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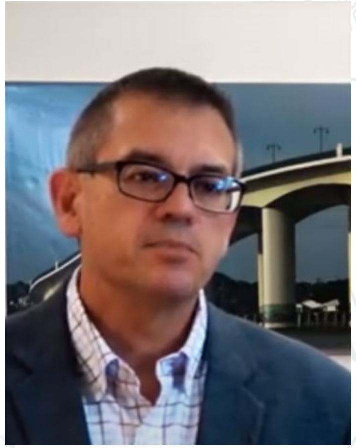
SEPTEMBER 21-24 2020
A VIRTUAL EXPERIENCE

Advancements in composite infrastructure deployment in Florida

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



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September 21-24, 2020 / www.theCAMX.org

ABSTRACT

PUT IT DOWN
IT'S THE LAW

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

Need, Rules & Tools

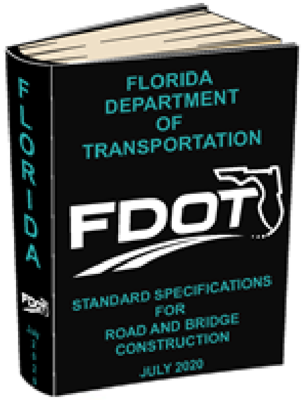
1. Expanding Range of Reliable FRP Materials & Structural Solutions
2. Recent Full-Scale Testing and Research on Beams and Piles
3. Durable Solutions and Life Cycle Cost Evaluation
4. Education Tools for Designers, Contractors, & Owners

Case Studies

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 msi.***
- but ***ASTM D7957-17*** implemented at ***$E_f \geq$ 6.5 msi.***
- ***CSA 807-19*** has three grades with the highest *(Grade III)* ***$E_f \geq$ 8.7 msi.***
- FDOT will be raising ***Spec 932-~~2~~3*** limits in mid-2021 to more closely match *Grade III* for straight bars.

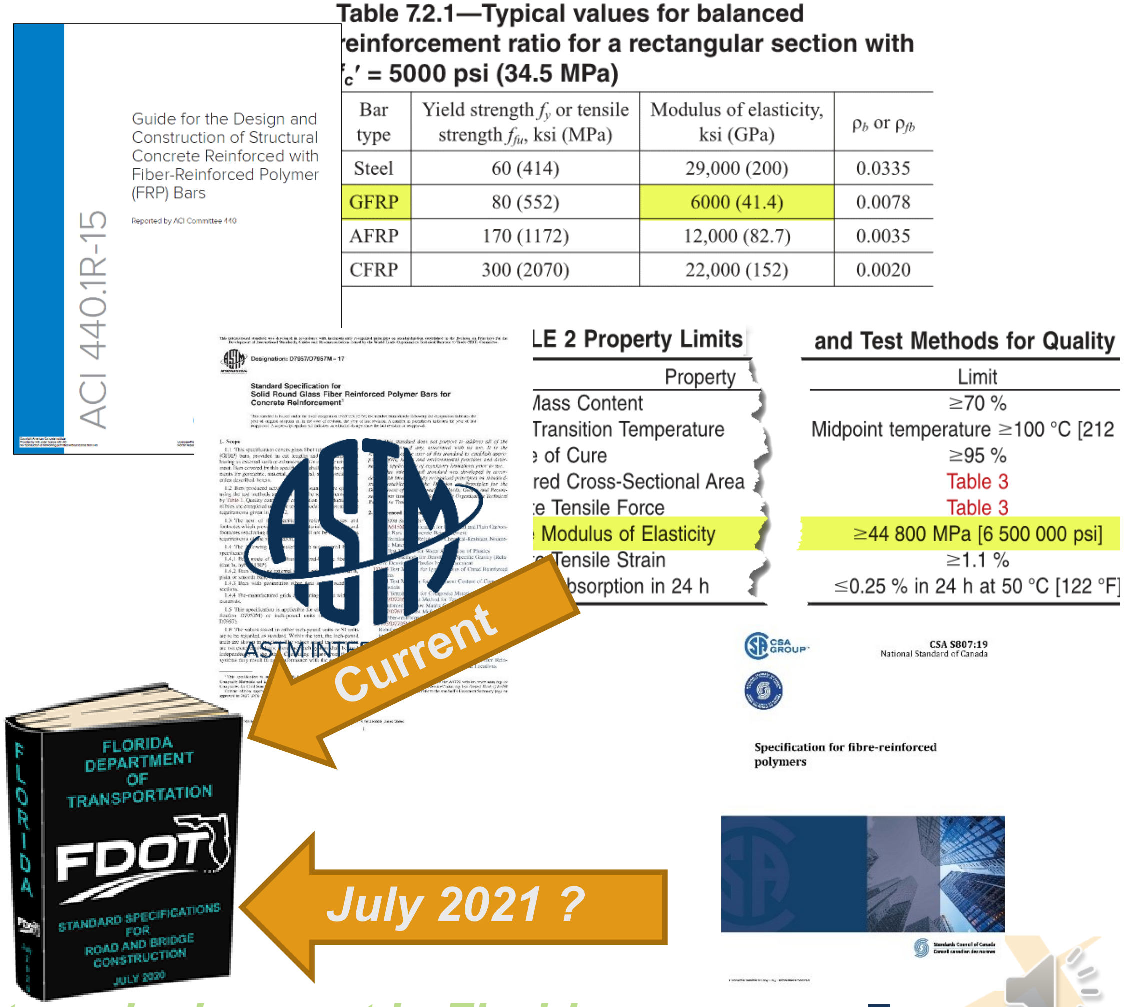


Table 7.2.1—Typical values for balanced reinforcement ratio for a rectangular section with f_c' = 5000 psi (34.5 MPa)

Bar type	Yield strength f_y or tensile strength f_{fu}, ksi (MPa)	Modulus of elasticity, ksi (GPa)	ρ_b or ρ_{fb}
Steel	60 (414)	29,000 (200)	0.0335
GFRP	80 (552)	6000 (41.4)	0.0078
AFRP	170 (1172)	12,000 (82.7)	0.0035
CFRP	300 (2070)	22,000 (152)	0.0020

LE 2 Property Limits and Test Methods for Quality

Property	Limit
lass Content	≥70 %
Transition Temperature	Midpoint temperature ≥100 °C [212
e of Cure	≥95 %
red Cross-Sectional Area	Table 3
e Tensile Force	Table 3
Modulus of Elasticity	≥44 800 MPa [6 500 000 psi]
Tensile Strain	≥1.1 %
bsorption in 24 h	≤0.25 % in 24 h at 50 °C [122 °F]

Expanding Range of Reliable FRP Materials & Structural Solutions

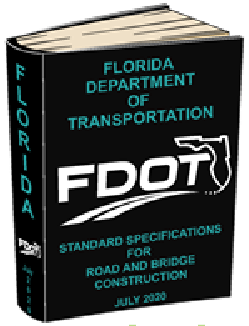
i. GFRP rebar & improved properties

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?

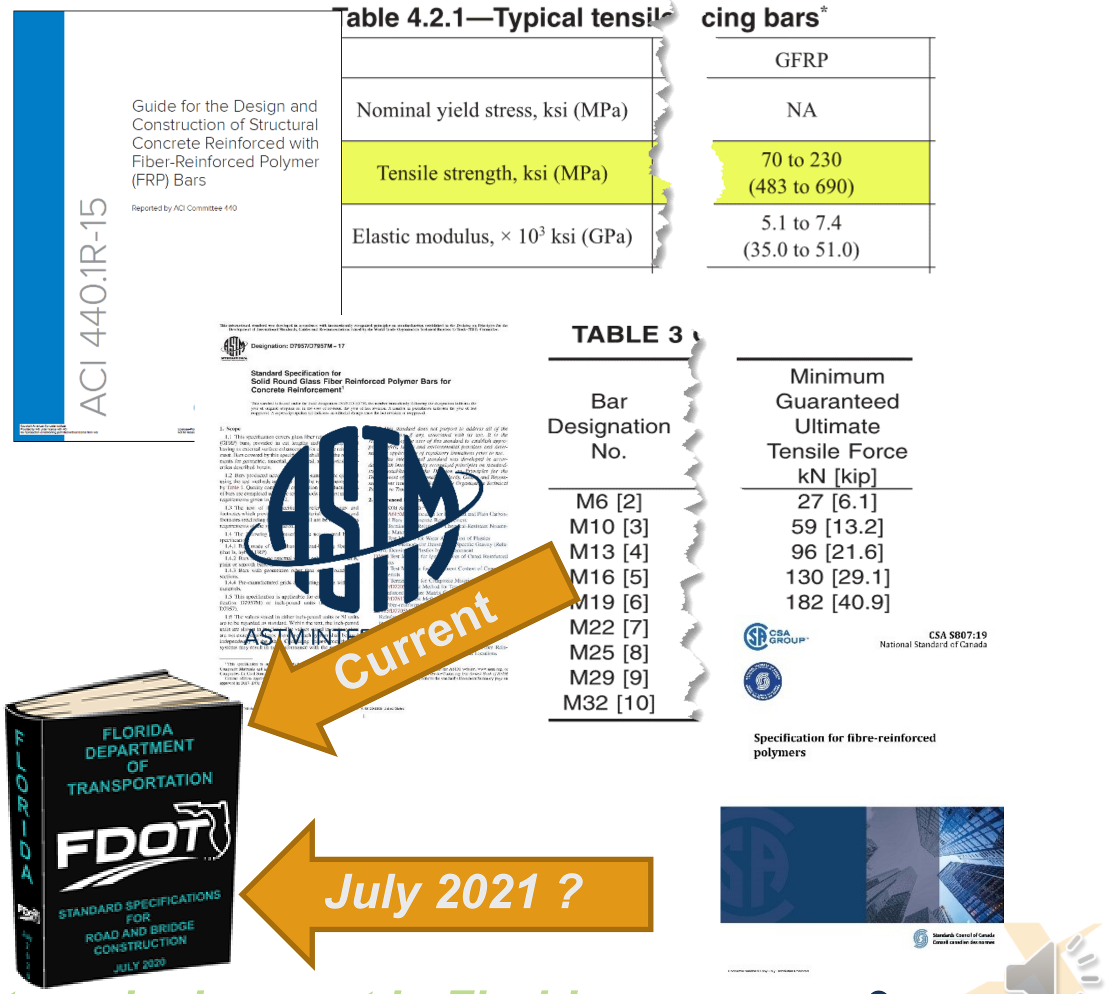
← Improves efficiency in design requiring either



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
- …?

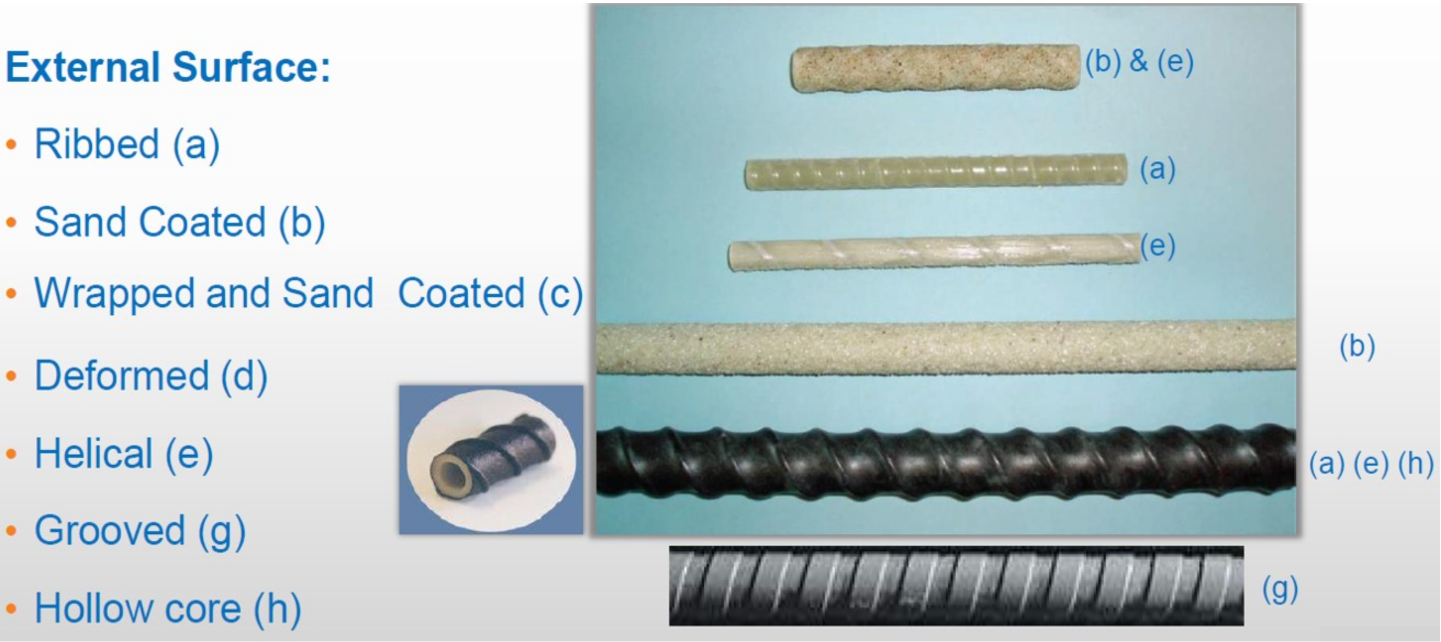


Figure: Different types of FRP [Fu et al. 2019]

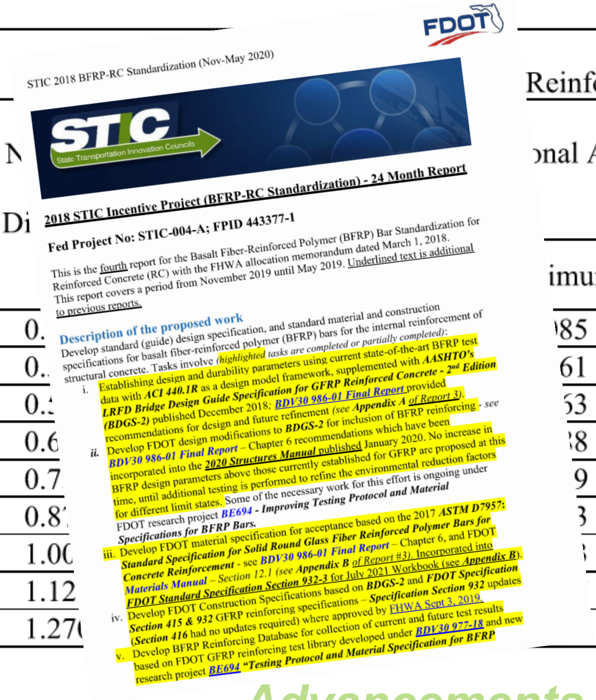
Expanding Range of Reliable FRP Materials & Structural Solutions

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.

Reinforcing Bars				
Bar Size Designation	N... Di...	...onal Area ...imum	Minimum Guaranteed Tensile Load (kips) BFRP and GFRP Bars	CFRP Bars
2	0.	985	6.1	10.3
3	0..	61	13.2	20.9
4	0.5	63	21.6	33.3
5	0.6	38	29.1	49.1
6	0.7	9	40.9	70.7
7	0.87	3	54.1	-
8	1.00	3	66.8	-
9	1.12		82.0	-
10	1.270		98.2	-


FDOT

STIC 2018 BFRP-RC Standardization (Nov-May 2020)

STIC State Transportation Innovation Councils

2018 STIC Incentive Project (BFRP-RC Standardization) - 24 Month Report

Fed Project No: STIC-004-A; FPID 443377-1

This is the fourth report for the Basalt Fiber-Reinforced Polymer (BFRP) Bar Standardization for Reinforced Concrete (RC) with the FHWA allocation memorandum dated March 1, 2018. This report covers a period from November 2019 until May 2019. Underlined text is additional to previous reports.

Description of the proposed work

Develop standard (guide) design specification, and standard material and construction specifications for basalt fiber-reinforced polymer (BFRP) bars for the internal reinforcement of structural concrete. Tasks involve (*highlighted tasks are completed or partially completed*):

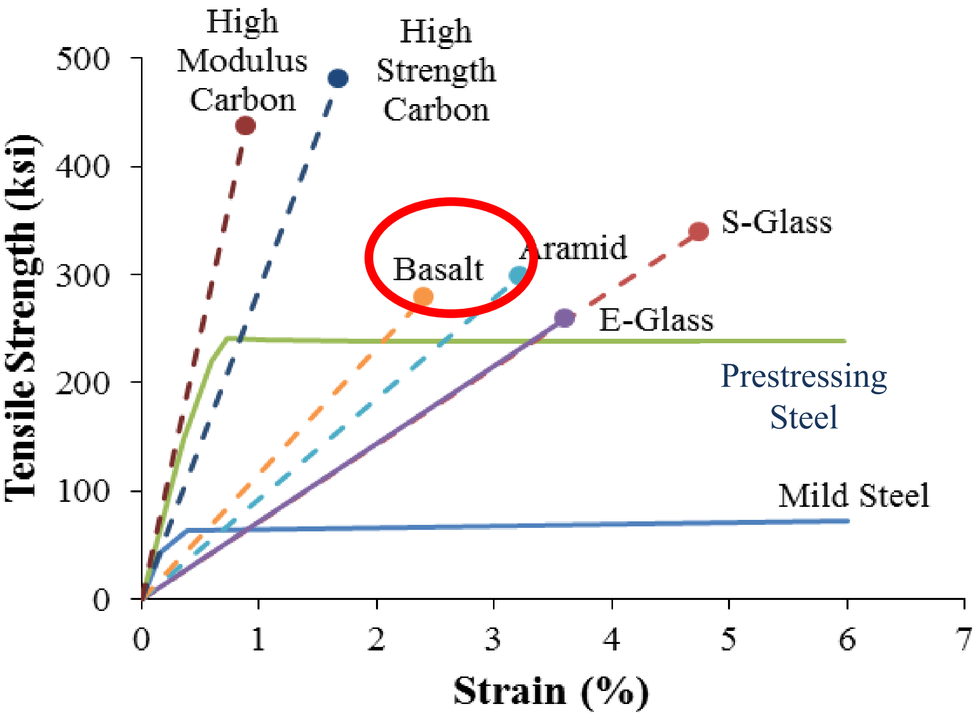
i. Establishing design and durability parameters using current state-of-the-art BFRP test data with ***ACI 440.1R*** as a design model framework, supplemented with ***AASHTO's LRFD Bridge Design Guide Specification for GFRP Reinforced Concrete - 2nd Edition (BDGS-2)*** published December 2018; *BDV30 986-01 Final Report* provided recommendations for design and future refinement (*see* ***Appendix A*** *of Report 3*).

ii. Develop FDOT design modifications to ***BDGS-2*** for inclusion of BFRP reinforcing - *see* ***BDV30 986-01 Final Report*** – Chapter 6 recommendations which have been incorporated into the ***2020 Structures Manual*** published January 2020. No increase in BFRP design parameters above those currently established for GFRP are proposed at this time, until additional testing is performed to refine the environmental reduction factors for different limit states. Some of the necessary work for this effort is ongoing under FDOT research project ***BE694 - Improving Testing Protocol and Material Specifications for BFRP Bars.***

iii. Develop FDOT material specification for acceptance based on the 2017 ***ASTM D7957: Standard Specification for Solid Round Glass Fiber Reinforced Polymer Bars for Concrete Reinforcement*** - see ***BDV30 986-01 Final Report*** – Chapter 6, and FDOT ***Materials Manual*** – *Section 12.1 (see* ***Appendix B*** *of Report #3).* Incorporated into ***FDOT Standard Specification Section 932-3*** for July 2021 Workbook (see ***Appendix B***).

iv. Develop FDOT Construction Specifications based on ***BDGS-2*** and ***FDOT Specification Section 415 & 932*** GFRP reinforcing specifications – ***Specification Section 932*** updates (***Section 416*** had no updates required) where approved by FHWA Sept 3, 2019.

v. Develop BFRP Reinforcing Database for collection of current and future test results based on FDOT GFRP reinforcing test library developed under BDV30 977-18 and new research project BE694 ***"Testing Protocol and Material Specification for BFRP***



Expanding Range of Reliable FRP Materials & Structural Solutions

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Table 1-2
Typical Sizes and Loads of CFRP Prestressing Strands and Bars

Type	Nominal Diameter (in)	Nominal Cross Sectional Area (in^2)	Nominal Ultimate Load (P_u) (kips)	Nominal Ultimate Tensile Stress (ksi)
Single Strand - 5.0mm Ø	0.20	0.025~~30~~	9.1	364~~00~~
7-strand - 7.9~~5~~mm Ø	0.31~~0~~	0.048~~50~~	17.8	37~~4~~0
7-strand - 10.8~~5~~mm Ø	0.43~~1~~	0.090	33.1~~2~~	367~~56~~
Single Strand - 9.5mm Ø	0.38	0.110	35.0	318
7-strand - 12.5mm Ø	0.49	0.117~~8~~	43.3~~1~~	370~~47~~
Single Strand - 12.7mm Ø	0.50	0.196	59.0	301
7-strand - 15.2mm Ø	0.60	0.179	66.2~~1~~	369~~41~~

Expanding Range of Reliable FRP Materials & Structural Solutions

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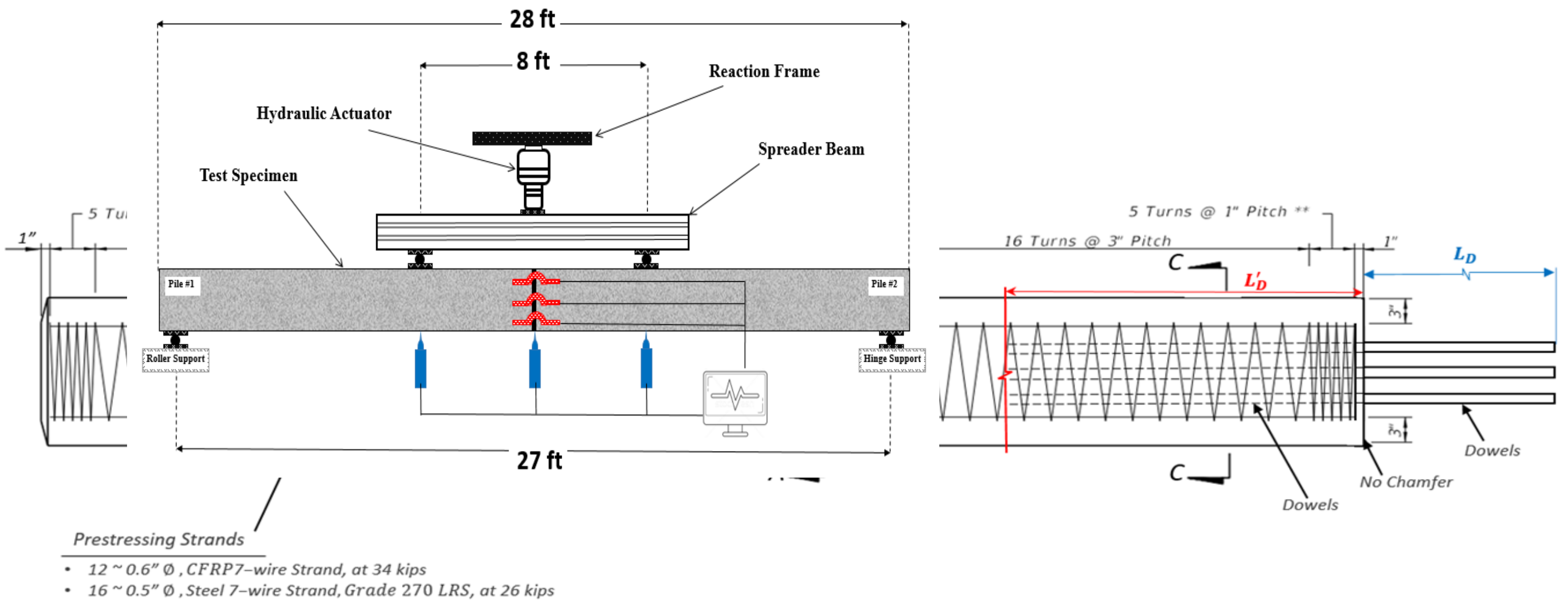
Recent Full-Scale Testing and Research on Beams and Piles

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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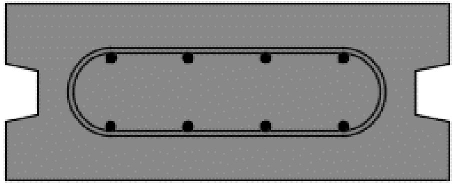

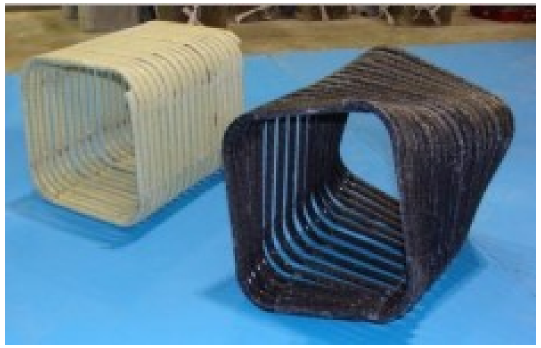

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Materials Research Report July 2014
Final Report

UNF Project
Contract No. BDK82-977-05

Degradation Assessment of Internal Continuous Fiber Reinforcement in Concrete Environment

Adel ElSafty, Ph.D., P.E. (Principal Investigator)
Brahim Benmokrane, Ph.D., P.E.
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Hamdy Mohamed, Ph.D., P.E.
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School of Engineering
College of Computing, Engineering, and Construction
University of North Florida
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UNF UNIVERSITY of NORTH FLORIDA

Testing Protocol and Material Specifications
for Basalt Fiber Reinforced Polymer Bars

Contract Number BE694
FSU Project ID: 042878

Submitted to:

Florida Department of Transportation
Research Center
605 Suwannee Street
Tallahassee, Florida 32399-0450

Chase C. Knight, Ph.D
Project Manager
FDOT State Materials Office

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BE694, Improving "Testing Protocol and Material Specifications for Basalt Fiber Reinforced Polymer Bars" (2019-2021):

Durable Solutions and Life Cycle Cost Evaluation

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

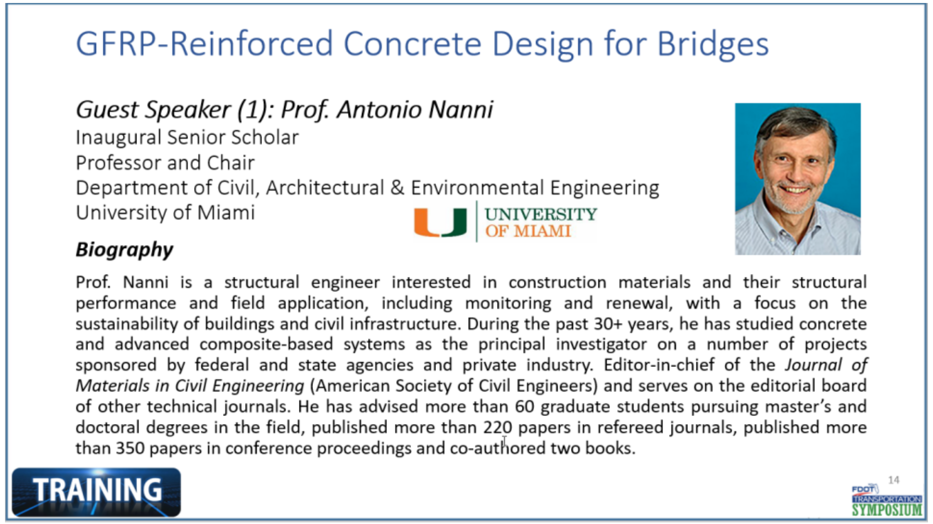
GUIDE SPECIFICATION FOR SERVICE LIFE DESIGN OF HIGHWAY BRIDGES, 1ST EDITION

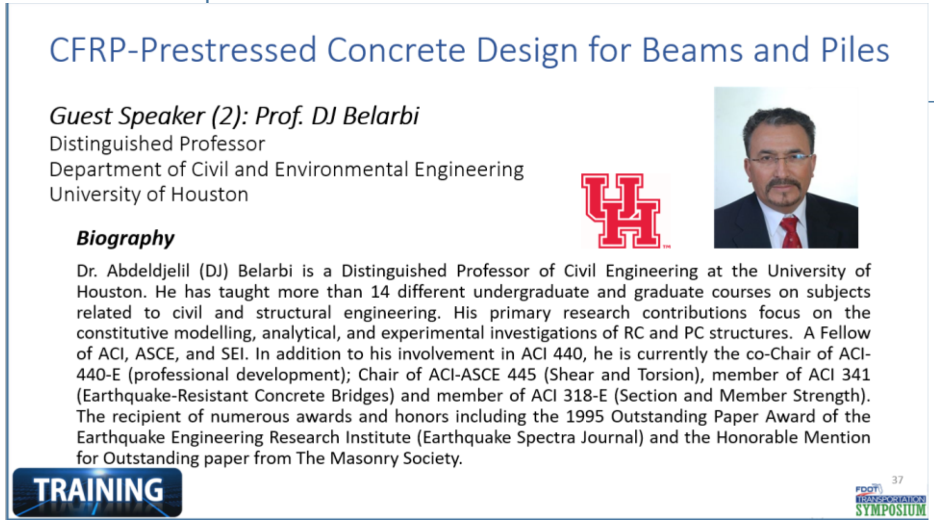
Item Code: HBSLD-1

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 Paticipation





Education Tools for Designers, Contractors, and Owners

i. FRP Designer Training
ii. Structural Design and LCC Tools
iii. Technology Transfer Participation

Florida Department of TRANSPORTATION

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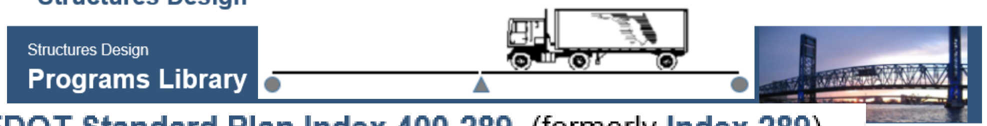
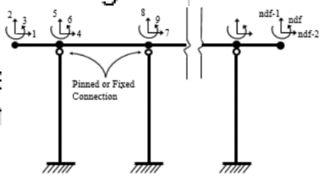
Structures Design



GFRP-RC in development →	**Box Culvert v4.0**	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.
*CFRP-PC Beta version ** (V6.0 coming Fall 2020) →*	**Prestressed Beam v5.2**	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.
GFRP-RC included (Worksheet 3b) →	**Bent Cap v1.0**	11/07/2018	Exe (Zip) (Mathcad 15)	Analyzes and designs fixed or pinned bent caps, including l loads, in accordance with the AASHTO LRFD Bridge Desig Specifications.
GFRP-RC included →	**Retaining Wall v4.0**	06/01/2020	Zip (Exe) (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.



Bent Cap Analysis Model

*** Available on request*

Education Tools for Designers, Contractors, and Owners

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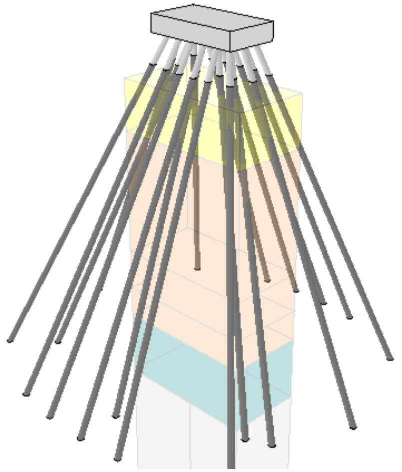
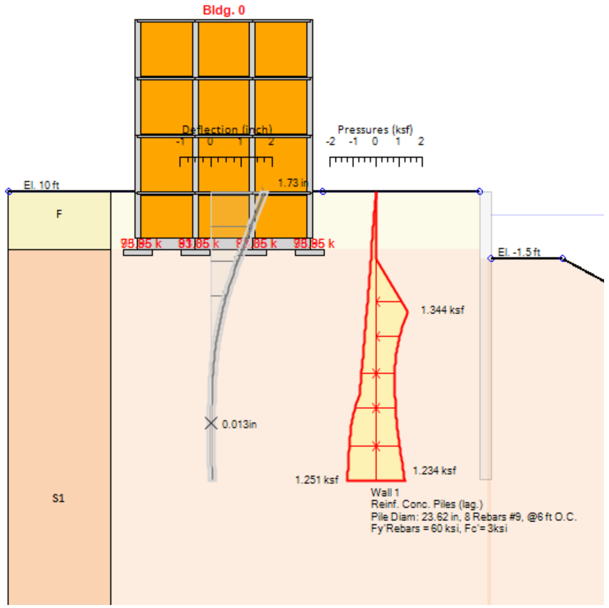
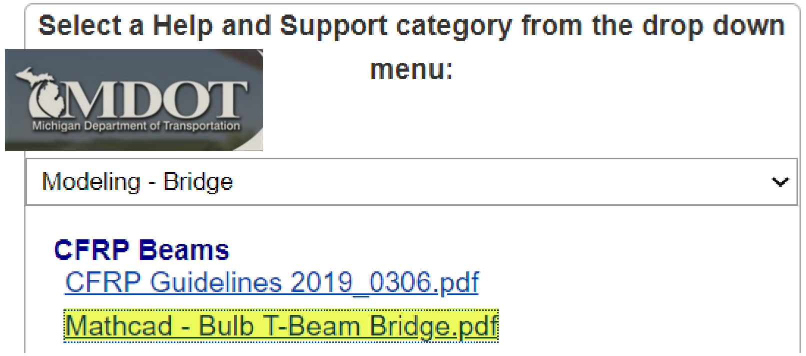




Other Design Software:

Adaption of FRP analysis or design enhancements:

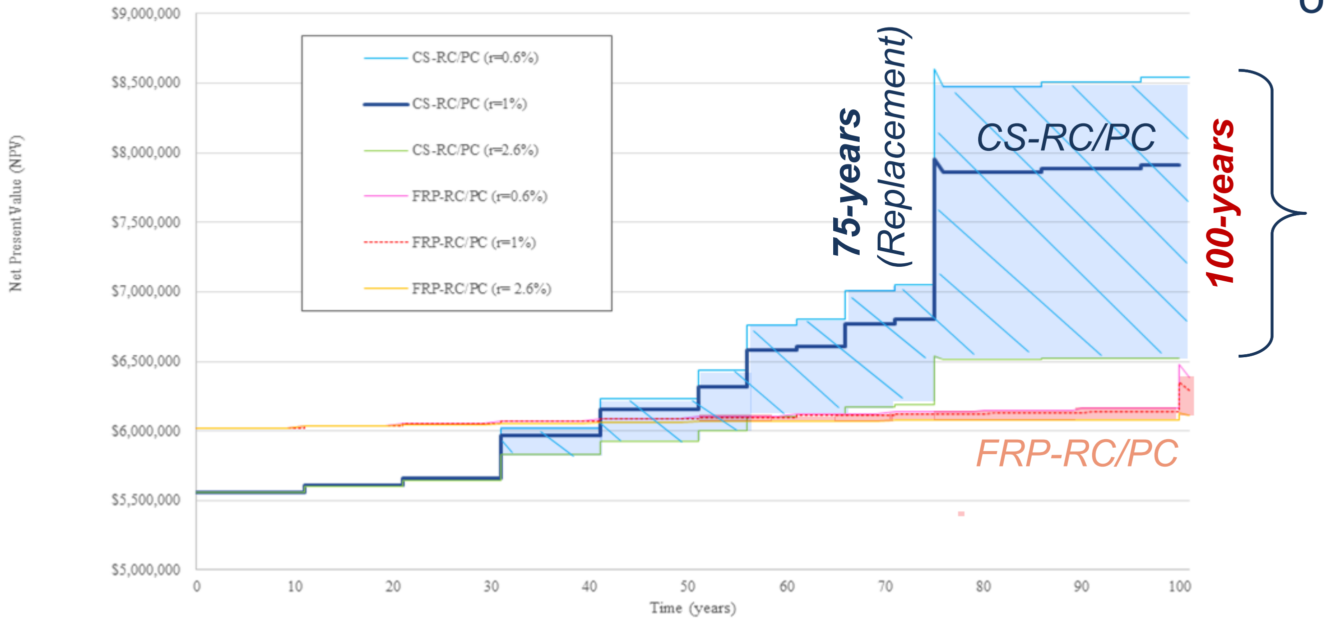
- **FBMP** (*BSI*) *pending*
- **DeepEx** (*Deep Excavation, LLC*) *pending*
  - DeepFND 2021: ~September 2020
  - DeepEX 2021: ~Jan 2021
  - RC-Solver 2021: ~ Oct. 2020
- **Michigan DOT/LTU** CFRP-Beam Design Mathcad: *https://mdotjboss.state.mi.us/SpecProv/trainingmaterials.htm* *(also see TRB Webinar Dec 3, 2019)*

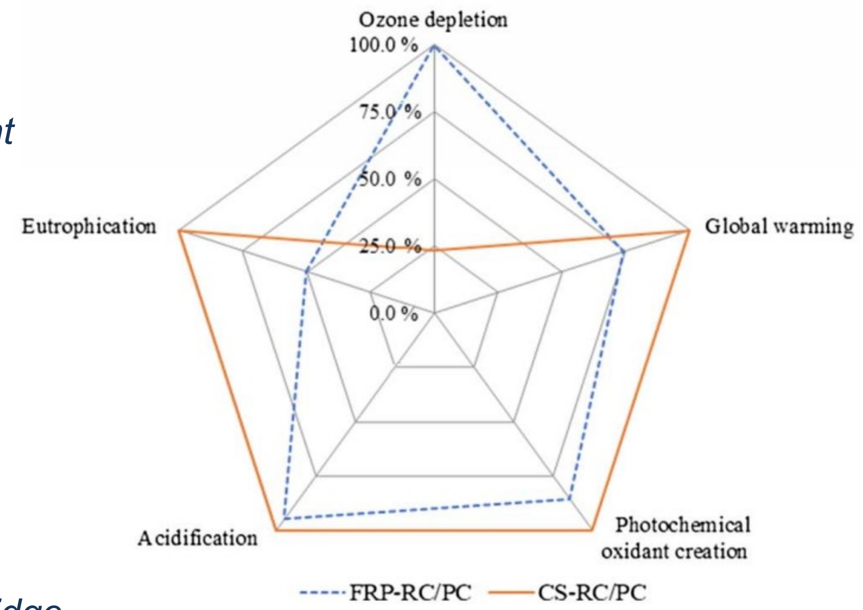


Education Tools for Designers, Contractors, and Owners

i. FRP Designer Training
ii. Structural Design and LCC Tools

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

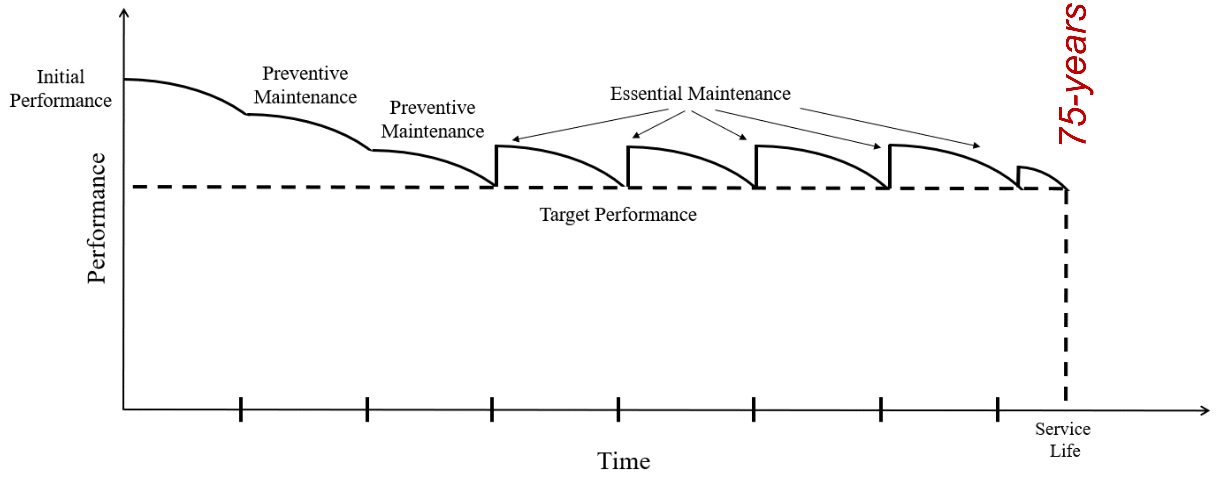




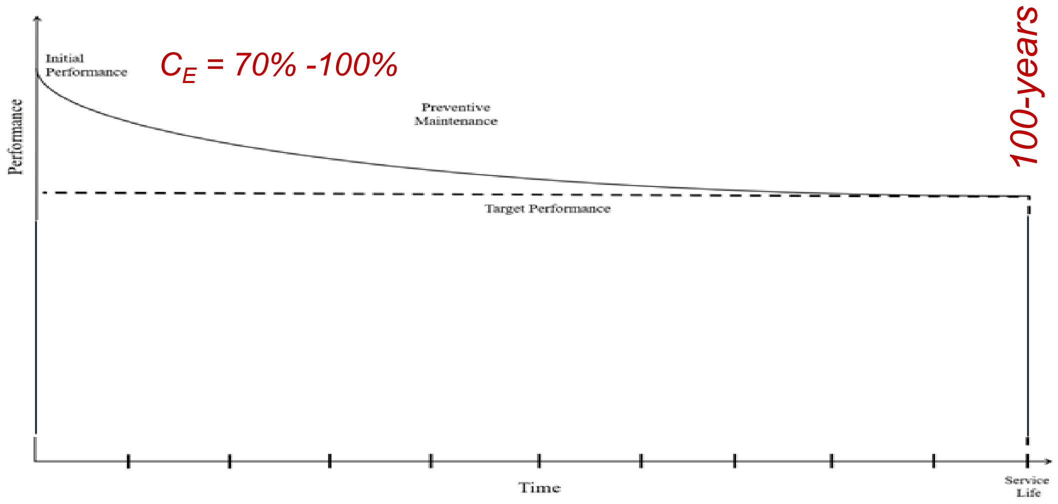
Example LCC & LCA Comparison of Carbon Steel-RC/PC verses FRP-RC/PC bridge (adapted from Cadenazzi et al. 2019)

Education Tools for Designers, Contractors, and Owners

i. FRP Designer Training
ii. Structural Design and LCC Tools
iii. Technology Transfer Participation



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.*

Education Tools for Designers, Contractors, and Owners

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ii. Structural Design and LCC Tools
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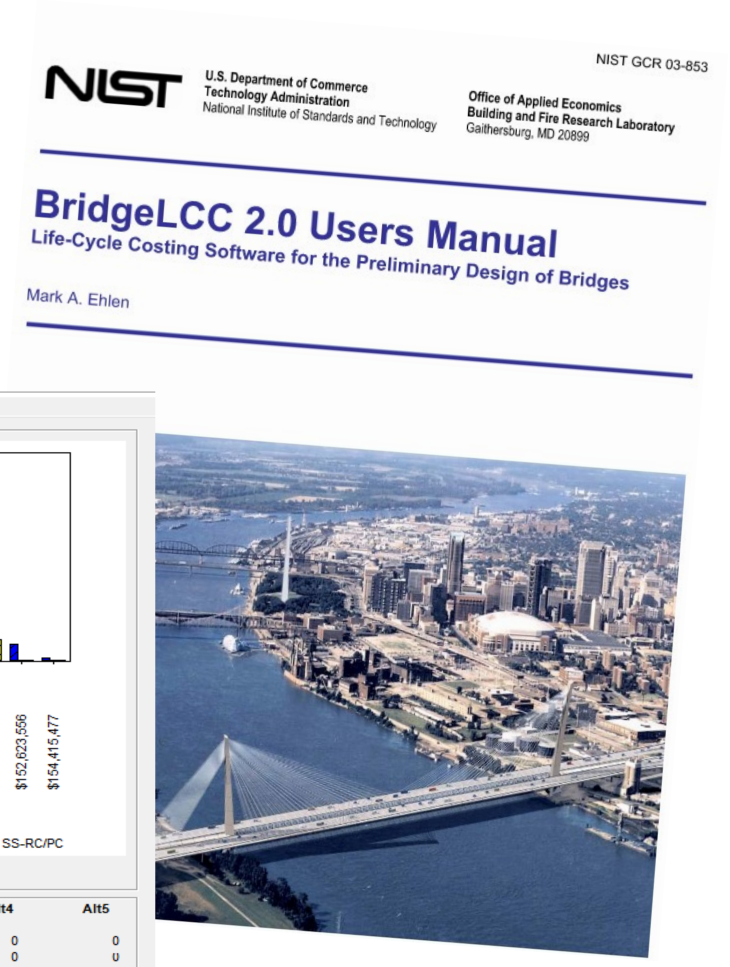
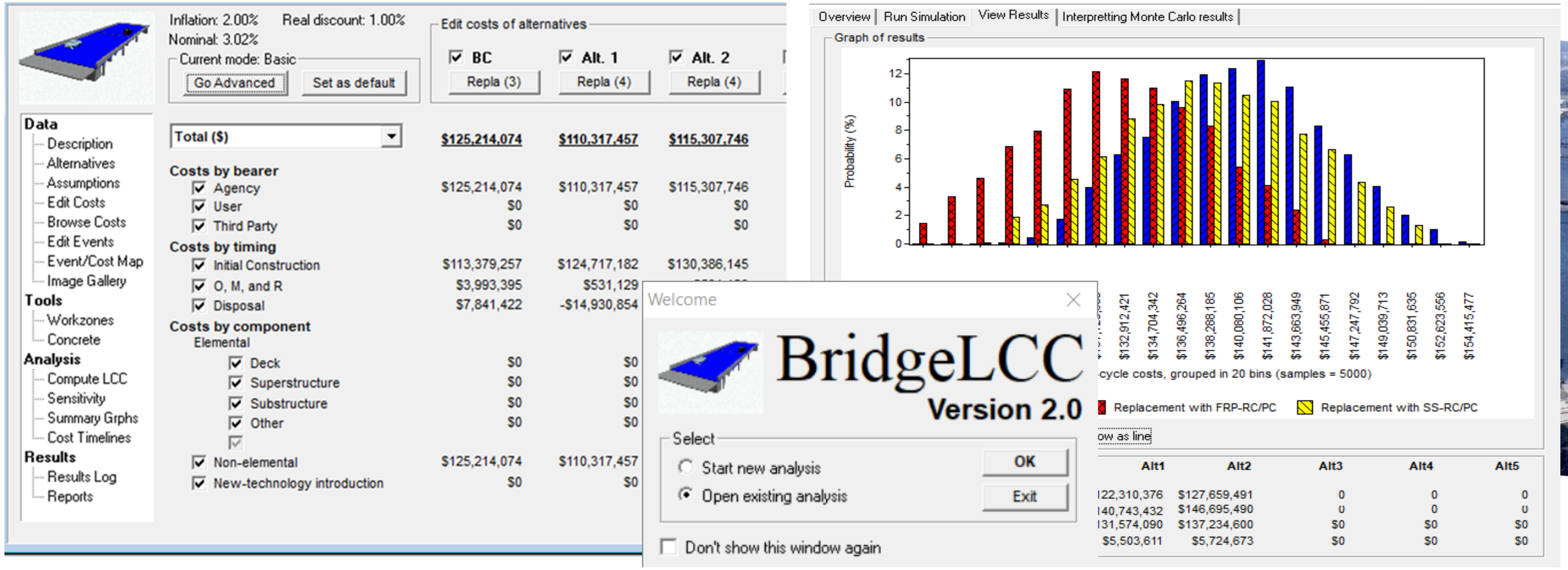




Education Tools for Designers, Contractors, and Owners

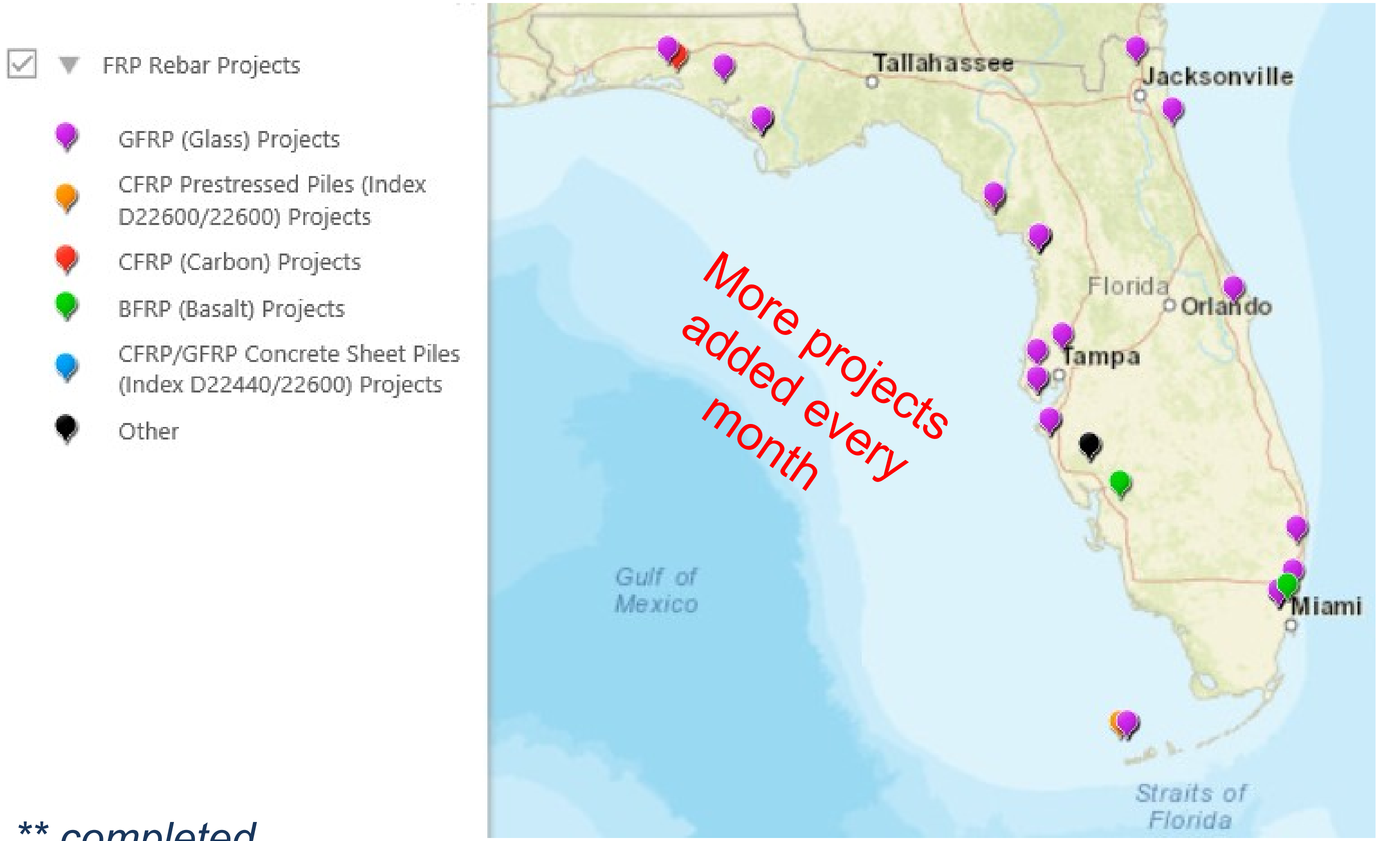
iii. Technology Transfer Participation:

1. **Research & Bridge Code Development:**
   TRB *AKB30 &* ***AASHTO*** *COBS T-6 & T-10*
   – **GFRP-RC Bridge Guide Spec – 2nd Edition:** 2018 Task team participation with UM and FDOT staff.
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* ***DOT****s* 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) LMC^2/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:*
   – UHPC, HSSS/CFRP-PC & GFRP-RC *(Dec. 3, 2019)*
8. **ACI coordination** (informal)
   – **343 & 440 Committees (Bridge & FRP)** *2020 Fall Convention*
   – ***Strategic Development Council*** – *Forum 46 (2019)*
9. **State Level Engagement:**
   – **FRP Industry Workshops** *(2016, 2017, 2018, & 2020)*
   – **FTBA/Contractors** *(2017 & 2018)*
   – **FES/FICE** *(2017)* & **ASCE-FL** *(2018)*
   – **GFRP-RC & CFRP-PC Training** *(Aug & Sept 2020)*

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]

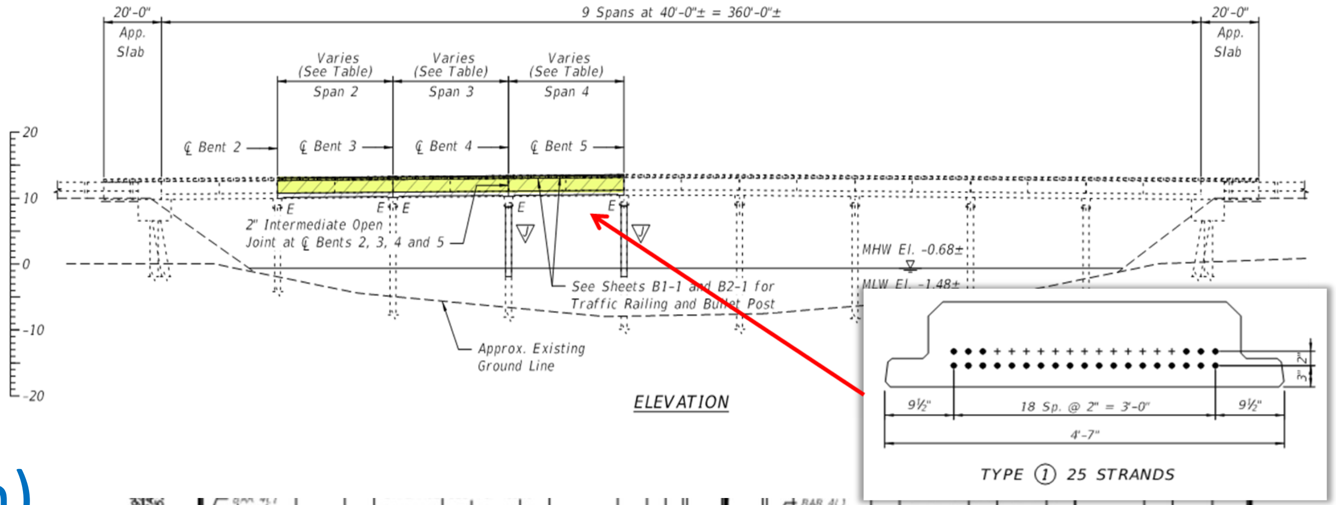
Current & Completed Projects in Florida

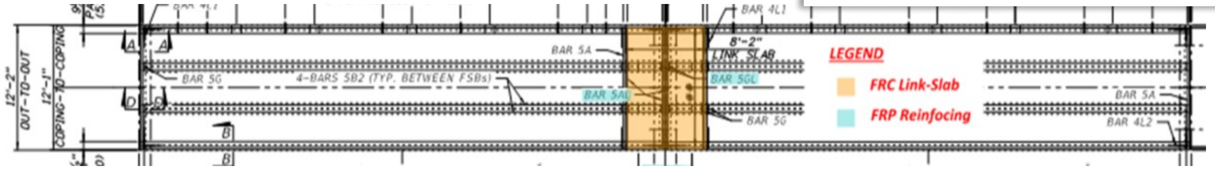


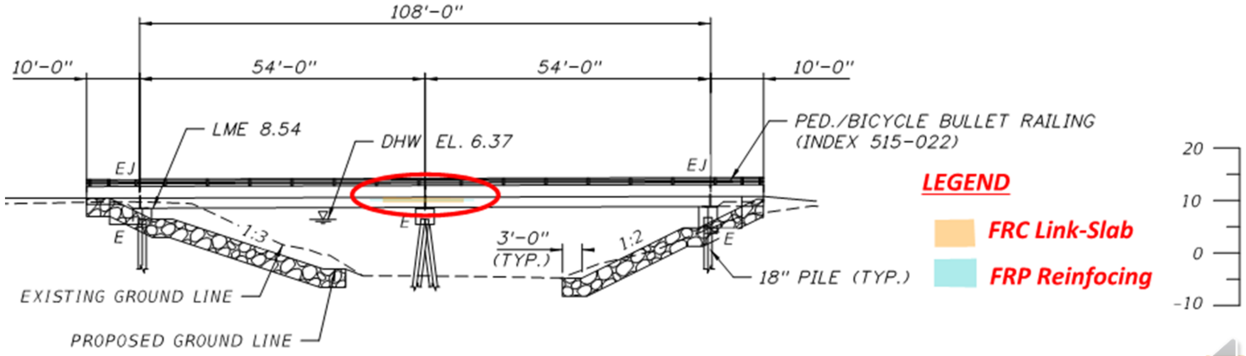
*** completed*

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)

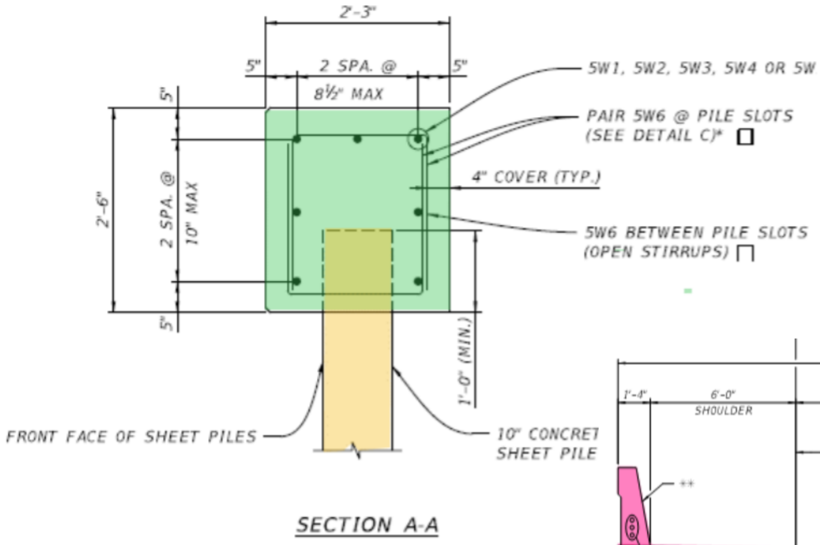


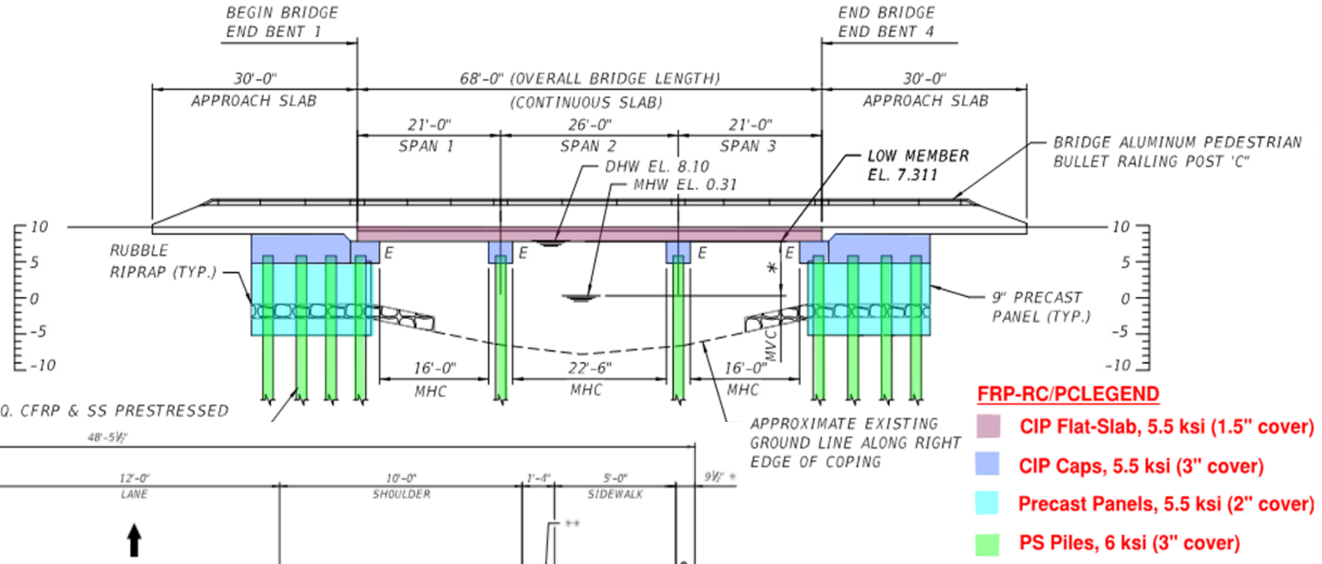


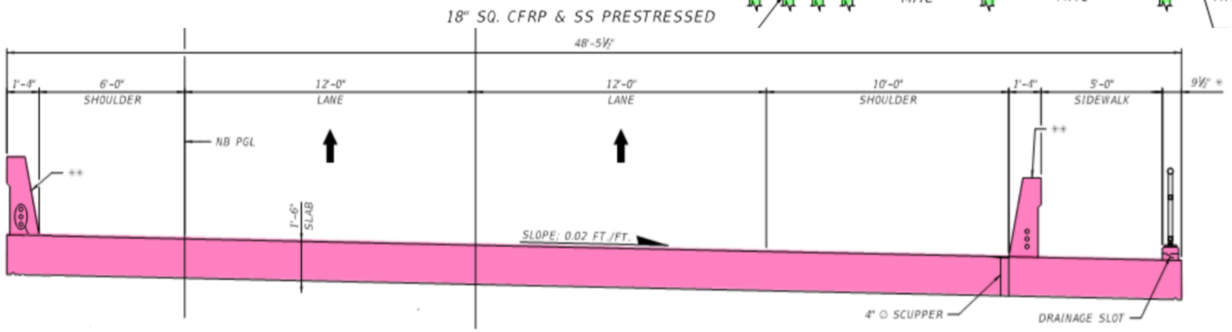


Projects Under Construction

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)







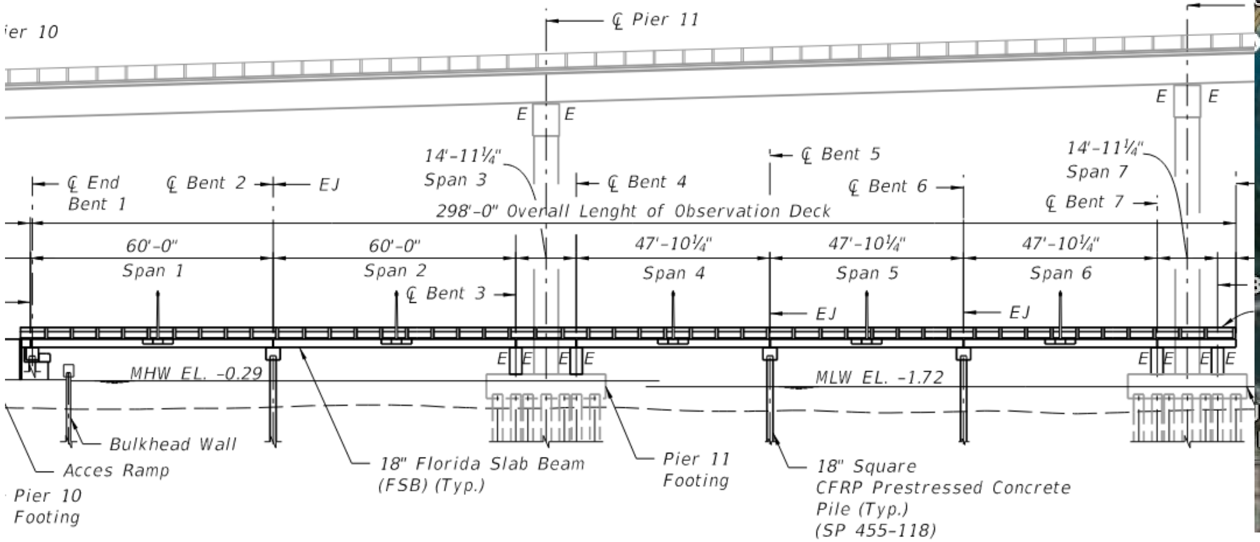
New Projects in Design

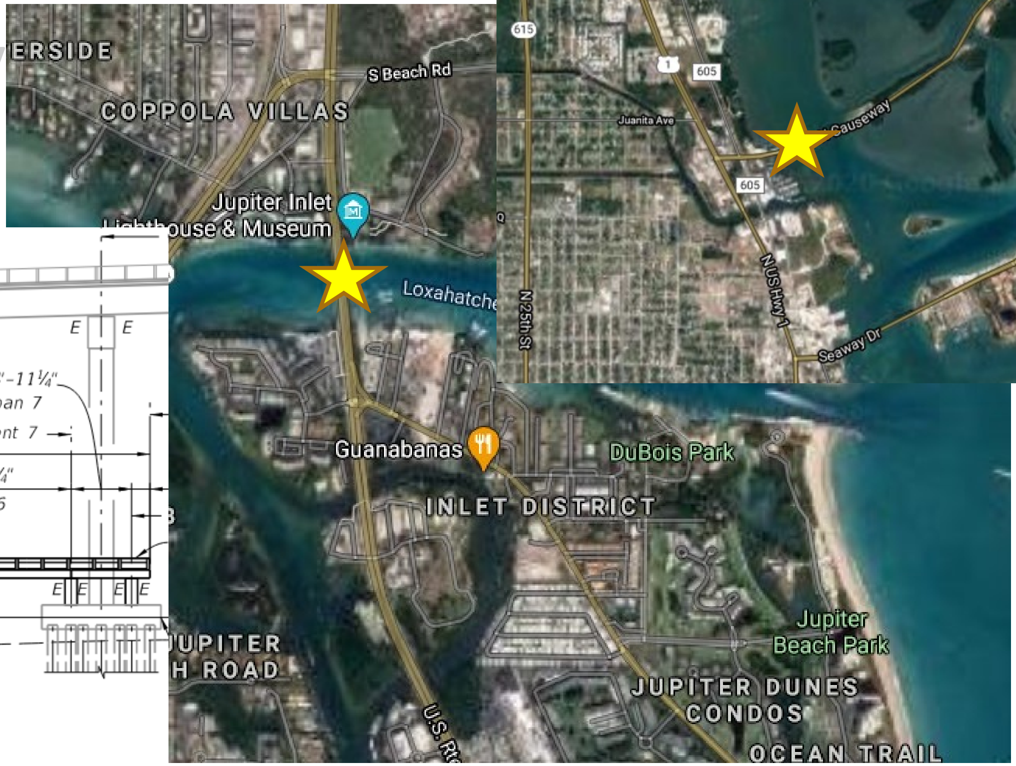
i. Pedestrian Piers (North Bridge, Jupiter)

ii. Prestressed Bridges (Earman Canal, Barracuda

iii. CIP Bridges (Turkey Creek)

iv. Bridge Foundations (4th St ov





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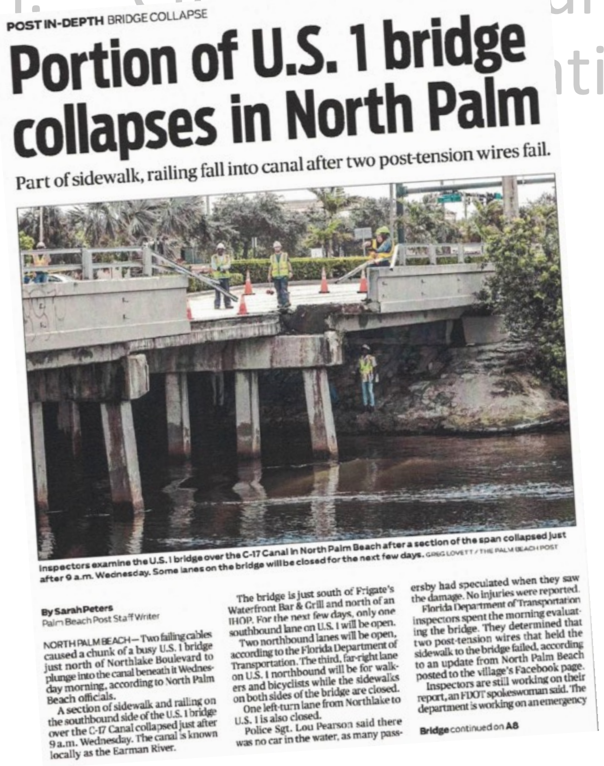


POST IN-DEPTH BRIDGE COLLAPSE

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.

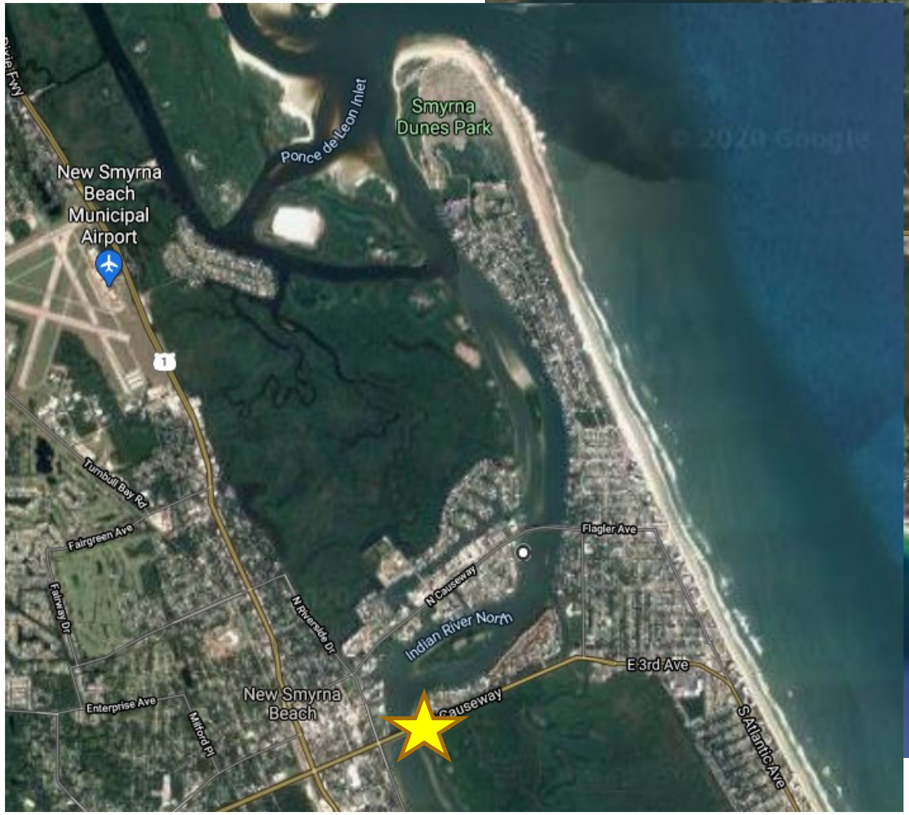
One left-turn lane from Northlake to U.S. 1 is also closed.

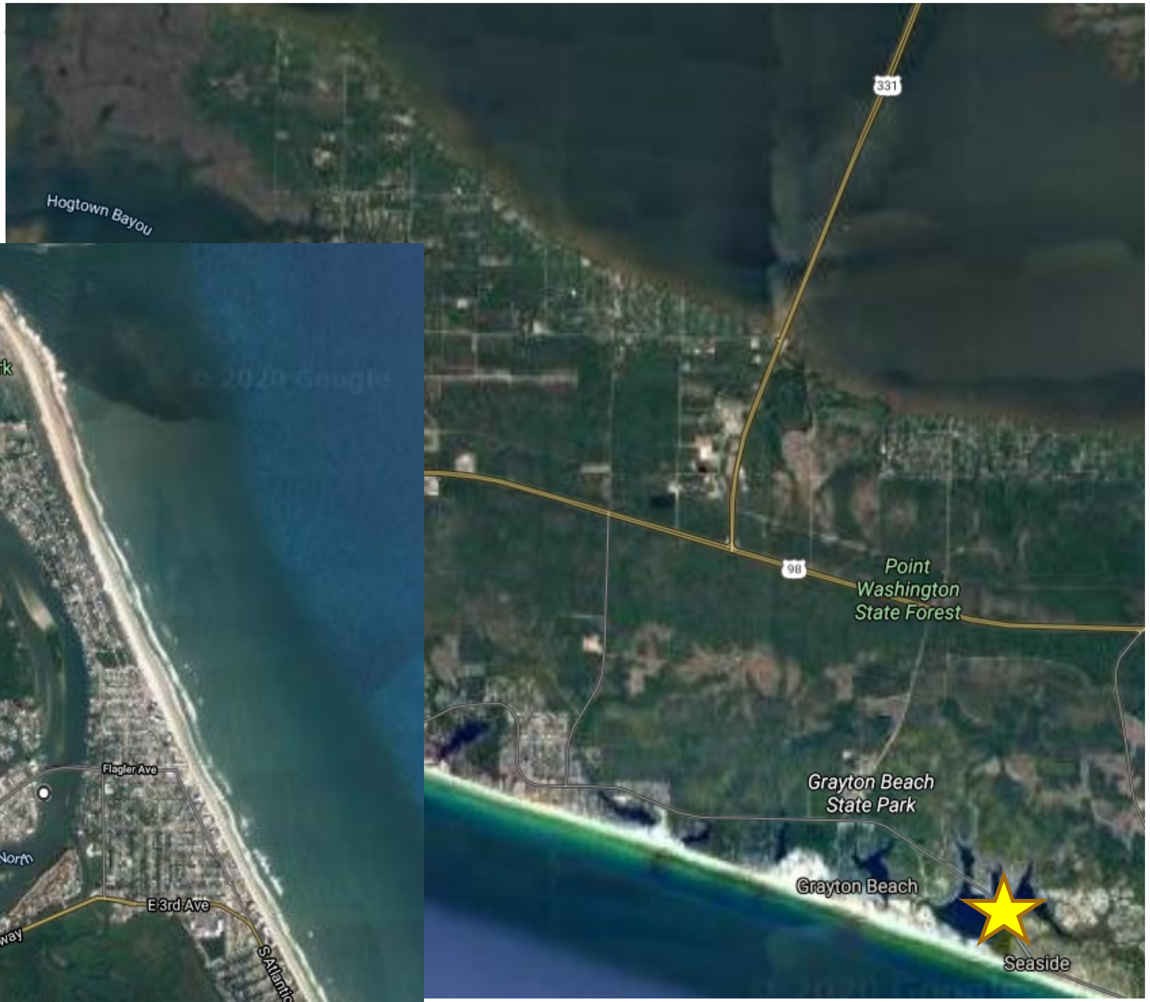
Police Sgt. Lou Pearson said there was no car in the water, as many passersby had speculated when they saw the damage. No injuries were reported.

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





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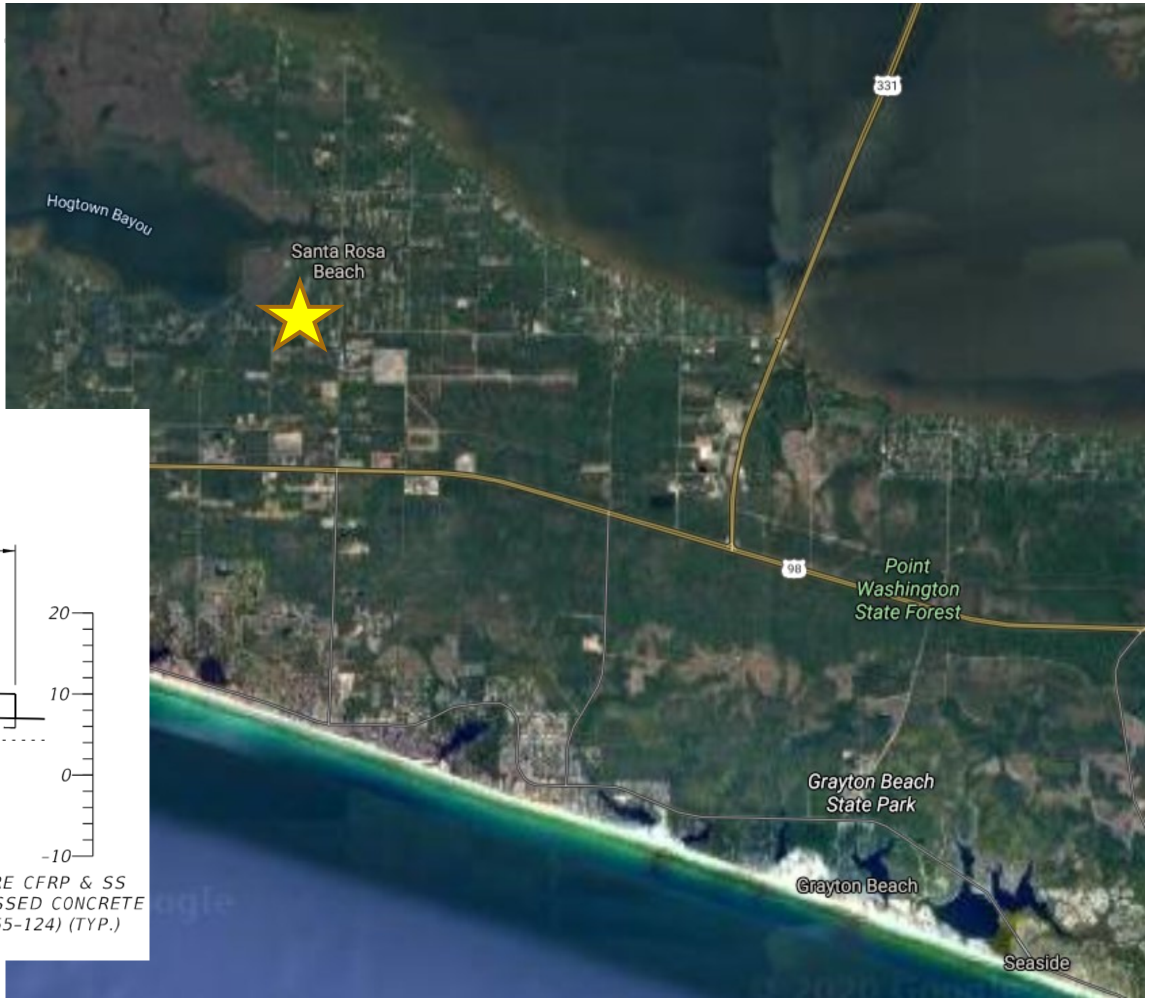

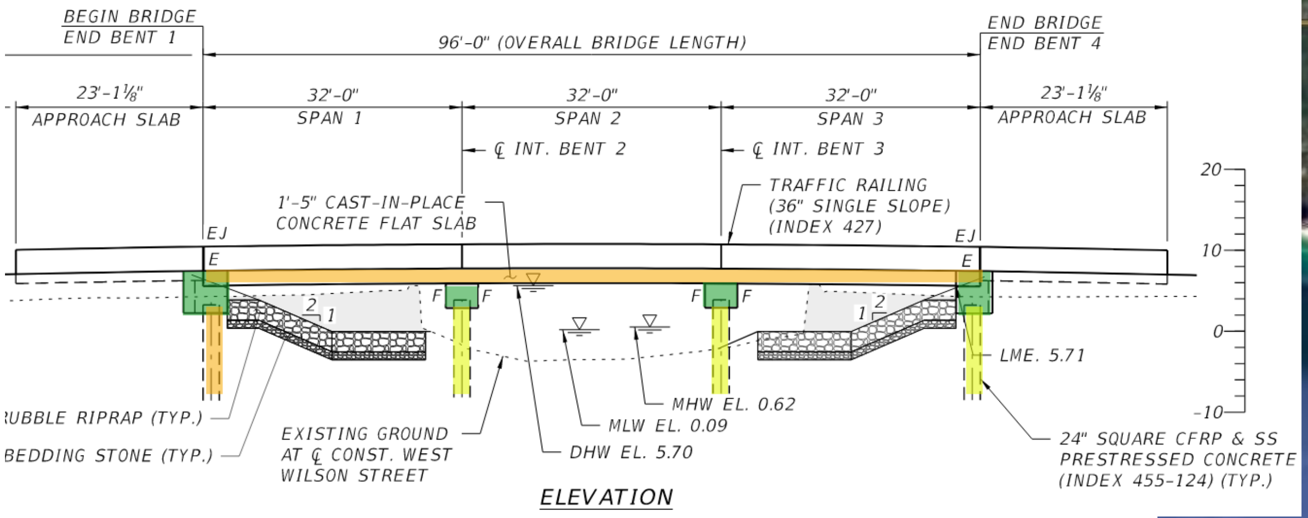

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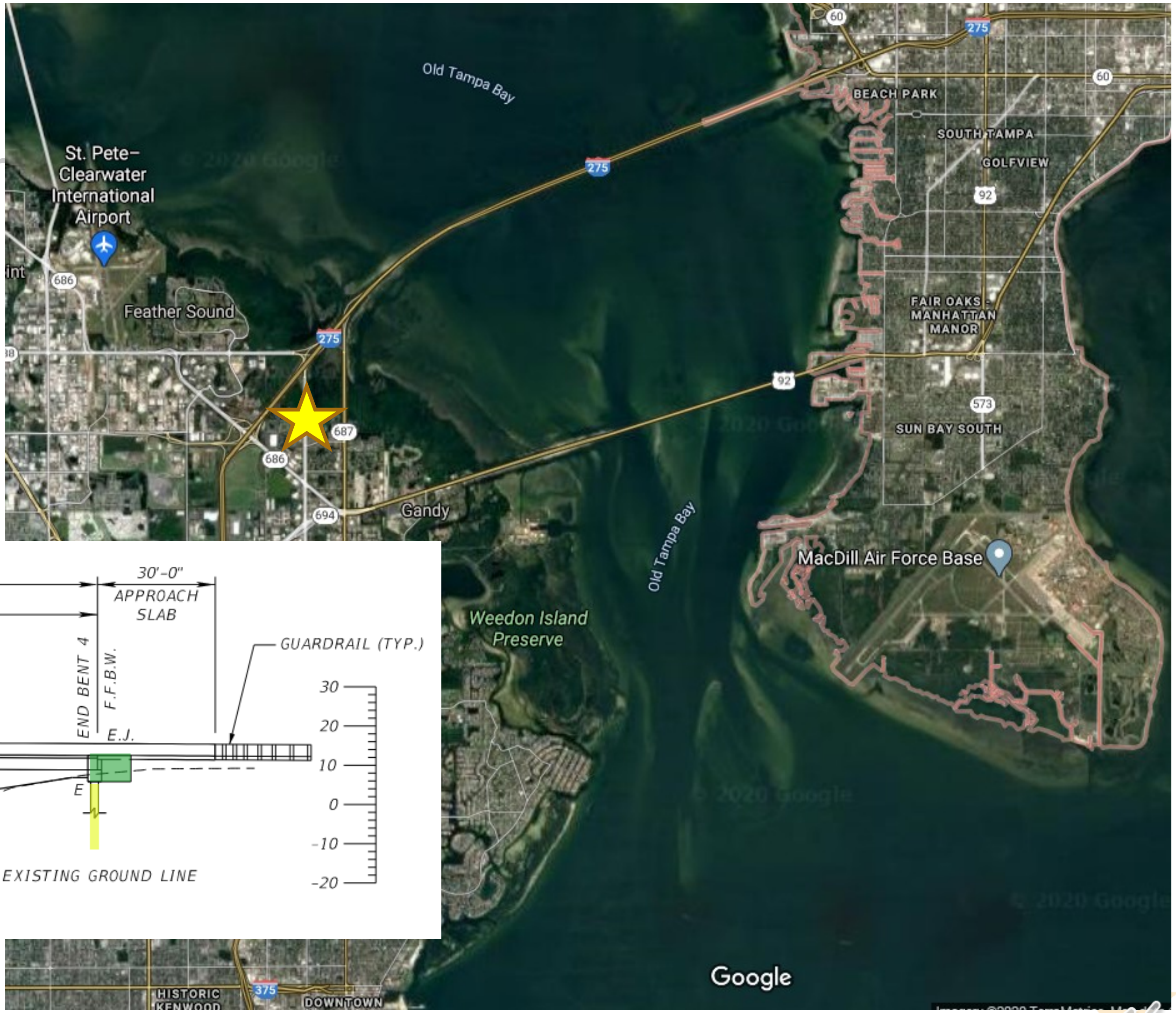

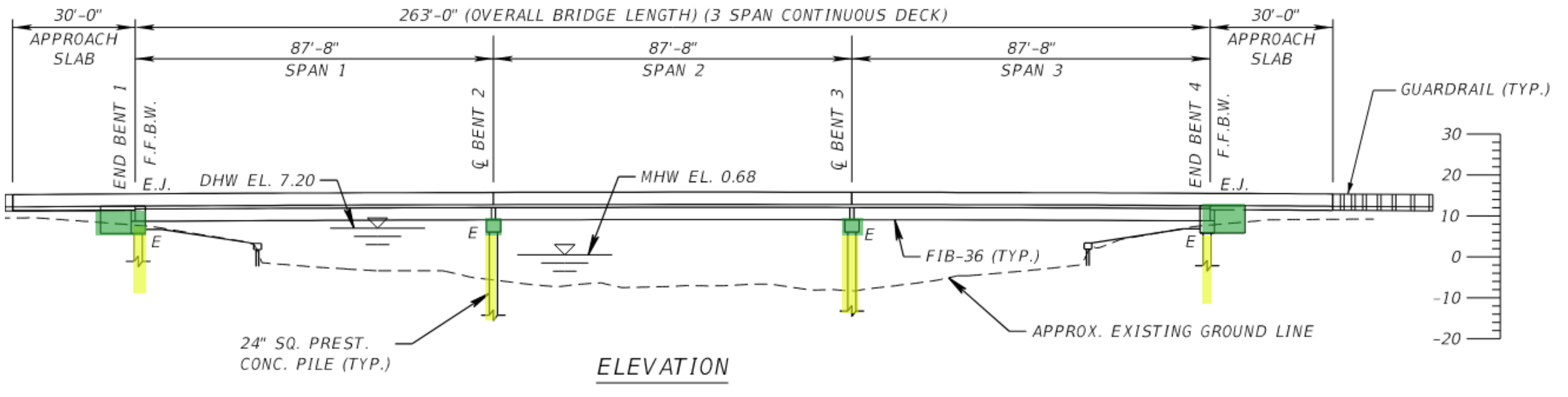

Lessons Learned from the Real World

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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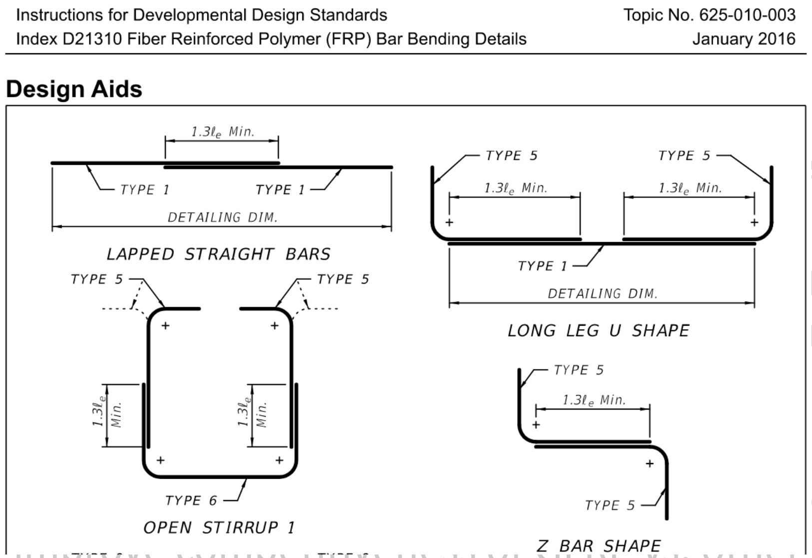
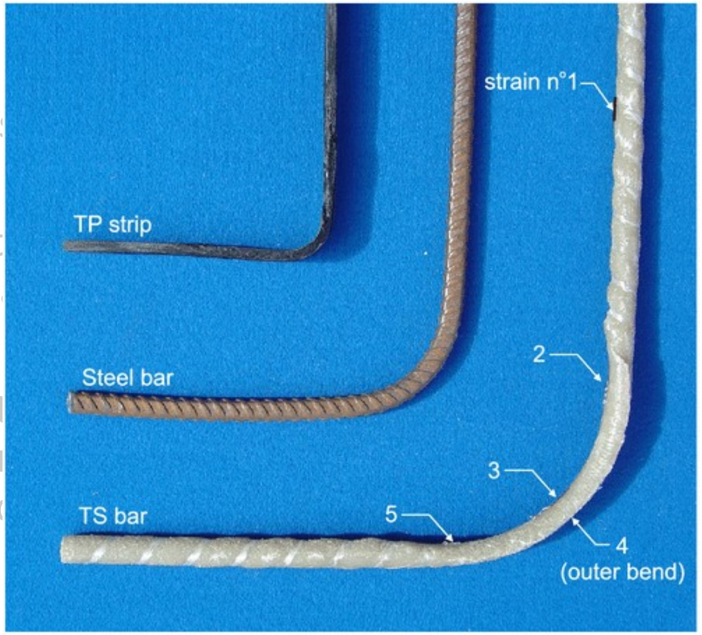

Instructions for Developmental Design Standards | Topic No. 625-010-003
Index D21310 Fiber Reinforced Polymer (FRP) Bar Bending Details | January 2016

Design Aids



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