2025 FRP Workshop
February 10

Case Study on CFRP/SS Florida Slab Beam with CFRP Prestressed Concrete Soldier Pile Walls and GFRP Reinforced Precast Panels

INTEGRITY · COMMITMENT · EXCELLENCE

PRESENTERS

Michael Mohney, PE

Patel, Greene & Associates, LLC

Chris Gooding, PE, SE

Patel, Greene & Associates, LLC

OVERVIEW

- FRP Material Properties and Design
  - FRP Characteristics
  - Coordination with SDO
  - Flexure and Shear Design Differences
- CR 372 (Surf Road) over Otter Creek Rise
  - Project Background
  - CFRP/Stainless-Steel Strands
  - GFRP Superstructure and Substructure
  - GFRP Bulkhead Walls
- Lessons Learned

- How many have designed a soldier pile wall system?
- How many have designed FRP materials?
- Importance of Resiliency
  - Recent hurricanes
  - Corrosion has been a challenge in FL
  - Need for innovation in transportation structures

Patel, Greene & Associates, LLC

- Founded in 2011
- Has grown to 160+ total staff
- Transportation focused with 7 offices across FL

PGA FRP PROJECTS

- CR 372 (Surf Road) over Otter Creek Rise (D3)
  - CFRP/SS Florida Slab Beams, GFRP Pile Bents, and GFRP Soldier Pile Wall
  - 3 Span – 90ft Total (27ft-36ft-27ft)
  - On the Shelf (Construction FY 2026)
- SR 105 (Heckscher Drive) over Browns Creek (D2)
  - CFRP/SS Florida I-Beams and GFRP Pile Bents
  - 10 Spans – 805ft Total (80ft and 85ft)
  - Phase II (Construction FY 2027)
- US 41 (SR 45) over North Creek (D1)
  - GFRP Flat Slab and FRP Pile Bents
  - 2 Spans – 45ft Total (22.5ft)
  - Constructed in 2019

US 41 (SR 45) over North Creek
GFRP Flat Slab

FRP Material Properties and Design

FRP COMPONENTS

- **Why use FRP?**
  - Eliminate corrosion concerns
- **Types of FRP materials?**
  - Glass Fiber Reinforced Polymer Reinforcement (GFRP)
  - Basalt Fiber Reinforced Polymer Reinforcement (BFRP)
  - Carbon Fiber Reinforced Polymer Bars or Strands (CFRP)
- **Other non-corrosive materials?**
  - Stainless-Steel Strands
  - Stainless-Steel Cladded Reinforcement (SSCR)

- **FRP Rebar Use in USA?**
  - 67 Bridges – 27 States (as of 2016)

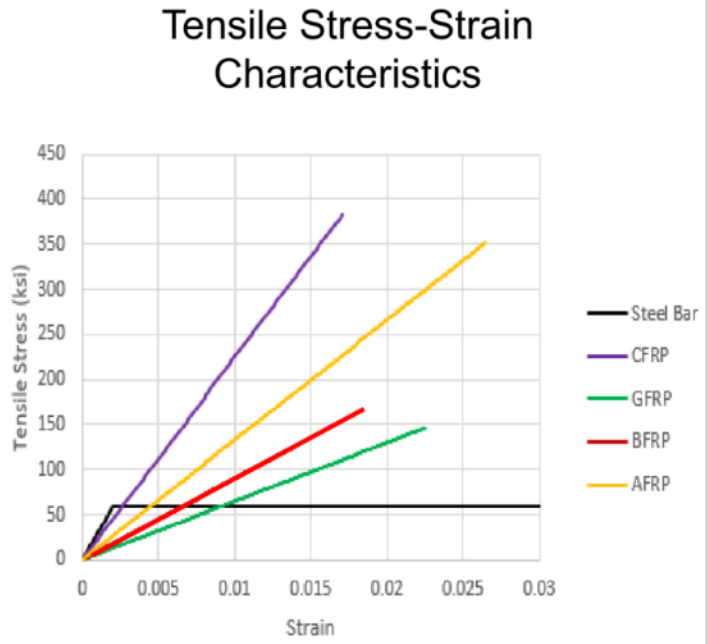
18 FDOT Bridges Utilizing FRP
75 FDOT Constructed/Active Projects
(as of 2025)

Colorado	2	New Hampshire	1
Connecticut	1	New York	3
Florida	8	North Carolina	1
Georgia	2	Ohio	4
Indiana	1	Oregon	1
Iowa	2	PA/NJ	1
Kansas	1	Pennsylvania	1
Kentucky	2	Texas	3
Mass	1	Utah	2
Maine	4	Vermont	1
Michigan	2	Virginia	1
Minnesota	1	West Virginia	9
Missouri	6	Wisconson	3
Nebraska	1		

  - 211 Bridges in Canada (as of 2016)

GFRP BARS

- **Differences from Carbon Steel Reinforcement**
  - High longitudinal strength to weight ratio
  - Corrosion-resistant!
  - Electro-magnetic neutrality (tolling facilities)
  - Low thermal and electrical conductivity
  - Lightweight (25% of steel weight)
  - No yielding before failure
  - Low transverse strength
  - Low modulus
  - Susceptibility to UV
  - Sensitivity to alkaline environment
  - Susceptible to fire and smoke production
- **Available Design Guidance & Tools:**
  - FDOT Structures Manual, Volume 4
  - FDOT Specifications 932
  - AASHTO LRFD Bridge Design Guide Specifications for GFRP-Reinforced Concrete, 2nd Edition (2018)
  - AASHTO Guide Specification for the Design of Concrete Bridge Beams Prestressed with CFRP Systems



FRP APPLICATION AND COORDINATION WITH SDO

- Permitted uses in Structures Manual Volume 4, 2.1.A
- Collaborate closely with Department and SDO
- Allow some leniency in design
- Superstructure Design
  - Splitting design check
  - Confinement reinforcement
  - Can substitute carbon steel bars in some locations (Project specific)
    - ie. approach slabs or inboard railings
- FRP Railing Developmental Standard Plans
- No FDOT APL Couplers

2 BASALT AND GLASS FIBER REINFORCED POLYMER (BFRP, GFRP) AND CARBON FIBER REINFORCED POLYMER (CFRP) REINFORCING BARS

2.1 PERMITTED USE

A. BFRP, GFRP and/or CFRP reinforcing bars may be used in the following concrete components:

- Approach Slabs
- Bridge Decks and Bridge Deck overlays
- Cast-in-Place Flat Slab Superstructures
- Pile Bent Caps (Only specify GFRP and/or CFRP for submerged locations)
- Pile Jackets
- Pier Columns and Caps (Only specify GFRP and/or CFRP for submerged locations)
- Retaining Walls, Noise Walls, Perimeter Walls
- Pedestrian/Bicycle Railings
- Bulkheads and Bulkhead Copings with or without Traffic or Pedestrian/Bicycle Railings
- MSE Wall Panels and Copings
- Drainage Structures
- Dowel bars for expansion joints in junction slabs when paired with a keyed joint.

DESIGN OF GFRP BARS

- **Serviceability – Crack Control**
  - Allowed larger crack widths since non-corrosive
  - 0.028 inches versus 0.017 inches
- **Serviceability likely to control if compression-controlled**
- **AASHTO requires direct method of limiting computed deflections**
  - Short-term deflection uses effective inertia (sustained load = DL +0.2LL)
  - Long-term deflection uses 3.0 multiplied by short-term deflection
- **Creep Rupture or Static Fatigue**
  - Sustained Load = DL + 0.2LL
  - Max Tensile Stress = 0.3 x Tensile Strength of GFRP
  - Conservative when compared to test results
- **Lap Splices (OK), Mechanical Coupler (Tensile Test)**

DESIGN OF GFRP BARS

- **Tensile Strength (FDOT Specs. Table 932-8)**

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	-	-

  - Type 0 – Bent or Straight Bars
  - Type III – Straight Bars

- **Tensile Modulus (FDOT Specs. Table 932-9)**

Table 932-9
Testing Requirements for Project Material Acceptance of FRP Reinforcing Bars

Property	Test Method	Requirement	Test Required for Straight Bar	Test Required for Bent Bar
Fiber Mass Fraction	ASTM D2584 or ASTM D3171	≥70%	Yes	Yes – bent portion[b]
Short-Term Moisture Absorption	ASTM D570, Procedure 7.1; 24 hours immersion at 122°F	≤0.25%	Yes	Yes – bent portion[b]
Glass Transition Temperature	ASTM D7028 (DMA) or ASTM E1356 (DSC; T_m)/ ASTM D3418 (DSC; T_{mg})	≥230°F ≥212°F	Yes	Yes – bent portion[b]
Degree of Cure	ASTM E2160	≥95% of Total polymerization enthalpy	Yes	Yes – bent portion[b]
Measured Cross-sectional Area		Within the range listed in Table 932-6	Yes	Yes – straight portion
Guaranteed Tensile Load[a]		≥ Value listed in Table 932-6	Yes	No
Tensile Modulus	ASTM D7205	≥6,500 ksi for BFRP and GFRP ≥18,000 ksi for CFRP (Type I) Bars ≥22,400 ksi for CFRP (Type II) Strands	Yes	No

a – Guaranteed tensile load shall be equal to the average test result from all three LOTs minus three standard deviations.
b – Bent portion specimens shall be extracted from a central location within a 90° bend.

  - E_s = 6,500ksi vs. 29,000ksi for Carbon Steel

DESIGN OF GFRP BARS

- **Comparison of design criteria:**

Design Factor	AASHTO Design Spec (9th Edition)	AASHTO Guide Spec (2nd Edition)	Critical Design Parameter Description
Φ_C	0.75	0.75	Resistance Factor Concrete Failure
Φ_T	0.90	0.55	Resistance Factor Reinforcement Failure
Φ_S	0.90	0.75	Resistance Factor Shear Failure
C_{deck}	2 (2.5)	1.5 (2)	Clear Cover for Top Deck Surface of Short Bridges (Long Bridges)
$C_{sub.formed}$	3-4	2	Clear Cover for Formed Substructure
$C_{sub.earth}$	4-4.5	3	Clear Cover for Unformed Substructure (Excluding DS)

DESIGN OF GFRP BARS (FLEXURE LIMITS)

- **Flexure Limits of Reinforcement (Carbon)**
  - **Cracking moment of concrete:**

$$M_{cr} = \gamma_3 \left[\left(\gamma_1 f_r + \gamma_2 f_{cpe} \right) S_c - M_{dnc} \left(\frac{S_c}{S_{nc}} - 1 \right) \right]$$

  - **Flexural cracking variability factor γ_1**
    - 1.6 Non-precast segmental structures
  - **Ratio of specified minimum yield strength to ultimate tensile strength (non-prestressed) γ_3**
    - 0.67 for Grade 60 (ASTM A615)
  - **Cracking moment of concrete:**

$$M_{cr} = 0.67 \left[(1.6 f_r) S_c - M_{dnc} \left(\frac{S_c}{S_{nc}} - 1 \right) \right]$$

- **Flexure Limits of Reinforcement (GFRP)**
  - **Modified Cracking moment of concrete:**

$$1.6 f_r S_c - M_{dnc} \left(\frac{S_c}{S_{nc}} - 1 \right)$$

  - **Same general criteria; greater than or equal to the less of:**
    - 1.33 x factored moment
    - Modified cracking moment
  - **Generally, need 1.33 x factored moment reinforcement**

DESIGN OF GFRP BARS (CONCRETE SHEAR)

- **Shear Design – Concrete (Carbon)**
  - **Nominal shear resistance of concrete:**

$$V_c = 0.0316\beta\lambda\sqrt{f'_c}\ b_v d_v$$

  - **Factor indicating ability of diagonally cracked concrete to transmit tension and shear (Simplified Method):**
    - β = 2.0

- **Shear Design – Concrete (GFRP)**
  - **Nominal shear resistance of concrete:**

$$V_c = 0.0316\beta\lambda\sqrt{f'_c}\ b_v d_v$$

  - **Factor indicating ability of diagonally cracked concrete to transmit tension and shear (Simplified Method):**
    - β = 5.0*k
    - k = Ratio of depth of neutral axis to reinforcement depth

$$k = \sqrt{2\rho_f n_f + (\rho_f n_f)^2} - \rho_f n_f$$

    - β = ~0.5
  - **Due to lower stiffness of GFRP**
    - Neutral axis shifts up
    - Less aggregate interlock

DESIGN OF GFRP BARS (REINFORCEMENT SHEAR)

- **Shear Design – Reinforcement (Carbon)**
  - **Nominal shear resistance of transverse reinforcement:**

$$V_s = \frac{A_v f_y d_v \cot\theta}{s}$$

  - **Minimum yield strength of reinforcement (f_y)**
    - f_y = 60ksi

- **Shear Design – Reinforcement (GFRP)**
  - **Nominal shear resistance of transverse reinforcement:**

$$V_f = \frac{A_{fv} f_{fv} d_v \cot\theta}{s}$$

  - **Design tensile strength of transverse reinforcement (f_{fv})**
    - Function of the bar diameter and bend radius, tensile modulus and design tensile strength
    - Limiting values

$$f_{fv} = 0.004 E_f \le f_{fb}$$

$$f_{fb} = \left(0.05\frac{r_b}{d_b} + 0.3\right) f_{fd} \le f_{fd}$$

  - **Generally limited to 0.004*E_f = ~26ksi**
  - **Limited the strain limits the shear crack width, and prevent degradation of aggregate interlock**

DESIGN OF GFRP BARS (LAP LENGTHS)

- **Lap Length – Reinforcement (Carbon)**
  - **Basic Development Length**

$$\ell_{db} = 2.4 d_b \frac{f_y}{\sqrt{f'_c}}$$

  - **Tension Development Length**

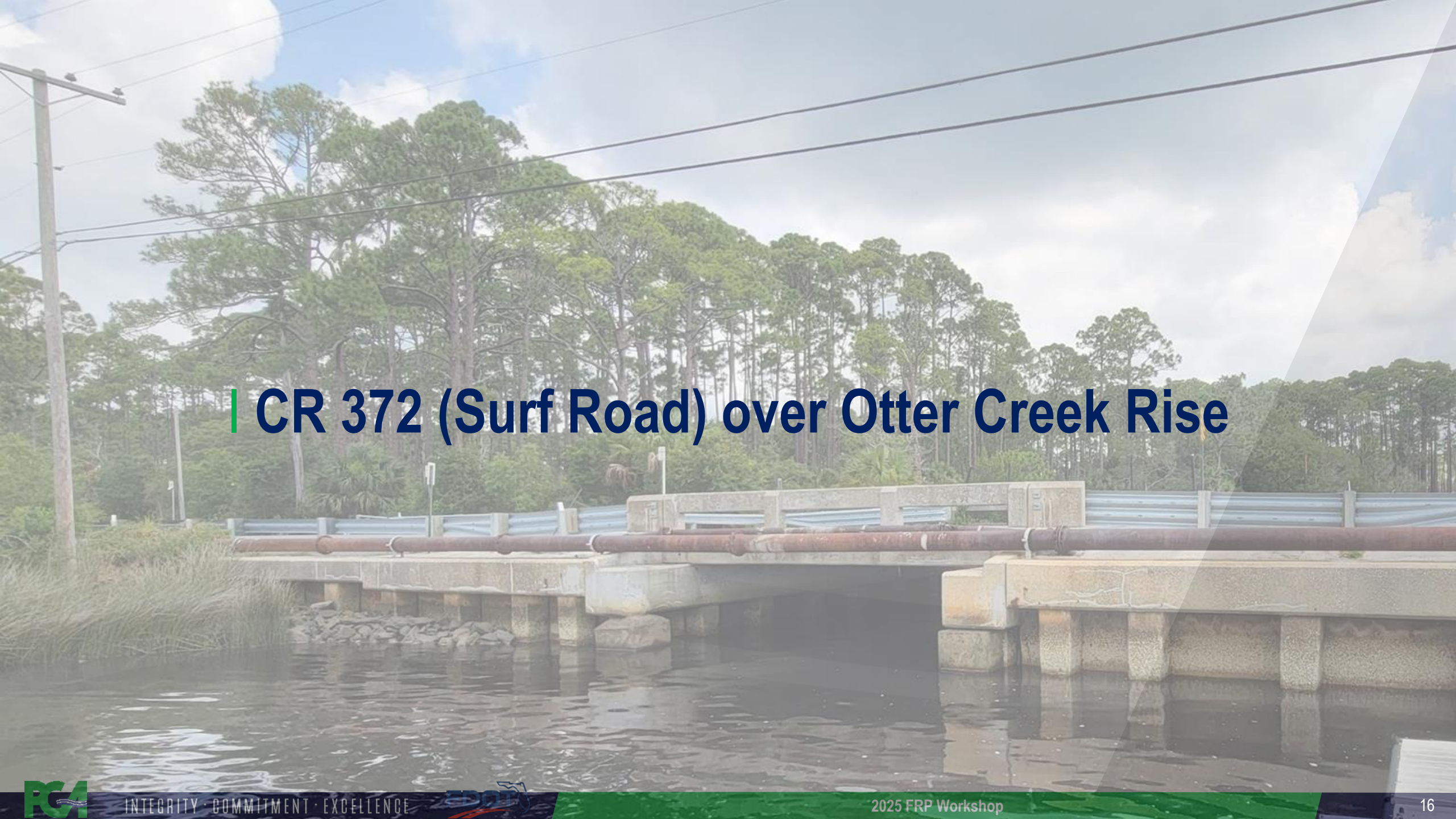
$$\ell_d = \ell_{db} \times \left(\frac{\lambda_{rl} \times \lambda_{cf} \times \lambda_{rc} \times \lambda_{er}}{\lambda} \right)$$

  - **Bar location factor, λ_{rl}**
    - 1.3 for Carbon when more than 12" of fresh concrete is below

- **Lap Length – Reinforcement (GFRP)**
  - **Tension Development Length**

$$\ell_d \geq \max \left(\frac{31.6\,\alpha \frac{f_{fr}}{\sqrt{f'_c}} - 340}{13.6 + \frac{C}{d_b}} d_b;\ 20 d_b \right)$$

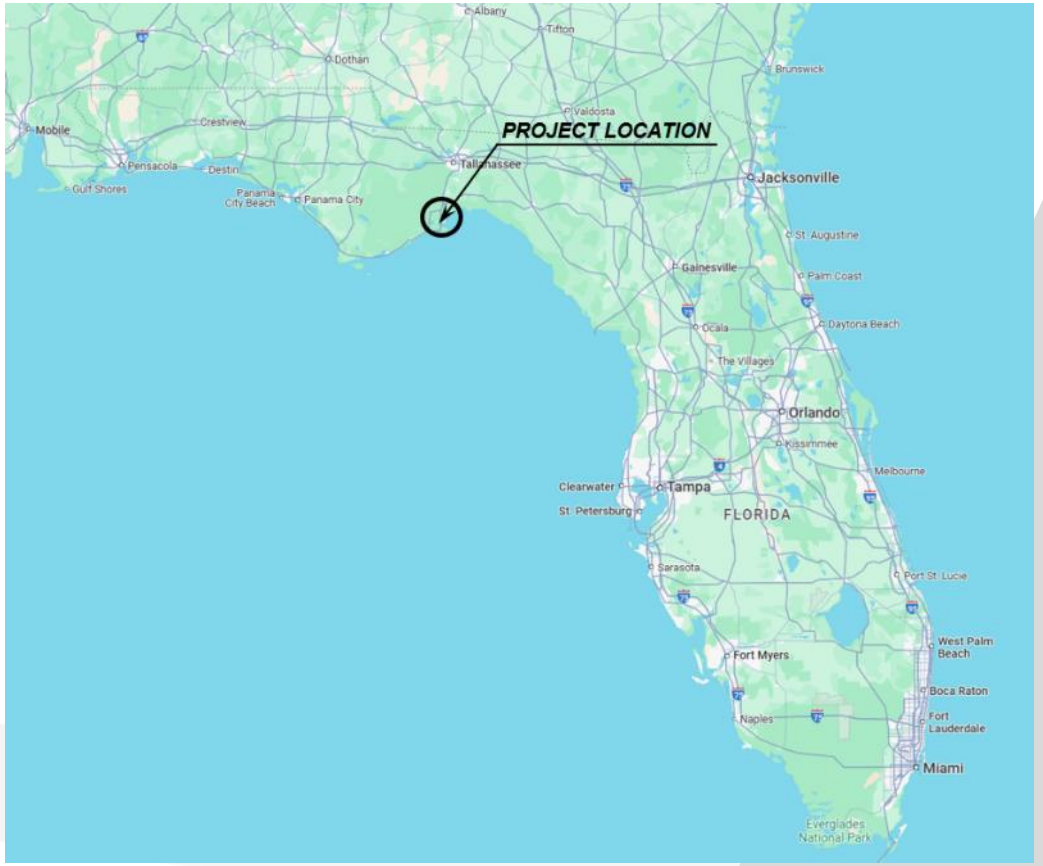
  - **No Lamda modification factors**
  - **Factor for bar location, α**
    - 1.5 for GFRP when more than 12" of fresh concrete is below
  - **No APL couplers**



CR 372 (Surf Road) over Otter Creek Rise

CR 372 (SURF ROAD) OVER OTTER CREEK RISE

- **Project Location**
  - Wakulla County, Florida (FDOT District 3)
  - Ochlockonee Bay
  - St. Mark's Wildlife National Refuge
- **Existing Structure**
  - Constructed in 1974
  - Two-Lane, Single-Span, 24-ft bridge
  - Vertical Abutment Walls
  - Approximately 460-ft of total seawall at bridge approaches



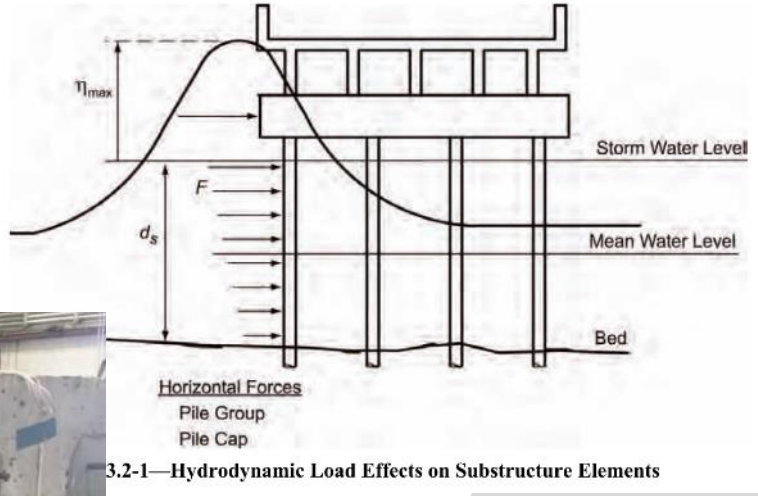
CR 372 (SURF ROAD) OVER OTTER CREEK RISE

- **Structural Deficiencies**
  - **Bridge Inspection**
    - Sufficiency Rating: 49.7
    - NBI Rating: Poor
      - Deck, Superstructure, Substructure
  - **Reinforcement Corrosion**
  - **Undermining of Retained Embankment**
- **Environmental Conditions**
  - **Extremely Aggressive Environment**
  - **Coastal Wave Action**

CR 372 (SURF ROAD) OVER OTTER CREEK RISE

- **Proposed Structure**
  - Complete Bridge Replacement
  - Reduction in Bulkhead Wall Limits
    - Spill-Through Abutments
    - High Cost of Wall and Maintenance
    - Increased Project Resiliency
  - Increased Bridge Length: 90-ft, 3-span
  - 12-inch Deep Florida Slab Beams (FSB)
    - 6-inch Cast-in-Place Topping
  - Soldier Pile Bulkhead Walls
    - Presence of Shallow Limerock
  - 24-inch PSPC
  - Non-Corrosive Materials Considerations

- **Wave Loading**
  - "Critical" Classification per FDOT SDG
  - 100-year wave crest design elevation
  - "Repairable Damage" performance rating per AASHTO BVCS



3.2-1—Hydrodynamic Load Effects on Substructure Elements

FRP MATERIAL APPLICATIONS

CR 372 (Surf Road) over Otter Creek Rise

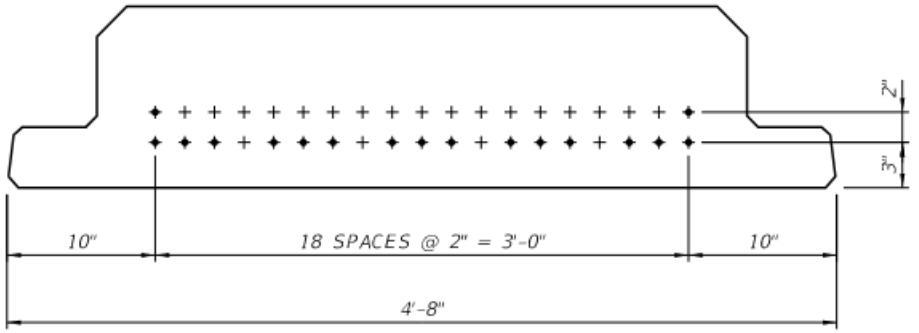
- **Summary of Proposed CFRP Components:**
  - 12" Florida Slab Beam (FSB) Prestressed Strands (CFRP or SS)
  - 24" Square Prestressed Concrete Piles Prestressed Strands (CFRP or SS)

- **Summary of Proposed GFRP Components:**
  - 12" Florida Slab Beam (FSB) Reinforcing (Stirrups and 6" Cast-in-Place Topping)
  - Bridge Bents and Vertical Abutment Wall Panels
  - Concrete Bulkhead Cap and Wall Panels
  - Outboard Concrete Traffic Railing
  - 27" Concrete Pedestrian Parapet

DESIGN OF CFRP FLORIDA SLAB BEAMS (FSB)

- Utilize FDOT Standard Index 450-450 series
- CFRP/Stainless Steel Design
- Splitting Resistance
  - On-going AASHTO Research
- Cast-in-Place Topping
  - #5 GFRP Bars, 9" Spacing
    - Matches Carbon Equivalent
  - GFRP Higher Rupture than Carbon
- Shear Stirrups
  - #4 GFRP Bars: 6" Spacing
  - #4 SS Bars: 12" Spacing

Bridge Span Length	Strand Material	Strand Diameter	Number of Strands
27-ft Span	CFRP	0.6-inch	15 Strands – Bottom Row 2 Strands – Top Row
36-ft Span	CFRP	0.6-inch	15 Strands – Bottom Row 2 Strands – Top Row
27-ft Span	SS	0.62-inch	19 Strands – Bottom Row 2 Strands – Top Row
36-ft Span	SS	0.62-inch	19 Strands – Bottom Row 2 Strands – Top Row



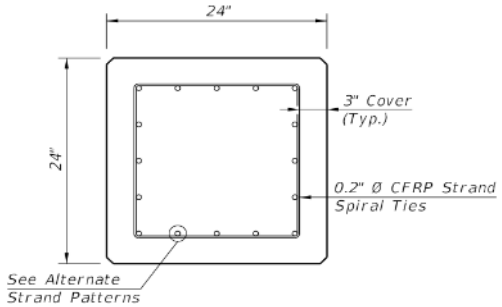
DESIGN OF CFRP PSPC PILES

- Utilize FDOT Standard Index 455-101 series
- Identical pile driving NBR
- Similar pile flexural capacities
  - 24” PSPC Pile Strand Pattern Comparison
- Deflection values will be different
- Model CFRP strands in FB-Multipier to perform lateral stability analysis

CFRP Strands:

ALTERNATE STRAND PATTERNS

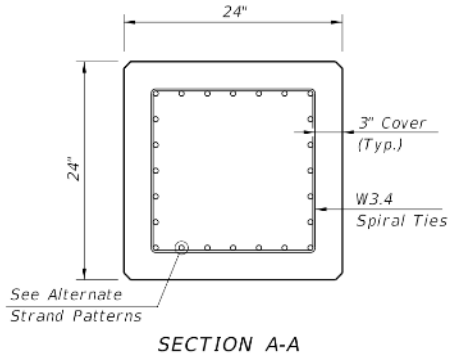
16 ~ 0.6" Ø, CFRP 7-Strand, at 42 kips
20 ~ ½" Ø, CFRP Single-Strand, at 35 kips



Carbon Steel Strands:

ALTERNATE STRAND PATTERNS

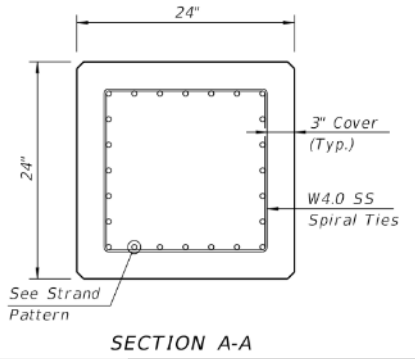
16 ~ 0.6" Ø, Grade 270 LRS, at 44 kips
20 ~ ½" Ø (Special), Grade 270 LRS, at 34 kips
24 ~ ½" Ø, Grade 270 LRS, at 31 kips



Stainless Steel Strands:

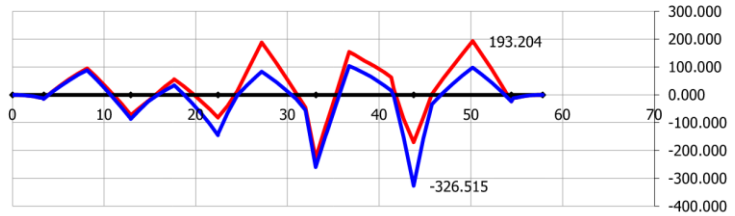
STRAND PATTERN

28 ~ 0.52" Ø, HSSS at 26 kips
20 ~ 0.62" Ø, HSSS at 35 kips

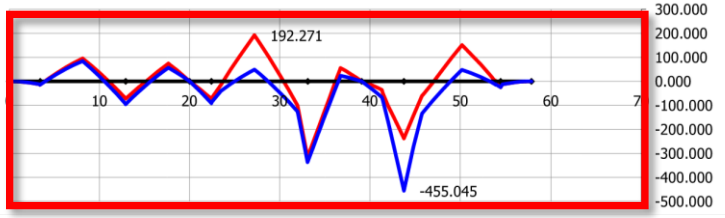


DESIGN OF SUBSTRUCTURE BENT CAPS

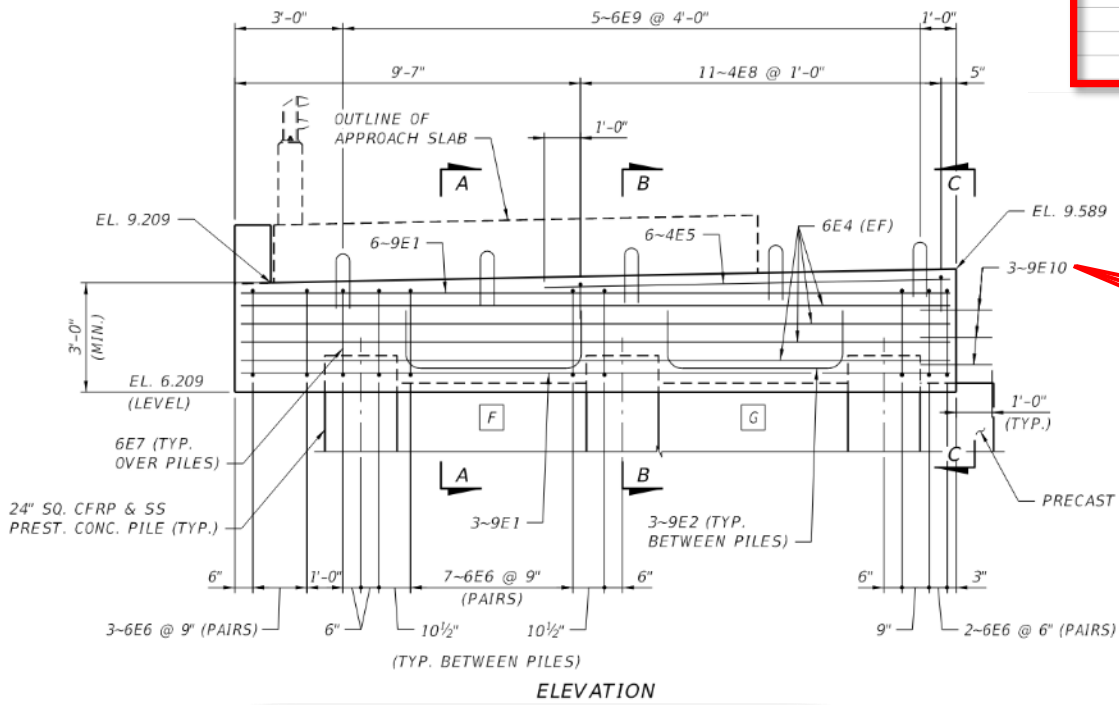
- #9 GFRP Flexural Bars
- Phase Constructed
- #9 GFRP Shear Dowels
  - Reduction in Splice Lengths Req'd
- Higher Negative Moments (39% Increase)



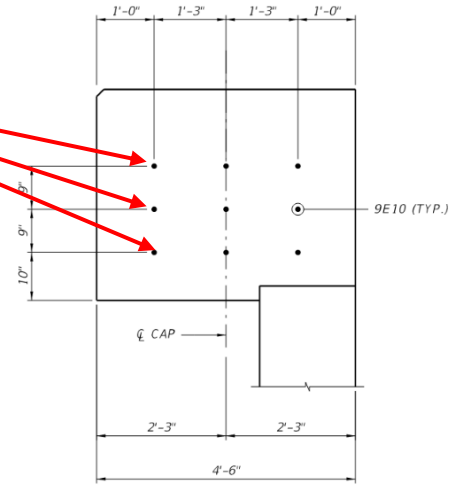
Moment, kip*ft		X, ft
Max =	193.204	50.1935
Min =	-326.515	43.75



Moment, kip*ft		X, ft
Max =	192.271	27.2001
Min =	-455.045	43.75



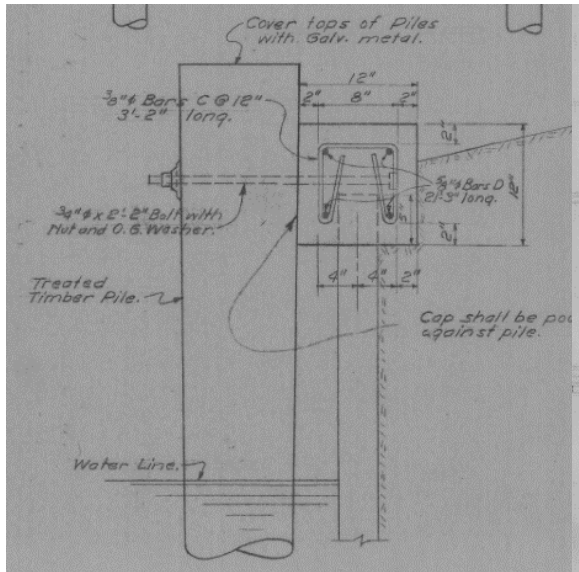
ELEVATION



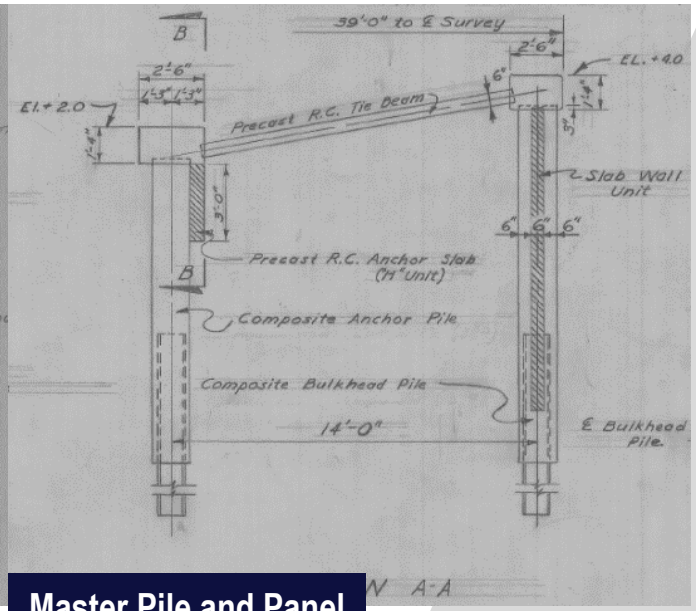
VIEW C-C

SOLDIER PILE WALL SYSTEMS

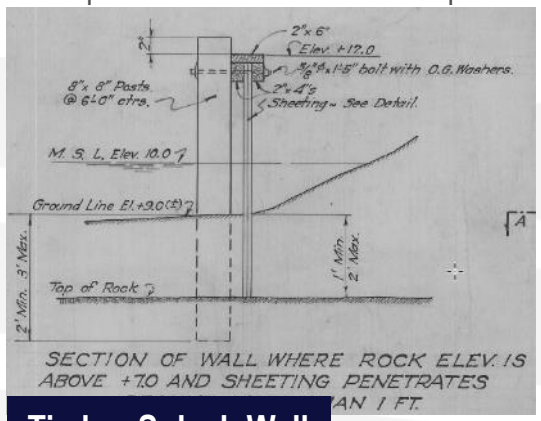
- **Historical Use of Soldier Pile Walls in FL:**
  - 1939 – FDOT Index 1442 – Timber Panel Bulkhead
  - 1942 – FDOT Index 1786 – Timber Splash Wall
  - 1953 – FDOT Index 3040 – Precast Sheet – Timber King Pile
  - 1954 – FDOT Index 3204 – Master Pile and Panel
  - 1960's to 2000's
    - Concrete Soldier Pile Wall Use in South Florida
      - Miami Beach Seawall Standards
    - Application mainly due to shallow limerock geology
    - Later applications used a reinforced concrete panel with a tie-back anchor pile for shallower installation depths



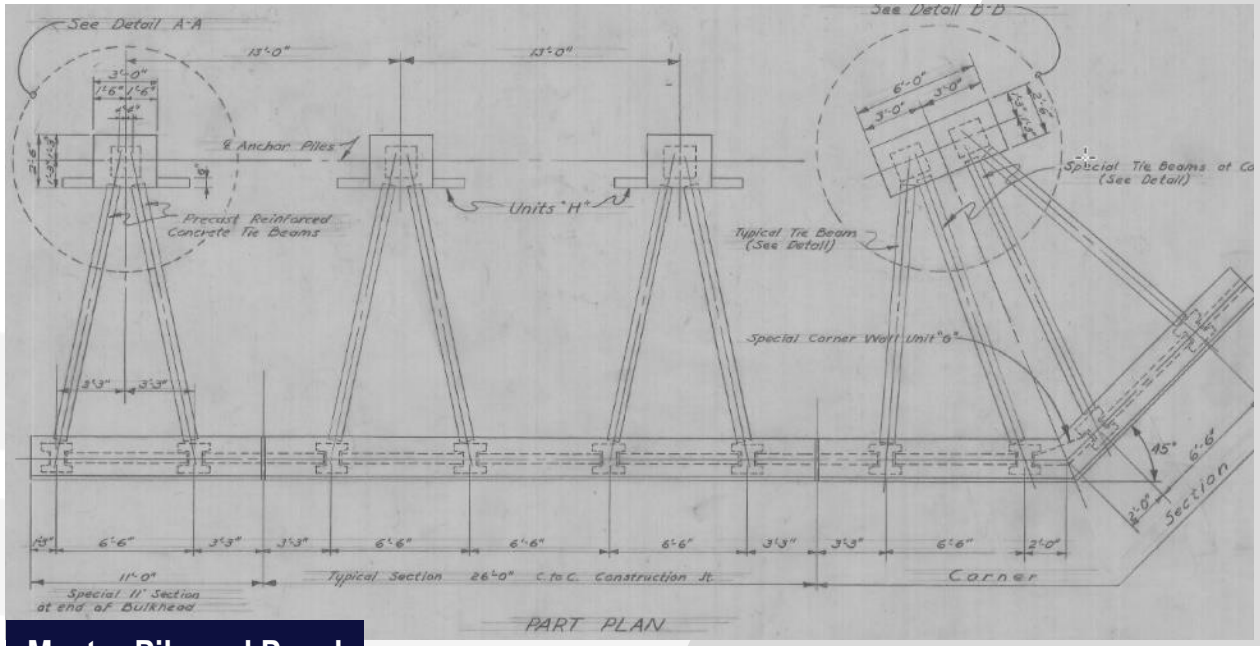
Precast Sheet – Timber King Pile



Master Pile and Panel



Timber Splash Wall



Master Pile and Panel

SOLDIER PILE WALL SYSTEMS

- **Wall System Components:**
  - **Uses a driven pile acting as soldier piles (various material types)**
  - **Retaining element uses concrete panels or concrete sheets**
- **Why Soldier Pile Walls:**
  - **Typical/Conventional bridge abutment and seawall systems**
    - Steel sheet pile
    - Concrete sheet pile
    - CIP concrete walls
    - MSE Retaining Wall System
  - **When to consider soldier pile wall system?**
    - Presence of shallow rock
    - Significant variation in subsoil
- **Allowed per FDOT SDG 3.12**

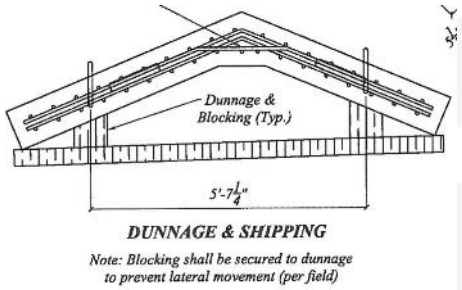
5. Soldier Pile & Panel Wall
   a. Concrete - a project specific design is required
   b. Steel - a project specific design is required
      - Sacrificial thickness (see ***SDG*** Table 3.1-1) requirements may eliminate wall type.

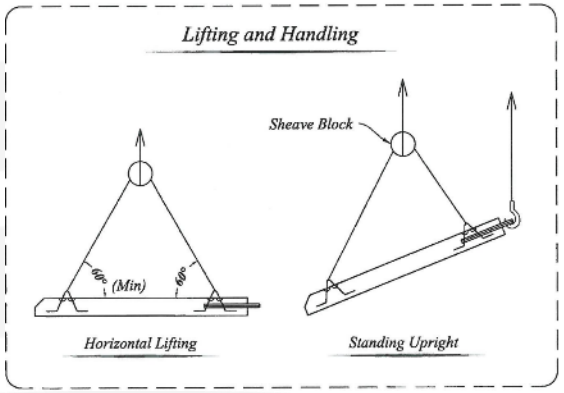
SOLDIER PILE WALL SYSTEMS

- **Advantages of a Soldier Pile Wall System:**
  - Driven soldier piles reduces deep wall components
  - Soldier pile installation can be designed for various soil topographies
  - Shallow rock layers can be preformed and achieve desired minimum pile tip elevations
  - Soil retaining wall panel can be precast eliminating need for CIP wall component
  - Dewatering is reduced or eliminated in some cases
  - Since most components can be concrete, use of non-corrosive materials such as GFRP, CFRP, and SS can be considered
    - Biggest challenge with historical use has been corrosion of carbon steel components
    - Use of FRP components eliminate the main challenge in contemporary use of this wall system

SOLDIER PILE WALL SYSTEMS

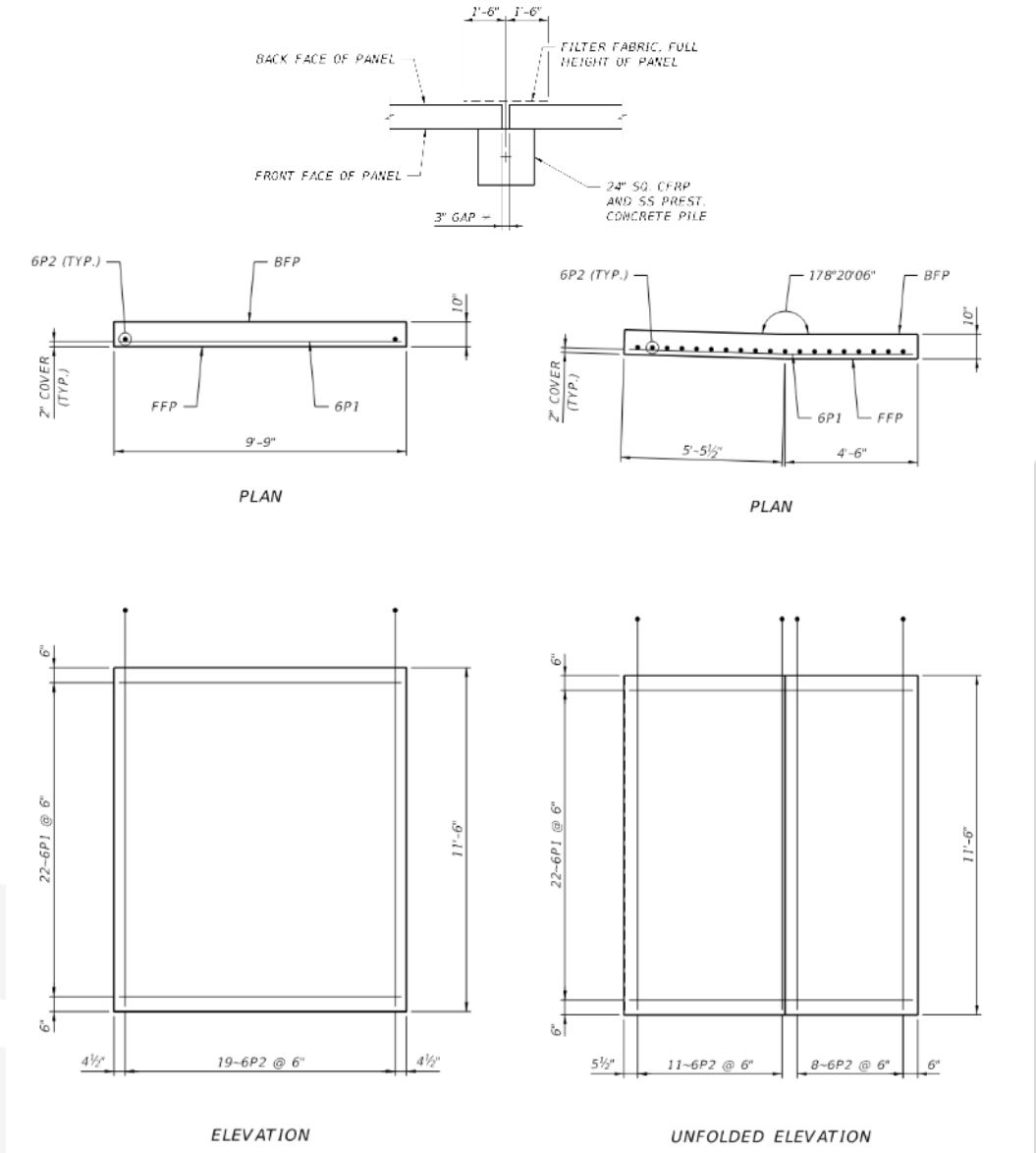
- **Construction Considerations:**
  - Require shop drawings of precast concrete panels after pile driving
  - May need to adjust panel geometry depending on final pile as-builts
  - Add a chamfer on the bottom of precast panels to allow contractor to wedge panels into place
  - Require contractor to submit sequence of construction for panels
    - Confirm lateral stability analysis matches proposed construction sequence
  - Ensure adequate panel bearing distance remains on soldier piles after pile driving tolerance is included
  - Review transportation and storage details in shop drawing





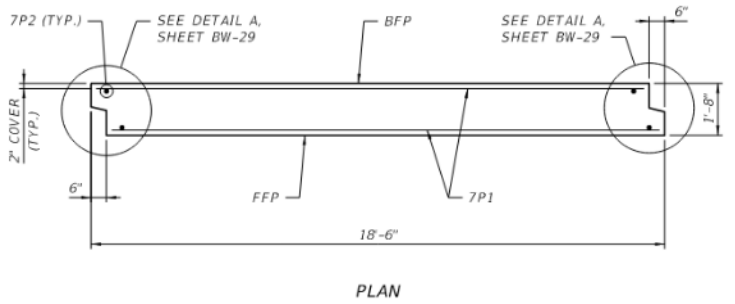
DESIGN OF BULKHEAD WALLS

- **Design of Soldier Pile PSPC Piles**
  - Identical design as bridge foundation PSPC piles
  - Requires a lateral stability analysis to determine minimum tip
  - Results in minimal axial load and D/C ratio governed by flexure
  - Fill gap between panel and pile with grout
  - Avoid anchor piles when possible
- **Design of Precast Concrete Panels**
  - One layer of reinforcement
  - 10-inch thickness
  - Design as simple span between solider piles
  - Utilize hooked bars from panel to concrete cap
  - Account for pile driving tolerance in span length
  - Embed 2-ft to 3-ft below groundline
  - Tie-in to existing marina wall

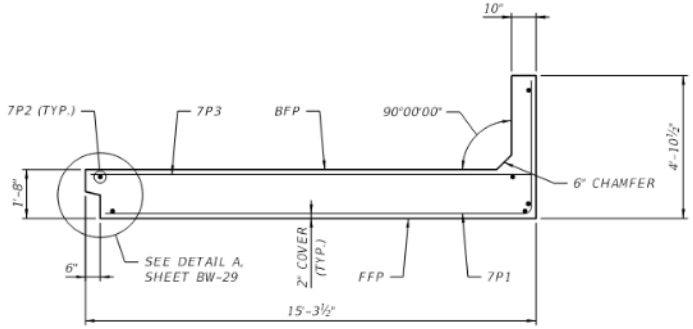


DESIGN OF ABUTMENT WALLS

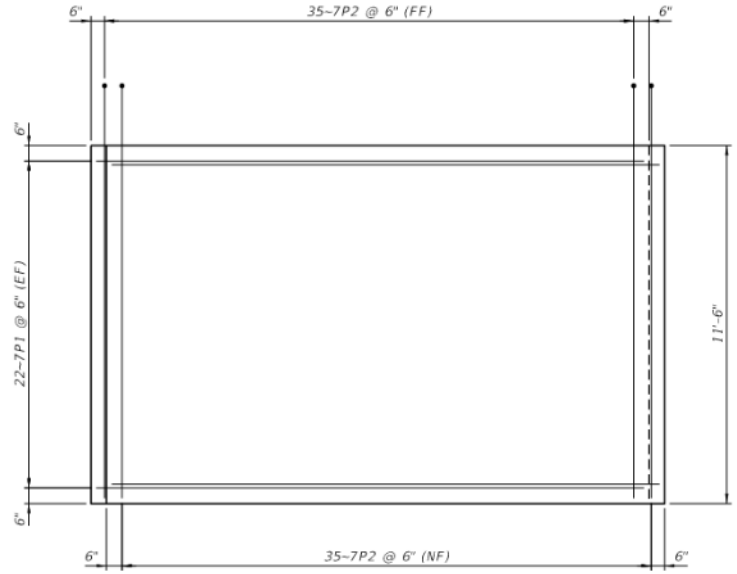
- **Design of Precast Concrete Panels**
  - Two layers of reinforcement
  - 20-inch thickness
  - Design as simple span cantilevered members between abutment piles
    - Due to bridge construction phasing
  - Concrete shear key between panels



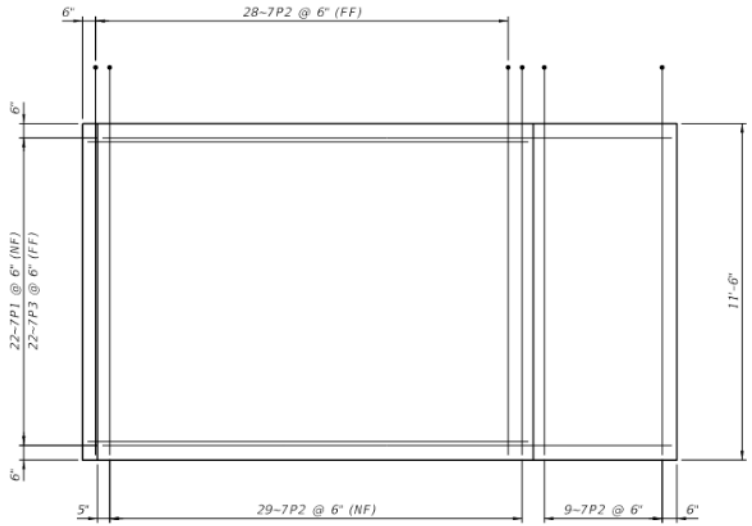
PLAN



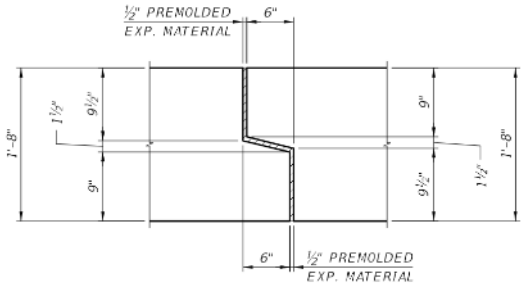
PLAN



ELEVATION



UNFOLDED ELEVATION

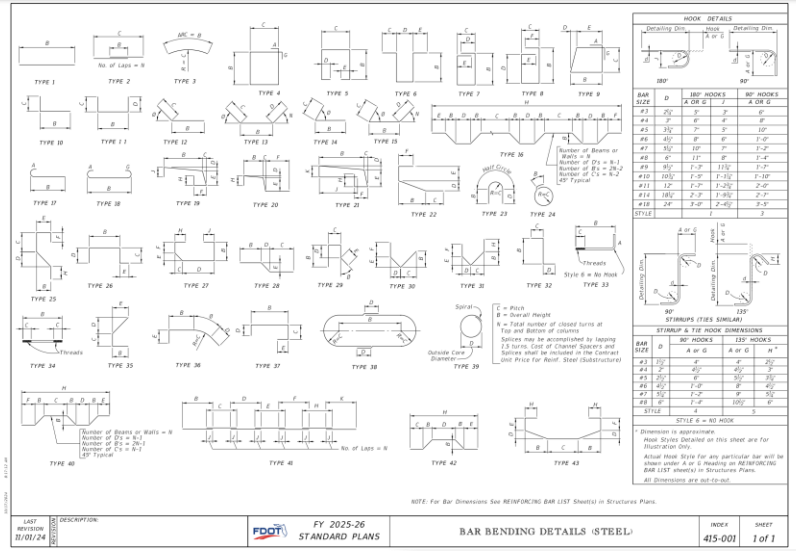


DETAIL A

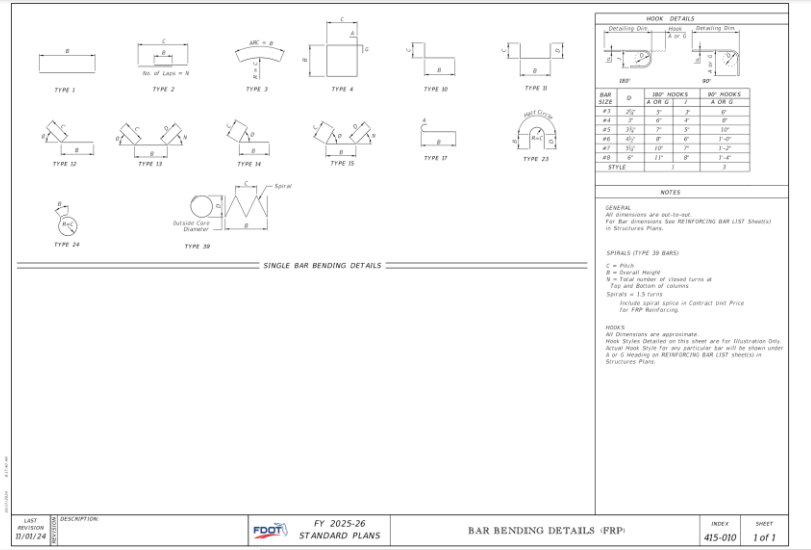
Lessons Learned / Conclusions

DESIGN/CONSTRUCTION LESSONS LEARNED

- Lighter than carbon (75% lighter)
  - Small construction equipment, reduced transportation cost and time
- Reduced construction maintenance cost over life of project
- No concrete admixtures (HRPs) required
- Bar bending
  - Can't field bend/brittle
  - Bend length limitations
- Long procurement
- More reinforcement than carbon steel/bigger concrete elements
- No current mechanical coupler system (APL)



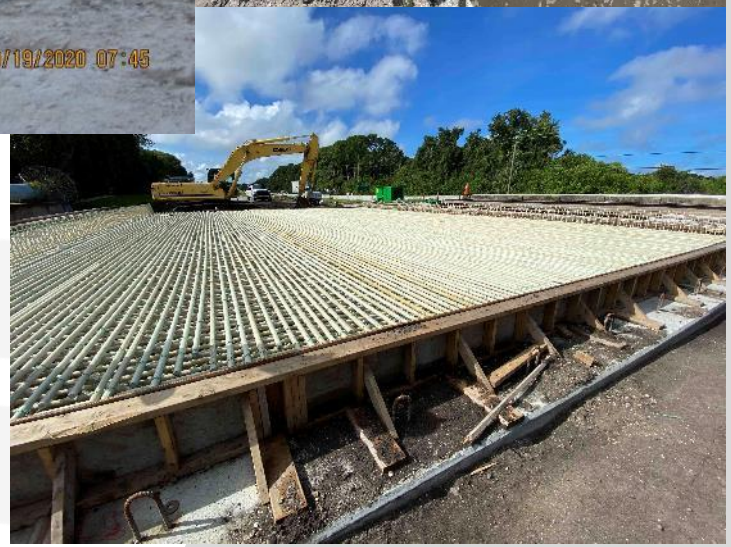
Steel Bending Details



FRP Bending Details

CR 372 (SURF ROAD) OVER OTTER CREEK RISE BRIDGE REPLACEMENT

- **Conclusions:**
  - **Soldier pile walls with prestressed piles and precast panels together with FRP materials provide a resilient alternative to other retaining wall systems**
  - **Continuous refinement of the design criteria allow further cost competitiveness of these systems**
  - **There are still challenges that remain with GFRP:**
    - Rebar breaking during handling
    - Need for coupler system for phased construction
    - Standardized procedure for bond development
    - Low modulus



QUESTIONS?

Thank you for your time and consideration!