

Orlando, FL

November 7-8, 2024



2024 TRANSPORTATION SYMPOSIUM



FRP Reinforced Concrete Structures: 10-year update, Lessons Learned, and Emerging Best Practices (7th November 2024)

Steven Nolan, P.E.

State Structures Design Office (Tallahassee, FL.)

Syed (Hamed) Kazimi, P.E.

District 7 Structures Design Office (Tampa, FL.)



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 knowledge, 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.



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SYMPOSIUM**



Schedule

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

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*).

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 Back: CFRP Prestressing Strand

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

II. APPLICATIONS OF CFCC



CFCC has been used in over 300 civil engineering projects .



1. Concrete Structures (PC and RC)
2. Cable for Stay Cable Bridges
3. Ground Anchors
4. Other (Architectures)

Courtesy the Danish highways Directorate

II. APPLICATIONS OF CFCC



1. CONCRETE STRUCTURES (PRE-TENSIONING)

Shinmiya Bridge 1988.10 in Japan

World's first PC bridge with CFRP tendon



Former Bridge



Bottom side of the bridge After 20-year life

SYMPOSIUM

Way Back: CFRP Prestressing Strand

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



TOKYO ROPE INTERNATIONAL

1. CONCRETE STRUCTURES (TRANSVERSE POST-TENSIONING & EXTERNAL TENDON)

Bridge Street Bridge May. 2001 in Southfield, Michigan
Funded by FHWA and MDOT **United States's first bridge constructed using CFRP**

TPT

CFCC 1 × 37 40.0φ : 9.2 m × 10 tendons,
9.4 m × 7 tendons
CFCC 1 × 19 21.8φ : 9.0 m × 6 tendons

External Tendons

CFCC 1 × 37 40.0φ : 16.8 m × 24 tendons,
17.0 m × 30 tendons

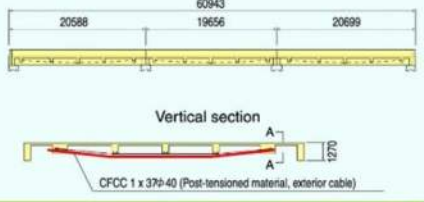
Transverse Cables



External Cables

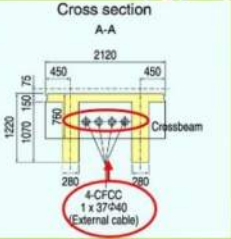


Vertical section



CFCC 1 × 37φ40 (Post-tensioned material, exterior cable)

Cross section A-A



4-CFCC 1 × 37φ40 (External cable)

Back a Decade: CFRP Prestressing Strand

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

TOKYO ROPE INTERNATIONAL

1. CONCRETE STRUCTURES (TRANSVERSE POST-TENSIONING)
Little Pond Bridge Aug. 2012 in Fryeburg, Maine
Bridge Length : 133' - 6" , Bridge Width : 49' - 4.5"
TPT CFCC 1 × 37 40φ : 50' - 10" (15.5 m) × 20 tendons



TOKYO ROPE INTERNATIONAL

1. CONCRETE STRUCTURES (PRESTRESSED CONCRETE PILE)
NIMMO PARKWAY in Virginia 2 Test Piles, 16 Piles 2012&2013

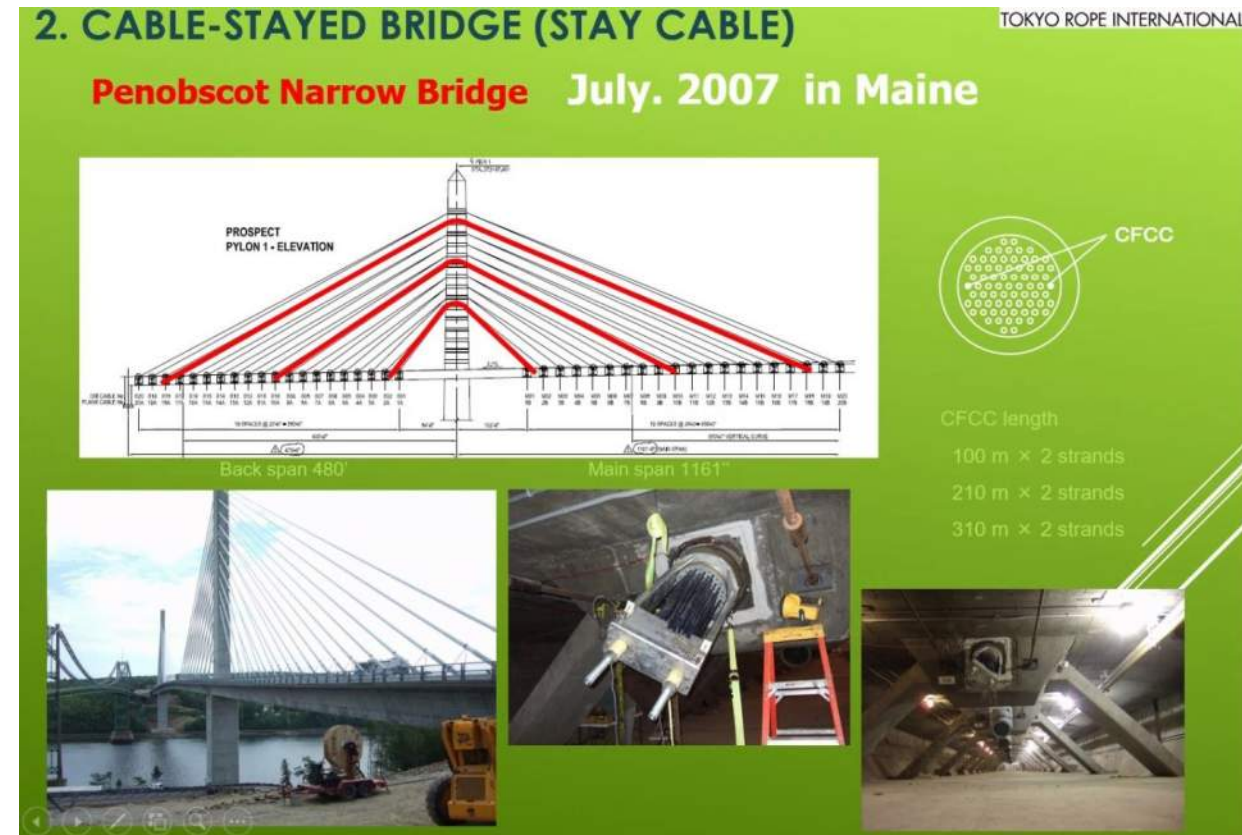
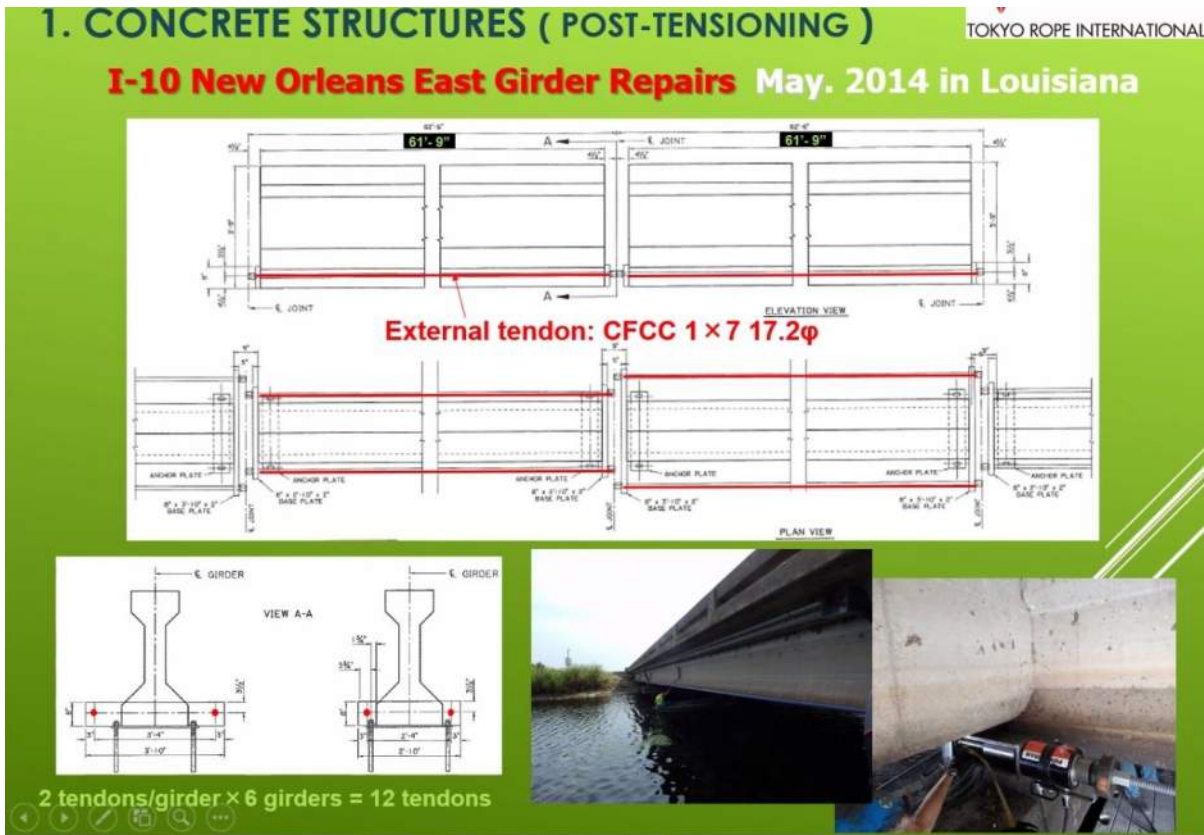


24" square pile
16 strands: CFCC 1 × 7 15.2mm
Spiral: CFCC U 5.7mm



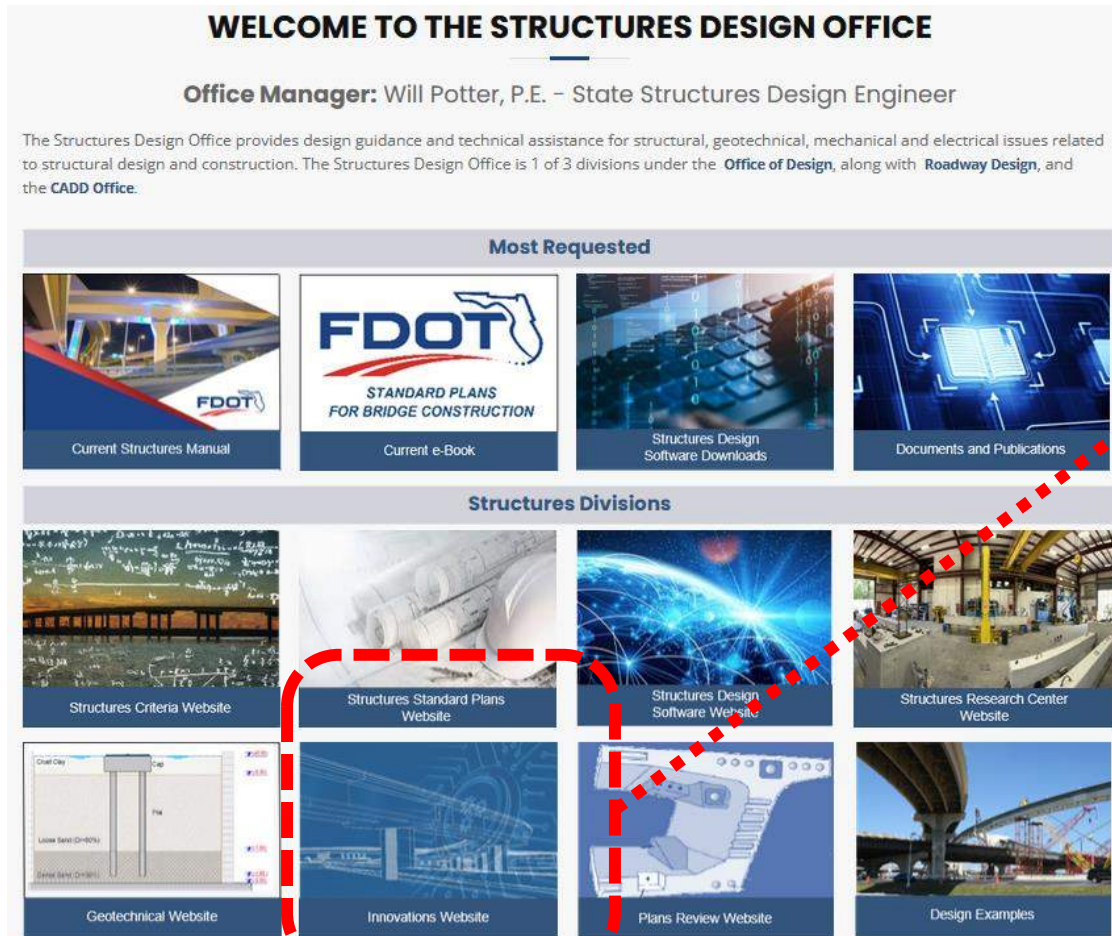
Back a Decade : CFRP Prestressing Strand

- 2014 (Louisiana) & 2016 (Maine)



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 \(T²\)](#)
[FDOT Research](#)
[Contact](#)

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CFRP Prestressing Strand & more... at FDOT



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

Design: Practices and Standards for FRP-RC/PC



FRP Reinforced Concrete Design

Presented in 2017 by:

Rick Vallier, P.E.

Updates in 2024 by:

Steven Nolan, P.E.

**TRANSPORTATION
SYMPOSIUM**

2017 vs. 2022 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 ($\sim 60\%$).
- 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 ($70\% f_u$).

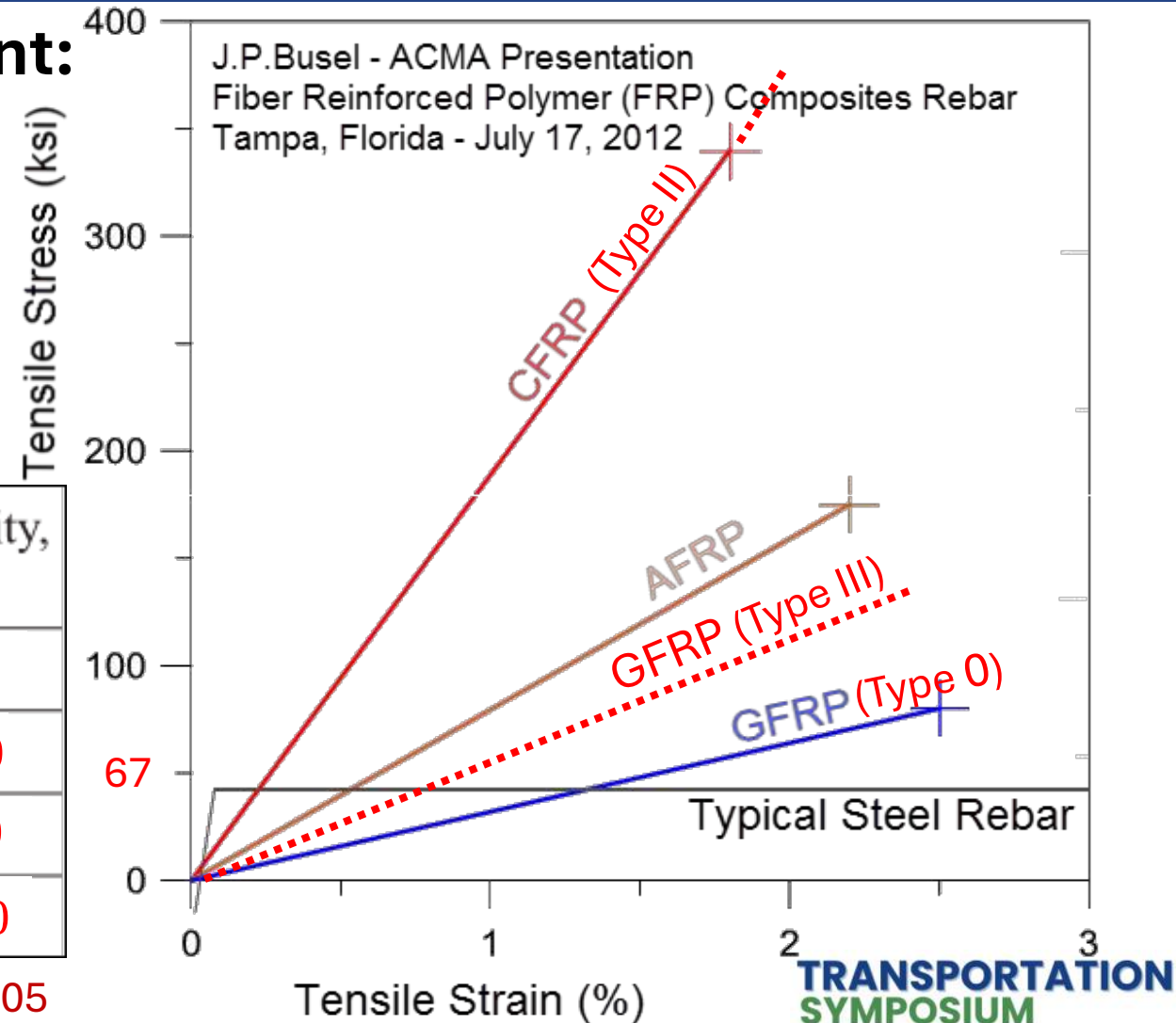
A. Reinforcing Bars

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_{tu} , ksi	Modulus of elasticity, ksi
Steel	60	29,000
GFRP (Type 0)	80 to 120	6,000 6,500
A FRP (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



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 (*$C_E = 0.70$*)



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. (***T_g***)

Property	Test Method	Requirement
Glass Transition Temperature (<i>T_g</i>)	ASTM E1640 (DMA)	$\geq 230^{\circ}\text{F}$
	or ASTM E1356 (DSC)	$\geq 212^{\circ}\text{F}$

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

A. Reinforcing Bars

Characteristics of FRP Reinforcement:

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



A. Reinforcing Bars

Bent Bars Characteristics:

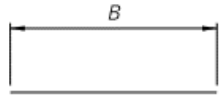
- FRP is pultruded from thermoset resin (*viable thermoplastic resins are emerging*)
- FRP is fabricated with bends (*thermoplastic and olefin resin will allow controlled thermal bending – [NCHRP IDEA-207](#) validated this*):
 - Sharp bends can be manufactured, but avoided due to potential **low stress**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



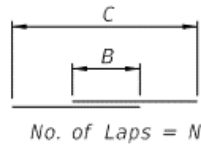
Plan Index [415-010](#) D21310 Bar Bending Details

A. Reinforcing Bars

From ~~Developmental Design Standard~~ **Plans Index D21310 415-010:**
(renumbering to match steel bar bending Index)



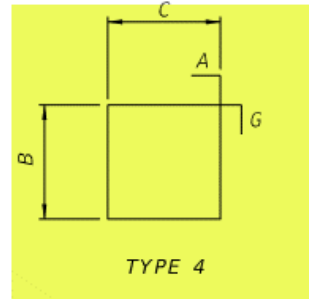
TYPE 1



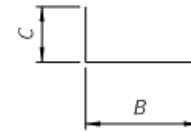
TYPE 2



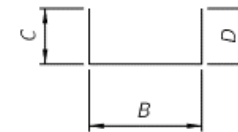
TYPE 3



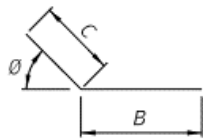
TYPE 4



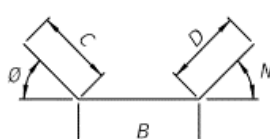
TYPE 10



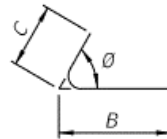
TYPE 11



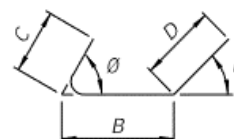
TYPE 12



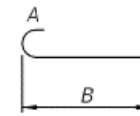
TYPE 13



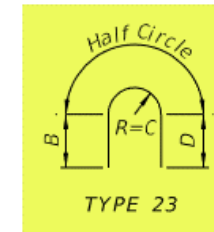
TYPE 14



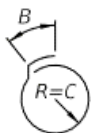
TYPE 15



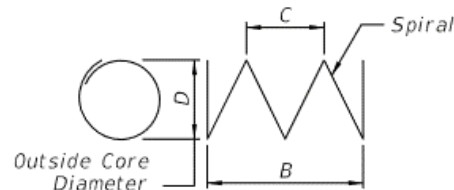
TYPE 17



TYPE 23



TYPE 24

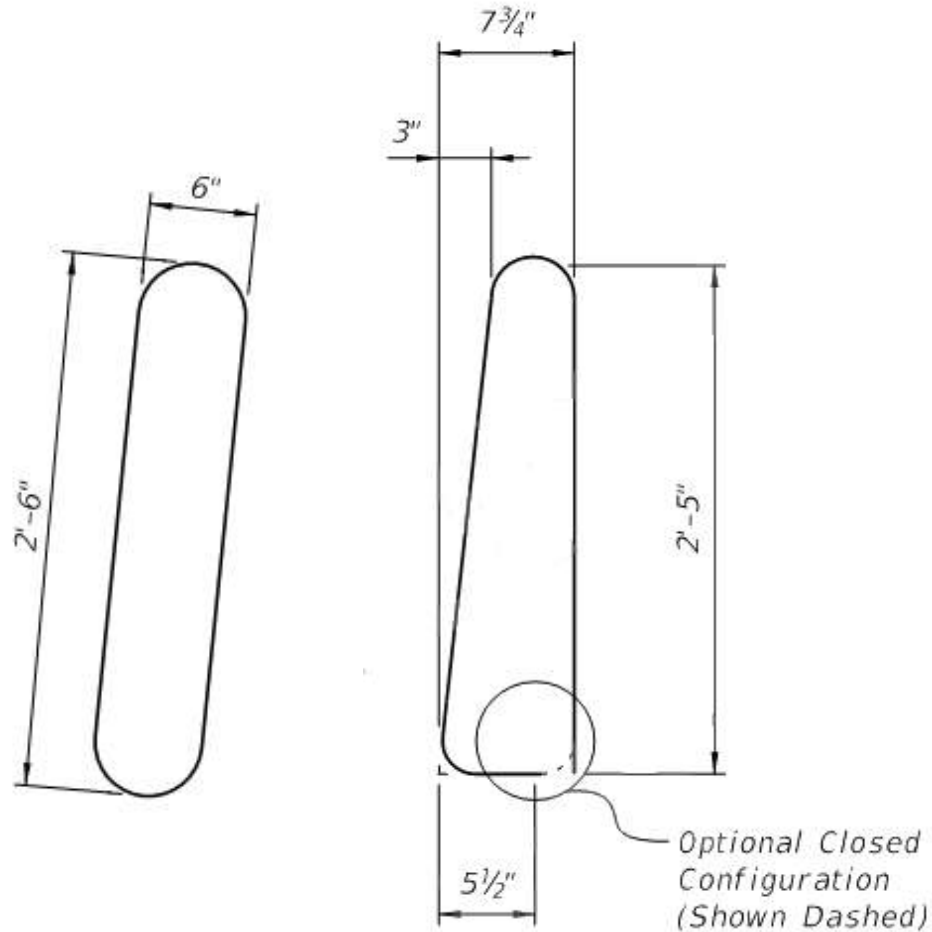


TYPE 39

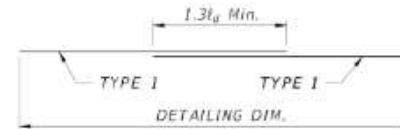
HOOK DETAILS				
BAR SIZE	D	180° HOOKS		90° HOOKS
		A OR G	J	A OR G
#3	2 1/4"	5"	3"	6"
#4	3"	6"	4"	8"
#5	3 3/4"	7"	5"	10"
#6	4 1/2"	8"	6"	1'-0"
#7	5 1/2"	10"	7"	1'-2"
#8	6"	11"	8"	1'-4"
STYLE		1		3

A. Reinforcing Bars

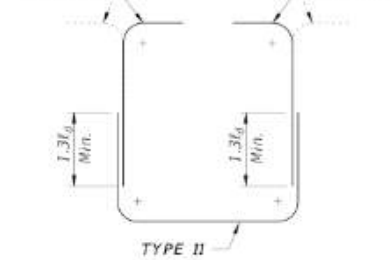
Complex Shapes:



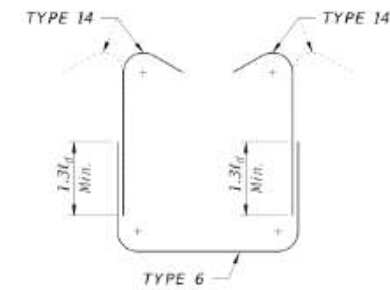
Design Aids



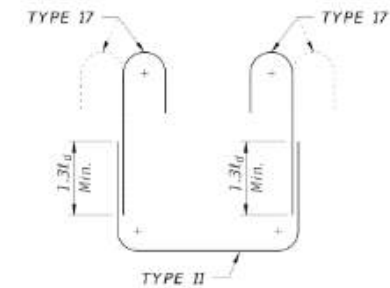
LAPPED STRAIGHT BARS (TYPE 2)



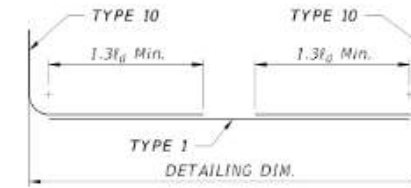
OPEN STIRRUP 1



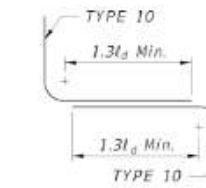
OPEN STIRRUP 2



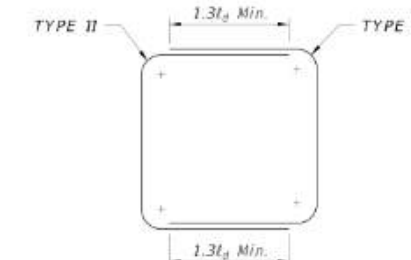
OPEN STIRRUP 3



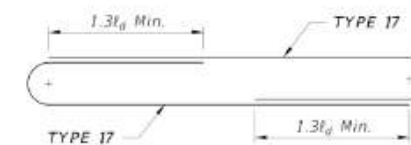
LONG LEG U SHAPE



Z BAR SHAPE



CLOSED STIRRUP 1



CLOSED STIRRUP 2

NOTE: See Developmental Standard D415-010 for referenced Single Bar Bending Types.

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.

**** 2023 FDOT Bid Avg.**

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.

A. Reinforcing Bars

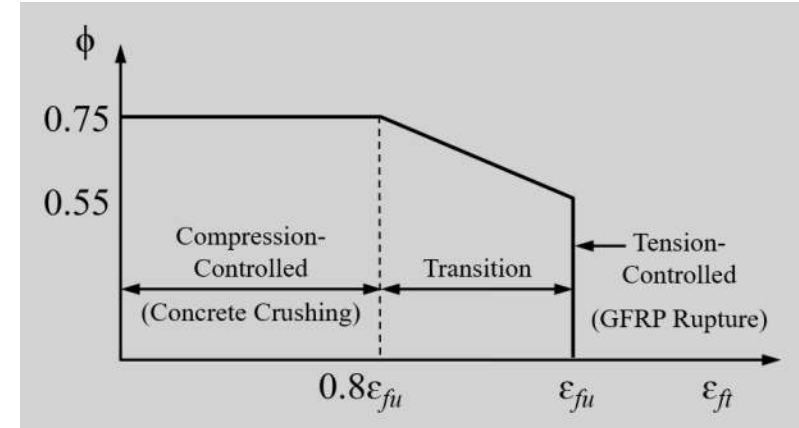
Flexural Strength Design Philosophy

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	<u>Performance Evaluation of Basalt Fiber Reinforced Polymer (BFRP) Reinforcing Bars Embedded in Concrete</u>	R. Kampmann	FAMU-FSU	BVD30 986-01
April 2022	<u>Epoxy Dowel Pile Splice Evaluation</u> with FRP Bars	A. Mehrabi	FIU	BDV29 977-52
Dec. 2020	<u>“Stainless Steel Strands and Lightweight Concrete for Pretensioned Concrete Girders”</u> (w/ GFRP shear stirrups)	M. Roddenberry	FAMU-FSU	BDV30 977-27 (Report A)
07/30/2022	<u>Improving Testing Protocol and Material Specifications for Basalt Fiber Reinforced Polymer Bars</u>	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	<u>Development of GFRP Reinforced Single Slope Bridge Rail</u>	G. Consolazio	UF	BDV31 977-110
12/31/2023	<u>Evaluation of Glass Fiber Reinforced Polymers (GFRP) Spirals in Corrosion Resistant Concrete Piles</u>	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	<i>Waterline Pile Cap Footings for Bridges using Large Diameter FRP Reinforcing – Material Characterization and Design</i>	A. Nanni	UM	BEE76 977-01
May 2025	<i>HRB Extraction and Physio-Mechanical Testing of FRP Reinforcing Bars from 5-year-old Seawater Concrete Test Blocks on Halls River Bridge Bulkhead</i>	F. De Caso	UM	BEE76 977-02

C. FDOT Structures Manual

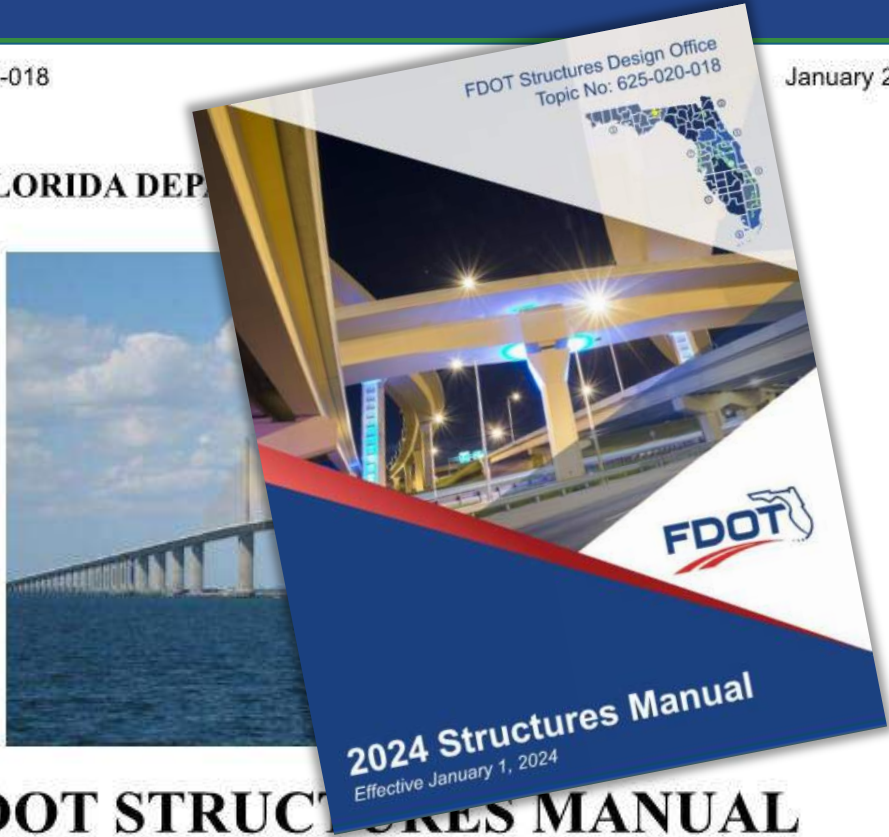
FDOT Design Criteria for FRP:

Topic No. 625-020-018

FDOT Structures Design Office
Topic No: 625-020-018

January 2017

FLORIDA DEPARTMENT OF TRANSPORTATION



2024 Structures Manual
Effective January 1, 2024

FDOT STRUCTURES MANUAL

- Volume 1 - Structures Design Guidelines**
- Volume 2 - Structures Detailing Manual**
- Volume 3 - FDOT Modifications to LRFDLTS-1**
- Volume 4 - Fiber Reinforced Polymer Guidelines**

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

**TRANSPORTATION
SYMPOSIUM**

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.



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**.

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.

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>

C. FDOT Structures Manual

GFRP/CFRP Reinforcing Bars – Section 2 – Design Criteria

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

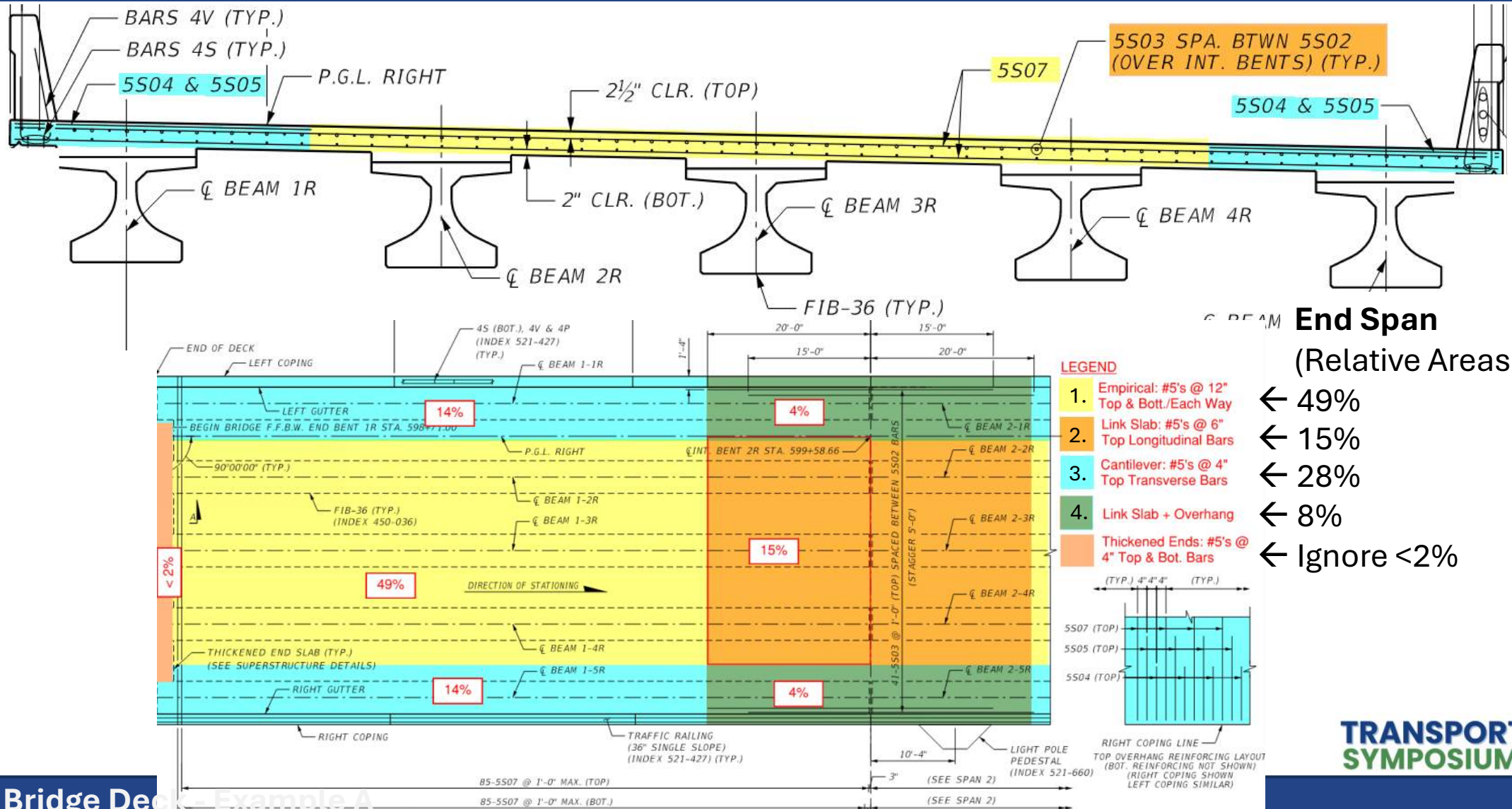
- *AASHTO LRFD Bridge Design Guide Specifications for GFRP-Reinforced Concrete* ~~ACI 440.1 Guide for the Design and Construction of Structural Concrete Reinforced with FRP Bars.~~
- *AASHTO Guide Specification for the Design of Concrete Bridge Beams Prestressed with CFRP Systems.* ~~ACI 440.4 Prestressing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

Design **Bridge Decks** according to:

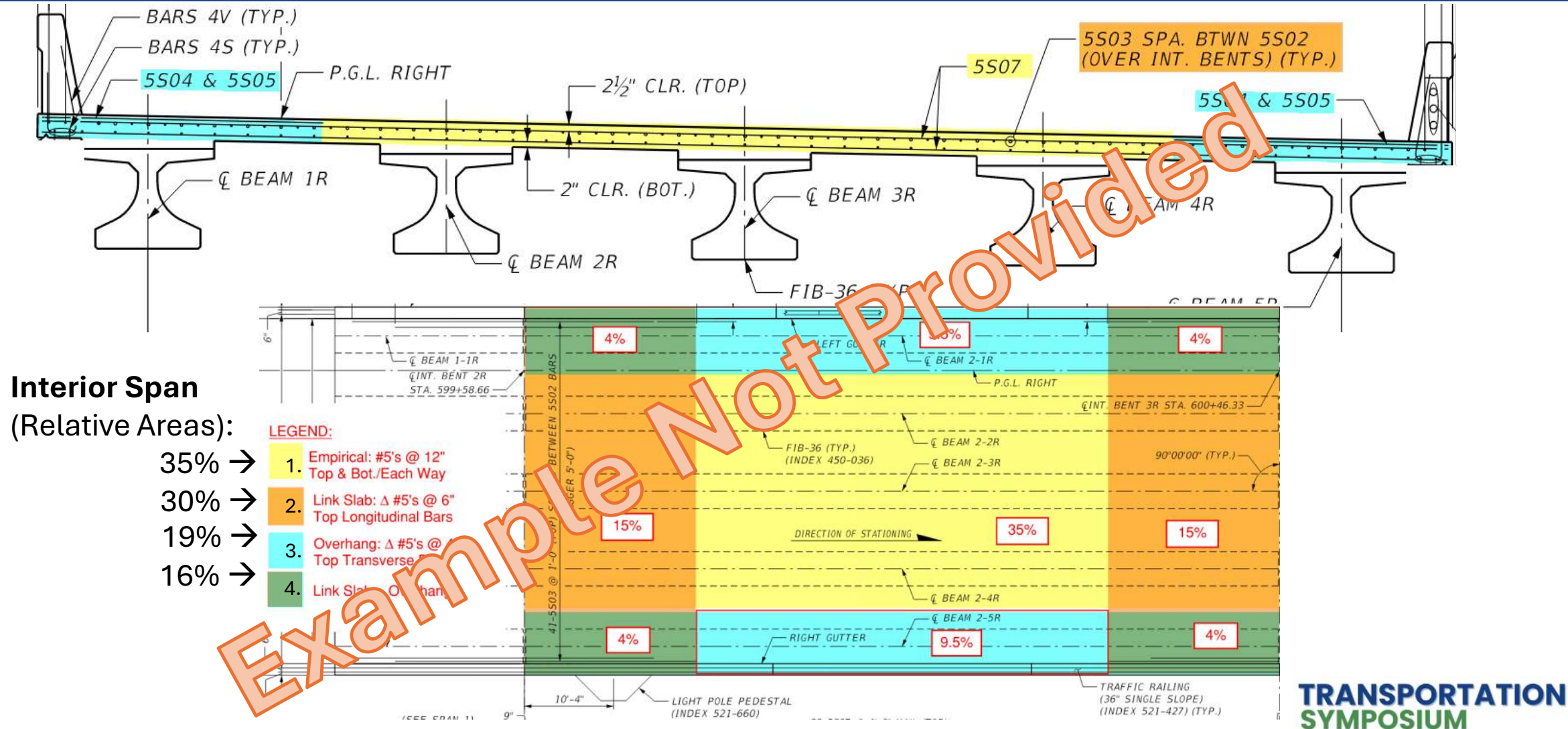
- *AASHTO LRFD Bridge Design Guide Specifications for GFRP-Reinforced Concrete Bridge Decks and Traffic Railings* (2nd Edition)

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

Comparison of Rebar Qty. Bridge Deck Example A



Comparison of Rebar Qty. Bridge Deck Example B



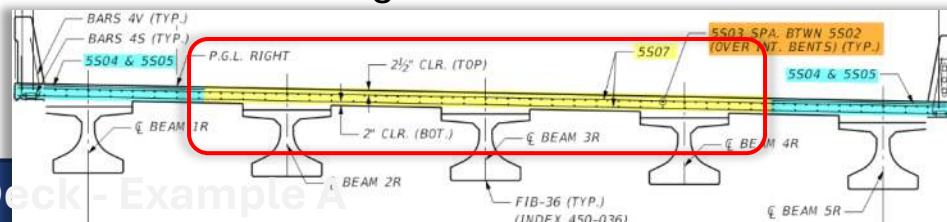
Comparison of Material Qty. Deck Area 1 (Example A)

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" ($0.27 \text{ in}^2/\text{ft}$); Top layers = #4's @ 13.3" ($0.18 \text{ in}^2/\text{ft}$)
- Empirical (FDOT): #5's @ 12" **
- Total Rebar (AASHTO): $A_s = 0.90 \text{ in}^2/\text{ft}^2$;
(FDOT): $A_s = 1.24 \text{ in}^2/\text{ft}^2$

GFRP-RC (ASTM D8505-23):

- Thickness = 7" $\rightarrow \Delta_{\text{vol.}} = -12\%$; $\Delta_{\text{weight}} = -15\%$
- 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: $A_f = 1.50 \text{ in}^2/\text{ft}^2 \text{ deck}$
 $\rightarrow \Delta_{\text{volume}} \text{ (AASHTO)} = +67\%$; $\Delta_{\text{weight}} = -58\%$
 $\rightarrow \Delta_{\text{volume}} \text{ (FDOT)} = +21\%$; $\Delta_{\text{weight}} = -70\%$



Interior Section

TRANSPORTATION
SYMPOSIUM

** Minimum bar size and spacing governs

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

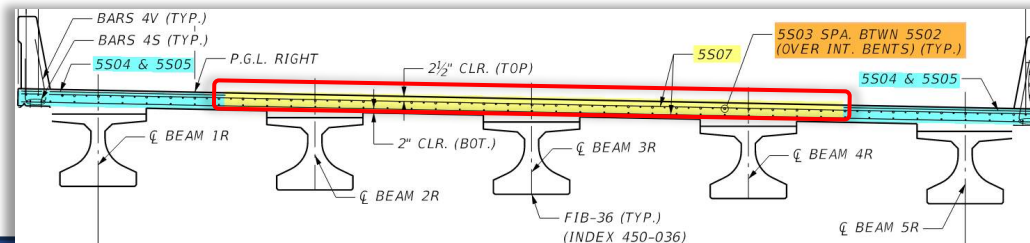
Convention CS-RC (ASTM A615):

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

Link-Slab Section

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" ($0.83\% = 0.57 \text{ in}^2$); Other 2-layers = #5's @ 12" ($0.35\% = 0.31 \text{ in}^2$); + Top long. = #5's @ 6" ($0.62 \text{ in}^2/\text{ft}$)
- Total Rebar: $A_f = 1.81 \text{ in}^2/\text{ft}^2$
→ $\Delta_{vol.}$ (AASHTO) = +35%; $\Delta_{weight} = -66\%$
→ $\Delta_{vol.}$ (FDOT) = +17%; $\Delta_{weight} = -71\%$



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

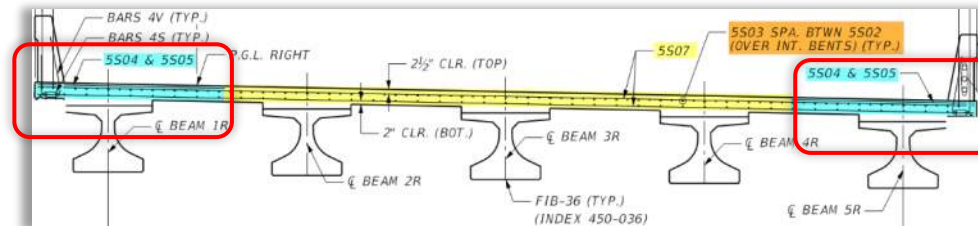
Convention CS-RC (ASTM A615):

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

Overhangs (midspan)

GFRP-RC (ASTM D8505-23):

- Thickness = 7" $\rightarrow \Delta_{vol.} = 88\%$; $\Delta_{weight} = 85\%$
- Concrete Cover = 1"
- Flexural Depth (#5's) $d = 5.7"$
- Empirical (**AASHTO-GSG**): Bot. ** transv. = #5's @ 6.5" ($\geq 0.83\% = 0.57 \text{ in}^2$); 2~long. layers = #5's @ 12" ($\geq 0.35\% = 0.31 \text{ in}^2$); Top transv. = #5's @ 4" ($0.93 \text{ in}^2/\text{ft}$).
- Total Rebar: $A_f = 2.12 \text{ in}^2/\text{ft}^2 \text{ deck}$
 $\rightarrow \Delta_{volume} \text{ (AASHTO)} = +38\%$; $\Delta_{weight} = -66\%$
 $\rightarrow \Delta_{volume} \text{ (FDOT)} = +14\%$; $\Delta_{weight} = -72\%$



TRANSPORTATION
SYMPOSIUM

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

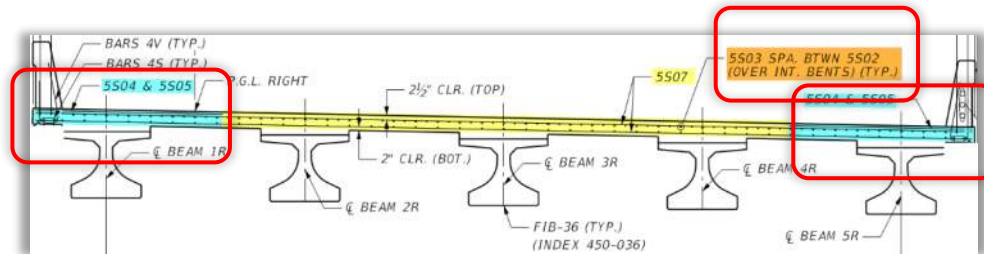
Convention CS-RC (ASTM A615):

- 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" ($0.27 \text{ in}^2/\text{ft}$); Top long. = #4's & #5's @ 6.7" ($0.46 \text{ in}^2/\text{ft}$); Top transv. = #4's + #5's @ 4" ($0.82 \text{ in}^2/\text{ft}$).
- Empirical-Link (FDOT): 2~Bot. layers #5's @ 12" ** ($0.31 \text{ in}^2/\text{ft}$); Top Transv. = #5's @ 4" ($0.93 \text{ in}^2/\text{ft}$). Top long. = #5's @ 6" ($0.62 \text{ in}^2/\text{ft}$).
- Total Rebar (AASHTO): $A_s = 1.82 \text{ in}^2/\text{ft}^2$;
(FDOT): $A_s = 2.17 \text{ in}^2/\text{ft}^2$.

Overhangs @ Link-Slab

GFRP-RC (ASTM D8505-23):

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



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): $A_s = 0.49 \times 0.90 + 0.15 \times 1.34 + 0.28 \times 1.54 + 0.08 \times 1.82 = 1.22 \text{ in}^2/\text{ft}^2$

- Empirical (FDOT): $A_s = 0.49 \times 1.24 + 0.15 \times 1.55 + 0.28 \times 1.86 + 0.08 \times 2.17 = 1.53 \text{ in}^2/\text{ft}^2$

GFRP-RC (ASTM D8505-23):

• **Example A** (End Span Rebar)

- Empirical (both): $A_s = 0.49 \times 1.50 + 0.15 \times 1.81 + 0.28 \times 2.12 + 0.08 \times 2.69 = 1.82 \text{ in}^2/\text{ft}^2$

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

Rebar $\rightarrow \Delta_{volume}$ (AASHTO) = +49%; Δ_{weight} = -63 %.

Rebar $\rightarrow \Delta_{volume}$ (FDOT) = +19%; Δ_{weight} = -70 %.

TRANSPORTATION
SYMPOSIUM

Comparison of Rebar Qty. Pile Bent Cap Example C



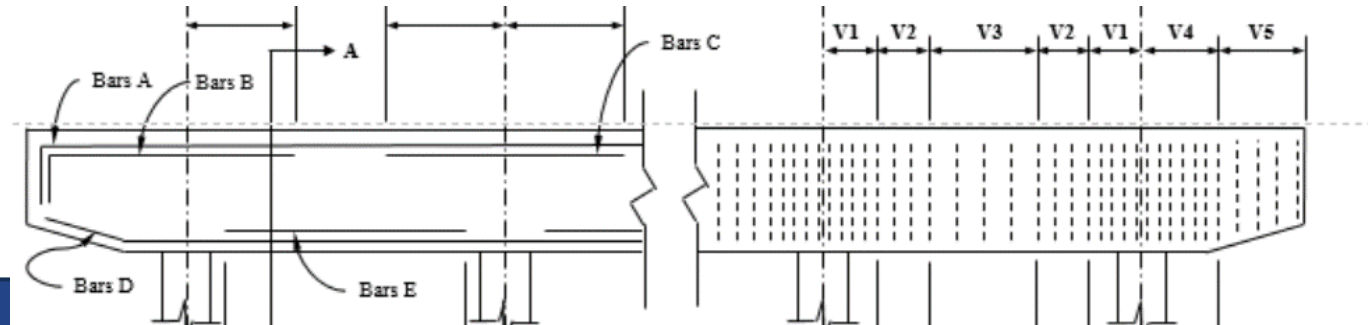
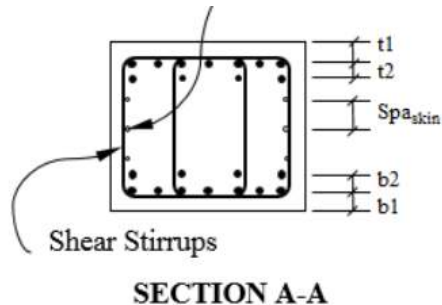
10/20/2022 GFRP Reinforced Concrete Design for Pile Bent Caps Presentation

**TRANSPORTATION
SYMPOSIUM**

Design Example for Pile Bent Cap Summary

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

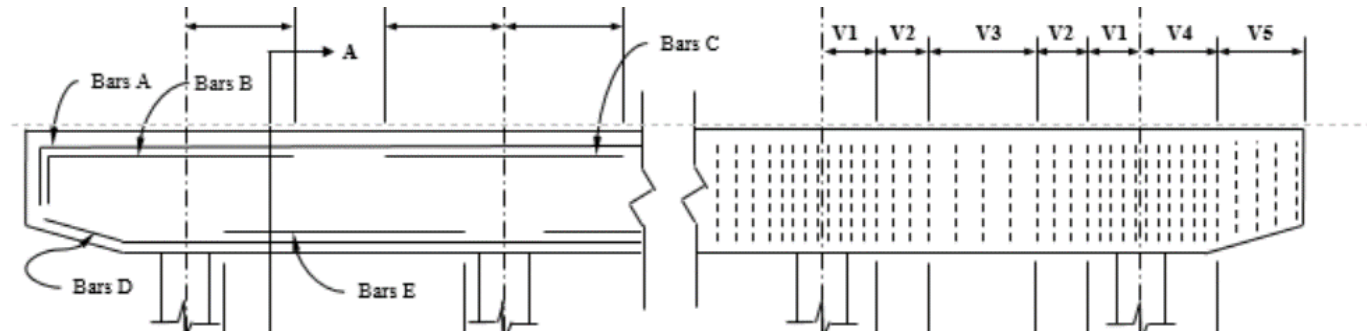
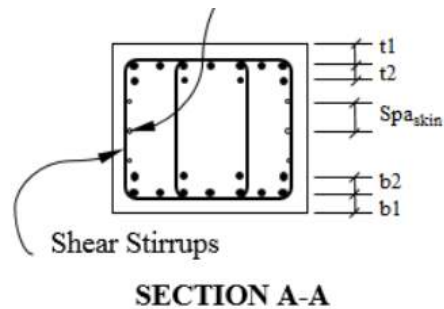
Rebar Location	GFRP-RC (Type 0) 3-ft Deep Cap ($E_f = 6,500$ ksi)	GFRP-RC 3-ft Deep Cap ($E_f = 7,250$ ksi)	GFRP-RC (Type III) 3-ft Deep Cap ($E_f = 8,700$ ksi)
Bars A - Flexural Top	6 ~ #8's ($A_f = 4.7$ in ²)	7 ~ #7's ($A_f = 4.2$ in ²)	6 ~ #7's ($A_f = 3.6$ in ²)
Bars D & E - Flexural Bottom	8 ~ #8's ($A_f = 6.3$ 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

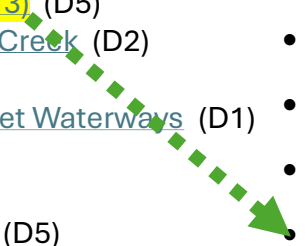
- Comparison of different design alternates for 5-piles @ 9-ft spacing (Example 1)

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 ($A_f = 4.7 \text{ in}^2$)	+80% or (+38%)	6 ~ #6's ($A_s = 2.6 \text{ in}^2$)
Bars D & E - Flexural Bottom	8 ~ #8's ($A_f = 6.3 \text{ in}^2$)	+50% or (+12%)	7 ~ #7's ($A_s = 4.2 \text{ in}^2$)
Bars V3 - Shear Stirrups	4-legs #5 at 11" sp. ($A_f = 1.4 \text{ in}^2/\text{ft}$)	+75% or (+25%)	4-legs #4 at 12" sp. ($A_s = 0.8 \text{ in}^2$)



Construction: Example Projects & Lessons Learned

Projects with Fast-Facts Sheet

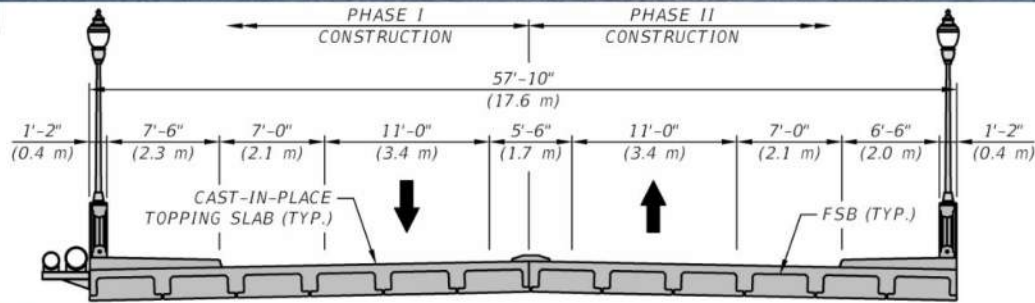
- 4th St North over Big Island Gap (D7) – **In-house Design.**
 - 40th Ave NE over Placido Bayou (D7)
 - Arthur Drive over Lynn Haven Bayou (D3)
 - **Bakers Haulover Cut Bulkhead Replacement** (D6)
 - Bimini Dr Bridge on Duck Key (D6)
 - Cedar Key Bulkhead Rehab (D2)
 - **Halls River Bridge** (D7) – **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](#))

Construction: D7 Example Project

- **40th Ave NE over Placido Bayou (FPID: 443600-1)**



- **4th St North over Big Island Gap (FPID: 430500-1)**



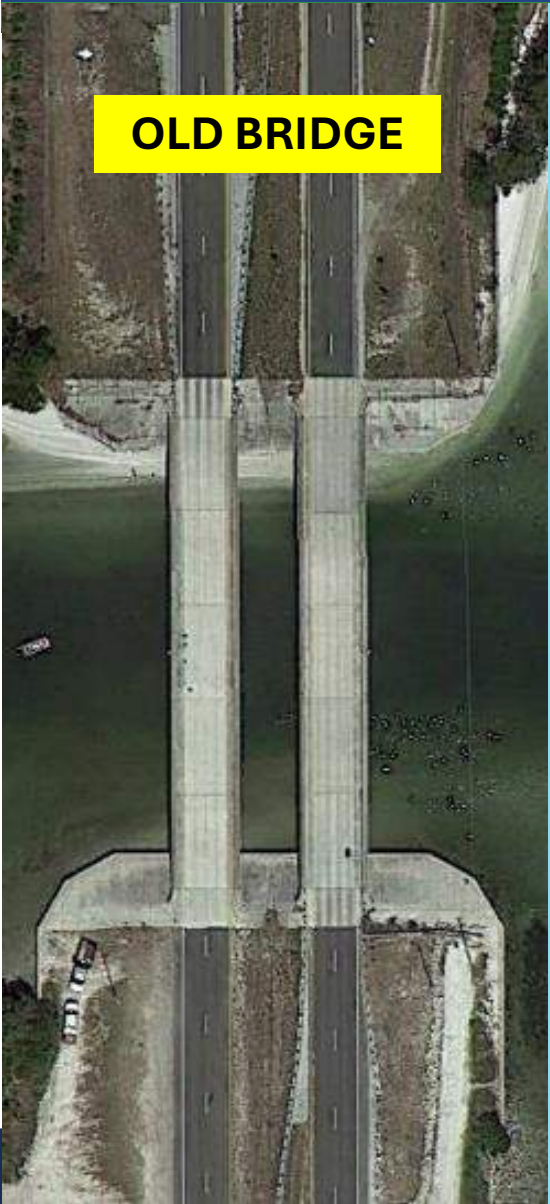
In-house Design

**TRANSPORTATION
SYMPOSIUM**

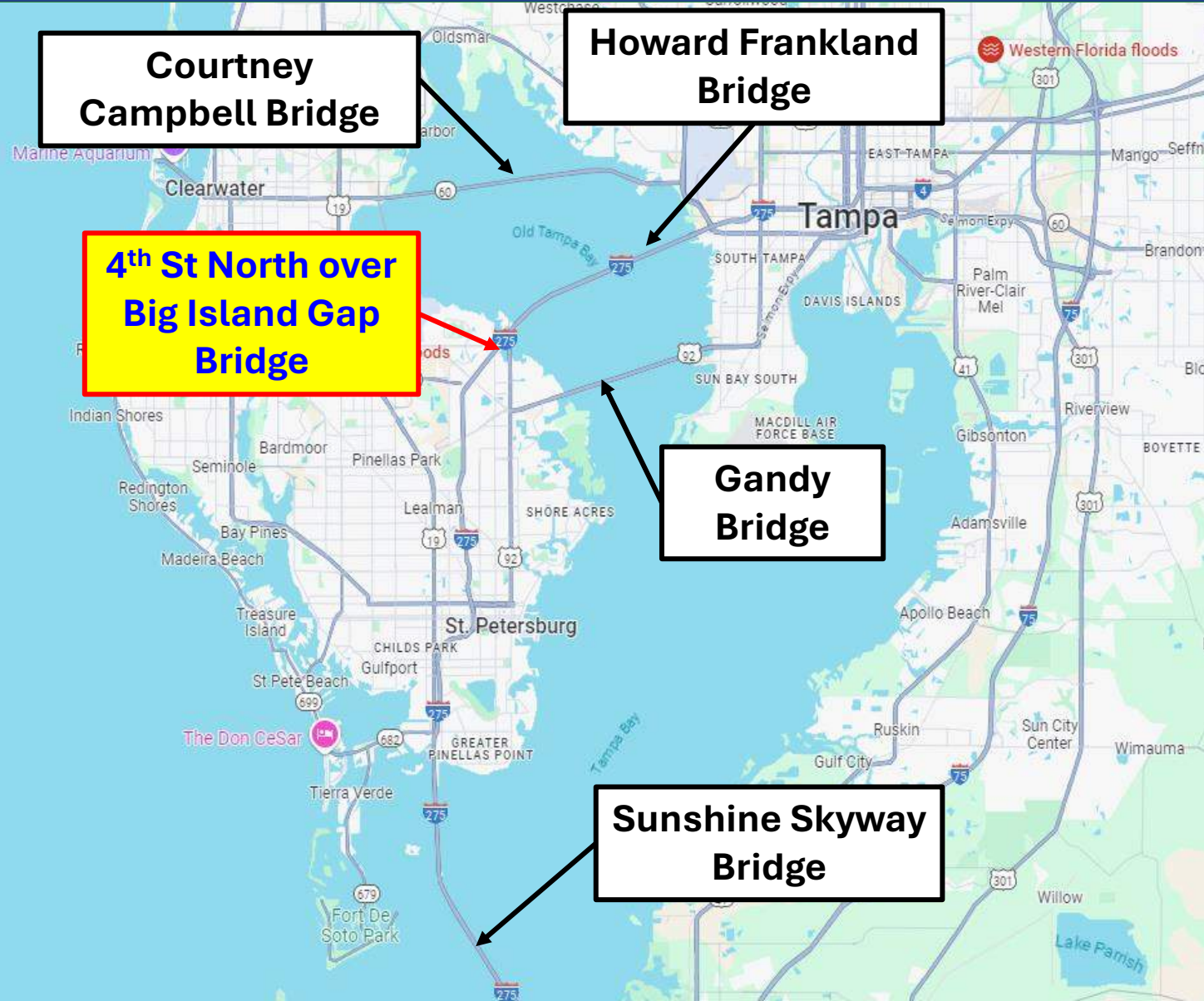
Construction: D7 Example Project

Bridge Location

4th St North over
Big Island Gap
(430500-1)



OLD BRIDGE



NEW BRIDGE

4th St North over
Big Island Gap
(430500-1)

Construction: D7 Example Project

Existing Bridges



4th St North over
Big Island Gap
(430500-1)

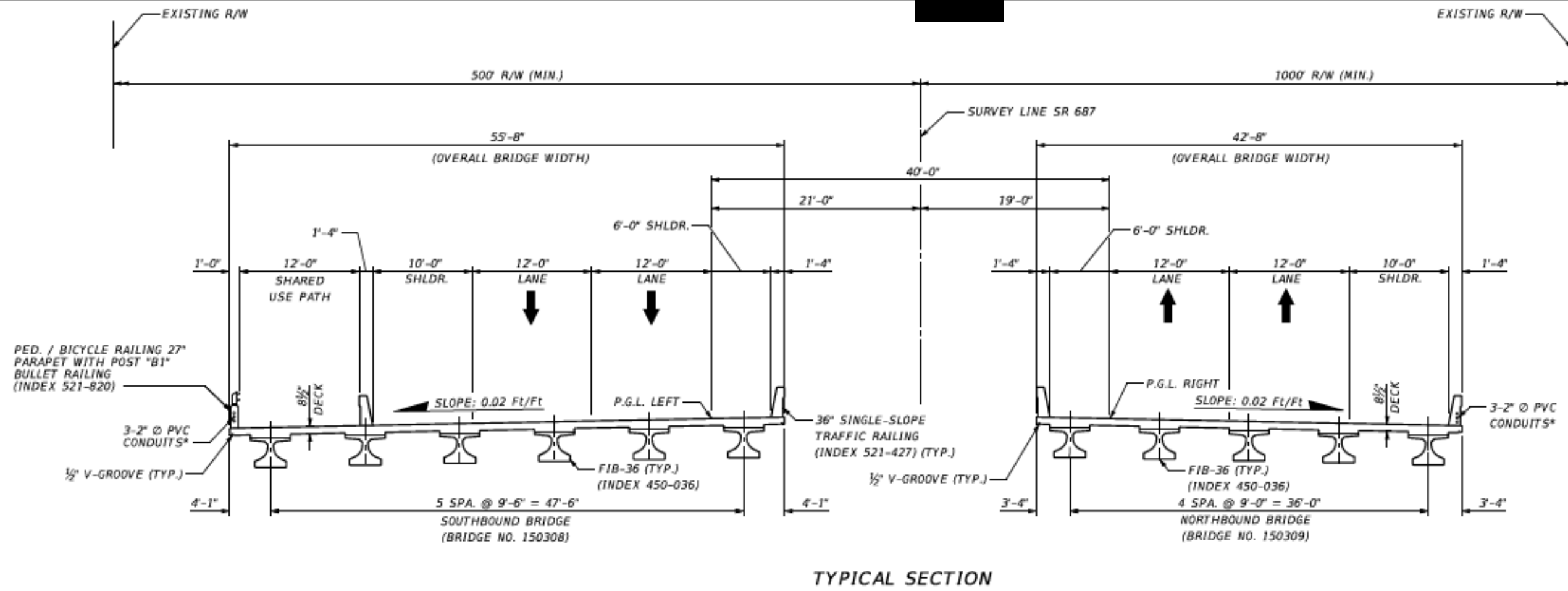
Construction: D7 Example Project

Existing Bridges Pile Jackets



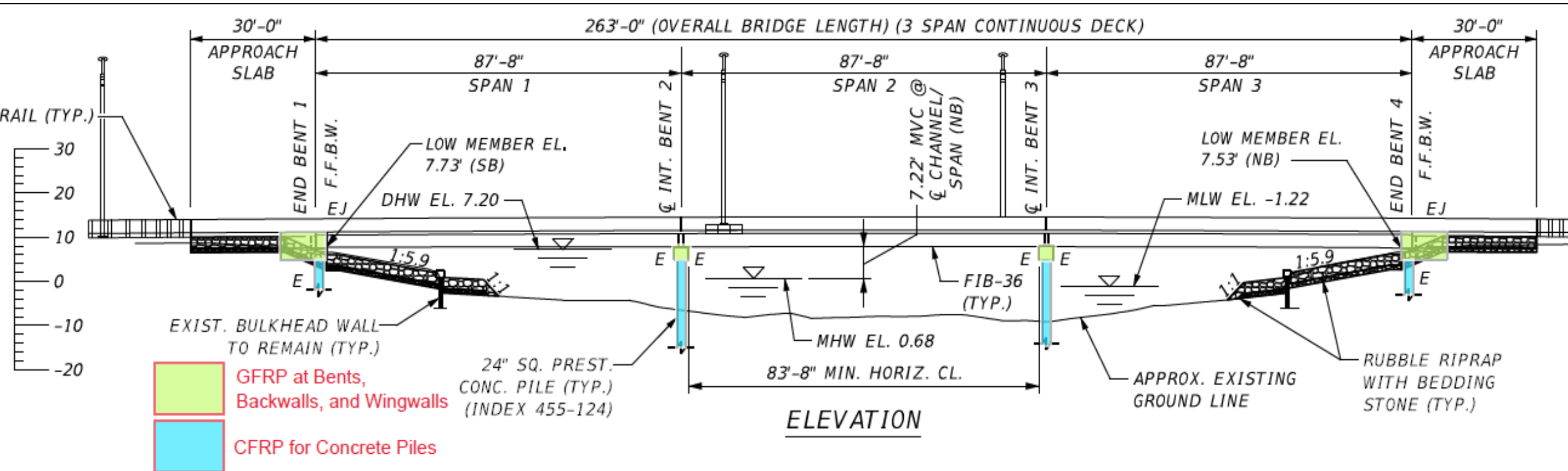
Construction: D7 Example Project

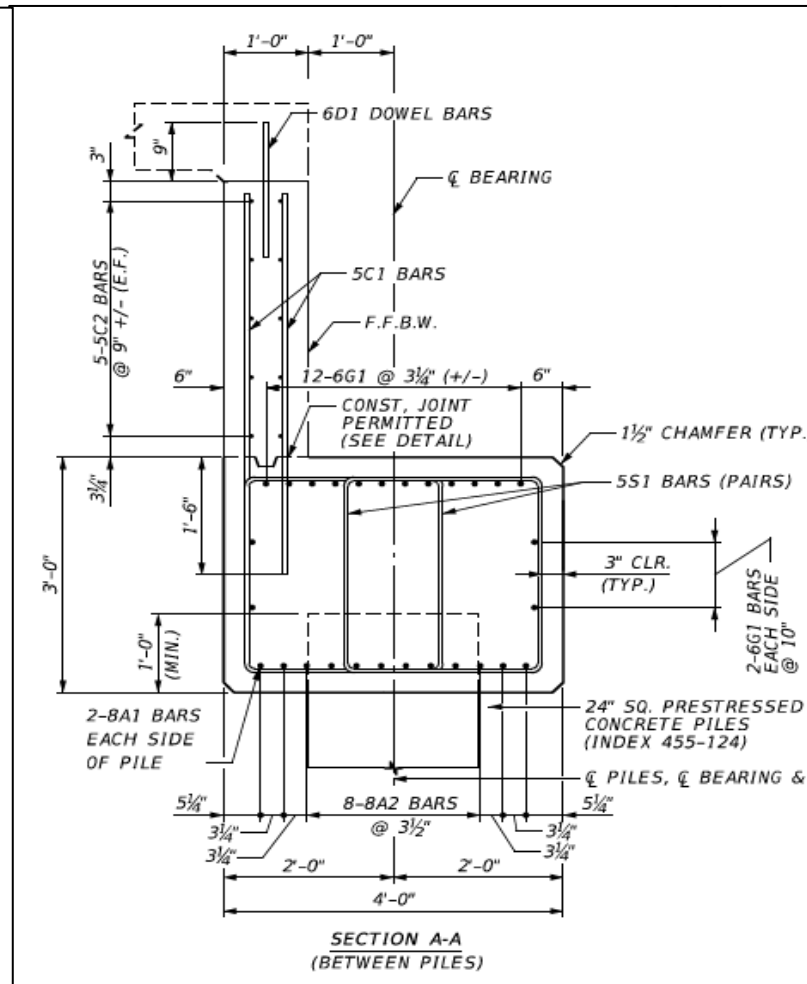
New Bridges Typical Section



Construction: D7 Example Project

New Bridge Elevation View

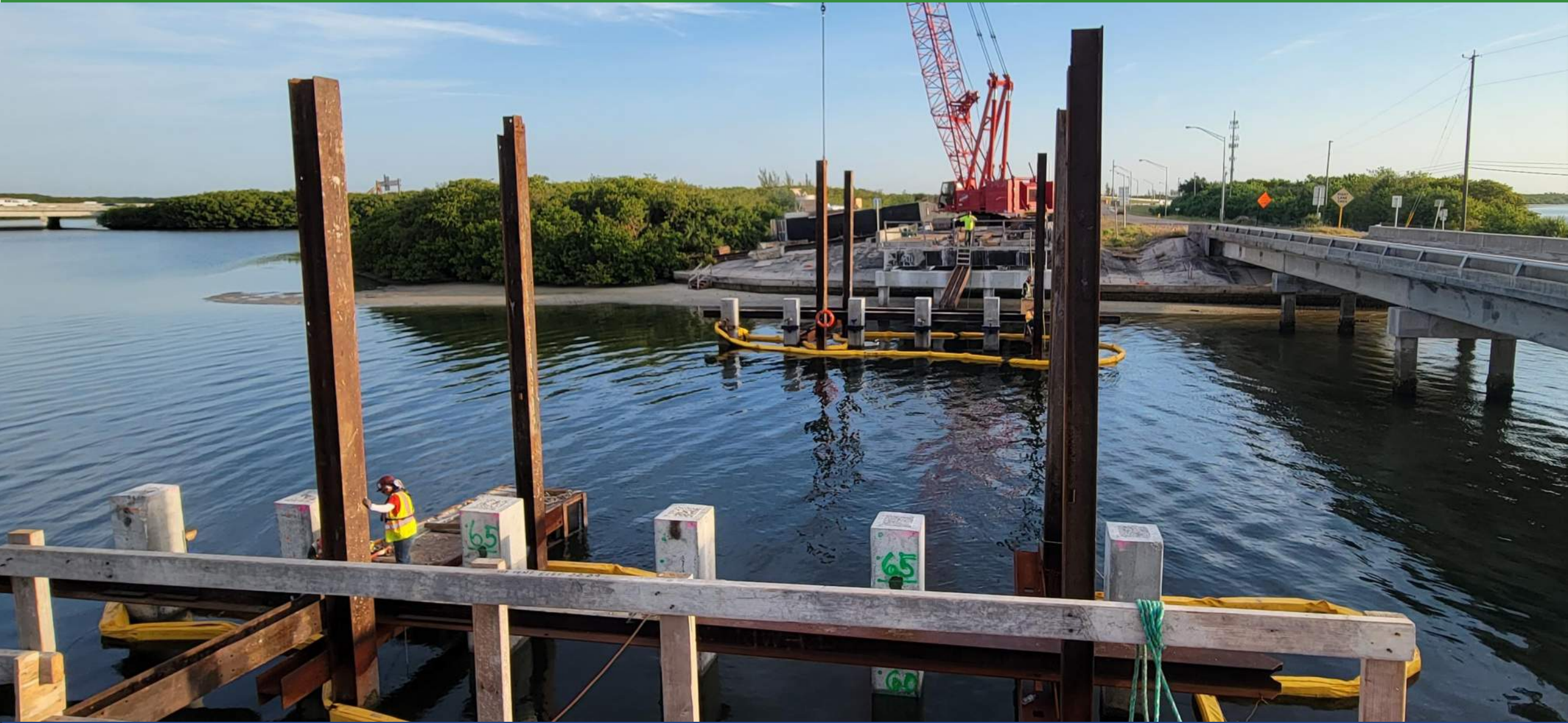




4th St North over
Big Island Gap
(430500-1)

Construction: D7 Example Project

Pile Installation & Pile Crack Repair

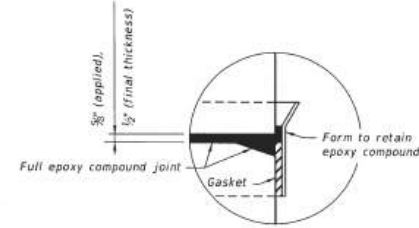


Construction: D7 Example Project

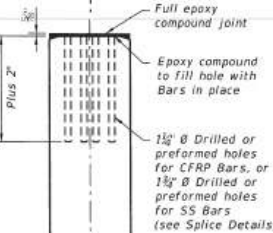
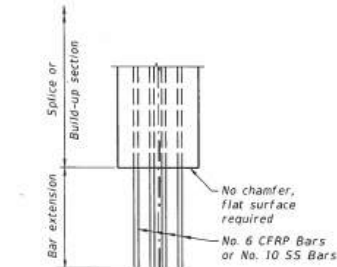
Pile Splice Build-Up Detail

NOTES:

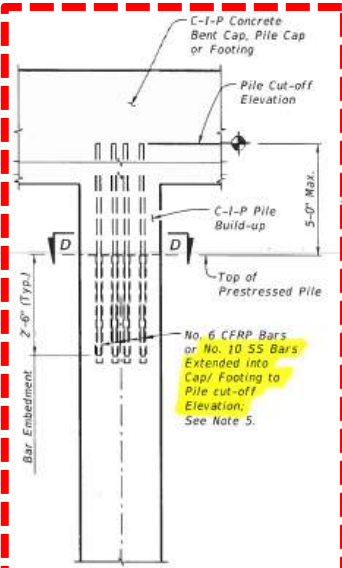
1. For Sections D-D, & E-E, see Index 455-112, 455-114, 455-118, 455-124 or 455-130 for applicable concrete pile size and Pile Splice Reinforcement Details.
2. Prestressing strands, spiral ties and/or reinforcement are not shown for clarity.
3. In cases where pile splices are desired due to length limitations in shipping and/or handling, the "Drivable Preplanned Prestressed Precast Splice Detail" shall be used.
4. When preformed dowel holes are utilized, the 1" spiral tie pitch shall be continued to 4'-0" below the head of the pile. See Index 455-118, 455-124. Preformed holes shall utilize either removable preforming material or stay-in-place corrugated galvanized steel ducts. Stay-in-place ducts shall be fabricated from galvanized sheet steel meeting the requirements of ASTM A653, Coating Designation G90, 26 gauge. Ducts shall be 1½" diameter for CFRP Bars, and 2" diameter for SS Bars with a minimum corrugation (rib) height of 0.12 in. Ducts shall be fabricated with either welded or interlocked seams. Galvanizing of welded seams will not be required.
5. For tension piles where top of Prestressed Pile is less than 3 feet below Pile Cut-off Elevation, extend No. 6 CFRP Bars or No. 10 SS into cap beyond Pile Cut-off Elevation to achieve development as approved by the Engineer.



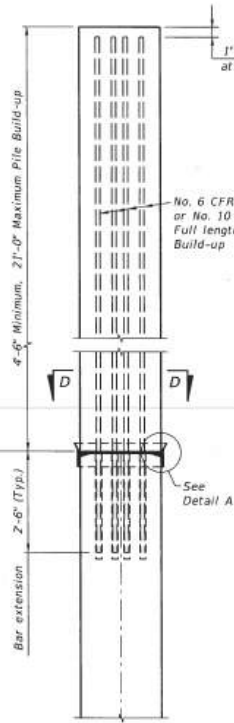
DETAIL A



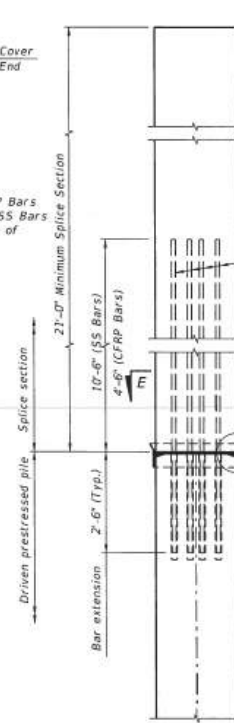
TYPICAL SPLICE BEFORE BONDING



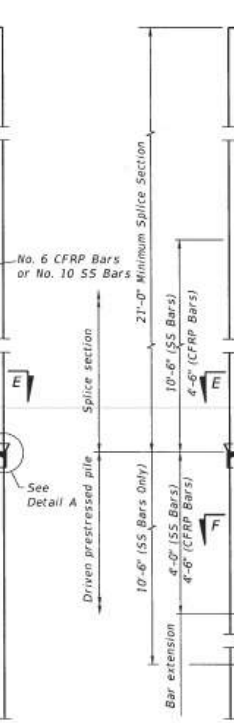
UNFORESEEN REINFORCED C-I-P PILE BUILD-UP DETAIL



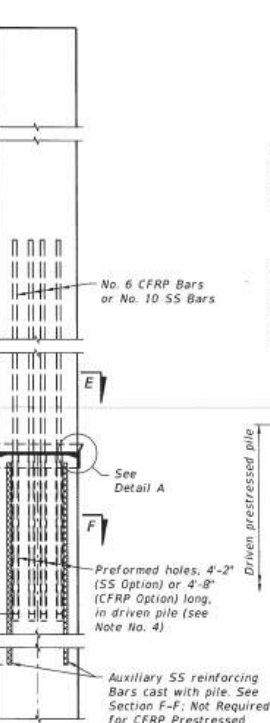
NONDRIVABLE UNFORESEEN REINFORCED PRECAST PILE BUILD-UP DETAIL



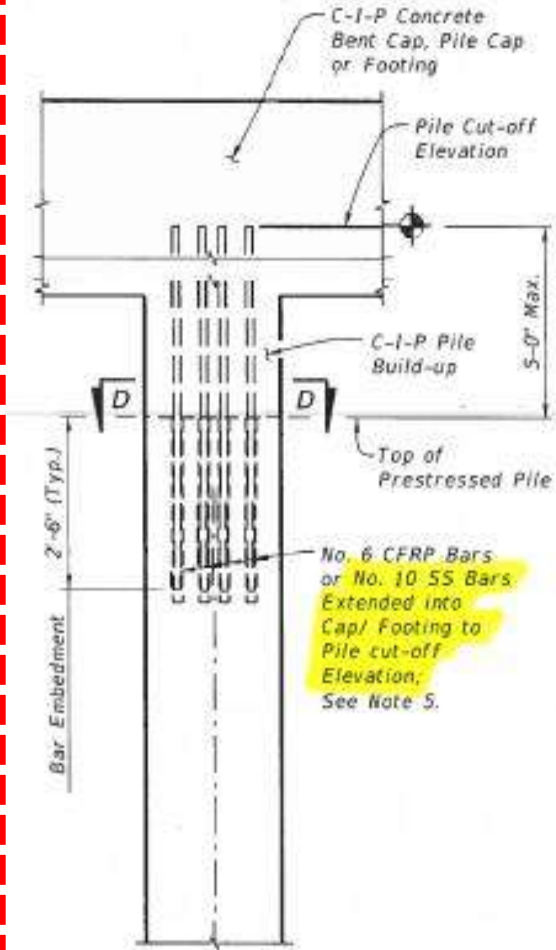
DRIVABLE UNFORESEEN PRESTRESSED PRECAST PILE SPLICE DETAIL



DRIVABLE PREPLANNED PRESTRESSED PRECAST PILE SPLICE DETAIL



DRIVABLE PREPLANNED PRESTRESSED PRECAST PILE SPLICE DETAIL



UNFORESEEN REINFORCED C-I-P PILE BUILD-UP DETAIL

01/24/21 44

01/24/21

REVISION
01/01/16

DESCRIPTION
REVISED

FDOT

FY 2021-22
STANDARD PLANS

SQUARE CFRP & SS PRESTRESSED
CONCRETE PILE SPLICES

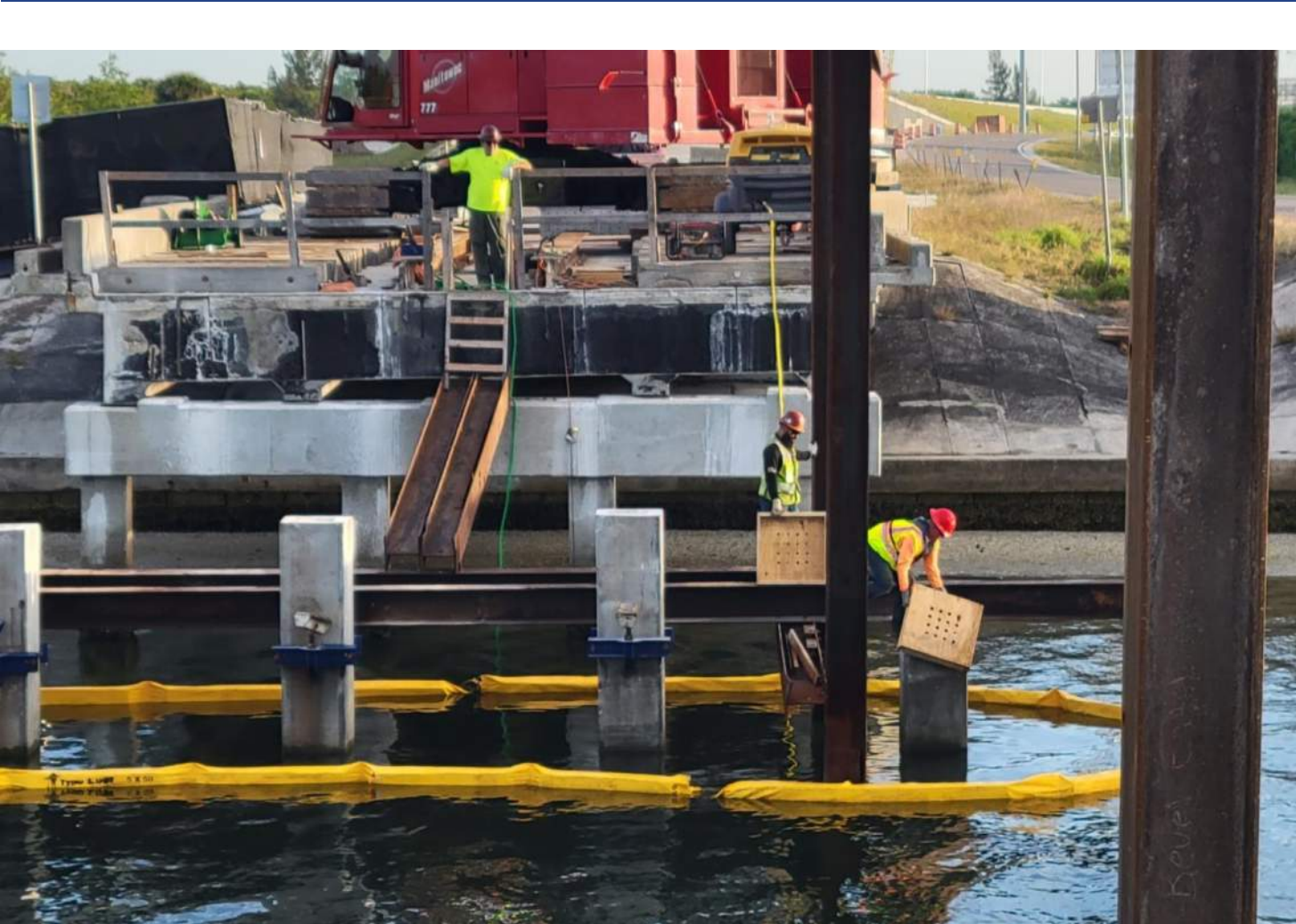
INDEX
455-102

SHEET
1 of 1

4th St North over
Big Island Gap
(430500-1)

Construction: D7 Example Project

Pile Splice Build-Up Construction



4th St North over
Big Island Gap
(430500-1)

Construction: D7 Example Project

Pile Splice Build-Up Construction



4th St North over
Big Island Gap
(430500-1)

Construction: D7 Example Project

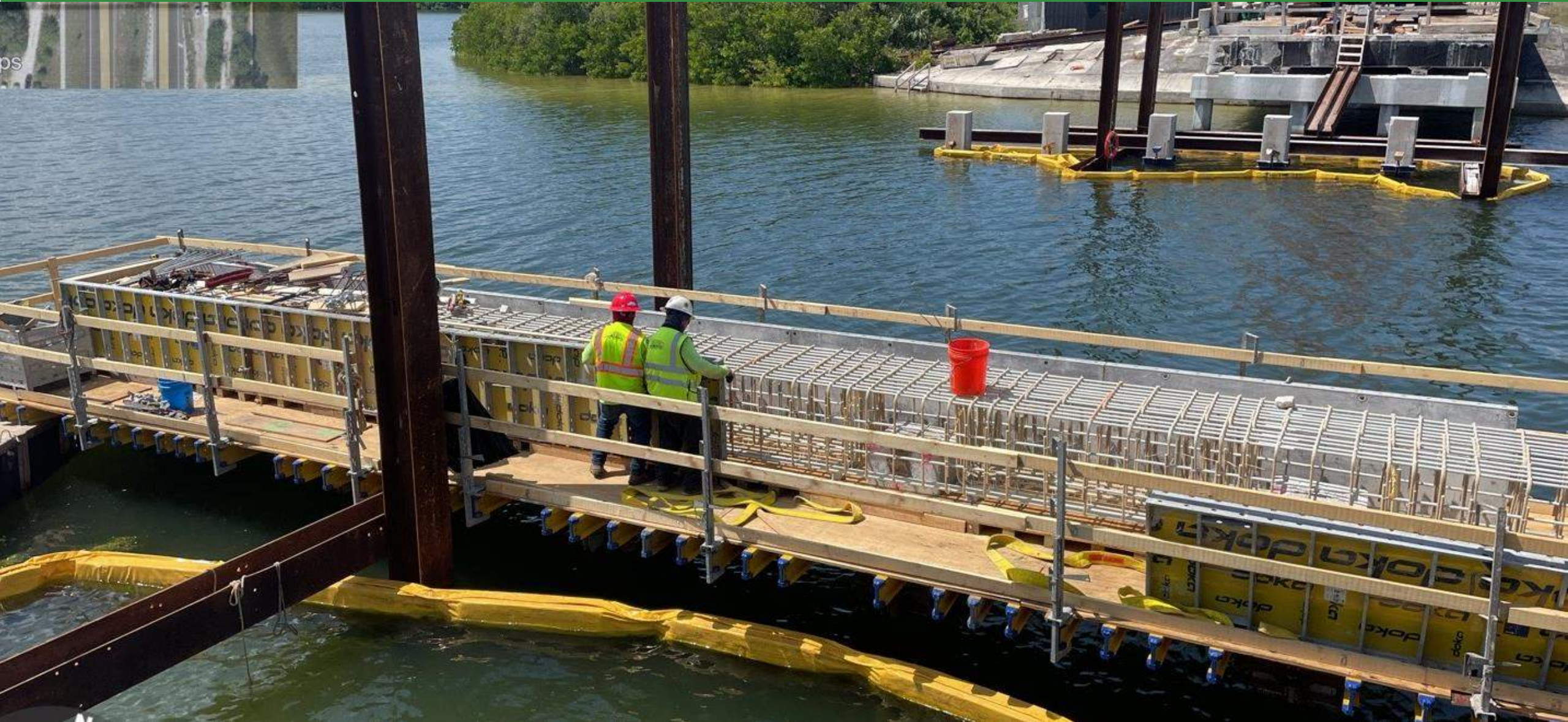
Cap, Backwall & Wingwall Construction



4th St North over
Big Island Gap
(430500-1)

Construction: D7 Example Project

Cap, Backwall & Wingwall Construction



4th St North over
Big Island Gap
(430500-1)

Construction: D7 Example Project Cap, Backwall & Wingwall Construction



4th St North over
Big Island Gap
(430500-1)

Construction: D7 Example Project

SB FIB-36 Placement (Span 2)



4th St North over
Big Island Gap
(430500-1)

Construction: D7 Example Project

SB FIB-36 Placement (Span 2)



4th St North over
Big Island Gap
(430500-1)

Construction: D7 Example Project

Cap, Backwall & Wingwall Construction



4th St North over
Big Island Gap
(430500-1)

Construction: D7 Example Project Cap, Backwall & Wingwall Construction



4th St North over
Big Island Gap
(430500-1)

Construction: D7 Example Project Cap, Backwall & Wingwall Construction



4th St North over
Big Island Gap
(430500-1)

Construction: D7 Example Project

Cap, Backwall & Wingwall Construction



4th St North over
Big Island Gap
(430500-1)

Construction: D7 Example Project

Hurricane Storm Surge



Hurricane Idalia

Category 4 Hurricane

August 30, 2023

**TRANSPORTATION
SYMPOSIUM**

4th St North over
Big Island Gap
(430500-1)

Construction: D7 Example Project

Hurricane Storm Surge



Hurricane Idalia

Category 4 Hurricane

August 30, 2023

TRANSPORTATION
SYMPOSIUM

4th St North over
Big Island Gap
(430500-1)

Construction: D7 Example Project

Completed Bridge November 2023

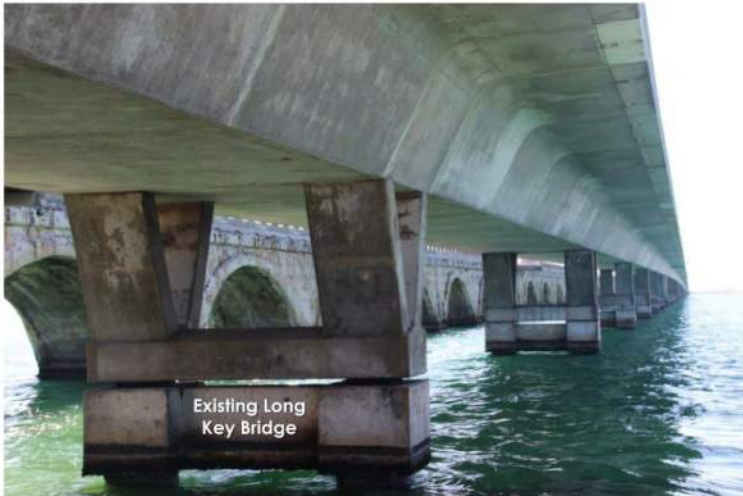


Future Construction: D6 Example Projects

- Long Key Bridge Replacement ([448206-1](#) & [448207-1](#))

FDOT SR 5/US 1 LONG KEY BRIDGE OVER LONG KEY CHANNEL PD&E STUDY | FPID 448206-1-22-01 | ETDM 14451
DISTRICT 6 ALTERNATIVE BRIDGE REINFORCEMENT COORDINATION MEETING

Long Key Bridge Facts

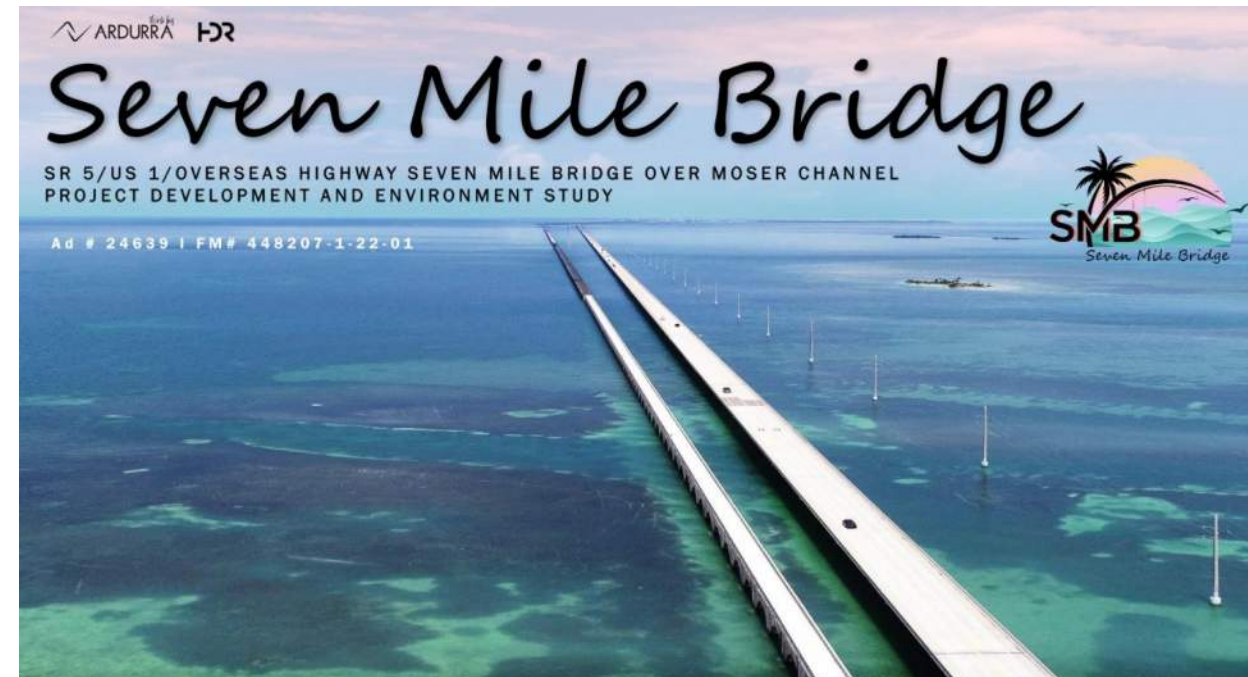


Part of the 110-mile Florida Keys National Scenic Highway / All-American Road

Also known as the Dante B. Fascell Bridge	
	Year Constructed: 1981
	Bridge Type: Precast Segmental Box Bridge
	Vertical Clearance: 25.54 feet
	Horizontal Clearance: 111.0 feet
	Bridge Length: 12,152 feet (2.3 miles)
	Travel Lanes: Two 12-foot travel lanes
	Shoulders: 6-foot paved shoulders on both sides of the bridge also function as undesignated bicycle lanes
	Sidewalks: No existing sidewalks

Letting Date: 03/15/2027

- Seven Mile Bridge Replacement ([448207-1](#))

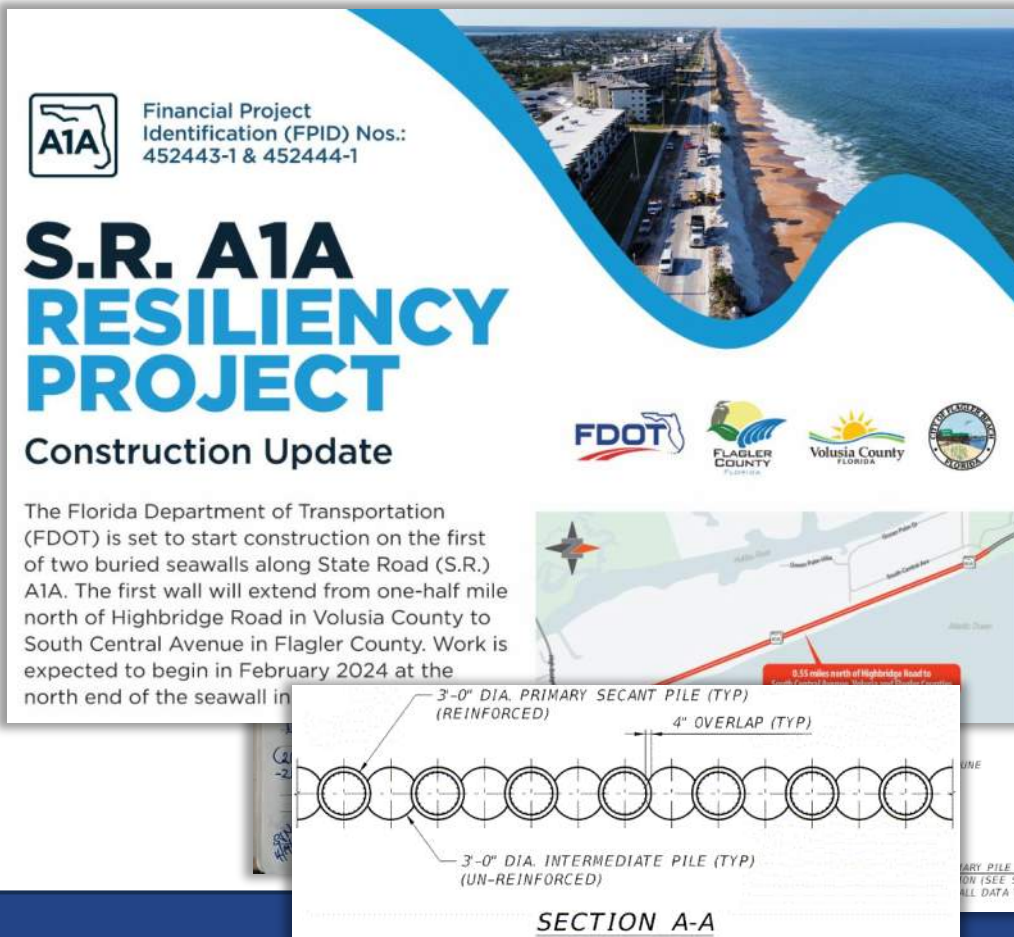


Letting Date: 03/11/2030

**TRANSPORTATION
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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*



Financial Project Identification (FPID) Nos.: 452443-1 & 452444-1

S.R. A1A RESILIENCY PROJECT

Construction Update

The Florida Department of Transportation (FDOT) is set to start construction on the first of two buried seawalls along State Road (S.R.) A1A. The first wall will extend from one-half mile north of Highbridge Road in Volusia County to South Central Avenue in Flagler County. Work is expected to begin in February 2024 at the north end of the seawall in

FDOT **FLAGLER COUNTY** **Volusia County** **FLORIDA**

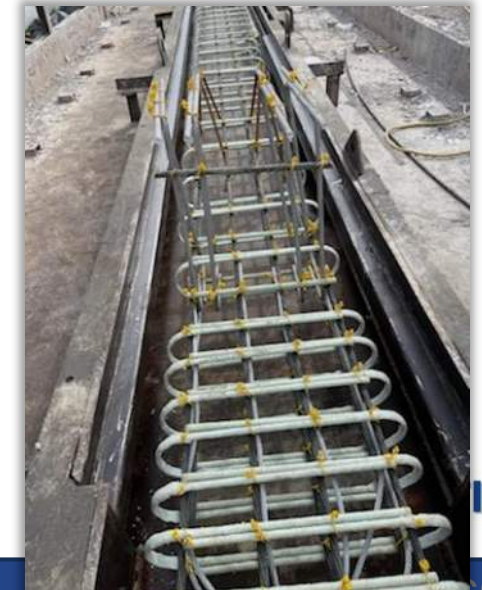
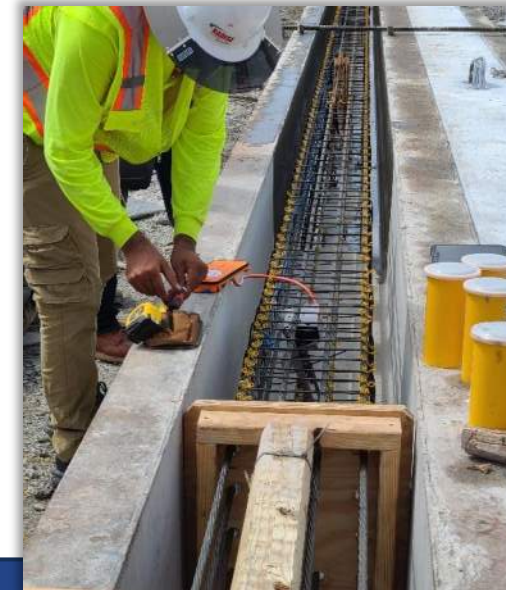
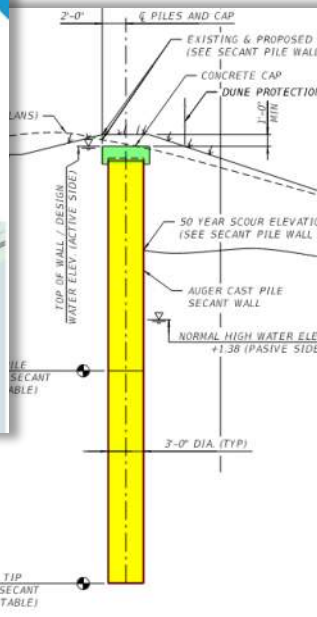
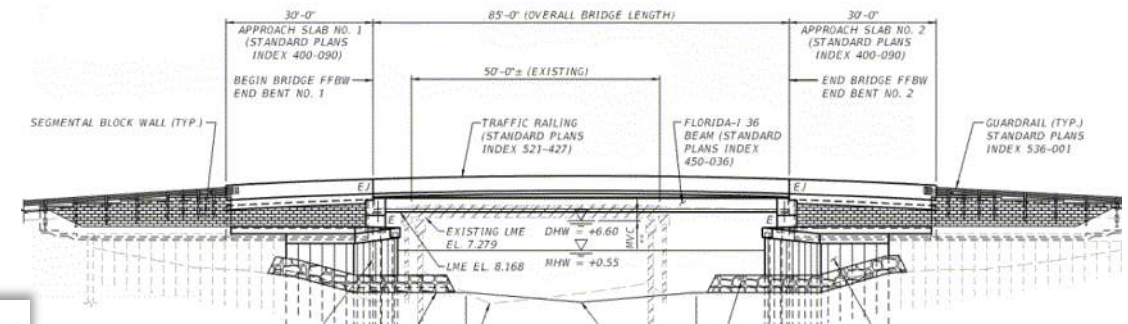
0.55 miles north of Highbridge Road to

SECTION A-A

3'-0" DIA. PRIMARY SECANT PILE (TYP) (REINFORCED)

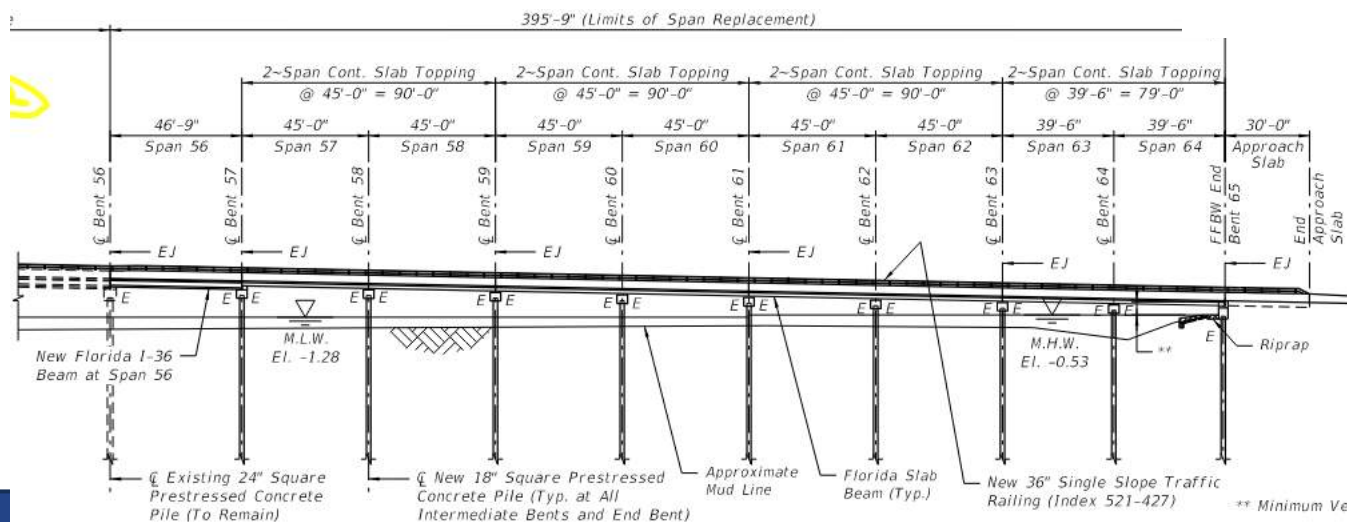
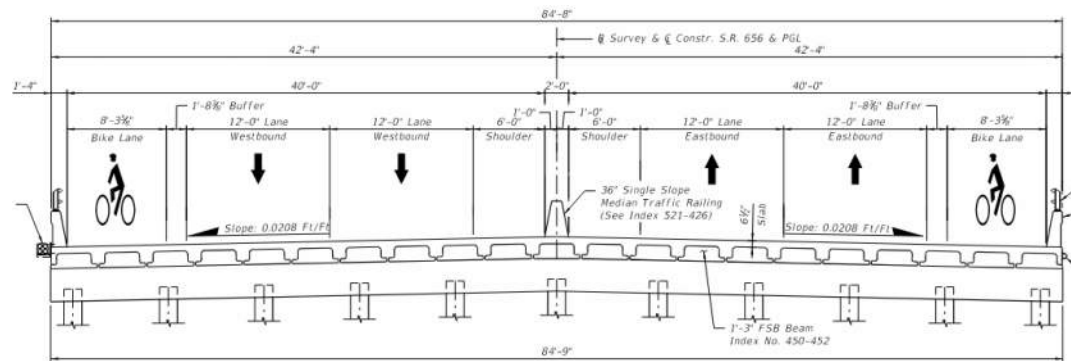
4" OVERLAP (TYP)

3'-0" DIA. INTERMEDIATE PILE (TYP) (UN-REINFORCED)

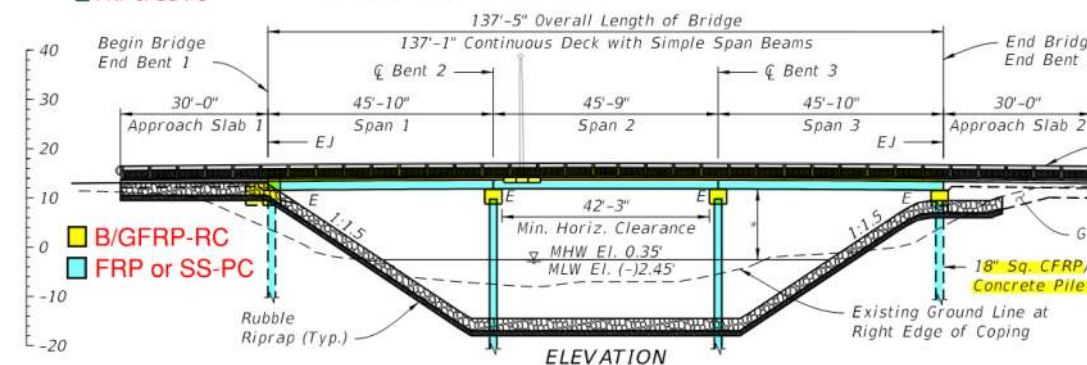
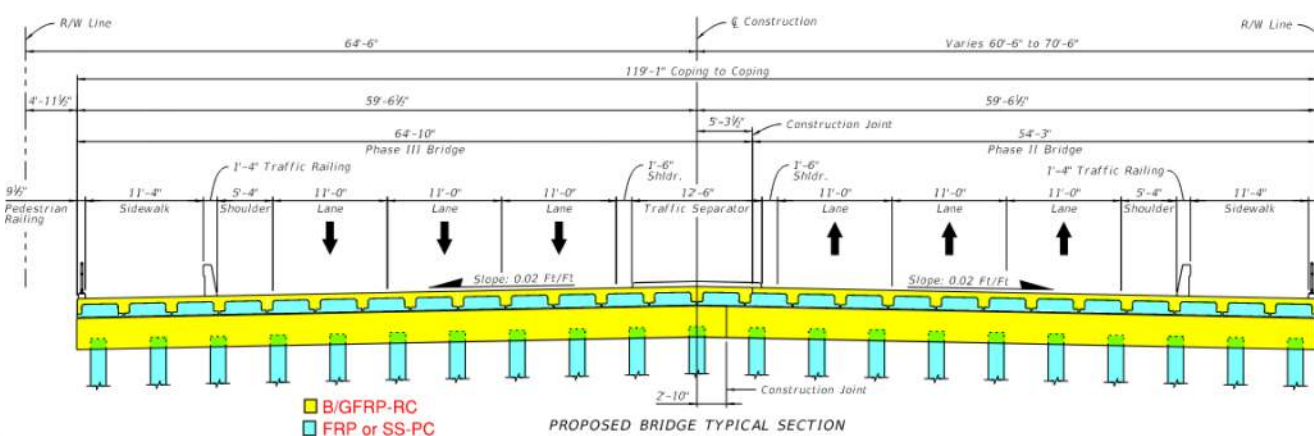


Construction: D4 Example Projects

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

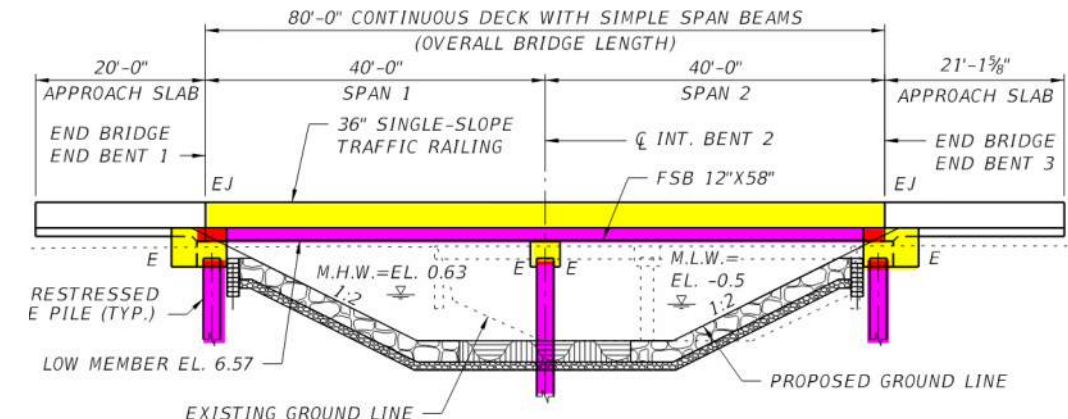
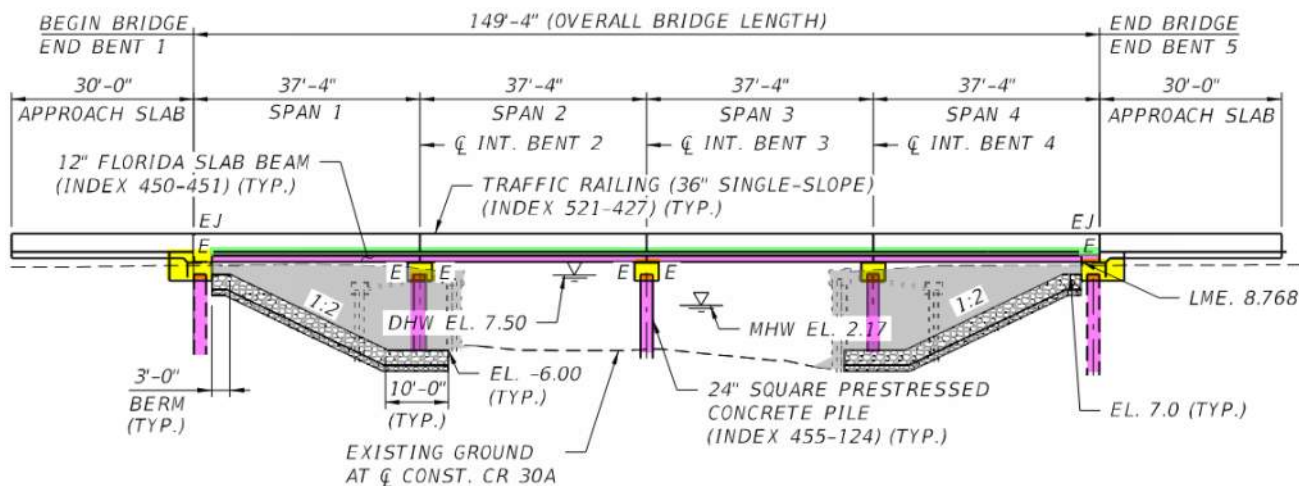
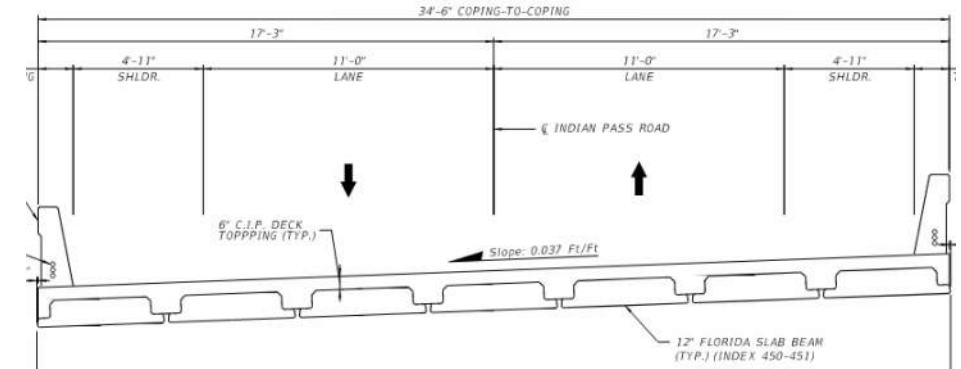
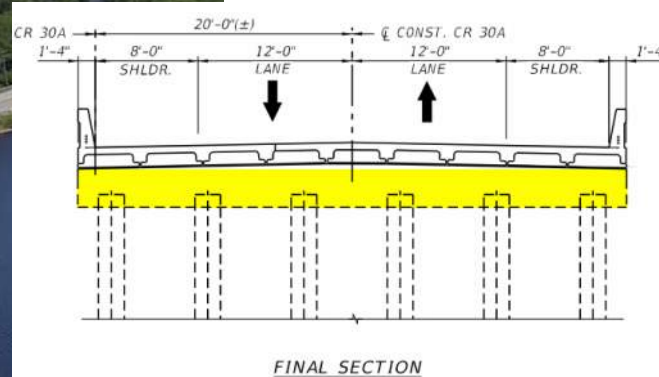
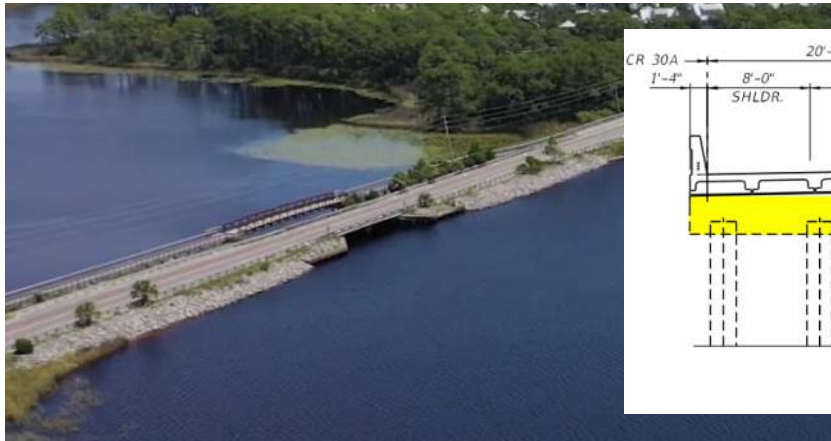


- SR 5/US 1 Over Earman River
([442891-1](#)) *In-house Design*



Construction: D3 Example Projects

- CR30A over Western Lake ([443331-1](#))
- CR30B/Indian Lagoon ([441185-2](#))



Future Construction: D2 Example Projects

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

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

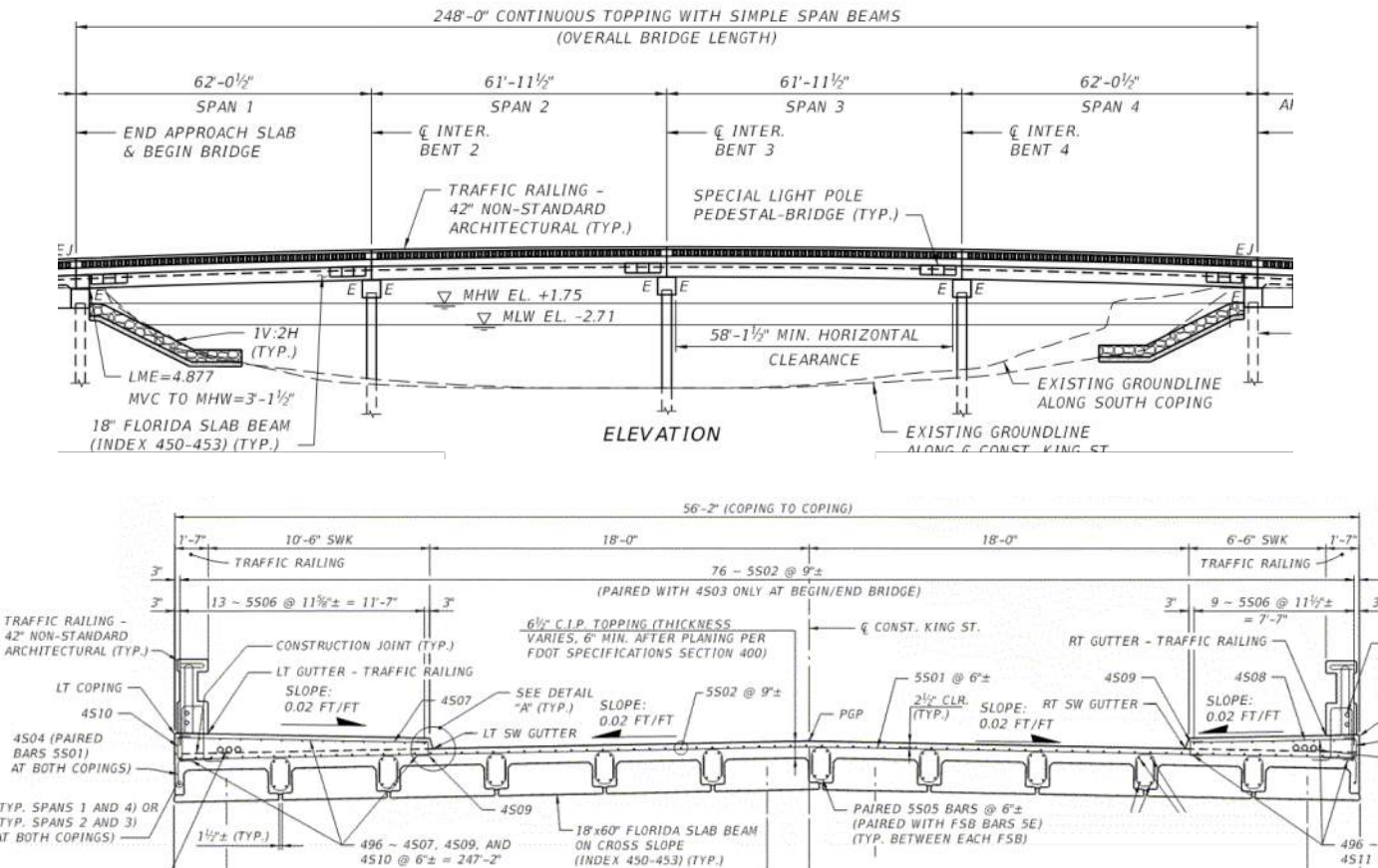
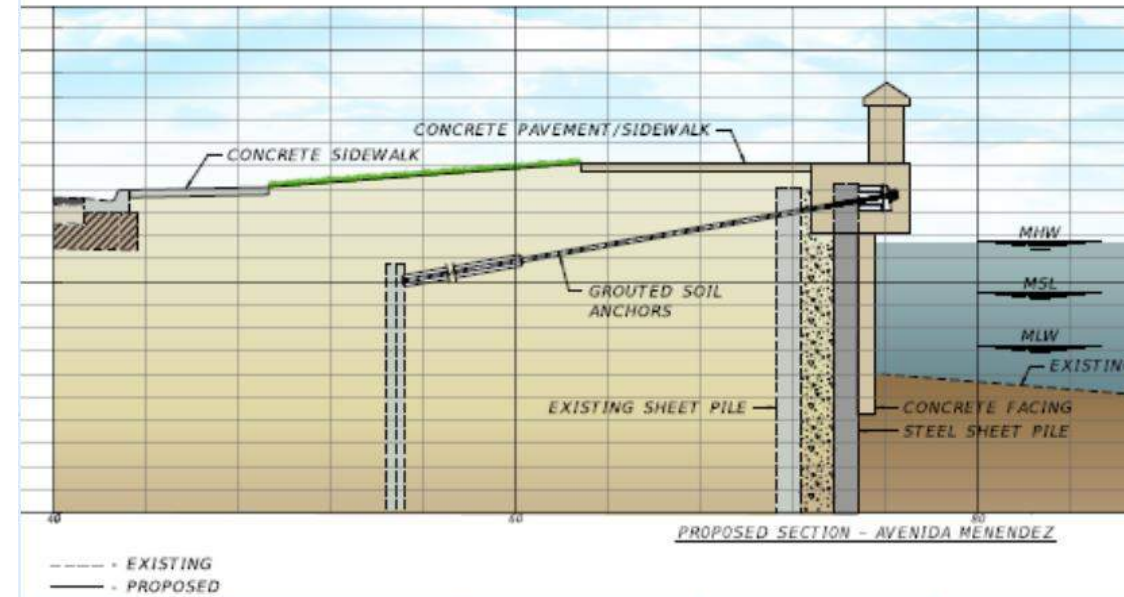


Figure 2 - Proposed Bulkhead Typical Section



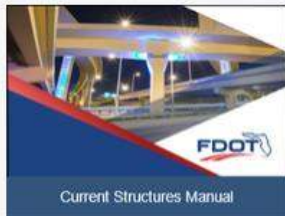
More Info: FRP RC/PC Design Innovation Webpage

WELCOME TO THE STRUCTURES DESIGN OFFICE

Office Manager: Will Potter, P.E. – State Structures Design Engineer

The Structures Design Office provides design guidance and technical assistance for structural, geotechnical, mechanical and electrical issues related to structural design and construction. The Structures Design Office is 1 of 3 divisions under the **Office of Design**, along with **Roadway Design**, and the **CADD Office**.

Most Requested



Current Structures Manual



Current e-Book



Structures Design Software Downloads



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Structures Divisions



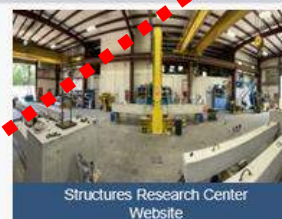
Structures Criteria Website



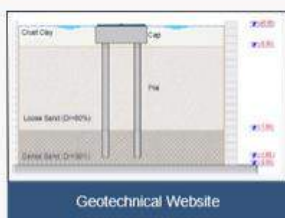
Structures Design Software Website



Structures Design Software Website



Structures Research Center Website



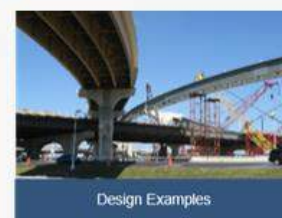
Geotechnical Website



Innovations Website



Plans Review Website



Design Examples

Structures Design Office

Contact: [Steven Nolan, P.E.](#) Phone: (850) 414-4272



Curved Precast Spliced U-Girder Bridges



Fiber-Reinforced Polymer Reinforcing (Bars & Strands)



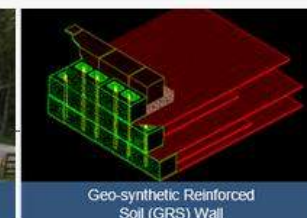
Fiber-Reinforced Polymer Members and Structures



Geo-synthetic Reinforced Soil Integrated Bridge System



Segmental Block Walls (SBW)



Geo-synthetic Reinforced Soil (GRS) Wall



Ultra-High Performance Concrete (UHPC)

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 \(T²\)](#)

[FDOT Research](#)

[Contact](#)

**TRANSPORTATION
SYMPOSIUM**

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



NO text.

NO call.

NOTHING

is worth losing a life over.



Syed (Hamed) Kazimi, P.E.

District 7 Structures Design Office
Florida Dept. of Transportation

Email: Syed.Kazimi@dot.state.fl.us

Office #: 813-975-6771



Steven Nolan, P.E.

State Structures Design Office
Florida Dept. of Transportation

Email: steven.nolan@dot.state.fl.us

Office #: 850-414-4272

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





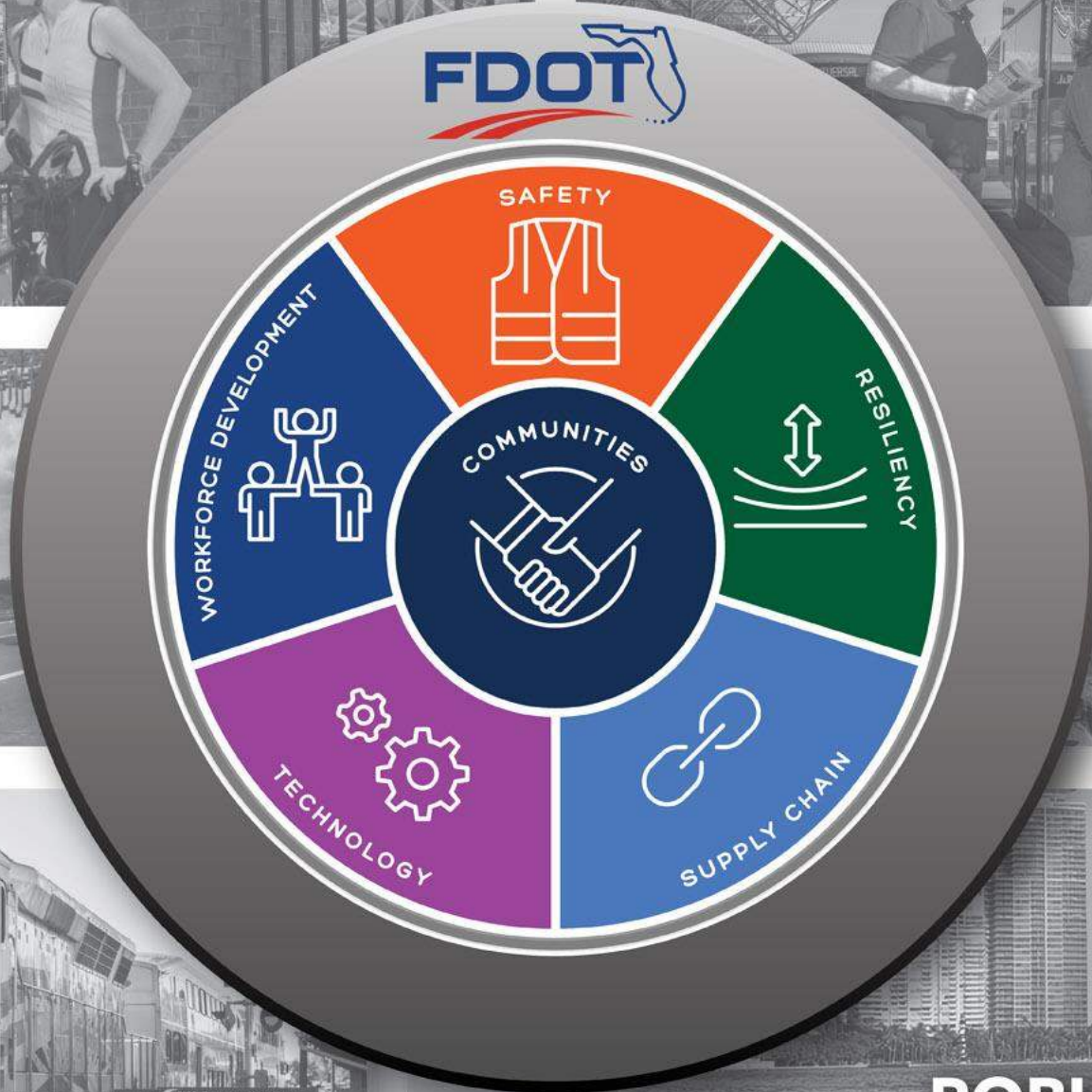
SAFETY



COMMUNITIES



**WORKFORCE
DEVELOPMENT**



RESILIENCY



TECHNOLOGY



ROBUST SUPPLY CHAIN