precast Panels, 5.5 ksi (2" cover)
- PS Piles, 6 ksi (3" cover)



[NE 23rd Ave/Ibis Waterway](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)]

Questions ?

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FDOT Materials and Manufacturer Approvals

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