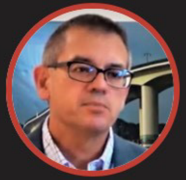
Pultrusion Conference 2021

- **Field Case Studies of Projects using FRP Rebar and Prestressing Tendons in Florida**

Steven Nolan, P.E.

Florida Department of Transportation

State Structures Design Office (Tallahassee, FL)



Steven J. Nolan
Senior Structures Design Engineer
Florida Department of Transportation

Florida Department of Transportation has been sponsoring research on FRP tendons since the 1980s. Full implementation of this technology in the field of pultruded FRP structural products has taken several decades to emerge with more than 20 bridges using FRP prestressed piling along with and a similar number of sea walls and dock structures throughout Florida. This presentation will present some of the typical installations using pultruded FRP in concrete structures and explore the challenges with publicly funded infrastructure implementation and scaling for broader application.

Outline

- Pultruded Structural Products
- Research Journey
- Implementation Journey
- Typical Project Examples
  - Prestressed Concrete
  - Reinforced Concrete
  - Structural Members & Systems
- What is needed for scaling deployment

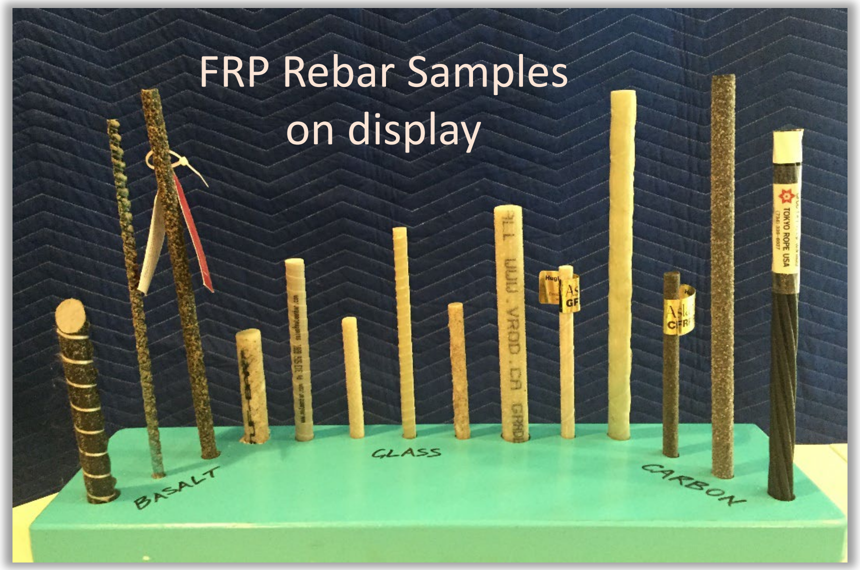
Pultruded Structural Products

FDOT FRP-Design Innovation Initiative

Pultruded Structural Products used by FDOT

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

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



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

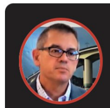
Pultruded Structural Product Design Guidance

- Prestressing
- Reinforcing Bars
- FRP Structural Members

Field Case Studies of Projects using FRP Rebar and Prestressing Tendons in Florida

12:05 PM-12:30 PM

Applications



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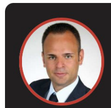
You Are Here

Composite Rebar's Next Generation Breakthrough

11:30 AM-11:55 AM

Equipment and Tooling



Aleksandar Georgiev
Expert Sales Manager
KraussMaffei Technologies GmbH

Concrete's high pH-value of al
attacks every medium and act
real challenge in long-term co
resistance. Composite rebar is
durable, high performance anc
lightweight solution, but many
expensive and may still see cc
problems. Recent standards a
array of pilot projects have ope
industry after decades of testir
development of engineering
guidelines. This session will e
recent breakthrough in compo
rebar that uses a fast curing e
amine resin.

Thursday

Pultruded Fiberglass Rebar for Infrastructure Applications

1:30 PM-1:55 PM

Applications

David R. Hartman
Sr. Principal Scientist
Owens Corning

Fiberglass rebars are finding increased adaption into concrete structures due to intrinsic lightweight & long-term durability. This session encourages the adoption of improved pultruded rods used for ASTM D7957 and CSA S807 grade III GFRP structural rebar for more effective bridge design with improved material endurance limits in ACI and AASHTO specifications and standards. The session will report the expanded use of GFRP structural rebar for reinforced concrete bridge decks, traffic barriers, abutments, and retaining walls, with a higher 60 GPa (8700 ksi) elastic modulus for a more sustainable substitution of steel rebar.

New Standard for LRFD Design of Pultruded FRP Structures

12:15 PM-12:40 PM

Standards

Max Porter, Ph.D., P.E./S.E.
University Professor Emeritus, Iowa State University; President Porter Engineering, LLC
Iowa State University and Porter Engineering, LLC

Mehdi S. Zarghamee
Senior Principal
Simpson Gumpertz & Heger Inc.

John P. Busel, F.ASI
Vice President, Composites Growth Initiative
American Composites Manufacturers Association

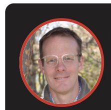
Attendees will learn about the key content, guidance, and equations to safely and efficiently design constructed facilities using FRP composites in a new standard that provides both requirements and commentary on design. The LRFD will be most useful to all those interested in the design and manufacture of pultruded composites structures. This session will provide engineers, designers, and composite manufacturers the ability to improve the accuracy of a design for pultruded composite structures. This new standard has been initiated by the American Composite Manufacturers Association (ACMA) Pultrusion Industry Council (PIC) as they foresaw the critical need to develop an LRFD design approach and worked with ASCE to explore test data and literature generated on FRP pultruded composites.

Wednesday

The Composites Project at The National Institute of Standards and Technology (NIST)

3:05 PM-3:30 PM

Testing



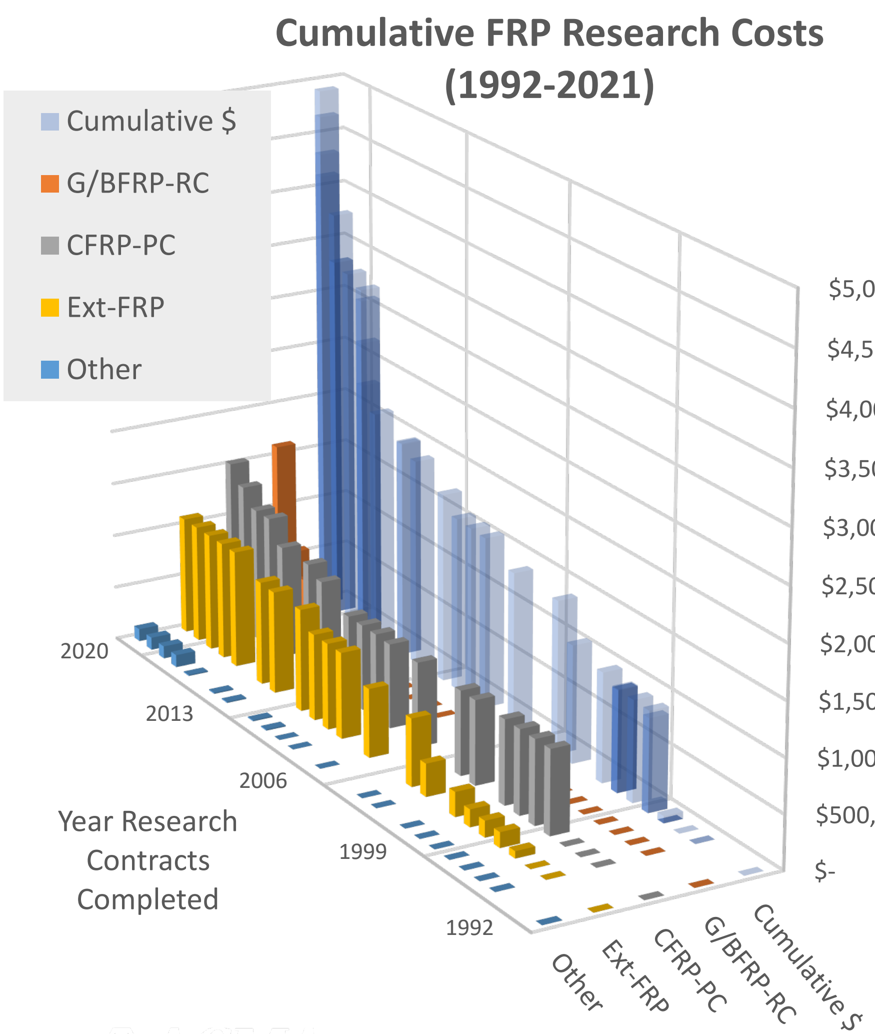
Dr. Christopher L. Soles
Leader, Functional Polymers Group
National Institute of Standards and Technology (NIST)

This presentation will provide a brief overview of the Composites Project at the National Institute of Standards and Technology (NIST), which develops measurements, models, and novel materials to advance the understanding of fiber-reinforced polymer (FRP) composites. The rational design of advanced composites requires that data, models, and measurements be used together for specific composites performance goals, such as manufacturability, multi-functionality, toughness, and sustainability. This presentation will highlight an example of such an approach and provide an update on the proposed Infrastructure Composites Standards Project.

FDOT Research Journey for Pultruded Structural Products

Materials & Structures Research 1990-2020+

FDOT Research Journey for Pultruded Structural Products



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

~~Strike-through~~ = Not pultruded materials

FDOT Research Journey for Pultruded Structural Products

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

~~Strike-through~~ = Not pultruded materials

FDOT Research Journey for Pultruded Structural Products

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

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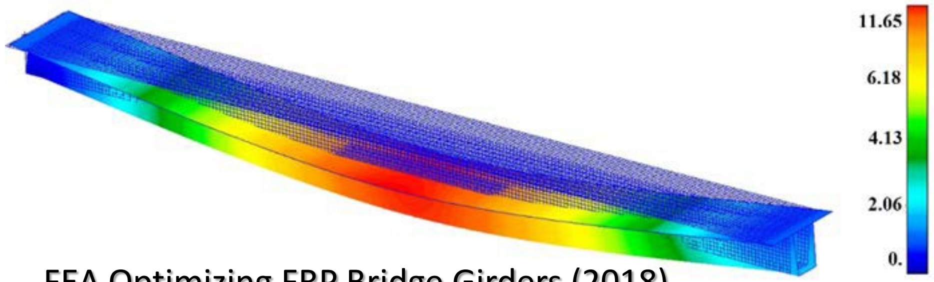
FDOT Research Journey for Pultruded Structural Products



FEA Optimizing FRP Bridge Girders (2018)

Pendulum Impact Testing
Traffic Railings (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

~~Strike-through~~ = Not pultruded materials

FDOT Implementation Journey for Pultruded Structural Products

Design and Construction

FRP Structural Technology 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 & some Pultruded Strips)*
- **2006** 1st FRP fender system Specs & Standard Index issued *(Pultruded Piles & Wales)*
- **2014** PortMiami: Tunnel approach retaining walls 5 & 6 *(Pultruded BFRP Rebar)*
- **2015** University of Miami: FRP-Prestress Double-T Innovation Bridge *(Pultruded CFRP Strands, BFRP & GFRP Rebar)*
- **2016-19** Halls River: FDOT 1st complete FRP-PC/RC/HCB bridge *(Pultruded CFRP Strands, BFRP & GFRP Rebar)*
- **2018** Ocala Water Recharge Park Boardwalk *(Pultruded GFRP Hollow Sections)*
- **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 *(Pultruded FRP Rebar & Strands)*

FDOT Implementation Journey for Pultruded Structural Products

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):

What?

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

Complementary or Competitive?

Structural Advancement

- **Light-weight Concrete or FRP** *(Longer spans and/or less shipping cost)*

Highly Corrosion-Resistant

- **Ultra-High Performance Concrete** *(UHPC)*
- **HSSS-Prestressed Concrete** *(2205 Duplex Stainless-Steel)*

FDOT Implementation Journey for Pultruded Structural Products

FDOT Florida Department of TRANSPORTATION

Safety, Innovation, Mobility, Attract, Retain & Train

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Office of Design

Office of Design / Design Innovation

Design Innovation

Office of Design
Florida's Transportation Engineers

Non-Corrosive

The Florida Department of Transportation (FDOT) continually strives to enhance all areas of its operations. In support of these efforts, the department recently moved into a bold new era for innovative ideas, research and accelerated implementation. Success will depend on our ability to carefully evaluate or implement the products and services provided to the users of Florida's transportation system. Our goal is to utilize newly developed technology or employ creative thinking to generate greater value for every transportation dollar invested.

After researching and evaluating many innovative ideas, the Central Office has developed a list of concepts, products and services that may be the best solution to the project's needs or design challenges. Some items on the list are completely developed, and only need tailoring to your project. We encourage you to propose one or more of these innovations for project specific solutions with confidence of approval by the Districts. Other items are not fully detailed and will require coordination with and approval by the District's Design Office. Many of these innovations have been successfully implemented in other states and countries. Not all projects benefit from these innovations and the Department is not advocating the general use of new products or designs where an economical well proven solution exists and is the most appropriate solution for the situation.

Highly Corrosion-Resistant

FDOT Transportation Innovation Challenge

The Department invites you to share your thoughts on ways we can challenge ourselves to be innovative, efficient and exceptional at our **Invitation to Innovation website**

How?

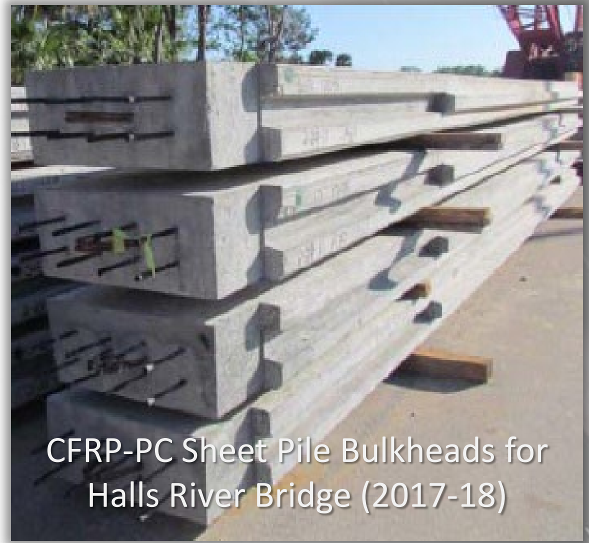
Structures Design Office

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


GFRP rebar for bridge deck & bent caps of Halls River Bridge (2017-19)


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 Elements using Pultruded FRP

Design and Construction

- Prestressed Concrete
- Reinforced Concrete
- Structural Members & Systems

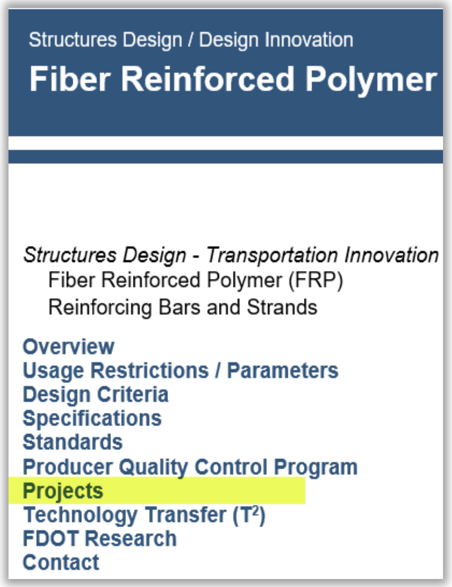

Pinellas Bayway "C" Fender Piles (2013)

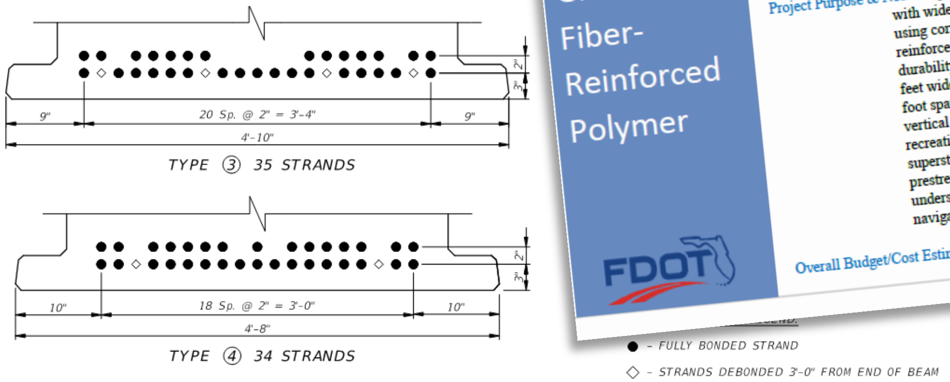
Typical Project Examples of Structural Elements using Pultruded FRP

- Prestressed Concrete
  - Bridge Girders & Slabs
  - Bearing Piles
  - Sheet Piles
- Reinforced Concrete
  - Bridge Decks
  - Bent Caps
  - Columns & Pier
  - Retaining Walls
  - Box Culverts
  - Seawalls Panels & Bulkhead Caps
- Structural Members & Systems

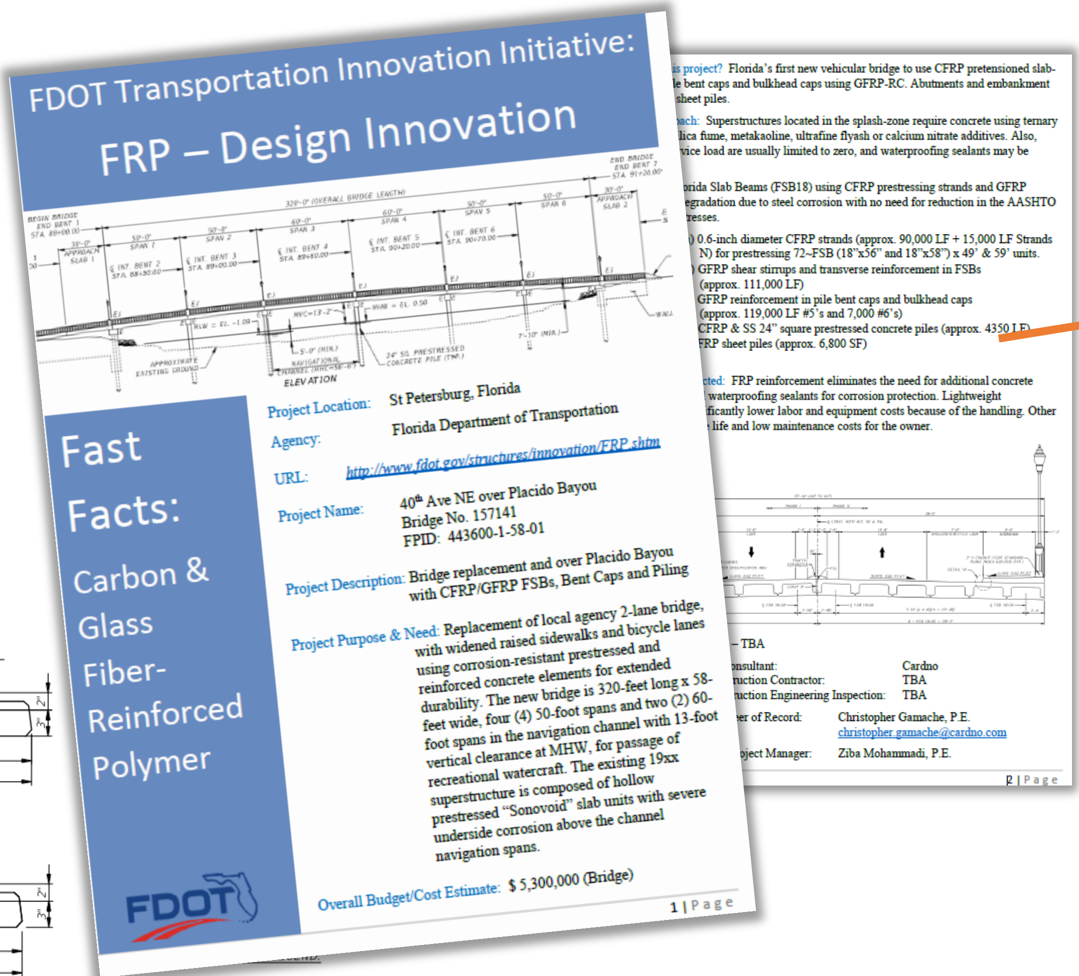
Typical Project Examples: FRP-RC & PC

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





40th Ave NE/Placido Bayou



FDOT Transportation Innovation Initiative:

FRP – Design Innovation

ELEVATION

Fast Facts: Carbon & Glass Fiber-Reinforced Polymer

Project Location: St Petersburg, Florida

Agency: Florida Department of Transportation

URL: http://www.fdot.gov/structures/innovation/FRP.shtm

Project Name: 40th Ave NE over Placido Bayou
Bridge No. 157141
FPID: 443600-1-58-01

Project Description: Bridge replacement and over Placido Bayou with CFRP/GFRP FSBs, Bent Caps and Piling

Project Purpose & Need: Replacement of local agency 2-lane bridge, with widened raised sidewalks and bicycle lanes using corrosion-resistant prestressed and reinforced concrete elements for extended durability. The new bridge is 320-feet long x 58-feet wide, four (4) 50-foot spans and two (2) 60-foot spans in the navigation channel with 13-foot vertical clearance at MHW, for passage of recreational watercraft. The existing 19xx superstructure is composed of hollow prestressed "Sonovoid" slab units with severe underside corrosion above the channel navigation spans.

Overall Budget/Cost Estimate: $ 5,300,000 (Bridge)

FDOT

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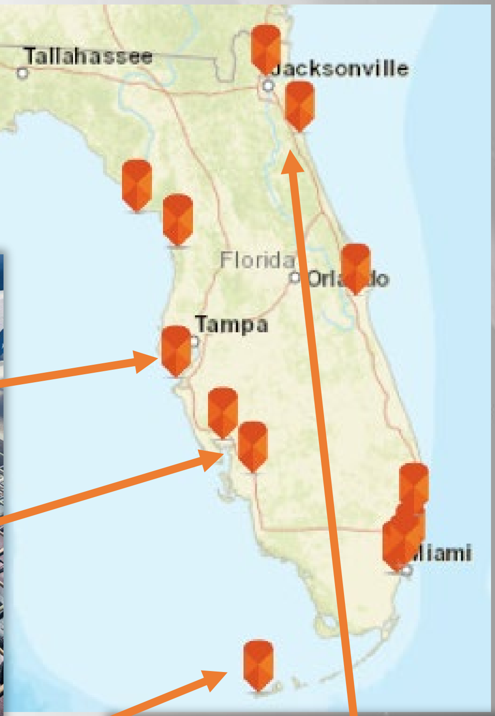
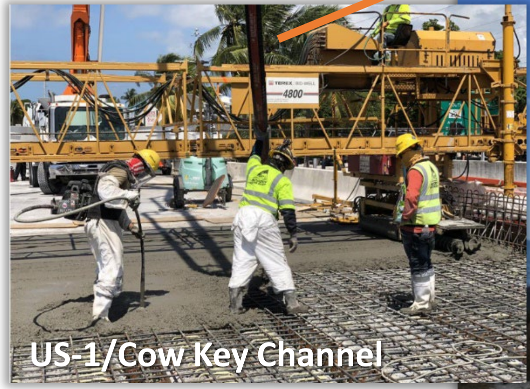
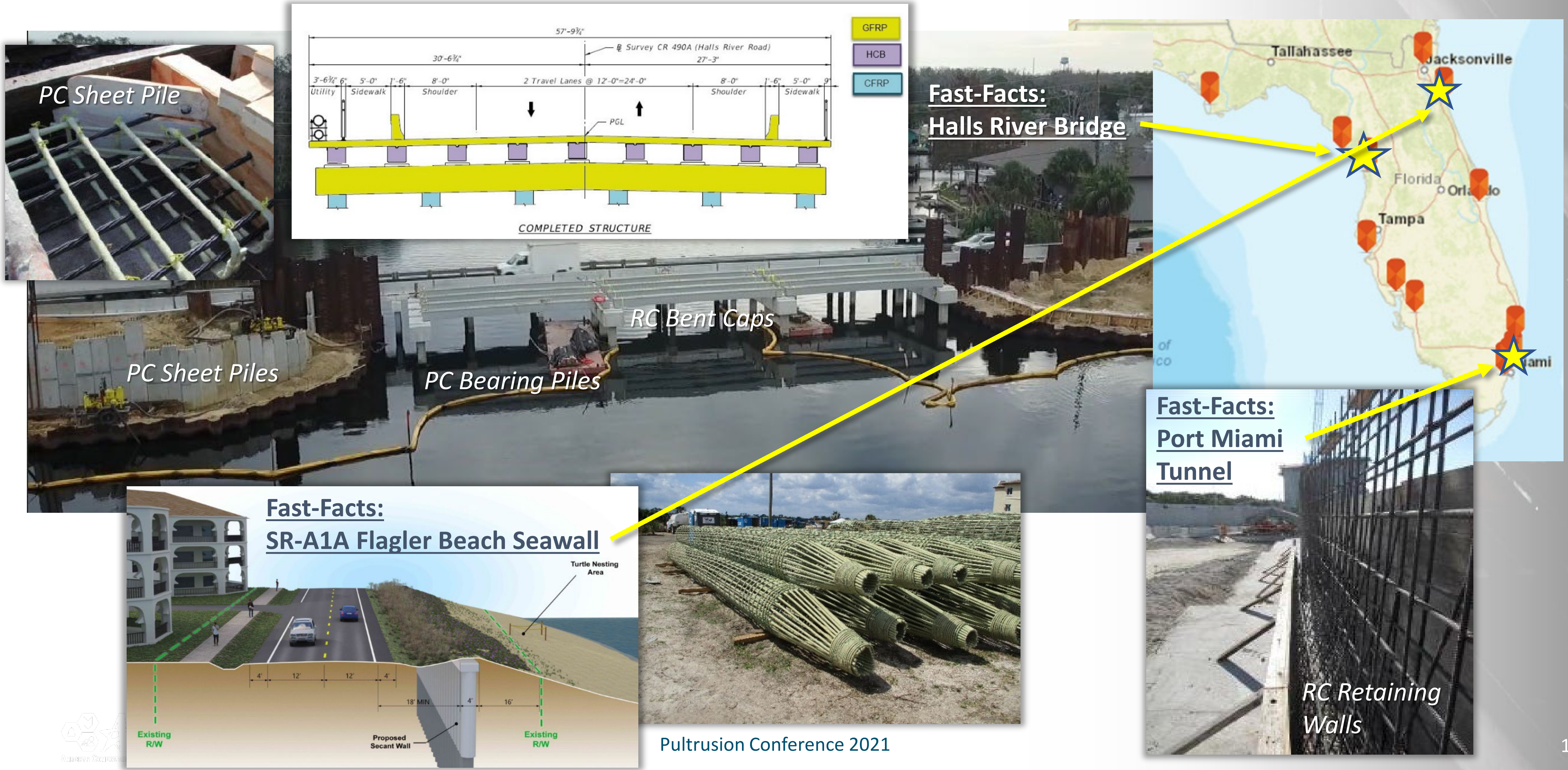




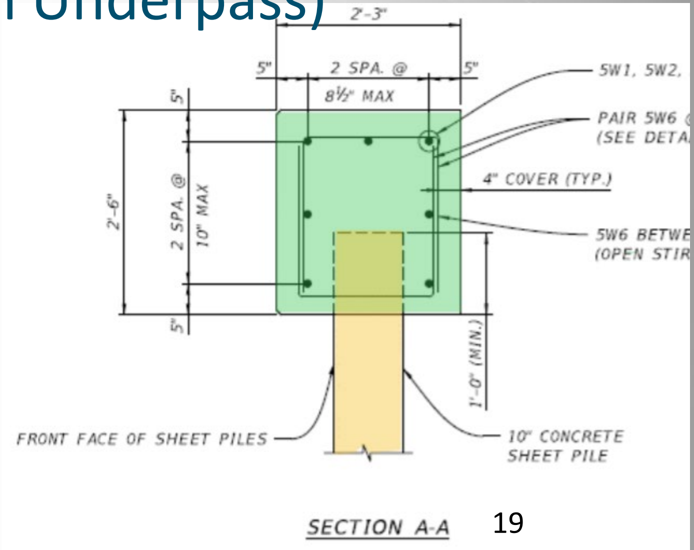
Typical Project Examples: FRP-RC & PC



Other Typical Projects Under Construction

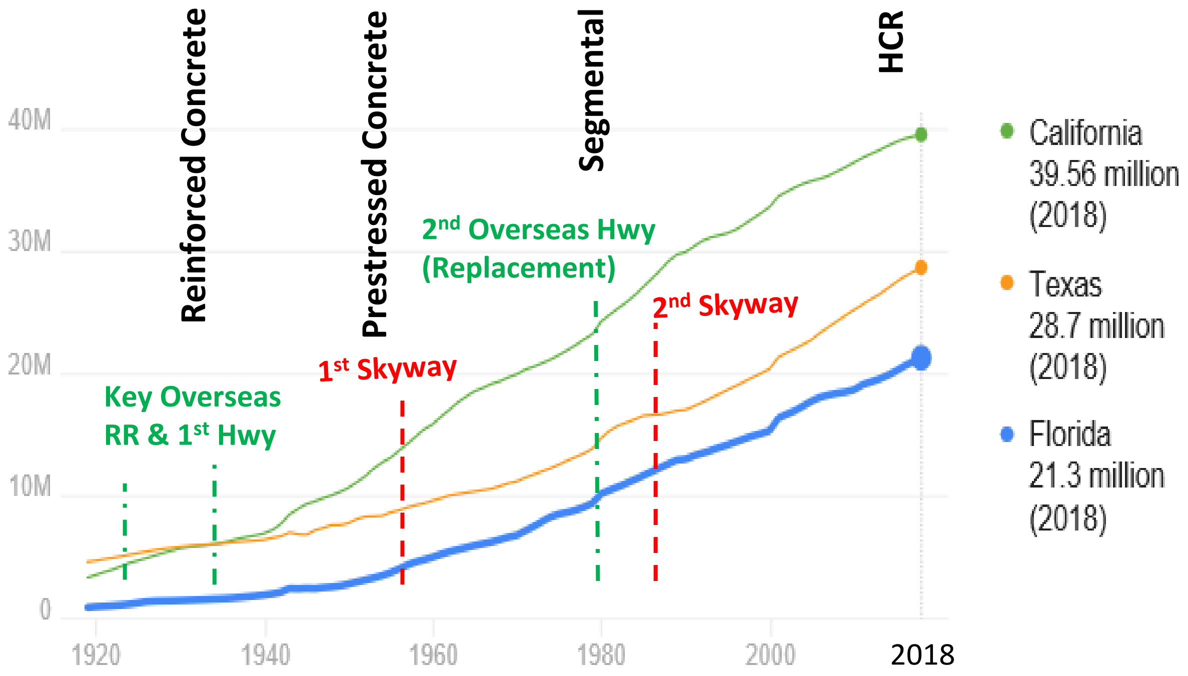
- Bridge Superstructures (US-1/Cow Key Channel, US41/North Creek, NE23rd Ave/Ibis; 40th Ave N/Placido Bayou)

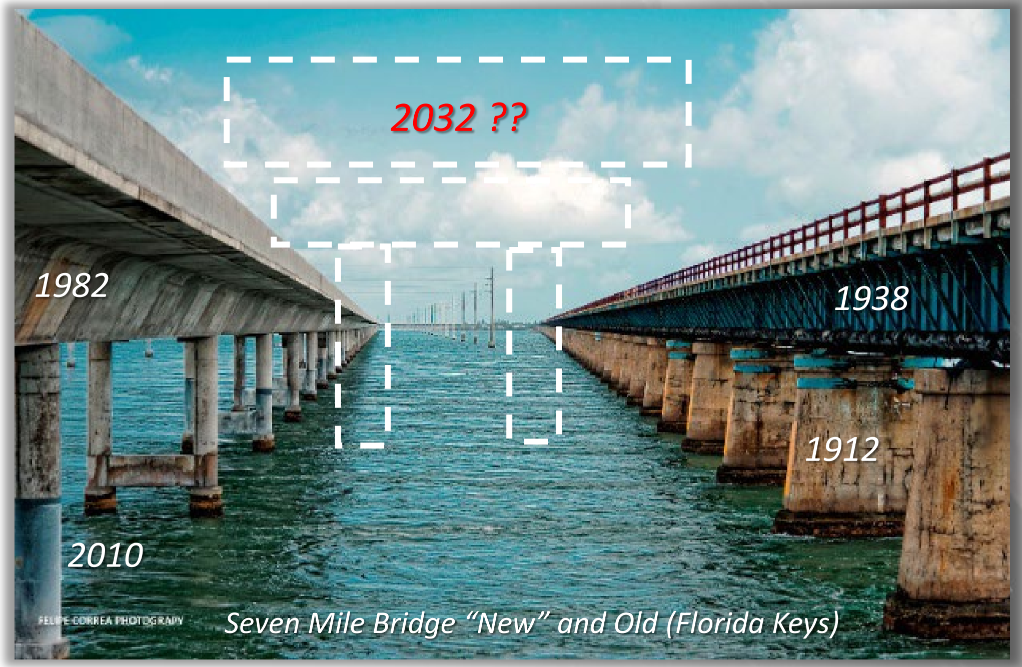
- Bridge Foundations (South Maydell Dr; SR30 Inlet Beach Underpass)
- Seawalls (SR30/St Joe Bay Inlet, Pinellas Bayway E)



New 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
  - Barracuda Ave/North Indian Lagoon
  - Kings St/San Sebastian River;
- CIP Bridges –
  - West Wilson St/Turkey Creek (3-span slab, bent caps, piles)
- Bridge Foundations –
  - 4th St over Big Island Gap (bent caps & piles)
  - 5th St/Yacht Club Cut (piles)





POPULATION GROWTH & STRUCTURAL TECH. IMPLEMENTATION

What is needed for scaling deployment

Design and Manufacturing

What is needed for scaling deployment

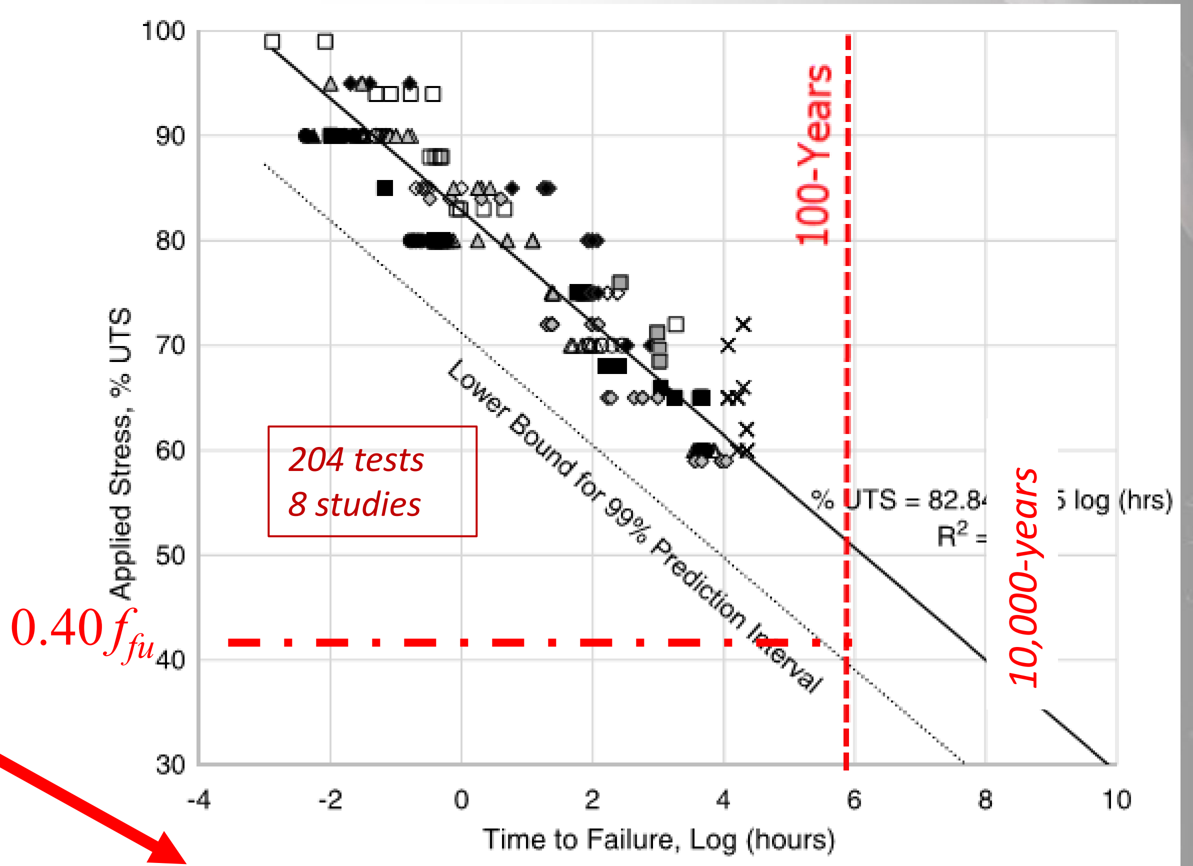
- Design
    1. Code update standards to reflect current material properties
    2. Harmonize provisions from different codes (national & international
    3. Improve detailing of structural members to reflect FRP specificity
    4. …
- Manufacturing
    1. Improve the procurement process
    2. Improve production and supply of rebar bent shapes potentially separate from pultruder of straight bars
    3. Define and control bend radii for rebar
    4. Rebar cage prefabrication?
    5. Improve pultruded member joint connections
    6. …

What is needed for scaling deployment

- Design
  - Improved creep rupture limits;
  - Improved fatigue stress limits;
  - Environmental Factor refinement.

$\times\, C_E = 0.21\, f_{fu}$

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.



Source: "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 is needed for scaling deployment

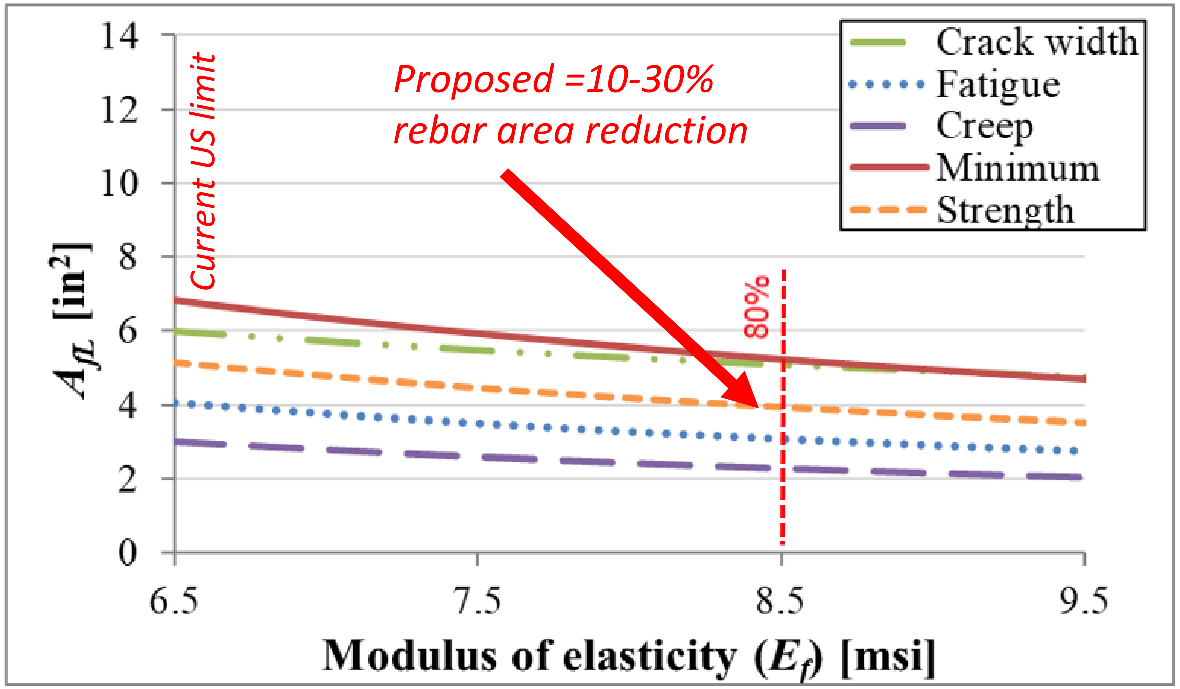


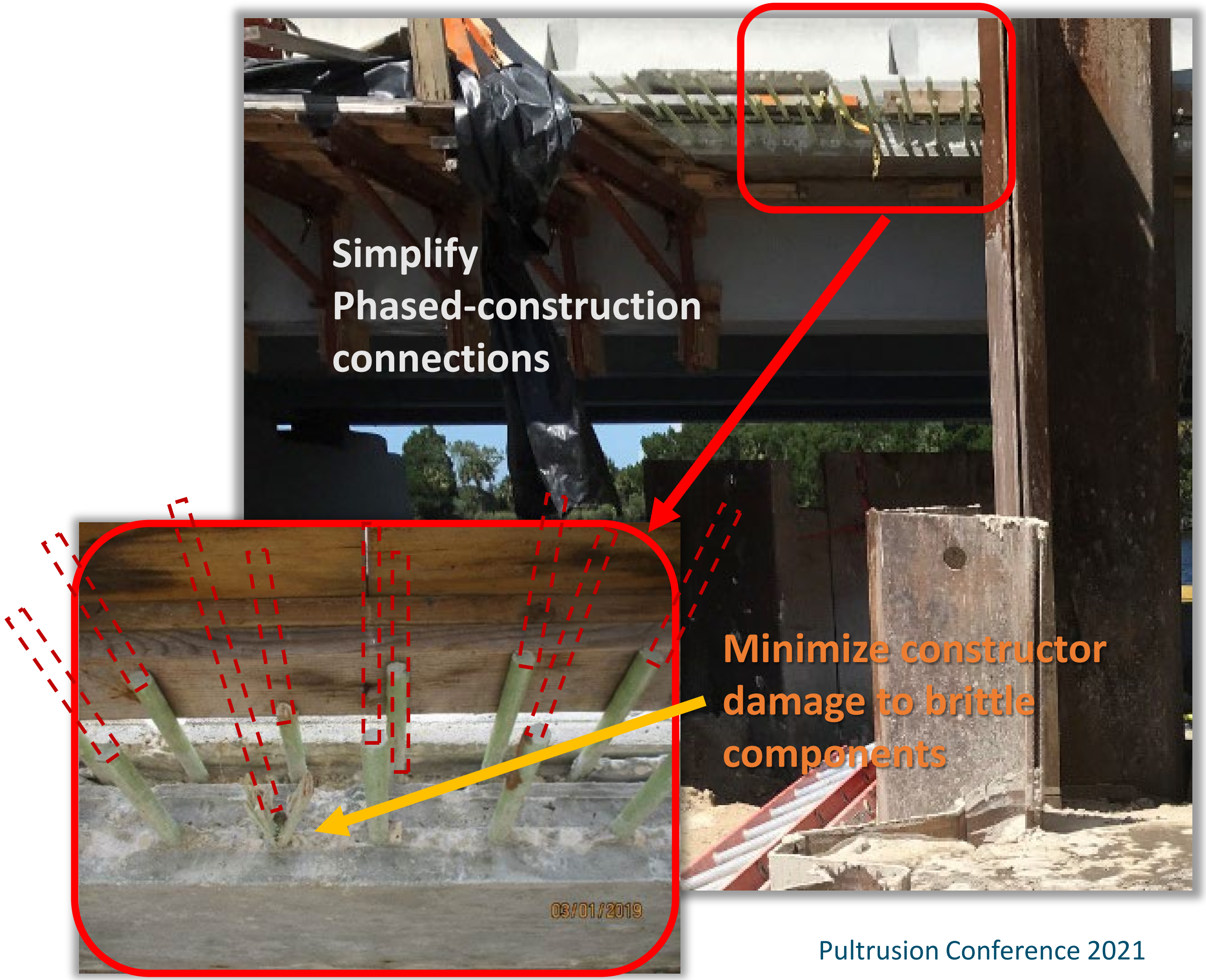
Chart: Parametric analysis of flexural design requirements per AASHTO GFRP-RC 2nd edition for HRB Pile Bent Cap

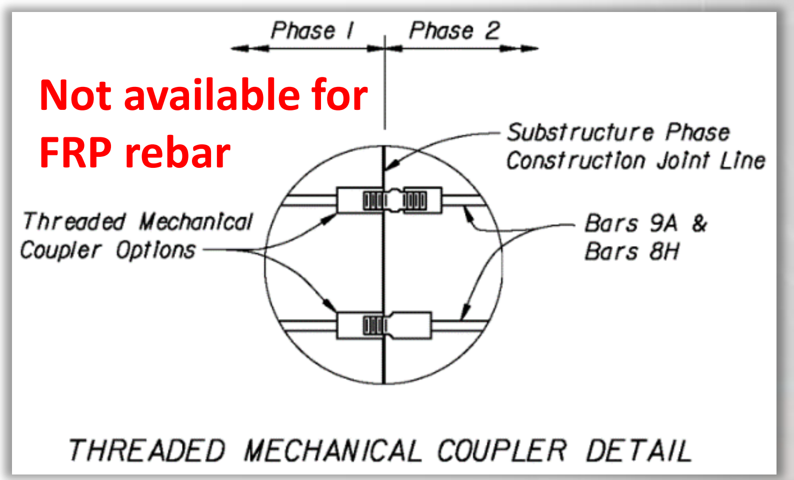
Source: M.Rossini, F.Matta, S.Nolan and A.Nanni, extended abstract *"Overview of Proposed AASHTO Design Specifications for GFRP-RC Bridges 2nd Edition using Case-Specific Parametric Analysis"* (2017)

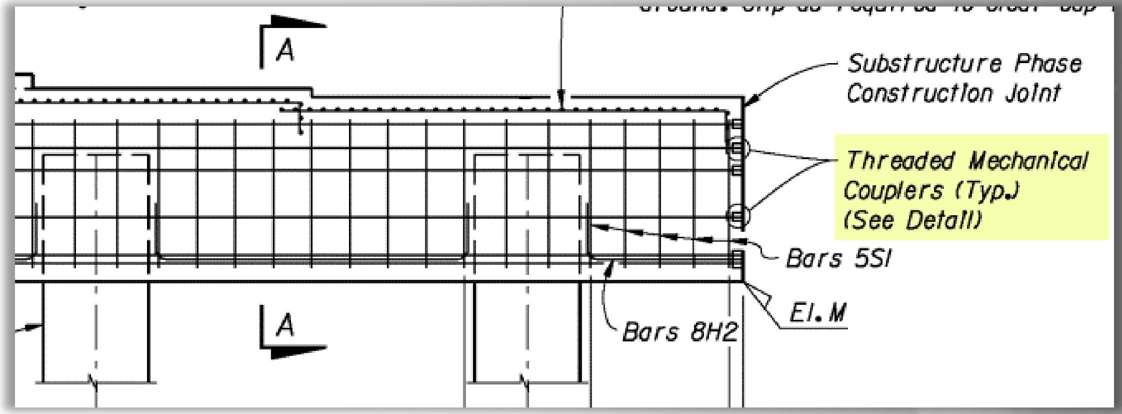
- Manufacturing:
  - Increased Elastic Modulus (stiffness)
  - Bent Bars (thermo-set vs. thermo-plastic, & quality)

What is needed for scaling deployment

- Manufacturing:
  - Connections/mechanical couplers







Questions?

Contact Information:

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PUT IT DOWN

IT'S THE LAW

ARTBA American Road & Transportation Builders Association

Bridge Conditions Report

(March 2021) *https://artbabridgereport.org/*

Top 10 Takeaways

- 220,000 U.S. bridges—36 percent—need repair work. 79,500 need replacement.
- More than 45,000 bridges are in poor condition and were classified as "structurally deficient" (SD) in 2020, decreasing by 1,140 structures compared to 2019.
- The good news is that the number of SD bridges has declined for the last five years. This is tempered by the trend of more bridges being downgraded from good to fair condition over the same time period.
- The number of bridges rated in good condition declined by 1,155, from 279,582 structures in 2019 to 278,427 in 2020.
- At the current pace, it would take nearly 40 years to repair the current backlog of SD bridges.
- The estimated cost to repair or replace the 45,000 SD bridges, based on average price data from the U.S. Department of Transportation (DOT), would be $41.8 billion.
- A SD bridge, on average, is nearly 68 years old, compared to 32 years for a bridge in good condition and 54 years for a bridge in fair condition.