FDOT experience using FRP structural composites and the evolution of implementation.

- **FDOT perspective and project examples**

Steven Nolan, P.E.

Florida Department of Transportation

State Structures Design Office (Tallahassee, FL)

Wednesday July 28th, 2021

Structural Composites in Highway Transportation – Guest Speaker and Panel Discussion

Outline

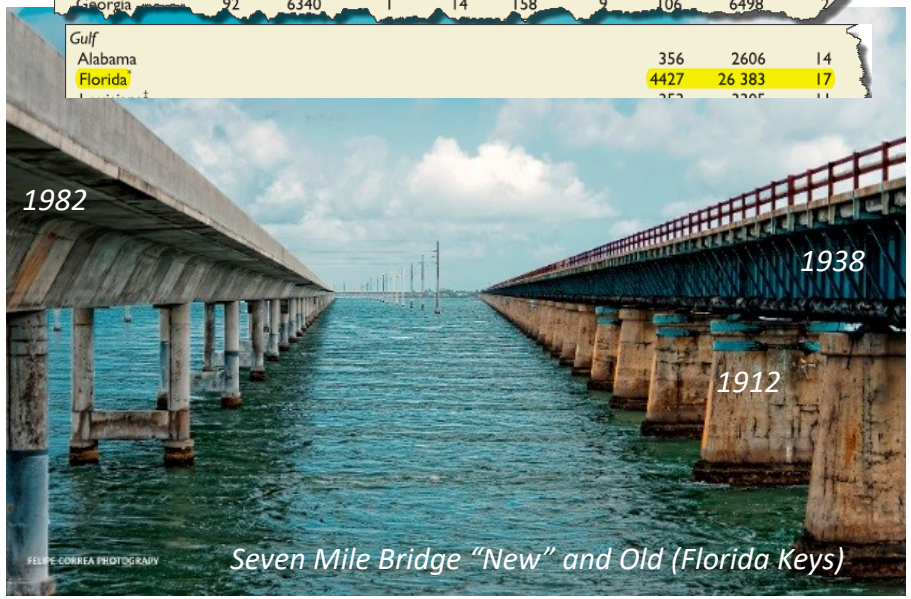
- FRP Structural Composite Type
- FDOT Research
- Implementation
- Typical Project Examples
- Scaling up for broader deployment

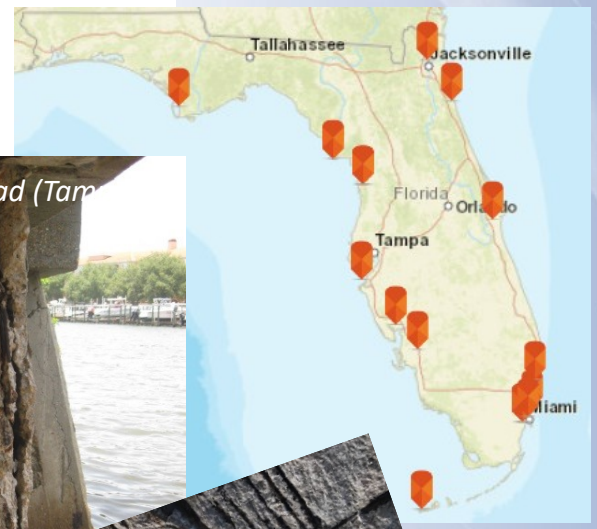
Why use FRP materials for Bridges & Structures

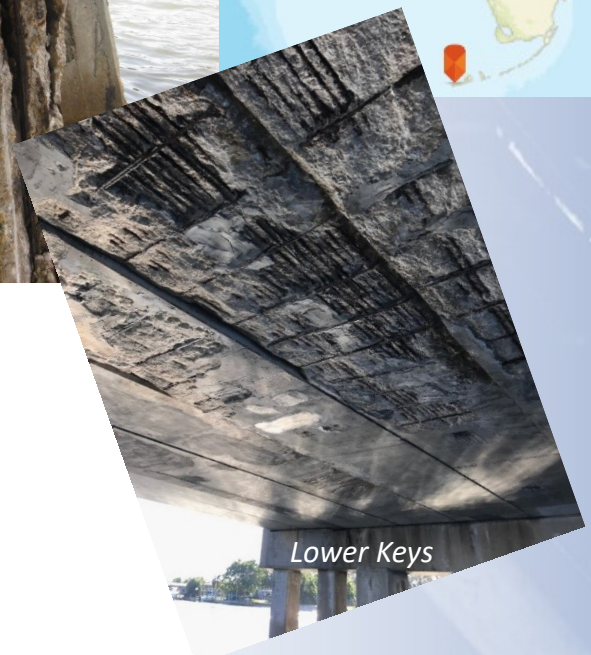
- Florida maintains more than 150 million sq.ft. of bridge area *(7044 FDOT bridges[2]);*
- Florida has more than 4,000 miles seawall-bulkheads[3].

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
Georgia	92	6340	1	14	158	9	106	6498	2
Gulf									
Alabama							356	2606	14
Florida*							4427	26 383	17







(1) Gittman et al. (2015) https://esajournals.onlinelibrary.wiley.com/doi/abs/10.1890/150065
(2) FDOT Bridge Inventory – 2020 Annual Report
(3) Estimates from Gittman et al. (2015)

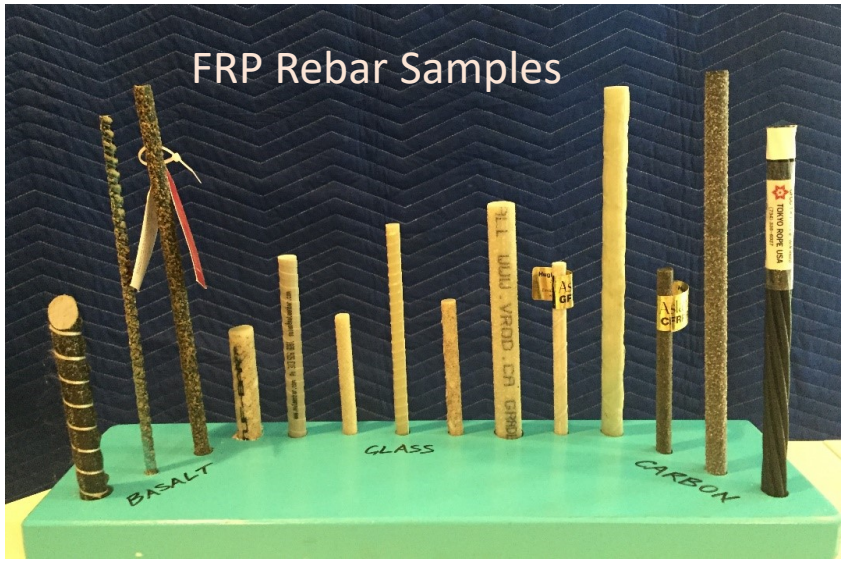
FRP Structural Composite Types

FDOT FRP-Design Innovation Initiative

FRP Structural Reinforcement & Members

- Prestressing *(internal - pretensioned concrete)*
  - Carbon FRP Cable
  - GFRP & BFRP rods emerging

- Reinforcing Bars *(internal & NSM)*
  - Basalt FRP
  - Carbon Bar FRP
  - Glass FRP



- FRP Structural Members & Systems
  - Fender Piles & Wales (incl. internal bars)
  - Hollow Profiles (square, rectangular, circular)
  - Assembled Frames and Trusses
  - Beams and Arch CFFT

FRP Structural Reinforcement for Repairs/Rehab.

- Girder Strengthening for load capacity
- Restoration due to Corrosion
- Repair from Over-height Truck Impact Damage.

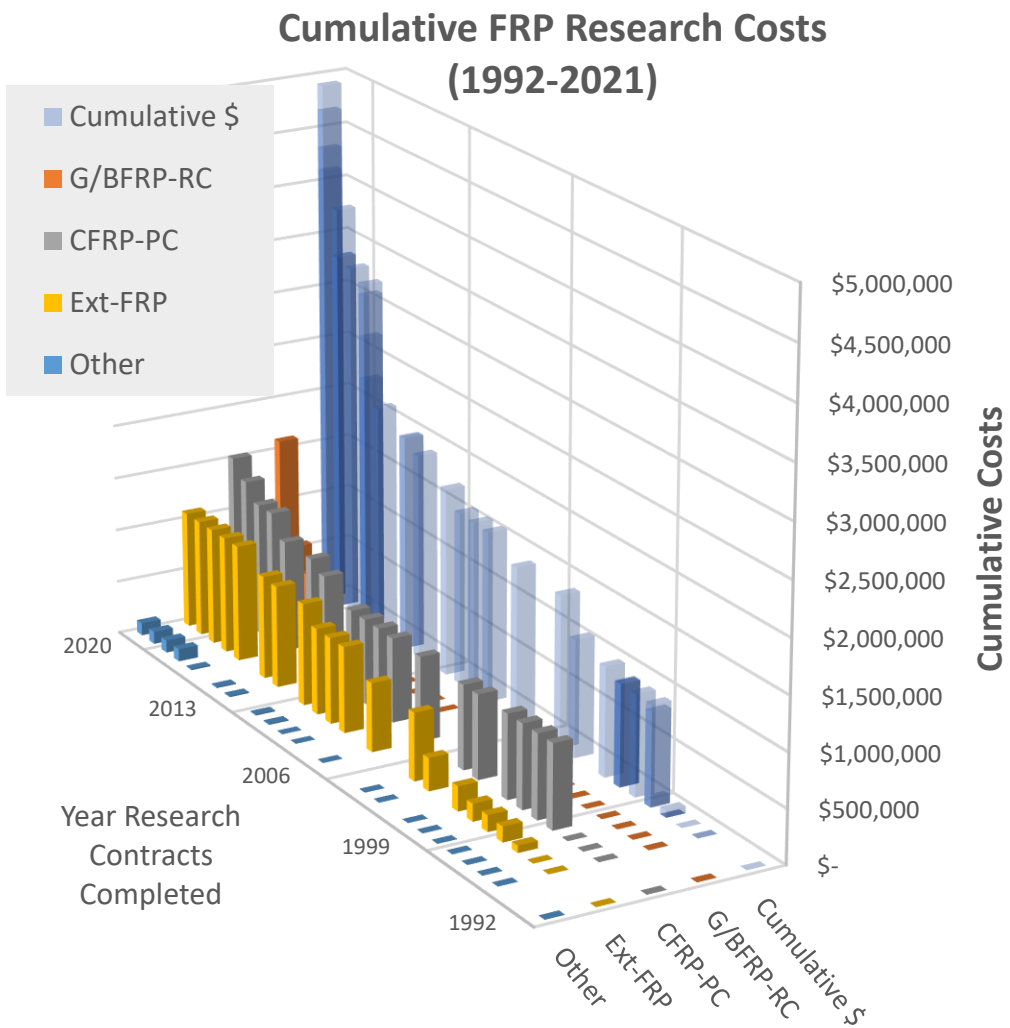
Strengthening – Corrosion Damage

Impact Damaged Concrete

FDOT Research on FRP Structural Composites

Materials & Structures Research 1990-2020+

FDOT Research on FRP Structural Composites



1992	Feasibility of Fiberglass Pretensioned Piles in a Marine Environment	Sen, R.	USF
1995	Active Deformation Control of Bridges with AFRP Cables	Arockiasamy, M.	FAU
1995	Durability of CFRP Pretensioned Piles in a Marine Environment – Phase II	Sen, R.	USF
1997	Mechanical and Microscopy Analysis of CFRP Matrix Composite Materials	Garmestani, H.	FAMU/FSU
1997	FRP Composite Column and Pile Jacket Splicing	*Mirmiran, A.*	*UCF*
1997	An Analytical and Experimental Investigation of Concrete Filled FRP Tubes	*Mirmiran, A.*	*UCF*
1997	Flexural Reliability of RC Bridge Girders Strengthened with CFRP Laminates	Okeil, A.	UCF
1998	Studies of CFRP Prestressed Concrete Bridge Columns and Piles in Marine Environment	Arockiasamy, M.	FAU
1998	Analysis and Modeling of Fiber-Wrapped Columns and Concrete-Filled Tubes	*Shahawy, M.*	*FDOT*
1999	LRFD Flexural Provisions for PSC Bridge Girders Strengthened with CFRP Laminates	El-Tawil, S.	UCF

https://www.fdot.gov/structures/structuresresearchcenter/default.shtm

FDOT Research on FRP Structural Composites

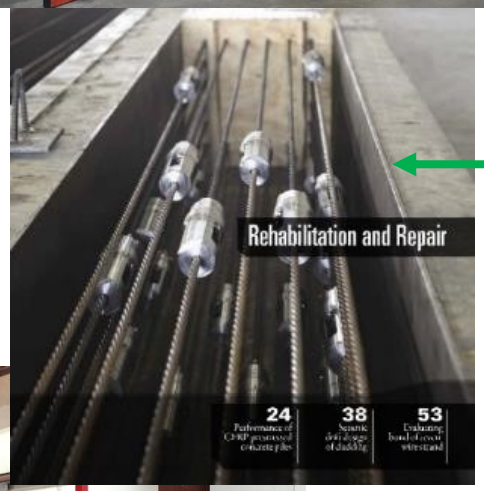
CFRP Laminate Strengthening for Berth 21 - Port of Tampa (2011)

NSM of Old Overseas Highway Deck in Florida Keys (2006)

1999	Behavior of Reinforced Concrete Beam-Column Retrofitted with Composite Wrapping Systems	*Chaallal, O.*	*FDOT*
2000	Effect of Concrete Strength on the Performance of FRP Wrapped RC Column Under Combined Axial-Flexure Loading	*Chaallal, O.*	*FDOT*
2000	Behavior of Axially Loaded Short Rectangular Columns Strengthened with CFRP Composite Wrapping	Chaallal, O.	FDOT
2000	Investigation of Fender Systems for Vessel Impact	Yazdani, N.	FAMU/FSU
2000	Short-Term Tensile Strength of CFRP Laminates for Flexural Strengthening of Concrete Girders	Okeil, A.	UCF
2001	Design of Concrete Bridge Girders Strengthened with CFRP Laminates	El-Tawil, S.	UCF
2003	Hybrid FRP-Concrete Column	*Mirmiran, A.*	*NC State*
2004	CFRP Repair of Impact Damaged Bridge Girders	Hamilton, T	UF
2007	Testing Bridge Decks with Near-Surface mounted FRP Bars Embedded in Cement Based Grout	Hamilton, T	UF
2009	Thermo-Mechanical Durability of CFRP Strengthened RC Beams	Mackie, K	UCF

FDOT Research on FRP Structural Composites

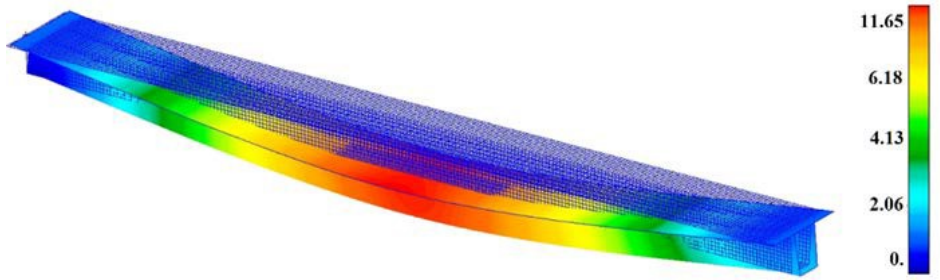

Flexural Testing of CFRP Prestressed Piles (2014)




1969 Indian River T-Beam with 1999 CFRP Strengthening (2014)

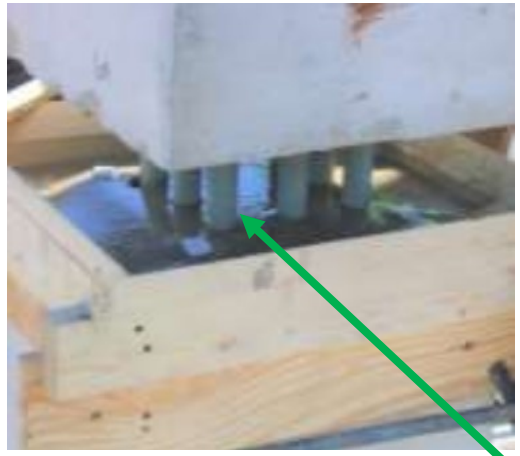
2010	Testing Precast Piles with Carbon Fiber Reinforced Polymer Mesh	Abalo, V.	FDOT
2011	Testing of Trelleborg Structural Plastics	Wagner, D.	FDOT
2012	The Repair of Damaged Bridge Girders with CFRP Laminates	El-Safty, A.	UNF
2014	Investigation of CFCC in Prestressed Concrete Piles	Roddenberry, M.	FAMU/FSU
2015	Use of CFRP Cable for Post-Tensioning Applications	Mirmiran, A.	FIU
2015	Repair of Impact Damaged Utility Poles with FRP, Phase II	*Mackie, K.*	*UCF*
2017	Durability Evaluation of Florida's FRP Composite Reinforcement for Concrete Structures	Hamilton, T.	UF
2018	Testing, Evaluation, and Specification for Polymeric Materials used for Transportation Structures	El-Safty, A.	UNF
2018	Degradation Mechanisms and Service Life Estimation of FRP Concrete Reinforcements	El-Safty, A.	UNF

FDOT Research on FRP Structural Composites



FEA Optimizing FRP Bridge Girders (2018)

Epoxy Dowel Splice (2021)



2018	Bridge Girder Alternatives for Extremely Aggressive Environments	Brown, J.	ERAU
2018	Performance Evaluation of GFRP Reinforcing Bars Embedded in Concrete Under Aggressive Environments	Kampmann, R.	FAMU/ FSU
2019	Performance Evaluation, Material and Specifications for Basalt FRP Reinforcing Bars Embedded in Concrete	Kampmann, R. Roddenberry, M.	FAMU/ FSU
2020	Basalt FRP-FRC Link-Slab Demonstration Project Monitoring (STIC-Phase 1)	El-Safty, A.	UNF
2020	Inspection and Monitoring of Fabrication and Construction for the Halls River Bridge Replacement	Roddenberry, M.	FAMU/ FSU
2020	HSSS Strands and Lightweight Concrete for Pretensioned Concrete Girders (w/ Shear & Confinement Rebar)	*Roddenberry, M.*	*FAMU/ FSU*
2021	Testing Protocol and Material Specifications for Basalt Fiber Reinforced Polymer Bars (Long-term Durability Modelling)	Kampmann, R. Tang, Y	FAMU/ FSU
2021	Evaluation of GFRP Spirals in Corrosion Resistant Concrete Piles	Jung, S.	FAMU/ FSU
2021	Development of GFRP Reinforced Single-Slope Railing	Consolazio, G.	UF
2021	Epoxy Dowelled Pile Splice Evaluation & Testing	Mehrabi, A.	FIU

https://www.fdot.gov/structures/structuresresearchcenter/default.shtm

FDOT Implementation

Design and Construction

FRP Implementation for Florida Bridges and Structures...

- **Mid-1990's** 1st recorded GFRP & CFRP bridge beam strengthening *(Spray up & Wraps)*
- **1990-2000's** Expanded CFRP bridge beam strengthening *(Wraps & Laminate Strips)*
- **2006** 1st FRP fender system Specs & Standard Index issued *(Piles & Wales)*
- **2014** PortMiami: Tunnel approach retaining walls 5 & 6 *(BFRP Rebar)*
- **2015** University of Miami: FRP-Prestress Double-T Innovation Bridge *(CFRP Strands, BFRP & GFRP Rebar)*
- **2016-19** Halls River: FDOT 1st complete FRP-PC/RC/HCB bridge *(Hybrid Composite Beam, CFRP Strands, BFRP & GFRP Rebar)*
- **2019** US41/North Creek & NE 23rd/Ibis Waterway: 1st 2-span & 3-span cast-in-place GFRP-RC Flat-Slab bridges, and soldier pile precast panels *(FRP Rebar & Strands)*

FDOT Implementation of FRP Structural Reinforcement

Why?

- **Durability** needs – low-maintenance, extended service-life, cost-effective solutions, reducing work zones.
- **Structural** needs – Inspectable, repairable, robust, extended span lengths (light-weight and/or high-strength & high-endurance):

Structural Advancement

Highly Corrosion-Resistant

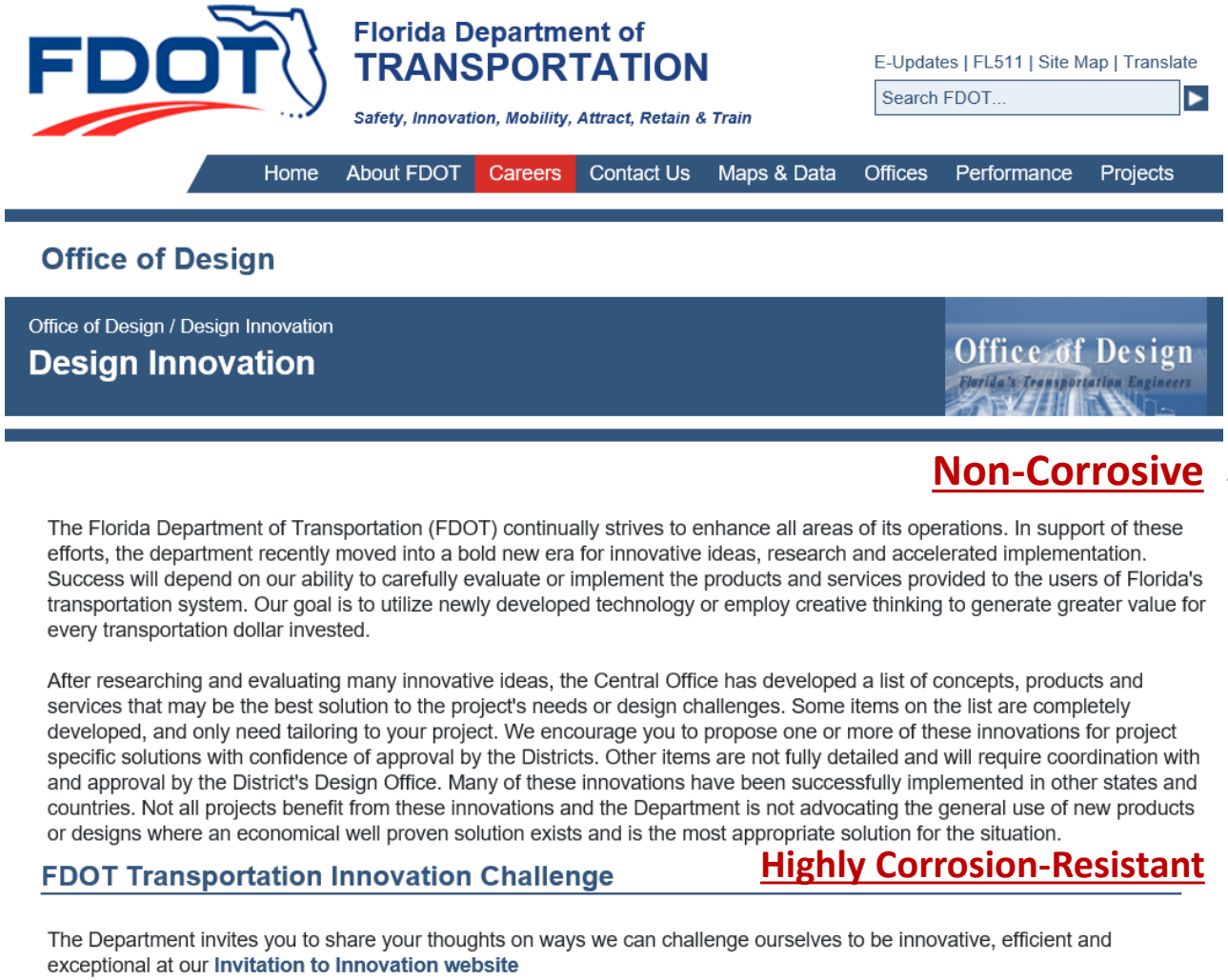
What?

- **FRP-Prestressed Concrete** *(Carbon strands)*
- **FRP-Reinforced Concrete** *(Glass & Basalt)*
- **TP Piles and TS Structural Shapes** *(GFR/GFRP reinforced)*

Complementary or Competitive?

- **Light-weight Concrete or FRP** *(Longer spans and/or less shipping cost)*
- **Ultra-High Performance Concrete** *(UHPC)*
- **HSSS-Prestressed Concrete** *(2205 Duplex Stainless-Steel)*

FDOT Implementation of FRP Structural Reinforcement



https://www.fdot.gov/design/innovation/

Structures Design Office

Non-Corrosive

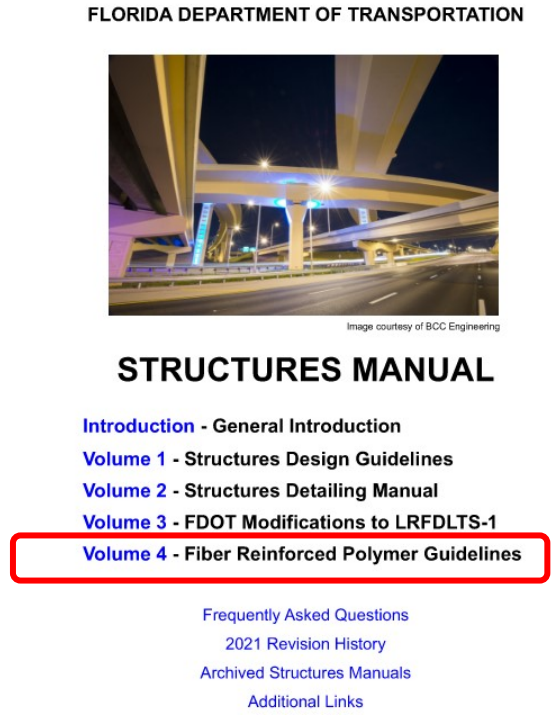
- Curved Precast Spliced U-Girder Bridges
- Fiber Reinforced Polymer Reinforcing [2015]
- FRP Members and Structures [2019]
- Geosynthetic Reinforced Soil Integrated Bridge System
- Geosynthetic Reinforced Soil Wall
- Prefabricated Bridge Elements and Systems
- Segmental Block Walls

Highly Corrosion-Resistant

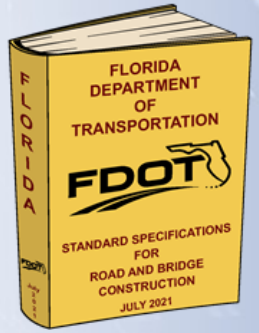
- Ultra-High Performance Concrete (UHPC) [2020]
- + Stainless-Steel Prestressing Strand & Rebar [2021]

FDOT FRP Implementation Resources

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



https://www.fdot.gov/programmanagement/Implemented/SpecBooks/default.shtm



FDOT FRP Implementation Resources

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

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Fiber Reinforced Polymer Production Facility Listing

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

FRP-02 OWENS CORNING (SEWARD NE)
Company: Hughes Brothers, Inc.

FRP-06 PULTRALL

FRP-07 MATEENBAR MIDDLE EAST FZE

FRP-08 ATP

FRP-10 B&B FRP MANUFACTURING
Company: B&B FRP Manufacturing

FRP-12 TUF-BAR INC (EDMONTON CANADA)
Company: Tuf-Bar Inc.

FRP-11 TOKYO ROPE USA (MICHIGAN)
Company: Tokyo Rope MFG. CO., LTD
Contact: KYUSO MORINO
Phone: (734) 335-6037
Email: kyuso.morino@tokyoropeu
Fax:

FRP-14 TUF-BAR INC (ONTARIO CANADA)
Company: Tuf-Bar Inc.
Contact: Jay Christopher
Phone: (519) 833-5050
Physical Address: 7 Erin Park Dr CANADA
Email: jay@tufbarcana
Fax:
Mailing Address: 7 Erin Park Dr CANADA
QC Plan Status: Quality Control Plan ACCEPTED 12/11/2017

FRP-01 CREATIVE PULTRUSIONS
Company: Creativ
Contact: Donald A
Phone: (814) 839
Physical Address: 214 Industrial Lane Alum Bank, PA 15521
QC Plan Status:
FRP FENDE
FRP SHEET
FRP SPLICE

FRP-05 TANGENT TECHNOLOGIES LLC - WINCHESTER VA PLANT

FRP-18 TANGENT TECHNOLOGIES
Company: Tangent Technologies, LLC
Contact: Dave Schaa
Phone: (507) 372-1
Physical Address: 1001 Sullivan Road Aurora, IL 60506
QC Plan Status: Qu
PLASTIC LUM
PLASTIC WAL

FRP-13 COMPOSITE ADVANTAGE
Company: Composite Advantage LLC
Contact: JONATH
Phone: (937) 72
Physical Address: 750 Rosedale Drive Dayton, OH 45402
QC Plan Status:
FRP FENDE
FRP SPLICE

FRP-17 WAGNERS CFT
Company: Wagners CFT, LLC
Contact: JON HANSEN
Phone: (813) 777-4440
Physical Address: 11 Ballera Ct AUSTRAL
QC Plan Status: Quality Control Plan ACCEPTED 5/30/2019
FRP STRUCTURAL SHAPES Thermoset Pult

https://mac.fdot.gov/smoreports


GFRP rebar for precast panels & bent caps of NE 23rd Ave (2020-21)


GFRP Secant-Pile Shaft cages for A1A-Flagler Beach seawall (2019)


CFRP-PC FSB's US-1/Cow Key span replacements (2020)


CFRP-PC Sheet Pile Bulkheads for Halls River Bridge (2017-18)

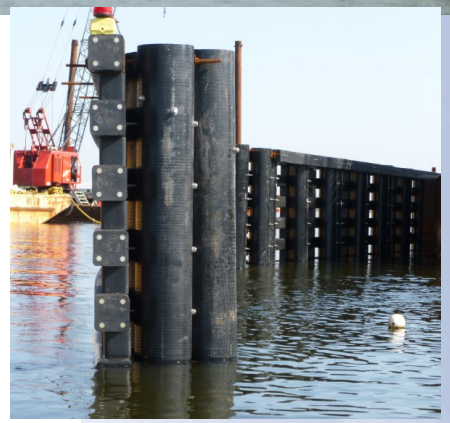
Typical Project Examples of Structural FRP Reinforcement

Design and Construction

- Prestressed Concrete
- Reinforced Concrete
- Structural Members & Systems


HCBs Halls River Bridge (2017-19)


Navigation Fender Systems



Typical Project Examples: FRP-RC & PC

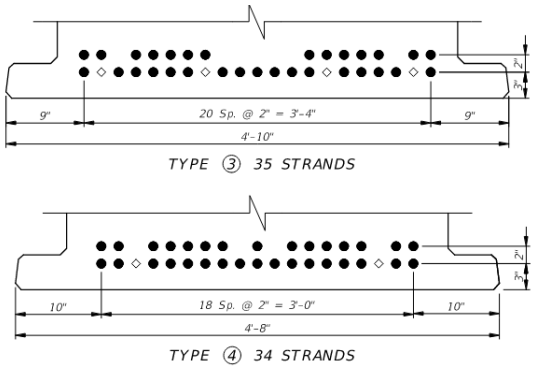
Fast-Facts:
https://www.fdot.gov/structures/innovation/FRP.shtm#link9

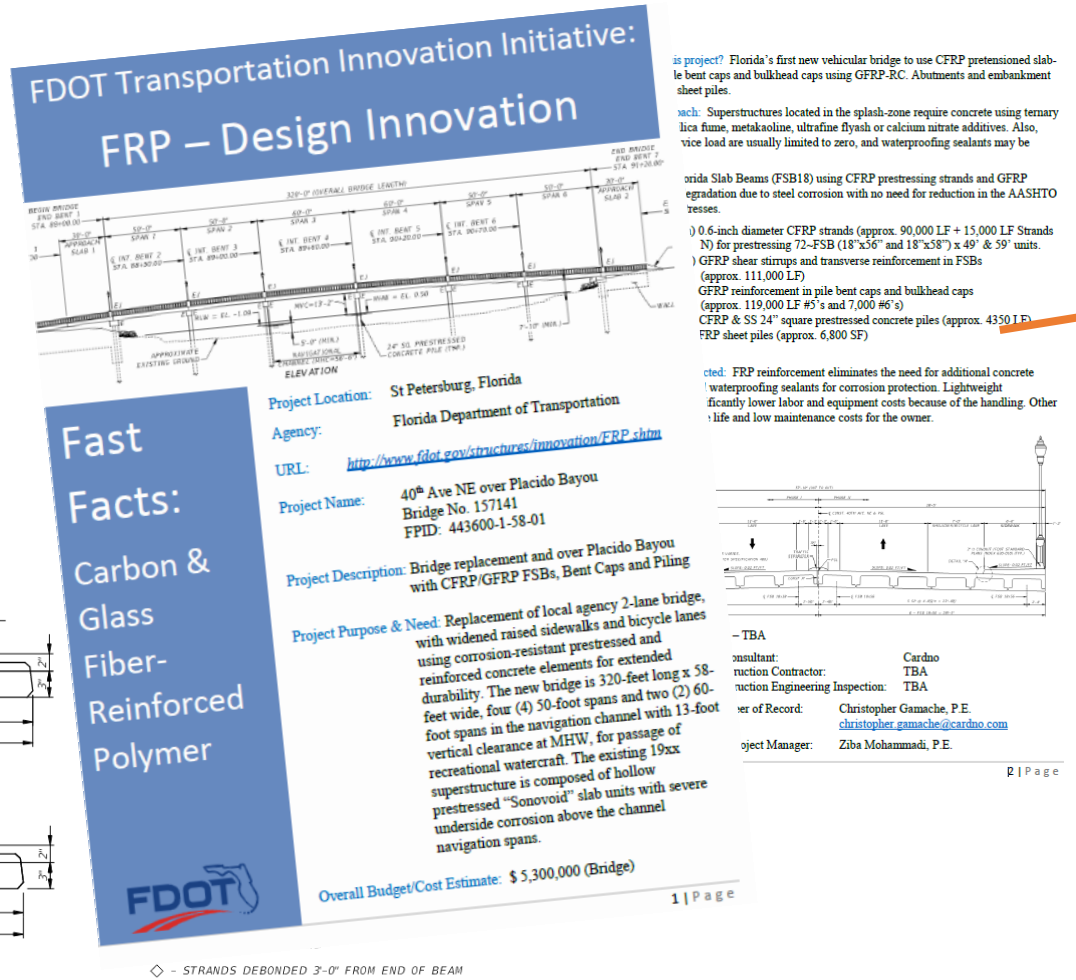
Structures Design / Design Innovation

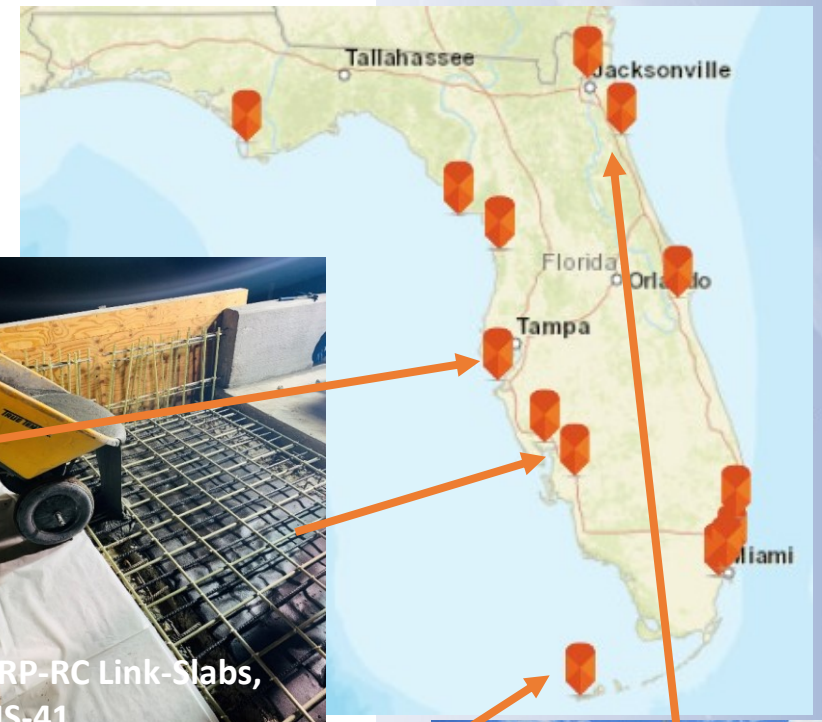
Fiber Reinforced Polymer

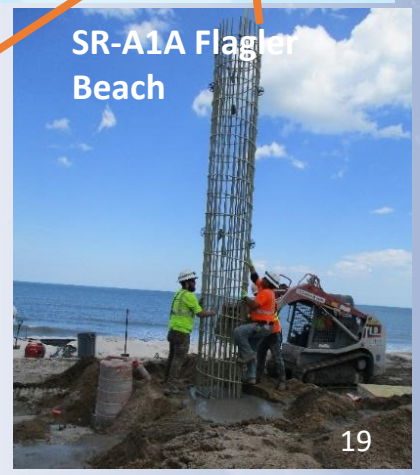
Structures Design - Transportation Innovation
Fiber Reinforced Polymer (FRP)
Reinforcing Bars and Strands

- Overview
- Usage Restrictions / Parameters
- Design Criteria
- Specifications
- Standards
- Producer Quality Control Program
- Projects
- Technology Transfer (T²)
- FDOT Research
- Contact



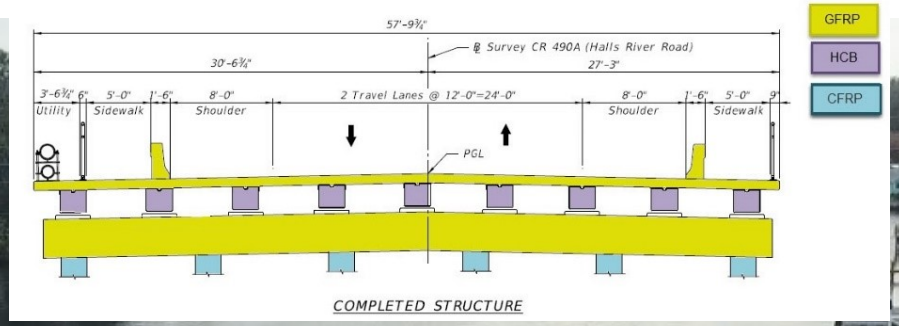


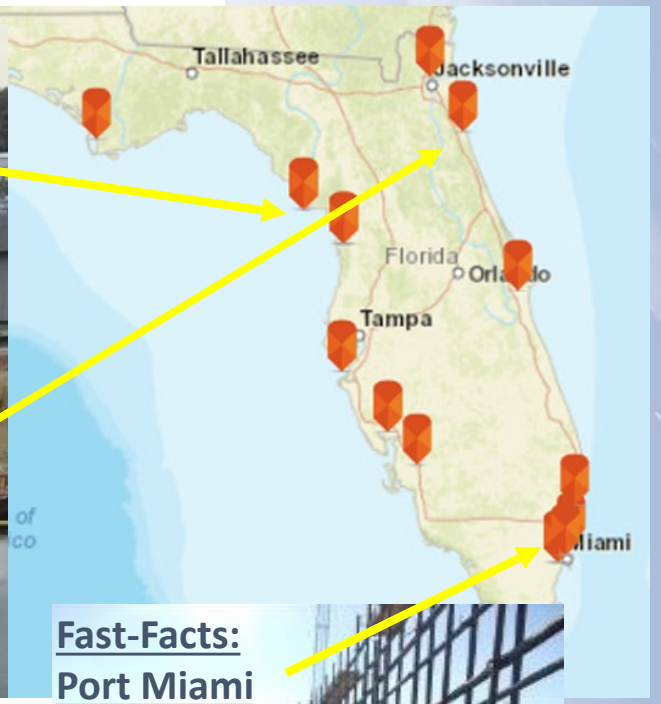


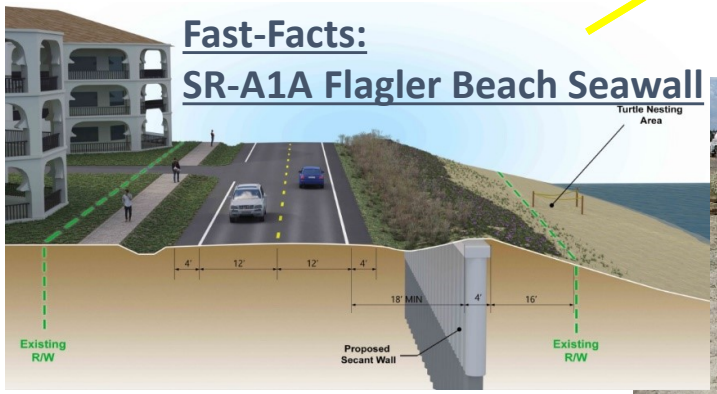


40th Ave NE/Placido Bayou

Typical Project Examples: FRP-RC & PC



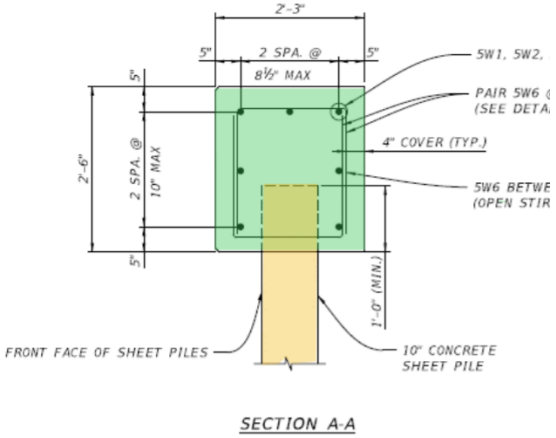




Typical Project Examples: FRP-RC & PC

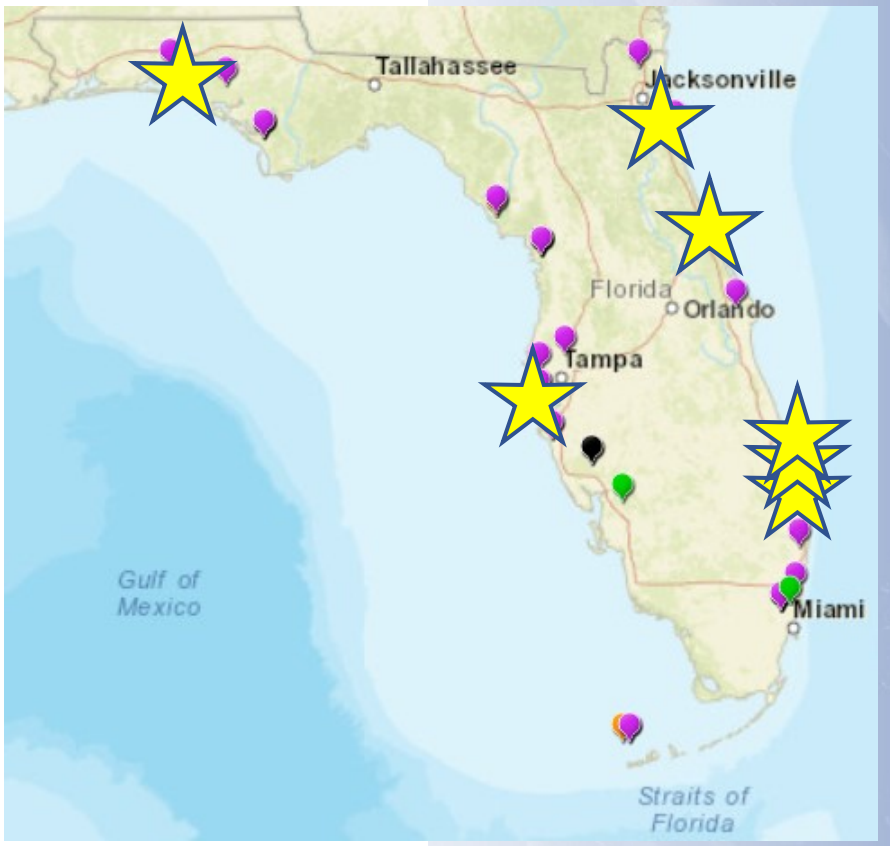
- Bridge Superstructures (US-1/Cow Key Channel, US41/North Creek, NE23rd Ave/Ibis; 40th Ave N/Placido Bayou)

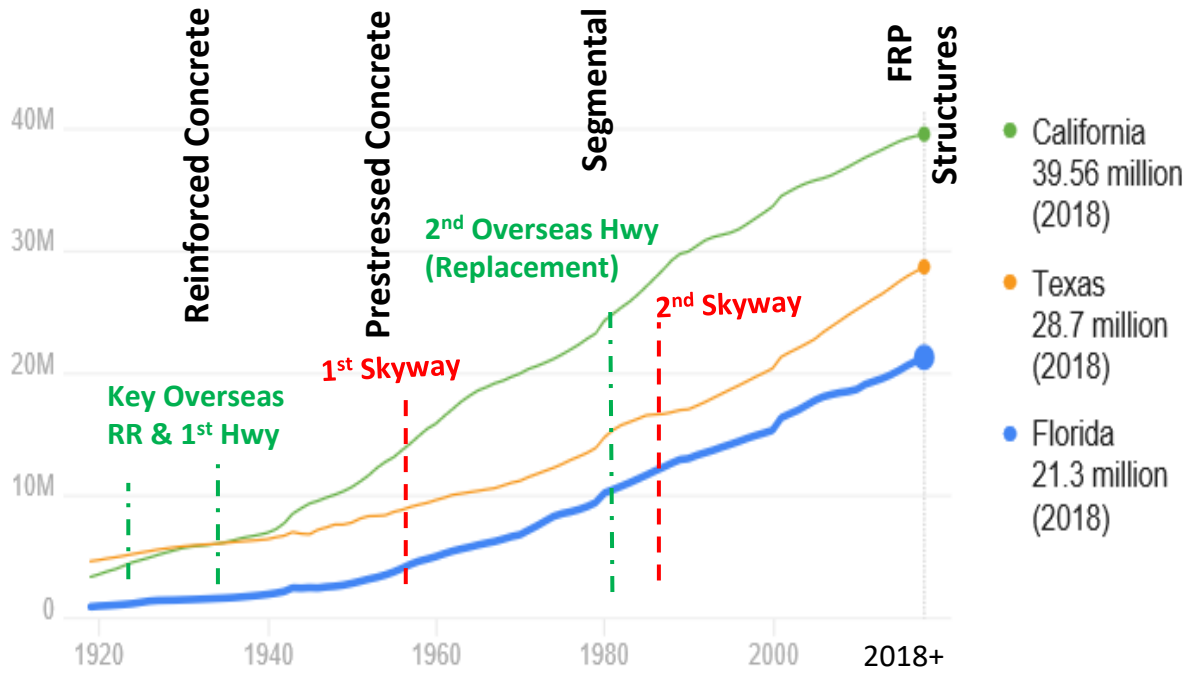
- Bridge Foundations (South Maydell Dr; SR30 Inlet Beach Underpass)
- Seawalls (Skyway SB Approach, SR30/St Joe Bay Inlet, Pinellas Bayway E)

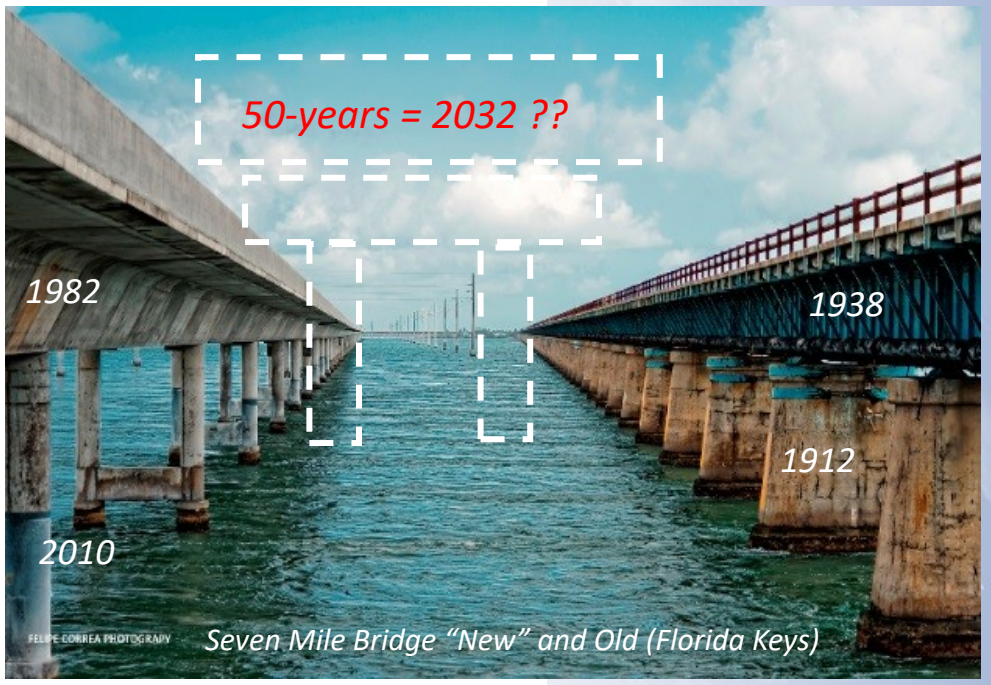


New FRP-PC/RC Projects in Design

- Low-level Pedestrian Piers -
  - SR-A1A North Bridge/Indian River Lagoon
  - US-1/Jupiter Inlet
- Prestressed Bridges
  - CR30A/Western Lake
  - SR82/Earman Canal
  - Kings St/San Sebastian River;
- Bridge Foundations –
  - 4th St over Big Island Gap (bent caps & piles)
  - Barracuda Ave/North Indian Lagoon







POPULATION GROWTH & STRUCTURAL TECH. IMPLEMENTATION

What is needed for scaling deployment

Design and Manufacturing

What is needed for scaling deployment

- Design
  1. Cost Justification & competitive bidding
  2. Standards & Specs that reflect current material properties
  3. Harmonize provisions from different codes (national & international
  4. Improve detailing of structural members to reflect FRP specificity
  5. Standardized Precast/Prestressed Design Shapes… but FRP shapes???
  6. Reliable Design Software…

- Manufacturing
  1. Reliable Producer approval/certification and Quality Assurance.
  2. Improve the procurement process
  3. Improve production and supply of rebar bent shapes potentially separate from pultruder of straight bars
  4. Rebar cage prefabrication?
  5. Improve connections/coupling

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2021 Transportation Infrastructure Durability Conference

The Mission is Possible: Solving Critical Issues in Transportation

Tuesday, July 27th - Thursday, July 29th, 2021