Hollywood, FL

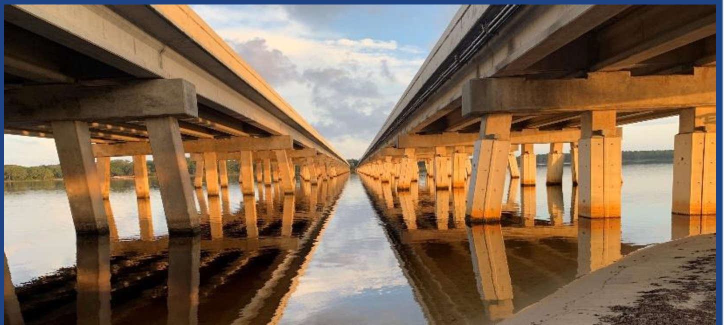
June 13-14, 2024

2024 TRANSPORTATION SYMPOSIUM

FRP Reinforced Concrete Structures:
10-year update, Lessons Learned, and Emerging Best Practices

Steven Nolan, P.E.

State Structures Design Office, FDOT (Tallahassee)



FDOT

Objectives

What is a symposium?
Symposiums are organized, often large-scale meetings, that bring together experts, researchers, practitioners, and professionals. The purpose of a symposium is to discuss and exchange knowled research findings, and insights on a particular topic or theme.

- Highlight the improvements in FRP Reinforced and Prestressed Concrete since 2014, including:
  - Structural design practices and standards
  - Materials specifications, testing, and qualification
  - Construction including representative projects
- Provide Lessons Learned during both design and construction.
- Highlight latest research and planned improvements future implementation.

Schedule

PUT IT DOWN
IT'S THE LAW

Friday, June 14th					
Time			DIPLOMAT 3	DIPLOMAT 4/5	REGENCY 1
8:00 AM	FDOT [illegible] Wh[illegible] Irene Cabral	[illegible]enge [illegible]ge * Marie Tucker, Holly Cohen & Ronald Meyer	**Innovations in Safety *** Emmeth Duran	**FRP Reinforced Concrete Structures, 10-year update, Lessons Learned, & Emerging Best Practices** Steve Nolan	**Planning Consistency in PD&E *** Jennifer Marshall & Nicholas Reid
9:00 AM	**Meeting the Challenge of Rail Safety in Florida *** Brian Owens & Ana Quero	**FHWA Proven Safety Countermeasures *** Elliott Moore & Mark Doctor (FHWA)	**Smart Work Zone Design** Derwood Sheppard, James McGinnis & W.D. Baldwin	**NexGen Lessons Learned** Kevin Lopez & Billy Scott	**PD&E & Alternative Delivery *** Jennifer Marshall & Jason Watts
Networking Break 9:50 AM - 10:10 AM					
10:10 AM	**FDOT Freight Mobility Initiatives in Miami Dade County *** Daniel Lameck & Armando Moscoso	**Deciphering the Process: Permitting & Coordination for Sebastian Inlet Bridge Replacement *** Binod Basnet & Ann Broadwell	**District Case Studies - Resilience *** Tony Frye, Kevin Lopez, Lindsey Koren & Brad Salisbury	**Safety Analysis Using Signal 4 Analytics *** Benjamin Jacobs	**Model-Centric Design Initiatives** Vern Danforth
11:10 AM	**District Case Studies - Cultural Resources *** Jennifer Marshall, Lynn Kelley, Victoria Vogt & Max Imberman	**STRIDES 2 Zero Program Implementation & Challenges *** Dibakar Saha, Cristina Morales & Maria Anaya de Yeats	**Strategies for Enhancing Pedestrian Safety at Intersections *** Elliott Moore & Mark Doctor (FHWA)	**Henry E Kinney Tunnel Rehabilitation Project** Binod Basnet, Ron Wallace, Naldo Gonzalez, Brian Seip & Eric Pineres	**Non-State Bridges on State ROW** Darren Lucas & Pablo Orozco
Transportation Symposium - Adjourn @ 12:00 PM					

1. Design: Practices and Standards for FRP-RC/PC.
2. Materials: Specifications, Testing, and Qualification.
3. Construction: Example Projects & Lessons Learned.

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Speaker Bio:

Steven Nolan, P.E.

Professional Engineer in Florida since 2003, current technical lead coordinator for Florida DOT for implementation of Fiber-Reinforced Polymer reinforcing and prestressing, stainless-steel prestressing, and UHPC for structural applications. 10-years' experience with development of design guidance for FRP, 30-years' experience with concrete design and construction including 25-years with bridge design specification and standards development. Current member of ***TRB*** committee **AKB10**-Innovative Highway Structures, ***ACI*** 440C & CSAO, ***ASCE***-Structural Engineering Institute, Bridge Engineering Institute, and ***fib*** *(International Federation for Structural Concrete).*

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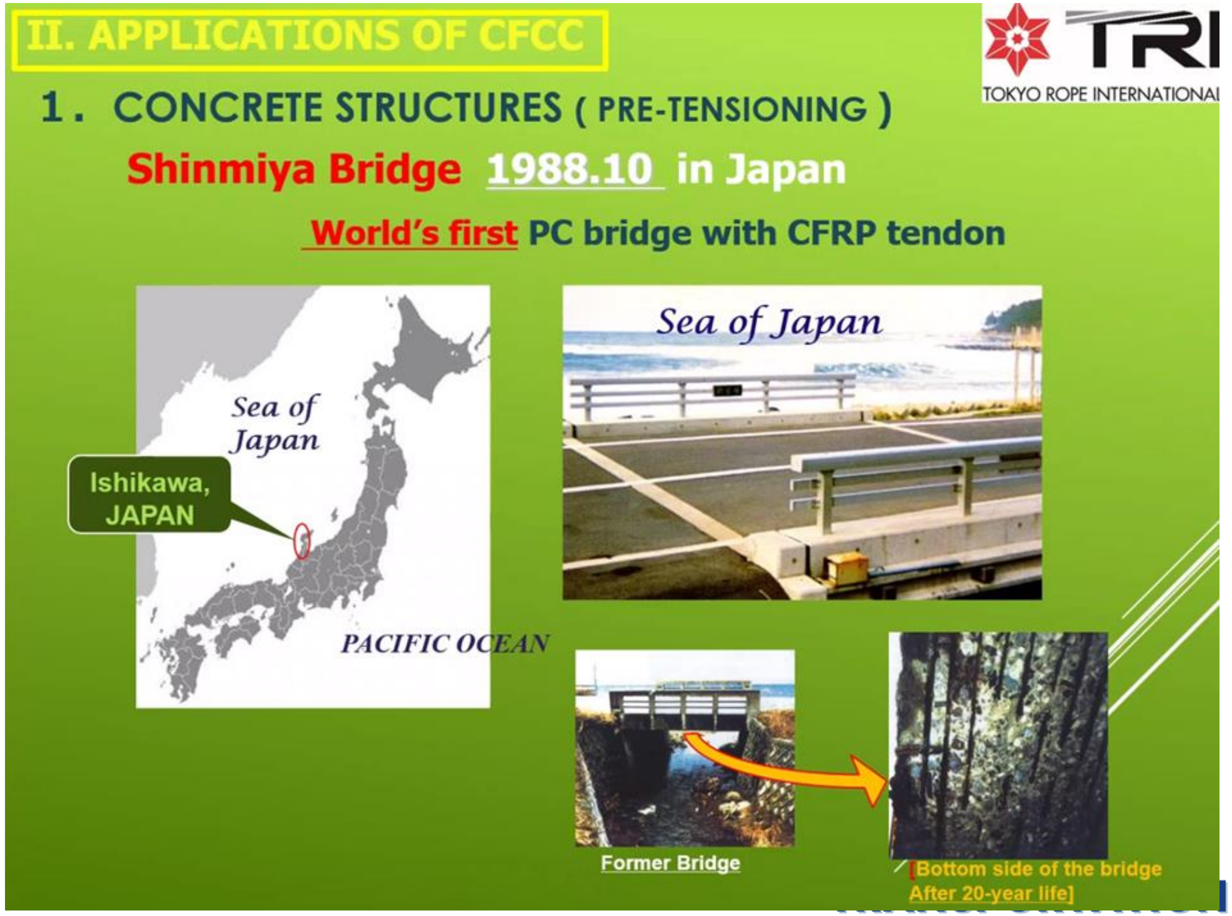
Background:

- FDOT introduced guidance for the implementation of Fiber-Reinforced Polymer-Reinforced and Prestressed Concrete (FRP-RC & FRP-PC) at the ***2014 Design Training Expo***. We highlighted the planned release of ***Standard Specifications***, ***Structures Manual***, and ***Materials Manual*** updates, and the early design work for the seminal demonstration project - Halls River Bridge.
- Reflecting on 10 years of implementation and the evolution of design guidance, standard specifications and plans, many projects have now been successful completed and continue to be monitored with the goal of improving the state-of-the-practice and cost efficiency.

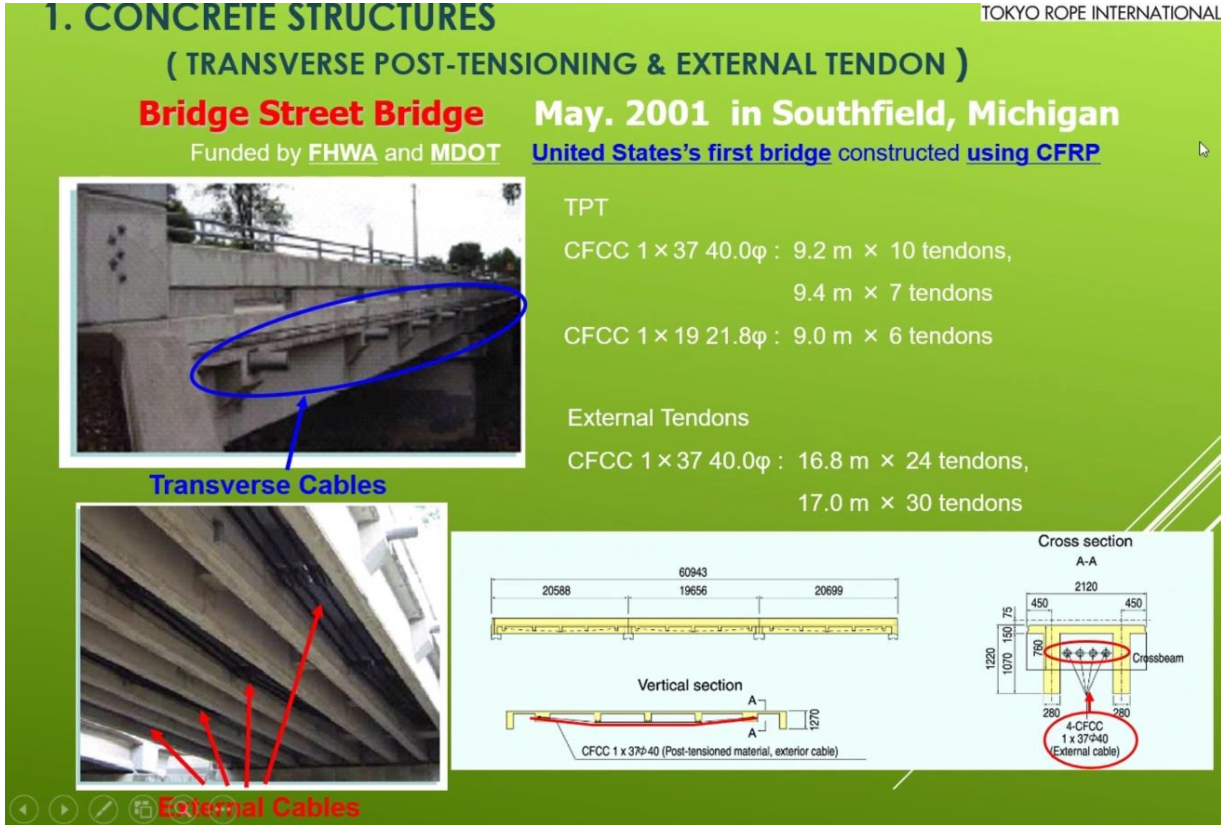
Way Way Back: CFRP Prestressing Strand

- CFCC: Developed in Japan with first prestressed bridge application in 1988



Way Back: CFRP Prestressing Strand

- CFCC: First USA bridge application in Michigan in 2001 – Post-Tensioning

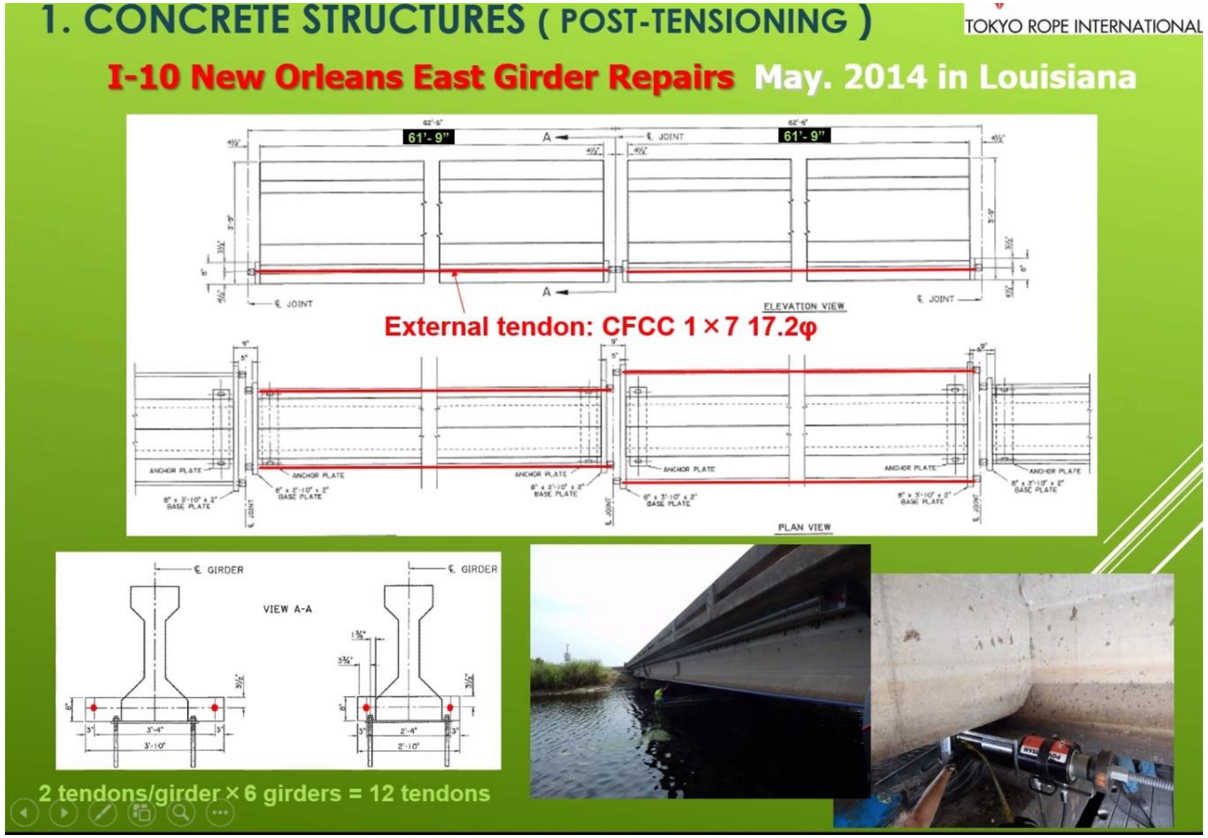


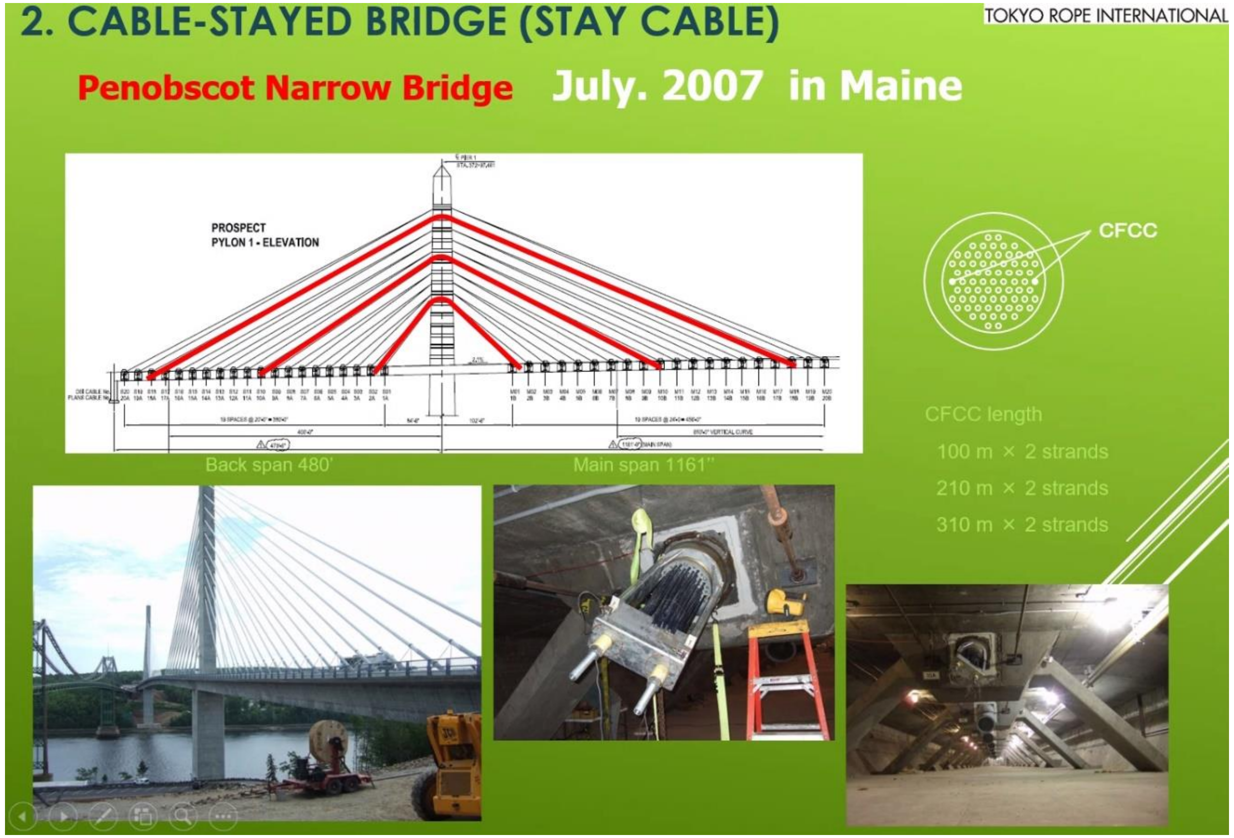
Back a Decade: CFRP Prestressing Strand

- 2012 (Maine) & 2012-13 (Virginia)

Back a Decade : CFRP Prestressing Strand

- 2014 (Louisiana) & 2016 (Maine)





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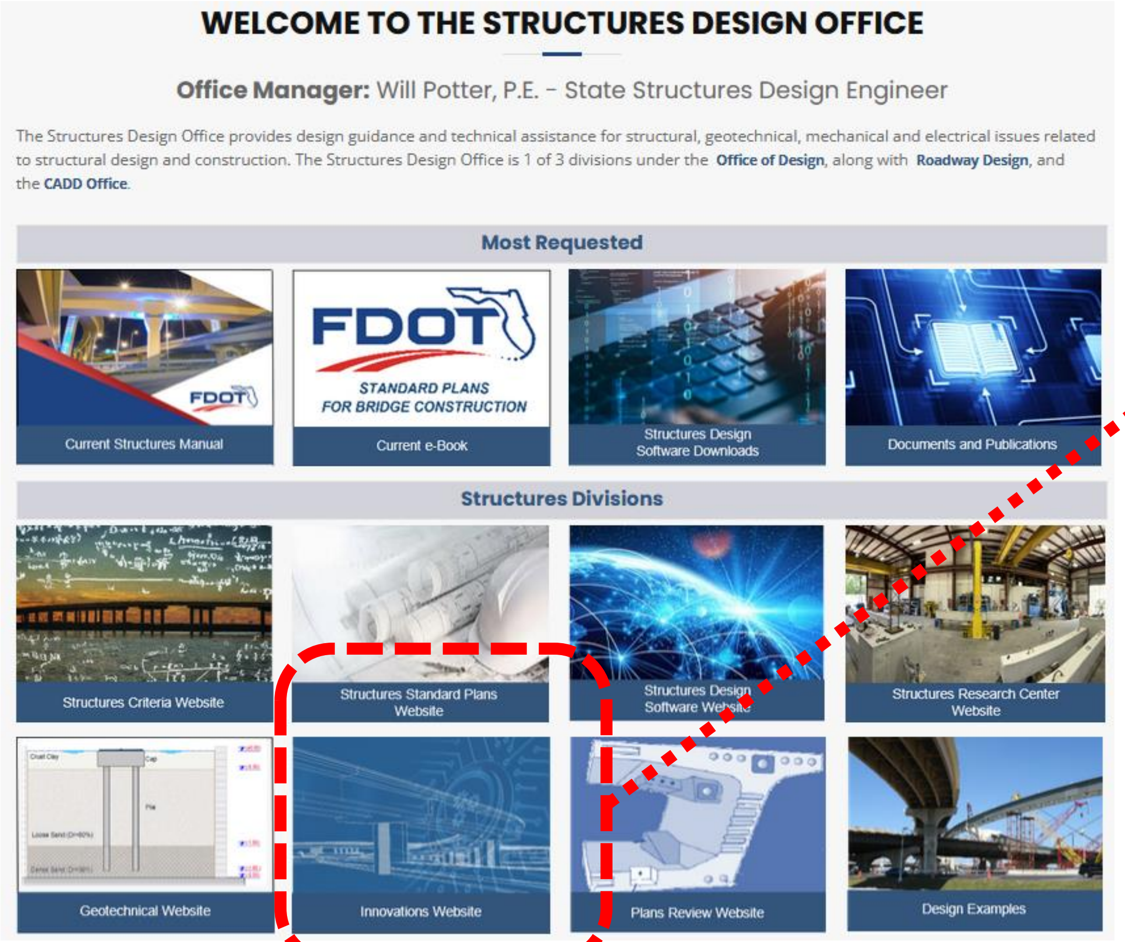
Back a Decade : Launched FRP Innovation Webpage

- 2014 FDOT (Invitation to Innovation)



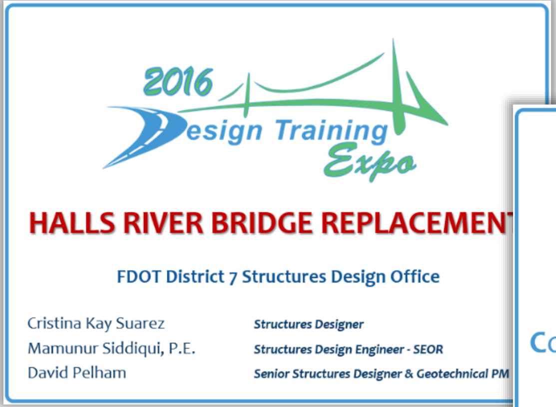
Fiber Reinforced Polymer Reinforcing

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 (T^2)
- FDOT Research
- Contact

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

CFRP Prestressing Strand & more… at FDOT



8/1/1992	Feasibility of Fiberglass Pretensioned Piles in a Marine Environment	Sen, Rajan (USF)
8/1/1995	Durability of CFRP Pretensioned Piles in Marine Environment Volume II	Sen, Rajan (USF)
11/30/1998	Studies on Carbon FRP (CFRP) Prestressed Concrete Bridge Columns and Piles in Marine Environment	Arockiasamy, M. (FAU)

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Design: Practices and Standards for FRP-RC/PC

2017 Design Training Expo VS.

FRP Reinforced Concrete Design

Presented in 2017 by: Rick Vallier, P.E.

Updates in 2024 by: Steven Nolan, P.E.

2017 vs. 2024 FRP Reinforced Concrete Outline

A. FRP Reinforcing Bars

B. Research

C. Structures Manual

~~D. Design Standards~~

~~E. Developmental Design Standards~~

~~E. Standard Specifications~~

~~F. Challenges~~

A. Reinforcing Bars

Spec. 932-4.2 Bar Sizes and Loads

Table 932-8
Sizes and Tensile Loads of FRP Reinforcing Bars

Bar Size Designation	Nominal Bar Diameter (in)	Nominal Cross Sectional Area (in^2)	Measured Cross-Sectional Area (in^2)		Minimum Guaranteed Tensile Load (kips)			
			Minimum	Maximum	BFRP & GFRP Bars (Type 0)	BFRP & GFRP Bars (Type III)	CFRP (Type II) Single & 7-Wire Strands	CFRP (Type I) Bars
2.1-CFRP	0.21	0.028	0.026	0.042	-	-	7.1	-
2	0.250	0.049	0.046	0.085	6.1	7.4	-	10.3
2.8-CFRP	0.280	0.051	0.048	0.085	-	-	13.1	-
3	0.375	0.11	0.104	0.161	13.2	16.0	-	20.9
3.8-CFRP	0.380	0.09	0.087	0.134	-	-	23.7	-
4	0.500	0.20	0.185	0.263	21.6	27.9	-	33.3
5	0.625	0.31	0.288	0.388	29.1	40.8	-	49.1
6	0.750	0.44	0.415	0.539	40.9	57.3	-	70.7
6.3-CFRP	0.630	0.19	0.184	0.242	-	-	49.8	-
7	0.875	0.60	0.565	0.713	54.1	75.8	-	-
7.7-CFRP	0.770	0.29	0.274	0.355	-	-	74.8	-
8	1.000	0.79	0.738	0.913	66.8	94.9	-	-
9	1.128	1.00	0.934	1.159	82.0	115.0	-	-
10	1.270	1.27	1.154	1.473	98.2	138.7	-	-
11	1.410	1.56	1.500	1.700	105.8	160.0	-	-

A. Reinforcing Bars

Characteristics of FRP Reinforcement:

- Polymer resin matrix relatively weak:
  - Bond force is transferred through resin to fibers.
  - Shear resistance is considered relatively weak *(~60%).*
- Low compressive strength of FRP:
  - Design contribution of FRP reinforcement to resist compression is ~~not recommended~~ ignored.
- Modulus of elasticity is low:
  - Due to lower stiffness (*6.5 msi & 8.7 msi*), serviceability often controls the design.
- Creep-rupture threshold is low (~~*25%*~~ *30%* f_u):
  - Sustained high tension can cause fibers to fail after a period of time
  - GFRP is considered more susceptible than CFRP (*70%* f_u).

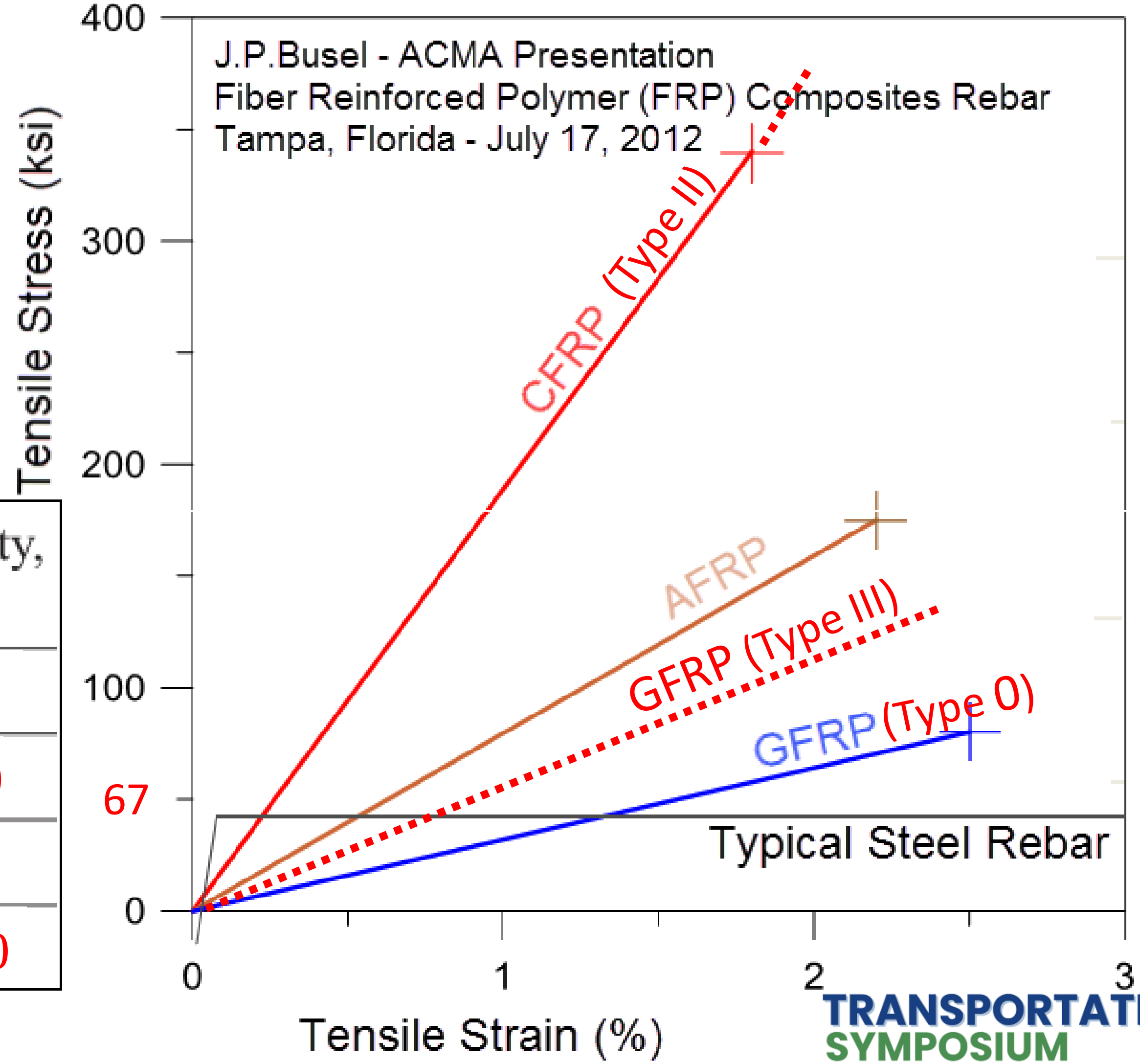
A. Reinforcing Bars

Characteristics of FRP Reinforcement:

- Linear Elastic to Failure
- No Yielding (but higher strain at 60 ksi)
- Higher Ultimate Strength
- Lower Strain at Failure

Bar type	Yield strength f_y or tensile strength f_{fu}, ksi	Modulus of elasticity, ksi
Steel	60	29,000
GFRP (Type 0)	80 to 120	~~6000~~ 6,500
~~AFRP~~ (Type III)	~~170~~ 105 to 150	~~12,000~~ 8,700
CFRP (Type II)	~~300~~	~~22,000~~ 22,480

From ~~ACI 440.1R-15~~ FDOT Spec 932-4, ASTM D7957 & D8505



TRANSPORTATION SYMPOSIUM

A. Reinforcing Bars

FRP Bar Mechanical Characteristics Influenced By:

Pre-Construction

- Manufacturing Process *(FDOT MM Chapter 12.1)*
- Rate of Curing
- Quality and Quantity of Constituents

Construction and Post-Construction

- Moisture *(current limitation on BFRP in submerged marine environments. See **FRPG** 2.1)*
- Ultraviolet Exposure *(Spec. 416 limits on exposure)*
- Elevated Temperature *(Fire < T_g)*
- Alkaline, Acidic, Saline Solutions *(C_E = 0.70)*

TRANSPORTATION SYMPOSIUM

A. Reinforcing Bars

Characteristics of FRP Reinforcement:

- Endurance time in fire or elevated temperature less than for steel for anchorage zones *(**ACI 440-H** is working on criteria):*
  - Reinforcement type, aggregate type, and concrete cover will influence fire performance
  - Tensile, compressive, and shear properties of the resin material diminish as temperature approaches the glass transition temp. (***Tg***)

Property	Test Method	Requirement
Glass Transition Temperature (Tg)	ASTM E1640 (DMA) or ASTM E1356 (DSC)	≥230°F ≥212°F

Specification 932-4 https://www.fdot.gov/programmanagement/specs.shtm

A. Reinforcing Bars

Characteristics of FRP Reinforcement:

- <u>Life cycle costs</u> ~~likely~~ lower where steel corrosion is a concern *(see HRB).*
- <u>SCMs</u> (HRPs) for corrosion protection are ~~may~~ not ~~be~~ needed:
  - Silica Fume
  - Metakaolin
  - Ultrafine Fly Ash
  - ~~Calcium Nitrite~~
- <u>Transportation costs</u> are lower and handling easier for FRP due to light weight *(~25%).*
- <u>Concrete cover</u> reduction is allowed *(see **FRPG** Table 2.2).*

A. Reinforcing Bars

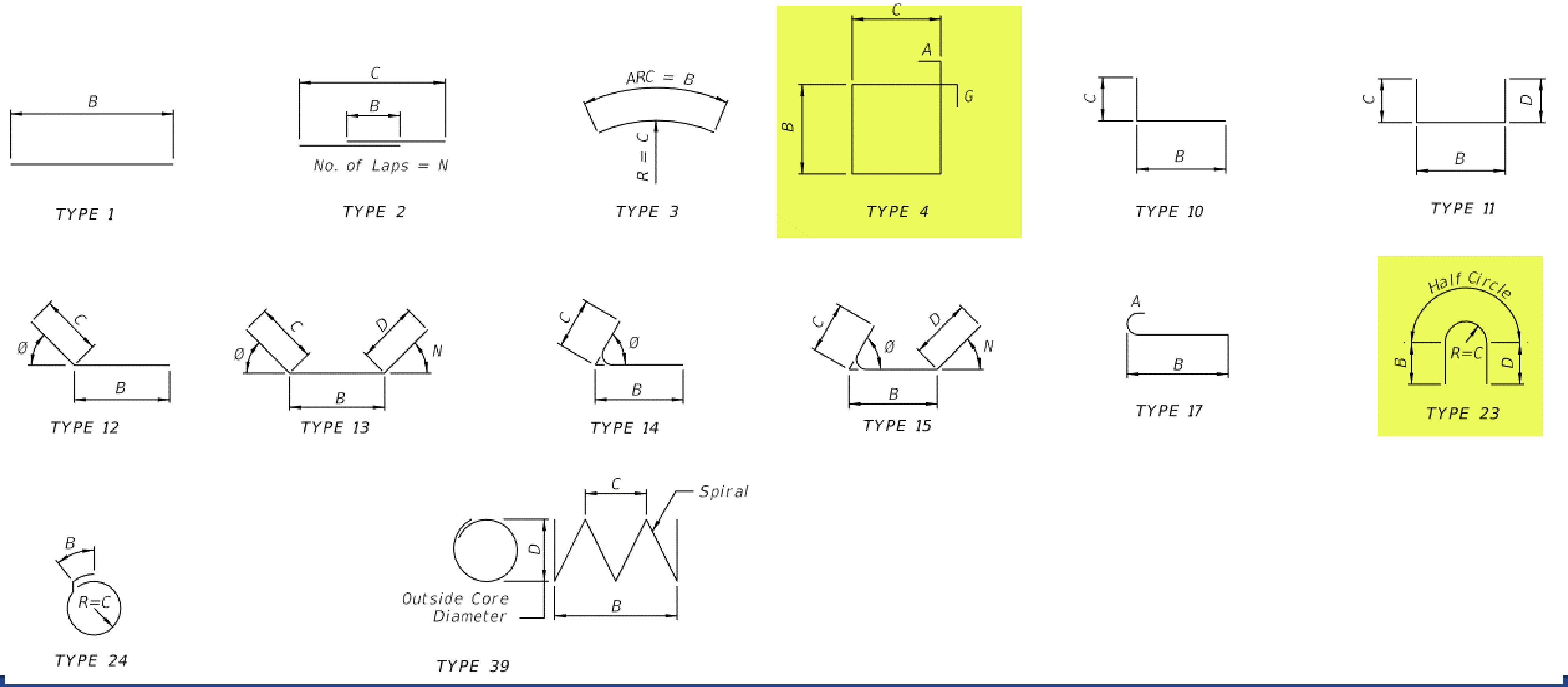
Bent Bars Characteristics:

- FRP is pultruded from thermoset resin *(viable thermoplastic resins are emerging)*
- FRP is fabricated with bends *(thermoplastic and olefin resin will allow controlled thermal bending – **NCHRP IDEA-207** validated this):*
  - Sharp bends can be manufactured, but avoided due to potential low stress failure.
  - Bend Radius / Bar Diameter ≥ 3.
  - Tail Length = 12 x Bar Diameter.
  - Field bending not permitted.
- ~~Developmental Design~~ ***Standard Plan Index 415-010*** ~~D21310~~ Bar Bending Details

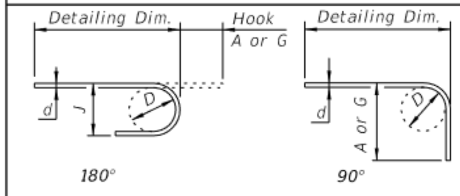
A. Reinforcing Bars

From ~~Developmental Design~~ Standard Plans Index ~~D21310~~ 415-010:

(renumbering to match steel bar bending Index)



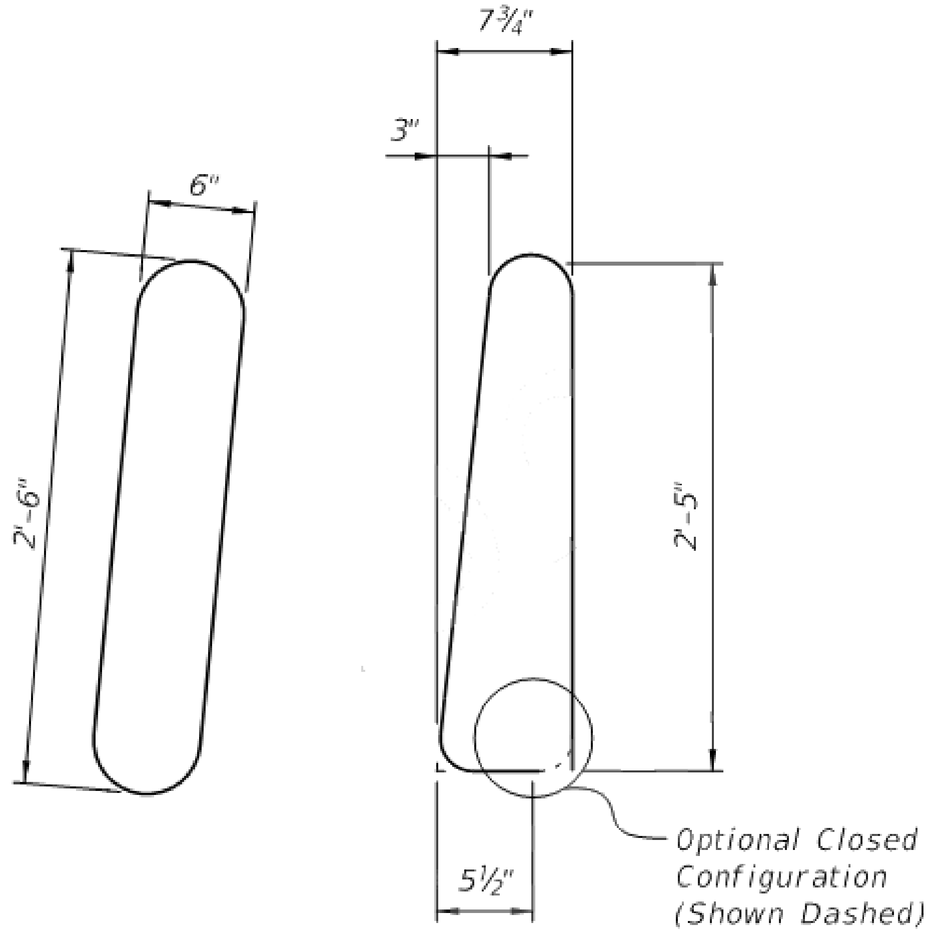
HOOK DETAILS

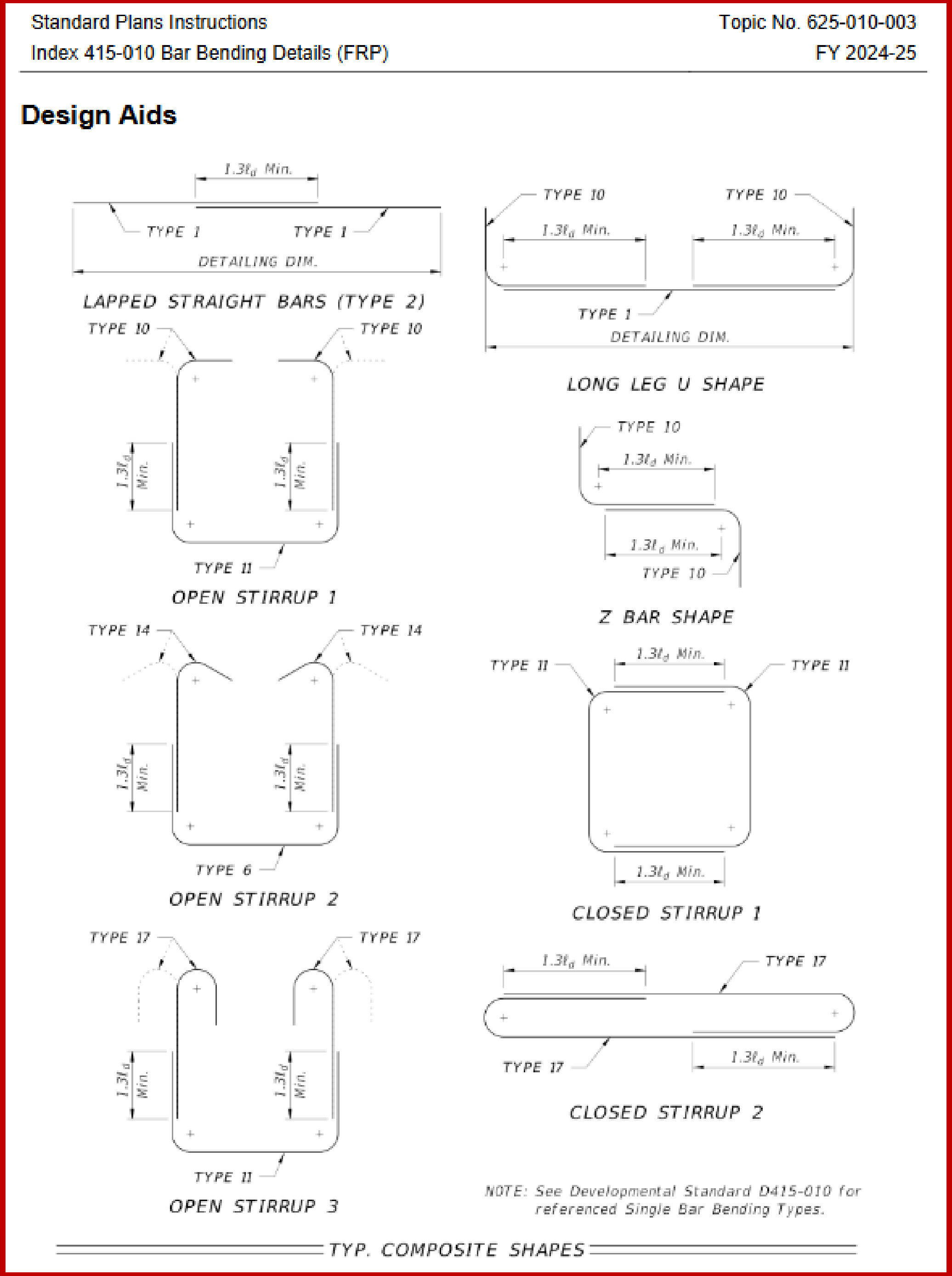


BAR SIZE	D	180° HOOKS A OR G	180° HOOKS J	90° HOOKS A OR G
#3	2¼"	5"	3"	6"
#4	3"	6"	4"	8"
#5	3¾"	7"	5"	10"
#6	4½"	8"	6"	1'-0"
#7	5¼"	10"	7"	1'-2"
#8	6"	11"	8"	1'-4"
STYLE		1		3

A. Reinforcing Bars

Complex Shapes:





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A. Reinforcing Bars

Cost Comparison (Installed Price)

Bar Size	Nominal Diameter	Average Unit Costs HRB (3-bids) / **		FDOT Structures Manual for BDR Cost Estimating / **	
		GFRP Bars 2016	GFRP Bars 2023	Grade 60 Steel	Stainless-Steel
#4	0.500"	$1.18 / LF	$1.90 / LF	$~~0.60~~ 1.11 / LF	$~~2.72~~ 5.25 / LF
#5	0.625"	$1.37 / LF	$2.29/ LF	$~~0.94~~ 1.74 / LF	$~~4.19~~ 8.09 / LF
#6	0.750"	$1.55 / LF	$2.71/ LF	$~~1.35~~ 2.51 / LF	$~~5.98~~ 11.54 / LF
#8	1.000"	$2.54 / LF	$4.04/ LF	$~~2.40~~ 4.45 / LF	$~~10.74~~ 20.73 / LF

Note: There is not 1:1 substitution of FRP for steel bars.
Black steel bar based on $1.67** ~~$0.90~~ / lb for all bar sizes.
Stainless steel bar based on $7.72** ~~$4.00~~ / lb for all bar sizes.

** 2023 FDOT Bid Avg.

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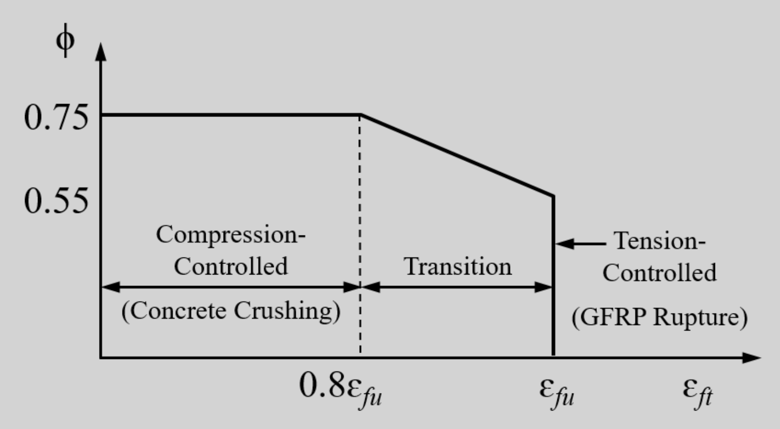
A. Reinforcing Bars

Flexural Strength Design Philosophy

Steel Reinforced Concrete Design

- Tension-Controlled Behavior
- Yielding of Steel Prior to Concrete Crushing Provides Ductility and Warning of Distress through extensive cracking and deformation



FRP Reinforced Concrete Design

- Tension-Controlled Behavior
  - FRP Rupture *(phi = 0.55)*
- Compression-Controlled Behavior
  - Concrete Crushing prior to FRP Rupture *(phi = ~~0.65~~ 0.75)*
- Margin of Safety is Higher than for Steel Reinforced Design

A. Reinforcing Bars

Design Assumptions

- Plane sections remain plane
- Flexural strength using equivalent rectangular concrete stress distribution
- Compressive strain in concrete assumed to be 0.003
- Tensile strength of concrete is ignored
- Perfect bond exists between concrete and FRP reinforcement
- Tensile behavior of FRP reinforcement is linear elastic until failure
- Compressive strength of FRP reinforcement is ignored

B. FDOT Research

Research and field implementation of FRP materials is ongoing and design recommendations continue to evolve and improved.

Completed	Title	Researcher	Institution	Research No.
Nov. 2018	**Performance Evaluation** of GFRP Reinforcing Bars Embedded in Concrete Under Aggressive Environments	R. Kampmann	FAMU-FSU	BDV30 977-18
April 2019	**Degradation Mechanisms** and **Service Life Estimation** of FRP Concrete Reinforcements	A. El Safty	UNF	BDV34 977-05
6/30/2019	Performance Evaluation of Basalt Fiber Reinforced Polymer (BFRP) Reinforcing Bars Embedded in Concrete	R. Kampmann	FAMU-FSU	BVD30 986-01
April 2022	Epoxy Dowel Pile Splice Evaluation with FRP Bars	A. Mehrabi	FIU	BDV29 977-52
Dec. 2020	"Stainless Steel Strands and Lightweight Concrete for Pretensioned Concrete Girders" (w/ GFRP shear stirrups)	M. Roddenberry	FAMU-FSU	BDV30 977-27 (Report A)
07/30/2022	Improving Testing Protocol and Material Specifications for Basalt Fiber Reinforced Polymer Bars	R. Kampmann	FAMU-FSU	BE694

B. FDOT Research - Completed and In-progress

Research and field implementation of FRP materials is ongoing and expanding…

Completion Date	Title	Researcher	Institution	Research No.
08/29/2022	Development of GFRP Reinforced Single Slope Bridge Rail	G. Consolazio	UF	BDV31 977-110
12/31/2023	Evaluation of Glass Fiber Reinforced Polymers (GFRP) Spirals in Corrosion Resistant Concrete Piles	S. Jung	FAMU-FSU	BDV30 977-27
Feb. 2025	FSBs With Stainless Steel Strands and GFRP Shear Reinforcement	M. Roddenberry	FAMU-FSU	BED30 977-09
April 2025	*Waterline Pile Cap Footings for Bridges using Large Diameter FRP Reinforcing – Material Characterization and Design*	A. Nanni	UM	BEE76 977-01
May 2025	*HRB Extraction and Physio-Mechanical Testing of FRP Reinforcing Bars from 5-year-old Seawater Concrete Test Blocks on Halls River Bridge Bulkhead*	F. De Caso	UM	BEE76 977-02

C. FDOT Structures Manual

FDOT Design Criteria for FRP:

Vol. 1 – SDG

- Bearing Piles – 3.5
- Fender Systems – 3.14
- Structural FRC– 3.17
- BDR Cost Estimating – 9.2
  - Bearing Piles
  - Sheet Pile

Vol. 2 – SDM

- Fender Systems – 24

Vol. 4 – FRPG

- Reinforcing Bars – 2
- Strands – 3
- Strengthening – 4
- Pultruded Shapes – 5
- VIP Shapes – 6
- Thermoplastic Shapes – 7

C. FDOT Structures Manual

FDOT Design Criteria for using FRP Composites:

The Structures Manual implements ***basic design guidelines*** for FRP composites in specific applications.

As is the case with all structural materials, the engineer must practice the ***appropriate standard of care*** when designing components using FRP composites.

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C. FDOT Structures Manual

Volume 4 - Fiber Reinforced Polymer Guidelines *(FRPG)*

Unless otherwise stated within the ***FRPG***, the **use of FRP composites requires approval** of the State Structures Design Office.

Obtain concept approval before proceeding with any design effort.

After concept is approved, submit the design to the State Structures Design Office for review.

FDM 121.3.2: *"Any component designed using Fiber Reinforced Polymer (FRP) composite materials except components in the Standard Plans"* is designated as **Category 2 Structure.**

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C. FDOT Structures Manual

Volume 4 - Fiber Reinforced Polymer Guidelines *(FRPG)* – Section 2:

Permitted use ~~when approved by the SSDE:~~

- Approach Slabs
- Bridge Decks & Bridge Overlays
- Cast-in-Place Flat Slab Superstructure
- Pile Bent Caps ~~not in direct contact with water~~
- Pile Jackets
- Pier Columns and Caps ~~not in direct contact with water~~
- Retaining Walls, Noise Walls, Perimeter Walls
- ~~Traffic Railings~~
- Pedestrian/Bicycle Railings
- Bulkheads and Bulkhead Copings
- MSE Wall Panels and Copings
- Drainage Structures
- Dowel Bars for Exp. Joints

Note: Other locations will be considered on a case-by-case basis.

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C. FDOT Structures Manual

FDOT Structures Manual – Vol. 4 FRPG 2.3

Concrete Cover Requirements in Extremely Aggressive Environments

Component	FRP Cover Requirements	Steel Cover Requirements
External Surface Cast Against Earth	3 in.	4.5 in.
Box Culverts	~~2.5~~ 2 in.	3 in.
C.I.P. Cantilever Retaining Walls	~~2.5~~ 2 in.	3 in.
MSE Walls	~~2~~ 1.5 in.	3 in.
Bulkheads and Sheet Pile Caps	~~3~~ 2 in.	4 in.

See ***FDOT Structures Manual*** for cover requirements for other components.

http://www.fdot.gov/structures

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C. FDOT Structures Manual

GFRP/CFRP Reinforcing Bars – Section 2 – Design Criteria

Design **concrete members** with FRP reinforcement according to:

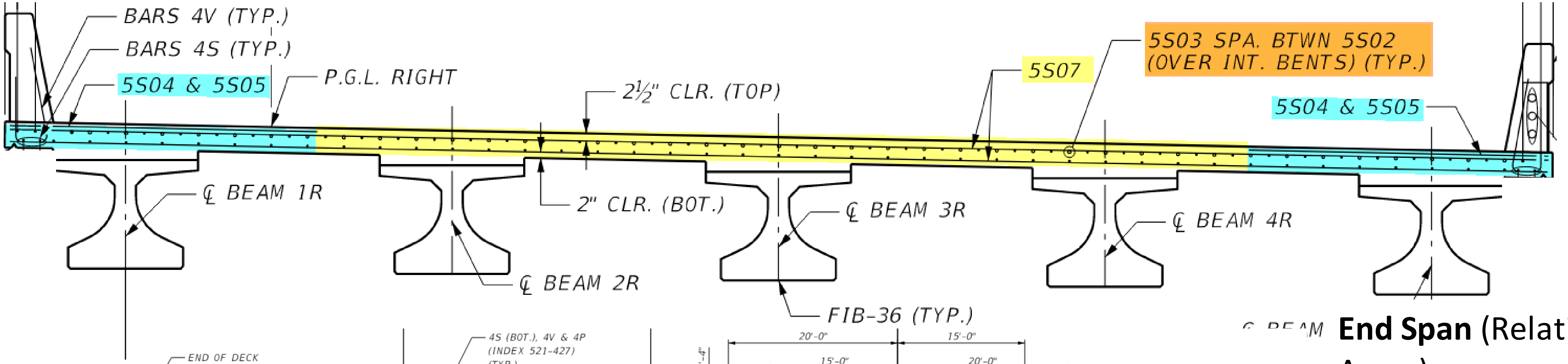
- *AASHTO LRFD Bridge Design Guide Specifications for GFRP-Reinforced Concrete ~~ACI 440.1 Guide for the Design and Construction of Structural Concrete Reinforced with FRP Bars.~~*
- *AASHTO Guide Specification for the Design of Concrete Bridge Beams Prestressed with CFRP Systems. ~~ACI 440.4 Prestressing Concrete Structures with FRP Tendons~~*

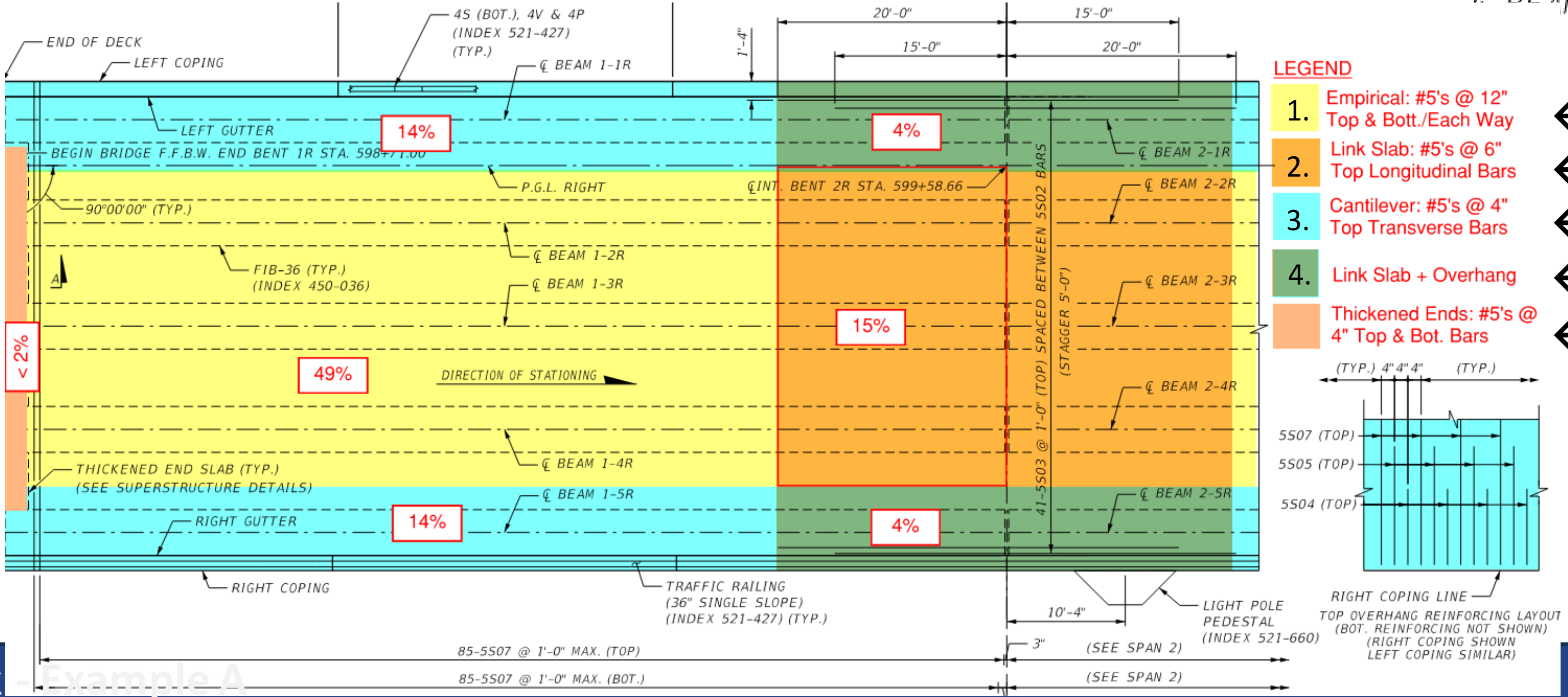
Design **Bridge Decks** according to:

- *AASHTO LRFD Bridge Design Guide Specifications for GFRP-Reinforced Concrete ~~Bridge Decks and Traffic Railings~~ (2nd Edition)*

*Use FRP **Mechanical Properties** per FDOT Section 932-4.*

Comparison of Rebar Qty. – Bridge Deck Example A





End Span (Relative Areas):

- ← 49%
- ← 15%
- ← 28%
- ← 8%
- ← Ignore <2%

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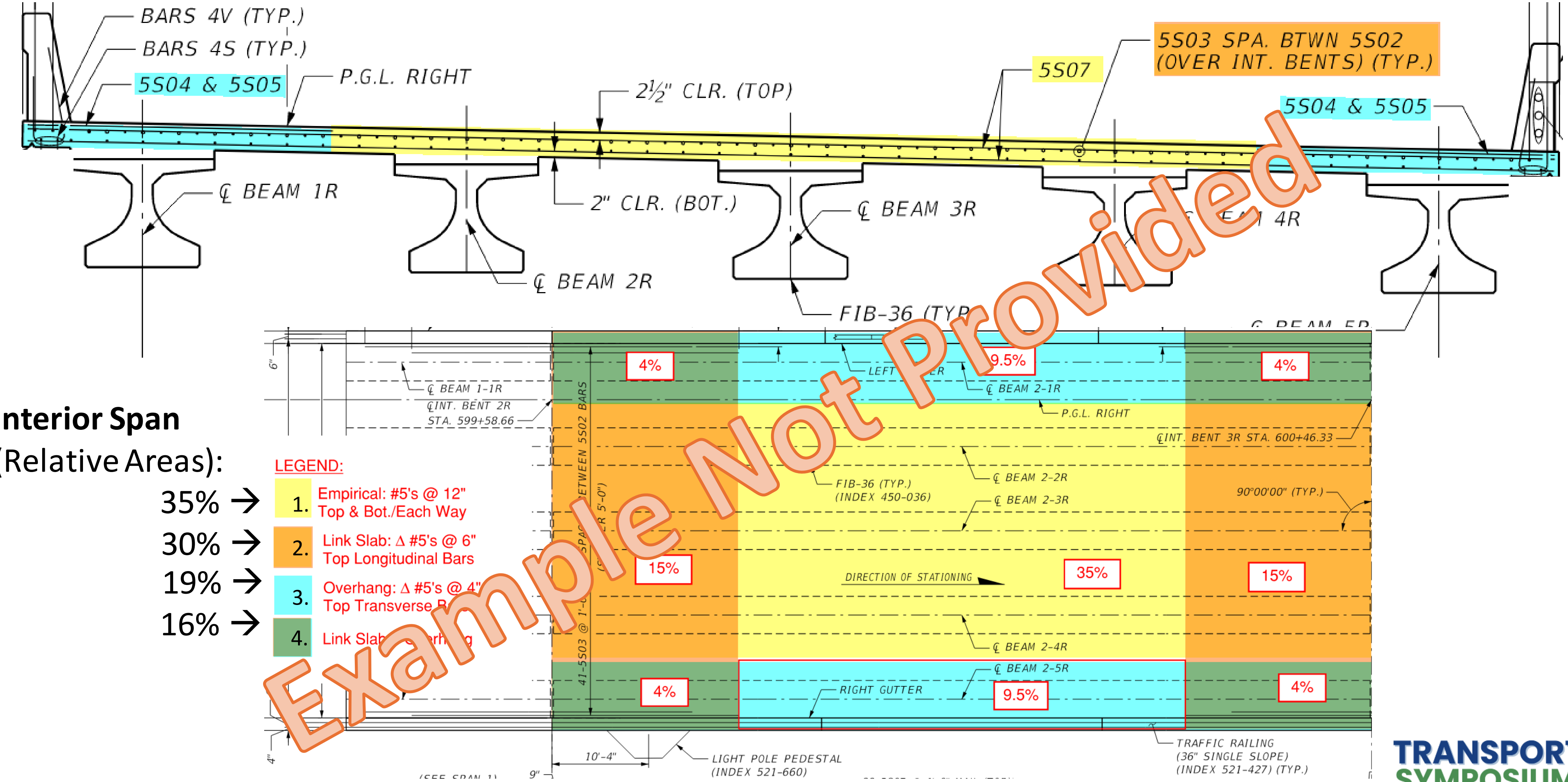
Comparison of Rebar Qty. – Bridge Deck Example B

Interior Span
(Relative Areas):

35% →
30% →
19% →
16% →



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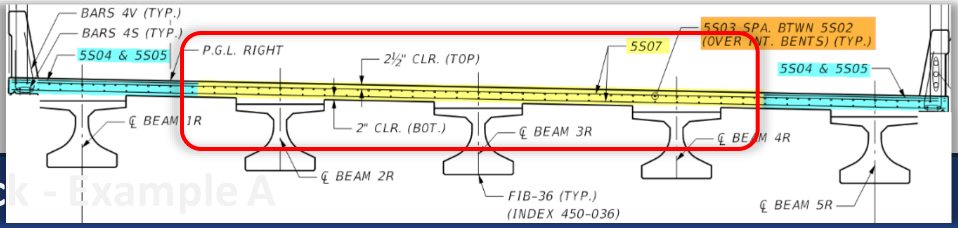
Comparison of Material Qty. – Deck Area 1 (Example A)

Convention CS-RC *(ASTM A615):*

- Thickness = *8”*
- Concrete Cover = *2”*
- Flexural Depth (#5’s) *d = 5.7”*
- Empirical ***(AASHTO-BDS)***: Bottom layers = *#5’s @ 13.8” (0.27 in²/ft)*; Top layers = *#4’s @ 13.3” (0.18 in²/ft)*
- Empirical ***(FDOT)***: *#5’s @ 12”* **
- Total Rebar ***(AASHTO)***: $A_s = 0.90\ in^2/ft^2$;
  (FDOT): $A_s = 1.24\ in^2/ft^2$

GFRP-RC *(ASTM D8505-23):*

- Thickness = *7”* → $\Delta_{vol.} = -12\%$; $\Delta_{weight} = -15\%$
- Concrete Cover = *1”*
- Flexural Depth (#5’s) *d = 5.7”*
- Empirical ***(AASHTO-GSG)***: ** Bottom transverse layer = *#5’s @ 6.5” (0.83%)* Other 3-layers = *#5’s @ 12” (0.35%)*
- Total Rebar: $A_f = 1.50\ in^2/ft^2$ *deck)*
  → Δ_{volume} ***(AASHTO)*** = *+67%*; $\Delta_{weight} = -58\%$
  → Δ_{volume} ***(FDOT)*** = *+21%*; $\Delta_{weight} = -70\%$



Interior Section

TRANSPORTATION SYMPOSIUM

*** Minimum bar size and spacing governs*

Comparison of Material Qty. – Deck Area 2 (Example A)

Convention CS-RC *(ASTM A615):*

- Thickness = *8"*
- Concrete Cover = *2"*
- Flexural Depth (#5's) *d = 5.7"*
- Empirical: ***(AASHTO)***: Bottom layers = #5's @ *13.8"* *(0.27 in²/ft)*; Top transverse = #4's @ 13.3" *(0.18 in²/ft)*; + Top long. = *#5's @ 6"* *(0.62 in²/ft)*
- Empirical: ***(FDOT)***: *3-layers @ #5's @ 12"* ** *(0.31 in²/ft)*;
- Total Rebar ***(AASHTO)***: $A_s = 1.34\ in^2/ft^2$
  (FDOT): $A_s = 1.55\ in^2/ft^2$

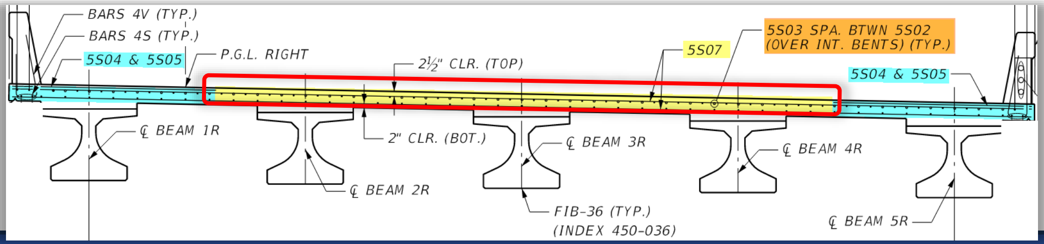
GFRP-RC *(ASTM D8505-23):*

- Thickness = *7"* → $D_{vol.} = -12\%$; $D_{weight} = -15\%$
- Concrete Cover = *1"*
- Flexural Depth (#5's) *d = 5.7"*
- Empirical ***(FDOT/AASHTO-GSG)***: **Bottom transverse = *#5's @ 6.5"* *(0.83% = 0.57 in²)*; Other *2-layers = #5's @ 12"* *(0.35% = 0.31 in²)*; + Top long. = *#5's @ 6"* *(0.62 in²/ft)*
- Total Rebar: $A_f = 1.81\ in^2/ft^2$

→ $\Delta_{vol.}$ ***(AASHTO)*** $= +35\%$; $\Delta_{weight} = -66\ \%$

→ $\Delta_{vol.}$ ***(FDOT)*** $= +17\%$; $\Delta_{weight} = -71\ \%$

Link-Slab Section



TRANSPORTATION SYMPOSIUM

** *Minimum bar size and spacing governs*

Comparison of Material Qty. – Deck Area 3 (Example A)

<u>Convention CS-RC</u> *(ASTM A615):*

- Thickness = *8”*
- Concrete Cover = *2”*
- Flexural Depth (#5’s) *d = 5.7”*
- Empirical ***(AASHTO-BDS)***: 2~Bot. layers = #5’s @ *13.8” (0.27 in²/ft)*; Top long. = #4’s @ 13.3” *(0.18 in²/ft)*; Top transv. = #4’s + #5’s @ 4” *(0.82 in²/ft)*.
- Empirical ***(FDOT)***: 3-layers #5’s @ 12” ** *(0.31 in²/ft)*; Top Tranv. = #5’s @ 4” *(0.93 in²/ft)*.
- Total Rebar ***(AASHTO)***: $A_s = 1.54\ in^2/ft^2$;
  (FDOT): $A_s = 1.86\ in^2/ft^2$.

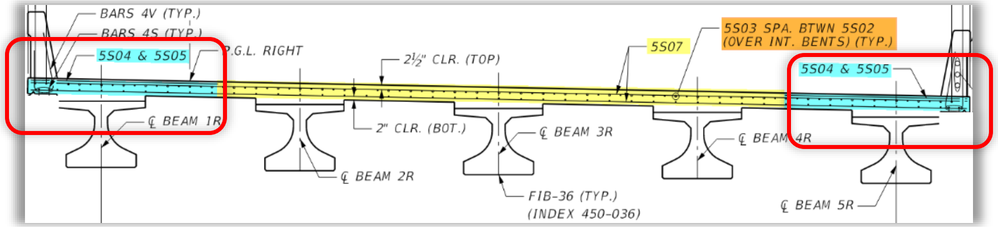
<u>GFRP-RC</u> *(ASTM D8505-23):*

- Thickness = *7”* → $\Delta_{vol.} = 88\%$; $\Delta_{weight} = 85\%$
- Concrete Cover = *1”*
- Flexural Depth (#5’s) *d = 5.7”*
- Empirical ***(AASHTO-GSG)***: Bot. ** transv. = *#5’s @ 6.5” (≥0.83% = 0.57 in²)*; 2~long. layers = *#5’s @ 12” (≥ 0.35% = 0.31 in²)*; Top transv. = *#5’s @ 4” (0.93 in²/ft)*.
- Total Rebar: $A_f = 2.12\ in^2/ft^2$ *deck)*

→ Δ_{volume} **(AASHTO)** = +38%; $\Delta_{weight} = -66\ \%$

→ Δ_{volume} **(FDOT)** = +14%; $\Delta_{weight} = -72\ \%$

Overhangs (midspan)



TRANSPORTATION SYMPOSIUM

*** Minimum bar size and spacing governs*

Comparison of Material Qty. – Deck Area 4 (Example A)

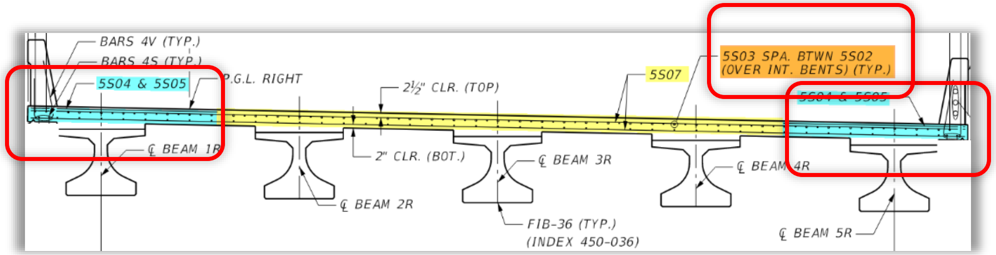
Convention CS-RC *(ASTM A615):*

- Thickness = *8"*
- Concrete Cover = *2"*
- Flexural Depth (#5's) *d = 5.7"*
- Empirical Overhang + Link-Slab ***(AASHTO-BDS)***: 2~Bot. layers = #5's @ *13.8" (0.27 in²/ft)*; Top long. = #4's & #5's @ 6.7" *(0.46 in²/ft)*; Top transv. = #4's + #5's @ 4" *(0.82 in²/ft)*.
- Empirical-Link ***(FDOT):*** 2~Bot. layers #5's @ 12" ** *(0.31 in²/ft)*; Top Tranv. = #5's @ 4" *(0.93 in²/ft)*. Top. long. = #5's @ 6" *(0.62 in²/ft)*.
- Total Rebar ***(AASHTO):*** $A_s = 1.82\ in^2/ft^2$;
  (FDOT): $A_s = 2.17\ in^2/ft^2$.

GFRP-RC *(ASTM D8505-23):*

- Thickness = *7"* → $\Delta_{vol.} = -12\%$; $\Delta_{weight} = -15\%$
- Concrete Cover = *1"*
- Flexural Depth (#5's) *d = 5.7"*
- Empirical Overhang + Link-Slab ***(AASHTO-GSG)***: Bot. ** transv. = *#5's @ 6.5" (≥0.83% = 0.57 in²)*; Bot. long. = *#5's @ 12" (≥ 0.35% = 0.31 in²)*; Top transv. = *#5's @ 4" (0.93 in²/ft)*. Top long. = *#5's @ 6" (0.62 in²)*
- Total Rebar: $A_f = 2.69\ in^2/ft^2$ *deck)*
  → Δ_{volume} **(AASHTO)** = +48%; $\Delta_{weight} = -67\ \%$
  → Δ_{volume} **(FDOT)** = +24%; $\Delta_{weight} = -69\ \%$

Overhangs @ Link-Slab



TRANSPORTATION SYMPOSIUM

*** Minimum bar size and spacing governs*

Comparison of Material Quantities – Example A Summary

Convention CS-RC *(ASTM A615):*

- **Example A** (End Span Rebar)
  - Empirical (AASHTO): As= 0.49*0.90 + 0.15*1.34 + 0.28*1.54 + 0.08*1.82 = **1.22 in^2/ft^2**
  - Empirical (FDOT): A_s = 0.49*1.24 + 0.15*1.55 + 0.28*1.86 + 0.08*2.17 = **1.53 in^2/ft^2**

GFRP-RC *(ASTM D8505-23):*

- **Example A** (End Span Rebar)
  - Empirical (both): As= 0.49*1.50 + 0.15*1.81 + 0.28*2.12 + 0.08*2.69 = **1.82 in^2/ft^2**

*Concrete → $\Delta_{vol.}$ **(AASHTO)** = -12%; Δ_{weight} = -15% for GFRP-RC*

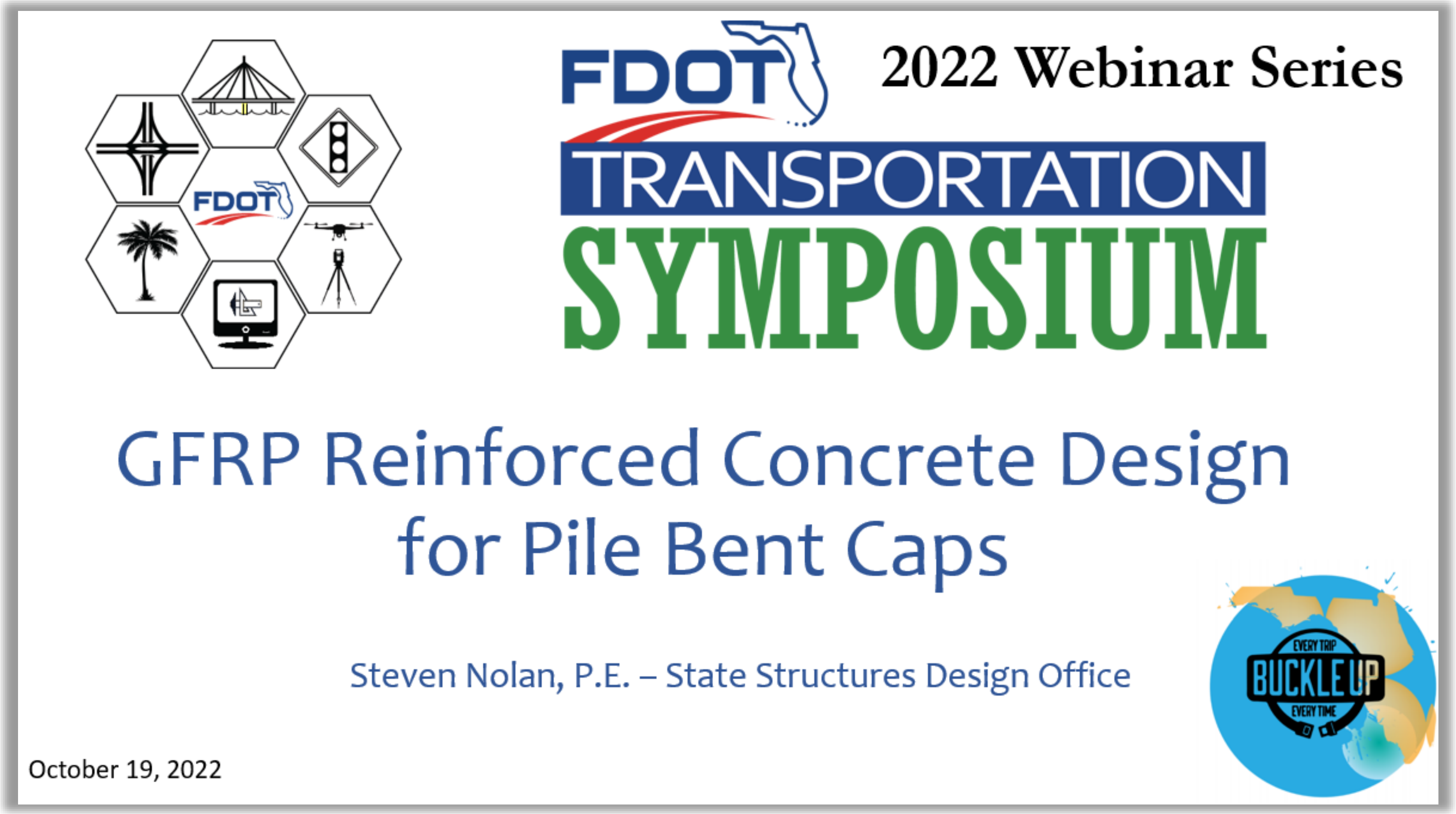
*Rebar → Δ_{volume} **(AASHTO)** = +49%; Δ_{weight} = -63 %.*

*Rebar → Δ_{volume} **(FDOT)** = +19%; Δ_{weight} = -70 %.*

TRANSPORTATION SYMPOSIUM

*** Minimum bar size and spacing governs*

Comparison of Rebar Qty. – Pile Bent Cap Example C

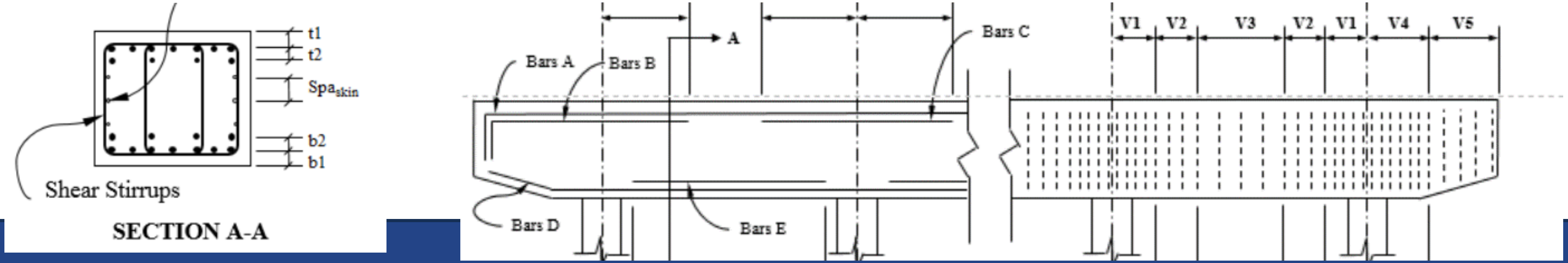


10/20/2022	GFRP Reinforced Concrete Design for Pile Bent Caps	Presentation

Design Example for Pile Bent Cap Summary

- **Comparison of different design alternates for 5-piles @ 9-ft spacing (Example 1) – Higher Modulus GFRP Rebar (Ef = 6,500 psi to 8,700 psi for future enhancements to ASTM D7957)**

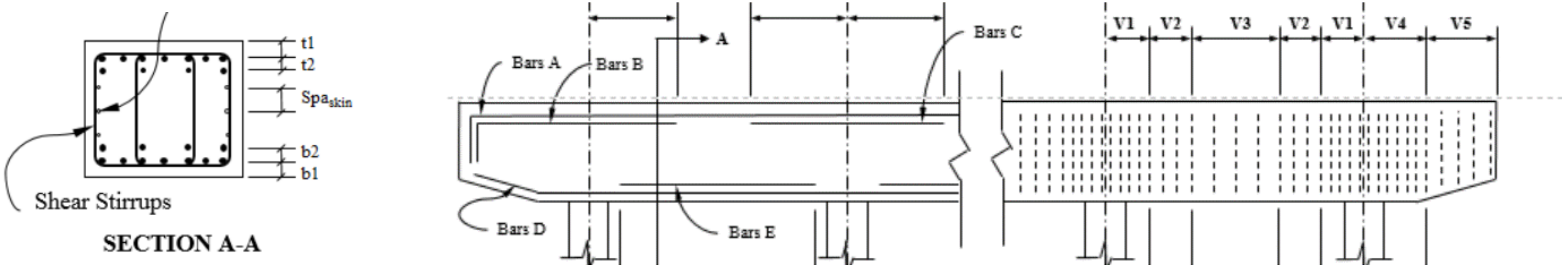
Rebar Location	GFRP-RC (Type 0) 3-ft Deep Cap (E_f = 6,500 ksi)	GFRP-RC 3-ft Deep Cap (E_f = 7,250 ksi)	GFRP-RC (Type III) 3-ft Deep Cap (E_f = 8,700 ksi)
Bars A - Flexural Top	**6 ~ #8's** (A_f = 4.7 in^2)	**7 ~ #7's** (A_f = 4.2 in^2)	**6 ~ #7's** (A_f = 3.6 in^2)
Bars D & E - Flexural Bottom	**8 ~ #8's** (A_f = 6.3 in^2)	**7 ~ #8's** (A_f = 5.5 in^2)	**6 ~ #8's** (A_f = 4.7 in^2)
Bars V3 - Shear Stirrups	**4-legs #5 at 11" sp.** (A_f = 1.4 in^2/ft)	**4-legs #5 at 13" sp.** (A_f = 1.1 in^2/ft)	**4-legs #4 at 10" sp.** (A_f = 1.0 in^2/ft)



Design Example for Pile Bent Cap Summary

- **Comparison of different design alternates for 5-piles @ 9-ft spacing (Example 1)**

Rebar Location	GFRP-RC (Type 0) 3-ft Deep Cap	Δ_{volume} *Type 0 or (Type III)*	Steel-RC 3-ft Deep Cap
Bars A - Flexural Top	**6 ~ #8's** (A_f = 4.7 in^2)	*+80% or (+38%)*	**6 ~ #6's** (A_s = 2.6 in^2)
Bars D & E - Flexural Bottom	**8 ~ #8's** (A_f = 6.3 in^2)	*+50% or (+12%)*	**7 ~ #7's** (A_s = 4.2 in^2)
Bars V3 - Shear Stirrups	**4-legs #5 at 11" sp.** (A_f = 1.4 in^2/ft)	*+75% or (+25%)*	**4-legs #4 at 12" sp.** (A_s = 0.8 in^2)



TRANSPORTATION SYMPOSIUM

Construction: Example Projects & Lessons Learned

Projects with Fast-Facts Sheet

- 4th St North over Big Island Gap (D7) – ***In-house Design.***
- 40th Ave NE over Placido Bayou (D7)
- Arthur Drive over Lynn Haven Bayou (D3)
- Bakers Haulover Cut Bulkhead Replacement (D6)
- Bimini Dr Bridge on Duck Key (D6)
- Cedar Key Bulkhead Rehab (D2)
- Halls River Bridge (D7) – ***In-house Design.***
- Key West Bight Ferry Terminal Extension (D7)
- NE 23rd Ave over Ibis Waterway (D6)
- PortMiami Tunnel Retaining Walls (D6)
- South Maydell Dr over Palm River (D7)
- SR-A1A Flagler Beach Seawall (Segment 3) (D5)
- SR-A1A over Myrtle Creek and Simpson Creek (D2)
- SR-5 (US-17) over Trout River (D2)
- SR-5 (US 41) over Morning Star and Sunset Waterways (D1)
- SR-30 over St Joe Inlet (D3)
- SR-45 (US 41) over North Creek (D1)
- SR 112/I-195 Over Westshore Waterway (D5)
- SR-312 over Matanzas River (D2)
- SR-520 over Indian River Bulkhead Rehab (D5)
- Sunshine Skyway Seawall Rehabilitation (D7)
- UM Innovation Bridge
- UM Fate Bridge
- UM I-Dock
- US-1 over Cow Key Channel (D6)

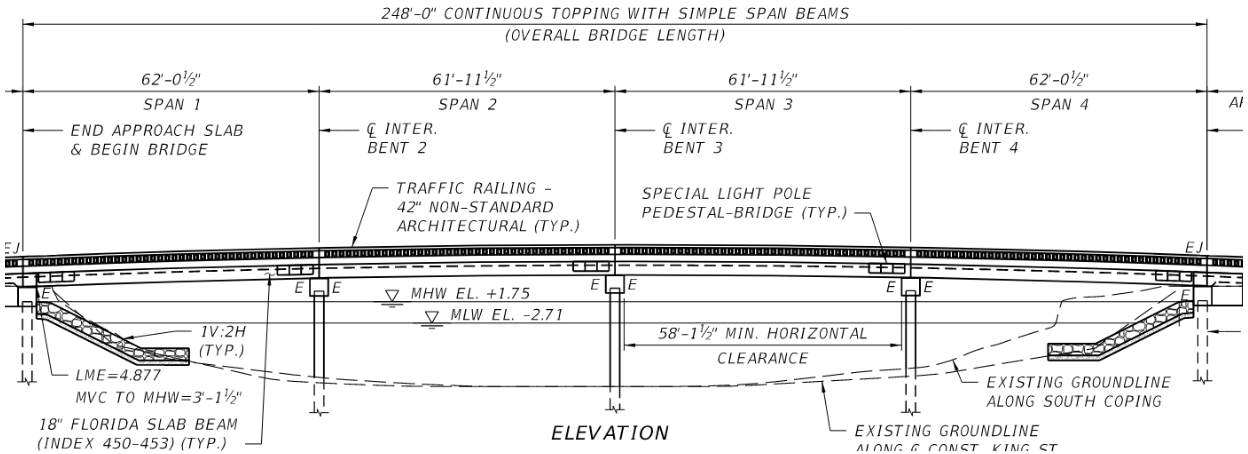
Upcoming Bridge and Seawall Projects

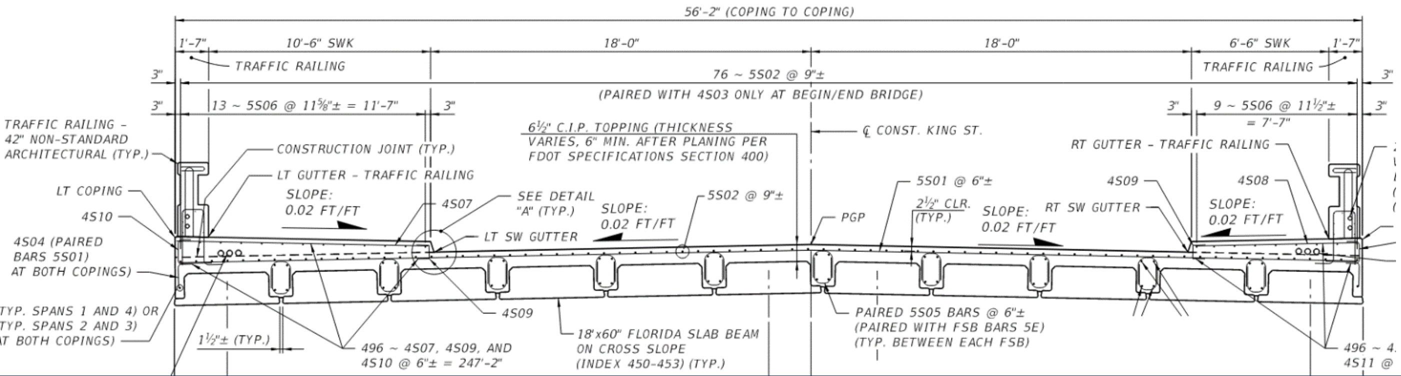
- D2: US1/King St over San Sebastian River (437428-1)
- D2: St. Augustine A1A/Avenida Menendez Seawall replacement (428271-2)
- D2: CR 357 over Shired Creek (437402-1)
- D3: CR30A over Western Lake (443331-1)
- D3: CR30B/Indian Lagoon (441185-2)
- D3: CR 372/Surf Road over Otter Creek Rise (442951-1)
- D4: US 1/Jupiter Federal Observation Platform (428400-2)
- D4: SR-A1A North Causeway Bridge Observation Platform (429936-2)
- D4: 17th St/Indian River, East End-Vero (446106-2)
- D4: SR 5/US 1 Over Earman River (442891-1) – ***In-house Design.***
- D5: SR-A1A Seawalls - Flagler Beach & Nth Volusia Co. (452443-1 & 452444-1)
- D5: Barracuda Blvd New Smyrna (437935-1) – ***In-house Design.***
- D5: 5th Street over Yacht Club Cut (437936-1)
- D5: US1 over Pellicer Ck (447118-1)
- D6: FKOSH Bridge Replacement… (448206-1 & (448207-1)

TRANSPORTATION SYMPOSIUM

Future Construction: D2 Example Projects

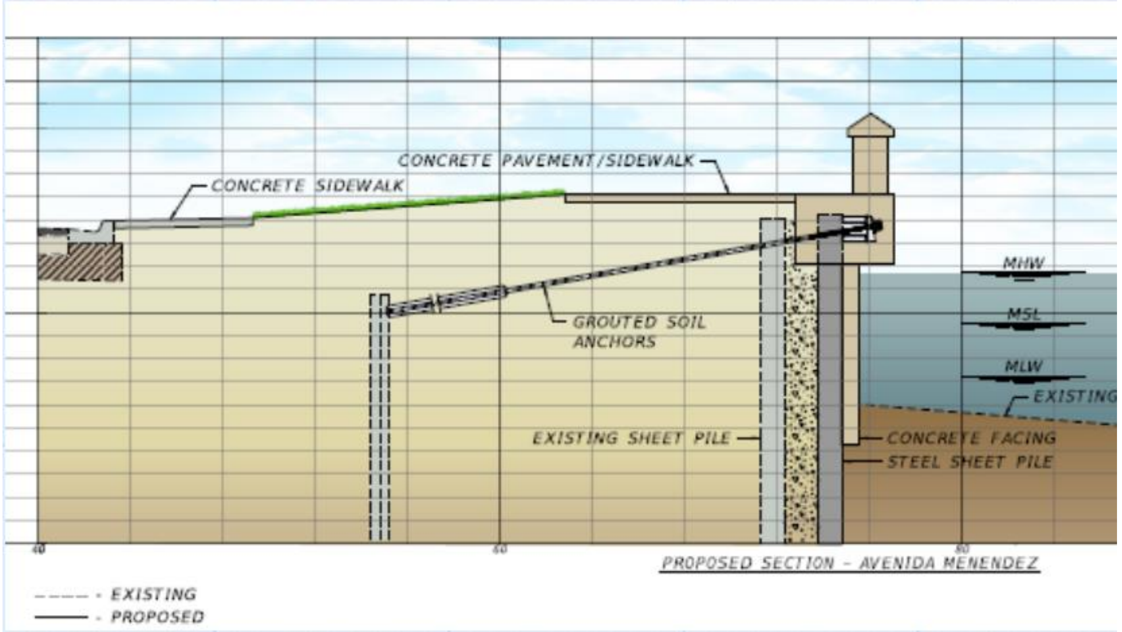
- US1/King St over San Sebastian River (437428-1)





- St. Augustine A1A/Avenida Menendez Seawall Replacement (428271-2)

Figure 2 - Proposed Bulkhead Typical Section



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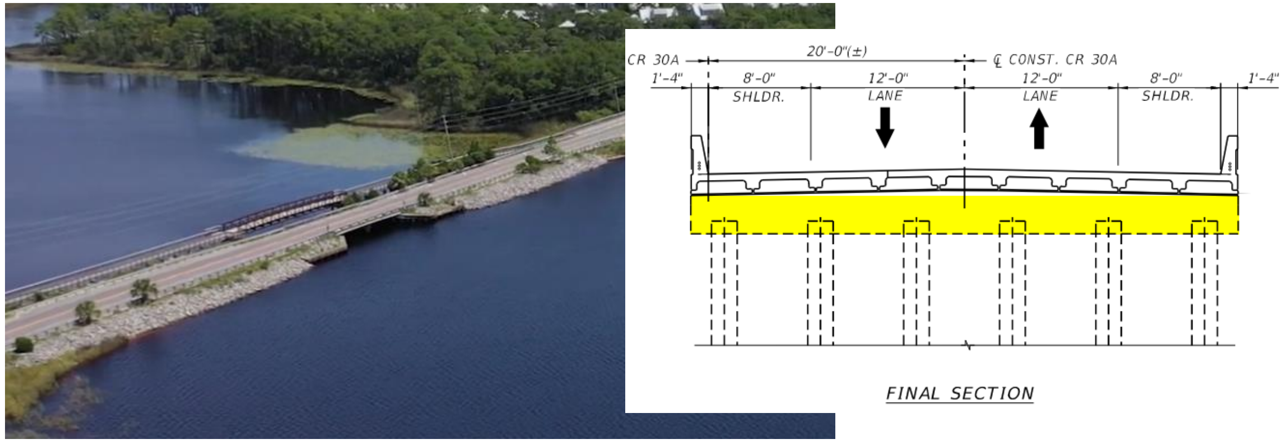
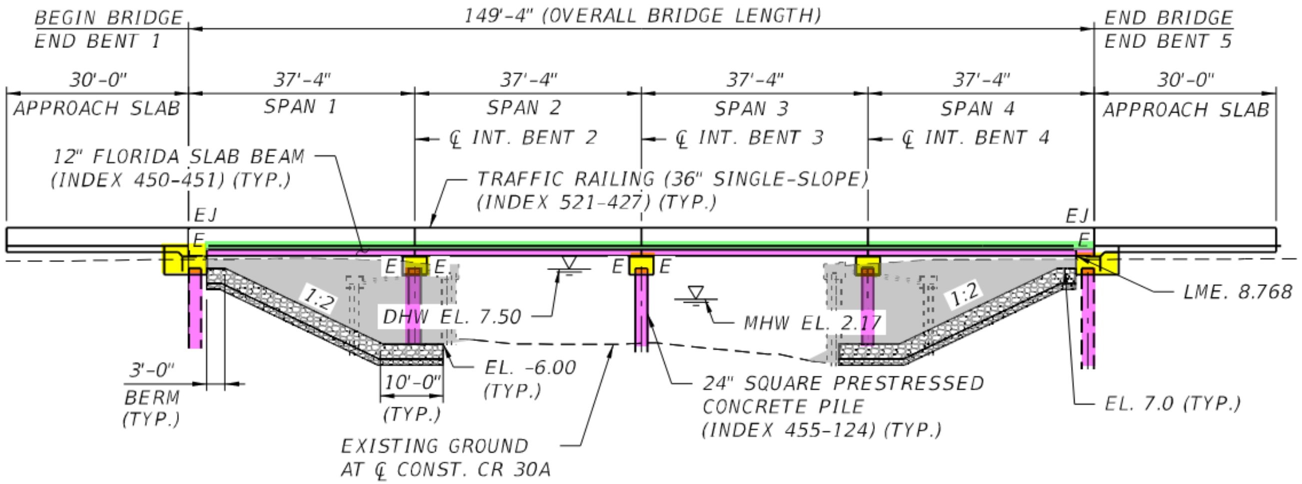
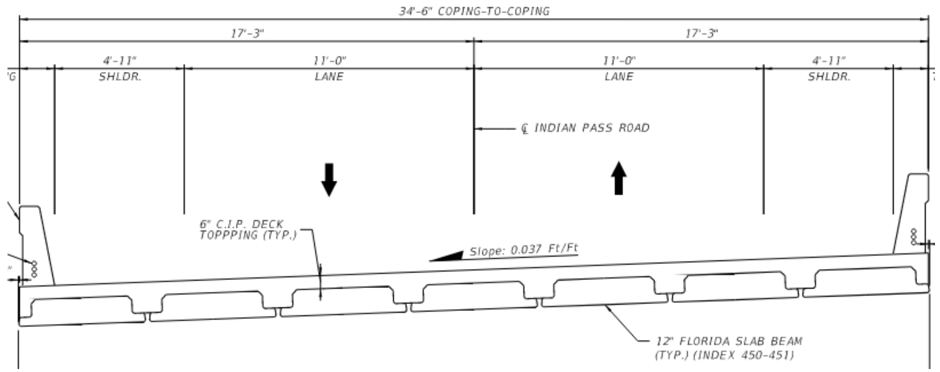
Construction: D3 Example Projects

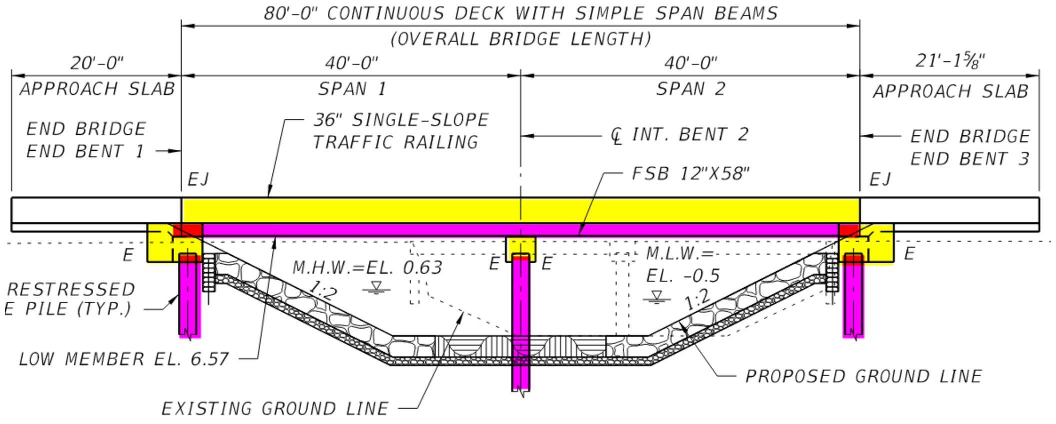
- CR30A over Western Lake (443331-1)





- CR30B/Indian Lagoon (441185-2)





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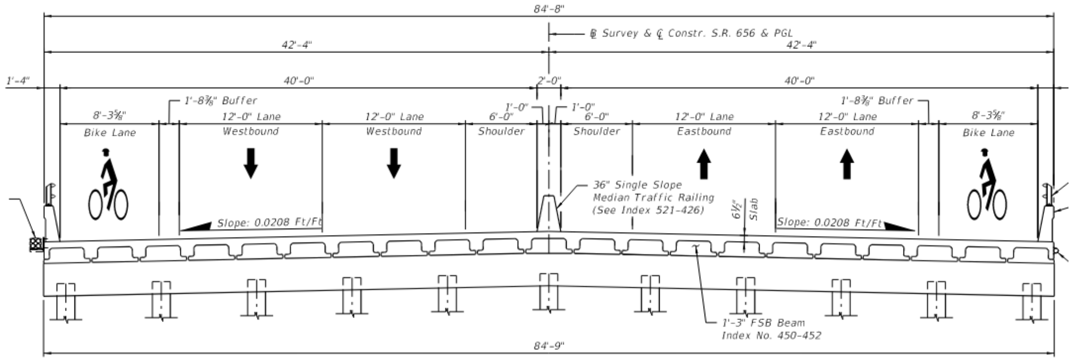
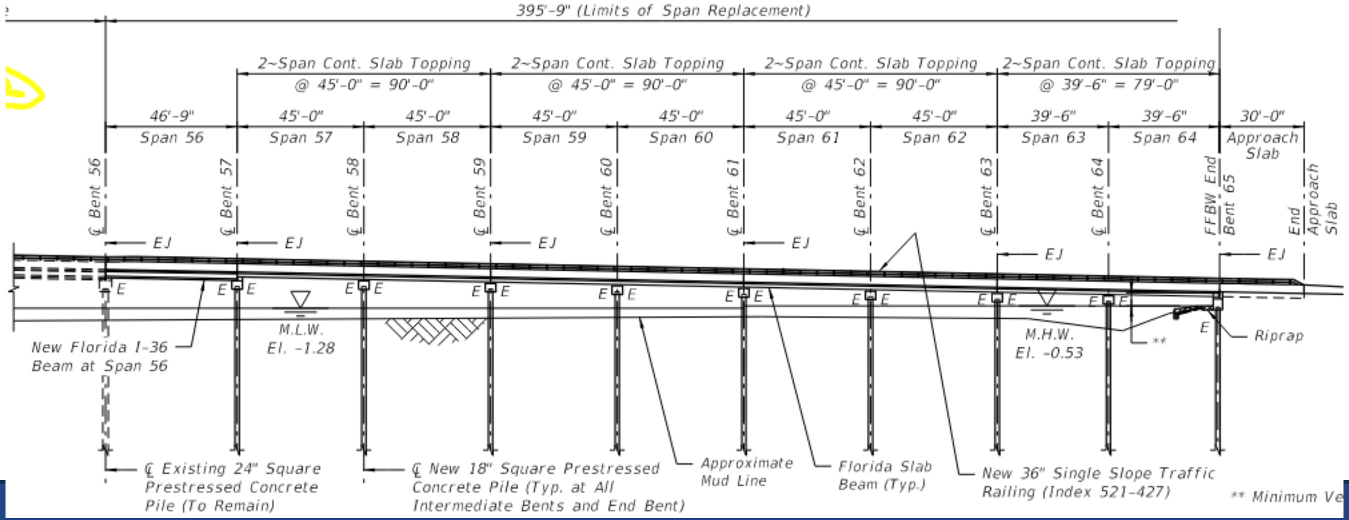
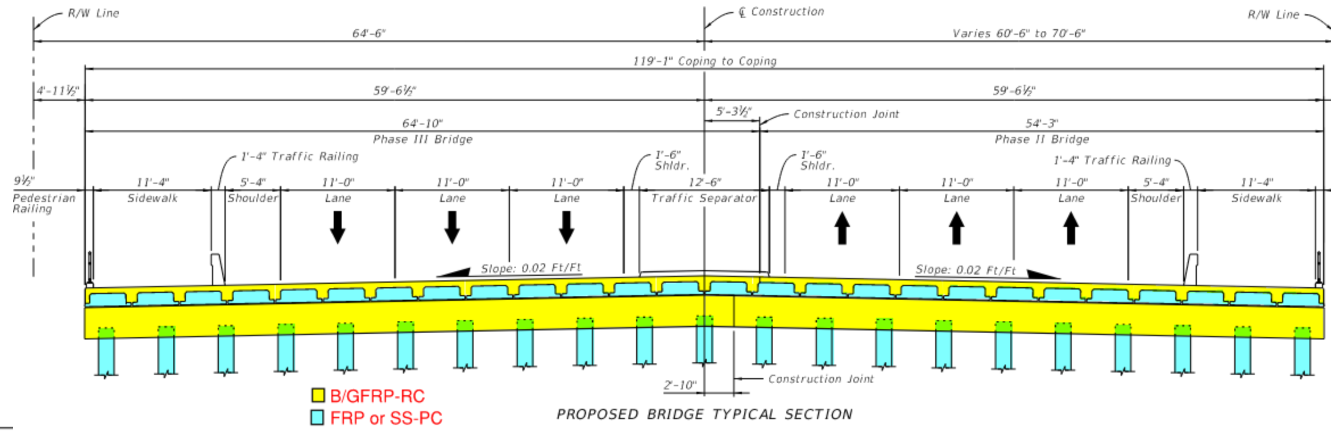
Construction: D4 Example Projects

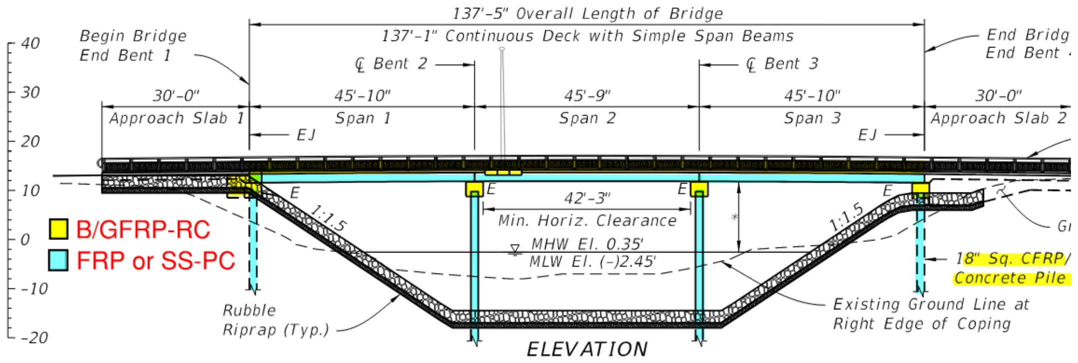
- 17th St/Indian River, East End-Vero (446106-2)





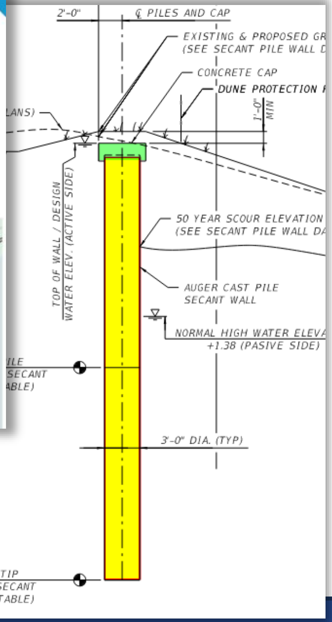
- SR 5/US 1 Over Earman River (442891-1) *In-house Design*

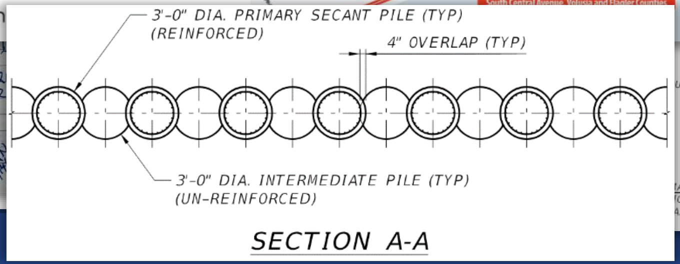




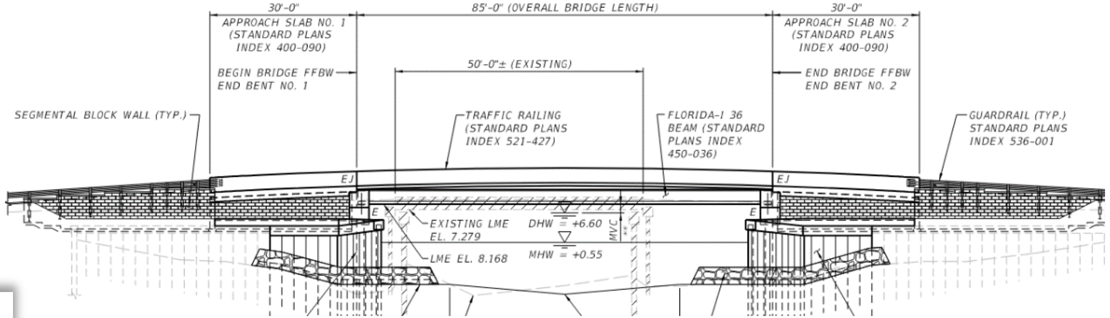
Construction: D5 Example Projects

- SR-A1A Seawalls - Flagler Beach & Nth Volusia Co. (452443-1 & 452444-1)



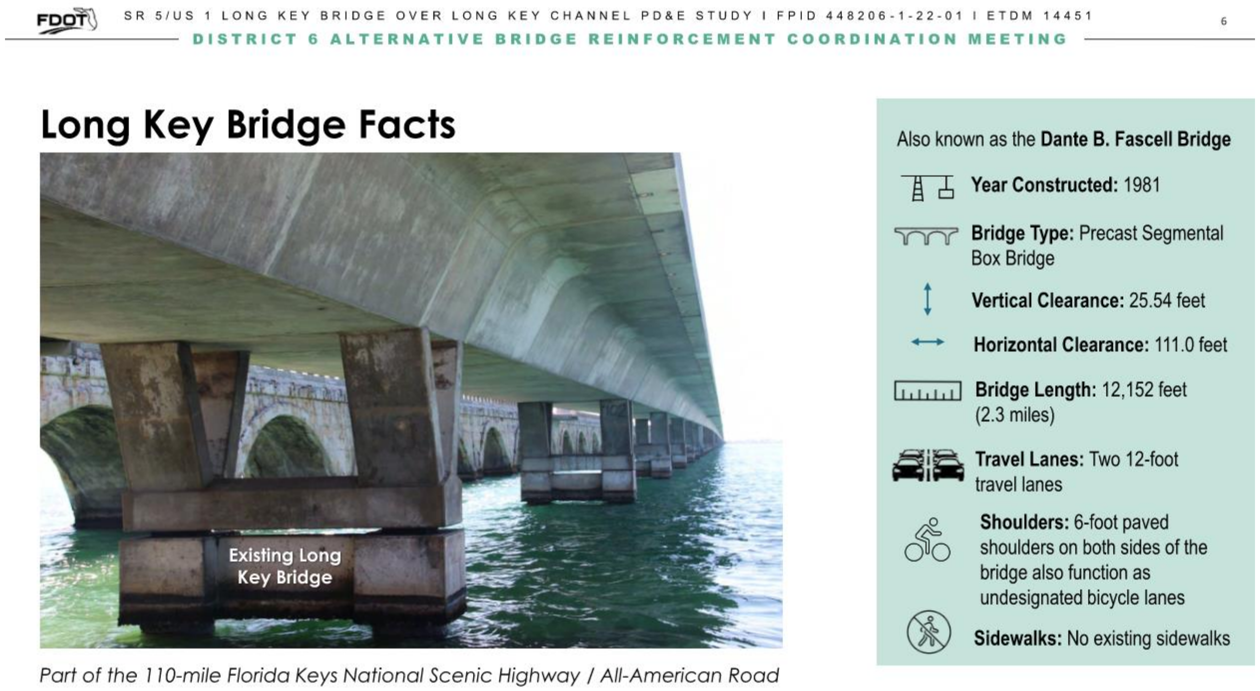


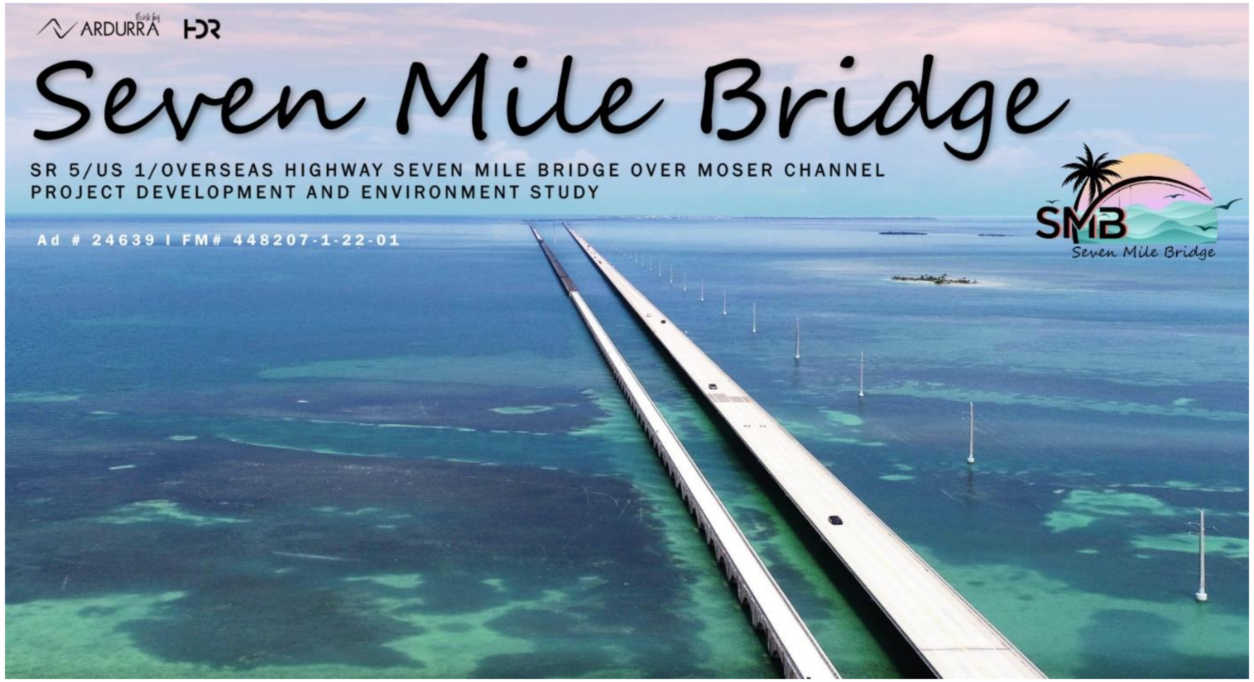
- Barracuda Blvd over Canal Bradano (437935-1) *In-house Design*



Future Construction: D6 Example Projects

- Long Key Bridge Replacement (448206-1 & (448207-1)
- Seven Mile Bridge Replacement (448207-1)





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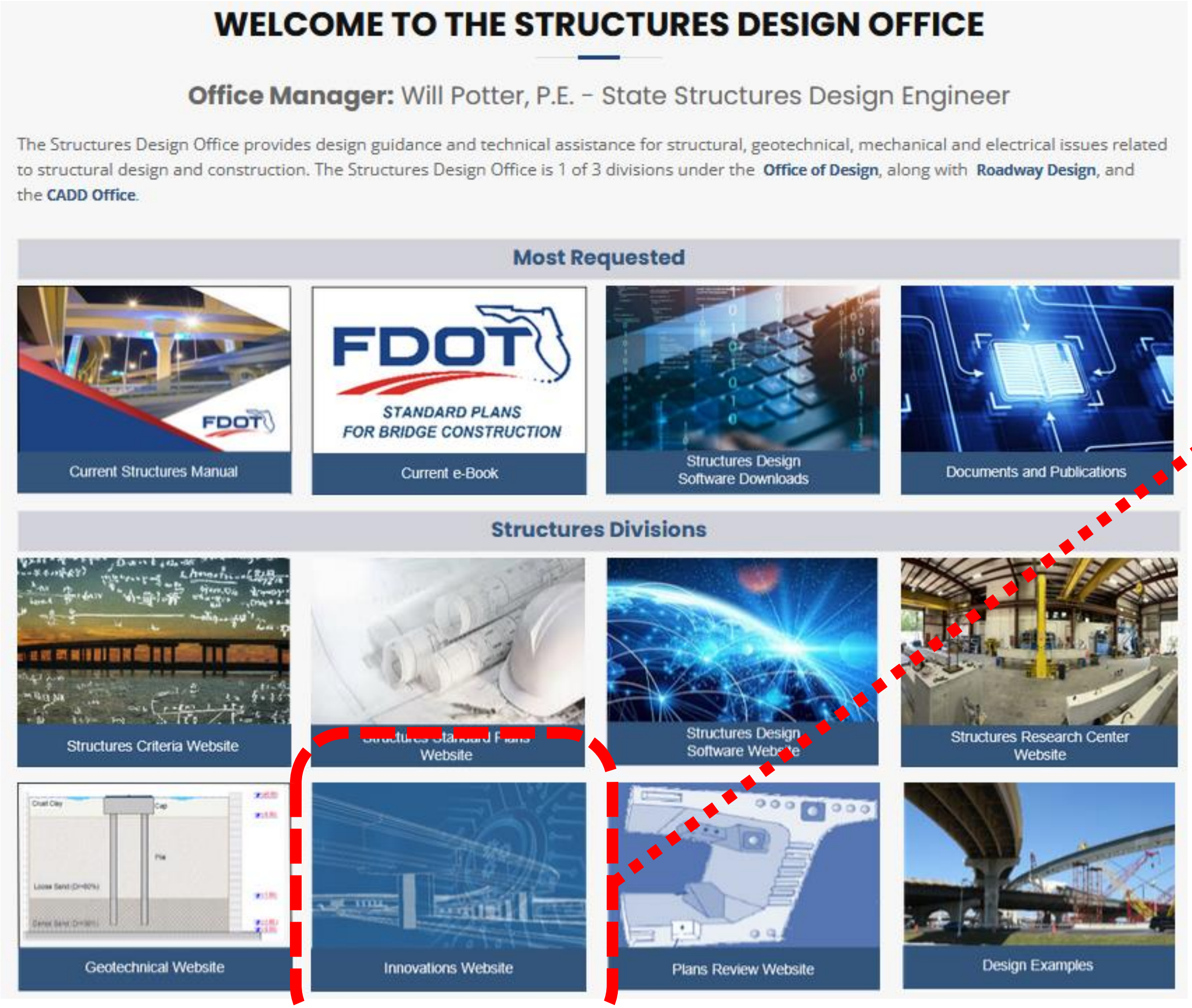
FRP RC/PC Design Innovation webpage



Fiber Reinforced Polymer Reinforcing

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 (T^2)
- FDOT Research
- Contact

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

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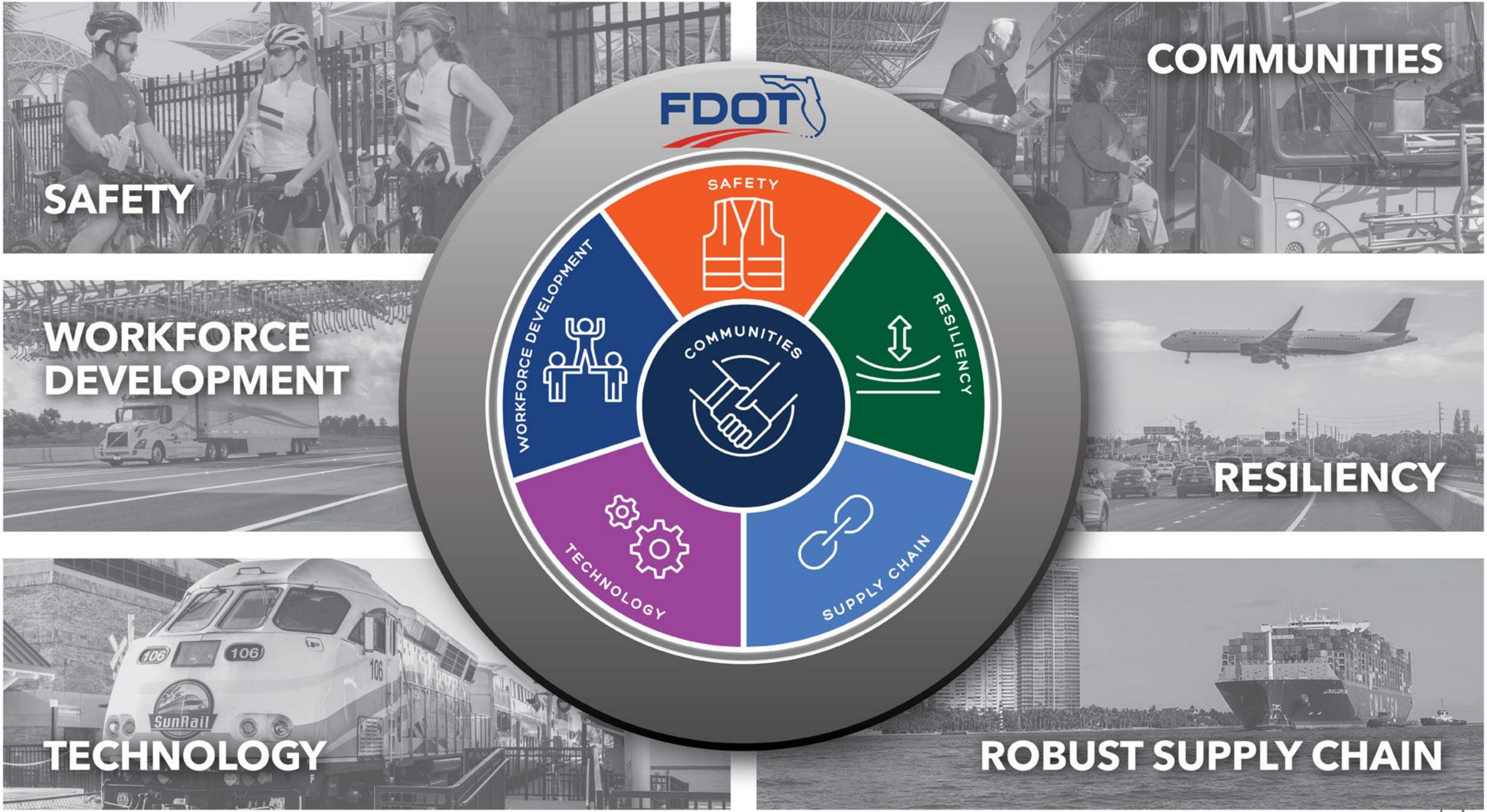
Office #: 850-414-4272
Website: https://www.fdot.gov/design/Innovation/


SAFETY
COMMUNITIES
WORKFORCE DEVELOPMENT
RESILIENCY
TECHNOLOGY
ROBUST SUPPLY CHAIN
FDOT
SAFETY
RESILIENCY
SUPPLY CHAIN
TECHNOLOGY
WORKFORCE DEVELOPMENT
COMMUNITIES
106
106
SunRail