Florida Bridges and Structures for 100+ Years' Service with FRP Composites

Bruno Vasconcelos / Steve Nolan

Florida DOT

Contributing Partners:

MIAMI WAGNERS AIT BRIDGES FAMU-FSU Engineering FDOT CAMX THE COMPOSITES AND ADVANCED MATERIALS EXPO

Anaheim Convention Center | Anaheim, CA, USA

Abstract

Recent applications for new construction using Fiber-reinforced Polymer (FRP) composites is expanding in Florida. This presentation will highlight projects from 2018/2019 that utilize a variety of FRP materials for construction of new highway infrastructure applications including: Basalt-FRP & Glass-FRP reinforcing bars for concrete bridge structures; Carbon-FRP prestressed bridge beams; FRP structural shapes and pilings. Recent publication of Glass-FRP and Carbon-FRP Guide Specifications by the American Association of State Highway Officials (AASHTO) have enabled expanded and streamlined deployment of these innovative materials in highway infrastructure. Additional research and evaluation is ongoing to refine these standards and improve the economy of FRP composite structures. Brief case studies on three bridges and three non-bridge infrastructure applications exceeding $25M construction.

The bridge case-studies involve cast-in-place continuous slabs, prestressed slab and girder bridge applications (including coupling FRP elements with Ultra-High Performance Concrete). The non-bridge applications include: precast and cast-in-place retaining walls and seawalls; and thermoset piling and structural shape elements for various in-water structures.

Life-Cycle Cost (LCC) analysis can range from simple to complex depending on the desired level of precision and effort. Three levels of analysis are presented for use by designers during the Bridge Alternatives Development process for selecting the final design option:

- Level 1 – Basic (Average Acquisition Cost per Year);
- Level 2 – Intermediate (Stepwise LCC for discrete construction and maintenance);
- Level 3 – Advanced (Probabilistic analysis of stepwise methodology).

These strategies for a tiered LCC approach using increasing levels of complexity will be presented with selected application to some of the case study projects

Key Topics

- The Value Proposition of FRP for Bridges and Marine Structures;
- Authoritative resources, guidelines, and specifications;
- Example Projects from Florida 2018-2020;
- Ongoing Applied Research and Future Opportunities;
- Challenges to the Manufacturing Industry.

The Value Proposition of FRP for Bridges and Marine Structures

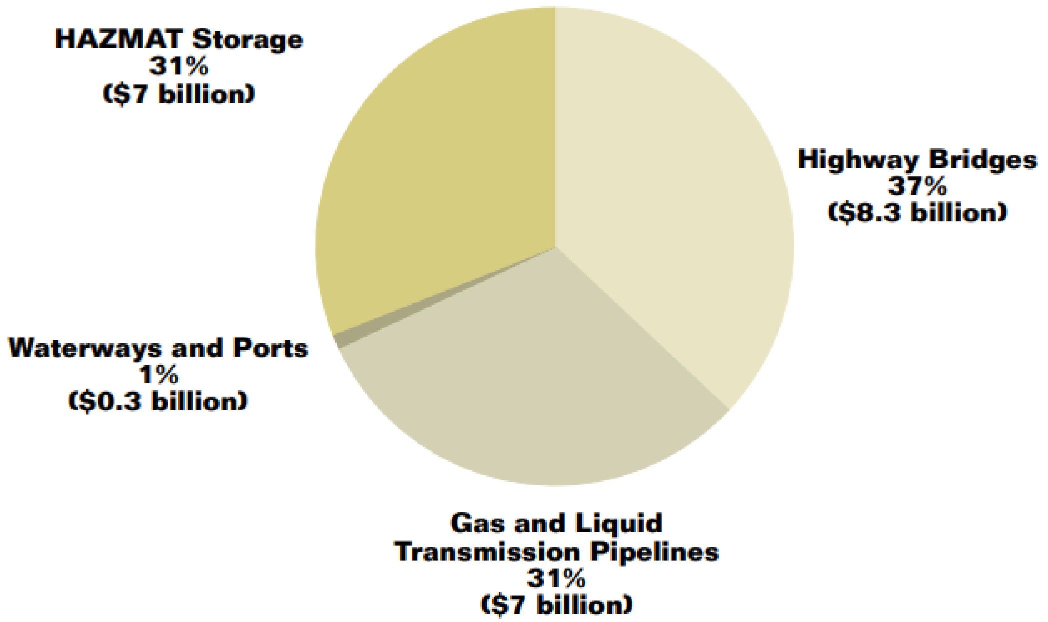
- Durability vs. Cost (repair and replacement);
- Extended Service-Life vs. Cost (LCC & LCA);
- Reliability vs. Cost. (Quality is an investment);
- Embracing the competition (and taking a larger piece of the pie).

Value Proposition…

- Mostly motivated by corrosion durability concerns…

FIGURE 2

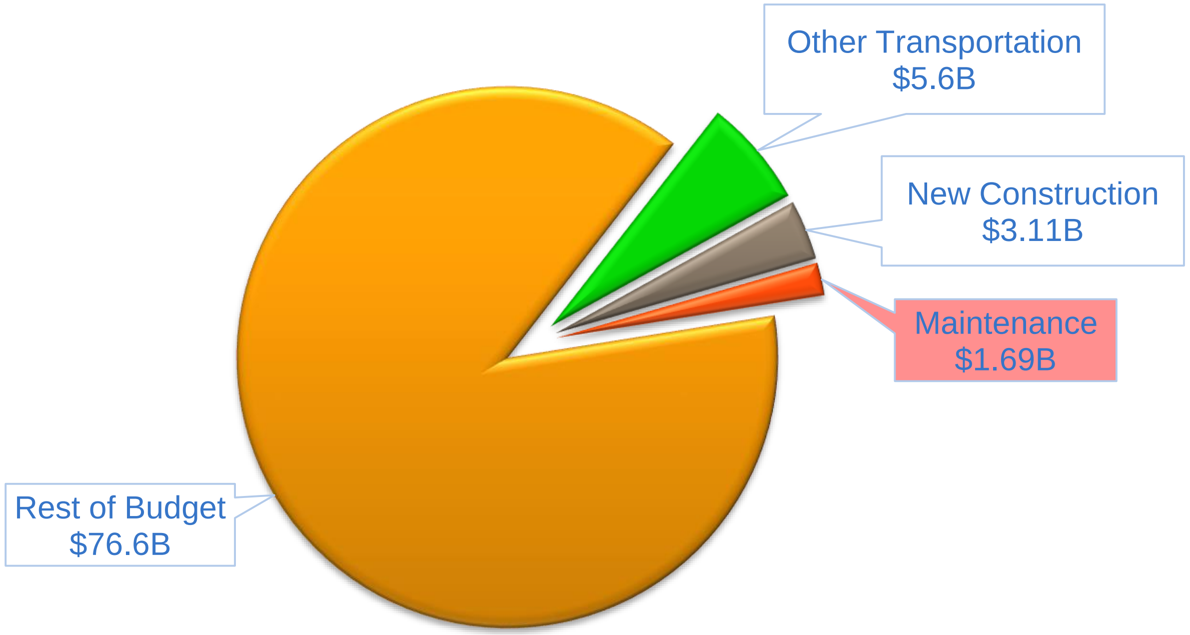
INFRASTRUCTURE ($22.6 BILLION)



Annual cost of corrosion in the infrastructure category.

http://impact.nace.org/documents/ccsupp.pdf

FDOT Budget FY 2018-19



http://floridafirstbudget.com/web%20forms/Budget/BudgetAgency.aspx

Value Proposition…

- Florida is ranked ***2nd*** behind Alaska in the longest US coastline.


RESEARCH COMMUNICATIONS RESEARCH COMMUNICATIONS

301

Engineering away our natural defenses: an analysis of shoreline hardening in the US

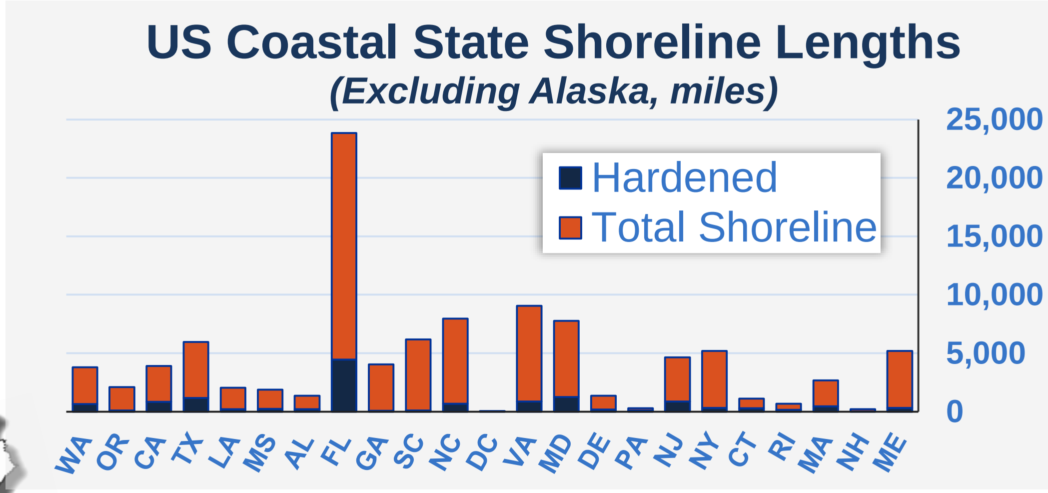
Rachel K Gittman[1*†], F Joel Fodrie[1], Alyssa M Popowich[2], Danielle A Keller[1], John F Bruno[3], Carolyn A Currin[4], Charles H Peterson[1], and Michael F Piehler[3]

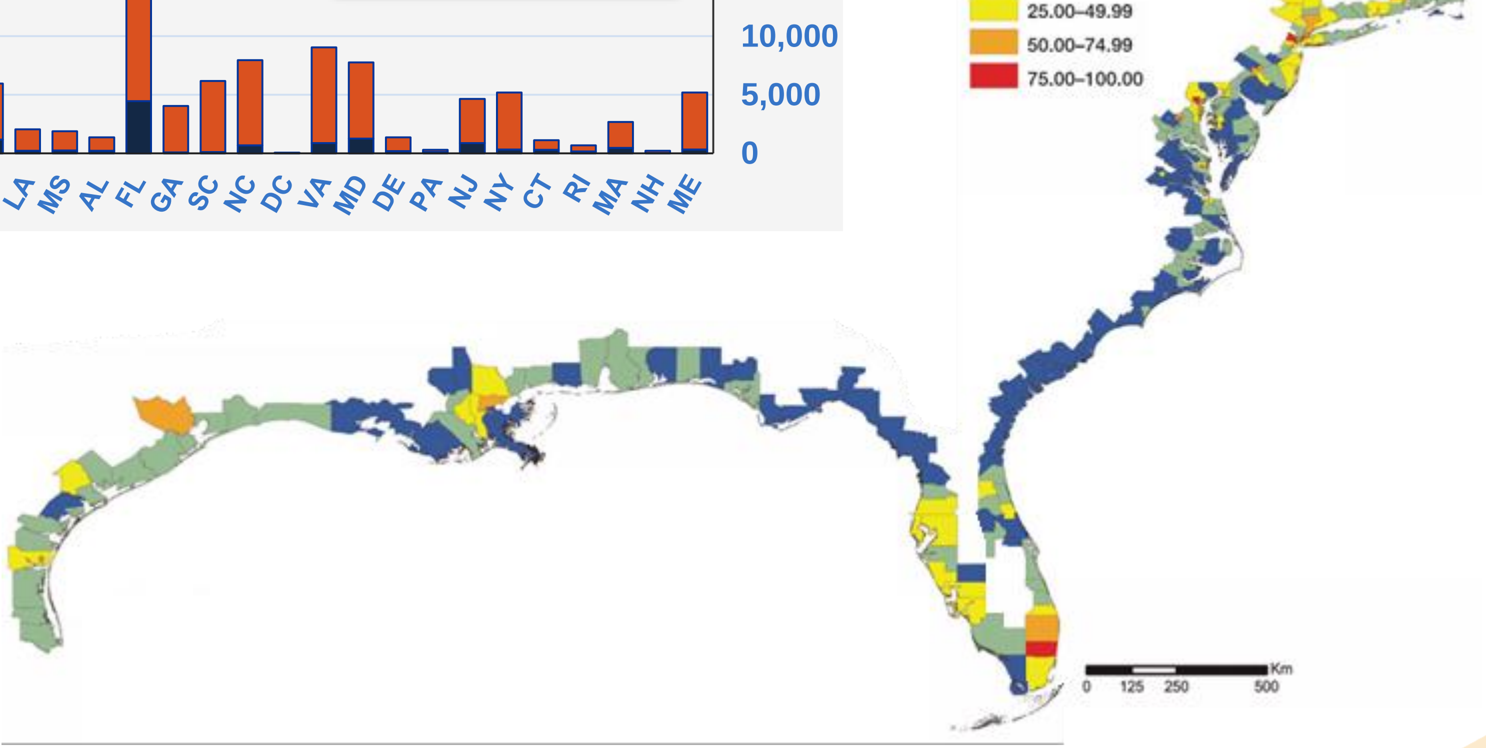
Rapid population growth and coastal development are primary drivers of marine habitat degradation. Although shoreline hardening or armoring (the addition of concrete structures such as seawalls, jetties, and groins), a byproduct of development, can accelerate erosion and loss of beaches and tidal wetlands, it is a common practice globally. Here, we provide the first estimate of shoreline hardening along US Pacific, Atlantic, and Gulf of Mexico coasts and predict where future armoring may result in tidal wetland loss if coastal management practices remain unchanged. Our analysis indicates that 22 842 km of continental US shoreline – approximately 14% of the total US coastline – has been armored. We also consider how socioeconomic and physical factors relate to the pervasiveness of shoreline armoring and show that housing density, gross domestic product, storms, and wave height are positively correlated with hardening. Over 50% of South Atlantic and Gulf of Mexico coasts are fringed with tidal wetlands that could be threatened by future hardening, based on projected population growth, storm frequency, and an absence of coastal development restrictions.

Front Ecol Environ 2015; 13(6): 301–307, doi:10.1890/150065

Although coastal regions constitute less than 4% of the Earth's land area, coastal habitats (eg beaches and tidal wetlands; Figure 1) rank among the most valuable natural resources globally (MA 2005). Over one-third of the human population lives within 100 …

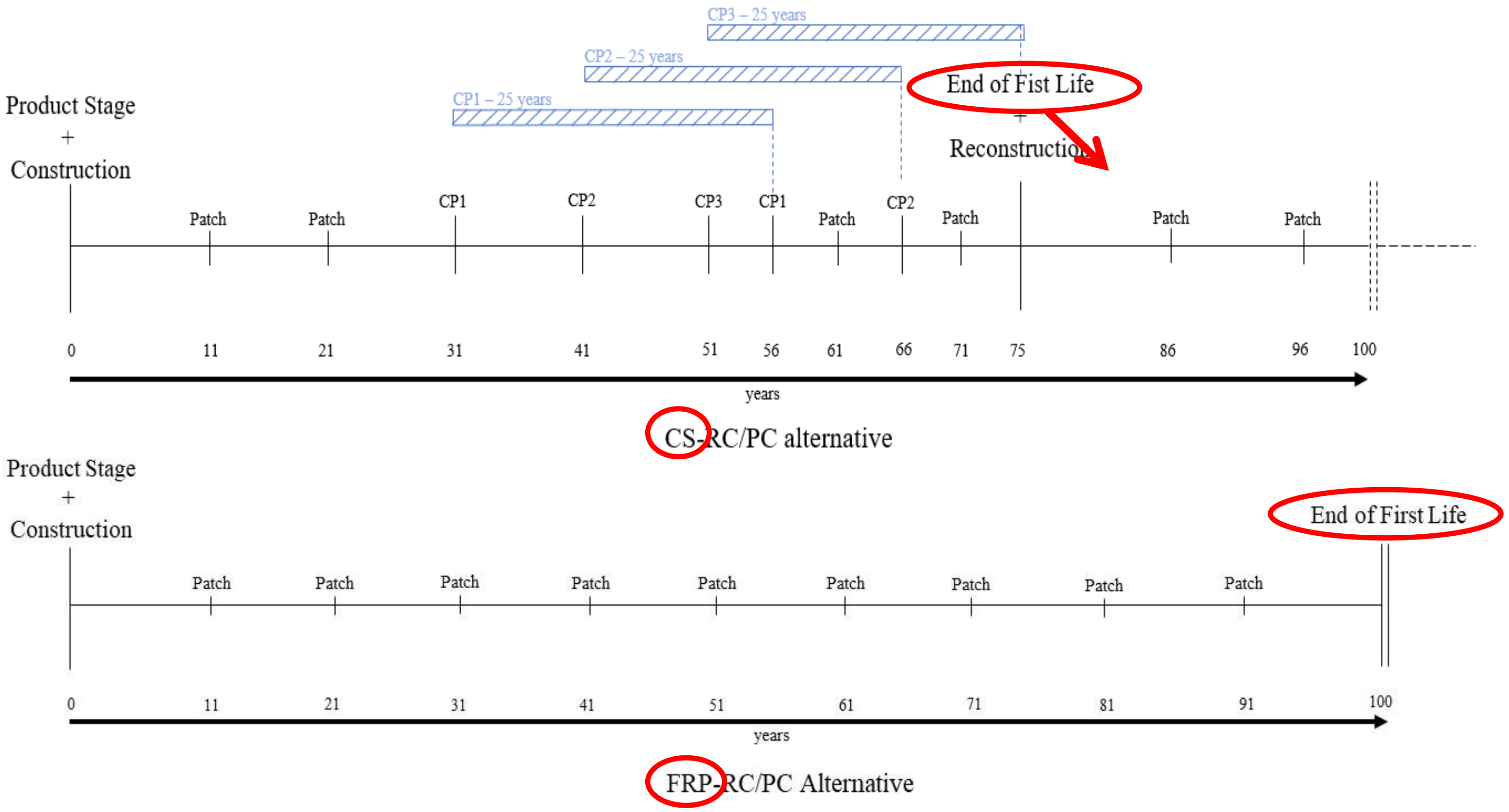
… also provide less physically complex habitat as compared with natural shorelines, so that hardened shorelines generally support fewer species (Figure 1; Seitz et al. 2006; Gittman et al. in press). When constructed landward of … structures may also increase …





Value Proposition…

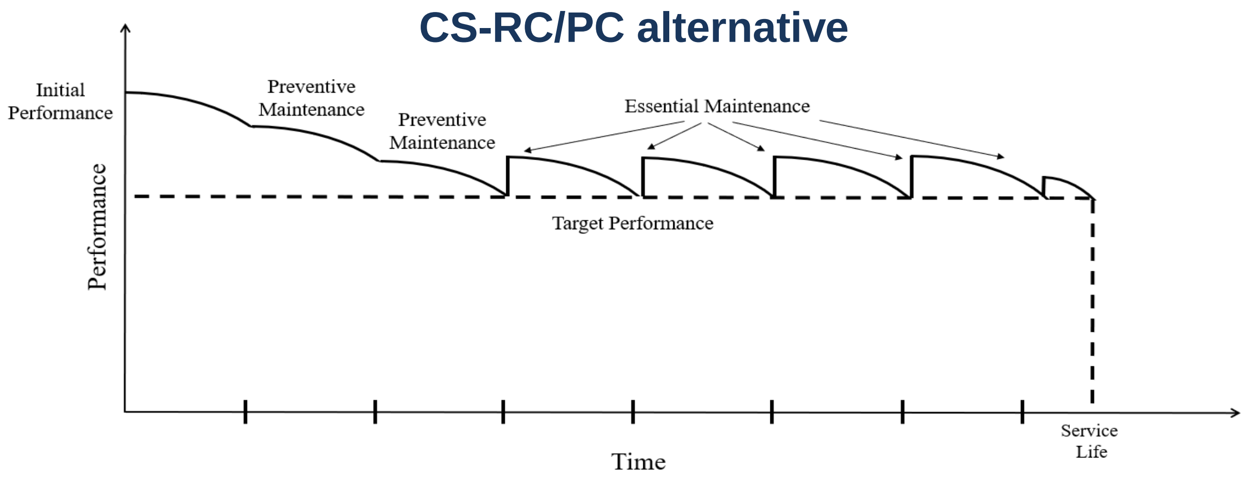
- Extended Service-Life vs. cost (LCC & LCA);

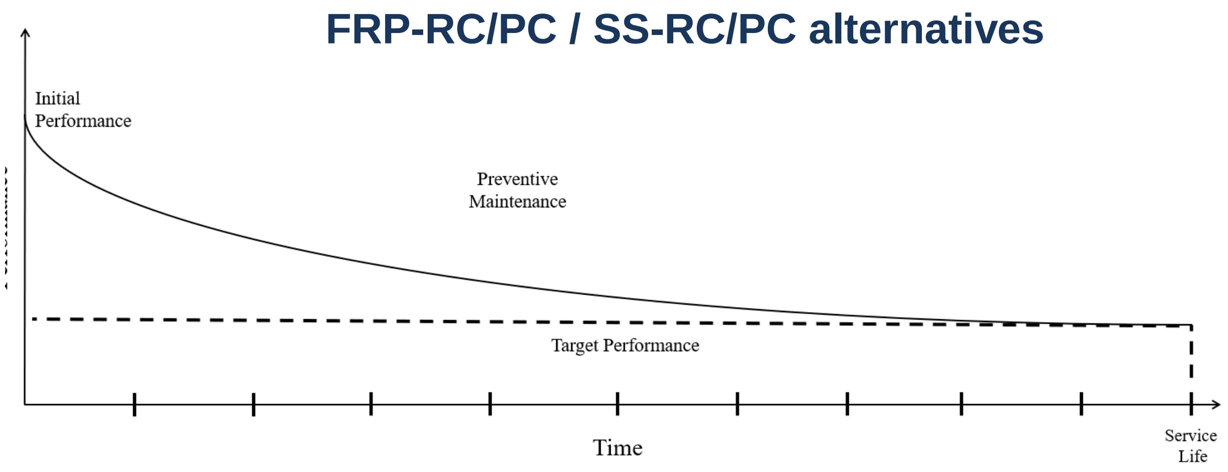


Charts: Cadenazzi, T., Dotelli, G., Rossini, M., Nolan, S., and A. Nanni. (2019). Life-Cycle Cost and Life-Cycle Assessment Analysis at the Design Stage of a Fiber-Reinforced Polymer-Reinforced Concrete Bridge in Florida. Advances in Civil Engineering Materials. ASTM.

Value Proposition…

- Embracing the competition (and taking a larger piece of the pie).

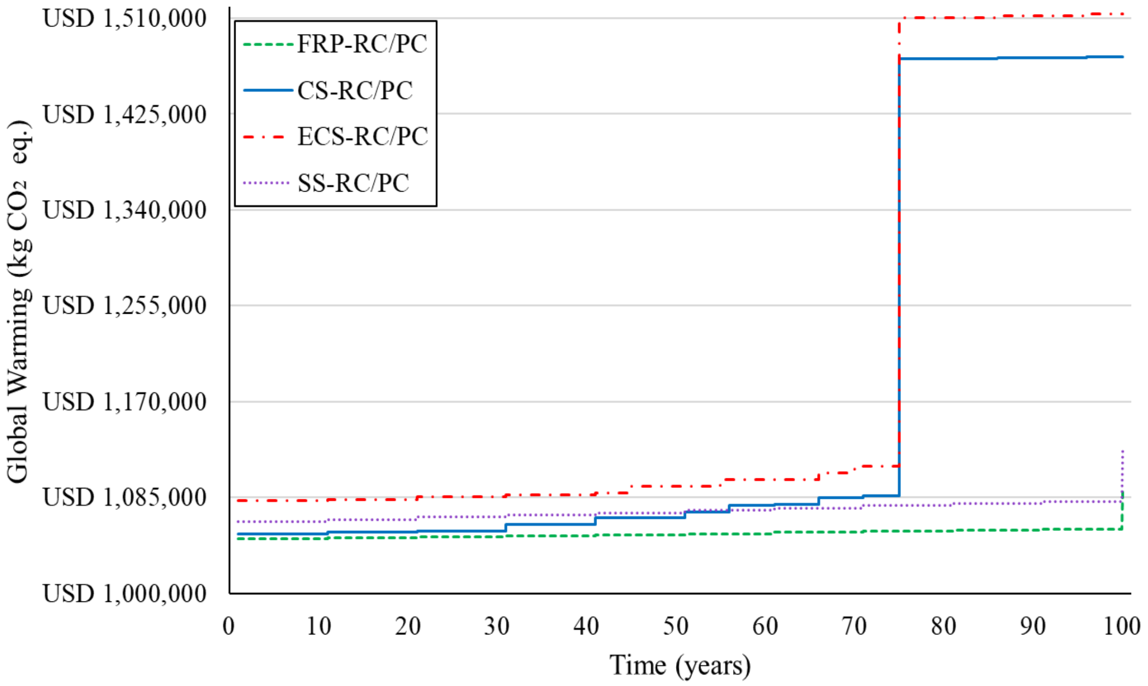


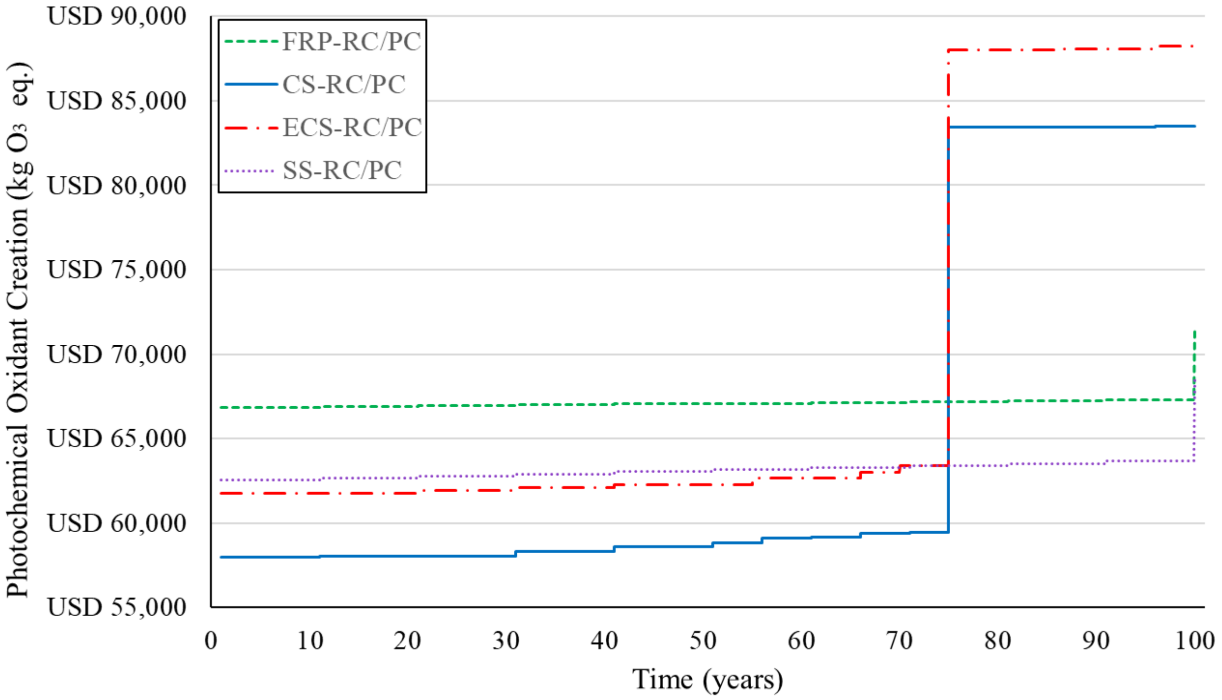


Charts: Cadenazzi, T., Dotelli, G., Rossini, M., Nolan, S., and A. Nanni. (2019). Cost and Environmental Analyses of Reinforcement Alternatives for a Concrete Bridge. Structure and Infrastructure Engineering.

Value Proposition…

- Environmental implications (LCA);





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Authoritative resources, guidelines, and specifications

- AASHTO for Concrete Structures (GFRP-RC & CFRP-PC Guide Specs);
- AASHTO & ASCE FRP Composite Structures (various Guide Specs);
- CSA for Concrete Structures (S807 & S6)
- National & International harmonization;
- FDOT's Implementation Strategy (Design, Manufacturer Approval, Construction);

Authoritative resources…

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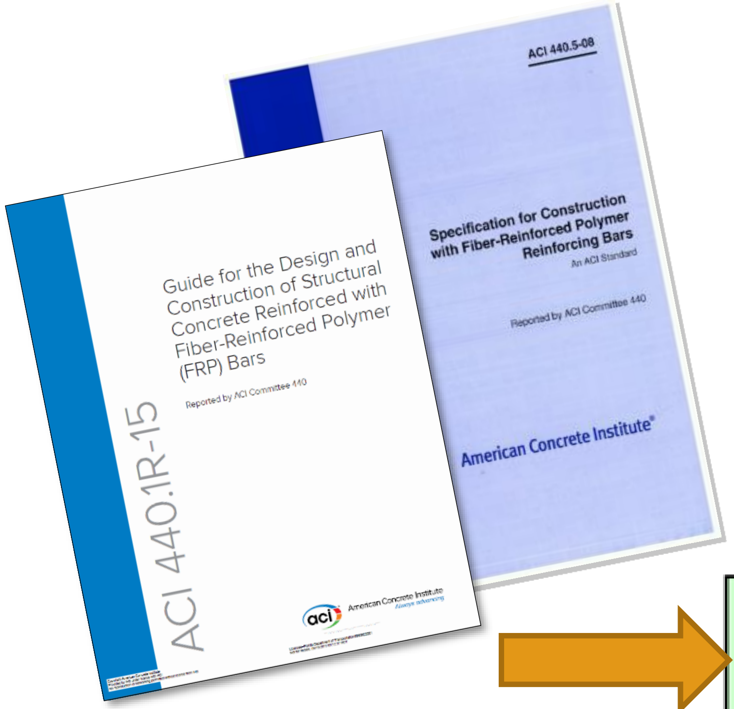
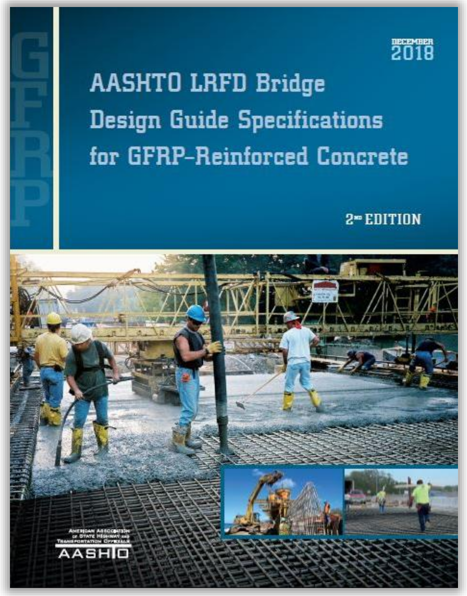
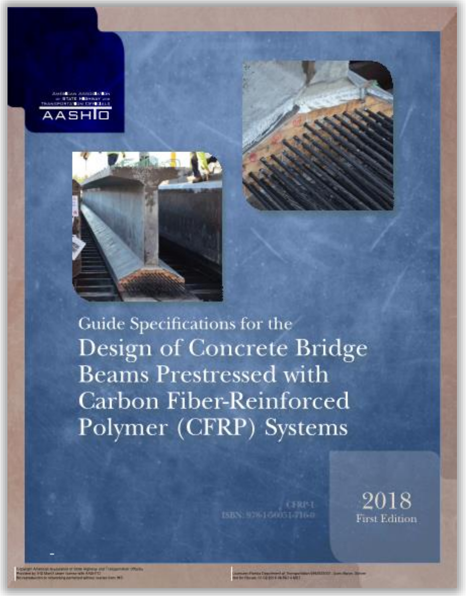


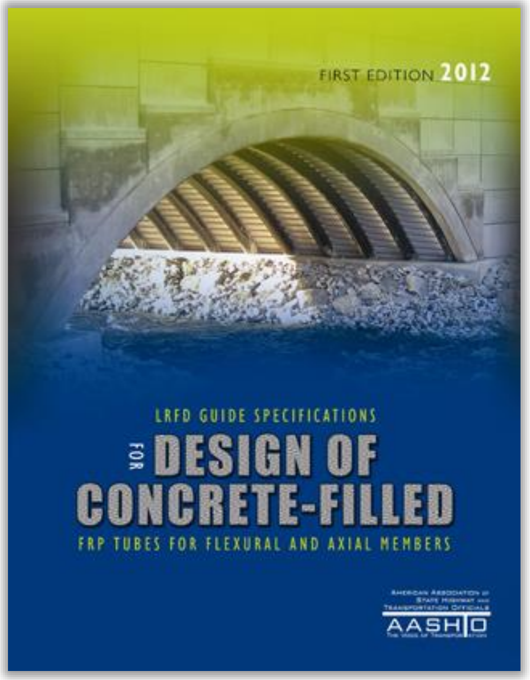


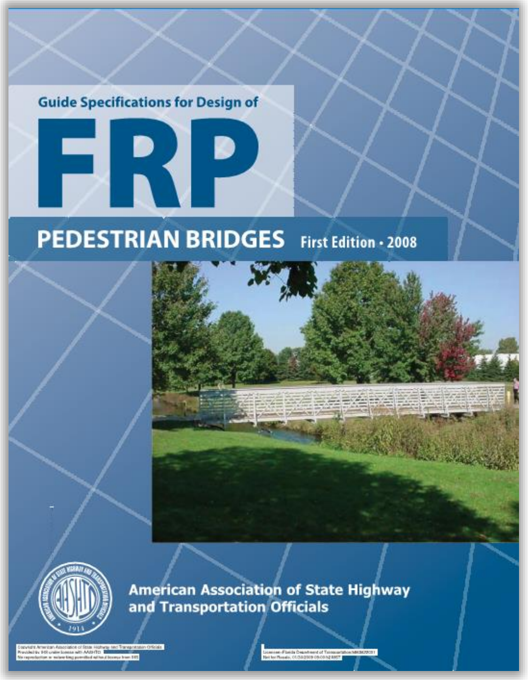


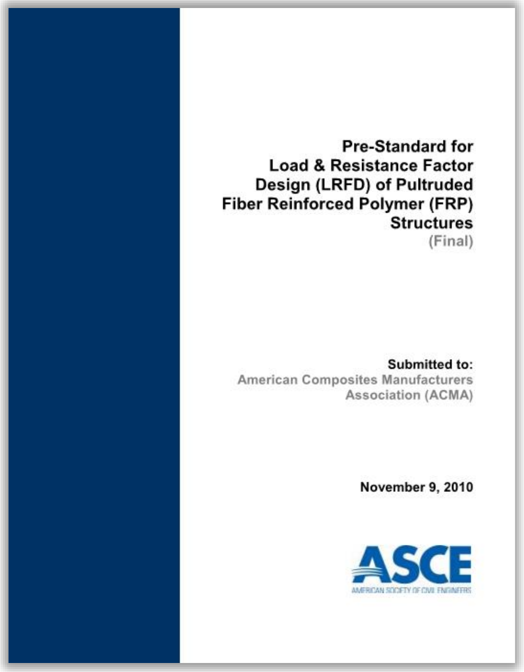
Document	Doc Ballot by Sub	Doc Ballot by 440 Main	Resolve Negative 440 Main Ballot	Doc to ACI for TAC Review	TAC Review	440 Reply to TAC Comments Ballot	Return to ACI for Layout	In Print
440-H CODE	Complete Fall 2019	Complete Spring 2020	Complete Fall 2020	Spring 2021				
Bar Const. Spec	Done	Done	Done	Done	Done	Spring 2018		

Authoritative resources…

- AASHTO & ASCE FRP Composite Structures (various Guide Specs)

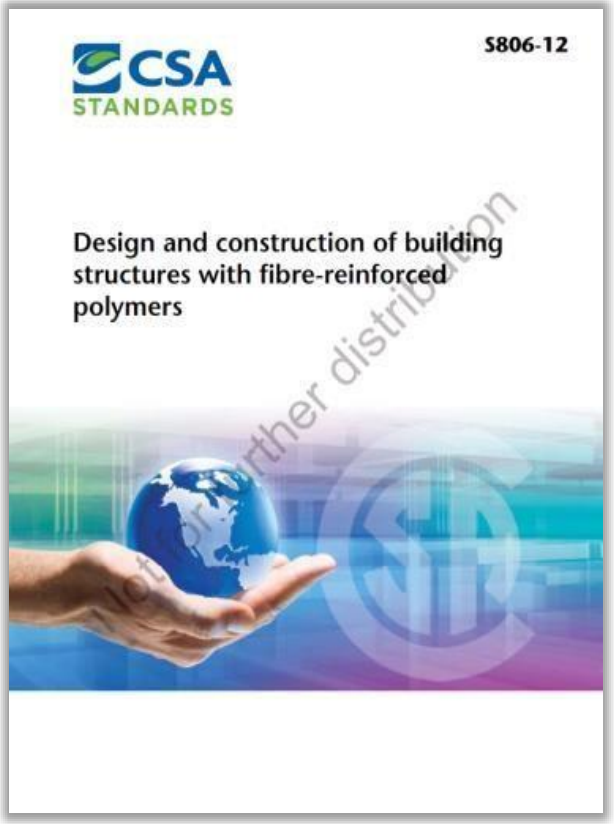


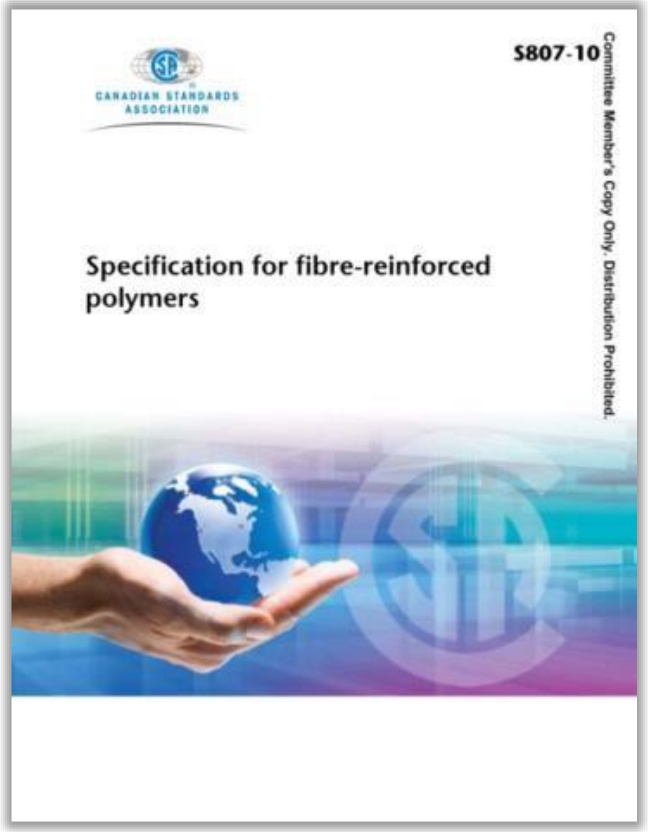


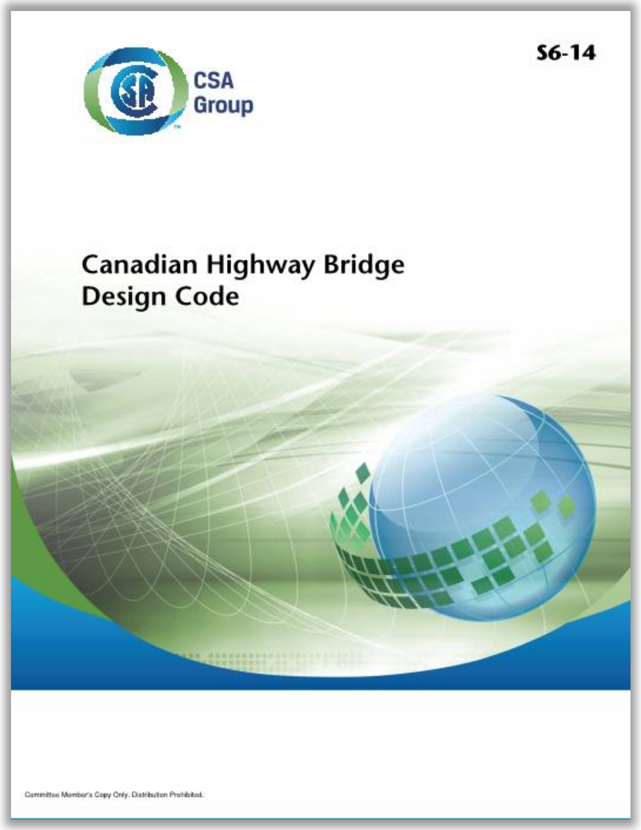


Authoritative resources…

- CSA for Concrete Structures (S806, S807 & S6)







Authoritative resources…

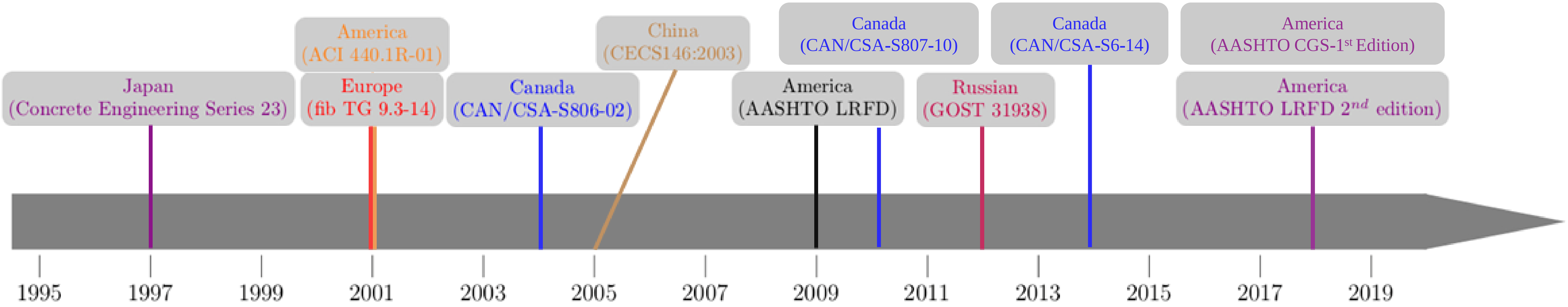
- National Harmonization (Example GFRP-RC):

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

***To be finalized*

Authoritative resources, guidelines, and specifications

- Development Worldwide of major FRP-RC/PC Guidelines:



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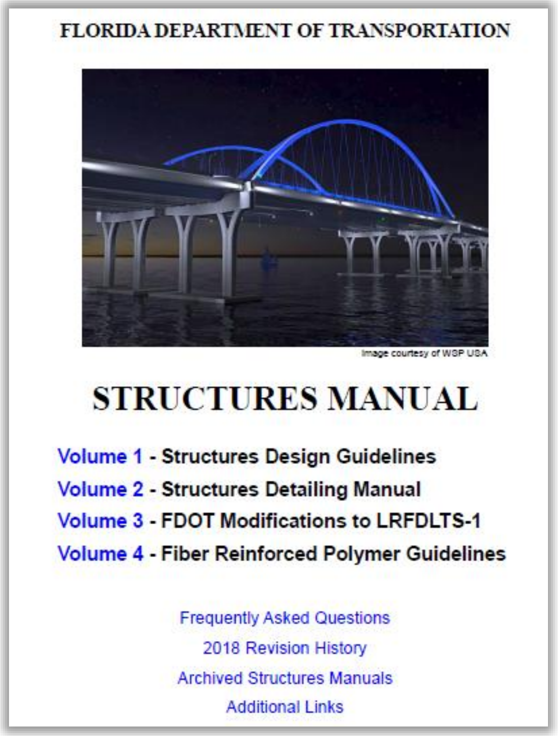
- FDOT's Implementation Strategy (Design, Manufacturer Approval, Construction);



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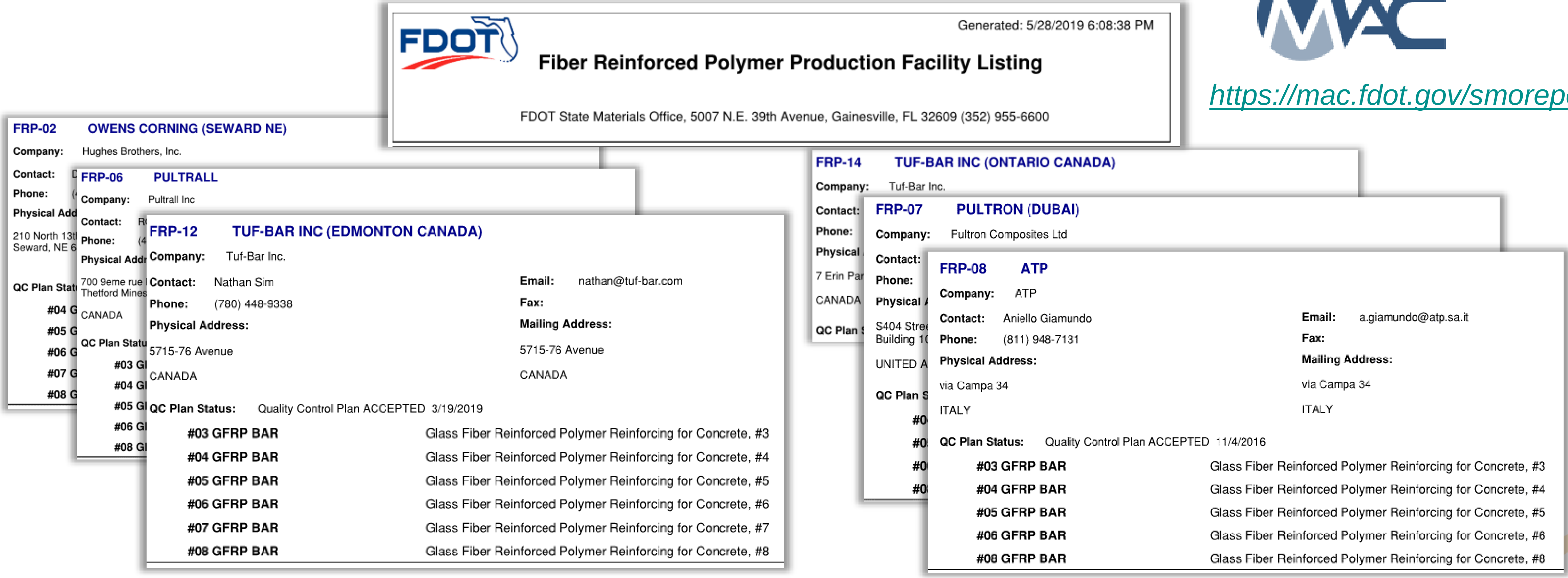
https://mac.fdot.gov/smoreports



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FDOT

Fiber Reinforced Polymer Production Facility Listing

FDOT State Materials Office, 5007 N.E. 39th Avenue, Gainesville, FL 32609 (352) 955-6600

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: 5715-76 Avenue CANADA

Mailing Address: 5715-76 Avenue 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-08 ATP

Company: ATP

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

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

Physical Address: via Campa 34 ITALY

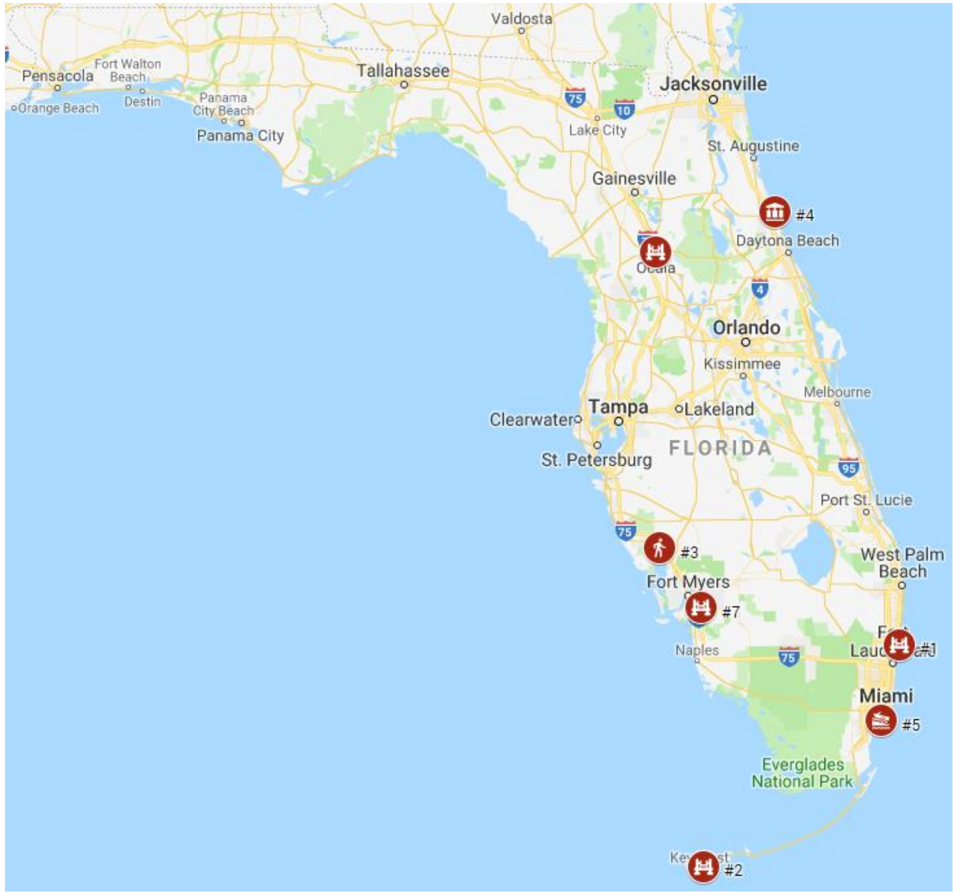
Mailing Address: via Campa 34 ITALY

QC Plan Status: Quality Control Plan ACCEPTED 11/4/2016

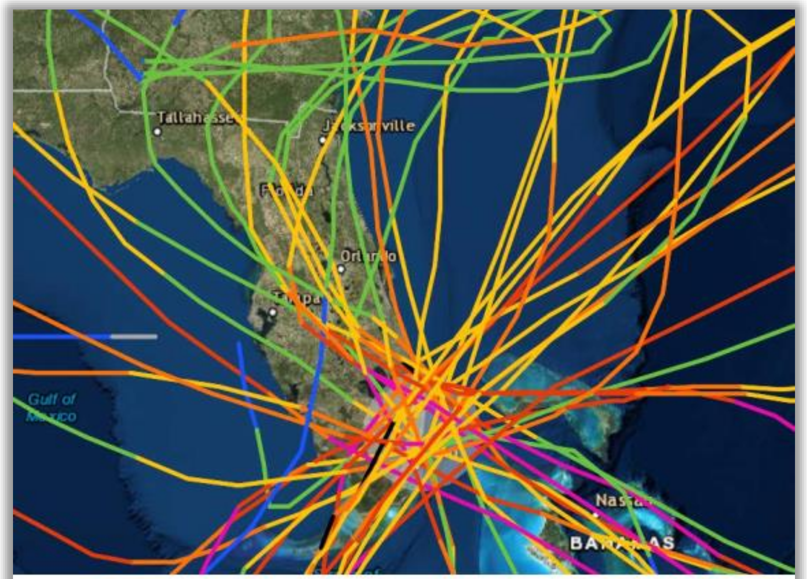
#03 GFRP BAR	Glass Fiber Reinforced Polymer Reinforcing for Concrete, #3
#04 GFRP BAR	Glass Fiber Reinforced Polymer Reinforcing for Concrete, #4
#05 GFRP BAR	Glass Fiber Reinforced Polymer Reinforcing for Concrete, #5
#06 GFRP BAR	Glass Fiber Reinforced Polymer Reinforcing for Concrete, #6
#08 GFRP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

Example Projects from Florida 2018-2020

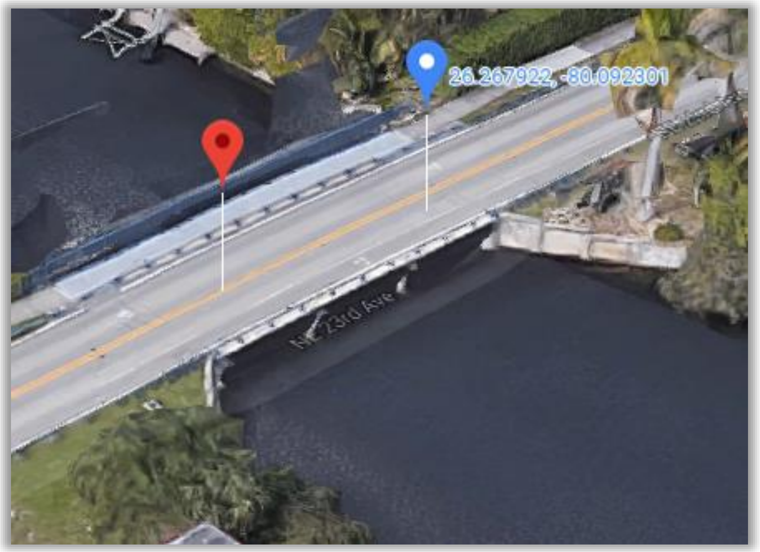
1) NE 23rd Ave over Ibis Waterway
2) US1 over Cow Key Channel
3) US41 Pedestrian Bridge Link-Slabs
4) SR-A1A Secant-Pile Seawall
5) I-dock Biscayne Bay
6) Recharge-Water Park Boardwalks
7) Skyplex Composite Arch Bridge



Example Project 1: NE 23rd Ave/Ibis Waterway

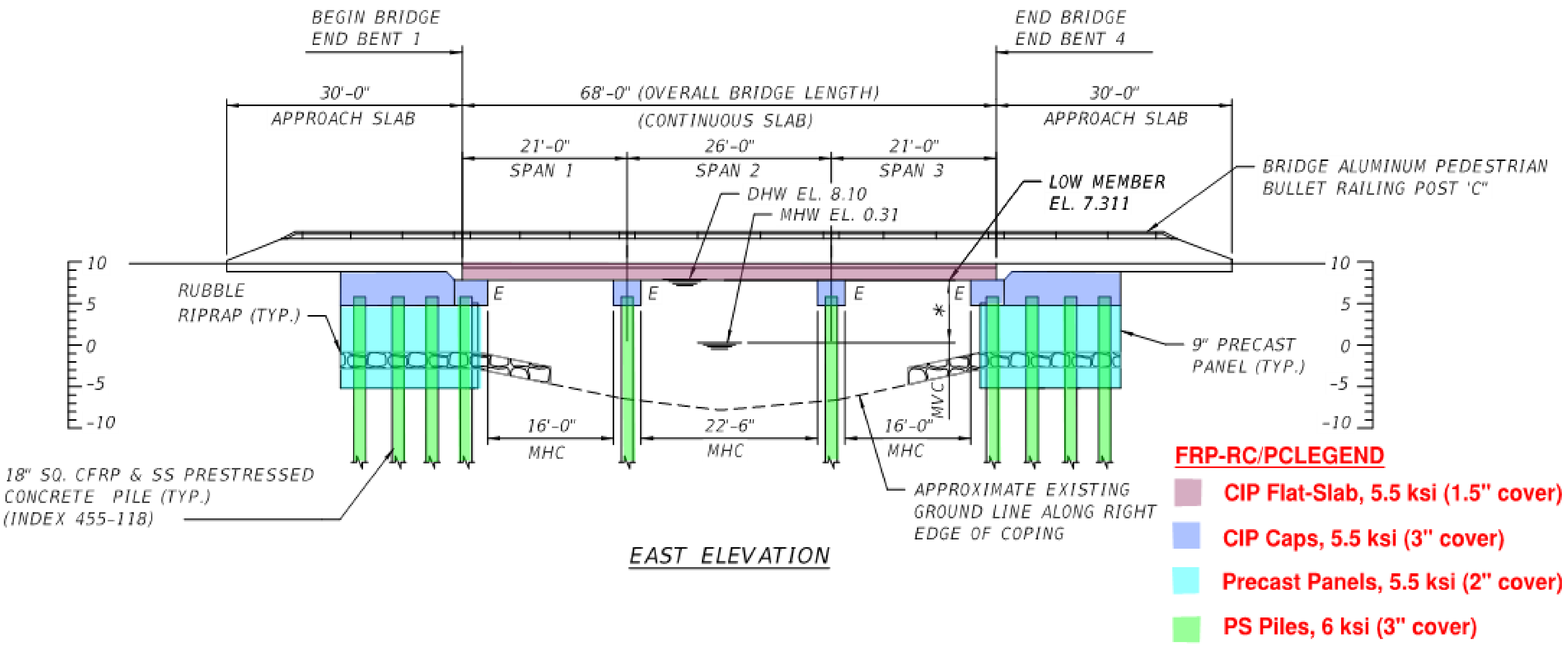


Historical Hurricanes Passing within 50 nmi of the project site (1842-2015) (Source: https://coast.noaa.gov/hurricanes/)



NE 23rd Ave/Ibis Waterway

- First GFRP-RC 3-span continuous flat-slab bridge in Florida. First soldier pile bulkhead-seawall with GFRP-RC precast panels.



Example Project 2: US1/Cow Key Channel

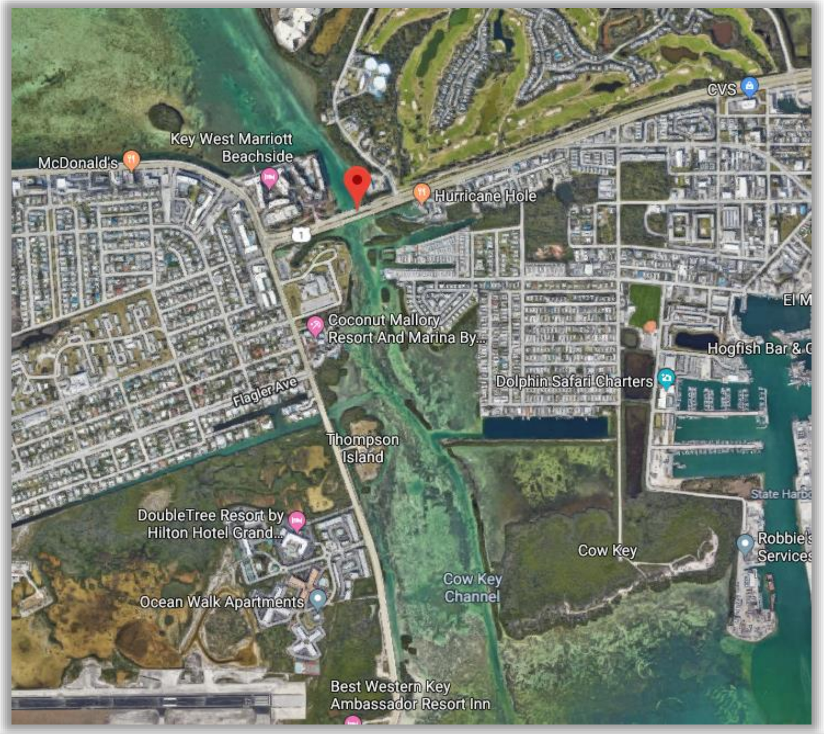
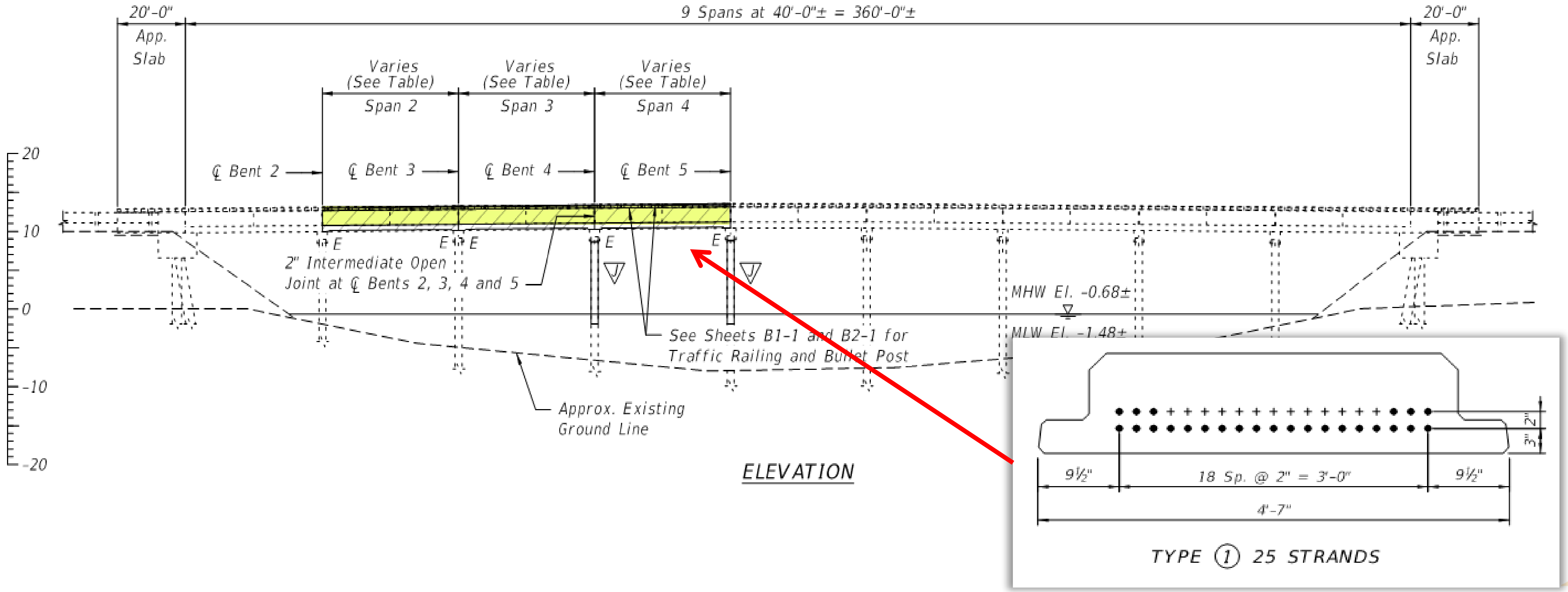


Figure 2: **Deterioration on Underside of Slab Units of Spans 3 and 4 (Bridge No 900086)**

US1/Cow Key Channel

- FRP eliminates need for additional concrete cover, additives, and waterproofing.
- CFRP Prestressing and GFRP Reinforcing with no reduction in AASHTO tensile stresses.



Example Project 3: SR-A1A Secant-Pile Seawall

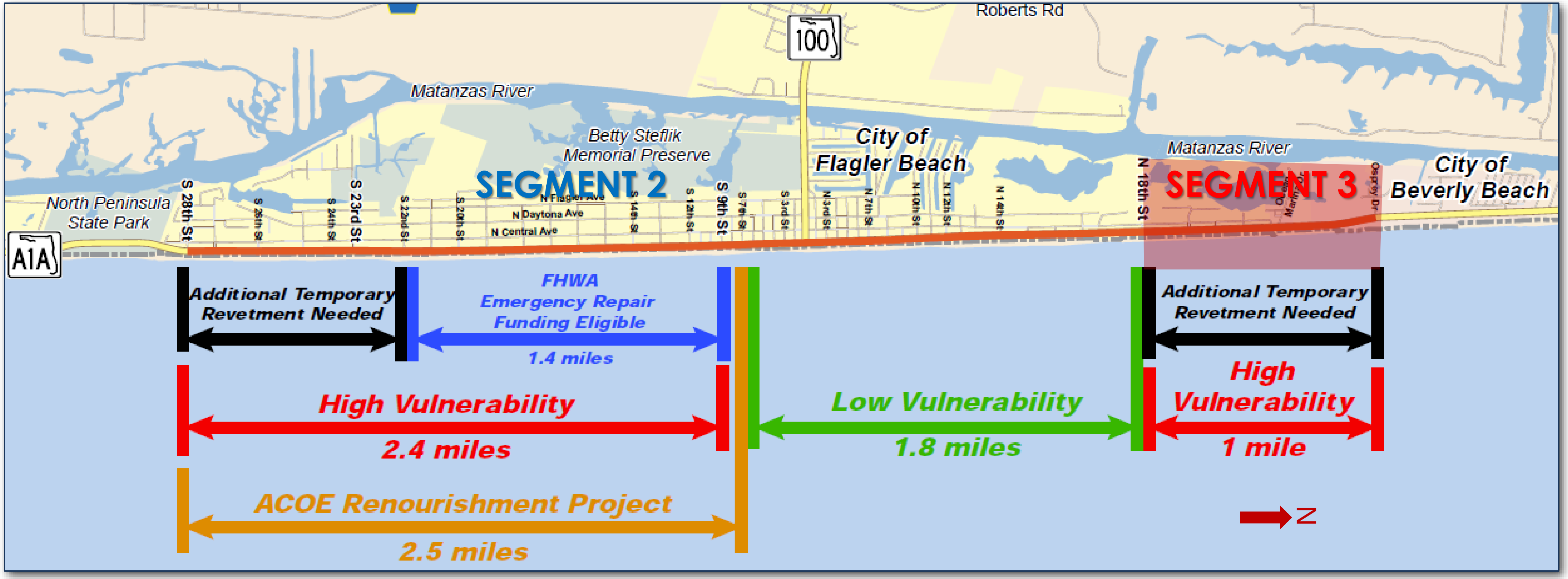
Project Background:

- Historical erosion issues due to hurricane impacts
- Provide a long term, permanent solution to protect A1A roadway. A wall design was needed to protect roadway in the most vulnerable areas
- Governor’s commitment – accelerated acquisition, design, & construction schedule

2006 Emergency Contract Wall

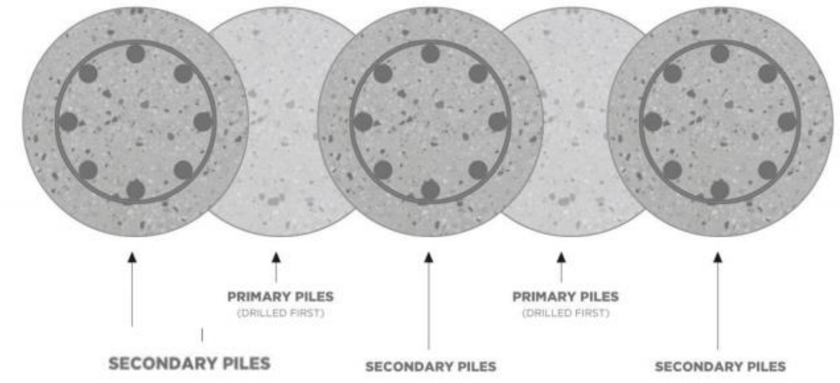
SR-A1A Secant-Pile Seawall

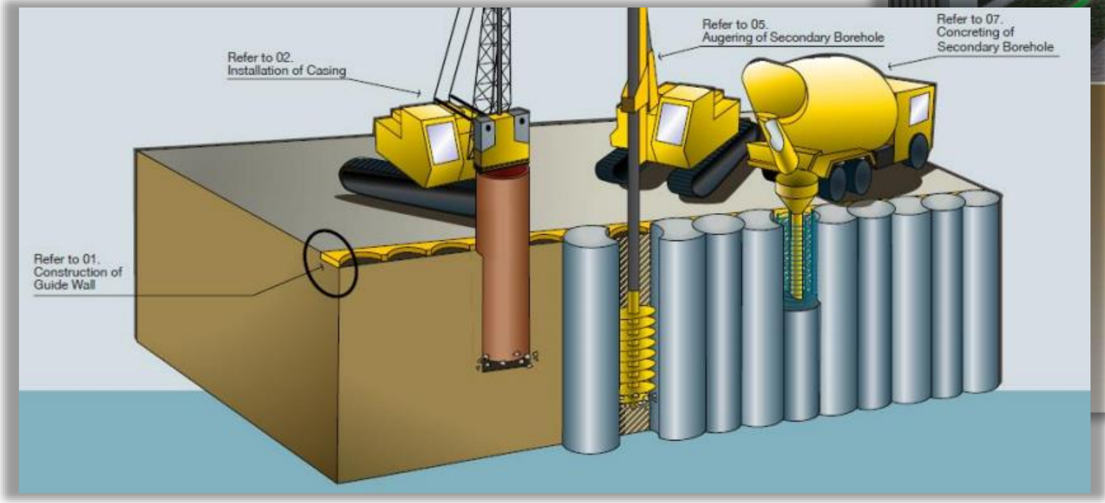
- N. 18th St. to Osprey Dr.
- 4920 ft of beach along E. Flagler Beach
- Wall constructed along entire limits of segment 3

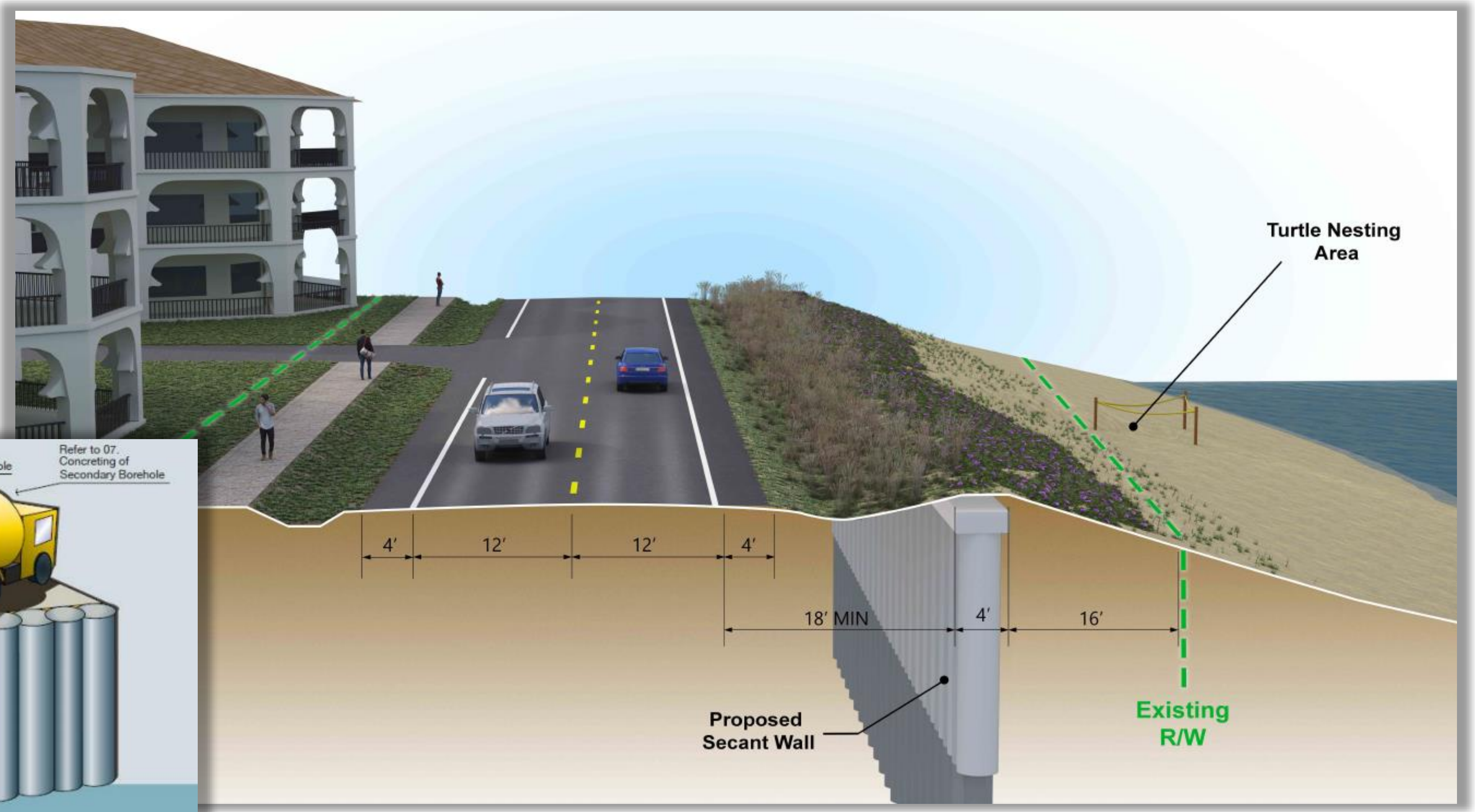


SR-A1A Secant-Pile Seawall

Concept and Design







SR-A1A Secant-Pile Seawall

Construction Process:

Example 4: Ocala Water-Recharge Park Boardwalks

- **Ocala's water recharge park to have 'cutting edge' technology**
  - 1,700 Linear Feet of boardwalk and viewing platforms spanning over 3 reclaimed water filtration ponds. Creating a city park and learning center.

Ocala Water-Recharge Park Boardwalks

Installation Process

Pile Driving 5”x 5” Composite Sections

Installing the Bonded Stringer Sections

Ocala Water-Recharge Park Boardwalks

Installation Process

Installing the Bonded Bearers and Stringer Sections

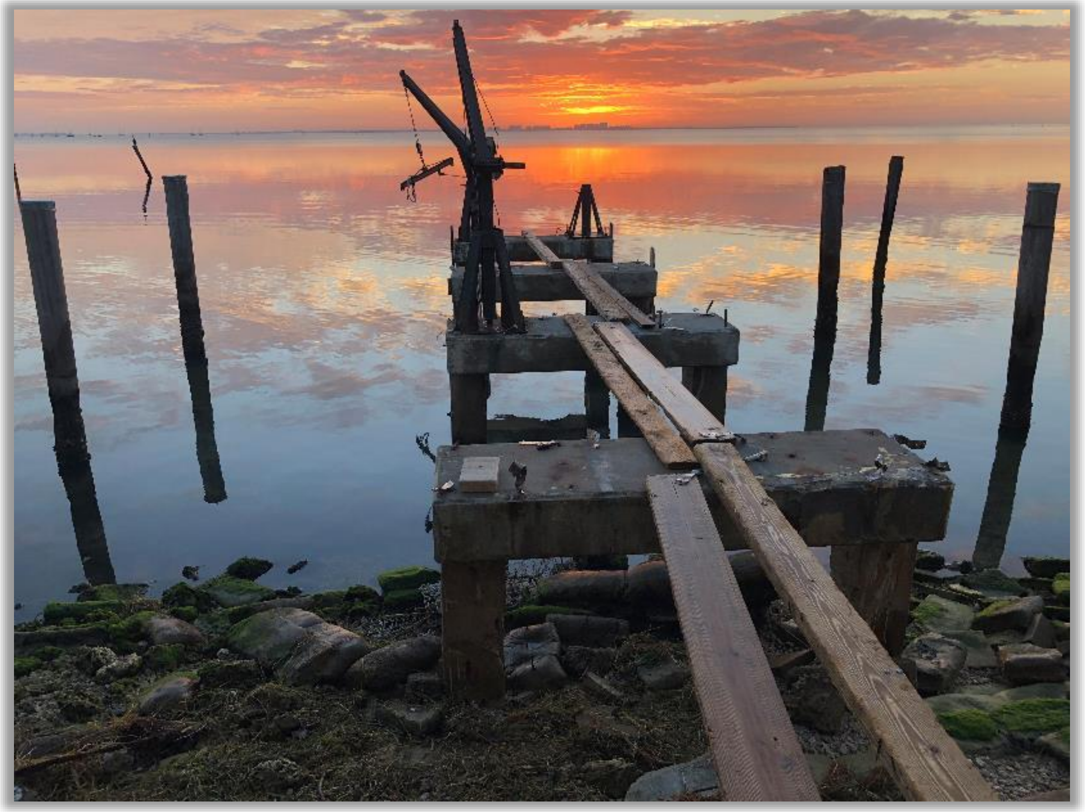
Ocala Water-Recharge Park Boardwalks

A completed pond walk-over. Waiting to flood the cell

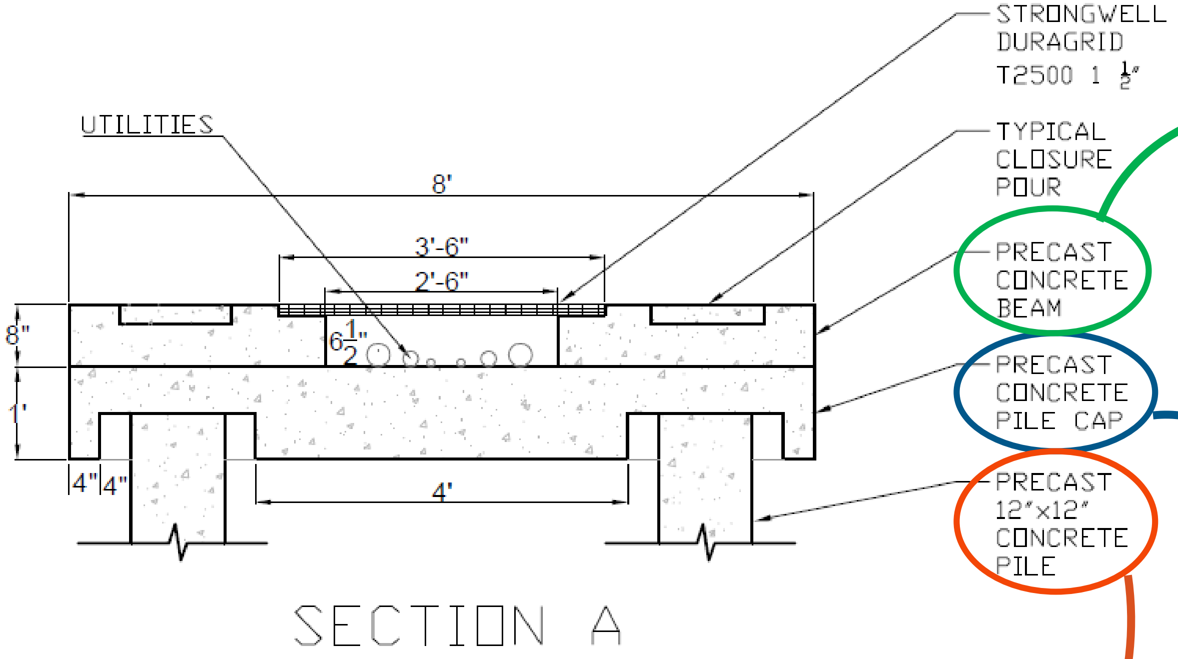
Example Project 5: I-Dock on Biscayne Bay

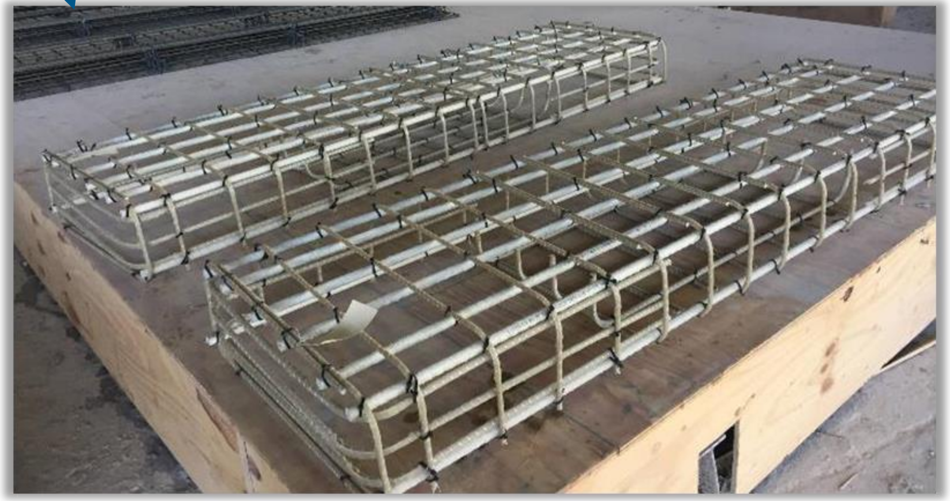
Project Background:

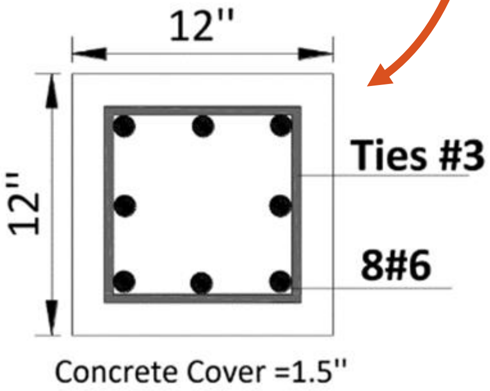
- 2018 Condition:
  - Existing dock damaged by Hurricane Irma (2017)



I-Dock on Biscayne Bay





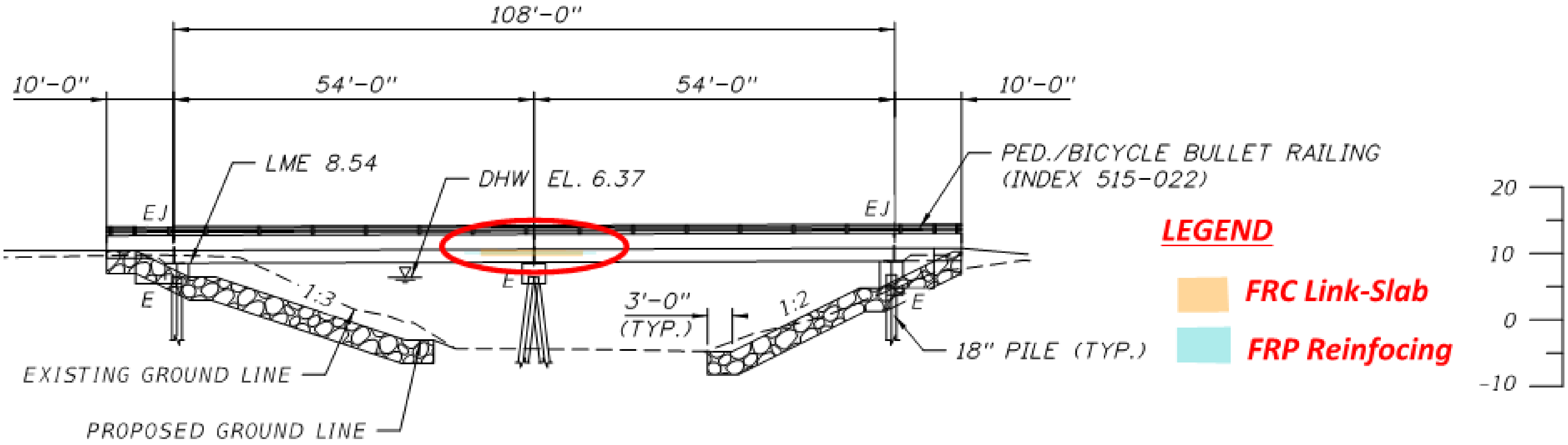


I-Dock on Biscayne Bay

Installation Process

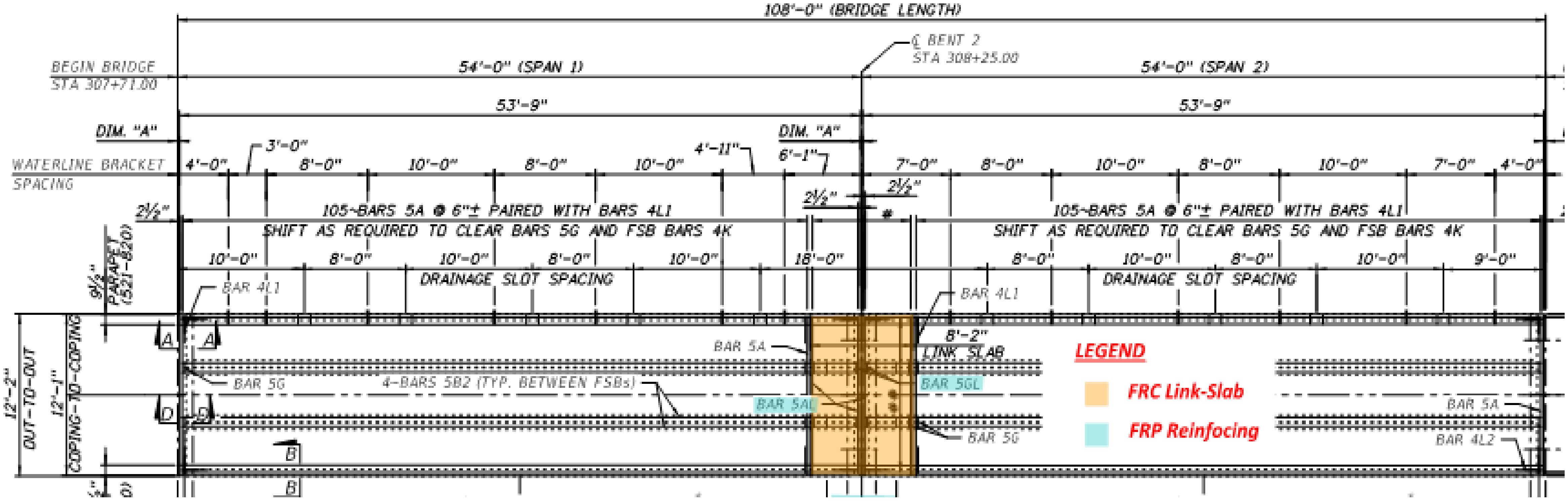
Example Project 6: US41 Pedestrian Bridges Link-Slabs

- SR-5 (US 41) over Morning Star (FRP rebar – FRC)
- SR-5 (US 41) over Sunset Waterways (FRP rebar – UHPC)



US41 Pedestrian Bridge Link-Slabs

- Elimination of expansion joint maintenance, and better transfer of lateral load
- Utilization of low modulus GFRP bars and fibers in concrete



Plan view of Morning Star bridge

Example 7: Skyplex Composite Arch

- Easy to built, innovative solution

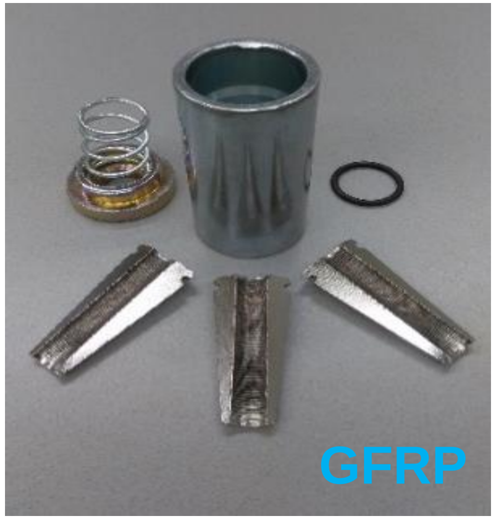
Ongoing Applied Research and Future Opportunities

- Mild Prestressing for Concrete applications of low-cost FRP-PC elements;
- Refined Durability and Endurance Modeling;
- Ultra-High Performance Concrete (UHPC) and FRP; rebar/prestressing;
- Hybrid systems and Other synergistic combinations.

MILDGLASS: NCHRP-IDEA #207

Possible Benefits:

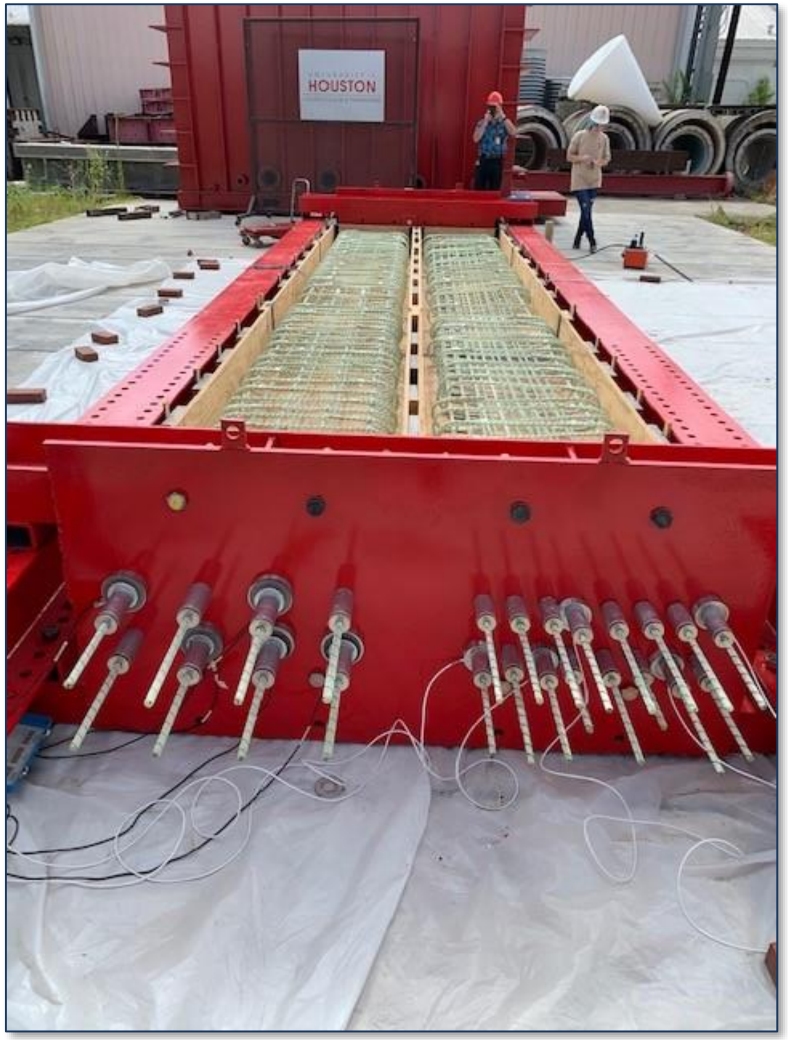
- Concept: GFRP Mild Prestressing
- Limits cracking and splitting at release
- Safe pulling with traditional techniques
- Targets Coastal Structures
- Experience Highest corrosion
- Requires Lowest prestress

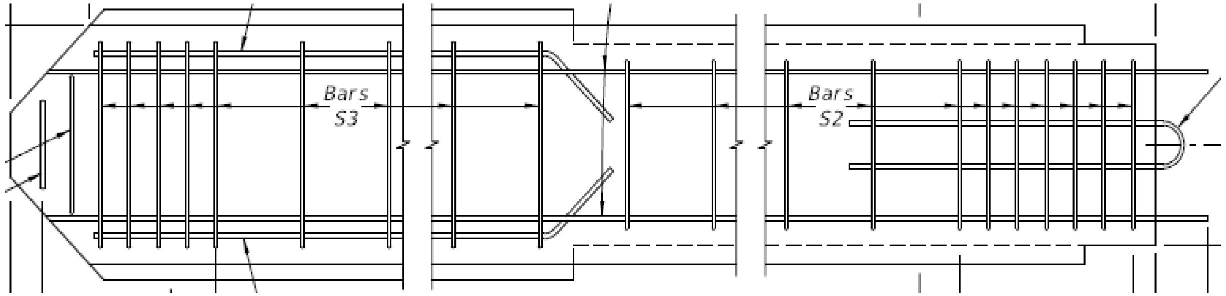


MILDGLASS: NCHRP-IDEA #207

Structural Tests at U-Houston

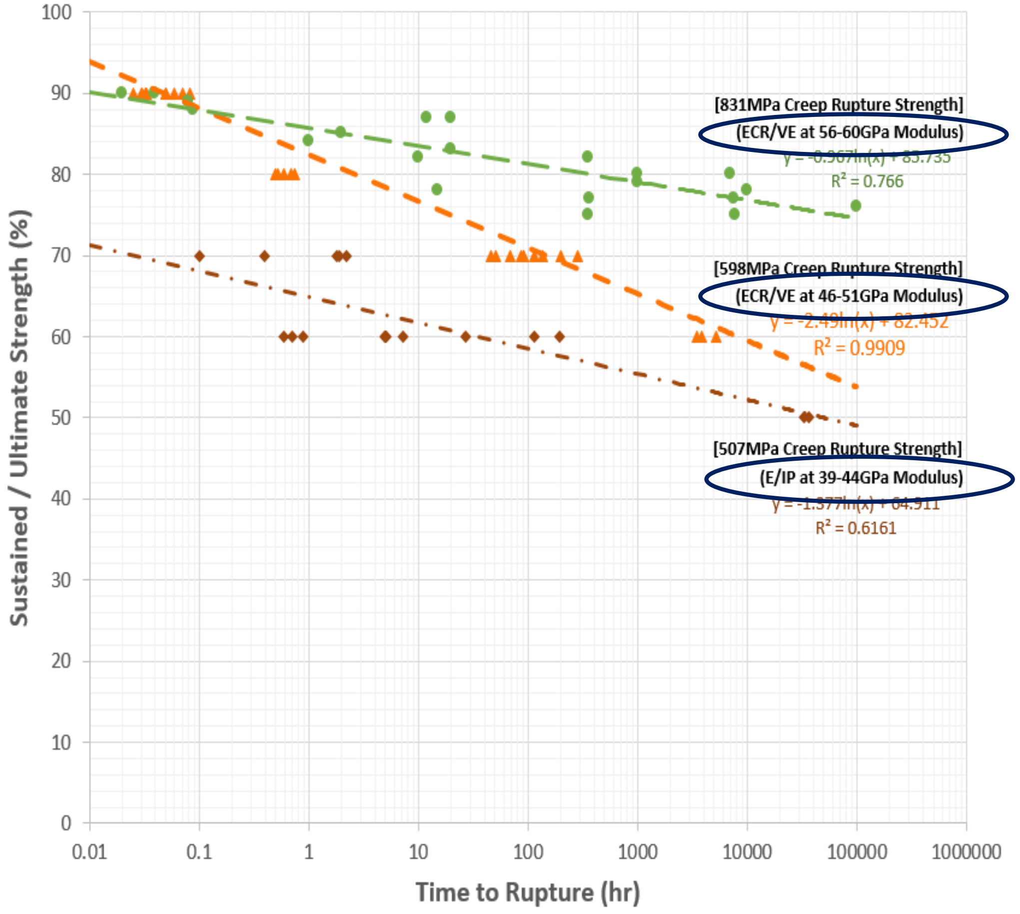
- Cross Section 10x30 inches
- Length: 20 feet
- Prestress: 36-41% GTS
- Conf. A: 16 GFRP No.4 at 10-kip
- Conf. B: 16 GFRP No.5 at 13-kip
- Conf. C: 8 GFRP No.5 at 13-kip

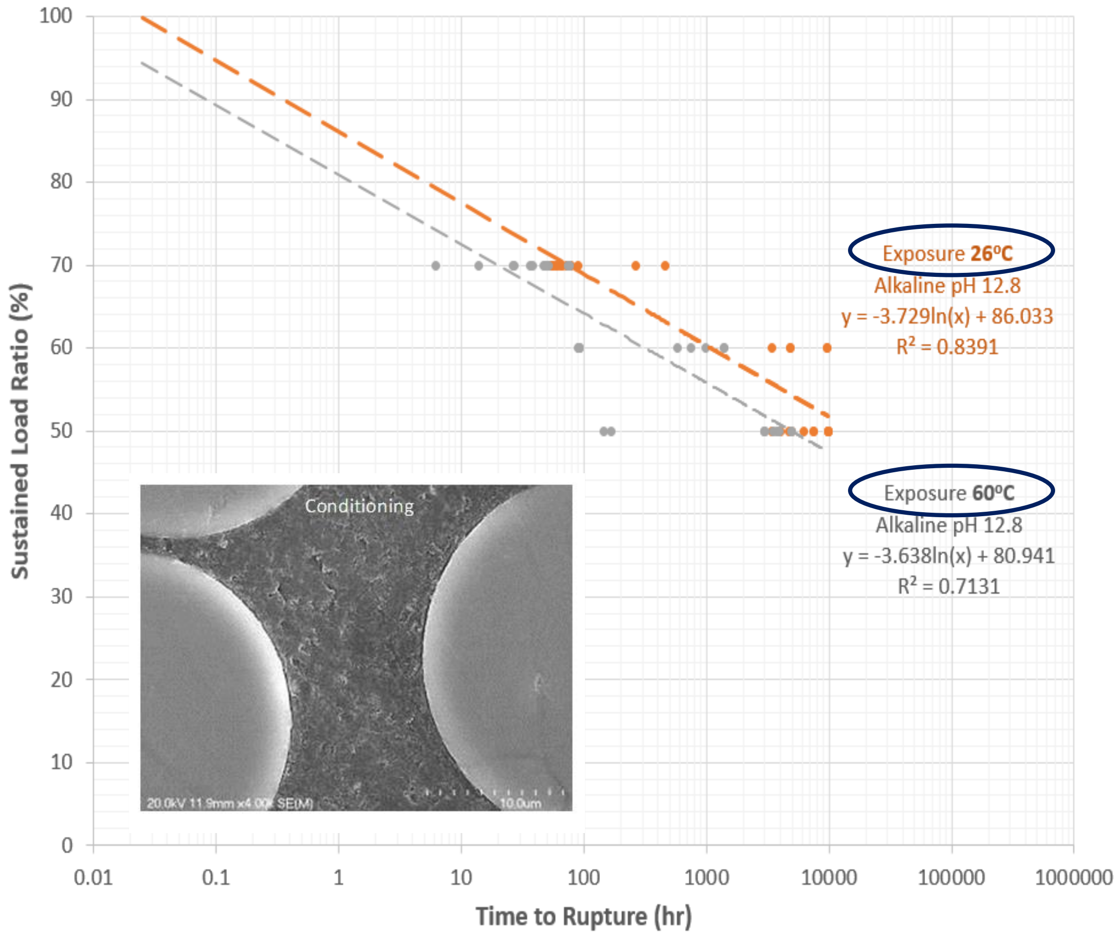




Ongoing Applied Research and Future Opportunities

- Refined Durability and Endurance Modeling;





Ongoing Applied Research and Future Opportunities

- Refined Durability and Endurance Modeling
  - Creep rupture knock-down factor = 0.46
  - ~50% more than 0.30 recommended by AASHTO

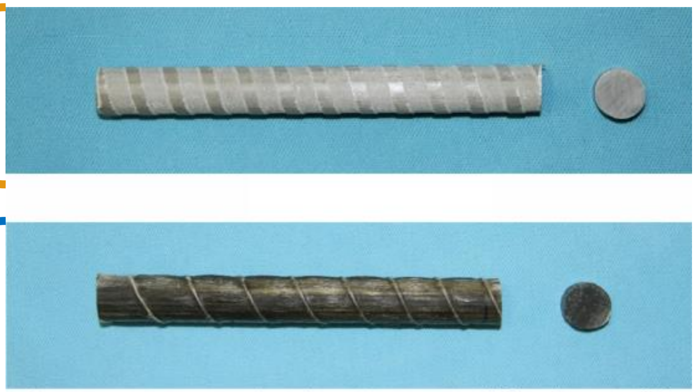


Fig. 2. Cross section and surface of bar M13(1) [a] and M13(2) [b].

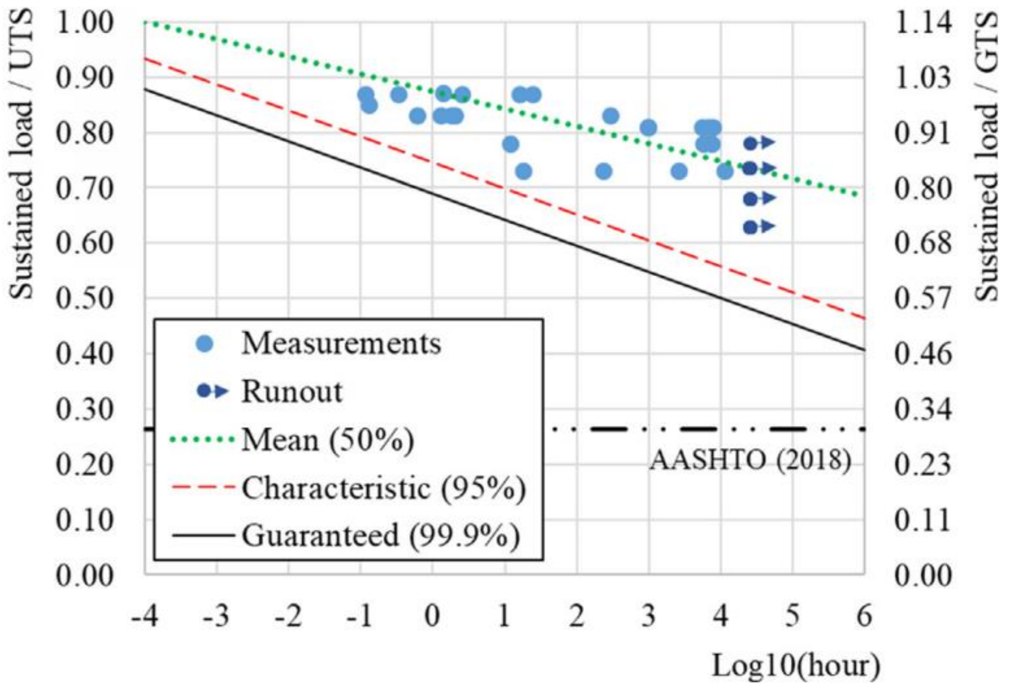


Fig. 10. Sustained load versus logarithmic time-to-failure for batch M13(1).

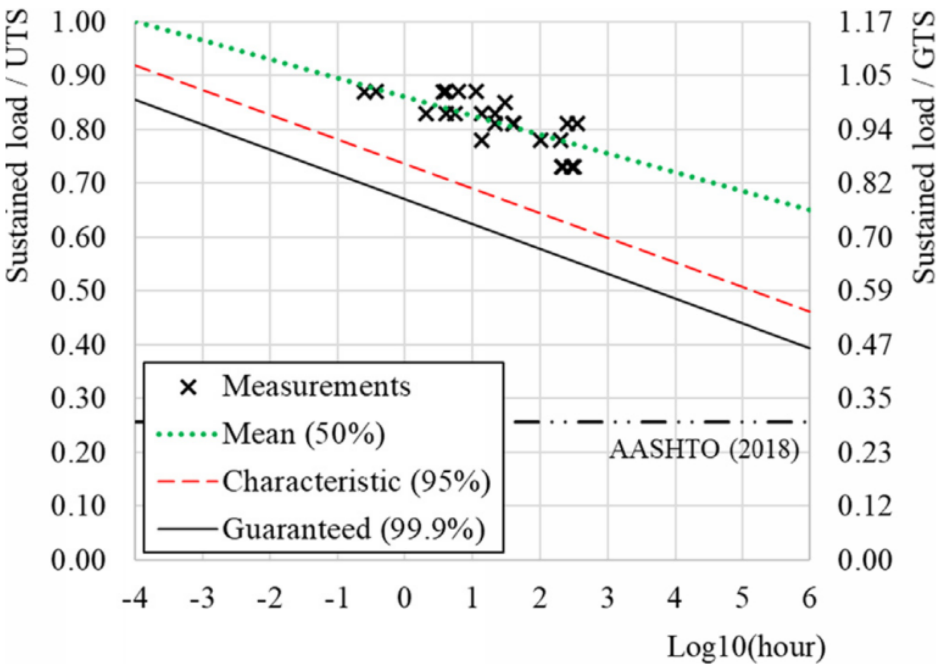
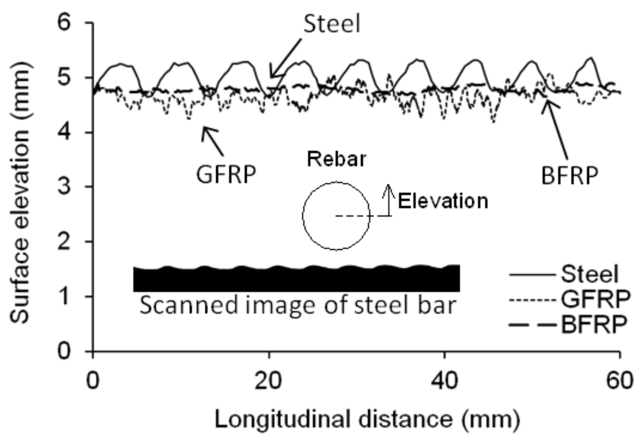
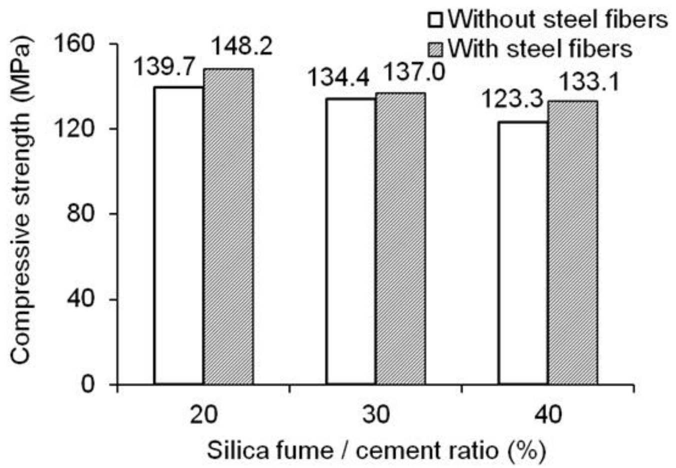


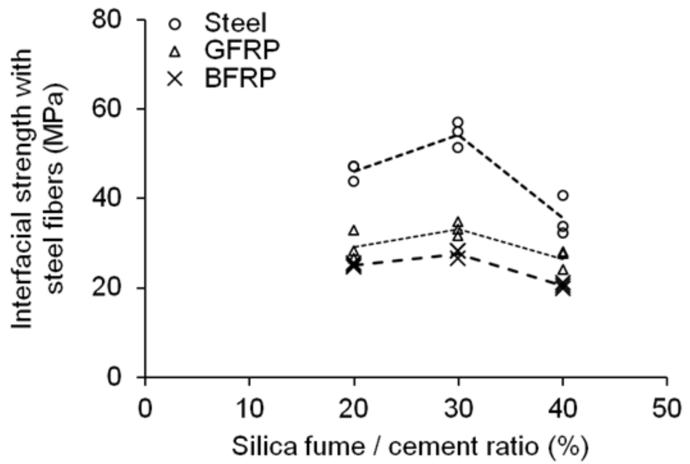
Fig. 11. Sustained load versus logarithmic time-to-failure for batch M13(2).

Ongoing Applied Research and Future Opportunities

- Ultra-High Performance Concrete (UHPC) and FRP; rebar/prestressing;



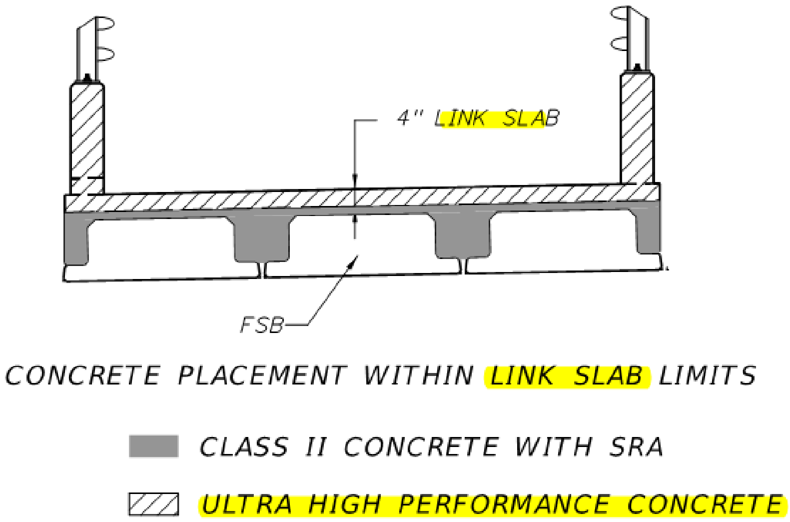


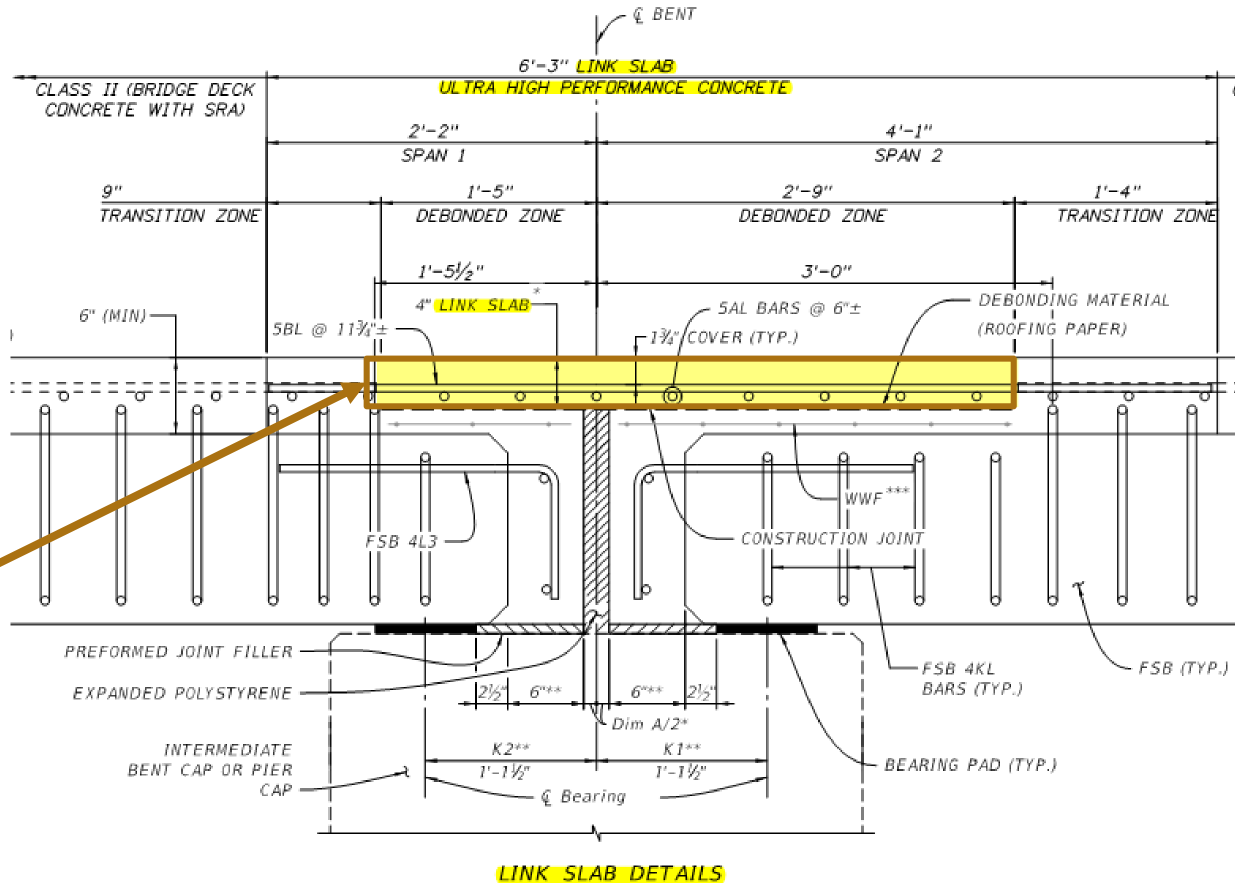


Application of GFRP Bars to Ultra-High Performance Concrete *Jun Wang and Yail J. Kim (University of Colorado Denver), 2019.*
https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/structures/innovation-docs/iw-gfrpcs2-casestudypapers.pdf?sfvrsn=57afb4e3_2

Ongoing Applied Research and Future Opportunities

- Ultra-High Performance Concrete (UHPC) and FRP; rebar/prestressing;

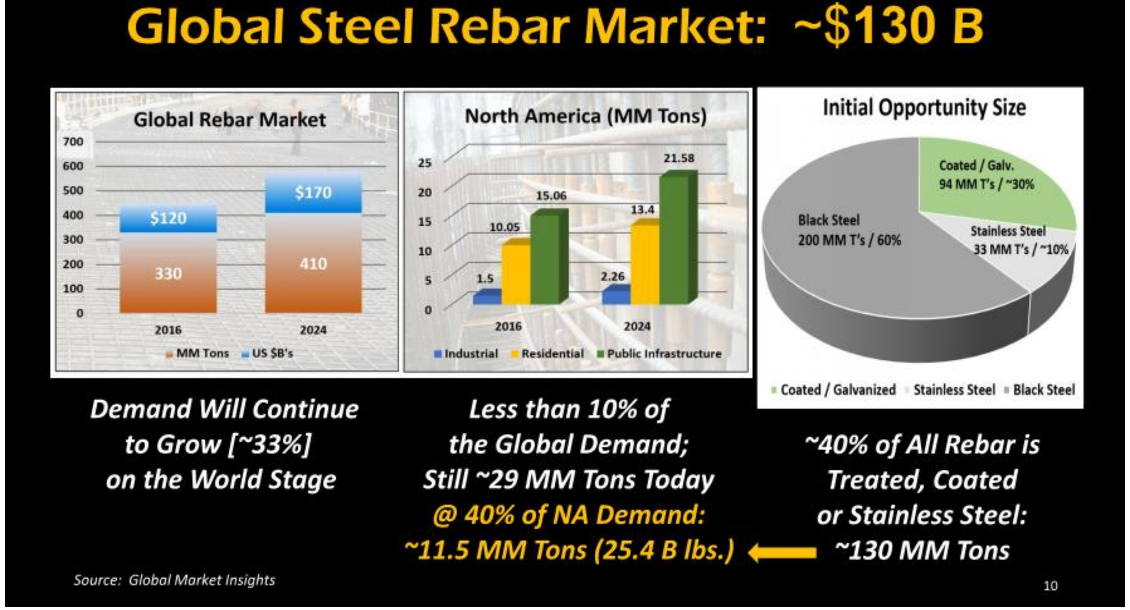




Challenges to the Manufacturing Industry

- Product Certification
- Instilling Asset Owner Confidence in Quality
- Scalability for Mainstream Infrastructure?

From https://ir.basaniteindustries.com/



QUESTIONS?

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

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