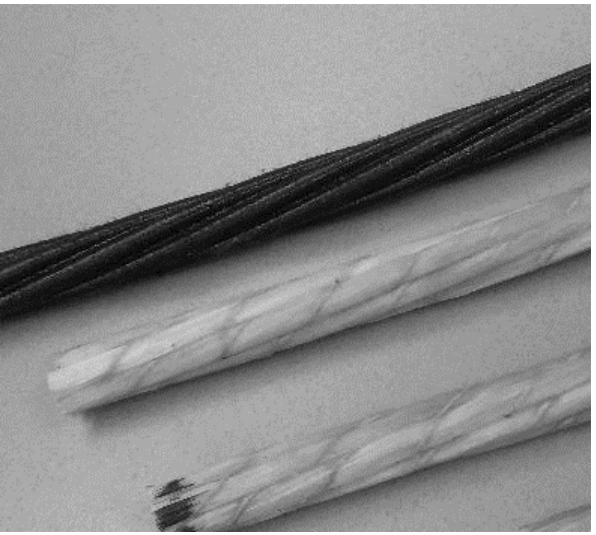
2021 TRB ANNUAL MEETING
Transportation Research Board

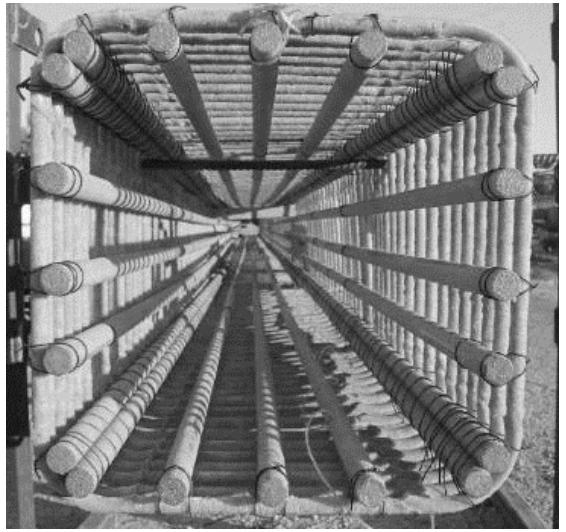
100TH Annual Meeting
A Virtual Event
January 2021

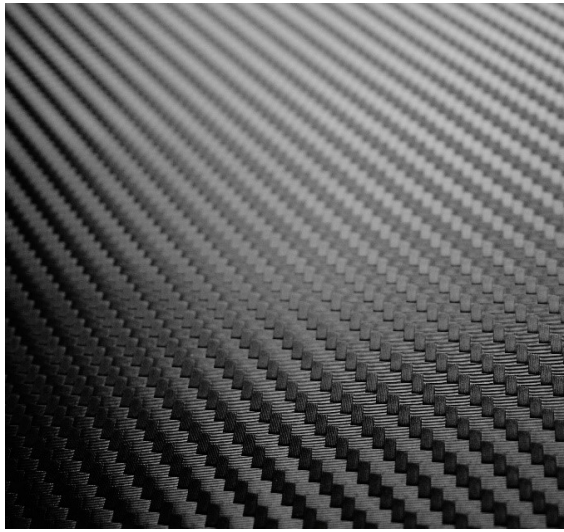
Forecasting the FRP Future for FDOT Highway Bridges & Structures

Presenter: Steven Nolan, P.E. (FDOT State Structures Design Office)

Jan. 25th 10:00 AM - 11:30 AM EST

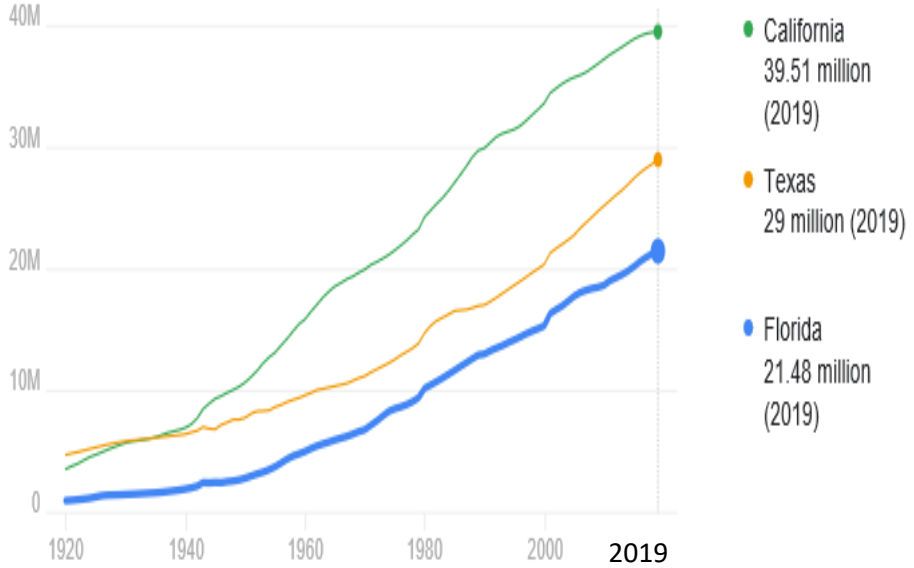






Forecasting the FRP Future for FDOT Highway Bridges & Structures

1. **The Value Proposition**
2. **How does FRP align with Florida's Transportation Plan**
3. **FRP Material Systems used in Florida**
4. **FDOT Design Guidance, Specs, & Tools**
5. **Life-Cycle Cost analysis**
6. **Forecasting the Future**
7. **Technology Transfer & Future Development**

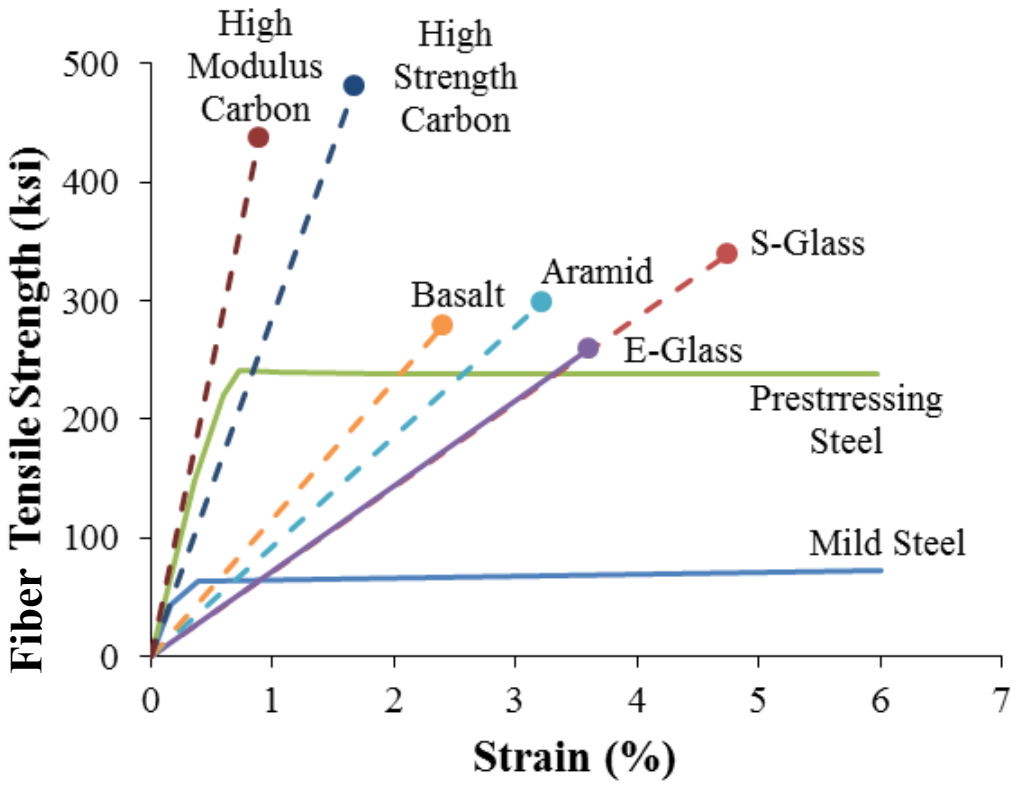


FLORIDA POPULATION GROWTH

Also see **IW-GFRPCS2** Case Study #4: "*FDOT GFRP-RC Market Size Estimate for Cast-In-Place Concrete by 2020*"

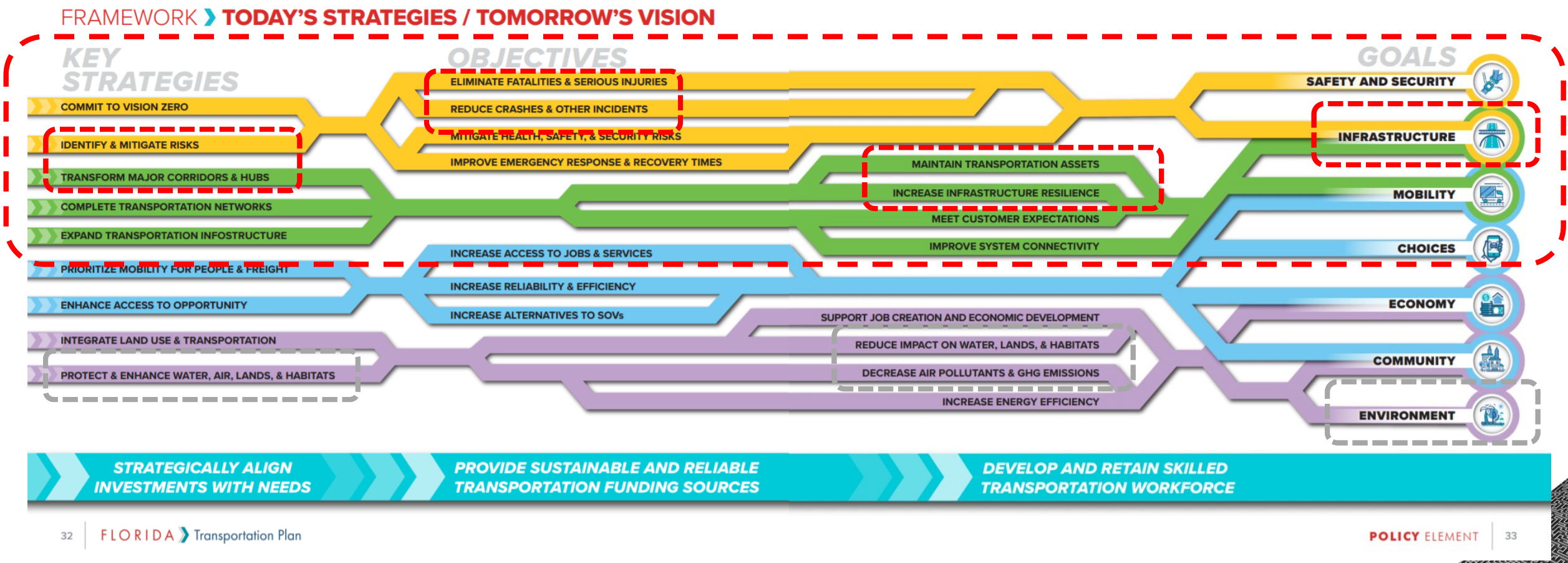
The Value Proposition - structural advancement, durability & sustainability

1. High Tensile Strength
2. Low Unit Weight
3. High Durability (corrosion-free)
4. Low Carbon Footprint
5. Innovative Technology Development
6. Local/Regional Manufacturing Opportunities



The Value Proposition - structural advancement, durability & sustainability

How does FRP align or complement the (draft) ***2045 Florida Transportation Plan*** ?



The Value Proposition - structural advancement, durability & sustainability

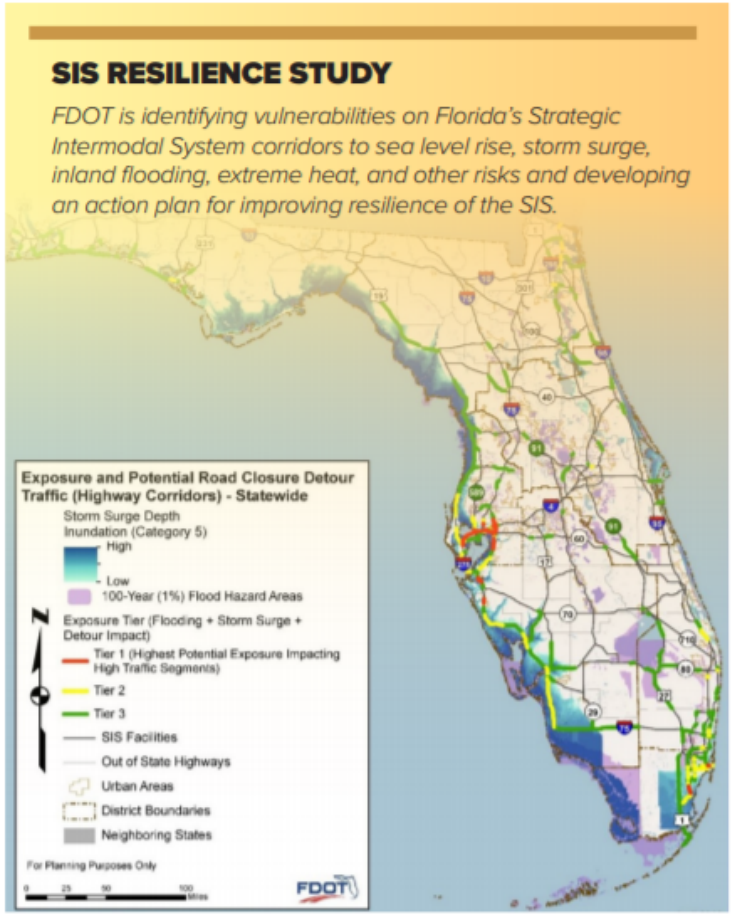
2045 Florida Transportation Plan

A. relevant **Key Strategies** for Infrastructures:
   - Address long-term costs
   - Adaptability
   - Advanced Materials
   - …

KEY STRATEGIES › IDENTIFY & MITIGATE RISKS

Florida will place a high priority on identifying risks to its transportation system and the customers that use it. Florida will incorporate these risks into planning and management decisions for all modes. Florida will:

- **Identify vulnerabilities** to hazards such as sea level rise, storm surge, coastal and inland flooding, and extreme heat and precipitation. Implement actions to avoid, reduce the likelihood of, or prepare the system to withstand these risks.
- **Improve the agility of the transportation system** during emergencies and disruptions by expanding real-time information sharing, enhancing system management, providing more multimodal options, and supporting greater redundancy for critical infrastructure.
- Expand asset management decisions to **address the long-term costs of known vulnerabilities**, such as the need for retrofitting existing facilities or repairing certain facilities multiple times.
- **Adapt transportation design, construction, and maintenance techniques** to reduce vulnerability and improve resilience of existing and new transportation facilities, such as use of emerging technologies and advanced materials, stormwater management, and infrastructure modifications.
- Identify and implement approaches for coordinating environmental management, land use, and urban design decisions to **improve overall infrastructure and community resilience**.
- Establish a long-term approach to incentivize, where appropriate, the **transition of infrastructure and development** away from vulnerable areas.
- **Update emergency management plans** covering preparedness, response, recovery, and mitigation to reflect the increasing intensity and severity of extreme weather events and other risks; shifts in Florida's population, development patterns, and travel choices; and increasing use of technologies such as automated and electric vehicles.



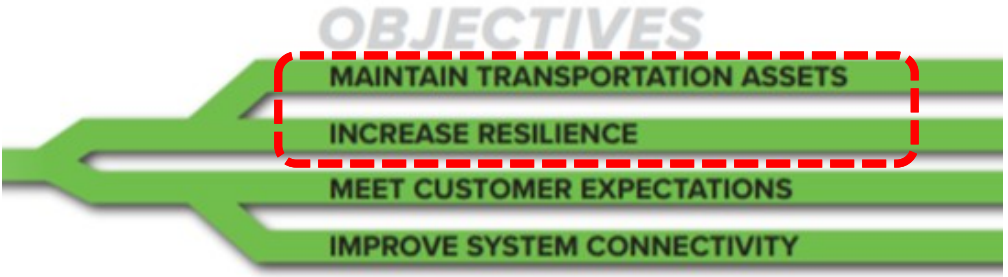
The Value Proposition - structural advancement, durability & sustainability

2045 Florida Transportation Plan

B. relevant **Key Objectives:**

- Maintain Assets in good repair
- Increase Resilience
- Quality Infrastructure
- …

OBJECTIVES	PROGRESS INDICATORS	
Maintain Florida's transportation assets in a state of good repair for all modes	• *Pavement condition* • *Bridge condition*	• *Vulnerability to flooding or storm surge*
Increase the resilience of infrastructure	• *Transit vehicle and facility condition*	• *Hours or days of transportation facility closure due to smoke, fire, flooding, wind, or extreme temperature*
Meet customer expectations for infrastructure quality and service	• *Airport pavement condition* • *Seaport infrastructure condition*	• *Frequency of repairs due to damage from extreme weather or other events*
Improve transportation system connectivity	• *Spaceport infrastructure condition* • *Sidewalk and trail condition*	• *Customer satisfaction* • *Connections between modes/ systems and extent of system gaps*

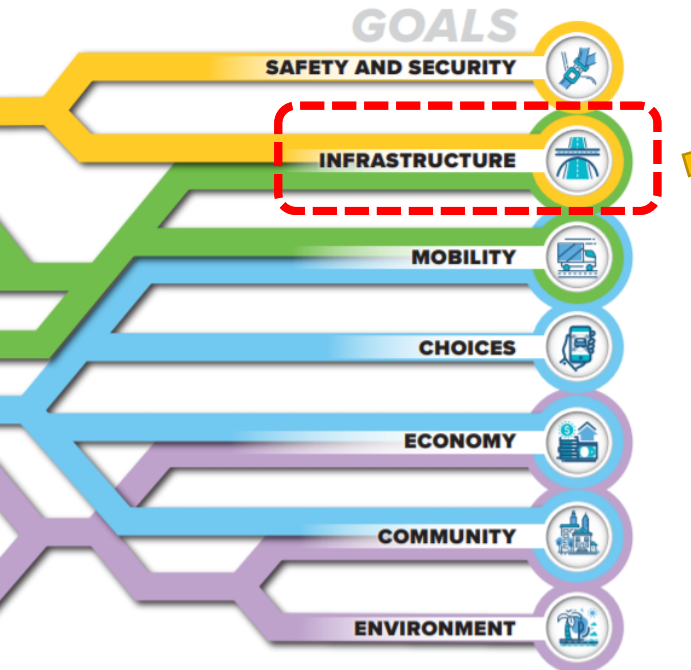


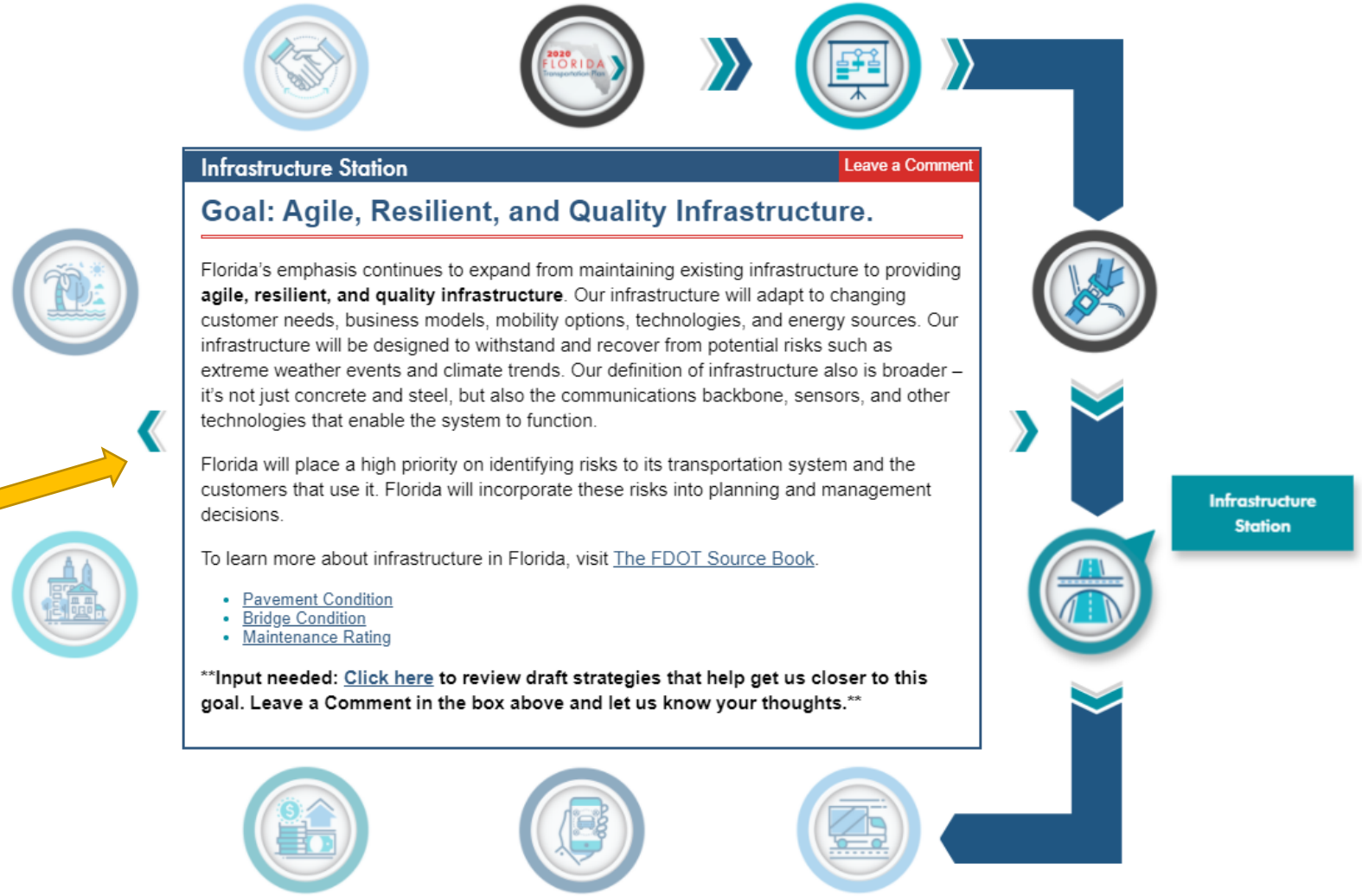
The Value Proposition - structural advancement, durability & sustainability

2045 Florida Transportation Plan

C. relevant **Goals**:

- Agile
- Resilient
- Quality infrastructure





The Value Proposition - structural advancement, durability & sustainability

Cost : Benefit ???

FDOT

Florida Department of Transportation

RON DESANTIS
GOVERNOR

605 Suwannee Street
Tallahassee, FL 32399-0450

KEVIN J. THIBAULT, P.E.
SECRETARY

For Immediate Release
January 7, 2021

Contact: Beth Frady
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FDOT Macroeconomic Analysis Shows Transportation Projects Yield $4 of Benefits for Every Dollar Invested

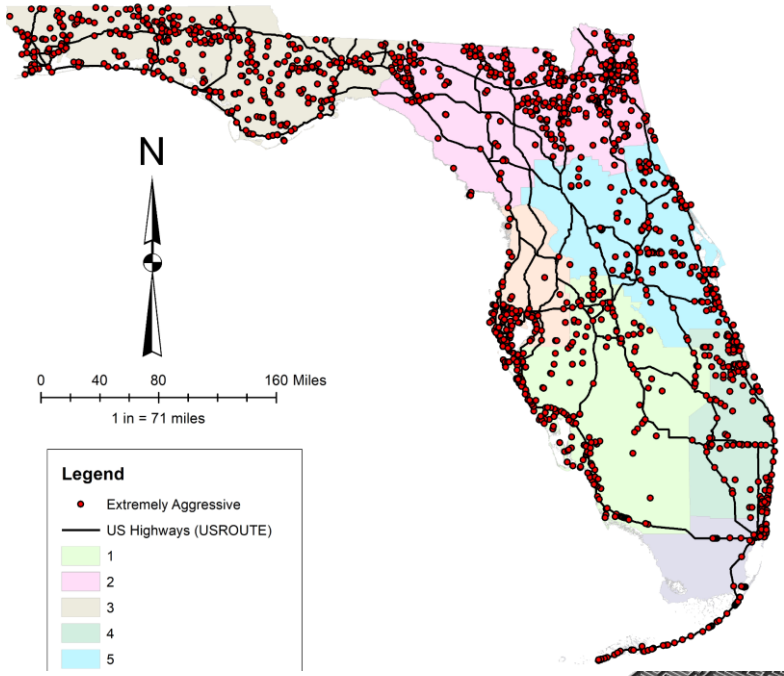
~ Investments provide short- and long-term benefits to transportation system users as well as the state's overall economy ~

TALLAHASSEE, Fla. – The Florida Department of Transportation (FDOT) recently completed a macroeconomic analysis and found that Florida's transportation projects are expected to yield an average $4 of benefits for every dollar invested. In addition, the analysis found the benefits included investments across all transportation modes, including highway, transit, rail, airports, seaports and waterways, and spaceports. The investments will provide short- and long-term benefits for transportation system users as well as Florida's overall economy.

This study shows a lower overall benefit-cost ratio than the 2014 Macroeconomic Analysis. Indeed, the benefit-cost ratio has fallen with each iteration of the analysis since 2002. This trend reflects increasing construction costs and the advancing maturity of the system. Major highway expansion and construction that would reduce congestion on local roads has been accomplished over the past decades in many regions of Florida, and highway investments increasingly serve to meet FDOT's statutory commitment to maintaining pavement and bridges in good condition.

FRP material systems used in FDOT's Highway Bridges & Structures

1. **FRP-Prestressed Concrete (PC):**
   - **Prestressed Beams** - CFRP strands, GFRP/BFRP auxiliary
   - **Bearing Piles –** CFRP strands, spirals, & splice dowels, (GFRP/BFRP auxiliary??)
   - **Sheet Piles -** CFRP strands, GFRP (BFRP ? *submerged)* stirrups
2. **FRP-Reinforced Concrete (RC):**
   - **CIP Decks & Flat-Slab Bridges** - GFRP (BFRP *now allowed*)
   - **Seawalls –** GFRP *(submerged)*
   - **Bulkhead Caps –** GFRP/BFRP
   - **Retaining Walls -** GFRP/BFRP
   - **Drainage Structures/Box Culverts** – *(no recent examples)*
3. **FRP Elements (MS):**
   - **Fenders, Piles, HCBs, Pedestrian Structures**



FRP RC/PC material systems used in Florida's Highway Bridges & Structures

Recent Completed Projects

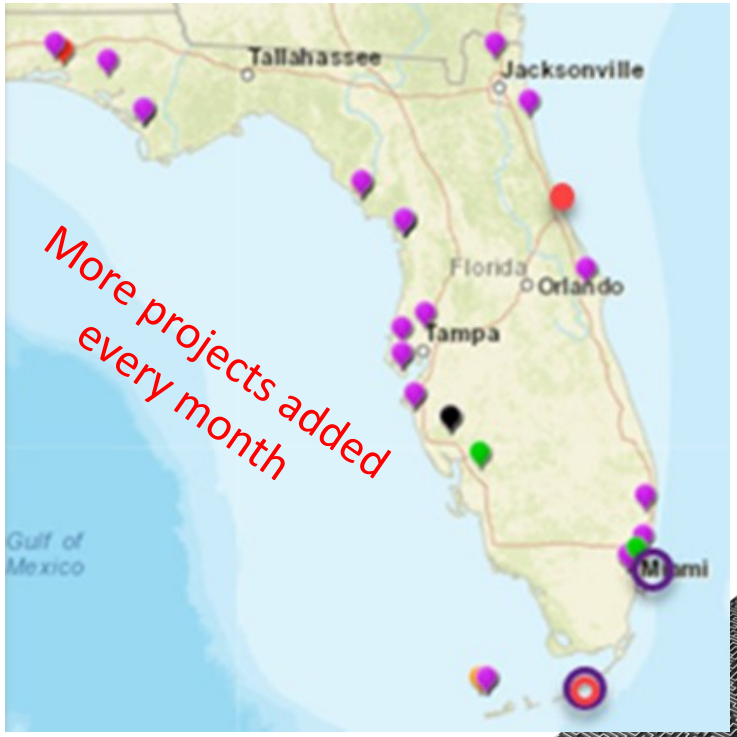
Arthur Drive over Lynn Haven Bayou **
Bakers Haulover Cut Bulkhead Replacement *
Cedar Key Bulkhead Rehab *
Key West Bight Ferry Terminal Extension **
Halls River Bridge ***
PortMiami Tunnel Retaining Walls
South Maydell Dr over Palm River *
SR-A1A Flagler Beach Seawall (Segment 3) *
SR-5 (US-17) over Trout River Rehab **
SR-5 (US 41)/Morning Star and Sunset link-slabs
SR-45 (US 41) over North Creek ***
SR-312 over Matanzas River Rehab **
SR-520 over Indian River Bulkhead Rehab *
Sunshine Skyway Seawall Rehab & Extension*
UM Innovation Bridge ***
UM Fate Bridge superstructure
UM i-Dock ***
US-1 over Cow Key Channel FSB's

Current Projects

4th St at Big Island Gap **
40th Ave NE over Placido Bayou ***
Barracuda Blvd over Canal Bradano **
Bayway Structure-E Seawall Cap *
Bimini Dr over Duck Key Canal *
CR30A over Western Lake ***
Jupiter Federal Observation Platform ***
NE 23rd Ave over Ibis Waterway ***
S. Maydell Dr/Palm River Bulkhead *
SR-A1A over Myrtle Creek and Simpson Creek
SR-A1A N. Bridge Observation Platform ***
SR 404 & 528 Indian & Banana Rivers Rehab *
SR5 over Oyster Creek *
SR 5/US 1 over Earman River Canal ***
SR-30 over St Joe Inlet *
SR-112/I-195 Westshore waterway *
Village of North Bay Seawall *
West Wilson St over Turkey Creek **

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

* *bulkhead/seawall only*
** *piling/substructure only*
*** *complete bridge*



FRP structural member systems used in Florida's Highway Bridges & Structures

Recent Completed Projects

Acosta Bridge fender replacement *
Bayway Structure-E fender *
US-331/Choctawhatchee Bay fender wales
Halls-River Bridge - Hybrid Composite Beams
Howard Frankland Bridge NB fender *
Ocala Water-Recharge Park Boardwalk ***
Skyplex Blvd - Composite Arch Bridge **
SR-A1A/Sisters Creek fender *
SR-A1A/Blue Heron fender replacement *
SR-3 over Barge Canal fender replacement *
SR-44 over Indian River fender replacement *
SR 714/South Fork St Lucie River *

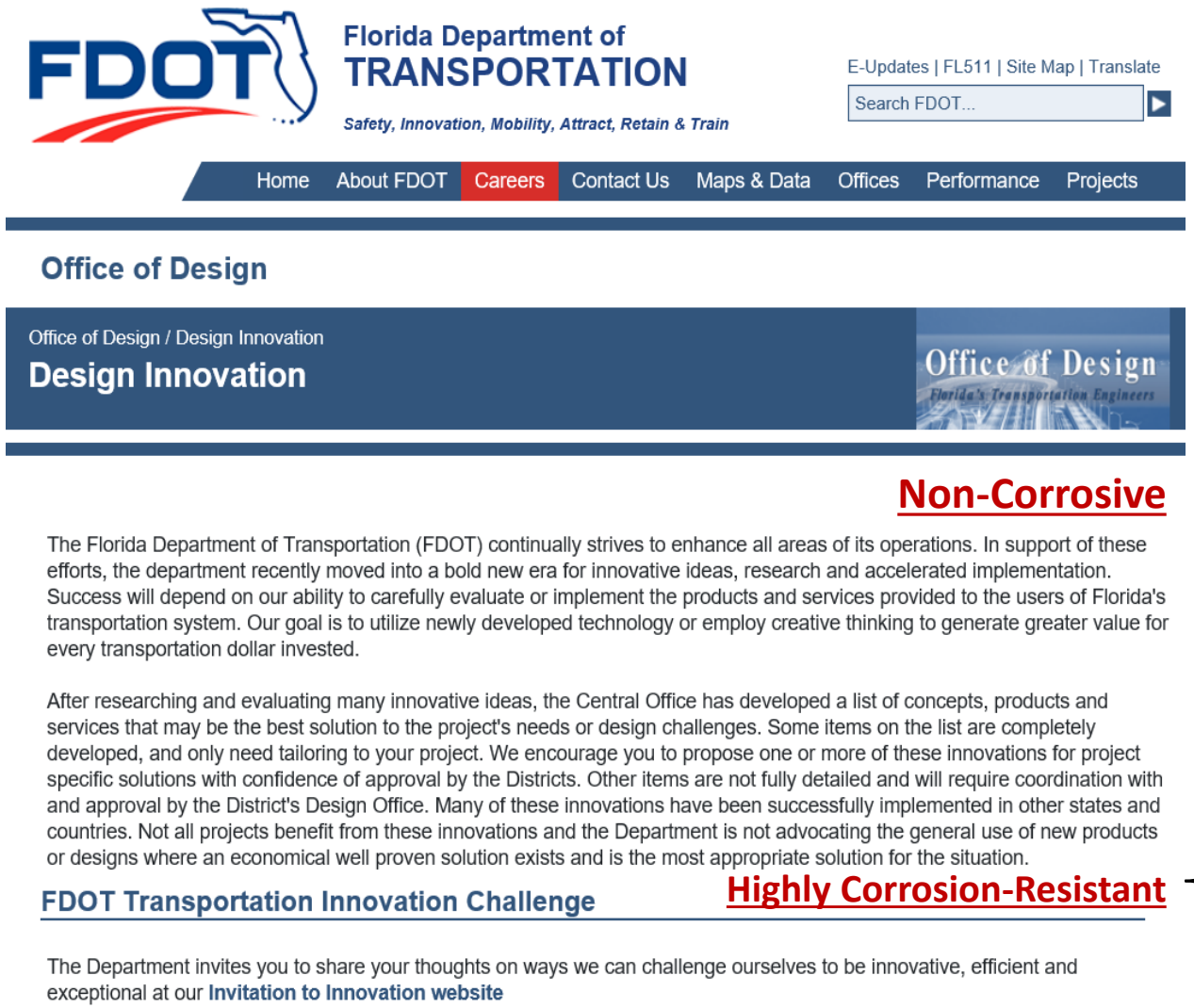
Current & Future Projects

Bimini Dr over Duck Key Canal ? **
CR510 3-Sided Culvert-Bridge ? **
Marco Island Winter Berry Bridge
I-10/Apalachicola River Fender replace *
Jax. Main St Bridge Fender rehab *
SR-40 over Halifax River fender replacement *
SR-292 Perdido Key/ICWW fender replacement *
SR-520 over Indian River fender replacement *
US-192 over Indian River fender replacement *
SR-401 over Barge Canal fender replacement *
SR-518 over Indian River fender replacement *

https://www.fdot.gov/structures/innovation/frpms

* *complete fender system*
** *FRP concrete filled arch*
*** *FRP pedestrian structure*

FRP Design Guidance, Specs, & Tools: Florida DOT



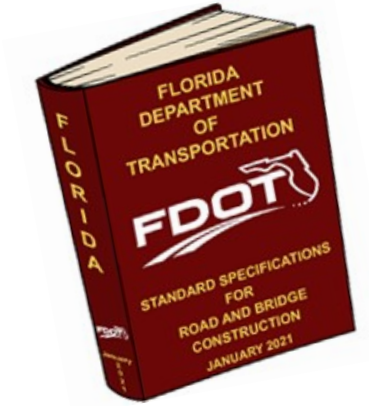
"High-Performance Materials"

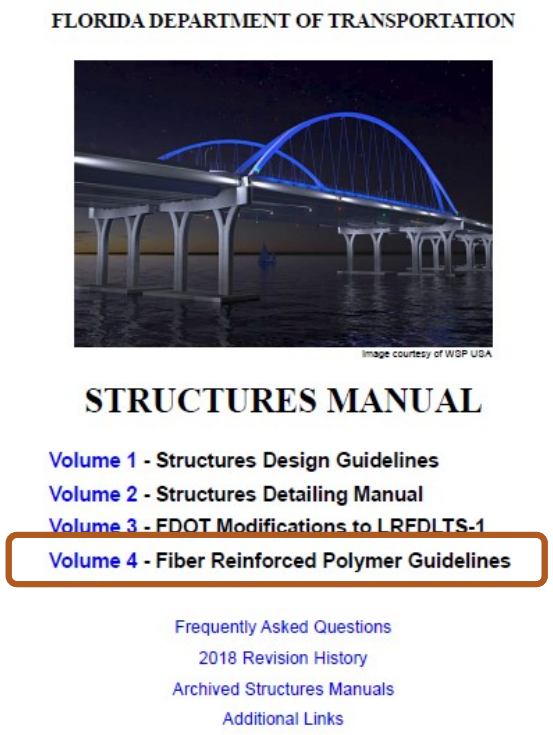
Structures Design Office

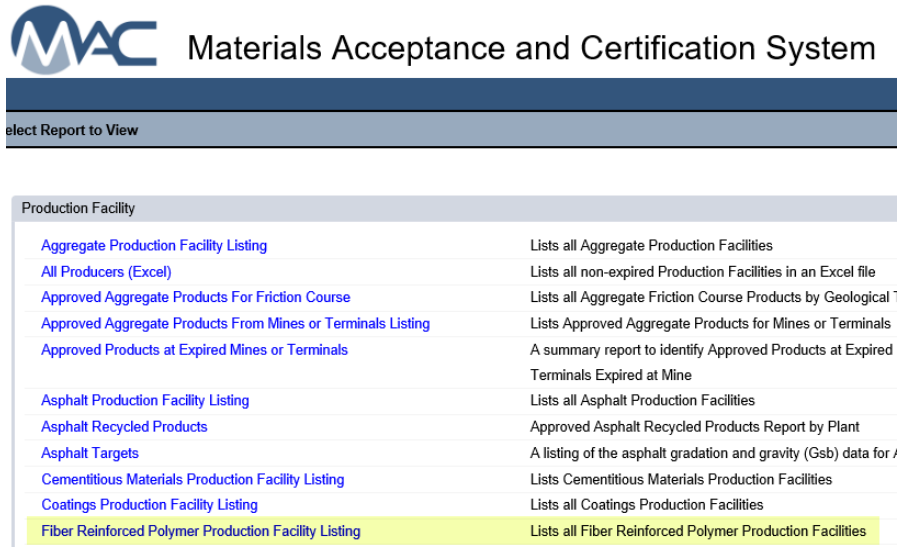
- Curved Precast Spliced U-Girder Bridges
- Fiber Reinforced Polymer Reinforcing
- FRP Members and Structures
- Geosynthetic Reinforced Soil Integrated Bridge System
- Geosynthetic Reinforced Soil Wall
- Prefabricated Bridge Elements and Systems
- Segmental Block Walls
- Ultra-High Performance Concrete (UHPC)
- + Stainless-Steel Prestressing Strand & Rebar

FRP Design Guidance, Specs, & Tools: Florida DOT

- **Mandatory Specifications**
- **Uniform Approval Processes**
  - Manufacturer Approval vs. Product Approval
- **Design Tools**







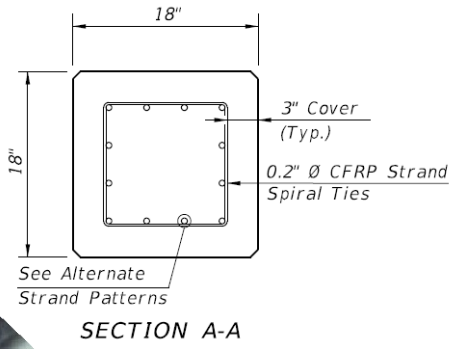
https://www.fdot.gov/structures/innovation/

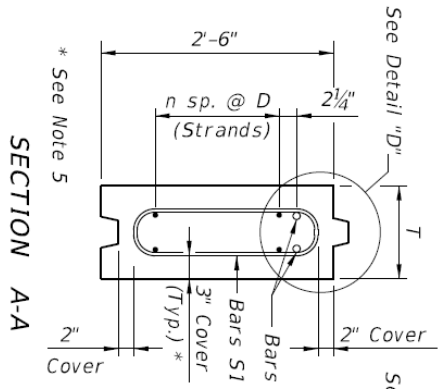
FRP Design Guidance, Specs, & Tools: Florida DOT

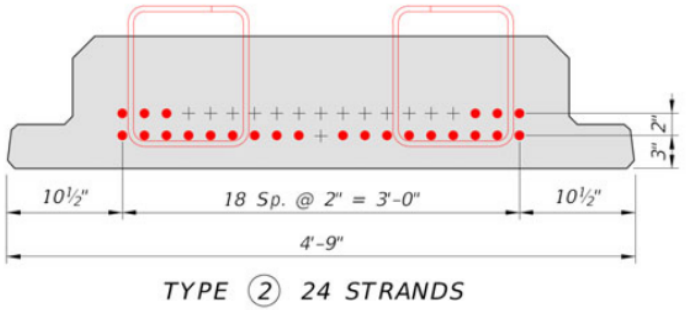
Prestressed Concrete (CFRP-PC) Design & Construction Standards

		Structures Foundations
455-001		Square Prestressed Concrete Piles - Typical Details and Notes
455-101		Square CFRP and SS Prestressed Concrete Piles - Typical Details and Notes
455-102		Square CFRP and SS Prestressed Concrete Pile Splices
455-112		12" Square CFRP and SS Prestressed Concrete Pile
455-114		14" Square CFRP and SS Prestressed Concrete Pile
455-118		18" Square CFRP and SS Prestressed Concrete Pile
455-124		24" Square CFRP and SS Prestressed Concrete Pile
455-130		30" Square CFRP and SS Prestressed Concrete Pile
455-154		54" Precast/Post-Tensioned CFRP and SS Concrete Cylinder Pile
455-160		60" Prestressed CFRP and SS Concrete Cylinder Pile
455-400		Precast Concrete Sheet Pile (Conventional)
455-440		Precast Concrete Sheet Pile (CFRP/GFRP and HSSS/GFRP)

	Florida Slab
D20450	**Typical Florida Slab Beam Details and Notes**
Certification Statement	Permitted Projects FPID No(s):
D20451	**12" Florida Slab Beam**
Certification Statement	Permitted Projects FPID No(s):
D20452	**15" Florida Slab Beam**
Certification Statement	Permitted Projects FPID No(s):
D20453	**18" Florida Slab Beam**
Certification Statement	Permitted Projects FPID No(s):

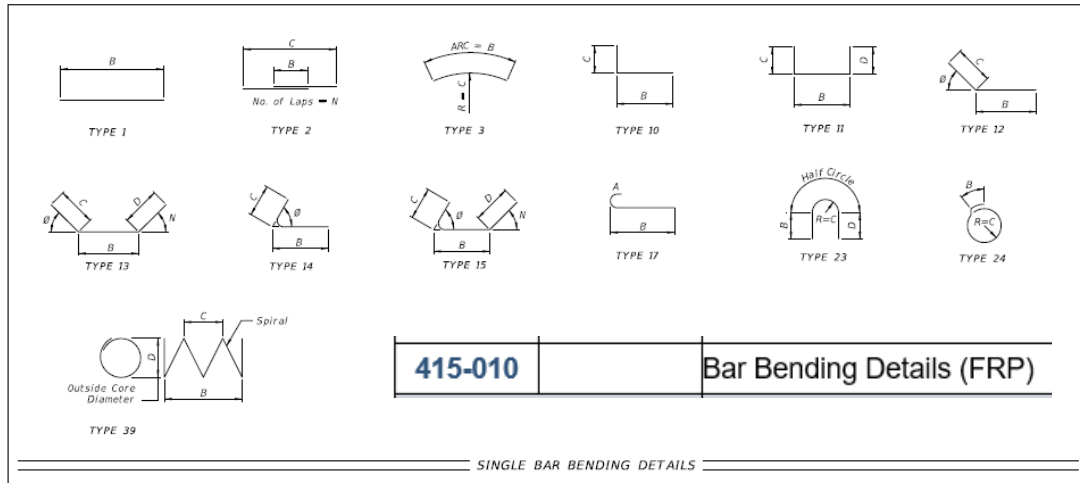






FRP Design Guidance, Specs, & Tools: Florida DOT

Reinforced Concrete (RP-RC) Design & Construction Standards

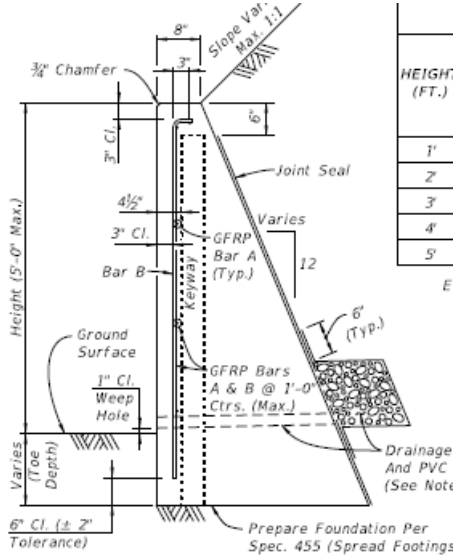


FRP REINFORCED TRAFFIC RAILINGS RAILINGS

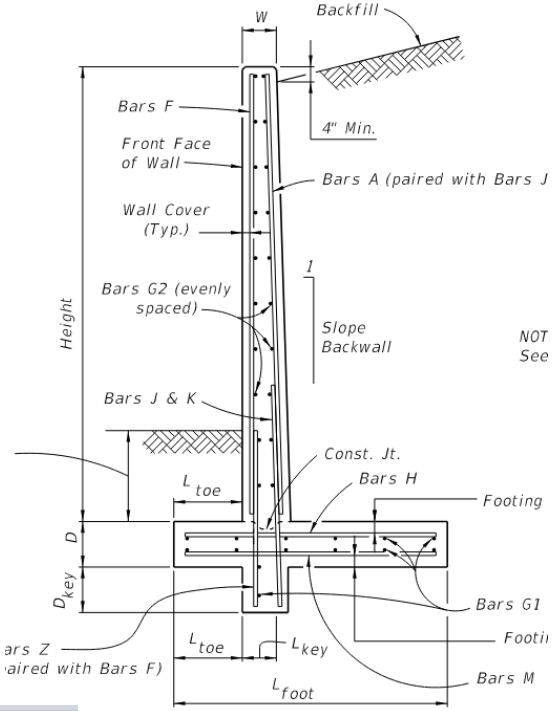
D22420	**Traffic Railing (32" F Shape - GFRP Reinforced)**
Certification Statement	Permitted Projects FPID No(s): 430021-1

FRP REINFORCED APPROACH SLABS

D22900	**Approach Slab - GFRP Reinforced (Flexible Pavement Approach)**
Certification Statement	Permitted Projects FPID No(s): 430021-1



TYPICAL SECTION
CORROSION RESISTANT GRAVITY WALL

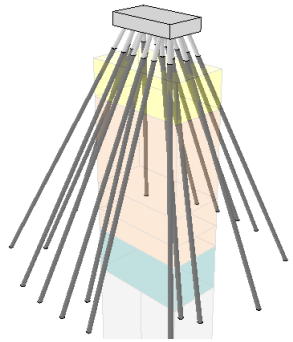


TYPICAL SECTION

		Concrete Structures
400-010		Cantilever Retaining Wall (C-I-P)
D6011c		**Gravity Wall - Option C (GFRP Reinforced)**
Certification Statement		Permitted Projects FPID No(s): 405600-2 430021-1

FRP Design Guidance, Specs, & Tools: Florida DOT +

- Mandatory Specs
- Uniform Approval Processes
  - Manufacturer Approval vs. Product Approval
- **Design Tools – Structural software**



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Structures Design

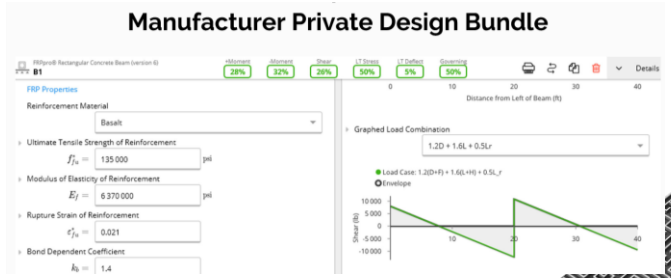
Structures Design
Programs Library

	Box Culvert v4.0 *(FRP-RC in development)*	11/07/2018	Exe (Zip) (Mathcad 15)
V6.0 coming early 2021 →	**Prestressed Beam v5.2** *(beta version CFRP-PC)*	11/07/2018	Exe (Zip) (Mathcad 15)
Includes FRP-RC →	**Bent Cap v1.0**	11/07/2018	Exe (Zip) (Mathcad 15)
Includes FRP-RC →	**Retaining Wall v4.0**	06/01/2020	Zip (Exe) (Mathcad 15)

Other's Design Software:

Adaption of FRP analysis or design enhancements:

- **FB-MultiPier** *(BSI) CFRP-PC available in Jan. 2021*
- **Michigan DOT/LTU** CFRP-Beam Design Mathcad: *https://mdotjboss.state.mi.us/SpecProv/trainingmaterials.htm (also see TRB Webinar Dec 3, 2019)*
- **DeepEx** *(Deep Excavation, LLC) available*
- **FRPpro™** *pending*
- **…**



LCC Design Guidance & Tools: AASHTO/NCHRP/ASCE

- Mandatory Specs
- Uniform Approval Proc
  - Manufacturer Approval v
- **Design Tools –**

  SLD & LCC Guides

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

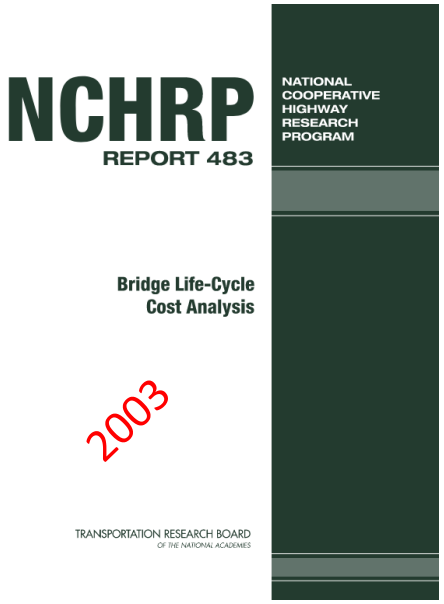
Item Code: HBSLD-1

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.

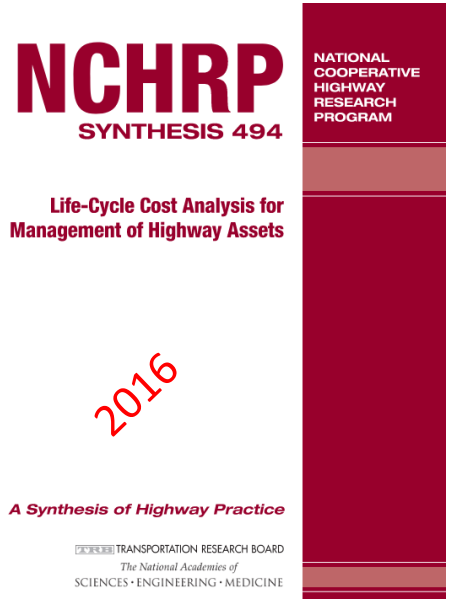
2020

- Service Life Expectations for Structures
  50 years *(AASHTO LFD < 1993)*
  75 years *(AASHTO LRFD > 2007)*
  100 or 150 years? *(HBSLD-1, 2020)*

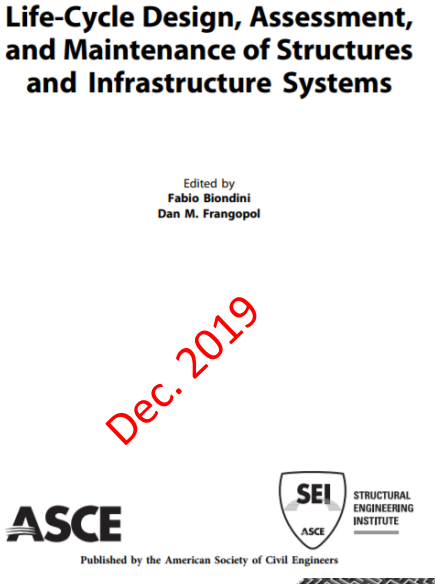
- Life Cycle Cost policies & comparisons



2003



2016

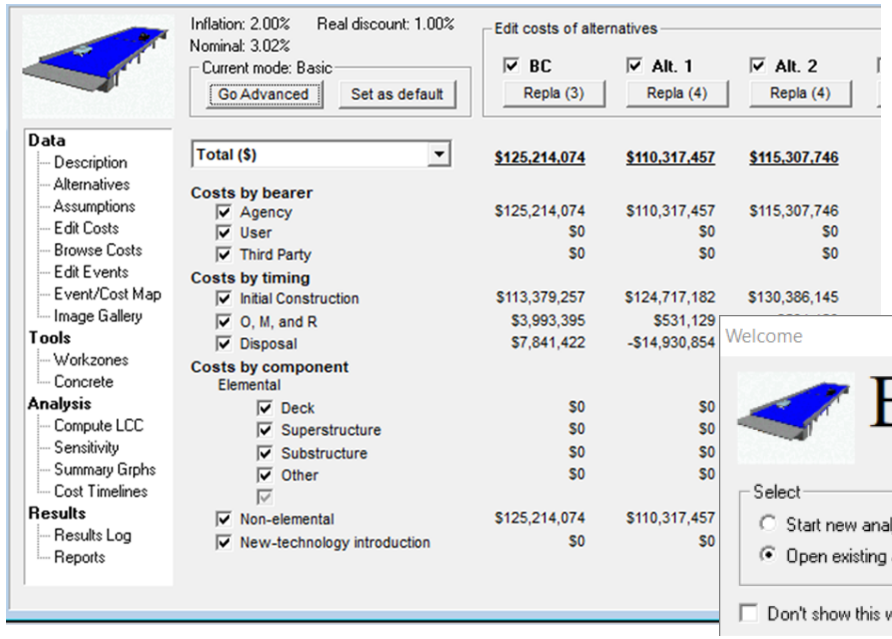


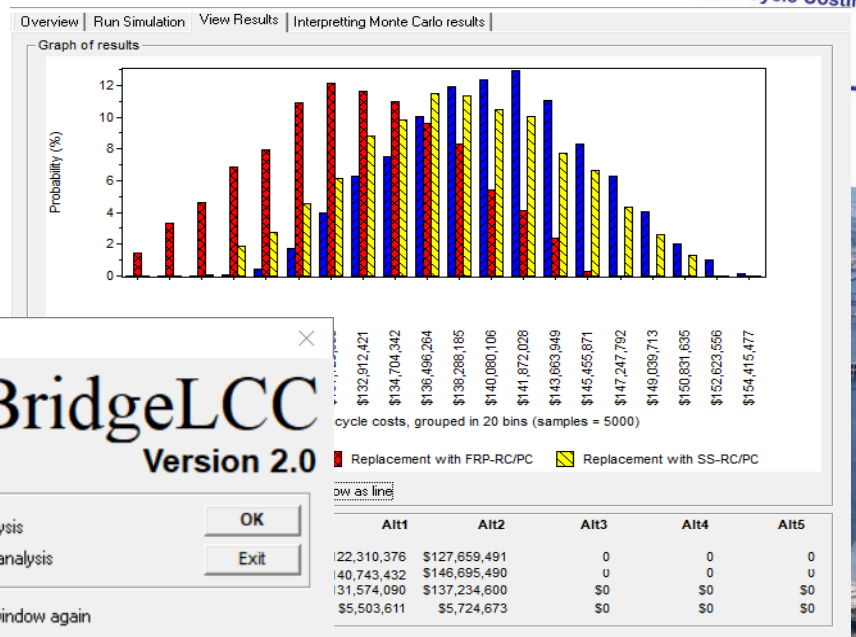
Dec. 2019

LCC Design Guidance & Tools: USDOT/NIST

- Mandatory Specs
- Uniform Approval Processes
  - Manufacturer Approval vs. Product Approval
- **Design Tools – LCC software**

https://www.nist.gov/services-resources/software/bridgelcc





FRP-RC Evaluation of Durability: ACI selected Bridges

- **Eleven bridges** located across the United States in 2017-18
- Each bridge contains GFRP bars in deck or other location and has been in service for **at least 15 years**

https://www.acifoundation.org/Portals/12/Files/PDFs/GFRP-Bars-Full-Report-with-Addendum.pdf

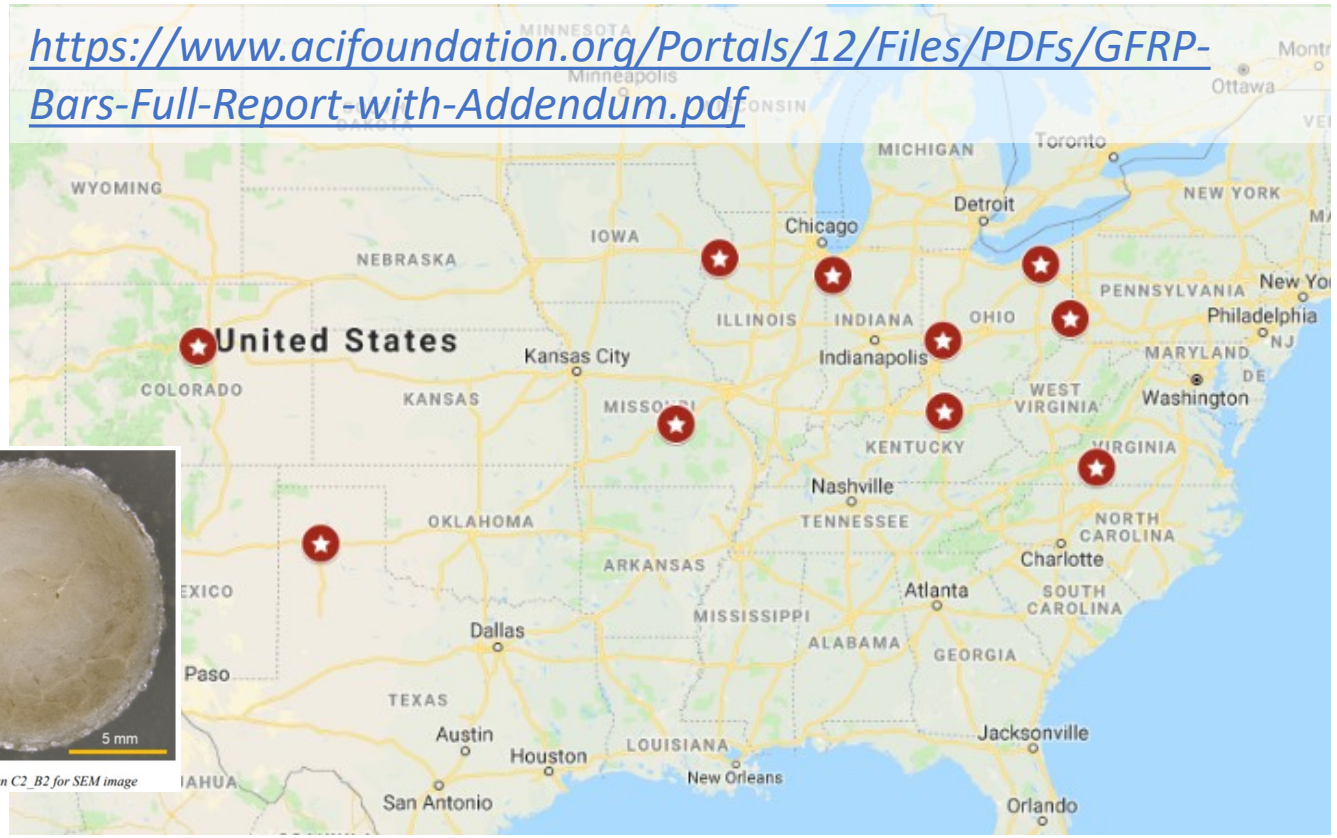


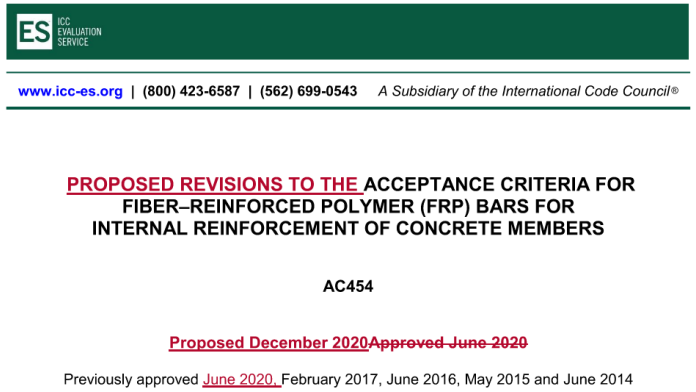
Fig. 34 –Specimen C2_B2 for SEM image

- Gills Creek Bridge (VA)
- O'Fallon Park Bridge (CO)
- Salem Ave Bridge (OH)
- Bettendorf Bridge (IA)
- Cuyahoga County Bridge (OH)
- McKinleyville Bridge (WV)
- Thayer Road Bridge (IN)
- Roger's Creek Bridge (KY)
- Sierrita de la Cruz Creek Bridge (TX)
- Walker Box Culvert Bridge (MO)
- Southview Bridge (MO)

\+ Pearl Harbor Dry Dock #4 (HI)

FRP-RC Evolution from Durability Research

- **Envionmental Reduction Factors** will be relaxed (~20-25%) for GFRP 100-year+
- **BFRP** rebar will be broadly adopted, sooner rather than later, if recent import tariffs are rescinded (~30%)
- **B&G-FRP** rebar design stiffness and strength will be significantly increase (~20-25%)
- **B&G-FRP** creep rupture limits will increase (20~30%), so partial/mild prestressing will become feasible.
- **Thermoplastic resin** FRP rebar will become predominant for bent bars
- **Sustainability** will become more important , so
- **FRP synergy** with recycled aggregates, seawater, & by-product SCM's will be advantageous.

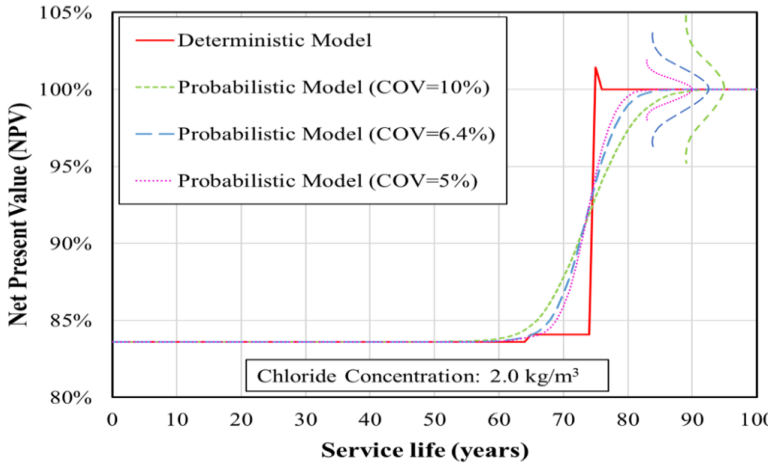


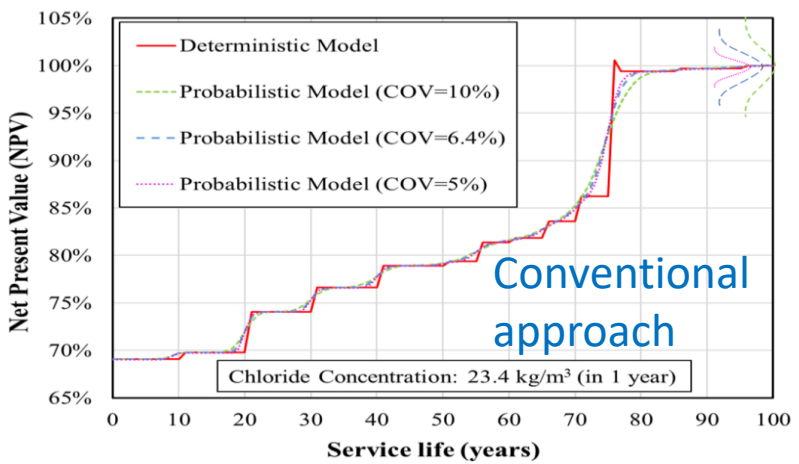
Parallel progress for Building Codes

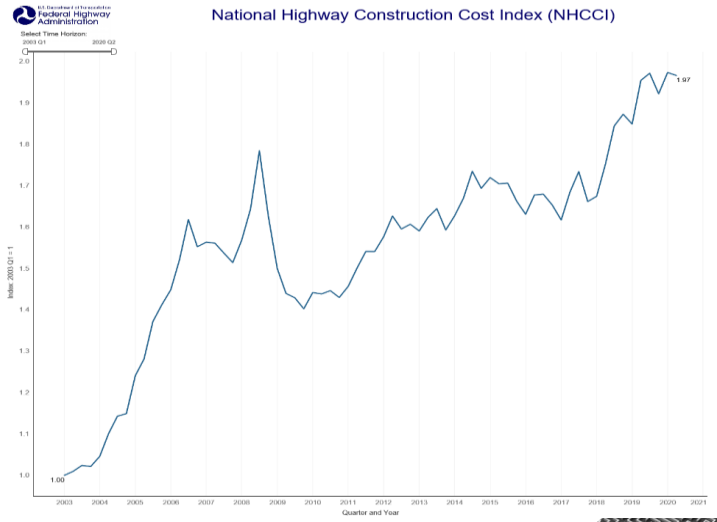
Life-Cycle Cost analysis

- Comparisons and synergies
  - Economics is in the eye of the beholder
  - Save now, $$$ later or $$$ now adaption later
  - Use realistic discount rates:

    (i) recognizing long-term investment using government bonding rates – highway/bridge construction inflation rates (NHCCI) = < 1%



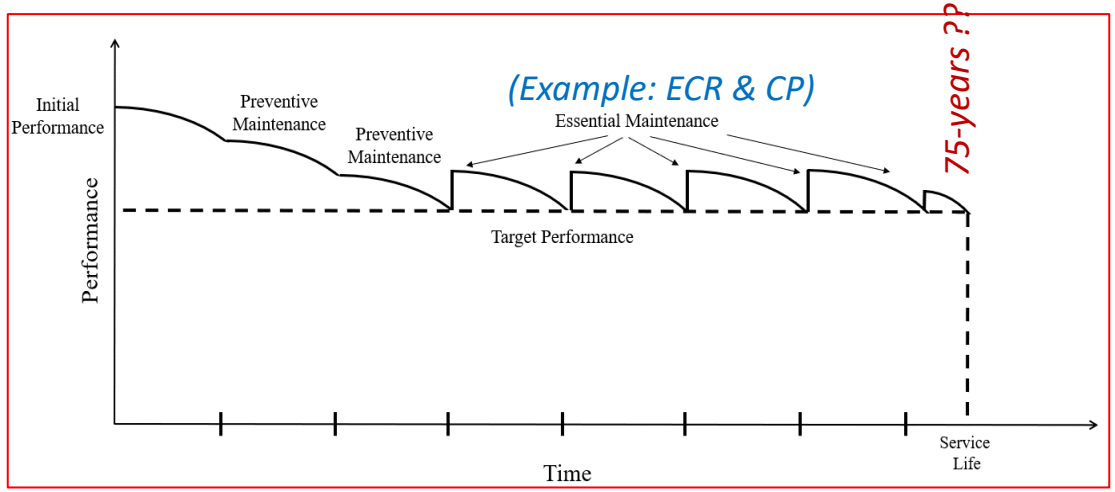


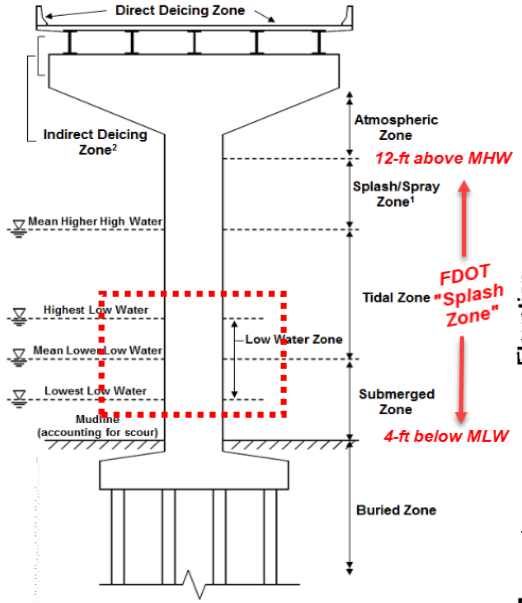


Idiom: "Penny wise and pound foolish"

Life-Cycle Cost analysis

- Comparisons and synergies
  - Conventional-RC with periodic Repair & Rehabilitation





Source: AASHTO. 2020, Guide Specification for Service Life Design of Highway Bridges (1st Edition).

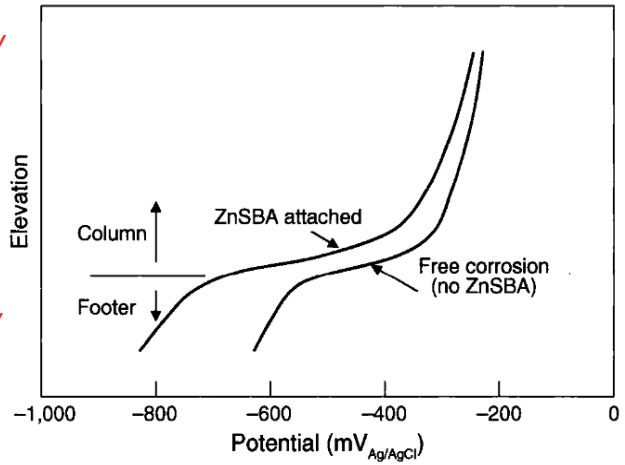


FIGURE 10. *Schematic illustration of the potential shift of footer and column reinforcement that is expected to accompany ZnSBA activation.*

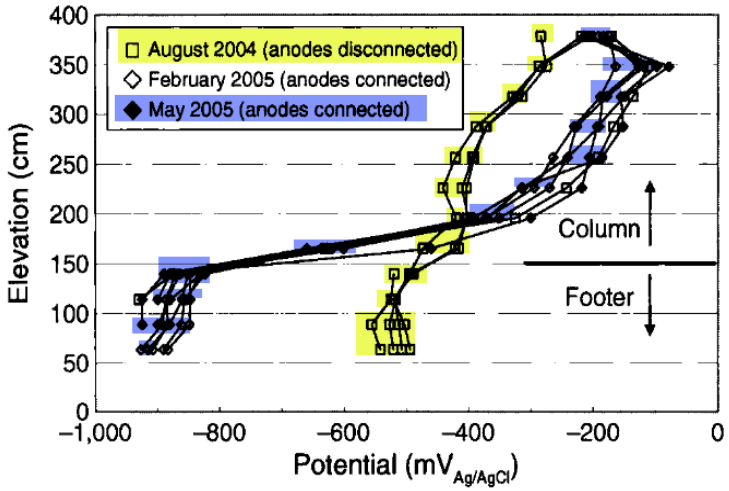


FIGURE 8. *Free corrosion and polarized potentials as a function of elevation for the footer and column on Pier 40W-East. Elevation is referenced to the bottom of the footer.*

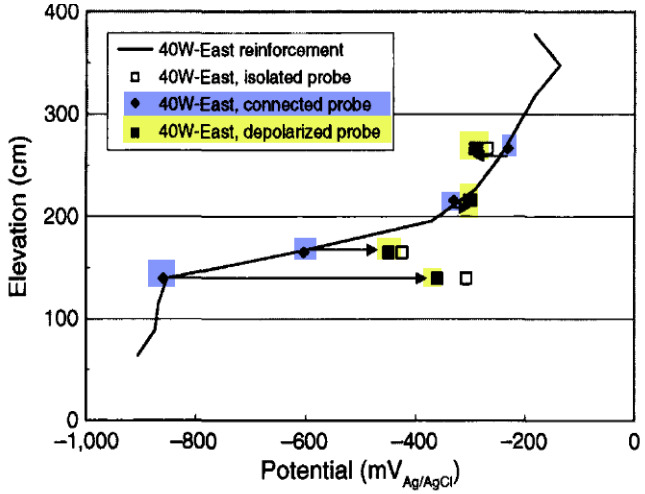
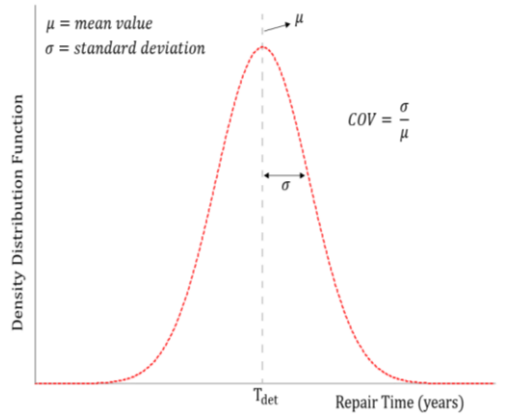
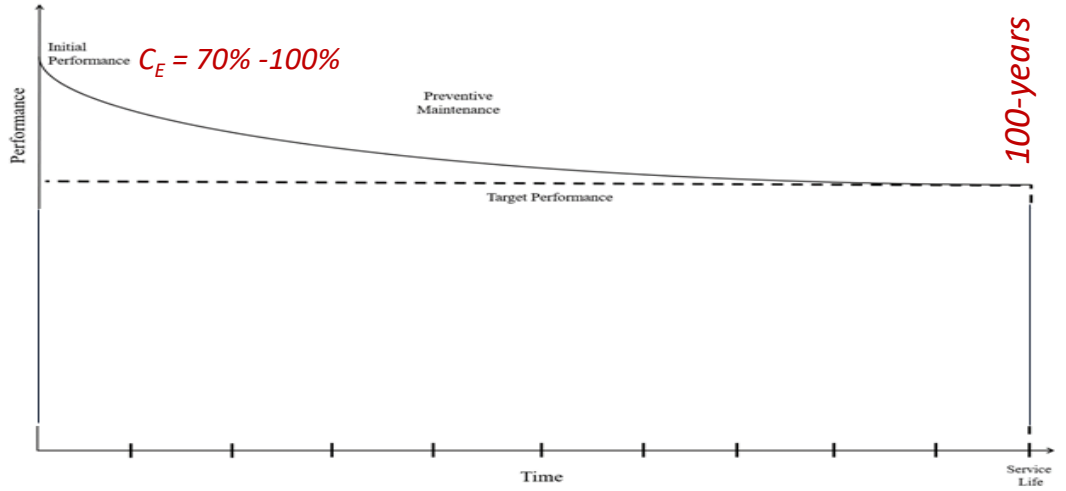


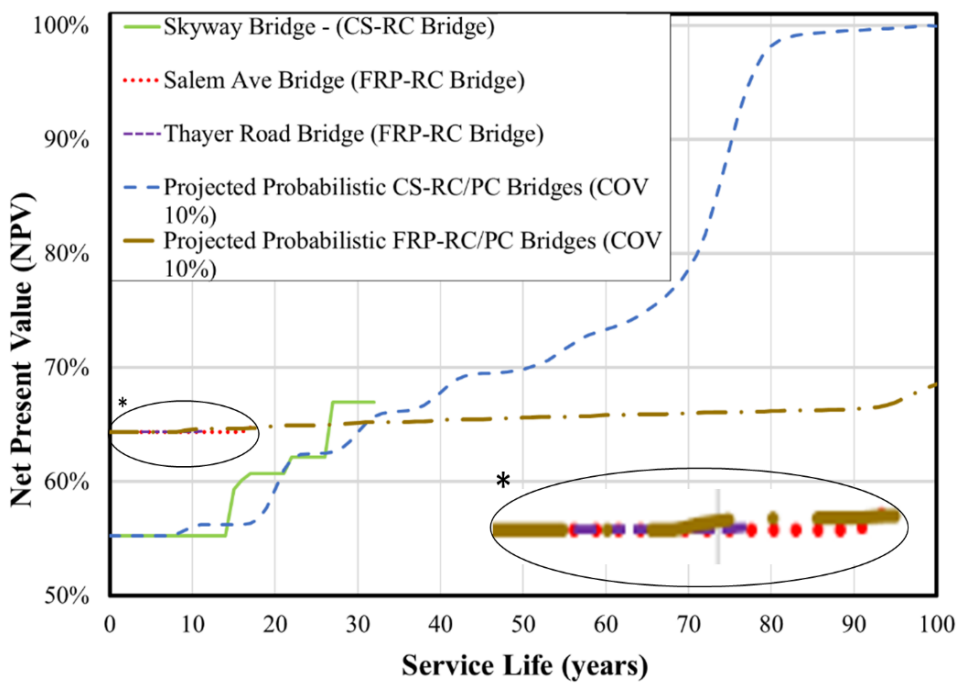
FIGURE 13. *Polarized potential data for reinforcement and free corrosion, polarized, and depolarized potentials for probes on pier 40W-East.*

Life-Cycle Cost analysis

- Future enhancements or needs
  - Highly Corrosion-resistant solutions
  - Improvement of Probabilistic techniques

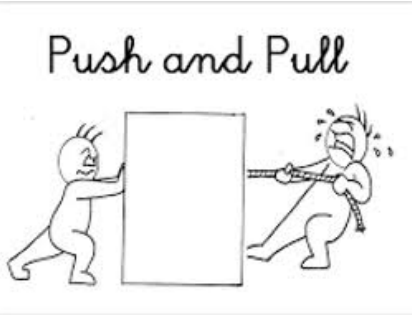






Cadenazzi at al. (2021), "Evaluation of Probabilistic and Deterministic Life-Cycle Cost Analyses for Concrete Bridges Exposed to Chlorides". *Journal of Cleaner Production (pending)*

Forecasting the Future



BIDEN-HARRIS TRANSITION

President-Elect | Vice President-Elect | Nominees and Appointees

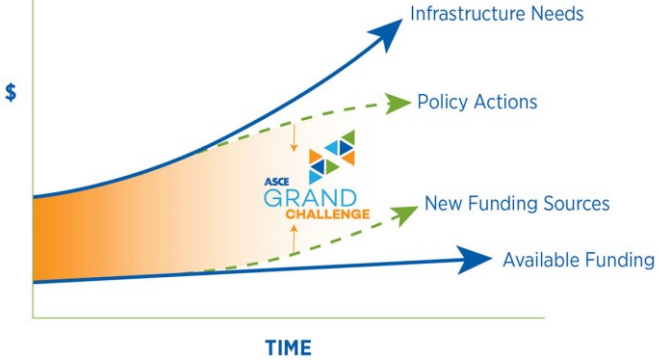
- new Federal "Push Factor"

https://buildbackbetter.gov/priorities/

President-elect Biden is working to make far-reaching investments in:

- **Infrastructure:** Create millions of good, union jobs rebuilding America's crumbling infrastructure – from roads and bridges to green spaces and water systems to electricity grids and universal broadband – to lay a new foundation for sustainable growth, compete in the global economy, withstand the impacts of climate change, and improve public health, including access to clean air and clean water.
- **Innovation:** Drive dramatic cost reductions in critical clean energy technologies, including battery storage, negative emissions technologies, the next generation of building materials, renewable hydrogen, and advanced nuclear – and rapidly commercialize them, ensuring that those new technologies are made in America.

- Industry "Push Factors"
  - **Closing the infrastructure Gap**: Shared goal of reducing infrastructure life cycle costs by 50% by 2025



- State/Owner "Pull Factors"
  - **Reducing Asset Management Risk:** limit need for corrosion related repairs, MOT, etc.
  - **Benefits from Enlarging the Market:** increase supply chain security, regional manufacturing opportunity, etc.

Technology Transfer & Future Development

- Strategies
  - Seek to inform, not to persuade… *Inception!*
  - Recognize that it is easier to do nothing than to change
  - Encourage ownership of the challenges…
- Engagement and Education
  - Need for mentorship of future designers
  - Foster passion and curiosity
  - Engineers can learn best, by doing

Technology Transfer & Future Development

- **8th International Conference on Advanced Composite Materials in Bridges and Structures (ACMBS-VIII)**

August 5-7, 2021, **Online**, https://acmbs2020.ca/

Person-contact : Professor Brahim Benmokrane, University of Sherbrooke,
E-mail :brahim.benmokrane@usherbrooke.ca

- **Third International Workshop on GFRP Bars for Concrete Structures (IW-GFRP-3) - *Workshop Theme : 'Advances in concrete reinforcement'***

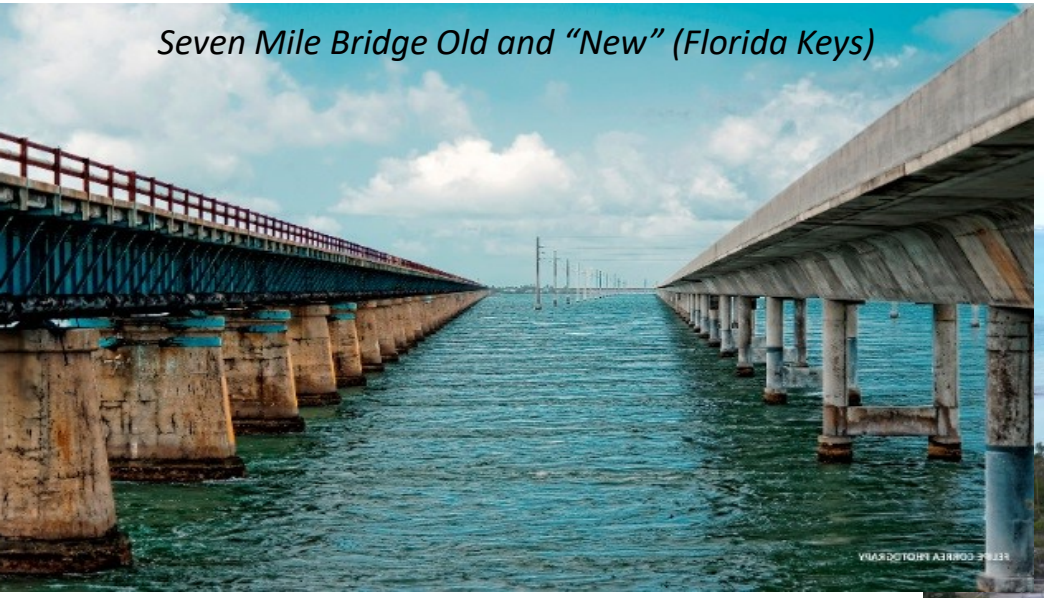
August 3-4, 2021, **Online**, https://acmbs2020.ca/iw-gfrpcs3/

Person-contact : Professor Brahim Benmokrane, University of Sherbrooke,
E-mail :brahim.benmokrane@usherbrooke.ca

Conclusions

- Seek to inform, not to persuade
- Be good custodians for public infrastructure
- Get familiar… FRP is here to stay

as an essential tool for our future!



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

Questions ???

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Website: https://www.fdot.gov/design/Innovation/

100 YEARS TRB
MOVING IDEAS: ADVANCING SOCIETY