Orlando, FL

November 7-8, 2024

2024 TRANSPORTATION SYMPOSIUM

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


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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 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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# 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.

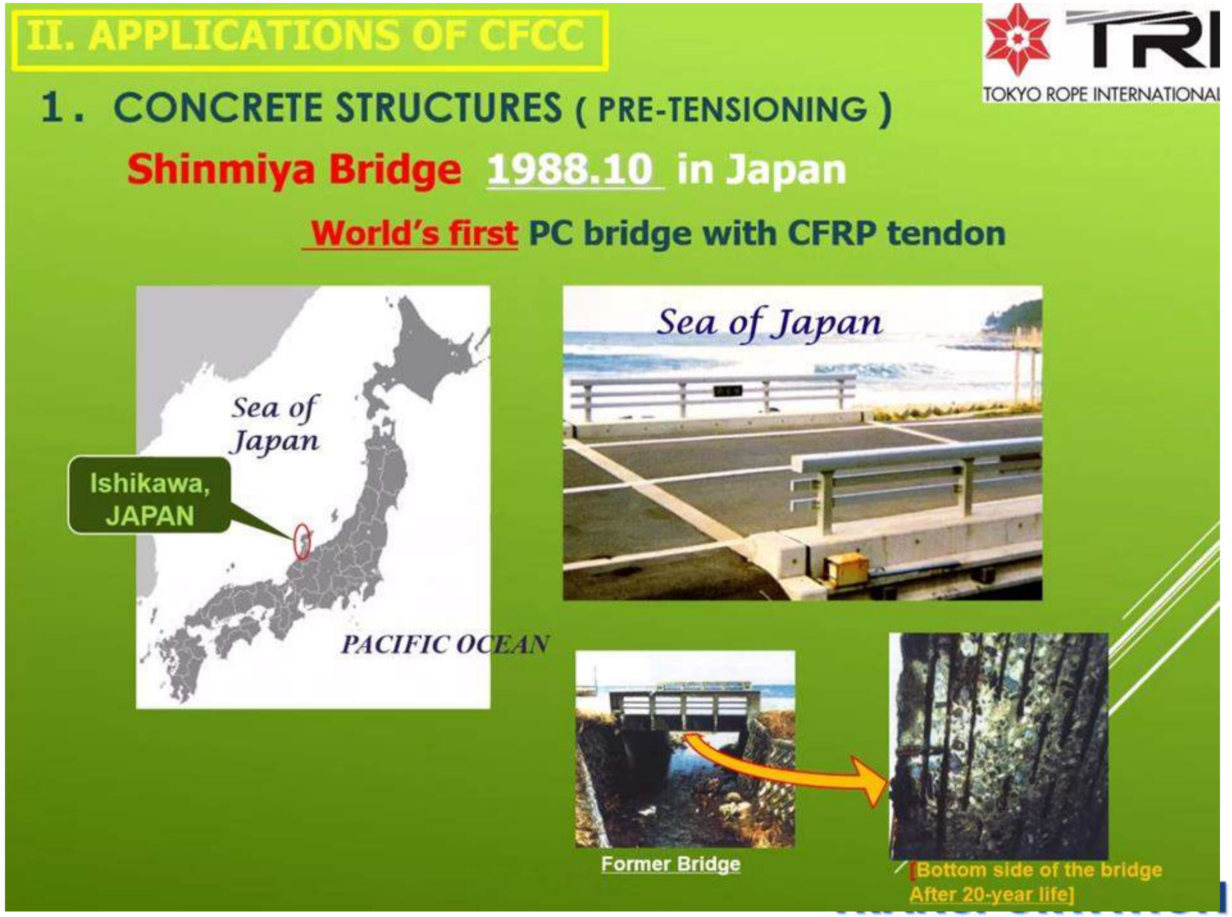
Professional Engineer in Florida since 2003, current technical lead coordinator for Florida DOT for implementation of Fiber-Reinforced Polymer reinforcing and prestressing, stainless-steel prestressing, and UHPC for structural applications. 10-years' experience with development of design guidance for 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 Wa[redacted]Back: CFRP Prestressing Strand

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



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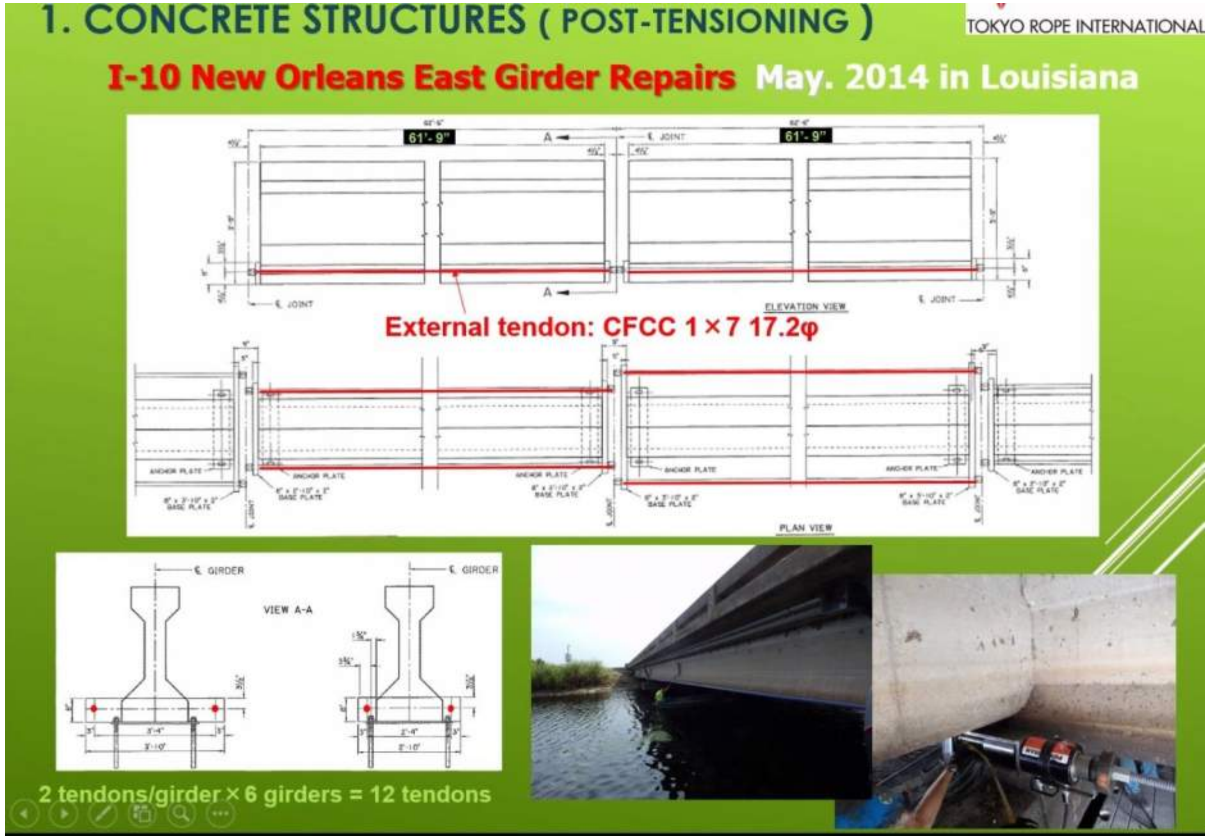
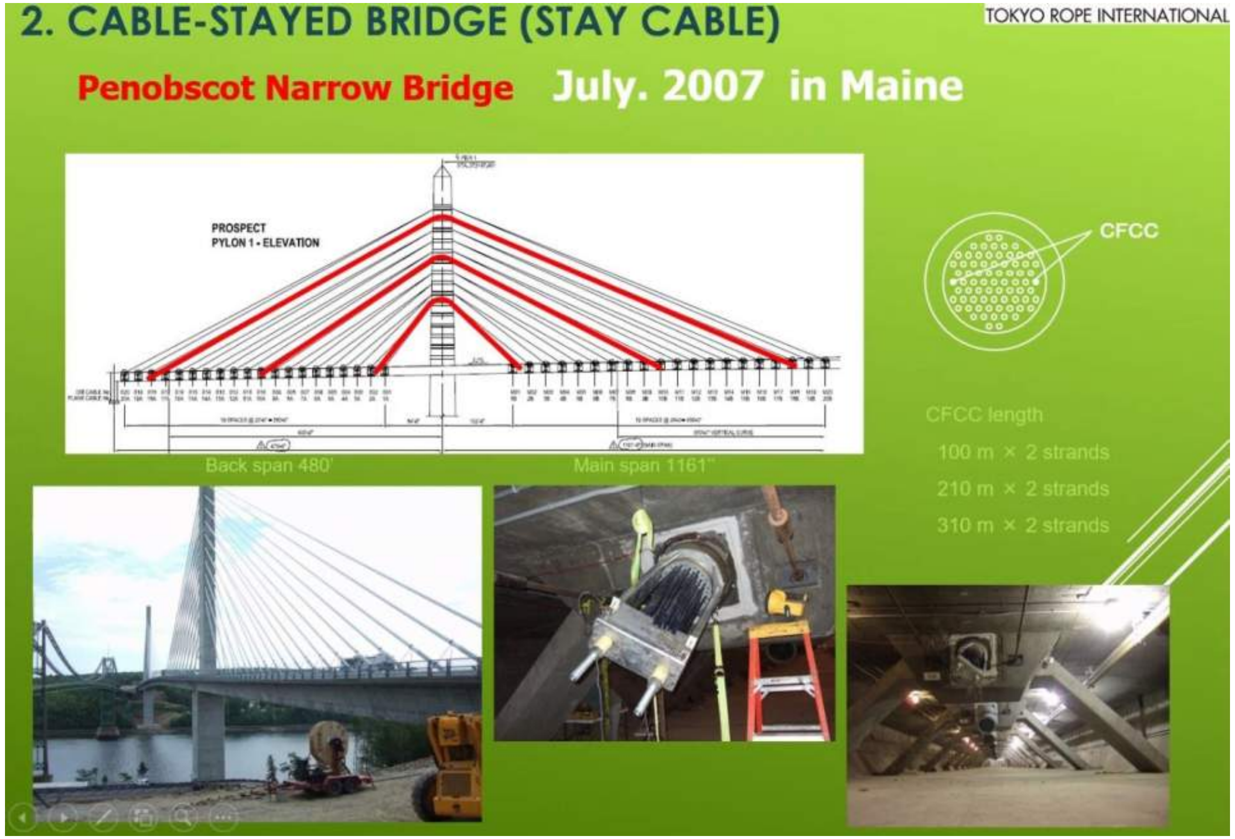
# Back a Decade : CFRP Prestressing Strand

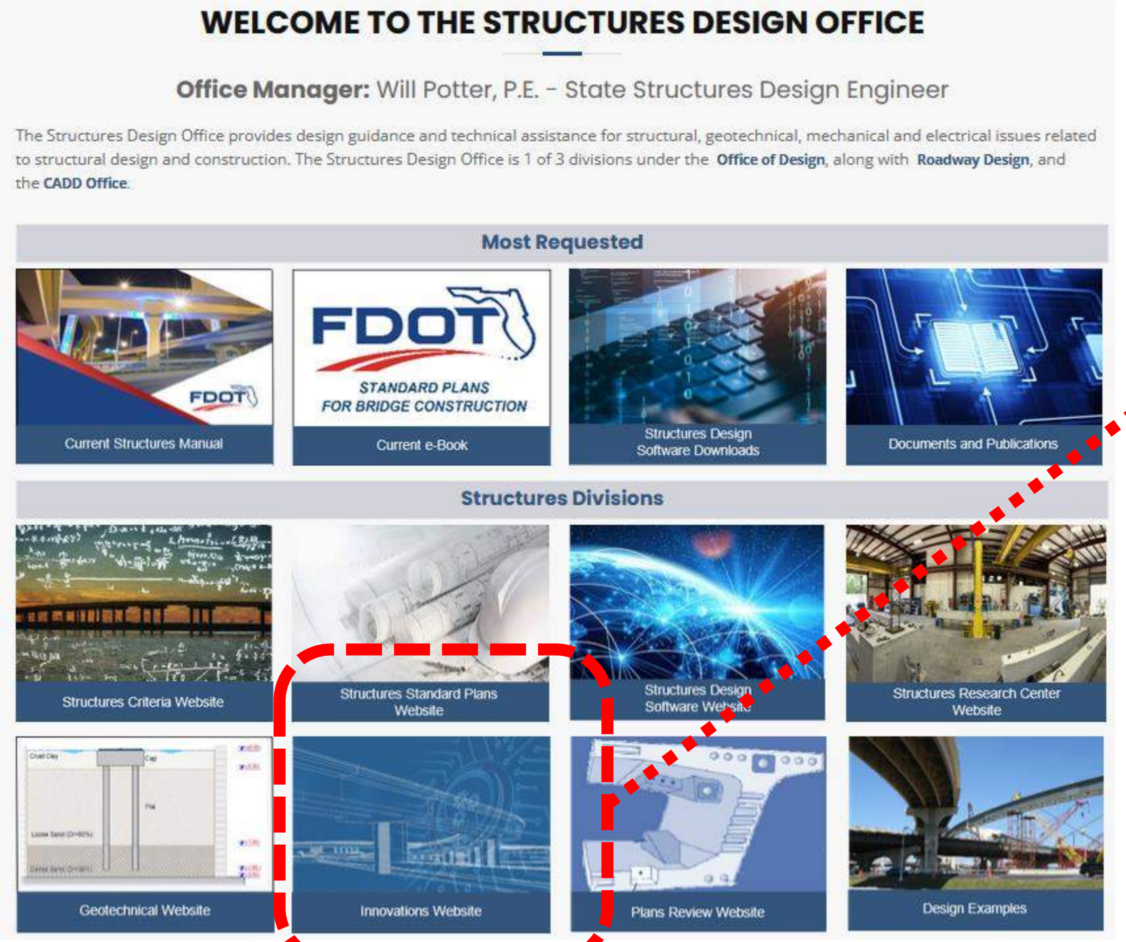
- 2014 (Louisiana) & 2016 (Maine)



# 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 (T[2])
- FDOT Research
- Contact

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*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) |

# 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. 202[redacted]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 | - | - |

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# 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%* $f_u$).

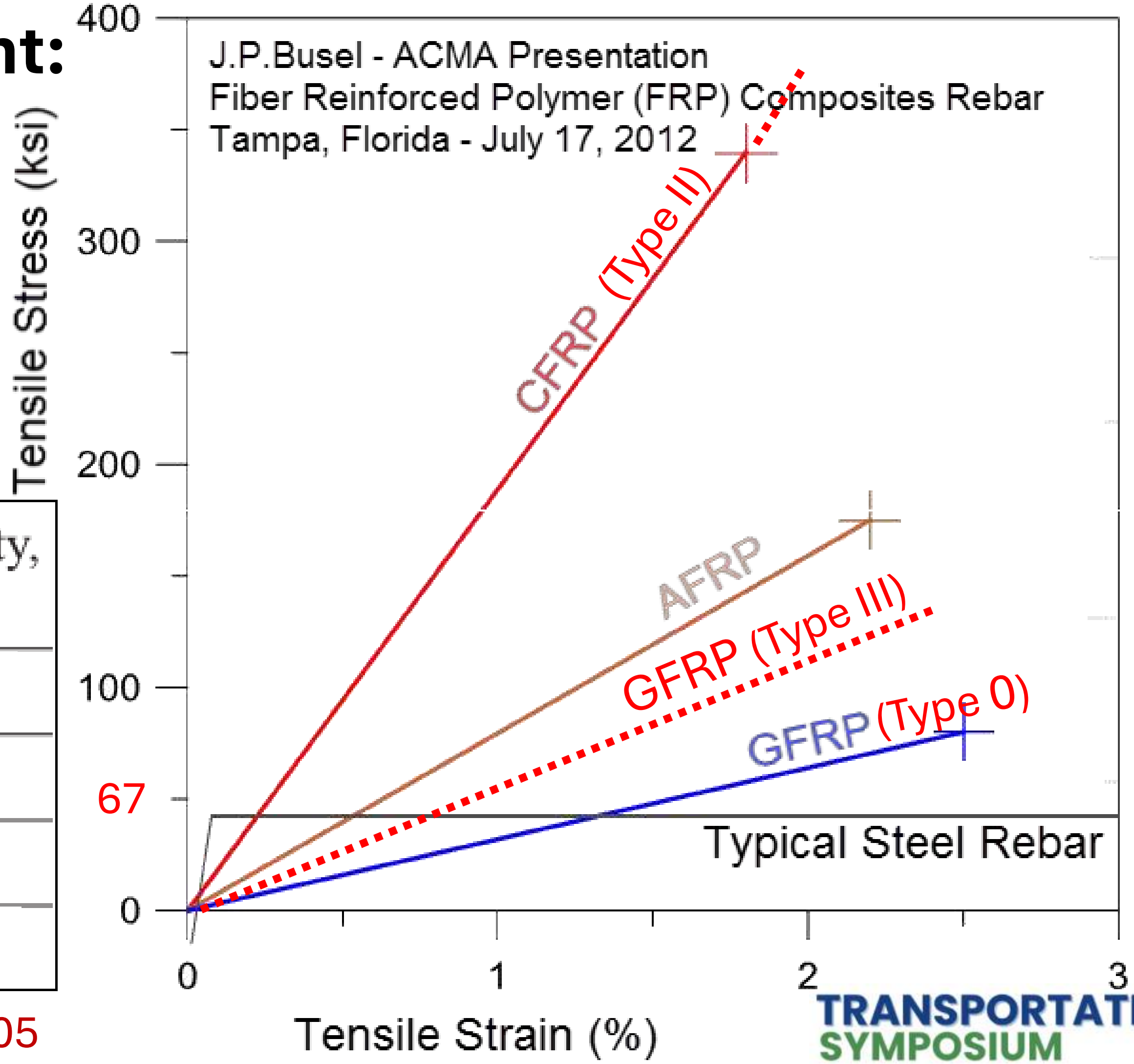
# A. Reinforcing Bars

**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

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# 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 *($C_E = 0.70$)*

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# 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)<br>or<br>ASTM E1356 (DSC) | ≥230°F<br><br>≥212°F |

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

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# 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
  - Metakaolin
  - Ultrafine Fly Ash
  - ~~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

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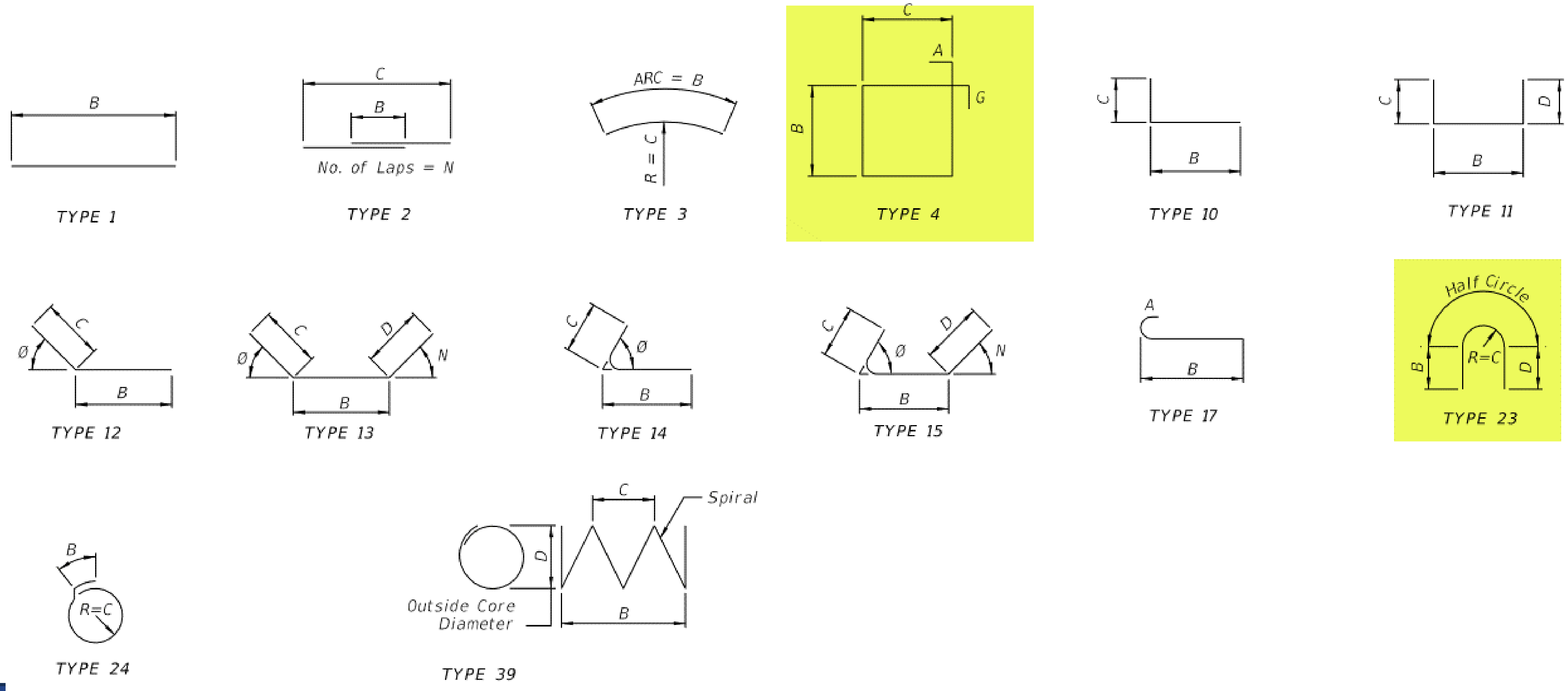
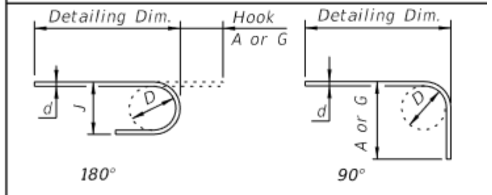
# A. Reinforcing Bars

**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 | 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 |

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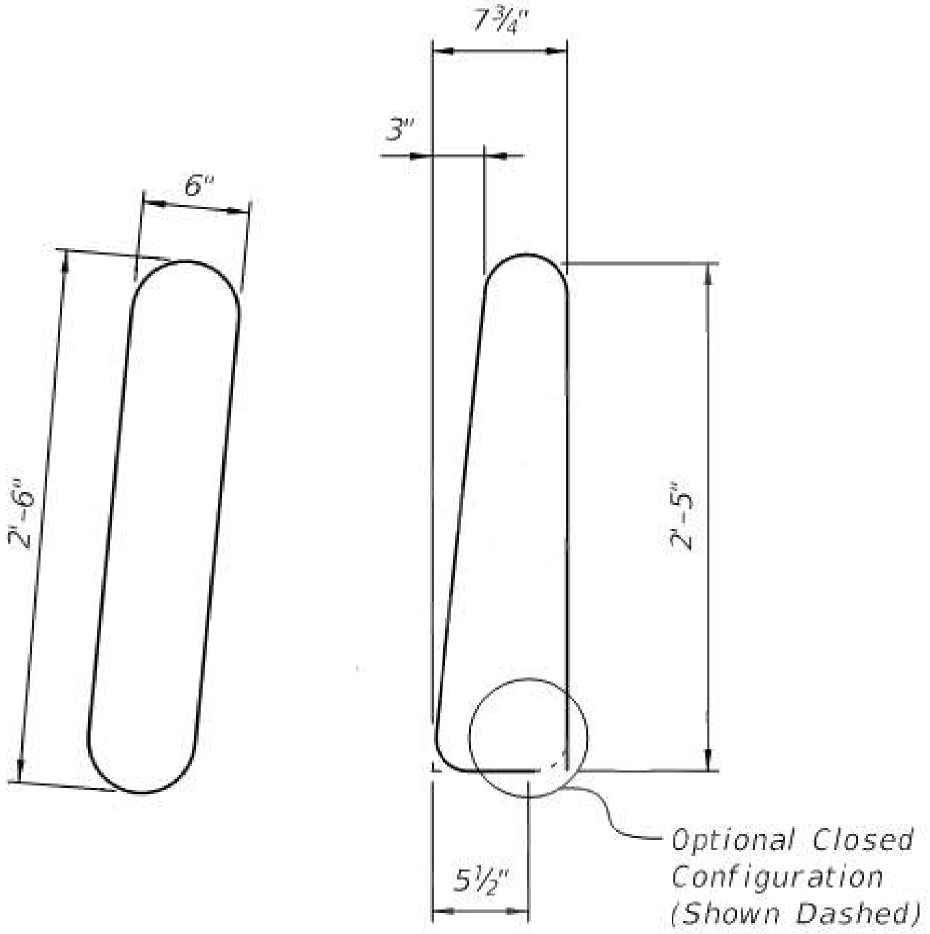
# A. Reinforcing Bars

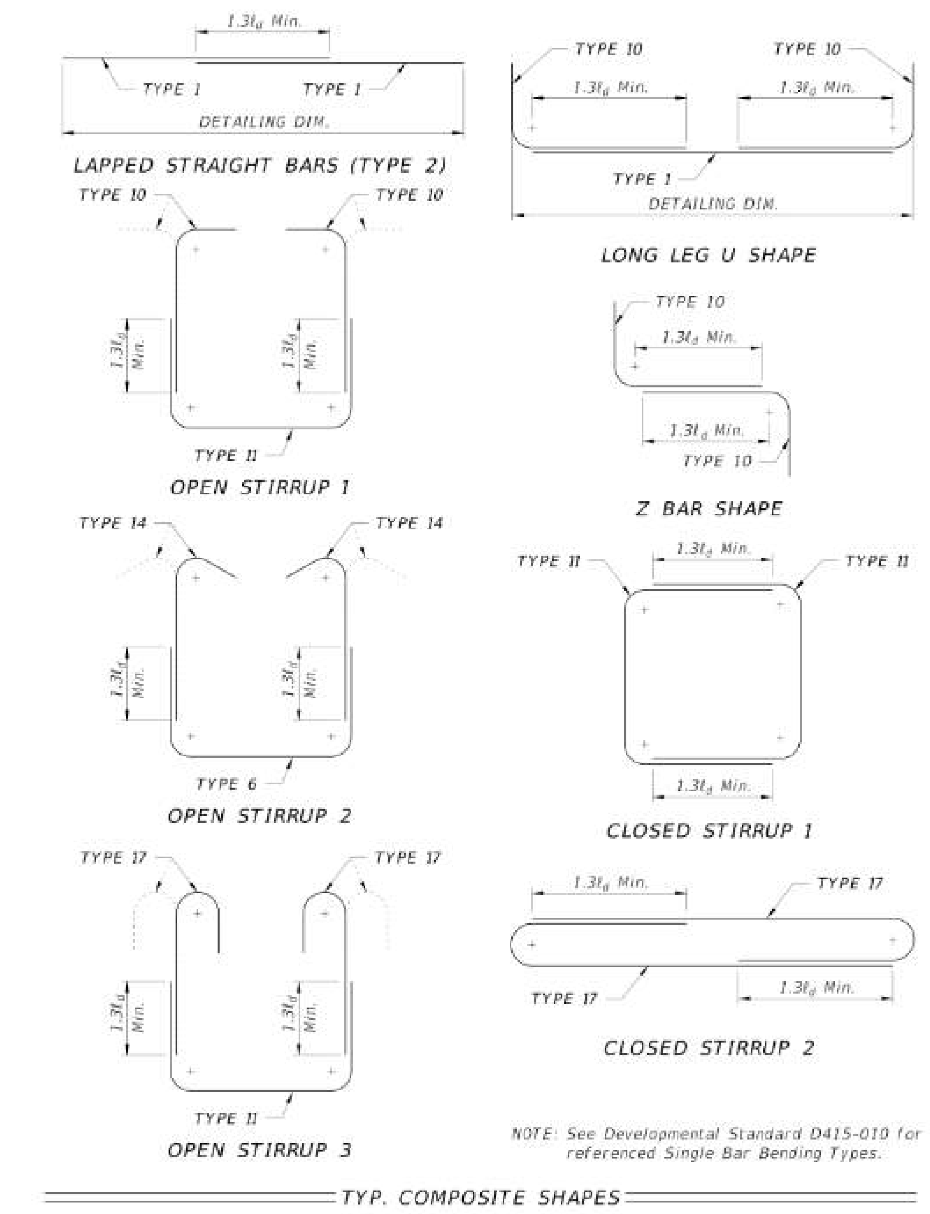
**Complex Shapes:**




Standard Plans Instructions | Topic No. 625-010-003

Index 415-010 Bar Bending Details (FRP) | FY 2024-25

**Design Aids**

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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

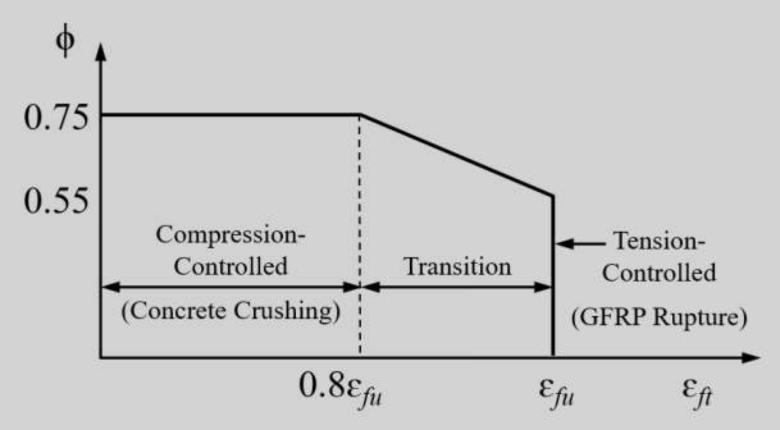
**Flexural Strength Design Philosophy**

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

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# 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 |

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

# B. FDOT Research [redacted] 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

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# 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.**

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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

# 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.~~*

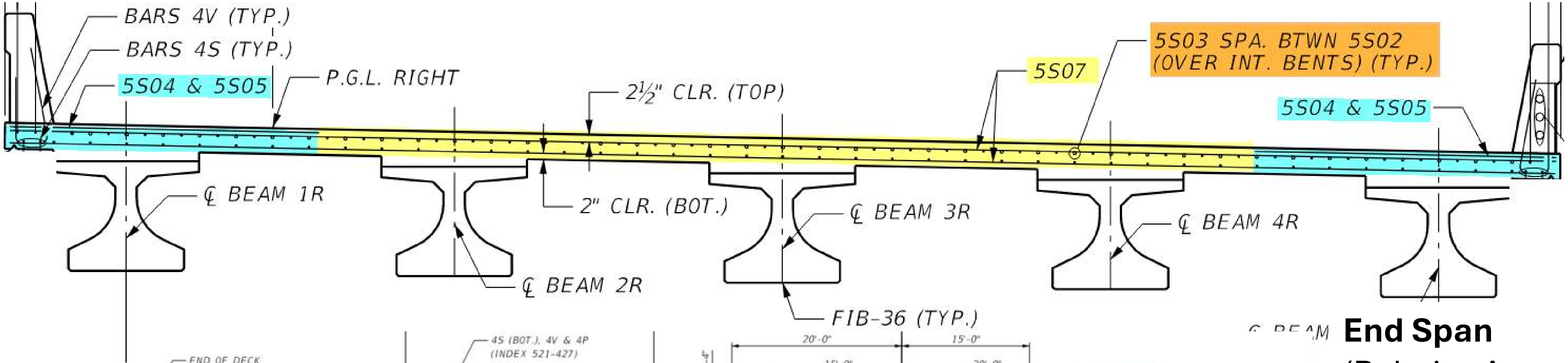
- *AASHTO Guide Specification for the Design of Concrete Bridge Beams Prestressed with CFRP Systems. ~~ACI 440.4 Prestressing Concrete Structures with FRP Tendons~~*

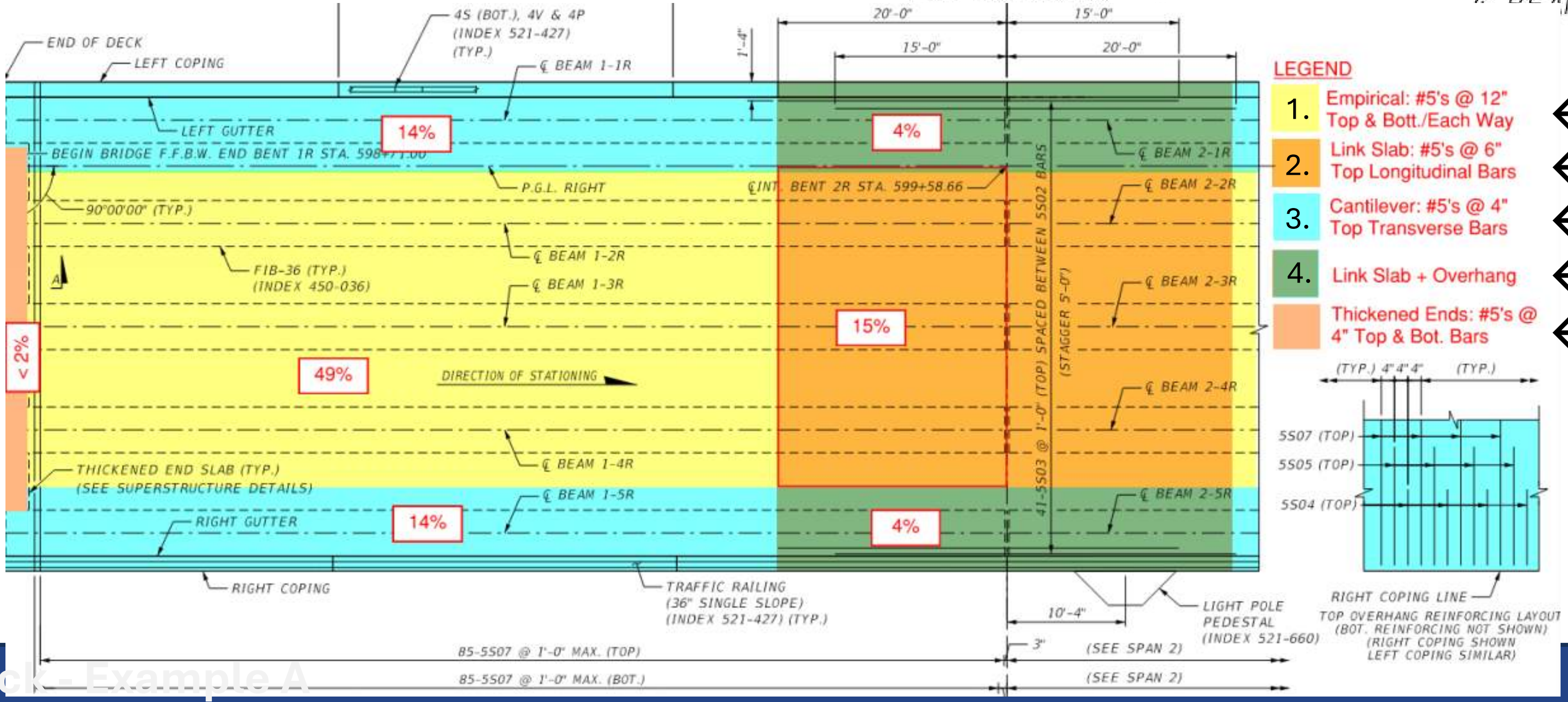
Design **Bridge Decks** according to:

- *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. [redacted] Bridge Deck Example A




**End Span**
(Relative Areas):

← 49%
← 15%
← 28%
← 8%
← Ignore <2%

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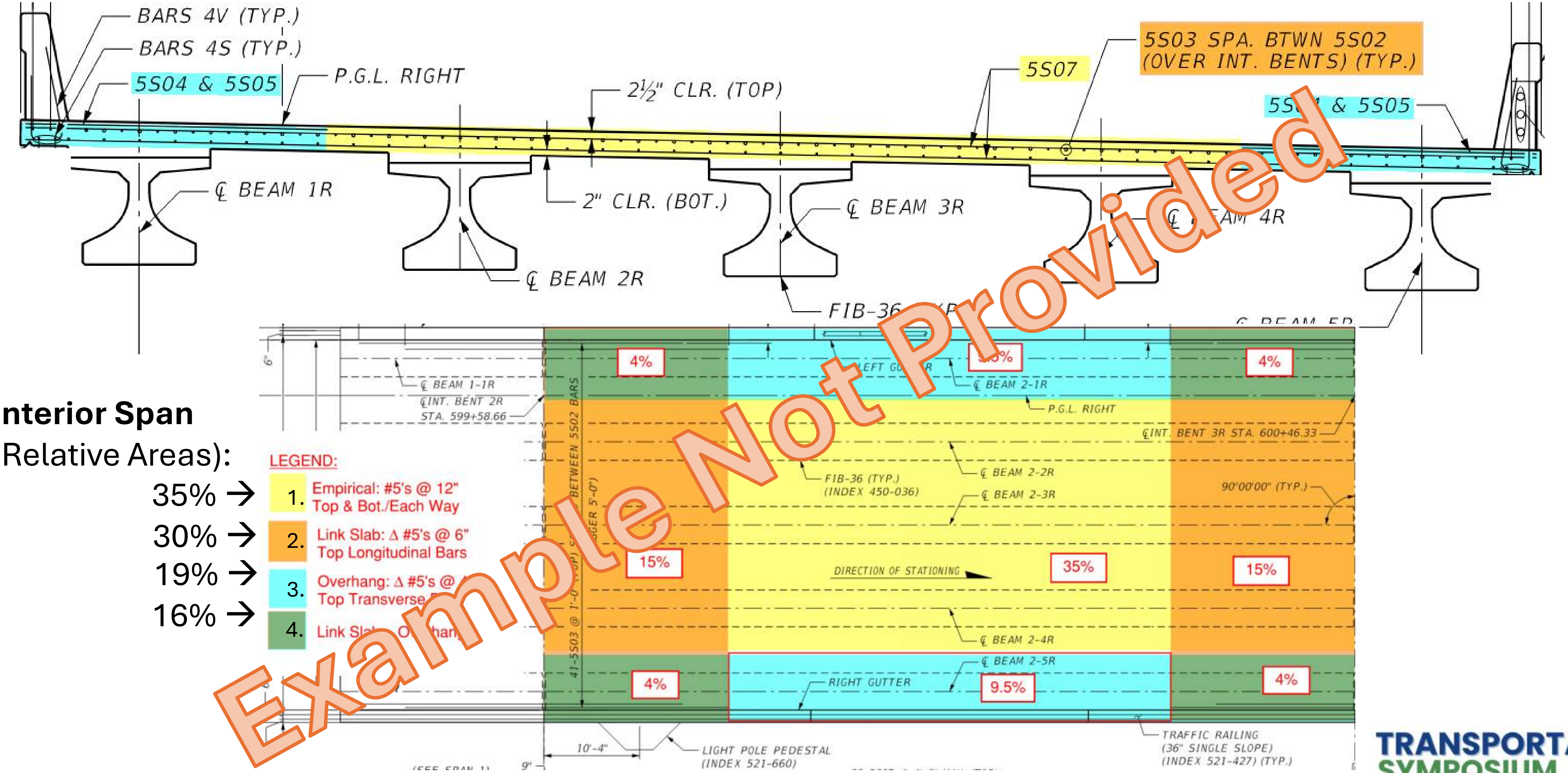
# Comparison of Rebar Qty. [redacted] Bridge Deck Example B




**Interior Span**
(Relative Areas):

35% →
30% →
19% →
16% →

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# Comparison of Material Qty. [redacted] Deck Area 1 (Example A)

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

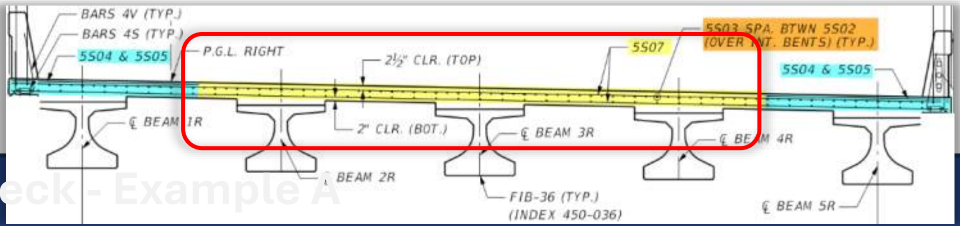
- Thickness = *8"*
- Concrete Cover = *2"*
- Flexural Depth (#5's) $d$ = *5.7"*
- Empirical ***(AASHTO-BDS)***: Bottom layers = #5's @ *13.8" (0.27 in²/ft)*; Top layers = #4's @ *13.3" (0.18 in²/ft)*
- Empirical ***(FDOT)***: *#5's @ 12"* **
- Total Rebar ***(AASHTO)***: $A_s = 0.90\ in^2/ft^2$; ***(FDOT)***: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

**<u>GFRP-RC</u>** *(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)*

→ $\Delta_{volume}$ ***(AASHTO)*** $= +67\%$; $\Delta_{weight} = -58\%$

→ $\Delta_{volume}$ ***(FDOT)*** $= +21\%$; $\Delta_{weight} = -70\%$




Interior Section

*** Minimum bar size and spacing governs*

# Comparison of Material Qty. [redacted] 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 in$^2$/ft)*; Top transverse = #4's @ 13.3" *(0.18 in$^2$/ft)*; + Top long. = *#5's @ 6"* *(0.62 in$^2$/ft)*
- Empirical: ***(FDOT)***: *3-layers @ #5's @ 12"* ** *(0.31 in$^2$/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):*

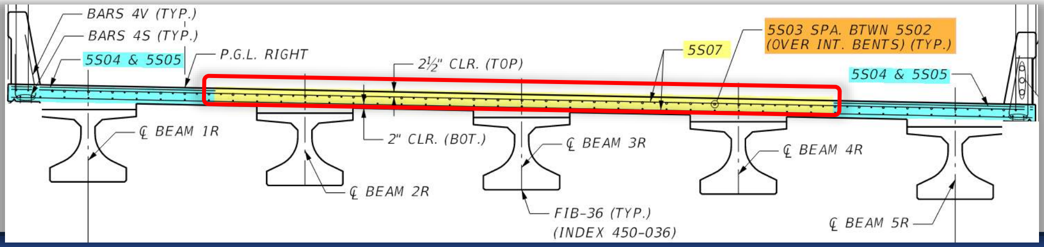
- Thickness = *7"* → $D_{vol.} = -12\%$; $D_{weight} = -15\%$
- Concrete Cover = *1"*
- Flexural Depth (#5's) *d* = *5.7"*
- Empirical ***(FDOT/AASHTO-GSG)***: **Bottom transverse = *#5's @ 6.5"* *(0.83% = 0.57 in$^2$)*; Other 2-layers = *#5's @ 12"* *(0.35% = 0.31 in$^2$)*;

  + Top long. = *#5's @ 6"* *(0.62 in$^2$/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. [redacted] 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)***: $A_s = 1.54$ in²/ft²;
  ***(FDOT)***: $A_s = 1.86$ in²/ ft².

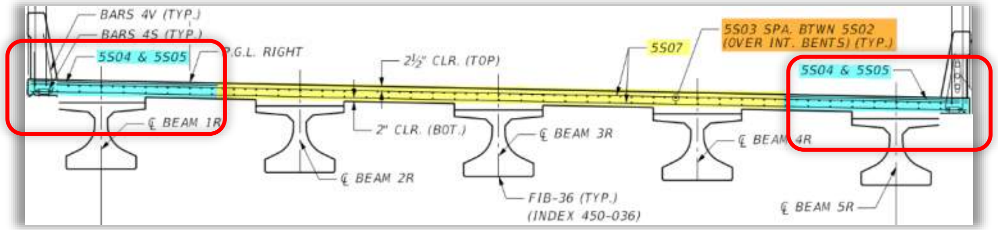
**<u>GFRP-RC</u>** *(ASTM D8505-23):*

- 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: $A_f = 2.12$ in²/ft² deck)

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

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

Overhangs (midspan)




TRANSPORTATION SYMPOSIUM



** *Minimum bar size and spacing governs*

# Comparison of Material Qty. [redacted] Deck Area 4 (Example A)

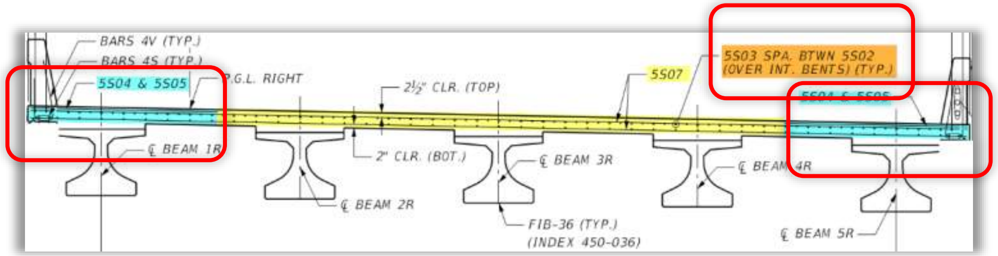
**<u>Convention CS-RC</u>** *(ASTM A615):*

- 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):*** $A_s = 2.17\ in^2/ft^2$.

**<u>GFRP-RC</u>** *(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)*
  → $\Delta_{volume}$ ***(AASHTO)*** = *+48%*; $\Delta_{weight} = -67\ \%$
  → $\Delta_{volume}$ ***(FDOT)*** = *+24%*; $\Delta_{weight} = -69\ \%$

**Overhangs @ Link-Slab**




TRANSPORTATION SYMPOSIUM



*** Minimum bar size and spacing governs*

# Comparison of Material Quantities [redacted] 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 in²/ ft²**
  - Empirical (FDOT): $A_s$ = 0.49*1.24 + 0.15*1.55 + 0.28*1.86 + 0.08*2.17 = **1.53 in²/ ft²**

## 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 in²/ ft²**

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

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

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

TRANSPORTATION SYMPOSIUM



*** Minimum bar size and spacing governs*

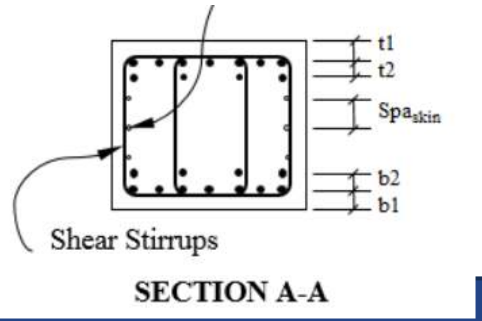
# Comparison of Rebar Qty. [redacted] Pile Bent Cap Example C

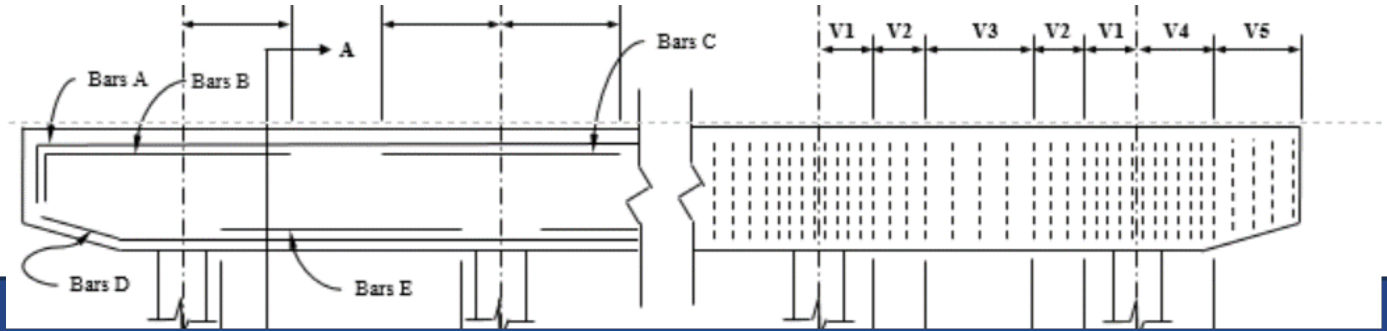

| | | |
|---|---|---|
| 10/20/2022 | GFRP Reinforced Concrete Design for Pile Bent Caps | Presentation |

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

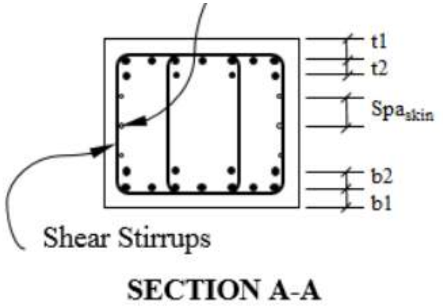


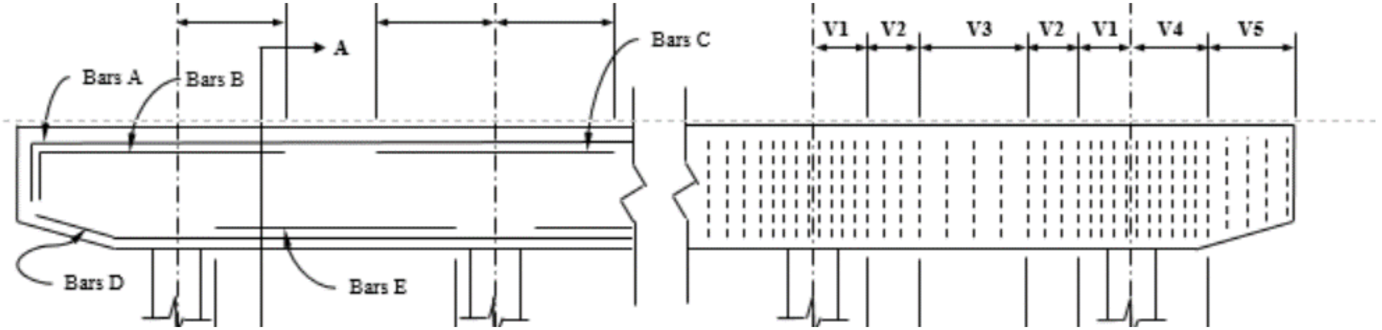



# Design Example for Pile Bent Cap Summary

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

| **Rebar Location** | **GFRP-RC (Type 0) 3-ft Deep Cap** | ***$\Delta_{volume}$* *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$^2$) |

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# 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)

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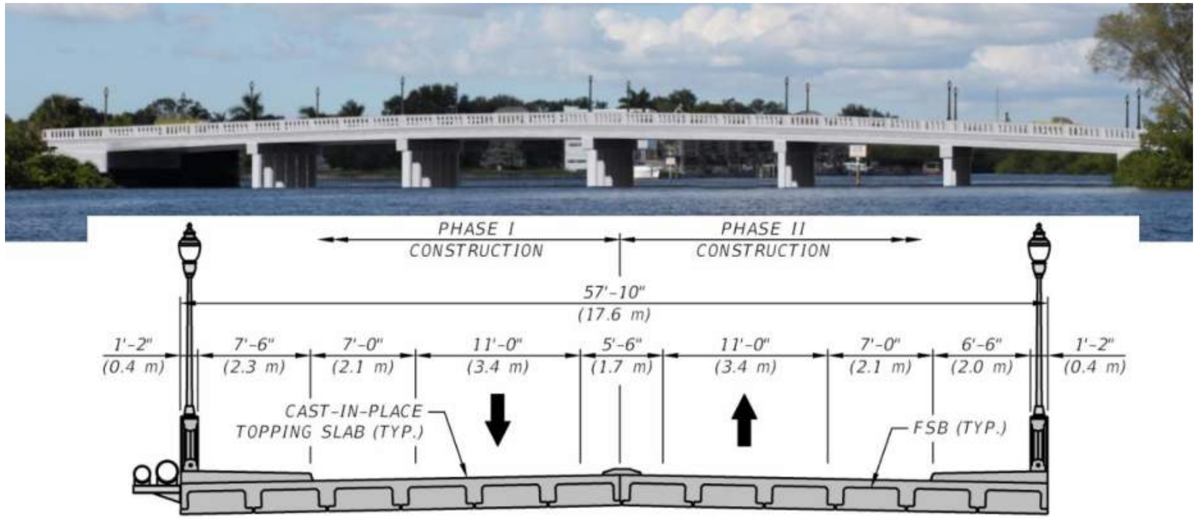
# Construction: D7 Example Project

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




*LAP Consultant Design*

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

*In-house Design*

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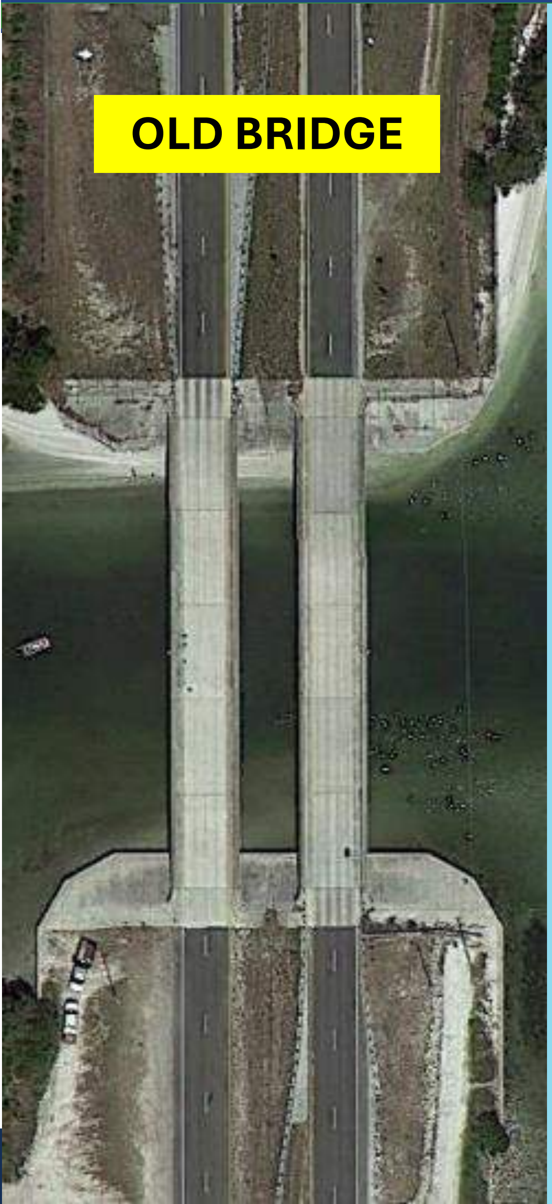
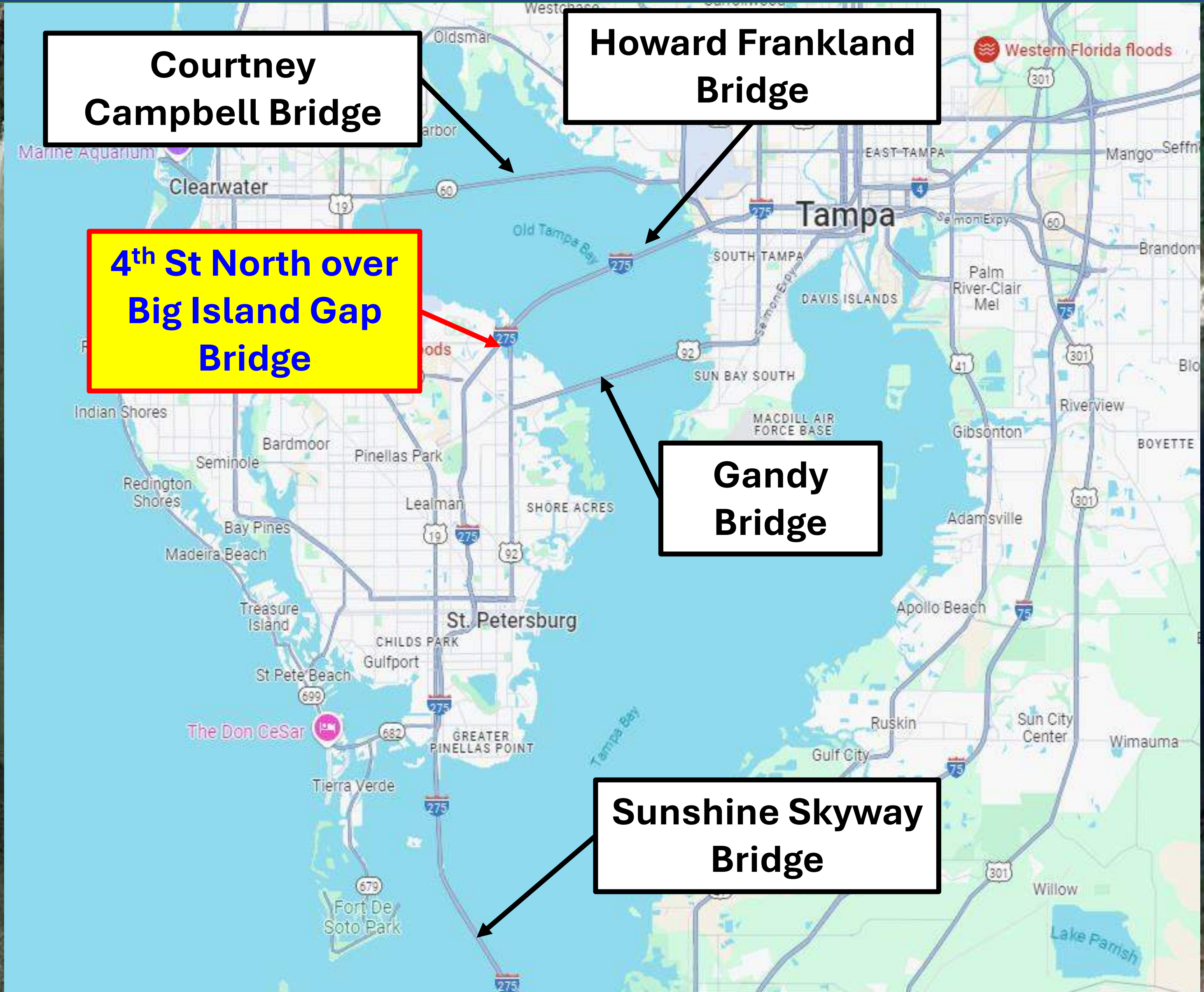
4th St North over
Big Island Gap
(430500-1)

# Construction: D7 Example Project
## Bridge Location




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

# Construction: D7 Example Project

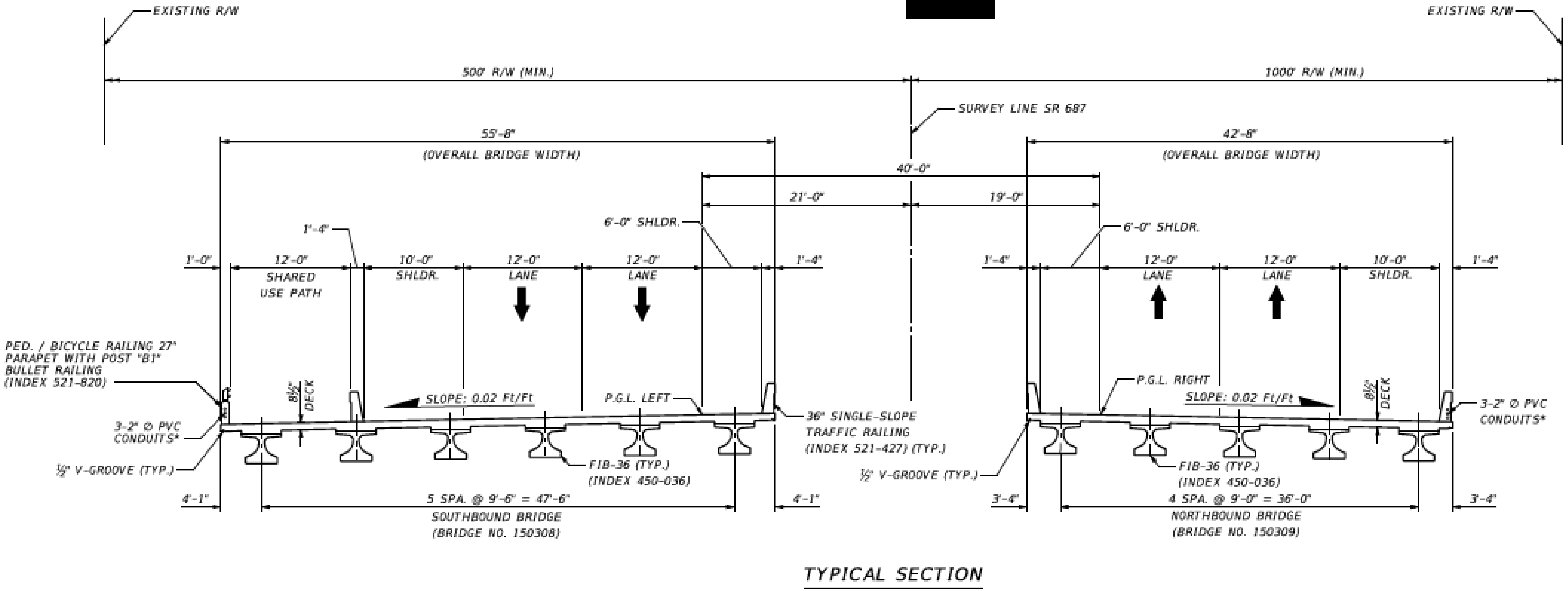
## Existing Bridges

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

# Construction: D7 Example Project

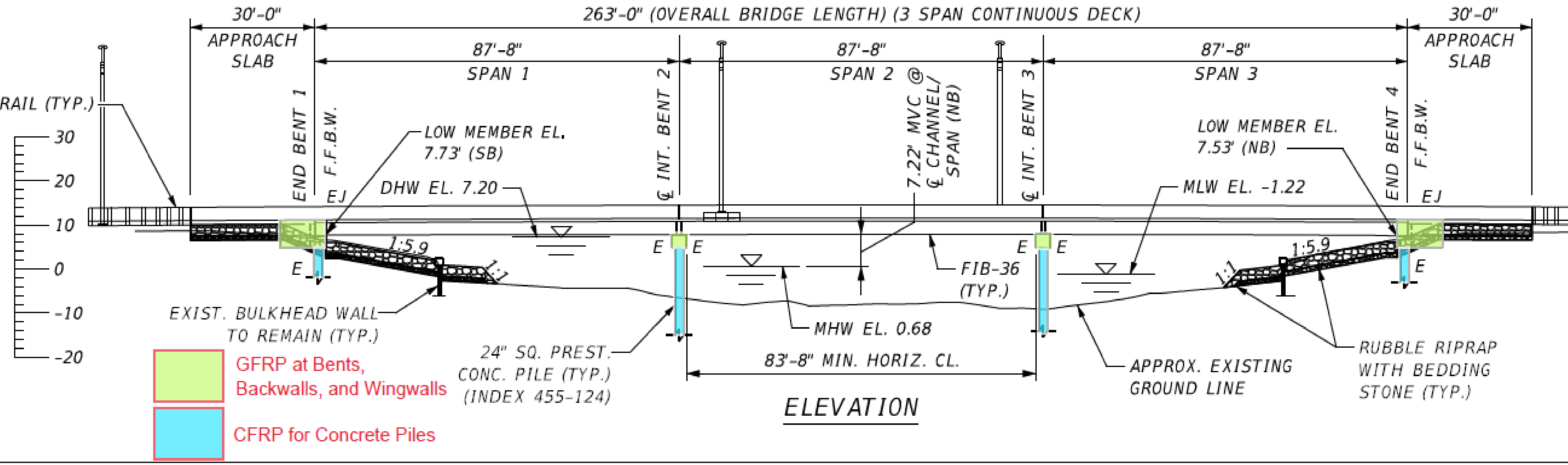
## Existing Bridges [redacted] Pile Jackets

# Construction: D7 Example Project
## New Bridges [redacted] Typical Section



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

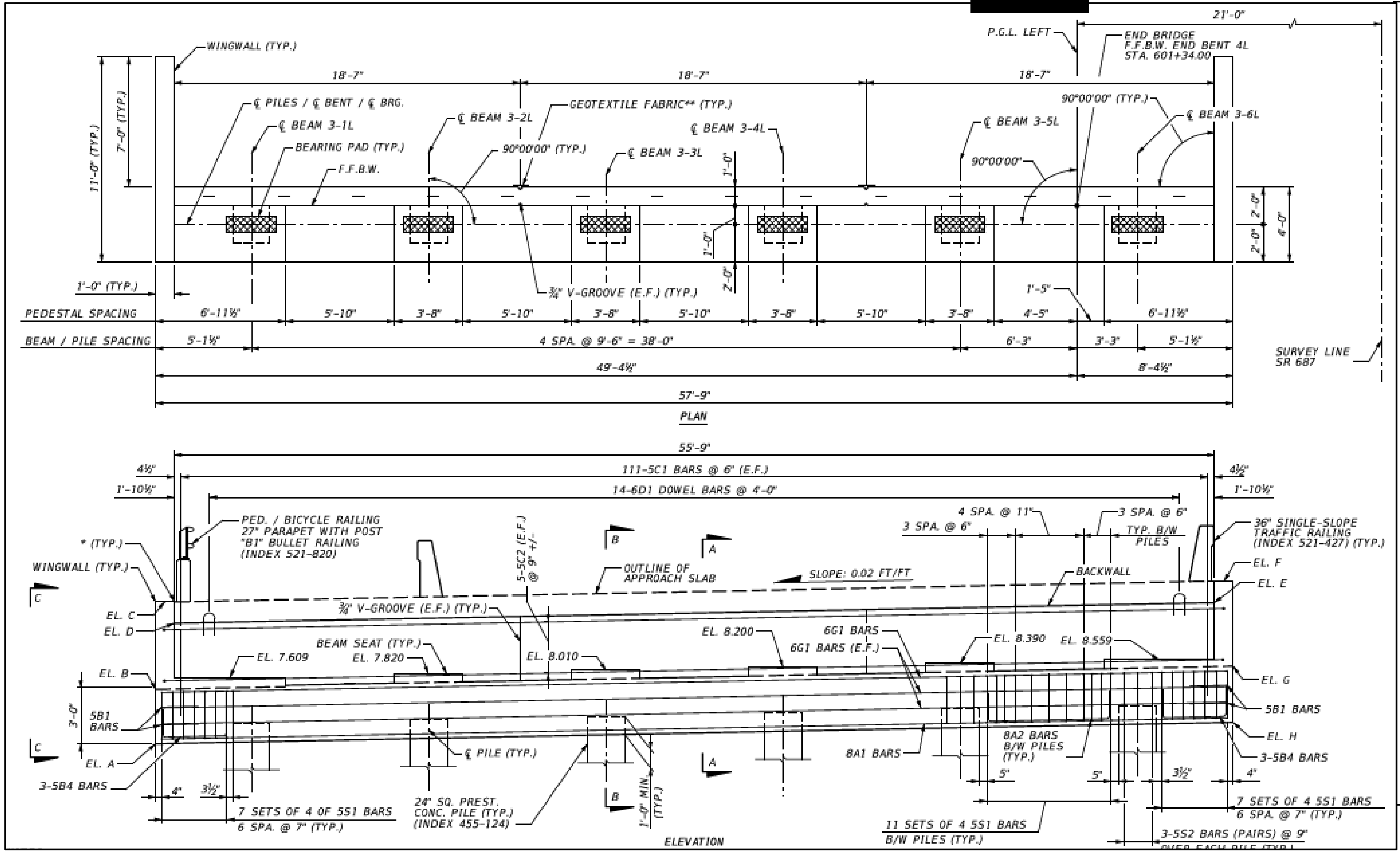
# Construction: D7 Example Project
## New Bridge [redacted] Elevation View

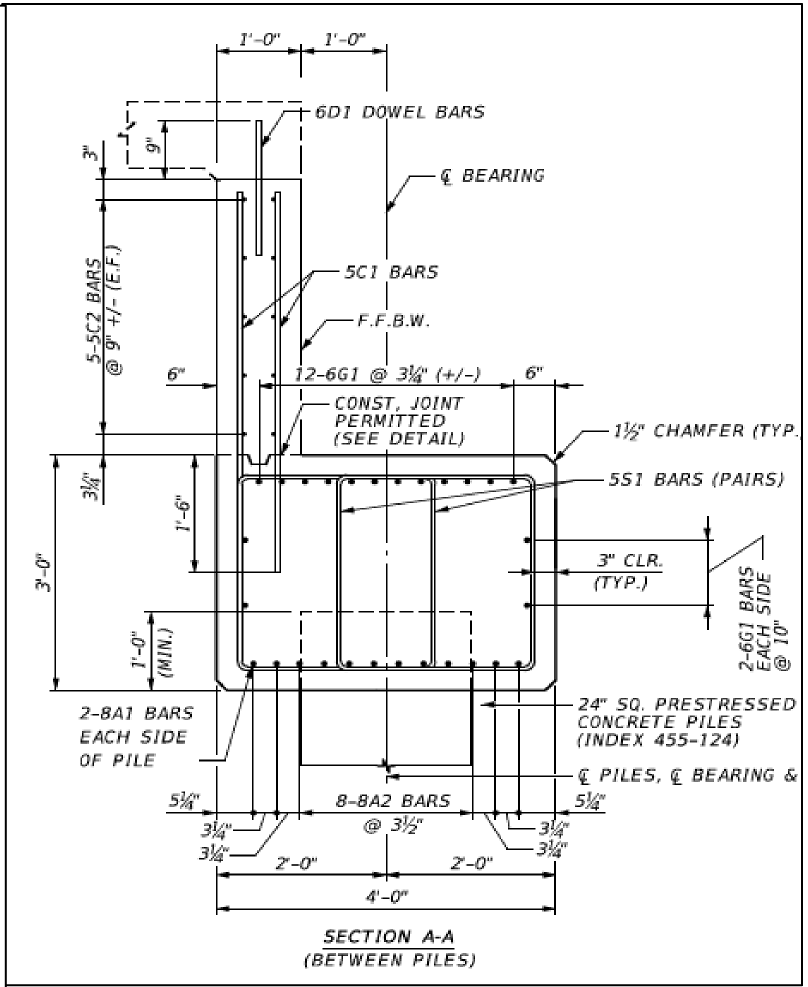


# 4th St North over Big Island Gap (430500-1)

# Construction: D7 Example Project

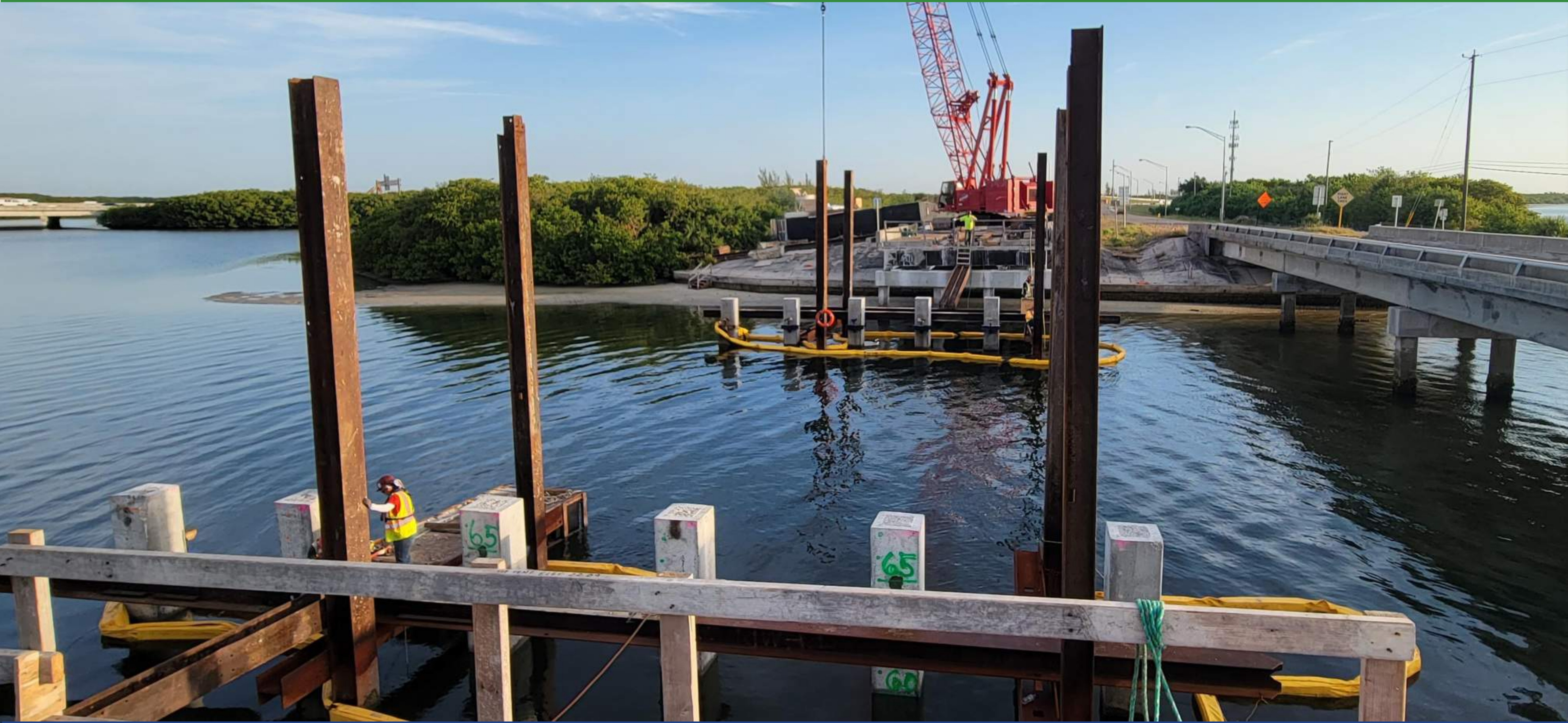
## End Bent [redacted] Plan & Elevation / Details



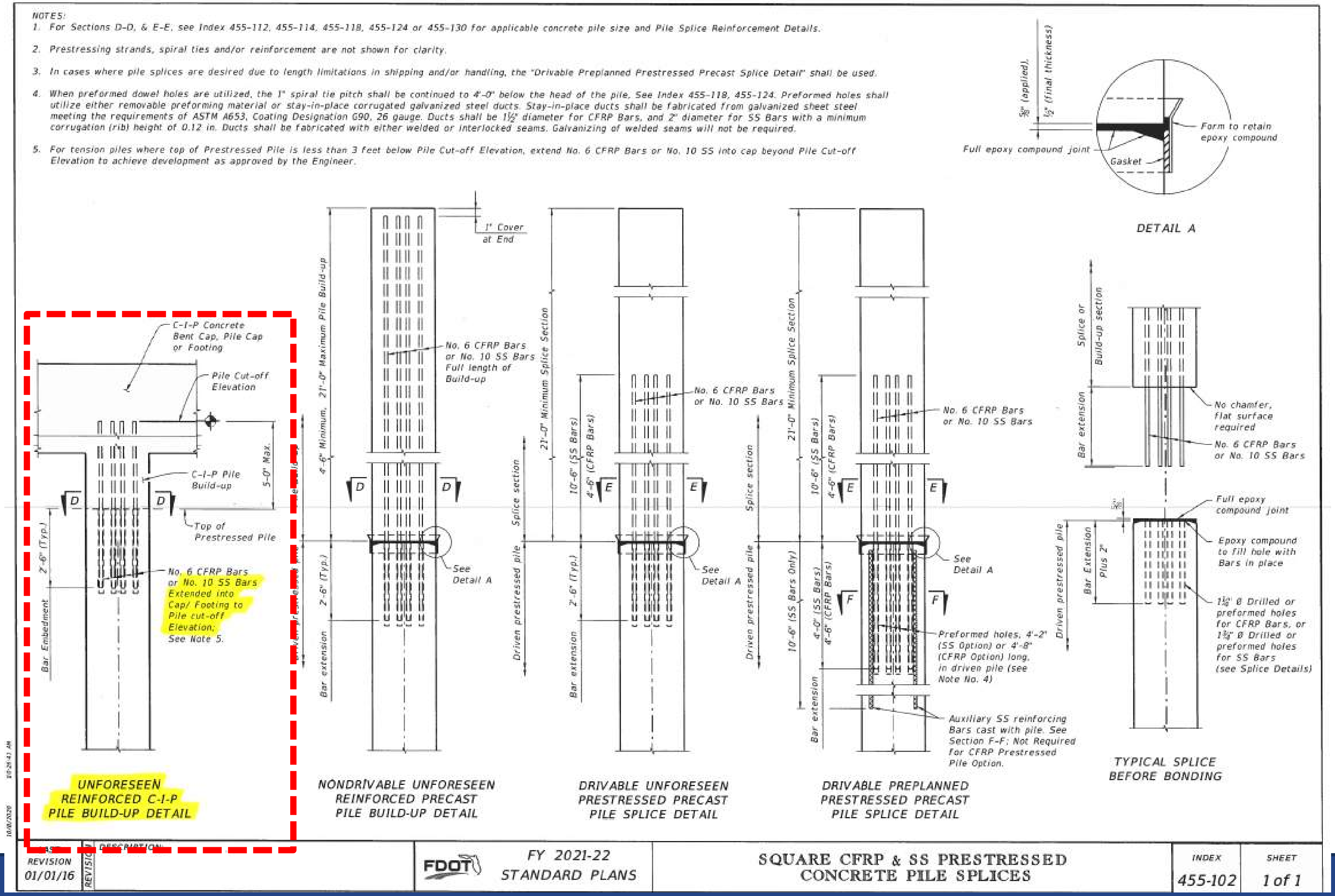
4th St North over
Big Island Gap
(430500-1)

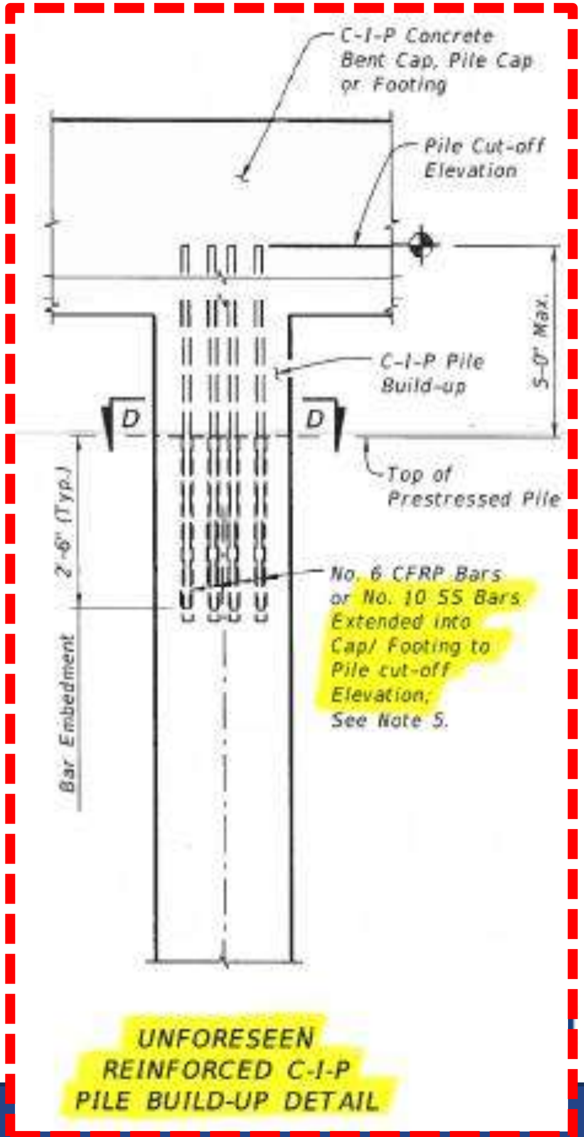
# Construction: D7 Example Project
## Pile Installation & Pile Crack Repair



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

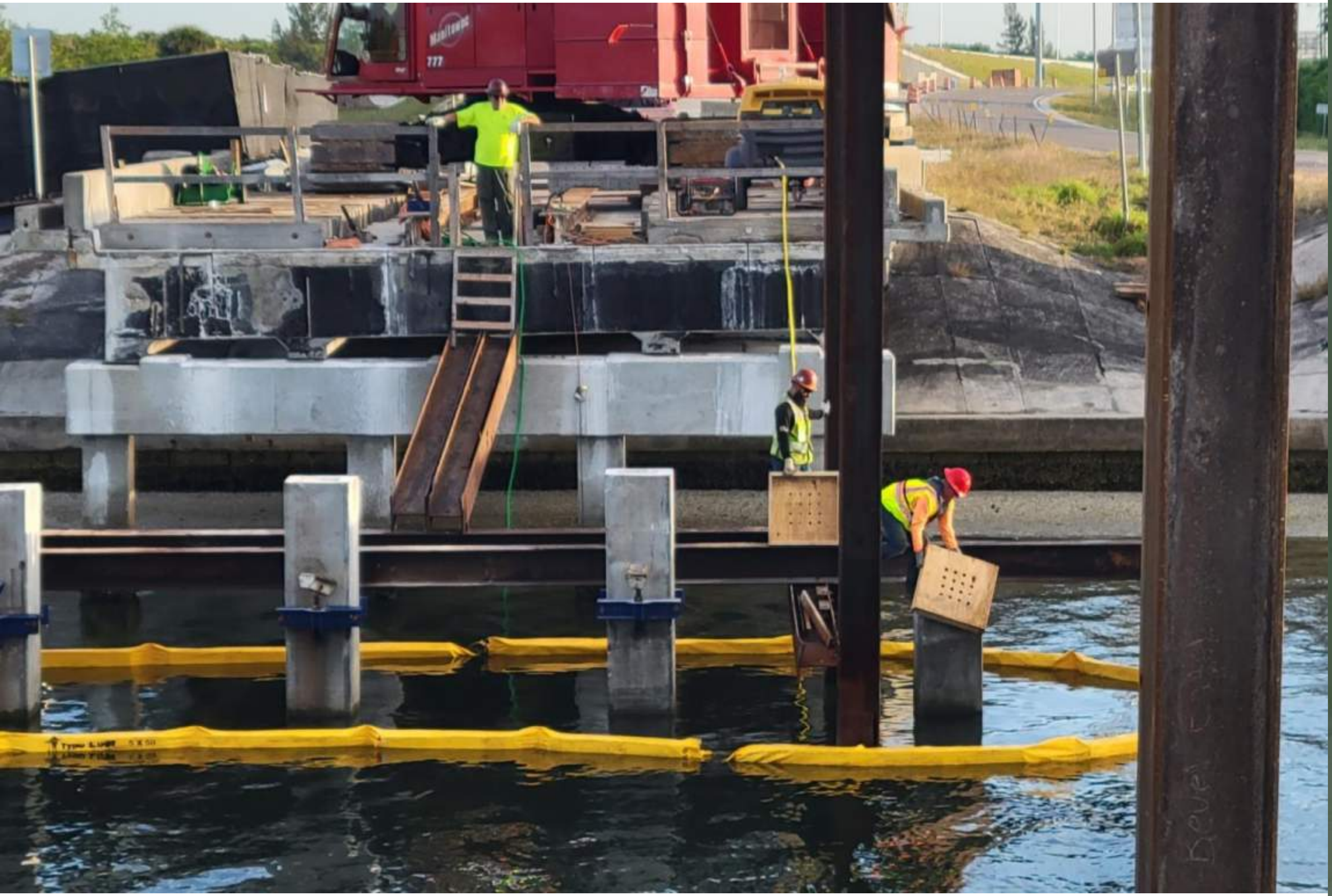
# Construction: D7 Example Project
## Pile Splice Build-Up Detail



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

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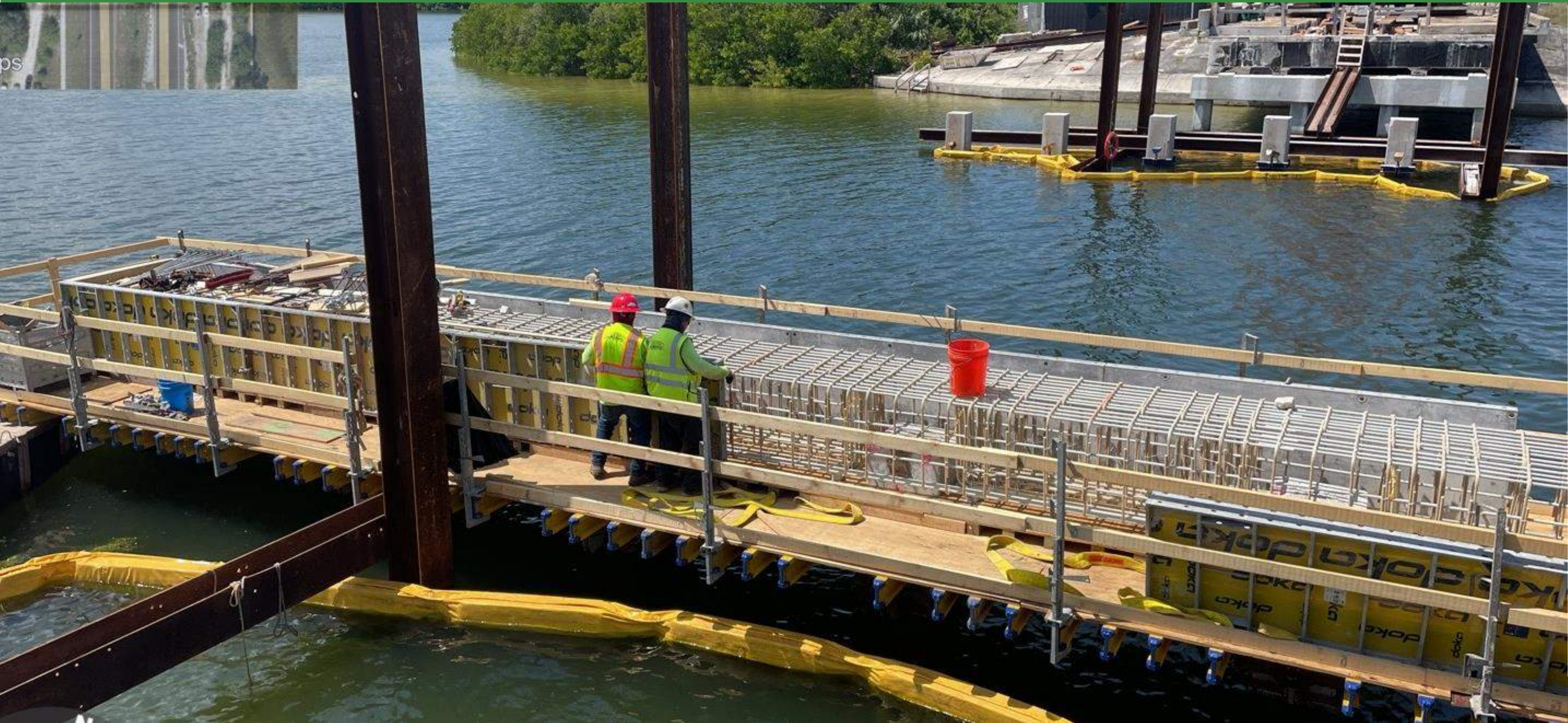
4th St North over
Big Island Gap
(430500-1)

# 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 [redacted] Storm Surge

**Hurricane Idalia**

**Category 4 Hurricane**
**August 30, 2023**

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SYMPOSIUM

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

# Construction: D7 Example Project

## Hurricane [redacted] Storm Surge

**Hurricane Idalia**

**Category 4 Hurricane**

**August 30, 2023**

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

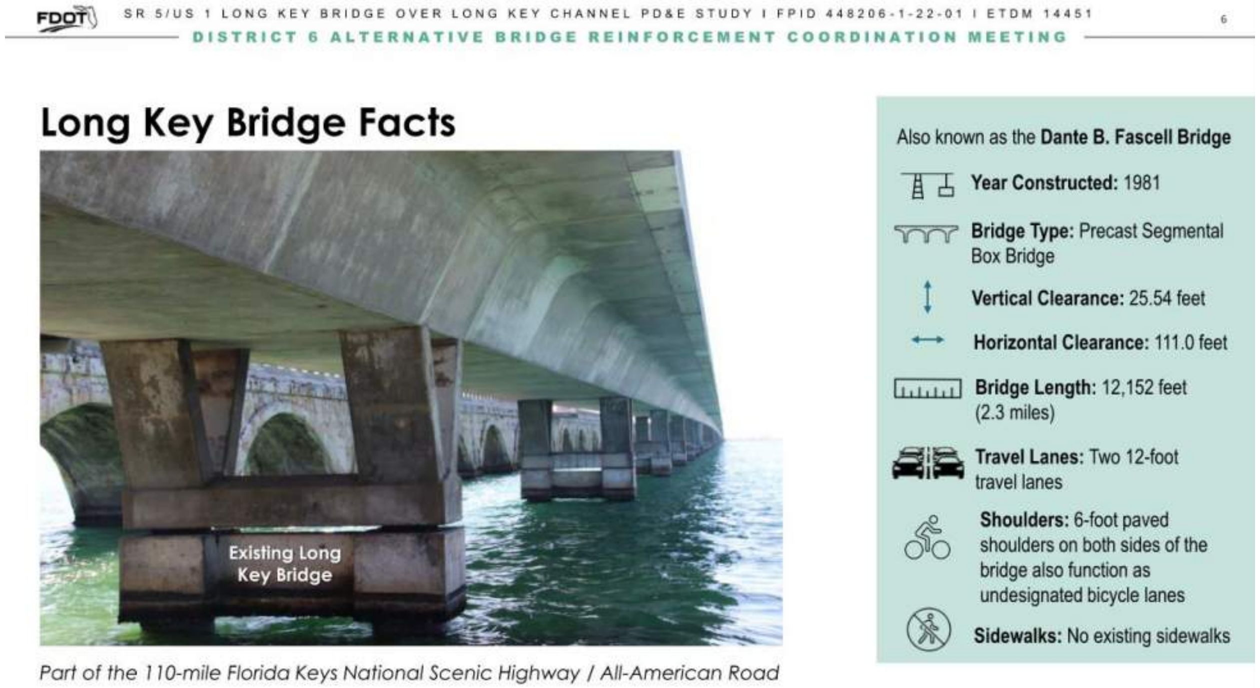
# Construction: D7 Example Project

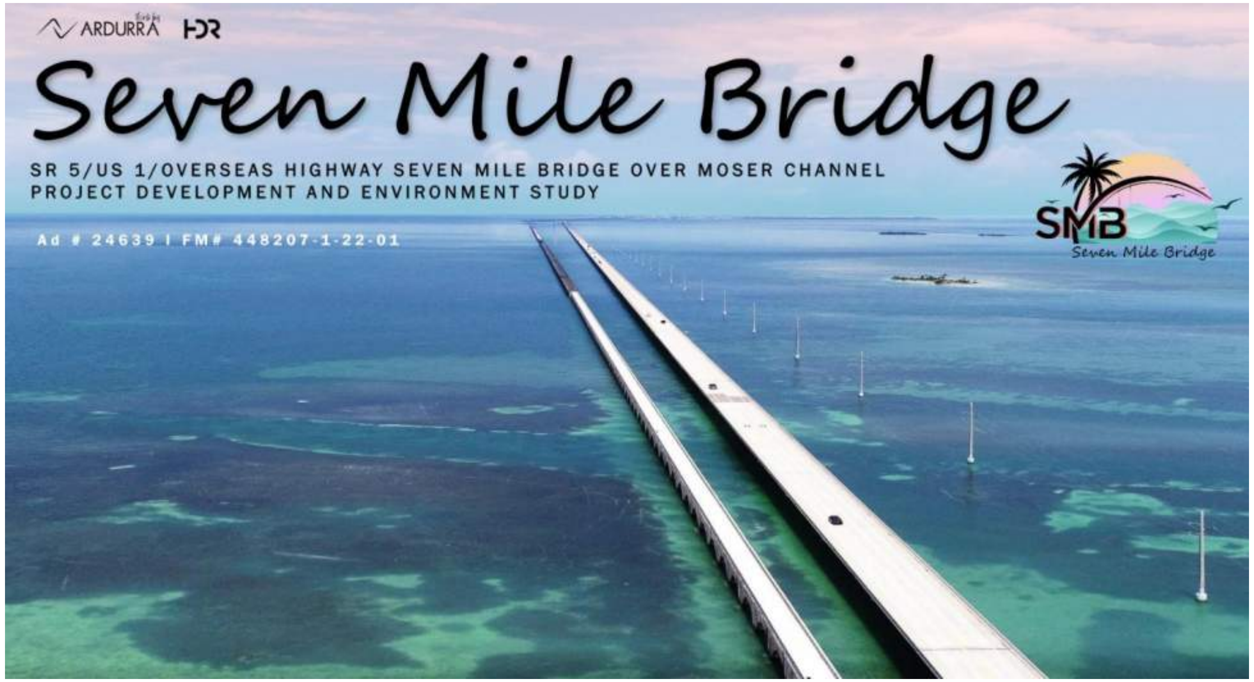
## Completed Bridge [redacted] November 2023

# Future Construction: D6 Example Projects

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

- Seven Mile Bridge Replacement (448207-1)



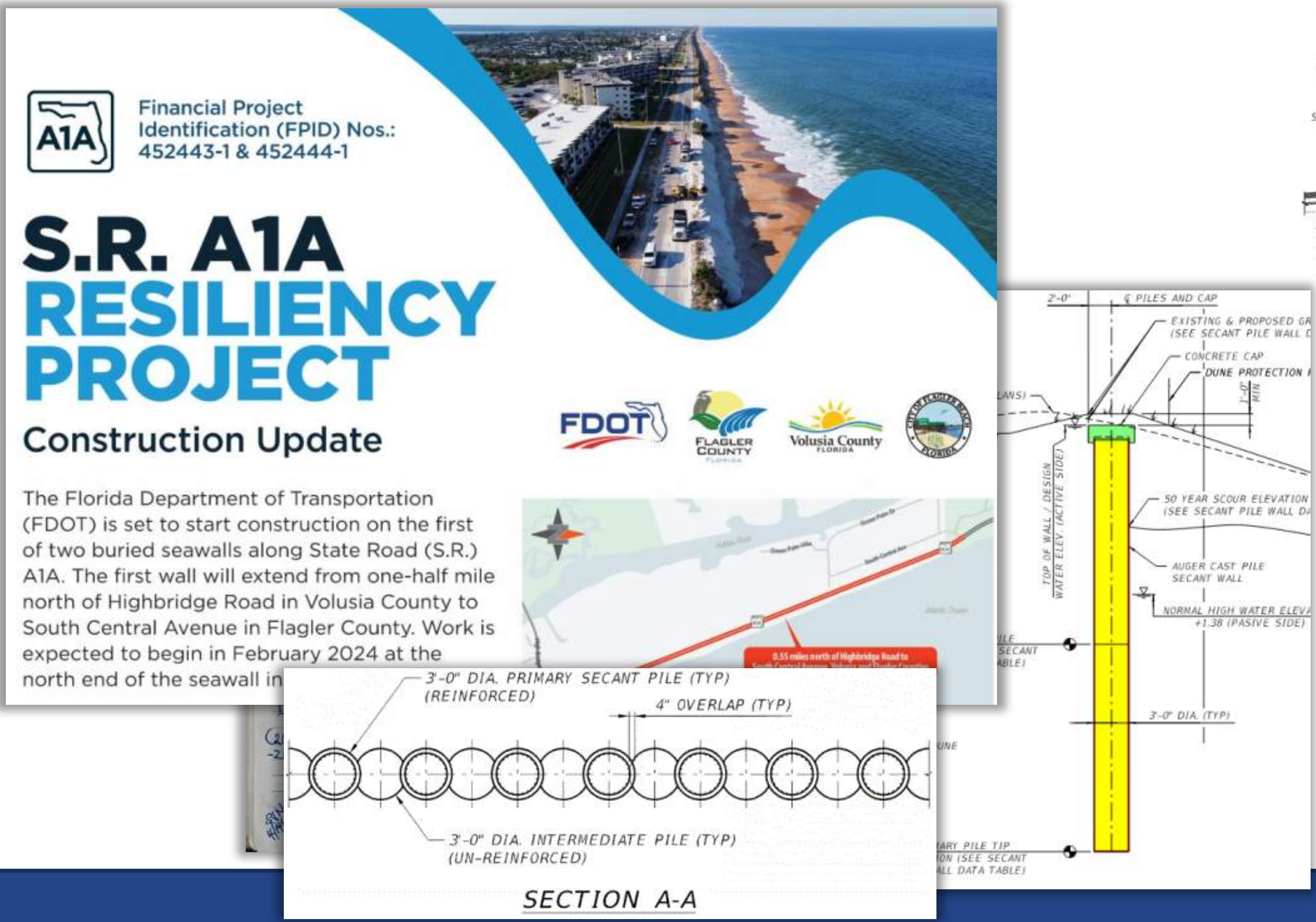




**Letting Date:** 03/15/2027

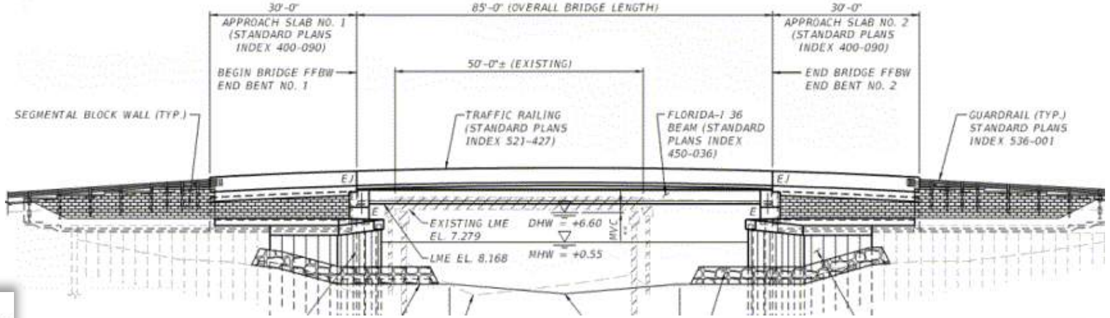
**Letting Date:** 03/11/2030

# Construction: D5 Example Projects

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

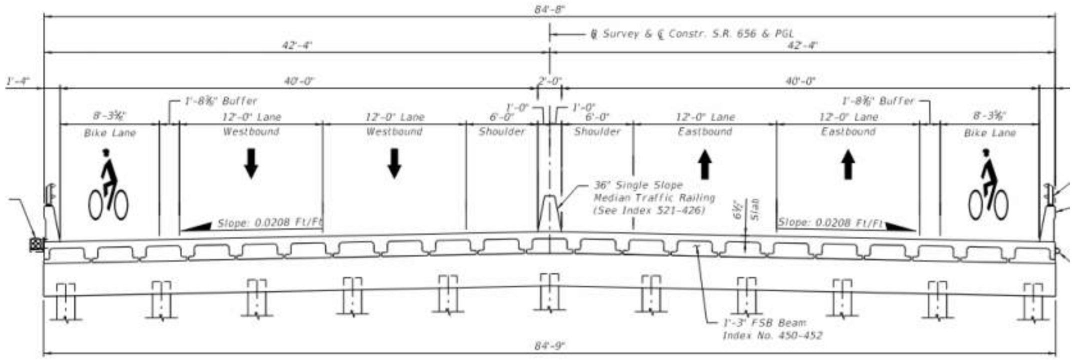


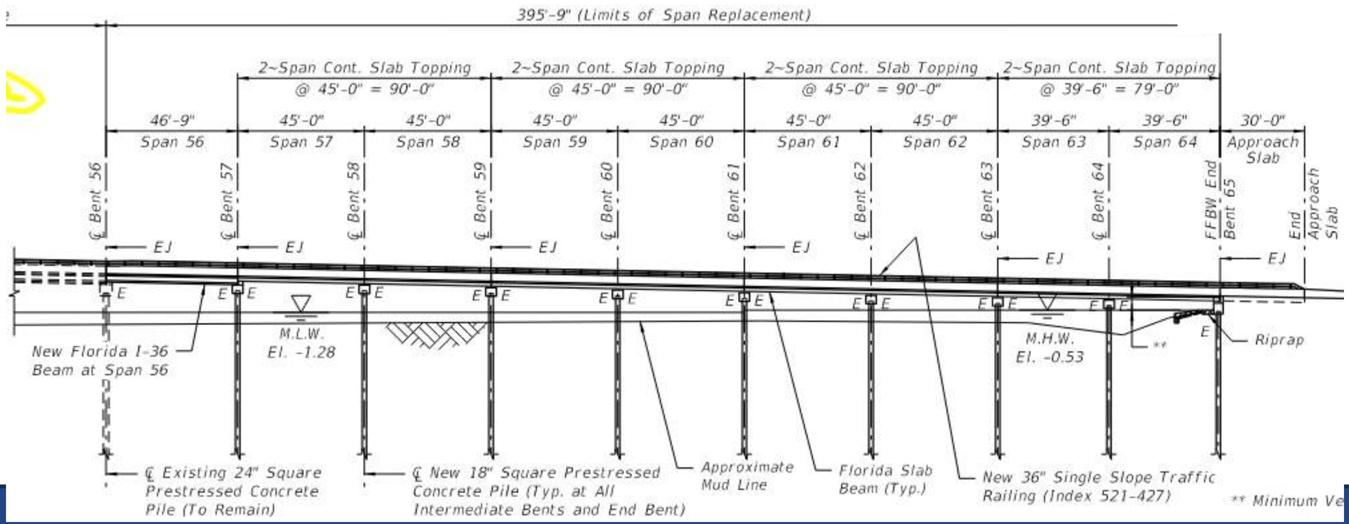

- Barracuda Blvd over Canal Bradano ([437935-1]()) *In-house Design*



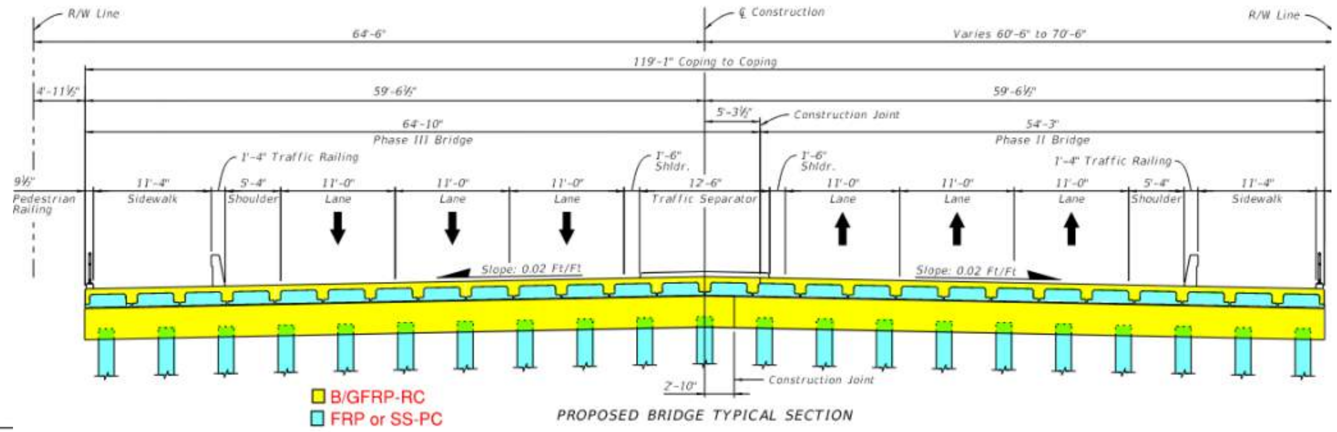

# Construction: D4 Example Projects

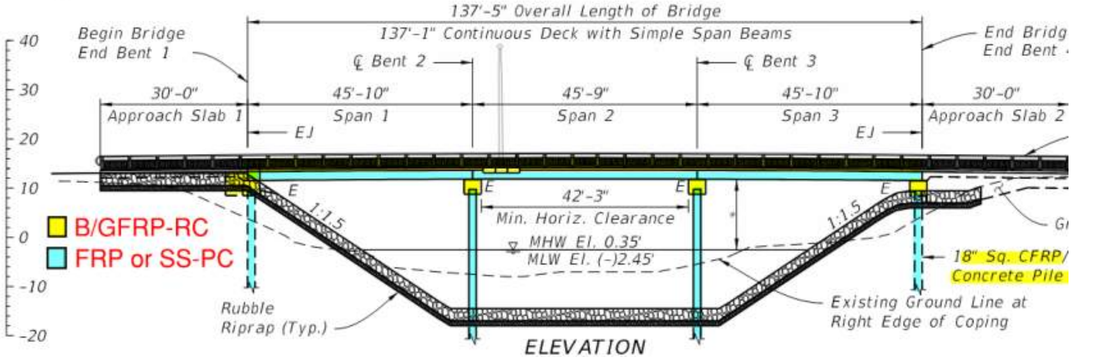
- 17th St/Indian River, East End-Vero (446106-2)




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

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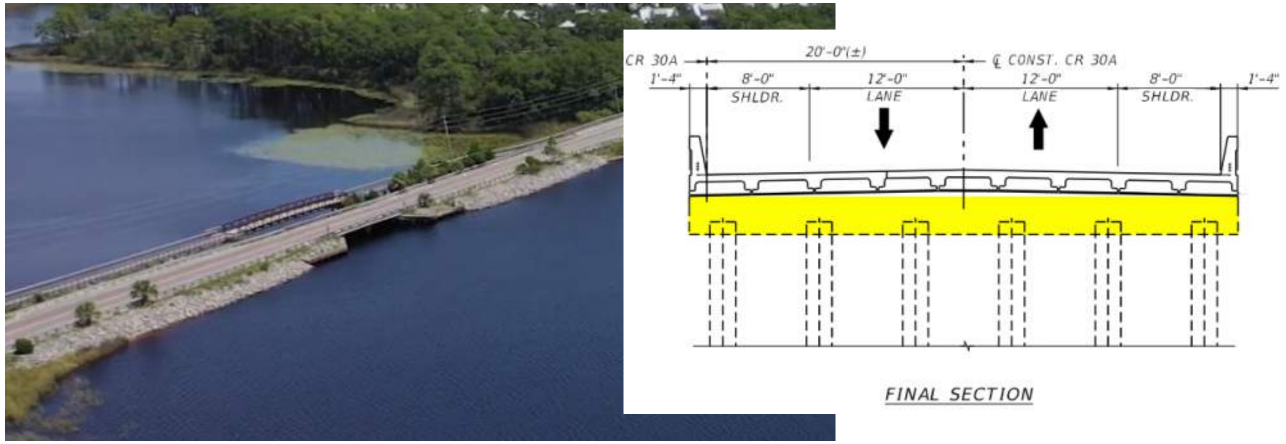
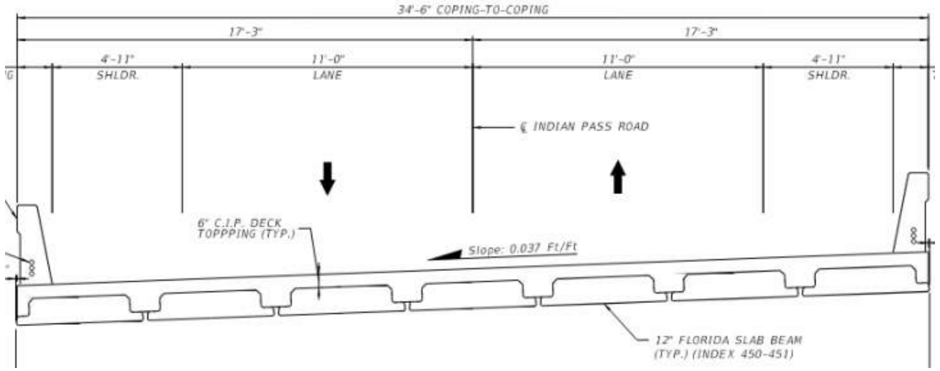
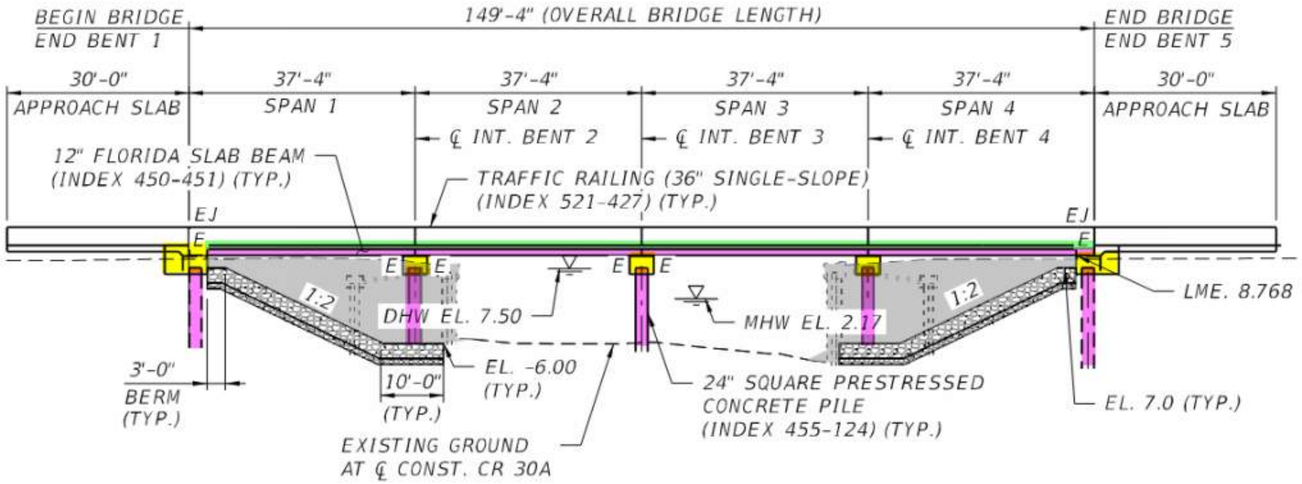
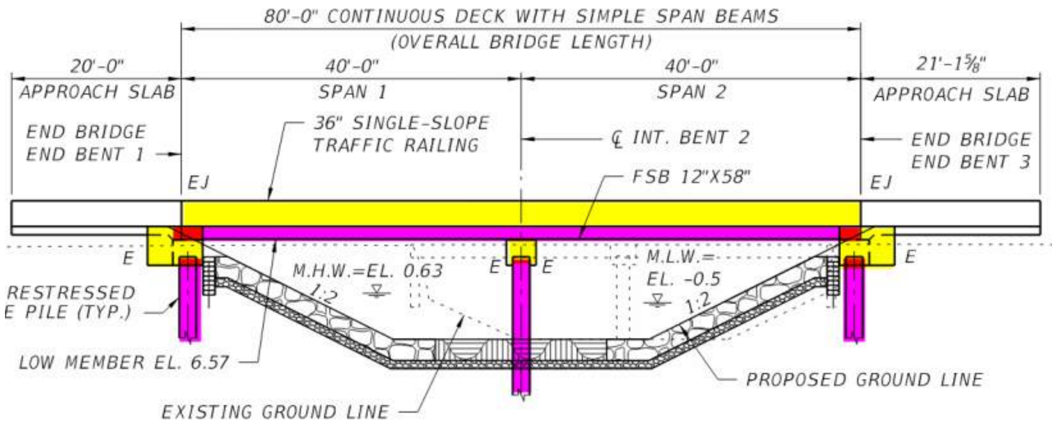
# Construction: D3 Example Projects

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

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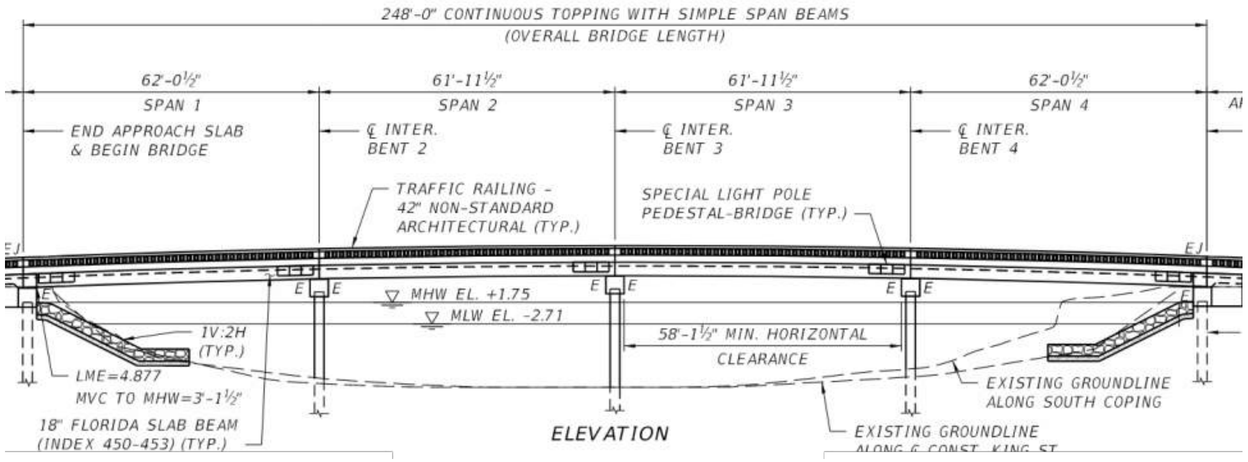
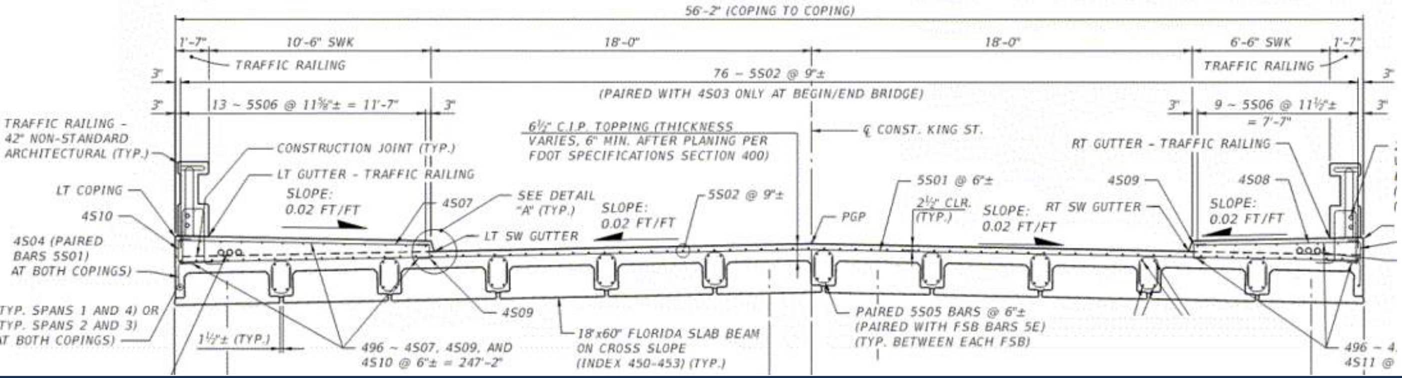
# Future Construction: D2 Example Projects

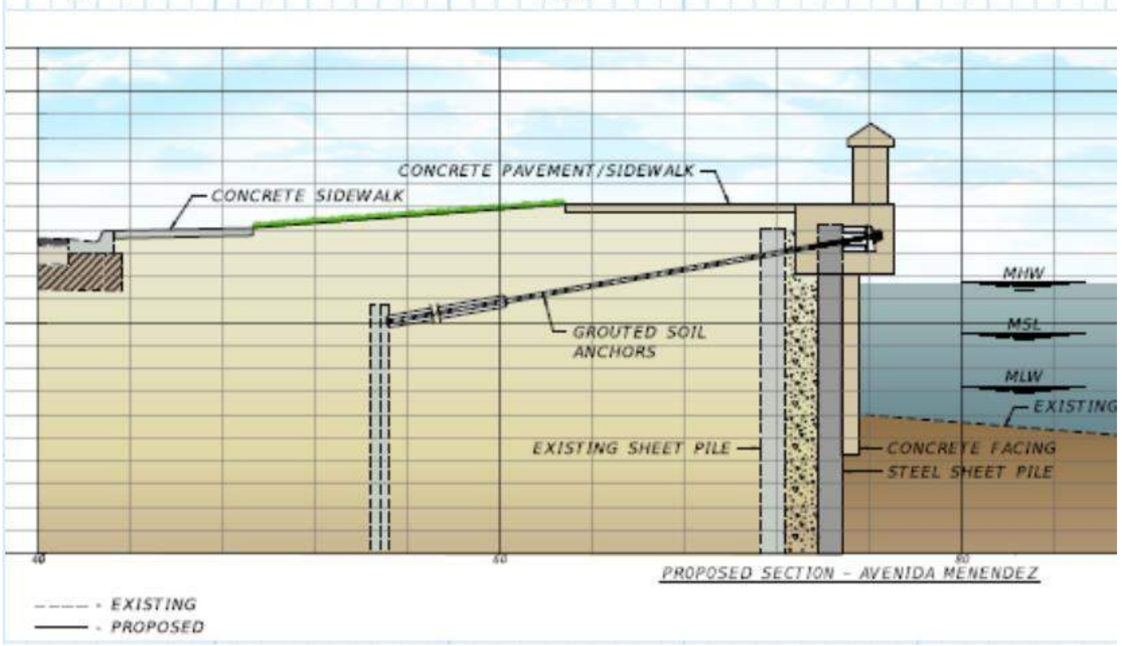
- US1/King St over San Sebastian River (437428-1)




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

**Figure 2 - Proposed Bulkhead Typical Section**

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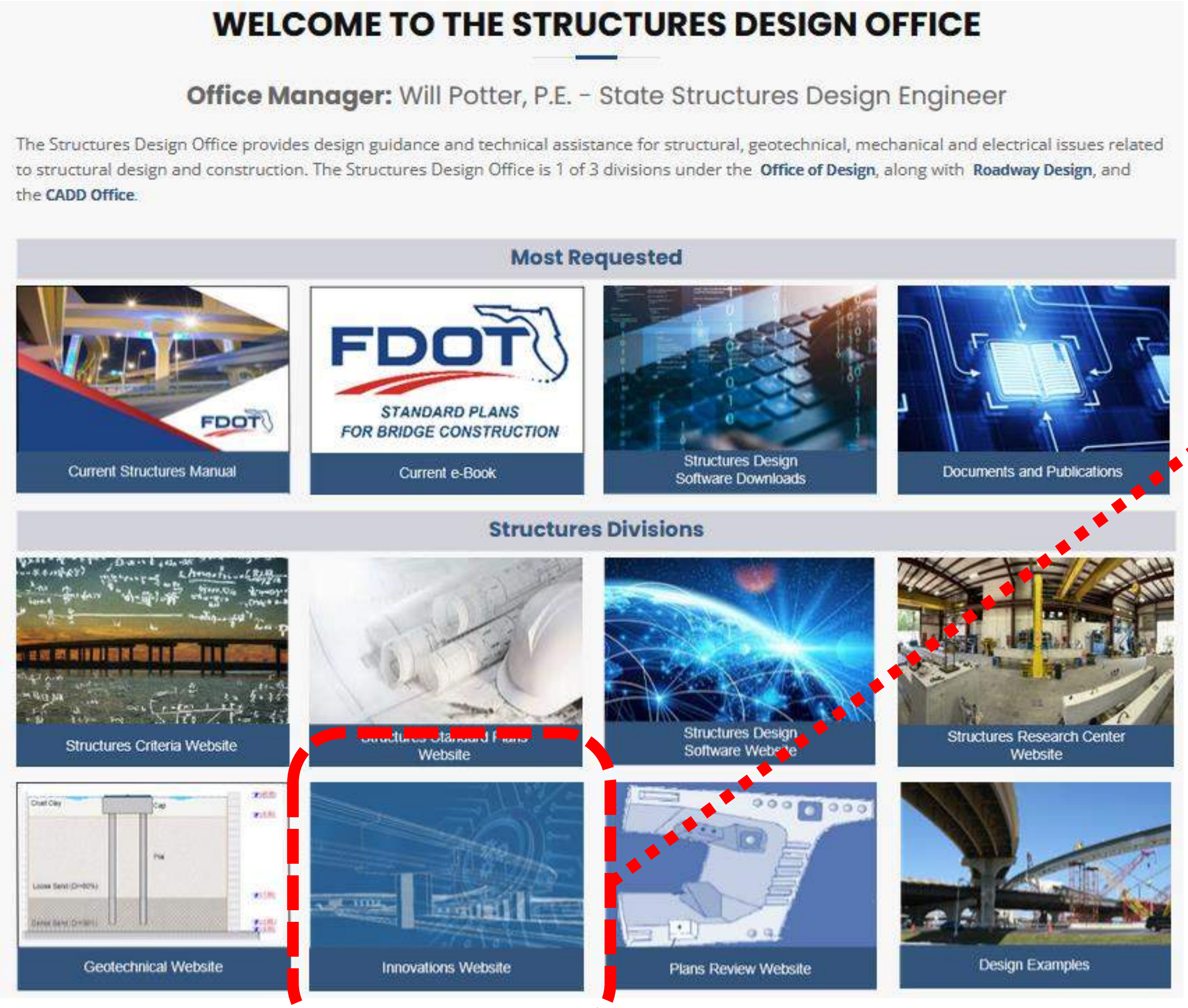
# More Info: FRP RC/PC Design Innovation Webpage





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

# Safety Message

**NO text.**
**NO call.**
**NOTHING**
**is worth losing a life over.**

PUT IT DOWN
IT'S THE LAW

# Contact Us


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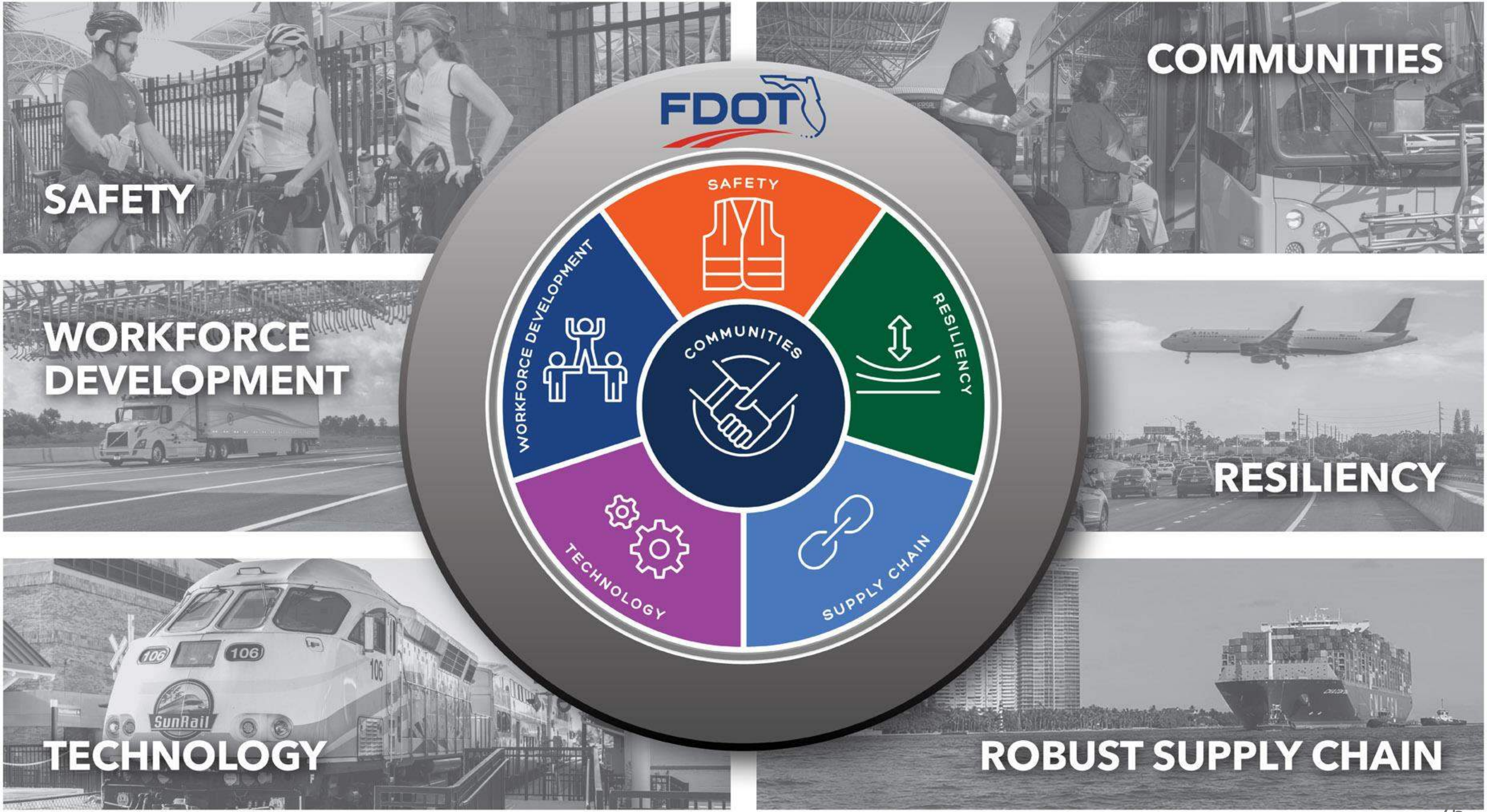
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TECHNOLOGY
WORKFORCE DEVELOPMENT
COMMUNITIES
106
106
SunRail